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# **SciPy Reference Guide**

*Release 1.0.0*

**Written by the SciPy community**

**October 25, 2017**



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*Release* 1.0.0  
*Date* October 25, 2017

SciPy (pronounced “Sigh Pie”) is open-source software for mathematics, science, and engineering.



## RELEASE NOTES

### 1.1 SciPy 1.0.0 Release Notes

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We are extremely pleased to announce the release of SciPy 1.0, 16 years after version 0.1 saw the light of day. It has been a long, productive journey to get here, and we anticipate many more exciting new features and releases in the future.

### 1.1.1 Why 1.0 now?

A version number should reflect the maturity of a project - and SciPy was a mature and stable library that is heavily used in production settings for a long time already. From that perspective, the 1.0 version number is long overdue.

Some key project goals, both technical (e.g. Windows wheels and continuous integration) and organisational (a governance structure, code of conduct and a roadmap), have been achieved recently.

Many of us are a bit perfectionist, and therefore are reluctant to call something “1.0” because it may imply that it’s “finished” or “we are 100% happy with it”. This is normal for many open source projects, however that doesn’t make it right. We acknowledge to ourselves that it’s not perfect, and there are some dusty corners left (that will probably always be the case). Despite that, SciPy is extremely useful to its users, on average has high quality code and documentation, and gives the stability and backwards compatibility guarantees that a 1.0 label imply.

### 1.1.2 Some history and perspectives

- 2001: the first SciPy release
- 2005: transition to NumPy
- 2007: creation of scikits
- 2008: `scipy.spatial` module and first Cython code added
- 2010: moving to a 6-monthly release cycle
- 2011: SciPy development moves to GitHub
- 2011: Python 3 support
- 2012: adding a sparse graph module and unified optimization interface
- 2012: removal of `scipy.maxentropy`
- 2013: continuous integration with TravisCI
- 2015: adding Cython interface for BLAS/LAPACK and a benchmark suite
- 2017: adding a unified C API with `scipy.LowLevelCallable`; removal of `scipy.weave`
- 2017: SciPy 1.0 release

**Pauli Virtanen** is SciPy’s Benevolent Dictator For Life (BDFL). He says:

*Truthfully speaking, we could have released a SciPy 1.0 a long time ago, so I’m happy we do it now at long last. The project has a long history, and during the years it has matured also as a software project. I believe it has well proved its merit to warrant a version number starting with unity.*

*Since its conception 15+ years ago, SciPy has largely been written by and for scientists, to provide a box of basic tools that they need. Over time, the set of people active in its development has undergone some rotation, and we have evolved towards a somewhat more systematic approach to development. Regardless, this underlying drive has stayed the same, and I think it will also continue propelling the project forward in future. This is all good, since not long after 1.0 comes 1.1.*

**Travis Oliphant** is one of SciPy’s creators. He says:

*I’m honored to write a note of congratulations to the SciPy developers and the entire SciPy community for the release of SciPy 1.0. This release represents a dream of many that has been patiently pursued by a stalwart group of pioneers*

for nearly 2 decades. Efforts have been broad and consistent over that time from many hundreds of people. From initial discussions to efforts coding and packaging to documentation efforts to extensive conference and community building, the SciPy effort has been a global phenomenon that it has been a privilege to participate in.

The idea of SciPy was already in multiple people's minds in 1997 when I first joined the Python community as a young graduate student who had just fallen in love with the expressibility and extensibility of Python. The internet was just starting to bringing together like-minded mathematicians and scientists in nascent electronically-connected communities. In 1998, there was a concerted discussion on the matrix-SIG, python mailing list with people like Paul Barrett, Joe Harrington, Perry Greenfield, Paul Dubois, Konrad Hinsien, David Ascher, and others. This discussion encouraged me in 1998 and 1999 to procrastinate my PhD and spend a lot of time writing extension modules to Python that mostly wrapped battle-tested Fortran and C-code making it available to the Python user. This work attracted the help of others like Robert Kern, Pearu Peterson and Eric Jones who joined their efforts with mine in 2000 so that by 2001, the first SciPy release was ready. This was long before Github simplified collaboration and input from others and the "patch" command and email was how you helped a project improve.

Since that time, hundreds of people have spent an enormous amount of time improving the SciPy library and the community surrounding this library has dramatically grown. I stopped being able to participate actively in developing the SciPy library around 2010. Fortunately, at that time, Pauli Virtanen and Ralf Gommers picked up the pace of development supported by dozens of other key contributors such as David Cournapeau, Evgeni Burovski, Josef Perktold, and Warren Weckesser. While I have only been able to admire the development of SciPy from a distance for the past 7 years, I have never lost my love of the project and the concept of community-driven development. I remain driven even now by a desire to help sustain the development of not only the SciPy library but many other affiliated and related open-source projects. I am extremely pleased that SciPy is in the hands of a world-wide community of talented developers who will ensure that SciPy remains an example of how grass-roots, community-driven development can succeed.

**Fernando Perez** offers a wider community perspective:

*The existence of a nascent Scipy library, and the incredible –if tiny by today's standards– community surrounding it is what drew me into the scientific Python world while still a physics graduate student in 2001. Today, I am awed when I see these tools power everything from high school education to the research that led to the 2017 Nobel Prize in physics.*

*Don't be fooled by the 1.0 number: this project is a mature cornerstone of the modern scientific computing ecosystem. I am grateful for the many who have made it possible, and hope to be able to contribute again to it in the future. My sincere congratulations to the whole team!*

### 1.1.3 Highlights of this release

Some of the highlights of this release are:

- Major build improvements. Windows wheels are available on PyPI for the first time, and continuous integration has been set up on Windows and OS X in addition to Linux.
- A set of new ODE solvers and a unified interface to them (`scipy.integrate.solve_ivp`).
- Two new trust region optimizers and a new linear programming method, with improved performance compared to what `scipy.optimize` offered previously.
- Many new BLAS and LAPACK functions were wrapped. The BLAS wrappers are now complete.

### 1.1.4 Upgrading and compatibility

There have been a number of deprecations and API changes in this release, which are documented below. Before upgrading, we recommend that users check that their own code does not use deprecated SciPy functionality (to do so, run your code with `python -Wd` and check for `DeprecationWarning`s).

This release requires Python 2.7 or  $\geq 3.4$  and NumPy 1.8.2 or greater.

This is also the last release to support LAPACK 3.1.x - 3.3.x. Moving the lowest supported LAPACK version to  $>3.2.x$  was long blocked by Apple Accelerate providing the LAPACK 3.2.1 API. We have decided that it's time to either drop Accelerate or, if there is enough interest, provide shims for functions added in more recent LAPACK versions so it can still be used.

### New features

#### 1.1.5 `scipy.cluster` improvements

`scipy.cluster.hierarchy.optimal_leaf_ordering`, a function to reorder a linkage matrix to minimize distances between adjacent leaves, was added.

#### 1.1.6 `scipy.fftpack` improvements

N-dimensional versions of the discrete sine and cosine transforms and their inverses were added as `dctn`, `idctn`, `dstn` and `idstn`.

#### 1.1.7 `scipy.integrate` improvements

A set of new ODE solvers have been added to `scipy.integrate`. The convenience function `scipy.integrate.solve_ivp` allows uniform access to all solvers. The individual solvers (RK23, RK45, Radau, BDF and LSODA) can also be used directly.

#### 1.1.8 `scipy.linalg` improvements

The BLAS wrappers in `scipy.linalg.blas` have been completed. Added functions are `*gbmv`, `*hbmvm`, `*hpmvm`, `*hpr`, `*hpr2`, `*spmv`, `*spr`, `*tbmv`, `*tbsv`, `*tpmv`, `*tpsv`, `*trsm`, `*trsv`, `*sbmv`, `*spr2`,

Wrappers for the LAPACK functions `*gels`, `*stev`, `*sytrd`, `*hetrd`, `*sytf2`, `*hetrf`, `*sytrf`, `*sycon`, `*hecon`, `*gglse`, `*stebz`, `*stemr`, `*sterf`, and `*stein` have been added.

The function `scipy.linalg.subspace_angles` has been added to compute the subspace angles between two matrices.

The function `scipy.linalg.clarkson_woodruff_transform` has been added. It finds low-rank matrix approximation via the Clarkson-Woodruff Transform.

The functions `scipy.linalg.eigh_tridiagonal` and `scipy.linalg.eigvalsh_tridiagonal`, which find the eigenvalues and eigenvectors of tridiagonal hermitian/symmetric matrices, were added.

#### 1.1.9 `scipy.ndimage` improvements

Support for homogeneous coordinate transforms has been added to `scipy.ndimage.affine_transform`.

The `ndimage` C code underwent a significant refactoring, and is now a lot easier to understand and maintain.

### 1.1.10 `scipy.optimize` improvements

The methods `trust-region-exact` and `trust-krylov` have been added to the function `scipy.optimize.minimize`. These new trust-region methods solve the subproblem with higher accuracy at the cost of more Hessian factorizations (compared to `dogleg`) or more matrix vector products (compared to `ncg`) but usually require less non-linear iterations and are able to deal with indefinite Hessians. They seem very competitive against the other Newton methods implemented in `scipy`.

`scipy.optimize.linprog` gained an interior point method. Its performance is superior (both in accuracy and speed) to the older simplex method.

### 1.1.11 `scipy.signal` improvements

An argument `fs` (sampling frequency) was added to the following functions: `firwin`, `firwin2`, `firls`, and `remez`. This makes these functions consistent with many other functions in `scipy.signal` in which the sampling frequency can be specified.

`scipy.signal.freqz` has been sped up significantly for FIR filters.

### 1.1.12 `scipy.sparse` improvements

Iterating over and slicing of CSC and CSR matrices is now faster by up to ~35%.

The `tocsr` method of COO matrices is now several times faster.

The `diagonal` method of sparse matrices now takes a parameter, indicating which diagonal to return.

### 1.1.13 `scipy.sparse.linalg` improvements

A new iterative solver for large-scale nonsymmetric sparse linear systems, `scipy.sparse.linalg.gcrotmk`, was added. It implements GCROT ( $m, k$ ), a flexible variant of GCROT.

`scipy.sparse.linalg.lsmr` now accepts an initial guess, yielding potentially faster convergence.

SuperLU was updated to version 5.2.1.

### 1.1.14 `scipy.spatial` improvements

Many distance metrics in `scipy.spatial.distance` gained support for weights.

The signatures of `scipy.spatial.distance.pdist` and `scipy.spatial.distance.cdist` were changed to `*args, **kwargs` in order to support a wider range of metrics (e.g. string-based metrics that need extra keywords). Also, an optional `out` parameter was added to `pdist` and `cdist` allowing the user to specify where the resulting distance matrix is to be stored

### 1.1.15 `scipy.stats` improvements

The methods `cdf` and `logcdf` were added to `scipy.stats.multivariate_normal`, providing the cumulative distribution function of the multivariate normal distribution.

New statistical distance functions were added, namely `scipy.stats.wasserstein_distance` for the first Wasserstein distance and `scipy.stats.energy_distance` for the energy distance.

### Deprecated features

The following functions in `scipy.misc` are deprecated: `bytescale`, `fromimage`, `imfilter`, `imread`, `imresize`, `imrotate`, `imsave`, `imshow` and `toimage`. Most of those functions have unexpected behavior (like rescaling and type casting image data without the user asking for that). Other functions simply have better alternatives.

`scipy.interpolate.interpolate_wrapper` and all functions in that submodule are deprecated. This was a never finished set of wrapper functions which is not relevant anymore.

The fillvalue of `scipy.signal.convolve2d` will be cast directly to the dtypes of the input arrays in the future and checked that it is a scalar or an array with a single element.

`scipy.spatial.distance.matching` is deprecated. It is an alias of `scipy.spatial.distance.hamming`, which should be used instead.

Implementation of `scipy.spatial.distance.wminkowski` was based on a wrong interpretation of the metric definition. In scipy 1.0 it has been just deprecated in the documentation to keep retro-compatibility but is recommended to use the new version of `scipy.spatial.distance.minkowski` that implements the correct behaviour.

Positional arguments of `scipy.spatial.distance.pdist` and `scipy.spatial.distance.cdist` should be replaced with their keyword version.

### Backwards incompatible changes

The following deprecated functions have been removed from `scipy.stats`: `betai`, `chisqprob`, `f_value`, `histogram`, `histogram2`, `pdf_fromgamma`, `signaltonoise`, `square_of_sums`, `ss` and `threshold`.

The following deprecated functions have been removed from `scipy.stats.mstats`: `betai`, `f_value_wilks_lambda`, `signaltonoise` and `threshold`.

The deprecated `a` and `reta` keywords have been removed from `scipy.stats.shapiro`.

The deprecated functions `sparse.csgraph.cs_graph_components` and `sparse.linalg.symeig` have been removed from `scipy.sparse`.

The following deprecated keywords have been removed in `scipy.sparse.linalg`: `drop_tol` from `splu`, and `xtype` from `bicg`, `bicgstab`, `cg`, `cgs`, `gmres`, `qmr` and `minres`.

The deprecated functions `expm2` and `expm3` have been removed from `scipy.linalg`. The deprecated keyword `q` was removed from `scipy.linalg.expm`. And the deprecated submodule `linalg.calc_lwork` was removed.

The deprecated functions `C2K`, `K2C`, `F2C`, `C2F`, `F2K` and `K2F` have been removed from `scipy.constants`.

The deprecated `ppform` class was removed from `scipy.interpolate`.

The deprecated keyword `iprint` was removed from `scipy.optimize.fmin_cobyla`.

The default value for the `zero_phase` keyword of `scipy.signal.decimate` has been changed to `True`.

The `kmeans` and `kmeans2` functions in `scipy.cluster.vq` changed the method used for random initialization, so using a fixed random seed will not necessarily produce the same results as in previous versions.

`scipy.special.gammaln` does not accept complex arguments anymore.

The deprecated functions `sph_jn`, `sph_yn`, `sph_jnyn`, `sph_in`, `sph_kn`, and `sph_inkn` have been removed. Users should instead use the functions `spherical_jn`, `spherical_yn`, `spherical_in`, and `spherical_kn`. Be aware that the new functions have different signatures.

The cross-class properties of `scipy.signal.lti` systems have been removed. The following properties/setters have been removed:

Name - (accessing/setting has been removed) - (setting has been removed)

- `StateSpace` - (num, den, gain) - (zeros, poles)
- `TransferFunction` (A, B, C, D, gain) - (zeros, poles)
- `ZerosPolesGain` (A, B, C, D, num, den) - ()

`signal.freqz(b, a)` with `b` or `a > 1-D` raises a `ValueError`. This was a corner case for which it was unclear that the behavior was well-defined.

The method `var` of `scipy.stats.dirichlet` now returns a scalar rather than an ndarray when the length of `alpha` is 1.

## Other changes

SciPy now has a formal governance structure. It consists of a BDFL (Pauli Virtanen) and a Steering Committee. See [the governance document](#) for details.

It is now possible to build SciPy on Windows with MSVC + gfortran! Continuous integration has been set up for this build configuration on Appveyor, building against OpenBLAS.

Continuous integration for OS X has been set up on TravisCI.

The SciPy test suite has been migrated from `nose` to `pytest`.

`scipy/_distributor_init.py` was added to allow redistributors of SciPy to add custom code that needs to run when importing SciPy (e.g. checks for hardware, DLL search paths, etc.).

Support for PEP 518 (specifying build system requirements) was added - see `pyproject.toml` in the root of the SciPy repository.

In order to have consistent function names, the function `scipy.linalg.solve_lyapunov` is renamed to `scipy.linalg.solve_continuous_lyapunov`. The old name is kept for backwards-compatibility.

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A total of 121 people contributed to this release. People with a “+” by their names contributed a patch for the first time. This list of names is automatically generated, and may not be fully complete.

### 1.1.16 Issues closed for 1.0.0

- #2300: `scipy.misc.toimage` (and therefore `imresize`) converts to `uint32`...
- #2347: Several `misc.im*` functions incorrectly handle 3 or 4-channeled...
- #2442: `scipy.misc.pilutil` -> `scipy.ndimage`?
- #2829: Mingw Gfortran on Windows?
- #3154: `scipy.misc.imsave` creates wrong bitmap header
- #3505: `scipy.linalg.lstsq()` residual's help text is a lil strange
- #3808: Is Brent's method for minimizing the value of a function implemented...
- #4121: Add `cdf()` method to `stats.multivariate_normal`
- #4458: `scipy.misc.imresize` changes image range
- #4575: Docs for L-BFGS-B mention non-existent parameter
- #4893: `misc.imsave` does not work with file type defined
- #5231: Discrepancies in `scipy.optimize.minimize(method='L-BFGS-B')`
- #5238: Optimal leaf ordering in `scipy.cluster.hierarchy.dendrogram`
- #5305: Wrong image scaling in `scipy/misc/pilutil.py` with `misc.imsave`?
- #5823: test failure in `filter_design`
- #6061: `scipy.stats.spearmanr` return values outside range -1 to 1
- #6242: Inconsistency / duplication for `imread` and `imshow`, `imsave`
- #6265: BUG: `signal.iirfilter` of bandpass type is unstable when high...
- #6370: `scipy.optimize.linear_sum_assignment` hangs on undefined matrix
- #6417: `scipy.misc.imresize` converts images to `uint8`
- #6618: `splrep` and `splprep` inconsistent
- #6854: Support PEP 519 in I/O functions
- #6921: [Feature request] Random unitary matrix
- #6930: `uniform_filter1d` appears to truncate rather than round when output...
- #6949: `interp2d` function crashes python
- #6959: `scipy.interpolate.LSQUnivariateSpline` - check for increasing...
- #7005: `linear_sum_assignment` in `scipy.optimize` never return if one of...
- #7010: `scipy.stats.binned_statistic_2d`: incorrect binnumbers returned
- #7049: `expm_multiply` is excessively slow when called for intervals
- #7050: Documenting `_argcheck` for `rv_discrete`
- #7077: `coo_matrix.tocsr()` still slow
- #7093: Wheels licensing
- #7122: Sketching-based Matrix Computations
- #7133: Discontinuity of a scipy special function
- #7141: Improve documentation for Elliptic Integrals

- #7181: A change in `numpy.poly1d` is causing the scipy tests to fail.
- #7220: String Formatting Issue in `LinearOperator.__init__`
- #7239: Source tarball distribution
- #7247: `genlaguerre poly1d`-object doesn't respect 'monic' option at evaluation
- #7248: BUG: regression in Legendre polynomials on master
- #7316: `dgels` is missing
- #7381: Krogh interpolation fails to produce derivatives for complex...
- #7416: `scipy.stats.kappa4(h,k)` raise a `ValueError` for positive integer...
- #7421: `scipy.stats.arcsine().pdf` and `scipy.stats.beta(0.5, 0.5).pdf`...
- #7429: `test_matrix_norms()` in `scipy/linalg/tests/test_basic.py` calls...
- #7444: Doc: `stats.dirichlet.var` output description is wrong
- #7475: Parameter `amax` in `scalar_search_wolfe2` is not used
- #7510: Operations between `numpy.array` and `scipy.sparse` matrix return...
- #7550: DOC: signal tutorial: Typo in explanation of convolution
- #7551: `stdint.h` included in SuperLU header files, but does not exist...
- #7553: Build for master broken on OS X
- #7557: Error in `scipy.signal.periodogram` example
- #7590: OSX test fail - `test_ltisys.TestPlacePoles.test_real`
- #7658: `optimize.BenchGlobal` broken
- #7669: nan result from `multivariate_normal.cdf`
- #7733: Inconsistent usage of indices, `indptr` in `Delaunay.vertex_neighbor_vertices`
- #7747: Numpy changes in `np.random.dirichlet` cause test failures
- #7772: Fix numpy `lstsq rcond=` parameter
- #7776: tests require `nose`
- #7798: contributor names for 1.0 release notes
- #7828: 32-bit Linux test errors on TestCephes
- #7893: `scipy.spatial.distance.wminkowski` behaviour change in 1.0.0b1
- #7898: DOC: Window functions
- #7959: BUG maybe: `fmin_bfgs` possibly broken in 1.0
- #7969: `scipy 1.0.0rc1` windows wheels depend on missing `msvcpl40.dll`

### 1.1.17 Pull requests for 1.0.0

- #4978: WIP: add `pre_center` and `normalize` options to `lombscargle`
- #5796: TST: Remove all permanent filter changes from tests
- #5910: ENH: `sparse.linalg`: add `GCROT(m,k)`
- #6326: ENH: New ODE solvers

- #6480: ENH: Make `signal.decimate` default to `zero_phase=True`
- #6705: ENH: add initial guess to `sparse.linalg.lsqr`
- #6706: ENH: add initial guess to `sparse.linalg.lsmr`
- #6769: BUG: optimize: add sufficient descent condition check to CG line...
- #6855: Handle objects supporting PEP 519 in I/O functions
- #6945: MAINT: ckdtree codebase clean up
- #6953: DOC: add a SciPy Project Governance document
- #6998: fix documentation of spearman rank `corrcoef`
- #7017: ENH: add methods `logcdf` and `cdf` to `scipy.stats.multivariate_normal`
- #7027: Add random unitary matrices
- #7030: ENH: Add strictly-increasing checks for `x` to 1D splines
- #7031: BUG: Fix `linear_sum_assignment` hanging on an undefined matrix
- #7041: DOC: Clarify that windows are DFT-even by default
- #7048: DOC: modified docs for `find_peak_cwt`. Fixes #6922
- #7056: Fix insufficient precision when calculating spearman/kendall...
- #7057: MAINT: change dtype comparison in `optimize.linear_sum_assignment`.
- #7059: TST: make `Xdist_deprecated_args` cover all metrics
- #7061: Fix msvc 9 and 10 compile errors
- #7070: ENH: sparse: optimizing CSR/CSC slicing fast paths
- #7078: ENH: sparse: defer `sum_duplicates` to `csr/csc`
- #7079: ENH: sparse: allow subclasses to override specific math operations
- #7081: ENH: sparse: speed up `CSR/CSC toarray()`
- #7082: MAINT: Add missing `PyType_Ready(&SuperLUGlobalType)` for Py3
- #7083: Corrected typo in the doc of `scipy.linalg.lstsq()`
- #7086: Fix bug #7049 causing excessive slowness in `expm_multiply`
- #7088: Documented `_argcheck` for `rv_discrete`
- #7094: MAINT: Fix mistake in PR #7082
- #7098: BF: return NULL from failed Py3 module check
- #7105: MAINT: Customize `?TRSYL` call in `lyapunov` solver
- #7111: Fix error message typo in `UnivariateSpline`
- #7113: FIX: Add `add float` to return type in documentation
- #7119: ENH: `sparse.linalg`: remove `_count_nonzero` hack
- #7123: ENH: added “interior-point” method for `scipy.optimize.linprog`
- #7137: DOC: clarify `stats.linregress` docstring, closes gh-7074
- #7138: DOC: special: Add an example to the `airy` docstring.
- #7139: DOC: stats: Update stats tutorial

- #7142: BUG: special: prevent segfault in `pbwa`
- #7143: DOC: special: warn about alternate elliptic integral parameterizations
- #7146: fix docstring of `NearestNDInterpolator`
- #7148: DOC: special: Add Parameters, Returns and Examples to `gamma` docstring
- #7152: MAINT: spatial: Remove two unused variables in `ckdtree/src/distance.h`
- #7153: MAINT: special: remove deprecated variant of `gammaln`
- #7154: MAINT: Fix some code that generates C compiler warnings
- #7155: DOC: `linalg`: Add examples for `solve_banded` and `solve_triangular`
- #7156: DOC: fix docstring of `NearestNDInterpolator`
- #7159: BUG: special: fix sign of derivative when  $x < 0$  in `pbwa`
- #7161: MAINT: `interpolate`: make `Rbf.A` array a property
- #7163: MAINT: special: return nan for inaccurate regions of `pbwa`
- #7165: ENH: optimize: changes to make BFGS implementation more efficient.
- #7166: BUG: Prevent infinite loop in `optimize._lsq.trf_linear.py`
- #7173: BUG: `sparse`: return a numpy matrix from `_add_dense`
- #7179: DOC: Fix an error in `sparse.argmax` docstring
- #7180: MAINT: `interpolate`: A bit of clean up in `interpolate/src/_interpolate.cpp`
- #7182: Allow homogeneous coordinate transforms in `affine_transform`
- #7184: MAINT: Remove hack modifying a readonly attr
- #7185: ENH: Add evaluation of periodic splines #6730
- #7186: MAINT: `PPoly`: improve error messages for wrong shape/axis
- #7187: DEP: `interpolate`: deprecate `interpolate_wrapper`
- #7198: DOC: `linalg`: Add examples for `solveh_banded` and `solve_toeplitz`.
- #7200: DOC: `stats`: Added tutorial documentation for the generalized...
- #7208: DOC: Added docstrings to `issparse/isspmatrix(...)` methods and...
- #7213: DOC: Added examples to `circmean`, `circvar`, `circstd`
- #7215: DOC: Adding examples to `scipy.sparse.linalg....` docstrings
- #7223: DOC: special: Add examples for `expit` and `logit`.
- #7224: BUG: `interpolate`: fix integer overflow in `fitpack.bispev`
- #7225: DOC: update 1.0 release notes for several recent PRs.
- #7226: MAINT: update docs and code for mailing list move to `python.org`
- #7233: Fix issue #7232: Do not mask exceptions in objective func evaluation
- #7234: MAINT: `cluster`: cleaning up VQ/k-means code
- #7236: DOC: Fixed typo
- #7238: BUG: fix syntaxerror due to unicode character in `trustregion_exact`.
- #7243: DOC: Update docstring in `misc/pilutil.py`

- #7246: DEP: misc: deprecate imported names
- #7249: DOC: Add plotted example to `scipy.cluster.vq.kmeans`
- #7252: Fix 5231: docs of `factr`, `ftol` in sync w/ code
- #7254: ENH: SphericalVoronoi Input Handling
- #7256: fix for issue #7255 - Circular statistics functions give wrong...
- #7263: CI: use python's fault handler to ease tracing segfaults
- #7288: ENH: linalg: add `subspace_angles` function.
- #7290: BUG: stats: Fix spurious warnings in `genextreme`.
- #7292: ENH: optimize: added trust region method `trust-trlib`
- #7296: DOC: stats: Add an example to the `ttest_ind_from_stats` docstring.
- #7297: DOC: signal: Add examples for `chirp()` and `sweep_poly()`.
- #7299: DOC: Made difference between `brent` and `fminbound` clearer
- #7305: Simplify if-statements and constructor calls in `integrate._ode`
- #7309: Comply with PEP 518.
- #7313: REL: add `python_requires` to `setup.py`, fix Python version check.
- #7315: BUG: Fixed bug with Laguerre and Legendre polynomials
- #7320: DOC: clarify meaning of flags in `ode.integrate`
- #7333: DOC: Add examples to `scipy.ndimage.gaussian_filter1d`
- #7337: ENH: add n-dimensional DCT and IDCT to `fftpack`
- #7353: Add `_gels` functions
- #7357: DOC: linalg: Add examples to the `svdvals` docstring.
- #7359: Bump Sphinx version to 1.5.5
- #7361: DOC: linalg: Add some 'See Also' links among special matrices...
- #7362: TST: Fix some Fedora 25 test failures.
- #7363: DOC: linalg: tweak the docstring example of `svd`
- #7365: MAINT: fix `refguide_check.py` for Sphinx  $\geq 1.5$
- #7367: BUG: `odrpack`: fix invalid stride checks in `d_lpkbls.f`
- #7368: DOC: constants: Add examples to the 'find' docstring.
- #7376: MAINT: bundle Mathjax with built docs
- #7377: MAINT: optimize: Better name for trust-region-exact method.
- #7378: Improve wording in tutorial
- #7383: fix `KroghInterpolator.derivatives` failure with complex input
- #7389: FIX: Copy mutable window in `resample_poly`
- #7390: DOC: optimize: A few tweaks of the examples in the `curve_fit`
- #7391: DOC: Add examples to `scipy.stats`
- #7394: "Weight" is actually mass. Add slugs and slinches/blobs to mass

- #7398: DOC: Correct minor typo in `optimize.{brenth,brentq}`
- #7401: DOC: `zeta` only accepts real input
- #7413: BUG: fix error messages in `_minimize_trustregion_exact`
- #7414: DOC: fix `ndimage.distance_transform_bf` docstring [ci skip]
- #7415: DOC: fix skew docstring [ci skip]
- #7423: Expand `binnumbers` with correct dimensions
- #7431: BUG: Extend `scipy.stats.arcsine.pdf` to endpoints 0 and 1 #7427
- #7432: DOC: Add examples to `scipy.cluster.hierarchy`
- #7448: ENH: stats: Implement the survival function for `pareto`.
- #7454: FIX Replaced `np.assert_allclose` with imported `assert_allclose`
- #7460: TST: fix `integrate.ivp` test that fails on 32-bit Python.
- #7461: Doc: Added tutorial documentation for stats distributions `ksone`
- #7463: DOC: Fix typos and remove trailing whitespace
- #7465: Fix some `ndimage.interpolation` endianness bugs
- #7468: del `redundance` in `interpolate.py`
- #7470: Initialize “info” in `minpack_lmdif`
- #7478: Added more testing of `smirnov/smironvi` functions
- #7479: MAINT: update for new `FutureWarning`’s in `numpy 1.13.0`
- #7480: DOC: correctly describe output shape of `dirichlet.mean()` and...
- #7482: `signal.lti`: Remove deprecated cross-system properties
- #7484: MAINT: Clean-up uses of `np.asarray` in `ndimage`
- #7485: ENH: support any order  $\geq 0$  in `ndimage.gaussian_filter`
- #7486: ENH: Support `k!=0` for `sparse.diagonal()`
- #7498: BUG: `sparse`: pass `assumeSortedIndices` option to `scikit.umfpack`
- #7501: ENH: add optimal leaf ordering for linkage matrices
- #7506: MAINT: remove overflow in `Metropolis` fixes #7495
- #7507: TST: speed up full test suite by less eval points in `mpmath` tests.
- #7509: BUG: fix issue when using `python setup.py somecommand --force`.
- #7511: fix some alerts found with `lgtm`
- #7514: Add explanation what the integer returned mean.
- #7516: BUG: Fix roundoff errors in `ndimage.uniform_filter1d`.
- #7517: TST: fix `signal.convolve` test that was effectively being skipped.
- #7523: ENH: `linalg`: allow `lstsq` to work with 0-shaped arrays
- #7525: TST: Warning cleanup
- #7526: DOC: params in `ndimage.interpolation` functions not optional
- #7527: MAINT: Encapsulate error message handling in `NI_LineBuffer`.

- #7528: MAINT: Remove ndimage aliases for NPY\_MAXDIMS.
- #7529: MAINT: Remove NI\_(UN) LIKELY macros in favor of numpy ones.
- #7537: MAINT: Use accessor function for numpy array internals
- #7541: MAINT: Remove some uses of Numarray types in ndimage.
- #7543: MAINT: Replace all NumarrayTypes uses in ni\_fourier.c
- #7544: MAINT: Replace all uses of NumarrayTypes in ni\_interpolation.c
- #7545: MAINT: Replace all uses of NumarrayTypes in ni\_measure.c
- #7546: MAINT: Replace all uses of NumarrayTypes in ni\_morphology.c
- #7548: DOC: make a note in benchmarks README on how to run without rebuilding.
- #7549: MAINT: Get rid of NumarrayTypes.
- #7552: TST: Fix new warnings -> error bugs found on OSX
- #7554: Update superlu to 5.2.1 + fix stdint.h issue on MSVC
- #7556: MAINT: Fix some types from #7549 + miscellaneous warnings.
- #7558: MAINT: Use correct #define NO\_IMPORT\_ARRAY, not NO\_ARRAY\_IMPORT...
- #7562: BUG: Copy import\_nose from numpy.
- #7563: ENH: Add the first Wasserstein and the Cramér-von Mises statistical...
- #7568: Test janitoring
- #7571: Test janitoring pt. 2
- #7572: Pytestifying
- #7574: TST: Remove ignore warnings filters from stats
- #7577: MAINT: Remove unused code in ndimage/ni\_measure.c and .h
- #7578: TST: Remove ignore warnings filters from sparse, clean up warning...
- #7581: BUG: properly deallocate memory from PyArray\_IntpConverter.
- #7582: DOC: signal tutorial: Typo in explanation of convolution
- #7583: Remove remaining ignore warnings filters
- #7586: DOC: add note to HACKING.rst on where to find build docs.
- #7587: DOC: Add examples to scipy.optimize
- #7594: TST: Add tests for ndimage converter functions.
- #7596: Added a sanity check to signal.savgol\_filter
- #7599: \_upfirdn\_apply stopping condition bugfix
- #7601: MAINT: special: remove sph\_jn et al.
- #7602: TST: fix test failures in trimmed statistics tests with numpy...
- #7605: Be clear about required dimension order
- #7606: MAINT: Remove unused function NI\_NormalizeType.
- #7607: TST: add osx to travis matrix
- #7608: DOC: improve HACKING guide - mention reviewing PRs as contribution.

- #7609: MAINT: Remove unnecessary warning filter by avoding unnecessary...
- #7610: #7557 : fix example code in periodogram
- #7611: #7220 : fix TypeError while raising ValueError for invalid shape
- #7612: Convert yield tests to pytest parametrized tests
- #7613: Add distributor init file
- #7614: fixup header
- #7615: BUG: sparse: Fix assignment w/ non-canonical sparse argument
- #7617: DOC: Clarify digital filter functions
- #7619: ENH: scipy.sparse.spmatrix.astype: casting and copy parameter...
- #7621: Expose VODE/ZVODE/LSODE IDID return code to user
- #7622: MAINT: special: remove out-of-date comment for `ellpk`
- #7625: TST: Add a test for “ignore” warning filters
- #7628: MAINT: refactoring and cleaning `distance.py/c/h`
- #7629: DEP: deprecate args usage in `xdist`
- #7630: ENH: weighted metrics
- #7634: Follow-up to #6855
- #7635: `interpolate.splprep`: Test some error cases, give slightly better...
- #7642: Add an example to `interpolate.lagrange`
- #7643: ENH: Added wrappers for LAPACK `<s,d>stev`
- #7649: Fix #7636, add PEP 519 test coverage to remaining I/O functions
- #7650: DOC: signal: Add ‘Examples’ to the docstring for `sosfiltfilt`.
- #7651: Fix up `ccache` usage on Travis + try enabling on OSX
- #7653: DOC: transition of examples from 2 to 3. Closes #7366
- #7659: BENCH: fix `optimize.BenchGlobal`. Closes gh-7658.
- #7662: CI: speed up continuous integration builds
- #7664: Update `odr` documentation
- #7665: BUG: `wolfe2` line/scalar search now uses `amax` parameter
- #7671: MAINT: `_lib/ccallback.h`: `PyCapsule_GetName` returns `const char*`
- #7672: TST: `interpolate`: test integrating periodic b-splines against...
- #7674: Tests tuning
- #7675: CI: move `refguide-check` to faster build
- #7676: DOC: bump `scipy-sphinx-theme` to fix `copybutton.js`
- #7678: Note the zero-padding of the results of `splrep` and `splprep`
- #7681: MAINT: `_lib`: add user-overrideable available memory determination
- #7684: TST: `linalg`: explicitly close opened `npz` files
- #7686: MAINT: remove unnecessary shebang lines and executable bits

- #7687: BUG: stats: don't emit invalid warnings if moments are infinite
- #7690: ENH: allow int-like parameters in several routines
- #7691: DOC: Drop non-working source links from docs
- #7694: fix `ma.array` to `ma.array` in `func median_cihs`
- #7698: BUG: stats: fix nan result from `multivariate_normal.cdf` (#7669)
- #7703: DOC: special: Update the docstrings for noncentral F functions.
- #7709: BLD: integrate: avoid symbol clash between `lsoda` and `vode`
- #7711: TST: `_lib`: make `test_parallel_threads` to not fail falsely
- #7712: TST: stats: bump test tolerance in `TestMultivariateNormal.test_broadcasting`
- #7715: MAINT: fix deprecated use of `numpy.issubdtype`
- #7716: TST: integrate: drop timing tests
- #7717: MAINT: `mstats.winsorize` inclusion bug fix
- #7719: DOC: stats: Add a note about the special cases of the `rdist` distribution.
- #7720: DOC: Add example and math to `stats.pearsonr`
- #7723: DOC: Added Mann-Whitney U statistic reference
- #7727: BUG: special/cdflib: deal with nan and nonfinite inputs
- #7728: BLD: spatial: fix `ckdtree` depends header list
- #7732: BLD: update Bento build for `optimal_leaf_ordering` addition
- #7734: DOC: signal: Copy-edit and add examples to the Kaiser-related...
- #7736: BUG: Fixes #7735: Prevent integer overflow in concatenated index...
- #7737: DOC: rename `indices/indptr` for `spatial.Delaunay` `vertex_neighbor_vertices`
- #7738: ENH: Speed up `freqz` computation
- #7739: TST: ignore `ncfdtridfn` failure in `win32` and warn on FPU mode changes
- #7740: Fix overflow in Anderson-Darling k-sample test
- #7742: TST: special: limit `expm1` `mpmath` comparison range
- #7748: TST: stats: don't pass invalid `alpha` to `np.random.dirichlet`
- #7749: BUG/DOC: optimize: method is 'interior-point', not 'interior...
- #7751: BUG: optimize: `show_options('linprog', method='interior-point')`...
- #7753: ENH: io: easier syntax for `FortranFile` read/write of mixed records
- #7754: BLD: add `_lib._fpumode` extension to Bento build.
- #7756: DOC: Show probability density functions as math
- #7757: MAINT: remove outdated OS X build scripts. Fixes `pytest` failure.
- #7758: MAINT: stats: `pep8`, wrap lines
- #7760: DOC: special: add instructions on how to add special functions
- #7761: DOC: allow specifying Python version for Sphinx makefile
- #7765: TST: fix test coverage of `mstats_extras.py`

- #7767: DOC: update 1.0 release notes.
- #7768: DOC: update notes on how to release. Also change paver file to...
- #7769: Add the `_sf` and `_logsf` function for `planck` dist
- #7770: DOC: Replace rotten links in the docstring of `minres`
- #7771: MAINT: `f2py` build output cleanup
- #7773: DOC: optimize: Some copy-editing of `linprog` docs.
- #7774: MAINT: set `rcond` explicitly for `np.linalg.lstsq` calls
- #7777: remove leftover `nose` imports
- #7780: ENH: Wrap LAPACK's `dsytrd`
- #7781: DOC: Link `rfft`
- #7782: MAINT: run `pyx` autogeneration in `cythonize` & remove `autogen` files
- #7783: FIX: Disallow `Wn==1` in digital filters
- #7790: Fix test errors introduced by `gh-5910`
- #7792: MAINT: fix syntax in `pyproject.toml`
- #7809: ENH: sketches - Clarkson Woodruff Transform
- #7810: ENH: Add `eig(vals)_tridiagonal`
- #7811: BUG: stats: Fix warnings in `binned_statistics_dd`
- #7814: ENH: signal: Replace 'nyq' and 'Hz' arguments with 'fs'.
- #7820: DOC: update 1.0 release notes and `mailmap`
- #7823: BUG: memory leak in `messagestream / qhull.pyx`
- #7830: DOC: `linalg`: Add an example to the `lstsq` docstring.
- #7835: ENH: Automatic FIR order for `decimate`
- #7838: MAINT: stats: Deprecate `frechet_l` and `frechet_r`.
- #7841: `slsqp` PEP8 formatting fixes, typos, etc.
- #7843: ENH: Wrap all BLAS routines
- #7844: DOC: update `LICENSE.txt` with licenses of bundled libs as needed.
- #7851: ENH: Add wrappers for `?GGLSE`, `?(HE/SY)CON`, `?SYTF2`, `?(HE/SY)TRF`
- #7856: ENH: added out argument to `Xdist`
- #7858: BUG: `special/cdflib`: fix fatal loss of precision issues in `cumfnc`
- #7859: FIX: Squash `place_poles` warning corner case
- #7861: dummy statement for undefined `WITH_THREAD`
- #7863: MAINT: add license texts to binary distributions
- #7866: DOC, MAINT: fix links in the doc
- #7867: DOC: fix up descriptions of pdf's in distribution docstrings.
- #7869: DEP: deprecate `misc.pilutil` functions
- #7870: DEP: remove deprecated functions

- #7872: TST: silence RuntimeWarning for stats.truncnorm test marked as...
- #7874: TST: fix an optimize.linprog test that fails intermittently.
- #7875: TST: filter two integration warnings in stats tests.
- #7876: GEN: Add comments to the tests for clarification
- #7891: ENH: backport #7879 to 1.0.x
- #7902: MAINT: signal: Make freqz handling of multidim. arrays match...
- #7905: REV: restore wminkowski
- #7908: FIX: Avoid bad `__del__` (close) behavior
- #7918: TST: mark two optimize.linprog tests as xfail. See gh-7877.
- #7929: MAINT: changed defaults to lower in sytf2, sytrf and hetrf
- #7939: Fix umfpack solver construction for win-amd64
- #7948: DOC: add note on checking for deprecations before upgrade to...
- #7952: DOC: update SciPy Roadmap for 1.0 release and recent discussions.
- #7960: BUG: optimize: revert changes to bfgs in gh-7165
- #7962: TST: special: mark a failing hyp2f1 test as xfail
- #7973: BUG: fixed keyword in 'info' in `_get_mem_available` utility
- #8001: TST: fix test failures from Matplotlib 2.1 update
- #8010: BUG: signal: fix crash in lfilter
- #8019: MAINT: fix test failures with NumPy master

## 1.2 SciPy 0.19.1 Release Notes

SciPy 0.19.1 is a bug-fix release with no new features compared to 0.19.0. The most important change is a fix for a severe memory leak in `integrate.quad`.

### 1.2.1 Authors

- Evgeni Burovski
- Patrick Callier +
- Yu Feng
- Ralf Gommers
- Ilhan Polat
- Eric Quintero
- Scott Sievert
- Pauli Virtanen
- Warren Weckesser

A total of 9 people contributed to this release. People with a “+” by their names contributed a patch for the first time. This list of names is automatically generated, and may not be fully complete.

### Issues closed for 0.19.1

- #7214: Memory use in `integrate.quad` in `scipy-0.19.0`
- #7258: `linalg.matrix_balance` gives wrong transformation matrix
- #7262: Segfault in daily testing
- #7273: `scipy.interpolate._bspl.evaluate_spline` gets wrong type
- #7335: `scipy.signal.dlti(A,B,C,D).freqresp()` fails

### Pull requests for 0.19.1

- #7211: BUG: `convolve` may yield inconsistent dtypes with method changed
- #7216: BUG: `integrate`: fix recounting bug in `quad()`
- #7229: MAINT: special: Rewrite a test of `wrightomega`
- #7261: FIX: Corrected the transformation matrix permutation
- #7265: BUG: Fix broken axis handling in spectral functions
- #7266: FIX 7262: `ckdtree` crashes in `query_knn`.
- #7279: Upcast half- and single-precision floats to doubles in BSpline...
- #7336: BUG: Fix `signal.dfreqresp` for StateSpace systems
- #7419: Fix several issues in `sparse.load_npz`, `save_npz`
- #7420: BUG: `stats`: allow integers as `kappa4` shape parameters

## 1.3 SciPy 0.19.0 Release Notes

### Contents

- *SciPy 0.19.0 Release Notes*
  - *New features*
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    - \* *scipy.ndimage improvements*
    - \* *scipy.optimize improvements*
    - \* *scipy.signal improvements*
    - \* *scipy.fftpack improvements*
    - \* *scipy.cluster improvements*
    - \* *scipy.sparse improvements*
    - \* *scipy.special improvements*

- \* `scipy.stats` *improvements*
- \* `scipy.interpolate` *improvements*
- \* `scipy.integrate` *improvements*
- *Deprecated features*
- *Backwards incompatible changes*
- *Other changes*
- *Authors*
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SciPy 0.19.0 is the culmination of 7 months of hard work. It contains many new features, numerous bug-fixes, improved test coverage and better documentation. There have been a number of deprecations and API changes in this release, which are documented below. All users are encouraged to upgrade to this release, as there are a large number of bug-fixes and optimizations. Moreover, our development attention will now shift to bug-fix releases on the 0.19.x branch, and on adding new features on the master branch.

This release requires Python 2.7 or 3.4-3.6 and NumPy 1.8.2 or greater.

Highlights of this release include:

- A unified foreign function interface layer, `scipy.LowLevelCallable`.
- Cython API for scalar, typed versions of the universal functions from the `scipy.special` module, via `import scipy.special.cython_special`.

### 1.3.1 New features

#### Foreign function interface improvements

`scipy.LowLevelCallable` provides a new unified interface for wrapping low-level compiled callback functions in the Python space. It supports Cython imported “api” functions, ctypes function pointers, CFFI function pointers, PyCapsules, Numba jitted functions and more. See [gh-6509](#) for details.

#### `scipy.linalg` improvements

The function `scipy.linalg.solve` obtained two more keywords `assume_a` and `transposed`. The underlying LAPACK routines are replaced with “expert” versions and now can also be used to solve symmetric, hermitian and positive definite coefficient matrices. Moreover, ill-conditioned matrices now cause a warning to be emitted with the estimated condition number information. Old `sym_pos` keyword is kept for backwards compatibility reasons however it is identical to using `assume_a='pos'`. Moreover, the `debug` keyword, which had no function but only printing the `overwrite_<a, b>` values, is deprecated.

The function `scipy.linalg.matrix_balance` was added to perform the so-called matrix balancing using the LAPACK xGEBAL routine family. This can be used to approximately equate the row and column norms through diagonal similarity transformations.

The functions `scipy.linalg.solve_continuous_are` and `scipy.linalg.solve_discrete_are` have numerically more stable algorithms. These functions can also solve generalized algebraic matrix Riccati equations. Moreover, both gained a `balanced` keyword to turn balancing on and off.

### scipy.spatial improvements

`scipy.spatial.SphericalVoronoi.sort_vertices_of_regions` has been re-written in Cython to improve performance.

`scipy.spatial.SphericalVoronoi` can handle > 200 k points (at least 10 million) and has improved performance.

The function `scipy.spatial.distance.directed_hausdorff` was added to calculate the directed Hausdorff distance.

`count_neighbors` method of `scipy.spatial.cKDTree` gained an ability to perform weighted pair counting via the new keywords `weights` and `cumulative`. See [gh-5647](#) for details.

`scipy.spatial.distance.pdist` and `scipy.spatial.distance.cdist` now support non-double custom metrics.

### scipy.ndimage improvements

The callback function C API supports PyCapsules in Python 2.7

Multidimensional filters now allow having different extrapolation modes for different axes.

### scipy.optimize improvements

The `scipy.optimize.basinhopping` global minimizer obtained a new keyword, `seed`, which can be used to seed the random number generator and obtain repeatable minimizations.

The keyword `sigma` in `scipy.optimize.curve_fit` was overloaded to also accept the covariance matrix of errors in the data.

### scipy.signal improvements

The function `scipy.signal.correlate` and `scipy.signal.convolve` have a new optional parameter `method`. The default value of `auto` estimates the fastest of two computation methods, the direct approach and the Fourier transform approach.

A new function has been added to choose the convolution/correlation method, `scipy.signal.choose_conv_method` which may be appropriate if convolutions or correlations are performed on many arrays of the same size.

New functions have been added to calculate complex short time fourier transforms of an input signal, and to invert the transform to recover the original signal: `scipy.signal.stft` and `scipy.signal.istft`. This implementation also fixes the previously incorrect output of `scipy.signal.spectrogram` when complex output data were requested.

The function `scipy.signal.sosfreqz` was added to compute the frequency response from second-order sections.

The function `scipy.signal.unit_impulse` was added to conveniently generate an impulse function.

The function `scipy.signal.iirnotch` was added to design second-order IIR notch filters that can be used to remove a frequency component from a signal. The dual function `scipy.signal.iirpeak` was added to compute the coefficients of a second-order IIR peak (resonant) filter.

The function `scipy.signal.minimum_phase` was added to convert linear-phase FIR filters to minimum phase.

The functions `scipy.signal.upfirdn` and `scipy.signal.resample_poly` are now substantially faster when operating on some n-dimensional arrays when  $n > 1$ . The largest reduction in computation time is realized in cases where the size of the array is small (<1k samples or so) along the axis to be filtered.

### **scipy.fftpack improvements**

Fast Fourier transform routines now accept `np.float16` inputs and upcast them to `np.float32`. Previously, they would raise an error.

### **scipy.cluster improvements**

Methods "centroid" and "median" of `scipy.cluster.hierarchy.linkage` have been significantly sped up. Long-standing issues with using `linkage` on large input data (over 16 GB) have been resolved.

### **scipy.sparse improvements**

The functions `scipy.sparse.save_npz` and `scipy.sparse.load_npz` were added, providing simple serialization for some sparse formats.

The `prune` method of classes `bsr_matrix`, `csc_matrix`, and `csr_matrix` was updated to reallocate backing arrays under certain conditions, reducing memory usage.

The methods `argmin` and `argmax` were added to classes `coo_matrix`, `csc_matrix`, `csr_matrix`, and `bsr_matrix`.

New function `scipy.sparse.csgraph.structural_rank` computes the structural rank of a graph with a given sparsity pattern.

New function `scipy.sparse.linalg.spsolve_triangular` solves a sparse linear system with a triangular left hand side matrix.

### **scipy.special improvements**

Scalar, typed versions of universal functions from `scipy.special` are available in the Cython space via `cimport` from the new module `scipy.special.cython_special`. These scalar functions can be expected to be significantly faster than the universal functions for scalar arguments. See the `scipy.special` tutorial for details.

Better control over special-function errors is offered by the functions `scipy.special.geterr` and `scipy.special.seterr` and the context manager `scipy.special.errstate`.

The names of orthogonal polynomial root functions have been changed to be consistent with other functions relating to orthogonal polynomials. For example, `scipy.special.j_roots` has been renamed `scipy.special.roots_jacobi` for consistency with the related functions `scipy.special.jacobi` and `scipy.special.eval_jacobi`. To preserve back-compatibility the old names have been left as aliases.

Wright Omega function is implemented as `scipy.special.wrightomega`.

### **scipy.stats improvements**

The function `scipy.stats.weightedtau` was added. It provides a weighted version of Kendall's tau.

New class `scipy.stats.multinomial` implements the multinomial distribution.

New class `scipy.stats.rv_histogram` constructs a continuous univariate distribution with a piecewise linear CDF from a binned data sample.

New class `scipy.stats.argus` implements the Argus distribution.

### scipy.interpolate improvements

New class `scipy.interpolate.BSpline` represents splines. `BSpline` objects contain knots and coefficients and can evaluate the spline. The format is consistent with FITPACK, so that one can do, for example:

```
>>> t, c, k = splrep(x, y, s=0)
>>> spl = BSpline(t, c, k)
>>> np.allclose(spl(x), y)
```

`spl*` functions, `scipy.interpolate.splev`, `scipy.interpolate.splint`, `scipy.interpolate.splder` and `scipy.interpolate.splantider`, accept both `BSpline` objects and `(t, c, k)` tuples for backwards compatibility.

For multidimensional splines, `c.ndim > 1`, `BSpline` objects are consistent with piecewise polynomials, `scipy.interpolate.PPoly`. This means that `BSpline` objects are not immediately consistent with `scipy.interpolate.splprep`, and one *cannot* do `>>> BSpline(*splprep([x, y])[0])`. Consult the `scipy.interpolate` test suite for examples of the precise equivalence.

In new code, prefer using `scipy.interpolate.BSpline` objects instead of manipulating `(t, c, k)` tuples directly.

New function `scipy.interpolate.make_interp_spline` constructs an interpolating spline given data points and boundary conditions.

New function `scipy.interpolate.make_lsq_spline` constructs a least-squares spline approximation given data points.

### scipy.integrate improvements

Now `scipy.integrate.fixed_quad` supports vector-valued functions.

## 1.3.2 Deprecated features

`scipy.interpolate.splmake`, `scipy.interpolate.spleval` and `scipy.interpolate.spline` are deprecated. The format used by `splmake/spleval` was inconsistent with `splrep/splev` which was confusing to users.

`scipy.special.errprint` is deprecated. Improved functionality is available in `scipy.special.seterr`.

calling `scipy.spatial.distance.pdist` or `scipy.spatial.distance.cdist` with arguments not needed by the chosen metric is deprecated. Also, metrics “`old_cosine`” and “`old_cos`” are deprecated.

## 1.3.3 Backwards incompatible changes

The deprecated `scipy.weave` submodule was removed.

`scipy.spatial.distance.squareform` now returns arrays of the same dtype as the input, instead of always `float64`.

`scipy.special.errprint` now returns a boolean.

The function `scipy.signal.find_peaks_cwt` now returns an array instead of a list.

`scipy.stats.kendalltau` now computes the correct p-value in case the input contains ties. The p-value is also identical to that computed by `scipy.stats.mstats.kendalltau` and by R. If the input does not contain ties there is no change w.r.t. the previous implementation.

The function `scipy.linalg.block_diag` will not ignore zero-sized matrices anymore. Instead it will insert rows or columns of zeros of the appropriate size. See [gh-4908](#) for more details.

### 1.3.4 Other changes

SciPy wheels will now report their dependency on `numpy` on all platforms. This change was made because Numpy wheels are available, and because the `pip` upgrade behavior is finally changing for the better (use `--upgrade-strategy=only-if-needed` for `pip >= 8.2`; that behavior will become the default in the next major version of `pip`).

Numerical values returned by `scipy.interpolate.interpld` with `kind="cubic"` and `"quadratic"` may change relative to previous `scipy` versions. If your code depended on specific numeric values (i.e., on implementation details of the interpolators), you may want to double-check your results.

### 1.3.5 Authors

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A total of 121 people contributed to this release. People with a “+” by their names contributed a patch for the first time. This list of names is automatically generated, and may not be fully complete.

### Issues closed for 0.19.0

- [#1767](#): Function definitions in `__fitpack.h` should be moved. (Trac #1240)
- [#1774](#): `_kmeans` chokes on large thresholds (Trac #1247)
- [#2089](#): Integer overflows cause segfault in linkage function with large...
- [#2190](#): Are odd-length window functions supposed to be always symmetrical?...
- [#2251](#): `solve_discrete_are` in `scipy.linalg` does (sometimes) not solve...
- [#2580](#): `scipy.interpolate.UnivariateSpline` (or a new superclass of it)...
- [#2592](#): `scipy.stats.anderson` assumes `gumbel_1`
- [#3054](#): `scipy.linalg.eig` does not handle infinite eigenvalues
- [#3160](#): multinomial pmf / logpmf
- [#3904](#): `scipy.special.ellipj` dn wrong values at quarter period

- #4044: Inconsistent code book initialization in kmeans
- #4234: scipy.signal.flattop documentation doesn't list a source for...
- #4831: Bugs in C code in \_\_quadpack.h
- #4908: bug: unnessesary validity check for block dimension in scipy.sparse.block\_diag
- #4917: BUG: indexing error for sparse matrix with `ix_`
- #4938: Docs on extending ndimage need to be updated.
- #5056: sparse matrix element-wise multiplying dense matrix returns dense...
- #5337: Formula in documentation for correlate is wrong
- #5537: use OrderedDict in io.netcdf
- #5750: [doc] missing data index value in KDTree, cKDTree
- #5755: p-value computation in scipy.stats.kendalltau() in broken in...
- #5757: BUG: Incorrect complex output of signal.spectrogram
- #5964: ENH: expose scalar versions of scipy.special functions to cython
- #6107: scipy.cluster.hierarchy.single segmentation fault with 2\*\*16...
- #6278: optimize.basinhopping should take a RandomState object
- #6296: InterpolatedUnivariateSpline: check\_finite fails when w is unspecified
- #6306: Anderson-Darling bad results
- #6314: scipy.stats.kendaltau() p value not in agreement with R, SPSS...
- #6340: Curve\_fit bounds and maxfev
- #6377: expm\_multiply, complex matrices not working using start,stop,ect...
- #6382: optimize.differential\_evolution stopping criterion has unintuitive...
- #6391: Global Benchmarking times out at 600s.
- #6397: mmwrite errors with large (but still 64-bit) integers
- #6413: scipy.stats.dirichlet computes multivariate gaussian differential...
- #6428: scipy.stats.mstats.mode modifies input
- #6440: Figure out ABI break policy for scipy.special Cython API
- #6441: Using Qhull for halfspace intersection : segfault
- #6442: scipy.spatial : In incremental mode volume is not recomputed
- #6451: Documentation for scipy.cluster.hierarchy.to\_tree is confusing...
- #6490: interp1d (kind=zero) returns wrong value for rightmost interpolation...
- #6521: scipy.stats.entropy does *not* calculate the KL divergence
- #6530: scipy.stats.spearmanr unexpected NaN handling
- #6541: Test runner does not run scipy.\_lib/tests?
- #6552: BUG: misc.bytescale returns unexpected results when using cmin/cmax...
- #6556: RectSphereBivariateSpline(u, v, r) fails if min(v) >= pi
- #6559: Differential\_evolution maxiter causing memory overflow

- #6565: Coverage of spectral functions could be improved
- #6628: Incorrect parameter name in binomial documentation
- #6634: Expose LAPACK's xGESVX family for `linalg.solve` ill-conditioned...
- #6657: Confusing documentation for `scipy.special.sph_harm`
- #6676: optimize: Incorrect size of Jacobian returned by `'minimize(...,...`
- #6681: add a new context manager to wrap `scipy.special.seterr`
- #6700: BUG: `scipy.io.wavfile.read` stays in infinite loop, warns on wav...
- #6721: `scipy.special.chebyt(N)` throw a `'TypeError'` when `N > 64`
- #6727: Documentation for `scipy.stats.norm.fit` is incorrect
- #6764: Documentation for `scipy.spatial.Delaunay` is partially incorrect
- #6811: `scipy.spatial.SphericalVoronoi` fails for large number of points
- #6841: `spearmanr` fails when `nan_policy='omit'` is set
- #6869: Currently in `gaussian_kde`, the `logpdf` function is calculated...
- #6875: SLSQP inconsistent handling of invalid bounds
- #6876: Python stopped working (Segfault?) with minimum/maximum filter...
- #6889: `dblquad` gives different results under `scipy 0.17.1` and `0.18.1`
- #6898: BUG: `dblquad` ignores error tolerances
- #6901: Solving sparse linear systems in CSR format with complex values
- #6903: issue in `spatial.distance.pdist` docstring
- #6917: Problem in passing `drop_rule` to `scipy.sparse.linalg.spilu`
- #6926: signature mismatches for `LowLevelCallable`
- #6961: Scipy contains shebang pointing to `/usr/bin/python` and `/bin/bash...`
- #6972: BUG: special: `generate_ufuncs.py` is broken
- #6984: Assert raises test failure for `test_ill_condition_warning`
- #6990: BUG: sparse: Bad documentation of the `k` argument in `sparse.linalg.eigs`
- #6991: Division by zero in `linregress()`
- #7011: possible speed improvement in `rv_continuous.fit()`
- #7015: Test failure with Python 3.5 and numpy master
- #7055: SciPy 0.19.0rc1 test errors and failures on Windows
- #7096: macOS test failues for `test_solve_continuous_are`
- #7100: `test_distance.test_Xdist_deprecated_args` test error in 0.19.0rc2

### Pull requests for 0.19.0

- #2908: Scipy 1.0 Roadmap
- #3174: add b-splines
- #4606: ENH: Add a unit impulse waveform function

- #5608: Adds keyword argument to choose faster convolution method
- #5647: ENH: Faster count\_neighbour in cKDTree / + weighted input data
- #6021: Netcdf append
- #6058: ENH: scipy.signal - Add stft and istft
- #6059: ENH: More accurate signal.freqresp for zpk systems
- #6195: ENH: Cython interface for special
- #6234: DOC: Fixed a typo in ward() help
- #6261: ENH: add docstring and clean up code for signal.normalize
- #6270: MAINT: special: add tests for cdflib
- #6271: Fix for scipy.cluster.hierarchy.is\_isomorphic
- #6273: optimize: rewrite while loops as for loops
- #6279: MAINT: Bessel tweaks
- #6291: Fixes gh-6219: remove runtime warning from genextreme distribution
- #6294: STY: Some PEP8 and cleaning up imports in stats/\_continuous\_distns.py
- #6297: Clarify docs in misc/\_\_init\_\_.py
- #6300: ENH: sparse: Loosen input validation for *diags* with empty inputs
- #6301: BUG: standardizes check\_finite behavior re optional weights,...
- #6303: Fixing example in \_lazysselect docstring.
- #6307: MAINT: more improvements to gammainc/gammaincc
- #6308: Clarified documentation of hypergeometric distribution.
- #6309: BUG: stats: Improve calculation of the Anderson-Darling statistic.
- #6315: ENH: Descending order of x in PPoly
- #6317: ENH: stats: Add support for nan\_policy to stats.median\_test
- #6321: TST: fix a typo in test name
- #6328: ENH: sosfreqz
- #6335: Define LinregressResult outside of linregress
- #6337: In anderson test, added support for right skewed gumbel distribution.
- #6341: Accept several spellings for the curve\_fit max number of function...
- #6342: DOC: cluster: clarify hierarchy.linkage usage
- #6352: DOC: removed brentq from its own 'see also'
- #6362: ENH: stats: Use explicit formulas for sf, logsf, etc in weibull...
- #6369: MAINT: special: add a comment to hyp0f1\_complex
- #6375: Added the multinomial distribution.
- #6387: MAINT: special: improve accuracy of ellipj's *dn* at quarter...
- #6388: BenchmarkGlobal - getting it to work in Python3
- #6394: ENH: scipy.sparse: add save and load functions for sparse matrices

- #6400: MAINT: moves global benchmark run from `setup_cache` to `track_all`
- #6403: ENH: seed kwd for `basinhopping`. Closes #6278
- #6404: ENH: signal: added `irrnotch` and `iirpeak` functions.
- #6406: ENH: special: extend `sici/shichi` to complex arguments
- #6407: ENH: Window functions should not accept non-integer or negative...
- #6408: MAINT: `_differentialevolution` now uses `_lib._util.check_random_state`
- #6427: MAINT: Fix `gmpy` build & test that `mpmath` uses `gmpy`
- #6439: MAINT: `ndimage`: update callback function c api
- #6443: BUG: Fix volume computation in incremental mode
- #6447: Fixes issue #6413 - Minor documentation fix in the entropy function...
- #6448: ENH: Add halfspace mode to `Qhull`
- #6449: ENH: `rtol` and `atol` for `differential_evolution` termination fixes...
- #6453: DOC: Add some See Also links between similar functions
- #6454: DOC: `linalg`: clarify callable signature in `ordqz`
- #6457: ENH: spatial: enable non-double dtypes in `squareform`
- #6459: BUG: Complex matrices not handled correctly by `expm_multiply...`
- #6465: TST DOC Window docs, tests, etc.
- #6469: ENH: `linalg`: better handling of infinite eigenvalues in `eig/eigvals`
- #6475: DOC: calling `interp1d/interp2d` with NaNs is undefined
- #6477: Document magic numbers in `optimize.py`
- #6481: TST: Suppress some warnings from `test_windows`
- #6485: DOC: spatial: correct typo in `procrustes`
- #6487: Fix Bray-Curtis formula in `pdist` docstring
- #6493: ENH: Add covariance functionality to `scipy.optimize.curve_fit`
- #6494: ENH: stats: Use `log1p()` to improve some calculations.
- #6495: BUG: Use MST algorithm instead of SLINK for single linkage clustering
- #6497: MRG: Add `minimum_phase` filter function
- #6505: reset `scipy.signal.resample` window shape to 1-D
- #6507: BUG: linkage: Raise exception if `y` contains non-finite elements
- #6509: ENH: `_lib`: add common machinery for low-level callback functions
- #6520: `scipy.sparse.base.__mul__` non-numpy/scipy objects with 'shape'...
- #6522: Replace `kl_div` by `rel_entr` in entropy
- #6524: DOC: add `next_fast_len` to list of functions
- #6527: DOC: Release notes to reflect the new covariance feature in `optimize.curve_fit`
- #6532: ENH: Simplify `_cos_win`, document it, add symmetric/periodic arg
- #6535: MAINT: `sparse.csgraph`: updating old cython loops

- #6540: DOC: add to documentation of orthogonal polynomials
- #6544: TST: Ensure tests for `scipy._lib` are run by `scipy.test()`
- #6546: updated docstring of `stats.linregress`
- #6553: committed changes that I originally submitted for `scipy.signal.cspline...`
- #6561: BUG: modify `signal.find_peaks_cwt()` to return array and accept...
- #6562: DOC: Negative binomial distribution clarification
- #6563: MAINT: be more liberal in requiring numpy
- #6567: MAINT: use `xrange` for iteration in `differential_evolution` fixes...
- #6572: BUG: “`sp.linalg.solve_discrete_are`” fails for random data
- #6578: BUG: misc: allow both `cmin/cmax` and `low/high` params in `bytescale`
- #6581: Fix some unfortunate typos
- #6582: MAINT: `linalg`: make handling of infinite eigenvalues in `ordqz...`
- #6585: DOC: `interpolate`: correct `seealso` links to `ndimage`
- #6588: Update docstring of `scipy.spatial.distance_matrix`
- #6592: DOC: Replace ‘first’ by ‘smallest’ in `mode`
- #6593: MAINT: remove `scipy.weave` submodule
- #6594: DOC: `distance.squareform`: fix html docs, add note about `dtype...`
- #6598: [DOC] Fix incorrect error message in `medfilt2d`
- #6599: MAINT: `linalg`: turn a `solve_discrete_are` test back on
- #6600: DOC: Add SOS goals to roadmap
- #6601: DEP: Raise minimum numpy version to 1.8.2
- #6605: MAINT: ‘new’ module is deprecated, don’t use it
- #6607: DOC: add note on change in wheel dependency on numpy and pip...
- #6609: Fixes #6602 - Typo in docs
- #6616: ENH: generalization of continuous and discrete Riccati solvers...
- #6621: DOC: improve `cluster.hierarchy` docstrings.
- #6623: CS matrix prune method should copy data from large unpruned arrays
- #6625: DOC: `special`: complete documentation of `eval_*` functions
- #6626: TST: `special`: silence some deprecation warnings
- #6631: fix parameter name doc for discrete distributions
- #6632: MAINT: `stats`: change some instances of *special* to *sc*
- #6633: MAINT: `refguide`: py2k long integers are equal to py3k integers
- #6638: MAINT: change type declaration in `cluster.linkage`, prevent overflow
- #6640: BUG: fix issue with duplicate values used in `cluster.vq.kmeans`
- #6641: BUG: fix corner case in `cluster.vq.kmeans` for large thresholds
- #6643: MAINT: clean up truncation modes of dendrogram

- #6645: MAINT: special: rename `*_roots` functions
- #6646: MAINT: clean up `mpmath` imports
- #6647: DOC: add `sqrt` to Mahalanobis description for `pdist`
- #6648: DOC: special: add a section on `cython_special` to the tutorial
- #6649: ENH: Added `scipy.spatial.distance.directed_hausdorff`
- #6650: DOC: add Sphinx roles for DOI and arXiv links
- #6651: BUG: `mstats`: make sure `mode(..., None)` does not modify its input
- #6652: DOC: special: add section to tutorial on functions not in special
- #6653: ENH: special: add the Wright Omega function
- #6656: ENH: don't coerce input to double with custom metric in `cdist...`
- #6658: Faster/shorter code for computation of discordances
- #6659: DOC: special: make `__init__` summaries and html summaries match
- #6661: `general.rst`: Fix a typo
- #6664: TST: Spectral functions' window correction factor
- #6665: [DOC] Conditions on `v` in `RectSphereBivariateSpline`
- #6668: DOC: Mention negative masses for center of mass
- #6675: MAINT: special: remove outdated README
- #6677: BUG: Fixes computation of p-values.
- #6679: BUG: optimize: return correct Jacobian for method 'SLSQP' in...
- #6680: ENH: Add structural rank to `sparse.csgraph`
- #6686: TST: Added Airspeed Velocity benchmarks for `SphericalVoronoi`
- #6687: DOC: add section "deciding on new features" to developer guide.
- #6691: ENH: Clearer error when `fmin_slsqp` obj doesn't return scalar
- #6702: TST: Added airspeed velocity benchmarks for `scipy.spatial.distance.cdist`
- #6707: TST: interpolate: test `fitpack` wrappers, not `_impl`
- #6709: TST: fix a number of test failures on 32-bit systems
- #6711: MAINT: move function definitions from `__fitpack.h` to `_fitpackmodule.c`
- #6712: MAINT: clean up wishlist in `stats.morestats`, and copyright statement.
- #6715: DOC: update the release notes with BSpline et al.
- #6716: MAINT: `scipy.io.wavfile`: No infinite loop when trying to read...
- #6717: some style cleanup
- #6723: BUG: special: cast to float before in-place multiplication in...
- #6726: address performance regressions in `interp1d`
- #6728: DOC: made code examples in `integrate` tutorial copy-pasteable
- #6731: DOC: `scipy.optimize`: Added an example for wrapping complex-valued...
- #6732: MAINT: `cython_special`: remove `errprint`

- #6733: MAINT: special: fix some pyflakes warnings
- #6734: DOC: sparse.linalg: fixed matrix description in *bicgstab* doc
- #6737: BLD: update *cythonize.py* to detect changes in pxi files
- #6740: DOC: special: some small fixes to docstrings
- #6741: MAINT: remove dead code in *interpolate.py*
- #6742: BUG: fix *linalg.block\_diag* to support zero-sized matrices.
- #6744: ENH: interpolate: make *PPoly.from\_spline* accept *BSpline* objects
- #6746: DOC: special: clarify use of Condon-Shortley phase in *sph\_harm\_lpmv*
- #6750: ENH: sparse: avoid densification on broadcasted elem-wise mult
- #6751: sinm doc explained cosm
- #6753: ENH: special: allow for more fine-tuned error handling
- #6759: Move *logsumexp* and *pade* from *scipy.misc* to *scipy.special* and...
- #6761: ENH: *argmax* and *argmin* methods for sparse matrices
- #6762: DOC: Improve docstrings of sparse matrices
- #6763: ENH: Weighted tau
- #6768: ENH: cythonized spherical Voronoi region polygon vertex sorting
- #6770: Correction of Delaunay class' documentation
- #6775: ENH: Integrating LAPACK "expert" routines with conditioning warnings...
- #6776: MAINT: Removing the trivial *f2py* warnings
- #6777: DOC: Update *rv\_continuous.fit* doc.
- #6778: MAINT: *cluster.hierarchy*: Improved wording of error msgs
- #6786: BLD: increase minimum Cython version to 0.23.4
- #6787: DOC: expand on *linalg.block\_diag* changes in 0.19.0 release...
- #6789: ENH: Add further documentation for *norm.fit*
- #6790: MAINT: Fix a potential problem in *nn\_chain* linkage algorithm
- #6791: DOC: Add examples to *scipy.ndimage.fourier*
- #6792: DOC: fix some *numpydoc* / *Sphinx* issues.
- #6793: MAINT: fix circular import after moving functions out of *misc*
- #6796: TST: test importing each submodule. Regression test for gh-6793.
- #6799: ENH: stats: Argus distribution
- #6801: ENH: stats: Histogram distribution
- #6803: TST: make sure tests for *\_build\_utils* are run.
- #6804: MAINT: more fixes in *loggamma*
- #6806: ENH: Faster linkage for 'centroid' and 'median' methods
- #6810: ENH: speed up *upfirdn* and *resample\_poly* for n-dimensional arrays
- #6812: TST: Added *ConvexHull* asv benchmark code

- #6814: ENH: Different extrapolation modes for different dimensions in...
- #6826: Signal spectral window default fix
- #6828: BUG: SphericalVoronoi Space Complexity (Fixes #6811)
- #6830: RealData docstring correction
- #6834: DOC: Added reference for skewtest function. See #6829
- #6836: DOC: Added mode='mirror' in the docstring for the functions accepting...
- #6838: MAINT: sparse: start removing old BSR methods
- #6844: handle incompatible dimensions when input is not an ndarray in...
- #6847: Added maxiter to golden search.
- #6850: BUG: added check for optional param scipy.stats.spearmanr
- #6858: MAINT: Removing redundant tests
- #6861: DEP: Fix escape sequences deprecated in Python 3.6.
- #6862: DOC: dx should be float, not int
- #6863: updated documentation curve\_fit
- #6866: DOC : added some documentation to j1 referring to spherical\_jn
- #6867: DOC: cdist move long examples list into Notes section
- #6868: BUG: Make stats.mode return a ModeResult namedtuple on empty...
- #6871: Corrected documentation.
- #6874: ENH: gaussian\_kde.logpdf based on logsumexp
- #6877: BUG: ndimage: guard against footprints of all zeros
- #6881: python 3.6
- #6885: Vectorized integrate.fixed\_quad
- #6886: fixed typo
- #6891: TST: fix failures for linalg.dare/care due to tightened test...
- #6892: DOC: fix a bunch of Sphinx errors.
- #6894: TST: Added asv benchmarks for scipy.spatial.Voronoi
- #6908: BUG: Fix return dtype for complex input in spsolve
- #6909: ENH: fftpack: use float32 routines for float16 inputs.
- #6911: added min/max support to binned\_statistic
- #6913: Fix 6875: SLSQP raise ValueError for all invalid bounds.
- #6914: DOCS: GH6903 updating docs of Spatial.distance.pdist
- #6916: MAINT: fix some issues for 32-bit Python
- #6924: BLD: update Bento build for scipy.LowLevelCallable
- #6932: ENH: Use OrderedDict in io.netcdf. Closes gh-5537
- #6933: BUG: fix LowLevelCallable issue on 32-bit Python.
- #6936: BUG: sparse: handle size-1 2D indexes correctly

- #6938: TST: fix test failures in special on 32-bit Python.
- #6939: Added attributes list to cKDTree docstring
- #6940: improve efficiency of dok\_matrix.tocoo
- #6942: DOC: add link to liac-arff package in the io.arff docstring.
- #6943: MAINT: Docstring fixes and an additional test for linalg.solve
- #6944: DOC: Add example of odeint with a banded Jacobian to the integrate...
- #6946: ENH: hypergeom.logpmf in terms of betaln
- #6947: TST: speedup distance tests
- #6948: DEP: Deprecate the keyword “debug” from linalg.solve
- #6950: BUG: Correctly treat large integers in MMIO (fixes #6397)
- #6952: ENH: Minor user-friendliness cleanup in LowLevelCallable
- #6956: DOC: improve description of ‘output’ keyword for convolve
- #6957: ENH more informative error in sparse.bmat
- #6962: Shebang fixes
- #6964: DOC: note argmin/argmax addition
- #6965: BUG: Fix issues passing error tolerances in dblquad and tplquad.
- #6971: fix the docstring of signaltools.correlate
- #6973: Silence expected numpy warnings in scipy.ndimage.interpolation.zoom()
- #6975: BUG: special: fix regex in *generate\_ufuncs.py*
- #6976: Update docstring for griddata
- #6978: Avoid division by zero in zoom factor calculation
- #6979: BUG: ARE solvers did not check the generalized case carefully
- #6985: ENH: sparse: add scipy.sparse.linalg.spsolve\_triangular
- #6994: MAINT: spatial: updates to plotting utils
- #6995: DOC: Bad documentation of k in sparse.linalg.eigs See #6990
- #6997: TST: Changed the test with a less singular example
- #7000: DOC: clarify interp1d ‘zero’ argument
- #7007: BUG: Fix division by zero in linregress() for 2 data points
- #7009: BUG: Fix problem in passing drop\_rule to scipy.sparse.linalg.spilu
- #7012: speed improvement in \_distn\_infrastructure.py
- #7014: Fix Typo: add a single quotation mark to fix a slight typo
- #7021: MAINT: stats: use machine constants from np.finfo, not machar
- #7026: MAINT: update .mailmap
- #7032: Fix layout of rv\_histogram docs
- #7035: DOC: update 0.19.0 release notes
- #7036: ENH: Add more boundary options to signal.stft

- #7040: TST: stats: skip too slow tests
- #7042: MAINT: sparse: speed up setdiag tests
- #7043: MAINT: refactor and code cleaning Xdist
- #7053: Fix msvc 9 and 10 compile errors
- #7060: DOC: updated release notes with #7043 and #6656
- #7062: MAINT: Change default STFT boundary kwarg to “zeros”
- #7064: Fix ValueError: path is on mount ‘X:’, start on mount ‘D:’ on...
- #7067: TST: Fix PermissionError: [Errno 13] Permission denied on Windows
- #7068: TST: Fix UnboundLocalError: local variable ‘data’ referenced...
- #7069: Fix OverflowError: Python int too large to convert to C long...
- #7071: TST: silence RuntimeWarning for nan test of stats.spearmanr
- #7072: Fix OverflowError: Python int too large to convert to C long...
- #7084: TST: linalg: bump tolerance in test\_falker
- #7095: TST: linalg: bump more tolerances in test\_falker
- #7101: TST: Relax solve\_continuous\_are test case 2 and 12
- #7106: BUG: stop cdist “correlation” modifying input
- #7116: Backports to 0.19.0rc2

## 1.4 SciPy 0.18.1 Release Notes

SciPy 0.18.1 is a bug-fix release with no new features compared to 0.18.0.

### 1.4.1 Authors

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A total of 9 people contributed to this release. People with a “+” by their names contributed a patch for the first time. This list of names is automatically generated, and may not be fully complete.

### Issues closed for 0.18.1

- #6357: scipy 0.17.1 piecewise cubic hermite interpolation does not return...
- #6420: circmean() changed behaviour from 0.17 to 0.18
- #6421: scipy.linalg.solve\_banded overwrites input 'b' when the inversion...
- #6425: cKDTree INF bug
- #6435: scipy.stats.ks\_2samp returns different values on different computers
- #6458: Error in scipy.integrate.dblquad when using variable integration...

### Pull requests for 0.18.1

- #6405: BUG: sparse: fix elementwise divide for CSR/CSC
- #6431: BUG: result for insufficient neighbours from cKDTree is wrong.
- #6432: BUG Issue #6421: scipy.linalg.solve\_banded overwrites input 'b'...
- #6455: DOC: add links to release notes
- #6462: BUG: interpolate: fix .roots method of PchipInterpolator
- #6492: BUG: Fix regression in dblquad: #6458
- #6543: fix the regression in circmean
- #6545: Revert gh-5938, restore ks\_2samp
- #6557: Backports for 0.18.1

## 1.5 SciPy 0.18.0 Release Notes

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  - \* `scipy.io`
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- *Other changes*
- *Authors*
  - \* *Issues closed for 0.18.0*
  - \* *Pull requests for 0.18.0*

SciPy 0.18.0 is the culmination of 6 months of hard work. It contains many new features, numerous bug-fixes, improved test coverage and better documentation. There have been a number of deprecations and API changes in this release, which are documented below. All users are encouraged to upgrade to this release, as there are a large number of bug-fixes and optimizations. Moreover, our development attention will now shift to bug-fix releases on the 0.19.x branch, and on adding new features on the master branch.

This release requires Python 2.7 or 3.4-3.5 and NumPy 1.7.1 or greater.

Highlights of this release include:

- A new ODE solver for two-point boundary value problems, `scipy.optimize.solve_bvp`.
- A new class, `CubicSpline`, for cubic spline interpolation of data.
- N-dimensional tensor product polynomials, `scipy.interpolate.NdPPoly`.
- Spherical Voronoi diagrams, `scipy.spatial.SphericalVoronoi`.
- Support for discrete-time linear systems, `scipy.signal.dlti`.

### 1.5.1 New features

#### `scipy.integrate` improvements

A solver of two-point boundary value problems for ODE systems has been implemented in `scipy.integrate.solve_bvp`. The solver allows for non-separated boundary conditions, unknown parameters and certain singular terms. It finds a C1 continuous solution using a fourth-order collocation algorithm.

#### `scipy.interpolate` improvements

Cubic spline interpolation is now available via `scipy.interpolate.CubicSpline`. This class represents a piecewise cubic polynomial passing through given points and C2 continuous. It is represented in the standard polynomial basis on each segment.

A representation of n-dimensional tensor product piecewise polynomials is available as the `scipy.interpolate.NdPPoly` class.

Univariate piecewise polynomial classes, `PPoly` and `Bpoly`, can now be evaluated on periodic domains. Use `extrapolate="periodic"` keyword argument for this.

### scipy.fftpack improvements

`scipy.fftpack.next_fast_len` function computes the next “regular” number for FFTPACK. Padding the input to this length can give significant performance increase for `scipy.fftpack.fft`.

### scipy.signal improvements

Resampling using polyphase filtering has been implemented in the function `scipy.signal.resample_poly`. This method upsamples a signal, applies a zero-phase low-pass FIR filter, and downsamples using `scipy.signal.upfirdn` (which is also new in 0.18.0). This method can be faster than FFT-based filtering provided by `scipy.signal.resample` for some signals.

`scipy.signal.firls`, which constructs FIR filters using least-squares error minimization, was added.

`scipy.signal.sosfiltfilt`, which does forward-backward filtering like `scipy.signal.filtfilt` but for second-order sections, was added.

### Discrete-time linear systems

`scipy.signal.dlti` provides an implementation of discrete-time linear systems. Accordingly, the `StateSpace`, `TransferFunction` and `ZerosPolesGain` classes have learned a the new keyword, `dt`, which can be used to create discrete-time instances of the corresponding system representation.

### scipy.sparse improvements

The functions `sum`, `max`, `mean`, `min`, `transpose`, and `reshape` in `scipy.sparse` have had their signatures augmented with additional arguments and functionality so as to improve compatibility with analogously defined functions in `numpy`.

Sparse matrices now have a `count_nonzero` method, which counts the number of nonzero elements in the matrix. Unlike `getnnz()` and `nnz` property, which return the number of stored entries (the length of the data attribute), this method counts the actual number of non-zero entries in data.

### scipy.optimize improvements

The implementation of Nelder-Mead minimization, `scipy.optimize.minimize(..., method="Nelder-Mead")`, obtained a new keyword, `initial_simplex`, which can be used to specify the initial simplex for the optimization process.

Initial step size selection in CG and BFGS minimizers has been improved. We expect that this change will improve numeric stability of optimization in some cases. See pull request gh-5536 for details.

Handling of infinite bounds in SLSQP optimization has been improved. We expect that this change will improve numeric stability of optimization in the some cases. See pull request gh-6024 for details.

A large suite of global optimization benchmarks has been added to `scipy/benchmarks/go_benchmark_functions`. See pull request gh-4191 for details.

Nelder-Mead and Powell minimization will now only set defaults for maximum iterations or function evaluations if neither limit is set by the caller. In some cases with a slow converging function and only 1 limit set, the minimization may continue for longer than with previous versions and so is more likely to reach convergence. See issue gh-5966.

### scipy.stats improvements

Trapezoidal distribution has been implemented as `scipy.stats.trapz`. Skew normal distribution has been implemented as `scipy.stats.skewnorm`. Burr type XII distribution has been implemented as `scipy.stats.burr12`. Three- and four-parameter kappa distributions have been implemented as `scipy.stats.kappa3` and `scipy.stats.kappa4`, respectively.

New `scipy.stats.iqr` function computes the interquartile region of a distribution.

#### Random matrices

`scipy.stats.special_ortho_group` and `scipy.stats.ortho_group` provide generators of random matrices in the SO(N) and O(N) groups, respectively. They generate matrices in the Haar distribution, the only uniform distribution on these group manifolds.

`scipy.stats.random_correlation` provides a generator for random correlation matrices, given specified eigenvalues.

### scipy.linalg improvements

`scipy.linalg.svd` gained a new keyword argument, `lapack_driver`. Available drivers are `gesdd` (default) and `gesvd`.

`scipy.linalg.lapack.ilaver` returns the version of the LAPACK library SciPy links to.

### scipy.spatial improvements

Boolean distances, `scipy.spatial.pdist`, have been sped up. Improvements vary by the function and the input size. In many cases, one can expect a speed-up of x2–x10.

New class `scipy.spatial.SphericalVoronoi` constructs Voronoi diagrams on the surface of a sphere. See pull request gh-5232 for details.

### scipy.cluster improvements

A new clustering algorithm, the nearest neighbor chain algorithm, has been implemented for `scipy.cluster.hierarchy.linkage`. As a result, one can expect a significant algorithmic improvement ( $O(N^2)$  instead of  $O(N^3)$ ) for several linkage methods.

### scipy.special improvements

The new function `scipy.special.loggamma` computes the principal branch of the logarithm of the Gamma function. For real input, `loggamma` is compatible with `scipy.special.gammaln`. For complex input, it has more consistent behavior in the complex plane and should be preferred over `gammaln`.

Vectorized forms of spherical Bessel functions have been implemented as `scipy.special.spherical_jn`, `scipy.special.spherical_kn`, `scipy.special.spherical_in` and `scipy.special.spherical_yn`. They are recommended for use over `sph_*` functions, which are now deprecated.

Several special functions have been extended to the complex domain and/or have seen domain/stability improvements. This includes `spence`, `digamma`, `log1p` and several others.

## 1.5.2 Deprecated features

The cross-class properties of *lti* systems have been deprecated. The following properties/setters will raise a *DeprecationWarning*:

Name - (accessing/setting raises warning) - (setting raises warning) \* StateSpace - (*num, den, gain*) - (*zeros, poles*) \* TransferFunction (*A, B, C, D, gain*) - (*zeros, poles*) \* ZerosPolesGain (*A, B, C, D, num, den*) - ()

Spherical Bessel functions, `sph_in`, `sph_jn`, `sph_kn`, `sph_yn`, `sph_jnyn` and `sph_inkn` have been deprecated in favor of `scipy.special.spherical_jn` and `spherical_kn`, `spherical_yn`, `spherical_in`.

The following functions in `scipy.constants` are deprecated: `C2K`, `K2C`, `C2F`, `F2C`, `F2K` and `K2F`. They are superseded by a new function `scipy.constants.convert_temperature` that can perform all those conversions plus to/from the Rankine temperature scale.

## 1.5.3 Backwards incompatible changes

### `scipy.optimize`

The convergence criterion for `optimize.bisect`, `optimize.brentq`, `optimize.brenth`, and `optimize.ridder` now works the same as `numpy.allclose`.

### `scipy.ndimage`

The offset in `ndimage.interpolation.affine_transform` is now consistently added after the matrix is applied, independent of if the matrix is specified using a one-dimensional or a two-dimensional array.

### `scipy.stats`

`stats.ks_2samp` used to return nonsensical values if the input was not real or contained nans. It now raises an exception for such inputs.

Several deprecated methods of `scipy.stats` distributions have been removed: `est_loc_scale`, `vecfunc`, `veccdf` and `vec_generic_moment`.

Deprecated functions `nanmean`, `nanstd` and `nanmedian` have been removed from `scipy.stats`. These functions were deprecated in `scipy 0.15.0` in favor of their `numpy` equivalents.

A bug in the `rvs()` method of the distributions in `scipy.stats` has been fixed. When arguments to `rvs()` were given that were shaped for broadcasting, in many cases the returned random samples were not random. A simple example of the problem is `stats.norm.rvs(loc=np.zeros(10))`. Because of the bug, that call would return 10 identical values. The bug only affected code that relied on the broadcasting of the shape, location and scale parameters.

The `rvs()` method also accepted some arguments that it should not have. There is a potential for backwards incompatibility in cases where `rvs()` accepted arguments that are not, in fact, compatible with broadcasting. An example is

```
stats.gamma.rvs([2, 5, 10, 15], size=(2,2))
```

The shape of the first argument is not compatible with the requested size, but the function still returned an array with shape (2, 2). In `scipy 0.18`, that call generates a `ValueError`.

### `scipy.io`

`scipy.io.netcdf` masking now gives precedence to the `_FillValue` attribute over the `missing_value` attribute, if both are given. Also, data are only treated as missing if they match one of these attributes exactly: values that differ by roundoff from `_FillValue` or `missing_value` are no longer treated as missing values.

### `scipy.interpolate`

`scipy.interpolate.PiecewisePolynomial` class has been removed. It has been deprecated in `scipy 0.14.0`, and `scipy.interpolate.BPoly.from_derivatives` serves as a drop-in replacement.

## 1.5.4 Other changes

Scipy now uses `setuptools` for its builds instead of plain `distutils`. This fixes usage of `install_requires='scipy'` in the `setup.py` files of projects that depend on Scipy (see Numpy issue [gh-6551](#) for details). It potentially affects the way that build/install methods for Scipy itself behave though. Please report any unexpected behavior on the Scipy issue tracker.

PR [#6240](#) changes the interpretation of the `maxfun` option in `L-BFGS-B` based routines in the `scipy.optimize` module. An `L-BFGS-B` search consists of multiple iterations, with each iteration consisting of one or more function evaluations. Whereas the old search strategy terminated immediately upon reaching `maxfun` function evaluations, the new strategy allows the current iteration to finish despite reaching `maxfun`.

The bundled copy of Qhull in the `scipy.spatial` subpackage has been upgraded to version 2015.2.

The bundled copy of ARPACK in the `scipy.sparse.linalg` subpackage has been upgraded to `arpack-ng 3.3.0`.

The bundled copy of SuperLU in the `scipy.sparse` subpackage has been upgraded to version 5.1.1.

## 1.5.5 Authors

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A total of 99 people contributed to this release. People with a “+” by their names contributed a patch for the first time. This list of names is automatically generated, and may not be fully complete.

### Issues closed for 0.18.0

- #1484: SVD using \*GESVD lapack drivers (Trac #957)
- #1547: Inconsistent use of offset in `ndimage.interpolation.affine_transform()`...
- #1609: `special.hyp0f1` returns nan (Trac #1082)
- #1656: `fmin_slsqp` enhancement (Trac #1129)
- #2069: stats broadcasting in `rvs` (Trac #1544)
- #2165: `sph_jn` returns false results for some orders/values (Trac #1640)
- #2255: Incorrect order of translation and rotation in `affine_transform...`
- #2332: `hyp0f1` args and return values are unumpyic (Trac #1813)
- #2534: The sparse `.sum()` method with `uint8` dtype does not act like the...
- #3113: Implement `ufuncs` for `CSPHJY`, `SPHJ`, `SPHY`, `CSPHIK`, `SPHI`, `SPHIK...`
- #3568: SciPy 0.13.3 - CentOS5 - Errors in `test_arpack`
- #3581: `optimize`: `stepsize` in `fmin_bfgs` is “bad”
- #4476: `scipy.sparse` non-native endian bug
- #4484: `ftol` in `optimize.fmin` fails to work
- #4510: `sparsetools.cxx` `call_thunk` can segfault due to out of bounds...
- #5051: `ftol` and `xtol` for `_minimize_neldermead` are absolute instead of...
- #5097: proposal: spherical Voronoi diagrams
- #5123: Call to `scipy.sparse.coo_matrix` fails when passed Cython typed...
- #5220: `scipy.cluster.hierarchy`.`{ward,median,centroid}` does not work...
- #5379: Add a build step at the end of `.travis.yml` that uploads working...
- #5440: `scipy.optimize.basinhopping`: `accept_test` returning `numpy.bool_...`

- #5452: Error in `scipy.integrate.nquad` when using variable integration...
- #5520: Cannot inherit `csr_matrix` properly
- #5533: Kendall tau implementation uses Python mergesort
- #5553: `stats.tiecorrect` overflows
- #5589: Add the Type XII Burr distribution to `stats`.
- #5612: `sparse.linalg` factorizations slow for small `k` due to default...
- #5626: `io.netcdf` masking should use `masked_equal` rather than `masked_value`
- #5637: Simple cubic spline interpolation?
- #5683: BUG: `Akima1DInterpolator` may return nans given multidimensional...
- #5686: `scipy.stats.ttest_ind_from_stats` does not accept arrays
- #5702: `scipy.ndimage.interpolation.affine_transform` lacks documentation...
- #5718: Wrong computation of weighted minkowski distance in `cdist`
- #5745: move to `setuptools` for next release
- #5752: DOC: `solve_discrete_lyapunov` equation puts transpose in wrong...
- #5760: `signal.ss2tf` doesn't handle zero-order state-space models
- #5764: Hypergeometric function `hyp0f1` behaves incorrectly for complex...
- #5814: `stats` NaN Policy Error message inconsistent with code
- #5833: docstring of `stats.binom_test()` needs an update
- #5853: Error in `scipy.linalg.expm` for complex matrix with shape (1,1)
- #5856: Specify Nelder-Mead initial simplex
- #5865: `scipy.linalg.expm` fails for certain numpy matrices
- #5915: `optimize.basinhopping` - variable referenced before assignment.
- #5916: `LSQUnivariateSpline` fitting failed with knots generated from...
- #5927: unicode vs. string comparison in `scipy.stats.binned_statistic_dd`
- #5936: faster implementation of `ks_2samp`
- #5948: `csc` matrix `.mean` returns single element matrix rather than scalar
- #5959: BUG: `optimize` test error for root when using `lgmres`
- #5972: Test failures for sparse sum tests on 32-bit Python
- #5976: Unexpected exception in `scipy.sparse.bmat` while using 0 x 0 matrix
- #6008: `scipy.special.kl_div` not available in 0.14.1
- #6011: The von-Mises entropy is broken
- #6016: python crashes for `linalg.interpolative.svd` with certain large...
- #6017: Wilcoxon signed-rank test with `zero_method="pratt"` or `"zsplit"`...
- #6028: `stats.distributions` does not have trapezoidal distribution
- #6035: Wrong link in `f_oneway`
- #6056: BUG: `signal.decimate` should only accept discrete LTI objects

- #6093: Precision error on Linux 32 bit with openblas
- #6101: Barycentric transforms test error on Python3, 32-bit Linux
- #6105: scipy.misc.face docstring is incorrect
- #6113: scipy.linalg.logm fails for a trivial matrix
- #6128: Error in dot method of sparse COO array, when used with numpy...
- #6132: Failures with latest MKL
- #6136: Failures on *master* with MKL
- #6162: fmin\_l\_bfgs\_b returns inconsistent results (fmin f(xmin)) and...
- #6165: optimize.minimize infinite loop with Newton-CG
- #6167: incorrect distribution fitting for data containing boundary values.
- #6194: lstsq() and others detect numpy.complex256 as real
- #6216: ENH: improve accuracy of ppf cdf roundtrip for bradford
- #6217: BUG: weibull\_min.logpdf return nan for c=1 and x=0
- #6218: Is there a method to cap shortest path search distances?
- #6222: PchipInterpolator no longer handles a 2-element array
- #6226: ENH: improve accuracy for logistic.ppf and logistic.isf
- #6227: ENH: improve accuracy for rayleigh.logpdf and rayleigh.logsf...
- #6228: ENH: improve accuracy of ppf cdf roundtrip for gumbel\_l
- #6235: BUG: alpha.pdf and alpha.logpdf returns nan for x=0
- #6245: ENH: improve accuracy for ppf-cdf and sf-isf roundtrips for invgamma
- #6263: BUG: stats: Inconsistency in the multivariate\_normal docstring
- #6292: Python 3 unorderable type errors in test\_sparsetools.TestInt32Overflow
- #6316: TestCloughTocher2DInterpolator.test\_dense crashes python3.5.2rc1\_64bit...
- #6318: Scipy interp1d 'nearest' not working for high values on x-axis

### Pull requests for 0.18.0

- #3226: DOC: Change *nb* and *na* to conventional *m* and *n*
- #3867: allow cKDTree.query taking a list input in *k*.
- #4191: ENH: Benchmarking global optimizers
- #4356: ENH: add PPoly.solve(*y*) for solving  $p(x) == y$
- #4370: DOC separate boolean distance functions for clarity
- #4678: BUG: sparse: ensure index dtype is large enough to pass all parameters...
- #4881: scipy.signal: Add the class *dlti* for linear discrete-time systems....
- #4901: MAINT: add benchmark and improve docstring for signal.lfilter
- #5043: ENH: sparse: add count\_nonzero method
- #5136: Attribute kurtosistest() to Anscombe & Glynn (1983)

- #5186: ENH: Port upfirdn
- #5232: ENH: adding spherical Voronoi diagram algorithm to scipy.spatial
- #5279: ENH: Bessel filters with different normalizations, high order
- #5384: BUG: Closes #5027 distance function always casts bool to double
- #5392: ENH: Add zero\_phase kwarg to signal.decimate
- #5394: MAINT: sparse: non-canonical test cleanup and fixes
- #5424: DOC: add Scipy developers guide
- #5442: STY: PEP8 amendments
- #5472: Online QR in LGMRES
- #5526: BUG: stats: Fix broadcasting in the rvs() method of the distributions.
- #5530: MAINT: sparse: set *format* attr explicitly
- #5536: optimize: fix up cg/bfgs initial step sizes
- #5548: PERF: improves performance in stats.kendalltau
- #5549: ENH: Nearest-neighbor chain algorithm for hierarchical clustering
- #5554: MAINT/BUG: closes overflow bug in stats.tiecorrect
- #5557: BUG: modify optimize.bisect to achieve desired tolerance
- #5581: DOC: Tutorial for least\_squares
- #5606: ENH: differential\_evolution - moving core loop of solve method...
- #5609: [MRG] test against numpy dev
- #5611: use setuptools for bdist\_egg distributions
- #5615: MAINT: linalg: tighten \_decomp\_update + special: remove unused...
- #5622: Add SO(N) rotation matrix generator
- #5623: ENH: special: Add vectorized spherical Bessel functions.
- #5627: Response to issue #5160, implements the skew normal distribution...
- #5628: DOC: Align the description and operation
- #5632: DOC: special: Expanded docs for Airy, elliptic, Bessel functions.
- #5633: MAINT: linalg: unchecked malloc in \_decomp\_update
- #5634: MAINT: optimize: tighten \_group\_columns
- #5640: Fixes for io.netcdf masking
- #5645: MAINT: size 0 vector handling in cKDTree range queries
- #5649: MAINT: update license text
- #5650: DOC: Clarify Exponent Order in ltsys.py
- #5651: DOC: Clarify Documentation for scipy.special.gammaln
- #5652: DOC: Fixed scipy.special.betaln Doc
- #5653: [MRG] ENH: CubicSpline interpolator
- #5654: ENH: Burr12 distribution to stats module

- #5659: DOC: Define BEFORE/AFTER in `runtests.py -h` for `bench-compare`
- #5660: MAINT: remove functions deprecated before 0.16.0
- #5662: ENH: Circular statistic optimization
- #5663: MAINT: remove uses of `np.testing.rand`
- #5665: MAINT: spatial: remove matching distance implementation
- #5667: Change some HTTP links to HTTPS
- #5669: DOC: `zpk2sos` can't do `analog`, `array_like`, etc.
- #5670: Update `conf.py`
- #5672: MAINT: move a sample distribution to a subclass of `rv_discrete`
- #5678: MAINT: stats: remove `est_loc_scale` method
- #5679: MAINT: DRY up generic computations for discrete distributions
- #5680: MAINT: stop shadowing builtins in `stats.distributions`
- #5681: forward port ENH: Re-enable broadcasting of `fill_value`
- #5684: BUG: Fix `Akima1DInterpolator` returning nans
- #5690: BUG: fix `stats.ttest_ind_from_stats` to handle arrays.
- #5691: BUG: fix generator in `io._loadarff` to comply with PEP 0479
- #5693: ENH: use `math.factorial` for exact factorials
- #5695: DOC: `dx` might be a float, not only an integer
- #5699: MAINT: io: micro-optimize Matlab reading code for size
- #5701: Implement `OptimizeResult.__dir__`
- #5703: ENH: stats: make  $R^2$  printing optional in `probplot`
- #5704: MAINT: typo `ouf->out`
- #5705: BUG: fix typo in `query_pairs`
- #5707: DOC: Add some explanation for `ftol` `xtol` in `scipy.optimize.fmin`
- #5708: DOC: optimize: PEP8 minimize docstring
- #5709: MAINT: optimize Cython code for speed and size
- #5713: [DOC] Fix broken link to reference
- #5717: DOC: `curve_fit` raises `RuntimeError` on failure.
- #5724: forward port `gh-5720`
- #5728: STY: remove a blank line
- #5729: ENH: spatial: speed up boolean distances
- #5732: MAINT: `differential_evolution` changes to default keywords `break...`
- #5733: TST: `differential_evolution` - population initiation tests
- #5736: Complex number support in `log1p`, `expm1`, and `xlog1py`
- #5741: MAINT: sparse: clean up extraction functions
- #5742: DOC: signal: Explain `ftbins` in `get_window`

- #5748: ENH: Add O(N) random matrix generator
- #5749: ENH: Add polyphase resampling
- #5756: RFC: Bump the minimum numpy version, drop older python versions
- #5761: DOC: Some improvements to least squares docstrings
- #5762: MAINT: spatial: distance refactoring
- #5768: DOC: Fix io.loadmat docstring for mdict param
- #5770: BUG: Accept anything np.dtype can handle for a dtype in sparse.random
- #5772: Update sparse.csgraph.laplacian docstring
- #5777: BUG: fix special.hyp0f1 to work correctly for complex inputs.
- #5780: DOC: Update PIL error install URL
- #5781: DOC: Fix documentation on solve\_discrete\_lyapunov
- #5782: DOC: cKDTree and KDTree now reference each other
- #5783: DOC: Clarify finish behaviour in scipy.optimize.brute
- #5784: MAINT: Change default tolerances of least\_squares to 1e-8
- #5787: BUG: Allow Processing of Zero Order State Space Models in signal.ss2tf
- #5788: DOC, BUG: Clarify and Enforce Input Types to 'Data' Objects
- #5789: ENH: sparse: speedup LIL matrix slicing (was #3338)
- #5791: DOC: README: remove coveralls.io
- #5792: MAINT: remove uses of deprecated np.random.random\_integers
- #5794: fix affine\_transform (fixes #1547 and #5702)
- #5795: DOC: Removed uniform method from kmeans2 doc
- #5797: DOC: Clarify the computation of weighted minkowski
- #5798: BUG: Ensure scipy's \_asfarray returns ndarray
- #5799: TST: Mpmath testing patch
- #5801: allow reading of certain IDL 8.0 .sav files
- #5803: DOC: fix module name in error message
- #5804: DOC: special: Expanded docs for special functions.
- #5805: DOC: Fix order of returns in \_spectral\_helper
- #5806: ENH: sparse: vectorized coo\_matrix.diagonal
- #5808: ENH: Added iqr function to compute IQR metric in scipy/stats/stats.py
- #5810: MAINT/BENCH: sparse: Benchmark cleanup and additions
- #5811: DOC: sparse.linalg: shape, not size
- #5813: Update sparse ARPACK functions min *ncv* value
- #5815: BUG: Error message contained wrong values
- #5816: remove dead code from stats tests
- #5820: "in"->"a" in order\_filter docstring

- #5821: DOC: README: INSTALL.txt was renamed in 2014
- #5825: DOC: typo in the docstring of `least_squares`
- #5826: MAINT: sparse: increase test coverage
- #5827: NdPPoly rebase
- #5828: Improve numerical stability of `hyp0f1` for large orders
- #5829: ENH: sparse: Add copy parameter to all `.toXXX()` methods in sparse...
- #5830: DOC: rework `INSTALL.rst.txt`
- #5831: Adds plotting options to `voronoi_plot_2d`
- #5834: Update `stats.binom_test()` docstring
- #5836: ENH, TST: Allow SIMO tf's for `tf2ss`
- #5837: DOC: Image examples
- #5838: ENH: sparse: add `eliminate_zeros()` to `coo_matrix`
- #5839: BUG: Fixed name of `NumpyVersion.__repr__`
- #5845: MAINT: Fixed typos in documentation
- #5847: Fix bugs in `sparsetools`
- #5848: BUG: `sparse.linalg`: add locks to ensure ARPACK threadsafety
- #5849: ENH: `sparse.linalg`: upgrade to `superlu 5.1.1`
- #5851: ENH: expose `lapack's ilaver` to python to allow `lapack verion...`
- #5852: MAINT: `runtests.py`: ensure Ctrl-C interrupts the build
- #5854: DOC: Minor update to documentation
- #5855: Pr 5640
- #5859: ENH: Add random correlation matrix generator
- #5862: BUG: Allow `expm` for complex matrix with shape (1, 1)
- #5863: FIX: Fix test
- #5864: DOC: add a little note about the Normal survival function (Q-function)
- #5867: Fix for #5865
- #5869: extend normal distribution cdf to complex domain
- #5872: DOC: Note that `morlet` and `cwt` don't work together
- #5875: DOC: `interp2d` class description
- #5876: MAINT: `spatial`: remove a stray print statement
- #5878: MAINT: Fixed noisy `UserWarnings` in `ndimage` tests. Fixes #5877
- #5879: MAINT: `sparse.linalg/superlu`: add explicit casts to resolve compiler...
- #5880: MAINT: `signal`: import `gcd` from `math` and not `fractions` when on...
- #5887: Neldermead initial simplex
- #5894: BUG: `_CustomLinearOperator` unpickalable in python3.5
- #5895: DOC: `special`: slightly improve the `multigammaln` docstring

- #5900: Remove duplicate assignment.
- #5901: Update bundled ARPACK
- #5904: ENH: Make convolve and correlate order-agnostic
- #5905: ENH: sparse.linalg: further LGMRES cleanups
- #5906: Enhancements and cleanup in scipy.integrate (attempt #2)
- #5907: ENH: Change sparse *sum* and *mean* dtype casting to match...
- #5909: changes for convolution symmetry
- #5913: MAINT: basinhopping remove instance test closes #5440
- #5919: MAINT: uninitialised var if basinhopping niter=0. closes #5915
- #5920: BLD: Fix missing lsame.c error for MKL
- #5921: DOC: interpolate: add example showing how to work around issue...
- #5926: MAINT: spatial: upgrade to Qhull 2015.2
- #5928: MAINT: sparse: optimize DIA sum/diagonal, csgraph.laplacian
- #5929: Update info/URL for octave-maintainers discussion
- #5930: TST: special: silence DeprecationWarnings from sph\_yn
- #5931: ENH: implement the principle branch of the logarithm of Gamma.
- #5934: Typo: “mush” => “must”
- #5935: BUG:string comparison stats.\_binned\_statistic closes #5927
- #5938: Cythonize stats.ks\_2samp for a ~33% gain in speed.
- #5939: DOC: fix optimize.fmin convergence docstring
- #5941: Fix minor typo in squareform docstring
- #5942: Update linregress stderr description.
- #5943: ENH: Improve numerical accuracy of lognorm
- #5944: Merge vonmises into stats.pyx
- #5945: MAINT: interpolate: Tweak declaration to avoid cython warning...
- #5946: MAINT: sparse: clean up format conversion methods
- #5949: BUG: fix sparse .mean to return a scalar instead of a matrix
- #5955: MAINT: Replace calls to *hanning* with *hann*
- #5956: DOC: Missing periods interfering with parsing
- #5958: MAINT: add a test for lognorm.sf underflow
- #5961: MAINT *\_centered()*: rename size to shape
- #5962: ENH: constants: Add multi-scale temperature conversion function
- #5965: ENH: special: faster way for calculating *comb()* for *exact=True*
- #5975: ENH: Improve FIR path of *signal.decimate*
- #5977: MAINT/BUG: sparse: remove overzealous *bmat* checks
- #5978: *minimize\_neldermead()* stop at user requested *maxiter* or *maxfev*

- #5983: ENH: make sparse *sum* cast dtypes like NumPy *sum* for 32-bit...
- #5985: BUG, API: Add *jac* parameter to *curve\_fit*
- #5989: ENH: Add *firls* least-squares fitting
- #5990: BUG: *read* tries to handle 20-bit WAV files but shouldn't
- #5991: DOC: Cleanup *wav* read/write docs and add tables for common types
- #5994: ENH: Add *gesvd* method for *svd*
- #5996: MAINT: Wave cleanup
- #5997: TST: Break up *upfirdn* tests & compare to *lfilter*
- #6001: Filter design docs
- #6002: COMPAT: Expand compatibility from *numeric.py*
- #6007: ENH: Skip conversion of TF to TF in *freqresp*
- #6009: DOC: fix incorrect *versionadded* for *entr*, *rel\_entr*, *kl\_div*
- #6013: Fixed the entropy calculation of the von Mises distribution.
- #6014: MAINT: make *gamma*, *rgamma* use *loggamma* for complex arguments
- #6020: WIP: ENH: add *exact=True* factorial for vectors
- #6022: Added 'lanczos' to the image interpolation function list.
- #6024: BUG: optimize: do not use dummy constraints in SLSQP when no...
- #6025: ENH: Boundary value problem solver for ODE systems
- #6029: MAINT: Future imports for *optimize.\_lsq*
- #6030: ENH: *stats.trap* - adding trapezoidal distribution closes #6028
- #6031: MAINT: Some improvements to *optimize.\_numdiff*
- #6032: MAINT: Add *special/\_comb.c* to *.gitignore*
- #6033: BUG: check the requested approximation rank in *interpolative.svd*
- #6034: DOC: Doc for *mannwhitneyu* in *stats.py* corrected
- #6040: FIX: Edit the wrong link in *f\_oneway*
- #6044: BUG: (*ordqz*) always increase parameter *lwork* by 1.
- #6047: ENH: extend *special.spence* to complex arguments.
- #6049: DOC: Add documentation of PR #5640 to the 0.18.0 release notes
- #6050: MAINT: small cleanups related to *loggamma*
- #6070: Add *asarray* to explicitly cast list to numpy array in *wilcoxon...*
- #6071: DOC: antialiasing filter and link *decimate* resample, etc.
- #6075: MAINT: reimplement *special.digamma* for complex arguments
- #6080: avoid multiple computation in *kstest*
- #6081: Clarified *pearson* correlation return value
- #6085: ENH: allow long indices of sparse matrix with *umfpack* in *spsolve()*
- #6086: fix description for associated Laguerre polynomials

- #6087: Corrected docstring of splrep.
- #6094: ENH: special: change zeta signature to  $\zeta(x, q=1)$
- #6095: BUG: fix integer overflow in special.spence
- #6106: Fixed Issue #6105
- #6116: BUG: matrix logarithm edge case
- #6119: TST: DeprecationWarnings in stats on python 3.5 closes #5885
- #6120: MAINT: sparse: clean up sputils.isintlike
- #6122: DOC: optimize: linprog docs should say minimize instead of maximize
- #6123: DOC: optimize: document the *fun* field in `scipy.optimize.OptimizeResult`
- #6124: Move FFT zero-padding calculation from signaltools to fftpack
- #6125: MAINT: improve special.gammaln in the  $a \sim x$  regime.
- #6130: BUG: sparse: Fix COO dot with zero columns
- #6138: ENH: stats: Improve behavior of `genextreme.sf` and `genextreme.isf`
- #6146: MAINT: simplify the expit implementation
- #6151: MAINT: special: make `generate_ufuncs.py` output deterministic
- #6152: TST: special: better test for `gammaln` at large arguments
- #6153: ENH: Make `next_fast_len` public and faster
- #6154: fix typo “mush”→”must”
- #6155: DOC: Fix some incorrect RST definition lists
- #6160: make `logsumexp` error out on a masked array
- #6161: added missing bracket to rosen documentation
- #6163: ENH: Added “kappa4” and “kappa3” distributions.
- #6164: DOC: Minor clean-up in `integrate._bvp`
- #6169: Fix `mpf_assert_allclose` to handle iterable results, such as maps
- #6170: Fix `pchip_interpolate` convenience function
- #6172: Corrected misplaced bracket in doc string
- #6175: ENH: `sparse.csgraph`: Pass indices to `shortest_path`
- #6178: TST: increase test coverage of `sf` and `isf` of a generalized extreme...
- #6179: TST: avoid a deprecation warning from numpy
- #6181: ENH: Boundary conditions for `CubicSpline`
- #6182: DOC: Add examples/graphs to `max_len_seq`
- #6183: BLD: update Bento build config files for recent changes.
- #6184: BUG: fix issue in `io/wavfile` for float96 input.
- #6186: ENH: Periodic extrapolation for `PPoly` and `BPoly`
- #6192: MRG: Add circle-CI
- #6193: ENH: sparse: avoid setitem densification

- #6196: Fixed missing sqrt in docstring of Mahalanobis distance in `cdist`,...
- #6206: MAINT: Minor changes in `solve_bvp`
- #6207: BUG: `linalg`: for BLAS, downcast `complex256` to `complex128`, not...
- #6209: BUG: `io.matlab`: avoid buffer overflows in `read_element_into`
- #6210: BLD: use `setuptools` when building.
- #6214: BUG: `sparse.linalg`: fix bug in LGMRES breakdown handling
- #6215: MAINT: `special`: make `loggamma` use `zdiv`
- #6220: DOC: Add parameter
- #6221: ENH: Improve Newton solver for `solve_bvp`
- #6223: `pchip` should work for length-2 arrays
- #6224: `signal.lti`: deprecate cross-class properties/setters
- #6229: BUG: `optimize`: avoid an infinite loop in Newton-CG
- #6230: Add example for application of gaussian filter
- #6236: MAINT: `gumbel_l` accuracy
- #6237: MAINT: `rayleigh` accuracy
- #6238: MAINT: `logistic` accuracy
- #6239: MAINT: `bradford` distribution accuracy
- #6240: MAINT: avoid bad `fmin` in `l-bfgs-b` due to `maxfun` interruption
- #6241: MAINT: `weibull_min` accuracy
- #6246: ENH: Add `_support_mask` to distributions
- #6247: fixed a print error for an example of `ode`
- #6249: MAINT: change x-axis label for `stats.probplot` to “theoretical...
- #6250: DOC: fix typos
- #6251: MAINT: `constants`: filter out test noise from deprecated conversions
- #6252: MAINT: `io.arff`: remove unused variable
- #6253: Add examples to `scipy.ndimage.filters`
- #6254: MAINT: `special`: fix some build warnings
- #6258: MAINT: `inverse gamma` distribution accuracy
- #6260: MAINT: `signal.decimate` - Use discrete-time objects
- #6262: BUG: `odr`: fix string formatting
- #6267: TST: fix some test issues in `interpolate` and `stats`.
- #6269: TST: fix some warnings in the test suite
- #6274: ENH: Add `sosfiltfilt`
- #6276: DOC: update release notes for 0.18.0
- #6277: MAINT: update the author name mapping
- #6282: DOC: Correcting references for `scipy.stats.normaltest`

- #6283: DOC: some more additions to 0.18.0 release notes.
- #6284: Add `versionadded::` directive to `loggamma`.
- #6285: BUG: stats: Inconsistency in the `multivariate_normal` docstring...
- #6290: Add author list, gh-lists to 0.18.0 release notes
- #6293: TST: special: relax a test's precision
- #6295: BUG: sparse: stop comparing `None` and `int` in `bsr_matrix` constructor
- #6313: MAINT: Fix for python 3.5 travis-ci build problem.
- #6327: TST: signal: use `assert_allclose` for testing near-equality in...
- #6330: BUG: spatial/qhull: allocate qhT via `malloc` to ensure CRT likes...
- #6332: TST: fix `stats.iqr` test to not emit warnings, and fix line lengths.
- #6334: MAINT: special: fix a test for `hyp0f1`
- #6347: TST: spatial.qhull: skip a test on 32-bit platforms
- #6350: BUG: optimize/slsqp: don't overwrite an array out of bounds
- #6351: BUG: #6318 `Interp1d` 'nearest' integer x-axis overflow issue fixed
- #6355: Backports for 0.18.0

## 1.6 SciPy 0.17.1 Release Notes

SciPy 0.17.1 is a bug-fix release with no new features compared to 0.17.0.

### 1.6.1 Issues closed for 0.17.1

- #5817: BUG: skew, kurtosis return `np.nan` instead of "propagate"
- #5850: Test failed with `sgelsy`
- #5898: `interpolate.interp1d` crashes using `float128`
- #5953: Massive performance regression in `cKDTree.query` with `L_inf` distance...
- #6062: `mannwhitneyu` breaks backward compatibility in 0.17.0
- #6134: T test does not handle nans

### 1.6.2 Pull requests for 0.17.1

- #5902: BUG: `interpolate`: make `interp1d` handle `np.float128` again
- #5957: BUG: slow down with `p=np.inf` in 0.17 `cKDTree.query`
- #5970: Actually propagate nans through stats functions with `nan_policy="propagate"`
- #5971: BUG: `linalg`: fix `lwork` check in `*gelsy`
- #6074: BUG: special: fixed violation of strict aliasing rules.
- #6083: BUG: Fix dtype for sum of linear operators
- #6100: BUG: Fix `mannwhitneyu` to be backward compatible

- #6135: Don't pass null pointers to LAPACK, even during workspace queries.
- #6148: stats: fix handling of nan values in T tests and kendalltau

## 1.7 SciPy 0.17.0 Release Notes

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- *SciPy 0.17.0 Release Notes*
  - *New features*
    - \* *scipy.cluster improvements*
    - \* *scipy.io improvements*
    - \* *scipy.optimize improvements*
      - *Linear assignment problem solver*
      - *Least squares optimization*
    - \* *scipy.signal improvements*
    - \* *scipy.stats improvements*
    - \* *scipy.sparse improvements*
    - \* *scipy.spatial improvements*
    - \* *scipy.interpolate improvements*
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  - *Deprecated features*
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    - \* *Issues closed for 0.17.0*
    - \* *Pull requests for 0.17.0*

SciPy 0.17.0 is the culmination of 6 months of hard work. It contains many new features, numerous bug-fixes, improved test coverage and better documentation. There have been a number of deprecations and API changes in this release, which are documented below. All users are encouraged to upgrade to this release, as there are a large number of bug-fixes and optimizations. Moreover, our development attention will now shift to bug-fix releases on the 0.17.x branch, and on adding new features on the master branch.

This release requires Python 2.6, 2.7 or 3.2-3.5 and NumPy 1.6.2 or greater.

Release highlights:

- New functions for linear and nonlinear least squares optimization with constraints: `scipy.optimize.lsq_linear` and `scipy.optimize.least_squares`
- Support for fitting with bounds in `scipy.optimize.curve_fit`.
- Significant improvements to `scipy.stats`, providing many functions with better handling of inputs which have NaNs or are empty, improved documentation, and consistent behavior between `scipy.stats` and

`scipy.stats.mstats`.

- Significant performance improvements and new functionality in `scipy.spatial.cKDTree`.

## 1.7.1 New features

### `scipy.cluster` improvements

A new function `scipy.cluster.hierarchy.cut_tree`, which determines a cut tree from a linkage matrix, was added.

### `scipy.io` improvements

`scipy.io.mmwrite` gained support for symmetric sparse matrices.

`scipy.io.netcdf` gained support for masking and scaling data based on data attributes.

### `scipy.optimize` improvements

#### *Linear assignment problem solver*

`scipy.optimize.linear_sum_assignment` is a new function for solving the linear sum assignment problem. It uses the Hungarian algorithm (Kuhn-Munkres).

#### *Least squares optimization*

A new function for *nonlinear* least squares optimization with constraints was added: `scipy.optimize.least_squares`. It provides several methods: Levenberg-Marquardt for unconstrained problems, and two trust-region methods for constrained ones. Furthermore it provides different loss functions. New trust-region methods also handle sparse Jacobians.

A new function for *linear* least squares optimization with constraints was added: `scipy.optimize.lsq_linear`. It provides a trust-region method as well as an implementation of the Bounded-Variable Least-Squares (BVLS) algorithm.

`scipy.optimize.curve_fit` now supports fitting with bounds.

### `scipy.signal` improvements

A `mode` keyword was added to `scipy.signal.spectrogram`, to let it return other spectrograms than power spectral density.

### `scipy.stats` improvements

Many functions in `scipy.stats` have gained a `nan_policy` keyword, which allows specifying how to treat input with NaNs in them: propagate the NaNs, raise an error, or omit the NaNs.

Many functions in `scipy.stats` have been improved to correctly handle input arrays that are empty or contain infs/nans.

A number of functions with the same name in `scipy.stats` and `scipy.stats.mstats` were changed to have matching signature and behavior. See [gh-5474](#) for details.

`scipy.stats.binom_test` and `scipy.stats.mannwhitneyu` gained a keyword `alternative`, which allows specifying the hypothesis to test for. Eventually all hypothesis testing functions will get this keyword.

For methods of many continuous distributions, complex input is now accepted.

Matrix normal distribution has been implemented as `scipy.stats.matrix_normal`.

### **scipy.sparse improvements**

The `axis` keyword was added to sparse norms, `scipy.sparse.linalg.norm`.

### **scipy.spatial improvements**

`scipy.spatial.cKDTree` was partly rewritten for improved performance and several new features were added to it:

- the `query_ball_point` method became significantly faster
- `query` and `query_ball_point` gained an `n_jobs` keyword for parallel execution
- build and query methods now release the GIL
- full pickling support
- support for periodic spaces
- the `sparse_distance_matrix` method can now return a sparse matrix type

### **scipy.interpolate improvements**

Out-of-bounds behavior of `scipy.interpolate.interpld` has been improved. Use a two-element tuple for the `fill_value` argument to specify separate fill values for input below and above the interpolation range. Linear and nearest interpolation kinds of `scipy.interpolate.interpld` support extrapolation via the `fill_value="extrapolate"` keyword.

`fill_value` can also be set to an array-like (or a two-element tuple of array-likes for separate below and above values) so long as it broadcasts properly to the non-interpolated dimensions of an array. This was implicitly supported by previous versions of `scipy`, but support has now been formalized and gets compatibility-checked before use. For example, a set of `y` values to interpolate with shape `(2, 3, 5)` interpolated along the last axis (2) could accept a `fill_value` array with shape `()` (singleton), `(1,)`, `(2, 1)`, `(1, 3)`, `(3,)`, or `(2, 3)`; or it can be a 2-element tuple to specify separate below and above bounds, where each of the two tuple elements obeys proper broadcasting rules.

### **scipy.linalg improvements**

The default algorithm for `scipy.linalg.leastsq` has been changed to use LAPACK's function `*gelsd`. Users wanting to get the previous behavior can use a new keyword `lapack_driver="gelss"` (allowed values are "gelss", "gelsd" and "gelsy").

`scipy.sparse` matrices and linear operators now support the `matmul` (`@`) operator when available (Python 3.5+). See [PEP 465](<http://legacy.python.org/dev/peps/pep-0465/>)

A new function `scipy.linalg.ordqz`, for QZ decomposition with reordering, has been added.

## 1.7.2 Deprecated features

`scipy.stats.histogram` is deprecated in favor of `np.histogram`, which is faster and provides the same functionality.

`scipy.stats.threshold` and `scipy.mstats.threshold` are deprecated in favor of `np.clip`. See issue #617 for details.

`scipy.stats.ss` is deprecated. This is a support function, not meant to be exposed to the user. Also, the name is unclear. See issue #663 for details.

`scipy.stats.square_of_sums` is deprecated. This too is a support function not meant to be exposed to the user. See issues #665 and #663 for details.

`scipy.stats.f_value`, `scipy.stats.f_value_multivariate`, `scipy.stats.f_value_wilks_lambda`, and `scipy.mstats.f_value_wilks_lambda` are deprecated. These are related to ANOVA, for which `scipy.stats` provides quite limited functionality and these functions are not very useful standalone. See issues #660 and #650 for details.

`scipy.stats.chisqprob` is deprecated. This is an alias. `stats.chi2.sf` should be used instead.

`scipy.stats.betainc` is deprecated. This is an alias for `special.betainc` which should be used instead.

## 1.7.3 Backwards incompatible changes

The functions `stats.triml` and `stats.trimboth` now make sure the elements trimmed are the lowest and/or highest, depending on the case. Slicing without at least partial sorting was previously done, but didn't make sense for unsorted input.

When `variable_names` is set to an empty list, `scipy.io.loadmat` now correctly returns no values instead of all the contents of the MAT file.

Element-wise multiplication of sparse matrices now returns a sparse result in all cases. Previously, multiplying a sparse matrix with a dense matrix or array would return a dense matrix.

The function `misc.lena` has been removed due to license incompatibility.

The constructor for `sparse.coo_matrix` no longer accepts `(None, (m, n))` to construct an all-zero matrix of shape `(m, n)`. This functionality was deprecated since at least 2007 and was already broken in the previous SciPy release. Use `coo_matrix((m, n))` instead.

The Cython wrappers in `linalg.cython_lapack` for the LAPACK routines `*gges`, `*ggev`, `*gelsx`, `*geqpf`, `*ggsvd`, `*ggsvp`, `*lahrd`, `*latzm`, `*tZRqf` have been removed since these routines are not present in the new LAPACK 3.6.0 release. With the exception of the routines `*ggsvd` and `*ggsvp`, these were all deprecated in favor of routines that are currently present in our Cython LAPACK wrappers.

Because the LAPACK `*ggev` routines were removed in LAPACK 3.6.0. The corresponding Python wrappers in `scipy.linalg.lapack` are now deprecated and will be removed in a future release. The source files for these routines have been temporarily included as a part of `scipy.linalg` so that SciPy can be built against LAPACK versions that do not provide these deprecated routines.

## 1.7.4 Other changes

Html and pdf documentation of development versions of Scipy is now automatically rebuilt after every merged pull request.

`scipy.constants` is updated to the CODATA 2014 recommended values.

Usage of `scipy.fftpack` functions within Scipy has been changed in such a way that `PyFFTW` can easily replace `scipy.fftpack` functions (with improved performance). See [gh-5295](#) for details.

The `imread` functions in `scipy.misc` and `scipy.ndimage` were unified, for which a `mode` argument was added to `scipy.misc.imread`. Also, bugs for 1-bit and indexed RGB image formats were fixed.

`runtests.py`, the development script to build and test Scipy, now allows building in parallel with `--parallel`.

## 1.7.5 Authors

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- Jacob Vanderplas
- Gael Varoquaux +
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- Stefan van der Walt
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- Josh Wilson +
- Nat Wilson +
- Peter Yin +

A total of 101 people contributed to this release. People with a “+” by their names contributed a patch for the first time. This list of names is automatically generated, and may not be fully complete.

### Issues closed for 0.17.0

- #1923: problem with numpy 0's in stats.poisson.rvs (Trac #1398)
- #2138: scipy.misc.imread segfaults on 1 bit png (Trac #1613)
- #2237: distributions do not accept complex arguments (Trac #1718)
- #2282: scipy.special.hyp1f1(0.5, 1.5, -1000) fails (Trac #1763)
- #2618: poisson.pmf returns NaN if mu is 0
- #2957: hyp1f1 precision issue
- #2997: FAIL: test\_qhull.TestUtilities.test\_more\_barycentric\_transforms
- #3129: No way to set ranges for fitting parameters in Optimize functions
- #3191: interp1d should contain a fill\_value\_below and a fill\_value\_above...
- #3453: PchipInterpolator sets slopes at edges differently than Matlab's...
- #4106: ndimage.\_ni\_support.\_normalize\_sequence() fails with numpy.int64
- #4118: `scipy.integrate.ode.set_solout` called after `scipy.integrate.ode.set_initial_value` fails silently
- #4233: 1D scipy.interpolate.griddata using method=nearest produces nans...
- #4375: All tests fail due to bad file permissions
- #4580: scipy.ndimage.filters.convolve documentation is incorrect
- #4627: logsumexp with sign indicator - enable calculation with negative...
- #4702: logsumexp with zero scaling factor
- #4834: gammainc should return 1.0 instead of NaN for infinite x
- #4838: enh: exprel special function
- #4862: the scipy.special.boxcox function is inaccurate for denormal...
- #4887: Spherical harmonic incongruences
- #4895: some scipy ufuncs have inconsistent output dtypes?
- #4923: logm does not aggressively convert complex outputs to float
- #4932: BUG: stats: The *fit* method of the distributions silently ignores...
- #4956: Documentation error in `scipy.special.bi_zeros`
- #4957: Docstring for *pbvv\_seq* is wrong
- #4967: block\_diag should look at dtypes of all arguments, not only the...
- #5037: scipy.optimize.minimize error messages are printed to stdout...
- #5039: Cubic interpolation: On entry to DGESDD parameter number 12 had...
- #5163: Base case example of Hierarchical Clustering (offer)
- #5181: BUG: stats.genextreme.entropy should use the explicit formula
- #5184: Some? wheels don't express a numpy dependency

- #5197: mstats: test\_kurtosis fails (ULP max is 2)
- #5260: Typo causing an error in splrep
- #5263: Default epsilon in rbf.py fails for colinear points
- #5276: Reading empty (no data) arff file fails
- #5280: 1d scipy.signal.convolve much slower than numpy.convolve
- #5326: Implementation error in scipy.interpolate.PchipInterpolator
- #5370: Test issue with test\_quadpack and libm.so as a linker script
- #5426: ERROR: test\_stats.test\_chisquare\_masked\_arrays
- #5427: Automate installing correct numpy versions in numpy-vendor image
- #5430: Python3 : Numpy scalar types “not iterable”; specific instance...
- #5450: BUG: spatial.ConvexHull triggers a seg. fault when given nans.
- #5478: clarify the relation between matrix normal distribution and *multivariate\_normal*
- #5539: lstsq related test failures on windows binaries from numpy-vendor
- #5560: doc: scipy.stats.burr pdf issue
- #5571: lstsq test failure after lapack\_driver change
- #5577: ordqz segfault on Python 3.4 in Wine
- #5578: scipy.linalg test failures on python 3 in Wine
- #5607: Overloaded ‘isnan(double&)’ is ambiguous when compiling with...
- #5629: Test for lstsq randomly failed
- #5630: memory leak with scipy 0.16 spatial cKDtree
- #5689: isnan errors compiling scipy/special/Faddeeva.cc with clang++
- #5694: fftpack test failure in test\_import
- #5719: curve\_fit(method!="lm") ignores initial guess

### Pull requests for 0.17.0

- #3022: hyp1f1: better handling of large negative arguments
- #3107: ENH: Add ordered QZ decomposition
- #4390: ENH: Allow axis and keepdims arguments to be passed to scipy.linalg.norm.
- #4671: ENH: add axis to sparse norms
- #4796: ENH: Add cut tree function to scipy.cluster.hierarchy
- #4809: MAINT: cauchy moments are undefined
- #4821: ENH: stats: make distribution instances picklable
- #4839: ENH: Add scipy.special.exprel relative error exponential ufunc
- #4859: Logsumexp fixes - allows sign flags and b==0
- #4865: BUG: scipy.io.mmio.write: error with big indices and low precision
- #4869: add as\_inexact option to \_lib.\_util.\_asarray\_validated

- #4884: ENH: Finite difference approximation of Jacobian matrix
- #4890: ENH: Port cKDTree query methods to C++, allow pickling on Python...
- #4892: how much doctesting is too much?
- #4896: MAINT: work around a possible numpy ufunc loop selection bug
- #4898: MAINT: A bit of pyflakes-driven cleanup.
- #4899: ENH: add 'alternative' keyword to hypothesis tests in stats
- #4903: BENCH: Benchmarks for interpolate module
- #4905: MAINT: prepend underscore to mask\_to\_limits; delete masked\_var.
- #4906: MAINT: Benchmarks for optimize.leastsq
- #4910: WIP: Trimmed statistics functions have inconsistent API.
- #4912: MAINT: fix typo in stats tutorial. Closes gh-4911.
- #4914: DEP: deprecate *scipy.stats.ss* and *scipy.stats.square\_of\_sums*.
- #4924: MAINT: if the imaginary part of logm of a real matrix is small,...
- #4930: BENCH: Benchmarks for signal module
- #4941: ENH: update *find\_repeats*.
- #4942: MAINT: use np.float64\_t instead of np.float\_t in cKDTree
- #4944: BUG: integer overflow in correlate\_nd
- #4951: do not ignore invalid kwargs in distributions fit method
- #4958: Add some detail to docstrings for special functions
- #4961: ENH: stats.describe: add bias kw and empty array handling
- #4963: ENH: scipy.sparse.coo.coo\_matrix.\_\_init\_\_: less memory needed
- #4968: DEP: deprecate *stats.f\_value\** and *mstats.f\_value\** functions.
- #4969: ENH: review *stats.relfreq* and *stats.cumfreq*; fixes to *stats.histogram*
- #4971: Extend github source links to line ranges
- #4972: MAINT: improve the error message in validate\_runtests\_log
- #4976: DEP: deprecate *scipy.stats.threshold*
- #4977: MAINT: more careful dtype treatment in block diagonal matrix...
- #4979: ENH: distributions, complex arguments
- #4984: clarify dirichlet distribution error handling
- #4992: ENH: *stats.fligner* and *stats.bartlett* empty input handling.
- #4996: DOC: fix stats.spearmanr docs
- #4997: Fix up boxcox for underflow / loss of precision
- #4998: DOC: improved documentation for *stats.ppcc\_max*
- #5000: ENH: added empty input handling *scipy.moment*; doc enhancements
- #5003: ENH: improves rankdata algorithm
- #5005: scipy.stats: numerical stability improvement

- #5007: ENH: nan handling in functions that use *stats.\_chk\_asarray*
- #5009: remove coveralls.io
- #5010: Hypergeometric distribution log survival function
- #5014: Patch to compute the volume and area of convex hulls
- #5015: DOC: Fix mistaken variable name in sawtooth
- #5016: DOC: resample example
- #5017: DEP: deprecate *stats.betainc* and *stats.chisqprob*
- #5018: ENH: Add test on random input to volume computations
- #5026: BUG: Fix return dtype of *lil\_matrix.getnnz(axis=0)*
- #5030: DOC: resample slow for prime output too
- #5033: MAINT: integrate, special: remove unused R1MACH and Makefile
- #5034: MAINT: signal: lift *max\_len\_seq* validation out of Cython
- #5035: DOC/MAINT: refguide / doctest drudgery
- #5041: BUG: fixing some small memory leaks detected by cppcheck
- #5044: [GSoC] ENH: New least-squares algorithms
- #5050: MAINT: C fixes, trimmed a lot of dead code from Cephes
- #5057: ENH: sparse: avoid densifying on sparse/dense elementwise mult
- #5058: TST: stats: add a sample distribution to the test loop
- #5061: ENH: spatial: faster 2D Voronoi and Convex Hull plotting
- #5065: TST: improve test coverage for *stats.mvsnorm* and *stats.bayes\_mvsnorm*
- #5066: MAINT: fitpack: remove a noop
- #5067: ENH: empty and nan input handling for *stats.kstest* and *stats.kstestvar*
- #5071: DOC: optimize: Correct paper reference, add doi
- #5072: MAINT: scipy.sparse cleanup
- #5073: DOC: special: Add an example showing the relation of *diric* to...
- #5075: DOC: clarified parameterization of *stats.lognorm*
- #5076: use int, float, bool instead of *np.int*, *np.float*, *np.bool*
- #5078: DOC: Rename *fftpack* docs to README
- #5081: BUG: Correct handling of scalar 'b' in *lsqr* and *lsqr*
- #5082: *loadmat* *variable\_names*: don't confuse [] and None.
- #5083: Fix *integrate.fixed\_quad* docstring to indicate None return value
- #5086: Use *solve()* instead of *inv()* for *gaussian\_kde*
- #5090: MAINT: stats: add explicit *\_sf*, *\_isf* to *gengamma* distribution
- #5094: ENH: *scipy.interpolate.NearestNDInterpolator*: *cKDTree* configurable
- #5098: DOC: special: fix typesetting in *\*\_roots* quadrature functions
- #5099: DOC: make the docstring of *stats.moment* raw

- #5104: DOC/ENH fixes and micro-optimizations for `scipy.linalg`
- #5105: enh: made `l-bfgs-b` parameter for the maximum number of line search...
- #5106: TST: add NIST test cases to `stats.f_oneway`
- #5110: [GSoC]: Bounded linear least squares
- #5111: MAINT: special: Cephes cleanup
- #5118: BUG: FIR path failed if `len(x) < len(b)` in `lfilter`.
- #5124: ENH: move the filliben approximation to a publicly visible function
- #5126: StatisticsCleanup: `stats.kruskal` review
- #5130: DOC: update PyPi trove classifiers. Beta -> Stable. Add license.
- #5131: DOC: `differential_evolution`, improve docstring for mutation and...
- #5132: MAINT: `differential_evolution` improve `init_population_lhs` comments...
- #5133: MRG: rebased `mmio` refactoring
- #5135: MAINT: `stats.mstats` consistency with `stats.stats`
- #5139: TST: `linalg`: add a smoke test for gh-5039
- #5140: EHN: Update constants.codata to CODATA 2014
- #5145: added `ValueError` to docstring as possible error raised
- #5146: MAINT: Improve implementation details and doc in `stats.shapiro`
- #5147: [GSoC] ENH: Upgrades to `curve_fit`
- #5150: Fix misleading wavelets/cwt example
- #5152: BUG: `cluster.hierarchy.dendrogram`: missing font size doesn't...
- #5153: add keywords to control the summation in discrete distributions...
- #5156: DOC: added comments on algorithms used in Legendre function
- #5158: ENH: optimize: add the Hungarian algorithm
- #5162: FIX: Remove `lena`
- #5164: MAINT: fix `cluster.hierarchy.dendrogram` issues and docs
- #5166: MAINT: changed `stats.pointbiserialr` to delegate to `stats.pearsonr`
- #5167: ENH: add `nan_policy` to `stats.kendalltau`.
- #5168: TST: added nist test case (Norris) to `stats.linregress`.
- #5169: update `lpmv` docstring
- #5171: Clarify metric parameter in linkage docstring
- #5172: ENH: add mode keyword to `signal.spectrogram`
- #5177: DOC: graphical example for `KDTree.query_ball_point`
- #5179: MAINT: stats: tweak the formula for `ncx2.pdf`
- #5188: MAINT: `linalg`: A bit of clean up.
- #5189: BUG: stats: Use the explicit formula in `stats.genextreme.entropy`
- #5193: BUG: fix uninitialized use in `lartg`

- #5194: BUG: properly return error to fortran from ode\_jacobian\_function
- #5198: TST: Fix TestCtypesQuad failure on Python 3.5 for Windows
- #5201: allow extrapolation in interp1d
- #5209: MAINT: Change complex parameter to boolean in Y\_()
- #5213: BUG: sparse: fix logical comparison dtype conflicts
- #5216: BUG: sparse: fixing unbound local error
- #5218: DOC and BUG: Bessel function docstring improvements, fix array\_like,...
- #5222: MAINT: sparse: fix COO ctor
- #5224: DOC: optimize: type of OptimizeResult.hess\_inv varies
- #5228: ENH: Add maskandscale support to netcdf; based on pupynere and...
- #5229: DOC: sparse.linalg.svds doc typo fixed
- #5234: MAINT: sparse: simplify COO ctor
- #5235: MAINT: sparse: warn on todia() with many diagonals
- #5236: MAINT: ndimage: simplify thread handling/recursion + constness
- #5239: BUG: integrate: Fixed issue 4118
- #5241: qr\_insert fixes, closes #5149
- #5246: Doctest tutorial files
- #5247: DOC: optimize: typo/import fix in linear\_sum\_assignment
- #5248: remove inspect.getargspec and test python 3.5 on Travis CI
- #5250: BUG: Fix sparse multiply by single-element zero
- #5261: Fix bug causing a TypeError in splrep when a runtime warning...
- #5262: Follow up to 4489 (Addition LAPACK routines in linalg.lstsq)
- #5264: ignore zero-length edges for default epsilon
- #5269: DOC: Typos and spell-checking
- #5272: MAINT: signal: Convert array syntax to memoryviews
- #5273: DOC: raw strings for docstrings with math
- #5274: MAINT: sparse: update cython code for MST
- #5278: BUG: io: Stop guessing the data delimiter in ARFF files.
- #5289: BUG: misc: Fix the Pillow work-around for 1-bit images.
- #5291: ENH: call np.correlate for 1d in scipy.signal.correlate
- #5294: DOC: special: Remove a potentially misleading example from the...
- #5295: Simplify replacement of fftpack by pyfftw
- #5296: ENH: Add matrix normal distribution to stats
- #5297: Fixed leaf\_rotation and leaf\_font\_size in Python 3
- #5303: MAINT: stats: rewrite find\_repeats
- #5307: MAINT: stats: remove unused Fortran routine

- #5313: BUG: sparse: fix diags for nonsquare matrices
- #5315: MAINT: special: Cephes cleanup
- #5316: fix input check for sparse.linalg.svds
- #5319: MAINT: Cython code maintenance
- #5328: BUG: Fix place\_poles return values
- #5329: avoid a spurious divide-by-zero in Student t stats
- #5334: MAINT: integrate: miscellaneous cleanup
- #5340: MAINT: Printing Error Msg to STDERR and Removing iterate.dat
- #5347: ENH: add Py3.5-style matmul operator (e.g.  $A @ B$ ) to sparse linear...
- #5350: FIX error, when reading 32-bit float wav files
- #5351: refactor the PCHIP interpolant's algorithm
- #5354: MAINT: construct csr and csc matrices from integer lists
- #5359: add a fast path to interp1d
- #5364: Add two fill\_values to interp1d.
- #5365: ABCD docstrings
- #5366: Fixed typo in the documentation for scipy.signal.cwt() per #5290.
- #5367: DOC updated scipy.spatial.Delaunay example
- #5368: ENH: Do not create a throwaway class at every function call
- #5372: DOC: spectral: fix reference formatting
- #5375: PEP8 amendments to fftpack\_basic.py
- #5377: BUG: integrate: builtin name no longer shadowed
- #5381: PEP8ified fftpack\_pseudo\_diffs.py
- #5385: BLD: fix Bento build for changes to optimize and spatial
- #5386: STY: PEP8 amendments to interpolate.py
- #5387: DEP: deprecate stats.histogram
- #5388: REL: add "make upload" command to doc/Makefile.
- #5389: DOC: updated origin param of scipy.ndimage.filters.convolve
- #5395: BUG: special: fix a number of edge cases related to  $x = np.inf$ .
- #5398: MAINT: stats: avoid spurious warnings in lognorm.pdf(0, s)
- #5407: ENH: stats: Handle mu=0 in stats.poisson
- #5409: Fix the behavior of discrete distributions at the right-hand...
- #5412: TST: stats: skip a test to avoid a spurious log(0) warning
- #5413: BUG: linalg: work around LAPACK single-precision lwork computation...
- #5414: MAINT: stats: move creation of namedtuples outside of function...
- #5415: DOC: fix up sections in ToC in the pdf reference guide
- #5416: TST: fix issue with a ctypes test for integrate on Fedora.

- #5418: DOC: fix bugs in signal.TransferFunction docstring. Closes gh-5287.
- #5419: MAINT: sparse: fix usage of NotImplementedError
- #5420: Raise proper error if maxiter < 1
- #5422: DOC: changed documentation of brent to be consistent with bracket
- #5444: BUG: gaussian\_filter, BPoly.from\_derivatives fail on numpy int...
- #5445: MAINT: stats: fix incorrect deprecation warnings and test noise
- #5446: DOC: add note about PyFFTW in fftpack tutorial.
- #5459: DOC: integrate: Some improvements to the differential equation...
- #5465: BUG: Relax mstats kurtosis test tolerance by a few ulp
- #5471: ConvexHull should raise ValueError for NaNs.
- #5473: MAINT: update decorators.py module to version 4.0.5
- #5476: BUG: imsave searches for wrong channel axis if image has 3 or...
- #5477: BLD: add numpy to setup/install\_requires for OS X wheels
- #5479: ENH: return Jacobian/Hessian from BasinHopping
- #5484: BUG: fix ttest zero division handling
- #5486: Fix crash on kmeans2
- #5491: MAINT: Expose parallel build option to runtests.py
- #5494: Sort OptimizeResult.\_\_repr\_\_ by key
- #5496: DOC: update the author name mapping
- #5497: Enhancement to binned\_statistic: option to unraveled returned...
- #5498: BUG: sparse: fix a bug in sparsertools input dtype resolution
- #5500: DOC: detect unprintable characters in docstrings
- #5505: BUG: misc: Ensure fromimage converts mode 'P' to 'RGB' or 'RGBA'.
- #5514: DOC: further update the release notes
- #5515: ENH: optionally disable fixed-point acceleration
- #5517: DOC: Improvements and additions to the matrix\_normal doc
- #5518: Remove wrappers for LAPACK deprecated routines
- #5521: TST: skip a linalg.orth memory test on 32-bit platforms.
- #5523: DOC: change a few floats to integers in docstring examples
- #5524: DOC: more updates to 0.17.0 release notes.
- #5525: Fix to minor typo in documentation for scipy.integrate.ode
- #5527: TST: bump arccosh tolerance to allow for inaccurate numpy or...
- #5535: DOC: signal: minor clarification to docstring of TransferFunction.
- #5538: DOC: signal: fix find\_peaks\_cwt documentation
- #5545: MAINT: Fix typo in linalg/basic.py
- #5547: TST: mark TestEig.test\_singular as knownfail in master.

- #5550: MAINT: work around lstsq driver selection issue
- #5556: BUG: Fixed broken dogbox trust-region radius update
- #5561: BUG: eliminate warnings, exception (on Win) in test\_maskandscale;...
- #5567: TST: a few cleanups in the test suite; run\_module\_suite and clearer...
- #5568: MAINT: simplify poisson's \_argcheck
- #5569: TST: bump GMean test tolerance to make it pass on Wine
- #5572: TST: lstsq: bump test tolerance for TravisCI
- #5573: TST: remove use of np.fromfile from cluster.vq tests
- #5576: Lapack deprecations
- #5579: TST: skip tests of linalg.norm axis keyword on numpy <= 1.7.x
- #5582: Clarify language of survival function documentation
- #5583: MAINT: stats/tests: A bit of clean up.
- #5588: DOC: stats: Add a note that stats.burr is the Type III Burr distribution.
- #5595: TST: fix test\_lamch failures on Python 3
- #5600: MAINT: Ignore spatial/ckdtree.cxx and .h
- #5602: Explicitly numbered replacement fields for maintainability
- #5605: MAINT: collection of small fixes to test suite
- #5614: Minor doc change.
- #5624: FIX: Fix interpolate
- #5625: BUG: msvc9 binaries crash when indexing std::vector of size 0
- #5635: BUG: misspelled \_\_dealloc\_\_ in cKDTree.
- #5642: STY: minor fixup of formatting of 0.17.0 release notes.
- #5643: BLD: fix a build issue in special/Faddeeva.cc with isnan.
- #5661: TST: linalg tests used stdlib random instead of numpy.random.
- #5682: backports for 0.17.0
- #5696: Minor improvements to least\_squares' docstring.
- #5697: BLD: fix for isnan/isinf issues in special/Faddeeva.cc
- #5720: TST: fix for file opening error in fftpack test\_import.py
- #5722: BUG: Make curve\_fit respect an initial guess with bounds
- #5726: Backports for v0.17.0rc2
- #5727: API: Changes to least\_squares API

## 1.8 SciPy 0.16.1 Release Notes

SciPy 0.16.1 is a bug-fix release with no new features compared to 0.16.0.

### 1.8.1 Issues closed for 0.16.1

- #5077: cKDTree not indexing properly for arrays with too many elements
- #5127: Regression in 0.16.0: solve\_banded errors out in patsy test suite
- #5149: linalg tests apparently cause python to crash with numpy 1.10.0b1
- #5154: 0.16.0 fails to build on OS X; can't find Python.h
- #5173: failing stats.histogram test with numpy 1.10
- #5191: Scipy 0.16.x - TypeError: \_asarray\_validated() got an unexpected...
- #5195: tarballs missing documentation source
- #5363: FAIL: test\_orthogonal.test\_j\_roots, test\_orthogonal.test\_js\_roots

### 1.8.2 Pull requests for 0.16.1

- #5088: BUG: fix logic error in cKDTree.sparse\_distance\_matrix
- #5089: BUG: Don't overwrite b in lfilter's FIR path
- #5128: BUG: solve\_banded failed when solving 1x1 systems
- #5155: BLD: fix missing Python include for Homebrew builds.
- #5192: BUG: backport as\_inexact kwarg to \_asarray\_validated
- #5203: BUG: fix uninitialized use in lartg 0.16 backport
- #5204: BUG: properly return error to fortran from ode\_jacobian\_function...
- #5207: TST: Fix TestCtypesQuad failure on Python 3.5 for Windows
- #5352: TST: sparse: silence warnings about boolean indexing
- #5355: MAINT: backports for 0.16.1 release
- #5356: REL: update Paver file to ensure sdist contents are OK for releases.
- #5382: 0.16.x backport: MAINT: work around a possible numpy ufunc loop...
- #5393: TST:special: bump tolerance levels for test\_j\_roots and test\_js\_roots
- #5417: MAINT: stats: move namedtuple creating outside function calls.

## 1.9 SciPy 0.16.0 Release Notes

### Contents

- *SciPy 0.16.0 Release Notes*
  - *New features*
    - \* *Benchmark suite*
    - \* *scipy.linalg improvements*
    - \* *scipy.signal improvements*

- \* `scipy.sparse` *improvements*
- \* `scipy.spatial` *improvements*
- \* `scipy.stats` *improvements*
- \* `scipy.optimize` *improvements*
- *Deprecated features*
- *Backwards incompatible changes*
- *Other changes*
- *Authors*
  - \* *Issues closed for 0.16.0*
  - \* *Pull requests for 0.16.0*

SciPy 0.16.0 is the culmination of 7 months of hard work. It contains many new features, numerous bug-fixes, improved test coverage and better documentation. There have been a number of deprecations and API changes in this release, which are documented below. All users are encouraged to upgrade to this release, as there are a large number of bug-fixes and optimizations. Moreover, our development attention will now shift to bug-fix releases on the 0.16.x branch, and on adding new features on the master branch.

This release requires Python 2.6, 2.7 or 3.2-3.4 and NumPy 1.6.2 or greater.

Highlights of this release include:

- A Cython API for BLAS/LAPACK in `scipy.linalg`
- A new benchmark suite. It's now straightforward to add new benchmarks, and they're routinely included with performance enhancement PRs.
- Support for the second order sections (SOS) format in `scipy.signal`.

### 1.9.1 New features

#### Benchmark suite

The benchmark suite has switched to using [Airspeed Velocity](#) for benchmarking. You can run the suite locally via `python runtests.py --bench`. For more details, see `benchmarks/README.rst`.

#### `scipy.linalg` improvements

A full set of Cython wrappers for BLAS and LAPACK has been added in the modules `scipy.linalg.cython_blas` and `scipy.linalg.cython_lapack`. In Cython, these wrappers can now be imported from their corresponding modules and used without linking directly against BLAS or LAPACK.

The functions `scipy.linalg.qr_delete`, `scipy.linalg.qr_insert` and `scipy.linalg.qr_update` for updating QR decompositions were added.

The function `scipy.linalg.solve_circulant` solves a linear system with a circulant coefficient matrix.

The function `scipy.linalg.invpascal` computes the inverse of a Pascal matrix.

The function `scipy.linalg.solve_toeplitz`, a Levinson-Durbin Toeplitz solver, was added.

Added wrapper for potentially useful LAPACK function `*lasd4`. It computes the square root of the *i*-th updated eigenvalue of a positive symmetric rank-one modification to a positive diagonal matrix. See its LAPACK documentation and unit tests for it to get more info.

Added two extra wrappers for LAPACK least-square solvers. Namely, they are `*gelsd` and `*gelsy`.

Wrappers for the LAPACK `*lange` functions, which calculate various matrix norms, were added.

Wrappers for `*gtsv` and `*ptsv`, which solve  $A \cdot X = B$  for tri-diagonal matrix *A*, were added.

### scipy.signal improvements

Support for second order sections (SOS) as a format for IIR filters was added. The new functions are:

- `scipy.signal.sosfilt`
- `scipy.signal.sosfilt_zi`,
- `scipy.signal.sos2tf`
- `scipy.signal.sos2zpk`
- `scipy.signal.tf2sos`
- `scipy.signal.zpk2sos`.

Additionally, the filter design functions `iirdesign`, `iirfilter`, `butter`, `cheby1`, `cheby2`, `ellip`, and `bessel` can return the filter in the SOS format.

The function `scipy.signal.place_poles`, which provides two methods to place poles for linear systems, was added.

The option to use Gustafsson's method for choosing the initial conditions of the forward and backward passes was added to `scipy.signal.filtfilt`.

New classes `TransferFunction`, `StateSpace` and `ZerosPolesGain` were added. These classes are now returned when instantiating `scipy.signal.lti`. Conversion between those classes can be done explicitly now.

An exponential (Poisson) window was added as `scipy.signal.exponential`, and a Tukey window was added as `scipy.signal.tukey`.

The function for computing digital filter group delay was added as `scipy.signal.group_delay`.

The functionality for spectral analysis and spectral density estimation has been significantly improved: `scipy.signal.welch` became ~8x faster and the functions `scipy.signal.spectrogram`, `scipy.signal.coherence` and `scipy.signal.csd` (cross-spectral density) were added.

`scipy.signal.lsim` was rewritten - all known issues are fixed, so this function can now be used instead of `lsim2`; `lsim` is orders of magnitude faster than `lsim2` in most cases.

### scipy.sparse improvements

The function `scipy.sparse.norm`, which computes sparse matrix norms, was added.

The function `scipy.sparse.random`, which allows to draw random variates from an arbitrary distribution, was added.

### scipy.spatial improvements

`scipy.spatial.cKDTree` has seen a major rewrite, which improved the performance of the `query` method significantly, added support for parallel queries, pickling, and options that affect the tree layout. See pull request 4374 for more details.

The function `scipy.spatial.procrustes` for Procrustes analysis (statistical shape analysis) was added.

### scipy.stats improvements

The Wishart distribution and its inverse have been added, as `scipy.stats.wishart` and `scipy.stats.invwishart`.

The Exponentially Modified Normal distribution has been added as `scipy.stats.exponnorm`.

The Generalized Normal distribution has been added as `scipy.stats.gennorm`.

All distributions now contain a `random_state` property and allow specifying a specific `numpy.random.RandomState` random number generator when generating random variates.

Many statistical tests and other `scipy.stats` functions that have multiple return values now return `namedtuples`. See pull request 4709 for details.

### scipy.optimize improvements

A new derivative-free method DF-SANE has been added to the nonlinear equation system solving function `scipy.optimize.root`.

## 1.9.2 Deprecated features

`scipy.stats.pdf_fromgamma` is deprecated. This function was undocumented, untested and rarely used. `Statsmodels` provides equivalent functionality with `statsmodels.distributions.ExpandedNormal`.

`scipy.stats.fastsort` is deprecated. This function is unnecessary, `numpy.argsort` can be used instead.

`scipy.stats.signaltonoise` and `scipy.stats.mstats.signaltonoise` are deprecated. These functions did not belong in `scipy.stats` and are rarely used. See issue #609 for details.

`scipy.stats.histogram2` is deprecated. This function is unnecessary, `numpy.histogram2d` can be used instead.

## 1.9.3 Backwards incompatible changes

The deprecated global optimizer `scipy.optimize.anneal` was removed.

The following deprecated modules have been removed: `scipy.lib.blas`, `scipy.lib.lapack`, `scipy.linalg.cblas`, `scipy.linalg.fblas`, `scipy.linalg.clapack`, `scipy.linalg.flapack`. They had been deprecated since SciPy 0.12.0, the functionality should be accessed as `scipy.linalg.blas` and `scipy.linalg.lapack`.

The deprecated function `scipy.special.all_mat` has been removed.

The deprecated functions `fprob`, `ksprob`, `zprob`, `randwcdf` and `randwppf` have been removed from `scipy.stats`.

## 1.9.4 Other changes

The version numbering for development builds has been updated to comply with PEP 440.

Building with `python setup.py develop` is now supported.

## 1.9.5 Authors

- @axiru +
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- Pauli Virtanen
- Matteo Visconti +
- Warren Weckesser
- Florian Wilhelm +
- Nathan Woods
- Haochen Wu +
- Daan Wynen +

A total of 93 people contributed to this release. People with a “+” by their names contributed a patch for the first time. This list of names is automatically generated, and may not be fully complete.

### Issues closed for 0.16.0

- [#1063](#): Implement a wishart distribution (Trac #536)
- [#1885](#): Rbf: floating point warnings - possible bug (Trac #1360)
- [#2020](#): Rbf default epsilon too large (Trac #1495)
- [#2325](#): extending distributions, hypergeom, to degenerate cases (Trac...)
- [#3502](#): [ENH] linalg.hessenberg should use ORGHR for calc\_q=True

- #3603: Passing array as window into `signal.resample()` fails
- #3675: Intermittent failures for `signal.slepian` on Windows
- #3742: Pchipinterpolator inconvenient as `ppoly`
- #3786: add `procrustes?`
- #3798: `scipy.io.savemat` fails for empty dicts
- #3975: Use `RandomState` in `scipy.stats`
- #4022: `savemat` incorrectly saves logical arrays
- #4028: `scipy.stats.geom.logpmf(1,1)` returns `nan`. The correct value is...
- #4030: simplify `scipy.stats.betaprime.cdf`
- #4031: improve accuracy of `scipy.stats.gompertz` distribution for small...
- #4033: improve accuracy of `scipy.stats.lomax` distribution for small...
- #4034: improve accuracy of `scipy.stats.rayleigh` distribution for large...
- #4035: improve accuracy of `scipy.stats.truncexpon` distribution for small...
- #4081: Error when reading matlab file: buffer is too small for requested...
- #4100: Why does `qr(a, lwork=0)` not fail?
- #4134: `scipy.stats: rv_frozen` has no `expect()` method
- #4204: Please add docstring to `scipy.optimize.RootResults`
- #4206: Wrap LAPACK tridiagonal solve routine `gtsv`
- #4208: Empty sparse matrices written to MAT file cannot be read by MATLAB
- #4217: use a TravisCI configuration with `numpy` built with `NPY_RELAXED_STRIDES_CHECKING=1`
- #4282: `integrate.odeint` raises an exception when `full_output=1` and the...
- #4301: `scipy` and `numpy` version names do not follow pep 440
- #4355: `PPoly.antiderivative()` produces incorrect output
- #4391: `spsolve` becomes extremely slow with large `b` matrix
- #4393: Documentation glitsch in `sparse.linalg.spilu`
- #4408: Vector-valued constraints in `minimize()` et al
- #4412: Documentation of `scipy.signal.cwt` error
- #4428: `dok.__setitem__` problem with negative indices
- #4434: Incomplete documentation for `sparse.linalg.spsolve`
- #4438: `linprog()` documentation example wrong
- #4445: Typo in `scipy.special.expit` doc
- #4467: Documentation Error in `scipy.optimize` options for TNC
- #4492: `solve_toeplitz` benchmark is bitrotting already
- #4506: `lobpcg/sparse` performance regression Jun 2014?
- #4520: `g77_abi_wrappers` needed on Linux for MKL as well
- #4521: Broken check in `uses_mkl` for newer versions of the library

- #4523: rbf with gaussian kernel seems to produce more noise than original...
- #4526: error in site documentation for poisson.pmf() method
- #4527: KDTree example doesn't work in Python 3
- #4550: `scipy.stats.mode` - UnboundLocalError on empty sequence
- #4554: filter out convergence warnings in optimization tests
- #4565: odeint messages
- #4569: remez: "ValueError: Failure to converge after 25 iterations...."
- #4582: DOC: optimize: `_minimize_scalar_brent` does not have a disp option
- #4585: DOC: Erroneous latex-related characters in tutorial.
- #4590: sparse.linalg.svds should throw an exception if which not in...
- #4594: scipy.optimize.linprog IndexError when a callback is provided
- #4596: scipy.linalg.block\_diag misbehavior with empty array inputs (v0.13.3)
- #4599: scipy.integrate.nquad should call `_OptFunc` when called with only...
- #4612: Crash in signal.lfilter on nd input with wrong shaped zi
- #4613: scipy.io.readsav error on reading sav file
- #4673: scipy.interpolate.RectBivariateSpline construction locks PyQt...
- #4681: Broadcasting in signal.lfilter still not quite right.
- #4705: kmeans `k_or_guess` parameter error if guess is not square array
- #4719: Build failure on 14.04.2
- #4724: GenGamma `_munp` function fails due to overflow
- #4726: FAIL: `test_cobyla.test_vector_constraints`
- #4734: Failing tests in stats with numpy master.
- #4736: qr\_update bug or incompatibility with numpy 1.10?
- #4746: linprog returns solution violating equality constraint
- #4757: optimize.leastsq docstring mismatch
- #4774: Update contributor list for v0.16
- #4779: circmean and others do not appear in the documentation
- #4788: problems with scipy sparse.linalg.isolve.iterative.py when complex
- #4791: BUG: scipy.spatial: incremental Voronoi doesn't increase size...

### Pull requests for 0.16.0

- #3116: sparse: enhancements for DIA format
- #3157: ENH: linalg: add the function 'solve\_circulant' for solving a...
- #3442: ENH: signal: Add Gustafsson's method as an option for the filtfilt...
- #3679: WIP: fix sporadic slepian failures
- #3680: Some cleanups in stats

- #3717: ENH: Add second-order sections filtering
- #3741: Dltisys changes
- #3956: add note to scipy.signal.resample about prime sample numbers
- #3980: Add check\_finite flag to UnivariateSpline
- #3996: MAINT: stricter linalg argument checking
- #4001: BUG: numerical precision in dirichlet
- #4012: ENH: linalg: Add a function to compute the inverse of a Pascal...
- #4021: ENH: Cython api for lapack and blas
- #4089: Fixes for various PEP8 issues.
- #4116: MAINT: fitpack: trim down compiler warnings (unused labels, variables)
- #4129: ENH: stats: add a random\_state property to distributions
- #4135: ENH: Add Wishart and inverse Wishart distributions
- #4195: improve the interpolate docs
- #4200: ENH: Add t-test from descriptive stats function.
- #4202: Dendrogram threshold color
- #4205: BLD: fix a number of Bento build warnings.
- #4211: add an ufunc for the inverse Box-Cox transform
- #4212: MRG:fix for gh-4208
- #4213: ENH: specific warning if matlab file is empty
- #4215: Issue #4209: splprep documentation updated to reflect dimensional...
- #4219: DOC: silence several Sphinx warnings when building the docs
- #4223: MAINT: remove two redundant lines of code
- #4226: try forcing the numpy rebuild with relaxed strides
- #4228: BLD: some updates to Bento config files and docs. Closes gh-3978.
- #4232: wrong references in the docs
- #4242: DOC: change example sample spacing
- #4245: Arff fixes
- #4246: MAINT: C fixes
- #4247: MAINT: remove some unused code
- #4249: Add routines for updating QR decompositions
- #4250: MAINT: Some pyflakes-driven cleanup in linalg and sparse
- #4252: MAINT trim away >10 kLOC of generated C code
- #4253: TST: stop shadowing ellip\* tests vs boost data
- #4254: MAINT: special: use NPY\_PI, not M\_PI
- #4255: DOC: INSTALL: use Py3-compatible print syntax, and don't mention...
- #4256: ENH: spatial: reimplement cdist\_cosine using np.dot

- #4258: BUG: io.arff #4429 #2088
- #4261: MAINT: signal: PEP8 and related style clean up.
- #4262: BUG: newton\_krylov() was ignoring norm\_tol argument, closes #4259
- #4263: MAINT: clean up test noise and optimize tests for docstrings...
- #4266: MAINT: io: Give an informative error when attempting to read...
- #4268: MAINT: fftpack benchmark integer division vs true division
- #4269: MAINT: avoid shadowing the eigvals function
- #4272: BUG: sparse: Fix bench\_sparse.py
- #4276: DOC: remove confusing parts of the documentation related to writing...
- #4281: Sparse matrix multiplication: only convert array if needed (with...
- #4284: BUG: integrate: odeint crashed when the integration time was...
- #4286: MRG: fix matlab output type of logical array
- #4287: DEP: deprecate stats.pdf\_fromgamma. Closes gh-699.
- #4291: DOC: linalg: fix layout in cholesky\_banded docstring
- #4292: BUG: allow empty dict as proxy for empty struct
- #4293: MAINT: != -> not\_equal in hamming distance implementation
- #4295: Pole placement
- #4296: MAINT: some cleanups in tests of several modules
- #4302: ENH: Solve toeplitz linear systems
- #4306: Add benchmark for conjugate gradient solver.
- #4307: BLD: PEP 440
- #4310: BUG: make stats.geom.logpmf(1,1) return 0.0 instead of nan
- #4311: TST: restore a test that uses slogdet now that we have dropped...
- #4313: Some minor fixes for stats.wishart addition.
- #4315: MAINT: drop numpy 1.5 compatibility code in sparse matrix tests
- #4318: ENH: Add random\_state to multivariate distributions
- #4319: MAINT: fix hamming distance regression for exotic arrays, with...
- #4320: TST: a few changes like self.assertTrue(x == y, message) -> assert\_equal(x,...
- #4321: TST: more changes like self.assertTrue(x == y, message) -> assert\_equal(x,...
- #4322: TST: in test\_signaltools, changes like self.assertTrue(x == y,...
- #4323: MAINT: clean up benchmarks so they can all be run as single files.
- #4324: Add more detailed committer guidelines, update MAINTAINERS.txt
- #4326: TST: use numpy.testing in test\_hierarchy.py
- #4329: MAINT: stats: rename check\_random\_state test function
- #4330: Update distance tests
- #4333: MAINT: import comb, factorial from scipy.special, not scipy.misc

- #4338: TST: more conversions from nose to numpy.testing
- #4339: MAINT: remove the deprecated all\_mat function from special\_matrices.py
- #4340: add several features to frozen distributions
- #4344: BUG: Fix/test invalid lwork param in qr
- #4345: Fix test noise visible with Python 3.x
- #4347: Remove deprecated blas/lapack imports, rename lib to \_lib
- #4349: DOC: add a nontrivial example to stats.binned\_statistic.
- #4350: MAINT: remove optimize.anneal for 0.16.0 (was deprecated in 0.14.0).
- #4351: MAINT: fix usage of deprecated Numpy C API in optimize...
- #4352: MAINT: fix a number of special test failures
- #4353: implement cdf for betaprime distribution
- #4357: BUG: piecewise polynomial antiderivative
- #4358: BUG: integrate: fix handling of banded Jacobians in odeint, plus...
- #4359: MAINT: remove a code path taken for Python version < 2.5
- #4360: MAINT: stats.mstats: Remove some unused variables (thanks, pyflakes).
- #4362: Removed erroneous reference to smoothing parameter #4072
- #4363: MAINT: interpolate: clean up in fitpack.py
- #4364: MAINT: lib: don't export "partial" from decorator
- #4365: svdvals now returns a length-0 sequence of singular values given...
- #4367: DOC: slightly improve TeX rendering of wishart/invwishart docstring
- #4373: ENH: wrap gtsv and ptsv for solve\_banded and solveh\_banded.
- #4374: ENH: Enhancements to spatial.cKDTree
- #4376: BF: fix reading off-spec matlab logical sparse
- #4377: MAINT: integrate: Clean up some Fortran test code.
- #4378: MAINT: fix usage of deprecated Numpy C API in signal
- #4380: MAINT: scipy.optimize, removing further anneal references
- #4381: ENH: Make DCT and DST accept int and complex types like fft
- #4392: ENH: optimize: add DF-SANE nonlinear derivative-free solver
- #4394: Make reordering algorithms 64-bit clean
- #4396: BUG: bundle cblas.h in Accelerate ABI wrappers to enable compilation...
- #4398: FIX pdist bug where wminkowski's w.dtype != double
- #4402: BUG: fix stat.hypergeom argcheck
- #4404: MAINT: Fill in the full symmetric squareform in the C loop
- #4405: BUG: avoid  $X += X.T$  (refs #4401)
- #4407: improved accuracy of gompertz distribution for small x
- #4414: DOC:fix error in scipy.signal.cwt documentation.

- #4415: ENH: Improve accuracy of lomax for small x.
- #4416: DOC: correct a parameter name in docstring of SuperLU.solve....
- #4419: Restore scipy.linalg.calc\_lwork also in master
- #4420: fix a performance issue with a sparse solver
- #4423: ENH: improve rayleigh accuracy for large x.
- #4424: BUG: optimize.minimize: fix overflow issue with integer x0 input.
- #4425: ENH: Improve accuracy of truncexpon for small x
- #4426: ENH: improve rayleigh accuracy for large x.
- #4427: MAINT: optimize: cleanup of TNC code
- #4429: BLD: fix build failure with numpy 1.7.x and 1.8.x.
- #4430: BUG: fix a sparse.dok\_matrix set/get copy-paste bug
- #4433: Update \_minimize.py
- #4435: ENH: release GIL around batch distance computations
- #4436: Fixed incomplete documentation for spsolve
- #4439: MAINT: integrate: Some clean up in the tests.
- #4440: Fast permutation t-test
- #4442: DOC: optimize: fix wrong result in docstring
- #4447: DOC: signal: Some additional documentation to go along with the...
- #4448: DOC: tweak the docstring of lapack.linalg module
- #4449: fix a typo in the expit docstring
- #4451: ENH: vectorize distance loops with gcc
- #4456: MAINT: don't fail large data tests on MemoryError
- #4461: CI: use travis\_retry to deal with network timeouts
- #4462: DOC: rationalize minimize() et al. documentation
- #4470: MAINT: sparse: inherit dok\_matrix.toarray from spmatrix
- #4473: BUG: signal: Fix validation of the zi shape in sosfilt.
- #4475: BLD: setup.py: update min numpy version and support "setup.py...
- #4481: ENH: add a new linalg special matrix: the Helmert matrix
- #4485: MRG: some changes to allow reading bad mat files
- #4490: [ENH] linalg.hessenberg: use orghr - rebase
- #4491: ENH: linalg: Adding wrapper for potentially useful LAPACK function...
- #4493: BENCH: the solve\_toeplitz benchmark used outdated syntax and...
- #4494: MAINT: stats: remove duplicated code
- #4496: References added for watershed\_ift algorithm
- #4499: DOC: reshuffle stats distributions documentation
- #4501: Replace benchmark suite with airspeed velocity

- #4502: SLSQP should strictly satisfy bound constraints
- #4503: DOC: forward port 0.15.x release notes and update author name...
- #4504: ENH: option to avoid computing possibly unused svd matrix
- #4505: Rebase of PR 3303 (sparse matrix norms)
- #4507: MAINT: fix lobpcg performance regression
- #4509: DOC: sparse: replace dead link
- #4511: Fixed differential evolution bug
- #4512: Change to fully PEP440 compliant dev version numbers (always...
- #4525: made tiny style corrections (pep8)
- #4533: Add exponentially modified gaussian distribution (scipy.stats.expongauss)
- #4534: MAINT: benchmarks: make benchmark suite importable on all scipy...
- #4535: BUG: Changed zip() to list(zip()) so that it could work in Python...
- #4536: Follow up to pr 4348 (exponential window)
- #4540: ENH: spatial: Add procrustes analysis
- #4541: Bench fixes
- #4542: TST: NumpyVersion dev -> dev0
- #4543: BUG: Overflow in savgol\_coeffs
- #4544: pep8 fixes for stats
- #4546: MAINT: use reduction axis arguments in one-norm estimation
- #4549: ENH : Added group\_delay to scipy.signal
- #4553: ENH: Significantly faster moment function
- #4556: DOC: document the changes of the sparse.linalg.svds (optional...
- #4559: DOC: stats: describe loc and scale parameters in the docstring...
- #4563: ENH: rewrite of stats.ppc\_plot
- #4564: Be more (or less) forgiving when user passes +-inf instead of...
- #4566: DEP: remove a bunch of deprecated function from scipy.stats,...
- #4570: MNT: Suppress LineSearchWarning's in scipy.optimize tests
- #4572: ENH: Extract inverse hessian information from L-BFGS-B
- #4576: ENH: Split signal.lti into subclasses, part of #2912
- #4578: MNT: Reconcile docstrings and function signatures
- #4581: Fix build with Intel MKL on Linux
- #4583: DOC: optimize: remove references to unused disp kwarg
- #4584: ENH: scipy.signal - Tukey window
- #4587: Hermite asymptotic
- #4593: DOC - add example to RegularGridInterpolator
- #4595: DOC: Fix erroneous latex characters in tutorial/optimize.

- #4600: Add return codes to optimize.tnc docs
- #4603: ENH: Wrap LAPACK `*lange` functions for matrix norms
- #4604: scipy.stats: generalized normal distribution
- #4609: MAINT: interpolate: fix a few inconsistencies between docstrings...
- #4610: MAINT: make runtest.py `-bench-compare` use asv continuous and...
- #4611: DOC: stats: explain rice scaling; add a note to the tutorial...
- #4614: BUG: lfilter, the size of zi was not checked correctly for nd...
- #4617: MAINT: integrate: Clean the C code behind odeint.
- #4618: FIX: Raise error when window length != data length
- #4619: Issue #4550: `scipy.stats.mode` - UnboundLocalError on empty...
- #4620: Fixed a problem (#4590) with svds accepting wrong eigenvalue...
- #4621: Speed up special.ai\_zeros/bi\_zeros by 10x
- #4623: MAINT: some tweaks to spatial.procrustes (private file, html...
- #4628: Speed up signal.lfilter and add a convolution path for FIR filters
- #4629: Bug: integrate.nquad; resolve issue #4599
- #4631: MAINT: integrate: Remove unused variables in a Fortran test function.
- #4633: MAINT: Fix convergence message for remez
- #4635: PEP8: indentation (so that pep8 bot does not complain)
- #4637: MAINT: generalize a sign function to do the right thing for complex...
- #4639: Amended typo in apple\_sgemv\_fix.c
- #4642: MAINT: use lapack for scipy.linalg.norm
- #4643: RBF default epsilon too large 2020
- #4646: Added `atleast_1d` around poly in invres and invresz
- #4647: fix doc pdf build
- #4648: BUG: Fixes #4408: Vector-valued constraints in minimize() et...
- #4649: Vonmisesfix
- #4650: Signal example clean up in Tukey and place\_poles
- #4652: DOC: Fix the error in convolve for same mode
- #4653: improve erf performance
- #4655: DEP: deprecate scipy.stats.histogram2 in favour of np.histogram2d
- #4656: DEP: deprecate scipy.stats.signaltonoise
- #4660: Avoid extra copy for sparse compressed `[:, seq]` and `[seq, :]`...
- #4661: Clean, rebase of #4478, adding `?gelsy` and `?gelsd` wrappers
- #4662: MAINT: Correct odeint messages
- #4664: Update `_monotone.py`
- #4672: fix behavior of scipy.linalg.block\_diag for empty input

- #4675: Fix lsim
- #4676: Added missing colon to `:math:` directive in docstring.
- #4679: ENH: sparse randn
- #4682: ENH: `scipy.signal` - Addition of CSD, coherence; Enhancement of...
- #4684: BUG: various errors in weight calculations in `orthogonal.py`
- #4685: BUG: Fixes #4594: `optimize.linprog` `IndexError` when a callback...
- #4686: MAINT: `cluster`: Clean up duplicated exception raising code.
- #4688: Improve `is_distance_dm` exception message
- #4692: MAINT: `stats`: Simplify the calculation in `tukeylambda._ppf`
- #4693: ENH: added functionality to handle scalars in `stats._chk_asarray`
- #4694: Vectorization of Anderson-Darling computations.
- #4696: Fix singleton expansion in `lfilter`.
- #4698: MAINT: quiet warnings from `cephes`.
- #4701: add `Bpoly.antiderivatives / integrals`
- #4703: Add citation of published paper
- #4706: MAINT: `special`: avoid out-of-bounds access in `specfun`
- #4707: MAINT: fix issues with `np.matrix` as input to functions related...
- #4709: ENH: `scipy.stats` now returns namedtuples.
- #4710: `scipy.io.idl`: make reader more robust to missing variables in...
- #4711: Fix crash for unknown chunks at the end of file
- #4712: Reduce `onenormest` memory usage
- #4713: MAINT: `interpolate`: no need to pass `dtype` around if it can be...
- #4714: BENCH: Add benchmarks for `stats` module
- #4715: MAINT: polish `signal.place_poles` and `signal/test_ltisys.py`
- #4716: DEP: deprecate `mstats.signaltonoise ...`
- #4717: MAINT: `basinhopping`: fix error in tests, silence `/0` warning,...
- #4718: ENH: `stats`: can specify f-shapes to fix in fitting by name
- #4721: Document that `imresize` converts the input to a PIL image
- #4722: MAINT: `PyArray_BASE` is not an lvalue unless the deprecated API...
- #4725: Fix `gengamma _numpy` failure
- #4728: DOC: add `poch` to the list of `scipy` special function descriptions
- #4735: MAINT: `stats`: avoid (a spurious) division-by-zero in `skew`
- #4738: TST: silence runtime warnings for some corner cases in `stats...`
- #4739: BLD: try to build `numpy` instead of using the one on TravisCI
- #4740: DOC: Update some docstrings with 'versionadded'.
- #4742: BLD: make sure that relaxed strides checking is in effect on...

- #4750: DOC: special: TeX typesetting of `rel ENTR`, `kl DIV` and `pseudo_huber`
- #4751: BENCH: add sparse null slice benchmark
- #4753: BUG: Fixed compilation with recent Cython versions.
- #4756: BUG: Fixes #4733: `optimize.brute` finish option is not compatible...
- #4758: DOC: `optimize.leastsq` default `maxfev` clarification
- #4759: improved stats mle fit
- #4760: MAINT: count bfgs updates more carefully
- #4762: BUGS: Fixes #4746 and #4594: `linprog` returns solution violating...
- #4763: fix small `linprog` bugs
- #4766: BENCH: add `signal.lsim` benchmark
- #4768: fix python syntax errors in docstring examples
- #4769: Fixes #4726: `test_cobyla.test_vector_constraints`
- #4770: Mark FITPACK functions as thread safe.
- #4771: edited `scipy/stats/stats.py` to fix doctest for `fisher_exact`
- #4773: DOC: update 0.16.0 release notes.
- #4775: DOC: `linalg`: add `funm_psd` as a docstring example
- #4778: Use a dictionary for function name synonyms
- #4780: Include apparently-forgotten functions in docs
- #4783: Added many missing special functions to docs
- #4784: add an axis attribute to `PPoly` and friends
- #4785: Brief note about origin of Lena image
- #4786: DOC: reformat the Methods section of the KDE docstring
- #4787: Add `rice` cdf and `ppf`.
- #4792: CI: add a kludge for detecting test failures which try to disguise...
- #4795: Make `refguide_check` smarter about false positives
- #4797: BUG/TST: `numpoints` not updated for incremental Voronoi
- #4799: BUG: `spatial`: Fix a couple edge cases for the Mahalanobis metric...
- #4801: BUG: Fix `TypeError` in `scipy.optimize._trust-region.py` when `disp=True`.
- #4803: Issues with relaxed strides in QR updating routines
- #4806: MAINT: use an informed initial guess for cauchy fit
- #4810: PEP8ify `codata.py`
- #4812: BUG: Relaxed strides cleanup in `decomp_update.pyx.in`
- #4820: BLD: update Bento build for `sgemv` fix and install cython blas/lapack...
- #4823: ENH: `scipy.signal` - Addition of spectrogram function
- #4827: DOC: add `csd` and `coherence` to `__init__.py`
- #4833: BLD: fix issue in `linalg *lange` wrappers for g77 builds.

- #4841: TST: fix test failures in scipy.special with mingw32 due to test...
- #4842: DOC: update site.cfg.example. Mostly taken over from Numpy
- #4845: BUG: signal: Make spectrogram's return values order match the...
- #4849: DOC: Fix error in ode docstring example
- #4856: BUG: fix typo causing memleak

## 1.10 SciPy 0.15.1 Release Notes

SciPy 0.15.1 is a bug-fix release with no new features compared to 0.15.0.

### 1.10.1 Issues fixed

- #4413: BUG: Tests too strict, f2py doesn't have to overwrite this array
- #4417: BLD: avoid using NPY\_API\_VERSION to check not using deprecated...
- #4418: Restore and deprecate scipy.linalg.calc\_work

## 1.11 SciPy 0.15.0 Release Notes

### Contents

- *SciPy 0.15.0 Release Notes*
  - *New features*
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\* *Pull requests*

SciPy 0.15.0 is the culmination of 6 months of hard work. It contains several new features, numerous bug-fixes, improved test coverage and better documentation. There have been a number of deprecations and API changes in this release, which are documented below. All users are encouraged to upgrade to this release, as there are a large number of bug-fixes and optimizations. Moreover, our development attention will now shift to bug-fix releases on the 0.16.x branch, and on adding new features on the master branch.

This release requires Python 2.6, 2.7 or 3.2-3.4 and NumPy 1.5.1 or greater.

## 1.11.1 New features

### Linear Programming Interface

The new function `scipy.optimize.linprog` provides a generic linear programming similar to the way `scipy.optimize.minimize` provides a generic interface to nonlinear programming optimizers. Currently the only method supported is `simplex` which provides a two-phase, dense-matrix-based simplex algorithm. Callbacks functions are supported, allowing the user to monitor the progress of the algorithm.

### Differential evolution, a global optimizer

A new `scipy.optimize.differential_evolution` function has been added to the `optimize` module. Differential Evolution is an algorithm used for finding the global minimum of multivariate functions. It is stochastic in nature (does not use gradient methods), and can search large areas of candidate space, but often requires larger numbers of function evaluations than conventional gradient based techniques.

### `scipy.signal` improvements

The function `scipy.signal.max_len_seq` was added, which computes a Maximum Length Sequence (MLS) signal.

### `scipy.integrate` improvements

It is now possible to use `scipy.integrate` routines to integrate multivariate ctypes functions, thus avoiding callbacks to Python and providing better performance.

### `scipy.linalg` improvements

The function `scipy.linalg.orthogonal_procrustes` for solving the procrustes linear algebra problem was added.

BLAS level 2 functions `her`, `syr`, `her2` and `syr2` are now wrapped in `scipy.linalg`.

### `scipy.sparse` improvements

`scipy.sparse.linalg.svds` can now take a `LinearOperator` as its main input.

### **scipy.special improvements**

Values of ellipsoidal harmonic (i.e. Lamé) functions and associated normalization constants can be now computed using `ellip_harm`, `ellip_harm_2`, and `ellip_normal`.

New convenience functions `entr`, `rel_entr`, `kl_div`, `huber`, and `pseudo_huber` were added.

### **scipy.sparse.csgraph improvements**

Routines `reverse_cuthill_mckee` and `maximum_bipartite_matching` for computing reorderings of sparse graphs were added.

### **scipy.stats improvements**

Added a Dirichlet multivariate distribution, `scipy.stats.dirichlet`.

The new function `scipy.stats.median_test` computes Mood's median test.

The new function `scipy.stats.combine_pvalues` implements Fisher's and Stouffer's methods for combining p-values.

`scipy.stats.describe` returns a namedtuple rather than a tuple, allowing users to access results by index or by name.

## **1.11.2 Deprecated features**

The `scipy.weave` module is deprecated. It was the only module never ported to Python 3.x, and is not recommended to be used for new code - use Cython instead. In order to support existing code, `scipy.weave` has been packaged separately: <https://github.com/scipy/weave>. It is a pure Python package, and can easily be installed with `pip install weave`.

`scipy.special.bessel_diff_formula` is deprecated. It is a private function, and therefore will be removed from the public API in a following release.

`scipy.stats.nanmean`, `nanmedian` and `nanstd` functions are deprecated in favor of their numpy equivalents.

## **1.11.3 Backwards incompatible changes**

The functions `scipy.ndimage.minimum_positions`, `scipy.ndimage.maximum_positions` and `scipy.ndimage.extrema` return positions as ints instead of floats.

The format of banded Jacobians in `scipy.integrate.ode` solvers is changed. Note that the previous documentation of this feature was erroneous.

## **1.11.4 Authors**

- Abject +
- Ankit Agrawal +
- Sylvain Bellemare +
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- Tiziano Zito +

A total of 99 people contributed to this release. People with a “+” by their names contributed a patch for the first time. This list of names is automatically generated, and may not be fully complete.

### Issues closed

- #1431: `ellipk(x)` extending its domain for  $x < 0$  (Trac #904)
- #1727: consistency of `std` interface (Trac #1200)
- #1851: Shape parameter negated in `genextreme` (relative to R, MATLAB,...)
- #1889: `interp2d` is weird (Trac #1364)
- #2188: `splev` gives wrong values or crashes outside of support when der...
- #2343: `scipy.insterpolate`'s `splrep` function fails with certain combinations...
- #2669: `.signal.ltisys.ss2tf` should only apply to MISO systems in current...
- #2911: `interpolate.splder()` failure on Fedora
- #3171: future of `weave` in `scipy`
- #3176: Suggestion to improve error message in `scipy.integrate.odeint`

- #3198: pdf() and logpdf() methods for scipy.stats.gaussian\_kde
- #3318: Travis CI is breaking on test("full")
- #3329: scipy.stats.scoreatpercentile backward-incompatible change not...
- #3362: Reference cycle in scipy.sparse.linalg.eigs with shift-invert...
- #3364: BUG: linalg.hessenberg broken (wrong results)
- #3376: stats f\_oneway needs floats
- #3379: Installation of scipy 0.13.3 via zc.buildout fails
- #3403: hierarchy.linkage raises an ugly exception for a compressed 2x2...
- #3422: optimize.curve\_fit() handles NaN by returning all parameters...
- #3457: linalg.fractional\_matrix\_power has no docstring
- #3469: DOC: *ndimage.find\_object* ignores zero-values
- #3491: optimize.leastsq() documentation should mention it does not work...
- #3499: cluster.vq.whiten return nan for all zeros column in observations
- #3503: minimize attempts to do vector addition when numpy arrays are...
- #3508: exponweib.logpdf fails for valid parameters
- #3509: libatlas3-base-dev does not exist
- #3550: BUG: anomalous values computed by special.ellipkinc
- #3555: *scipy.ndimage* positions are float instead of int
- #3557: UnivariateSpline.\_\_call\_\_ should pass all relevant args through...
- #3569: No license statement for test data imported from boost?
- #3576: mstats test failure (too sensitive?)
- #3579: Errors on scipy 0.14.x branch using MKL, Ubuntu 14.04 x86\_64
- #3580: Operator overloading with sparse matrices
- #3587: Wrong alphabetical order in continuous statistical distribution...
- #3596: scipy.signal.fftconvolve no longer threadsafe
- #3623: BUG: signal.convolve takes longer than it needs to
- #3655: Integer returned from integer data in scipy.signal.periodogram...
- #3662: Travis failure on Numpy 1.5.1 (not reproducible?)
- #3668: dendrogram(orientation='foo')
- #3669: KroghInterpolator doesn't pass through points
- #3672: Inserting a knot in a spline
- #3682: misleading documentation of scipy.optimize.curve\_fit
- #3699: BUG?: minor problem with scipy.signal.lfilter w/initial conditions
- #3700: Inconsistent exceptions raised by scipy.io.loadmat
- #3703: TypeError for RegularGridInterpolator with big-endian data
- #3714: Misleading error message in eigsh: k must be between 1 and rank(A)-1

- #3720: `coo_matrix.setdiag()` fails
- #3740: `Scipy.Spatial.KdTree (Query) Return Type?`
- #3761: Invalid result from `scipy.special.btdtri`
- #3784: DOC - Special Functions - Drum example fix for higher modes
- #3785: `minimize()` should have friendlier args=
- #3787: BUG: signal: Division by zero in `lombscargle`
- #3800: BUG: `scipy.sparse.csgraph.shortest_path` overwrites input matrix
- #3817: Warning in calculating moments from Binomial distribution for...
- #3821: review scipy usage of `np.ma.is_masked`
- #3829: Linear algebra function documentation doesn't mention default...
- #3830: A bug in Docstring of `scipy.linalg.eig`
- #3844: Issue with shape parameter returned by `genextreme`
- #3858: "ImportError: No module named Cython.Compiler.Main" on install
- #3876: `savgol_filter` not in release notes and has no versionadded
- #3884: `scipy.stats.kendalltau` empty array error
- #3895: `ValueError: illegal value in 12-th argument of internal gesdd...`
- #3898: `skimage` test broken by `minmax` filter change
- #3901: `scipy sparse` errors with `numpy master`
- #3905: DOC: `optimize: linprog` docstring has two "Returns" sections
- #3915: DOC: `sphinx` warnings because of `**kws` in the stats distributions...
- #3935: Split `stats.distributions` files in tutorial
- #3969: `gh-3607` breaks backward compatibility in `ode` solver banded jacobians
- #4025: DOC: signal: The return value of `find_peaks_cwt` is not documented.
- #4029: `scipy.stats.nbinom.logpmf(0,1,1)` returns nan. Correct value is...
- #4032: ERROR: `test_imresize (test_pilutil.TestPILUtil)`
- #4038: errors do not propagate through `scipy.integrate.odeint` properly
- #4171: `orthogonal_procrustes` always returns scale.
- #4176: Solving the Discrete Lyapunov Equation does not work with matrix...

### Pull requests

- #3109: ENH Added Fisher's method and Stouffer's Z-score method
- #3225: Add the limiting distributions to generalized Pareto distribution...
- #3262: Implement back end of faster multivariate integration
- #3266: ENH: signal: add `type=False` as parameter for `periodogram` and...
- #3273: Add PEP8 check to Travis-CI
- #3342: ENH: `linprog` function for linear programming

- #3348: BUG: add proper error handling when using `interp2d` on regular...
- #3351: ENH: Add MLS method
- #3382: ENH: `scipy.special` information theory functions
- #3396: ENH: improve `stats.nanmedian` more by assuming nans are rare
- #3398: Added two wrappers to the `gaussian_kde` class.
- #3405: BUG: `cluster.linkage` array conversion to double dtype
- #3407: MAINT: use `assert_warns` instead of a more complicated mechanism
- #3409: ENH: change to use array view in `signal/_peak_finding.py`
- #3416: Issue 3376 : `stats.f_oneway` needs floats
- #3419: BUG: tools: Fix list of FMA instructions in `detect_cpu_extensions_wine.py`
- #3420: DOC: stats: Add 'entropy' to the stats package-level documentation.
- #3429: BUG: close intermediate file descriptor right after it is used...
- #3430: MAINT: Fix some cython variable declarations to avoid warnings...
- #3433: Correcting the normalization of chebwin window function
- #3435: Add more precise link to R's quantile documentation
- #3446: ENH: `scipy.optimize` - adding `differential_evolution`
- #3450: MAINT: remove unused function `scipy.stats.mstats._basic._kolmog1`
- #3458: Reworked version of PR-3084 (mstats-stats comparison)
- #3462: MAINT : Returning a warning for low attenuation values of `chebwin`...
- #3463: DOC: `linalg`: Add examples to functions in `matfuncs.py`
- #3477: ENH: `sparse`: release GIL in `sparsetools` routines
- #3480: DOC: Add more details to `deconvolve` docstring
- #3484: BLD: fix Qhull build issue with MinGW-w64. Closes gh-3237.
- #3498: MAINT: io: remove old warnings from `idl.py`
- #3504: BUG: `cluster.vq.whiten` returns nan or inf when `std==0`
- #3510: MAINT: stats: Reimplement the `pdf` and `logpdf` methods of `exponweib`.
- #3512: Fix PEP8 errors showing up on TravisCI after pep8 1.5 release
- #3514: DOC: `libatlas3-base-dev` seems to have never been a thing
- #3516: DOC improve `scipy.sparse` docstrings
- #3517: ENH: speed-up `ndimage.filters.min(max)imum_filter1d`
- #3518: Issues in `scipy.misc.logsumexp`
- #3526: DOC: graphical example for `cwt`, and use a more interesting signal
- #3527: ENH: Implement `min(max)imum_filter1d` using the MINLIST algorithm
- #3537: STY: reduce number of C compiler warnings
- #3540: DOC: `linalg`: add docstring to `fractional_matrix_power`
- #3542: `kde.py` Doc Typo

- #3545: BUG: stats: stats.levy.cdf with small arguments loses precision.
- #3547: BUG: special: erfcinv with small arguments loses precision.
- #3553: DOC: Convolve examples
- #3561: FIX: in ndimage.measurements return positions as int instead...
- #3564: Fix test failures with numpy master. Closes gh-3554
- #3565: ENH: make interp2d accept unsorted arrays for interpolation.
- #3566: BLD: add numpy requirement to metadata if it can't be imported.
- #3567: DOC: move matfuncs docstrings to user-visible functions
- #3574: Fixes multiple bugs in mstats.theilslopes
- #3577: TST: decrease sensitivity of an mstats test
- #3585: Cleanup of code in scipy.constants
- #3589: BUG: sparse: allow operator overloading
- #3594: BUG: lobpcg returned wrong values for small matrices ( $n < 10$ )
- #3598: MAINT: fix coverage and coveralls
- #3599: MAINT: symeig – now that's a name I've not heard in a long time
- #3602: MAINT: clean up the new optimize.linprog and add a few more tests
- #3607: BUG: integrate: Fix some bugs and documentation errors in the...
- #3609: MAINT integrate/odepack: kill dead Fortran code
- #3616: FIX: Invalid values
- #3617: Sort netcdf variables in a Python-3 compatible way
- #3622: DOC: Added 0.15.0 release notes entry for linprog function.
- #3625: Fix documentation for cKDTree.sparse\_distance\_matrix
- #3626: MAINT: linalg.orth memory efficiency
- #3627: MAINT: stats: A bit of clean up
- #3628: MAINT: signal: remove a useless function from wavelets.py
- #3632: ENH: stats: Add Mood's median test.
- #3636: MAINT: cluster: some clean up
- #3638: DOC: docstring of optimize.basinhopping confuses singular and...
- #3639: BUG: change ddof default to 1 in mstats.sem, consistent with...
- #3640: Weave: deprecate the module and disable slow tests on TravisCI
- #3641: ENH: Added support for date attributes to io.arff.arffread
- #3644: MAINT: stats: remove superfluous alias in mstats\_basic.py
- #3646: ENH: adding *sum\_duplicates* method to COO sparse matrix
- #3647: Fix for #3596: Make fftconvolve threadsafe
- #3650: BUG: sparse: smarter random index selection
- #3652: fix wrong option name in power\_divergence docstring example

- #3654: Changing EPD to Canopy
- #3657: BUG: signal.welch: ensure floating point dtype regardless of...
- #3660: TST: mark a test as known fail
- #3661: BLD: ignore pep8 E302 (expected 2 blank lines, found 1)
- #3663: BUG: fix leaking errstate, and ignore invalid= errors in a test
- #3664: BUG: correlate was extremely slow when in2.size > in1.size
- #3667: ENH: Adds default params to pdfs of multivariate\_norm
- #3670: ENH: Small speedup of FFT size check
- #3671: DOC: adding differential\_evolution function to 0.15 release notes
- #3673: BUG: interpolate/fitpack: arguments to fortran routines may not...
- #3674: Add support for appending to existing netcdf files
- #3681: Speed up test('full'), solve Travis CI timeout issues
- #3683: ENH: cluster: rewrite and optimize *vq* in Cython
- #3684: Update special docs
- #3688: Spacing in special docstrings
- #3692: ENH: scipy.special: Improving sph\_harm function
- #3693: Update refguide entries for signal and fftpack
- #3695: Update continuous.rst
- #3696: ENH: check for valid 'orientation' kwarg in dendrogram()
- #3701: make 'a' and 'b' coefficients atleast\_1d array in filtfilt
- #3702: BUG: cluster: \_vq unable to handle large features
- #3704: BUG: special: ellip(k,e)inc nan and double expected value
- #3707: BUG: handle fill\_value dtype checks correctly in RegularGridInterpolator
- #3708: Reraise exception on failure to read mat file.
- #3709: BUG: cast 'x' to correct dtype in KroghInterpolator.\_evaluate
- #3712: ENH: cluster: reimplement the update-step of K-means in Cython
- #3713: FIX: Check type of lfiltic
- #3718: Changed INSTALL file extension to rst
- #3719: address svds returning nans for zero input matrix
- #3722: MAINT: spatial: static, unused code, sqrt(sqeclidean)
- #3725: ENH: use numpys nanmedian if available
- #3727: TST: add a new fixed\_point test and change some test function...
- #3731: BUG: fix romb in scipy.integrate.quadrature
- #3734: DOC: simplify examples with semilogx
- #3735: DOC: Add minimal docstrings to lti.impulse/step
- #3736: BUG: cast pchip arguments to floats

- #3744: stub out inherited methods of Akima1DInterpolator
- #3746: DOC: Fix formatting for Raises section
- #3748: ENH: Added discrete Lyapunov transformation solve
- #3750: Enable automated testing with Python 3.4
- #3751: Reverse Cuthill-McKee and Maximum Bipartite Matching reorderings...
- #3759: MAINT: avoid indexing with a float array
- #3762: TST: filter out RuntimeWarning in vq tests
- #3766: TST: cluster: some cleanups in test\_hierarchy.py
- #3767: ENH/BUG: support negative m in elliptic integrals
- #3769: ENH: avoid repeated matrix inverse
- #3770: BUG: signal: In lfilter\_zi, b was not rescaled correctly when...
- #3772: STY avoid unnecessary transposes in csr\_matrix.getcol/row
- #3773: ENH: Add ext parameter to UnivariateSpline call
- #3774: BUG: in integrate/quadpack.h, put all declarations before statements.
- #3779: Incbet fix
- #3788: BUG: Fix lombscargle ZeroDivisionError
- #3791: Some maintenance for doc builds
- #3795: scipy.special.legendre docstring
- #3796: TYPO: sheroidal -> spheroidal
- #3801: BUG: shortest\_path overwrite
- #3803: TST: lombscargle regression test related to atan vs atan2
- #3809: ENH: orthogonal procrustes solver
- #3811: ENH: scipy.special, Implemented Ellipsoidal harmonic function:...
- #3819: BUG: make a fully connected csgraph from an ndarray with no zeros
- #3820: MAINT: avoid spurious warnings in binom(n, p=0).mean() etc
- #3825: Don't claim scipy.cluster does distance matrix calculations.
- #3827: get and set diagonal of coo\_matrix, and related csgraph laplacian...
- #3832: DOC: Minor additions to integrate/nquad docstring.
- #3845: Bug fix for #3842: Bug in scipy.optimize.line\_search
- #3848: BUG: edge case where the covariance matrix is exactly zero
- #3850: DOC: typo
- #3851: DOC: document default argument values for some arpack functions
- #3860: DOC: sparse: add the function 'find' to the module-level docstring
- #3861: BUG: Removed unnecessary storage of args as instance variables...
- #3862: BUG: signal: fix handling of multi-output systems in ss2tf.
- #3865: Feature request: ability to read heterogeneous types in FortranFile

- #3866: MAINT: update pip wheelhouse for installs
- #3871: MAINT: linalg: get rid of calc\_lwork.f
- #3872: MAINT: use scipy.linalg instead of np.dual
- #3873: BLD: show a more informative message if Cython wasn't installed.
- #3874: TST: cluster: cleanup the hierarchy test data
- #3877: DOC: Savitzky-Golay filter version added
- #3878: DOC: move versionadded to notes
- #3879: small tweaks to the docs
- #3881: FIX incorrect sorting during fancy assignment
- #3885: kendalltau function now returns a nan tuple if empty arrays used...
- #3886: BUG: fixing linprog's kwarg order to match docs
- #3888: BUG: optimize: In `_linprog_simplex`, handle the case where the...
- #3891: BUG: stats: Fix ValueError message in `chi2_contingency`.
- #3892: DOC: sparse.linalg: Fix lobpcg docstring.
- #3894: DOC: stats: Assorted docstring edits.
- #3896: Fix 2 mistakes in MatrixMarket format parsing
- #3897: BUG: associated Legendre function of second kind for  $1 < x < 1.0001$
- #3899: BUG: fix undefined behavior in `alngam`
- #3906: MAINT/DOC: Whitespace tweaks in several docstrings.
- #3907: TST: relax bounds of interpolate test to accomodate rounding...
- #3909: MAINT: Create a common version of `count_nonzero` for compatibility...
- #3910: Fix a couple of test errors in master
- #3911: Use MathJax for the html docs
- #3914: Rework the `_roots` functions and document them.
- #3916: Remove all `linpack_lite` code and replace with LAPACK routines
- #3917: splines, constant extrapolation
- #3918: DOC: tweak the `rv_discrete` docstring example
- #3919: Quadrature speed-up: `scipy.special.orthogonal.p_roots` with cache
- #3920: DOC: Clarify docstring for `sigma` parameter for `curve_fit`
- #3922: Fixed Docstring issues in `linprog` (Fixes #3905).
- #3924: Coerce args into tuple if necessary.
- #3926: DOC: Surround stats class methods in docstrings with backticks.
- #3927: Changed doc for `romb`'s `dx` parameter to int.
- #3928: check FITPACK conditions in `LSQUnivariateSpline`
- #3929: Added a warning about `leastsq` using with NaNs.
- #3930: ENH: optimize: `curve_fit` now warns if `pcov` is undetermined

- #3932: Clarified the  $k > n$  case.
- #3933: DOC: remove *import scipy as sp* abbreviation here and there
- #3936: Add license and copyright holders to test data imported from...
- #3938: DOC: Corrected documentation for return types.
- #3939: DOC: fitpack: add a note about Sch-W conditions to splrep docstring
- #3940: TST: integrate: Remove an invalid test of odeint.
- #3942: FIX: Corrected error message of eigsh.
- #3943: ENH: release GIL for filter and interpolation of ndimage
- #3944: FIX: Raise value error if window data-type is unsupported
- #3946: Fixed signal.get\_window with unicode window name
- #3947: MAINT: some docstring fixes and style cleanups in stats.mstats
- #3949: DOC: fix a couple of issues in stats docstrings.
- #3950: TST: sparse: remove known failure that doesn't fail
- #3951: TST: switch from Rackspace wheelhouse to numpy/cython source...
- #3952: DOC: stats: Small formatting correction to the 'chi' distribution...
- #3953: DOC: stats: Several corrections and small additions to docstrings.
- #3955: signal.\_\_init\_\_.py: remove duplicated *get\_window* entry
- #3959: TST: sparse: more "known failures" for DOK that don't fail
- #3960: BUG: io.netcdf: do not close mmap if there are references left...
- #3965: DOC: Fix a few more sphinx warnings that occur when building...
- #3966: DOC: add guidelines for using test generators in HACKING
- #3968: BUG: sparse.linalg: make Inv objects in arpack garbage-collectable...
- #3971: Remove all linpack\_lite code and replace with LAPACK routines
- #3972: fix typo in error message
- #3973: MAINT: better error message for multivariate normal.
- #3981: turn the cryptically named scipy.special information theory functions...
- #3984: Wrap her, syr, her2, syr2 blas routines
- #3990: improve UnivariateSpline docs
- #3991: ENH: stats: return namedtuple for describe output
- #3993: DOC: stats: percentileofscore references np.percentile
- #3997: BUG: linalg: pascal(35) was incorrect: last element overflowed...
- #3998: MAINT: use isMaskedArray instead of is\_masked to check type
- #3999: TST: test against all of boost data files.
- #4000: BUG: stats: Fix edge-case handling in a few distributions.
- #4003: ENH: using python's warnings instead of prints in fitpack.
- #4004: MAINT: optimize: remove a couple unused variables in zeros.c

- #4006: BUG: Fix C90 compiler warnings in *NI\_MinOrMaxFilter1D*
- #4007: MAINT/DOC: Fix spelling of 'decomposition' in several files.
- #4008: DOC: stats: Split the descriptions of the distributions in the...
- #4015: TST: logsumexp regression test
- #4016: MAINT: remove some inf-related warnings from logsumexp
- #4020: DOC: stats: fix whitespace in docstrings of several distributions
- #4023: Exactly one space required before assignments
- #4024: In dendrogram(): Correct an argument name and a grammar issue...
- #4041: BUG: misc: Ensure that the 'size' argument of PIL's 'resize'...
- #4049: BUG: Return of `_logpmf`
- #4051: BUG: expm of integer matrices
- #4052: ENH: integrate: odeint: Handle exceptions in the callback functions.
- #4053: BUG: stats: Refactor argument validation to avoid a unicode issue.
- #4057: Added newline to `scipy.sparse.linalg.svds` documentation for correct...
- #4058: MAINT: stats: Add note about change to `scoreatpercentile` in release...
- #4059: ENH: interpolate: Allow `splev` to accept an n-dimensional array.
- #4064: Documented the return value for `scipy.signal.find_peaks_cwt`
- #4074: ENH: Support `LinearOperator` as input to `svds`
- #4084: BUG: Match exception declarations in `scipy/io/matlab/streams.pyx`...
- #4091: DOC: special: more clear instructions on how to evaluate polynomials
- #4105: BUG: Workaround for SGEMV segfault in Accelerate
- #4107: DOC: get rid of 'import \*' in examples
- #4113: DOC: fix typos in `distance.yule`
- #4114: MAINT C fixes
- #4117: deprecate `nanmean`, `nanmedian` and `nanstd` in favor of their numpy...
- #4126: `scipy.io.idl`: support description records and fix bug with null...
- #4131: ENH: release GIL in more ndimage functions
- #4132: MAINT: stats: fix a typo [skip ci]
- #4145: DOC: Fix documentation error for `nc` chi-squared dist
- #4150: Fix `_nd_image.geometric_transform` endianness bug
- #4153: MAINT: remove use of deprecated numpy API in `lib/lapack/f2py`...
- #4156: MAINT: optimize: remove dead code
- #4159: MAINT: optimize: clean up Zeros code
- #4165: DOC: add missing special functions to `__doc__`
- #4172: DOC: remove misleading `procrustes` docstring line
- #4175: DOC: sparse: clarify CSC and CSR constructor usage

- #4177: MAINT: enable np.matrix inputs to solve\_discrete\_lyapunov
- #4179: TST: fix an intermittently failing test case for special.legendre
- #4181: MAINT: remove unnecessary null checks before free
- #4182: Ellipsoidal harmonics
- #4183: Skip Cython build in Travis-CI
- #4184: Pr 4074
- #4187: Pr/3923
- #4190: BUG: special: fix up ellip\_harm build
- #4193: BLD: fix msvc compiler errors
- #4194: BUG: fix buffer dtype mismatch on win-amd64
- #4199: ENH: Changed scipy.stats.describe output from datalen to nobs
- #4201: DOC: add blas2 and nan\* deprecations to the release notes
- #4243: TST: bump test tolerances

## 1.12 SciPy 0.14.1 Release Notes

SciPy 0.14.1 is a bug-fix release with no new features compared to 0.14.0.

### 1.12.1 Issues closed

- #3630: NetCDF reading results in a segfault
- #3631: SuperLU object not working as expected for complex matrices
- #3733: segfault from map\_coordinates
- #3780: Segfault when using CSR/CSC matrix and uint32/uint64
- #3781: BUG: sparse: fix omitted types in sparsertools typemaps
- #3802: 0.14.0 API breakage: \_gen generators are missing from scipy.stats.distributions API
- #3805: ndimage test failures with numpy 1.10
- #3812: == sometimes wrong on csr\_matrix
- #3853: Many scipy.sparse test errors/failures with numpy 1.9.0b2
- #4084: fix exception declarations for Cython 0.21.1 compatibility
- #4093: BUG: fitpack: avoid a memory error in splev(x, tck, der=k)
- #4104: BUG: Workaround SGEMV segfault in Accelerate (maintenance 0.14.x)
- #4143: BUG: fix ndimage functions for large data
- #4149: Bug in expm for integer arrays
- #4154: Backport gh-4041 for 0.14.1 (Ensure that the 'size' argument of PIL's 'resize' method is a tuple)
- #4163: Backport #4142 (ZeroDivisionError in scipy.sparse.linalg.lsqr)
- #4164: Backport gh-4153 (remove use of deprecated numpy API in lib/lapack/ f2py wrapper)

- #4180: backport pil resize support tuple fix
- #4168: Lots of arpack test failures on windows 32 bits with numpy 1.9.1
- #4203: Matrix multiplication in 0.14.x is more than 10x slower compared...
- #4218: attempt to make ndimage interpolation compatible with numpy relaxed...
- #4225: BUG: off-by-one error in PPoly shape checks
- #4248: BUG: optimize: fix issue with incorrect use of closure for slsqp.

## 1.13 SciPy 0.14.0 Release Notes

### Contents

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  - *New features*
    - \* *scipy.interpolate improvements*
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    - \* *scipy.optimize improvements*
    - \* *scipy.stats improvements*
    - \* *scipy.signal improvements*
    - \* *scipy.special improvements*
    - \* *scipy.sparse improvements*
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SciPy 0.14.0 is the culmination of 8 months of hard work. It contains many new features, numerous bug-fixes, improved test coverage and better documentation. There have been a number of deprecations and API changes in this release, which are documented below. All users are encouraged to upgrade to this release, as there are a large

number of bug-fixes and optimizations. Moreover, our development attention will now shift to bug-fix releases on the 0.14.x branch, and on adding new features on the master branch.

This release requires Python 2.6, 2.7 or 3.2-3.4 and NumPy 1.5.1 or greater.

### 1.13.1 New features

#### **scipy.interpolate improvements**

A new wrapper function `scipy.interpolate.interpn` for interpolation on regular grids has been added. `interpn` supports linear and nearest-neighbor interpolation in arbitrary dimensions and spline interpolation in two dimensions.

Faster implementations of piecewise polynomials in power and Bernstein polynomial bases have been added as `scipy.interpolate.PPoly` and `scipy.interpolate.BPoly`. New users should use these in favor of `scipy.interpolate.PiecewisePolynomial`.

`scipy.interpolate.interpld` now accepts non-monotonic inputs and sorts them. If performance is critical, sorting can be turned off by using the new `assume_sorted` keyword.

Functionality for evaluation of bivariate spline derivatives in `scipy.interpolate` has been added.

The new class `scipy.interpolate.Akima1DInterpolator` implements the piecewise cubic polynomial interpolation scheme devised by H. Akima.

Functionality for fast interpolation on regular, unevenly spaced grids in arbitrary dimensions has been added as `scipy.interpolate.RegularGridInterpolator`.

#### **scipy.linalg improvements**

The new function `scipy.linalg.dft` computes the matrix of the discrete Fourier transform.

A condition number estimation function for matrix exponential, `scipy.linalg.expm_cond`, has been added.

#### **scipy.optimize improvements**

A set of benchmarks for `optimize`, which can be run with `optimize.bench()`, has been added.

`scipy.optimize.curve_fit` now has more controllable error estimation via the `absolute_sigma` keyword.

Support for passing custom minimization methods to `optimize.minimize()` and `optimize.minimize_scalar()` has been added, currently useful especially for combining `optimize.basinhopping()` with custom local optimizer routines.

#### **scipy.stats improvements**

A new class `scipy.stats.multivariate_normal` with functionality for multivariate normal random variables has been added.

A lot of work on the `scipy.stats` distribution framework has been done. Moment calculations (skew and kurtosis mainly) are fixed and verified, all examples are now runnable, and many small accuracy and performance improvements for individual distributions were merged.

The new function `scipy.stats.anderson_ksamp` computes the k-sample Anderson-Darling test for the null hypothesis that k samples come from the same parent population.

### **scipy.signal improvements**

`scipy.signal.iirfilter` and related functions to design Butterworth, Chebyshev, elliptical and Bessel IIR filters now all use pole-zero (“zpk”) format internally instead of using transformations to numerator/denominator format. The accuracy of the produced filters, especially high-order ones, is improved significantly as a result.

The Savitzky-Golay filter was added with the new functions `scipy.signal.savgol_filter` and `scipy.signal.savgol_coeffs`.

The new function `scipy.signal.vectorstrength` computes the vector strength, a measure of phase synchrony, of a set of events.

### **scipy.special improvements**

The functions `scipy.special.boxcox` and `scipy.special.boxcox1p`, which compute the Box-Cox transformation, have been added.

### **scipy.sparse improvements**

- Significant performance improvement in CSR, CSC, and DOK indexing speed.
- When using Numpy  $\geq 1.9$  (to be released in MM 2014), sparse matrices function correctly when given to arguments of `np.dot`, `np.multiply` and other ufuncs. With earlier Numpy and Scipy versions, the results of such operations are undefined and usually unexpected.
- Sparse matrices are no longer limited to  $2^{31}$  nonzero elements. They automatically switch to using 64-bit index data type for matrices containing more elements. User code written assuming the sparse matrices use `int32` as the index data type will continue to work, except for such large matrices. Code dealing with larger matrices needs to accept either `int32` or `int64` indices.

## 1.13.2 Deprecated features

### **anneal**

The global minimization function `scipy.optimize.anneal` is deprecated. All users should use the `scipy.optimize.basinhopping` function instead.

### **scipy.stats**

`randwcdf` and `randwppf` functions are deprecated. All users should use distribution-specific `rvs` methods instead.

Probability calculation aliases `zprob`, `fprob` and `ksprob` are deprecated. Use instead the `sf` methods of the corresponding distributions or the `special` functions directly.

### **scipy.interpolate**

`PiecewisePolynomial` class is deprecated.

### 1.13.3 Backwards incompatible changes

`lpmn` no longer accepts complex-valued arguments. A new function `clpmn` with uniform complex analytic behavior has been added, and it should be used instead.

Eigenvectors in the case of generalized eigenvalue problem are normalized to unit vectors in 2-norm, rather than following the LAPACK normalization convention.

The deprecated UMFPACK wrapper in `scipy.sparse.linalg` has been removed due to license and install issues. If available, `scikits.umfpack` is still used transparently in the `spsolve` and `factorized` functions. Otherwise, SuperLU is used instead in these functions.

The deprecated functions `glm`, `oneway` and `cmedian` have been removed from `scipy.stats`.

`stats.scoreatpercentile` now returns an array instead of a list of percentiles.

The API for computing derivatives of a monotone piecewise interpolation has changed: if  $p$  is a `PchipInterpolator` object, `p.derivative(der)` returns a callable object representing the derivative of  $p$ . For in-place derivatives use the second argument of the `__call__` method: `p(0.1, der=2)` evaluates the second derivative of  $p$  at  $x=0.1$ .

The method `p.derivatives` has been removed.

### 1.13.4 Other changes

#### 1.13.5 Authors

- Marc Abramowitz +
- Anders Bech Borchersen +
- Vincent Arel-Bundock +
- Petr Baudis +
- Max Bolingbroke
- François Boulogne
- Matthew Brett
- Lars Buitinck
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- CJ Carey +
- Thomas A Caswell +
- Pawel Chojnacki +
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- David Cournapeau
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- Francisco de la Peña +
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- Jim Garrison +
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- Todd Jennings +
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- Eric Larson +
- Justin Lavoie +
- Denis Laxalde
- Jussi Leinonen +
- lemonlaug +
- Tim Leslie
- Alain Leufroy +
- George Lewis +
- Max Linke +
- Brandon Liu +
- Benny Malengier +
- Matthias Kümmerer +
- Cimarron Mittelsteadt +
- Eric Moore
- Andrew Nelson +

- Niklas Hambüchen +
- Joel Nothman +
- Clemens Novak
- Emanuele Olivetti +
- Stefan Otte +
- peb +
- Josef Perktold
- pjwernerneck
- poolio
- Jérôme Roy +
- Carl Sandrock +
- Andrew Sczesnak +
- Shauna +
- Fabrice Silva
- Daniel B. Smith
- Patrick Snape +
- Thomas Spura +
- Jacob Stevenson
- Julian Taylor
- Tomas Tomecek
- Richard Tsai
- Jacob Vanderplas
- Joris Vankerschaver +
- Pauli Virtanen
- Warren Weckesser

A total of 80 people contributed to this release. People with a “+” by their names contributed a patch for the first time. This list of names is automatically generated, and may not be fully complete.

### Issues closed

- [#1325](#): add custom axis keyword to dendrogram function in `scipy.cluster.hierarchy...`
- [#1437](#): Wrong pochhammer symbol for negative integers (Trac #910)
- [#1555](#): `scipy.io.netcdf` leaks file descriptors (Trac #1028)
- [#1569](#): sparse matrix failed with element-wise multiplication using `numpy.multiply()`...
- [#1833](#): Sparse matrices are limited to  $2^{32}$  non-zero elements (Trac #1307)
- [#1834](#): `scipy.linalg.eig` does not normalize eigenvector if B is given...
- [#1866](#): stats for `invgamma` (Trac #1340)

- #1886: stats.zipf floating point warnings (Trac #1361)
- #1887: Stats continuous distributions - floating point warnings (Trac...)
- #1897: scoreatpercentile() does not handle empty list inputs (Trac #1372)
- #1918: splint returns incorrect results (Trac #1393)
- #1949: kurtosistest fails in mstats with type error (Trac #1424)
- #2092: scipy.test leaves darwin27compiled\_catalog, cpp and so files...
- #2106: stats ENH: shape parameters in distribution docstrings (Trac...)
- #2123: Bad behavior of sparse matrices in a binary ufunc (Trac #1598)
- #2152: Fix mmio/fromfile on gzip on Python 3 (Trac #1627)
- #2164: stats.rice.pdf(x, 0) returns nan (Trac #1639)
- #2169: scipy.optimize.fmin\_bfgs not handling functions with boundaries...
- #2177: scipy.cluster.hierarchy.ClusterNode.pre\_order returns IndexError...
- #2179: coo.todense() segfaults (Trac #1654)
- #2185: Precision of scipy.ndimage.gaussian\_filter\*() limited (Trac #1660)
- #2186: scipy.stats.mstats.kurtosistest crashes on 1d input (Trac #1661)
- #2238: Negative p-value on hypergeom.cdf (Trac #1719)
- #2283: ascending order in interpolation routines (Trac #1764)
- #2288: mstats.kurtosistest is incorrectly converting to float, and fails...
- #2396: lpmn wrong results for  $|z| > 1$  (Trac #1877)
- #2398: ss2tf returns num as 2D array instead of 1D (Trac #1879)
- #2406: linkage does not take Unicode strings as method names (Trac #1887)
- #2443: IIR filter design should not transform to tf representation internally
- #2572: class method solve of splu return object corrupted or falsely...
- #2667: stats endless loop ?
- #2671: .stats.hypergeom documentation error in the note about pmf
- #2691: BUG scipy.linalg.lapack: potrf/ptroi interpret their 'lower'...
- #2721: Allow use of ellipsis in scipy.sparse slicing
- #2741: stats: deprecate and remove alias for special functions
- #2742: stats add rvs to rice distribution
- #2765: bugs stats entropy
- #2832: argrextrema returns tuple of 2 empty arrays when no peaks found...
- #2861: scipy.stats.scoreatpercentile broken for vector *per*
- #2891: COBYLA successful termination when constraints violated
- #2919: test failure with the current master
- #2922: ndimage.percentile\_filter ignores origin argument for multidimensional...
- #2938: Sparse/dense matrix inplace operations fail due to `__numpy_ufunc__`

- #2944: MacPorts builds yield 40Mb worth of build warnings
- #2945: FAIL: test\_random\_complex (test\_basic.TestDet)
- #2947: FAIL: Test some trivial edge cases for savgol\_filter()
- #2953: Scipy Delaunay triangulation is not oriented
- #2971: scipy.stats.mstats.winsorize documentation error
- #2980: Problems running what seems a perfectly valid example
- #2996: entropy for rv\_discrete is incorrect?!
- #2998: Fix numpy version comparisons
- #3002: python setup.py install fails
- #3014: Bug in stats.fisher\_exact
- #3030: relative entropy using scipy.stats.distribution.entropy when...
- #3037: scipy.optimize.curve\_fit leads to unexpected behavior when input...
- #3047: mstats.ttest\_rel axis=None, requires masked array
- #3059: BUG: Slices of sparse matrices return incorrect dtype
- #3063: range keyword in binned\_statistics incorrect
- #3067: cumtrapz not working as expected
- #3069: sinc
- #3086: standard error calculation inconsistent between 'stats' and 'mstats'
- #3094: Add a *perm* function into *scipy.misc* and an enhancement of...
- #3111: scipy.sparse.[hv]stack don't respect anymore the dtype parameter
- #3172: optimize.curve\_fit uses different nomenclature from optimize.leastsq
- #3196: scipy.stats.mstats.gmean does not actually take dtype
- #3212: Dot product of csr\_matrix causes segmentation fault
- #3227: ZeroDivisionError in broyden1 when initial guess is the right...
- #3238: lbfgsb output not suppressed by disp=0
- #3249: Sparse matrix min/max/etc don't support axis=-1
- #3251: cdist performance issue with 'sqeuclidean' metric
- #3279: logm fails for singular matrix
- #3285: signal.chirp(method='hyp') disallows hyperbolic upsweep
- #3299: MEMORY LEAK: fmin\_tnc
- #3330: test failures with the current master
- #3345: scipy and/or numpy change is causing tests to fail in another...
- #3363: splu does not work for non-vector inputs
- #3385: expit does not handle large arguments well
- #3395: specfun.f doesn't compile with MinGW
- #3399: Error message bug in scipy.cluster.hierarchy.linkage

- #3404: interpolate.\_ppoly doesn't build with MinGW
- #3412: Test failures in signal
- #3466: ``scipy.sparse.csgraph.shortest_path`` does not work on ``scipy.sparse.csr_matrix`` or ``lil_matrix``

### Pull requests

- #442: ENH: sparse: enable 64-bit index arrays &  $\text{nnz} > 2^{*}31$
- #2766: DOC: remove doc/seps/technology-preview.rst
- #2772: TST: stats: Added a regression test for stats.wilcoxon. Closes...
- #2778: Clean up stats.\_support, close statistics review issues
- #2792: BUG io: fix file descriptor closing for netcdf variables
- #2847: Rice distribution: extend to  $b=0$ , add an explicit rvs method.
- #2878: [stats] fix formulas for higher moments of dweibull distribution
- #2904: ENH: moments for the zipf distribution
- #2907: ENH: add coverage info with coveralls.io for Travis runs.
- #2932: BUG+TST: setdiag implementation for dia\_matrix (Close #2931)...
- #2942: Misc fixes pointed out by Eclipse PyDev static code analysis
- #2946: ENH: allow non-monotonic input in interp1d
- #2986: BUG: runtests: chdir away from root when running tests
- #2987: DOC: linalg: don't recommend np.linalg.norm
- #2992: ENH: Add "limit" parameter to dijkstra calculation
- #2995: ENH: Use int shape
- #3006: DOC: stats: add a log base note to the docstring
- #3007: DEP: stats: Deprecate randwppf and randwcdf
- #3008: Fix mstats.kurtosistest, and test coverage for skewtest/normaltest
- #3009: Minor reST typo
- #3010: Add `scipy.optimize.Result` to API docs
- #3012: Corrects documentation error
- #3052: PEP-8 conformance improvements
- #3064: Binned statistic
- #3068: Fix Issue #3067 fix cumtrapz that was raising an exception when...
- #3073: Arff reader with nominal value of 1 character
- #3074: Some maintenance work
- #3080: Review and clean up all Box-Cox functions
- #3083: Bug: should return 0 if no regions found
- #3085: BUG: Use zpk in IIR filter design to improve accuracy

- #3101: refactor stats tests a bit
- #3112: ENH: implement Akima interpolation in 1D
- #3123: MAINT: an easier way to make ranges from slices
- #3124: File object support for imread and imsave
- #3126: pep8ify stats/distributions.py
- #3134: MAINT: split distributions.py into three files
- #3138: clean up tests for discrete distributions
- #3155: special: handle the edge case lambda=0 in pdtr, pdtrc and pdtrik
- #3156: Rename optimize.Result to OptimizeResult
- #3166: BUG: make curve\_fit() work with array\_like input. Closes gh-3037.
- #3170: Fix numpy version checks
- #3175: use numpy sinc
- #3177: Update numpy version warning, remove oldnumeric import
- #3178: DEP: remove deprecated umfpack wrapper. Closes gh-3002.
- #3179: DOC: add BPoly to the docs
- #3180: Suppress warnings when running stats.test()
- #3181: altered sem func in mstats to match stats
- #3182: Make weave tests behave
- #3183: ENH: Add k-sample Anderson-Darling test to stats module
- #3186: Fix stats.scoreatpercentile
- #3187: DOC: make curve\_fit nomenclature same as leastsq
- #3201: Added axis keyword to dendrogram function
- #3207: Make docstring examples in stats.distributions docstrings runnable
- #3218: BUG: integrate: Fix banded jacobian handling in the “vode” and...
- #3222: BUG: limit input ranges in special.nctdtr
- #3223: Fix test errors with numpy master
- #3224: Fix int32 overflows in sparsertools
- #3228: DOC: tf2ss zpk2ss note controller canonical form
- #3234: Add See Also links and Example graphs to filter design \*ord functions
- #3235: Updated the buttord function to be consistent with the other...
- #3239: correct doc for pchip interpolation
- #3240: DOC: fix ReST errors in the BPoly docstring
- #3241: RF: check write attr of fileobject without writing
- #3243: a bit of maintenance work in stats
- #3245: BUG/ENH: stats: make frozen distributions hold separate instances
- #3247: ENH function to return nnz per row/column in some sparse matrices

- #3248: ENH much more efficient sparse min/max with axis
- #3252: Fast sseuclidean
- #3253: FIX support axis=-1 and -2 for sparse reduce methods
- #3254: TST tests for non-canonical input to sparse matrix operations
- #3272: BUG: sparse: fix bugs in dia\_matrix.setdiag
- #3278: Also generate a tar.xz when running paver sdist
- #3286: DOC: update 0.14.0 release notes.
- #3289: TST: remove insecure mktemp use in tests
- #3292: MAINT: fix a backwards incompatible change to stats.distributions.\_\_all\_\_
- #3293: ENH: signal: Allow upsweeps of frequency in the 'hyperbolic'...
- #3302: ENH: add dtype arg to stats.mstats.gmean and stats.mstats.hmean
- #3307: DOC: add note about different ba forms in tf2zpk
- #3309: doc enhancements to scipy.stats.mstats.winsorize
- #3310: DOC: clarify matrix vs array in mmio docstrings
- #3314: BUG: fix scipy.io.mmread() of gzipped files under Python3
- #3323: ENH: Efficient interpolation on regular grids in arbitrary dimensions
- #3332: DOC: clean up scipy.special docs
- #3335: ENH: improve nanmedian performance
- #3347: BUG: fix use of np.max in stats.fisher\_exact
- #3356: ENH: sparse: speed up LIL indexing + assignment via Cython
- #3357: Fix "imresize does not work with size = int"
- #3358: MAINT: rename AkimaInterpolator to Akima1DInterpolator
- #3366: WHT: sparse: reindent dsolve/\*.c \*.h
- #3367: BUG: sparse/dsolve: fix dense matrix fortran order bugs in superlu...
- #3369: ENH minimize, minimize\_scalar: Add support for user-provided...
- #3371: scipy.stats.sigmaclip doesn't appear in the html docs.
- #3373: BUG: sparse/dsolve: detect invalid LAPACK parameters in superlu...
- #3375: ENH: sparse/dsolve: make the L and U factors of splu and spilu...
- #3377: MAINT: make travis build one target against Numpy 1.5
- #3378: MAINT: fftpack: Remove the use of 'import \*' in a couple test...
- #3381: MAINT: replace np.isinf(x) & (x>0) -> np.isposinf(x) to avoid...
- #3383: MAINT: skip float96 tests on platforms without float96
- #3384: MAINT: add pyflakes to Travis-CI
- #3386: BUG: stable evaluation of expit
- #3388: BUG: SuperLU: fix missing declaration of dlamch
- #3389: BUG: sparse: downcast 64-bit indices safely to intp when required

- #3390: BUG: nonlinear solvers are not confused by lucky guess
- #3391: TST: fix sparse test errors due to axis=-1,-2 usage in `np.matrix.sum()`.
- #3392: BUG: sparse/lil: fix up Cython bugs in fused type lookup
- #3393: BUG: sparse/compressed: work around bug in `np.unique` in earlier...
- #3394: BUG: allow `ClusterNode.pre_order()` for non-root nodes
- #3400: BUG: `cluster.linkage` `ValueError` typo bug
- #3402: BUG: special: In `specfun.f`, replace the use of `CMPLX` with `DCMPLX`,...
- #3408: MAINT: sparse: Numpy 1.5 compatibility fixes
- #3410: MAINT: interpolate: fix blas defs in `_ppoly`
- #3411: MAINT: Numpy 1.5 fixes in `interpolate`
- #3413: Fix more test issues with older numpy versions
- #3414: TST: signal: loosen some error tolerances in the filter tests....
- #3415: MAINT: tools: automated close issue + pr listings for release...
- #3440: MAINT: wrap `sparsetools` manually instead via SWIG
- #3460: TST: open image file in binary mode
- #3467: BUG: fix validation in `csgraph.shortest_path`

## 1.14 SciPy 0.13.2 Release Notes

SciPy 0.13.2 is a bug-fix release with no new features compared to 0.13.1.

### 1.14.1 Issues fixed

- 3096: require Cython 0.19, earlier versions have memory leaks in fused types
- 3079: `ndimage.label` fix swapped 64-bitness test
- 3108: `optimize.fmin_slsqp` constraint violation

## 1.15 SciPy 0.13.1 Release Notes

SciPy 0.13.1 is a bug-fix release with no new features compared to 0.13.0. The only changes are several fixes in `ndimage`, one of which was a serious regression in `ndimage.label` (Github issue 3025), which gave incorrect results in 0.13.0.

### 1.15.1 Issues fixed

- 3025: `ndimage.label` returns incorrect results in `scipy 0.13.0`
- 1992: `ndimage.label` return type changed from `int32` to `uint32`
- 1992: `ndimage.find_objects` doesn't work with `int32` input in some cases

## 1.16 SciPy 0.13.0 Release Notes

### Contents

- *SciPy 0.13.0 Release Notes*
  - *New features*
    - \* *scipy.integrate improvements*
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    - \* *scipy.linalg improvements*
      - *Interpolative decompositions*
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    - \* *scipy.special improvements*
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      - *Unformatted Fortran file reader*
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    - \* *scipy.stats improvements*
  - *Deprecated features*
    - \* *expm2 and expm3*
    - \* *scipy.stats functions*
  - *Backwards incompatible changes*
    - \* *LIL matrix assignment*
    - \* *Deprecated radon function removed*
    - \* *Removed deprecated keywords xa and xb from stats.distributions*

\* *Changes to MATLAB file readers / writers*

- *Other changes*
- *Authors*

SciPy 0.13.0 is the culmination of 7 months of hard work. It contains many new features, numerous bug-fixes, improved test coverage and better documentation. There have been a number of deprecations and API changes in this release, which are documented below. All users are encouraged to upgrade to this release, as there are a large number of bug-fixes and optimizations. Moreover, our development attention will now shift to bug-fix releases on the 0.13.x branch, and on adding new features on the master branch.

This release requires Python 2.6, 2.7 or 3.1-3.3 and NumPy 1.5.1 or greater. Highlights of this release are:

- support for fancy indexing and boolean comparisons with sparse matrices
- interpolative decompositions and matrix functions in the linalg module
- two new trust-region solvers for unconstrained minimization

## 1.16.1 New features

### `scipy.integrate` improvements

#### *N-dimensional numerical integration*

A new function `scipy.integrate.nquad`, which provides N-dimensional integration functionality with a more flexible interface than `dblquad` and `tplquad`, has been added.

#### *dopri\* improvements*

The intermediate results from the `dopri` family of ODE solvers can now be accessed by a `solout` callback function.

### `scipy.linalg` improvements

#### *Interpolative decompositions*

SciPy now includes a new module `scipy.linalg.interpolative` containing routines for computing interpolative matrix decompositions (ID). This feature is based on the ID software package by P.G. Martinsson, V. Rokhlin, Y. Shkolnisky, and M. Tygert, previously adapted for Python in the PymatrixId package by K.L. Ho.

#### *Polar decomposition*

A new function `scipy.linalg.polar`, to compute the polar decomposition of a matrix, was added.

#### *BLAS level 3 functions*

The BLAS functions `symm`, `syrk`, `syr2k`, `hemm`, `herk` and `her2k` are now wrapped in `scipy.linalg`.

#### *Matrix functions*

Several matrix function algorithms have been implemented or updated following detailed descriptions in recent papers of Nick Higham and his co-authors. These include the matrix square root (`sqrtn`), the matrix logarithm (`logm`), the matrix exponential (`expm`) and its Frechet derivative (`expm_frechet`), and fractional matrix powers (`fractional_matrix_power`).

### `scipy.optimize` improvements

#### *Trust-region unconstrained minimization algorithms*

The `minimize` function gained two trust-region solvers for unconstrained minimization: `dogleg` and `trust-ncg`.

### `scipy.sparse` improvements

#### *Boolean comparisons and sparse matrices*

All sparse matrix types now support boolean data, and boolean operations. Two sparse matrices  $A$  and  $B$  can be compared in all the expected ways  $A < B$ ,  $A >= B$ ,  $A != B$ , producing similar results as dense Numpy arrays. Comparisons with dense matrices and scalars are also supported.

#### *CSR and CSC fancy indexing*

Compressed sparse row and column sparse matrix types now support fancy indexing with boolean matrices, slices, and lists. So where  $A$  is a (CSC or CSR) sparse matrix, you can do things like:

```
>>> A[A > 0.5] = 1 # since Boolean sparse matrices work
>>> A[:, :3] = 2
>>> A[[1,2], 2] = 3
```

### `scipy.sparse.linalg` improvements

The new function `onenormest` provides a lower bound of the 1-norm of a linear operator and has been implemented according to Higham and Tisseur (2000). This function is not only useful for sparse matrices, but can also be used to estimate the norm of products or powers of dense matrices without explicitly building the intermediate matrix.

The multiplicative action of the matrix exponential of a linear operator (`expm_multiply`) has been implemented following the description in Al-Mohy and Higham (2011).

Abstract linear operators (`scipy.sparse.linalg.LinearOperator`) can now be multiplied, added to each other, and exponentiated, producing new linear operators. This enables easier construction of composite linear operations.

### `scipy.spatial` improvements

The vertices of a `ConvexHull` can now be accessed via the `vertices` attribute, which gives proper orientation in 2-D.

### `scipy.signal` improvements

The cosine window function `scipy.signal.cosine` was added.

### `scipy.special` improvements

New functions `scipy.special.xlogy` and `scipy.special.xlog1py` were added. These functions can simplify and speed up code that has to calculate  $x * \log(y)$  and give 0 when  $x == 0$ .

## scipy.io improvements

### *Unformatted Fortran file reader*

The new class `scipy.io.FortranFile` facilitates reading unformatted sequential files written by Fortran code.

### *scipy.io.wavfile enhancements*

`scipy.io.wavfile.write` now accepts a file buffer. Previously it only accepted a filename.

`scipy.io.wavfile.read` and `scipy.io.wavfile.write` can now handle floating point WAV files.

## scipy.interpolate improvements

### *B-spline derivatives and antiderivatives*

`scipy.interpolate.splder` and `scipy.interpolate.splantider` functions for computing B-splines that represent derivatives and antiderivatives of B-splines were added. These functions are also available in the class-based FITPACK interface as `UnivariateSpline.derivative` and `UnivariateSpline.antiderivative`.

## scipy.stats improvements

Distributions now allow using keyword parameters in addition to positional parameters in all methods.

The function `scipy.stats.power_divergence` has been added for the Cressie-Read power divergence statistic and goodness of fit test. Included in this family of statistics is the “G-test” (<http://en.wikipedia.org/wiki/G-test>).

`scipy.stats.mood` now accepts multidimensional input.

An option was added to `scipy.stats.wilcoxon` for continuity correction.

`scipy.stats.chisquare` now has an `axis` argument.

`scipy.stats.mstats.chisquare` now has `axis` and `ddof` arguments.

## 1.16.2 Deprecated features

### **expm2 and expm3**

The matrix exponential functions `scipy.linalg.expm2` and `scipy.linalg.expm3` are deprecated. All users should use the numerically more robust `scipy.linalg.expm` function instead.

### **scipy.stats functions**

`scipy.stats.oneway` is deprecated; `scipy.stats.f_oneway` should be used instead.

`scipy.stats.glm` is deprecated. `scipy.stats.ttest_ind` is an equivalent function; more full-featured general (and generalized) linear model implementations can be found in `statsmodels`.

`scipy.stats.cmedian` is deprecated; `numpy.median` should be used instead.

### 1.16.3 Backwards incompatible changes

#### LIL matrix assignment

Assigning values to LIL matrices with two index arrays now works similarly as assigning into ndarrays:

```
>>> x = lil_matrix((3, 3))
>>> x[[0,1,2],[0,1,2]]= [0,1,2]
>>> x.todense()
matrix([[ 0.,  0.,  0.],
        [ 0.,  1.,  0.],
        [ 0.,  0.,  2.]])
```

rather than giving the result:

```
>>> x.todense()
matrix([[ 0.,  1.,  2.],
        [ 0.,  1.,  2.],
        [ 0.,  1.,  2.]])
```

Users relying on the previous behavior will need to revisit their code. The previous behavior is obtained by `x[numpy.ix_([0,1,2],[0,1,2])] = ...`

#### Deprecated `radon` function removed

The `misc.radon` function, which was deprecated in `scipy 0.11.0`, has been removed. Users can find a more full-featured `radon` function in `scikit-image`.

#### Removed deprecated keywords `xa` and `xb` from `stats.distributions`

The keywords `xa` and `xb`, which were deprecated since `0.11.0`, have been removed from the distributions in `scipy.stats`.

#### Changes to MATLAB file readers / writers

The major change is that 1D arrays in `numpy` now become row vectors (shape `1, N`) when saved to a MATLAB 5 format file. Previously 1D arrays saved as column vectors (`N, 1`). This is to harmonize the behavior of writing MATLAB 4 and 5 formats, and adapt to the defaults of `numpy` and MATLAB - for example `np.atleast_2d` returns 1D arrays as row vectors.

Trying to save arrays of greater than 2 dimensions in MATLAB 4 format now raises an error instead of silently reshaping the array as 2D.

`scipy.io.loadmat('afile')` used to look for *afile* on the Python system path (`sys.path`); now `loadmat` only looks in the current directory for a relative path filename.

### 1.16.4 Other changes

Security fix: `scipy.weave` previously used temporary directories in an insecure manner under certain circumstances.

Cython is now required to build *unreleased* versions of `scipy`. The C files generated from Cython sources are not included in the git repo anymore. They are however still shipped in source releases.

The code base received a fairly large PEP8 cleanup. A `tox pep8` command has been added; new code should pass this test command.

Scipy cannot be compiled with gfortran 4.1 anymore (at least on RH5), likely due to that compiler version not supporting entry constructs well.

### 1.16.5 Authors

This release contains work by the following people (contributed at least one patch to this release, names in alphabetical order):

- Jorge Cañardo Alastuey +
- Tom Aldcroft +
- Max Bolingbroke +
- Joseph Jon Booker +
- François Boulogne
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- Nathan Woods +
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A total of 65 people contributed to this release. People with a “+” by their names contributed a patch for the first time.

## 1.17 SciPy 0.12.1 Release Notes

SciPy 0.12.1 is a bug-fix release with no new features compared to 0.12.0. The single issue fixed by this release is a security issue in `scipy.weave`, which was previously using temporary directories in an insecure manner under certain circumstances.

## 1.18 SciPy 0.12.0 Release Notes

### Contents

- *SciPy 0.12.0 Release Notes*
  - *New features*
    - \* *scipy.spatial improvements*
      - *cKDTree feature-complete*
      - *Voronoi diagrams and convex hulls*
      - *Delaunay improvements*
    - \* *Spectral estimators (scipy.signal)*
    - \* *scipy.optimize improvements*
      - *Callback functions in L-BFGS-B and TNC*
      - *Basin hopping global optimization (scipy.optimize.basinhopping)*
    - \* *scipy.special improvements*
      - *Revised complex error functions*
      - *Faster orthogonal polynomials*
    - \* *scipy.sparse.linalg features*
    - \* *Listing Matlab(R) file contents in scipy.io*
    - \* *Documented BLAS and LAPACK low-level interfaces (scipy.linalg)*
    - \* *Polynomial interpolation improvements (scipy.interpolate)*
  - *Deprecated features*
    - \* *scipy.lib.lapack*
    - \* *fblas and cblas*
  - *Backwards incompatible changes*
    - \* *Removal of scipy.io.save\_as\_module*
    - \* *axis argument added to scipy.stats.scoreatpercentile*
  - *Authors*

SciPy 0.12.0 is the culmination of 7 months of hard work. It contains many new features, numerous bug-fixes, improved test coverage and better documentation. There have been a number of deprecations and API changes in this release, which are documented below. All users are encouraged to upgrade to this release, as there are a large number of bug-fixes and optimizations. Moreover, our development attention will now shift to bug-fix releases on the 0.12.x branch, and on adding new features on the master branch.

Some of the highlights of this release are:

- Completed QHull wrappers in `scipy.spatial`.
- `cKDTree` now a drop-in replacement for `KDTree`.
- A new global optimizer, `basinhopping`.
- Support for Python 2 and Python 3 from the same code base (no more 2to3).

This release requires Python 2.6, 2.7 or 3.1-3.3 and NumPy 1.5.1 or greater. Support for Python 2.4 and 2.5 has been dropped as of this release.

### 1.18.1 New features

#### `scipy.spatial` improvements

##### *cKDTree feature-complete*

Cython version of `KDTree`, `cKDTree`, is now feature-complete. Most operations (construction, query, `query_ball_point`, `query_pairs`, `count_neighbors` and `sparse_distance_matrix`) are between 200 and 1000 times faster in `cKDTree` than in `KDTree`. With very minor caveats, `cKDTree` has exactly the same interface as `KDTree`, and can be used as a drop-in replacement.

##### *Voronoi diagrams and convex hulls*

`scipy.spatial` now contains functionality for computing Voronoi diagrams and convex hulls using the Qhull library. (Delaunay triangulation was available since Scipy 0.9.0.)

##### *Delaunay improvements*

It's now possible to pass in custom Qhull options in Delaunay triangulation. Coplanar points are now also recorded, if present. Incremental construction of Delaunay triangulations is now also possible.

#### Spectral estimators (`scipy.signal`)

The functions `scipy.signal.periodogram` and `scipy.signal.welch` were added, providing DFT-based spectral estimators.

#### `scipy.optimize` improvements

##### *Callback functions in L-BFGS-B and TNC*

A callback mechanism was added to L-BFGS-B and TNC minimization solvers.

##### *Basin hopping global optimization (`scipy.optimize.basinhopping`)*

A new global optimization algorithm. Basinhopping is designed to efficiently find the global minimum of a smooth function.

## scipy.special improvements

### *Revised complex error functions*

The computation of special functions related to the error function now uses a new [Faddeeva library from MIT](#) which increases their numerical precision. The scaled and imaginary error functions `erfcx` and `erfi` were also added, and the Dawson integral `dawsn` can now be evaluated for a complex argument.

### *Faster orthogonal polynomials*

Evaluation of orthogonal polynomials (the `eval_*` routines) is now faster in `scipy.special`, and their `out=` argument functions properly.

## scipy.sparse.linalg features

- In `scipy.sparse.linalg.spsolve`, the `b` argument can now be either a vector or a matrix.
- `scipy.sparse.linalg.inv` was added. This uses `spsolve` to compute a sparse matrix inverse.
- `scipy.sparse.linalg.expm` was added. This computes the exponential of a sparse matrix using a similar algorithm to the existing dense array implementation in `scipy.linalg.expm`.

## Listing Matlab(R) file contents in scipy.io

A new function `whosmat` is available in `scipy.io` for inspecting contents of MAT files without reading them to memory.

## Documented BLAS and LAPACK low-level interfaces (`scipy.linalg`)

The modules `scipy.linalg.blas` and `scipy.linalg.lapack` can be used to access low-level BLAS and LAPACK functions.

## Polynomial interpolation improvements (`scipy.interpolate`)

The barycentric, Krogh, piecewise and `pchip` polynomial interpolators in `scipy.interpolate` accept now an `axis` argument.

## 1.18.2 Deprecated features

### *scipy.lib.lapack*

The module `scipy.lib.lapack` is deprecated. You can use `scipy.linalg.lapack` instead. The module `scipy.lib.blas` was deprecated earlier in SciPy 0.10.0.

### *fblas and cblas*

Accessing the modules `scipy.linalg.fblas`, `cblas`, `flapack`, `clapack` is deprecated. Instead, use the modules `scipy.linalg.lapack` and `scipy.linalg.blas`.

### 1.18.3 Backwards incompatible changes

#### Removal of `scipy.io.save_as_module`

The function `scipy.io.save_as_module` was deprecated in Scipy 0.11.0, and is now removed.

Its private support modules `scipy.io.dumbdbm_patched` and `scipy.io.dumb_shelve` are also removed.

#### *axis* argument added to `scipy.stats.scoreatpercentile`

The function `scipy.stats.scoreatpercentile` has been given an *axis* argument. The default argument is *axis=None*, which means the calculation is done on the flattened array. Before this change, `scoreatpercentile` would act as if *axis=0* had been given. Code using `scoreatpercentile` with a multidimensional array will need to add *axis=0* to the function call to preserve the old behavior. (This API change was not noticed until long after the release of 0.12.0.)

### 1.18.4 Authors

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A total of 75 people contributed to this release. People with a “+” by their names contributed a patch for the first time.

## 1.19 SciPy 0.11.0 Release Notes

### Contents

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  - *New features*
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    - \* *scipy.optimize improvements*
      - *Unified interfaces to minimizers*
      - *Unified interface to root finding algorithms*
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    - \* *Sparse matrix construction and operations*
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    - \* *Discrete Sine Transform*
    - \* *scipy.interpolate improvements*

- \* *Binned statistics* (`scipy.stats`)
- *Deprecated features*
- *Backwards incompatible changes*
  - \* *Removal of `scipy.maxentropy`*
  - \* *Minor change in behavior of `splev`*
  - \* *Behavior of `scipy.integrate.complex_ode`*
  - \* *Minor change in behavior of T-tests*
- *Other changes*
- *Authors*

SciPy 0.11.0 is the culmination of 8 months of hard work. It contains many new features, numerous bug-fixes, improved test coverage and better documentation. Highlights of this release are:

- A new module has been added which provides a number of common sparse graph algorithms.
- New unified interfaces to the existing optimization and root finding functions have been added.

All users are encouraged to upgrade to this release, as there are a large number of bug-fixes and optimizations. Our development attention will now shift to bug-fix releases on the 0.11.x branch, and on adding new features on the master branch.

This release requires Python 2.4-2.7 or 3.1-3.2 and NumPy 1.5.1 or greater.

## 1.19.1 New features

### Sparse Graph Submodule

The new submodule `scipy.sparse.csgraph` implements a number of efficient graph algorithms for graphs stored as sparse adjacency matrices. Available routines are:

- `connected_components` - determine connected components of a graph
- `laplacian` - compute the laplacian of a graph
- `shortest_path` - compute the shortest path between points on a positive graph
- `dijkstra` - use Dijkstra's algorithm for shortest path
- `floyd_warshall` - use the Floyd-Warshall algorithm for shortest path
- `breadth_first_order` - compute a breadth-first order of nodes
- `depth_first_order` - compute a depth-first order of nodes
- `breadth_first_tree` - construct the breadth-first tree from a given node
- `depth_first_tree` - construct a depth-first tree from a given node
- `minimum_spanning_tree` - construct the minimum spanning tree of a graph

### `scipy.optimize` improvements

The `optimize` module has received a lot of attention this release. In addition to added tests, documentation improvements, bug fixes and code clean-up, the following improvements were made:

- A unified interface to minimizers of univariate and multivariate functions has been added.
- A unified interface to root finding algorithms for multivariate functions has been added.
- The L-BFGS-B algorithm has been updated to version 3.0.

### *Unified interfaces to minimizers*

Two new functions `scipy.optimize.minimize` and `scipy.optimize.minimize_scalar` were added to provide a common interface to minimizers of multivariate and univariate functions respectively. For multivariate functions, `scipy.optimize.minimize` provides an interface to methods for unconstrained optimization (*fmin*, *fmin\_powell*, *fmin\_cg*, *fmin\_ncg*, *fmin\_bfgs* and *anneal*) or constrained optimization (*fmin\_l\_bfgs\_b*, *fmin\_tnc*, *fmin\_cobyla* and *fmin\_slsqp*). For univariate functions, `scipy.optimize.minimize_scalar` provides an interface to methods for unconstrained and bounded optimization (*brent*, *golden*, *fminbound*). This allows for easier comparing and switching between solvers.

### *Unified interface to root finding algorithms*

The new function `scipy.optimize.root` provides a common interface to root finding algorithms for multivariate functions, embedding *fsolve*, *leastsq* and *nonlin* solvers.

## **scipy.linalg improvements**

### *New matrix equation solvers*

Solvers for the Sylvester equation (`scipy.linalg.solve_sylvester`, discrete and continuous Lyapunov equations (`scipy.linalg.solve_lyapunov`, `scipy.linalg.solve_discrete_lyapunov`) and discrete and continuous algebraic Riccati equations (`scipy.linalg.solve_continuous_are`, `scipy.linalg.solve_discrete_are`) have been added to `scipy.linalg`. These solvers are often used in the field of linear control theory.

### *QZ and QR Decomposition*

It is now possible to calculate the QZ, or Generalized Schur, decomposition using `scipy.linalg.qz`. This function wraps the LAPACK routines *sgges*, *dgges*, *cgges*, and *zgges*.

The function `scipy.linalg.qr_multiply`, which allows efficient computation of the matrix product of Q (from a QR decomposition) and a vector, has been added.

### *Pascal matrices*

A function for creating Pascal matrices, `scipy.linalg.pascal`, was added.

## **Sparse matrix construction and operations**

Two new functions, `scipy.sparse.diags` and `scipy.sparse.block_diag`, were added to easily construct diagonal and block-diagonal sparse matrices respectively.

`scipy.sparse.csc_matrix` and `csr_matrix` now support the operations *sin*, *tan*, *arcsin*, *arctan*, *sinh*, *tanh*, *arcsinh*, *arctanh*, *rint*, *sign*, *expm1*, *log1p*, *deg2rad*, *rad2deg*, *floor*, *ceil* and *trunc*. Previously, these operations had to be performed by operating on the matrices' `data` attribute.

### **LSMR iterative solver**

LSMR, an iterative method for solving (sparse) linear and linear least-squares systems, was added as `scipy.sparse.linalg.lsmr`.

## Discrete Sine Transform

Bindings for the discrete sine transform functions have been added to `scipy.fftpack`.

### `scipy.interpolate` improvements

For interpolation in spherical coordinates, the three classes `scipy.interpolate.SmoothSphereBivariateSpline`, `scipy.interpolate.LSQSphereBivariateSpline`, and `scipy.interpolate.RectSphereBivariateSpline` have been added.

### Binned statistics (`scipy.stats`)

The stats module has gained functions to do binned statistics, which are a generalization of histograms, in 1-D, 2-D and multiple dimensions: `scipy.stats.binned_statistic`, `scipy.stats.binned_statistic_2d` and `scipy.stats.binned_statistic_dd`.

## 1.19.2 Deprecated features

`scipy.sparse.cs_graph_components` has been made a part of the sparse graph submodule, and renamed to `scipy.sparse.csgraph.connected_components`. Calling the former routine will result in a deprecation warning.

`scipy.misc.radon` has been deprecated. A more full-featured radon transform can be found in `scikits-image`.

`scipy.io.save_as_module` has been deprecated. A better way to save multiple Numpy arrays is the `numpy.savez` function.

The `xa` and `xb` parameters for all distributions in `scipy.stats.distributions` already weren't used; they have now been deprecated.

## 1.19.3 Backwards incompatible changes

### Removal of `scipy.maxentropy`

The `scipy.maxentropy` module, which was deprecated in the 0.10.0 release, has been removed. Logistic regression in `scikits.learn` is a good and modern alternative for this functionality.

### Minor change in behavior of `splev`

The spline evaluation function now behaves similarly to `interp1d` for size-1 arrays. Previous behavior:

```
>>> from scipy.interpolate import splev, splrep, interp1d
>>> x = [1, 2, 3, 4, 5]
>>> y = [4, 5, 6, 7, 8]
>>> tck = splrep(x, y)
>>> splev([1], tck)
4.
>>> splev(1, tck)
4.
```

Corrected behavior:

```
>>> splev([1], tck)
array([ 4.])
>>> splev(1, tck)
array(4.)
```

This affects also the `UnivariateSpline` classes.

### Behavior of `scipy.integrate.complex_ode`

The behavior of the `y` attribute of `complex_ode` is changed. Previously, it expressed the complex-valued solution in the form:

```
z = ode.y[:, :2] + 1j * ode.y[1::2]
```

Now, it is directly the complex-valued solution:

```
z = ode.y
```

### Minor change in behavior of T-tests

The T-tests `scipy.stats.ttest_ind`, `scipy.stats.ttest_rel` and `scipy.stats.ttest_1samp` have been changed so that `0 / 0` now returns `NaN` instead of `1`.

## 1.19.4 Other changes

The SuperLU sources in `scipy.sparse.linalg` have been updated to version 4.3 from upstream.

The function `scipy.signal.bode`, which calculates magnitude and phase data for a continuous-time system, has been added.

The two-sample T-test `scipy.stats.ttest_ind` gained an option to compare samples with unequal variances, i.e. Welch's T-test.

`scipy.misc.logsumexp` now takes an optional `axis` keyword argument.

## 1.19.5 Authors

This release contains work by the following people (contributed at least one patch to this release, names in alphabetical order):

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A total of 55 people contributed to this release. People with a “+” by their names contributed a patch for the first time.

## 1.20 SciPy 0.10.1 Release Notes

### Contents

- *SciPy 0.10.1 Release Notes*
  - *Main changes*
  - *Other issues fixed*

SciPy 0.10.1 is a bug-fix release with no new features compared to 0.10.0.

### 1.20.1 Main changes

The most important changes are:

1. The single precision routines of `eigs` and `eigsh` in `scipy.sparse.linalg` have been disabled (they internally use double precision now).
2. A compatibility issue related to changes in NumPy macros has been fixed, in order to make `scipy 0.10.1` compile with the upcoming `numpy 1.7.0` release.

### 1.20.2 Other issues fixed

- #835: stats: nan propagation in `stats.distributions`
- #1202: io: `netcdf` segfault
- #1531: optimize: make `curve_fit` work with method as callable.
- #1560: linalg: fixed mistake in `eig_banded` documentation.
- #1565: ndimage: bug in `ndimage.variance`
- #1457: ndimage: `standard_deviation` does not work with sequence of indexes
- #1562: cluster: segfault in linkage function

- #1568: stats: One-sided fisher\_exact() returns  $p < 1$  for 0 successful attempts
- #1575: stats: zscore and zmap handle the axis keyword incorrectly

## 1.21 SciPy 0.10.0 Release Notes

### Contents

- *SciPy 0.10.0 Release Notes*
  - *New features*
    - \* *Bento: new optional build system*
    - \* *Generalized and shift-invert eigenvalue problems in `scipy.sparse.linalg`*
    - \* *Discrete-Time Linear Systems (`scipy.signal`)*
    - \* *Enhancements to `scipy.signal`*
    - \* *Additional decomposition options (`scipy.linalg`)*
    - \* *Additional special matrices (`scipy.linalg`)*
    - \* *Enhancements to `scipy.stats`*
    - \* *Enhancements to `scipy.special`*
    - \* *Basic support for Harwell-Boeing file format for sparse matrices*
  - *Deprecated features*
    - \* *`scipy.maxentropy`*
    - \* *`scipy.lib.blas`*
    - \* *Numscons build system*
  - *Backwards-incompatible changes*
  - *Other changes*
  - *Authors*

SciPy 0.10.0 is the culmination of 8 months of hard work. It contains many new features, numerous bug-fixes, improved test coverage and better documentation. There have been a limited number of deprecations and backwards-incompatible changes in this release, which are documented below. All users are encouraged to upgrade to this release, as there are a large number of bug-fixes and optimizations. Moreover, our development attention will now shift to bug-fix releases on the 0.10.x branch, and on adding new features on the development master branch.

Release highlights:

- Support for Bento as optional build system.
- Support for generalized eigenvalue problems, and all shift-invert modes available in ARPACK.

This release requires Python 2.4-2.7 or 3.1- and NumPy 1.5 or greater.

## 1.21.1 New features

### Bento: new optional build system

SciPy can now be built with **Bento**. Bento has some nice features like parallel builds and partial rebuilds, that are not possible with the default build system (distutils). For usage instructions see BENTO\_BUILD.txt in the scipy top-level directory.

Currently SciPy has three build systems, distutils, numscs and bento. Numscs is deprecated and is planned and will likely be removed in the next release.

### Generalized and shift-invert eigenvalue problems in `scipy.sparse.linalg`

The sparse eigenvalue problem solver functions `scipy.sparse.eigs/eigh` now support generalized eigenvalue problems, and all shift-invert modes available in ARPACK.

### Discrete-Time Linear Systems (`scipy.signal`)

Support for simulating discrete-time linear systems, including `scipy.signal.dlsim`, `scipy.signal.dimpulse`, and `scipy.signal.dstep`, has been added to SciPy. Conversion of linear systems from continuous-time to discrete-time representations is also present via the `scipy.signal.cont2discrete` function.

### Enhancements to `scipy.signal`

A Lomb-Scargle periodogram can now be computed with the new function `scipy.signal.lombscargle`.

The forward-backward filter function `scipy.signal.filtfilt` can now filter the data in a given axis of an n-dimensional numpy array. (Previously it only handled a 1-dimensional array.) Options have been added to allow more control over how the data is extended before filtering.

FIR filter design with `scipy.signal.firwin2` now has options to create filters of type III (zero at zero and Nyquist frequencies) and IV (zero at zero frequency).

### Additional decomposition options (`scipy.linalg`)

A sort keyword has been added to the Schur decomposition routine (`scipy.linalg.schur`) to allow the sorting of eigenvalues in the resultant Schur form.

### Additional special matrices (`scipy.linalg`)

The functions `hilbert` and `invhilbert` were added to `scipy.linalg`.

### Enhancements to `scipy.stats`

- The *one-sided form* of Fisher's exact test is now also implemented in `stats.fisher_exact`.
- The function `stats.chi2_contingency` for computing the chi-square test of independence of factors in a contingency table has been added, along with the related utility functions `stats.contingency.margins` and `stats.contingency.expected_freq`.

## Enhancements to `scipy.special`

The functions  $\text{logit}(p) = \log(p/(1-p))$  and  $\text{expit}(x) = 1/(1+\exp(-x))$  have been implemented as `scipy.special.logit` and `scipy.special.expit` respectively.

## Basic support for Harwell-Boeing file format for sparse matrices

Both read and write are support through a simple function-based API, as well as a more complete API to control number format. The functions may be found in `scipy.sparse.io`.

The following features are supported:

- Read and write sparse matrices in the CSC format
- Only real, symmetric, assembled matrix are supported (RUA format)

### 1.21.2 Deprecated features

#### `scipy.maxentropy`

The `maxentropy` module is unmaintained, rarely used and has not been functioning well for several releases. Therefore it has been deprecated for this release, and will be removed for `scipy 0.11`. Logistic regression in `scikits.learn` is a good alternative for this functionality. The `scipy.maxentropy.logsumexp` function has been moved to `scipy.misc`.

#### `scipy.lib.blas`

There are similar BLAS wrappers in `scipy.linalg` and `scipy.lib`. These have now been consolidated as `scipy.linalg.blas`, and `scipy.lib.blas` is deprecated.

## Numscons build system

The `numscons` build system is being replaced by `Bento`, and will be removed in one of the next `scipy` releases.

### 1.21.3 Backwards-incompatible changes

The deprecated name `invnorm` was removed from `scipy.stats.distributions`, this distribution is available as `invgauss`.

The following deprecated nonlinear solvers from `scipy.optimize` have been removed:

```
- ``broyden_modified`` (bad performance)
- ``broyden1_modified`` (bad performance)
- ``broyden_generalized`` (equivalent to ``anderson``)
- ``anderson2`` (equivalent to ``anderson``)
- ``broyden3`` (obsoleted by new limited-memory broyden methods)
- ``vackar`` (renamed to ``diagbroyden``)
```

### 1.21.4 Other changes

`scipy.constants` has been updated with the CODATA 2010 constants.

`__all__` dicts have been added to all modules, which has cleaned up the namespaces (particularly useful for interactive work).

An API section has been added to the documentation, giving recommended import guidelines and specifying which submodules are public and which aren't.

### 1.21.5 Authors

This release contains work by the following people (contributed at least one patch to this release, names in alphabetical order):

- Jeff Armstrong +
- Matthew Brett
- Lars Buitinck +
- David Cournapeau
- FISH 2000 +
- Michael McNeil Forbes +
- Matty G +
- Christoph Gohlke
- Ralf Gommers
- Yaroslav Halchenko
- Charles Harris
- Thouis (Ray) Jones +
- Chris Jordan-Squire +
- Robert Kern
- Chris Lasher +
- Wes McKinney +
- Travis Oliphant
- Fabian Pedregosa
- Josef Perktold
- Thomas Robitaille +
- Pim Schellart +
- Anthony Scopatz +
- Skipper Seabold +
- Fazlul Shahriar +
- David Simcha +
- Scott Sinclair +

- Andrey Smirnov +
- Collin RM Stocks +
- Martin Teichmann +
- Jake Vanderplas +
- Gaël Varoquaux +
- Pauli Virtanen
- Stefan van der Walt
- Warren Weckesser
- Mark Wiebe +

A total of 35 people contributed to this release. People with a “+” by their names contributed a patch for the first time.

## 1.22 SciPy 0.9.0 Release Notes

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- *SciPy 0.9.0 Release Notes*
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    - \* *N-dimensional interpolation (`scipy.interpolate`)*
    - \* *Nonlinear equation solvers (`scipy.optimize`)*
    - \* *New linear algebra routines (`scipy.linalg`)*
    - \* *Improved FIR filter design functions (`scipy.signal`)*
    - \* *Improved statistical tests (`scipy.stats`)*
  - *Deprecated features*
    - \* *Obsolete nonlinear solvers (in `scipy.optimize`)*
  - *Removed features*
    - \* *Old correlate/convolve behavior (in `scipy.signal`)*
    - \* *`scipy.stats`*
    - \* *`scipy.sparse`*
    - \* *`scipy.sparse.linalg.arpack.speigs`*
  - *Other changes*
    - \* *ARPACK interface changes*

SciPy 0.9.0 is the culmination of 6 months of hard work. It contains many new features, numerous bug-fixes, improved test coverage and better documentation. There have been a number of deprecations and API changes in this release,

which are documented below. All users are encouraged to upgrade to this release, as there are a large number of bug-fixes and optimizations. Moreover, our development attention will now shift to bug-fix releases on the 0.9.x branch, and on adding new features on the development trunk.

This release requires Python 2.4 - 2.7 or 3.1 - and NumPy 1.5 or greater.

Please note that SciPy is still considered to have “Beta” status, as we work toward a SciPy 1.0.0 release. The 1.0.0 release will mark a major milestone in the development of SciPy, after which changing the package structure or API will be much more difficult. Whilst these pre-1.0 releases are considered to have “Beta” status, we are committed to making them as bug-free as possible.

However, until the 1.0 release, we are aggressively reviewing and refining the functionality, organization, and interface. This is being done in an effort to make the package as coherent, intuitive, and useful as possible. To achieve this, we need help from the community of users. Specifically, we need feedback regarding all aspects of the project - everything - from which algorithms we implement, to details about our function’s call signatures.

### 1.22.1 Python 3

Scipy 0.9.0 is the first SciPy release to support Python 3. The only module that is not yet ported is `scipy.weave`.

### 1.22.2 Scipy source code location to be changed

Soon after this release, Scipy will stop using SVN as the version control system, and move to Git. The development source code for Scipy can from then on be found at

<http://github.com/scipy/scipy>

### 1.22.3 New features

#### Delaunay tessellations (`scipy.spatial`)

Scipy now includes routines for computing Delaunay tessellations in N dimensions, powered by the `Qhull` computational geometry library. Such calculations can now make use of the new `scipy.spatial.Delaunay` interface.

#### N-dimensional interpolation (`scipy.interpolate`)

Support for scattered data interpolation is now significantly improved. This version includes a `scipy.interpolate.griddata` function that can perform linear and nearest-neighbour interpolation for N-dimensional scattered data, in addition to cubic spline (C1-smooth) interpolation in 2D and 1D. An object-oriented interface to each interpolator type is also available.

#### Nonlinear equation solvers (`scipy.optimize`)

Scipy includes new routines for large-scale nonlinear equation solving in `scipy.optimize`. The following methods are implemented:

- Newton-Krylov (`scipy.optimize.newton_krylov`)
- (Generalized) secant methods:
  - Limited-memory Broyden methods (`scipy.optimize.broyden1`, `scipy.optimize.broyden2`)
  - Anderson method (`scipy.optimize.anderson`)

- **Simple iterations** (`scipy.optimize.diagbroyden`, `scipy.optimize.excitingmixing`, `scipy.optimize.linear mixing`)

The `scipy.optimize.nonlin` module was completely rewritten, and some of the functions were deprecated (see above).

### New linear algebra routines (`scipy.linalg`)

SciPy now contains routines for effectively solving triangular equation systems (`scipy.linalg.solve_triangular`).

### Improved FIR filter design functions (`scipy.signal`)

The function `scipy.signal.firwin` was enhanced to allow the design of highpass, bandpass, bandstop and multi-band FIR filters.

The function `scipy.signal.firwin2` was added. This function uses the window method to create a linear phase FIR filter with an arbitrary frequency response.

The functions `scipy.signal.kaiser_atten` and `scipy.signal.kaiser_beta` were added.

### Improved statistical tests (`scipy.stats`)

A new function `scipy.stats.fisher_exact` was added, that provides Fisher's exact test for 2x2 contingency tables.

The function `scipy.stats.kendalltau` was rewritten to make it much faster ( $O(n \log(n))$  vs  $O(n^2)$ ).

## 1.22.4 Deprecated features

### Obsolete nonlinear solvers (in `scipy.optimize`)

The following nonlinear solvers from `scipy.optimize` are deprecated:

- `broyden_modified` (bad performance)
- `broyden1_modified` (bad performance)
- `broyden_generalized` (equivalent to `anderson`)
- `anderson2` (equivalent to `anderson`)
- `broyden3` (obsoleted by new limited-memory broyden methods)
- `vackar` (renamed to `diagbroyden`)

## 1.22.5 Removed features

The deprecated modules `helpmod`, `pexec` and `ppimport` were removed from `scipy.misc`.

The `output_type` keyword in many `scipy.ndimage` interpolation functions has been removed.

The `econ` keyword in `scipy.linalg.qr` has been removed. The same functionality is still available by specifying `mode='economic'`.

### Old correlate/convolve behavior (in `scipy.signal`)

The old behavior for `scipy.signal.convolve`, `scipy.signal.convolve2d`, `scipy.signal.correlate` and `scipy.signal.correlate2d` was deprecated in 0.8.0 and has now been removed. Convolve and correlate used to swap their arguments if the second argument has dimensions larger than the first one, and the mode was relative to the input with the largest dimension. The current behavior is to never swap the inputs, which is what most people expect, and is how correlation is usually defined.

### `scipy.stats`

Many functions in `scipy.stats` that are either available from `numpy` or have been superseded, and have been deprecated since version 0.7, have been removed: `std`, `var`, `mean`, `median`, `cov`, `corrcoef`, `z`, `zs`, `stderr`, `samplestd`, `samplevar`, `pdfapprox`, `pdf_moments` and `erfc`. These changes are mirrored in `scipy.stats.mstats`.

### `scipy.sparse`

Several methods of the sparse matrix classes in `scipy.sparse` which had been deprecated since version 0.7 were removed: `save`, `rowcol`, `getdata`, `listprint`, `ensure_sorted_indices`, `matvec`, `matmat` and `rmatvec`.

The functions `spkron`, `speye`, `spidentity`, `lil_eye` and `lil_diags` were removed from `scipy.sparse`. The first three functions are still available as `scipy.sparse.kron`, `scipy.sparse.eye` and `scipy.sparse.identity`.

The `dims` and `nzmax` keywords were removed from the sparse matrix constructor. The `colind` and `rowind` attributes were removed from CSR and CSC matrices respectively.

### `scipy.sparse.linalg.arpack.speigs`

A duplicated interface to the ARPACK library was removed.

## 1.22.6 Other changes

### ARPACK interface changes

The interface to the ARPACK eigenvalue routines in `scipy.sparse.linalg` was changed for more robustness.

The eigenvalue and SVD routines now raise `ArpackNoConvergence` if the eigenvalue iteration fails to converge. If partially converged results are desired, they can be accessed as follows:

```
import numpy as np
from scipy.sparse.linalg import eigs, ArpackNoConvergence

m = np.random.randn(30, 30)
try:
    w, v = eigs(m, 6)
except ArpackNoConvergence, err:
    partially_converged_w = err.eigenvalues
    partially_converged_v = err.eigenvectors
```

Several bugs were also fixed.

The routines were moreover renamed as follows:

- `eigen` → `eigs`

- `eigen_symmetric` → `eigsh`
- `svd` → `svds`

## 1.23 SciPy 0.8.0 Release Notes

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    - \* *Improved waveform generators (`scipy.signal`)*
    - \* *New functions and other changes in `scipy.linalg`*
    - \* *New function and changes in `scipy.optimize`*
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    - \* *Alternative behavior available for `scipy.constants.find`*
    - \* *Incomplete sparse LU decompositions*
    - \* *Faster matlab file reader and default behavior change*
    - \* *Faster evaluation of orthogonal polynomials*
    - \* *Lambert W function*
    - \* *Improved hypergeometric 2F1 function*
    - \* *More flexible interface for Radial basis function interpolation*
  - *Removed features*
    - \* *`scipy.io`*

SciPy 0.8.0 is the culmination of 17 months of hard work. It contains many new features, numerous bug-fixes, improved test coverage and better documentation. There have been a number of deprecations and API changes in this release, which are documented below. All users are encouraged to upgrade to this release, as there are a large number of bug-fixes and optimizations. Moreover, our development attention will now shift to bug-fix releases on the

0.8.x branch, and on adding new features on the development trunk. This release requires Python 2.4 - 2.6 and NumPy 1.4.1 or greater.

Please note that SciPy is still considered to have “Beta” status, as we work toward a SciPy 1.0.0 release. The 1.0.0 release will mark a major milestone in the development of SciPy, after which changing the package structure or API will be much more difficult. Whilst these pre-1.0 releases are considered to have “Beta” status, we are committed to making them as bug-free as possible.

However, until the 1.0 release, we are aggressively reviewing and refining the functionality, organization, and interface. This is being done in an effort to make the package as coherent, intuitive, and useful as possible. To achieve this, we need help from the community of users. Specifically, we need feedback regarding all aspects of the project - everything - from which algorithms we implement, to details about our function’s call signatures.

### 1.23.1 Python 3

Python 3 compatibility is planned and is currently technically feasible, since Numpy has been ported. However, since the Python 3 compatible Numpy 1.5 has not been released yet, support for Python 3 in Scipy is not yet included in Scipy 0.8. SciPy 0.9, planned for fall 2010, will very likely include experimental support for Python 3.

### 1.23.2 Major documentation improvements

SciPy documentation is greatly improved.

### 1.23.3 Deprecated features

#### Swapping inputs for correlation functions (`scipy.signal`)

Concern `correlate`, `correlate2d`, `convolve` and `convolve2d`. If the second input is larger than the first input, the inputs are swapped before calling the underlying computation routine. This behavior is deprecated, and will be removed in `scipy` 0.9.0.

#### Obsolete code deprecated (`scipy.misc`)

The modules `helpmod`, `ppimport` and `pexec` from `scipy.misc` are deprecated. They will be removed from SciPy in version 0.9.

#### Additional deprecations

- `linalg`: The function `solveh_banded` currently returns a tuple containing the Cholesky factorization and the solution to the linear system. In SciPy 0.9, the return value will be just the solution.
- The function `constants.codata.find` will generate a `DeprecationWarning`. In Scipy version 0.8.0, the keyword argument ‘`disp`’ was added to the function, with the default value ‘`True`’. In 0.9.0, the default will be ‘`False`’.
- The `qshape` keyword argument of `signal.chirp` is deprecated. Use the argument `vertex_zero` instead.
- Passing the coefficients of a polynomial as the argument `f0` to `signal.chirp` is deprecated. Use the function `signal.sweep_poly` instead.
- The `io.recaster` module has been deprecated and will be removed in 0.9.0.

## 1.23.4 New features

### DCT support (`scipy.fftpack`)

New realtransforms have been added, namely `dct` and `idct` for Discrete Cosine Transform; type I, II and III are available.

### Single precision support for fft functions (`scipy.fftpack`)

fft functions can now handle single precision inputs as well: `fft(x)` will return a single precision array if `x` is single precision.

At the moment, for FFT sizes that are not composites of 2, 3, and 5, the transform is computed internally in double precision to avoid rounding error in FFTPACK.

### Correlation functions now implement the usual definition (`scipy.signal`)

The outputs should now correspond to their matlab and R counterparts, and do what most people expect if the `old_behavior=False` argument is passed:

- `correlate`, `convolve` and their 2d counterparts do not swap their inputs depending on their relative shape anymore;
- correlation functions now conjugate their second argument while computing the slided sum-products, which correspond to the usual definition of correlation.

### Additions and modification to LTI functions (`scipy.signal`)

- The functions `impulse2` and `step2` were added to `scipy.signal`. They use the function `scipy.signal.lsim2` to compute the impulse and step response of a system, respectively.
- The function `scipy.signal.lsim2` was changed to pass any additional keyword arguments to the ODE solver.

### Improved waveform generators (`scipy.signal`)

Several improvements to the `chirp` function in `scipy.signal` were made:

- The waveform generated when `method="logarithmic"` was corrected; it now generates a waveform that is also known as an “exponential” or “geometric” chirp. (See <http://en.wikipedia.org/wiki/Chirp>.)
- A new `chirp` method, “hyperbolic”, was added.
- Instead of the keyword `qshape`, `chirp` now uses the keyword `vertex_zero`, a boolean.
- `chirp` no longer handles an arbitrary polynomial. This functionality has been moved to a new function, `sweep_poly`.

A new function, `sweep_poly`, was added.

### New functions and other changes in `scipy.linalg`

The functions `cho_solve_banded`, `circulant`, `companion`, `hadamard` and `leslie` were added to `scipy.linalg`.

The function `block_diag` was enhanced to accept scalar and 1D arguments, along with the usual 2D arguments.

### New function and changes in `scipy.optimize`

The `curve_fit` function has been added; it takes a function and uses non-linear least squares to fit that to the provided data.

The `leastsq` and `fsolve` functions now return an array of size one instead of a scalar when solving for a single parameter.

### New sparse least squares solver

The `lsqr` function was added to `scipy.sparse`. This routine finds a least-squares solution to a large, sparse, linear system of equations.

### ARPACK-based sparse SVD

A naive implementation of SVD for sparse matrices is available in `scipy.sparse.linalg.eigen.arpack`. It is based on using an symmetric solver on  $\langle A, A \rangle$ , and as such may not be very precise.

### Alternative behavior available for `scipy.constants.find`

The keyword argument `disp` was added to the function `scipy.constants.find`, with the default value `True`. When `disp` is `True`, the behavior is the same as in Scipy version 0.7. When `False`, the function returns the list of keys instead of printing them. (In SciPy version 0.9, the default will be reversed.)

### Incomplete sparse LU decompositions

Scipy now wraps SuperLU version 4.0, which supports incomplete sparse LU decompositions. These can be accessed via `scipy.sparse.linalg.spilu`. Upgrade to SuperLU 4.0 also fixes some known bugs.

### Faster matlab file reader and default behavior change

We've rewritten the matlab file reader in Cython and it should now read matlab files at around the same speed that Matlab does.

The reader reads matlab named and anonymous functions, but it can't write them.

Until scipy 0.8.0 we have returned arrays of matlab structs as numpy object arrays, where the objects have attributes named for the struct fields. As of 0.8.0, we return matlab structs as numpy structured arrays. You can get the older behavior by using the optional `struct_as_record=False` keyword argument to `scipy.io.loadmat` and friends.

There is an inconsistency in the matlab file writer, in that it writes numpy 1D arrays as column vectors in matlab 5 files, and row vectors in matlab 4 files. We will change this in the next version, so both write row vectors. There is a `FutureWarning` when calling the writer to warn of this change; for now we suggest using the `oned_as='row'` keyword argument to `scipy.io.savemat` and friends.

### Faster evaluation of orthogonal polynomials

Values of orthogonal polynomials can be evaluated with new vectorized functions in `scipy.special`: `eval_legendre`, `eval_chebyt`, `eval_chebyu`, `eval_chebyc`, `eval_chebys`, `eval_jacobi`, `eval_laguerre`, `eval_genlaguerre`, `eval_hermite`, `eval_hermitenorm`, `eval_gegenbauer`, `eval_sh_legendre`, `eval_sh_chebyt`, `eval_sh_chebyu`, `eval_sh_jacobi`. This is faster than constructing the full coefficient representation of the polynomials, which was previously the only available way.

Note that the previous orthogonal polynomial routines will now also invoke this feature, when possible.

### Lambert W function

`scipy.special.lambertw` can now be used for evaluating the Lambert W function.

### Improved hypergeometric 2F1 function

Implementation of `scipy.special.hyp2f1` for real parameters was revised. The new version should produce accurate values for all real parameters.

### More flexible interface for Radial basis function interpolation

The `scipy.interpolate.Rbf` class now accepts a callable as input for the “function” argument, in addition to the built-in radial basis functions which can be selected with a string argument.

## 1.23.5 Removed features

`scipy.stsci`: the package was removed

The module `scipy.misc.limits` was removed.

The IO code in both NumPy and SciPy is being extensively reworked. NumPy will be where basic code for reading and writing NumPy arrays is located, while SciPy will house file readers and writers for various data formats (data, audio, video, images, matlab, etc.).

Several functions in `scipy.io` are removed in the 0.8.0 release including: `npfile`, `save`, `load`, `create_module`, `create_shelf`, `objload`, `objsave`, `fopen`, `read_array`, `write_array`, `fread`, `fwrite`, `bswap`, `packbits`, `unpackbits`, and `convert_objectarray`. Some of these functions have been replaced by NumPy’s raw reading and writing capabilities, memory-mapping capabilities, or array methods. Others have been moved from SciPy to NumPy, since basic array reading and writing capability is now handled by NumPy.

## 1.24 SciPy 0.7.2 Release Notes

### Contents

- *SciPy 0.7.2 Release Notes*

SciPy 0.7.2 is a bug-fix release with no new features compared to 0.7.1. The only change is that all C sources from Cython code have been regenerated with Cython 0.12.1. This fixes the incompatibility between binaries of SciPy 0.7.1 and NumPy 1.4.

## 1.25 SciPy 0.7.1 Release Notes

### Contents

- *SciPy 0.7.1 Release Notes*
  - *scipy.io*
  - *scipy.odr*
  - *scipy.signal*
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  - *scipy.special*
  - *scipy.stats*
  - *Windows binaries for python 2.6*
  - *Universal build for scipy*

SciPy 0.7.1 is a bug-fix release with no new features compared to 0.7.0.

Bugs fixed:

- Several fixes in Matlab file IO

Bugs fixed:

- Work around a failure with Python 2.6

Memory leak in lfilter have been fixed, as well as support for array object

Bugs fixed:

- #880, #925: lfilter fixes
- #871: bicgstab fails on Win32

Bugs fixed:

- #883: `scipy.io.mmread` with `scipy.sparse.lil_matrix` broken
- `lil_matrix` and `csc_matrix` reject now unexpected sequences, cf. <http://thread.gmane.org/gmane.comp.python.scientific.user/19996>

Several bugs of varying severity were fixed in the special functions:

- #503, #640: `iv`: problems at large arguments fixed by new implementation
- #623: `jv`: fix errors at large arguments
- #679: `struve`: fix wrong output for  $v < 0$
- #803: `pbdv` produces invalid output
- #804: `lqmn`: fix crashes on some input
- #823: `betainc`: fix documentation
- #834: `exp1` strange behavior near negative integer values
- #852: `jn_zeros`: more accurate results for large  $s$ , also in `jnp/yn/ynp_zeros`
- #853: `jv`, `yv`, `iv`: invalid results for non-integer  $v < 0$ , complex  $x$
- #854: `jv`, `yv`, `iv`, `: return nan more consistently when out-of-domain`
- #927: `ellipj`: fix segfault on Windows
- #946: `ellpj`: fix segfault on Mac OS X/python 2.6 combination.

- `ive`, `jve`, `yve`, `kv`, `kve`: with real-valued input, return nan for out-of-domain instead of returning only the real part of the result.

Also, when `scipy.special.errprint(1)` has been enabled, warning messages are now issued as Python warnings instead of printing them to `stderr`.

- `linregress`, `mannwhitneyu`, `describe`: errors fixed
- `kstwobign`, `norm`, `expon`, `exponweib`, `exponpow`, `frechet`, `genexpon`, `rdist`, `truncexpon`, `planck`: improvements to numerical accuracy in distributions

### 1.25.1 Windows binaries for python 2.6

python 2.6 binaries for windows are now included. The binary for python 2.5 requires numpy 1.2.0 or above, and the one for python 2.6 requires numpy 1.3.0 or above.

### 1.25.2 Universal build for scipy

Mac OS X binary installer is now a proper universal build, and does not depend on gfortran anymore (libgfortran is statically linked). The python 2.5 version of scipy requires numpy 1.2.0 or above, the python 2.6 version requires numpy 1.3.0 or above.

## 1.26 SciPy 0.7.0 Release Notes

### Contents

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  - *Running Tests*
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  - *Reworking of IO package*
  - *New Hierarchical Clustering module*
  - *New Spatial package*
  - *Reworked fftpack package*
  - *New Constants package*
  - *New Radial Basis Function module*
  - *New complex ODE integrator*
  - *New generalized symmetric and hermitian eigenvalue problem solver*

- *Bug fixes in the interpolation package*
- *Weave clean up*
- *Known problems*

SciPy 0.7.0 is the culmination of 16 months of hard work. It contains many new features, numerous bug-fixes, improved test coverage and better documentation. There have been a number of deprecations and API changes in this release, which are documented below. All users are encouraged to upgrade to this release, as there are a large number of bug-fixes and optimizations. Moreover, our development attention will now shift to bug-fix releases on the 0.7.x branch, and on adding new features on the development trunk. This release requires Python 2.4 or 2.5 and NumPy 1.2 or greater.

Please note that SciPy is still considered to have “Beta” status, as we work toward a SciPy 1.0.0 release. The 1.0.0 release will mark a major milestone in the development of SciPy, after which changing the package structure or API will be much more difficult. Whilst these pre-1.0 releases are considered to have “Beta” status, we are committed to making them as bug-free as possible. For example, in addition to fixing numerous bugs in this release, we have also doubled the number of unit tests since the last release.

However, until the 1.0 release, we are aggressively reviewing and refining the functionality, organization, and interface. This is being done in an effort to make the package as coherent, intuitive, and useful as possible. To achieve this, we need help from the community of users. Specifically, we need feedback regarding all aspects of the project - everything - from which algorithms we implement, to details about our function’s call signatures.

Over the last year, we have seen a rapid increase in community involvement, and numerous infrastructure improvements to lower the barrier to contributions (e.g., more explicit coding standards, improved testing infrastructure, better documentation tools). Over the next year, we hope to see this trend continue and invite everyone to become more involved.

### 1.26.1 Python 2.6 and 3.0

A significant amount of work has gone into making SciPy compatible with Python 2.6; however, there are still some issues in this regard. The main issue with 2.6 support is NumPy. On UNIX (including Mac OS X), NumPy 1.2.1 mostly works, with a few caveats. On Windows, there are problems related to the compilation process. The upcoming NumPy 1.3 release will fix these problems. Any remaining issues with 2.6 support for SciPy 0.7 will be addressed in a bug-fix release.

Python 3.0 is not supported at all; it requires NumPy to be ported to Python 3.0. This requires immense effort, since a lot of C code has to be ported. The transition to 3.0 is still under consideration; currently, we don’t have any timeline or roadmap for this transition.

### 1.26.2 Major documentation improvements

SciPy documentation is greatly improved; you can view a HTML reference manual [online](#) or download it as a PDF file. The new reference guide was built using the popular [Sphinx](#) tool.

This release also includes an updated tutorial, which hadn’t been available since SciPy was ported to NumPy in 2005. Though not comprehensive, the tutorial shows how to use several essential parts of Scipy. It also includes the `ndimage` documentation from the `numarray` manual.

Nevertheless, more effort is needed on the documentation front. Luckily, contributing to Scipy documentation is now easier than before: if you find that a part of it requires improvements, and want to help us out, please register a user name in our web-based documentation editor at <https://docs.scipy.org/> and correct the issues.

### 1.26.3 Running Tests

NumPy 1.2 introduced a new testing framework based on `nose`. Starting with this release, SciPy now uses the new NumPy test framework as well. Taking advantage of the new testing framework requires `nose` version 0.10, or later. One major advantage of the new framework is that it greatly simplifies writing unit tests - which has all ready paid off, given the rapid increase in tests. To run the full test suite:

```
>>> import scipy
>>> scipy.test('full')
```

For more information, please see [The NumPy/SciPy Testing Guide](#).

We have also greatly improved our test coverage. There were just over 2,000 unit tests in the 0.6.0 release; this release nearly doubles that number, with just over 4,000 unit tests.

### 1.26.4 Building SciPy

Support for NumScons has been added. NumScons is a tentative new build system for NumPy/SciPy, using `SCons` at its core.

`SCons` is a next-generation build system, intended to replace the venerable `Make` with the integrated functionality of `autoconf/automake` and `ccache`. `Scons` is written in Python and its configuration files are Python scripts. NumScons is meant to replace NumPy's custom version of `distutils` providing more advanced functionality, such as `autoconf`, improved fortran support, more tools, and support for `numpy.distutils/scons` cooperation.

### 1.26.5 Sandbox Removed

While porting SciPy to NumPy in 2005, several packages and modules were moved into `scipy.sandbox`. The sandbox was a staging ground for packages that were undergoing rapid development and whose APIs were in flux. It was also a place where broken code could live. The sandbox has served its purpose well, but was starting to create confusion. Thus `scipy.sandbox` was removed. Most of the code was moved into `scipy`, some code was made into a `scikit`, and the remaining code was just deleted, as the functionality had been replaced by other code.

### 1.26.6 Sparse Matrices

Sparse matrices have seen extensive improvements. There is now support for integer dtypes such `int8`, `uint32`, etc. Two new sparse formats were added:

- new class `dia_matrix`: the sparse `DIAGONAL` format
- new class `bsr_matrix`: the Block `CSR` format

Several new sparse matrix construction functions were added:

- `sparse.kron`: sparse Kronecker product
- `sparse.bmat`: sparse version of `numpy.bmat`
- `sparse.vstack`: sparse version of `numpy.vstack`
- `sparse.hstack`: sparse version of `numpy.hstack`

Extraction of submatrices and nonzero values have been added:

- `sparse.tril`: extract lower triangle
- `sparse.triu`: extract upper triangle

- `sparse.find`: nonzero values and their indices

`csc_matrix` and `csc_matrix` now support slicing and fancy indexing (e.g., `A[1:3, 4:7]` and `A[[3, 2, 6, 8], :]`). Conversions among all sparse formats are now possible:

- using member functions such as `.tocsc()` and `.tolil()`
- using the `.asformat()` member function, e.g. `A.asformat('csr')`
- using constructors `A = lil_matrix([[1,2]]); B = csc_matrix(A)`

All sparse constructors now accept dense matrices and lists of lists. For example:

- `A = csc_matrix( rand(3,3) )` and `B = lil_matrix( [[1,2], [3,4]] )`

The handling of diagonals in the `spdiags` function has been changed. It now agrees with the MATLAB(TM) function of the same name.

Numerous efficiency improvements to format conversions and sparse matrix arithmetic have been made. Finally, this release contains numerous bugfixes.

### 1.26.7 Statistics package

Statistical functions for masked arrays have been added, and are accessible through `scipy.stats.mstats`. The functions are similar to their counterparts in `scipy.stats` but they have not yet been verified for identical interfaces and algorithms.

Several bugs were fixed for statistical functions, of those, `kstest` and `percentileofscore` gained new keyword arguments.

Added deprecation warning for `mean`, `median`, `var`, `std`, `cov`, and `corrcoef`. These functions should be replaced by their numpy counterparts. Note, however, that some of the default options differ between the `scipy.stats` and `numpy` versions of these functions.

Numerous bug fixes to `stats.distributions`: all generic methods now work correctly, several methods in individual distributions were corrected. However, a few issues remain with higher moments (`skew`, `kurtosis`) and entropy. The maximum likelihood estimator, `fit`, does not work out-of-the-box for some distributions - in some cases, starting values have to be carefully chosen, in other cases, the generic implementation of the maximum likelihood method might not be the numerically appropriate estimation method.

We expect more bugfixes, increases in numerical precision and enhancements in the next release of `scipy`.

### 1.26.8 Reworking of IO package

The IO code in both NumPy and SciPy is being extensively reworked. NumPy will be where basic code for reading and writing NumPy arrays is located, while SciPy will house file readers and writers for various data formats (data, audio, video, images, matlab, etc.).

Several functions in `scipy.io` have been deprecated and will be removed in the 0.8.0 release including `npfile`, `save`, `load`, `create_module`, `create_shelf`, `objload`, `objsave`, `fopen`, `read_array`, `write_array`, `fread`, `fwrite`, `bswap`, `packbits`, `unpackbits`, and `convert_objectarray`. Some of these functions have been replaced by NumPy's raw reading and writing capabilities, memory-mapping capabilities, or array methods. Others have been moved from SciPy to NumPy, since basic array reading and writing capability is now handled by NumPy.

The Matlab (TM) file readers/writers have a number of improvements:

- default version 5
- v5 writers for structures, cell arrays, and objects

- v5 readers/writers for function handles and 64-bit integers
- new `struct_as_record` keyword argument to `loadmat`, which loads struct arrays in matlab as record arrays in numpy
- string arrays have `dtype='U...'` instead of `dtype=object`
- `loadmat` no longer squeezes singleton dimensions, i.e. `squeeze_me=False` by default

### 1.26.9 New Hierarchical Clustering module

This module adds new hierarchical clustering functionality to the `scipy.cluster` package. The function interfaces are similar to the functions provided MATLAB(TM)'s Statistics Toolbox to help facilitate easier migration to the NumPy/SciPy framework. Linkage methods implemented include single, complete, average, weighted, centroid, median, and ward.

In addition, several functions are provided for computing inconsistency statistics, cophenetic distance, and maximum distance between descendants. The `fcluster` and `fclusterdata` functions transform a hierarchical clustering into a set of flat clusters. Since these flat clusters are generated by cutting the tree into a forest of trees, the `leaders` function takes a linkage and a flat clustering, and finds the root of each tree in the forest. The `ClusterNode` class represents a hierarchical clusterings as a field-navigable tree object. `to_tree` converts a matrix-encoded hierarchical clustering to a `ClusterNode` object. Routines for converting between MATLAB and SciPy linkage encodings are provided. Finally, a `dendrogram` function plots hierarchical clusterings as a dendrogram, using `matplotlib`.

### 1.26.10 New Spatial package

The new spatial package contains a collection of spatial algorithms and data structures, useful for spatial statistics and clustering applications. It includes rapidly compiled code for computing exact and approximate nearest neighbors, as well as a pure-python kd-tree with the same interface, but that supports annotation and a variety of other algorithms. The API for both modules may change somewhat, as user requirements become clearer.

It also includes a `distance` module, containing a collection of distance and dissimilarity functions for computing distances between vectors, which is useful for spatial statistics, clustering, and kd-trees. Distance and dissimilarity functions provided include Bray-Curtis, Canberra, Chebyshev, City Block, Cosine, Dice, Euclidean, Hamming, Jaccard, Kulsinski, Mahalanobis, Matching, Minkowski, Rogers-Tanimoto, Russell-Rao, Squared Euclidean, Standardized Euclidean, Sokal-Michener, Sokal-Sneath, and Yule.

The `pdist` function computes pairwise distance between all unordered pairs of vectors in a set of vectors. The `cdist` computes the distance on all pairs of vectors in the Cartesian product of two sets of vectors. Pairwise distance matrices are stored in condensed form; only the upper triangular is stored. `squareform` converts distance matrices between square and condensed forms.

### 1.26.11 Reworked fftpack package

FFTW2, FFTW3, MKL and DJBFFT wrappers have been removed. Only (NETLIB) `fftpack` remains. By focusing on one backend, we hope to add new features - like float32 support - more easily.

### 1.26.12 New Constants package

`scipy.constants` provides a collection of physical constants and conversion factors. These constants are taken from CODATA Recommended Values of the Fundamental Physical Constants: 2002. They may be found at [physics.nist.gov/constants](http://physics.nist.gov/constants). The values are stored in the dictionary `physical_constants` as a tuple containing the value, the units, and the relative precision - in that order. All constants are in SI units, unless otherwise stated. Several helper functions are provided.

### 1.26.13 New Radial Basis Function module

`scipy.interpolate` now contains a Radial Basis Function module. Radial basis functions can be used for smoothing/interpolating scattered data in n-dimensions, but should be used with caution for extrapolation outside of the observed data range.

### 1.26.14 New complex ODE integrator

`scipy.integrate.ode` now contains a wrapper for the ZVODE complex-valued ordinary differential equation solver (by Peter N. Brown, Alan C. Hindmarsh, and George D. Byrne).

### 1.26.15 New generalized symmetric and hermitian eigenvalue problem solver

`scipy.linalg.eigh` now contains wrappers for more LAPACK symmetric and hermitian eigenvalue problem solvers. Users can now solve generalized problems, select a range of eigenvalues only, and choose to use a faster algorithm at the expense of increased memory usage. The signature of the `scipy.linalg.eigh` changed accordingly.

### 1.26.16 Bug fixes in the interpolation package

The shape of return values from `scipy.interpolate.interpld` used to be incorrect, if interpolated data had more than 2 dimensions and the `axis` keyword was set to a non-default value. This has been fixed. Moreover, `interpld` returns now a scalar (0D-array) if the input is a scalar. Users of `scipy.interpolate.interpld` may need to revise their code if it relies on the previous behavior.

### 1.26.17 Weave clean up

There were numerous improvements to `scipy.weave`. `blitz++` was relicensed by the author to be compatible with the SciPy license. `wx_spec.py` was removed.

### 1.26.18 Known problems

Here are known problems with `scipy 0.7.0`:

- weave test failures on windows: those are known, and are being revised.
- weave test failure with gcc 4.3 (std::labs): this is a gcc 4.3 bug. A workaround is to add `#include <cstdlib>` in `scipy/weave/blitz/blitz/funcs.h` (line 27). You can make the change in the installed `scipy` (in site-packages).

## API - IMPORTING FROM SCIPY

In Python the distinction between what is the public API of a library and what are private implementation details is not always clear. Unlike in other languages like Java, it is possible in Python to access “private” function or objects. Occasionally this may be convenient, but be aware that if you do so your code may break without warning in future releases. Some widely understood rules for what is and isn’t public in Python are:

- Methods / functions / classes and module attributes whose names begin with a leading underscore are private.
- If a class name begins with a leading underscore none of its members are public, whether or not they begin with a leading underscore.
- If a module name in a package begins with a leading underscore none of its members are public, whether or not they begin with a leading underscore.
- If a module or package defines `__all__` that authoritatively defines the public interface.
- If a module or package doesn’t define `__all__` then all names that don’t start with a leading underscore are public.

---

**Note:** Reading the above guidelines one could draw the conclusion that every private module or object starts with an underscore. This is not the case; the presence of underscores do mark something as private, but the absence of underscores do not mark something as public.

---

In Scipy there are modules whose names don’t start with an underscore, but that should be considered private. To clarify which modules these are we define below what the public API is for Scipy, and give some recommendations for how to import modules/functions/objects from Scipy.

### 2.1 Guidelines for importing functions from Scipy

The `scipy` namespace itself only contains functions imported from `numpy`. These functions still exist for backwards compatibility, but should be imported from `numpy` directly.

Everything in the namespaces of `scipy` submodules is public. In general, it is recommended to import functions from submodule namespaces. For example, the function `curve_fit` (defined in `scipy/optimize/minpack.py`) should be imported like this:

```
from scipy import optimize
result = optimize.curve_fit(...)
```

This form of importing submodules is preferred for all submodules except `scipy.io` (because `io` is also the name of a module in the Python stdlib):

```
from scipy import interpolate
from scipy import integrate
import scipy.io as spio
```

In some cases, the public API is one level deeper. For example the `scipy.sparse.linalg` module is public, and the functions it contains are not available in the `scipy.sparse` namespace. Sometimes it may result in more easily understandable code if functions are imported from one level deeper. For example, in the following it is immediately clear that `lomax` is a distribution if the second form is chosen:

```
# first form
from scipy import stats
stats.lomax(...)

# second form
from scipy.stats import distributions
distributions.lomax(...)
```

In that case the second form can be chosen, **if** it is documented in the next section that the submodule in question is public.

## 2.2 API definition

Every submodule listed below is public. That means that these submodules are unlikely to be renamed or changed in an incompatible way, and if that is necessary a deprecation warning will be raised for one Scipy release before the change is made.

- `scipy.cluster`
  - `vq`
  - `hierarchy`
- `scipy.constants`
- `scipy.fftpack`
- `scipy.integrate`
- `scipy.interpolate`
- `scipy.io`
  - `arff`
  - `harwell_boeing`
  - `idl`
  - `matlab`
  - `netcdf`
  - `wavfile`
- `scipy.linalg`
  - `scipy.linalg.blas`
  - `scipy.linalg.cython_blas`
  - `scipy.linalg.lapack`

- `scipy.linalg.cython_lapack`
  - `scipy.linalg.interpolative`
- `scipy.misc`
- `scipy.ndimage`
- `scipy.odr`
- `scipy.optimize`
- `scipy.signal`
- `scipy.sparse`
  - `linalg`
  - `csgraph`
- `scipy.spatial`
  - `distance`
- `scipy.special`
- `scipy.stats`
  - `distributions`
  - `mstats`



Tutorials with worked examples and background information for most SciPy submodules.

## 3.1 SciPy Tutorial

### 3.1.1 Introduction

#### Contents

- *Introduction*
  - *SciPy Organization*
  - *Finding Documentation*

SciPy is a collection of mathematical algorithms and convenience functions built on the Numpy extension of Python. It adds significant power to the interactive Python session by providing the user with high-level commands and classes for manipulating and visualizing data. With SciPy an interactive Python session becomes a data-processing and system-prototyping environment rivaling systems such as MATLAB, IDL, Octave, R-Lab, and SciLab.

The additional benefit of basing SciPy on Python is that this also makes a powerful programming language available for use in developing sophisticated programs and specialized applications. Scientific applications using SciPy benefit from the development of additional modules in numerous niches of the software landscape by developers across the world. Everything from parallel programming to web and data-base subroutines and classes have been made available to the Python programmer. All of this power is available in addition to the mathematical libraries in SciPy.

This tutorial will acquaint the first-time user of SciPy with some of its most important features. It assumes that the user has already installed the SciPy package. Some general Python facility is also assumed, such as could be acquired by working through the Python distribution's Tutorial. For further introductory help the user is directed to the Numpy documentation.

For brevity and convenience, we will often assume that the main packages (numpy, scipy, and matplotlib) have been imported as:

```
>>> import numpy as np
>>> import matplotlib as mpl
>>> import matplotlib.pyplot as plt
```

These are the import conventions that our community has adopted after discussion on public mailing lists. You will see these conventions used throughout NumPy and SciPy source code and documentation. While we obviously don't require you to follow these conventions in your own code, it is highly recommended.

## SciPy Organization

SciPy is organized into subpackages covering different scientific computing domains. These are summarized in the following table:

Subpackage	Description
<code>cluster</code>	Clustering algorithms
<code>constants</code>	Physical and mathematical constants
<code>fftpack</code>	Fast Fourier Transform routines
<code>integrate</code>	Integration and ordinary differential equation solvers
<code>interpolate</code>	Interpolation and smoothing splines
<code>io</code>	Input and Output
<code>linalg</code>	Linear algebra
<code>ndimage</code>	N-dimensional image processing
<code>odr</code>	Orthogonal distance regression
<code>optimize</code>	Optimization and root-finding routines
<code>signal</code>	Signal processing
<code>sparse</code>	Sparse matrices and associated routines
<code>spatial</code>	Spatial data structures and algorithms
<code>special</code>	Special functions
<code>stats</code>	Statistical distributions and functions

Scipy sub-packages need to be imported separately, for example:

```
>>> from scipy import linalg, optimize
```

Because of their ubiquitousness, some of the functions in these subpackages are also made available in the `scipy` namespace to ease their use in interactive sessions and programs. In addition, many basic array functions from `numpy` are also available at the top-level of the `scipy` package. Before looking at the sub-packages individually, we will first look at some of these common functions.

## Finding Documentation

SciPy and NumPy have documentation versions in both HTML and PDF format available at <https://docs.scipy.org/>, that cover nearly all available functionality. However, this documentation is still work-in-progress and some parts may be incomplete or sparse. As we are a volunteer organization and depend on the community for growth, your participation - everything from providing feedback to improving the documentation and code - is welcome and actively encouraged.

Python's documentation strings are used in SciPy for on-line documentation. There are two methods for reading them and getting help. One is Python's command `help` in the `pydoc` module. Entering this command with no arguments (i.e. `>>> help`) launches an interactive help session that allows searching through the keywords and modules available to all of Python. Secondly, running the command `help(obj)` with an object as the argument displays that object's calling signature, and documentation string.

The `pydoc` method of `help` is sophisticated but uses a pager to display the text. Sometimes this can interfere with the terminal you are running the interactive session within. A `numpy/scipy`-specific help system is also available under the command `numpy.info`. The signature and documentation string for the object passed to the `help` command are printed to standard output (or to a writable object passed as the third argument). The second keyword argument of `numpy.info` defines the maximum width of the line for printing. If a module is passed as the argument to `help` then a list of the functions and classes defined in that module is printed. For example:

```
>>> np.info(optimize.fmin)
fmin(func, x0, args=(), xtol=0.0001, ftol=0.0001, maxiter=None, maxfun=None,
      full_output=0, disp=1, retall=0, callback=None)
```

```

Minimize a function using the downhill simplex algorithm.

Parameters
-----
func : callable func(x,*args)
    The objective function to be minimized.
x0 : ndarray
    Initial guess.
args : tuple
    Extra arguments passed to func, i.e. ``f(x,*args)``.
callback : callable
    Called after each iteration, as callback(xk), where xk is the
    current parameter vector.

Returns
-----
xopt : ndarray
    Parameter that minimizes function.
fopt : float
    Value of function at minimum: ``fopt = func(xopt)``.
iter : int
    Number of iterations performed.
funcalls : int
    Number of function calls made.
warnflag : int
    1 : Maximum number of function evaluations made.
    2 : Maximum number of iterations reached.
allvecs : list
    Solution at each iteration.

Other parameters
-----
xtol : float
    Relative error in xopt acceptable for convergence.
ftol : number
    Relative error in func(xopt) acceptable for convergence.
maxiter : int
    Maximum number of iterations to perform.
maxfun : number
    Maximum number of function evaluations to make.
full_output : bool
    Set to True if fopt and warnflag outputs are desired.
disp : bool
    Set to True to print convergence messages.
retall : bool
    Set to True to return list of solutions at each iteration.

Notes
-----
Uses a Nelder-Mead simplex algorithm to find the minimum of function of
one or more variables.

```

Another useful command is `source`. When given a function written in Python as an argument, it prints out a listing of the source code for that function. This can be helpful in learning about an algorithm or understanding exactly what a function is doing with its arguments. Also don't forget about the Python command `dir` which can be used to look at the namespace of a module or package.

## 3.1.2 Basic functions

### Contents

- *Basic functions*
  - *Interaction with Numpy*
    - \* *Index Tricks*
    - \* *Shape manipulation*
    - \* *Polynomials*
    - \* *Vectorizing functions (vectorize)*
    - \* *Type handling*
    - \* *Other useful functions*

### Interaction with Numpy

Scipy builds on Numpy, and for all basic array handling needs you can use Numpy functions:

```
>>> import numpy as np
>>> np.some_function()
```

Rather than giving a detailed description of each of these functions (which is available in the Numpy Reference Guide or by using the `help`, `info` and `source` commands), this tutorial will discuss some of the more useful commands which require a little introduction to use to their full potential.

To use functions from some of the Scipy modules, you can do:

```
>>> from scipy import some_module
>>> some_module.some_function()
```

The top level of `scipy` also contains functions from `numpy` and `numpy.lib.scimath`. However, it is better to use them directly from the `numpy` module instead.

### *Index Tricks*

There are some class instances that make special use of the slicing functionality to provide efficient means for array construction. This part will discuss the operation of `np.mgrid`, `np.ogrid`, `np.r_`, and `np.c_` for quickly constructing arrays.

For example, rather than writing something like the following

```
>>> a = np.concatenate(([3], [0]*5, np.arange(-1, 1.002, 2/9.0)))
```

with the `r_` command one can enter this as

```
>>> a = np.r_[3, [0]*5, -1:1:10j]
```

which can ease typing and make for more readable code. Notice how objects are concatenated, and the slicing syntax is (ab)used to construct ranges. The other term that deserves a little explanation is the use of the complex number `10j` as the step size in the slicing syntax. This non-standard use allows the number to be interpreted as the number of points to produce in the range rather than as a step size (note we would have used the long integer notation, `10L`, but this notation may go away in Python as the integers become unified). This non-standard usage may be unsightly to

some, but it gives the user the ability to quickly construct complicated vectors in a very readable fashion. When the number of points is specified in this way, the end- point is inclusive.

The “r” stands for row concatenation because if the objects between commas are 2 dimensional arrays, they are stacked by rows (and thus must have commensurate columns). There is an equivalent command `c_` that stacks 2d arrays by columns but works identically to `r_` for 1d arrays.

Another very useful class instance which makes use of extended slicing notation is the function `mgrid`. In the simplest case, this function can be used to construct 1d ranges as a convenient substitute for `arange`. It also allows the use of complex-numbers in the step-size to indicate the number of points to place between the (inclusive) end-points. The real purpose of this function however is to produce N, N-d arrays which provide coordinate arrays for an N-dimensional volume. The easiest way to understand this is with an example of its usage:

```
>>> np.mgrid[0:5,0:5]
array([[0, 0, 0, 0, 0],
       [1, 1, 1, 1, 1],
       [2, 2, 2, 2, 2],
       [3, 3, 3, 3, 3],
       [4, 4, 4, 4, 4]],
      [[0, 1, 2, 3, 4],
       [0, 1, 2, 3, 4],
       [0, 1, 2, 3, 4],
       [0, 1, 2, 3, 4],
       [0, 1, 2, 3, 4]])
>>> np.mgrid[0:5:4j,0:5:4j]
array([[ 0.      ,  0.      ,  0.      ,  0.      ],
       [ 1.6667,  1.6667,  1.6667,  1.6667],
       [ 3.3333,  3.3333,  3.3333,  3.3333],
       [ 5.      ,  5.      ,  5.      ,  5.      ]],
      [[ 0.      ,  1.6667,  3.3333,  5.      ],
       [ 0.      ,  1.6667,  3.3333,  5.      ],
       [ 0.      ,  1.6667,  3.3333,  5.      ],
       [ 0.      ,  1.6667,  3.3333,  5.      ]])
```

Having meshed arrays like this is sometimes very useful. However, it is not always needed just to evaluate some N-dimensional function over a grid due to the array-broadcasting rules of Numpy and SciPy. If this is the only purpose for generating a meshgrid, you should instead use the function `ogrid` which generates an “open” grid using `newaxis` judiciously to create N, N-d arrays where only one dimension in each array has length greater than 1. This will save memory and create the same result if the only purpose for the meshgrid is to generate sample points for evaluation of an N-d function.

### Shape manipulation

In this category of functions are routines for squeezing out length- one dimensions from N-dimensional arrays, ensuring that an array is at least 1-, 2-, or 3-dimensional, and stacking (concatenating) arrays by rows, columns, and “pages” (in the third dimension). Routines for splitting arrays (roughly the opposite of stacking arrays) are also available.

### Polynomials

There are two (interchangeable) ways to deal with 1-d polynomials in SciPy. The first is to use the `poly1d` class from Numpy. This class accepts coefficients or polynomial roots to initialize a polynomial. The polynomial object can then be manipulated in algebraic expressions, integrated, differentiated, and evaluated. It even prints like a polynomial:

```
>>> from numpy import poly1d
>>> p = poly1d([3,4,5])
>>> print(p)
  2
3 x + 4 x + 5
>>> print(p*p)
```

```

      4      3      2
9 x + 24 x + 46 x + 40 x + 25
>>> print(p.integ(k=6))
      3      2
1 x + 2 x + 5 x + 6
>>> print(p.deriv())
6 x + 4
>>> p([4, 5])
array([ 69, 100])

```

The other way to handle polynomials is as an array of coefficients with the first element of the array giving the coefficient of the highest power. There are explicit functions to add, subtract, multiply, divide, integrate, differentiate, and evaluate polynomials represented as sequences of coefficients.

### Vectorizing functions (*vectorize*)

One of the features that NumPy provides is a class `vectorize` to convert an ordinary Python function which accepts scalars and returns scalars into a “vectorized-function” with the same broadcasting rules as other Numpy functions (*i.e.* the Universal functions, or ufuncs). For example, suppose you have a Python function named `addsubtract` defined as:

```

>>> def addsubtract(a,b):
...     if a > b:
...         return a - b
...     else:
...         return a + b

```

which defines a function of two scalar variables and returns a scalar result. The class `vectorize` can be used to “vectorize” this function so that

```

>>> vec_addsubtract = np.vectorize(addsubtract)

```

returns a function which takes array arguments and returns an array result:

```

>>> vec_addsubtract([0,3,6,9],[1,3,5,7])
array([1, 6, 1, 2])

```

This particular function could have been written in vector form without the use of `vectorize`. However, functions that employ optimization or integration routines can likely only be vectorized using `vectorize`.

### Type handling

Note the difference between `np.iscomplex/np.isreal` and `np.iscomplexobj/np.isrealobj`. The former command is array based and returns byte arrays of ones and zeros providing the result of the element-wise test. The latter command is object based and returns a scalar describing the result of the test on the entire object.

Often it is required to get just the real and/or imaginary part of a complex number. While complex numbers and arrays have attributes that return those values, if one is not sure whether or not the object will be complex-valued, it is better to use the functional forms `np.real` and `np.imag`. These functions succeed for anything that can be turned into a Numpy array. Consider also the function `np.real_if_close` which transforms a complex-valued number with tiny imaginary part into a real number.

Occasionally the need to check whether or not a number is a scalar (Python (long)int, Python float, Python complex, or rank-0 array) occurs in coding. This functionality is provided in the convenient function `np.isscalar` which returns a 1 or a 0.

Finally, ensuring that objects are a certain Numpy type occurs often enough that it has been given a convenient interface in SciPy through the use of the `np.cast` dictionary. The dictionary is keyed by the type it is desired to cast to and

the dictionary stores functions to perform the casting. Thus, `np.cast['f'](d)` returns an array of `np.float32` from `d`. This function is also useful as an easy way to get a scalar of a certain type:

```
>>> np.cast['f'](np.pi)
array(3.1415927410125732, dtype=float32)
```

### Other useful functions

There are also several other useful functions which should be mentioned. For doing phase processing, the functions `angle`, and `unwrap` are useful. Also, the `linspace` and `logspace` functions return equally spaced samples in a linear or log scale. Finally, it's useful to be aware of the indexing capabilities of Numpy. Mention should be made of the function `select` which extends the functionality of `where` to include multiple conditions and multiple choices. The calling convention is `select(condlist, choicelist, default=0)`. `select` is a vectorized form of the multiple if-statement. It allows rapid construction of a function which returns an array of results based on a list of conditions. Each element of the return array is taken from the array in a `choicelist` corresponding to the first condition in `condlist` that is true. For example

```
>>> x = np.r_[-2:3]
>>> x
array([-2, -1,  0,  1,  2])
>>> np.select([x > 3, x >= 0], [0, x+2])
array([0, 0, 2, 3, 4])
```

Some additional useful functions can also be found in the module `scipy.misc`. For example the `factorial` and `comb` functions compute  $n!$  and  $n!/k!(n-k)!$  using either exact integer arithmetic (thanks to Python's Long integer object), or by using floating-point precision and the gamma function. Another function returns a common image used in image processing: `lena`.

Finally, two functions are provided that are useful for approximating derivatives of functions using discrete-differences. The function `central_diff_weights` returns weighting coefficients for an equally-spaced  $N$ -point approximation to the derivative of order  $o$ . These weights must be multiplied by the function corresponding to these points and the results added to obtain the derivative approximation. This function is intended for use when only samples of the function are available. When the function is an object that can be handed to a routine and evaluated, the function `derivative` can be used to automatically evaluate the object at the correct points to obtain an  $N$ -point approximation to the  $o$ -th derivative at a given point.

## 3.1.3 Special functions (`scipy.special`)

The main feature of the `scipy.special` package is the definition of numerous special functions of mathematical physics. Available functions include `airy`, `elliptic`, `bessel`, `gamma`, `beta`, `hypergeometric`, `parabolic cylinder`, `mathieu`, `spheroidal wave`, `struve`, and `kelvin`. There are also some low-level stats functions that are not intended for general use as an easier interface to these functions is provided by the `stats` module. Most of these functions can take array arguments and return array results following the same broadcasting rules as other math functions in Numerical Python. Many of these functions also accept complex numbers as input. For a complete list of the available functions with a one-line description type `>>> help(special)`. Each function also has its own documentation accessible using `help`. If you don't see a function you need, consider writing it and contributing it to the library. You can write the function in either C, Fortran, or Python. Look in the source code of the library for examples of each of these kinds of functions.

### Bessel functions of real order(`jn`, `jn_zeros`)

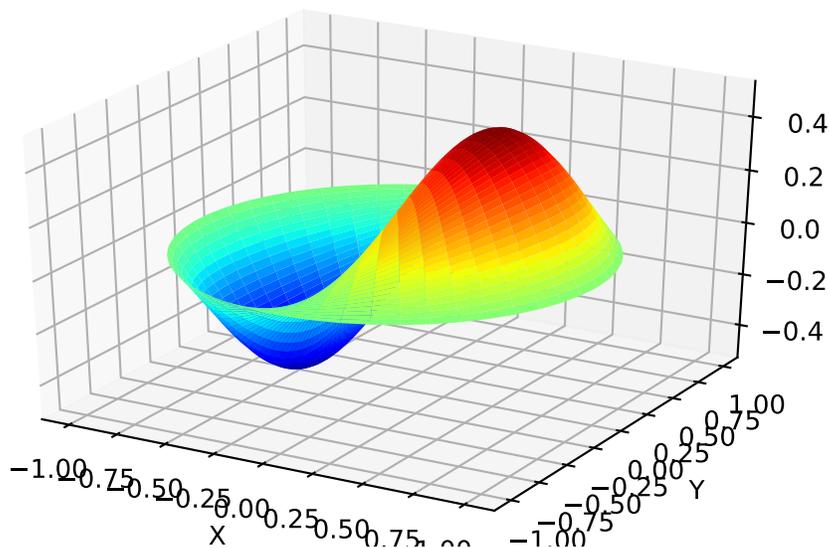
Bessel functions are a family of solutions to Bessel's differential equation with real or complex order  $\alpha$ :

$$x^2 \frac{d^2 y}{dx^2} + x \frac{dy}{dx} + (x^2 - \alpha^2)y = 0$$

Among other uses, these functions arise in wave propagation problems such as the vibrational modes of a thin drum head. Here is an example of a circular drum head anchored at the edge:

```
>>> from scipy import special
>>> def drumhead_height(n, k, distance, angle, t):
...     kth_zero = special.jn_zeros(n, k)[-1]
...     return np.cos(t) * np.cos(n*angle) * special.jn(n, distance*kth_zero)
>>> theta = np.r_[0:2*np.pi:50j]
>>> radius = np.r_[0:1:50j]
>>> x = np.array([r * np.cos(theta) for r in radius])
>>> y = np.array([r * np.sin(theta) for r in radius])
>>> z = np.array([drumhead_height(1, 1, r, theta, 0.5) for r in radius])
```

```
>>> import matplotlib.pyplot as plt
>>> from mpl_toolkits.mplot3d import Axes3D
>>> from matplotlib import cm
>>> fig = plt.figure()
>>> ax = Axes3D(fig)
>>> ax.plot_surface(x, y, z, rstride=1, cstride=1, cmap=cm.jet)
>>> ax.set_xlabel('X')
>>> ax.set_ylabel('Y')
>>> ax.set_zlabel('Z')
>>> plt.show()
```



### Cython Bindings for Special Functions (`scipy.special.cython_special`)

Scipy also offers Cython bindings for scalar, typed versions of many of the functions in `special`. The following Cython code gives a simple example of how to use these functions:

```
cimport scipy.special.cython_special as csc

cdef:
    double x = 1
    double complex z = 1 + 1j
    double si, ci, rgam
    double complex cgam
```

```

rgam = csc.gamma(x)
print(rgam)
cgam = csc.gamma(z)
print(cgam)
csc.sici(x, &si, &ci)
print(si, ci)

```

(See the [Cython documentation](#) for help with compiling Cython.) In the example the function `csc.gamma` works essentially like its ufunc counterpart `gamma`, though it takes C types as arguments instead of NumPy arrays. Note in particular that the function is overloaded to support real and complex arguments; the correct variant is selected at compile time. The function `csc.sici` works slightly differently from `sici`; for the ufunc we could write `ai, bi = sici(x)` whereas in the Cython version multiple return values are passed as pointers. It might help to think of this as analogous to calling a ufunc with an output array: `sici(x, out=(si, ci))`.

There are two potential advantages to using the Cython bindings:

- They avoid Python function overhead
- They do not require the Python Global Interpreter Lock (GIL)

The following sections discuss how to use these advantages to potentially speed up your code, though of course one should always profile the code first to make sure putting in the extra effort will be worth it.

### *Avoiding Python Function Overhead*

For the ufuncs in `special`, Python function overhead is avoided by vectorizing, that is, by passing an array to the function. Typically this approach works quite well, but sometimes it is more convenient to call a special function on scalar inputs inside a loop, for example when implementing your own ufunc. In this case the Python function overhead can become significant. Consider the following example:

```

import scipy.special as sc
cimport scipy.special.cython_special as csc

def python_tight_loop():
    cdef:
        int n
        double x = 1

    for n in range(100):
        sc.jv(n, x)

def cython_tight_loop():
    cdef:
        int n
        double x = 1

    for n in range(100):
        csc.jv(n, x)

```

On one computer `python_tight_loop` took about 131 microseconds to run and `cython_tight_loop` took about 18.2 microseconds to run. Obviously this example is contrived: one could just call `special.jv(np.arange(100), 1)` and get results just as fast as in `cython_tight_loop`. The point is that if Python function overhead becomes significant in your code then the Cython bindings might be useful.

### *Releasing the GIL*

One often needs to evaluate a special function at many points, and typically the evaluations are trivially parallelizable. Since the Cython bindings do not require the GIL, it is easy to run them in parallel using Cython's `prange` function.

For example, suppose that we wanted to compute the fundamental solution to the Helmholtz equation:

$$\Delta_x G(x, y) + k^2 G(x, y) = \delta(x - y),$$

where  $k$  is the wavenumber and  $\delta$  is the Dirac delta function. It is known that in two dimensions the unique (radiating) solution is

$$G(x, y) = \frac{i}{4} H_0^{(1)}(k|x - y|),$$

where  $H_0^{(1)}$  is the Hankel function of the first kind, i.e. the function `hankell1`. The following example shows how we could compute this function in parallel:

```
from libc.math cimport fabs
cimport cython
from cython.parallel cimport prange

import numpy as np
import scipy.special as sc
cimport scipy.special.cython_special as csc

def serial_G(k, x, y):
    return 0.25j*sc.hankell1(0, k*np.abs(x - y))

@cython.boundscheck(False)
@cython.wraparound(False)
cdef void _parallel_G(double k, double[:, :] x, double[:, :] y,
                    double complex[:, :] out) nogil:

    cdef int i, j

    for i in prange(x.shape[0]):
        for j in range(y.shape[0]):
            out[i, j] = 0.25j*csc.hankell1(0, k*fabs(x[i, j] - y[i, j]))

def parallel_G(k, x, y):
    out = np.empty_like(x, dtype='complex128')
    _parallel_G(k, x, y, out)
    return out
```

(For help with compiling parallel code in Cython see [here](#).) If the above Cython code is in a file `test.pyx`, then we can write an informal benchmark which compares the parallel and serial versions of the function:

```
import timeit

import numpy as np

from test import serial_G, parallel_G

def main():
    k = 1
    x, y = np.linspace(-100, 100, 1000), np.linspace(-100, 100, 1000)
    x, y = np.meshgrid(x, y)

    def serial():
        serial_G(k, x, y)

    def parallel():
        parallel_G(k, x, y)
```

```

time_serial = timeit.timeit(serial, number=3)
time_parallel = timeit.timeit(parallel, number=3)
print("Serial method took {:.3} seconds".format(time_serial))
print("Parallel method took {:.3} seconds".format(time_parallel))

if __name__ == "__main__":
    main()

```

On one quad-core computer the serial method took 1.29 seconds and the parallel method took 0.29 seconds.

### Functions not in `scipy.special`

Some functions are not included in `special` because they are straightforward to implement with existing functions in NumPy and SciPy. To prevent reinventing the wheel, this section provides implementations of several such functions which hopefully illustrate how to handle similar functions. In all examples NumPy is imported as `np` and `special` is imported as `sc`.

The binary entropy function:

```

def binary_entropy(x):
    return -(sc.xlogy(x, x) + sc.xlog1py(1 - x, -x))/np.log(2)

```

The Heaviside step function:

```

def heaviside(x):
    return 0.5*(np.sign(x) + 1)

```

A similar idea can also be used to get a step function on `[0, 1]`:

```

def step(x):
    return 0.5*(np.sign(x) + np.sign(1 - x))

```

Translating and scaling can be used to get an arbitrary step function.

The ramp function:

```

def ramp(x):
    return np.maximum(0, x)

```

## 3.1.4 Integration (`scipy.integrate`)

The `scipy.integrate` sub-package provides several integration techniques including an ordinary differential equation integrator. An overview of the module is provided by the help command:

```

>>> help(integrate)
Methods for Integrating Functions given function object.

quad          -- General purpose integration.
dblquad       -- General purpose double integration.
tplquad       -- General purpose triple integration.
fixed_quad    -- Integrate func(x) using Gaussian quadrature of order n.
quadrature    -- Integrate with given tolerance using Gaussian quadrature.
romberg       -- Integrate func using Romberg integration.

Methods for Integrating Functions given fixed samples.

```

```

trapez      -- Use trapezoidal rule to compute integral from samples.
cumtrapz    -- Use trapezoidal rule to cumulatively compute integral.
simps       -- Use Simpson's rule to compute integral from samples.
romb        -- Use Romberg Integration to compute integral from
              (2**k + 1) evenly-spaced samples.

```

See the special module's orthogonal polynomials (special) for Gaussian quadrature roots and weights for other weighting factors and regions.

Interface to numerical integrators of ODE systems.

```

odeint      -- General integration of ordinary differential equations.
ode         -- Integrate ODE using VODE and ZVODE routines.

```

### General integration (quad)

The function `quad` is provided to integrate a function of one variable between two points. The points can be  $\pm\infty$  (`± inf`) to indicate infinite limits. For example, suppose you wish to integrate a Bessel function `jv(2.5, x)` along the interval `[0, 4.5]`.

$$I = \int_0^{4.5} J_{2.5}(x) dx.$$

This could be computed using `quad`:

```

>>> import scipy.integrate as integrate
>>> import scipy.special as special
>>> result = integrate.quad(lambda x: special.jv(2.5,x), 0, 4.5)
>>> result
(1.1178179380783249, 7.8663172481899801e-09)

```

```

>>> from numpy import sqrt, sin, cos, pi
>>> I = sqrt(2/pi)*(18.0/27*sqrt(2)*cos(4.5) - 4.0/27*sqrt(2)*sin(4.5) +
...         sqrt(2*pi) * special.fresnel(3/sqrt(pi)) [0])
>>> I
1.117817938088701

```

```

>>> print(abs(result[0]-I))
1.03761443881e-11

```

The first argument to `quad` is a “callable” Python object (*i.e.* a function, method, or class instance). Notice the use of a lambda- function in this case as the argument. The next two arguments are the limits of integration. The return value is a tuple, with the first element holding the estimated value of the integral and the second element holding an upper bound on the error. Notice, that in this case, the true value of this integral is

$$I = \sqrt{\frac{2}{\pi}} \left( \frac{18}{27} \sqrt{2} \cos(4.5) - \frac{4}{27} \sqrt{2} \sin(4.5) + \sqrt{2\pi} \text{Si} \left( \frac{3}{\sqrt{\pi}} \right) \right),$$

where

$$\text{Si}(x) = \int_0^x \sin\left(\frac{\pi}{2}t^2\right) dt.$$

is the Fresnel sine integral. Note that the numerically-computed integral is within  $1.04 \times 10^{-11}$  of the exact result — well below the reported error bound.

If the function to integrate takes additional parameters, they can be provided in the `args` argument. Suppose that the following integral shall be calculated:

$$I(a, b) = \int_0^1 ax^2 + b dx.$$

This integral can be evaluated by using the following code:

```
>>> from scipy.integrate import quad
>>> def integrand(x, a, b):
...     return a*x**2 + b
...
>>> a = 2
>>> b = 1
>>> I = quad(integrand, 0, 1, args=(a,b))
>>> I
(1.6666666666666667, 1.8503717077085944e-14)
```

Infinite inputs are also allowed in `quad` by using  $\pm \text{inf}$  as one of the arguments. For example, suppose that a numerical value for the exponential integral:

$$E_n(x) = \int_1^\infty \frac{e^{-xt}}{t^n} dt.$$

is desired (and the fact that this integral can be computed as `special.expn(n, x)` is forgotten). The functionality of the function `special.expn` can be replicated by defining a new function `vec_expint` based on the routine `quad`:

```
>>> from scipy.integrate import quad
>>> def integrand(t, n, x):
...     return np.exp(-x*t) / t**n
...
...

```

```
>>> def expint(n, x):
...     return quad(integrand, 1, np.inf, args=(n, x))[0]
...
...

```

```
>>> vec_expint = np.vectorize(expint)
```

```
>>> vec_expint(3, np.arange(1.0, 4.0, 0.5))
array([ 0.1097,  0.0567,  0.0301,  0.0163,  0.0089,  0.0049])
>>> import scipy.special as special
>>> special.expn(3, np.arange(1.0, 4.0, 0.5))
array([ 0.1097,  0.0567,  0.0301,  0.0163,  0.0089,  0.0049])
```

The function which is integrated can even use the `quad` argument (though the error bound may underestimate the error due to possible numerical error in the integrand from the use of `quad`). The integral in this case is

$$I_n = \int_0^\infty \int_1^\infty \frac{e^{-xt}}{t^n} dt dx = \frac{1}{n}.$$

```
>>> result = quad(lambda x: expint(3, x), 0, np.inf)
>>> print(result)
(0.33333333324560266, 2.8548934485373678e-09)
```

```
>>> I3 = 1.0/3.0
>>> print(I3)
0.333333333333
```

```
>>> print(I3 - result[0])
8.77306560731e-11
```

This last example shows that multiple integration can be handled using repeated calls to *quad*.

### General multiple integration (*dblquad*, *tplquad*, *nquad*)

The mechanics for double and triple integration have been wrapped up into the functions *dblquad* and *tplquad*. These functions take the function to integrate and four, or six arguments, respectively. The limits of all inner integrals need to be defined as functions.

An example of using double integration to compute several values of  $I_n$  is shown below:

```
>>> from scipy.integrate import quad, dblquad
>>> def I(n):
...     return dblquad(lambda t, x: np.exp(-x*t)/t**n, 0, np.inf, lambda x: 1, lambda x: np.inf)
... 
```

```
>>> print(I(4))
(0.25000000000043577, 1.29830334693681e-08)
>>> print(I(3))
(0.33333333325010883, 1.3888461883425516e-08)
>>> print(I(2))
(0.499999999985751, 1.3894083651858995e-08)
```

As example for non-constant limits consider the integral

$$I = \int_{y=0}^{1/2} \int_{x=0}^{1-2y} xy \, dx \, dy = \frac{1}{96}.$$

This integral can be evaluated using the expression below (Note the use of the non-constant lambda functions for the upper limit of the inner integral):

```
>>> from scipy.integrate import dblquad
>>> area = dblquad(lambda x, y: x*y, 0, 0.5, lambda x: 0, lambda x: 1-2*x)
>>> area
(0.010416666666666668, 1.1564823173178715e-16)
```

For n-fold integration, *scipy* provides the function *nquad*. The integration bounds are an iterable object: either a list of constant bounds, or a list of functions for the non-constant integration bounds. The order of integration (and therefore the bounds) is from the innermost integral to the outermost one.

The integral from above

$$I_n = \int_0^\infty \int_1^\infty \frac{e^{-xt}}{t^n} dt \, dx = \frac{1}{n}$$

can be calculated as

```
>>> from scipy import integrate
>>> N = 5
```

```
>>> def f(t, x):
...     return np.exp(-x*t) / t**N
...
>>> integrate.nquad(f, [[1, np.inf],[0, np.inf]])
(0.200000000000002294, 1.2239614263187945e-08)
```

Note that the order of arguments for  $f$  must match the order of the integration bounds; i.e. the inner integral with respect to  $t$  is on the interval  $[1, \infty]$  and the outer integral with respect to  $x$  is on the interval  $[0, \infty]$ .

Non-constant integration bounds can be treated in a similar manner; the example from above

$$I = \int_{y=0}^{1/2} \int_{x=0}^{1-2y} xy \, dx \, dy = \frac{1}{96}.$$

can be evaluated by means of

```
>>> from scipy import integrate
>>> def f(x, y):
...     return x*y
...
>>> def bounds_y():
...     return [0, 0.5]
...
>>> def bounds_x(y):
...     return [0, 1-2*y]
...
>>> integrate.nquad(f, [bounds_x, bounds_y])
(0.010416666666666668, 4.101620128472366e-16)
```

which is the same result as before.

## Gaussian quadrature

A few functions are also provided in order to perform simple Gaussian quadrature over a fixed interval. The first is *fixed\_quad* which performs fixed-order Gaussian quadrature. The second function is *quadrature* which performs Gaussian quadrature of multiple orders until the difference in the integral estimate is beneath some tolerance supplied by the user. These functions both use the module `special.orthogonal` which can calculate the roots and quadrature weights of a large variety of orthogonal polynomials (the polynomials themselves are available as special functions returning instances of the polynomial class — e.g. *special.legendre*).

## Romberg Integration

Romberg's method [*WPR*] is another method for numerically evaluating an integral. See the help function for *romberg* for further details.

## Integrating using Samples

If the samples are equally-spaced and the number of samples available is  $2^k + 1$  for some integer  $k$ , then Romberg *romb* integration can be used to obtain high-precision estimates of the integral using the available samples. Romberg integration uses the trapezoid rule at step-sizes related by a power of two and then performs Richardson extrapolation on these estimates to approximate the integral with a higher-degree of accuracy.

In case of arbitrary spaced samples, the two functions *trapz* (defined in numpy [*NPT*]) and *simps* are available. They are using Newton-Coates formulas of order 1 and 2 respectively to perform integration. The trapezoidal rule

approximates the function as a straight line between adjacent points, while Simpson's rule approximates the function between three adjacent points as a parabola.

For an odd number of samples that are equally spaced Simpson's rule is exact if the function is a polynomial of order 3 or less. If the samples are not equally spaced, then the result is exact only if the function is a polynomial of order 2 or less.

```
>>> import numpy as np
>>> def f1(x):
...     return x**2
...
>>> def f2(x):
...     return x**3
...
>>> x = np.array([1,3,4])
>>> y1 = f1(x)
>>> from scipy.integrate import simps
>>> I1 = simps(y1, x)
>>> print(I1)
21.0
```

This corresponds exactly to

$$\int_1^4 x^2 dx = 21,$$

whereas integrating the second function

```
>>> y2 = f2(x)
>>> I2 = integrate.simps(y2, x)
>>> print(I2)
61.5
```

does not correspond to

$$\int_1^4 x^3 dx = 63.75$$

because the order of the polynomial in f2 is larger than two.

### Faster integration using low-level callback functions

A user desiring reduced integration times may pass a C function pointer through `scipy.LowLevelCallable` to `quad`, `dblquad`, `tplquad` or `nquad` and it will be integrated and return a result in Python. The performance increase here arises from two factors. The primary improvement is faster function evaluation, which is provided by compilation of the function itself. Additionally we have a speedup provided by the removal of function calls between C and Python in `quad`. This method may provide a speed improvements of ~2x for trivial functions such as sine but can produce a much more noticeable improvements (10x+) for more complex functions. This feature then, is geared towards a user with numerically intensive integrations willing to write a little C to reduce computation time significantly.

The approach can be used, for example, via `ctypes` in a few simple steps:

- 1.) Write an integrand function in C with the function signature `double f(int n, double *x, void *user_data)`, where `x` is an array containing the point the function `f` is evaluated at, and `user_data` to arbitrary additional data you want to provide.

```

/* testlib.c */
double f(int n, double *x, void *user_data) {
    double c = *(double *)user_data;
    return c + x[0] - x[1] * x[2]; /* corresponds to c + x - y * z */
}

```

2.) Now compile this file to a shared/dynamic library (a quick search will help with this as it is OS-dependent). The user must link any math libraries, etc. used. On linux this looks like:

```
$ gcc -shared -fPIC -o testlib.so testlib.c
```

The output library will be referred to as `testlib.so`, but it may have a different file extension. A library has now been created that can be loaded into Python with `ctypes`.

3.) Load shared library into Python using `ctypes` and set `restypes` and `argtypes` - this allows SciPy to interpret the function correctly:

```

import os, ctypes
from scipy import integrate, LowLevelCallable

lib = ctypes.CDLL(os.path.abspath('testlib.so'))
lib.f.restype = ctypes.c_double
lib.f.argtypes = (ctypes.c_int, ctypes.POINTER(ctypes.c_double), ctypes.c_void_p)

c = ctypes.c_double(1.0)
user_data = ctypes.cast(ctypes.pointer(c), ctypes.c_void_p)

func = LowLevelCallable(lib.f, user_data)

```

The last `void *user_data` in the function is optional and can be omitted (both in the C function and `ctypes` `argtypes`) if not needed. Note that the coordinates are passed in as an array of doubles rather than a separate argument.

4.) Now integrate the library function as normally, here using `nquad`:

```

>>> integrate.nquad(func, [[0, 10], [-10, 0], [-1, 1]])
(1200.0, 1.1102230246251565e-11)

```

The Python tuple is returned as expected in a reduced amount of time. All optional parameters can be used with this method including specifying singularities, infinite bounds, etc.

### Ordinary differential equations (`odeint`)

Integrating a set of ordinary differential equations (ODEs) given initial conditions is another useful example. The function `odeint` is available in SciPy for integrating a first-order vector differential equation:

$$\frac{dy}{dt} = \mathbf{f}(\mathbf{y}, t),$$

given initial conditions  $\mathbf{y}(0) = \mathbf{y}_0$ , where  $\mathbf{y}$  is a length  $N$  vector and  $\mathbf{f}$  is a mapping from  $\mathcal{R}^N$  to  $\mathcal{R}^N$ . A higher-order ordinary differential equation can always be reduced to a differential equation of this type by introducing intermediate derivatives into the  $\mathbf{y}$  vector.

For example suppose it is desired to find the solution to the following second-order differential equation:

$$\frac{d^2w}{dz^2} - zw(z) = 0$$

with initial conditions  $w(0) = \frac{1}{\sqrt[3]{3^2}\Gamma(\frac{2}{3})}$  and  $\frac{dw}{dz}|_{z=0} = -\frac{1}{\sqrt[3]{3}\Gamma(\frac{1}{3})}$ . It is known that the solution to this differential equation with these boundary conditions is the Airy function

$$w = \text{Ai}(z),$$

which gives a means to check the integrator using `special.airy`.

First, convert this ODE into standard form by setting  $\mathbf{y} = \begin{bmatrix} \frac{dw}{dz} \\ w \end{bmatrix}$  and  $t = z$ . Thus, the differential equation becomes

$$\frac{d\mathbf{y}}{dt} = \begin{bmatrix} ty_1 \\ y_0 \end{bmatrix} = \begin{bmatrix} 0 & t \\ 1 & 0 \end{bmatrix} \begin{bmatrix} y_0 \\ y_1 \end{bmatrix} = \begin{bmatrix} 0 & t \\ 1 & 0 \end{bmatrix} \mathbf{y}.$$

In other words,

$$\mathbf{f}(\mathbf{y}, t) = \mathbf{A}(t) \mathbf{y}.$$

As an interesting reminder, if  $\mathbf{A}(t)$  commutes with  $\int_0^t \mathbf{A}(\tau) d\tau$  under matrix multiplication, then this linear differential equation has an exact solution using the matrix exponential:

$$\mathbf{y}(t) = \exp\left(\int_0^t \mathbf{A}(\tau) d\tau\right) \mathbf{y}(0),$$

However, in this case,  $\mathbf{A}(t)$  and its integral do not commute.

There are many optional inputs and outputs available when using `odeint` which can help tune the solver. These additional inputs and outputs are not needed much of the time, however, and the three required input arguments and the output solution suffice. The required inputs are the function defining the derivative, `fprime`, the initial conditions vector, `y0`, and the time points to obtain a solution, `t`, (with the initial value point as the first element of this sequence). The output to `odeint` is a matrix where each row contains the solution vector at each requested time point (thus, the initial conditions are given in the first output row).

The following example illustrates the use of `odeint` including the usage of the `Dfun` option which allows the user to specify a gradient (with respect to  $\mathbf{y}$ ) of the function,  $\mathbf{f}(\mathbf{y}, t)$ .

```
>>> from scipy.integrate import odeint
>>> from scipy.special import gamma, airy
>>> y1_0 = 1.0 / 3**(2.0/3.0) / gamma(2.0/3.0)
>>> y0_0 = -1.0 / 3**(1.0/3.0) / gamma(1.0/3.0)
>>> y0 = [y0_0, y1_0]
>>> def func(y, t):
...     return [t*y[1], y[0]]
...
...

```

```
>>> def gradient(y, t):
...     return [[0,t], [1,0]]
...
...

```

```
>>> x = np.arange(0, 4.0, 0.01)
>>> t = x
>>> ychk = airy(x)[0]
>>> y = odeint(func, y0, t)
>>> y2 = odeint(func, y0, t, Dfun=gradient)

```

```
>>> ychk[:36:6]
array([0.355028, 0.339511, 0.324068, 0.308763, 0.293658, 0.278806])

```

```
>>> y[:36:6,1]
array([0.355028, 0.339511, 0.324067, 0.308763, 0.293658, 0.278806])
```

```
>>> y2[:36:6,1]
array([0.355028, 0.339511, 0.324067, 0.308763, 0.293658, 0.278806])
```

### Solving a system with a banded Jacobian matrix

`odeint` can be told that the Jacobian is *banded*. For a large system of differential equations that are known to be stiff, this can improve performance significantly.

As an example, we'll solve the one-dimensional Gray-Scott partial differential equations using the method of lines [MOL]. The Gray-Scott equations for the functions  $u(x, t)$  and  $v(x, t)$  on the interval  $x \in [0, L]$  are

$$\begin{aligned}\frac{\partial u}{\partial t} &= D_u \frac{\partial^2 u}{\partial x^2} - uv^2 + f(1 - u) \\ \frac{\partial v}{\partial t} &= D_v \frac{\partial^2 v}{\partial x^2} + uv^2 - (f + k)v\end{aligned}$$

where  $D_u$  and  $D_v$  are the diffusion coefficients of the components  $u$  and  $v$ , respectively, and  $f$  and  $k$  are constants. (For more information about the system, see <http://groups.csail.mit.edu/mac/projects/amorphous/GrayScott/>)

We'll assume Neumann (i.e. "no flux") boundary conditions:

$$\frac{\partial u}{\partial x}(0, t) = 0, \quad \frac{\partial v}{\partial x}(0, t) = 0, \quad \frac{\partial u}{\partial x}(L, t) = 0, \quad \frac{\partial v}{\partial x}(L, t) = 0$$

To apply the method of lines, we discretize the  $x$  variable by defining the uniformly spaced grid of  $N$  points  $\{x_0, x_1, \dots, x_{N-1}\}$ , with  $x_0 = 0$  and  $x_{N-1} = L$ . We define  $u_j(t) \equiv u(x_j, t)$  and  $v_j(t) \equiv v(x_j, t)$ , and replace the  $x$  derivatives with finite differences. That is,

$$\frac{\partial^2 u}{\partial x^2}(x_j, t) \rightarrow \frac{u_{j-1}(t) - 2u_j(t) + u_{j+1}(t)}{(\Delta x)^2}$$

We then have a system of  $2N$  ordinary differential equations:

$$\begin{aligned}\frac{du_j}{dt} &= \frac{D_u}{(\Delta x)^2} (u_{j-1} - 2u_j + u_{j+1}) - u_j v_j^2 + f(1 - u_j) \\ \frac{dv_j}{dt} &= \frac{D_v}{(\Delta x)^2} (v_{j-1} - 2v_j + v_{j+1}) + u_j v_j^2 - (f + k)v_j\end{aligned}\tag{3.1}$$

For convenience, the  $(t)$  arguments have been dropped.

To enforce the boundary conditions, we introduce "ghost" points  $x_{-1}$  and  $x_N$ , and define  $u_{-1}(t) \equiv u_1(t)$ ,  $u_N(t) \equiv u_{N-2}(t)$ ;  $v_{-1}(t)$  and  $v_N(t)$  are defined analogously.

Then

$$\begin{aligned}\frac{du_0}{dt} &= \frac{D_u}{(\Delta x)^2} (2u_1 - 2u_0) - u_0 v_0^2 + f(1 - u_0) \\ \frac{dv_0}{dt} &= \frac{D_v}{(\Delta x)^2} (2v_1 - 2v_0) + u_0 v_0^2 - (f + k)v_0\end{aligned}\tag{3.2}$$

and

$$\begin{aligned}\frac{du_{N-1}}{dt} &= \frac{D_u}{(\Delta x)^2} (2u_{N-2} - 2u_{N-1}) - u_{N-1} v_{N-1}^2 + f(1 - u_{N-1}) \\ \frac{dv_{N-1}}{dt} &= \frac{D_v}{(\Delta x)^2} (2v_{N-2} - 2v_{N-1}) + u_{N-1} v_{N-1}^2 - (f + k)v_{N-1}\end{aligned}\tag{3.3}$$

Our complete system of  $2N$  ordinary differential equations is (??) for  $k = 1, 2, \dots, N - 2$ , along with (??) and (??).

We can now start implementing this system in code. We must combine  $\{u_k\}$  and  $\{v_k\}$  into a single vector of length  $2N$ . The two obvious choices are  $\{u_0, u_1, \dots, u_{N-1}, v_0, v_1, \dots, v_{N-1}\}$  and  $\{u_0, v_0, u_1, v_1, \dots, u_{N-1}, v_{N-1}\}$ . Mathematically, it does not matter, but the choice affects how efficiently `odeint` can solve the system. The reason is in how the order affects the pattern of the nonzero elements of the Jacobian matrix.

When the variables are ordered as  $\{u_0, u_1, \dots, u_{N-1}, v_0, v_1, \dots, v_{N-1}\}$ , the pattern of nonzero elements of the Jacobian matrix is

```

* * 0 0 0 0 0 * 0 0 0 0 0 0
* * * 0 0 0 0 0 * 0 0 0 0 0
0 * * * 0 0 0 0 0 * 0 0 0 0
0 0 * * * 0 0 0 0 0 * 0 0 0
0 0 0 * * * 0 0 0 0 0 * 0 0
0 0 0 0 * * * 0 0 0 0 0 * 0
* 0 0 0 0 0 * * * 0 0 0 0 0
0 * 0 0 0 0 0 * * * 0 0 0 0
0 0 * 0 0 0 0 0 * * * 0 0 0
0 0 0 * 0 0 0 0 0 * * * 0 0
0 0 0 0 * 0 0 0 0 0 * * * 0
0 0 0 0 0 * 0 0 0 0 0 * * *
0 0 0 0 0 0 * 0 0 0 0 0 * *
    
```

The Jacobian pattern with variables interleaved as  $\{u_0, v_0, u_1, v_1, \dots, u_{N-1}, v_{N-1}\}$  is

```

* * * 0 0 0 0 0 0 0 0 0 0 0 0
* * 0 * 0 0 0 0 0 0 0 0 0 0
* 0 * * * 0 0 0 0 0 0 0 0 0
0 * * * 0 * 0 0 0 0 0 0 0 0
0 0 * 0 * * * 0 0 0 0 0 0 0
0 0 0 * * * 0 * 0 0 0 0 0 0
0 0 0 0 * 0 * * * 0 0 0 0 0
0 0 0 0 0 * * * 0 * 0 0 0 0
0 0 0 0 0 0 * 0 * * * 0 0 0
0 0 0 0 0 0 0 * 0 * * * 0
0 0 0 0 0 0 0 0 * 0 * * * 0
0 0 0 0 0 0 0 0 0 * 0 * * *
0 0 0 0 0 0 0 0 0 0 * 0 * *
    
```

In both cases, there are just five nontrivial diagonals, but when the variables are interleaved, the bandwidth is much smaller. That is, the main diagonal and the two diagonals immediately above and the two immediately below the main diagonal are the nonzero diagonals. This is important, because the inputs `mu` and `m1` of `odeint` are the upper and lower bandwidths of the Jacobian matrix. When the variables are interleaved, `mu` and `m1` are 2. When the variables are stacked with  $\{v_k\}$  following  $\{u_k\}$ , the upper and lower bandwidths are  $N$ .

With that decision made, we can write the function that implements the system of differential equations.

First, we define the functions for the source and reaction terms of the system:

```

def G(u, v, f, k):
    return f * (1 - u) - u*v**2

def H(u, v, f, k):
    return -(f + k) * v + u*v**2
    
```

Next we define the function that computes the right-hand-side of the system of differential equations:

```

def graycott1d(y, t, f, k, Du, Dv, dx):
    """
    Differential equations for the 1D Gray-Scott equations.

    The ODEs are derived using the method of lines.
    """
    # The vectors u and v are interleaved in y. We define
    # views of u and v by slicing y.
    u = y[::2]
    v = y[1::2]

    # dydt is the return value of this function.
    dydt = np.empty_like(y)
    
```

```

# Just like u and v are views of the interleaved vectors
# in y, dudt and dvdt are views of the interleaved output
# vectors in dydt.
dudt = dydt[:,2]
dvdt = dydt[1:,2]

# Compute du/dt and dv/dt. The end points and the interior points
# are handled separately.
dudt[0] = G(u[0], v[0], f, k) + Du * (-2.0*u[0] + 2.0*u[1]) / dx**2
dudt[1:-1] = G(u[1:-1], v[1:-1], f, k) + Du * np.diff(u,2) / dx**2
dudt[-1] = G(u[-1], v[-1], f, k) + Du * (-2.0*u[-1] + 2.0*u[-2]) / dx**2
dvdt[0] = H(u[0], v[0], f, k) + Dv * (-2.0*v[0] + 2.0*v[1]) / dx**2
dvdt[1:-1] = H(u[1:-1], v[1:-1], f, k) + Dv * np.diff(v,2) / dx**2
dvdt[-1] = H(u[-1], v[-1], f, k) + Dv * (-2.0*v[-1] + 2.0*v[-2]) / dx**2

return dydt

```

We won't implement a function to compute the Jacobian, but we will tell `odeint` that the Jacobian matrix is banded. This allows the underlying solver (LSODA) to avoid computing values that it knows are zero. For a large system, this improves the performance significantly, as demonstrated in the following ipython session.

First, we define the required inputs:

```

In [31]: y0 = np.random.randn(5000)
In [32]: t = np.linspace(0, 50, 11)
In [33]: f = 0.024
In [34]: k = 0.055
In [35]: Du = 0.01
In [36]: Dv = 0.005
In [37]: dx = 0.025

```

Time the computation without taking advantage of the banded structure of the Jacobian matrix:

```

In [38]: %timeit sola = odeint(grayscott1d, y0, t, args=(f, k, Du, Dv, dx))
1 loop, best of 3: 25.2 s per loop

```

Now set `m1=2` and `mu=2`, so `odeint` knows that the Jacobian matrix is banded:

```

In [39]: %timeit solb = odeint(grayscott1d, y0, t, args=(f, k, Du, Dv, dx), m1=2,
↪mu=2)
10 loops, best of 3: 191 ms per loop

```

That is quite a bit faster!

Let's ensure that they have computed the same result:

```

In [41]: np.allclose(sola, solb)
Out[41]: True

```

## References

### 3.1.5 Optimization (`scipy.optimize`)

The `scipy.optimize` package provides several commonly used optimization algorithms. A detailed listing is available: `scipy.optimize` (can also be found by `help(scipy.optimize)`).

The module contains:

1. Unconstrained and constrained minimization of multivariate scalar functions (`minimize`) using a variety of algorithms (e.g. BFGS, Nelder-Mead simplex, Newton Conjugate Gradient, COBYLA or SLSQP)
2. Global (brute-force) optimization routines (e.g. `basinhopping`, `differential_evolution`)
3. Least-squares minimization (`least_squares`) and curve fitting (`curve_fit`) algorithms
4. Scalar univariate functions minimizers (`minimize_scalar`) and root finders (`newton`)
5. Multivariate equation system solvers (`root`) using a variety of algorithms (e.g. hybrid Powell, Levenberg-Marquardt or large-scale methods such as Newton-Krylov).

Below, several examples demonstrate their basic usage.

#### Unconstrained minimization of multivariate scalar functions (`minimize`)

The `minimize` function provides a common interface to unconstrained and constrained minimization algorithms for multivariate scalar functions in `scipy.optimize`. To demonstrate the minimization function consider the problem of minimizing the Rosenbrock function of  $N$  variables:

$$f(\mathbf{x}) = \sum_{i=1}^{N-1} 100(x_i - x_{i-1}^2)^2 + (1 - x_{i-1})^2.$$

The minimum value of this function is 0 which is achieved when  $x_i = 1$ .

Note that the Rosenbrock function and its derivatives are included in `scipy.optimize`. The implementations shown in the following sections provide examples of how to define an objective function as well as its jacobian and hessian functions.

#### Nelder-Mead Simplex algorithm (`method='Nelder-Mead'`)

In the example below, the `minimize` routine is used with the *Nelder-Mead* simplex algorithm (selected through the `method` parameter):

```
>>> import numpy as np
>>> from scipy.optimize import minimize
```

```
>>> def rosen(x):
...     """The Rosenbrock function"""
...     return sum(100.0*(x[1:]-x[:-1]**2.0)**2.0 + (1-x[:-1])**2.0)
```

```
>>> x0 = np.array([1.3, 0.7, 0.8, 1.9, 1.2])
>>> res = minimize(rosen, x0, method='nelder-mead',
...               options={'xtol': 1e-8, 'disp': True})
Optimization terminated successfully.
Current function value: 0.000000
Iterations: 339
Function evaluations: 571
```

```
>>> print(res.x)
[ 1.  1.  1.  1.  1.]
```

The simplex algorithm is probably the simplest way to minimize a fairly well-behaved function. It requires only function evaluations and is a good choice for simple minimization problems. However, because it does not use any gradient evaluations, it may take longer to find the minimum.

Another optimization algorithm that needs only function calls to find the minimum is *Powell's* method available by setting `method='powell'` in `minimize`.

#### ***Broyden-Fletcher-Goldfarb-Shanno algorithm (method='BFGS')***

In order to converge more quickly to the solution, this routine uses the gradient of the objective function. If the gradient is not given by the user, then it is estimated using first-differences. The Broyden-Fletcher-Goldfarb-Shanno (BFGS) method typically requires fewer function calls than the simplex algorithm even when the gradient must be estimated.

To demonstrate this algorithm, the Rosenbrock function is again used. The gradient of the Rosenbrock function is the vector:

$$\begin{aligned}\frac{\partial f}{\partial x_j} &= \sum_{i=1}^N 200 (x_i - x_{i-1}^2) (\delta_{i,j} - 2x_{i-1}\delta_{i-1,j}) - 2(1 - x_{i-1})\delta_{i-1,j} \\ &= 200 (x_j - x_{j-1}^2) - 400x_j (x_{j+1} - x_j^2) - 2(1 - x_j).\end{aligned}$$

This expression is valid for the interior derivatives. Special cases are

$$\begin{aligned}\frac{\partial f}{\partial x_0} &= -400x_0 (x_1 - x_0^2) - 2(1 - x_0), \\ \frac{\partial f}{\partial x_{N-1}} &= 200 (x_{N-1} - x_{N-2}^2).\end{aligned}$$

A Python function which computes this gradient is constructed by the code-segment:

```
>>> def rosen_der(x):
...     xm = x[1:-1]
...     xm_m1 = x[:-2]
...     xm_p1 = x[2:]
...     der = np.zeros_like(x)
...     der[1:-1] = 200*(xm-xm_m1**2) - 400*(xm_p1 - xm**2)*xm - 2*(1-xm)
...     der[0] = -400*x[0]*(x[1]-x[0]**2) - 2*(1-x[0])
...     der[-1] = 200*(x[-1]-x[-2]**2)
...     return der
```

This gradient information is specified in the `minimize` function through the `jac` parameter as illustrated below.

```
>>> res = minimize(rosen, x0, method='BFGS', jac=rosen_der,
...                 options={'disp': True})
Optimization terminated successfully.
    Current function value: 0.000000
    Iterations: 51 # may vary
    Function evaluations: 63
    Gradient evaluations: 63
>>> res.x
array([1., 1., 1., 1., 1.])
```

#### ***Newton-Conjugate-Gradient algorithm (method='Newton-CG')***

Newton-Conjugate Gradient algorithm is a modified Newton's method and uses a conjugate gradient algorithm to (approximately) invert the local Hessian *[NW]*. Newton's method is based on fitting the function locally to a quadratic

form:

$$f(\mathbf{x}) \approx f(\mathbf{x}_0) + \nabla f(\mathbf{x}_0) \cdot (\mathbf{x} - \mathbf{x}_0) + \frac{1}{2} (\mathbf{x} - \mathbf{x}_0)^T \mathbf{H}(\mathbf{x}_0) (\mathbf{x} - \mathbf{x}_0).$$

where  $\mathbf{H}(\mathbf{x}_0)$  is a matrix of second-derivatives (the Hessian). If the Hessian is positive definite then the local minimum of this function can be found by setting the gradient of the quadratic form to zero, resulting in

$$\mathbf{x}_{\text{opt}} = \mathbf{x}_0 - \mathbf{H}^{-1} \nabla f.$$

The inverse of the Hessian is evaluated using the conjugate-gradient method. An example of employing this method to minimizing the Rosenbrock function is given below. To take full advantage of the Newton-CG method, a function which computes the Hessian must be provided. The Hessian matrix itself does not need to be constructed, only a vector which is the product of the Hessian with an arbitrary vector needs to be available to the minimization routine. As a result, the user can provide either a function to compute the Hessian matrix, or a function to compute the product of the Hessian with an arbitrary vector.

### Full Hessian example:

The Hessian of the Rosenbrock function is

$$\begin{aligned} H_{ij} = \frac{\partial^2 f}{\partial x_i \partial x_j} &= 200(\delta_{i,j} - 2x_{i-1}\delta_{i-1,j}) - 400x_i(\delta_{i+1,j} - 2x_i\delta_{i,j}) - 400\delta_{i,j}(x_{i+1} - x_i^2) + 2\delta_{i,j}, \\ &= (202 + 1200x_i^2 - 400x_{i+1})\delta_{i,j} - 400x_i\delta_{i+1,j} - 400x_{i-1}\delta_{i-1,j}, \end{aligned}$$

if  $i, j \in [1, N-2]$  with  $i, j \in [0, N-1]$  defining the  $N \times N$  matrix. Other non-zero entries of the matrix are

$$\begin{aligned} \frac{\partial^2 f}{\partial x_0^2} &= 1200x_0^2 - 400x_1 + 2, \\ \frac{\partial^2 f}{\partial x_0 \partial x_1} = \frac{\partial^2 f}{\partial x_1 \partial x_0} &= -400x_0, \\ \frac{\partial^2 f}{\partial x_{N-1} \partial x_{N-2}} = \frac{\partial^2 f}{\partial x_{N-2} \partial x_{N-1}} &= -400x_{N-2}, \\ \frac{\partial^2 f}{\partial x_{N-1}^2} &= 200. \end{aligned}$$

For example, the Hessian when  $N = 5$  is

$$\mathbf{H} = \begin{bmatrix} 1200x_0^2 - 400x_1 + 2 & -400x_0 & 0 & 0 & 0 \\ -400x_0 & 202 + 1200x_1^2 - 400x_2 & -400x_1 & 0 & 0 \\ 0 & -400x_1 & 202 + 1200x_2^2 - 400x_3 & -400x_2 & 0 \\ 0 & 0 & -400x_2 & 202 + 1200x_3^2 - 400x_4 & -400x_3 \\ 0 & 0 & 0 & -400x_3 & 200 \end{bmatrix}.$$

The code which computes this Hessian along with the code to minimize the function using Newton-CG method is shown in the following example:

```
>>> def rosen_hess(x):
...     x = np.asarray(x)
...     H = np.diag(-400*x[:-1], 1) - np.diag(400*x[:-1], -1)
...     diagonal = np.zeros_like(x)
...     diagonal[0] = 1200*x[0]**2 - 400*x[1] + 2
...     diagonal[-1] = 200
...     diagonal[1:-1] = 202 + 1200*x[1:-1]**2 - 400*x[2:]
...     H = H + np.diag(diagonal)
...     return H
```

```

>>> res = minimize(rosen, x0, method='Newton-CG',
...                 jac=rosen_der, hess=rosen_hess,
...                 options={'xtol': 1e-8, 'disp': True})
Optimization terminated successfully.
    Current function value: 0.000000
    Iterations: 19                # may vary
    Function evaluations: 22
    Gradient evaluations: 19
    Hessian evaluations: 19
>>> res.x
array([1., 1., 1., 1., 1.])

```

### Hessian product example:

For larger minimization problems, storing the entire Hessian matrix can consume considerable time and memory. The Newton-CG algorithm only needs the product of the Hessian times an arbitrary vector. As a result, the user can supply code to compute this product rather than the full Hessian by giving a `hess` function which take the minimization vector as the first argument and the arbitrary vector as the second argument (along with extra arguments passed to the function to be minimized). If possible, using Newton-CG with the Hessian product option is probably the fastest way to minimize the function.

In this case, the product of the Rosenbrock Hessian with an arbitrary vector is not difficult to compute. If  $\mathbf{p}$  is the arbitrary vector, then  $\mathbf{H}(\mathbf{x})\mathbf{p}$  has elements:

$$\mathbf{H}(\mathbf{x})\mathbf{p} = \begin{bmatrix} (1200x_0^2 - 400x_1 + 2)p_0 - 400x_0p_1 \\ \vdots \\ -400x_{i-1}p_{i-1} + (202 + 1200x_i^2 - 400x_{i+1})p_i - 400x_ip_{i+1} \\ \vdots \\ -400x_{N-2}p_{N-2} + 200p_{N-1} \end{bmatrix}.$$

Code which makes use of this Hessian product to minimize the Rosenbrock function using `minimize` follows:

```

>>> def rosen_hess_p(x, p):
...     x = np.asarray(x)
...     Hp = np.zeros_like(x)
...     Hp[0] = (1200*x[0]**2 - 400*x[1] + 2)*p[0] - 400*x[0]*p[1]
...     Hp[1:-1] = -400*x[:-2]*p[:-2] + (202+1200*x[1:-1]**2-400*x[2:]) *p[1:-1] \
...               -400*x[1:-1]*p[2:]
...     Hp[-1] = -400*x[-2]*p[-2] + 200*p[-1]
...     return Hp

```

```

>>> res = minimize(rosen, x0, method='Newton-CG',
...                 jac=rosen_der, hessp=rosen_hess_p,
...                 options={'xtol': 1e-8, 'disp': True})
Optimization terminated successfully.
    Current function value: 0.000000
    Iterations: 20                # may vary
    Function evaluations: 23
    Gradient evaluations: 20
    Hessian evaluations: 44
>>> res.x
array([1., 1., 1., 1., 1.])

```

According to [NW] p. 170 the Newton-CG algorithm can be inefficient when the Hessian is ill-conditioned because

of the poor quality search directions provided by the method in those situations. The method `trust-ncg`, according to the authors, deals more effectively with this problematic situation and will be described next.

#### *Trust-Region Newton-Conjugate-Gradient Algorithm (method= 'trust-ncg')*

The `Newton-CG` method is a line search method: it finds a direction of search minimizing a quadratic approximation of the function and then uses a line search algorithm to find the (nearly) optimal step size in that direction. An alternative approach is to, first, fix the step size limit  $\Delta$  and then find the optimal step  $\mathbf{p}$  inside the given trust-radius by solving the following quadratic subproblem:

$$\min_{\mathbf{p}} f(\mathbf{x}_k) + \nabla f(\mathbf{x}_k) \cdot \mathbf{p} + \frac{1}{2} \mathbf{p}^T \mathbf{H}(\mathbf{x}_k) \mathbf{p};$$

subject to:  $\|\mathbf{p}\| \leq \Delta$ .

The solution is then updated  $\mathbf{x}_{k+1} = \mathbf{x}_k + \mathbf{p}$  and the trust-radius  $\Delta$  is adjusted according to the degree of agreement of the quadratic model with the real function. This family of methods is known as trust-region methods. The `trust-ncg` algorithm is a trust-region method that uses a conjugate gradient algorithm to solve the trust-region subproblem [NW].

#### Full Hessian example:

```
>>> res = minimize(rosen, x0, method='trust-ncg',
...               jac=rosen_der, hess=rosen_hess,
...               options={'gtol': 1e-8, 'disp': True})
Optimization terminated successfully.
    Current function value: 0.000000
    Iterations: 20          # may vary
    Function evaluations: 21
    Gradient evaluations: 20
    Hessian evaluations: 19
>>> res.x
array([1., 1., 1., 1., 1.])
```

#### Hessian product example:

```
>>> res = minimize(rosen, x0, method='trust-ncg',
...               jac=rosen_der, hessp=rosen_hess_p,
...               options={'gtol': 1e-8, 'disp': True})
Optimization terminated successfully.
    Current function value: 0.000000
    Iterations: 20          # may vary
    Function evaluations: 21
    Gradient evaluations: 20
    Hessian evaluations: 0
>>> res.x
array([1., 1., 1., 1., 1.])
```

#### *Trust-Region Truncated Generalized Lanczos / Conjugate Gradient Algorithm (method= 'trust-krylov')*

Similar to the `trust-ncg` method, the `trust-krylov` method is a method suitable for large-scale problems as it uses the hessian only as linear operator by means of matrix-vector products. It solves the quadratic subproblem more

accurately than the `trust-ncg` method.

$$\min_{\mathbf{p}} f(\mathbf{x}_k) + \nabla f(\mathbf{x}_k) \cdot \mathbf{p} + \frac{1}{2} \mathbf{p}^T \mathbf{H}(\mathbf{x}_k) \mathbf{p};$$

subject to:  $\|\mathbf{p}\| \leq \Delta$ .

This method wraps the *[TRLIB]* implementation of the *[GLTR]* method solving exactly a trust-region subproblem restricted to a truncated Krylov subspace. For indefinite problems it is usually better to use this method as it reduces the number of nonlinear iterations at the expense of few more matrix-vector products per subproblem solve in comparison to the `trust-ncg` method.

### Full Hessian example:

```
>>> res = minimize(rosen, x0, method='trust-krylov',
...                 jac=rosen_der, hess=rosen_hess,
...                 options={'gtol': 1e-8, 'disp': True})
Optimization terminated successfully.
      Current function value: 0.000000
      Iterations: 19          # may vary
      Function evaluations: 20
      Gradient evaluations: 20
      Hessian evaluations: 18
>>> res.x
array([1., 1., 1., 1., 1.]
```

### Hessian product example:

```
>>> res = minimize(rosen, x0, method='trust-krylov',
...                 jac=rosen_der, hessp=rosen_hess_p,
...                 options={'gtol': 1e-8, 'disp': True})
Optimization terminated successfully.
      Current function value: 0.000000
      Iterations: 19          # may vary
      Function evaluations: 20
      Gradient evaluations: 20
      Hessian evaluations: 0
>>> res.x
array([1., 1., 1., 1., 1.]
```

### *Trust-Region Nearly Exact Algorithm (method='trust-exact')*

All methods Newton-CG, `trust-ncg` and `trust-krylov` are suitable for dealing with large-scale problems (problems with thousands of variables). That is because the conjugate gradient algorithm approximately solve the trust-region subproblem (or invert the Hessian) by iterations without the explicit Hessian factorization. Since only the product of the Hessian with an arbitrary vector is needed, the algorithm is specially suited for dealing with sparse Hessians, allowing low storage requirements and significant time savings for those sparse problems.

For medium-size problems, for which the storage and factorization cost of the Hessian are not critical, it is possible to obtain a solution within fewer iteration by solving the trust-region subproblems almost exactly. To achieve that, a certain nonlinear equations is solved iteratively for each quadratic subproblem *[CGT]*. This solution requires usually 3 or 4 Cholesky factorizations of the Hessian matrix. As the result, the method converges in fewer number of iterations and takes fewer evaluations of the objective function than the other implemented trust-region methods. The Hessian product option is not supported by this algorithm. An example using the Rosenbrock function follows:

```

>>> res = minimize(rosen, x0, method='trust-exact',
...                 jac=rosen_der, hess=rosen_hess,
...                 options={'gtol': 1e-8, 'disp': True})
Optimization terminated successfully.
    Current function value: 0.000000
    Iterations: 13          # may vary
    Function evaluations: 14
    Gradient evaluations: 13
    Hessian evaluations: 14
>>> res.x
array([1., 1., 1., 1., 1.])

```

### Constrained minimization of multivariate scalar functions (`minimize`)

The `minimize` function also provides an interface to several constrained minimization algorithm. As an example, the Sequential Least Squares Programming optimization algorithm (SLSQP) will be considered here. This algorithm allows to deal with constrained minimization problems of the form:

$$\begin{aligned}
 & \min F(x) \\
 & \text{subject to} \quad C_j(X) = 0, \quad j = 1, \dots, \text{MEQ} \\
 & \quad \quad \quad C_j(x) \geq 0, \quad j = \text{MEQ} + 1, \dots, M \\
 & \quad \quad \quad XL \leq x \leq XU, \quad I = 1, \dots, N.
 \end{aligned}$$

As an example, let us consider the problem of maximizing the function:

$$f(x, y) = 2xy + 2x - x^2 - 2y^2$$

subject to an equality and an inequality constraints defined as:

$$\begin{aligned}
 x^3 - y &= 0 \\
 y - 1 &\geq 0
 \end{aligned}$$

The objective function and its derivative are defined as follows.

```

>>> def func(x, sign=1.0):
...     """ Objective function """
...     return sign*(2*x[0]*x[1] + 2*x[0] - x[0]**2 - 2*x[1]**2)

```

```

>>> def func_deriv(x, sign=1.0):
...     """ Derivative of objective function """
...     dfdx0 = sign*(-2*x[0] + 2*x[1] + 2)
...     dfdx1 = sign*(2*x[0] - 4*x[1])
...     return np.array([ dfdx0, dfdx1 ])

```

Note that since `minimize` only minimizes functions, the `sign` parameter is introduced to multiply the objective function (and its derivative) by -1 in order to perform a maximization.

Then constraints are defined as a sequence of dictionaries, with keys `type`, `fun` and `jac`.

```

>>> cons = ( {'type': 'eq',
...           'fun' : lambda x: np.array([x[0]**3 - x[1]]),
...           'jac' : lambda x: np.array([3.0*(x[0]**2.0), -1.0])},
...          { 'type': 'ineq',
...           'fun' : lambda x: np.array([x[1] - 1]),
...           'jac' : lambda x: np.array([0.0, 1.0])})

```

Now an unconstrained optimization can be performed as:

```
>>> res = minimize(func, [-1.0,1.0], args=(-1.0,), jac=func_deriv,
...               method='SLSQP', options={'disp': True})
Optimization terminated successfully.      (Exit mode 0)
      Current function value: -2.0
      Iterations: 4                # may vary
      Function evaluations: 5
      Gradient evaluations: 4
>>> print(res.x)
[ 2.  1.]
```

and a constrained optimization as:

```
>>> res = minimize(func, [-1.0,1.0], args=(-1.0,), jac=func_deriv,
...               constraints=cons, method='SLSQP', options={'disp': True})
Optimization terminated successfully.      (Exit mode 0)
      Current function value: -1.00000018311
      Iterations: 9                # may vary
      Function evaluations: 14
      Gradient evaluations: 9
>>> print(res.x)
[ 1.00000009  1.          ]
```

### Least-squares minimization (`least_squares`)

SciPy is capable of solving robustified bound constrained nonlinear least-squares problems:

$$\min_{\mathbf{x}} \frac{1}{2} \sum_{i=1}^m \rho(f_i(\mathbf{x})^2) \quad (3.4)$$

$$\text{subject to } \mathbf{lb} \leq \mathbf{x} \leq \mathbf{ub} \quad (3.5)$$

Here  $f_i(\mathbf{x})$  are smooth functions from  $\mathbb{R}^n$  to  $\mathbb{R}$ , we refer to them as residuals. The purpose of a scalar valued function  $\rho(\cdot)$  is to reduce the influence of outlier residuals and contribute to robustness of the solution, we refer to it as a loss function. A linear loss function gives a standard least-squares problem. Additionally, constraints in a form of lower and upper bounds on some of  $x_j$  are allowed.

All methods specific to least-squares minimization utilize a  $m \times n$  matrix of partial derivatives called Jacobian and defined as  $J_{ij} = \partial f_i / \partial x_j$ . It is highly recommended to compute this matrix analytically and pass it to `least_squares`, otherwise it will be estimated by finite differences which takes a lot of additional time and can be very inaccurate in hard cases.

Function `least_squares` can be used for fitting a function  $\varphi(t; \mathbf{x})$  to empirical data  $\{(t_i, y_i), i = 0, \dots, m - 1\}$ . To do this one should simply precompute residuals as  $f_i(\mathbf{x}) = w_i(\varphi(t_i; \mathbf{x}) - y_i)$ , where  $w_i$  are weights assigned to each observation.

#### Example of solving a fitting problem

Here we consider “Analysis of an Enzyme Reaction” problem formulated in<sup>1</sup>. There are 11 residuals defined as

$$f_i(x) = \frac{x_0(u_i^2 + u_i x_1)}{u_i^2 + u_i x_2 + x_3} - y_i, \quad i = 0, \dots, 10,$$

<sup>1</sup> Brett M. Averick et al., “The MINPACK-2 Test Problem Collection”.

where  $y_i$  are measurement values and  $u_i$  are values of the independent variable. The unknown vector of parameters is  $\mathbf{x} = (x_0, x_1, x_2, x_3)^T$ . As was said previously, it is recommended to compute Jacobian matrix in a closed form:

$$J_{i0} = \frac{\partial f_i}{\partial x_0} = \frac{u_i^2 + u_i x_1}{u_i^2 + u_i x_2 + x_3} \quad (3.6)$$

$$J_{i1} = \frac{\partial f_i}{\partial x_1} = \frac{u_i x_0}{u_i^2 + u_i x_2 + x_3} \quad (3.7)$$

$$J_{i2} = \frac{\partial f_i}{\partial x_2} = -\frac{x_0(u_i^2 + u_i x_1)u_i}{(u_i^2 + u_i x_2 + x_3)^2} \quad (3.8)$$

$$J_{i3} = \frac{\partial f_i}{\partial x_3} = -\frac{x_0(u_i^2 + u_i x_1)}{(u_i^2 + u_i x_2 + x_3)^2} \quad (3.9)$$

We are going to use the “hard” starting point defined in<sup>1</sup>. To find a physically meaningful solution, avoid potential division by zero and assure convergence to the global minimum we impose constraints  $0 \leq x_j \leq 100, j = 0, 1, 2, 3$ .

The code below implements least-squares estimation of  $\mathbf{x}$  and finally plots the original data and the fitted model function:

```
>>> from scipy.optimize import least_squares
```

```
>>> def model(x, u):
...     return x[0] * (u ** 2 + x[1] * u) / (u ** 2 + x[2] * u + x[3])
```

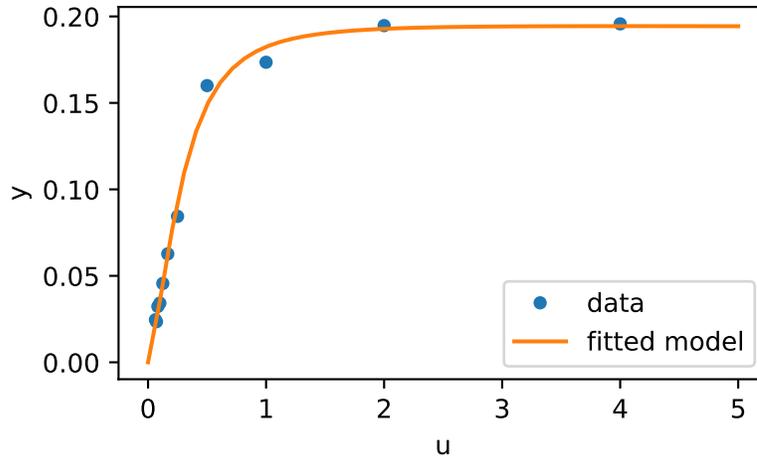
```
>>> def fun(x, u, y):
...     return model(x, u) - y
```

```
>>> def jac(x, u, y):
...     J = np.empty((u.size, x.size))
...     den = u ** 2 + x[2] * u + x[3]
...     num = u ** 2 + x[1] * u
...     J[:, 0] = num / den
...     J[:, 1] = x[0] * u / den
...     J[:, 2] = -x[0] * num * u / den ** 2
...     J[:, 3] = -x[0] * num / den ** 2
...     return J
```

```
>>> u = np.array([4.0, 2.0, 1.0, 5.0e-1, 2.5e-1, 1.67e-1, 1.25e-1, 1.0e-1,
...              8.33e-2, 7.14e-2, 6.25e-2])
>>> y = np.array([1.957e-1, 1.947e-1, 1.735e-1, 1.6e-1, 8.44e-2, 6.27e-2,
...              4.56e-2, 3.42e-2, 3.23e-2, 2.35e-2, 2.46e-2])
>>> x0 = np.array([2.5, 3.9, 4.15, 3.9])
>>> res = least_squares(fun, x0, jac=jac, bounds=(0, 100), args=(u, y), verbose=1)
`ftol` termination condition is satisfied.
Function evaluations 130, initial cost 4.4383e+00, final cost 1.5375e-04, first-order_
↳optimality 4.92e-08.
>>> res.x
array([ 0.19280596,  0.19130423,  0.12306063,  0.13607247])
```

```
>>> import matplotlib.pyplot as plt
>>> u_test = np.linspace(0, 5)
>>> y_test = model(res.x, u_test)
>>> plt.plot(u, y, 'o', markersize=4, label='data')
>>> plt.plot(u_test, y_test, label='fitted model')
>>> plt.xlabel("u")
>>> plt.ylabel("y")
```

```
>>> plt.legend(loc='lower right')
>>> plt.show()
```



### Further examples

Three interactive examples below illustrate usage of `least_squares` in greater detail.

1. [Large-scale bundle adjustment in scipy](#) demonstrates large-scale capabilities of `least_squares` and how to efficiently compute finite difference approximation of sparse Jacobian.
2. [Robust nonlinear regression in scipy](#) shows how to handle outliers with a robust loss function in a nonlinear regression.
3. [Solving a discrete boundary-value problem in scipy](#) examines how to solve a large system of equations and use bounds to achieve desired properties of the solution.

For the details about mathematical algorithms behind the implementation refer to documentation of `least_squares`.

### Univariate function minimizers (`minimize_scalar`)

Often only the minimum of an univariate function (i.e. a function that takes a scalar as input) is needed. In these circumstances, other optimization techniques have been developed that can work faster. These are accessible from the `minimize_scalar` function which proposes several algorithms.

#### Unconstrained minimization (`method='brent'`)

There are actually two methods that can be used to minimize an univariate function: `brent` and `golden`, but `golden` is included only for academic purposes and should rarely be used. These can be respectively selected through the `method` parameter in `minimize_scalar`. The `brent` method uses Brent's algorithm for locating a minimum. Optimally a bracket (the `bracket` parameter) should be given which contains the minimum desired. A bracket is a triple  $(a, b, c)$  such that  $f(a) > f(b) < f(c)$  and  $a < b < c$ . If this is not given, then alternatively two starting points can be chosen and a bracket will be found from these points using a simple marching algorithm. If these two starting points are not provided `0` and `1` will be used (this may not be the right choice for your function and result in an unexpected minimum being returned).

Here is an example:

```
>>> from scipy.optimize import minimize_scalar
>>> f = lambda x: (x - 2) * (x + 1)**2
>>> res = minimize_scalar(f, method='brent')
>>> print(res.x)
1.0
```

### Bounded minimization (*method='bounded'*)

Very often, there are constraints that can be placed on the solution space before minimization occurs. The *bounded* method in *minimize\_scalar* is an example of a constrained minimization procedure that provides a rudimentary interval constraint for scalar functions. The interval constraint allows the minimization to occur only between two fixed endpoints, specified using the mandatory *bounds* parameter.

For example, to find the minimum of  $J_1(x)$  near  $x = 5$ , *minimize\_scalar* can be called using the interval  $[4, 7]$  as a constraint. The result is  $x_{\min} = 5.3314$ :

```
>>> from scipy.special import j1
>>> res = minimize_scalar(j1, bounds=(4, 7), method='bounded')
>>> res.x
5.33144184241
```

### Custom minimizers

Sometimes, it may be useful to use a custom method as a (multivariate or univariate) minimizer, for example when using some library wrappers of *minimize* (e.g. *basinhopping*).

We can achieve that by, instead of passing a method name, we pass a callable (either a function or an object implementing a *\_\_call\_\_* method) as the *method* parameter.

Let us consider an (admittedly rather virtual) need to use a trivial custom multivariate minimization method that will just search the neighborhood in each dimension independently with a fixed step size:

```
>>> from scipy.optimize import OptimizeResult
>>> def custmin(fun, x0, args=(), maxfev=None, stepsize=0.1,
...           maxiter=100, callback=None, **options):
...     bestx = x0
...     besty = fun(x0)
...     funcalls = 1
...     niter = 0
...     improved = True
...     stop = False
...
...     while improved and not stop and niter < maxiter:
...         improved = False
...         niter += 1
...         for dim in range(np.size(x0)):
...             for s in [bestx[dim] - stepsize, bestx[dim] + stepsize]:
...                 testx = np.copy(bestx)
...                 testx[dim] = s
...                 testy = fun(testx, *args)
...                 funcalls += 1
...                 if testy < besty:
...                     besty = testy
...                     bestx = testx
...                     improved = True
...             if callback is not None:
...                 callback(bestx)
```

```

...         if maxfev is not None and funcalls >= maxfev:
...             stop = True
...             break
...
...     return OptimizeResult(fun=besty, x=bestx, nit=niter,
...                           nfev=funcalls, success=(niter > 1))
>>> x0 = [1.35, 0.9, 0.8, 1.1, 1.2]
>>> res = minimize(rosen, x0, method=custmin, options=dict(stepsize=0.05))
>>> res.x
array([1., 1., 1., 1., 1.])

```

This will work just as well in case of univariate optimization:

```

>>> def custmin(fun, bracket, args=(), maxfev=None, stepsize=0.1,
...             maxiter=100, callback=None, **options):
...     bestx = (bracket[1] + bracket[0]) / 2.0
...     besty = fun(bestx)
...     funcalls = 1
...     niter = 0
...     improved = True
...     stop = False
...
...     while improved and not stop and niter < maxiter:
...         improved = False
...         niter += 1
...         for testx in [bestx - stepsize, bestx + stepsize]:
...             testy = fun(testx, *args)
...             funcalls += 1
...             if testy < besty:
...                 besty = testy
...                 bestx = testx
...                 improved = True
...         if callback is not None:
...             callback(bestx)
...         if maxfev is not None and funcalls >= maxfev:
...             stop = True
...             break
...
...     return OptimizeResult(fun=besty, x=bestx, nit=niter,
...                           nfev=funcalls, success=(niter > 1))
>>> def f(x):
...     return (x - 2)**2 * (x + 2)**2
>>> res = minimize_scalar(f, bracket=(-3.5, 0), method=custmin,
...                       options=dict(stepsize = 0.05))
>>> res.x
-2.0

```

## Root finding

### Scalar functions

If one has a single-variable equation, there are four different root finding algorithms that can be tried. Each of these algorithms requires the endpoints of an interval in which a root is expected (because the function changes signs). In general *brentq* is the best choice, but the other methods may be useful in certain circumstances or for academic purposes.

### Fixed-point solving

A problem closely related to finding the zeros of a function is the problem of finding a fixed-point of a function. A fixed point of a function is the point at which evaluation of the function returns the point:  $g(x) = x$ . Clearly the fixed point of  $g$  is the root of  $f(x) = g(x) - x$ . Equivalently, the root of  $f$  is the fixed\_point of  $g(x) = f(x) + x$ . The routine `fixed_point` provides a simple iterative method using Aitkens sequence acceleration to estimate the fixed point of  $g$  given a starting point.

### Sets of equations

Finding a root of a set of non-linear equations can be achieved using the `root` function. Several methods are available, amongst which `hybr` (the default) and `lm` which respectively use the hybrid method of Powell and the Levenberg-Marquardt method from MINPACK.

The following example considers the single-variable transcendental equation

$$x + 2 \cos(x) = 0,$$

a root of which can be found as follows:

```
>>> import numpy as np
>>> from scipy.optimize import root
>>> def func(x):
...     return x + 2 * np.cos(x)
>>> sol = root(func, 0.3)
>>> sol.x
array([-1.02986653])
>>> sol.fun
array([-6.66133815e-16])
```

Consider now a set of non-linear equations

$$\begin{aligned} x_0 \cos(x_1) &= 4, \\ x_0 x_1 - x_1 &= 5. \end{aligned}$$

We define the objective function so that it also returns the Jacobian and indicate this by setting the `jac` parameter to `True`. Also, the Levenberg-Marquardt solver is used here.

```
>>> def func2(x):
...     f = [x[0] * np.cos(x[1]) - 4,
...          x[1]*x[0] - x[1] - 5]
...     df = np.array([[np.cos(x[1]), -x[0] * np.sin(x[1])],
...                    [x[1], x[0] - 1]])
...     return f, df
>>> sol = root(func2, [1, 1], jac=True, method='lm')
>>> sol.x
array([ 6.50409711,  0.90841421])
```

### Root finding for large problems

Methods `hybr` and `lm` in `root` cannot deal with a very large number of variables ( $N$ ), as they need to calculate and invert a dense  $N \times N$  Jacobian matrix on every Newton step. This becomes rather inefficient when  $N$  grows.

Consider for instance the following problem: we need to solve the following integrodifferential equation on the square  $[0, 1] \times [0, 1]$ :

$$(\partial_x^2 + \partial_y^2)P + 5 \left( \int_0^1 \int_0^1 \cosh(P) dx dy \right)^2 = 0$$

with the boundary condition  $P(x, 1) = 1$  on the upper edge and  $P = 0$  elsewhere on the boundary of the square. This can be done by approximating the continuous function  $P$  by its values on a grid,  $P_{n,m} \approx P(nh, mh)$ , with a small grid spacing  $h$ . The derivatives and integrals can then be approximated; for instance  $\partial_x^2 P(x, y) \approx (P(x+h, y) - 2P(x, y) + P(x-h, y))/h^2$ . The problem is then equivalent to finding the root of some function `residual(P)`, where `P` is a vector of length  $N_x N_y$ .

Now, because  $N_x N_y$  can be large, methods `hybr` or `lm` in `root` will take a long time to solve this problem. The solution can however be found using one of the large-scale solvers, for example `krylov`, `broyden2`, or `anderson`. These use what is known as the inexact Newton method, which instead of computing the Jacobian matrix exactly, forms an approximation for it.

The problem we have can now be solved as follows:

```
import numpy as np
from scipy.optimize import root
from numpy import cosh, zeros_like, mgrid, zeros

# parameters
nx, ny = 75, 75
hx, hy = 1./(nx-1), 1./(ny-1)

P_left, P_right = 0, 0
P_top, P_bottom = 1, 0

def residual(P):
    d2x = zeros_like(P)
    d2y = zeros_like(P)

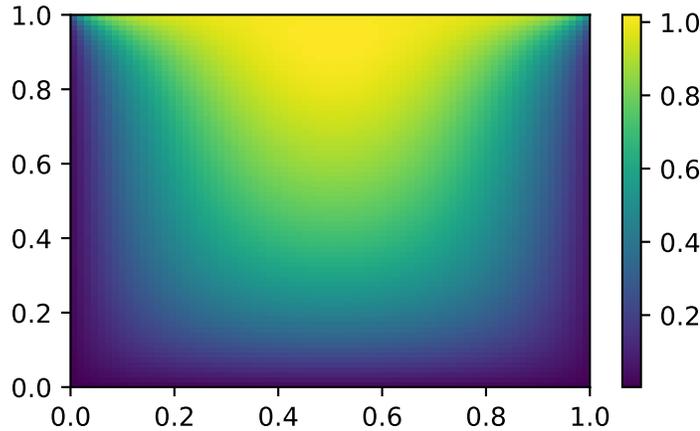
    d2x[1:-1] = (P[2:] - 2*P[1:-1] + P[:-2]) / hx/hx
    d2x[0] = (P[1] - 2*P[0] + P_left) / hx/hx
    d2x[-1] = (P_right - 2*P[-1] + P[-2]) / hx/hx

    d2y[:,1:-1] = (P[:,2:] - 2*P[:,1:-1] + P[:, :-2]) / hy/hy
    d2y[:,0] = (P[:,1] - 2*P[:,0] + P_bottom) / hy/hy
    d2y[:, -1] = (P_top - 2*P[:, -1] + P[:, -2]) / hy/hy

    return d2x + d2y + 5*cosh(P).mean()**2

# solve
guess = zeros((nx, ny), float)
sol = root(residual, guess, method='krylov', options={'disp': True})
#sol = root(residual, guess, method='broyden2', options={'disp': True, 'max_rank': 50})
#sol = root(residual, guess, method='anderson', options={'disp': True, 'M': 10})
print('Residual: %g' % abs(residual(sol.x)).max())

# visualize
import matplotlib.pyplot as plt
x, y = mgrid[0:1:(nx*1j), 0:1:(ny*1j)]
plt.pcolor(x, y, sol.x)
plt.colorbar()
plt.show()
```



### Still too slow? Preconditioning.

When looking for the zero of the functions  $f_i(\mathbf{x}) = 0$ ,  $i = 1, 2, \dots, N$ , the `krylov` solver spends most of its time inverting the Jacobian matrix,

$$J_{ij} = \frac{\partial f_i}{\partial x_j}.$$

If you have an approximation for the inverse matrix  $M \approx J^{-1}$ , you can use it for *preconditioning* the linear inversion problem. The idea is that instead of solving  $J\mathbf{s} = \mathbf{y}$  one solves  $MJ\mathbf{s} = M\mathbf{y}$ : since matrix  $MJ$  is “closer” to the identity matrix than  $J$  is, the equation should be easier for the Krylov method to deal with.

The matrix  $M$  can be passed to `root` with method `krylov` as an option `options['jac_options']['inner_M']`. It can be a (sparse) matrix or a `scipy.sparse.linalg.LinearOperator` instance.

For the problem in the previous section, we note that the function to solve consists of two parts: the first one is application of the Laplace operator,  $[\partial_x^2 + \partial_y^2]P$ , and the second is the integral. We can actually easily compute the Jacobian corresponding to the Laplace operator part: we know that in one dimension

$$\partial_x^2 \approx \frac{1}{h_x^2} \begin{pmatrix} -2 & 1 & 0 & 0 \dots \\ 1 & -2 & 1 & 0 \dots \\ 0 & 1 & -2 & 1 \dots \\ \dots & & & \dots \end{pmatrix} = h_x^{-2} L$$

so that the whole 2-D operator is represented by

$$J_1 = \partial_x^2 + \partial_y^2 \simeq h_x^{-2} L \otimes I + h_y^{-2} I \otimes L$$

The matrix  $J_2$  of the Jacobian corresponding to the integral is more difficult to calculate, and since *all* of its entries are nonzero, it will be difficult to invert.  $J_1$  on the other hand is a relatively simple matrix, and can be inverted by `scipy.sparse.linalg.splu` (or the inverse can be approximated by `scipy.sparse.linalg.spilu`). So we are content to take  $M \approx J_1^{-1}$  and hope for the best.

In the example below, we use the preconditioner  $M = J_1^{-1}$ .

```
import numpy as np
from scipy.optimize import root
```

```

from scipy.sparse import spdiags, kron
from scipy.sparse.linalg import spilu, LinearOperator
from numpy import cosh, zeros_like, mgrid, zeros, eye

# parameters
nx, ny = 75, 75
hx, hy = 1./(nx-1), 1./(ny-1)

P_left, P_right = 0, 0
P_top, P_bottom = 1, 0

def get_preconditioner():
    """Compute the preconditioner M"""
    diags_x = zeros((3, nx))
    diags_x[0,:] = 1/hx/hx
    diags_x[1,:] = -2/hx/hx
    diags_x[2,:] = 1/hx/hx
    Lx = spdiags(diags_x, [-1,0,1], nx, nx)

    diags_y = zeros((3, ny))
    diags_y[0,:] = 1/hy/hy
    diags_y[1,:] = -2/hy/hy
    diags_y[2,:] = 1/hy/hy
    Ly = spdiags(diags_y, [-1,0,1], ny, ny)

    J1 = kron(Lx, eye(ny)) + kron(eye(nx), Ly)

    # Now we have the matrix `J_1`. We need to find its inverse `M` --
    # however, since an approximate inverse is enough, we can use
    # the *incomplete LU* decomposition

    J1_ilu = spilu(J1)

    # This returns an object with a method .solve() that evaluates
    # the corresponding matrix-vector product. We need to wrap it into
    # a LinearOperator before it can be passed to the Krylov methods:

    M = LinearOperator(shape=(nx*ny, nx*ny), matvec=J1_ilu.solve)
    return M

def solve(preconditioning=True):
    """Compute the solution"""
    count = [0]

    def residual(P):
        count[0] += 1

        d2x = zeros_like(P)
        d2y = zeros_like(P)

        d2x[1:-1] = (P[2:] - 2*P[1:-1] + P[:-2])/hx/hx
        d2x[0] = (P[1] - 2*P[0] + P_left)/hx/hx
        d2x[-1] = (P_right - 2*P[-1] + P[-2])/hx/hx

        d2y[:,1:-1] = (P[:,2:] - 2*P[:,1:-1] + P[:, :-2])/hy/hy
        d2y[:,0] = (P[:,1] - 2*P[:,0] + P_bottom)/hy/hy
        d2y[:, -1] = (P_top - 2*P[:, -1] + P[:, -2])/hy/hy

```

```

    return d2x + d2y + 5*cosh(P).mean()**2

# preconditioner
if preconditioning:
    M = get_preconditioner()
else:
    M = None

# solve
guess = zeros((nx, ny), float)

sol = root(residual, guess, method='krylov',
           options={'disp': True,
                    'jac_options': {'inner_M': M}})
print('Residual', abs(residual(sol.x)).max())
print('Evaluations', count[0])

return sol.x

def main():
    sol = solve(preconditioning=True)

# visualize
import matplotlib.pyplot as plt
x, y = mgrid[0:1:(nx*1j), 0:1:(ny*1j)]
plt.clf()
plt.pcolor(x, y, sol)
plt.clim(0, 1)
plt.colorbar()
plt.show()

if __name__ == "__main__":
    main()

```

Resulting run, first without preconditioning:

```

0: |F(x)| = 803.614; step 1; tol 0.000257947
1: |F(x)| = 345.912; step 1; tol 0.166755
2: |F(x)| = 139.159; step 1; tol 0.145657
3: |F(x)| = 27.3682; step 1; tol 0.0348109
4: |F(x)| = 1.03303; step 1; tol 0.00128227
5: |F(x)| = 0.0406634; step 1; tol 0.00139451
6: |F(x)| = 0.00344341; step 1; tol 0.00645373
7: |F(x)| = 0.000153671; step 1; tol 0.00179246
8: |F(x)| = 6.7424e-06; step 1; tol 0.00173256
Residual 3.57078908664e-07
Evaluations 317

```

and then with preconditioning:

```

0: |F(x)| = 136.993; step 1; tol 7.49599e-06
1: |F(x)| = 4.80983; step 1; tol 0.00110945
2: |F(x)| = 0.195942; step 1; tol 0.00149362
3: |F(x)| = 0.000563597; step 1; tol 7.44604e-06
4: |F(x)| = 1.00698e-09; step 1; tol 2.87308e-12
Residual 9.29603061195e-11
Evaluations 77

```

Using a preconditioner reduced the number of evaluations of the `residual` function by a factor of 4. For problems where the residual is expensive to compute, good preconditioning can be crucial — it can even decide whether the problem is solvable in practice or not.

Preconditioning is an art, science, and industry. Here, we were lucky in making a simple choice that worked reasonably well, but there is a lot more depth to this topic than is shown here.

### References

Some further reading and related software:

## 3.1.6 Interpolation (`scipy.interpolate`)

### Contents

- *Interpolation* (`scipy.interpolate`)
  - *1-D interpolation* (`interp1d`)
  - *Multivariate data interpolation* (`griddata`)
  - *Spline interpolation*
    - \* *Spline interpolation in 1-d: Procedural* (`interpolate.sp1XXX`)
    - \* *Spline interpolation in 1-d: Object-oriented* (`UnivariateSpline`)
    - \* *Two-dimensional spline representation: Procedural* (`bisplrep`)
    - \* *Two-dimensional spline representation: Object-oriented* (`BivariateSpline`)
  - *Using radial basis functions for smoothing/interpolation*
    - \* *1-d Example*
    - \* *2-d Example*

There are several general interpolation facilities available in SciPy, for data in 1, 2, and higher dimensions:

- A class representing an interpolant (`interp1d`) in 1-D, offering several interpolation methods.
- Convenience function `griddata` offering a simple interface to interpolation in N dimensions (N = 1, 2, 3, 4, ...). Object-oriented interface for the underlying routines is also available.
- Functions for 1- and 2-dimensional (smoothed) cubic-spline interpolation, based on the FORTRAN library FITPACK. There are both procedural and object-oriented interfaces for the FITPACK library.
- Interpolation using Radial Basis Functions.

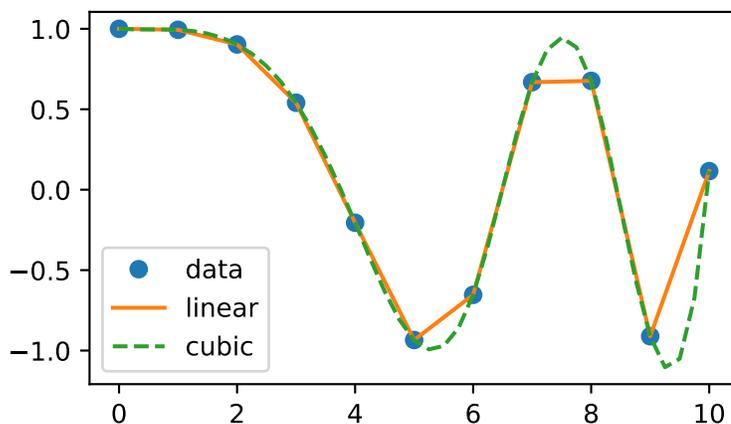
### 1-D interpolation (`interp1d`)

The `interp1d` class in `scipy.interpolate` is a convenient method to create a function based on fixed data points which can be evaluated anywhere within the domain defined by the given data using linear interpolation. An instance of this class is created by passing the 1-d vectors comprising the data. The instance of this class defines a `__call__` method and can therefore be treated like a function which interpolates between known data values to obtain unknown values (it also has a docstring for help). Behavior at the boundary can be specified at instantiation time. The following example demonstrates its use, for linear and cubic spline interpolation:

```
>>> from scipy.interpolate import interp1d
```

```
>>> x = np.linspace(0, 10, num=11, endpoint=True)
>>> y = np.cos(-x**2/9.0)
>>> f = interp1d(x, y)
>>> f2 = interp1d(x, y, kind='cubic')
```

```
>>> xnew = np.linspace(0, 10, num=41, endpoint=True)
>>> import matplotlib.pyplot as plt
>>> plt.plot(x, y, 'o', xnew, f(xnew), '-', xnew, f2(xnew), '--')
>>> plt.legend(['data', 'linear', 'cubic'], loc='best')
>>> plt.show()
```



### Multivariate data interpolation (`griddata`)

Suppose you have multidimensional data, for instance for an underlying function  $f(x, y)$  you only know the values at points  $(x[i], y[i])$  that do not form a regular grid.

Suppose we want to interpolate the 2-D function

```
>>> def func(x, y):
...     return x*(1-x)*np.cos(4*np.pi*x) * np.sin(4*np.pi*y**2)**2
```

on a grid in  $[0, 1] \times [0, 1]$

```
>>> grid_x, grid_y = np.mgrid[0:1:100j, 0:1:200j]
```

but we only know its values at 1000 data points:

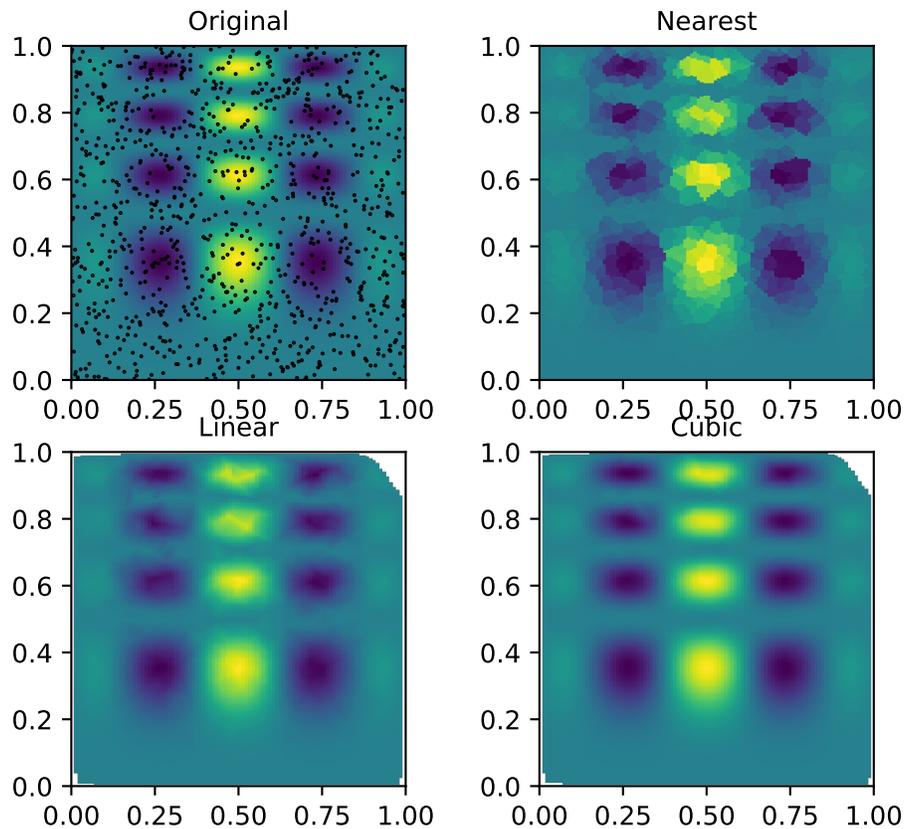
```
>>> points = np.random.rand(1000, 2)
>>> values = func(points[:,0], points[:,1])
```

This can be done with `griddata` – below we try out all of the interpolation methods:

```
>>> from scipy.interpolate import griddata
>>> grid_z0 = griddata(points, values, (grid_x, grid_y), method='nearest')
>>> grid_z1 = griddata(points, values, (grid_x, grid_y), method='linear')
>>> grid_z2 = griddata(points, values, (grid_x, grid_y), method='cubic')
```

One can see that the exact result is reproduced by all of the methods to some degree, but for this smooth function the piecewise cubic interpolant gives the best results:

```
>>> import matplotlib.pyplot as plt
>>> plt.subplot(221)
>>> plt.imshow(func(grid_x, grid_y).T, extent=(0,1,0,1), origin='lower')
>>> plt.plot(points[:,0], points[:,1], 'k.', ms=1)
>>> plt.title('Original')
>>> plt.subplot(222)
>>> plt.imshow(grid_z0.T, extent=(0,1,0,1), origin='lower')
>>> plt.title('Nearest')
>>> plt.subplot(223)
>>> plt.imshow(grid_z1.T, extent=(0,1,0,1), origin='lower')
>>> plt.title('Linear')
>>> plt.subplot(224)
>>> plt.imshow(grid_z2.T, extent=(0,1,0,1), origin='lower')
>>> plt.title('Cubic')
>>> plt.gcf().set_size_inches(6, 6)
>>> plt.show()
```



## Spline interpolation

### *Spline interpolation in 1-d: Procedural (interpolate.spIXXX)*

Spline interpolation requires two essential steps: (1) a spline representation of the curve is computed, and (2) the spline is evaluated at the desired points. In order to find the spline representation, there are two different ways to represent a curve and obtain (smoothing) spline coefficients: directly and parametrically. The direct method finds the spline representation of a curve in a two-dimensional plane using the function `splrep`. The first two arguments are the only ones required, and these provide the  $x$  and  $y$  components of the curve. The normal output is a 3-tuple,  $(t, c, k)$ , containing the knot-points,  $t$ , the coefficients  $c$  and the order  $k$  of the spline. The default spline order is cubic, but this can be changed with the input keyword,  $k$ .

For curves in  $N$ -dimensional space the function `splprep` allows defining the curve parametrically. For this function only 1 input argument is required. This input is a list of  $N$ -arrays representing the curve in  $N$ -dimensional space. The length of each array is the number of curve points, and each array provides one component of the  $N$ -dimensional data point. The parameter variable is given with the keyword argument,  $u$ , which defaults to an equally-spaced monotonic sequence between 0 and 1. The default output consists of two objects: a 3-tuple,  $(t, c, k)$ , containing the spline

representation and the parameter variable  $u$ .

The keyword argument,  $s$ , is used to specify the amount of smoothing to perform during the spline fit. The default value of  $s$  is  $s = m - \sqrt{2m}$  where  $m$  is the number of data-points being fit. Therefore, **if no smoothing is desired a value of  $s = 0$  should be passed to the routines.**

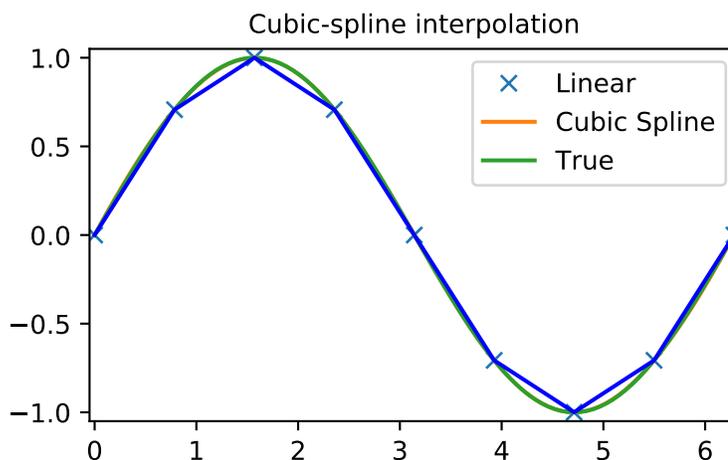
Once the spline representation of the data has been determined, functions are available for evaluating the spline ( $splev$ ) and its derivatives ( $splev$ ,  $spalde$ ) at any point and the integral of the spline between any two points ( $splint$ ). In addition, for cubic splines ( $k = 3$ ) with 8 or more knots, the roots of the spline can be estimated ( $sproot$ ). These functions are demonstrated in the example that follows.

```
>>> import numpy as np
>>> import matplotlib.pyplot as plt
>>> from scipy import interpolate
```

### Cubic-spline

```
>>> x = np.arange(0, 2*np.pi+np.pi/4, 2*np.pi/8)
>>> y = np.sin(x)
>>> tck = interpolate.splrep(x, y, s=0)
>>> xnew = np.arange(0, 2*np.pi, np.pi/50)
>>> ynew = interpolate.splev(xnew, tck, der=0)
```

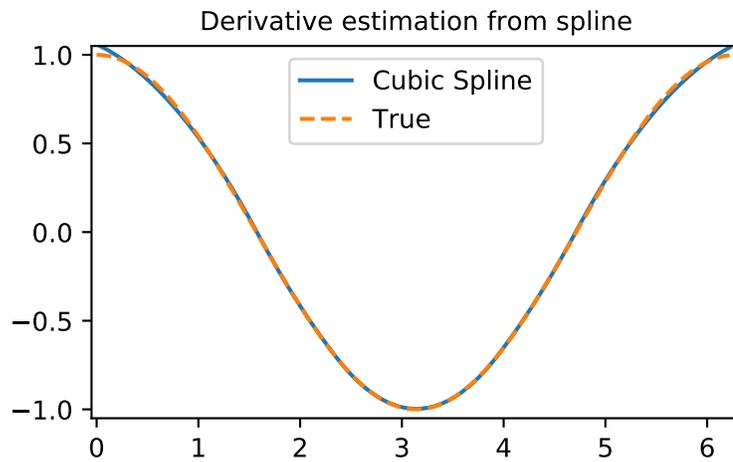
```
>>> plt.figure()
>>> plt.plot(x, y, 'x', xnew, ynew, xnew, np.sin(xnew), x, y, 'b')
>>> plt.legend(['Linear', 'Cubic Spline', 'True'])
>>> plt.axis([-0.05, 6.33, -1.05, 1.05])
>>> plt.title('Cubic-spline interpolation')
>>> plt.show()
```



### Derivative of spline

```
>>> yder = interpolate.splev(xnew, tck, der=1)
>>> plt.figure()
>>> plt.plot(xnew, yder, xnew, np.cos(xnew), '--')
>>> plt.legend(['Cubic Spline', 'True'])
>>> plt.axis([-0.05, 6.33, -1.05, 1.05])
```

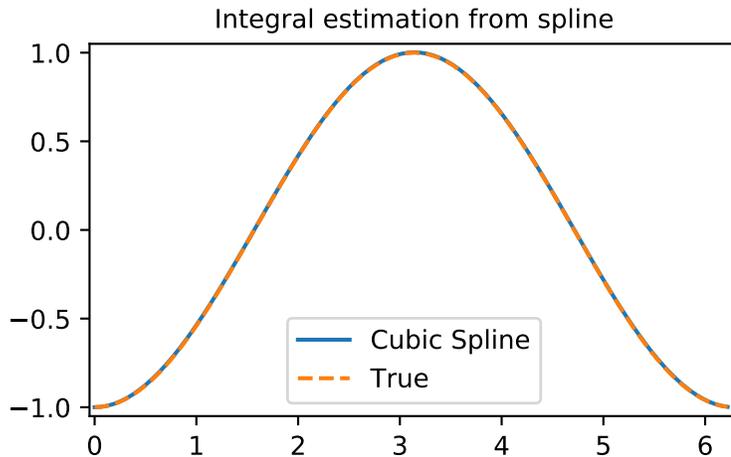
```
>>> plt.title('Derivative estimation from spline')
>>> plt.show()
```



#### Integral of spline

```
>>> def integ(x, tck, constant=-1):
...     x = np.atleast_1d(x)
...     out = np.zeros(x.shape, dtype=x.dtype)
...     for n in range(len(out)):
...         out[n] = interpolate.splint(0, x[n], tck)
...     out += constant
...     return out
```

```
>>> yint = integ(xnew, tck)
>>> plt.figure()
>>> plt.plot(xnew, yint, xnew, -np.cos(xnew), '--')
>>> plt.legend(['Cubic Spline', 'True'])
>>> plt.axis([-0.05, 6.33, -1.05, 1.05])
>>> plt.title('Integral estimation from spline')
>>> plt.show()
```



### Roots of spline

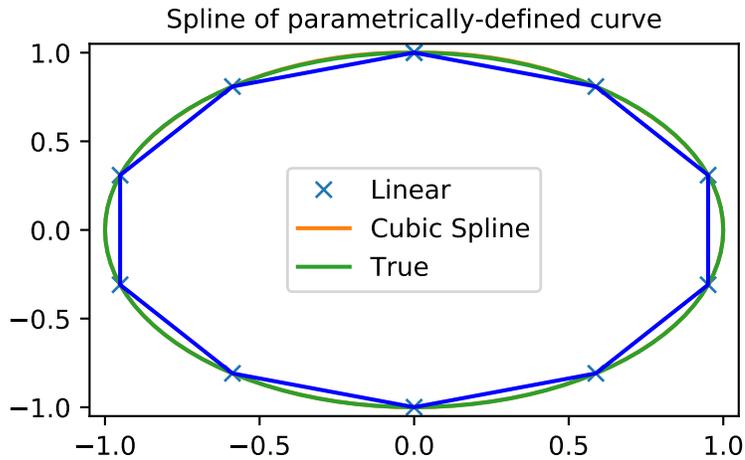
```
>>> interpolate.sproot(tck)
array([3.1416])
```

Notice that `sproot` failed to find an obvious solution at the edge of the approximation interval,  $x = 0$ . If we define the spline on a slightly larger interval, we recover both roots  $x = 0$  and  $x = 2\pi$ :

```
>>> x = np.linspace(-np.pi/4, 2.*np.pi + np.pi/4, 21)
>>> y = np.sin(x)
>>> tck = interpolate.splprep(x, y, s=0)
>>> interpolate.sproot(tck)
array([0., 3.1416])
```

### Parametric spline

```
>>> t = np.arange(0, 1.1, .1)
>>> x = np.sin(2*np.pi*t)
>>> y = np.cos(2*np.pi*t)
>>> tck, u = interpolate.splprep([x, y], s=0)
>>> unew = np.arange(0, 1.01, 0.01)
>>> out = interpolate.splev(unew, tck)
>>> plt.figure()
>>> plt.plot(x, y, 'x', out[0], out[1], np.sin(2*np.pi*unew), np.cos(2*np.pi*unew), x,
↳ y, 'b')
>>> plt.legend(['Linear', 'Cubic Spline', 'True'])
>>> plt.axis([-1.05, 1.05, -1.05, 1.05])
>>> plt.title('Spline of parametrically-defined curve')
>>> plt.show()
```



### *Spline interpolation in 1-d: Object-oriented (UnivariateSpline)*

The spline-fitting capabilities described above are also available via an object-oriented interface. The one dimensional splines are objects of the `UnivariateSpline` class, and are created with the  $x$  and  $y$  components of the curve provided as arguments to the constructor. The class defines `__call__`, allowing the object to be called with the  $x$ -axis values at which the spline should be evaluated, returning the interpolated  $y$ -values. This is shown in the example below for the subclass `InterpolatedUnivariateSpline`. The `integral`, `derivatives`, and `roots` methods are also available on `UnivariateSpline` objects, allowing definite integrals, derivatives, and roots to be computed for the spline.

The `UnivariateSpline` class can also be used to smooth data by providing a non-zero value of the smoothing parameter  $s$ , with the same meaning as the  $s$  keyword of the `splrep` function described above. This results in a spline that has fewer knots than the number of data points, and hence is no longer strictly an interpolating spline, but rather a smoothing spline. If this is not desired, the `InterpolatedUnivariateSpline` class is available. It is a subclass of `UnivariateSpline` that always passes through all points (equivalent to forcing the smoothing parameter to 0). This class is demonstrated in the example below.

The `LSQUnivariateSpline` class is the other subclass of `UnivariateSpline`. It allows the user to specify the number and location of internal knots explicitly with the parameter  $t$ . This allows creation of customized splines with non-linear spacing, to interpolate in some domains and smooth in others, or change the character of the spline.

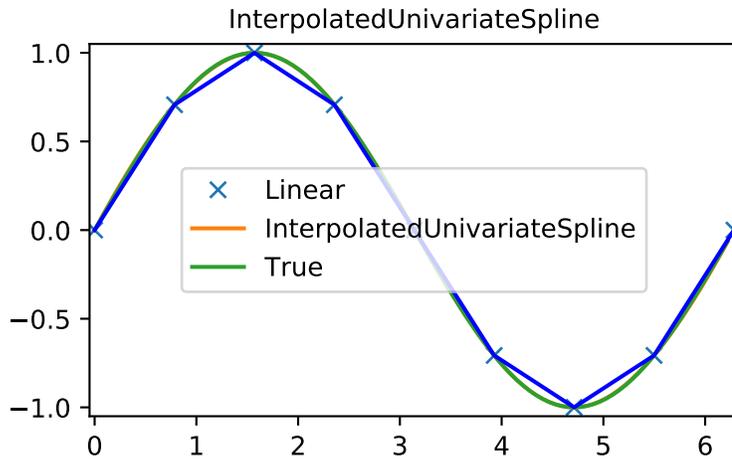
```
>>> import numpy as np
>>> import matplotlib.pyplot as plt
>>> from scipy import interpolate
```

#### InterpolatedUnivariateSpline

```
>>> x = np.arange(0, 2*np.pi+np.pi/4, 2*np.pi/8)
>>> y = np.sin(x)
>>> s = interpolate.InterpolatedUnivariateSpline(x, y)
>>> xnew = np.arange(0, 2*np.pi, np.pi/50)
>>> ynew = s(xnew)
```

```
>>> plt.figure()
>>> plt.plot(x, y, 'x', xnew, ynew, xnew, np.sin(xnew), x, y, 'b')
>>> plt.legend(['Linear', 'InterpolatedUnivariateSpline', 'True'])
>>> plt.axis([-0.05, 6.33, -1.05, 1.05])
```

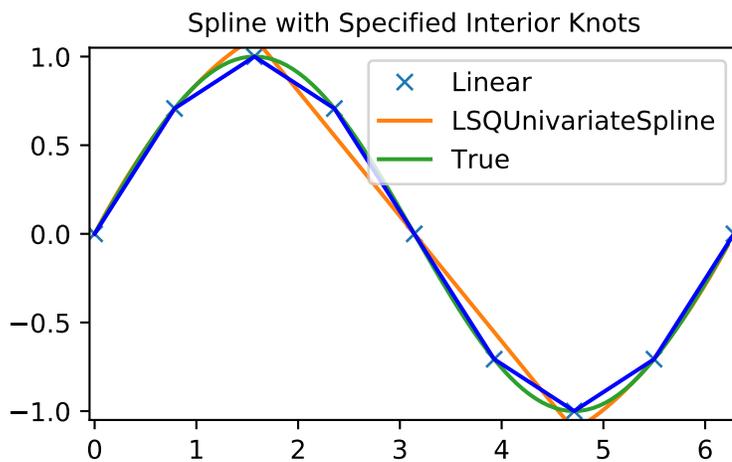
```
>>> plt.title('InterpolatedUnivariateSpline')
>>> plt.show()
```



LSQUnivariateSpline with non-uniform knots

```
>>> t = [np.pi/2-.1, np.pi/2+.1, 3*np.pi/2-.1, 3*np.pi/2+.1]
>>> s = interpolate.LSQUnivariateSpline(x, y, t, k=2)
>>> ynew = s(xnew)
```

```
>>> plt.figure()
>>> plt.plot(x, y, 'x', xnew, ynew, xnew, np.sin(xnew), x, y, 'b')
>>> plt.legend(['Linear', 'LSQUnivariateSpline', 'True'])
>>> plt.axis([-0.05, 6.33, -1.05, 1.05])
>>> plt.title('Spline with Specified Interior Knots')
>>> plt.show()
```



**Two-dimensional spline representation: Procedural (*bisplrep*)**

For (smooth) spline-fitting to a two dimensional surface, the function *bisplrep* is available. This function takes as required inputs the **1-D** arrays *x*, *y*, and *z* which represent points on the surface  $z = f(x, y)$ . The default output is a list [*tx*, *ty*, *c*, *kx*, *ky*] whose entries represent respectively, the components of the knot positions, the coefficients of the spline, and the order of the spline in each coordinate. It is convenient to hold this list in a single object, *tck*, so that it can be passed easily to the function *bisplev*. The keyword, *s*, can be used to change the amount of smoothing performed on the data while determining the appropriate spline. The default value is  $s = m - \sqrt{2m}$  where *m* is the number of data points in the *x*, *y*, and *z* vectors. As a result, if no smoothing is desired, then  $s = 0$  should be passed to *bisplrep*.

To evaluate the two-dimensional spline and its partial derivatives (up to the order of the spline), the function *bisplev* is required. This function takes as the first two arguments **two 1-D arrays** whose cross-product specifies the domain over which to evaluate the spline. The third argument is the *tck* list returned from *bisplrep*. If desired, the fourth and fifth arguments provide the orders of the partial derivative in the *x* and *y* direction respectively.

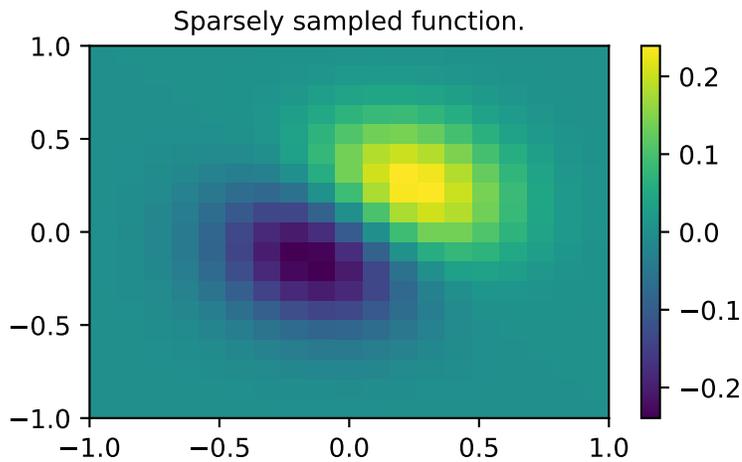
It is important to note that two dimensional interpolation should not be used to find the spline representation of images. The algorithm used is not amenable to large numbers of input points. The signal processing toolbox contains more appropriate algorithms for finding the spline representation of an image. The two dimensional interpolation commands are intended for use when interpolating a two dimensional function as shown in the example that follows. This example uses the *mgrid* command in NumPy which is useful for defining a “mesh-grid” in many dimensions. (See also the *ogrid* command if the full-mesh is not needed). The number of output arguments and the number of dimensions of each argument is determined by the number of indexing objects passed in *mgrid*.

```
>>> import numpy as np
>>> from scipy import interpolate
>>> import matplotlib.pyplot as plt
```

Define function over sparse 20x20 grid

```
>>> x, y = np.mgrid[-1:1:20j, -1:1:20j]
>>> z = (x+y) * np.exp(-6.0*(x*x+y*y))
```

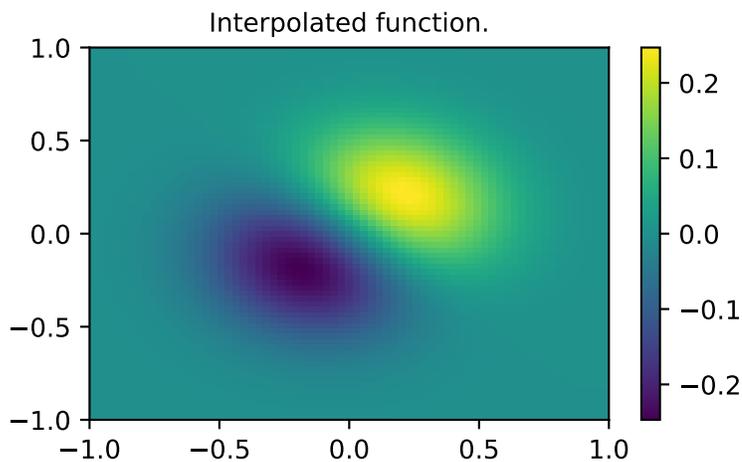
```
>>> plt.figure()
>>> plt.pcolor(x, y, z)
>>> plt.colorbar()
>>> plt.title("Sparsely sampled function.")
>>> plt.show()
```



Interpolate function over new 70x70 grid

```
>>> xnew, ynew = np.mgrid[-1:1:70j, -1:1:70j]
>>> tck = interpolate.bisplrep(x, y, z, s=0)
>>> znew = interpolate.bisplev(xnew[:,0], ynew[0,:], tck)
```

```
>>> plt.figure()
>>> plt.pcolor(xnew, ynew, znew)
>>> plt.colorbar()
>>> plt.title("Interpolated function.")
>>> plt.show()
```



### *Two-dimensional spline representation: Object-oriented (*BivariateSpline*)*

The *BivariateSpline* class is the 2-dimensional analog of the *UnivariateSpline* class. It and its subclasses implement the FITPACK functions described above in an object oriented fashion, allowing objects to be instantiated that can be called to compute the spline value by passing in the two coordinates as the two arguments.

## Using radial basis functions for smoothing/interpolation

Radial basis functions can be used for smoothing/interpolating scattered data in n-dimensions, but should be used with caution for extrapolation outside of the observed data range.

### 1-d Example

This example compares the usage of the *Rbf* and *UnivariateSpline* classes from the `scipy.interpolate` module.

```
>>> import numpy as np
>>> from scipy.interpolate import Rbf, InterpolatedUnivariateSpline
>>> import matplotlib.pyplot as plt
```

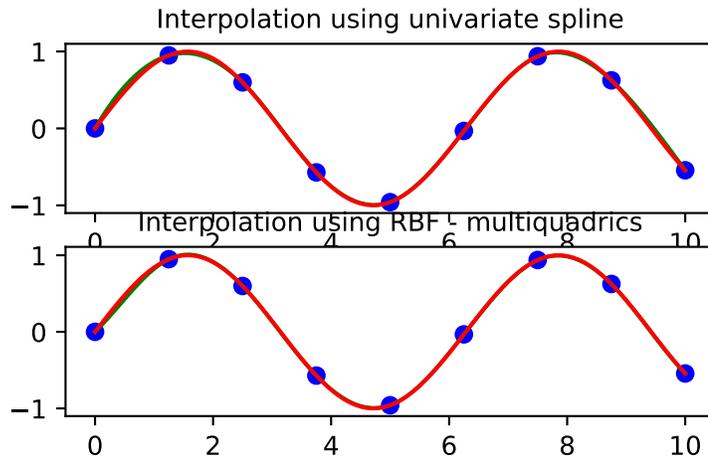
```
>>> # setup data
>>> x = np.linspace(0, 10, 9)
>>> y = np.sin(x)
>>> xi = np.linspace(0, 10, 101)
```

```
>>> # use fitpack2 method
>>> ius = InterpolatedUnivariateSpline(x, y)
>>> yi = ius(xi)
```

```
>>> plt.subplot(2, 1, 1)
>>> plt.plot(x, y, 'bo')
>>> plt.plot(xi, yi, 'g')
>>> plt.plot(xi, np.sin(xi), 'r')
>>> plt.title('Interpolation using univariate spline')
```

```
>>> # use RBF method
>>> rbf = Rbf(x, y)
>>> fi = rbf(xi)
```

```
>>> plt.subplot(2, 1, 2)
>>> plt.plot(x, y, 'bo')
>>> plt.plot(xi, fi, 'g')
>>> plt.plot(xi, np.sin(xi), 'r')
>>> plt.title('Interpolation using RBF - multiquadrics')
>>> plt.show()
```



### 2-d Example

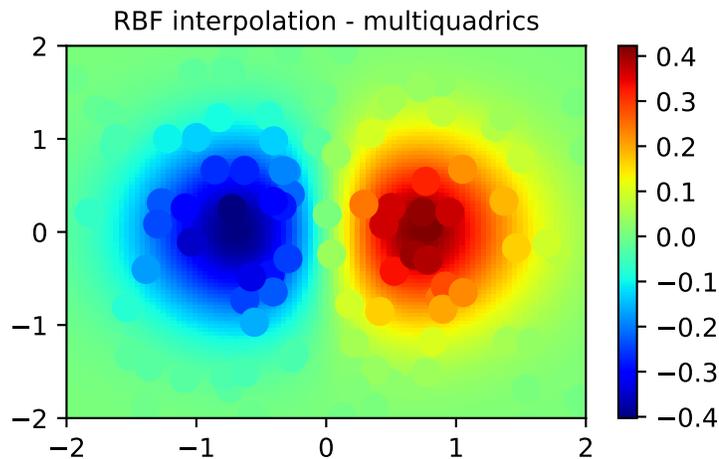
This example shows how to interpolate scattered 2d data.

```
>>> import numpy as np
>>> from scipy.interpolate import Rbf
>>> import matplotlib.pyplot as plt
>>> from matplotlib import cm
```

```
>>> # 2-d tests - setup scattered data
>>> x = np.random.rand(100)*4.0-2.0
>>> y = np.random.rand(100)*4.0-2.0
>>> z = x*np.exp(-x**2-y**2)
>>> ti = np.linspace(-2.0, 2.0, 100)
>>> XI, YI = np.meshgrid(ti, ti)
```

```
>>> # use RBF
>>> rbf = Rbf(x, y, z, epsilon=2)
>>> ZI = rbf(XI, YI)
```

```
>>> # plot the result
>>> plt.subplot(1, 1, 1)
>>> plt.pcolor(XI, YI, ZI, cmap=cm.jet)
>>> plt.scatter(x, y, 100, z, cmap=cm.jet)
>>> plt.title('RBF interpolation - multiquadrics')
>>> plt.xlim(-2, 2)
>>> plt.ylim(-2, 2)
>>> plt.colorbar()
```



### 3.1.7 Fourier Transforms (`scipy.fftpack`)

#### Contents

- *Fourier Transforms* (`scipy.fftpack`)
  - *Fast Fourier transforms*
    - \* *One dimensional discrete Fourier transforms*
    - \* *Two and n-dimensional discrete Fourier transforms*
    - \* *FFT convolution*
  - *Discrete Cosine Transforms*
    - \* *Type I DCT*
    - \* *Type II DCT*
    - \* *Type III DCT*
    - \* *DCT and IDCT*
    - \* *Example*
  - *Discrete Sine Transforms*
    - \* *Type I DST*
    - \* *Type II DST*
    - \* *Type III DST*
    - \* *DST and IDST*
  - *Cache Destruction*
  - *References*

Fourier analysis is a method for expressing a function as a sum of periodic components, and for recovering the signal

from those components. When both the function and its Fourier transform are replaced with discretized counterparts, it is called the discrete Fourier transform (DFT). The DFT has become a mainstay of numerical computing in part because of a very fast algorithm for computing it, called the Fast Fourier Transform (FFT), which was known to Gauss (1805) and was brought to light in its current form by Cooley and Tukey [CT65]. Press et al. [NR07] provide an accessible introduction to Fourier analysis and its applications.

**Note:** PyFFTW provides a way to replace a number of functions in `scipy.fftpack` with its own functions, which are usually significantly faster, via `pyfftw.interfaces`. Because PyFFTW relies on the GPL-licensed FFTW it cannot be included in SciPy. Users for whom the speed of FFT routines is critical should consider installing PyFFTW.

## Fast Fourier transforms

### One dimensional discrete Fourier transforms

The FFT  $y[k]$  of length  $N$  of the length- $N$  sequence  $x[n]$  is defined as

$$y[k] = \sum_{n=0}^{N-1} e^{-2\pi j \frac{kn}{N}} x[n],$$

and the inverse transform is defined as follows

$$x[n] = \frac{1}{N} \sum_{k=0}^{N-1} e^{2\pi j \frac{kn}{N}} y[k].$$

These transforms can be calculated by means of `fft` and `ifft`, respectively as shown in the following example.

```
>>> from scipy.fftpack import fft, ifft
>>> x = np.array([1.0, 2.0, 1.0, -1.0, 1.5])
>>> y = fft(x)
>>> y
array([ 4.50000000+0.j          ,  2.08155948-1.65109876j,
        -1.83155948+1.60822041j, -1.83155948-1.60822041j,
         2.08155948+1.65109876j])
>>> yinv = ifft(y)
>>> yinv
array([ 1.0+0.j,  2.0+0.j,  1.0+0.j, -1.0+0.j,  1.5+0.j])
```

From the definition of the FFT it can be seen that

$$y[0] = \sum_{n=0}^{N-1} x[n].$$

In the example

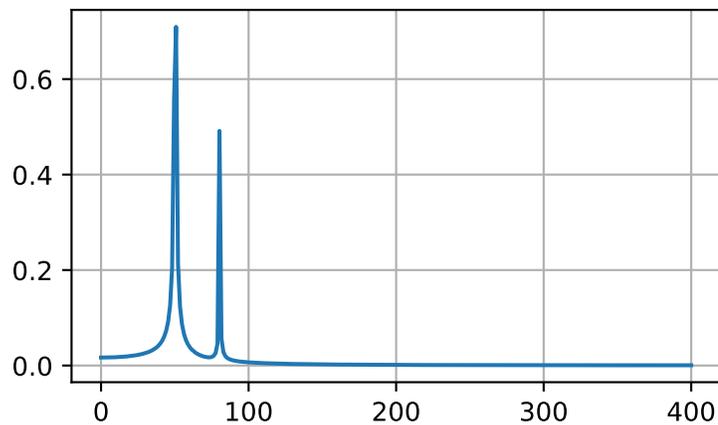
```
>>> np.sum(x)
4.5
```

which corresponds to  $y[0]$ . For  $N$  even, the elements  $y[1] \dots y[N/2 - 1]$  contain the positive-frequency terms, and the elements  $y[N/2] \dots y[N - 1]$  contain the negative-frequency terms, in order of decreasingly negative frequency. For  $N$  odd, the elements  $y[1] \dots y[(N - 1)/2]$  contain the positive-frequency terms, and the elements  $y[(N + 1)/2] \dots y[N - 1]$  contain the negative-frequency terms, in order of decreasingly negative frequency.

In case the sequence  $x$  is real-valued, the values of  $y[n]$  for positive frequencies is the conjugate of the values  $y[n]$  for negative frequencies (because the spectrum is symmetric). Typically, only the FFT corresponding to positive frequencies is plotted.

The example plots the FFT of the sum of two sines.

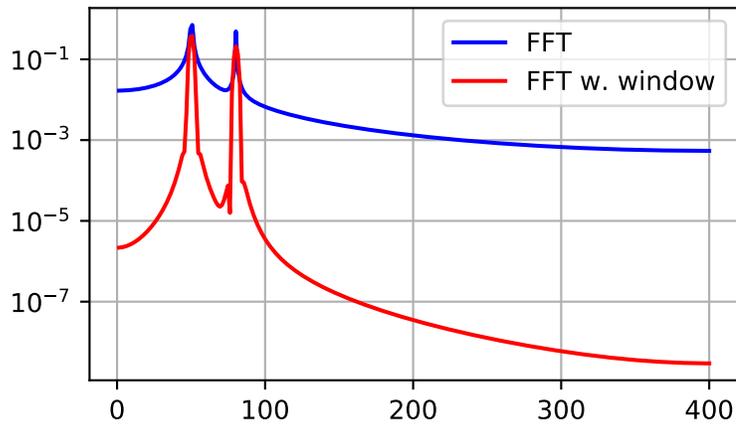
```
>>> from scipy.fftpack import fft
>>> # Number of sample points
>>> N = 600
>>> # sample spacing
>>> T = 1.0 / 800.0
>>> x = np.linspace(0.0, N*T, N)
>>> y = np.sin(50.0 * 2.0*np.pi*x) + 0.5*np.sin(80.0 * 2.0*np.pi*x)
>>> yf = fft(y)
>>> xf = np.linspace(0.0, 1.0/(2.0*T), N//2)
>>> import matplotlib.pyplot as plt
>>> plt.plot(xf, 2.0/N * np.abs(yf[0:N//2]))
>>> plt.grid()
>>> plt.show()
```



The FFT input signal is inherently truncated. This truncation can be modelled as multiplication of an infinite signal with a rectangular window function. In the spectral domain this multiplication becomes convolution of the signal spectrum with the window function spectrum, being of form  $\sin(x)/x$ . This convolution is the cause of an effect called spectral leakage (see *[WPW]*). Windowing the signal with a dedicated window function helps mitigate spectral leakage. The example below uses a Blackman window from `scipy.signal` and shows the effect of windowing (the zero component of the FFT has been truncated for illustrative purposes).

```
>>> from scipy.fftpack import fft
>>> # Number of sample points
>>> N = 600
>>> # sample spacing
>>> T = 1.0 / 800.0
>>> x = np.linspace(0.0, N*T, N)
>>> y = np.sin(50.0 * 2.0*np.pi*x) + 0.5*np.sin(80.0 * 2.0*np.pi*x)
>>> yf = fft(y)
>>> from scipy.signal import blackman
>>> w = blackman(N)
>>> ywf = fft(y*w)
>>> xf = np.linspace(0.0, 1.0/(2.0*T), N/2)
>>> import matplotlib.pyplot as plt
>>> plt.semilogy(xf[1:N//2], 2.0/N * np.abs(yf[1:N//2]), '-b')
>>> plt.semilogy(xf[1:N//2], 2.0/N * np.abs(ywf[1:N//2]), '-r')
```

```
>>> plt.legend(['FFT', 'FFT w. window'])
>>> plt.grid()
>>> plt.show()
```



In case the sequence  $x$  is complex-valued, the spectrum is no longer symmetric. To simplify working with the FFT functions, SciPy provides the following two helper functions.

The function `fftfreq` returns the FFT sample frequency points.

```
>>> from scipy.fftpack import fftfreq
>>> freq = fftfreq(8, 0.125)
>>> freq
array([ 0.,  1.,  2.,  3., -4., -3., -2., -1.] )
```

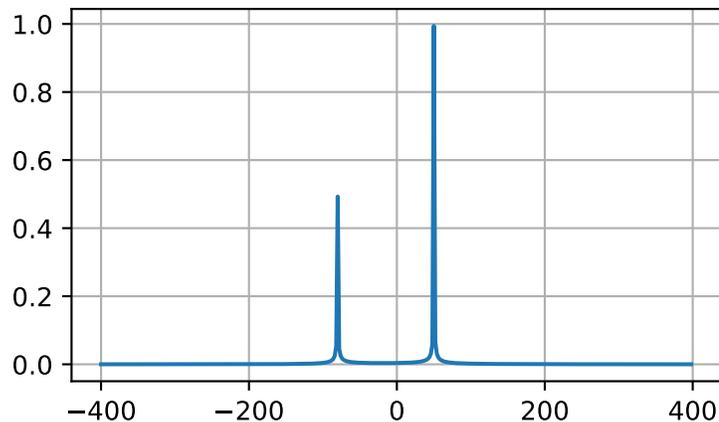
In a similar spirit, the function `fftshift` allows swapping the lower and upper halves of a vector, so that it becomes suitable for display.

```
>>> from scipy.fftpack import fftshift
>>> x = np.arange(8)
>>> fftshift(x)
array([4, 5, 6, 7, 0, 1, 2, 3])
```

The example below plots the FFT of two complex exponentials; note the asymmetric spectrum.

```
>>> from scipy.fftpack import fft, fftfreq, fftshift
>>> # number of signal points
>>> N = 400
>>> # sample spacing
>>> T = 1.0 / 800.0
>>> x = np.linspace(0.0, N*T, N)
>>> y = np.exp(50.0 * 1.j * 2.0*np.pi*x) + 0.5*np.exp(-80.0 * 1.j * 2.0*np.pi*x)
>>> yf = fft(y)
>>> xf = fftfreq(N, T)
>>> xf = fftshift(xf)
>>> yplot = fftshift(yf)
>>> import matplotlib.pyplot as plt
>>> plt.plot(xf, 1.0/N * np.abs(yplot))
```

```
>>> plt.grid()
>>> plt.show()
```



The function `rfft` calculates the FFT of a real sequence and outputs the FFT coefficients  $y[n]$  with separate real and imaginary parts. In case of  $N$  being even:  $[y[0], \text{Re}(y[1]), \text{Im}(y[1]), \dots, \text{Re}(y[N/2])]$ ; in case  $N$  being odd  $[y[0], \text{Re}(y[1]), \text{Im}(y[1]), \dots, \text{Re}(y[N/2]), \text{Im}(y[N/2])]$ .

The corresponding function `irfft` calculates the IFFT of the FFT coefficients with this special ordering.

```
>>> from scipy.fftpack import fft, rfft, irfft
>>> x = np.array([1.0, 2.0, 1.0, -1.0, 1.5, 1.0])
>>> fft(x)
array([ 5.50+0.j           ,  2.25-0.4330127j , -2.75-1.29903811j,
        1.50+0.j           , -2.75+1.29903811j,  2.25+0.4330127j ])
>>> yr = rfft(x)
>>> yr
array([ 5.5          ,  2.25          , -0.4330127 , -2.75          , -1.29903811,
        1.5          ])
>>> irfft(yr)
array([ 1. ,  2. ,  1. , -1. ,  1.5,  1. ])
>>> x = np.array([1.0, 2.0, 1.0, -1.0, 1.5])
>>> fft(x)
array([ 4.50000000+0.j           ,  2.08155948-1.65109876j,
        -1.83155948+1.60822041j, -1.83155948-1.60822041j,
        2.08155948+1.65109876j])
>>> yr = rfft(x)
>>> yr
array([ 4.5          ,  2.08155948, -1.65109876, -1.83155948,  1.60822041])
```

### Two and n-dimensional discrete Fourier transforms

The functions `fft2` and `ifft2` provide 2-dimensional FFT, and IFFT, respectively. Similar, `fftn` and `ifftn` provide n-dimensional FFT, and IFFT, respectively.

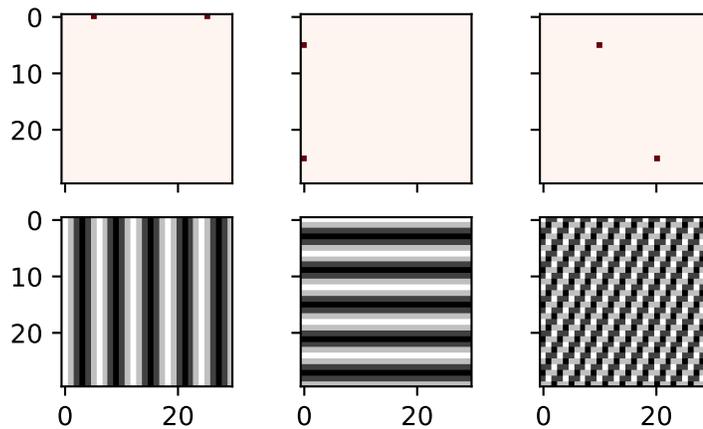
The example below demonstrates a 2-dimensional IFFT and plots the resulting (2-dimensional) time-domain signals.

```
>>> from scipy.fftpack import ifftn
>>> import matplotlib.pyplot as plt
```

```

>>> import matplotlib.cm as cm
>>> N = 30
>>> f, ((ax1, ax2, ax3), (ax4, ax5, ax6)) = plt.subplots(2, 3, sharex='col', sharey=
↳ 'row')
>>> xf = np.zeros((N,N))
>>> xf[0, 5] = 1
>>> xf[0, N-5] = 1
>>> Z = ifftn(xf)
>>> ax1.imshow(xf, cmap=cm.Red)
>>> ax4.imshow(np.real(Z), cmap=cm.gray)
>>> xf = np.zeros((N, N))
>>> xf[5, 0] = 1
>>> xf[N-5, 0] = 1
>>> Z = ifftn(xf)
>>> ax2.imshow(xf, cmap=cm.Red)
>>> ax5.imshow(np.real(Z), cmap=cm.gray)
>>> xf = np.zeros((N, N))
>>> xf[5, 10] = 1
>>> xf[N-5, N-10] = 1
>>> Z = ifftn(xf)
>>> ax3.imshow(xf, cmap=cm.Red)
>>> ax6.imshow(np.real(Z), cmap=cm.gray)
>>> plt.show()

```



### FFT convolution

`scipy.fftpack.convolve` performs a convolution of two one-dimensional arrays in frequency domain.

### Discrete Cosine Transforms

SciPy provides a DCT with the function `dct` and a corresponding IDCT with the function `idct`. There are 8 types of the DCT [WPC], [Mak]; however, only the first 3 types are implemented in SciPy. “The” DCT generally refers to DCT type 2, and “the” Inverse DCT generally refers to DCT type 3. In addition, the DCT coefficients can be normalized differently (for most types, SciPy provides `None` and `ortho`). Two parameters of the `dct/idct` function calls allow setting the DCT type and coefficient normalization.

For a single dimension array `x`, `dct(x, norm='ortho')` is equal to MATLAB `dct(x)`.

**Type I DCT**

Scipy uses the following definition of the unnormalized DCT-I (`norm='None'`):

$$y[k] = x_0 + (-1)^k x_{N-1} + 2 \sum_{n=1}^{N-2} x[n] \cos\left(\frac{\pi nk}{N-1}\right), \quad 0 \leq k < N.$$

Only `None` is supported as normalization mode for DCT-I. Note also that the DCT-I is only supported for input size  $> 1$

**Type II DCT**

Scipy uses the following definition of the unnormalized DCT-II (`norm='None'`):

$$y[k] = 2 \sum_{n=0}^{N-1} x[n] \cos\left(\frac{\pi(2n+1)k}{2N}\right) \quad 0 \leq k < N.$$

In case of the normalized DCT (`norm='ortho'`), the DCT coefficients  $y[k]$  are multiplied by a scaling factor  $f$ :

$$f = \begin{cases} \sqrt{1/(4N)}, & \text{if } k = 0 \\ \sqrt{1/(2N)}, & \text{otherwise} \end{cases}.$$

In this case, the DCT “base functions”  $\phi_k[n] = 2f \cos\left(\frac{\pi(2n+1)k}{2N}\right)$  become orthonormal:

$$\sum_{n=0}^{N-1} \phi_k[n] \phi_l[n] = \delta_{lk}$$

**Type III DCT**

Scipy uses the following definition of the unnormalized DCT-III (`norm='None'`):

$$y[k] = x_0 + 2 \sum_{n=1}^{N-1} x[n] \cos\left(\frac{\pi n(2k+1)}{2N}\right) \quad 0 \leq k < N,$$

or, for `norm='ortho'`:

$$y[k] = \frac{x_0}{\sqrt{N}} + \frac{2}{\sqrt{N}} \sum_{n=1}^{N-1} x[n] \cos\left(\frac{\pi n(2k+1)}{2N}\right) \quad 0 \leq k < N.$$

**DCT and IDCT**

The (unnormalized) DCT-III is the inverse of the (unnormalized) DCT-II, up to a factor  $2N$ . The orthonormalized DCT-III is exactly the inverse of the orthonormalized DCT-II. The function `idct` performs the mappings between the DCT and IDCT types.

The example below shows the relation between DCT and IDCT for different types and normalizations.

```
>>> from scipy.fftpack import dct, idct
>>> x = np.array([1.0, 2.0, 1.0, -1.0, 1.5])
>>> dct(dct(x, type=2, norm='ortho'), type=3, norm='ortho')
[1.0, 2.0, 1.0, -1.0, 1.5]
>>> # scaling factor 2*N = 10
>>> idct(dct(x, type=2), type=2)
array([ 10., 20., 10., -10., 15.])
>>> # no scaling factor
```

```

>>> idct(dct(x, type=2, norm='ortho'), type=2, norm='ortho')
array([ 1. ,  2. ,  1. , -1. ,  1.5])
>>> # scaling factor 2*N = 10
>>> idct(dct(x, type=3), type=3)
array([ 10.,  20.,  10., -10.,  15.])
>>> # no scaling factor
>>> idct(dct(x, type=3, norm='ortho'), type=3, norm='ortho')
array([ 1. ,  2. ,  1. , -1. ,  1.5])
>>> # scaling factor 2*(N-1) = 8
>>> idct(dct(x, type=1), type=1)
array([ 8.,  16.,  8., -8.,  12.])

```

### Example

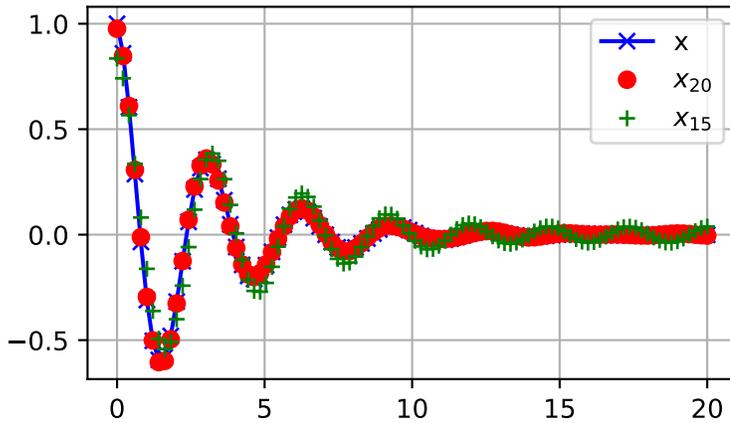
The DCT exhibits the “energy compaction property”, meaning that for many signals only the first few DCT coefficients have significant magnitude. Zeroing out the other coefficients leads to a small reconstruction error, a fact which is exploited in lossy signal compression (e.g. JPEG compression).

The example below shows a signal  $x$  and two reconstructions ( $x_{20}$  and  $x_{15}$ ) from the signal’s DCT coefficients. The signal  $x_{20}$  is reconstructed from the first 20 DCT coefficients,  $x_{15}$  is reconstructed from the first 15 DCT coefficients. It can be seen that the relative error of using 20 coefficients is still very small ( $\sim 0.1\%$ ), but provides a five-fold compression rate.

```

>>> from scipy.fftpack import dct, idct
>>> import matplotlib.pyplot as plt
>>> N = 100
>>> t = np.linspace(0, 20, N)
>>> x = np.exp(-t/3)*np.cos(2*t)
>>> y = dct(x, norm='ortho')
>>> window = np.zeros(N)
>>> window[:20] = 1
>>> yr = idct(y*window, norm='ortho')
>>> sum(abs(x-yr)**2) / sum(abs(x)**2)
0.0010901402257
>>> plt.plot(t, x, '-bx')
>>> plt.plot(t, yr, 'ro')
>>> window = np.zeros(N)
>>> window[:15] = 1
>>> yr = idct(y*window, norm='ortho')
>>> sum(abs(x-yr)**2) / sum(abs(x)**2)
0.0718818065008
>>> plt.plot(t, yr, 'g+')
>>> plt.legend(['x', '$x_{20}$', '$x_{15}$'])
>>> plt.grid()
>>> plt.show()

```



## Discrete Sine Transforms

SciPy provides a DST [Mak] with the function `dst` and a corresponding IDST with the function `idst`.

There are theoretically 8 types of the DST for different combinations of even/odd boundary conditions and boundary off sets [WPS], only the first 3 types are implemented in scipy.

### Type I DST

DST-I assumes the input is odd around  $n=-1$  and  $n=N$ . SciPy uses the following definition of the unnormalized DST-I (`norm='None'`):

$$y[k] = 2 \sum_{n=0}^{N-1} x[n] \sin\left(\frac{\pi(n+1)(k+1)}{N+1}\right), \quad 0 \leq k < N.$$

Only `None` is supported as normalization mode for DST-I. Note also that the DST-I is only supported for input size  $> 1$ . The (unnormalized) DST-I is its own inverse, up to a factor  $2(N+1)$ .

### Type II DST

DST-II assumes the input is odd around  $n=-1/2$  and even around  $n=N$ . SciPy uses the following definition of the unnormalized DST-II (`norm='None'`):

$$y[k] = 2 \sum_{n=0}^{N-1} x[n] \sin\left(\frac{\pi(n+1/2)(k+1)}{N}\right), \quad 0 \leq k < N.$$

### Type III DST

DST-III assumes the input is odd around  $n=-1$  and even around  $n=N-1$ . SciPy uses the following definition of the unnormalized DST-III (`norm='None'`):

$$y[k] = (-1)^k x[N-1] + 2 \sum_{n=0}^{N-2} x[n] \sin\left(\frac{\pi(n+1)(k+1/2)}{N}\right), \quad 0 \leq k < N.$$

## DST and IDST

The example below shows the relation between DST and IDST for different types and normalizations.

```

>>> from scipy.fftpack import dst, idst
>>> x = np.array([1.0, 2.0, 1.0, -1.0, 1.5])
>>> # scaling factor 2*N = 10
>>> idst(dst(x, type=2), type=2)
array([ 10., 20., 10., -10., 15.])
>>> # no scaling factor
>>> idst(dst(x, type=2, norm='ortho'), type=2, norm='ortho')
array([ 1. , 2. , 1. , -1. , 1.5])
>>> # scaling factor 2*N = 10
>>> idst(dst(x, type=3), type=3)
array([ 10., 20., 10., -10., 15.])
>>> # no scaling factor
>>> idst(dst(x, type=3, norm='ortho'), type=3, norm='ortho')
array([ 1. , 2. , 1. , -1. , 1.5])
>>> # scaling factor 2*(N+1) = 8
>>> idst(dst(x, type=1), type=1)
array([ 12., 24., 12., -12., 18.])

```

## Cache Destruction

To accelerate repeat transforms on arrays of the same shape and dtype, `scipy.fftpack` keeps a cache of the prime factorization of length of the array and pre-computed trigonometric functions. These caches can be destroyed by calling the appropriate function in `scipy.fftpack._fftpack`. `dst(type=1)` and `idst(type=1)` share a cache (`*dst1_cache`). As do `dst(type=2)`, `dst(type=3)`, `idst(type=3)`, and `idst(type=3)` (`*dst2_cache`).

## References

### 3.1.8 Signal Processing (`scipy.signal`)

The signal processing toolbox currently contains some filtering functions, a limited set of filter design tools, and a few B-spline interpolation algorithms for one- and two-dimensional data. While the B-spline algorithms could technically be placed under the interpolation category, they are included here because they only work with equally-spaced data and make heavy use of filter-theory and transfer-function formalism to provide a fast B-spline transform. To understand this section you will need to understand that a signal in SciPy is an array of real or complex numbers.

## B-splines

A B-spline is an approximation of a continuous function over a finite- domain in terms of B-spline coefficients and knot points. If the knot- points are equally spaced with spacing  $\Delta x$ , then the B-spline approximation to a 1-dimensional function is the finite-basis expansion.

$$y(x) \approx \sum_j c_j \beta^o \left( \frac{x}{\Delta x} - j \right).$$

In two dimensions with knot-spacing  $\Delta x$  and  $\Delta y$ , the function representation is

$$z(x, y) \approx \sum_j \sum_k c_{jk} \beta^o \left( \frac{x}{\Delta x} - j \right) \beta^o \left( \frac{y}{\Delta y} - k \right).$$

In these expressions,  $\beta^o(\cdot)$  is the space-limited B-spline basis function of order,  $o$ . The requirement of equally-spaced knot-points and equally-spaced data points, allows the development of fast (inverse-filtering) algorithms for

determining the coefficients,  $c_j$ , from sample-values,  $y_n$ . Unlike the general spline interpolation algorithms, these algorithms can quickly find the spline coefficients for large images.

The advantage of representing a set of samples via B-spline basis functions is that continuous-domain operators (derivatives, re- sampling, integral, etc.) which assume that the data samples are drawn from an underlying continuous function can be computed with relative ease from the spline coefficients. For example, the second-derivative of a spline is

$$y''(x) = \frac{1}{\Delta x^2} \sum_j c_j \beta^{o''} \left( \frac{x}{\Delta x} - j \right).$$

Using the property of B-splines that

$$\frac{d^2 \beta^o(w)}{dw^2} = \beta^{o-2}(w+1) - 2\beta^{o-2}(w) + \beta^{o-2}(w-1)$$

it can be seen that

$$y''(x) = \frac{1}{\Delta x^2} \sum_j c_j \left[ \beta^{o-2} \left( \frac{x}{\Delta x} - j + 1 \right) - 2\beta^{o-2} \left( \frac{x}{\Delta x} - j \right) + \beta^{o-2} \left( \frac{x}{\Delta x} - j - 1 \right) \right].$$

If  $o = 3$ , then at the sample points,

$$\begin{aligned} \Delta x^2 y'(x)|_{x=n\Delta x} &= \sum_j c_j \delta_{n-j+1} - 2c_j \delta_{n-j} + c_j \delta_{n-j-1}, \\ &= c_{n+1} - 2c_n + c_{n-1}. \end{aligned}$$

Thus, the second-derivative signal can be easily calculated from the spline fit. if desired, smoothing splines can be found to make the second-derivative less sensitive to random-errors.

The savvy reader will have already noticed that the data samples are related to the knot coefficients via a convolution operator, so that simple convolution with the sampled B-spline function recovers the original data from the spline coefficients. The output of convolutions can change depending on how boundaries are handled (this becomes increasingly more important as the number of dimensions in the data- set increases). The algorithms relating to B-splines in the signal- processing sub package assume mirror-symmetric boundary conditions. Thus, spline coefficients are computed based on that assumption, and data-samples can be recovered exactly from the spline coefficients by assuming them to be mirror-symmetric also.

Currently the package provides functions for determining second- and third- order cubic spline coefficients from equally spaced samples in one- and two- dimensions (*qspline1d*, *qspline2d*, *cspline1d*, *cspline2d*). The package also supplies a function (*bspline*) for evaluating the bspline basis function,  $\beta^o(x)$  for arbitrary order and  $x$ . For large  $o$ , the B-spline basis function can be approximated well by a zero-mean Gaussian function with standard-deviation equal to  $\sigma_o = (o+1)/12$ :

$$\beta^o(x) \approx \frac{1}{\sqrt{2\pi\sigma_o^2}} \exp\left(-\frac{x^2}{2\sigma_o}\right).$$

A function to compute this Gaussian for arbitrary  $x$  and  $o$  is also available (*gauss\_spline*). The following code and Figure uses spline-filtering to compute an edge-image (the second-derivative of a smoothed spline) of a raccoon's face which is an array returned by the command `misc.face`. The command *sepfir2d* was used to apply a separable two-dimensional FIR filter with mirror- symmetric boundary conditions to the spline coefficients. This function is ideally suited for reconstructing samples from spline coefficients and is faster than *convolve2d* which convolves arbitrary two-dimensional filters and allows for choosing mirror-symmetric boundary conditions.

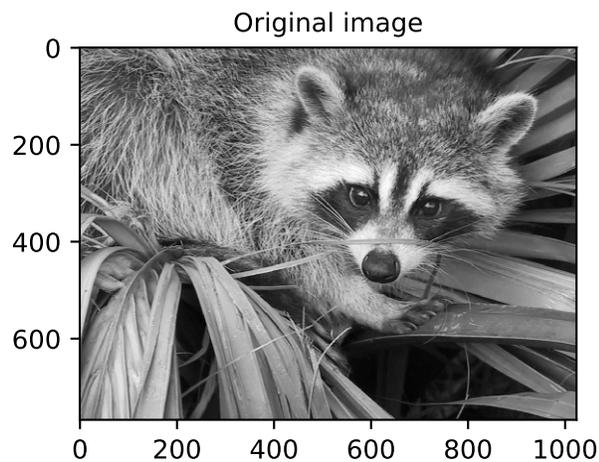
```
>>> import numpy as np
>>> from scipy import signal, misc
>>> import matplotlib.pyplot as plt
```

```
>>> image = misc.face(gray=True).astype(np.float32)
>>> derfilt = np.array([1.0, -2, 1.0], dtype=np.float32)
>>> ck = signal.cspline2d(image, 8.0)
>>> deriv = (signal.sepfir2d(ck, derfilt, [1]) +
...         signal.sepfir2d(ck, [1], derfilt))
```

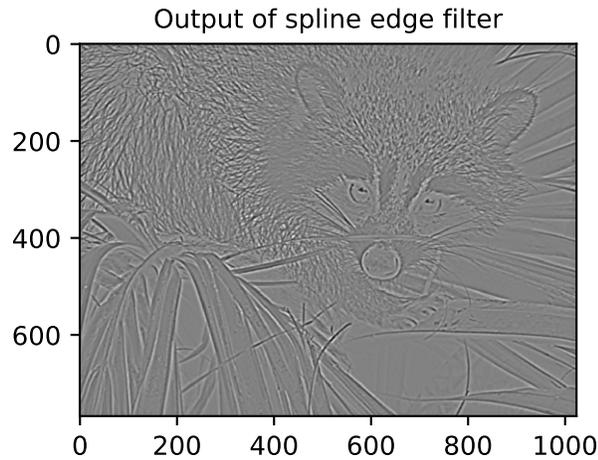
Alternatively we could have done:

```
laplacian = np.array([[0,1,0], [1,-4,1], [0,1,0]], dtype=np.float32)
deriv2 = signal.convolve2d(ck,laplacian,mode='same',boundary='symm')
```

```
>>> plt.figure()
>>> plt.imshow(image)
>>> plt.gray()
>>> plt.title('Original image')
>>> plt.show()
```



```
>>> plt.figure()
>>> plt.imshow(deriv)
>>> plt.gray()
>>> plt.title('Output of spline edge filter')
>>> plt.show()
```



## Filtering

Filtering is a generic name for any system that modifies an input signal in some way. In SciPy a signal can be thought of as a Numpy array. There are different kinds of filters for different kinds of operations. There are two broad kinds of filtering operations: linear and non-linear. Linear filters can always be reduced to multiplication of the flattened Numpy array by an appropriate matrix resulting in another flattened Numpy array. Of course, this is not usually the best way to compute the filter as the matrices and vectors involved may be huge. For example filtering a  $512 \times 512$  image with this method would require multiplication of a  $512^2 \times 512^2$  matrix with a  $512^2$  vector. Just trying to store the  $512^2 \times 512^2$  matrix using a standard Numpy array would require 68,719,476,736 elements. At 4 bytes per element this would require 256GB of memory. In most applications most of the elements of this matrix are zero and a different method for computing the output of the filter is employed.

### *Convolution/Correlation*

Many linear filters also have the property of shift-invariance. This means that the filtering operation is the same at different locations in the signal and it implies that the filtering matrix can be constructed from knowledge of one row (or column) of the matrix alone. In this case, the matrix multiplication can be accomplished using Fourier transforms.

Let  $x[n]$  define a one-dimensional signal indexed by the integer  $n$ . Full convolution of two one-dimensional signals can be expressed as

$$y[n] = \sum_{k=-\infty}^{\infty} x[k] h[n-k].$$

This equation can only be implemented directly if we limit the sequences to finite support sequences that can be stored in a computer, choose  $n = 0$  to be the starting point of both sequences, let  $K + 1$  be that value for which  $x[n] = 0$  for all  $n \geq K + 1$  and  $M + 1$  be that value for which  $h[n] = 0$  for all  $n \geq M + 1$ , then the discrete convolution expression is

$$y[n] = \sum_{k=\max(n-M,0)}^{\min(n,K)} x[k] h[n-k].$$

For convenience assume  $K \geq M$ . Then, more explicitly the output of this operation is

$$\begin{aligned}
 y[0] &= x[0]h[0] \\
 y[1] &= x[0]h[1] + x[1]h[0] \\
 y[2] &= x[0]h[2] + x[1]h[1] + x[2]h[0] \\
 &\vdots \\
 y[M] &= x[0]h[M] + x[1]h[M-1] + \cdots + x[M]h[0] \\
 y[M+1] &= x[1]h[M] + x[2]h[M-1] + \cdots + x[M+1]h[0] \\
 &\vdots \\
 y[K] &= x[K-M]h[M] + \cdots + x[K]h[0] \\
 y[K+1] &= x[K+1-M]h[M] + \cdots + x[K]h[1] \\
 &\vdots \\
 y[K+M-1] &= x[K-1]h[M] + x[K]h[M-1] \\
 y[K+M] &= x[K]h[M].
 \end{aligned}$$

Thus, the full discrete convolution of two finite sequences of lengths  $K+1$  and  $M+1$  respectively results in a finite sequence of length  $K+M+1 = (K+1) + (M+1) - 1$ .

One dimensional convolution is implemented in SciPy with the function `convolve`. This function takes as inputs the signals  $x, h$ , and two optional flags ‘mode’ and ‘method’ and returns the signal  $y$ .

The first optional flag ‘mode’ allows for specification of which part of the output signal to return. The default value of ‘full’ returns the entire signal. If the flag has a value of ‘same’ then only the middle  $K$  values are returned starting at  $y[\lfloor \frac{M-1}{2} \rfloor]$  so that the output has the same length as the first input. If the flag has a value of ‘valid’ then only the middle  $K-M+1 = (K+1) - (M+1) + 1$  output values are returned where  $z$  depends on all of the values of the smallest input from  $h[0]$  to  $h[M]$ . In other words only the values  $y[M]$  to  $y[K]$  inclusive are returned.

The second optional flag ‘method’ determines how the convolution is computed, either through the Fourier transform approach with `fftconvolve` or through the direct method. By default, it selects the expected faster method. The Fourier transform method has order  $O(N \log N)$  while the direct method has order  $O(N^2)$ . Depending on the big O constant and the value of  $N$ , one of these two methods may be faster. The default value ‘auto’ performs a rough calculation and chooses the expected faster method, while the values ‘direct’ and ‘fft’ force computation with the other two methods.

The code below shows a simple example for convolution of 2 sequences

```

>>> x = np.array([1.0, 2.0, 3.0])
>>> h = np.array([0.0, 1.0, 0.0, 0.0, 0.0])
>>> signal.convolve(x, h)
array([ 0.,  1.,  2.,  3.,  0.,  0.,  0.])
>>> signal.convolve(x, h, 'same')
array([ 2.,  3.,  0.])

```

This same function `convolve` can actually take  $N$ -dimensional arrays as inputs and will return the  $N$ -dimensional convolution of the two arrays as is shown in the code example below. The same input flags are available for that case as well.

```

>>> x = np.array([[1., 1., 0., 0.], [1., 1., 0., 0.], [0., 0., 0., 0.], [0., 0., 0., 0.],
                  ↪0.])
>>> h = np.array([[1., 0., 0., 0.], [0., 0., 0., 0.], [0., 0., 1., 0.], [0., 0., 0., 0.],
                  ↪0.])
>>> signal.convolve(x, h)
array([[ 1.,  1.,  0.,  0.,  0.,  0.,  0.],

```

```
[ 1., 1., 0., 0., 0., 0., 0.],
 [ 0., 0., 1., 1., 0., 0., 0.],
 [ 0., 0., 1., 1., 0., 0., 0.],
 [ 0., 0., 0., 0., 0., 0., 0.],
 [ 0., 0., 0., 0., 0., 0., 0.],
 [ 0., 0., 0., 0., 0., 0., 0.]])
```

Correlation is very similar to convolution except for the minus sign becomes a plus sign. Thus

$$w[n] = \sum_{k=-\infty}^{\infty} y[k] x[n+k]$$

is the (cross) correlation of the signals  $y$  and  $x$ . For finite-length signals with  $y[n] = 0$  outside of the range  $[0, K]$  and  $x[n] = 0$  outside of the range  $[0, M]$ , the summation can simplify to

$$w[n] = \sum_{k=\max(0, -n)}^{\min(K, M-n)} y[k] x[n+k].$$

Assuming again that  $K \geq M$  this is

$$\begin{aligned} w[-K] &= y[K] x[0] \\ w[-K+1] &= y[K-1] x[0] + y[K] x[1] \\ &\vdots \\ w[M-K] &= y[K-M] x[0] + y[K-M+1] x[1] + \cdots + y[K] x[M] \\ w[M-K+1] &= y[K-M-1] x[0] + \cdots + y[K-1] x[M] \\ &\vdots \\ w[-1] &= y[1] x[0] + y[2] x[1] + \cdots + y[M+1] x[M] \\ w[0] &= y[0] x[0] + y[1] x[1] + \cdots + y[M] x[M] \\ w[1] &= y[0] x[1] + y[1] x[2] + \cdots + y[M-1] x[M] \\ w[2] &= y[0] x[2] + y[1] x[3] + \cdots + y[M-2] x[M] \\ &\vdots \\ w[M-1] &= y[0] x[M-1] + y[1] x[M] \\ w[M] &= y[0] x[M]. \end{aligned}$$

The SciPy function `correlate` implements this operation. Equivalent flags are available for this operation to return the full  $K + M + 1$  length sequence ('full') or a sequence with the same size as the largest sequence starting at  $w[-K + \lfloor \frac{M-1}{2} \rfloor]$  ('same') or a sequence where the values depend on all the values of the smallest sequence ('valid'). This final option returns the  $K - M + 1$  values  $w[M - K]$  to  $w[0]$  inclusive.

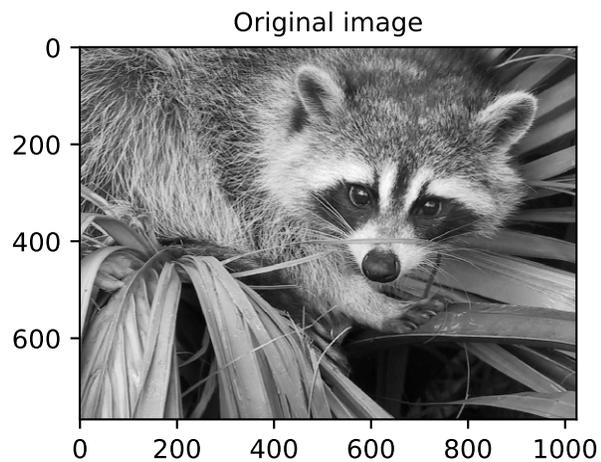
The function `correlate` can also take arbitrary  $N$ -dimensional arrays as input and return the  $N$ -dimensional convolution of the two arrays on output.

When  $N = 2$ , `correlate` and/or `convolve` can be used to construct arbitrary image filters to perform actions such as blurring, enhancing, and edge-detection for an image.

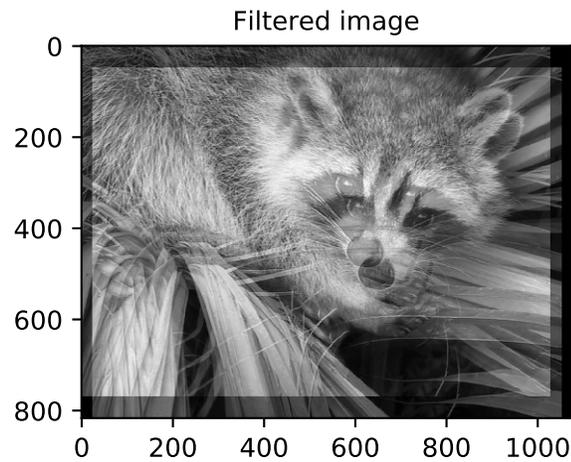
```
>>> import numpy as np
>>> from scipy import signal, misc
>>> import matplotlib.pyplot as plt
```

```
>>> image = misc.face(gray=True)
>>> w = np.zeros((50, 50))
>>> w[0][0] = 1.0
>>> w[49][25] = 1.0
>>> image_new = signal.fftconvolve(image, w)
```

```
>>> plt.figure()
>>> plt.imshow(image)
>>> plt.gray()
>>> plt.title('Original image')
>>> plt.show()
```



```
>>> plt.figure()
>>> plt.imshow(image_new)
>>> plt.gray()
>>> plt.title('Filtered image')
>>> plt.show()
```



Calculating the convolution in the time domain as above is mainly used for filtering when one of the signals is much smaller than the other ( $K \gg M$ ), otherwise linear filtering is more efficiently calculated in the frequency domain provided by the function `fftconvolve`. By default, `convolve` estimates the fastest method using `choose_conv_method`.

If the filter function  $w[n, m]$  can be factored according to

$$h[n, m] = h_1[n]h_2[m],$$

convolution can be calculated by means of the function `sepfir2d`. As an example we consider a Gaussian filter `gaussian`

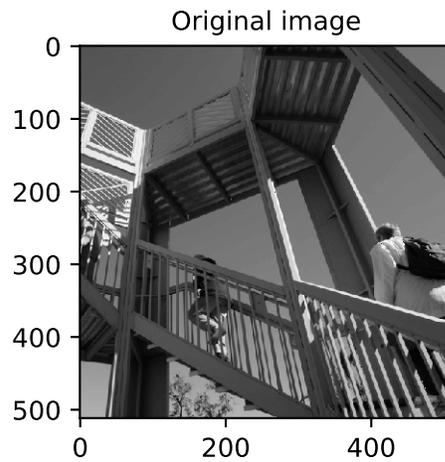
$$h[n, m] \propto e^{-x^2-y^2} = e^{-x^2} e^{-y^2}$$

which is often used for blurring.

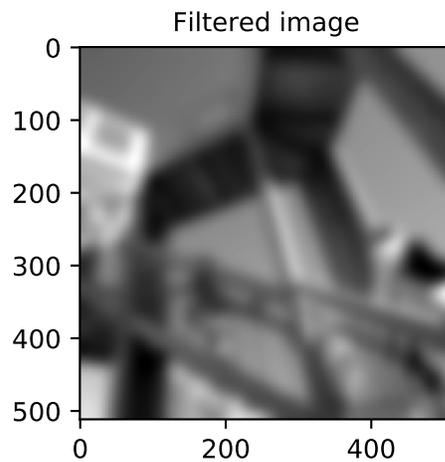
```
>>> import numpy as np
>>> from scipy import signal, misc
>>> import matplotlib.pyplot as plt
```

```
>>> image = misc.ascent()
>>> w = signal.gaussian(50, 10.0)
>>> image_new = signal.sepfir2d(image, w, w)
```

```
>>> plt.figure()
>>> plt.imshow(image)
>>> plt.gray()
>>> plt.title('Original image')
>>> plt.show()
```



```
>>> plt.figure()
>>> plt.imshow(image_new)
>>> plt.gray()
>>> plt.title('Filtered image')
>>> plt.show()
```



### *Difference-equation filtering*

A general class of linear one-dimensional filters (that includes convolution filters) are filters described by the difference equation

$$\sum_{k=0}^N a_k y[n-k] = \sum_{k=0}^M b_k x[n-k]$$

where  $x[n]$  is the input sequence and  $y[n]$  is the output sequence. If we assume initial rest so that  $y[n] = 0$  for  $n < 0$ , then this kind of filter can be implemented using convolution. However, the convolution filter sequence  $h[n]$  could

be infinite if  $a_k \neq 0$  for  $k \geq 1$ . In addition, this general class of linear filter allows initial conditions to be placed on  $y[n]$  for  $n < 0$  resulting in a filter that cannot be expressed using convolution.

The difference equation filter can be thought of as finding  $y[n]$  recursively in terms of it's previous values

$$a_0 y[n] = -a_1 y[n-1] - \dots - a_N y[n-N] + \dots + b_0 x[n] + \dots + b_M x[n-M].$$

Often  $a_0 = 1$  is chosen for normalization. The implementation in SciPy of this general difference equation filter is a little more complicated than would be implied by the previous equation. It is implemented so that only one signal needs to be delayed. The actual implementation equations are (assuming  $a_0 = 1$ ).

$$\begin{aligned} y[n] &= b_0 x[n] + z_0[n-1] \\ z_0[n] &= b_1 x[n] + z_1[n-1] - a_1 y[n] \\ z_1[n] &= b_2 x[n] + z_2[n-1] - a_2 y[n] \\ &\vdots \\ z_{K-2}[n] &= b_{K-1} x[n] + z_{K-1}[n-1] - a_{K-1} y[n] \\ z_{K-1}[n] &= b_K x[n] - a_K y[n], \end{aligned}$$

where  $K = \max(N, M)$ . Note that  $b_K = 0$  if  $K > M$  and  $a_K = 0$  if  $K > N$ . In this way, the output at time  $n$  depends only on the input at time  $n$  and the value of  $z_0$  at the previous time. This can always be calculated as long as the  $K$  values  $z_0[n-1] \dots z_{K-1}[n-1]$  are computed and stored at each time step.

The difference-equation filter is called using the command `lfiltfilt` in SciPy. This command takes as inputs the vector  $b$ , the vector  $a$ , a signal  $x$  and returns the vector  $y$  (the same length as  $x$ ) computed using the equation given above. If  $x$  is  $N$ -dimensional, then the filter is computed along the axis provided. If, desired, initial conditions providing the values of  $z_0[-1]$  to  $z_{K-1}[-1]$  can be provided or else it will be assumed that they are all zero. If initial conditions are provided, then the final conditions on the intermediate variables are also returned. These could be used, for example, to restart the calculation in the same state.

Sometimes it is more convenient to express the initial conditions in terms of the signals  $x[n]$  and  $y[n]$ . In other words, perhaps you have the values of  $x[-M]$  to  $x[-1]$  and the values of  $y[-N]$  to  $y[-1]$  and would like to determine what values of  $z_m[-1]$  should be delivered as initial conditions to the difference-equation filter. It is not difficult to show that for  $0 \leq m < K$ ,

$$z_m[n] = \sum_{p=0}^{K-m-1} (b_{m+p+1} x[n-p] - a_{m+p+1} y[n-p]).$$

Using this formula we can find the initial condition vector  $z_0[-1]$  to  $z_{K-1}[-1]$  given initial conditions on  $y$  (and  $x$ ). The command `lfiltfilt` performs this function.

As an example consider the following system:

$$y[n] = \frac{1}{2}x[n] + \frac{1}{4}x[n-1] + \frac{1}{3}y[n-1]$$

The code calculates the signal  $y[n]$  for a given signal  $x[n]$ ; first for initial conditions  $y[-1] = 0$  (default case), then for  $y[-1] = 2$  by means of `lfiltfilt`.

```
>>> import numpy as np
>>> from scipy import signal
```

```
>>> x = np.array([1., 0., 0., 0.])
>>> b = np.array([1.0/2, 1.0/4])
>>> a = np.array([1.0, -1.0/3])
>>> signal.lfilter(b, a, x)
array([0.5, 0.41666667, 0.13888889, 0.0462963])
```

```
>>> zi = signal.lfiltic(b, a, y=[2.])
>>> signal.lfilter(b, a, x, zi=zi)
(array([ 1.16666667,  0.63888889,  0.21296296,  0.07098765]), array([0.02366]))
```

Note that the output signal  $y[n]$  has the same length as the length as the input signal  $x[n]$ .

## Analysis of Linear Systems

Linear system described a linear difference equation can be fully described by the coefficient vectors  $a$  and  $b$  as was done above; an alternative representation is to provide a factor  $k$ ,  $N_z$  zeros  $z_k$  and  $N_p$  poles  $p_k$ , respectively, to describe the system by means of its transfer function  $H(z)$  according to

$$H(z) = k \frac{(z - z_1)(z - z_2)\dots(z - z_{N_z})}{(z - p_1)(z - p_2)\dots(z - p_{N_p})}$$

This alternative representation can be obtain with the scipy function `tf2zpk`; the inverse is provided by `zpk2tf`.

For the example from above we have

```
>>> b = np.array([1.0/2, 1.0/4])
>>> a = np.array([1.0, -1.0/3])
>>> signal.tf2zpk(b, a)
(array([-0.5]), array([ 0.33333333]), 0.5)
```

i.e. the system has a zero at  $z = -1/2$  and a pole at  $z = 1/3$ .

The scipy function `freqz` allows calculation of the frequency response of a system described by the coefficients  $a_k$  and  $b_k$ . See the help of the `freqz` function of a comprehensive example.

## Filter Design

Time-discrete filters can be classified into finite response (FIR) filters and infinite response (IIR) filters. FIR filters can provide a linear phase response, whereas IIR filters cannot. Scipy provides functions for designing both types of filters.

## FIR Filter

The function `firwin` designs filters according to the window method. Depending on the provided arguments, the function returns different filter types (e.g. low-pass, band-pass...).

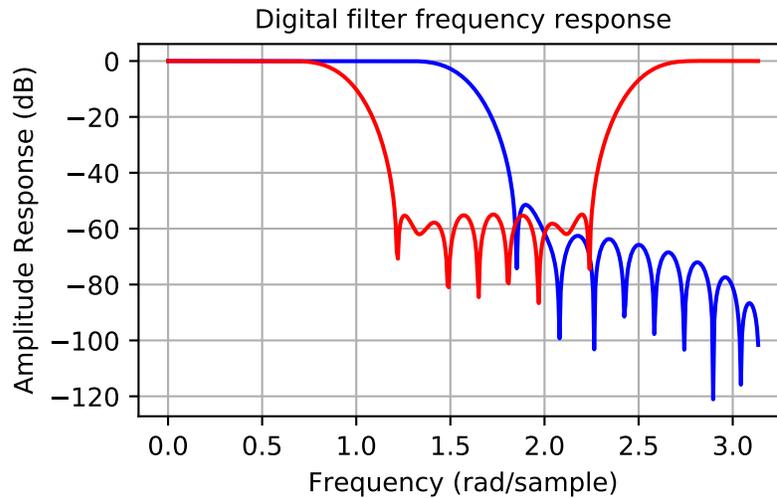
The example below designs a low-pass and a band-stop filter, respectively.

```
>>> import numpy as np
>>> import scipy.signal as signal
>>> import matplotlib.pyplot as plt
```

```
>>> b1 = signal.firwin(40, 0.5)
>>> b2 = signal.firwin(41, [0.3, 0.8])
>>> w1, h1 = signal.freqz(b1)
>>> w2, h2 = signal.freqz(b2)
```

```
>>> plt.title('Digital filter frequency response')
>>> plt.plot(w1, 20*np.log10(np.abs(h1)), 'b')
>>> plt.plot(w2, 20*np.log10(np.abs(h2)), 'r')
>>> plt.ylabel('Amplitude Response (dB)')
```

```
>>> plt.xlabel('Frequency (rad/sample)')
>>> plt.grid()
>>> plt.show()
```



Note that *firwin* uses per default a normalized frequency defined such that the value 1 corresponds to the Nyquist frequency, whereas the function *freqz* is defined such that the value  $\pi$  corresponds to the Nyquist frequency.

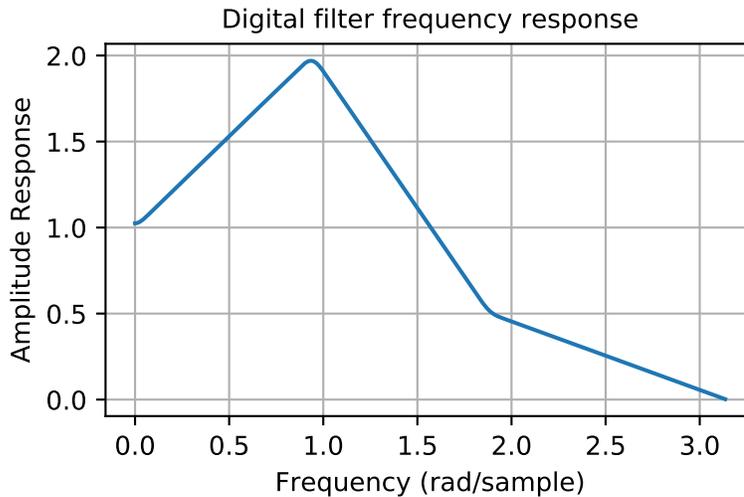
The function *firwin2* allows design of almost arbitrary frequency responses by specifying an array of corner frequencies and corresponding gains, respectively.

The example below designs a filter with such an arbitrary amplitude response.

```
>>> import numpy as np
>>> import scipy.signal as signal
>>> import matplotlib.pyplot as plt
```

```
>>> b = signal.firwin2(150, [0.0, 0.3, 0.6, 1.0], [1.0, 2.0, 0.5, 0.0])
>>> w, h = signal.freqz(b)
```

```
>>> plt.title('Digital filter frequency response')
>>> plt.plot(w, np.abs(h))
>>> plt.title('Digital filter frequency response')
>>> plt.ylabel('Amplitude Response')
>>> plt.xlabel('Frequency (rad/sample)')
>>> plt.grid()
>>> plt.show()
```



Note the linear scaling of the y-axis and the different definition of the Nyquist frequency in *firwin2* and *freqz* (as explained above).

### IIR Filter

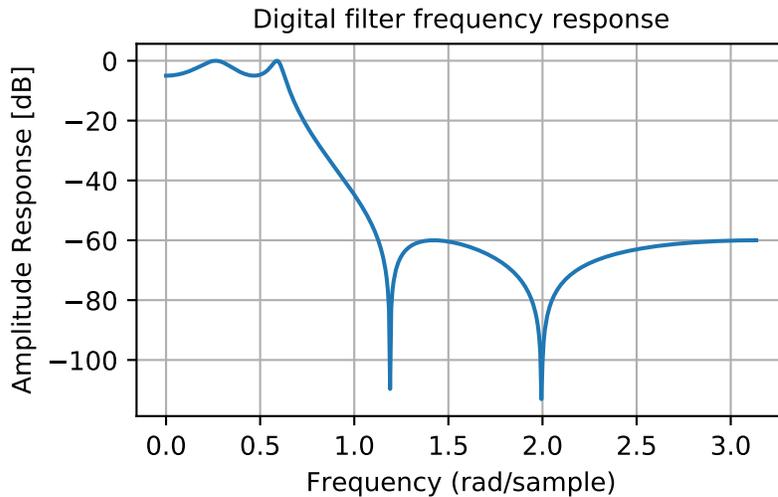
SciPy provides two functions to directly design IIR *iirdesign* and *iirfilter* where the filter type (e.g. elliptic) is passed as an argument and several more filter design functions for specific filter types; e.g. *ellip*.

The example below designs an elliptic low-pass filter with defined passband and stopband ripple, respectively. Note the much lower filter order (order 4) compared with the FIR filters from the examples above in order to reach the same stop-band attenuation of  $\approx 60$  dB.

```
>>> import numpy as np
>>> import scipy.signal as signal
>>> import matplotlib.pyplot as plt
```

```
>>> b, a = signal.iirfilter(4, Wn=0.2, rp=5, rs=60, btype='lowpass', ftype='ellip')
>>> w, h = signal.freqz(b, a)
```

```
>>> plt.title('Digital filter frequency response')
>>> plt.plot(w, 20*np.log10(np.abs(h)))
>>> plt.title('Digital filter frequency response')
>>> plt.ylabel('Amplitude Response [dB]')
>>> plt.xlabel('Frequency (rad/sample)')
>>> plt.grid()
>>> plt.show()
```



## Filter Coefficients

Filter coefficients can be stored in several different formats:

- ‘ba’ or ‘tf’ = transfer function coefficients
- ‘zpk’ = zeros, poles, and overall gain
- ‘ss’ = state-space system representation
- ‘sos’ = transfer function coefficients of second-order sections

Functions such as `tf2zpk` and `zpk2ss` can convert between them.

## Transfer function representation

The `ba` or `tf` format is a 2-tuple  $(b, a)$  representing a transfer function, where  $b$  is a length  $M+1$  array of coefficients of the  $M$ -order numerator polynomial, and  $a$  is a length  $N+1$  array of coefficients of the  $N$ -order denominator, as positive, descending powers of the transfer function variable. So the tuple of  $b = [b_0, b_1, \dots, b_M]$  and  $a = [a_0, a_1, \dots, a_N]$  can represent an analog filter of the form:

$$H(s) = \frac{b_0 s^M + b_1 s^{(M-1)} + \dots + b_M}{a_0 s^N + a_1 s^{(N-1)} + \dots + a_N} = \frac{\sum_{i=0}^M b_i s^{(M-i)}}{\sum_{i=0}^N a_i s^{(N-i)}}$$

or a discrete-time filter of the form:

$$H(z) = \frac{b_0 z^M + b_1 z^{(M-1)} + \dots + b_M}{a_0 z^N + a_1 z^{(N-1)} + \dots + a_N} = \frac{\sum_{i=0}^M b_i z^{(M-i)}}{\sum_{i=0}^N a_i z^{(N-i)}}$$

This “positive powers” form is found more commonly in controls engineering. If  $M$  and  $N$  are equal (which is true for all filters generated by the bilinear transform), then this happens to be equivalent to the “negative powers” discrete-time form preferred in DSP:

$$H(z) = \frac{b_0 + b_1 z^{-1} + \dots + b_M z^{-M}}{a_0 + a_1 z^{-1} + \dots + a_N z^{-N}} = \frac{\sum_{i=0}^M b_i z^{-i}}{\sum_{i=0}^N a_i z^{-i}}$$

Although this is true for common filters, remember that this is not true in the general case. If  $M$  and  $N$  are not equal, the discrete-time transfer function coefficients must first be converted to the “positive powers” form before finding the poles and zeros.

This representation suffers from numerical error at higher orders, so other formats are preferred when possible.

### Zeros and poles representation

The `zpk` format is a 3-tuple  $(z, p, k)$ , where  $z$  is an  $M$ -length array of the complex zeros of the transfer function  $z = [z_0, z_1, \dots, z_{M-1}]$ ,  $p$  is an  $N$ -length array of the complex poles of the transfer function  $p = [p_0, p_1, \dots, p_{N-1}]$ , and  $k$  is a scalar gain. These represent the digital transfer function:

$$H(z) = k \cdot \frac{(z - z_0)(z - z_1) \cdots (z - z_{(M-1)})}{(z - p_0)(z - p_1) \cdots (z - p_{(N-1)})} = k \frac{\prod_{i=0}^{M-1} (z - z_i)}{\prod_{i=0}^{N-1} (z - p_i)}$$

or the analog transfer function:

$$H(s) = k \cdot \frac{(s - z_0)(s - z_1) \cdots (s - z_{(M-1)})}{(s - p_0)(s - p_1) \cdots (s - p_{(N-1)})} = k \frac{\prod_{i=0}^{M-1} (s - z_i)}{\prod_{i=0}^{N-1} (s - p_i)}$$

Although the sets of roots are stored as ordered NumPy arrays, their ordering does not matter;  $([-1, -2], [-3, -4], 1)$  is the same filter as  $([-2, -1], [-4, -3], 1)$ .

### State-space system representation

The `ss` format is a 4-tuple of arrays  $(A, B, C, D)$  representing the state-space of an  $N$ -order digital/discrete-time system of the form:

$$\begin{aligned} \mathbf{x}[k+1] &= A\mathbf{x}[k] + B\mathbf{u}[k] \\ \mathbf{y}[k] &= C\mathbf{x}[k] + D\mathbf{u}[k] \end{aligned}$$

or a continuous/analog system of the form:

$$\begin{aligned} \dot{\mathbf{x}}(t) &= A\mathbf{x}(t) + B\mathbf{u}(t) \\ \mathbf{y}(t) &= C\mathbf{x}(t) + D\mathbf{u}(t) \end{aligned}$$

with  $P$  inputs,  $Q$  outputs and  $N$  state variables, where:

- $x$  is the state vector
- $y$  is the output vector of length  $Q$
- $u$  is the input vector of length  $P$
- $A$  is the state matrix, with shape  $(N, N)$
- $B$  is the input matrix with shape  $(N, P)$
- $C$  is the output matrix with shape  $(Q, N)$
- $D$  is the feedthrough or feedforward matrix with shape  $(Q, P)$ . (In cases where the system does not have a direct feedthrough, all values in  $D$  are zero.)

State-space is the most general representation, and the only one that allows for multiple-input, multiple-output (MIMO) systems. There are multiple state-space representations for a given transfer function. Specifically, the “controllable canonical form” and “observable canonical form” have the same coefficients as the `tf` representation, and therefore suffer from the same numerical errors.

## Second-order sections representation

The `sos` format is a single 2D array of shape  $(n\_sections, 6)$ , representing a sequence of second-order transfer functions which, when cascaded in series, realize a higher-order filter with minimal numerical error. Each row corresponds to a second-order `tf` representation, with the first three columns providing the numerator coefficients and the last three providing the denominator coefficients:

$$[b_0, b_1, b_2, a_0, a_1, a_2]$$

The coefficients are typically normalized such that  $a_0$  is always 1. The section order is usually not important with floating-point computation; the filter output will be the same regardless.

## Filter transformations

The IIR filter design functions first generate a prototype analog lowpass filter with a normalized cutoff frequency of 1 rad/sec. This is then transformed into other frequencies and band types using the following substitutions:

Type	Transformation
<i>lp2lp</i>	$s \rightarrow \frac{s}{\omega_0}$
<i>lp2hp</i>	$s \rightarrow \frac{\omega_0}{s}$
<i>lp2bp</i>	$s \rightarrow \frac{s^2 + \omega_0^2}{s \cdot BW}$
<i>lp2bs</i>	$s \rightarrow \frac{s \cdot BW}{s^2 + \omega_0^2}$

Here,  $\omega_0$  is the new cutoff or center frequency, and BW is the bandwidth. These preserve symmetry on a logarithmic frequency axis.

To convert the transformed analog filter into a digital filter, the *bilinear* transform is used, which makes the following substitution:

$$s \rightarrow \frac{2}{T} \frac{z - 1}{z + 1}$$

where T is the sampling time (the inverse of the sampling frequency).

### Other filters

The signal processing package provides many more filters as well.

## Median Filter

A median filter is commonly applied when noise is markedly non-Gaussian or when it is desired to preserve edges. The median filter works by sorting all of the array pixel values in a rectangular region surrounding the point of interest. The sample median of this list of neighborhood pixel values is used as the value for the output array. The sample median is the middle array value in a sorted list of neighborhood values. If there are an even number of elements in the neighborhood, then the average of the middle two values is used as the median. A general purpose median filter that works on N-dimensional arrays is `medfilt`. A specialized version that works only for two-dimensional arrays is available as `medfilt2d`.

## Order Filter

A median filter is a specific example of a more general class of filters called order filters. To compute the output at a particular pixel, all order filters use the array values in a region surrounding that pixel. These array values are sorted and then one of them is selected as the output value. For the median filter, the sample median of the list of array values

is used as the output. A general order filter allows the user to select which of the sorted values will be used as the output. So, for example one could choose to pick the maximum in the list or the minimum. The order filter takes an additional argument besides the input array and the region mask that specifies which of the elements in the sorted list of neighbor array values should be used as the output. The command to perform an order filter is `order_filter`.

## Wiener filter

The Wiener filter is a simple deblurring filter for denoising images. This is not the Wiener filter commonly described in image reconstruction problems but instead it is a simple, local-mean filter. Let  $x$  be the input signal, then the output is

$$y = \begin{cases} \frac{\sigma_x^2}{\sigma_x^2 + \sigma^2} m_x + \left(1 - \frac{\sigma_x^2}{\sigma_x^2 + \sigma^2}\right) x & \sigma_x^2 \geq \sigma^2, \\ m_x & \sigma_x^2 < \sigma^2, \end{cases}$$

where  $m_x$  is the local estimate of the mean and  $\sigma_x^2$  is the local estimate of the variance. The window for these estimates is an optional input parameter (default is  $3 \times 3$ ). The parameter  $\sigma^2$  is a threshold noise parameter. If  $\sigma$  is not given then it is estimated as the average of the local variances.

## Hilbert filter

The Hilbert transform constructs the complex-valued analytic signal from a real signal. For example if  $x = \cos \omega n$  then  $y = \text{hilbert}(x)$  would return (except near the edges)  $y = \exp(j\omega n)$ . In the frequency domain, the hilbert transform performs

$$Y = X \cdot H$$

where  $H$  is 2 for positive frequencies, 0 for negative frequencies and 1 for zero-frequencies.

## Analog Filter Design

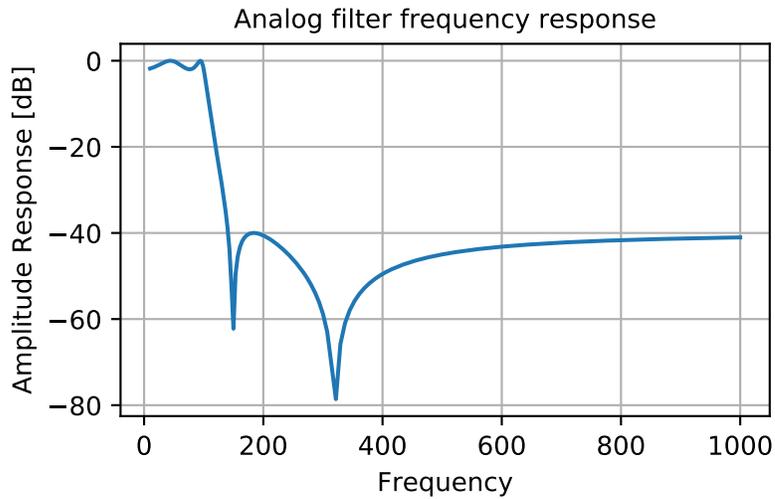
The functions `iirdesign`, `iirfilter`, and the filter design functions for specific filter types (e.g. `ellip`) all have a flag `analog` which allows design of analog filters as well.

The example below designs an analog (IIR) filter, obtains via `tf2zpk` the poles and zeros and plots them in the complex s-plane. The zeros at  $\omega \approx 150$  and  $\omega \approx 300$  can be clearly seen in the amplitude response.

```
>>> import numpy as np
>>> import scipy.signal as signal
>>> import matplotlib.pyplot as plt
```

```
>>> b, a = signal.iirdesign(wp=100, ws=200, gpass=2.0, gstop=40., analog=True)
>>> w, h = signal.freqs(b, a)
```

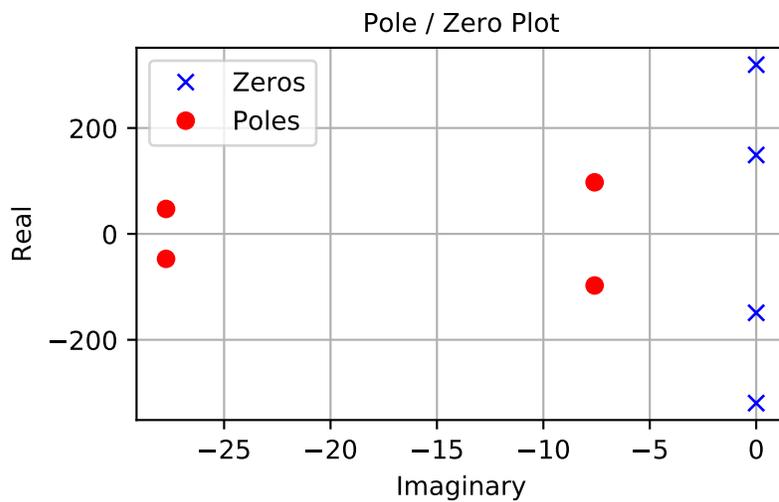
```
>>> plt.title('Analog filter frequency response')
>>> plt.plot(w, 20*np.log10(np.abs(h)))
>>> plt.ylabel('Amplitude Response [dB]')
>>> plt.xlabel('Frequency')
>>> plt.grid()
>>> plt.show()
```



```
>>> z, p, k = signal.tf2zpk(b, a)
```

```
>>> plt.plot(np.real(z), np.imag(z), 'xb')
>>> plt.plot(np.real(p), np.imag(p), 'or')
>>> plt.legend(['Zeros', 'Poles'], loc=2)
```

```
>>> plt.title('Pole / Zero Plot')
>>> plt.ylabel('Real')
>>> plt.xlabel('Imaginary')
>>> plt.grid()
>>> plt.show()
```



## Spectral Analysis

### Periodogram Measurements

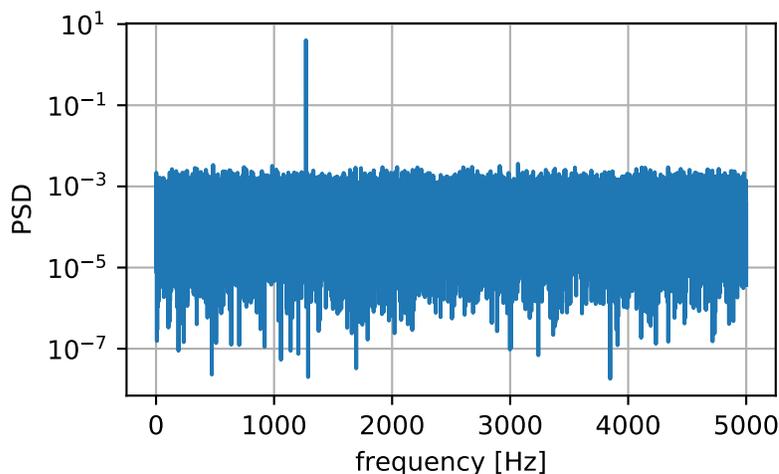
The scipy function `periodogram` provides a method to estimate the spectral density using the periodogram method. The example below calculates the periodogram of a sine signal in white Gaussian noise.

```
>>> import numpy as np
>>> import scipy.signal as signal
>>> import matplotlib.pyplot as plt
```

```
>>> fs = 10e3
>>> N = 1e5
>>> amp = 2*np.sqrt(2)
>>> freq = 1270.0
>>> noise_power = 0.001 * fs / 2
>>> time = np.arange(N) / fs
>>> x = amp*np.sin(2*np.pi*freq*time)
>>> x += np.random.normal(scale=np.sqrt(noise_power), size=time.shape)
```

```
>>> f, Pper_spec = signal.periodogram(x, fs, 'flattop', scaling='spectrum')
```

```
>>> plt.semilogy(f, Pper_spec)
>>> plt.xlabel('frequency [Hz]')
>>> plt.ylabel('PSD')
>>> plt.grid()
>>> plt.show()
```



### Spectral Analysis using Welch's Method

An improved method, especially with respect to noise immunity, is Welch's method which is implemented by the scipy function `welch`.

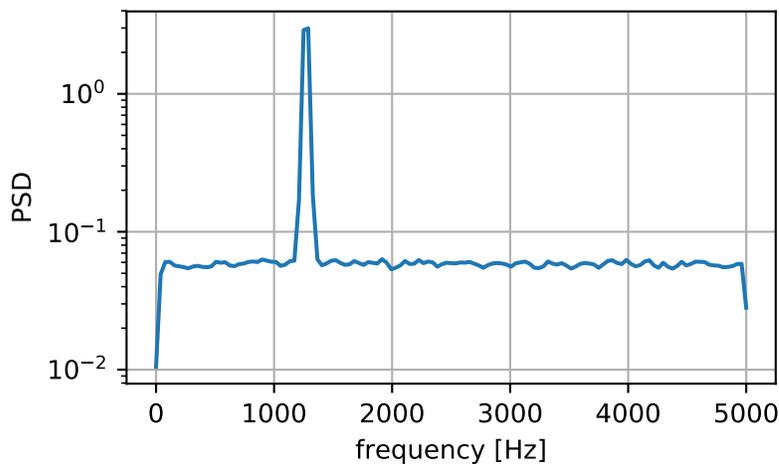
The example below estimates the spectrum using Welch's method and uses the same parameters as the example above. Note the much smoother noise floor of the spectrogram.

```
>>> import numpy as np
>>> import scipy.signal as signal
>>> import matplotlib.pyplot as plt
```

```
>>> fs = 10e3
>>> N = 1e5
>>> amp = 2*np.sqrt(2)
>>> freq = 1270.0
>>> noise_power = 0.001 * fs / 2
>>> time = np.arange(N) / fs
>>> x = amp*np.sin(2*np.pi*freq*time)
>>> x += np.random.normal(scale=np.sqrt(noise_power), size=time.shape)
```

```
>>> f, Pwelch_spec = signal.welch(x, fs, scaling='spectrum')
```

```
>>> plt.semilogy(f, Pwelch_spec)
>>> plt.xlabel('frequency [Hz]')
>>> plt.ylabel('PSD')
>>> plt.grid()
>>> plt.show()
```



### ***Lomb-Scargle Periodograms (`lombscargle`)***

Least-squares spectral analysis (LSSA) is a method of estimating a frequency spectrum, based on a least squares fit of sinusoids to data samples, similar to Fourier analysis. Fourier analysis, the most used spectral method in science, generally boosts long-periodic noise in long gapped records; LSSA mitigates such problems.

The Lomb-Scargle method performs spectral analysis on unevenly sampled data and is known to be a powerful way to find, and test the significance of, weak periodic signals.

For a time series comprising  $N_t$  measurements  $X_j \equiv X(t_j)$  sampled at times  $t_j$  where ( $j = 1, \dots, N_t$ ), assumed to have been scaled and shifted such that its mean is zero and its variance is unity, the normalized Lomb-Scargle periodogram at frequency  $f$  is

$$P_n(f) \frac{1}{2} \left\{ \frac{\left[ \sum_j^{N_t} X_j \cos \omega(t_j - \tau) \right]^2}{\sum_j^{N_t} \cos^2 \omega(t_j - \tau)} + \frac{\left[ \sum_j^{N_t} X_j \sin \omega(t_j - \tau) \right]^2}{\sum_j^{N_t} \sin^2 \omega(t_j - \tau)} \right\}.$$

Here,  $\omega \equiv 2\pi f$  is the angular frequency. The frequency dependent time offset  $\tau$  is given by

$$\tan 2\omega\tau = \frac{\sum_j^{N_t} \sin 2\omega t_j}{\sum_j^{N_t} \cos 2\omega t_j}.$$

The `lombscargle` function calculates the periodogram using a slightly modified algorithm due to Townsend<sup>3</sup> which allows the periodogram to be calculated using only a single pass through the input arrays for each frequency.

The equation is refactored as:

$$P_n(f) = \frac{1}{2} \left[ \frac{(c_\tau XC + s_\tau XS)^2}{c_\tau^2 CC + 2c_\tau s_\tau CS + s_\tau^2 SS} + \frac{(c_\tau XS - s_\tau XC)^2}{c_\tau^2 SS - 2c_\tau s_\tau CS + s_\tau^2 CC} \right]$$

and

$$\tan 2\omega\tau = \frac{2CS}{CC - SS}.$$

Here,

$$c_\tau = \cos \omega\tau, \quad s_\tau = \sin \omega\tau$$

while the sums are

$$XC = \sum_j^{N_t} X_j \cos \omega t_j$$

$$XS = \sum_j^{N_t} X_j \sin \omega t_j$$

$$CC = \sum_j^{N_t} \cos^2 \omega t_j$$

$$SS = \sum_j^{N_t} \sin^2 \omega t_j$$

$$CS = \sum_j^{N_t} \cos \omega t_j \sin \omega t_j.$$

This requires  $N_f(2N_t + 3)$  trigonometric function evaluations giving a factor of  $\sim 2$  speed increase over the straight-forward implementation.

## Detrend

SciPy provides the function `detrend` to remove a constant or linear trend in a data series in order to see effect of higher order.

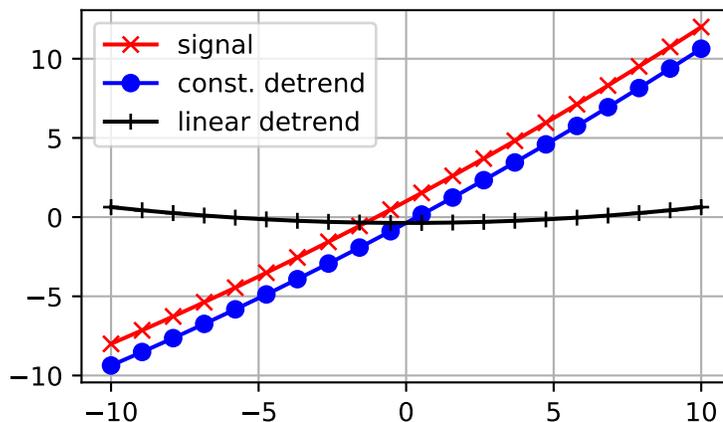
The example below removes the constant and linear trend of a 2-nd order polynomial time series and plots the remaining signal components.

```
>>> import numpy as np
>>> import scipy.signal as signal
>>> import matplotlib.pyplot as plt
```

<sup>3</sup> R.H.D. Townsend, "Fast calculation of the Lomb-Scargle periodogram using graphics processing units.", The Astrophysical Journal Supplement Series, vol 191, pp. 247-253, 2010

```
>>> t = np.linspace(-10, 10, 20)
>>> y = 1 + t + 0.01*t**2
>>> yconst = signal.detrend(y, type='constant')
>>> ylin = signal.detrend(y, type='linear')
```

```
>>> plt.plot(t, y, '-rx')
>>> plt.plot(t, yconst, '-bo')
>>> plt.plot(t, ylin, '-k+')
>>> plt.grid()
>>> plt.legend(['signal', 'const. detrend', 'linear detrend'])
>>> plt.show()
```



## References

Some further reading and related software:

### 3.1.9 Linear Algebra (`scipy.linalg`)

When SciPy is built using the optimized ATLAS LAPACK and BLAS libraries, it has very fast linear algebra capabilities. If you dig deep enough, all of the raw lapack and blas libraries are available for your use for even more speed. In this section, some easier-to-use interfaces to these routines are described.

All of these linear algebra routines expect an object that can be converted into a 2-dimensional array. The output of these routines is also a two-dimensional array.

`scipy.linalg` contains all the functions in `numpy.linalg`, plus some other more advanced ones not contained in `numpy.linalg`.

Another advantage of using `scipy.linalg` over `numpy.linalg` is that it is always compiled with BLAS/LAPACK support, while for `numpy` this is optional. Therefore, the `scipy` version might be faster depending on how `numpy` was installed.

Therefore, unless you don't want to add `scipy` as a dependency to your `numpy` program, use `scipy.linalg` instead of `numpy.linalg`.

## numpy.matrix vs 2D numpy.ndarray

The classes that represent matrices, and basic operations such as matrix multiplications and transpose are a part of `numpy`. For convenience, we summarize the differences between `numpy.matrix` and `numpy.ndarray` here.

`numpy.matrix` is matrix class that has a more convenient interface than `numpy.ndarray` for matrix operations. This class supports for example MATLAB-like creation syntax via the, has matrix multiplication as default for the `*` operator, and contains `I` and `T` members that serve as shortcuts for inverse and transpose:

```
>>> import numpy as np
>>> A = np.mat('[1 2;3 4]')
>>> A
matrix([[1, 2],
        [3, 4]])
>>> A.I
matrix([[ -2. ,  1. ],
        [ 1.5, -0.5]])
>>> b = np.mat('[5 6]')
>>> b
matrix([[5, 6]])
>>> b.T
matrix([[5],
        [6]])
>>> A*b.T
matrix([[17],
        [39]])
```

Despite its convenience, the use of the `numpy.matrix` class is discouraged, since it adds nothing that cannot be accomplished with 2D `numpy.ndarray` objects, and may lead to a confusion of which class is being used. For example, the above code can be rewritten as:

```
>>> import numpy as np
>>> from scipy import linalg
>>> A = np.array([[1,2],[3,4]])
>>> A
array([[1, 2],
       [3, 4]])
>>> linalg.inv(A)
array([[ -2. ,  1. ],
       [ 1.5, -0.5]])
>>> b = np.array([[5,6]]) #2D array
>>> b
array([[5, 6]])
>>> b.T
array([[5],
       [6]])
>>> A*b #not matrix multiplication!
array([[ 5, 12],
       [15, 24]])
>>> A.dot(b.T) #matrix multiplication
array([[17],
       [39]])
>>> b = np.array([5,6]) #1D array
>>> b
array([5, 6])
>>> b.T #not matrix transpose!
array([5, 6])
>>> A.dot(b) #does not matter for multiplication
```

```
array([17, 39])
```

scipy.linalg operations can be applied equally to numpy.matrix or to 2D numpy.ndarray objects.

## Basic routines

### Finding Inverse

The inverse of a matrix  $\mathbf{A}$  is the matrix  $\mathbf{B}$  such that  $\mathbf{AB} = \mathbf{I}$  where  $\mathbf{I}$  is the identity matrix consisting of ones down the main diagonal. Usually  $\mathbf{B}$  is denoted  $\mathbf{B} = \mathbf{A}^{-1}$ . In SciPy, the matrix inverse of the Numpy array,  $\mathbf{A}$ , is obtained using `linalg.inv(A)`, or using `A.I` if  $\mathbf{A}$  is a Matrix. For example, let

$$\mathbf{A} = \begin{bmatrix} 1 & 3 & 5 \\ 2 & 5 & 1 \\ 2 & 3 & 8 \end{bmatrix}$$

then

$$\mathbf{A}^{-1} = \frac{1}{25} \begin{bmatrix} -37 & 9 & 22 \\ 14 & 2 & -9 \\ 4 & -3 & 1 \end{bmatrix} = \begin{bmatrix} -1.48 & 0.36 & 0.88 \\ 0.56 & 0.08 & -0.36 \\ 0.16 & -0.12 & 0.04 \end{bmatrix}.$$

The following example demonstrates this computation in SciPy

```
>>> import numpy as np
>>> from scipy import linalg
>>> A = np.array([[1,3,5],[2,5,1],[2,3,8]])
>>> A
array([[1, 3, 5],
       [2, 5, 1],
       [2, 3, 8]])
>>> linalg.inv(A)
array([[ -1.48,  0.36,  0.88],
       [ 0.56,  0.08, -0.36],
       [ 0.16, -0.12,  0.04]])
>>> A.dot(linalg.inv(A)) #double check
array([[ 1.00000000e+00, -1.11022302e-16, -5.55111512e-17],
       [ 3.05311332e-16,  1.00000000e+00,  1.87350135e-16],
       [ 2.22044605e-16, -1.11022302e-16,  1.00000000e+00]])
```

### Solving linear system

Solving linear systems of equations is straightforward using the `scipy` command `linalg.solve`. This command expects an input matrix and a right-hand-side vector. The solution vector is then computed. An option for entering a symmetric matrix is offered which can speed up the processing when applicable. As an example, suppose it is desired to solve the following simultaneous equations:

$$\begin{aligned} x + 3y + 5z &= 10 \\ 2x + 5y + z &= 8 \\ 2x + 3y + 8z &= 3 \end{aligned}$$

We could find the solution vector using a matrix inverse:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} 1 & 3 & 5 \\ 2 & 5 & 1 \\ 2 & 3 & 8 \end{bmatrix}^{-1} \begin{bmatrix} 10 \\ 8 \\ 3 \end{bmatrix} = \frac{1}{25} \begin{bmatrix} -232 \\ 129 \\ 19 \end{bmatrix} = \begin{bmatrix} -9.28 \\ 5.16 \\ 0.76 \end{bmatrix}.$$

However, it is better to use the `linalg.solve` command which can be faster and more numerically stable. In this case it however gives the same answer as shown in the following example:

```
>>> import numpy as np
>>> from scipy import linalg
>>> A = np.array([[1, 2], [3, 4]])
>>> A
array([[1, 2],
       [3, 4]])
>>> b = np.array([[5], [6]])
>>> b
array([[5],
       [6]])
>>> linalg.inv(A).dot(b) # slow
array([[ -4. ],
       [ 4.5]])
>>> A.dot(linalg.inv(A).dot(b)) - b # check
array([[ 8.88178420e-16],
       [ 2.66453526e-15]])
>>> np.linalg.solve(A, b) # fast
array([[ -4. ],
       [ 4.5]])
>>> A.dot(np.linalg.solve(A, b)) - b # check
array([[ 0. ],
       [ 0.]])
```

### Finding Determinant

The determinant of a square matrix  $\mathbf{A}$  is often denoted  $|\mathbf{A}|$  and is a quantity often used in linear algebra. Suppose  $a_{ij}$  are the elements of the matrix  $\mathbf{A}$  and let  $M_{ij} = |\mathbf{A}_{ij}|$  be the determinant of the matrix left by removing the  $i^{\text{th}}$  row and  $j^{\text{th}}$  column from  $\mathbf{A}$ . Then for any row  $i$ ,

$$|\mathbf{A}| = \sum_j (-1)^{i+j} a_{ij} M_{ij}.$$

This is a recursive way to define the determinant where the base case is defined by accepting that the determinant of a  $1 \times 1$  matrix is the only matrix element. In SciPy the determinant can be calculated with `linalg.det`. For example, the determinant of

$$\mathbf{A} = \begin{bmatrix} 1 & 3 & 5 \\ 2 & 5 & 1 \\ 2 & 3 & 8 \end{bmatrix}$$

is

$$\begin{aligned} |\mathbf{A}| &= 1 \begin{vmatrix} 5 & 1 \\ 3 & 8 \end{vmatrix} - 3 \begin{vmatrix} 2 & 1 \\ 2 & 8 \end{vmatrix} + 5 \begin{vmatrix} 2 & 5 \\ 2 & 3 \end{vmatrix} \\ &= 1(5 \cdot 8 - 3 \cdot 1) - 3(2 \cdot 8 - 2 \cdot 1) + 5(2 \cdot 3 - 2 \cdot 5) = -25. \end{aligned}$$

In SciPy this is computed as shown in this example:

```
>>> import numpy as np
>>> from scipy import linalg
>>> A = np.array([[1, 2], [3, 4]])
>>> A
array([[1, 2],
       [3, 4]])
>>> linalg.det(A)
-2.0
```

### Computing norms

Matrix and vector norms can also be computed with SciPy. A wide range of norm definitions are available using different parameters to the order argument of `linalg.norm`. This function takes a rank-1 (vectors) or a rank-2 (matrices) array and an optional order argument (default is 2). Based on these inputs a vector or matrix norm of the requested order is computed.

For vector  $x$ , the order parameter can be any real number including `inf` or `-inf`. The computed norm is

$$\|x\| = \begin{cases} \max |x_i| & \text{ord} = \text{inf} \\ \min |x_i| & \text{ord} = -\text{inf} \\ \left(\sum_i |x_i|^{\text{ord}}\right)^{1/\text{ord}} & |\text{ord}| < \infty. \end{cases}$$

For matrix  $\mathbf{A}$  the only valid values for norm are  $\pm 2, \pm 1, \pm \text{inf}$ , and 'fro' (or 'f') Thus,

$$\|\mathbf{A}\| = \begin{cases} \max_i \sum_j |a_{ij}| & \text{ord} = \text{inf} \\ \min_i \sum_j |a_{ij}| & \text{ord} = -\text{inf} \\ \max_j \sum_i |a_{ij}| & \text{ord} = 1 \\ \min_j \sum_i |a_{ij}| & \text{ord} = -1 \\ \max \sigma_i & \text{ord} = 2 \\ \min \sigma_i & \text{ord} = -2 \\ \sqrt{\text{trace}(\mathbf{A}^H \mathbf{A})} & \text{ord} = \text{'fro'}$$

where  $\sigma_i$  are the singular values of  $\mathbf{A}$ .

Examples:

```
>>> import numpy as np
>>> from scipy import linalg
>>> A=np.array([[1,2],[3,4]])
>>> A
array([[1, 2],
       [3, 4]])
>>> linalg.norm(A)
5.4772255750516612
>>> linalg.norm(A,'fro') # frobenius norm is the default
5.4772255750516612
>>> linalg.norm(A,1) # L1 norm (max column sum)
6
>>> linalg.norm(A,-1)
4
>>> linalg.norm(A,np.inf) # L inf norm (max row sum)
7
```

### Solving linear least-squares problems and pseudo-inverses

Linear least-squares problems occur in many branches of applied mathematics. In this problem a set of linear scaling coefficients is sought that allow a model to fit data. In particular it is assumed that data  $y_i$  is related to data  $x_i$  through a set of coefficients  $c_j$  and model functions  $f_j(x_i)$  via the model

$$y_i = \sum_j c_j f_j(x_i) + \epsilon_i$$

where  $\epsilon_i$  represents uncertainty in the data. The strategy of least squares is to pick the coefficients  $c_j$  to minimize

$$J(\mathbf{c}) = \sum_i \left| y_i - \sum_j c_j f_j(x_i) \right|^2.$$

Theoretically, a global minimum will occur when

$$\frac{\partial J}{\partial c_n^*} = 0 = \sum_i \left( y_i - \sum_j c_j f_j(x_i) \right) (-f_n^*(x_i))$$

or

$$\sum_j c_j \sum_i f_j(x_i) f_n^*(x_i) = \sum_i y_i f_n^*(x_i)$$

$$\mathbf{A}^H \mathbf{A} \mathbf{c} = \mathbf{A}^H \mathbf{y}$$

where

$$\{\mathbf{A}\}_{ij} = f_j(x_i).$$

When  $\mathbf{A}^H \mathbf{A}$  is invertible, then

$$\mathbf{c} = (\mathbf{A}^H \mathbf{A})^{-1} \mathbf{A}^H \mathbf{y} = \mathbf{A}^\dagger \mathbf{y}$$

where  $\mathbf{A}^\dagger$  is called the pseudo-inverse of  $\mathbf{A}$ . Notice that using this definition of  $\mathbf{A}$  the model can be written

$$\mathbf{y} = \mathbf{A} \mathbf{c} + \boldsymbol{\epsilon}.$$

The command `linalg.lstsq` will solve the linear least squares problem for  $\mathbf{c}$  given  $\mathbf{A}$  and  $\mathbf{y}$ . In addition `linalg.pinv` or `linalg.pinv2` (uses a different method based on singular value decomposition) will find  $\mathbf{A}^\dagger$  given  $\mathbf{A}$ .

The following example and figure demonstrate the use of `linalg.lstsq` and `linalg.pinv` for solving a data-fitting problem. The data shown below were generated using the model:

$$y_i = c_1 e^{-x_i} + c_2 x_i$$

where  $x_i = 0.1i$  for  $i = 1 \dots 10$ ,  $c_1 = 5$ , and  $c_2 = 4$ . Noise is added to  $y_i$  and the coefficients  $c_1$  and  $c_2$  are estimated using linear least squares.

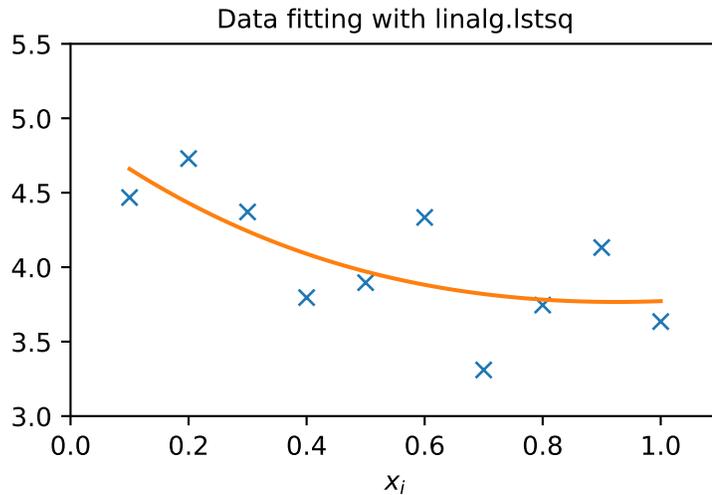
```
>>> import numpy as np
>>> from scipy import linalg
>>> import matplotlib.pyplot as plt
```

```
>>> c1, c2 = 5.0, 2.0
>>> i = np.r_[1:11]
>>> xi = 0.1*i
>>> yi = c1*np.exp(-xi) + c2*xi
>>> zi = yi + 0.05 * np.max(yi) * np.random.randn(len(yi))
```

```
>>> A = np.c_[np.exp(-xi)[:, np.newaxis], xi[:, np.newaxis]]
>>> c, resid, rank, sigma = linalg.lstsq(A, zi)
```

```
>>> xi2 = np.r_[0.1:1.0:100j]
>>> yi2 = c[0]*np.exp(-xi2) + c[1]*xi2
```

```
>>> plt.plot(xi, zi, 'x', xi2, yi2)
>>> plt.axis([0, 1.1, 3.0, 5.5])
>>> plt.xlabel('$x_i$')
>>> plt.title('Data fitting with linalg.lstsq')
>>> plt.show()
```



### Generalized inverse

The generalized inverse is calculated using the command `linalg.pinv` or `linalg.pinv2`. These two commands differ in how they compute the generalized inverse. The first uses the `linalg.lstsq` algorithm while the second uses singular value decomposition. Let  $\mathbf{A}$  be an  $M \times N$  matrix, then if  $M > N$  the generalized inverse is

$$\mathbf{A}^\dagger = (\mathbf{A}^H \mathbf{A})^{-1} \mathbf{A}^H$$

while if  $M < N$  matrix the generalized inverse is

$$\mathbf{A}^\# = \mathbf{A}^H (\mathbf{A} \mathbf{A}^H)^{-1}.$$

In both cases for  $M = N$ , then

$$\mathbf{A}^\dagger = \mathbf{A}^\# = \mathbf{A}^{-1}$$

as long as  $\mathbf{A}$  is invertible.

## Decompositions

In many applications it is useful to decompose a matrix using other representations. There are several decompositions supported by SciPy.

### Eigenvalues and eigenvectors

The eigenvalue-eigenvector problem is one of the most commonly employed linear algebra operations. In one popular form, the eigenvalue-eigenvector problem is to find for some square matrix  $\mathbf{A}$  scalars  $\lambda$  and corresponding vectors  $\mathbf{v}$  such that

$$\mathbf{A} \mathbf{v} = \lambda \mathbf{v}.$$

For an  $N \times N$  matrix, there are  $N$  (not necessarily distinct) eigenvalues — roots of the (characteristic) polynomial

$$|\mathbf{A} - \lambda \mathbf{I}| = 0.$$

The eigenvectors,  $\mathbf{v}$ , are also sometimes called right eigenvectors to distinguish them from another set of left eigenvectors that satisfy

$$\mathbf{v}_L^H \mathbf{A} = \lambda \mathbf{v}_L^H$$

or

$$\mathbf{A}^H \mathbf{v}_L = \lambda^* \mathbf{v}_L.$$

With its default optional arguments, the command `linalg.eig` returns  $\lambda$  and  $\mathbf{v}$ . However, it can also return  $\mathbf{v}_L$  and just  $\lambda$  by itself (`linalg.eigvals` returns just  $\lambda$  as well).

In addition, `linalg.eig` can also solve the more general eigenvalue problem

$$\begin{aligned} \mathbf{A} \mathbf{v} &= \lambda \mathbf{B} \mathbf{v} \\ \mathbf{A}^H \mathbf{v}_L &= \lambda^* \mathbf{B}^H \mathbf{v}_L \end{aligned}$$

for square matrices  $\mathbf{A}$  and  $\mathbf{B}$ . The standard eigenvalue problem is an example of the general eigenvalue problem for  $\mathbf{B} = \mathbf{I}$ . When a generalized eigenvalue problem can be solved, then it provides a decomposition of  $\mathbf{A}$  as

$$\mathbf{A} = \mathbf{B} \mathbf{V} \mathbf{\Lambda} \mathbf{V}^{-1}$$

where  $\mathbf{V}$  is the collection of eigenvectors into columns and  $\mathbf{\Lambda}$  is a diagonal matrix of eigenvalues.

By definition, eigenvectors are only defined up to a constant scale factor. In SciPy, the scaling factor for the eigenvectors is chosen so that  $\|\mathbf{v}\|^2 = \sum_i v_i^2 = 1$ .

As an example, consider finding the eigenvalues and eigenvectors of the matrix

$$\mathbf{A} = \begin{bmatrix} 1 & 5 & 2 \\ 2 & 4 & 1 \\ 3 & 6 & 2 \end{bmatrix}.$$

The characteristic polynomial is

$$\begin{aligned} |\mathbf{A} - \lambda \mathbf{I}| &= (1 - \lambda)[(4 - \lambda)(2 - \lambda) - 6] - \\ &5[2(2 - \lambda) - 3] + 2[12 - 3(4 - \lambda)] \\ &= -\lambda^3 + 7\lambda^2 + 8\lambda - 3. \end{aligned}$$

The roots of this polynomial are the eigenvalues of  $\mathbf{A}$ :

$$\begin{aligned} \lambda_1 &= 7.9579 \\ \lambda_2 &= -1.2577 \\ \lambda_3 &= 0.2997. \end{aligned}$$

The eigenvectors corresponding to each eigenvalue can be found using the original equation. The eigenvectors associated with these eigenvalues can then be found.

```
>>> import numpy as np
>>> from scipy import linalg
>>> A = np.array([[1, 2], [3, 4]])
>>> la, v = linalg.eig(A)
>>> l1, l2 = la
>>> print(l1, l2)      # eigenvalues
(-0.372281323269+0j) (5.37228132327+0j)
>>> print(v[:, 0])    # first eigenvector
[-0.82456484  0.56576746]
>>> print(v[:, 1])    # second eigenvector
[-0.41597356 -0.90937671]
>>> print(np.sum(abs(v**2), axis=0)) # eigenvectors are unitary
[ 1.  1.]
>>> v1 = np.array(v[:, 0]).T
>>> print(linalg.norm(A.dot(v1) - l1*v1)) # check the computation
3.23682852457e-16
```

### Singular value decomposition

Singular Value Decomposition (SVD) can be thought of as an extension of the eigenvalue problem to matrices that are not square. Let  $\mathbf{A}$  be an  $M \times N$  matrix with  $M$  and  $N$  arbitrary. The matrices  $\mathbf{A}^H \mathbf{A}$  and  $\mathbf{A} \mathbf{A}^H$  are square hermitian matrices<sup>1</sup> of size  $N \times N$  and  $M \times M$  respectively. It is known that the eigenvalues of square hermitian matrices are real and non-negative. In addition, there are at most  $\min(M, N)$  identical non-zero eigenvalues of  $\mathbf{A}^H \mathbf{A}$  and  $\mathbf{A} \mathbf{A}^H$ . Define these positive eigenvalues as  $\sigma_i^2$ . The square-root of these are called singular values of  $\mathbf{A}$ . The eigenvectors of  $\mathbf{A}^H \mathbf{A}$  are collected by columns into an  $N \times N$  unitary<sup>2</sup> matrix  $\mathbf{V}$  while the eigenvectors of  $\mathbf{A} \mathbf{A}^H$  are collected by columns in the unitary matrix  $\mathbf{U}$ , the singular values are collected in an  $M \times N$  zero matrix  $\mathbf{\Sigma}$  with main diagonal entries set to the singular values. Then

$$\mathbf{A} = \mathbf{U} \mathbf{\Sigma} \mathbf{V}^H$$

is the singular-value decomposition of  $\mathbf{A}$ . Every matrix has a singular value decomposition. Sometimes, the singular values are called the spectrum of  $\mathbf{A}$ . The command `linalg.svd` will return  $\mathbf{U}$ ,  $\mathbf{V}^H$ , and  $\sigma_i$  as an array of the singular values. To obtain the matrix  $\mathbf{\Sigma}$  use `linalg.diagsvd`. The following example illustrates the use of `linalg.svd`.

```
>>> import numpy as np
>>> from scipy import linalg
>>> A = np.array([[1, 2, 3], [4, 5, 6]])
>>> A
array([[1, 2, 3],
       [4, 5, 6]])
>>> M,N = A.shape
>>> U,s,Vh = linalg.svd(A)
>>> Sig = linalg.diagsvd(s,M,N)
>>> U, Vh = U, Vh
>>> U
array([[ -0.3863177 , -0.92236578],
       [-0.92236578,  0.3863177 ]])
>>> Sig
array([[ 9.508032 ,  0.          ,  0.          ],
       [ 0.          ,  0.77286964,  0.          ]])
>>> Vh
array([[ -0.42866713, -0.56630692, -0.7039467 ],
       [ 0.80596391,  0.11238241, -0.58119908],
       [ 0.40824829, -0.81649658,  0.40824829]])
>>> U.dot(Sig.dot(Vh)) #check computation
array([[ 1.,  2.,  3.],
       [ 4.,  5.,  6.]])
```

### LU decomposition

The LU decomposition finds a representation for the  $M \times N$  matrix  $\mathbf{A}$  as

$$\mathbf{A} = \mathbf{P} \mathbf{L} \mathbf{U}$$

where  $\mathbf{P}$  is an  $M \times M$  permutation matrix (a permutation of the rows of the identity matrix),  $\mathbf{L}$  is in  $M \times K$  lower triangular or trapezoidal matrix ( $K = \min(M, N)$ ) with unit-diagonal, and  $\mathbf{U}$  is an upper triangular or trapezoidal matrix. The SciPy command for this decomposition is `linalg.lu`.

Such a decomposition is often useful for solving many simultaneous equations where the left-hand-side does not change but the right hand side does. For example, suppose we are going to solve

$$\mathbf{A} \mathbf{x}_i = \mathbf{b}_i$$

<sup>1</sup> A hermitian matrix  $\mathbf{D}$  satisfies  $\mathbf{D}^H = \mathbf{D}$ .

<sup>2</sup> A unitary matrix  $\mathbf{D}$  satisfies  $\mathbf{D}^H \mathbf{D} = \mathbf{I} = \mathbf{D} \mathbf{D}^H$  so that  $\mathbf{D}^{-1} = \mathbf{D}^H$ .

for many different  $\mathbf{b}_i$ . The LU decomposition allows this to be written as

$$\mathbf{PLU}\mathbf{x}_i = \mathbf{b}_i.$$

Because  $\mathbf{L}$  is lower-triangular, the equation can be solved for  $\mathbf{U}\mathbf{x}_i$  and finally  $\mathbf{x}_i$  very rapidly using forward- and back-substitution. An initial time spent factoring  $\mathbf{A}$  allows for very rapid solution of similar systems of equations in the future. If the intent for performing LU decomposition is for solving linear systems then the command `linalg.lu_factor` should be used followed by repeated applications of the command `linalg.lu_solve` to solve the system for each new right-hand-side.

### *Cholesky decomposition*

Cholesky decomposition is a special case of LU decomposition applicable to Hermitian positive definite matrices. When  $\mathbf{A} = \mathbf{A}^H$  and  $\mathbf{x}^H \mathbf{A} \mathbf{x} \geq 0$  for all  $\mathbf{x}$ , then decompositions of  $\mathbf{A}$  can be found so that

$$\begin{aligned}\mathbf{A} &= \mathbf{U}^H \mathbf{U} \\ \mathbf{A} &= \mathbf{L} \mathbf{L}^H\end{aligned}$$

where  $\mathbf{L}$  is lower-triangular and  $\mathbf{U}$  is upper triangular. Notice that  $\mathbf{L} = \mathbf{U}^H$ . The command `linalg.cholesky` computes the cholesky factorization. For using cholesky factorization to solve systems of equations there are also `linalg.cho_factor` and `linalg.cho_solve` routines that work similarly to their LU decomposition counterparts.

### *QR decomposition*

The QR decomposition (sometimes called a polar decomposition) works for any  $M \times N$  array and finds an  $M \times M$  unitary matrix  $\mathbf{Q}$  and an  $M \times N$  upper-trapezoidal matrix  $\mathbf{R}$  such that

$$\mathbf{A} = \mathbf{Q}\mathbf{R}.$$

Notice that if the SVD of  $\mathbf{A}$  is known then the QR decomposition can be found

$$\mathbf{A} = \mathbf{U}\mathbf{\Sigma}\mathbf{V}^H = \mathbf{Q}\mathbf{R}$$

implies that  $\mathbf{Q} = \mathbf{U}$  and  $\mathbf{R} = \mathbf{\Sigma}\mathbf{V}^H$ . Note, however, that in SciPy independent algorithms are used to find QR and SVD decompositions. The command for QR decomposition is `linalg.qr`.

### *Schur decomposition*

For a square  $N \times N$  matrix,  $\mathbf{A}$ , the Schur decomposition finds (not-necessarily unique) matrices  $\mathbf{T}$  and  $\mathbf{Z}$  such that

$$\mathbf{A} = \mathbf{Z}\mathbf{T}\mathbf{Z}^H$$

where  $\mathbf{Z}$  is a unitary matrix and  $\mathbf{T}$  is either upper-triangular or quasi-upper triangular depending on whether or not a real schur form or complex schur form is requested. For a real schur form both  $\mathbf{T}$  and  $\mathbf{Z}$  are real-valued when  $\mathbf{A}$  is real-valued. When  $\mathbf{A}$  is a real-valued matrix the real schur form is only quasi-upper triangular because  $2 \times 2$  blocks extrude from the main diagonal corresponding to any complex-valued eigenvalues. The command `linalg.schur` finds the Schur decomposition while the command `linalg.rs2csf` converts  $\mathbf{T}$  and  $\mathbf{Z}$  from a real Schur form to a complex Schur form. The Schur form is especially useful in calculating functions of matrices.

The following example illustrates the schur decomposition:

```
>>> from scipy import linalg
>>> A = np.mat('[1 3 2; 1 4 5; 2 3 6]')
>>> T, Z = linalg.schur(A)
>>> T1, Z1 = linalg.schur(A, 'complex')
>>> T2, Z2 = linalg.rs2csf(T, Z)
>>> T
```

```

array([[ 9.90012467,  1.78947961, -0.65498528],
       [ 0.          ,  0.54993766, -1.57754789],
       [ 0.          ,  0.51260928,  0.54993766]])
>>> T2
array([[ 9.90012467 +0.00000000e+00j, -0.32436598 +1.55463542e+00j,
        -0.88619748 +5.69027615e-01j],
       [ 0.00000000 +0.00000000e+00j,  0.54993766 +8.99258408e-01j,
        1.06493862 -5.80496735e-16j],
       [ 0.00000000 +0.00000000e+00j,  0.00000000 +0.00000000e+00j,
        0.54993766 -8.99258408e-01j]])
>>> abs(T1 - T2) # different
array([[ 1.06604538e-14,  2.06969555e+00,  1.69375747e+00], # may vary
       [ 0.00000000e+00,  1.33688556e-15,  4.74146496e-01],
       [ 0.00000000e+00,  0.00000000e+00,  1.13220977e-15]])
>>> abs(Z1 - Z2) # different
array([[ 0.06833781,  0.88091091,  0.79568503], # may vary
       [ 0.11857169,  0.44491892,  0.99594171],
       [ 0.12624999,  0.60264117,  0.77257633]])
>>> T, Z, T1, Z1, T2, Z2 = map(np.mat, (T, Z, T1, Z1, T2, Z2))
>>> abs(A - Z*T*Z.H) # same
matrix([[ 5.55111512e-16,  1.77635684e-15,  2.22044605e-15],
        [ 0.00000000e+00,  3.99680289e-15,  8.88178420e-16],
        [ 1.11022302e-15,  4.44089210e-16,  3.55271368e-15]])
>>> abs(A - Z1*T1*Z1.H) # same
matrix([[ 4.26993904e-15,  6.21793362e-15,  8.00007092e-15],
        [ 5.77945386e-15,  6.21798014e-15,  1.06653681e-14],
        [ 7.16681444e-15,  8.90271058e-15,  1.77635764e-14]])
>>> abs(A - Z2*T2*Z2.H) # same
matrix([[ 6.02594127e-16,  1.77648931e-15,  2.22506907e-15],
        [ 2.46275555e-16,  3.99684548e-15,  8.91642616e-16],
        [ 8.88225111e-16,  8.88312432e-16,  4.44104848e-15]])
    
```

### Interpolative Decomposition

`scipy.linalg.interpolative` contains routines for computing the interpolative decomposition (ID) of a matrix. For a matrix  $A \in \mathbb{C}^{m \times n}$  of rank  $k \leq \min\{m, n\}$  this is a factorization

$$A\Pi = [A\Pi_1 \quad A\Pi_2] = A\Pi_1 [I \quad T],$$

where  $\Pi = [\Pi_1, \Pi_2]$  is a permutation matrix with  $\Pi_1 \in \{0, 1\}^{n \times k}$ , i.e.,  $A\Pi_2 = A\Pi_1 T$ . This can equivalently be written as  $A = BP$ , where  $B = A\Pi_1$  and  $P = [I, T]\Pi^T$  are the *skeleton* and *interpolation matrices*, respectively.

**See also:**

`scipy.linalg.interpolative` — for more information.

### Matrix Functions

Consider the function  $f(x)$  with Taylor series expansion

$$f(x) = \sum_{k=0}^{\infty} \frac{f^{(k)}(0)}{k!} x^k.$$

A matrix function can be defined using this Taylor series for the square matrix  $\mathbf{A}$  as

$$f(\mathbf{A}) = \sum_{k=0}^{\infty} \frac{f^{(k)}(0)}{k!} \mathbf{A}^k.$$

While, this serves as a useful representation of a matrix function, it is rarely the best way to calculate a matrix function.

### Exponential and logarithm functions

The matrix exponential is one of the more common matrix functions. The preferred method for implementing the matrix exponential is to use scaling and a Padé approximation for  $e^x$ . This algorithm is implemented as `linalg.expm`.

The inverse of the matrix exponential is the matrix logarithm defined as the inverse of the matrix exponential.

$$\mathbf{A} \equiv \exp(\log(\mathbf{A})).$$

The matrix logarithm can be obtained with `linalg.logm`.

### Trigonometric functions

The trigonometric functions `sin`, `cos`, and `tan` are implemented for matrices in `linalg.sinm`, `linalg.cosm`, and `linalg.tanm` respectively. The matrix `sin` and `cosine` can be defined using Euler's identity as

$$\begin{aligned}\sin(\mathbf{A}) &= \frac{e^{j\mathbf{A}} - e^{-j\mathbf{A}}}{2j} \\ \cos(\mathbf{A}) &= \frac{e^{j\mathbf{A}} + e^{-j\mathbf{A}}}{2}.\end{aligned}$$

The tangent is

$$\tan(x) = \frac{\sin(x)}{\cos(x)} = [\cos(x)]^{-1} \sin(x)$$

and so the matrix tangent is defined as

$$[\cos(\mathbf{A})]^{-1} \sin(\mathbf{A}).$$

### Hyperbolic trigonometric functions

The hyperbolic trigonometric functions `sinh`, `cosh`, and `tanh` can also be defined for matrices using the familiar definitions:

$$\begin{aligned}\sinh(\mathbf{A}) &= \frac{e^{\mathbf{A}} - e^{-\mathbf{A}}}{2} \\ \cosh(\mathbf{A}) &= \frac{e^{\mathbf{A}} + e^{-\mathbf{A}}}{2} \\ \tanh(\mathbf{A}) &= [\cosh(\mathbf{A})]^{-1} \sinh(\mathbf{A}).\end{aligned}$$

These matrix functions can be found using `linalg.sinhm`, `linalg.coshm`, and `linalg.tanhm`.

### Arbitrary function

Finally, any arbitrary function that takes one complex number and returns a complex number can be called as a matrix function using the command `linalg.funm`. This command takes the matrix and an arbitrary Python function. It then implements an algorithm from Golub and Van Loan's book "Matrix Computations" to compute the function applied to the matrix using a Schur decomposition. Note that *the function needs to accept complex numbers* as input in order to work with this algorithm. For example the following code computes the zeroth-order Bessel function applied to a matrix.

```
>>> from scipy import special, random, linalg
>>> np.random.seed(1234)
>>> A = random.rand(3, 3)
>>> B = linalg.funm(A, lambda x: special.jv(0, x))
>>> A
```

```
array([[ 0.19151945,  0.62210877,  0.43772774],
       [ 0.78535858,  0.77997581,  0.27259261],
       [ 0.27646426,  0.80187218,  0.95813935]])
>>> B
array([[ 0.86511146, -0.19676526, -0.13856748],
       [-0.17479869,  0.7259118 , -0.16606258],
       [-0.19212044, -0.32052767,  0.73590704]])
>>> linalg.eigvals(A)
array([ 1.73881510+0.j, -0.20270676+0.j,  0.39352627+0.j])
>>> special.jv(0, linalg.eigvals(A))
array([ 0.37551908+0.j,  0.98975384+0.j,  0.96165739+0.j])
>>> linalg.eigvals(B)
array([ 0.37551908+0.j,  0.98975384+0.j,  0.96165739+0.j])
```

Note how, by virtue of how matrix analytic functions are defined, the Bessel function has acted on the matrix eigenvalues.

### Special matrices

SciPy and NumPy provide several functions for creating special matrices that are frequently used in engineering and science.

Type	Function	Description
block diagonal	<code>scipy.linalg.block_diag</code>	Create a block diagonal matrix from the provided arrays.
circulant	<code>scipy.linalg.circulant</code>	Construct a circulant matrix.
companion	<code>scipy.linalg.companion</code>	Create a companion matrix.
Hadamard	<code>scipy.linalg.hadamard</code>	Construct a Hadamard matrix.
Hankel	<code>scipy.linalg.hankel</code>	Construct a Hankel matrix.
Hilbert	<code>scipy.linalg.hilbert</code>	Construct a Hilbert matrix.
Inverse Hilbert	<code>scipy.linalg.invhilbert</code>	Construct the inverse of a Hilbert matrix.
Leslie	<code>scipy.linalg.leslie</code>	Create a Leslie matrix.
Pascal	<code>scipy.linalg.pascal</code>	Create a Pascal matrix.
Toeplitz	<code>scipy.linalg toeplitz</code>	Construct a Toeplitz matrix.
Van der Monde	<code>numpy.vander</code>	Generate a Van der Monde matrix.

For examples of the use of these functions, see their respective docstrings.

## 3.1.10 Sparse Eigenvalue Problems with ARPACK

### Introduction

ARPACK is a Fortran package which provides routines for quickly finding a few eigenvalues/eigenvectors of large sparse matrices. In order to find these solutions, it requires only left-multiplication by the matrix in question. This operation is performed through a *reverse-communication* interface. The result of this structure is that ARPACK is able to find eigenvalues and eigenvectors of any linear function mapping a vector to a vector.

All of the functionality provided in ARPACK is contained within the two high-level interfaces `scipy.sparse.linalg.eigs` and `scipy.sparse.linalg.eigsh`. `eigs` provides interfaces to find the eigenvalues/vectors of real or complex nonsymmetric square matrices, while `eigsh` provides interfaces for real-symmetric or complex-hermitian matrices.

## Basic Functionality

ARPACK can solve either standard eigenvalue problems of the form

$$A\mathbf{x} = \lambda\mathbf{x}$$

or general eigenvalue problems of the form

$$A\mathbf{x} = \lambda M\mathbf{x}$$

The power of ARPACK is that it can compute only a specified subset of eigenvalue/eigenvector pairs. This is accomplished through the keyword `which`. The following values of `which` are available:

- `which = 'LM'` : Eigenvalues with largest magnitude (`eigs`, `eigsh`), that is, largest eigenvalues in the euclidean norm of complex numbers.
- `which = 'SM'` : Eigenvalues with smallest magnitude (`eigs`, `eigsh`), that is, smallest eigenvalues in the euclidean norm of complex numbers.
- `which = 'LR'` : Eigenvalues with largest real part (`eigs`)
- `which = 'SR'` : Eigenvalues with smallest real part (`eigs`)
- `which = 'LI'` : Eigenvalues with largest imaginary part (`eigs`)
- `which = 'SI'` : Eigenvalues with smallest imaginary part (`eigs`)
- `which = 'LA'` : Eigenvalues with largest algebraic value (`eigsh`), that is, largest eigenvalues inclusive of any negative sign.
- `which = 'SA'` : Eigenvalues with smallest algebraic value (`eigsh`), that is, smallest eigenvalues inclusive of any negative sign.
- `which = 'BE'` : Eigenvalues from both ends of the spectrum (`eigsh`)

Note that ARPACK is generally better at finding extremal eigenvalues: that is, eigenvalues with large magnitudes. In particular, using `which = 'SM'` may lead to slow execution time and/or anomalous results. A better approach is to use *shift-invert mode*.

## Shift-Invert Mode

Shift invert mode relies on the following observation. For the generalized eigenvalue problem

$$A\mathbf{x} = \lambda M\mathbf{x}$$

it can be shown that

$$(A - \sigma M)^{-1} M\mathbf{x} = \nu\mathbf{x}$$

where

$$\nu = \frac{1}{\lambda - \sigma}$$

## Examples

Imagine you'd like to find the smallest and largest eigenvalues and the corresponding eigenvectors for a large matrix. ARPACK can handle many forms of input: dense matrices such as `numpy.ndarray` instances, sparse matrices such as `scipy.sparse.csr_matrix`, or a general linear operator derived from `scipy.sparse.linalg.LinearOperator`. For this example, for simplicity, we'll construct a symmetric, positive-definite matrix.

```
>>> import numpy as np
>>> from scipy.linalg import eigh
>>> from scipy.sparse.linalg import eigsh
>>> np.set_printoptions(suppress=True)
>>>
>>> np.random.seed(0)
>>> X = np.random.random((100,100)) - 0.5
>>> X = np.dot(X, X.T) #create a symmetric matrix
```

We now have a symmetric matrix  $X$  with which to test the routines. First compute a standard eigenvalue decomposition using `eigh`:

```
>>> evals_all, evecs_all = eigh(X)
```

As the dimension of  $X$  grows, this routine becomes very slow. Especially if only a few eigenvectors and eigenvalues are needed, ARPACK can be a better option. First let's compute the largest eigenvalues (which = 'LM') of  $X$  and compare them to the known results:

```
>>> evals_large, evecs_large = eigsh(X, 3, which='LM')
>>> print(evals_all[-3:])
[ 29.1446102  30.05821805  31.19467646]
>>> print(evals_large)
[ 29.1446102  30.05821805  31.19467646]
>>> print(np.dot(evecs_large.T, evecs_all[:, -3:]))
array([[ -1.  0.  0.],          # may vary (signs)
       [ 0.  1.  0.],
       [-0.  0. -1.]])
```

The results are as expected. ARPACK recovers the desired eigenvalues, and they match the previously known results. Furthermore, the eigenvectors are orthogonal, as we'd expect. Now let's attempt to solve for the eigenvalues with smallest magnitude:

```
>>> evals_small, evecs_small = eigsh(X, 3, which='SM')
Traceback (most recent call last):          # may vary (convergence)
...
scipy.sparse.linalg.eigen.arpack.arpack.ArpackNoConvergence:
ARPACK error -1: No convergence (1001 iterations, 0/3 eigenvectors converged)
```

Oops. We see that as mentioned above, ARPACK is not quite as adept at finding small eigenvalues. There are a few ways this problem can be addressed. We could increase the tolerance (`tol`) to lead to faster convergence:

```
>>> evals_small, evecs_small = eigsh(X, 3, which='SM', tol=1E-2)
>>> evals_all[:3]
array([0.0003783, 0.00122714, 0.00715878])
>>> evals_small
array([0.00037831, 0.00122714, 0.00715881])
>>> np.dot(evecs_small.T, evecs_all[:, :3])
array([[ 0.99999999  0.00000024 -0.00000049],          # may vary (signs)
       [-0.00000023  0.99999999  0.00000056],
       [ 0.00000031 -0.00000037  0.99999852]])
```

This works, but we lose the precision in the results. Another option is to increase the maximum number of iterations (`maxiter`) from 1000 to 5000:

```
>>> evals_small, evecs_small = eigsh(X, 3, which='SM', maxiter=5000)
>>> evals_all[:3]
array([0.0003783, 0.00122714, 0.00715878])
```

```
>>> evals_small
array([0.0003783, 0.00122714, 0.00715878])
>>> np.dot(evecs_small.T, evecs_all[:, :3])
array([[ 1.  0.  0.],
       [-0.  1.  0.],
       [ 0.  0. -1.]])
# may vary (signs)
```

We get the results we'd hoped for, but the computation time is much longer. Fortunately, ARPACK contains a mode that allows quick determination of non-external eigenvalues: *shift-invert mode*. As mentioned above, this mode involves transforming the eigenvalue problem to an equivalent problem with different eigenvalues. In this case, we hope to find eigenvalues near zero, so we'll choose  $\sigma = 0$ . The transformed eigenvalues will then satisfy  $\nu = 1/(\sigma - \lambda) = 1/\lambda$ , so our small eigenvalues  $\lambda$  become large eigenvalues  $\nu$ .

```
>>> evals_small, evecs_small = eigsh(X, 3, sigma=0, which='LM')
>>> evals_all[:3]
array([0.0003783, 0.00122714, 0.00715878])
>>> evals_small
array([0.0003783, 0.00122714, 0.00715878])
>>> np.dot(evecs_small.T, evecs_all[:, :3])
array([[ 1.  0.  0.],
       [ 0. -1. -0.],
       [-0. -0.  1.]])
# may vary (signs)
```

We get the results we were hoping for, with much less computational time. Note that the transformation from  $\nu \rightarrow \lambda$  takes place entirely in the background. The user need not worry about the details.

The shift-invert mode provides more than just a fast way to obtain a few small eigenvalues. Say you desire to find internal eigenvalues and eigenvectors, e.g. those nearest to  $\lambda = 1$ . Simply set  $\sigma = 1$  and ARPACK takes care of the rest:

```
>>> evals_mid, evecs_mid = eigsh(X, 3, sigma=1, which='LM')
>>> i_sort = np.argsort(abs(1. / (1 - evals_all)))[-3:]
>>> evals_all[i_sort]
array([1.16577199, 0.85081388, 1.06642272])
>>> evals_mid
array([0.85081388, 1.06642272, 1.16577199])
>>> print(np.dot(evecs_mid.T, evecs_all[:, i_sort]))
array([[ -0.  1.  0.],
       [-0. -0.  1.],
       [ 1.  0.  0.]])
# may vary (signs)
```

The eigenvalues come out in a different order, but they're all there. Note that the shift-invert mode requires the internal solution of a matrix inverse. This is taken care of automatically by `eigsh` and `eigs`, but the operation can also be specified by the user. See the docstring of `scipy.sparse.linalg.eigsh` and `scipy.sparse.linalg.eigs` for details.

## References

### 3.1.11 Compressed Sparse Graph Routines (`scipy.sparse.csgraph`)

#### Example: Word Ladders

A [Word Ladder](#) is a word game invented by Lewis Carroll in which players find paths between words by switching one letter at a time. For example, one can link “ape” and “man” in the following way:

ape → apt → ait → bit → big → bag → mag → man

Note that each step involves changing just one letter of the word. This is just one possible path from “ape” to “man”, but is it the shortest possible path? If we desire to find the shortest word ladder path between two given words, the sparse graph submodule can help.

First we need a list of valid words. Many operating systems have such a list built-in. For example, on linux, a word list can often be found at one of the following locations:

```
/usr/share/dict
/var/lib/dict
```

Another easy source for words are the scrabble word lists available at various sites around the internet (search with your favorite search engine). We’ll first create this list. The system word lists consist of a file with one word per line. The following should be modified to use the particular word list you have available:

```
>>> word_list = open('/usr/share/dict/words').readlines()
>>> word_list = map(str.strip, word_list)
```

We want to look at words of length 3, so let’s select just those words of the correct length. We’ll also eliminate words which start with upper-case (proper nouns) or contain non alpha-numeric characters like apostrophes and hyphens. Finally, we’ll make sure everything is lower-case for comparison later:

```
>>> word_list = [word for word in word_list if len(word) == 3]
>>> word_list = [word for word in word_list if word[0].islower()]
>>> word_list = [word for word in word_list if word.isalpha()]
>>> word_list = list(map(str.lower, word_list))
>>> len(word_list)
586      # may vary
```

Now we have a list of 586 valid three-letter words (the exact number may change depending on the particular list used). Each of these words will become a node in our graph, and we will create edges connecting the nodes associated with each pair of words which differs by only one letter.

There are efficient ways to do this, and inefficient ways to do this. To do this as efficiently as possible, we’re going to use some sophisticated numpy array manipulation:

```
>>> import numpy as np
>>> word_list = np.asarray(word_list)
>>> word_list.dtype      # these are unicode characters in Python 3
dtype('<U3')
>>> word_list.sort()    # sort for quick searching later
```

We have an array where each entry is three unicode characters long. We’d like to find all pairs where exactly one character is different. We’ll start by converting each word to a three-dimensional vector:

```
>>> word_bytes = np.ndarray((word_list.size, word_list.itemsize),
...                          dtype='uint8',
...                          buffer=word_list.data)
>>> # each unicode character is four bytes long. We only need first byte
>>> # we know that there are three characters in each word
>>> word_bytes = word_bytes[:, ::word_list.itemsize//3]
>>> word_bytes.shape
(586, 3)      # may vary
```

Now we’ll use the [Hamming distance](#) between each point to determine which pairs of words are connected. The Hamming distance measures the fraction of entries between two vectors which differ: any two words with a hamming distance equal to  $1/N$ , where  $N$  is the number of letters, are connected in the word ladder:

```
>>> from scipy.spatial.distance import pdist, squareform
>>> from scipy.sparse import csr_matrix
>>> hamming_dist = pdist(word_bytes, metric='hamming')
>>> # there are three characters in each word
>>> graph = csr_matrix(squareform(hamming_dist < 1.5 / 3))
```

When comparing the distances, we don't use an equality because this can be unstable for floating point values. The inequality produces the desired result as long as no two entries of the word list are identical. Now that our graph is set up, we'll use a shortest path search to find the path between any two words in the graph:

```
>>> i1 = word_list.searchsorted('ape')
>>> i2 = word_list.searchsorted('man')
>>> word_list[i1]
'ape'
>>> word_list[i2]
'man'
```

We need to check that these match, because if the words are not in the list that will not be the case. Now all we need is to find the shortest path between these two indices in the graph. We'll use Dijkstra's algorithm, because it allows us to find the path for just one node:

```
>>> from scipy.sparse.csgraph import dijkstra
>>> distances, predecessors = dijkstra(graph, indices=i1,
...                               return_predecessors=True)
>>> print(distances[i2])
5.0 # may vary
```

So we see that the shortest path between 'ape' and 'man' contains only five steps. We can use the predecessors returned by the algorithm to reconstruct this path:

```
>>> path = []
>>> i = i2
>>> while i != i1:
...     path.append(word_list[i])
...     i = predecessors[i]
>>> path.append(word_list[i1])
>>> print(path[::-1])
['ape', 'apt', 'opt', 'oat', 'mat', 'man'] # may vary
```

This is three fewer links than our initial example: the path from ape to man is only five steps.

Using other tools in the module, we can answer other questions. For example, are there three-letter words which are not linked in a word ladder? This is a question of connected components in the graph:

```
>>> from scipy.sparse.csgraph import connected_components
>>> N_components, component_list = connected_components(graph)
>>> print(N_components)
15 # may vary
```

In this particular sample of three-letter words, there are 15 connected components: that is, 15 distinct sets of words with no paths between the sets. How many words are in each of these sets? We can learn this from the list of components:

```
>>> [np.sum(component_list == i) for i in range(N_components)]
[571, 1, 1, 1, 2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1] # may vary
```

There is one large connected set, and 14 smaller ones. Let's look at the words in the smaller ones:

```
>>> [list(word_list[np.where(component_list == i)]) for i in range(1, N_components)]
[['aha'],      # may vary
 ['chi'],
 ['ebb'],
 ['ems', 'emu'],
 ['gnu'],
 ['ism'],
 ['khz'],
 ['nth'],
 ['ova'],
 ['qua'],
 ['ugh'],
 ['ups'],
 ['urn'],
 ['use']]
```

These are all the three-letter words which do not connect to others via a word ladder.

We might also be curious about which words are maximally separated. Which two words take the most links to connect? We can determine this by computing the matrix of all shortest paths. Note that by convention, the distance between two non-connected points is reported to be infinity, so we'll need to remove these before finding the maximum:

```
>>> distances, predecessors = dijkstra(graph, return_predecessors=True)
>>> max_distance = np.max(distances[~np.isinf(distances)])
>>> print(max_distance)
13.0      # may vary
```

So there is at least one pair of words which takes 13 steps to get from one to the other! Let's determine which these are:

```
>>> i1, i2 = np.where(distances == max_distance)
>>> list(zip(word_list[i1], word_list[i2]))
[('imp', 'ohm'),      # may vary
 ('imp', 'ohs'),
 ('ohm', 'imp'),
 ('ohm', 'ump'),
 ('ohs', 'imp'),
 ('ohs', 'ump'),
 ('ump', 'ohm'),
 ('ump', 'ohs')]
```

We see that there are two pairs of words which are maximally separated from each other: 'imp' and 'ump' on one hand, and 'ohm' and 'ohs' on the other hand. We can find the connecting list in the same way as above:

```
>>> path = []
>>> i = i2[0]
>>> while i != i1[0]:
...     path.append(word_list[i])
...     i = predecessors[i1[0], i]
>>> path.append(word_list[i1[0]])
>>> print(path[::-1])
['imp', 'amp', 'asp', 'ass', 'ads', 'add', 'aid', 'mid', 'mod', 'moo', 'too', 'tho',
 ↪ 'oho', 'ohm']      # may vary
```

This gives us the path we desired to see.

Word ladders are just one potential application of scipy's fast graph algorithms for sparse matrices. Graph theory makes appearances in many areas of mathematics, data analysis, and machine learning. The sparse graph tools are

flexible enough to handle many of these situations.

### 3.1.12 Spatial data structures and algorithms (`scipy.spatial`)

`scipy.spatial` can compute triangulations, Voronoi diagrams, and convex hulls of a set of points, by leveraging the `Qhull` library.

Moreover, it contains `KDTree` implementations for nearest-neighbor point queries, and utilities for distance computations in various metrics.

#### Delaunay triangulations

The Delaunay triangulation is a subdivision of a set of points into a non-overlapping set of triangles, such that no point is inside the circumcircle of any triangle. In practice, such triangulations tend to avoid triangles with small angles.

Delaunay triangulation can be computed using `scipy.spatial` as follows:

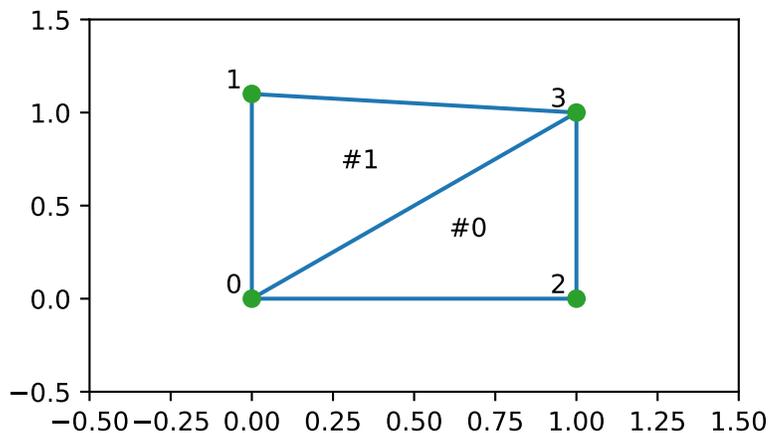
```
>>> from scipy.spatial import Delaunay
>>> points = np.array([[0, 0], [0, 1.1], [1, 0], [1, 1]])
>>> tri = Delaunay(points)
```

We can visualize it:

```
>>> import matplotlib.pyplot as plt
>>> plt.triplot(points[:,0], points[:,1], tri.simplices.copy())
>>> plt.plot(points[:,0], points[:,1], 'o')
```

And add some further decorations:

```
>>> for j, p in enumerate(points):
...     plt.text(p[0]-0.03, p[1]+0.03, j, ha='right') # label the points
>>> for j, s in enumerate(tri.simplices):
...     p = points[s].mean(axis=0)
...     plt.text(p[0], p[1], '#%d' % j, ha='center') # label triangles
>>> plt.xlim(-0.5, 1.5); plt.ylim(-0.5, 1.5)
>>> plt.show()
```



The structure of the triangulation is encoded in the following way: the `simplices` attribute contains the indices of the points in the `points` array that make up the triangle. For instance:

```
>>> i = 1
>>> tri.simplices[i,:]
array([3, 1, 0], dtype=int32)
>>> points[tri.simplices[i,:]]
array([[ 1. ,  1. ],
       [ 0. ,  1.1],
       [ 0. ,  0. ]])
```

Moreover, neighboring triangles can also be found out:

```
>>> tri.neighbors[i]
array([-1,  0, -1], dtype=int32)
```

What this tells us is that this triangle has triangle #0 as a neighbor, but no other neighbors. Moreover, it tells us that neighbor 0 is opposite the vertex 1 of the triangle:

```
>>> points[tri.simplices[i, 1]]
array([ 0. ,  1.1])
```

Indeed, from the figure we see that this is the case.

Qhull can also perform tessellations to simplices also for higher-dimensional point sets (for instance, subdivision into tetrahedra in 3-D).

### *Coplanar points*

It is important to note that not *all* points necessarily appear as vertices of the triangulation, due to numerical precision issues in forming the triangulation. Consider the above with a duplicated point:

```
>>> points = np.array([[0, 0], [0, 1], [1, 0], [1, 1], [1, 1]])
>>> tri = Delaunay(points)
>>> np.unique(tri.simplices.ravel())
array([0, 1, 2, 3], dtype=int32)
```

Observe that point #4, which is a duplicate, does not occur as a vertex of the triangulation. That this happened is recorded:

```
>>> tri.coplanar
array([[4, 0, 3]], dtype=int32)
```

This means that point 4 resides near triangle 0 and vertex 3, but is not included in the triangulation.

Note that such degeneracies can occur not only because of duplicated points, but also for more complicated geometrical reasons, even in point sets that at first sight seem well-behaved.

However, Qhull has the “QJ” option, which instructs it to perturb the input data randomly until degeneracies are resolved:

```
>>> tri = Delaunay(points, qhull_options="QJ Pp")
>>> points[tri.simplices]
array([[1, 0],
       [1, 1],
       [0, 0]],
      [[1, 1],
       [1, 1],
       [1, 0]],
```

```

[[1, 1],
 [0, 1],
 [0, 0]],
 [[0, 1],
 [1, 1],
 [1, 1]])

```

Two new triangles appeared. However, we see that they are degenerate and have zero area.

## Convex hulls

Convex hull is the smallest convex object containing all points in a given point set.

These can be computed via the Qhull wrappers in *scipy.spatial* as follows:

```

>>> from scipy.spatial import ConvexHull
>>> points = np.random.rand(30, 2) # 30 random points in 2-D
>>> hull = ConvexHull(points)

```

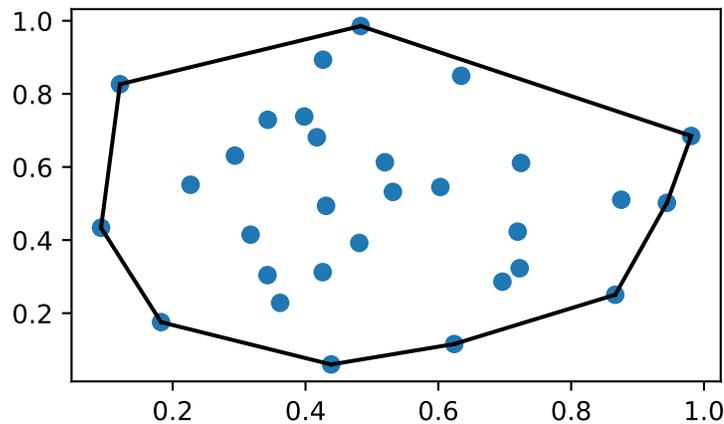
The convex hull is represented as a set of N-1 dimensional simplices, which in 2-D means line segments. The storage scheme is exactly the same as for the simplices in the Delaunay triangulation discussed above.

We can illustrate the above result:

```

>>> import matplotlib.pyplot as plt
>>> plt.plot(points[:,0], points[:,1], 'o')
>>> for simplex in hull.simplices:
...     plt.plot(points[simplex,0], points[simplex,1], 'k-')
>>> plt.show()

```



The same can be achieved with *scipy.spatial.convex\_hull\_plot\_2d*.

## Voronoi diagrams

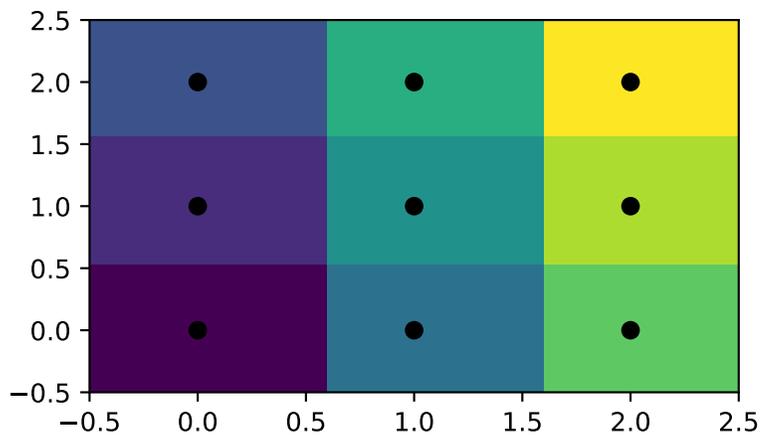
A Voronoi diagram is a subdivision of the space into the nearest neighborhoods of a given set of points.

There are two ways to approach this object using `scipy.spatial`. First, one can use the `KDTree` to answer the question “which of the points is closest to this one”, and define the regions that way:

```
>>> from scipy.spatial import KDTree
>>> points = np.array([[0, 0], [0, 1], [0, 2], [1, 0], [1, 1], [1, 2],
...                   [2, 0], [2, 1], [2, 2]])
>>> tree = KDTree(points)
>>> tree.query([0.1, 0.1])
(0.14142135623730953, 0)
```

So the point `(0.1, 0.1)` belongs to region 0. In color:

```
>>> x = np.linspace(-0.5, 2.5, 31)
>>> y = np.linspace(-0.5, 2.5, 33)
>>> xx, yy = np.meshgrid(x, y)
>>> xy = np.c_[xx.ravel(), yy.ravel()]
>>> import matplotlib.pyplot as plt
>>> plt.pcolor(x, y, tree.query(xy)[1].reshape(33, 31))
>>> plt.plot(points[:,0], points[:,1], 'ko')
>>> plt.show()
```



This does not, however, give the Voronoi diagram as a geometrical object.

The representation in terms of lines and points can be again obtained via the Qhull wrappers in `scipy.spatial`:

```
>>> from scipy.spatial import Voronoi
>>> vor = Voronoi(points)
>>> vor.vertices
array([[ 0.5,  0.5],
       [ 1.5,  0.5],
       [ 0.5,  1.5],
       [ 1.5,  1.5]])
```

The Voronoi vertices denote the set of points forming the polygonal edges of the Voronoi regions. In this case, there are 9 different regions:

```
>>> vor.regions
[[[], [-1, 0], [-1, 1], [1, -1, 0], [3, -1, 2], [-1, 3], [-1, 2], [3, 2, 0, 1], [2, -1,
→ 0], [3, -1, 1]]]
```

Negative value  $-1$  again indicates a point at infinity. Indeed, only one of the regions,  $[3, 1, 0, 2]$ , is bounded. Note here that due to similar numerical precision issues as in Delaunay triangulation above, there may be fewer Voronoi regions than input points.

The ridges (lines in 2-D) separating the regions are described as a similar collection of simplices as the convex hull pieces:

```
>>> vor.ridge_vertices
[[-1, 0], [-1, 0], [-1, 1], [-1, 1], [0, 1], [-1, 3], [-1, 2], [2, 3], [-1, 3], [-1, 2], [0, 2], [1, 3]]
```

These numbers indicate indices of the Voronoi vertices making up the line segments.  $-1$  is again a point at infinity — only four of the 12 lines is a bounded line segment while the others extend to infinity.

The Voronoi ridges are perpendicular to lines drawn between the input points. Which two points each ridge corresponds to is also recorded:

```
>>> vor.ridge_points
array([[0, 1],
       [0, 3],
       [6, 3],
       [6, 7],
       [3, 4],
       [5, 8],
       [5, 2],
       [5, 4],
       [8, 7],
       [2, 1],
       [4, 1],
       [4, 7]], dtype=int32)
```

This information, taken together, is enough to construct the full diagram.

We can plot it as follows. First the points and the Voronoi vertices:

```
>>> plt.plot(points[:, 0], points[:, 1], 'o')
>>> plt.plot(vor.vertices[:, 0], vor.vertices[:, 1], '*')
>>> plt.xlim(-1, 3); plt.ylim(-1, 3)
```

Plotting the finite line segments goes as for the convex hull, but now we have to guard for the infinite edges:

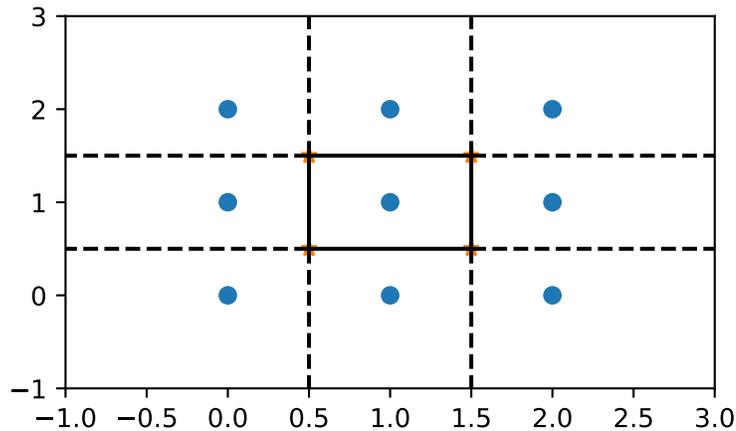
```
>>> for simplex in vor.ridge_vertices:
...     simplex = np.asarray(simplex)
...     if np.all(simplex >= 0):
...         plt.plot(vor.vertices[simplex, 0], vor.vertices[simplex, 1], 'k-')
```

The ridges extending to infinity require a bit more care:

```
>>> center = points.mean(axis=0)
>>> for pointidx, simplex in zip(vor.ridge_points, vor.ridge_vertices):
...     simplex = np.asarray(simplex)
...     if np.any(simplex < 0):
...         i = simplex[simplex >= 0][0] # finite end Voronoi vertex
...         t = points[pointidx[1]] - points[pointidx[0]] # tangent
...         t = t / np.linalg.norm(t)
...         n = np.array([-t[1], t[0]]) # normal
...         midpoint = points[pointidx].mean(axis=0)
```

```

...     far_point = vor.vertices[i] + np.sign(np.dot(midpoint - center, n)) * n * 100
...     plt.plot([vor.vertices[i,0], far_point[0]],
...             [vor.vertices[i,1], far_point[1]], 'k--')
...     plt.show()
    
```



This plot can also be created using `scipy.spatial.voronoi_plot_2d`.

### 3.1.13 Statistics (`scipy.stats`)

#### Introduction

In this tutorial we discuss many, but certainly not all, features of `scipy.stats`. The intention here is to provide a user with a working knowledge of this package. We refer to the [reference manual](#) for further details.

Note: This documentation is work in progress.

#### *Discrete Statistical Distributions*

Discrete random variables take on only a countable number of values. The commonly used distributions are included in SciPy and described in this document. Each discrete distribution can take one extra integer parameter:  $L$ . The relationship between the general distribution  $p$  and the standard distribution  $p_0$  is

$$p(x) = p_0(x - L)$$

which allows for shifting of the input. When a distribution generator is initialized, the discrete distribution can either specify the beginning and ending (integer) values  $a$  and  $b$  which must be such that

$$p_0(x) = 0 \quad x < a \text{ or } x > b$$

in which case, it is assumed that the pdf function is specified on the integers  $a + mk \leq b$  where  $k$  is a non-negative integer ( $0, 1, 2, \dots$ ) and  $m$  is a positive integer multiplier. Alternatively, the two lists  $x_k$  and  $p(x_k)$  can be provided directly in which case a dictionary is set up internally to evaluate probabilities and generate random variates.

## Probability Mass Function (PMF)

The probability mass function of a random variable  $X$  is defined as the probability that the random variable takes on a particular value.

$$p(x_k) = P[X = x_k]$$

This is also sometimes called the probability density function, although technically

$$f(x) = \sum_k p(x_k) \delta(x - x_k)$$

is the probability density function for a discrete distribution<sup>1</sup>.

## Cumulative Distribution Function (CDF)

The cumulative distribution function is

$$F(x) = P[X \leq x] = \sum_{x_k \leq x} p(x_k)$$

and is also useful to be able to compute. Note that

$$F(x_k) - F(x_{k-1}) = p(x_k)$$

## Survival Function

The survival function is just

$$S(x) = 1 - F(x) = P[X > k]$$

the probability that the random variable is strictly larger than  $k$ .

## Percent Point Function (Inverse CDF)

The percent point function is the inverse of the cumulative distribution function and is

$$G(q) = F^{-1}(q)$$

for discrete distributions, this must be modified for cases where there is no  $x_k$  such that  $F(x_k) = q$ . In these cases we choose  $G(q)$  to be the smallest value  $x_k = G(q)$  for which  $F(x_k) \geq q$ . If  $q = 0$  then we define  $G(0) = a - 1$ . This definition allows random variates to be defined in the same way as with continuous rv's using the inverse cdf on a uniform distribution to generate random variates.

## Inverse survival function

The inverse survival function is the inverse of the survival function

$$Z(\alpha) = S^{-1}(\alpha) = G(1 - \alpha)$$

and is thus the smallest non-negative integer  $k$  for which  $F(k) \geq 1 - \alpha$  or the smallest non-negative integer  $k$  for which  $S(k) \leq \alpha$ .

<sup>1</sup> XXX: Unknown layout Plain Layout: Note that we will be using  $p$  to represent the probability mass function and a parameter (a XXX: probability). The usage should be obvious from context.

## Hazard functions

If desired, the hazard function and the cumulative hazard function could be defined as

$$h(x_k) = \frac{p(x_k)}{1 - F(x_k)}$$

and

$$H(x) = \sum_{x_k \leq x} h(x_k) = \sum_{x_k \leq x} \frac{F(x_k) - F(x_{k-1})}{1 - F(x_k)}.$$

## Moments

Non-central moments are defined using the PDF

$$\mu'_m = E[X^m] = \sum_k x_k^m p(x_k).$$

Central moments are computed similarly  $\mu = \mu'_1$

$$\begin{aligned} \mu_m = E[(X - \mu)^m] &= \sum_k (x_k - \mu)^m p(x_k) \\ &= \sum_{k=0}^m (-1)^{m-k} \binom{m}{k} \mu^{m-k} \mu'_k \end{aligned}$$

The mean is the first moment

$$\mu = \mu'_1 = E[X] = \sum_k x_k p(x_k)$$

the variance is the second central moment

$$\mu_2 = E[(X - \mu)^2] = \sum_{x_k} x_k^2 p(x_k) - \mu^2.$$

Skewness is defined as

$$\gamma_1 = \frac{\mu_3}{\mu_2^{3/2}}$$

while (Fisher) kurtosis is

$$\gamma_2 = \frac{\mu_4}{\mu_2^2} - 3,$$

so that a normal distribution has a kurtosis of zero.

## Moment generating function

The moment generating function is defined as

$$M_X(t) = E[e^{Xt}] = \sum_{x_k} e^{x_k t} p(x_k)$$

Moments are found as the derivatives of the moment generating function evaluated at 0.

## Fitting data

To fit data to a distribution, maximizing the likelihood function is common. Alternatively, some distributions have well-known minimum variance unbiased estimators. These will be chosen by default, but the likelihood function will always be available for minimizing.

If  $f_i(k; \theta)$  is the PDF of a random-variable where  $\theta$  is a vector of parameters ( *e.g.*  $L$  and  $S$  ), then for a collection of  $N$  independent samples from this distribution, the joint distribution the random vector  $\mathbf{k}$  is

$$f(\mathbf{k}; \theta) = \prod_{i=1}^N f_i(k_i; \theta).$$

The maximum likelihood estimate of the parameters  $\theta$  are the parameters which maximize this function with  $\mathbf{x}$  fixed and given by the data:

$$\begin{aligned} \hat{\theta} &= \arg \max_{\theta} f(\mathbf{k}; \theta) \\ &= \arg \min_{\theta} l_{\mathbf{k}}(\theta). \end{aligned}$$

Where

$$\begin{aligned} l_{\mathbf{k}}(\theta) &= -\sum_{i=1}^N \log f(k_i; \theta) \\ &= -N \overline{\log f(k_i; \theta)} \end{aligned}$$

## Standard notation for mean

We will use

$$\overline{y(\mathbf{x})} = \frac{1}{N} \sum_{i=1}^N y(x_i)$$

where  $N$  should be clear from context.

## Combinations

Note that

$$k! = k \cdot (k-1) \cdot (k-2) \cdot \dots \cdot 1 = \Gamma(k+1)$$

and has special cases of

$$\begin{aligned} 0! &\equiv 1 \\ k! &\equiv 0 \quad k < 0 \end{aligned}$$

and

$$\binom{n}{k} = \frac{n!}{(n-k)!k!}.$$

If  $n < 0$  or  $k < 0$  or  $k > n$  we define  $\binom{n}{k} = 0$

## Discrete Distributions in `scipy.stats`

### Bernoulli Distribution

A Bernoulli random variable of parameter  $p$  takes one of only two values  $X = 0$  or  $X = 1$ . The probability of success ( $X = 1$ ) is  $p$ , and the probability of failure ( $X = 0$ ) is  $1 - p$ . It can be thought of as a binomial random variable with  $n = 1$ . The PMF is  $p(k) = 0$  for  $k \neq 0, 1$  and

$$\begin{aligned}
 p(k; p) &= \begin{cases} 1 - p & k = 0 \\ p & k = 1 \end{cases} \\
 F(x; p) &= \begin{cases} 0 & x < 0 \\ 1 - p & 0 \leq x < 1 \\ 1 & 1 \leq x \end{cases} \\
 G(q; p) &= \begin{cases} 0 & 0 \leq q < 1 - p \\ 1 & 1 - p \leq q \leq 1 \end{cases} \\
 \mu &= p \\
 \mu_2 &= p(1 - p) \\
 \gamma_3 &= \frac{1 - 2p}{\sqrt{p(1 - p)}} \\
 \gamma_4 &= \frac{1 - 6p(1 - p)}{p(1 - p)} \\
 M(t) &= 1 - p(1 - e^t) \\
 \mu'_m &= p \\
 h[X] &= p \log p + (1 - p) \log(1 - p)
 \end{aligned}$$

Implementation: `scipy.stats.bernoulli`

### Binomial Distribution

A binomial random variable with parameters  $(n, p)$  can be described as the sum of  $n$  independent Bernoulli random variables of parameter  $p$ ;

$$Y = \sum_{i=1}^n X_i.$$

Therefore, this random variable counts the number of successes in  $n$  independent trials of a random experiment where the probability of success is  $p$ .

$$\begin{aligned}
 p(k; n, p) &= \binom{n}{k} p^k (1 - p)^{n-k} \quad k \in \{0, 1, \dots, n\}, \\
 F(x; n, p) &= \sum_{k \leq x} \binom{n}{k} p^k (1 - p)^{n-k} = I_{1-p}(n - \lfloor x \rfloor, \lfloor x \rfloor + 1) \quad x \geq 0
 \end{aligned}$$

where the incomplete beta integral is

$$I_x(a, b) = \frac{\Gamma(a+b)}{\Gamma(a)\Gamma(b)} \int_0^x t^{a-1} (1-t)^{b-1} dt.$$

Now

$$\begin{aligned}\mu &= np \\ \mu_2 &= np(1-p) \\ \gamma_1 &= \frac{1-2p}{\sqrt{np(1-p)}} \\ \gamma_2 &= \frac{1-6p(1-p)}{np(1-p)} \\ M(t) &= [1-p(1-e^t)]^n\end{aligned}$$

Implementation: `scipy.stats.binom`

### Boltzmann (truncated Planck) Distribution

$$\begin{aligned}p(k; N, \lambda) &= \frac{1 - e^{-\lambda}}{1 - e^{-\lambda N}} \exp(-\lambda k) \quad k \in \{0, 1, \dots, N-1\} \\ F(x; N, \lambda) &= \begin{cases} 0 & x < 0 \\ \frac{1 - \exp[-\lambda(\lfloor x \rfloor + 1)]}{1 - \exp(-\lambda N)} & 0 \leq x \leq N-1 \\ 1 & x \geq N-1 \end{cases} \\ G(q, \lambda) &= \left\lceil -\frac{1}{\lambda} \log [1 - q(1 - e^{-\lambda N})] - 1 \right\rceil\end{aligned}$$

Define  $z = e^{-\lambda}$

$$\begin{aligned}\mu &= \frac{z}{1-z} - \frac{Nz^N}{1-z^N} \\ \mu_2 &= \frac{z}{(1-z)^2} - \frac{N^2z^N}{(1-z^N)^2} \\ \gamma_1 &= \frac{z(1+z) \left( \frac{1-z^N}{1-z} \right)^3 - N^3z^N(1+z^N)}{\left[ z \left( \frac{1-z^N}{1-z} \right)^2 - N^2z^N \right]^{3/2}} \\ \gamma_2 &= \frac{z(1+4z+z^2) \left( \frac{1-z^N}{1-z} \right)^4 - N^4z^N(1+4z^N+z^{2N})}{\left[ z \left( \frac{1-z^N}{1-z} \right)^2 - N^2z^N \right]^2} \\ M(t) &= \frac{1 - e^{N(t-\lambda)}}{1 - e^{t-\lambda}} \frac{1 - e^{-\lambda}}{1 - e^{-\lambda N}}\end{aligned}$$

Implementation: `scipy.stats.boltzmann`

### Planck (discrete exponential) Distribution

Named Planck because of its relationship to the black-body problem he solved.

$$\begin{aligned}p(k; \lambda) &= (1 - e^{-\lambda}) e^{-\lambda k} \quad k\lambda \geq 0 \\ F(x; \lambda) &= 1 - e^{-\lambda(\lfloor x \rfloor + 1)} \quad x\lambda \geq 0 \\ G(q; \lambda) &= \left\lceil -\frac{1}{\lambda} \log [1 - q] - 1 \right\rceil.\end{aligned}$$

$$\begin{aligned}\mu &= \frac{1}{e^\lambda - 1} \\ \mu_2 &= \frac{e^{-\lambda}}{(1 - e^{-\lambda})^2} \\ \gamma_1 &= 2 \cosh\left(\frac{\lambda}{2}\right) \\ \gamma_2 &= 4 + 2 \cosh(\lambda) \\ M(t) &= \frac{1 - e^{-\lambda}}{1 - e^{t-\lambda}} \\ h[X] &= \frac{\lambda e^{-\lambda}}{1 - e^{-\lambda}} - \log(1 - e^{-\lambda})\end{aligned}$$

Implementation: `scipy.stats.planck`

## Poisson Distribution

The Poisson random variable counts the number of successes in  $n$  independent Bernoulli trials in the limit as  $n \rightarrow \infty$  and  $p \rightarrow 0$  where the probability of success in each trial is  $p$  and  $np = \lambda \geq 0$  is a constant. It can be used to approximate the Binomial random variable or in it's own right to count the number of events that occur in the interval  $[0, t]$  for a process satisfying certain “sparsity” constraints. The functions are

$$\begin{aligned}p(k; \lambda) &= e^{-\lambda} \frac{\lambda^k}{k!} \quad k \geq 0, \\ F(x; \lambda) &= \sum_{n=0}^{\lfloor x \rfloor} e^{-\lambda} \frac{\lambda^n}{n!} = \frac{1}{\Gamma(\lfloor x \rfloor + 1)} \int_{\lambda}^{\infty} t^{\lfloor x \rfloor} e^{-t} dt, \\ \mu &= \lambda \\ \mu_2 &= \lambda \\ \gamma_1 &= \frac{1}{\sqrt{\lambda}} \\ \gamma_2 &= \frac{1}{\lambda}. \\ M(t) &= \exp[\lambda(e^t - 1)].\end{aligned}$$

Implementation: `scipy.stats.poisson`

## Geometric Distribution

The geometric random variable with parameter  $p \in (0, 1)$  can be defined as the number of trials required to obtain a success where the probability of success on each trial is  $p$ . Thus,

$$\begin{aligned}
 p(k; p) &= (1-p)^{k-1} p \quad k \geq 1 \\
 F(x; p) &= 1 - (1-p)^{\lfloor x \rfloor} \quad x \geq 1 \\
 G(q; p) &= \left\lceil \frac{\log(1-q)}{\log(1-p)} \right\rceil \\
 \mu &= \frac{1}{p} \\
 \mu_2 &= \frac{1-p}{p^2} \\
 \gamma_1 &= \frac{2-p}{\sqrt{1-p}} \\
 \gamma_2 &= \frac{p^2 - 6p + 6}{1-p}. \\
 M(t) &= \frac{p}{e^{-t} - (1-p)}
 \end{aligned}$$

Implementation: `scipy.stats.geom`

## Negative Binomial Distribution

The negative binomial random variable with parameters  $n$  and  $p \in (0, 1)$  can be defined as the number of *extra* independent trials (beyond  $n$ ) required to accumulate a total of  $n$  successes where the probability of a success on each trial is  $p$ . Equivalently, this random variable is the number of failures encountered while accumulating  $n$  successes during independent trials of an experiment that succeeds with probability  $p$ . Thus,

$$\begin{aligned}
 p(k; n, p) &= \binom{k+n-1}{n-1} p^n (1-p)^k \quad k \geq 0 \\
 F(x; n, p) &= \sum_{i=0}^{\lfloor x \rfloor} \binom{i+n-1}{i} p^n (1-p)^i \quad x \geq 0 \\
 &= I_p(n, \lfloor x \rfloor + 1) \quad x \geq 0 \\
 \mu &= n \frac{1-p}{p} \\
 \mu_2 &= n \frac{1-p}{p^2} \\
 \gamma_1 &= \frac{2-p}{\sqrt{n(1-p)}} \\
 \gamma_2 &= \frac{p^2 + 6(1-p)}{n(1-p)}.
 \end{aligned}$$

Recall that  $I_p(a, b)$  is the incomplete beta integral.

Implementation: `scipy.stats.nbinom`

## Hypergeometric Distribution

The hypergeometric random variable with parameters  $(M, n, N)$  counts the number of “good” objects in a sample of size  $N$  chosen without replacement from a population of  $M$  objects where  $n$  is the number of “good” objects in the total population.

$$p(k; N, n, M) = \frac{\binom{n}{k} \binom{M-n}{N-k}}{\binom{M}{N}} \quad N - (M - n) \leq k \leq \min(n, N)$$

$$F(x; N, n, M) = \sum_{k=0}^{\lfloor x \rfloor} \frac{\binom{m}{k} \binom{N-m}{n-k}}{\binom{N}{n}},$$

$$\mu = \frac{nN}{M}$$

$$\mu_2 = \frac{nN(M-n)(M-N)}{M^2(M-1)}$$

$$\gamma_1 = \frac{(M-2n)(M-2N)}{M-2} \sqrt{\frac{M-1}{nN(M-m)(M-n)}}$$

$$\gamma_2 = \frac{g(N, n, M)}{nN(M-n)(M-3)(M-2)(N-M)}$$

where (defining  $m = M - n$ )

$$g(N, n, M) = m^3 - m^5 + 3m^2n - 6m^3n + m^4n + 3mn^2 - 12m^2n^2 + 8m^3n^2 + n^3 - 6mn^3 + 8m^2n^3 + mn^4 - n^5 - 6m^3N + 6m^4N + 18m^2nN - 6m^3nN + 18mn^2N - 24m^2n^2N - 6n^3N - 6mn^3N + 6n^4N + 6m^2N^2 - 6m^3N^2 - 24mnN^2 + 12m^2nN^2 + 6n^2N^2 + 12mn^2N^2 - 6n^3N^2.$$

Implementation: `scipy.stats.hypergeom`

## Zipf (Zeta) Distribution

A random variable has the zeta distribution (also called the zipf distribution) with parameter  $\alpha > 1$  if its probability mass function is given by

$$p(k; \alpha) = \frac{1}{\zeta(\alpha) k^\alpha} \quad k \geq 1$$

where

$$\zeta(\alpha) = \sum_{n=1}^{\infty} \frac{1}{n^\alpha}$$

is the Riemann zeta function. Other functions of this distribution are

$$\begin{aligned}
 F(x; \alpha) &= \frac{1}{\zeta(\alpha)} \sum_{k=1}^{\lfloor x \rfloor} \frac{1}{k^\alpha} \\
 \mu &= \frac{\zeta_1}{\zeta_0} \quad \alpha > 2 \\
 \mu_2 &= \frac{\zeta_2 \zeta_0 - \zeta_1^2}{\zeta_0^2} \quad \alpha > 3 \\
 \gamma_1 &= \frac{\zeta_3 \zeta_0^2 - 3\zeta_0 \zeta_1 \zeta_2 + 2\zeta_1^3}{[\zeta_2 \zeta_0 - \zeta_1^2]^{3/2}} \quad \alpha > 4 \\
 \gamma_2 &= \frac{\zeta_4 \zeta_0^3 - 4\zeta_3 \zeta_1 \zeta_0^2 + 12\zeta_2 \zeta_1^2 \zeta_0 - 6\zeta_1^4 - 3\zeta_2^2 \zeta_0^2}{(\zeta_2 \zeta_0 - \zeta_1^2)^2} \\
 M(t) &= \frac{\text{Li}_\alpha(e^t)}{\zeta(\alpha)}
 \end{aligned}$$

where  $\zeta_i = \zeta(\alpha - i)$  and  $\text{Li}_n(z)$  is the  $n^{\text{th}}$  polylogarithm function of  $z$  defined as

$$\begin{aligned}
 \text{Li}_n(z) &\equiv \sum_{k=1}^{\infty} \frac{z^k}{k^n} \\
 \mu'_n = M^{(n)}(t) \Big|_{t=0} &= \frac{\text{Li}_{\alpha-n}(e^t)}{\zeta(\alpha)} \Big|_{t=0} = \frac{\zeta(\alpha - n)}{\zeta(\alpha)}
 \end{aligned}$$

Implementation: `scipy.stats.zipf`

### Logarithmic (Log-Series, Series) Distribution

The logarithmic distribution with parameter  $p$  has a probability mass function with terms proportional to the Taylor series expansion of  $\log(1 - p)$

$$\begin{aligned}
 p(k; p) &= -\frac{p^k}{k \log(1 - p)} \quad k \geq 1 \\
 F(x; p) &= -\frac{1}{\log(1 - p)} \sum_{k=1}^{\lfloor x \rfloor} \frac{p^k}{k} = 1 + \frac{p^{1+\lfloor x \rfloor} \Phi(p, 1, 1 + \lfloor x \rfloor)}{\log(1 - p)}
 \end{aligned}$$

where

$$\Phi(z, s, a) = \sum_{k=0}^{\infty} \frac{z^k}{(a + k)^s}$$

is the Lerch Transcendent. Also define  $r = \log(1 - p)$

$$\begin{aligned}
 \mu &= -\frac{p}{(1 - p)r} \\
 \mu_2 &= -\frac{p[p + r]}{(1 - p)^2 r^2} \\
 \gamma_1 &= -\frac{2p^2 + 3pr + (1 + p)r^2}{r(p + r)\sqrt{-p(p + r)}} r \\
 \gamma_2 &= -\frac{6p^3 + 12p^2 r + p(4p + 7)r^2 + (p^2 + 4p + 1)r^3}{p(p + r)^2}
 \end{aligned}$$

$$\begin{aligned} M(t) &= -\frac{1}{\log(1-p)} \sum_{k=1}^{\infty} \frac{e^{tk} p^k}{k} \\ &= \frac{\log(1-pe^t)}{\log(1-p)} \end{aligned}$$

Thus,

$$\mu'_n = M^{(n)}(t) \Big|_{t=0} = \frac{\text{Li}_{1-n}(pe^t)}{\log(1-p)} \Big|_{t=0} = -\frac{\text{Li}_{1-n}(p)}{\log(1-p)}.$$

Implementation: `scipy.stats.logser`

### Discrete Uniform (randint) Distribution

The discrete uniform distribution with parameters  $(a, b)$  constructs a random variable that has an equal probability of being any one of the integers in the half-open range  $[a, b)$ . If  $a$  is not given it is assumed to be zero and the only parameter is  $b$ . Therefore,

$$\begin{aligned} p(k, a, b) &= \frac{1}{b-a} \quad a \leq k < b \\ F(x; a, b) &= \frac{\lfloor x \rfloor - a}{b-a} \quad a \leq x \leq b \\ G(q; a, b) &= \lceil q(b-a) + a \rceil \\ \mu &= \frac{b+a-1}{2} \\ \mu_2 &= \frac{(b-a-1)(b-a+1)}{12} \\ \gamma_1 &= 0 \\ \gamma_2 &= -\frac{6}{5} \frac{(b-a)^2 + 1}{(b-a-1)(b-a+1)}. \end{aligned}$$

$$\begin{aligned} M(t) &= \frac{1}{b-a} \sum_{k=a}^{b-1} e^{tk} \\ &= \frac{e^{bt} - e^{at}}{(b-a)(e^t - 1)} \end{aligned}$$

Implementation: `scipy.stats.randint`

### Discrete Laplacian Distribution

Defined over all integers for  $a > 0$

$$\begin{aligned} p(k) &= \tanh\left(\frac{a}{2}\right) e^{-a|k|}, \\ F(x) &= \begin{cases} \frac{e^{a(\lfloor x \rfloor + 1)}}{e^a + 1} & \lfloor x \rfloor < 0, \\ 1 - \frac{e^{-a\lfloor x \rfloor}}{e^a + 1} & \lfloor x \rfloor \geq 0. \end{cases} \\ G(q) &= \begin{cases} \lceil \frac{1}{a} \log[q(e^a + 1)] - 1 \rceil & q < \frac{1}{1+e^{-a}}, \\ \lceil -\frac{1}{a} \log[(1-q)(1+e^a)] \rceil & q \geq \frac{1}{1+e^{-a}}. \end{cases} \end{aligned}$$

$$\begin{aligned}
 M(t) &= \tanh\left(\frac{a}{2}\right) \sum_{k=-\infty}^{\infty} e^{tk} e^{-a|k|} \\
 &= C \left( 1 + \sum_{k=1}^{\infty} e^{-(t+a)k} + \sum_{k=1}^{\infty} e^{(t-a)k} \right) \\
 &= \tanh\left(\frac{a}{2}\right) \left( 1 + \frac{e^{-(t+a)}}{1 - e^{-(t+a)}} + \frac{e^{t-a}}{1 - e^{t-a}} \right) \\
 &= \frac{\tanh\left(\frac{a}{2}\right) \sinh a}{\cosh a - \cosh t}.
 \end{aligned}$$

Thus,

$$\mu'_n = M^{(n)}(0) = [1 + (-1)^n] \text{Li}_{-n}(e^{-a})$$

where  $\text{Li}_{-n}(z)$  is the polylogarithm function of order  $-n$  evaluated at  $z$ .

$$h[X] = -\log\left(\tanh\left(\frac{a}{2}\right)\right) + \frac{a}{\sinh a}$$

Implementation: `scipy.stats.dlaplace`

## Continuous Statistical Distributions

### Overview

All distributions will have location (L) and Scale (S) parameters along with any shape parameters needed, the names for the shape parameters will vary. Standard form for the distributions will be given where  $L = 0.0$  and  $S = 1.0$ . The nonstandard forms can be obtained for the various functions using (note  $U$  is a standard uniform random variate).

Function Name	Standard Function	Transformation
Cumulative Distribution Function (CDF)	$F(x)$	$F(x; L, S) = F\left(\frac{(x-L)}{S}\right)$
Probability Density Function (PDF)	$f(x) = F'(x)$	$f(x; L, S) = \frac{1}{S} f\left(\frac{(x-L)}{S}\right)$
Percent Point Function (PPF)	$G(q) = F^{-1}(q)$	$G(q; L, S) = L + SG(q)$
Probability Sparsity Function (PSF)	$g(q) = G'(q)$	$g(q; L, S) = Sg(q)$
Hazard Function (HF)	$h_a(x) = \frac{f(x)}{1-F(x)}$	$h_a(x; L, S) = \frac{1}{S} h_a\left(\frac{(x-L)}{S}\right)$
Cumulative Hazard Function (CHF)	$H_a(x) = \log \frac{1}{1-F(x)}$	$H_a(x; L, S) = H_a\left(\frac{(x-L)}{S}\right)$
Survival Function (SF)	$S(x) = 1 - F(x)$	$S(x; L, S) = S\left(\frac{(x-L)}{S}\right)$
Inverse Survival Function (ISF)	$Z(\alpha) = S^{-1}(\alpha) = G(1 - \alpha)$	$Z(\alpha; L, S) = L + SZ(\alpha)$
Moment Generating Function (MGF)	$M_Y(t) = E[e^{Yt}]$	$M_X(t) = e^{Lt} M_Y(St)$
Random Variates	$Y = G(U)$	$X = L + SY$
(Differential) Entropy	$h[Y] = -\int f(y) \log f(y) dy$	$h[X] = h[Y] + \log S$
(Non-central) Moments	$\mu'_n = E[Y^n]$	$E[X^n] = L^n \sum_{k=0}^n \binom{n}{k} \left(\frac{S}{L}\right)^k \mu'_k$
Central Moments	$\mu_n = E[(Y - \mu)^n]$	$E[(X - \mu_X)^n] = S^n \mu_n$
mean (mode, median), var	$\mu, \mu_2$	$L + S\mu, S^2\mu_2$
skewness, kurtosis	$\gamma_1 = \frac{\mu_3}{(\mu_2)^{3/2}}, \gamma_2 = \frac{\mu_4}{(\mu_2)^2} - 3$	$\gamma_1, \gamma_2$

## Moments

Non-central moments are defined using the PDF

$$\mu'_n = \int_{-\infty}^{\infty} x^n f(x) dx.$$

Note, that these can always be computed using the PPF. Substitute  $x = G(q)$  in the above equation and get

$$\mu'_n = \int_0^1 G^n(q) dq$$

which may be easier to compute numerically. Note that  $q = F(x)$  so that  $dq = f(x) dx$ . Central moments are computed similarly  $\mu = \mu'_1$

$$\begin{aligned} \mu_n &= \int_{-\infty}^{\infty} (x - \mu)^n f(x) dx \\ &= \int_0^1 (G(q) - \mu)^n dq \\ &= \sum_{k=0}^n \binom{n}{k} (-\mu)^k \mu'_{n-k} \end{aligned}$$

In particular

$$\begin{aligned} \mu_3 &= \mu'_3 - 3\mu\mu'_2 + 2\mu^3 \\ &= \mu'_3 - 3\mu\mu_2 - \mu^3 \\ \mu_4 &= \mu'_4 - 4\mu\mu'_3 + 6\mu^2\mu'_2 - 3\mu^4 \\ &= \mu'_4 - 4\mu\mu_3 - 6\mu^2\mu_2 - \mu^4 \end{aligned}$$

Skewness is defined as

$$\gamma_1 = \sqrt{\beta_1} = \frac{\mu_3}{\mu_2^{3/2}}$$

while (Fisher) kurtosis is

$$\gamma_2 = \frac{\mu_4}{\mu_2^2} - 3,$$

so that a normal distribution has a kurtosis of zero.

## Median and mode

The median,  $m_n$  is defined as the point at which half of the density is on one side and half on the other. In other words,  $F(m_n) = \frac{1}{2}$  so that

$$m_n = G\left(\frac{1}{2}\right).$$

In addition, the mode,  $m_d$ , is defined as the value for which the probability density function reaches its peak

$$m_d = \arg \max_x f(x).$$

## Fitting data

To fit data to a distribution, maximizing the likelihood function is common. Alternatively, some distributions have well-known minimum variance unbiased estimators. These will be chosen by default, but the likelihood function will always be available for minimizing.

If  $f(x; \theta)$  is the PDF of a random-variable where  $\theta$  is a vector of parameters ( e.g.  $L$  and  $S$  ), then for a collection of  $N$  independent samples from this distribution, the joint distribution the random vector  $\mathbf{x}$  is

$$f(\mathbf{x}; \theta) = \prod_{i=1}^N f(x_i; \theta).$$

The maximum likelihood estimate of the parameters  $\theta$  are the parameters which maximize this function with  $\mathbf{x}$  fixed and given by the data:

$$\begin{aligned} \theta_{es} &= \arg \max_{\theta} f(\mathbf{x}; \theta) \\ &= \arg \min_{\theta} l_{\mathbf{x}}(\theta). \end{aligned}$$

Where

$$\begin{aligned} l_{\mathbf{x}}(\theta) &= -\sum_{i=1}^N \log f(x_i; \theta) \\ &= -N \overline{\log f(x_i; \theta)} \end{aligned}$$

Note that if  $\theta$  includes only shape parameters, the location and scale-parameters can be fit by replacing  $x_i$  with  $(x_i - L)/S$  in the log-likelihood function adding  $N \log S$  and minimizing, thus

$$\begin{aligned} l_{\mathbf{x}}(L, S; \theta) &= N \log S - \sum_{i=1}^N \log f\left(\frac{x_i - L}{S}; \theta\right) \\ &= N \log S + l_{\frac{\mathbf{x}-L}{S}}(\theta) \end{aligned}$$

If desired, sample estimates for  $L$  and  $S$  (not necessarily maximum likelihood estimates) can be obtained from samples estimates of the mean and variance using

$$\begin{aligned} \hat{S} &= \sqrt{\frac{\hat{\mu}_2}{\mu_2}} \\ \hat{L} &= \hat{\mu} - \hat{S}\mu \end{aligned}$$

where  $\mu$  and  $\mu_2$  are assumed known as the mean and variance of the **untransformed** distribution (when  $L = 0$  and  $S = 1$ ) and

$$\begin{aligned} \hat{\mu} &= \frac{1}{N} \sum_{i=1}^N x_i = \bar{\mathbf{x}} \\ \hat{\mu}_2 &= \frac{1}{N-1} \sum_{i=1}^N (x_i - \hat{\mu})^2 = \frac{N}{N-1} \overline{(\mathbf{x} - \bar{\mathbf{x}})^2} \end{aligned}$$

## Standard notation for mean

We will use

$$\overline{y(\mathbf{x})} = \frac{1}{N} \sum_{i=1}^N y(x_i)$$

where  $N$  should be clear from context as the number of samples  $x_i$

## References

- Documentation for `ranlib`, `rv2`, `cdflib`
- Eric Weisstein's world of mathematics <http://mathworld.wolfram.com/>, <http://mathworld.wolfram.com/topics/StatisticalDistributions.html>
- Documentation to Regress+ by Michael McLaughlin item Engineering and Statistics Handbook (NIST), <http://www.itl.nist.gov/div898/handbook/index.htm>
- Documentation for DATAPLOT from NIST, <http://www.itl.nist.gov/div898/software/dataplot/distribu.htm>
- Norman Johnson, Samuel Kotz, and N. Balakrishnan Continuous Univariate Distributions, second edition, Volumes I and II, Wiley & Sons, 1994.

## Continuous Distributions in `scipy.stats`

### Alpha Distribution

One shape parameters  $\alpha > 0$  (parameter  $\beta$  in DATAPLOT is a scale-parameter). Standard form is  $x > 0$  :

$$f(x; \alpha) = \frac{1}{x^2 \Phi(\alpha) \sqrt{2\pi}} \exp\left(-\frac{1}{2} \left(\alpha - \frac{1}{x}\right)^2\right)$$

$$F(x; \alpha) = \frac{\Phi\left(\alpha - \frac{1}{x}\right)}{\Phi(\alpha)}$$

$$G(q; \alpha) = [\alpha - \Phi^{-1}(q\Phi(\alpha))]^{-1}$$

$$M(t) = \frac{1}{\Phi(\alpha) \sqrt{2\pi}} \int_0^\infty \frac{e^{xt}}{x^2} \exp\left(-\frac{1}{2} \left(\alpha - \frac{1}{x}\right)^2\right) dx$$

No moments?

$$l_{\mathbf{x}}(\alpha) = N \log [\Phi(\alpha) \sqrt{2\pi}] + 2N \overline{\log \mathbf{x}} + \frac{N}{2} \alpha^2 - \alpha \overline{\mathbf{x}^{-1}} + \frac{1}{2} \overline{\mathbf{x}^{-2}}$$

Implementation: `scipy.stats.alpha`

### Anglit Distribution

Defined over  $x \in \left[-\frac{\pi}{4}, \frac{\pi}{4}\right]$

$$f(x) = \sin\left(2x + \frac{\pi}{2}\right) = \cos(2x)$$

$$F(x) = \sin^2\left(x + \frac{\pi}{4}\right)$$

$$G(q) = \arcsin(\sqrt{q}) - \frac{\pi}{4}$$

$$\mu = 0$$

$$\mu_2 = \frac{\pi^2}{16} - \frac{1}{2}$$

$$\gamma_1 = 0$$

$$\gamma_2 = -2 \frac{\pi^4 - 96}{(\pi^2 - 8)^2}$$

$$\begin{aligned} h[X] &= 1 - \log 2 \\ &\approx 0.30685281944005469058 \end{aligned}$$

$$\begin{aligned} M(t) &= \int_{-\frac{\pi}{4}}^{\frac{\pi}{4}} \cos(2x) e^{xt} dx \\ &= \frac{4 \cosh\left(\frac{\pi t}{4}\right)}{t^2 + 4} \end{aligned}$$

$$l_{\mathbf{x}}(\cdot) = -N \overline{\log[\cos(2\mathbf{x})]}$$

Implementation: `scipy.stats.anglit`

### Arcsine Distribution

Defined over  $x \in (0, 1)$ . To get the JKB definition put  $x = \frac{u+1}{2}$ . i.e.  $L = -1$  and  $S = 2$ .

$$f(x) = \frac{1}{\pi \sqrt{x(1-x)}}$$

$$F(x) = \frac{2}{\pi} \arcsin(\sqrt{x})$$

$$G(q) = \sin^2\left(\frac{\pi}{2}q\right)$$

$$M(t) = E^{t/2} I_0\left(\frac{t}{2}\right)$$

$$\begin{aligned} \mu'_n &= \frac{1}{\pi} \int_0^1 dx x^{n-1/2} (1-x)^{-1/2} \\ &= \frac{1}{\pi} B\left(\frac{1}{2}, n + \frac{1}{2}\right) = \frac{(2n-1)!!}{2^n n!} \end{aligned}$$

$$\mu = \frac{1}{2}$$

$$\mu_2 = \frac{1}{8}$$

$$\gamma_1 = 0$$

$$\gamma_2 = -\frac{3}{2}$$

$$h[X] \approx -0.24156447527049044468$$

$$l_{\mathbf{x}}(\cdot) = N \log \pi + \frac{N}{2} \overline{\log \mathbf{x}} + \frac{N}{2} \overline{\log(1-\mathbf{x})}$$

Implementation: `scipy.stats.arcsine`

### Beta Distribution

Two shape parameters

$$a, b > 0$$

$$\begin{aligned}
 f(x; a, b) &= \frac{\Gamma(a+b)}{\Gamma(a)\Gamma(b)} x^{a-1} (1-x)^{b-1} I_{(0,1)}(x) \\
 F(x; a, b) &= \int_0^x f(y; a, b) dy = I(x, a, b) \\
 G(\alpha; a, b) &= I^{-1}(\alpha; a, b) \\
 M(t) &= \frac{\Gamma(a)\Gamma(b)}{\Gamma(a+b)} {}_1F_1(a; a+b; t) \\
 \mu &= \frac{a}{a+b} \\
 \mu_2 &= \frac{ab(a+b+1)}{(a+b)^2} \\
 \gamma_1 &= 2 \frac{b-a}{a+b+2} \sqrt{\frac{a+b+1}{ab}} \\
 \gamma_2 &= \frac{6(a^3 + a^2(1-2b) + b^2(b+1) - 2ab(b+2))}{ab(a+b+2)(a+b+3)} \\
 m_d &= \frac{(a-1)}{(a+b-2)} a + b \neq 2
 \end{aligned}$$

$f(x; a, 1)$  is also called the Power-function distribution.

$$l_{\mathbf{x}}(a, b) = -N \log \Gamma(a+b) + N \log \Gamma(a) + N \log \Gamma(b) - N(a-1) \overline{\log \mathbf{x}} - N(b-1) \overline{\log(1-\mathbf{x})}$$

All of the  $x_i \in [0, 1]$

Implementation: `scipy.stats.beta`

### Beta Prime Distribution

Defined over  $0 < x < \infty$ .  $\alpha, \beta > 0$ . (Note the CDF evaluation uses Eq. 3.194.1 on pg. 313 of Gradshteyn & Ryzhik (sixth edition).

$$\begin{aligned}
 f(x; \alpha, \beta) &= \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} x^{\alpha-1} (1+x)^{-\alpha-\beta} \\
 F(x; \alpha, \beta) &= \frac{\Gamma(\alpha+\beta)}{\alpha\Gamma(\alpha)\Gamma(\beta)} x^\alpha {}_2F_1(\alpha+\beta, \alpha; 1+\alpha; -x) \\
 G(q; \alpha, \beta) &= F^{-1}(x; \alpha, \beta) \\
 \mu'_n &= \begin{cases} \frac{\Gamma(n+\alpha)\Gamma(\beta-n)}{\Gamma(\alpha)\Gamma(\beta)} = \frac{(\alpha)_n}{(\beta-n)_n} & \beta > n \\ \infty & \text{otherwise} \end{cases}
 \end{aligned}$$

Therefore,

$$\begin{aligned}
 \mu &= \frac{\alpha}{\beta-1} \quad \beta > 1 \\
 \mu_2 &= \frac{\alpha(\alpha+1)}{(\beta-2)(\beta-1)} - \frac{\alpha^2}{(\beta-1)^2} \quad \beta > 2 \\
 \gamma_1 &= \frac{\frac{\alpha(\alpha+1)(\alpha+2)}{(\beta-3)(\beta-2)(\beta-1)} - 3\mu\mu_2 - \mu^3}{\mu_2^{3/2}} \quad \beta > 3 \\
 \gamma_2 &= \frac{\mu_4}{\mu_2^2} - 3 \\
 \mu_4 &= \frac{\alpha(\alpha+1)(\alpha+2)(\alpha+3)}{(\beta-4)(\beta-3)(\beta-2)(\beta-1)} - 4\mu\mu_3 - 6\mu^2\mu_2 - \mu^4 \quad \beta > 4
 \end{aligned}$$

Implementation: `scipy.stats.betaprime`

**Bradford Distribution**

$$c > 0$$

$$k = \log(1 + c)$$

$$f(x; c) = \frac{c}{k(1 + cx)} I_{(0,1)}(x)$$

$$F(x; c) = \frac{\log(1 + cx)}{k}$$

$$G(\alpha c) = \frac{(1 + c)^\alpha - 1}{c}$$

$$M(t) = \frac{1}{k} e^{-t/c} \left[ \text{Ei} \left( t + \frac{t}{c} \right) - \text{Ei} \left( \frac{t}{c} \right) \right]$$

$$\mu = \frac{c - k}{ck}$$

$$\mu_2 = \frac{(c + 2)k - 2c}{2ck^2}$$

$$\gamma_1 = \frac{\sqrt{2} (12c^2 - 9kc(c + 2) + 2k^2(c(c + 3) + 3))}{\sqrt{c(c(k - 2) + 2k)} (3c(k - 2) + 6k)}$$

$$\gamma_2 = \frac{c^3(k - 3)(k(3k - 16) + 24) + 12kc^2(k - 4)(k - 3) + 6ck^2(3k - 14) + 12k^3}{3c(c(k - 2) + 2k)^2}$$

$$m_d = 0$$

$$m_n = \sqrt{1 + c} - 1$$

where  $\text{Ei}(z)$  is the exponential integral function. Also

$$h[X] = \frac{1}{2} \log(1 + c) - \log \left( \frac{c}{\log(1 + c)} \right)$$

Implementation: `scipy.stats.bradford`

**Burr Distribution**

$$c > 0$$

$$d > 0$$

$$k = \Gamma(d) \Gamma \left( 1 - \frac{2}{c} \right) \Gamma \left( \frac{2}{c} + d \right) - \Gamma^2 \left( 1 - \frac{1}{c} \right) \Gamma^2 \left( \frac{1}{c} + d \right)$$

$$\begin{aligned}
 f(x; c, d) &= \frac{cd}{x^{c+1} (1+x^{-c})^{d+1}} I_{(0, \infty)}(x) \\
 F(x; c, d) &= (1+x^{-c})^{-d} \\
 G(\alpha; c, d) &= (\alpha^{-1/d} - 1)^{-1/c} \\
 \mu &= \frac{\Gamma(1 - \frac{1}{c}) \Gamma(\frac{1}{c} + d)}{\Gamma(d)} \\
 \mu_2 &= \frac{k}{\Gamma^2(d)} \\
 \gamma_1 &= \frac{1}{\sqrt{k^3}} \left[ 2\Gamma^3\left(1 - \frac{1}{c}\right) \Gamma^3\left(\frac{1}{c} + d\right) + \Gamma^2(d) \Gamma\left(1 - \frac{3}{c}\right) \Gamma\left(\frac{3}{c} + d\right) \right. \\
 &\quad \left. - 3\Gamma(d) \Gamma\left(1 - \frac{2}{c}\right) \Gamma\left(1 - \frac{1}{c}\right) \Gamma\left(\frac{1}{c} + d\right) \Gamma\left(\frac{2}{c} + d\right) \right] \\
 \gamma_2 &= -3 + \frac{1}{k^2} \left[ 6\Gamma(d) \Gamma\left(1 - \frac{2}{c}\right) \Gamma^2\left(1 - \frac{1}{c}\right) \Gamma^2\left(\frac{1}{c} + d\right) \Gamma\left(\frac{2}{c} + d\right) \right. \\
 &\quad \left. - 3\Gamma^4\left(1 - \frac{1}{c}\right) \Gamma^4\left(\frac{1}{c} + d\right) + \Gamma^3(d) \Gamma\left(1 - \frac{4}{c}\right) \Gamma\left(\frac{4}{c} + d\right) \right. \\
 &\quad \left. - 4\Gamma^2(d) \Gamma\left(1 - \frac{3}{c}\right) \Gamma\left(1 - \frac{1}{c}\right) \Gamma\left(\frac{1}{c} + d\right) \Gamma\left(\frac{3}{c} + d\right) \right] \\
 m_d &= \left(\frac{cd-1}{c+1}\right)^{1/c} \text{ if } cd > 1 \text{ otherwise } 0 \\
 m_n &= (2^{1/d} - 1)^{-1/c}
 \end{aligned}$$

Implementation: `scipy.stats.burr`

## Cauchy Distribution

$$\begin{aligned}
 f(x) &= \frac{1}{\pi(1+x^2)} \\
 F(x) &= \frac{1}{2} + \frac{1}{\pi} \tan^{-1} x \\
 G(\alpha) &= \tan\left(\pi\alpha - \frac{\pi}{2}\right) \\
 m_d &= 0 \\
 m_n &= 0
 \end{aligned}$$

No finite moments. This is the t distribution with one degree of freedom.

$$\begin{aligned}
 h[X] &= \log(4\pi) \\
 &\approx 2.5310242469692907930.
 \end{aligned}$$

Implementation: `scipy.stats.cauchy`

## Chi Distribution

Generated by taking the (positive) square-root of chi-squared variates.

$$\begin{aligned}
 f(x; \nu) &= \frac{x^{\nu-1} e^{-x^2/2}}{2^{\nu/2-1} \Gamma(\frac{\nu}{2})} I_{(0, \infty)}(x) \\
 F(x; \nu) &= \Gamma\left(\frac{\nu}{2}, \frac{x^2}{2}\right) \\
 G(\alpha; \nu) &= \sqrt{2\Gamma^{-1}\left(\frac{\nu}{2}, \alpha\right)} \\
 M(t) &= \Gamma\left(\frac{\nu}{2}\right) {}_1F_1\left(\frac{\nu}{2}; \frac{1}{2}; \frac{t^2}{2}\right) + \frac{t}{\sqrt{2}} \Gamma\left(\frac{1+\nu}{2}\right) {}_1F_1\left(\frac{1+\nu}{2}; \frac{3}{2}; \frac{t^2}{2}\right) \\
 \mu &= \frac{\sqrt{2}\Gamma\left(\frac{\nu+1}{2}\right)}{\Gamma\left(\frac{\nu}{2}\right)} \\
 \mu_2 &= \nu - \mu^2 \\
 \gamma_1 &= \frac{2\mu^3 + \mu(1-2\nu)}{\mu_2^{3/2}} \\
 \gamma_2 &= \frac{2\nu(1-\nu) - 6\mu^4 + 4\mu^2(2\nu-1)}{\mu_2^2} \\
 m_d &= \sqrt{\nu-1} \quad \nu \geq 1 \\
 m_n &= \sqrt{2\Gamma^{-1}\left(\frac{\nu}{2}, \frac{1}{2}\right)}
 \end{aligned}$$

Implementation: `scipy.stats.chi`

## Chi-squared Distribution

This is the gamma distribution with  $L = 0.0$  and  $S = 2.0$  and  $\alpha = \nu/2$  where  $\nu$  is called the degrees of freedom. If  $Z_1 \dots Z_\nu$  are all standard normal distributions, then  $W = \sum_k Z_k^2$  has (standard) chi-square distribution with  $\nu$  degrees of freedom.

The standard form (most often used in standard form only) is  $x > 0$

$$\begin{aligned}
 f(x; \alpha) &= \frac{1}{2\Gamma\left(\frac{\nu}{2}\right)} \left(\frac{x}{2}\right)^{\nu/2-1} e^{-x/2} \\
 F(x; \alpha) &= \Gamma\left(\frac{\nu}{2}, \frac{x}{2}\right) \\
 G(q; \alpha) &= 2\Gamma^{-1}\left(\frac{\nu}{2}, q\right) \\
 M(t) &= \frac{\Gamma\left(\frac{\nu}{2}\right)}{\left(\frac{1}{2} - t\right)^{\nu/2}} \\
 \mu &= \nu \\
 \mu_2 &= 2\nu \\
 \gamma_1 &= \frac{2\sqrt{2}}{\sqrt{\nu}} \\
 \gamma_2 &= \frac{12}{\nu} \\
 m_d &= \frac{\nu}{2} - 1
 \end{aligned}$$

Implementation: `scipy.stats.chi2`

## Cosine Distribution

Approximation to the normal distribution.

$$\begin{aligned}
 f(x) &= \frac{1}{2\pi} [1 + \cos x] I_{[-\pi, \pi]}(x) \\
 F(x) &= \frac{1}{2\pi} [\pi + x + \sin x] I_{[-\pi, \pi]}(x) + I_{(\pi, \infty)}(x) \\
 G(\alpha) &= F^{-1}(\alpha) \\
 M(t) &= \frac{\sinh(\pi t)}{\pi t (1 + t^2)} \\
 \mu = m_d = m_n &= 0 \\
 \mu_2 &= \frac{\pi^2}{3} - 2 \\
 \gamma_1 &= 0 \\
 \gamma_2 &= \frac{-6(\pi^4 - 90)}{5(\pi^2 - 6)^2} \\
 h[X] &= \log(4\pi) - 1 \\
 &\approx 1.531024242469692907930.
 \end{aligned}$$

Implementation: `scipy.stats.cosine`

## Double Gamma Distribution

The double gamma is the signed version of the Gamma distribution. For  $\alpha > 0$  :

$$\begin{aligned}
 f(x; \alpha) &= \frac{1}{2\Gamma(\alpha)} |x|^{\alpha-1} e^{-|x|} \\
 F(x; \alpha) &= \begin{cases} \frac{1}{2} - \frac{1}{2}\Gamma(\alpha, |x|) & x \leq 0 \\ \frac{1}{2} + \frac{1}{2}\Gamma(\alpha, |x|) & x > 0 \end{cases} \\
 G(q; \alpha) &= \begin{cases} -\Gamma^{-1}(\alpha, |2q - 1|) & q \leq \frac{1}{2} \\ \Gamma^{-1}(\alpha, |2q - 1|) & q > \frac{1}{2} \end{cases} \\
 M(t) &= \frac{1}{2(1-t)^{\alpha}} + \frac{1}{2(1+t)^{\alpha}} \\
 \mu = m_n &= 0 \\
 \mu_2 &= \alpha(\alpha + 1) \\
 \gamma_1 &= 0 \\
 \gamma_2 &= \frac{(\alpha + 2)(\alpha + 3)}{\alpha(\alpha + 1)} - 3 \\
 m_d &= \text{NA}
 \end{aligned}$$

Implementation: `scipy.stats.dgamma`

## Double Weibull Distribution

This is a signed form of the Weibull distribution.

$$\begin{aligned}
 f(x; c) &= \frac{c}{2} |x|^{c-1} \exp(-|x|^c) \\
 F(x; c) &= \begin{cases} \frac{1}{2} \exp(-|x|^c) & x \leq 0 \\ 1 - \frac{1}{2} \exp(-|x|^c) & x > 0 \end{cases} \\
 G(q; c) &= \begin{cases} -\log^{1/c}\left(\frac{1}{2q}\right) & q \leq \frac{1}{2} \\ \log^{1/c}\left(\frac{1}{2q-1}\right) & q > \frac{1}{2} \end{cases} \\
 \mu'_n = \mu_n &= \begin{cases} \Gamma\left(1 + \frac{n}{c}\right) & \text{neven} \\ 0 & \text{nodd} \end{cases} \\
 m_d = \mu &= 0 \\
 \mu_2 &= \Gamma\left(\frac{c+2}{c}\right) \\
 \gamma_1 &= 0 \\
 \gamma_2 &= \frac{\Gamma\left(1 + \frac{4}{c}\right)}{\Gamma^2\left(1 + \frac{2}{c}\right)} \\
 m_d &= \text{NAbimodal}
 \end{aligned}$$

Implementation: `scipy.stats.dweibull`

## Erlang Distribution

This is just the Gamma distribution with shape parameter  $\alpha = n$  an integer.

Implementation: `scipy.stats.erlang`

## Exponential Distribution

This is a special case of the Gamma (and Erlang) distributions with shape parameter ( $\alpha = 1$ ) and the same location and scale parameters. The standard form is therefore ( $x \geq 0$ )

$$\begin{aligned}
 f(x) &= e^{-x} \\
 F(x) &= \Gamma(1, x) = 1 - e^{-x} \\
 G(q) &= -\log(1 - q) \\
 \mu'_n &= n! \\
 M(t) &= \frac{1}{1 - t} \\
 \mu &= 1 \\
 \mu_2 &= 1 \\
 \gamma_1 &= 2 \\
 \gamma_2 &= 6 \\
 m_d &= 0 \\
 h[X] &= 1.
 \end{aligned}$$

Implementation: `scipy.stats.expon`

### Exponentiated Weibull Distribution

Two positive shape parameters  $a$  and  $c$  and  $x \in (0, \infty)$

$$\begin{aligned} f(x; a, c) &= ac [1 - \exp(-x^c)]^{a-1} \exp(-x^c) x^{c-1} \\ F(x; a, c) &= [1 - \exp(-x^c)]^a \\ G(q; a, c) &= \left[-\log\left(1 - q^{1/a}\right)\right]^{1/c} \end{aligned}$$

Implementation: `scipy.stats.exponweib`

### Exponential Power Distribution

One positive shape parameter  $b$ . Defined for  $x \geq 0$ .

$$\begin{aligned} f(x; b) &= ebx^{b-1} \exp\left[x^b - e^{x^b}\right] \\ F(x; b) &= 1 - \exp\left[1 - e^{x^b}\right] \\ G(q; b) &= \log^{1/b}\left[1 - \log(1 - q)\right] \end{aligned}$$

Implementation: `scipy.stats.exponpow`

### Fatigue Life (Birnbaum-Saunders) Distribution

This distribution's pdf is the average of the inverse-Gaussian ( $\mu = 1$ ) and reciprocal inverse-Gaussian pdf ( $\mu = 1$ ). We follow the notation of JKB here with  $\beta = S$ , for  $x > 0$

$$\begin{aligned} f(x; c) &= \frac{x+1}{2c\sqrt{2\pi}x^3} \exp\left(-\frac{(x-1)^2}{2xc^2}\right) \\ F(x; c) &= \Phi\left(\frac{1}{c}\left(\sqrt{x} - \frac{1}{\sqrt{x}}\right)\right) \\ G(q; c) &= \frac{1}{4} \left[ c\Phi^{-1}(q) + \sqrt{c^2(\Phi^{-1}(q))^2 + 4} \right]^2 \\ M(t) &= c\sqrt{2\pi} \exp\left[\frac{1}{c^2}\left(1 - \sqrt{1 - 2c^2t}\right)\right] \left(1 + \frac{1}{\sqrt{1 - 2c^2t}}\right) \\ \mu &= \frac{c^2}{2} + 1 \\ \mu_2 &= c^2 \left(\frac{5}{4}c^2 + 1\right) \\ \gamma_1 &= \frac{4c\sqrt{11c^2 + 6}}{(5c^2 + 4)^{3/2}} \\ \gamma_2 &= \frac{6c^2(93c^2 + 41)}{(5c^2 + 4)^2} \end{aligned}$$

Implementation: `scipy.stats.fatiguelife`

## Fisk (Log Logistic) Distribution

Special case of the Burr distribution with  $d = 1$

$$c > 0$$

$$k = \Gamma\left(1 - \frac{2}{c}\right) \Gamma\left(\frac{2}{c} + 1\right) - \Gamma^2\left(1 - \frac{1}{c}\right) \Gamma^2\left(\frac{1}{c} + 1\right)$$

$$f(x; c, d) = \frac{cx^{c-1}}{(1+x^c)^2} I_{(0,\infty)}(x)$$

$$F(x; c, d) = (1+x^{-c})^{-1}$$

$$G(\alpha; c, d) = (\alpha^{-1} - 1)^{-1/c}$$

$$\mu = \Gamma\left(1 - \frac{1}{c}\right) \Gamma\left(\frac{1}{c} + 1\right)$$

$$\mu_2 = k$$

$$\gamma_1 = \frac{1}{\sqrt{k^3}} \left[ 2\Gamma^3\left(1 - \frac{1}{c}\right) \Gamma^3\left(\frac{1}{c} + 1\right) + \Gamma\left(1 - \frac{3}{c}\right) \Gamma\left(\frac{3}{c} + 1\right) - 3\Gamma\left(1 - \frac{2}{c}\right) \Gamma\left(1 - \frac{1}{c}\right) \Gamma\left(\frac{1}{c} + 1\right) \Gamma\left(\frac{2}{c} + 1\right) \right]$$

$$\gamma_2 = -3 + \frac{1}{k^2} \left[ 6\Gamma\left(1 - \frac{2}{c}\right) \Gamma^2\left(1 - \frac{1}{c}\right) \Gamma^2\left(\frac{1}{c} + 1\right) \Gamma\left(\frac{2}{c} + 1\right) - 3\Gamma^4\left(1 - \frac{1}{c}\right) \Gamma^4\left(\frac{1}{c} + 1\right) + \Gamma\left(1 - \frac{4}{c}\right) \Gamma\left(\frac{4}{c} + 1\right) - 4\Gamma\left(1 - \frac{3}{c}\right) \Gamma\left(1 - \frac{1}{c}\right) \Gamma\left(\frac{1}{c} + 1\right) \Gamma\left(\frac{3}{c} + 1\right) \right]$$

$$m_d = \left(\frac{c-1}{c+1}\right)^{1/c} \text{ if } c > 1 \text{ otherwise } 0$$

$$m_n = 1$$

$$h[X] = 2 - \log c.$$

Implementation: `scipy.stats.fisk`

## Folded Cauchy Distribution

This formula can be expressed in terms of the standard formulas for the Cauchy distribution (call the cdf  $C(x)$  and the pdf  $d(x)$ ), if  $Y$  is cauchy then  $|Y|$  is folded cauchy. Note that  $x \geq 0$ .

$$f(x; c) = \frac{1}{\pi(1+(x-c)^2)} + \frac{1}{\pi(1+(x+c)^2)}$$

$$F(x; c) = \frac{1}{\pi} \tan^{-1}(x-c) + \frac{1}{\pi} \tan^{-1}(x+c)$$

$$G(q; c) = F^{-1}(x; c)$$

No moments

Implementation: `scipy.stats.foldcauchy`

## Folded Normal Distribution

If  $Z$  is Normal with mean  $L$  and  $\sigma = S$ , then  $|Z|$  is a folded normal with shape parameter  $c = |L|/S$ , location parameter 0 and scale parameter  $S$ . This is a special case of the non-central chi distribution with one- degree of freedom and non-centrality parameter  $c^2$ . Note that  $c \geq 0$ . The standard form of the folded normal is

$$\begin{aligned}
 f(x; c) &= \sqrt{\frac{2}{\pi}} \cosh(cx) \exp\left(-\frac{x^2 + c^2}{2}\right) \\
 F(x; c) &= \Phi(x - c) - \Phi(-x - c) = \Phi(x - c) + \Phi(x + c) - 1 \\
 G(\alpha; c) &= F^{-1}(x; c) \\
 M(t) &= \exp\left[\frac{t}{2}(t - 2c)\right] (1 + e^{2ct}) \\
 k &= \operatorname{erf}\left(\frac{c}{\sqrt{2}}\right) \\
 p &= \exp\left(-\frac{c^2}{2}\right) \\
 \mu &= \sqrt{\frac{2}{\pi}} p + ck \\
 \mu_2 &= c^2 + 1 - \mu^2 \\
 \gamma_1 &= \frac{\sqrt{\frac{2}{\pi}} p^3 \left(4 - \frac{\pi}{p^2} (2c^2 + 1)\right) + 2ck (6p^2 + 3cpk\sqrt{2\pi} + \pi c (k^2 - 1))}{\pi \mu_2^{3/2}} \\
 \gamma_2 &= \frac{c^4 + 6c^2 + 3 + 6(c^2 + 1)\mu^2 - 3\mu^4 - 4p\mu \left(\sqrt{\frac{2}{\pi}} (c^2 + 2) + \frac{ck}{p} (c^2 + 3)\right)}{\mu_2^2}
 \end{aligned}$$

Implementation: `scipy.stats.foldnorm`

## Fratio (or F) Distribution

Defined for  $x > 0$ . The distribution of  $(X_1/X_2)(\nu_2/\nu_1)$  if  $X_1$  is chi-squared with  $\nu_1$  degrees of freedom and  $X_2$  is chi-squared with  $\nu_2$  degrees of freedom.

$$\begin{aligned}
 f(x; \nu_1, \nu_2) &= \frac{\nu_2^{\nu_2/2} \nu_1^{\nu_1/2} x^{\nu_1/2 - 1}}{(\nu_2 + \nu_1 x)^{(\nu_1 + \nu_2)/2} B\left(\frac{\nu_1}{2}, \frac{\nu_2}{2}\right)} \\
 F(x; \nu_1, \nu_2) &= I\left(\frac{\nu_1}{2}, \frac{\nu_2}{2}, \frac{\nu_2 x}{\nu_2 + \nu_1 x}\right) \\
 G(q; \nu_1, \nu_2) &= \left[ \frac{\nu_2}{I^{-1}(\nu_1/2, \nu_2/2, q)} - \frac{\nu_1}{\nu_2} \right]^{-1} \\
 \mu &= \frac{\nu_2}{\nu_2 - 2} \quad \nu_2 > 2 \\
 \mu_2 &= \frac{2\nu_2^2 (\nu_1 + \nu_2 - 2)}{\nu_1 (\nu_2 - 2)^2 (\nu_2 - 4)} \quad \nu_2 > 4 \\
 \gamma_1 &= \frac{2(2\nu_1 + \nu_2 - 2)}{\nu_2 - 6} \sqrt{\frac{2(\nu_2 - 4)}{\nu_1 (\nu_1 + \nu_2 - 2)}} \quad \nu_2 > 6 \\
 \gamma_2 &= \frac{3[8 + (\nu_2 - 6)\gamma_1^2]}{2\nu_2 - 16} \quad \nu_2 > 8
 \end{aligned}$$

Implementation: `scipy.stats.f`

## Gamma Distribution

The standard form for the gamma distribution is ( $\alpha > 0$ ) valid for  $x \geq 0$ .

$$f(x; \alpha) = \frac{1}{\Gamma(\alpha)} x^{\alpha-1} e^{-x}$$

$$F(x; \alpha) = \Gamma(\alpha, x)$$

$$G(q; \alpha) = \Gamma^{-1}(\alpha, q)$$

$$M(t) = \frac{1}{(1-t)^\alpha}$$

$$\mu = \alpha$$

$$\mu_2 = \alpha$$

$$\gamma_1 = \frac{2}{\sqrt{\alpha}}$$

$$\gamma_2 = \frac{6}{\alpha}$$

$$m_d = \alpha - 1$$

$$h[X] = \Psi(a)[1-a] + a + \log \Gamma(a)$$

where

$$\Psi(a) = \frac{\Gamma'(a)}{\Gamma(a)}.$$

Implementation: `scipy.stats.gamma`

## Generalized Logistic Distribution

Has been used in the analysis of extreme values. Has one shape parameter  $c > 0$ . And  $x > 0$

$$f(x; c) = \frac{c \exp(-x)}{[1 + \exp(-x)]^{c+1}}$$

$$F(x; c) = \frac{1}{[1 + \exp(-x)]^c}$$

$$G(q; c) = -\log(q^{-1/c} - 1)$$

$$M(t) = \frac{c}{1-t} {}_2F_1(1+c, 1-t; 2-t; -1)$$

$$\mu = \gamma + \psi_0(c)$$

$$\mu_2 = \frac{\pi^2}{6} + \psi_1(c)$$

$$\gamma_1 = \frac{\psi_2(c) + 2\zeta(3)}{\mu_2^{3/2}}$$

$$\gamma_2 = \frac{\left(\frac{\pi^4}{15} + \psi_3(c)\right)}{\mu_2^2}$$

$$m_d = \log c$$

$$m_n = -\log(2^{1/c} - 1)$$

Note that the polygamma function is

$$\begin{aligned}\psi_n(z) &= \frac{d^{n+1}}{dz^{n+1}} \log \Gamma(z) \\ &= (-1)^{n+1} n! \sum_{k=0}^{\infty} \frac{1}{(z+k)^{n+1}} \\ &= (-1)^{n+1} n! \zeta(n+1, z)\end{aligned}$$

where  $\zeta(k, x)$  is a generalization of the Riemann zeta function called the Hurwitz zeta function. Note that  $\zeta(n) \equiv \zeta(n, 1)$ .

Implementation: `scipy.stats.genlogistic`

### Generalized Pareto Distribution

Shape parameter  $c \neq 0$  and defined for  $x \geq 0$  for all  $c$  and  $x < \frac{1}{|c|}$  if  $c$  is negative.

$$\begin{aligned}f(x; c) &= (1 + cx)^{-1 - \frac{1}{c}} \\ F(x; c) &= 1 - \frac{1}{(1 + cx)^{1/c}} \\ G(q; c) &= \frac{1}{c} \left[ \left( \frac{1}{1 - q} \right)^c - 1 \right]\end{aligned}$$

$$M(t) = \begin{cases} \left(-\frac{t}{c}\right)^{\frac{1}{c}} e^{-\frac{t}{c}} \left[ \Gamma\left(1 - \frac{1}{c}\right) + \Gamma\left(-\frac{1}{c}, -\frac{t}{c}\right) - \pi \csc\left(\frac{\pi}{c}\right) / \Gamma\left(\frac{1}{c}\right) \right] & c > 0 \\ \left(\frac{|c|}{t}\right)^{1/|c|} \Gamma\left[\frac{1}{|c|}, \frac{t}{|c|}\right] & c < 0 \end{cases}$$

$$\mu'_n = \frac{(-1)^n}{c^n} \sum_{k=0}^n \binom{n}{k} \frac{(-1)^k}{1 - ck} \quad cn < 1$$

$$\mu'_1 = \frac{1}{1 - c} \quad c < 1$$

$$\mu'_2 = \frac{2}{(1 - 2c)(1 - c)} \quad c < \frac{1}{2}$$

$$\mu'_3 = \frac{6}{(1 - c)(1 - 2c)(1 - 3c)} \quad c < \frac{1}{3}$$

$$\mu'_4 = \frac{24}{(1 - c)(1 - 2c)(1 - 3c)(1 - 4c)} \quad c < \frac{1}{4}$$

Thus,

$$\begin{aligned}\mu &= \mu'_1 \\ \mu_2 &= \mu'_2 - \mu^2 \\ \gamma_1 &= \frac{\mu'_3 - 3\mu\mu_2 - \mu^3}{\mu_2^{3/2}} \\ \gamma_2 &= \frac{\mu'_4 - 4\mu\mu_3 - 6\mu^2\mu_2 - \mu^4}{\mu_2^2} - 3\end{aligned}$$

$$h[X] = 1 + c \quad c > 0$$

Implementation: `scipy.stats.genpareto`

## Generalized Exponential Distribution

Three positive shape parameters for  $x \geq 0$ . Note that  $a$ ,  $b$ , and  $c$  are all  $> 0$ .

$$\begin{aligned} f(x; a, b, c) &= (a + b(1 - e^{-cx})) \exp \left[ ax - bx + \frac{b}{c}(1 - e^{-cx}) \right] \\ F(x; a, b, c) &= 1 - \exp \left[ ax - bx + \frac{b}{c}(1 - e^{-cx}) \right] \\ G(q; a, b, c) &= F^{-1} \end{aligned}$$

Implementation: `scipy.stats.genexpon`

## Generalized Extreme Value Distribution

Extreme value distributions with shape parameter  $c$ .

For  $c > 0$  defined on  $-\infty < x \leq 1/c$ .

$$\begin{aligned} f(x; c) &= \exp \left[ -(1 - cx)^{1/c} \right] (1 - cx)^{1/c-1} \\ F(x; c) &= \exp \left[ -(1 - cx)^{1/c} \right] \\ G(q; c) &= \frac{1}{c} [1 - (-\log q)^c] \\ \mu'_n &= \frac{1}{c^n} \sum_{k=0}^n \binom{n}{k} (-1)^k \Gamma(ck + 1) \quad cn > -1 \end{aligned}$$

So,

$$\begin{aligned} \mu'_1 &= \frac{1}{c} (1 - \Gamma(1 + c)) \quad c > -1 \\ \mu'_2 &= \frac{1}{c^2} (1 - 2\Gamma(1 + c) + \Gamma(1 + 2c)) \quad c > -\frac{1}{2} \\ \mu'_3 &= \frac{1}{c^3} (1 - 3\Gamma(1 + c) + 3\Gamma(1 + 2c) - \Gamma(1 + 3c)) \quad c > -\frac{1}{3} \\ \mu'_4 &= \frac{1}{c^4} (1 - 4\Gamma(1 + c) + 6\Gamma(1 + 2c) - 4\Gamma(1 + 3c) + \Gamma(1 + 4c)) \quad c > -\frac{1}{4} \end{aligned}$$

For  $c < 0$  defined on  $\frac{1}{c} \leq x < \infty$ . For  $c = 0$  defined over all space

$$\begin{aligned} f(x; 0) &= \exp[-e^{-x}] e^{-x} \\ F(x; 0) &= \exp[-e^{-x}] \\ G(q; 0) &= -\log(-\log q) \end{aligned}$$

This is just the (left-skewed) Gumbel distribution for  $c=0$ .

$$\begin{aligned} \mu &= \gamma = -\psi_0(1) \\ \mu_2 &= \frac{\pi^2}{6} \\ \gamma_1 &= \frac{12\sqrt{6}}{\pi^3} \zeta(3) \\ \gamma_2 &= \frac{12}{5} \end{aligned}$$

Implementation: `scipy.stats.genextreme`

## Generalized Gamma Distribution

A general probability form that reduces to many common distributions:  $x > 0$   $a > 0$  and  $c \neq 0$ .

$$\begin{aligned}
 f(x; a, c) &= \frac{|c| x^{ca-1}}{\Gamma(a)} \exp(-x^c) \\
 F(x; a, c) &= \begin{cases} \frac{\Gamma(a, x^c)}{\Gamma(a)} & c > 0 \\ 1 - \frac{\Gamma(a, x^c)}{\Gamma(a)} & c < 0 \end{cases} \\
 G(q; a, c) &= \begin{cases} \{\Gamma^{-1}[a, \Gamma(a)q]\}^{1/c} & c > 0 \\ \{\Gamma^{-1}[a, \Gamma(a)(1-q)]\}^{1/c} & c < 0 \end{cases} \\
 \mu'_n &= \frac{\Gamma(a + \frac{n}{c})}{\Gamma(a)} \\
 \mu &= \frac{\Gamma(a + \frac{1}{c})}{\Gamma(a)} \\
 \mu_2 &= \frac{\Gamma(a + \frac{2}{c})}{\Gamma(a)} - \mu^2 \\
 \gamma_1 &= \frac{\Gamma(a + \frac{3}{c})/\Gamma(a) - 3\mu\mu_2 - \mu^3}{\mu_2^{3/2}} \\
 \gamma_2 &= \frac{\Gamma(a + \frac{4}{c})/\Gamma(a) - 4\mu\mu_3 - 6\mu^2\mu_2 - \mu^4}{\mu_2^2} - 3 \\
 m_d &= \left(\frac{ac-1}{c}\right)^{1/c}.
 \end{aligned}$$

Special cases are Weibull ( $a = 1$ ), half-normal ( $a = 1/2, c = 2$ ) and ordinary gamma distributions  $c = 1$ . If  $c = -1$  then it is the inverted gamma distribution.

$$h[X] = a - a\Psi(a) + \frac{1}{c}\Psi(a) + \log \Gamma(a) - \log |c|.$$

Implementation: `scipy.stats.gengamma`

## Generalized Half-Logistic Distribution

For  $x \in [0, 1/c]$  and  $c > 0$  we have

$$\begin{aligned}
 f(x; c) &= \frac{2(1-cx)^{\frac{1}{c}-1}}{\left(1 + (1-cx)^{1/c}\right)^2} \\
 F(x; c) &= \frac{1 - (1-cx)^{1/c}}{1 + (1-cx)^{1/c}} \\
 G(q; c) &= \frac{1}{c} \left[ 1 - \left( \frac{1-q}{1+q} \right)^c \right] \\
 h[X] &= 2 - (2c + 1) \log 2.
 \end{aligned}$$

Implementation: `scipy.stats.genhalflogistic`

## Generalized Normal Distribution

This distribution is also known as the exponential power distribution. It has a single shape parameter  $\beta > 0$ . It reduces to a number of common distributions.

### Functions

$$f(x; \beta) = \frac{\beta}{2\Gamma(1/\beta)} e^{-|x|^\beta}$$

$$F(x; \beta) = \frac{1}{2} + \operatorname{sgn}(x) \frac{\gamma(1/\beta, |x|^\beta)}{2\Gamma(1/\beta)}$$

$\gamma$  is the lower incomplete gamma function.  $\gamma(s, x) = \int_0^x t^{s-1} e^{-t} dt$

$$h[X; \beta] = \frac{1}{\beta} - \log \left[ \frac{\beta}{2\Gamma(1/\beta)} \right]$$

### Moments

$$\begin{aligned} \mu &= 0 \\ m_n &= 0 \\ m_d &= 0 \\ \mu_2 &= \frac{\Gamma(3/\beta)}{\Gamma(1/\beta)} \\ \gamma_1 &= 0 \\ \gamma_2 &= \frac{\Gamma(5/\beta)\Gamma(1/\beta)}{\Gamma(3/\beta)^2} - 3 \end{aligned}$$

### Special Cases

- Laplace distribution ( $\beta = 1$ )
- Normal distribution with  $\mu_2 = 1/2$  ( $\beta = 2$ )
- Uniform distribution over the interval  $[-1, 1]$  ( $\beta \rightarrow \infty$ )

### Sources

- [https://en.wikipedia.org/wiki/Generalized\\_normal\\_distribution#Version\\_1](https://en.wikipedia.org/wiki/Generalized_normal_distribution#Version_1)
- [https://en.wikipedia.org/wiki/Incomplete\\_gamma\\_function#Lower\\_incomplete\\_Gamma\\_function](https://en.wikipedia.org/wiki/Incomplete_gamma_function#Lower_incomplete_Gamma_function)

Implementation: `scipy.stats.gennorm`

## Gilbrat Distribution

Special case of the log-normal with  $\sigma = 1$  and  $S = 1.0$  (typically also  $L = 0.0$ )

$$\begin{aligned} f(x; \sigma) &= \frac{1}{x\sqrt{2\pi}} \exp\left[-\frac{1}{2}(\log x)^2\right] \\ F(x; \sigma) &= \Phi(\log x) = \frac{1}{2} \left[1 + \operatorname{erf}\left(\frac{\log x}{\sqrt{2}}\right)\right] \\ G(q; \sigma) &= \exp\{\Phi^{-1}(q)\} \end{aligned}$$

$$\begin{aligned} \mu &= \sqrt{e} \\ \mu_2 &= e[e - 1] \\ \gamma_1 &= \sqrt{e - 1}(2 + e) \\ \gamma_2 &= e^4 + 2e^3 + 3e^2 - 6 \end{aligned}$$

$$\begin{aligned} h[X] &= \log(\sqrt{2\pi}e) \\ &\approx 1.4189385332046727418 \end{aligned}$$

Implementation: `scipy.stats.gilbrat`

## Gompertz (Truncated Gumbel) Distribution

For  $x \geq 0$  and  $c > 0$ . In JKB the two shape parameters  $b, a$  are reduced to the single shape-parameter  $c = b/a$ . As  $a$  is just a scale parameter when  $a \neq 0$ . If  $a = 0$ , the distribution reduces to the exponential distribution scaled by  $1/b$ . Thus, the standard form is given as

$$\begin{aligned} f(x; c) &= ce^x \exp[-c(e^x - 1)] \\ F(x; c) &= 1 - \exp[-c(e^x - 1)] \\ G(q; c) &= \log\left[1 - \frac{1}{c} \log(1 - q)\right] \\ h[X] &= 1 - \log(c) - e^c \operatorname{Ei}(1, c), \end{aligned}$$

where

$$\operatorname{Ei}(n, x) = \int_1^\infty t^{-n} \exp(-xt) dt$$

Implementation: `scipy.stats.gompertz`

## Gumbel (LogWeibull, Fisher-Tippetts, Type I Extreme Value) Distribution

One of a class of extreme value distributions (right-skewed).

$$\begin{aligned} f(x) &= \exp(-(x + e^{-x})) \\ F(x) &= \exp(-e^{-x}) \\ G(q) &= -\log(-\log(q)) \\ M(t) &= \Gamma(1 - t) \end{aligned}$$

$$\begin{aligned}\mu &= \gamma = -\psi_0(1) \\ \mu_2 &= \frac{\pi^2}{6} \\ \gamma_1 &= \frac{12\sqrt{6}}{\pi^3} \zeta(3) \\ \gamma_2 &= \frac{12}{5} \\ m_d &= 0 \\ m_n &= -\log(\log 2)\end{aligned}$$

$$h[X] \approx 1.0608407169541684911$$

Implementation: `scipy.stats.gumbel_r`

### Gumbel Left-skewed (for minimum order statistic) Distribution

$$\begin{aligned}f(x) &= \exp(x - e^x) \\ F(x) &= 1 - \exp(-e^x) \\ G(q) &= \log(-\log(1 - q)) \\ M(t) &= \Gamma(1 + t)\end{aligned}$$

Note, that  $\mu$  is negative the mean for the right-skewed distribution. Similar for median and mode. All other moments are the same.

$$h[X] \approx 1.0608407169541684911.$$

Implementation: `scipy.stats.gumbel_l`

### HalfCauchy Distribution

If  $Z$  is Hyperbolic Secant distributed then  $e^Z$  is Half-Cauchy distributed. Also, if  $W$  is (standard) Cauchy distributed, then  $|W|$  is Half-Cauchy distributed. Special case of the Folded Cauchy distribution with  $c = 0$ . The standard form is

$$\begin{aligned}f(x) &= \frac{2}{\pi(1+x^2)} I_{[0,\infty)}(x) \\ F(x) &= \frac{2}{\pi} \arctan(x) I_{[0,\infty)}(x) \\ G(q) &= \tan\left(\frac{\pi}{2}q\right) \\ M(t) &= \cos t + \frac{2}{\pi} [\text{Si}(t) \cos t - \text{Ci}(-t) \sin t] \\ m_d &= 0 \\ m_n &= \tan\left(\frac{\pi}{4}\right)\end{aligned}$$

No moments, as the integrals diverge.

$$\begin{aligned}h[X] &= \log(2\pi) \\ &\approx 1.8378770664093454836.\end{aligned}$$

Implementation: `scipy.stats.halfcauchy`

## HalfNormal Distribution

This is a special case of the chi distribution with  $L = a$  and  $S = b$  and  $\nu = 1$ . This is also a special case of the folded normal with shape parameter  $c = 0$  and  $S = S$ . If  $Z$  is (standard) normally distributed then,  $|Z|$  is half-normal. The standard form is

$$f(x) = \sqrt{\frac{2}{\pi}} e^{-x^2/2} I_{(0,\infty)}(x)$$

$$F(x) = 2\Phi(x) - 1$$

$$G(q) = \Phi^{-1}\left(\frac{1+q}{2}\right)$$

$$M(t) = \sqrt{2\pi} e^{t^2/2} \Phi(t)$$

$$\mu = \sqrt{\frac{2}{\pi}}$$

$$\mu_2 = 1 - \frac{2}{\pi}$$

$$\gamma_1 = \frac{\sqrt{2}(4-\pi)}{(\pi-2)^{3/2}}$$

$$\gamma_2 = \frac{8(\pi-3)}{(\pi-2)^2}$$

$$m_d = 0$$

$$m_n = \Phi^{-1}\left(\frac{3}{4}\right)$$

$$h[X] = \log\left(\sqrt{\frac{\pi e}{2}}\right) \\ \approx 0.72579135264472743239.$$

Implementation: `scipy.stats.halfnorm`

## Half-Logistic Distribution

In the limit as  $c \rightarrow \infty$  for the generalized half-logistic we have the half-logistic defined over  $x \geq 0$ . Also, the distribution of  $|X|$  where  $X$  has logistic distribution.

$$f(x) = \frac{2e^{-x}}{(1+e^{-x})^2} = \frac{1}{2} \operatorname{sech}^2\left(\frac{x}{2}\right)$$

$$F(x) = \frac{1-e^{-x}}{1+e^{-x}} = \tanh\left(\frac{x}{2}\right)$$

$$G(q) = \log\left(\frac{1+q}{1-q}\right) = 2\operatorname{arctanh}(q)$$

$$M(t) = 1 - t\psi_0\left(\frac{1-t}{2}\right) + t\psi_0\left(1 - \frac{t}{2}\right)$$

$$\mu'_n = 2(1-2^{1-n})n!\zeta(n) \quad n \neq 1$$

$$\begin{aligned}\mu'_1 &= 2 \log(2) \\ \mu'_2 &= 2\zeta(2) = \frac{\pi^2}{3} \\ \mu'_3 &= 9\zeta(3) \\ \mu'_4 &= 42\zeta(4) = \frac{7\pi^4}{15}\end{aligned}$$

$$\begin{aligned}h[X] &= 2 - \log(2) \\ &\approx 1.3068528194400546906.\end{aligned}$$

Implementation: `scipy.stats.halflogistic`

### Hyperbolic Secant Distribution

Related to the logistic distribution and used in lifetime analysis. Standard form is (defined over all  $x$ )

$$\begin{aligned}f(x) &= \frac{1}{\pi} \operatorname{sech}(x) \\ F(x) &= \frac{2}{\pi} \arctan(e^x) \\ G(q) &= \log\left(\tan\left(\frac{\pi}{2}q\right)\right) \\ M(t) &= \sec\left(\frac{\pi}{2}t\right)\end{aligned}$$

$$\begin{aligned}\mu'_n &= \frac{1 + (-1)^n}{2\pi 2^{2n}} n! \left[ \zeta\left(n+1, \frac{1}{4}\right) - \zeta\left(n+1, \frac{3}{4}\right) \right] \\ &= \begin{cases} 0 & \text{nodd} \\ C_{n/2} \frac{\pi^n}{2^n} & \text{neven} \end{cases}\end{aligned}$$

where  $C_m$  is an integer given by

$$\begin{aligned}C_m &= \frac{(2m)! \left[ \zeta\left(2m+1, \frac{1}{4}\right) - \zeta\left(2m+1, \frac{3}{4}\right) \right]}{\pi^{2m+1} 2^{2m}} \\ &= 4(-1)^{m-1} \frac{16^m}{2m+1} B_{2m+1}\left(\frac{1}{4}\right)\end{aligned}$$

where  $B_{2m+1}\left(\frac{1}{4}\right)$  is the Bernoulli polynomial of order  $2m+1$  evaluated at  $1/4$ . Thus

$$\mu'_n = \begin{cases} 0 & \text{nodd} \\ 4(-1)^{n/2-1} \frac{(2\pi)^n}{n+1} B_{n+1}\left(\frac{1}{4}\right) & \text{neven} \end{cases}$$

$$\begin{aligned}m_d = m_n = \mu &= 0 \\ \mu_2 &= \frac{\pi^2}{4} \\ \gamma_1 &= 0 \\ \gamma_2 &= 2\end{aligned}$$

$$h[X] = \log(2\pi).$$

Implementation: `scipy.stats.hypsecant`

## Gauss Hypergeometric Distribution

$x \in [0, 1]$ ,  $\alpha > 0$ ,  $\beta > 0$

$$C^{-1} = B(\alpha, \beta) {}_2F_1(\gamma, \alpha; \alpha + \beta; -z)$$

$$f(x; \alpha, \beta, \gamma, z) = C x^{\alpha-1} \frac{(1-x)^{\beta-1}}{(1+zx)^\gamma}$$

$$\mu'_n = \frac{B(n+\alpha, \beta) {}_2F_1(\gamma, \alpha+n; \alpha+\beta+n; -z)}{B(\alpha, \beta) {}_2F_1(\gamma, \alpha; \alpha+\beta; -z)}$$

Implementation: `scipy.stats.gausshyper`

## Inverted Gamma Distribution

Special case of the generalized Gamma distribution with  $c = -1$  and  $a > 0$ ,  $x > 0$

$$f(x; a) = \frac{x^{-a-1}}{\Gamma(a)} \exp\left(-\frac{1}{x}\right)$$

$$F(x; a) = \frac{\Gamma\left(a, \frac{1}{x}\right)}{\Gamma(a)}$$

$$G(q; a) = \left\{ \Gamma^{-1}[a, \Gamma(a)q] \right\}^{-1}$$

$$\mu'_n = \frac{\Gamma(a-n)}{\Gamma(a)} \quad a > n$$

$$\mu = \frac{1}{a-1} \quad a > 1$$

$$\mu_2 = \frac{1}{(a-2)(a-1)} - \mu^2 \quad a > 2$$

$$\gamma_1 = \frac{\frac{1}{(a-3)(a-2)(a-1)} - 3\mu\mu_2 - \mu^3}{\mu_2^{3/2}}$$

$$\gamma_2 = \frac{\frac{1}{(a-4)(a-3)(a-2)(a-1)} - 4\mu\mu_3 - 6\mu^2\mu_2 - \mu^4}{\mu_2^2} - 3$$

$$m_d = \frac{1}{a+1}$$

$$h[X] = a - (a+1)\Psi(a) + \log \Gamma(a)$$

Implementation: `scipy.stats.invgamma`

## Inverse Normal (Inverse Gaussian) Distribution

The standard form involves the shape parameter  $\mu$  (in most definitions,  $L = 0.0$  is used). (In terms of the regress documentation  $\mu = A/B$ ) and  $B = S$  and  $L$  is not a parameter in that distribution. A standard form is  $x > 0$

$$f(x; \mu) = \frac{1}{\sqrt{2\pi x^3}} \exp\left(-\frac{(x-\mu)^2}{2x\mu^2}\right)$$

$$F(x; \mu) = \Phi\left(\frac{1}{\sqrt{x}} \frac{x-\mu}{\mu}\right) + \exp\left(\frac{2}{\mu}\right) \Phi\left(-\frac{1}{\sqrt{x}} \frac{x+\mu}{\mu}\right)$$

$$G(q; \mu) = F^{-1}(q; \mu)$$

$$\begin{aligned}
 \mu &= \mu \\
 \mu_2 &= \mu^3 \\
 \gamma_1 &= 3\sqrt{\mu} \\
 \gamma_2 &= 15\mu \\
 m_d &= \frac{\mu}{2} \left( \sqrt{9\mu^2 + 4} - 3\mu \right)
 \end{aligned}$$

This is related to the canonical form or JKB “two-parameter “inverse Gaussian when written in it’s full form with scale parameter  $S$  and location parameter  $L$  by taking  $L = 0$  and  $S \equiv \lambda$ , then  $\mu S$  is equal to  $\mu_2$  where  $\mu_2$  is the parameter used by JKB. We prefer this form because of it’s consistent use of the scale parameter. Notice that in JKB the skew ( $\sqrt{\beta_1}$ ) and the kurtosis ( $\beta_2 - 3$ ) are both functions only of  $\mu_2/\lambda = \mu S/S = \mu$  as shown here, while the variance and mean of the standard form here are transformed appropriately.

Implementation: `scipy.stats.invgauss`

### Inverted Weibull Distribution

Shape parameter  $c > 0$  and  $x > 0$ . Then

$$\begin{aligned}
 f(x; c) &= cx^{-c-1} \exp(-x^{-c}) \\
 F(x; c) &= \exp(-x^{-c}) \\
 G(q; c) &= (-\log q)^{-1/c} \\
 h[X] &= 1 + \gamma + \frac{\gamma}{c} - \log(c)
 \end{aligned}$$

where  $\gamma$  is Euler’s constant.

Implementation: `scipy.stats.invweibull`

### Johnson SB Distribution

Defined for  $x \in (0, 1)$  with two shape parameters  $a$  and  $b > 0$ .

$$\begin{aligned}
 f(x; a, b) &= \frac{b}{x(1-x)} \phi \left( a + b \log \frac{x}{1-x} \right) \\
 F(x; a, b) &= \Phi \left( a + b \log \frac{x}{1-x} \right) \\
 G(q; a, b) &= \frac{1}{1 + \exp \left[ -\frac{1}{b} (\Phi^{-1}(q) - a) \right]}
 \end{aligned}$$

Implementation: `scipy.stats.johnsonsb`

### Johnson SU Distribution

Defined for all  $x$  with two shape parameters  $a$  and  $b > 0$ .

$$\begin{aligned}
 f(x; a, b) &= \frac{b}{\sqrt{x^2 + 1}} \phi \left( a + b \log \left( x + \sqrt{x^2 + 1} \right) \right) \\
 F(x; a, b) &= \Phi \left( a + b \log \left( x + \sqrt{x^2 + 1} \right) \right) \\
 G(q; a, b) &= \sinh \left[ \frac{\Phi^{-1}(q) - a}{b} \right]
 \end{aligned}$$

Implementation: `scipy.stats.johnsonsu`

## KSone Distribution

This is the distribution of maximum positive differences between an empirical distribution function, computed from  $n$  samples or observations, and a comparison (or target) cumulative distribution function.

Writing  $D_n^+ = \sup_t (F_{\text{empirical},n}(t) - F_{\text{target}}(t))$ , `ksone` is the distribution of the  $D_n^+$  values. (The distribution of  $D_n^- = \sup_t (F_{\text{target}}(t) - F_{\text{empirical},n}(t))$  differences follows the same distribution, so `ksone` can be used for one-sided tests on either side.)

There is one shape parameter  $n$ , a positive integer, and the support is  $x \in [0, 1]$ .

$$\begin{aligned} F(n, x) &= 1 - \sum_{j=0}^{\lfloor n(1-x) \rfloor} \binom{n}{j} x \left(x + \frac{j}{n}\right)^{j-1} \left(1 - x - \frac{j}{n}\right)^{n-j} \\ &= 1 - \text{scipy.special.smirnov}(n, x) \\ \lim_{n \rightarrow \infty} F\left(n, \frac{x}{\sqrt{n}}\right) &= e^{-2x^2} \end{aligned}$$

## References

- “Kolmogorov-Smirnov test”, Wikipedia [https://en.wikipedia.org/wiki/Kolmogorov-Smirnov\\_test](https://en.wikipedia.org/wiki/Kolmogorov-Smirnov_test)
- Birnbaum, Z. W.; Tingey, Fred H. “One-Sided Confidence Contours for Probability Distribution Functions.” *Ann. Math. Statist.* 22 (1951), no. 4, 592–596.

Implementation: `scipy.stats.ksone`

## KStwo Distribution

This is the limiting distribution of the normalized maximum absolute differences between an empirical distribution function, computed from  $n$  samples or observations, and a comparison (or target) cumulative distribution function. (`ksone` is the distribution of the unnormalized positive differences,  $D_n^+$ .)

Writing  $D_n = \sup_t |F_{\text{empirical},n}(t) - F_{\text{target}}(t)|$ , the normalization factor is  $\sqrt{n}$ , and `kstwobign` is the limiting distribution of the  $\sqrt{n}D_n$  values as  $n \rightarrow \infty$ .

Note that  $D_n = \max(D_n^+, D_n^-)$ , but  $D_n^+$  and  $D_n^-$  are not independent.

`kstwobign` can also be used with the differences between two empirical distribution functions, for sets of observations with  $m$  and  $n$  samples respectively, where  $m$  and  $n$  are “big”. Writing  $D_{m,n} = \sup_t |F_{1,m}(t) - F_{2,n}(t)|$ , where  $F_{1,m}$  and  $F_{2,n}$  are the two empirical distribution functions, then `kstwobign` is also the limiting distribution of the  $\sqrt{\left(\frac{mn}{m+n}\right)} D_{m,n}$  values, as  $m, n \rightarrow \infty$ .

There are no shape parameters, and the support is  $x \in [0, \infty)$ .

$$\begin{aligned} F(x) &= 1 - 2 \sum_{k=1}^{\infty} (-1)^{k-1} e^{-2k^2 x^2} \\ &= \frac{\sqrt{2\pi}}{x} \sum_{k=1}^{\infty} e^{-(2k-1)^2 \pi^2 / (8x^2)} \\ &= 1 - \text{scipy.special.kolmogorov}(n, x) \\ f(x) &= 8x \sum_{k=1}^{\infty} (-1)^{k-1} k^2 e^{-2k^2 x^2} \end{aligned}$$

## References

- “Kolmogorov-Smirnov test”, Wikipedia [https://en.wikipedia.org/wiki/Kolmogorov-Smirnov\\_test](https://en.wikipedia.org/wiki/Kolmogorov-Smirnov_test)
- Kolmogoroff, A. “Confidence Limits for an Unknown Distribution Function.”” *Ann. Math. Statist.* 12 (1941), no. 4, 461–463.
- Feller, W. “On the Kolmogorov-Smirnov Limit Theorems for Empirical Distributions.” *Ann. Math. Statist.* 19 (1948), no. 2, 177–189. and “Errata” *Ann. Math. Statist.* 21 (1950), no. 2, 301–302.

Implementation: `scipy.stats.kstwobign`

## Laplace (Double Exponential, Bilateral Exponential) Distribution

$$\begin{aligned}
 f(x) &= \frac{1}{2}e^{-|x|} \\
 F(x) &= \begin{cases} \frac{1}{2}e^x & x \leq 0 \\ 1 - \frac{1}{2}e^{-x} & x > 0 \end{cases} \\
 G(q) &= \begin{cases} \log(2q) & q \leq \frac{1}{2} \\ -\log(2-2q) & q > \frac{1}{2} \end{cases} \\
 m_d = m_n = \mu &= 0 \\
 \mu_2 &= 2 \\
 \gamma_1 &= 0 \\
 \gamma_2 &= 3
 \end{aligned}$$

The ML estimator of the location parameter is

$$\hat{L} = \text{median}(X_i)$$

where  $X_i$  is a sequence of  $N$  mutually independent Laplace RV's and the median is some number between the  $\frac{1}{2}N$ th and the  $(N/2 + 1)$ th order statistic (e.g. take the average of these two) when  $N$  is even. Also,

$$\hat{S} = \frac{1}{N} \sum_{j=1}^N |X_j - \hat{L}|.$$

Replace  $\hat{L}$  with  $L$  if it is known. If  $L$  is known then this estimator is distributed as  $(2N)^{-1} S \cdot \chi_{2N}^2$ .

$$\begin{aligned}
 h[X] &= \log(2e) \\
 &\approx 1.693147180559453094.
 \end{aligned}$$

Implementation: `scipy.stats.laplace`

## Left-skewed Lévy Distribution

Special case of Lévy-stable distribution with  $\alpha = \frac{1}{2}$  and  $\beta = -1$  the support is  $x < 0$ . In standard form

$$\begin{aligned}
 f(x) &= \frac{1}{|x| \sqrt{2\pi|x|}} \exp\left(-\frac{1}{2|x|}\right) \\
 F(x) &= 2\Phi\left(\frac{1}{\sqrt{|x|}}\right) - 1 \\
 G(q) &= -\left[\Phi^{-1}\left(\frac{q+1}{2}\right)\right]^{-2}.
 \end{aligned}$$

No moments.

Implementation: `scipy.stats.levy_l`

### Lévy Distribution

A special case of Lévy-stable distributions with  $\alpha = \frac{1}{2}$  and  $\beta = 1$ . In standard form it is defined for  $x > 0$  as

$$\begin{aligned} f(x) &= \frac{1}{x\sqrt{2\pi x}} \exp\left(-\frac{1}{2x}\right) \\ F(x) &= 2 \left[ 1 - \Phi\left(\frac{1}{\sqrt{x}}\right) \right] \\ G(q) &= \left[ \Phi^{-1}\left(1 - \frac{q}{2}\right) \right]^{-2}. \end{aligned}$$

It has no finite moments.

Implementation: `scipy.stats.levy`

### Logistic (Sech-squared) Distribution

A special case of the Generalized Logistic distribution with  $c = 1$ . Defined for  $x > 0$

$$\begin{aligned} f(x) &= \frac{\exp(-x)}{[1 + \exp(-x)]^2} \\ F(x) &= \frac{1}{1 + \exp(-x)} \\ G(q) &= -\log(1/q - 1) \end{aligned}$$

$$\begin{aligned} \mu &= \gamma + \psi_0(1) = 0 \\ \mu_2 &= \frac{\pi^2}{6} + \psi_1(1) = \frac{\pi^2}{3} \\ \gamma_1 &= \frac{\psi_2(c) + 2\zeta(3)}{\mu_2^{3/2}} = 0 \\ \gamma_2 &= \frac{\left(\frac{\pi^4}{15} + \psi_3(c)\right)}{\mu_2^2} = \frac{6}{5} \\ m_d &= \log 1 = 0 \\ m_n &= -\log(2 - 1) = 0 \\ h[X] &= 1. \end{aligned}$$

Implementation: `scipy.stats.logistic`

### Log Double Exponential (Log-Laplace) Distribution

Defined over  $x > 0$  with  $c > 0$

$$f(x; c) = \begin{cases} \frac{c}{2} x^{c-1} & 0 < x < 1 \\ \frac{c}{2} x^{-c-1} & x \geq 1 \end{cases}$$

$$F(x; c) = \begin{cases} \frac{1}{2} x^c & 0 < x < 1 \\ 1 - \frac{1}{2} x^{-c} & x \geq 1 \end{cases}$$

$$G(q; c) = \begin{cases} (2q)^{1/c} & 0 \leq q < \frac{1}{2} \\ (2 - 2q)^{-1/c} & \frac{1}{2} \leq q \leq 1 \end{cases}$$

$$h[X] = \log\left(\frac{2e}{c}\right)$$

Implementation: `scipy.stats.loglaplace`

### Log Gamma Distribution

A single shape parameter  $c > 0$  (Defined for all  $x$ )

$$f(x; c) = \frac{\exp(cx - e^x)}{\Gamma(c)}$$

$$F(x; c) = \frac{\Gamma(c, e^x)}{\Gamma(c)}$$

$$G(q; c) = \log[\Gamma^{-1}[c, q\Gamma(c)]]$$

$$\mu'_n = \int_0^\infty [\log y]^n y^{c-1} \exp(-y) dy.$$

$$\mu = \mu'_1$$

$$\mu_2 = \mu'_2 - \mu^2$$

$$\gamma_1 = \frac{\mu'_3 - 3\mu\mu_2 - \mu^3}{\mu_2^{3/2}}$$

$$\gamma_2 = \frac{\mu'_4 - 4\mu\mu_3 - 6\mu^2\mu_2 - \mu^4}{\mu_2^2} - 3$$

Implementation: `scipy.stats.loggamma`

### Log Normal (Cobb-Douglass) Distribution

Has one shape parameter  $\sigma > 0$ . (Notice that the “Regress “ $A = \log S$  where  $S$  is the scale parameter and  $A$  is the mean of the underlying normal distribution). The standard form is  $x > 0$

$$f(x; \sigma) = \frac{1}{\sigma x \sqrt{2\pi}} \exp\left[-\frac{1}{2} \left(\frac{\log x}{\sigma}\right)^2\right]$$

$$F(x; \sigma) = \Phi\left(\frac{\log x}{\sigma}\right)$$

$$G(q; \sigma) = \exp\{\sigma \Phi^{-1}(q)\}$$

$$\begin{aligned}
 \mu &= \exp(\sigma^2/2) \\
 \mu_2 &= \exp(\sigma^2) [\exp(\sigma^2) - 1] \\
 \gamma_1 &= \sqrt{p-1} (2+p) \\
 \gamma_2 &= p^4 + 2p^3 + 3p^2 - 6 \quad p = e^{\sigma^2}
 \end{aligned}$$

Notice that using JKB notation we have  $\theta = L$ ,  $\zeta = \log S$  and we have given the so-called antilognormal form of the distribution. This is more consistent with the location, scale parameter description of general probability distributions.

$$h[X] = \frac{1}{2} [1 + \log(2\pi) + 2 \log(\sigma)].$$

Also, note that if  $X$  is a log-normally distributed random-variable with  $L = 0$  and  $S$  and shape parameter  $\sigma$ . Then,  $\log X$  is normally distributed with variance  $\sigma^2$  and mean  $\log S$ .

Implementation: `scipy.stats.lognorm`

### Maxwell Distribution

This is a special case of the Chi distribution with  $L = 0$  and  $S = S = \frac{1}{\sqrt{a}}$  and  $\nu = 3$ .

$$\begin{aligned}
 f(x) &= \sqrt{\frac{2}{\pi}} x^2 e^{-x^2/2} I_{(0,\infty)}(x) \\
 F(x) &= \Gamma\left(\frac{3}{2}, \frac{x^2}{2}\right) \\
 G(\alpha) &= \sqrt{2\Gamma^{-1}\left(\frac{3}{2}, \alpha\right)}
 \end{aligned}$$

$$\begin{aligned}
 \mu &= 2\sqrt{\frac{2}{\pi}} \\
 \mu_2 &= 3 - \frac{8}{\pi} \\
 \gamma_1 &= \sqrt{2} \frac{32 - 10\pi}{(3\pi - 8)^{3/2}} \\
 \gamma_2 &= \frac{-12\pi^2 + 160\pi - 384}{(3\pi - 8)^2} \\
 m_d &= \sqrt{2} \\
 m_n &= \sqrt{2\Gamma^{-1}\left(\frac{3}{2}, \frac{1}{2}\right)} \\
 h[X] &= \log\left(\sqrt{\frac{2\pi}{e}}\right) + \gamma.
 \end{aligned}$$

Implementation: `scipy.stats.maxwell`

### Mielke's Beta-Kappa Distribution

A generalized F distribution. Two shape parameters  $\kappa$  and  $\theta$ , and  $x > 0$ . The  $\beta$  in the DATAPLOT reference is a scale parameter.

$$\begin{aligned} f(x; \kappa, \theta) &= \frac{\kappa x^{\kappa-1}}{(1+x^\theta)^{1+\frac{\kappa}{\theta}}} \\ F(x; \kappa, \theta) &= \frac{x^\kappa}{(1+x^\theta)^{\kappa/\theta}} \\ G(q; \kappa, \theta) &= \left( \frac{q^{\theta/\kappa}}{1-q^{\theta/\kappa}} \right)^{1/\theta} \end{aligned}$$

Implementation: `scipy.stats.mielke`

### Nakagami Distribution

Generalization of the chi distribution. Shape parameter is  $\nu > 0$ . Defined for  $x > 0$ .

$$\begin{aligned} f(x; \nu) &= \frac{2\nu^\nu}{\Gamma(\nu)} x^{2\nu-1} \exp(-\nu x^2) \\ F(x; \nu) &= \Gamma(\nu, \nu x^2) \\ G(q; \nu) &= \sqrt{\frac{1}{\nu} \Gamma^{-1}(\nu, q)} \end{aligned}$$

$$\begin{aligned} \mu &= \frac{\Gamma(\nu + \frac{1}{2})}{\sqrt{\nu} \Gamma(\nu)} \\ \mu_2 &= [1 - \mu^2] \\ \gamma_1 &= \frac{\mu(1 - 4\nu\mu_2)}{2\nu\mu_2^{3/2}} \\ \gamma_2 &= \frac{-6\mu^4\nu + (8\nu - 2)\mu^2 - 2\nu + 1}{\nu\mu_2^2} \end{aligned}$$

Implementation: `scipy.stats.nakagami`

### Noncentral chi-squared Distribution

The distribution of  $\sum_{i=1}^{\nu} (Z_i + \delta_i)^2$  where  $Z_i$  are independent standard normal variables and  $\delta_i$  are constants.  $\lambda = \sum_{i=1}^{\nu} \delta_i^2 > 0$ . (In communications it is called the Marcum-Q function). Can be thought of as a Generalized Rayleigh-Rice distribution. For  $x > 0$

$$\begin{aligned} f(x; \nu, \lambda) &= e^{-(\lambda+x)/2} \frac{1}{2} \left( \frac{x}{\lambda} \right)^{(\nu-2)/4} I_{(\nu-2)/2}(\sqrt{\lambda x}) \\ F(x; \nu, \lambda) &= \sum_{j=0}^{\infty} \left\{ \frac{(\lambda/2)^j}{j!} e^{-\lambda/2} \right\} \Pr[\chi_{\nu+2j}^2 \leq x] \\ G(q; \nu, \lambda) &= F^{-1}(x; \nu, \lambda) \end{aligned}$$

$$\begin{aligned}\mu &= \nu + \lambda \\ \mu_2 &= 2(\nu + 2\lambda) \\ \gamma_1 &= \frac{\sqrt{8}(\nu + 3\lambda)}{(\nu + 2\lambda)^{3/2}} \\ \gamma_2 &= \frac{12(\nu + 4\lambda)}{(\nu + 2\lambda)^2}\end{aligned}$$

Implementation: `scipy.stats.ncx2`

### Noncentral F Distribution

Let  $\lambda > 0$  and  $\nu_1 > 0$  and  $\nu_2 > 0$ .

$$\begin{aligned}f(x; \lambda, \nu_1, \nu_2) &= \exp\left[\frac{\lambda}{2} + \frac{(\lambda\nu_1 x)}{2(\nu_1 x + \nu_2)}\right] \nu_1^{\nu_1/2} \nu_2^{\nu_2/2} x^{\nu_1/2-1} \\ &\times (\nu_2 + \nu_1 x)^{-(\nu_1+\nu_2)/2} \frac{\Gamma\left(\frac{\nu_1}{2}\right) \Gamma\left(1 + \frac{\nu_2}{2}\right) L_{\nu_2/2}^{\nu_1/2-1}\left(-\frac{\lambda\nu_1 x}{2(\nu_1 x + \nu_2)}\right)}{B\left(\frac{\nu_1}{2}, \frac{\nu_2}{2}\right) \Gamma\left(\frac{\nu_1+\nu_2}{2}\right)}\end{aligned}$$

Implementation: `scipy.stats.ncf`

### Noncentral t Distribution

The distribution of the ratio

$$\frac{U + \lambda}{\chi_\nu / \sqrt{\nu}}$$

where  $U$  and  $\chi_\nu$  are independent and distributed as a standard normal and chi with  $\nu$  degrees of freedom. Note  $\lambda > 0$  and  $\nu > 0$ .

$$\begin{aligned}f(x; \lambda, \nu) &= \frac{\nu^{\nu/2} \Gamma(\nu + 1)}{2^\nu e^{\lambda^2/2} (\nu + x^2)^{\nu/2} \Gamma(\nu/2)} \\ &\times \left\{ \frac{\sqrt{2}\lambda x {}_1F_1\left(\frac{\nu}{2} + 1; \frac{3}{2}; \frac{\lambda^2 x^2}{2(\nu + x^2)}\right)}{(\nu + x^2) \Gamma\left(\frac{\nu+1}{2}\right)} \right. \\ &\quad \left. - \frac{{}_1F_1\left(\frac{\nu+1}{2}; \frac{1}{2}; \frac{\lambda^2 x^2}{2(\nu + x^2)}\right)}{\sqrt{\nu + x^2} \Gamma\left(\frac{\nu}{2} + 1\right)} \right\} \\ &= \frac{\Gamma(\nu + 1)}{2^{(\nu-1)/2} \sqrt{\pi\nu} \Gamma(\nu/2)} \exp\left[-\frac{\nu\lambda^2}{\nu + x^2}\right] \\ &\times \left(\frac{\nu}{\nu + x^2}\right)^{(\nu-1)/2} Hh_\nu\left(-\frac{\lambda x}{\sqrt{\nu + x^2}}\right) \\ F(x; \lambda, \nu) &= \end{aligned}$$

Implementation: `scipy.stats.nct`

## Normal Distribution

$$f(x) = \frac{e^{-x^2/2}}{\sqrt{2\pi}}$$

$$F(x) = \Phi(x) = \frac{1}{2} + \frac{1}{2} \operatorname{erf}\left(\frac{x}{\sqrt{2}}\right)$$

$$G(q) = \Phi^{-1}(q)$$

$$m_d = m_n = \mu = 0$$

$$\mu_2 = 1$$

$$\gamma_1 = 0$$

$$\gamma_2 = 0$$

$$h[X] = \log(\sqrt{2\pi}e)$$

$$\approx 1.4189385332046727418$$

Implementation: `scipy.stats.norm`

## Pareto Distribution

For  $x \geq 1$  and  $b > 0$ . Standard form is

$$f(x; b) = \frac{b}{x^{b+1}}$$

$$F(x; b) = 1 - \frac{1}{x^b}$$

$$G(q; b) = (1 - q)^{-1/b}$$

$$\mu = \frac{b}{b-1} \quad b > 1$$

$$\mu_2 = \frac{b}{(b-2)(b-1)^2} \quad b > 2$$

$$\gamma_1 = \frac{2(b+1)\sqrt{b-2}}{(b-3)\sqrt{b}} \quad b > 3$$

$$\gamma_2 = \frac{6(b^3 + b^2 - 6b - 2)}{b(b^2 - 7b + 12)} \quad b > 4$$

$$h(X) = \frac{1}{c} + 1 - \log(c)$$

Implementation: `scipy.stats.pareto`

### Pareto Second Kind (Lomax) Distribution

$c > 0$ . This is Pareto of the first kind with  $L = -1.0$  so  $x \geq 0$

$$\begin{aligned}
 f(x; c) &= \frac{c}{(1+x)^{c+1}} \\
 F(x; c) &= 1 - \frac{1}{(1+x)^c} \\
 G(q; c) &= (1-q)^{-1/c} - 1 \\
 h[X] &= \frac{1}{c} + 1 - \log(c).
 \end{aligned}$$

Implementation: `scipy.stats.lomax`

### Power Log Normal Distribution

A generalization of the log-normal distribution  $\sigma > 0$  and  $c > 0$  and  $x > 0$

$$\begin{aligned}
 f(x; \sigma, c) &= \frac{c}{x\sigma} \phi\left(\frac{\log x}{\sigma}\right) \left(\Phi\left(-\frac{\log x}{\sigma}\right)\right)^{c-1} \\
 F(x; \sigma, c) &= 1 - \left(\Phi\left(-\frac{\log x}{\sigma}\right)\right)^c \\
 G(q; \sigma, c) &= \exp\left[-\sigma\Phi^{-1}\left[(1-q)^{1/c}\right]\right] \\
 \mu'_n &= \int_0^1 \exp\left[-n\sigma\Phi^{-1}\left(y^{1/c}\right)\right] dy \\
 \mu &= \mu'_1 \\
 \mu_2 &= \mu'_2 - \mu^2 \\
 \gamma_1 &= \frac{\mu'_3 - 3\mu\mu_2 - \mu^3}{\mu_2^{3/2}} \\
 \gamma_2 &= \frac{\mu'_4 - 4\mu\mu_3 - 6\mu^2\mu_2 - \mu^4}{\mu_2^2} - 3
 \end{aligned}$$

This distribution reduces to the log-normal distribution when  $c = 1$ .

Implementation: `scipy.stats.powerlognorm`

### Power Normal Distribution

A generalization of the normal distribution,  $c > 0$  for

$$\begin{aligned}
 f(x; c) &= c\phi(x) (\Phi(-x))^{c-1} \\
 F(x; c) &= 1 - (\Phi(-x))^c \\
 G(q; c) &= -\Phi^{-1}\left[(1-q)^{1/c}\right] \\
 \mu'_n &= (-1)^n \int_0^1 \left[\Phi^{-1}\left(y^{1/c}\right)\right]^n dy
 \end{aligned}$$

$$\begin{aligned}\mu &= \mu'_1 \\ \mu_2 &= \mu'_2 - \mu^2 \\ \gamma_1 &= \frac{\mu'_3 - 3\mu\mu_2 - \mu^3}{\mu_2^{3/2}} \\ \gamma_2 &= \frac{\mu'_4 - 4\mu\mu_3 - 6\mu^2\mu_2 - \mu^4}{\mu_2^2} - 3\end{aligned}$$

For  $c = 1$  this reduces to the normal distribution.

Implementation: `scipy.stats.powernorm`

### Power-function Distribution

A special case of the beta distribution with  $b = 1$  : defined for  $x \in [0, 1]$

$$a > 0$$

$$\begin{aligned}f(x; a) &= ax^{a-1} \\ F(x; a) &= x^a \\ G(q; a) &= q^{1/a} \\ \mu &= \frac{a}{a+1} \\ \mu_2 &= \frac{a(a+2)}{(a+1)^2} \\ \gamma_1 &= 2(1-a)\sqrt{\frac{a+2}{a(a+3)}} \\ \gamma_2 &= \frac{6(a^3 - a^2 - 6a + 2)}{a(a+3)(a+4)} \\ m_d &= 1 \\ h[X] &= 1 - \frac{1}{a} - \log(a)\end{aligned}$$

Implementation: `scipy.stats.powerlaw`

### R-distribution Distribution

A general-purpose distribution with a variety of shapes controlled by  $c > 0$ . Range of standard distribution is  $x \in [-1, 1]$

$$\begin{aligned}f(x; c) &= \frac{(1-x^2)^{c/2-1}}{B\left(\frac{1}{2}, \frac{c}{2}\right)} \\ F(x; c) &= \frac{1}{2} + \frac{x}{B\left(\frac{1}{2}, \frac{c}{2}\right)} {}_2F_1\left(\frac{1}{2}, 1 - \frac{c}{2}; \frac{3}{2}; x^2\right) \\ \mu'_n &= \frac{(1+(-1)^n)}{2} B\left(\frac{n+1}{2}, \frac{c}{2}\right)\end{aligned}$$

The R-distribution with parameter  $n$  is the distribution of the correlation coefficient of a random sample of size  $n$  drawn from a bivariate normal distribution with  $\rho = 0$ . The mean of the standard distribution is always zero and as the sample size grows, the distribution's mass concentrates more closely about this mean.

Implementation: `scipy.stats.rdist`

## Rayleigh Distribution

This is Chi distribution with  $L = 0.0$  and  $\nu = 2$  and  $S = S$  (no location parameter is generally used), the mode of the distribution is  $S$ .

$$\begin{aligned} f(r) &= r e^{-r^2/2} I_{[0,\infty)}(x) \\ F(r) &= 1 - e^{-r^2/2} I_{[0,\infty)}(x) \\ G(q) &= \sqrt{-2 \log(1-q)} \end{aligned}$$

$$\begin{aligned} \mu &= \sqrt{\frac{\pi}{2}} \\ \mu_2 &= \frac{4-\pi}{2} \\ \gamma_1 &= \frac{2(\pi-3)\sqrt{\pi}}{(4-\pi)^{3/2}} \\ \gamma_2 &= \frac{24\pi-6\pi^2-16}{(4-\pi)^2} \\ m_d &= 1 \\ m_n &= \sqrt{2 \log(2)} \\ h[X] &= \frac{\gamma}{2} + \log\left(\frac{e}{\sqrt{2}}\right) \\ \mu'_n &= \sqrt{2^n} \Gamma\left(\frac{n}{2} + 1\right) \end{aligned}$$

Implementation: `scipy.stats.rayleigh`

## Rice Distribution

Defined for  $x > 0$  and  $b > 0$

$$\begin{aligned} f(x; b) &= x \exp\left(-\frac{x^2 + b^2}{2}\right) I_0(xb) \\ F(x; b) &= \int_0^x \alpha \exp\left(-\frac{\alpha^2 + b^2}{2}\right) I_0(\alpha b) d\alpha \\ \mu'_n &= \sqrt{2^n} \Gamma\left(1 + \frac{n}{2}\right) {}_1F_1\left(-\frac{n}{2}; 1; -\frac{b^2}{2}\right) \end{aligned}$$

Implementation: `scipy.stats.rice`

## Reciprocal Distribution

Shape parameters  $a, b > 0$   $x \in [a, b]$

$$\begin{aligned} f(x; a, b) &= \frac{1}{x \log(b/a)} \\ F(x; a, b) &= \frac{\log(x/a)}{\log(b/a)} \\ G(q; a, b) &= a \exp(q \log(b/a)) = a \left(\frac{b}{a}\right)^q \end{aligned}$$

$$\begin{aligned}
 d &= \log(a/b) \\
 \mu &= \frac{a-b}{d} \\
 \mu_2 &= \mu \frac{a+b}{2} - \mu^2 = \frac{(a-b)[a(d-2)+b(d+2)]}{2d^2} \\
 \gamma_1 &= \frac{\sqrt{2} [12d(a-b)^2 + d^2(a^2(2d-9) + 2abd + b^2(2d+9))]}{3d\sqrt{a-b}[a(d-2)+b(d+2)]^{3/2}} \\
 \gamma_2 &= \frac{-36(a-b)^3 + 36d(a-b)^2(a+b) - 16d^2(a^3-b^3) + 3d^3(a^2+b^2)(a+b)}{3(a-b)[a(d-2)+b(d+2)]^2} - 3 \\
 m_d &= a \\
 m_n &= \sqrt{ab}
 \end{aligned}$$

$$h[X] = \frac{1}{2} \log(ab) + \log \left[ \log \left( \frac{b}{a} \right) \right].$$

Implementation: `scipy.stats.reciprocal`

### Reciprocal Inverse Gaussian Distribution

The pdf is found from the inverse gaussian (IG),  $f_{RIG}(x; \mu) = \frac{1}{x^2} f_{IG}(\frac{1}{x}; \mu)$  defined for  $x \geq 0$  as

$$\begin{aligned}
 f_{IG}(x; \mu) &= \frac{1}{\sqrt{2\pi x^3}} \exp\left(-\frac{(x-\mu)^2}{2x\mu^2}\right) \\
 F_{IG}(x; \mu) &= \Phi\left(\frac{1}{\sqrt{x}} \frac{x-\mu}{\mu}\right) + \exp\left(\frac{2}{\mu}\right) \Phi\left(-\frac{1}{\sqrt{x}} \frac{x+\mu}{\mu}\right) \\
 f_{RIG}(x; \mu) &= \frac{1}{\sqrt{2\pi x}} \exp\left(-\frac{(1-\mu x)^2}{2x\mu^2}\right) \\
 F_{RIG}(x; \mu) &= 1 - F_{IG}\left(\frac{1}{x}, \mu\right) \\
 &= 1 - \Phi\left(\frac{1}{\sqrt{x}} \frac{1-\mu x}{\mu}\right) - \exp\left(\frac{2}{\mu}\right) \Phi\left(-\frac{1}{\sqrt{x}} \frac{1+\mu x}{\mu}\right)
 \end{aligned}$$

Implementation: `scipy.stats.recipinvgauss`

### Semicircular Distribution

Defined on  $x \in [-1, 1]$

$$\begin{aligned}
 f(x) &= \frac{2}{\pi} \sqrt{1-x^2} \\
 F(x) &= \frac{1}{2} + \frac{1}{\pi} [x\sqrt{1-x^2} + \arcsin x] \\
 G(q) &= F^{-1}(q)
 \end{aligned}$$

$$\begin{aligned}
 m_d = m_n = \mu &= 0 \\
 \mu_2 &= \frac{1}{4} \\
 \gamma_1 &= 0 \\
 \gamma_2 &= -1
 \end{aligned}$$

$$h[X] = 0.64472988584940017414.$$

Implementation: `scipy.stats.semicircular`

### Student t Distribution

Shape parameter  $\nu > 0$ .  $I(a, b, x)$  is the incomplete beta integral and  $I^{-1}(a, b, I(a, b, x)) = x$

$$f(x; \nu) = \frac{\Gamma\left(\frac{\nu+1}{2}\right)}{\sqrt{\pi\nu}\Gamma\left(\frac{\nu}{2}\right)\left[1 + \frac{x^2}{\nu}\right]^{\frac{\nu+1}{2}}}$$

$$F(x; \nu) = \begin{cases} \frac{1}{2}I\left(\frac{\nu}{2}, \frac{1}{2}, \frac{\nu}{\nu+x^2}\right) & x \leq 0 \\ 1 - \frac{1}{2}I\left(\frac{\nu}{2}, \frac{1}{2}, \frac{\nu}{\nu+x^2}\right) & x \geq 0 \end{cases}$$

$$G(q; \nu) = \begin{cases} -\sqrt{\frac{\nu}{I^{-1}\left(\frac{\nu}{2}, \frac{1}{2}, 2q\right)} - \nu} & q \leq \frac{1}{2} \\ \sqrt{\frac{\nu}{I^{-1}\left(\frac{\nu}{2}, \frac{1}{2}, 2-2q\right)} - \nu} & q \geq \frac{1}{2} \end{cases}$$

$$m_n = m_d = \mu = 0$$

$$\mu_2 = \frac{\nu}{\nu - 2} \quad \nu > 2$$

$$\gamma_1 = 0 \quad \nu > 3$$

$$\gamma_2 = \frac{6}{\nu - 4} \quad \nu > 4$$

As  $\nu \rightarrow \infty$ , this distribution approaches the standard normal distribution.

$$h[X] = \frac{1}{4} \log \left( \frac{\pi c \Gamma^2\left(\frac{c}{2}\right)}{\Gamma^2\left(\frac{c+1}{2}\right)} \right) - \frac{(c+1)}{4} \left[ \Psi\left(\frac{c}{2}\right) - cZ(c) + \pi \tan\left(\frac{\pi c}{2}\right) + \gamma + 2 \log 2 \right]$$

where

$$Z(c) = {}_3F_2\left(1, 1, 1 + \frac{c}{2}; \frac{3}{2}, 2; 1\right) = \sum_{k=0}^{\infty} \frac{k!}{k+1} \frac{\Gamma\left(\frac{c}{2} + 1 + k\right)}{\Gamma\left(\frac{c}{2} + 1\right)} \frac{\Gamma\left(\frac{3}{2}\right)}{\Gamma\left(\frac{3}{2} + k\right)}$$

Implementation: `scipy.stats.t`

### Triangular Distribution

One shape parameter  $c \in [0, 1]$  giving the distance to the peak as a percentage of the total extent of the non-zero portion. The location parameter is the start of the non-zero portion, and the scale-parameter is the width of the non-zero portion. In standard form we have  $x \in [0, 1]$ .

$$f(x; c) = \begin{cases} 2\frac{x}{1-c} & x < c \\ 2\frac{1-x}{1-c} & x \geq c \end{cases}$$

$$F(x; c) = \begin{cases} \frac{x^2}{c} & x < c \\ \frac{x^2 - 2x + c}{c-1} & x \geq c \end{cases}$$

$$G(q; c) = \begin{cases} \sqrt{cq} & q < c \\ 1 - \sqrt{(1-c)(1-q)} & q \geq c \end{cases}$$

$$\begin{aligned}\mu &= \frac{c}{3} + \frac{1}{3} \\ \mu_2 &= \frac{1 - c + c^2}{18} \\ \gamma_1 &= \frac{\sqrt{2}(2c - 1)(c + 1)(c - 2)}{5(1 - c + c^2)^{3/2}} \\ \gamma_2 &= -\frac{3}{5} \\ h(X) &= \log\left(\frac{1}{2}\sqrt{e}\right) \\ &\approx -0.19314718055994530942.\end{aligned}$$

Implementation: `scipy.stats.triang`

### Truncated Exponential Distribution

This is an exponential distribution defined only over a certain region  $0 < x < B$ . In standard form this is

$$\begin{aligned}f(x; B) &= \frac{e^{-x}}{1 - e^{-B}} \\ F(x; B) &= \frac{1 - e^{-x}}{1 - e^{-B}} \\ G(q; B) &= -\log(1 - q + qe^{-B}) \\ \mu'_n &= \Gamma(1 + n) - \Gamma(1 + n, B) \\ h[X] &= \log(e^B - 1) + \frac{1 + e^B(B - 1)}{1 - e^B}.\end{aligned}$$

Implementation: `scipy.stats.truncexpon`

### Truncated Normal Distribution

A normal distribution restricted to lie within a certain range given by two parameters  $A$  and  $B$ . Notice that this  $A$  and  $B$  correspond to the bounds on  $x$  in standard form. For  $x \in [A, B]$  we get

$$\begin{aligned}f(x; A, B) &= \frac{\phi(x)}{\Phi(B) - \Phi(A)} \\ F(x; A, B) &= \frac{\Phi(x) - \Phi(A)}{\Phi(B) - \Phi(A)} \\ G(q; A, B) &= \Phi^{-1}[q\Phi(B) + \Phi(A)(1 - q)]\end{aligned}$$

where

$$\begin{aligned}\phi(x) &= \frac{1}{\sqrt{2\pi}}e^{-x^2/2} \\ \Phi(x) &= \int_{-\infty}^x \phi(u) du. \\ \mu &= \frac{\phi(A) - \phi(B)}{\Phi(B) - \Phi(A)} \\ \mu_2 &= 1 + \frac{A\phi(A) - B\phi(B)}{\Phi(B) - \Phi(A)} - \left(\frac{\phi(A) - \phi(B)}{\Phi(B) - \Phi(A)}\right)^2\end{aligned}$$

Implementation: `scipy.stats.truncnorm`

## Tukey-Lambda Distribution

$$\begin{aligned}
 f(x; \lambda) &= F'(x; \lambda) = \frac{1}{G'(F(x; \lambda); \lambda)} = \frac{1}{F^{\lambda-1}(x; \lambda) + [1 - F(x; \lambda)]^{\lambda-1}} \\
 F(x; \lambda) &= G^{-1}(x; \lambda) \\
 G(p; \lambda) &= \frac{p^\lambda - (1-p)^\lambda}{\lambda} \\
 \\
 \mu &= 0 \\
 \mu_2 &= \int_0^1 G^2(p; \lambda) dp \\
 &= \frac{2\Gamma(\lambda + \frac{3}{2}) - \lambda 4^{-\lambda} \sqrt{\pi} \Gamma(\lambda) (1 - 2\lambda)}{\lambda^2 (1 + 2\lambda) \Gamma(\lambda + \frac{3}{2})} \\
 \gamma_1 &= 0 \\
 \gamma_2 &= \frac{\mu_4}{\mu_2^2} - 3 \\
 \mu_4 &= \frac{3\Gamma(\lambda) \Gamma(\lambda + \frac{1}{2}) 2^{-2\lambda}}{\lambda^3 \Gamma(2\lambda + \frac{3}{2})} + \frac{2}{\lambda^4 (1 + 4\lambda)} \\
 &\quad - \frac{2\sqrt{3}\Gamma(\lambda) 2^{-6\lambda} 3^{3\lambda} \Gamma(\lambda + \frac{1}{3}) \Gamma(\lambda + \frac{2}{3})}{\lambda^3 \Gamma(2\lambda + \frac{3}{2}) \Gamma(\lambda + \frac{1}{2})}.
 \end{aligned}$$

Notice that the  $\lim_{\lambda \rightarrow 0} G(p; \lambda) = \log(p/(1-p))$

$$\begin{aligned}
 h[X] &= \int_0^1 \log[G'(p)] dp \\
 &= \int_0^1 \log[p^{\lambda-1} + (1-p)^{\lambda-1}] dp.
 \end{aligned}$$

Implementation: `scipy.stats.tukeylambda`

## Uniform Distribution

Standard form  $x \in (0, 1)$ . In general form, the lower limit is  $L$ , the upper limit is  $S + L$ .

$$\begin{aligned}
 f(x) &= 1 \\
 F(x) &= x \\
 G(q) &= q
 \end{aligned}$$

$$\begin{aligned}
 \mu &= \frac{1}{2} \\
 \mu_2 &= \frac{1}{12} \\
 \gamma_1 &= 0 \\
 \gamma_2 &= -\frac{6}{5} \\
 h[X] &= 0
 \end{aligned}$$

Implementation: `scipy.stats.uniform`

## Von Mises Distribution

Defined for  $x \in [-\pi, \pi]$  with shape parameter  $\kappa > 0$ . Note, the PDF and CDF functions are periodic and are always defined over  $x \in [-\pi, \pi]$  regardless of the location parameter. Thus, if an input beyond this range is given, it is converted to the equivalent angle in this range. For values of  $\kappa < 100$  the PDF and CDF formulas below are used. Otherwise, a normal approximation with variance  $1/\kappa$  is used.

$$\begin{aligned}
 f(x; \kappa) &= \frac{e^{\kappa \cos x}}{2\pi I_0(\kappa)} \\
 F(x; \kappa) &= \frac{1}{2} + \frac{x}{2\pi} + \sum_{k=1}^{\infty} \frac{I_k(\kappa) \sin(kx)}{I_0(\kappa) \pi k} \\
 G(q; \kappa) &= F^{-1}(x; \kappa) \\
 \mu &= 0 \\
 \mu_2 &= \int_{-\pi}^{\pi} x^2 f(x; \kappa) dx \\
 \gamma_1 &= 0 \\
 \gamma_2 &= \frac{\int_{-\pi}^{\pi} x^4 f(x; \kappa) dx}{\mu_2^2} - 3
 \end{aligned}$$

This can be used for defining circular variance.

Implementation: `scipy.stats.vonmises`

## Wald Distribution

Special case of the Inverse Normal with shape parameter set to 1.0. Defined for  $x > 0$ .

$$\begin{aligned}
 f(x) &= \frac{1}{\sqrt{2\pi x^3}} \exp\left(-\frac{(x-1)^2}{2x}\right) \\
 F(x) &= \Phi\left(\frac{x-1}{\sqrt{x}}\right) + \exp(2) \Phi\left(-\frac{x+1}{\sqrt{x}}\right) \\
 G(q; \mu) &= F^{-1}(q; \mu) \\
 \mu &= 1 \\
 \mu_2 &= 1 \\
 \gamma_1 &= 3 \\
 \gamma_2 &= 15 \\
 m_d &= \frac{1}{2}(\sqrt{13} - 3)
 \end{aligned}$$

Implementation: `scipy.stats.wald`

## Weibull Maximum Extreme Value Distribution

Defined for  $x < 0$  and  $c > 0$ .

$$\begin{aligned}
 f(x; c) &= c(-x)^{c-1} \exp(-(-x)^c) \\
 F(x; c) &= \exp(-(-x)^c) \\
 G(q; c) &= -(-\log q)^{1/c}
 \end{aligned}$$

The mean is the negative of the right-skewed Frechet distribution given above, and the other statistical parameters can be computed from

$$\mu'_n = (-1)^n \Gamma\left(1 + \frac{n}{c}\right).$$

$$\begin{aligned} \mu &= -\Gamma\left(1 + \frac{1}{c}\right) \\ \mu_2 &= \Gamma\left(1 + \frac{2}{c}\right) - \Gamma^2\left(1 + \frac{1}{c}\right) \\ \gamma_1 &= -\frac{\Gamma\left(1 + \frac{3}{c}\right) - 3\Gamma\left(1 + \frac{2}{c}\right)\Gamma\left(1 + \frac{1}{c}\right) + 2\Gamma^3\left(1 + \frac{1}{c}\right)}{\mu_2^{3/2}} \\ \gamma_2 &= \frac{\Gamma\left(1 + \frac{4}{c}\right) - 4\Gamma\left(1 + \frac{1}{c}\right)\Gamma\left(1 + \frac{3}{c}\right) + 6\Gamma^2\left(1 + \frac{1}{c}\right)\Gamma\left(1 + \frac{2}{c}\right) - 3\Gamma^4\left(1 + \frac{1}{c}\right)}{\mu_2^2} - 3 \\ m_d &= \begin{cases} -\left(\frac{c-1}{c}\right)^{\frac{1}{c}} & \text{if } c > 1 \\ 0 & \text{if } c \leq 1 \end{cases} \\ m_n &= -\ln(2)^{\frac{1}{c}} \end{aligned}$$

$$h[X] = -\frac{\gamma}{c} - \log(c) + \gamma + 1$$

where  $\gamma$  is Euler's constant and equal to

$$\gamma \approx 0.57721566490153286061.$$

Implementation: `scipy.stats.weibull_max`

### Weibull Minimum Extreme Value Distribution

A type of extreme-value distribution with a lower bound. Defined for  $x > 0$  and  $c > 0$

$$\begin{aligned} f(x; c) &= cx^{c-1} \exp(-x^c) \\ F(x; c) &= 1 - \exp(-x^c) \\ G(q; c) &= [-\log(1 - q)]^{1/c} \\ \mu'_n &= \Gamma\left(1 + \frac{n}{c}\right) \end{aligned}$$

$$\begin{aligned} \mu &= \Gamma\left(1 + \frac{1}{c}\right) \\ \mu_2 &= \Gamma\left(1 + \frac{2}{c}\right) - \Gamma^2\left(1 + \frac{1}{c}\right) \\ \gamma_1 &= \frac{\Gamma\left(1 + \frac{3}{c}\right) - 3\Gamma\left(1 + \frac{2}{c}\right)\Gamma\left(1 + \frac{1}{c}\right) + 2\Gamma^3\left(1 + \frac{1}{c}\right)}{\mu_2^{3/2}} \\ \gamma_2 &= \frac{\Gamma\left(1 + \frac{4}{c}\right) - 4\Gamma\left(1 + \frac{1}{c}\right)\Gamma\left(1 + \frac{3}{c}\right) + 6\Gamma^2\left(1 + \frac{1}{c}\right)\Gamma\left(1 + \frac{2}{c}\right) - 3\Gamma^4\left(1 + \frac{1}{c}\right)}{\mu_2^2} - 3 \\ m_d &= \begin{cases} \left(\frac{c-1}{c}\right)^{\frac{1}{c}} & \text{if } c > 1 \\ 0 & \text{if } c \leq 1 \end{cases} \\ m_n &= \ln(2)^{\frac{1}{c}} \end{aligned}$$

$$h[X] = -\frac{\gamma}{c} - \log(c) + \gamma + 1$$

where  $\gamma$  is Euler's constant and equal to

$$\gamma \approx 0.57721566490153286061.$$

Implementation: `scipy.stats.weibull_min`

## Wrapped Cauchy Distribution

For  $x \in [0, 2\pi]$   $c \in (0, 1)$

$$f(x; c) = \frac{1 - c^2}{2\pi(1 + c^2 - 2c \cos x)}$$

$$g_c(x) = \frac{1}{\pi} \arctan \left[ \frac{1 + c}{1 - c} \tan \left( \frac{x}{2} \right) \right]$$

$$r_c(q) = 2 \arctan \left[ \frac{1 - c}{1 + c} \tan(\pi q) \right]$$

$$F(x; c) = \begin{cases} g_c(x) & 0 \leq x < \pi \\ 1 - g_c(2\pi - x) & \pi \leq x \leq 2\pi \end{cases}$$

$$G(q; c) = \begin{cases} r_c(q) & 0 \leq q < \frac{1}{2} \\ 2\pi - r_c(1 - q) & \frac{1}{2} \leq q \leq 1 \end{cases}$$

$$h[X] = \log(2\pi(1 - c^2)).$$

Implementation: `scipy.stats.wrapcauchy`

## Random Variables

There are two general distribution classes that have been implemented for encapsulating *continuous random variables* and *discrete random variables*. Over 80 continuous random variables (RVs) and 10 discrete random variables have been implemented using these classes. Besides this, new routines and distributions can easily added by the end user. (If you create one, please contribute it).

All of the statistics functions are located in the sub-package `scipy.stats` and a fairly complete listing of these functions can be obtained using `info(stats)`. The list of the random variables available can also be obtained from the docstring for the stats sub-package.

In the discussion below we mostly focus on continuous RVs. Nearly all applies to discrete variables also, but we point out some differences here: *Specific Points for Discrete Distributions*.

In the code samples below we assume that the `scipy.stats` package is imported as

```
>>> from scipy import stats
```

and in some cases we assume that individual objects are imported as

```
>>> from scipy.stats import norm
```

For consistency between Python 2 and Python 3, we'll also ensure that `print` is a function:

```
>>> from __future__ import print_function
```

### Getting Help

First of all, all distributions are accompanied with help functions. To obtain just some basic information we print the relevant docstring: `print(stats.norm.__doc__)`.

To find the support, i.e., upper and lower bound of the distribution, call:

```
>>> print('bounds of distribution lower: %s, upper: %s' % (norm.a, norm.b))
bounds of distribution lower: -inf, upper: inf
```

We can list all methods and properties of the distribution with `dir(norm)`. As it turns out, some of the methods are private methods although they are not named as such (their name does not start with a leading underscore), for example `veccdf`, are only available for internal calculation (those methods will give warnings when one tries to use them, and will be removed at some point).

To obtain the *real* main methods, we list the methods of the frozen distribution. (We explain the meaning of a *frozen* distribution below).

```
>>> rv = norm()
>>> dir(rv) # reformatted
['_class__', '__delattr__', '__dict__', '__dir__', '__doc__', '__eq__',
 '__format__', '__ge__', '__getattr__', '__gt__', '__hash__',
 '__init__', '__le__', '__lt__', '__module__', '__ne__', '__new__',
 '__reduce__', '__reduce_ex__', '__repr__', '__setattr__', '__sizeof__',
 '__str__', '__subclasshook__', '__weakref__', 'a', 'args', 'b', 'cdf',
 'dist', 'entropy', 'expect', 'interval', 'isf', 'kws', 'logcdf',
 'logpdf', 'logpmf', 'logsf', 'mean', 'median', 'moment', 'pdf', 'pmf',
 'ppf', 'random_state', 'rvs', 'sf', 'stats', 'std', 'var']
```

Finally, we can obtain the list of available distribution through introspection:

```
>>> dist_continu = [d for d in dir(stats) if
...                 isinstance(getattr(stats, d), stats.rv_continuous)]
>>> dist_discrete = [d for d in dir(stats) if
...                  isinstance(getattr(stats, d), stats.rv_discrete)]
>>> print('number of continuous distributions: %d' % len(dist_continu))
number of continuous distributions: 96
>>> print('number of discrete distributions: %d' % len(dist_discrete))
number of discrete distributions: 13
```

### Common Methods

The main public methods for continuous RVs are:

- `rvs`: Random Variates
- `pdf`: Probability Density Function
- `cdf`: Cumulative Distribution Function
- `sf`: Survival Function (1-CDF)
- `ppf`: Percent Point Function (Inverse of CDF)
- `isf`: Inverse Survival Function (Inverse of SF)
- `stats`: Return mean, variance, (Fisher's) skew, or (Fisher's) kurtosis
- `moment`: non-central moments of the distribution

Let's take a normal RV as an example.

```
>>> norm.cdf(0)
0.5
```

To compute the `cdf` at a number of points, we can pass a list or a numpy array.

```
>>> norm.cdf([-1., 0, 1])
array([ 0.15865525,  0.5,  0.84134475])
>>> import numpy as np
>>> norm.cdf(np.array([-1., 0, 1]))
array([ 0.15865525,  0.5,  0.84134475])
```

Thus, the basic methods such as *pdf*, *cdf*, and so on are vectorized.

Other generally useful methods are supported too:

```
>>> norm.mean(), norm.std(), norm.var()
(0.0, 1.0, 1.0)
>>> norm.stats(moments="mv")
(array(0.0), array(1.0))
```

To find the median of a distribution we can use the percent point function `ppf`, which is the inverse of the `cdf`:

```
>>> norm.ppf(0.5)
0.0
```

To generate a sequence of random variates, use the `size` keyword argument:

```
>>> norm.rvs(size=3)
array([-0.35687759,  1.34347647, -0.11710531]) # random
```

Note that drawing random numbers relies on generators from `numpy.random` package. In the example above, the specific stream of random numbers is not reproducible across runs. To achieve reproducibility, you can explicitly seed a global variable

```
>>> np.random.seed(1234)
```

Relying on a global state is not recommended though. A better way is to use the `random_state` parameter which accepts an instance of `numpy.random.RandomState` class, or an integer which is then used to seed an internal `RandomState` object:

```
>>> norm.rvs(size=5, random_state=1234)
array([ 0.47143516, -1.19097569,  1.43270697, -0.3126519 , -0.72058873])
```

Don't think that `norm.rvs(5)` generates 5 variates:

```
>>> norm.rvs(5)
5.471435163732493
```

Here, 5 with no keyword is being interpreted as the first possible keyword argument, `loc`, which is the first of a pair of keyword arguments taken by all continuous distributions. This brings us to the topic of the next subsection.

### Shifting and Scaling

All continuous distributions take `loc` and `scale` as keyword parameters to adjust the location and scale of the distribution, e.g. for the standard normal distribution the location is the mean and the scale is the standard deviation.

```
>>> norm.stats(loc=3, scale=4, moments="mv")
(array(3.0), array(16.0))
```

In many cases the standardized distribution for a random variable  $X$  is obtained through the transformation  $(X - \text{loc}) / \text{scale}$ . The default values are  $\text{loc} = 0$  and  $\text{scale} = 1$ .

Smart use of `loc` and `scale` can help modify the standard distributions in many ways. To illustrate the scaling further, the cdf of an exponentially distributed RV with mean  $1/\lambda$  is given by

$$F(x) = 1 - \exp(-\lambda x)$$

By applying the scaling rule above, it can be seen that by taking `scale = 1./lambda` we get the proper scale.

```
>>> from scipy.stats import expon
>>> expon.mean(scale=3.)
3.0
```

**Note:** Distributions that take shape parameters may require more than simple application of `loc` and/or `scale` to achieve the desired form. For example, the distribution of 2-D vector lengths given a constant vector of length  $R$  perturbed by independent  $N(0, \sigma^2)$  deviations in each component is `rice( $R/\sigma$ , scale= $\sigma$ )`. The first argument is a shape parameter that needs to be scaled along with  $x$ .

The uniform distribution is also interesting:

```
>>> from scipy.stats import uniform
>>> uniform.cdf([0, 1, 2, 3, 4, 5], loc=1, scale=4)
array([ 0. ,  0. ,  0.25,  0.5 ,  0.75,  1. ])
```

Finally, recall from the previous paragraph that we are left with the problem of the meaning of `norm.rvs(5)`. As it turns out, calling a distribution like this, the first argument, i.e., the 5, gets passed to set the `loc` parameter. Let's see:

```
>>> np.mean(norm.rvs(5, size=500))
5.0098355106969992
```

Thus, to explain the output of the example of the last section: `norm.rvs(5)` generates a single normally distributed random variate with mean `loc=5`, because of the default `size=1`.

We recommend that you set `loc` and `scale` parameters explicitly, by passing the values as keywords rather than as arguments. Repetition can be minimized when calling more than one method of a given RV by using the technique of *Freezing a Distribution*, as explained below.

### Shape Parameters

While a general continuous random variable can be shifted and scaled with the `loc` and `scale` parameters, some distributions require additional shape parameters. For instance, the gamma distribution, with density

$$\gamma(x, a) = \frac{\lambda(\lambda x)^{a-1}}{\Gamma(a)} e^{-\lambda x},$$

requires the shape parameter  $a$ . Observe that setting  $\lambda$  can be obtained by setting the `scale` keyword to  $1/\lambda$ .

Let's check the number and name of the shape parameters of the gamma distribution. (We know from the above that this should be 1.)

```
>>> from scipy.stats import gamma
>>> gamma.numargs
1
>>> gamma.shapes
'a'
```

Now we set the value of the shape variable to 1 to obtain the exponential distribution, so that we compare easily whether we get the results we expect.

```
>>> gamma(1, scale=2.).stats(moments="mv")
(array(2.0), array(4.0))
```

Notice that we can also specify shape parameters as keywords:

```
>>> gamma(a=1, scale=2.).stats(moments="mv")
(array(2.0), array(4.0))
```

### Freezing a Distribution

Passing the `loc` and `scale` keywords time and again can become quite bothersome. The concept of *freezing* a RV is used to solve such problems.

```
>>> rv = gamma(1, scale=2.)
```

By using `rv` we no longer have to include the scale or the shape parameters anymore. Thus, distributions can be used in one of two ways, either by passing all distribution parameters to each method call (such as we did earlier) or by freezing the parameters for the instance of the distribution. Let us check this:

```
>>> rv.mean(), rv.std()
(2.0, 2.0)
```

This is indeed what we should get.

### Broadcasting

The basic methods `pdf` and so on satisfy the usual numpy broadcasting rules. For example, we can calculate the critical values for the upper tail of the t distribution for different probabilities and degrees of freedom.

```
>>> stats.t.isf([0.1, 0.05, 0.01], [[10], [11]])
array([[ 1.37218364,  1.81246112,  2.76376946],
       [ 1.36343032,  1.79588482,  2.71807918]])
```

Here, the first row are the critical values for 10 degrees of freedom and the second row for 11 degrees of freedom (d.o.f.). Thus, the broadcasting rules give the same result of calling `isf` twice:

```
>>> stats.t.isf([0.1, 0.05, 0.01], 10)
array([ 1.37218364,  1.81246112,  2.76376946])
>>> stats.t.isf([0.1, 0.05, 0.01], 11)
array([ 1.36343032,  1.79588482,  2.71807918])
```

If the array with probabilities, i.e., `[0.1, 0.05, 0.01]` and the array of degrees of freedom i.e., `[10, 11, 12]`, have the same array shape, then element wise matching is used. As an example, we can obtain the 10% tail for 10 d.o.f., the 5% tail for 11 d.o.f. and the 1% tail for 12 d.o.f. by calling

```
>>> stats.t.isf([0.1, 0.05, 0.01], [10, 11, 12])
array([ 1.37218364,  1.79588482,  2.68099799])
```

### Specific Points for Discrete Distributions

Discrete distribution have mostly the same basic methods as the continuous distributions. However `pdf` is replaced the probability mass function `pmf`, no estimation methods, such as `fit`, are available, and `scale` is not a valid keyword parameter. The location parameter, keyword `loc` can still be used to shift the distribution.

The computation of the cdf requires some extra attention. In the case of continuous distribution the cumulative distribution function is in most standard cases strictly monotonic increasing in the bounds (a,b) and has therefore a unique inverse. The cdf of a discrete distribution, however, is a step function, hence the inverse cdf, i.e., the percent point function, requires a different definition:

```
ppf(q) = min{x : cdf(x) >= q, x integer}
```

For further info, see the docs [here](#).

We can look at the hypergeometric distribution as an example

```
>>> from scipy.stats import hypergeom
>>> [M, n, N] = [20, 7, 12]
```

If we use the cdf at some integer points and then evaluate the ppf at those cdf values, we get the initial integers back, for example

```
>>> x = np.arange(4)*2
>>> x
array([0, 2, 4, 6])
>>> prb = hypergeom.cdf(x, M, n, N)
>>> prb
array([ 1.03199174e-04,   5.21155831e-02,   6.08359133e-01,
        9.89783282e-01])
>>> hypergeom.ppf(prb, M, n, N)
array([ 0.,  2.,  4.,  6.] )
```

If we use values that are not at the kinks of the cdf step function, we get the next higher integer back:

```
>>> hypergeom.ppf(prb + 1e-8, M, n, N)
array([ 1.,  3.,  5.,  7.])
>>> hypergeom.ppf(prb - 1e-8, M, n, N)
array([ 0.,  2.,  4.,  6.] )
```

### *Fitting Distributions*

The main additional methods of the not frozen distribution are related to the estimation of distribution parameters:

- *fit*: maximum likelihood estimation of distribution parameters, including location and scale
- *fit\_loc\_scale*: estimation of location and scale when shape parameters are given
- *nnlf*: negative log likelihood function
- *expect*: Calculate the expectation of a function against the pdf or pmf

### *Performance Issues and Cautionary Remarks*

The performance of the individual methods, in terms of speed, varies widely by distribution and method. The results of a method are obtained in one of two ways: either by explicit calculation, or by a generic algorithm that is independent of the specific distribution.

Explicit calculation, on the one hand, requires that the method is directly specified for the given distribution, either through analytic formulas or through special functions in `scipy.special` or `numpy.random` for `rvs`. These are usually relatively fast calculations.

The generic methods, on the other hand, are used if the distribution does not specify any explicit calculation. To define a distribution, only one of pdf or cdf is necessary; all other methods can be derived using numeric integration and

root finding. However, these indirect methods can be *very* slow. As an example, `rgn = stats.gausshyper.rvs(0.5, 2, 2, 2, size=100)` creates random variables in a very indirect way and takes about 19 seconds for 100 random variables on my computer, while one million random variables from the standard normal or from the *t* distribution take just above one second.

### Remaining Issues

The distributions in `scipy.stats` have recently been corrected and improved and gained a considerable test suite, however a few issues remain:

- the distributions have been tested over some range of parameters, however in some corner ranges, a few incorrect results may remain.
- the maximum likelihood estimation in *fit* does not work with default starting parameters for all distributions and the user needs to supply good starting parameters. Also, for some distribution using a maximum likelihood estimator might inherently not be the best choice.

## Building Specific Distributions

The next examples shows how to build your own distributions. Further examples show the usage of the distributions and some statistical tests.

### Making a Continuous Distribution, i.e., Subclassing `rv_continuous`

Making continuous distributions is fairly simple.

```
>>> from scipy import stats
>>> class deterministic_gen(stats.rv_continuous):
...     def _cdf(self, x):
...         return np.where(x < 0, 0., 1.)
...     def _stats(self):
...         return 0., 0., 0., 0.
```

```
>>> deterministic = deterministic_gen(name="deterministic")
>>> deterministic.cdf(np.arange(-3, 3, 0.5))
array([ 0.,  0.,  0.,  0.,  0.,  0.,  1.,  1.,  1.,  1.,  1.,  1.])
```

Interestingly, the pdf is now computed automatically:

```
>>> deterministic.pdf(np.arange(-3, 3, 0.5))
array([[ 0.00000000e+00,  0.00000000e+00,  0.00000000e+00,
         0.00000000e+00,  0.00000000e+00,  0.00000000e+00,
         5.83333333e+04,  4.16333634e-12,  4.16333634e-12,
         4.16333634e-12,  4.16333634e-12,  4.16333634e-12])
```

Be aware of the performance issues mentions in *Performance Issues and Cautionary Remarks*. The computation of unspecified common methods can become very slow, since only general methods are called which, by their very nature, cannot use any specific information about the distribution. Thus, as a cautionary example:

```
>>> from scipy.integrate import quad
>>> quad(deterministic.pdf, -1e-1, 1e-1)
(4.163336342344337e-13, 0.0)
```

But this is not correct: the integral over this pdf should be 1. Let's make the integration interval smaller:

```
>>> quad(deterministic.pdf, -1e-3, 1e-3) # warning removed
(1.000076872229173, 0.0010625571718182458)
```

This looks better. However, the problem originated from the fact that the pdf is not specified in the class definition of the deterministic distribution.

### Subclassing `rv_discrete`

In the following we use `stats.rv_discrete` to generate a discrete distribution that has the probabilities of the truncated normal for the intervals centered around the integers.

#### General Info

From the docstring of `rv_discrete`, `help(stats.rv_discrete)`,

“You can construct an arbitrary discrete rv where  $P\{X=x_k\} = p_k$  by passing to the `rv_discrete` initialization method (through the `values=` keyword) a tuple of sequences  $(x_k, p_k)$  which describes only those values of  $X$  ( $x_k$ ) that occur with nonzero probability ( $p_k$ ).”

Next to this, there are some further requirements for this approach to work:

- The keyword `name` is required.
- The support points of the distribution `xk` have to be integers.
- The number of significant digits (decimals) needs to be specified.

In fact, if the last two requirements are not satisfied an exception may be raised or the resulting numbers may be incorrect.

#### An Example

Let’s do the work. First

```
>>> npoints = 20 # number of integer support points of the distribution minus 1
>>> npointsh = npoints // 2
>>> npointsf = float(npoints)
>>> nbound = 4 # bounds for the truncated normal
>>> normbound = (1+1/npointsf) * nbound # actual bounds of truncated normal
>>> grid = np.arange(-npointsh, npointsh+2, 1) # integer grid
>>> gridlimitsnorm = (grid-0.5) / npointsh * nbound # bin limits for the truncnorm
>>> gridlimits = grid - 0.5 # used later in the analysis
>>> grid = grid[:-1]
>>> probs = np.diff(stats.truncnorm.cdf(gridlimitsnorm, -normbound, normbound))
>>> gridint = grid
```

And finally we can subclass `rv_discrete`:

```
>>> normdiscrete = stats.rv_discrete(values=(gridint,
...                                     np.round(probs, decimals=7)), name='normdiscrete')
```

Now that we have defined the distribution, we have access to all common methods of discrete distributions.

```
>>> print('mean = %6.4f, variance = %6.4f, skew = %6.4f, kurtosis = %6.4f' %
...       normdiscrete.stats(moments='mvsk'))
mean = -0.0000, variance = 6.3302, skew = 0.0000, kurtosis = -0.0076
```

```
>>> nd_std = np.sqrt(normdiscrete.stats(moments='v'))
```

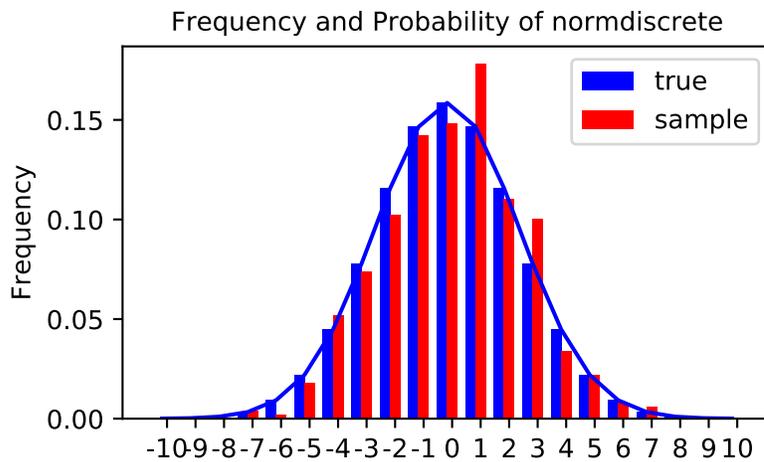
#### Testing the Implementation

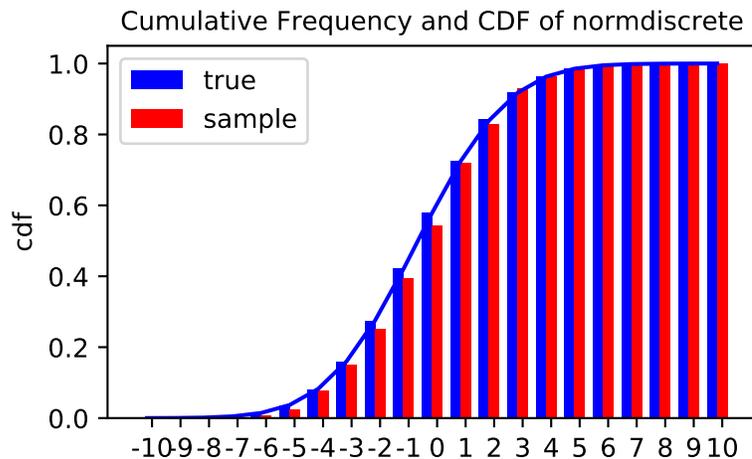
Let’s generate a random sample and compare observed frequencies with the probabilities.

```

>>> n_sample = 500
>>> np.random.seed(87655678) # fix the seed for replicability
>>> rvs = normdiscrete.rvs(size=n_sample)
>>> f, l = np.histogram(rvs, bins=gridlimits)
>>> sfreq = np.vstack([gridint, f, probs*n_sample]).T
>>> print(sfreq)
[[-1.00000000e+01  0.00000000e+00  2.95019349e-02]
 [ -9.00000000e+00  0.00000000e+00  1.32294142e-01]
 [ -8.00000000e+00  0.00000000e+00  5.06497902e-01]
 [ -7.00000000e+00  2.00000000e+00  1.65568919e+00]
 [ -6.00000000e+00  1.00000000e+00  4.62125309e+00]
 [ -5.00000000e+00  9.00000000e+00  1.10137298e+01]
 [ -4.00000000e+00  2.60000000e+01  2.24137683e+01]
 [ -3.00000000e+00  3.70000000e+01  3.89503370e+01]
 [ -2.00000000e+00  5.10000000e+01  5.78004747e+01]
 [ -1.00000000e+00  7.10000000e+01  7.32455414e+01]
 [  0.00000000e+00  7.40000000e+01  7.92618251e+01]
 [  1.00000000e+00  8.90000000e+01  7.32455414e+01]
 [  2.00000000e+00  5.50000000e+01  5.78004747e+01]
 [  3.00000000e+00  5.00000000e+01  3.89503370e+01]
 [  4.00000000e+00  1.70000000e+01  2.24137683e+01]
 [  5.00000000e+00  1.10000000e+01  1.10137298e+01]
 [  6.00000000e+00  4.00000000e+00  4.62125309e+00]
 [  7.00000000e+00  3.00000000e+00  1.65568919e+00]
 [  8.00000000e+00  0.00000000e+00  5.06497902e-01]
 [  9.00000000e+00  0.00000000e+00  1.32294142e-01]
 [ 1.00000000e+01  0.00000000e+00  2.95019349e-02]]

```





Next, we can test, whether our sample was generated by our normdiscrete distribution. This also verifies whether the random numbers are generated correctly.

The chisquare test requires that there are a minimum number of observations in each bin. We combine the tail bins into larger bins so that they contain enough observations.

```
>>> f2 = np.hstack([f[:5].sum(), f[5:-5], f[-5:].sum()])
>>> p2 = np.hstack([probs[:5].sum(), probs[5:-5], probs[-5:].sum()])
>>> ch2, pval = stats.chisquare(f2, p2*n_sample)
```

```
>>> print('chisquare for normdiscrete: chi2 = %6.3f pvalue = %6.4f' % (ch2, pval))
chisquare for normdiscrete: chi2 = 12.466 pvalue = 0.4090
```

The pvalue in this case is high, so we can be quite confident that our random sample was actually generated by the distribution.

## Analysing One Sample

First, we create some random variables. We set a seed so that in each run we get identical results to look at. As an example we take a sample from the Student t distribution:

```
>>> np.random.seed(282629734)
>>> x = stats.t.rvs(10, size=1000)
```

Here, we set the required shape parameter of the t distribution, which in statistics corresponds to the degrees of freedom, to 10. Using `size=1000` means that our sample consists of 1000 independently drawn (pseudo) random numbers. Since we did not specify the keyword arguments `loc` and `scale`, those are set to their default values zero and one.

### Descriptive Statistics

`x` is a numpy array, and we have direct access to all array methods, e.g.

```
>>> print(x.min()) # equivalent to np.min(x)
-3.78975572422
>>> print(x.max()) # equivalent to np.max(x)
5.26327732981
```

```
>>> print(x.mean()) # equivalent to np.mean(x)
0.0140610663985
>>> print(x.var()) # equivalent to np.var(x)
1.28899386208
```

How do the some sample properties compare to their theoretical counterparts?

```
>>> m, v, s, k = stats.t.stats(10, moments='mvsk')
>>> n, (smin, smax), sm, sv, ss, sk = stats.describe(x)
```

```
>>> sstr = '%-14s mean = %6.4f, variance = %6.4f, skew = %6.4f, kurtosis = %6.4f'
>>> print(sstr % ('distribution:', m, v, s, k))
distribution: mean = 0.0000, variance = 1.2500, skew = 0.0000, kurtosis = 1.0000
>>> print(sstr % ('sample:', sm, sv, ss, sk))
sample:      mean = 0.0141, variance = 1.2903, skew = 0.2165, kurtosis = 1.0556
```

Note: stats.describe uses the unbiased estimator for the variance, while np.var is the biased estimator.

For our sample the sample statistics differ a by a small amount from their theoretical counterparts.

### ***T-test and KS-test***

We can use the t-test to test whether the mean of our sample differs in a statistically significant way from the theoretical expectation.

```
>>> print('t-statistic = %6.3f pvalue = %6.4f' % stats.ttest_1samp(x, m))
t-statistic = 0.391 pvalue = 0.6955
```

The pvalue is 0.7, this means that with an alpha error of, for example, 10%, we cannot reject the hypothesis that the sample mean is equal to zero, the expectation of the standard t-distribution.

As an exercise, we can calculate our ttest also directly without using the provided function, which should give us the same answer, and so it does:

```
>>> tt = (sm-m)/np.sqrt(sv/float(n)) # t-statistic for mean
>>> pval = stats.t.sf(np.abs(tt), n-1)*2 # two-sided pvalue = Prob(abs(t)>tt)
>>> print('t-statistic = %6.3f pvalue = %6.4f' % (tt, pval))
t-statistic = 0.391 pvalue = 0.6955
```

The Kolmogorov-Smirnov test can be used to test the hypothesis that the sample comes from the standard t-distribution

```
>>> print('KS-statistic D = %6.3f pvalue = %6.4f' % stats.kstest(x, 't', (10,)))
KS-statistic D = 0.016 pvalue = 0.9606
```

Again the p-value is high enough that we cannot reject the hypothesis that the random sample really is distributed according to the t-distribution. In real applications, we don't know what the underlying distribution is. If we perform the Kolmogorov-Smirnov test of our sample against the standard normal distribution, then we also cannot reject the hypothesis that our sample was generated by the normal distribution given that in this example the p-value is almost 40%.

```
>>> print('KS-statistic D = %6.3f pvalue = %6.4f' % stats.kstest(x, 'norm'))
KS-statistic D = 0.028 pvalue = 0.3949
```

However, the standard normal distribution has a variance of 1, while our sample has a variance of 1.29. If we standardize our sample and test it against the normal distribution, then the p-value is again large enough that we cannot reject the hypothesis that the sample came from the normal distribution.

```
>>> d, pval = stats.kstest((x-x.mean())/x.std(), 'norm')
>>> print('KS-statistic D = %6.3f pvalue = %6.4f' % (d, pval))
KS-statistic D = 0.032 pvalue = 0.2402
```

Note: The Kolmogorov-Smirnov test assumes that we test against a distribution with given parameters, since in the last case we estimated mean and variance, this assumption is violated, and the distribution of the test statistic on which the p-value is based, is not correct.

### Tails of the distribution

Finally, we can check the upper tail of the distribution. We can use the percent point function `ppf`, which is the inverse of the cdf function, to obtain the critical values, or, more directly, we can use the inverse of the survival function

```
>>> crit01, crit05, crit10 = stats.t.ppf([1-0.01, 1-0.05, 1-0.10], 10)
>>> print('critical values from ppf at 1%, 5% and 10% %8.4f %8.4f %8.4f' % (crit01,
↳ crit05, crit10))
critical values from ppf at 1%, 5% and 10% 2.7638 1.8125 1.3722
>>> print('critical values from isf at 1%, 5% and 10% %8.4f %8.4f %8.4f' %
↳ tuple(stats.t.isf([0.01,0.05,0.10],10)))
critical values from isf at 1%, 5% and 10% 2.7638 1.8125 1.3722
```

```
>>> freq01 = np.sum(x>crit01) / float(n) * 100
>>> freq05 = np.sum(x>crit05) / float(n) * 100
>>> freq10 = np.sum(x>crit10) / float(n) * 100
>>> print('sample %-frequency at 1%, 5% and 10% tail %8.4f %8.4f %8.4f' % (freq01,
↳ freq05, freq10))
sample %-frequency at 1%, 5% and 10% tail 1.4000 5.8000 10.5000
```

In all three cases, our sample has more weight in the top tail than the underlying distribution. We can briefly check a larger sample to see if we get a closer match. In this case the empirical frequency is quite close to the theoretical probability, but if we repeat this several times the fluctuations are still pretty large.

```
>>> freq05l = np.sum(stats.t.rvs(10, size=10000) > crit05) / 10000.0 * 100
>>> print('larger sample %-frequency at 5% tail %8.4f' % freq05l)
larger sample %-frequency at 5% tail 4.8000
```

We can also compare it with the tail of the normal distribution, which has less weight in the tails:

```
>>> print('tail prob. of normal at 1%, 5% and 10% %8.4f %8.4f %8.4f' %
... tuple(stats.norm.sf([crit01, crit05, crit10])*100))
tail prob. of normal at 1%, 5% and 10% 0.2857 3.4957 8.5003
```

The chisquare test can be used to test, whether for a finite number of bins, the observed frequencies differ significantly from the probabilities of the hypothesized distribution.

```
>>> quantiles = [0.0, 0.01, 0.05, 0.1, 1-0.10, 1-0.05, 1-0.01, 1.0]
>>> crit = stats.t.ppf(quantiles, 10)
>>> crit
array([-inf, -2.76376946, -1.81246112, -1.37218364, 1.37218364,
1.81246112, 2.76376946, inf])
>>> n_sample = x.size
>>> freqcount = np.histogram(x, bins=crit)[0]
>>> tprob = np.diff(quantiles)
>>> nprob = np.diff(stats.norm.cdf(crit))
>>> tch, tpval = stats.chisquare(freqcount, tprob*n_sample)
>>> nch, npval = stats.chisquare(freqcount, nprob*n_sample)
>>> print('chisquare for t: chi2 = %6.2f pvalue = %6.4f' % (tch, tpval))
```

```

chisquare for t:      chi2 = 2.30 pvalue = 0.8901
>>> print('chisquare for normal: chi2 = %6.2f pvalue = %6.4f' % (nch, npval))
chisquare for normal: chi2 = 64.60 pvalue = 0.0000

```

We see that the standard normal distribution is clearly rejected while the standard t-distribution cannot be rejected. Since the variance of our sample differs from both standard distribution, we can again redo the test taking the estimate for scale and location into account.

The fit method of the distributions can be used to estimate the parameters of the distribution, and the test is repeated using probabilities of the estimated distribution.

```

>>> tdof, tloc, tscale = stats.t.fit(x)
>>> nloc, nscale = stats.norm.fit(x)
>>> tprob = np.diff(stats.t.cdf(crit, tdof, loc=tloc, scale=tscale))
>>> nprob = np.diff(stats.norm.cdf(crit, loc=nloc, scale=nscale))
>>> tch, tpval = stats.chisquare(freqcount, tprob*n_sample)
>>> nch, npval = stats.chisquare(freqcount, nprob*n_sample)
>>> print('chisquare for t:      chi2 = %6.2f pvalue = %6.4f' % (tch, tpval))
chisquare for t:      chi2 = 1.58 pvalue = 0.9542
>>> print('chisquare for normal: chi2 = %6.2f pvalue = %6.4f' % (nch, npval))
chisquare for normal: chi2 = 11.08 pvalue = 0.0858

```

Taking account of the estimated parameters, we can still reject the hypothesis that our sample came from a normal distribution (at the 5% level), but again, with a p-value of 0.95, we cannot reject the t distribution.

### *Special tests for normal distributions*

Since the normal distribution is the most common distribution in statistics, there are several additional functions available to test whether a sample could have been drawn from a normal distribution

First we can test if skew and kurtosis of our sample differ significantly from those of a normal distribution:

```

>>> print('normal skewtest teststat = %6.3f pvalue = %6.4f' % stats.skewtest(x))
normal skewtest teststat = 2.785 pvalue = 0.0054
>>> print('normal kurtosistest teststat = %6.3f pvalue = %6.4f' % stats.
↳kurtosistest(x))
normal kurtosistest teststat = 4.757 pvalue = 0.0000

```

These two tests are combined in the normality test

```

>>> print('normaltest teststat = %6.3f pvalue = %6.4f' % stats.normaltest(x))
normaltest teststat = 30.379 pvalue = 0.0000

```

In all three tests the p-values are very low and we can reject the hypothesis that the our sample has skew and kurtosis of the normal distribution.

Since skew and kurtosis of our sample are based on central moments, we get exactly the same results if we test the standardized sample:

```

>>> print('normaltest teststat = %6.3f pvalue = %6.4f' %
...       stats.normaltest((x-x.mean())/x.std()))
normaltest teststat = 30.379 pvalue = 0.0000

```

Because normality is rejected so strongly, we can check whether the normaltest gives reasonable results for other cases:

```

>>> print('normaltest teststat = %6.3f pvalue = %6.4f' %
...       stats.normaltest(stats.t.rvs(10, size=100)))

```

```
normaltest teststat = 4.698 pvalue = 0.0955
>>> print('normaltest teststat = %6.3f pvalue = %6.4f' %
...       stats.normaltest(stats.norm.rvs(size=1000)))
normaltest teststat = 0.613 pvalue = 0.7361
```

When testing for normality of a small sample of t-distributed observations and a large sample of normal distributed observation, then in neither case can we reject the null hypothesis that the sample comes from a normal distribution. In the first case this is because the test is not powerful enough to distinguish a t and a normally distributed random variable in a small sample.

## Comparing two samples

In the following, we are given two samples, which can come either from the same or from different distribution, and we want to test whether these samples have the same statistical properties.

### *Comparing means*

Test with sample with identical means:

```
>>> rvs1 = stats.norm.rvs(loc=5, scale=10, size=500)
>>> rvs2 = stats.norm.rvs(loc=5, scale=10, size=500)
>>> stats.ttest_ind(rvs1, rvs2)
Ttest_indResult(statistic=-0.54890361750887051, pvalue=0.58319437486639591)
```

Test with sample with different means:

```
>>> rvs3 = stats.norm.rvs(loc=8, scale=10, size=500)
>>> stats.ttest_ind(rvs1, rvs3)
Ttest_indResult(statistic=-4.5334142901750258, pvalue=6.5071281863890188e-06)
```

### *Kolmogorov-Smirnov test for two samples ks\_2samp*

For the example where both samples are drawn from the same distribution, we cannot reject the null hypothesis since the pvalue is high

```
>>> stats.ks_2samp(rvs1, rvs2)
Ks_2sampResult(statistic=0.025999999999999995, pvalue=0.99541195173064878)
```

In the second example, with different location, i.e. means, we can reject the null hypothesis since the pvalue is below 1%

```
>>> stats.ks_2samp(rvs1, rvs3)
Ks_2sampResult(statistic=0.11399999999999999, pvalue=0.0027132103661283141)
```

## Kernel Density Estimation

A common task in statistics is to estimate the probability density function (PDF) of a random variable from a set of data samples. This task is called density estimation. The most well-known tool to do this is the histogram. A histogram is a useful tool for visualization (mainly because everyone understands it), but doesn't use the available data very efficiently. Kernel density estimation (KDE) is a more efficient tool for the same task. The `gaussian_kde` estimator can be used to estimate the PDF of univariate as well as multivariate data. It works best if the data is unimodal.

### Univariate estimation

We start with a minimal amount of data in order to see how `gaussian_kde` works, and what the different options for bandwidth selection do. The data sampled from the PDF is show as blue dashes at the bottom of the figure (this is called a rug plot):

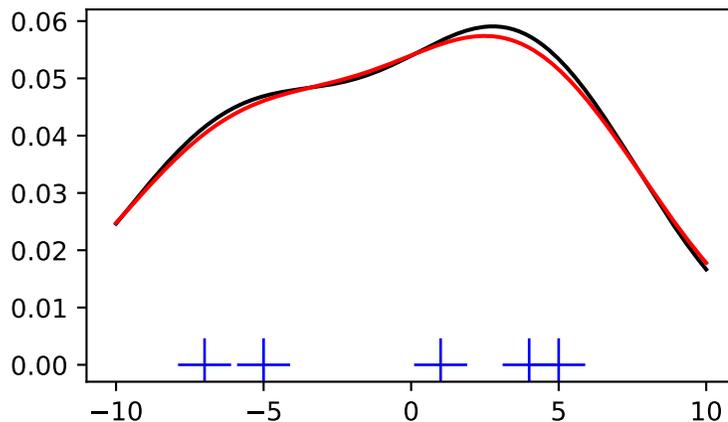
```
>>> from scipy import stats
>>> import matplotlib.pyplot as plt
```

```
>>> x1 = np.array([-7, -5, 1, 4, 5], dtype=np.float)
>>> kde1 = stats.gaussian_kde(x1)
>>> kde2 = stats.gaussian_kde(x1, bw_method='silverman')
```

```
>>> fig = plt.figure()
>>> ax = fig.add_subplot(111)
```

```
>>> ax.plot(x1, np.zeros(x1.shape), 'b+', ms=20) # rug plot
>>> x_eval = np.linspace(-10, 10, num=200)
>>> ax.plot(x_eval, kde1(x_eval), 'k-', label="Scott's Rule")
>>> ax.plot(x_eval, kde2(x_eval), 'r-', label="Silverman's Rule")
```

```
>>> plt.show()
```



We see that there is very little difference between Scott's Rule and Silverman's Rule, and that the bandwidth selection with a limited amount of data is probably a bit too wide. We can define our own bandwidth function to get a less smoothed out result.

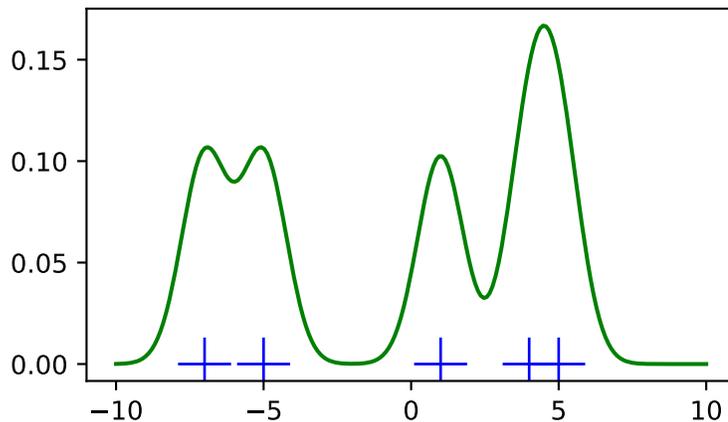
```
>>> def my_kde_bandwidth(obj, fac=1./5):
...     """We use Scott's Rule, multiplied by a constant factor."""
...     return np.power(obj.n, -1./(obj.d+4)) * fac
```

```
>>> fig = plt.figure()
>>> ax = fig.add_subplot(111)
```

```
>>> ax.plot(x1, np.zeros(x1.shape), 'b+', ms=20) # rug plot
>>> kde3 = stats.gaussian_kde(x1, bw_method=my_kde_bandwidth)
```

```
>>> ax.plot(x_eval, kde3(x_eval), 'g-', label="With smaller BW")
```

```
>>> plt.show()
```



We see that if we set bandwidth to be very narrow, the obtained estimate for the probability density function (PDF) is simply the sum of Gaussians around each data point.

We now take a more realistic example, and look at the difference between the two available bandwidth selection rules. Those rules are known to work well for (close to) normal distributions, but even for unimodal distributions that are quite strongly non-normal they work reasonably well. As a non-normal distribution we take a Student's T distribution with 5 degrees of freedom.

```
import numpy as np
import matplotlib.pyplot as plt
from scipy import stats

np.random.seed(12456)
x1 = np.random.normal(size=200) # random data, normal distribution
xs = np.linspace(x1.min()-1, x1.max()+1, 200)

kde1 = stats.gaussian_kde(x1)
kde2 = stats.gaussian_kde(x1, bw_method='silverman')

fig = plt.figure(figsize=(8, 6))

ax1 = fig.add_subplot(211)
ax1.plot(x1, np.zeros(x1.shape), 'b+', ms=12) # rug plot
ax1.plot(xs, kde1(xs), 'k-', label="Scott's Rule")
ax1.plot(xs, kde2(xs), 'b-', label="Silverman's Rule")
ax1.plot(xs, stats.norm.pdf(xs), 'r--', label="True PDF")

ax1.set_xlabel('x')
ax1.set_ylabel('Density')
ax1.set_title("Normal (top) and Student's T$_{df=5}$ (bottom) distributions")
ax1.legend(loc=1)
```

```

x2 = stats.t.rvs(5, size=200) # random data, T distribution
xs = np.linspace(x2.min() - 1, x2.max() + 1, 200)

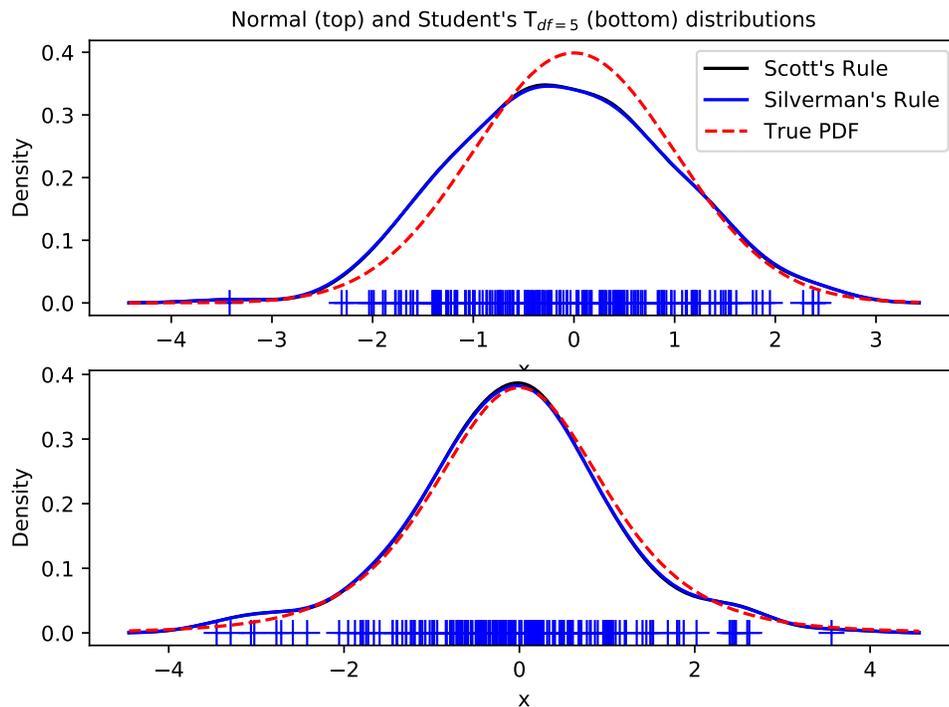
kde3 = stats.gaussian_kde(x2)
kde4 = stats.gaussian_kde(x2, bw_method='silverman')

ax2 = fig.add_subplot(212)
ax2.plot(x2, np.zeros(x2.shape), 'b+', ms=12) # rug plot
ax2.plot(xs, kde3(xs), 'k-', label="Scott's Rule")
ax2.plot(xs, kde4(xs), 'b-', label="Silverman's Rule")
ax2.plot(xs, stats.t.pdf(xs, 5), 'r--', label="True PDF")

ax2.set_xlabel('x')
ax2.set_ylabel('Density')

plt.show()

```



We now take a look at a bimodal distribution with one wider and one narrower Gaussian feature. We expect that this will be a more difficult density to approximate, due to the different bandwidths required to accurately resolve each feature.

```
>>> from functools import partial
```

```
>>> loc1, scale1, size1 = (-2, 1, 175)
>>> loc2, scale2, size2 = (2, 0.2, 50)
```

```
>>> x2 = np.concatenate([np.random.normal(loc=loc1, scale=scale1, size=size1),
...                       np.random.normal(loc=loc2, scale=scale2, size=size2)])
```

```
>>> x_eval = np.linspace(x2.min() - 1, x2.max() + 1, 500)
```

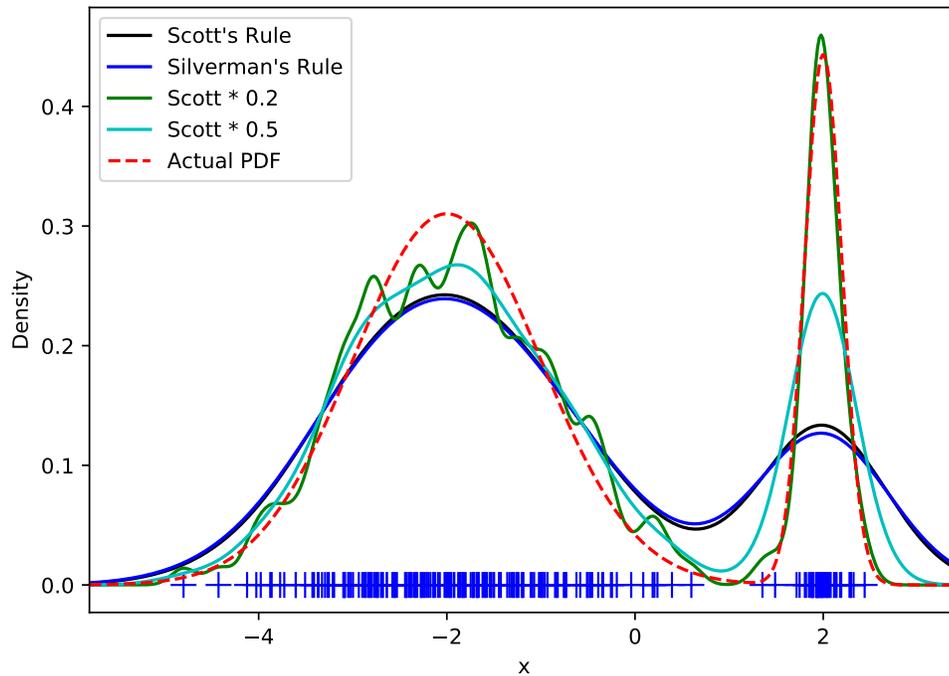
```
>>> kde = stats.gaussian_kde(x2)
>>> kde2 = stats.gaussian_kde(x2, bw_method='silverman')
>>> kde3 = stats.gaussian_kde(x2, bw_method=partial(my_kde_bandwidth, fac=0.2))
>>> kde4 = stats.gaussian_kde(x2, bw_method=partial(my_kde_bandwidth, fac=0.5))
```

```
>>> pdf = stats.norm.pdf
>>> bimodal_pdf = pdf(x_eval, loc=loc1, scale=scale1) * float(size1) / x2.size + \
...               pdf(x_eval, loc=loc2, scale=scale2) * float(size2) / x2.size
```

```
>>> fig = plt.figure(figsize=(8, 6))
>>> ax = fig.add_subplot(111)
```

```
>>> ax.plot(x2, np.zeros(x2.shape), 'b+', ms=12)
>>> ax.plot(x_eval, kde(x_eval), 'k-', label="Scott's Rule")
>>> ax.plot(x_eval, kde2(x_eval), 'b-', label="Silverman's Rule")
>>> ax.plot(x_eval, kde3(x_eval), 'g-', label="Scott * 0.2")
>>> ax.plot(x_eval, kde4(x_eval), 'c-', label="Scott * 0.5")
>>> ax.plot(x_eval, bimodal_pdf, 'r--', label="Actual PDF")
```

```
>>> ax.set_xlim([x_eval.min(), x_eval.max()])
>>> ax.legend(loc=2)
>>> ax.set_xlabel('x')
>>> ax.set_ylabel('Density')
>>> plt.show()
```



As expected, the KDE is not as close to the true PDF as we would like due to the different characteristic size of the two features of the bimodal distribution. By halving the default bandwidth (`Scott * 0.5`) we can do somewhat better, while using a factor 5 smaller bandwidth than the default doesn't smooth enough. What we really need though in this case is a non-uniform (adaptive) bandwidth.

### *Multivariate estimation*

With `gaussian_kde` we can perform multivariate as well as univariate estimation. We demonstrate the bivariate case. First we generate some random data with a model in which the two variates are correlated.

```
>>> def measure(n):
...     """Measurement model, return two coupled measurements."""
...     m1 = np.random.normal(size=n)
...     m2 = np.random.normal(scale=0.5, size=n)
...     return m1+m2, m1-m2
```

```
>>> m1, m2 = measure(2000)
>>> xmin = m1.min()
>>> xmax = m1.max()
>>> ymin = m2.min()
>>> ymax = m2.max()
```

Then we apply the KDE to the data:

```
>>> X, Y = np.mgrid[xmin:xmax:100j, ymin:ymax:100j]
>>> positions = np.vstack([X.ravel(), Y.ravel()])
>>> values = np.vstack([m1, m2])
>>> kernel = stats.gaussian_kde(values)
>>> Z = np.reshape(kernel.evaluate(positions).T, X.shape)
```

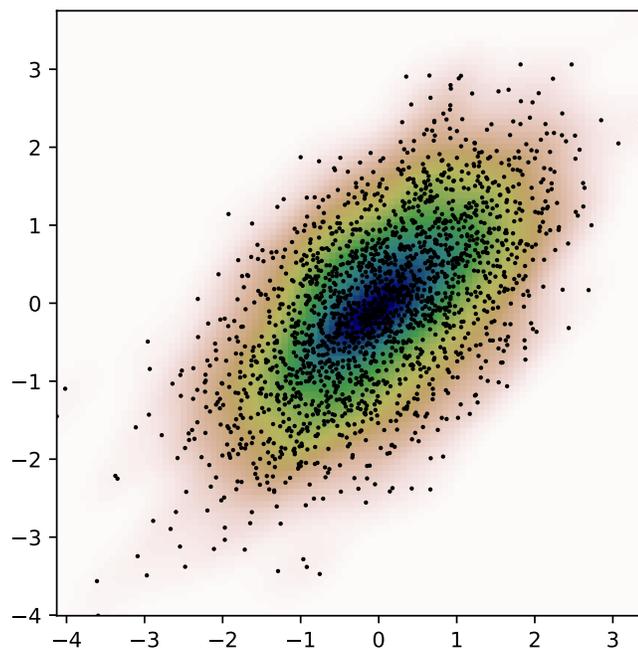
Finally we plot the estimated bivariate distribution as a colormap, and plot the individual data points on top.

```
>>> fig = plt.figure(figsize=(8, 6))
>>> ax = fig.add_subplot(111)
```

```
>>> ax.imshow(np.rot90(Z), cmap=plt.cm.gist_earth_r,
...           extent=[xmin, xmax, ymin, ymax])
>>> ax.plot(m1, m2, 'k.', markersize=2)
```

```
>>> ax.set_xlim([xmin, xmax])
>>> ax.set_ylim([ymin, ymax])
```

```
>>> plt.show()
```



### 3.1.14 Multidimensional image processing (`scipy.ndimage`)

#### Introduction

Image processing and analysis are generally seen as operations on two-dimensional arrays of values. There are however a number of fields where images of higher dimensionality must be analyzed. Good examples of these are medical imaging and biological imaging. `numpy` is suited very well for this type of applications due its inherent multidimensional nature. The `scipy.ndimage` packages provides a number of general image processing and analysis functions that are designed to operate with arrays of arbitrary dimensionality. The packages currently includes functions for linear and non-linear filtering, binary morphology, B-spline interpolation, and object measurements.

#### Properties shared by all functions

All functions share some common properties. Notably, all functions allow the specification of an output array with the `output` argument. With this argument you can specify an array that will be changed in-place with the result with the operation. In this case the result is not returned. Usually, using the `output` argument is more efficient, since an existing array is used to store the result.

The type of arrays returned is dependent on the type of operation, but it is in most cases equal to the type of the input. If, however, the `output` argument is used, the type of the result is equal to the type of the specified output argument. If no output argument is given, it is still possible to specify what the result of the output should be. This is done by simply assigning the desired `numpy` type object to the output argument. For example:

```
>>> from scipy.ndimage import correlate
>>> correlate(np.arange(10), [1, 2.5])
array([ 0,  2,  6,  9, 13, 16, 20, 23, 27, 30])
>>> correlate(np.arange(10), [1, 2.5], output=np.float64)
array([ 0. ,  2.5,  6. ,  9.5, 13. , 16.5, 20. , 23.5, 27. , 30.5])
```

#### Filter functions

The functions described in this section all perform some type of spatial filtering of the input array: the elements in the output are some function of the values in the neighborhood of the corresponding input element. We refer to this neighborhood of elements as the filter kernel, which is often rectangular in shape but may also have an arbitrary footprint. Many of the functions described below allow you to define the footprint of the kernel, by passing a mask through the `footprint` parameter. For example a cross shaped kernel can be defined as follows:

```
>>> footprint = np.array([[0, 1, 0], [1, 1, 1], [0, 1, 0]])
>>> footprint
array([[0, 1, 0],
       [1, 1, 1],
       [0, 1, 0]])
```

Usually the origin of the kernel is at the center calculated by dividing the dimensions of the kernel shape by two. For instance, the origin of a one-dimensional kernel of length three is at the second element. Take for example the correlation of a one-dimensional array with a filter of length 3 consisting of ones:

```
>>> from scipy.ndimage import correlate1d
>>> a = [0, 0, 0, 1, 0, 0, 0]
>>> correlate1d(a, [1, 1, 1])
array([0, 0, 1, 1, 1, 0, 0])
```

Sometimes it is convenient to choose a different origin for the kernel. For this reason most functions support the `origin` parameter which gives the origin of the filter relative to its center. For example:

```
>>> a = [0, 0, 0, 1, 0, 0, 0]
>>> correlate1d(a, [1, 1, 1], origin = -1)
array([0, 1, 1, 1, 0, 0, 0])
```

The effect is a shift of the result towards the left. This feature will not be needed very often, but it may be useful especially for filters that have an even size. A good example is the calculation of backward and forward differences:

```
>>> a = [0, 0, 1, 1, 1, 0, 0]
>>> correlate1d(a, [-1, 1]) # backward difference
array([ 0,  0,  1,  0,  0, -1,  0])
>>> correlate1d(a, [-1, 1], origin = -1) # forward difference
array([ 0,  1,  0,  0, -1,  0,  0])
```

We could also have calculated the forward difference as follows:

```
>>> correlate1d(a, [0, -1, 1])
array([ 0,  1,  0,  0, -1,  0,  0])
```

However, using the *origin* parameter instead of a larger kernel is more efficient. For multidimensional kernels *origin* can be a number, in which case the origin is assumed to be equal along all axes, or a sequence giving the origin along each axis.

Since the output elements are a function of elements in the neighborhood of the input elements, the borders of the array need to be dealt with appropriately by providing the values outside the borders. This is done by assuming that the arrays are extended beyond their boundaries according certain boundary conditions. In the functions described below, the boundary conditions can be selected using the *mode* parameter which must be a string with the name of the boundary condition. The following boundary conditions are currently supported:

“nearest”	Use the value at the boundary	[1 2 3]->[1 1 2 3 3]
“wrap”	Periodically replicate the array	[1 2 3]->[3 1 2 3 1]
“reflect”	Reflect the array at the boundary	[1 2 3]->[1 1 2 3 3]
“constant”	Use a constant value, default is 0.0	[1 2 3]->[0 1 2 3 0]

The “constant” mode is special since it needs an additional parameter to specify the constant value that should be used.

**Note:** The easiest way to implement such boundary conditions would be to copy the data to a larger array and extend the data at the borders according to the boundary conditions. For large arrays and large filter kernels, this would be very memory consuming, and the functions described below therefore use a different approach that does not require allocating large temporary buffers.

### Correlation and convolution

- The *correlate1d* function calculates a one-dimensional correlation along the given axis. The lines of the array along the given axis are correlated with the given *weights*. The *weights* parameter must be a one-dimensional sequences of numbers.
- The function *correlate* implements multidimensional correlation of the input array with a given kernel.
- The *convolve1d* function calculates a one-dimensional convolution along the given axis. The lines of the array along the given axis are convoluted with the given *weights*. The *weights* parameter must be a one-dimensional sequences of numbers.

**Note:** A convolution is essentially a correlation after mirroring the kernel. As a result, the *origin* parameter behaves differently than in the case of a correlation: the result is shifted in the opposite directions.

- The function `convolve` implements multidimensional convolution of the input array with a given kernel.

---

**Note:** A convolution is essentially a correlation after mirroring the kernel. As a result, the *origin* parameter behaves differently than in the case of a correlation: the results is shifted in the opposite direction.

---

### Smoothing filters

- The `gaussian_filter1d` function implements a one-dimensional Gaussian filter. The standard-deviation of the Gaussian filter is passed through the parameter *sigma*. Setting *order* = 0 corresponds to convolution with a Gaussian kernel. An order of 1, 2, or 3 corresponds to convolution with the first, second or third derivatives of a Gaussian. Higher order derivatives are not implemented.
- The `gaussian_filter` function implements a multidimensional Gaussian filter. The standard-deviations of the Gaussian filter along each axis are passed through the parameter *sigma* as a sequence or numbers. If *sigma* is not a sequence but a single number, the standard deviation of the filter is equal along all directions. The order of the filter can be specified separately for each axis. An order of 0 corresponds to convolution with a Gaussian kernel. An order of 1, 2, or 3 corresponds to convolution with the first, second or third derivatives of a Gaussian. Higher order derivatives are not implemented. The *order* parameter must be a number, to specify the same order for all axes, or a sequence of numbers to specify a different order for each axis.

---

**Note:** The multidimensional filter is implemented as a sequence of one-dimensional Gaussian filters. The intermediate arrays are stored in the same data type as the output. Therefore, for output types with a lower precision, the results may be imprecise because intermediate results may be stored with insufficient precision. This can be prevented by specifying a more precise output type.

---

- The `uniform_filter1d` function calculates a one-dimensional uniform filter of the given *size* along the given axis.
- The `uniform_filter` implements a multidimensional uniform filter. The sizes of the uniform filter are given for each axis as a sequence of integers by the *size* parameter. If *size* is not a sequence, but a single number, the sizes along all axis are assumed to be equal.

---

**Note:** The multidimensional filter is implemented as a sequence of one-dimensional uniform filters. The intermediate arrays are stored in the same data type as the output. Therefore, for output types with a lower precision, the results may be imprecise because intermediate results may be stored with insufficient precision. This can be prevented by specifying a more precise output type.

---

### Filters based on order statistics

- The `minimum_filter1d` function calculates a one-dimensional minimum filter of given *size* along the given axis.
- The `maximum_filter1d` function calculates a one-dimensional maximum filter of given *size* along the given axis.
- The `minimum_filter` function calculates a multidimensional minimum filter. Either the sizes of a rectangular kernel or the footprint of the kernel must be provided. The *size* parameter, if provided, must be a sequence of sizes or a single number in which case the size of the filter is assumed to be equal along each axis. The *footprint*, if provided, must be an array that defines the shape of the kernel by its non-zero elements.
- The `maximum_filter` function calculates a multidimensional maximum filter. Either the sizes of a rectangular kernel or the footprint of the kernel must be provided. The *size* parameter, if provided, must be a sequence of sizes or a single number in which case the size of the filter is assumed to be equal along each axis. The *footprint*, if provided, must be an array that defines the shape of the kernel by its non-zero elements.

- The `rank_filter` function calculates a multidimensional rank filter. The `rank` may be less than zero, i.e., `rank = -1` indicates the largest element. Either the sizes of a rectangular kernel or the footprint of the kernel must be provided. The `size` parameter, if provided, must be a sequence of sizes or a single number in which case the size of the filter is assumed to be equal along each axis. The `footprint`, if provided, must be an array that defines the shape of the kernel by its non-zero elements.
- The `percentile_filter` function calculates a multidimensional percentile filter. The `percentile` may be less than zero, i.e., `percentile = -20` equals `percentile = 80`. Either the sizes of a rectangular kernel or the footprint of the kernel must be provided. The `size` parameter, if provided, must be a sequence of sizes or a single number in which case the size of the filter is assumed to be equal along each axis. The `footprint`, if provided, must be an array that defines the shape of the kernel by its non-zero elements.
- The `median_filter` function calculates a multidimensional median filter. Either the sizes of a rectangular kernel or the footprint of the kernel must be provided. The `size` parameter, if provided, must be a sequence of sizes or a single number in which case the size of the filter is assumed to be equal along each axis. The `footprint` if provided, must be an array that defines the shape of the kernel by its non-zero elements.

### Derivatives

Derivative filters can be constructed in several ways. The function `gaussian_filter1d` described in *Smoothing filters* can be used to calculate derivatives along a given axis using the `order` parameter. Other derivative filters are the Prewitt and Sobel filters:

- The `prewitt` function calculates a derivative along the given axis.
- The `sobel` function calculates a derivative along the given axis.

The Laplace filter is calculated by the sum of the second derivatives along all axes. Thus, different Laplace filters can be constructed using different second derivative functions. Therefore we provide a general function that takes a function argument to calculate the second derivative along a given direction.

- The function `generic_laplace` calculates a laplace filter using the function passed through `derivative2` to calculate second derivatives. The function `derivative2` should have the following signature

```
derivative2(input, axis, output, mode, cval, *extra_arguments, **extra_keywords)
```

It should calculate the second derivative along the dimension `axis`. If `output` is not `None` it should use that for the output and return `None`, otherwise it should return the result. `mode`, `cval` have the usual meaning.

The `extra_arguments` and `extra_keywords` arguments can be used to pass a tuple of extra arguments and a dictionary of named arguments that are passed to `derivative2` at each call.

For example

```
>>> def d2(input, axis, output, mode, cval):
...     return correlate1d(input, [1, -2, 1], axis, output, mode, cval, 0)
...
>>> a = np.zeros((5, 5))
>>> a[2, 2] = 1
>>> from scipy.ndimage import generic_laplace
>>> generic_laplace(a, d2)
array([[ 0.,  0.,  0.,  0.,  0.],
       [ 0.,  0.,  1.,  0.,  0.],
       [ 0.,  1., -4.,  1.,  0.],
       [ 0.,  0.,  1.,  0.,  0.],
       [ 0.,  0.,  0.,  0.,  0.]])
```

To demonstrate the use of the `extra_arguments` argument we could do

```

>>> def d2(input, axis, output, mode, cval, weights):
...     return correlate2d(input, weights, axis, output, mode, cval, 0,)
...
>>> a = np.zeros((5, 5))
>>> a[2, 2] = 1
>>> generic_laplace(a, d2, extra_arguments = ([1, -2, 1],))
array([[ 0.,  0.,  0.,  0.,  0.],
       [ 0.,  0.,  1.,  0.,  0.],
       [ 0.,  1., -4.,  1.,  0.],
       [ 0.,  0.,  1.,  0.,  0.],
       [ 0.,  0.,  0.,  0.,  0.]])

```

or

```

>>> generic_laplace(a, d2, extra_keywords = {'weights': [1, -2, 1]})
array([[ 0.,  0.,  0.,  0.,  0.],
       [ 0.,  0.,  1.,  0.,  0.],
       [ 0.,  1., -4.,  1.,  0.],
       [ 0.,  0.,  1.,  0.,  0.],
       [ 0.,  0.,  0.,  0.,  0.]])

```

The following two functions are implemented using *generic\_laplace* by providing appropriate functions for the second derivative function:

- The function *laplace* calculates the Laplace using discrete differentiation for the second derivative (i.e. convolution with  $[1, -2, 1]$ ).
- The function *gaussian\_laplace* calculates the Laplace filter using *gaussian\_filter* to calculate the second derivatives. The standard-deviations of the Gaussian filter along each axis are passed through the parameter *sigma* as a sequence or numbers. If *sigma* is not a sequence but a single number, the standard deviation of the filter is equal along all directions.

The gradient magnitude is defined as the square root of the sum of the squares of the gradients in all directions. Similar to the generic Laplace function there is a *generic\_gradient\_magnitude* function that calculates the gradient magnitude of an array.

- The function *generic\_gradient\_magnitude* calculates a gradient magnitude using the function passed through *derivative* to calculate first derivatives. The function *derivative* should have the following signature

```
derivative(input, axis, output, mode, cval, *extra_arguments, **extra_keywords)
```

It should calculate the derivative along the dimension *axis*. If *output* is not None it should use that for the output and return None, otherwise it should return the result. *mode*, *cval* have the usual meaning.

The *extra\_arguments* and *extra\_keywords* arguments can be used to pass a tuple of extra arguments and a dictionary of named arguments that are passed to *derivative* at each call.

For example, the *sobel* function fits the required signature

```

>>> a = np.zeros((5, 5))
>>> a[2, 2] = 1
>>> from scipy.ndimage import sobel, generic_gradient_magnitude
>>> generic_gradient_magnitude(a, sobel)
array([[ 0.          ,  0.          ,  0.          ,  0.          ,  0.          ],
       [ 0.          ,  1.41421356,  2.          ,  1.41421356,  0.          ],
       [ 0.          ,  2.          ,  0.          ,  2.          ,  0.          ],
       [ 0.          ,  1.41421356,  2.          ,  1.41421356,  0.          ],
       [ 0.          ,  0.          ,  0.          ,  0.          ,  0.          ]])

```

See the documentation of `generic_laplace` for examples of using the `extra_arguments` and `extra_keywords` arguments.

The `sobel` and `prewitt` functions fit the required signature and can therefore directly be used with `generic_gradient_magnitude`.

- The function `gaussian_gradient_magnitude` calculates the gradient magnitude using `gaussian_filter` to calculate the first derivatives. The standard-deviations of the Gaussian filter along each axis are passed through the parameter `sigma` as a sequence or numbers. If `sigma` is not a sequence but a single number, the standard deviation of the filter is equal along all directions.

### Generic filter functions

To implement filter functions, generic functions can be used that accept a callable object that implements the filtering operation. The iteration over the input and output arrays is handled by these generic functions, along with such details as the implementation of the boundary conditions. Only a callable object implementing a callback function that does the actual filtering work must be provided. The callback function can also be written in C and passed using a `PyCapsule` (see *Extending scipy.ndimage in C* for more information).

- The `generic_filter1d` function implements a generic one-dimensional filter function, where the actual filtering operation must be supplied as a python function (or other callable object). The `generic_filter1d` function iterates over the lines of an array and calls `function` at each line. The arguments that are passed to `function` are one-dimensional arrays of the `tFloat64` type. The first contains the values of the current line. It is extended at the beginning and the end, according to the `filter_size` and `origin` arguments. The second array should be modified in-place to provide the output values of the line. For example consider a correlation along one dimension:

```
>>> a = np.arange(12).reshape(3,4)
>>> correlate1d(a, [1, 2, 3])
array([[ 3,  8, 14, 17],
       [27, 32, 38, 41],
       [51, 56, 62, 65]])
```

The same operation can be implemented using `generic_filter1d` as follows:

```
>>> def fnc(iline, oline):
...     oline[...] = iline[:-2] + 2 * iline[1:-1] + 3 * iline[2:]
...
>>> from scipy.ndimage import generic_filter1d
>>> generic_filter1d(a, fnc, 3)
array([[ 3,  8, 14, 17],
       [27, 32, 38, 41],
       [51, 56, 62, 65]])
```

Here the origin of the kernel was (by default) assumed to be in the middle of the filter of length 3. Therefore, each input line was extended by one value at the beginning and at the end, before the function was called.

Optionally extra arguments can be defined and passed to the filter function. The `extra_arguments` and `extra_keywords` arguments can be used to pass a tuple of extra arguments and/or a dictionary of named arguments that are passed to derivative at each call. For example, we can pass the parameters of our filter as an argument

```
>>> def fnc(iline, oline, a, b):
...     oline[...] = iline[:-2] + a * iline[1:-1] + b * iline[2:]
...
>>> generic_filter1d(a, fnc, 3, extra_arguments = (2, 3))
array([[ 3,  8, 14, 17],
       [27, 32, 38, 41],
       [51, 56, 62, 65]])
```

or

```
>>> generic_filter1d(a, fnc, 3, extra_keywords = {'a':2, 'b':3})
array([[ 3,  8, 14, 17],
       [27, 32, 38, 41],
       [51, 56, 62, 65]])
```

- The `generic_filter` function implements a generic filter function, where the actual filtering operation must be supplied as a python function (or other callable object). The `generic_filter` function iterates over the array and calls function at each element. The argument of function is a one-dimensional array of the `tFloat64` type, that contains the values around the current element that are within the footprint of the filter. The function should return a single value that can be converted to a double precision number. For example consider a correlation:

```
>>> a = np.arange(12).reshape(3,4)
>>> correlate(a, [[1, 0], [0, 3]])
array([[ 0,  3,  7, 11],
       [12, 15, 19, 23],
       [28, 31, 35, 39]])
```

The same operation can be implemented using `generic_filter` as follows:

```
>>> def fnc(buffer):
...     return (buffer * np.array([1, 3])).sum()
...
>>> from scipy.ndimage import generic_filter
>>> generic_filter(a, fnc, footprint = [[1, 0], [0, 1]])
array([[ 0,  3,  7, 11],
       [12, 15, 19, 23],
       [28, 31, 35, 39]])
```

Here a kernel footprint was specified that contains only two elements. Therefore the filter function receives a buffer of length equal to two, which was multiplied with the proper weights and the result summed.

When calling `generic_filter`, either the sizes of a rectangular kernel or the footprint of the kernel must be provided. The `size` parameter, if provided, must be a sequence of sizes or a single number in which case the size of the filter is assumed to be equal along each axis. The `footprint`, if provided, must be an array that defines the shape of the kernel by its non-zero elements.

Optionally extra arguments can be defined and passed to the filter function. The `extra_arguments` and `extra_keywords` arguments can be used to pass a tuple of extra arguments and/or a dictionary of named arguments that are passed to derivative at each call. For example, we can pass the parameters of our filter as an argument

```
>>> def fnc(buffer, weights):
...     weights = np.asarray(weights)
...     return (buffer * weights).sum()
...
>>> generic_filter(a, fnc, footprint = [[1, 0], [0, 1]], extra_arguments = ([1, 3],))
array([[ 0,  3,  7, 11],
       [12, 15, 19, 23],
       [28, 31, 35, 39]])
```

or

```
>>> generic_filter(a, fnc, footprint = [[1, 0], [0, 1]], extra_keywords= {'weights': [1, 3]})
array([[ 0,  3,  7, 11],
```

```
[12, 15, 19, 23],
 [28, 31, 35, 39]])
```

These functions iterate over the lines or elements starting at the last axis, i.e. the last index changes the fastest. This order of iteration is guaranteed for the case that it is important to adapt the filter depending on spatial location. Here is an example of using a class that implements the filter and keeps track of the current coordinates while iterating. It performs the same filter operation as described above for *generic\_filter*, but additionally prints the current coordinates:

```
>>> a = np.arange(12).reshape(3,4)
>>>
>>> class fnc_class:
...     def __init__(self, shape):
...         # store the shape:
...         self.shape = shape
...         # initialize the coordinates:
...         self.coordinates = [0] * len(shape)
...
...     def filter(self, buffer):
...         result = (buffer * np.array([1, 3])).sum()
...         print(self.coordinates)
...         # calculate the next coordinates:
...         axes = list(range(len(self.shape)))
...         axes.reverse()
...         for jj in axes:
...             if self.coordinates[jj] < self.shape[jj] - 1:
...                 self.coordinates[jj] += 1
...                 break
...             else:
...                 self.coordinates[jj] = 0
...         return result
...
>>> fnc = fnc_class(shape = (3,4))
>>> generic_filter(a, fnc.filter, footprint = [[1, 0], [0, 1]])
[0, 0]
[0, 1]
[0, 2]
[0, 3]
[1, 0]
[1, 1]
[1, 2]
[1, 3]
[2, 0]
[2, 1]
[2, 2]
[2, 3]
array([[ 0,  3,  7, 11],
       [12, 15, 19, 23],
       [28, 31, 35, 39]])
```

For the *generic\_filter1d* function the same approach works, except that this function does not iterate over the axis that is being filtered. The example for *generic\_filter1d* then becomes this:

```
>>> a = np.arange(12).reshape(3,4)
>>>
>>> class fnc1d_class:
...     def __init__(self, shape, axis = -1):
```

```

...     # store the filter axis:
...     self.axis = axis
...     # store the shape:
...     self.shape = shape
...     # initialize the coordinates:
...     self.coordinates = [0] * len(shape)
...
...     def filter(self, iline, oline):
...         oline[...] = iline[:-2] + 2 * iline[1:-1] + 3 * iline[2:]
...         print(self.coordinates)
...         # calculate the next coordinates:
...         axes = list(range(len(self.shape)))
...         # skip the filter axis:
...         del axes[self.axis]
...         axes.reverse()
...         for jj in axes:
...             if self.coordinates[jj] < self.shape[jj] - 1:
...                 self.coordinates[jj] += 1
...                 break
...             else:
...                 self.coordinates[jj] = 0
...
>>> fnc = fncld_class(shape = (3,4))
>>> generic_filter1d(a, fnc.filter, 3)
[0, 0]
[1, 0]
[2, 0]
array([[ 3,  8, 14, 17],
       [27, 32, 38, 41],
       [51, 56, 62, 65]])

```

### Fourier domain filters

The functions described in this section perform filtering operations in the Fourier domain. Thus, the input array of such a function should be compatible with an inverse Fourier transform function, such as the functions from the `numpy.fft` module. We therefore have to deal with arrays that may be the result of a real or a complex Fourier transform. In the case of a real Fourier transform only half of the of the symmetric complex transform is stored. Additionally, it needs to be known what the length of the axis was that was transformed by the real fft. The functions described here provide a parameter *n* that in the case of a real transform must be equal to the length of the real transform axis before transformation. If this parameter is less than zero, it is assumed that the input array was the result of a complex Fourier transform. The parameter *axis* can be used to indicate along which axis the real transform was executed.

- The `fourier_shift` function multiplies the input array with the multidimensional Fourier transform of a shift operation for the given shift. The *shift* parameter is a sequences of shifts for each dimension, or a single value for all dimensions.
- The `fourier_gaussian` function multiplies the input array with the multidimensional Fourier transform of a Gaussian filter with given standard-deviations *sigma*. The *sigma* parameter is a sequences of values for each dimension, or a single value for all dimensions.
- The `fourier_uniform` function multiplies the input array with the multidimensional Fourier transform of a uniform filter with given sizes *size*. The *size* parameter is a sequences of values for each dimension, or a single value for all dimensions.
- The `fourier_ellipsoid` function multiplies the input array with the multidimensional Fourier transform of an elliptically shaped filter with given sizes *size*. The *size* parameter is a sequences of values for each dimension, or a single value for all dimensions. This function is only implemented for dimensions 1, 2, and 3.

## Interpolation functions

This section describes various interpolation functions that are based on B-spline theory. A good introduction to B-splines can be found in<sup>1</sup>.

### Spline pre-filters

Interpolation using splines of an order larger than 1 requires a pre-filtering step. The interpolation functions described in section *Interpolation functions* apply pre-filtering by calling `spline_filter`, but they can be instructed not to do this by setting the `prefilter` keyword equal to `False`. This is useful if more than one interpolation operation is done on the same array. In this case it is more efficient to do the pre-filtering only once and use a prefiltered array as the input of the interpolation functions. The following two functions implement the pre-filtering:

- The `spline_filter1d` function calculates a one-dimensional spline filter along the given axis. An output array can optionally be provided. The order of the spline must be larger than 1 and less than 6.
- The `spline_filter` function calculates a multidimensional spline filter.

---

**Note:** The multidimensional filter is implemented as a sequence of one-dimensional spline filters. The intermediate arrays are stored in the same data type as the output. Therefore, if an output with a limited precision is requested, the results may be imprecise because intermediate results may be stored with insufficient precision. This can be prevented by specifying a output type of high precision.

---

### Interpolation functions

Following functions all employ spline interpolation to effect some type of geometric transformation of the input array. This requires a mapping of the output coordinates to the input coordinates, and therefore the possibility arises that input values outside the boundaries are needed. This problem is solved in the same way as described in *Filter functions* for the multidimensional filter functions. Therefore these functions all support a `mode` parameter that determines how the boundaries are handled, and a `cval` parameter that gives a constant value in case that the ‘constant’ mode is used.

- The `geometric_transform` function applies an arbitrary geometric transform to the input. The given `mapping` function is called at each point in the output to find the corresponding coordinates in the input. `mapping` must be a callable object that accepts a tuple of length equal to the output array rank and returns the corresponding input coordinates as a tuple of length equal to the input array rank. The output shape and output type can optionally be provided. If not given they are equal to the input shape and type.

For example:

```
>>> a = np.arange(12).reshape(4,3).astype(np.float64)
>>> def shift_func(output_coordinates):
...     return (output_coordinates[0] - 0.5, output_coordinates[1] - 0.5)
...
>>> from scipy.ndimage import geometric_transform
>>> geometric_transform(a, shift_func)
array([[ 0.    ,  0.    ,  0.    ],
       [ 0.    ,  1.3625,  2.7375],
       [ 0.    ,  4.8125,  6.1875],
       [ 0.    ,  8.2625,  9.6375]])
```

Optionally extra arguments can be defined and passed to the filter function. The `extra_arguments` and `extra_keywords` arguments can be used to pass a tuple of extra arguments and/or a dictionary of named arguments that are passed to derivative at each call. For example, we can pass the shifts in our example as arguments

---

<sup>1</sup> M. Unser, “Splines: A Perfect Fit for Signal and Image Processing,” IEEE Signal Processing Magazine, vol. 16, no. 6, pp. 22-38, November 1999.

```
>>> def shift_func(output_coordinates, s0, s1):
...     return (output_coordinates[0] - s0, output_coordinates[1] - s1)
...
>>> geometric_transform(a, shift_func, extra_arguments = (0.5, 0.5))
array([[ 0.    ,  0.    ,  0.    ],
       [ 0.    ,  1.3625,  2.7375],
       [ 0.    ,  4.8125,  6.1875],
       [ 0.    ,  8.2625,  9.6375]])
```

or

```
>>> geometric_transform(a, shift_func, extra_keywords = {'s0': 0.5, 's1': 0.5})
array([[ 0.    ,  0.    ,  0.    ],
       [ 0.    ,  1.3625,  2.7375],
       [ 0.    ,  4.8125,  6.1875],
       [ 0.    ,  8.2625,  9.6375]])
```

**Note:** The mapping function can also be written in C and passed using a *scipy.LowLevelCallable*. See *Extending scipy.ndimage in C* for more information.

- The function *map\_coordinates* applies an arbitrary coordinate transformation using the given array of coordinates. The shape of the output is derived from that of the coordinate array by dropping the first axis. The parameter *coordinates* is used to find for each point in the output the corresponding coordinates in the input. The values of *coordinates* along the first axis are the coordinates in the input array at which the output value is found. (See also the *numarray.coordinates* function.) Since the coordinates may be non-integer coordinates, the value of the input at these coordinates is determined by spline interpolation of the requested order.

Here is an example that interpolates a 2D array at (0.5, 0.5) and (1, 2):

```
>>> a = np.arange(12).reshape(4,3).astype(np.float64)
>>> a
array([[ 0.,  1.,  2.],
       [ 3.,  4.,  5.],
       [ 6.,  7.,  8.],
       [ 9., 10., 11.]])
>>> from scipy.ndimage import map_coordinates
>>> map_coordinates(a, [[0.5, 2], [0.5, 1]])
array([ 1.3625,  7.])
```

- The *affine\_transform* function applies an affine transformation to the input array. The given transformation *matrix* and *offset* are used to find for each point in the output the corresponding coordinates in the input. The value of the input at the calculated coordinates is determined by spline interpolation of the requested order. The transformation *matrix* must be two-dimensional or can also be given as a one-dimensional sequence or array. In the latter case, it is assumed that the matrix is diagonal. A more efficient interpolation algorithm is then applied that exploits the separability of the problem. The output shape and output type can optionally be provided. If not given they are equal to the input shape and type.
- The *shift* function returns a shifted version of the input, using spline interpolation of the requested *order*.
- The *zoom* function returns a rescaled version of the input, using spline interpolation of the requested *order*.
- The *rotate* function returns the input array rotated in the plane defined by the two axes given by the parameter *axes*, using spline interpolation of the requested *order*. The angle must be given in degrees. If *reshape* is true, then the size of the output array is adapted to contain the rotated input.

## Morphology

### Binary morphology

- The `generate_binary_structure` function generates a binary structuring element for use in binary morphology operations. The *rank* of the structure must be provided. The size of the structure that is returned is equal to three in each direction. The value of each element is equal to one if the square of the Euclidean distance from the element to the center is less or equal to *connectivity*. For instance, two dimensional 4-connected and 8-connected structures are generated as follows:

```
>>> from scipy.ndimage import generate_binary_structure
>>> generate_binary_structure(2, 1)
array([[False,  True,  False],
       [ True,  True,  True],
       [False,  True,  False]], dtype=bool)
>>> generate_binary_structure(2, 2)
array([[ True,  True,  True],
       [ True,  True,  True],
       [ True,  True,  True]], dtype=bool)
```

Most binary morphology functions can be expressed in terms of the basic operations erosion and dilation.

- The `binary_erosion` function implements binary erosion of arrays of arbitrary rank with the given structuring element. The origin parameter controls the placement of the structuring element as described in *Filter functions*. If no structuring element is provided, an element with connectivity equal to one is generated using `generate_binary_structure`. The *border\_value* parameter gives the value of the array outside boundaries. The erosion is repeated *iterations* times. If *iterations* is less than one, the erosion is repeated until the result does not change anymore. If a *mask* array is given, only those elements with a true value at the corresponding mask element are modified at each iteration.
- The `binary_dilation` function implements binary dilation of arrays of arbitrary rank with the given structuring element. The origin parameter controls the placement of the structuring element as described in *Filter functions*. If no structuring element is provided, an element with connectivity equal to one is generated using `generate_binary_structure`. The *border\_value* parameter gives the value of the array outside boundaries. The dilation is repeated *iterations* times. If *iterations* is less than one, the dilation is repeated until the result does not change anymore. If a *mask* array is given, only those elements with a true value at the corresponding mask element are modified at each iteration.

Here is an example of using `binary_dilation` to find all elements that touch the border, by repeatedly dilating an empty array from the border using the data array as the mask:

```
>>> struct = np.array([[0, 1, 0], [1, 1, 1], [0, 1, 0]])
>>> a = np.array([[1,0,0,0,0], [1,1,0,1,0], [0,0,1,1,0], [0,0,0,0,0]])
>>> a
array([[1, 0, 0, 0, 0],
       [1, 1, 0, 1, 0],
       [0, 0, 1, 1, 0],
       [0, 0, 0, 0, 0]])
>>> from scipy.ndimage import binary_dilation
>>> binary_dilation(np.zeros(a.shape), struct, -1, a, border_value=1)
array([[ True,  False,  False,  False,  False],
       [ True,  True,  False,  False,  False],
       [False,  False,  False,  False,  False],
       [False,  False,  False,  False,  False]], dtype=bool)
```

The `binary_erosion` and `binary_dilation` functions both have an *iterations* parameter which allows the erosion or dilation to be repeated a number of times. Repeating an erosion or a dilation with a given structure *n* times

is equivalent to an erosion or a dilation with a structure that is  $n-1$  times dilated with itself. A function is provided that allows the calculation of a structure that is dilated a number of times with itself:

- The `iterate_structure` function returns a structure by dilation of the input structure *iteration* - 1 times with itself.

For instance:

```
>>> struct = generate_binary_structure(2, 1)
>>> struct
array([[False,  True,  False],
       [ True,  True,  True],
       [False,  True,  False]], dtype=bool)
>>> from scipy.ndimage import iterate_structure
>>> iterate_structure(struct, 2)
array([[False,  False,  True,  False,  False],
       [False,  True,  True,  True,  False],
       [ True,  True,  True,  True,  True],
       [False,  True,  True,  True,  False],
       [False,  False,  True,  False,  False]], dtype=bool)
```

If the origin of the original structure is equal to 0, then it is also equal to 0 for the iterated structure. If not, the origin must also be adapted if the equivalent of the `*iterations*` erosions or dilations must be achieved with the iterated structure. The adapted origin is simply obtained by multiplying with the number of iterations. For convenience the `:func:`iterate_structure`` also returns the adapted origin if the `*origin*` parameter is not ```None```:

```
.. code:: python

>>> iterate_structure(struct, 2, -1)
(array([[False,  False,  True,  False,  False],
       [False,  True,  True,  True,  False],
       [ True,  True,  True,  True,  True],
       [False,  True,  True,  True,  False],
       [False,  False,  True,  False,  False]], dtype=bool), [-2, -2])
```

Other morphology operations can be defined in terms of erosion and dilation. The following functions provide a few of these operations for convenience:

- The `binary_opening` function implements binary opening of arrays of arbitrary rank with the given structuring element. Binary opening is equivalent to a binary erosion followed by a binary dilation with the same structuring element. The origin parameter controls the placement of the structuring element as described in *Filter functions*. If no structuring element is provided, an element with connectivity equal to one is generated using `generate_binary_structure`. The `iterations` parameter gives the number of erosions that is performed followed by the same number of dilations.
- The `binary_closing` function implements binary closing of arrays of arbitrary rank with the given structuring element. Binary closing is equivalent to a binary dilation followed by a binary erosion with the same structuring element. The origin parameter controls the placement of the structuring element as described in *Filter functions*. If no structuring element is provided, an element with connectivity equal to one is generated using `generate_binary_structure`. The `iterations` parameter gives the number of dilations that is performed followed by the same number of erosions.
- The `binary_fill_holes` function is used to close holes in objects in a binary image, where the structure defines the connectivity of the holes. The origin parameter controls the placement of the structuring element as described in *Filter functions*. If no structuring element is provided, an element with connectivity equal to one is

generated using `generate_binary_structure`.

- The `binary_hit_or_miss` function implements a binary hit-or-miss transform of arrays of arbitrary rank with the given structuring elements. The hit-or-miss transform is calculated by erosion of the input with the first structure, erosion of the logical *not* of the input with the second structure, followed by the logical *and* of these two erosions. The origin parameters control the placement of the structuring elements as described in *Filter functions*. If `origin2` equals `None` it is set equal to the `origin1` parameter. If the first structuring element is not provided, a structuring element with connectivity equal to one is generated using `generate_binary_structure`, if `structure2` is not provided, it is set equal to the logical *not* of `structure1`.

### **Grey-scale morphology**

Grey-scale morphology operations are the equivalents of binary morphology operations that operate on arrays with arbitrary values. Below we describe the grey-scale equivalents of erosion, dilation, opening and closing. These operations are implemented in a similar fashion as the filters described in *Filter functions*, and we refer to this section for the description of filter kernels and footprints, and the handling of array borders. The grey-scale morphology operations optionally take a `structure` parameter that gives the values of the structuring element. If this parameter is not given the structuring element is assumed to be flat with a value equal to zero. The shape of the structure can optionally be defined by the `footprint` parameter. If this parameter is not given, the structure is assumed to be rectangular, with sizes equal to the dimensions of the `structure` array, or by the `size` parameter if `structure` is not given. The `size` parameter is only used if both `structure` and `footprint` are not given, in which case the structuring element is assumed to be rectangular and flat with the dimensions given by `size`. The `size` parameter, if provided, must be a sequence of sizes or a single number in which case the size of the filter is assumed to be equal along each axis. The `footprint` parameter, if provided, must be an array that defines the shape of the kernel by its non-zero elements.

Similar to binary erosion and dilation there are operations for grey-scale erosion and dilation:

- The `grey_erosion` function calculates a multidimensional grey-scale erosion.
- The `grey_dilation` function calculates a multidimensional grey-scale dilation.

Grey-scale opening and closing operations can be defined similar to their binary counterparts:

- The `grey_opening` function implements grey-scale opening of arrays of arbitrary rank. Grey-scale opening is equivalent to a grey-scale erosion followed by a grey-scale dilation.
- The `grey_closing` function implements grey-scale closing of arrays of arbitrary rank. Grey-scale opening is equivalent to a grey-scale dilation followed by a grey-scale erosion.
- The `morphological_gradient` function implements a grey-scale morphological gradient of arrays of arbitrary rank. The grey-scale morphological gradient is equal to the difference of a grey-scale dilation and a grey-scale erosion.
- The `morphological_laplace` function implements a grey-scale morphological laplace of arrays of arbitrary rank. The grey-scale morphological laplace is equal to the sum of a grey-scale dilation and a grey-scale erosion minus twice the input.
- The `white_tophat` function implements a white top-hat filter of arrays of arbitrary rank. The white top-hat is equal to the difference of the input and a grey-scale opening.
- The `black_tophat` function implements a black top-hat filter of arrays of arbitrary rank. The black top-hat is equal to the difference of a grey-scale closing and the input.

### **Distance transforms**

Distance transforms are used to calculate the minimum distance from each element of an object to the background. The following functions implement distance transforms for three different distance metrics: Euclidean, City Block, and Chessboard distances.

- The function `distance_transform_cdt` uses a chamfer type algorithm to calculate the distance transform of the input, by replacing each object element (defined by values larger than zero) with the shortest distance to the background (all non-object elements). The structure determines the type of chamfering that is done. If the structure is equal to 'cityblock' a structure is generated using `generate_binary_structure` with a squared distance equal to 1. If the structure is equal to 'chessboard', a structure is generated using `generate_binary_structure` with a squared distance equal to the rank of the array. These choices correspond to the common interpretations of the cityblock and the chessboard distance metrics in two dimensions.

In addition to the distance transform, the feature transform can be calculated. In this case the index of the closest background element is returned along the first axis of the result. The `return_distances`, and `return_indices` flags can be used to indicate if the distance transform, the feature transform, or both must be returned.

The `distances` and `indices` arguments can be used to give optional output arrays that must be of the correct size and type (both `Int32`). The basics of the algorithm used to implement this function is described in<sup>2</sup>.

- The function `distance_transform_edt` calculates the exact euclidean distance transform of the input, by replacing each object element (defined by values larger than zero) with the shortest euclidean distance to the background (all non-object elements).

In addition to the distance transform, the feature transform can be calculated. In this case the index of the closest background element is returned along the first axis of the result. The `return_distances`, and `return_indices` flags can be used to indicate if the distance transform, the feature transform, or both must be returned.

Optionally the sampling along each axis can be given by the `sampling` parameter which should be a sequence of length equal to the input rank, or a single number in which the sampling is assumed to be equal along all axes.

The `distances` and `indices` arguments can be used to give optional output arrays that must be of the correct size and type (`Float64` and `Int32`). The algorithm used to implement this function is described in<sup>3</sup>.

- The function `distance_transform_bf` uses a brute-force algorithm to calculate the distance transform of the input, by replacing each object element (defined by values larger than zero) with the shortest distance to the background (all non-object elements). The metric must be one of "euclidean", "cityblock", or "chessboard".

In addition to the distance transform, the feature transform can be calculated. In this case the index of the closest background element is returned along the first axis of the result. The `return_distances`, and `return_indices` flags can be used to indicate if the distance transform, the feature transform, or both must be returned.

Optionally the sampling along each axis can be given by the `sampling` parameter which should be a sequence of length equal to the input rank, or a single number in which the sampling is assumed to be equal along all axes. This parameter is only used in the case of the euclidean distance transform.

The `distances` and `indices` arguments can be used to give optional output arrays that must be of the correct size and type (`Float64` and `Int32`).

---

**Note:** This function uses a slow brute-force algorithm, the function `distance_transform_cdt` can be used to more efficiently calculate cityblock and chessboard distance transforms. The function `distance_transform_edt` can be used to more efficiently calculate the exact euclidean distance transform.

---

## Segmentation and labeling

Segmentation is the process of separating objects of interest from the background. The most simple approach is probably intensity thresholding, which is easily done with `numpy` functions:

<sup>2</sup> G. Borgefors, "Distance transformations in arbitrary dimensions.", *Computer Vision, Graphics, and Image Processing*, 27:321-345, 1984.

<sup>3</sup> C. R. Maurer, Jr., R. Qi, and V. Raghavan, "A linear time algorithm for computing exact euclidean distance transforms of binary images in arbitrary dimensions. *IEEE Trans. PAMI* 25, 265-270, 2003.

```

>>> a = np.array([[1,2,2,1,1,0],
...               [0,2,3,1,2,0],
...               [1,1,1,3,3,2],
...               [1,1,1,1,2,1]])
>>> np.where(a > 1, 1, 0)
array([[0, 1, 1, 0, 0, 0],
       [0, 1, 1, 0, 1, 0],
       [0, 0, 0, 1, 1, 1],
       [0, 0, 0, 0, 1, 0]])
    
```

The result is a binary image, in which the individual objects still need to be identified and labeled. The function `label` generates an array where each object is assigned a unique number:

- The `label` function generates an array where the objects in the input are labeled with an integer index. It returns a tuple consisting of the array of object labels and the number of objects found, unless the `output` parameter is given, in which case only the number of objects is returned. The connectivity of the objects is defined by a structuring element. For instance, in two dimensions using a four-connected structuring element gives:

```

>>> a = np.array([[0,1,1,0,0,0],[0,1,1,0,1,0],[0,0,0,1,1,1],[0,0,0,0,1,0]])
>>> s = [[0, 1, 0], [1,1,1], [0,1,0]]
>>> from scipy.ndimage import label
>>> label(a, s)
(array([[0, 1, 1, 0, 0, 0],
       [0, 1, 1, 0, 2, 0],
       [0, 0, 0, 2, 2, 2],
       [0, 0, 0, 0, 2, 0]]), 2)
    
```

These two objects are not connected because there is no way in which we can place the structuring element such that it overlaps with both objects. However, an 8-connected structuring element results in only a single object:

```

>>> a = np.array([[0,1,1,0,0,0],[0,1,1,0,1,0],[0,0,0,1,1,1],[0,0,0,0,1,0]])
>>> s = [[1,1,1], [1,1,1], [1,1,1]]
>>> label(a, s)[0]
array([[0, 1, 1, 0, 0, 0],
       [0, 1, 1, 0, 1, 0],
       [0, 0, 0, 1, 1, 1],
       [0, 0, 0, 0, 1, 0]])
    
```

If no structuring element is provided, one is generated by calling `generate_binary_structure` (see *Binary morphology*) using a connectivity of one (which in 2D is the 4-connected structure of the first example). The input can be of any type, any value not equal to zero is taken to be part of an object. This is useful if you need to ‘re-label’ an array of object indices, for instance after removing unwanted objects. Just apply the `label` function again to the index array. For instance:

```

>>> l, n = label([1, 0, 1, 0, 1])
>>> l
array([1, 0, 2, 0, 3])
>>> l = np.where(l != 2, l, 0)
>>> l
array([1, 0, 0, 0, 3])
>>> label(l)[0]
array([1, 0, 0, 0, 2])
    
```

---

**Note:** The structuring element used by `label` is assumed to be symmetric.

---

There is a large number of other approaches for segmentation, for instance from an estimation of the borders of the objects that can be obtained for instance by derivative filters. One such an approach is watershed segmentation. The function `watershed_ift` generates an array where each object is assigned a unique label, from an array that localizes the object borders, generated for instance by a gradient magnitude filter. It uses an array containing initial markers for the objects:

- The `watershed_ift` function applies a watershed from markers algorithm, using an Iterative Forest Transform, as described in<sup>4</sup>.
- The inputs of this function are the array to which the transform is applied, and an array of markers that designate the objects by a unique label, where any non-zero value is a marker. For instance:

```
>>> input = np.array([[0, 0, 0, 0, 0, 0, 0],
...                   [0, 1, 1, 1, 1, 1, 0],
...                   [0, 1, 0, 0, 0, 1, 0],
...                   [0, 1, 0, 0, 0, 1, 0],
...                   [0, 1, 0, 0, 0, 1, 0],
...                   [0, 1, 1, 1, 1, 1, 0],
...                   [0, 0, 0, 0, 0, 0, 0]], np.uint8)
>>> markers = np.array([[1, 0, 0, 0, 0, 0, 0],
...                     [0, 0, 0, 0, 0, 0, 0],
...                     [0, 0, 0, 0, 0, 0, 0],
...                     [0, 0, 0, 2, 0, 0, 0],
...                     [0, 0, 0, 0, 0, 0, 0],
...                     [0, 0, 0, 0, 0, 0, 0],
...                     [0, 0, 0, 0, 0, 0, 0]], np.int8)
>>> from scipy.ndimage import watershed_ift
>>> watershed_ift(input, markers)
array([[1, 1, 1, 1, 1, 1, 1],
       [1, 1, 2, 2, 2, 1, 1],
       [1, 2, 2, 2, 2, 2, 1],
       [1, 2, 2, 2, 2, 2, 1],
       [1, 2, 2, 2, 2, 2, 1],
       [1, 1, 2, 2, 2, 1, 1],
       [1, 1, 1, 1, 1, 1, 1]], dtype=int8)
```

Here two markers were used to designate an object (*marker = 2*) and the background (*marker = 1*). The order in which these are processed is arbitrary: moving the marker for the background to the lower right corner of the array yields a different result:

```
>>> markers = np.array([[0, 0, 0, 0, 0, 0, 0],
...                     [0, 0, 0, 0, 0, 0, 0],
...                     [0, 0, 0, 0, 0, 0, 0],
...                     [0, 0, 0, 2, 0, 0, 0],
...                     [0, 0, 0, 0, 0, 0, 0],
...                     [0, 0, 0, 0, 0, 0, 0],
...                     [0, 0, 0, 0, 0, 0, 1]], np.int8)
>>> watershed_ift(input, markers)
array([[1, 1, 1, 1, 1, 1, 1],
       [1, 1, 1, 1, 1, 1, 1],
       [1, 1, 2, 2, 2, 1, 1],
       [1, 1, 2, 2, 2, 1, 1],
       [1, 1, 2, 2, 2, 1, 1],
       [1, 1, 1, 1, 1, 1, 1],
       [1, 1, 1, 1, 1, 1, 1]], dtype=int8)
```

<sup>4</sup> P. Felkel, R. Wegenkittl, and M. Bruckschwaiger. "Implementation and Complexity of the Watershed-from-Markers Algorithm Computed as a Minimal Cost Forest.", Eurographics 2001, pp. C:26-35.

The result is that the object (*marker* = 2) is smaller because the second marker was processed earlier. This may not be the desired effect if the first marker was supposed to designate a background object. Therefore *watershed\_ift* treats markers with a negative value explicitly as background markers and processes them after the normal markers. For instance, replacing the first marker by a negative marker gives a result similar to the first example:

```
>>> markers = np.array([[0, 0, 0, 0, 0, 0, 0],
...                     [0, 0, 0, 0, 0, 0, 0],
...                     [0, 0, 0, 0, 0, 0, 0],
...                     [0, 0, 0, 2, 0, 0, 0],
...                     [0, 0, 0, 0, 0, 0, 0],
...                     [0, 0, 0, 0, 0, 0, 0],
...                     [0, 0, 0, 0, 0, 0, -1]], np.int8)
>>> watershed_ift(input, markers)
array([[ -1,  -1,  -1,  -1,  -1,  -1,  -1],
       [ -1,  -1,   2,   2,   2,  -1,  -1],
       [ -1,   2,   2,   2,   2,   2,  -1],
       [ -1,   2,   2,   2,   2,   2,  -1],
       [ -1,   2,   2,   2,   2,   2,  -1],
       [ -1,  -1,   2,   2,   2,  -1,  -1],
       [ -1,  -1,  -1,  -1,  -1,  -1,  -1]], dtype=int8)
```

The connectivity of the objects is defined by a structuring element. If no structuring element is provided, one is generated by calling *generate\_binary\_structure* (see *Binary morphology*) using a connectivity of one (which in 2D is a 4-connected structure.) For example, using an 8-connected structure with the last example yields a different object:

```
>>> watershed_ift(input, markers,
...               structure = [[1,1,1], [1,1,1], [1,1,1]])
array([[ -1,  -1,  -1,  -1,  -1,  -1,  -1],
       [ -1,   2,   2,   2,   2,   2,  -1],
       [ -1,   2,   2,   2,   2,   2,  -1],
       [ -1,   2,   2,   2,   2,   2,  -1],
       [ -1,   2,   2,   2,   2,   2,  -1],
       [ -1,   2,   2,   2,   2,   2,  -1],
       [ -1,  -1,  -1,  -1,  -1,  -1,  -1]], dtype=int8)
```

---

**Note:** The implementation of *watershed\_ift* limits the data types of the input to `UInt8` and `UInt16`.

---

## Object measurements

Given an array of labeled objects, the properties of the individual objects can be measured. The *find\_objects* function can be used to generate a list of slices that for each object, give the smallest sub-array that fully contains the object:

- The *find\_objects* function finds all objects in a labeled array and returns a list of slices that correspond to the smallest regions in the array that contains the object.

For instance:

```
>>> a = np.array([[0,1,1,0,0,0],[0,1,1,0,1,0],[0,0,0,1,1,1],[0,0,0,0,1,0]])
>>> l, n = label(a)
>>> from scipy.ndimage import find_objects
>>> f = find_objects(l)
>>> a[f[0]]
```

```
array([[1, 1],
       [1, 1]])
>>> a[f[1]]
array([[0, 1, 0],
       [1, 1, 1],
       [0, 1, 0]])
```

The function `find_objects` returns slices for all objects, unless the `max_label` parameter is larger than zero, in which case only the first `max_label` objects are returned. If an index is missing in the `label` array, `None` is returned instead of a slice. For example:

```
>>> from scipy.ndimage import find_objects
>>> find_objects([1, 0, 3, 4], max_label = 3)
[(slice(0, 1, None),), None, (slice(2, 3, None),)]
```

The list of slices generated by `find_objects` is useful to find the position and dimensions of the objects in the array, but can also be used to perform measurements on the individual objects. Say we want to find the sum of the intensities of an object in image:

```
>>> image = np.arange(4 * 6).reshape(4, 6)
>>> mask = np.array([[0,1,1,0,0,0],[0,1,1,0,1,0],[0,0,0,1,1,1],[0,0,0,0,1,0]])
>>> labels = label(mask) [0]
>>> slices = find_objects(labels)
```

Then we can calculate the sum of the elements in the second object:

```
>>> np.where(labels[slices[1]] == 2, image[slices[1]], 0).sum()
80
```

That is however not particularly efficient, and may also be more complicated for other types of measurements. Therefore a few measurement functions are defined that accept the array of object labels and the index of the object to be measured. For instance calculating the sum of the intensities can be done by:

```
>>> from scipy.ndimage import sum as ndi_sum
>>> ndi_sum(image, labels, 2)
80
```

For large arrays and small objects it is more efficient to call the measurement functions after slicing the array:

```
>>> ndi_sum(image[slices[1]], labels[slices[1]], 2)
80
```

Alternatively, we can do the measurements for a number of labels with a single function call, returning a list of results. For instance, to measure the sum of the values of the background and the second object in our example we give a list of labels:

```
>>> ndi_sum(image, labels, [0, 2])
array([178.0, 80.0])
```

The measurement functions described below all support the `index` parameter to indicate which object(s) should be measured. The default value of `index` is `None`. This indicates that all elements where the label is larger than zero should be treated as a single object and measured. Thus, in this case the `labels` array is treated as a mask defined by the elements that are larger than zero. If `index` is a number or a sequence of numbers it gives the labels of the objects that are measured. If `index` is a sequence, a list of the results is returned. Functions that return more than one result, return their result as a tuple if `index` is a single number, or as a tuple of lists, if `index` is a sequence.

- The *sum* function calculates the sum of the elements of the object with label(s) given by *index*, using the *labels* array for the object labels. If *index* is `None`, all elements with a non-zero label value are treated as a single object. If *label* is `None`, all elements of *input* are used in the calculation.
- The *mean* function calculates the mean of the elements of the object with label(s) given by *index*, using the *labels* array for the object labels. If *index* is `None`, all elements with a non-zero label value are treated as a single object. If *label* is `None`, all elements of *input* are used in the calculation.
- The *variance* function calculates the variance of the elements of the object with label(s) given by *index*, using the *labels* array for the object labels. If *index* is `None`, all elements with a non-zero label value are treated as a single object. If *label* is `None`, all elements of *input* are used in the calculation.
- The *standard\_deviation* function calculates the standard deviation of the elements of the object with label(s) given by *index*, using the *labels* array for the object labels. If *index* is `None`, all elements with a non-zero label value are treated as a single object. If *label* is `None`, all elements of *input* are used in the calculation.
- The *minimum* function calculates the minimum of the elements of the object with label(s) given by *index*, using the *labels* array for the object labels. If *index* is `None`, all elements with a non-zero label value are treated as a single object. If *label* is `None`, all elements of *input* are used in the calculation.
- The *maximum* function calculates the maximum of the elements of the object with label(s) given by *index*, using the *labels* array for the object labels. If *index* is `None`, all elements with a non-zero label value are treated as a single object. If *label* is `None`, all elements of *input* are used in the calculation.
- The *minimum\_position* function calculates the position of the minimum of the elements of the object with label(s) given by *index*, using the *labels* array for the object labels. If *index* is `None`, all elements with a non-zero label value are treated as a single object. If *label* is `None`, all elements of *input* are used in the calculation.
- The *maximum\_position* function calculates the position of the maximum of the elements of the object with label(s) given by *index*, using the *labels* array for the object labels. If *index* is `None`, all elements with a non-zero label value are treated as a single object. If *label* is `None`, all elements of *input* are used in the calculation.
- The *extrema* function calculates the minimum, the maximum, and their positions, of the elements of the object with label(s) given by *index*, using the *labels* array for the object labels. If *index* is `None`, all elements with a non-zero label value are treated as a single object. If *label* is `None`, all elements of *input* are used in the calculation. The result is a tuple giving the minimum, the maximum, the position of the minimum and the position of the maximum. The result is the same as a tuple formed by the results of the functions *minimum*, *maximum*, *minimum\_position*, and *maximum\_position* that are described above.
- The *center\_of\_mass* function calculates the center of mass of the of the object with label(s) given by *index*, using the *labels* array for the object labels. If *index* is `None`, all elements with a non-zero label value are treated as a single object. If *label* is `None`, all elements of *input* are used in the calculation.
- The *histogram* function calculates a histogram of the of the object with label(s) given by *index*, using the *labels* array for the object labels. If *index* is `None`, all elements with a non-zero label value are treated as a single object. If *label* is `None`, all elements of *input* are used in the calculation. Histograms are defined by their minimum (*min*), maximum (*max*) and the number of bins (*bins*). They are returned as one-dimensional arrays of type `Int32`.

## Extending `scipy.ndimage` in C

A few functions in `scipy.ndimage` take a callback argument. This can be either a python function or a `scipy.LowLevelCallable` containing a pointer to a C function. Using a C function will generally be more efficient since it avoids the overhead of calling a python function on many elements of an array. To use a C function you must write a C extension that contains the callback function and a Python function that returns a `scipy.LowLevelCallable` containing a pointer to the callback.

An example of a function that supports callbacks is *geometric\_transform*, which accepts a callback function that defines a mapping from all output coordinates to corresponding coordinates in the input array. Consider the following python example which uses *geometric\_transform* to implement a shift function.

```
from scipy import ndimage

def transform(output_coordinates, shift):
    input_coordinates = output_coordinates[0] - shift, output_coordinates[1] - shift
    return input_coordinates

im = np.arange(12).reshape(4, 3).astype(np.float64)
shift = 0.5
print(ndimage.geometric_transform(im, transform, extra_arguments=(shift,)))
```

We can also implement the callback function with the following C code.

```
/* example.c */

#include <Python.h>
#include <numpy/npymath.h>

static int
_transform(npyp_intp *output_coordinates, double *input_coordinates,
           int output_rank, int input_rank, void *user_data)
{
    npyp_intp i;
    double shift = *(double *)user_data;

    for (i = 0; i < input_rank; i++) {
        input_coordinates[i] = output_coordinates[i] - shift;
    }
    return 1;
}

static char *transform_signature = "int (npyp_intp *, double *, int, int, void *)";

static PyObject *
py_get_transform(PyObject *obj, PyObject *args)
{
    if (!PyArg_ParseTuple(args, "")) return NULL;
    return PyCapsule_New(_transform, transform_signature, NULL);
}

static PyMethodDef ExampleMethods[] = {
    {"get_transform", (PyCFunction)py_get_transform, METH_VARARGS, ""},
    {NULL, NULL, 0, NULL}
};

/* Initialize the module */
#if PY_VERSION_HEX >= 0x03000000
static struct PyModuleDef example = {
    PyModuleDef_HEAD_INIT,
    "example",
    NULL,
    -1,
    ExampleMethods,
    NULL,
    NULL,
    NULL,
};
#endif
```

```

    NULL,
    NULL
};

PyMODINIT_FUNC
PyInit_example(void)
{
    return PyModule_Create(&example);
}
#else
PyMODINIT_FUNC
inittestexample(void)
{
    Py_InitModule("example", ExampleMethods);
}
#endif

```

More information on writing Python extension modules can be found [here](#). If the C code is in the file `example.c`, then it can be compiled with the following `setup.py`,

```

from distutils.core import setup, Extension
import numpy

shift = Extension('example',
                  ['example.c'],
                  include_dirs=[numpy.get_include()])

setup(name='example',
      ext_modules=[shift])

```

and now running the script

```

import ctypes
import numpy as np
from scipy import ndimage, LowLevelCallable

from example import get_transform

shift = 0.5

user_data = ctypes.c_double(shift)
ptr = ctypes.cast(ctypes.pointer(user_data), ctypes.c_void_p)
callback = LowLevelCallable(transform(), ptr)
im = np.arange(12).reshape(4, 3).astype(np.float64)
print(ndimage.geometric_transform(im, callback))

```

produces the same result as the original python script.

In the C version `_transform` is the callback function and the parameters `output_coordinates` and `input_coordinates` play the same role as they do in the python version while `output_rank` and `input_rank` provide the equivalents of `len(output_coordinates)` and `len(input_coordinates)`. The variable `shift` is passed through `user_data` instead of `extra_arguments`. Finally, the C callback function returns an integer status which is one upon success and zero otherwise.

The function `py_transform` wraps the callback function in a `PyCapsule`. The main steps are:

- Initialize a `PyCapsule`. The first argument is a pointer to the callback function.

- The second argument is the function signature which must match exactly the one expected by `ndimage`.
- Above, we used `scipy.LowLevelCallable` to specify `user_data` that we generated with `ctypes`.

A different approach would be to supply the data in the capsule context, that can be set by `:cfunc:'PyCapsule_SetContext'` and omit specifying `user_data` in `scipy.LowLevelCallable`. However, in this approach we would need to deal with allocation/freeing of the data — freeing the data after the capsule is destroyed can be done by specifying a non-NULL callback function in the third argument of `:cfunc:'PyCapsule_New'`.

C callback functions for `ndimage` all follow this scheme. The next section lists the `ndimage` functions that accept a C callback function and gives the prototype of the function.

#### See also:

The functions that support low-level callback arguments are:

`generic_filter`, `generic_filter1d`, `geometric_transform`

Below, we show alternative ways to write the code, using `Cython`, `ctypes`, or `ctffi` instead of writing wrapper code in C.

#### Numba

Numba provides a way to write low-level functions easily in Python. We can write the above using Numba as:

```
# example.py
import numpy as np
import ctypes
from scipy import ndimage, LowLevelCallable
from numba import cfunc, types, carray

@cfunc(types.intc(types.CPointer(types.intp),
                    types.CPointer(types.double)),
        types.intc,
        types.intc,
        types.voidptr)
def transform(output_coordinates_ptr, input_coordinates_ptr,
              output_rank, input_rank, user_data):
    input_coordinates = carray(input_coordinates_ptr, (input_rank,))
    output_coordinates = carray(output_coordinates_ptr, (output_rank,))
    shift = carray(user_data, (1,), types.double)[0]

    for i in range(input_rank):
        input_coordinates[i] = output_coordinates[i] - shift

    return 1

shift = 0.5

# Then call the function
user_data = ctypes.c_double(shift)
ptr = ctypes.cast(ctypes.pointer(user_data), ctypes.c_void_p)
callback = LowLevelCallable(transform.ctypes, ptr)

im = np.arange(12).reshape(4, 3).astype(np.float64)
print(ndimage.geometric_transform(im, callback))
```

#### Cython

Functionally the same code as above can be written in `Cython` with somewhat less boilerplate as follows.

```
# example.pyx

from numpy cimport npy_intp as intp

cdef api int transform(intp *output_coordinates, double *input_coordinates,
                      int output_rank, int input_rank, void *user_data):
    cdef intp i
    cdef double shift = (<double *>user_data)[0]

    for i in range(input_rank):
        input_coordinates[i] = output_coordinates[i] - shift
    return 1
```

```
# script.py

import ctypes
import numpy as np
from scipy import ndimage, LowLevelCallable

import example

shift = 0.5

user_data = ctypes.c_double(shift)
ptr = ctypes.cast(ctypes.pointer(user_data), ctypes.c_void_p)
callback = LowLevelCallable.from_cython(example, "transform", ptr)
im = np.arange(12).reshape(4, 3).astype(np.float64)
print(ndimage.geometric_transform(im, callback))
```

### *ffi*

With *ffi*, you can interface with a C function residing in a shared library (DLL). First, we need to write the shared library, which we do in C — this example is for Linux/OSX:

```
/*
  example.c
  Needs to be compiled with "gcc -std=c99 -shared -fPIC -o example.so example.c"
  or similar
*/

#include <stdint.h>

int
_transform(intptr_t *output_coordinates, double *input_coordinates,
           int output_rank, int input_rank, void *user_data)
{
    int i;
    double shift = *(double *)user_data;

    for (i = 0; i < input_rank; i++) {
        input_coordinates[i] = output_coordinates[i] - shift;
    }
    return 1;
}
```

The Python code calling the library is:

```

import os
import numpy as np
from scipy import ndimage, LowLevelCallable
import cffi

# Construct the FFI object, and copypaste the function declaration
ffi = cffi.FFI()
ffi.cdef("""
int _transform(intptr_t *output_coordinates, double *input_coordinates,
              int output_rank, int input_rank, void *user_data);
""")

# Open library
lib = ffi.dlopen(os.path.abspath("example.so"))

# Do the function call
user_data = ffi.new('double *', 0.5)
callback = LowLevelCallable(lib._transform, user_data)
im = np.arange(12).reshape(4, 3).astype(np.float64)
print(ndimage.geometric_transform(im, callback))

```

You can find more information in the [cffi](#) documentation.

### *ctypes*

With *ctypes*, the C code and the compilation of the so/DLL is as for *cffi* above. The Python code is different:

```

# script.py

import os
import ctypes
import numpy as np
from scipy import ndimage, LowLevelCallable

lib = ctypes.CDLL(os.path.abspath('example.so'))

shift = 0.5

user_data = ctypes.c_double(shift)
ptr = ctypes.cast(ctypes.pointer(user_data), ctypes.c_void_p)

# Ctypes has no built-in intptr type, so override the signature
# instead of trying to get it via ctypes
callback = LowLevelCallable(lib._transform, ptr,
                             "int _transform(intptr_t *, double *, int, int, void *)")

# Perform the call
im = np.arange(12).reshape(4, 3).astype(np.float64)
print(ndimage.geometric_transform(im, callback))

```

You can find more information in the [ctypes](#) documentation.

## References

### 3.1.15 File IO ([scipy.io](#))

See also:

numpy-reference.routines.io (in numpy)

### MATLAB files

<code>loadmat(file_name[, mdict, appendmat])</code>	Load MATLAB file.
<code>savemat(file_name, mdict[, appendmat, ...])</code>	Save a dictionary of names and arrays into a MATLAB-style .mat file.
<code>whosmat(file_name[, appendmat])</code>	List variables inside a MATLAB file.

### The basic functions

We'll start by importing `scipy.io` and calling it `sio` for convenience:

```
>>> import scipy.io as sio
```

If you are using IPython, try tab completing on `sio`. Among the many options, you will find:

```
sio.loadmat
sio.savemat
sio.whosmat
```

These are the high-level functions you will most likely use when working with MATLAB files. You'll also find:

```
sio.matlab
```

This is the package from which `loadmat`, `savemat` and `whosmat` are imported. Within `sio.matlab`, you will find the `mio` module. This module contains the machinery that `loadmat` and `savemat` use. From time to time you may find yourself re-using this machinery.

### How do I start?

You may have a .mat file that you want to read into Scipy. Or, you want to pass some variables from Scipy / Numpy into MATLAB.

To save us using a MATLAB license, let's start in [Octave](#). Octave has MATLAB-compatible save and load functions. Start Octave (`octave` at the command line for me):

```
octave:1> a = 1:12
a =
    1    2    3    4    5    6    7    8    9   10   11   12

octave:2> a = reshape(a, [1 3 4])
a =

ans(:,:,1) =
    1    2    3

ans(:,:,2) =
    4    5    6

ans(:,:,3) =
    7    8    9
```

```
ans(:, :, 4) =

    10    11    12

octave:3> save -6 octave_a.mat a % MATLAB 6 compatible
octave:4> ls octave_a.mat
octave_a.mat
```

Now, to Python:

```
>>> mat_contents = sio.loadmat('octave_a.mat')
>>> mat_contents
{'a': array([[ 1.,  4.,  7., 10.],
            [ 2.,  5.,  8., 11.],
            [ 3.,  6.,  9., 12.]])},
 '__version__': '1.0',
 '__header__': 'MATLAB 5.0 MAT-file, written by
Octave 3.6.3, 2013-02-17 21:02:11 UTC',
 '__globals__': []}
>>> oct_a = mat_contents['a']
>>> oct_a
array([[ 1.,  4.,  7., 10.],
       [ 2.,  5.,  8., 11.],
       [ 3.,  6.,  9., 12.]])
>>> oct_a.shape
(1, 3, 4)
```

Now let's try the other way round:

```
>>> import numpy as np
>>> vect = np.arange(10)
>>> vect.shape
(10,)
>>> sio.savemat('np_vector.mat', {'vect':vect})
```

Then back to Octave:

```
octave:8> load np_vector.mat
octave:9> vect
vect =

    0    1    2    3    4    5    6    7    8    9

octave:10> size(vect)
ans =

    1   10
```

If you want to inspect the contents of a MATLAB file without reading the data into memory, use the `whosmat` command:

```
>>> sio.whosmat('octave_a.mat')
[('a', (1, 3, 4), 'double')]
```

`whosmat` returns a list of tuples, one for each array (or other object) in the file. Each tuple contains the name, shape and data type of the array.

### *MATLAB structs*

MATLAB structs are a little bit like Python dicts, except the field names must be strings. Any MATLAB object can be a value of a field. As for all objects in MATLAB, structs are in fact arrays of structs, where a single struct is an array of shape (1, 1).

```
octave:11> my_struct = struct('field1', 1, 'field2', 2)
my_struct =
{
  field1 = 1
  field2 = 2
}

octave:12> save -6 octave_struct.mat my_struct
```

We can load this in Python:

```
>>> mat_contents = sio.loadmat('octave_struct.mat')
>>> mat_contents
{'my_struct': array([[[[1.0]], [[2.0]]]]),
  dtype=[('field1', 'O'), ('field2', 'O')], '__version__': '1.0', '__header__':
↳ 'MATLAB 5.0 MAT-file, written by Octave 3.6.3, 2013-02-17 21:23:14 UTC', '__globals_
↳ _': []}
>>> oct_struct = mat_contents['my_struct']
>>> oct_struct.shape
(1, 1)
>>> val = oct_struct[0,0]
>>> val
([[1.0]], [[2.0]])
>>> val['field1']
array([[ 1.]])
>>> val['field2']
array([[ 2.]])
>>> val.dtype
dtype([('field1', 'O'), ('field2', 'O')])
```

In versions of Scipy from 0.12.0, MATLAB structs come back as numpy structured arrays, with fields named for the struct fields. You can see the field names in the dtype output above. Note also:

```
>>> val = oct_struct[0,0]
```

and:

```
octave:13> size(my_struct)
ans =

  1  1
```

So, in MATLAB, the struct array must be at least 2D, and we replicate that when we read into Scipy. If you want all length 1 dimensions squeezed out, try this:

```
>>> mat_contents = sio.loadmat('octave_struct.mat', squeeze_me=True)
>>> oct_struct = mat_contents['my_struct']
>>> oct_struct.shape
()
```

Sometimes, it's more convenient to load the MATLAB structs as python objects rather than numpy structured arrays - it can make the access syntax in python a bit more similar to that in MATLAB. In order to do this, use the `struct_as_record=False` parameter setting to `loadmat`.

```
>>> mat_contents = sio.loadmat('octave_struct.mat', struct_as_record=False)
>>> oct_struct = mat_contents['my_struct']
>>> oct_struct[0,0].field1
array([[ 1.]])
```

struct\_as\_record=False works nicely with squeeze\_me:

```
>>> mat_contents = sio.loadmat('octave_struct.mat', struct_as_record=False, squeeze_
↳me=True)
>>> oct_struct = mat_contents['my_struct']
>>> oct_struct.shape # but no - it's a scalar
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
AttributeError: 'mat_struct' object has no attribute 'shape'
>>> type(oct_struct)
<class 'scipy.io.matlab.mio5_params.mat_struct'>
>>> oct_struct.field1
1.0
```

Saving struct arrays can be done in various ways. One simple method is to use dicts:

```
>>> a_dict = {'field1': 0.5, 'field2': 'a string'}
>>> sio.savemat('saved_struct.mat', {'a_dict': a_dict})
```

loaded as:

```
octave:21> load saved_struct
octave:22> a_dict
a_dict =

  scalar structure containing the fields:

   field2 = a string
   field1 = 0.50000
```

You can also save structs back again to MATLAB (or Octave in our case) like this:

```
>>> dt = [('f1', 'f8'), ('f2', 'S10')]
>>> arr = np.zeros((2,), dtype=dt)
>>> arr
array([(0.0, ''), (0.0, '')],
      dtype=[('f1', '<f8'), ('f2', 'S10')])
>>> arr[0]['f1'] = 0.5
>>> arr[0]['f2'] = 'python'
>>> arr[1]['f1'] = 99
>>> arr[1]['f2'] = 'not perl'
>>> sio.savemat('np_struct_arr.mat', {'arr': arr})
```

### **MATLAB cell arrays**

Cell arrays in MATLAB are rather like python lists, in the sense that the elements in the arrays can contain any type of MATLAB object. In fact they are most similar to numpy object arrays, and that is how we load them into numpy.

```
octave:14> my_cells = {1, [2, 3]}
my_cells =
{
  [1,1] = 1
  [1,2] =
```

```

    2  3
}
octave:15> save -6 octave_cells.mat my_cells

```

Back to Python:

```

>>> mat_contents = sio.loadmat('octave_cells.mat')
>>> oct_cells = mat_contents['my_cells']
>>> print(oct_cells.dtype)
object
>>> val = oct_cells[0,0]
>>> val
array([[ 1.]])
>>> print(val.dtype)
float64

```

Saving to a MATLAB cell array just involves making a numpy object array:

```

>>> obj_arr = np.zeros((2,), dtype=np.object)
>>> obj_arr[0] = 1
>>> obj_arr[1] = 'a string'
>>> obj_arr
array([1, 'a string'], dtype=object)
>>> sio.savemat('np_cells.mat', {'obj_arr':obj_arr})

```

```

octave:16> load np_cells.mat
octave:17> obj_arr
obj_arr =
{
  [1,1] = 1
  [2,1] = a string
}

```

## IDL files

<code>readsav(file_name[, idict, python_dict, ...])</code>	Read an IDL .sav file.
--	------------------------

---

## Matrix Market files

<code>mminfo(source)</code>	Return size and storage parameters from Matrix Market file-like 'source'.
<code>mmread(source)</code>	Reads the contents of a Matrix Market file-like 'source' into a matrix.
<code>mmwrite(target, a[, comment, field, ...])</code>	Writes the sparse or dense array <i>a</i> to Matrix Market file-like <i>target</i> .

---

## Wav sound files (`scipy.io.wavfile`)

---

<code>read(filename[, mmap])</code>	Open a WAV file
<code>write(filename, rate, data)</code>	Write a numpy array as a WAV file.

---

### Arff files (`scipy.io.arff`)

Module to read ARFF files, which are the standard data format for WEKA.

ARFF is a text file format which support numerical, string and data values. The format can also represent missing data and sparse data.

#### Notes

The ARFF support in `scipy.io` provides file reading functionality only. For more extensive ARFF functionality, see [liac-arff](#).

See the [WEKA website](#) for more details about the ARFF format and available datasets.

---

<code>loadarff(f)</code>	Read an arff file.
--------------------------	--------------------

---

### Netcdf (`scipy.io.netcdf`)

---

<code>netcdf_file(filename[, mode, mmap, version, ...])</code>	A file object for NetCDF data.
--	--------------------------------

---

Allows reading of NetCDF files (version of [pupynere](#) package)



## DEVELOPER'S GUIDE

Explanations of how to start contributing to SciPy, and descriptions of maintenance activities and policies.

### 4.1 SciPy Code of Conduct

#### 4.1.1 Introduction

This code of conduct applies to all spaces managed by the SciPy project, including all public and private mailing lists, issue trackers, wikis, blogs, Twitter, and any other communication channel used by our community. The SciPy project does not organise in-person events, however events related to our community should have a code of conduct similar in spirit to this one.

This code of conduct should be honored by everyone who participates in the SciPy community formally or informally, or claims any affiliation with the project, in any project-related activities and especially when representing the project, in any role.

This code is not exhaustive or complete. It serves to distill our common understanding of a collaborative, shared environment and goals. Please try to follow this code in spirit as much as in letter, to create a friendly and productive environment that enriches the surrounding community.

#### 4.1.2 Specific Guidelines

We strive to:

1. Be open. We invite anyone to participate in our community. We prefer to use public methods of communication for project-related messages, unless discussing something sensitive. This applies to messages for help or project-related support, too; not only is a public support request much more likely to result in an answer to a question, it also ensures that any inadvertent mistakes in answering are more easily detected and corrected.
2. Be empathetic, welcoming, friendly, and patient. We work together to resolve conflict, and assume good intentions. We may all experience some frustration from time to time, but we do not allow frustration to turn into a personal attack. A community where people feel uncomfortable or threatened is not a productive one.
3. Be collaborative. Our work will be used by other people, and in turn we will depend on the work of others. When we make something for the benefit of the project, we are willing to explain to others how it works, so that they can build on the work to make it even better. Any decision we make will affect users and colleagues, and we take those consequences seriously when making decisions.
4. Be inquisitive. Nobody knows everything! Asking questions early avoids many problems later, so we encourage questions, although we may direct them to the appropriate forum. We will try hard to be responsive and helpful.

5. Be careful in the words that we choose. We are careful and respectful in our communication and we take responsibility for our own speech. Be kind to others. Do not insult or put down other participants. We will not accept harassment or other exclusionary behaviour, such as:
  - Violent threats or language directed against another person.
  - Sexist, racist, or otherwise discriminatory jokes and language.
  - Posting sexually explicit or violent material.
  - Posting (or threatening to post) other people's personally identifying information ("doxing").
  - Sharing private content, such as emails sent privately or non-publicly, or unlogged forums such as IRC channel history, without the sender's consent.
  - Personal insults, especially those using racist or sexist terms.
  - Unwelcome sexual attention.
  - Excessive profanity. Please avoid swearwords; people differ greatly in their sensitivity to swearing.
  - Repeated harassment of others. In general, if someone asks you to stop, then stop.
  - Advocating for, or encouraging, any of the above behaviour.

### 4.1.3 Diversity Statement

The SciPy project welcomes and encourages participation by everyone. We are committed to being a community that everyone enjoys being part of. Although we may not always be able to accommodate each individual's preferences, we try our best to treat everyone kindly.

No matter how you identify yourself or how others perceive you: we welcome you. Though no list can hope to be comprehensive, we explicitly honour diversity in: age, culture, ethnicity, genotype, gender identity or expression, language, national origin, neurotype, phenotype, political beliefs, profession, race, religion, sexual orientation, socioeconomic status, subculture and technical ability.

Though we welcome people fluent in all languages, SciPy development is conducted in English.

Standards for behaviour in the SciPy community are detailed in the Code of Conduct above. Participants in our community should uphold these standards in all their interactions and help others to do so as well (see next section).

### 4.1.4 Reporting Guidelines

We know that it is painfully common for internet communication to start at or devolve into obvious and flagrant abuse. We also recognize that sometimes people may have a bad day, or be unaware of some of the guidelines in this Code of Conduct. Please keep this in mind when deciding on how to respond to a breach of this Code.

For clearly intentional breaches, report those to the Code of Conduct committee (see below). For possibly unintentional breaches, you may reply to the person and point out this code of conduct (either in public or in private, whatever is most appropriate). If you would prefer not to do that, please feel free to report to the Code of Conduct Committee directly, or ask the Committee for advice, in confidence.

You can report issues to the SciPy Code of Conduct committee, at [scipy-conduct@googlegroups.com](mailto:scipy-conduct@googlegroups.com). Currently, the committee consists of:

- Stefan van der Walt
- Nathaniel J. Smith
- Ralf Gommers

If your report involves any members of the committee, or if they feel they have a conflict of interest in handling it, then they will recuse themselves from considering your report. Alternatively, if for any reason you feel uncomfortable making a report to the committee, then you can also contact:

- Chair of the SciPy Steering Committee: Ralf Gommers, or
- Executive Director of NumFOCUS: Leah Silen

### 4.1.5 Incident reporting resolution & Code of Conduct enforcement

*This section summarizes the most important points, more details can be found in `CoC_reporting_manual`.*

We will investigate and respond to all complaints. The SciPy Code of Conduct Committee and the SciPy Steering Committee (if involved) will protect the identity of the reporter, and treat the content of complaints as confidential (unless the reporter agrees otherwise).

In case of severe and obvious breaches, e.g. personal threat or violent, sexist or racist language, we will immediately disconnect the originator from SciPy communication channels; please see the manual for details.

In cases not involving clear severe and obvious breaches of this code of conduct, the process for acting on any received code of conduct violation report will be:

1. acknowledge report is received
2. reasonable discussion/feedback
3. mediation (if feedback didn't help, and only if both reporter and reportee agree to this)
4. enforcement via transparent decision (see `CoC_resolutions`) by the Code of Conduct Committee

The committee will respond to any report as soon as possible, and at most within 72 hours.

### 4.1.6 Endnotes

We are thankful to the groups behind the following documents, from which we drew content and inspiration:

- [The Apache Foundation Code of Conduct](#)
- [The Contributor Covenant](#)
- [Jupyter Code of Conduct](#)
- [Open Source Guides - Code of Conduct](#)

## 4.2 Contributing to SciPy

This document aims to give an overview of how to contribute to SciPy. It tries to answer commonly asked questions, and provide some insight into how the community process works in practice. Readers who are familiar with the SciPy community and are experienced Python coders may want to jump straight to the [git workflow](#) documentation.

There are a lot of ways you can contribute:

- Contributing new code
- Fixing bugs and other maintenance work
- Improving the documentation
- Reviewing open pull requests
- Triaging issues

- Working on the [scipy.org](http://scipy.org) website
- Answering questions and participating on the [scipy-dev](#) and [scipy-user mailing lists](#).

### 4.2.1 Contributing new code

If you have been working with the scientific Python toolstack for a while, you probably have some code lying around of which you think “this could be useful for others too”. Perhaps it’s a good idea then to contribute it to SciPy or another open source project. The first question to ask is then, where does this code belong? That question is hard to answer here, so we start with a more specific one: *what code is suitable for putting into SciPy?* Almost all of the new code added to `scipy` has in common that it’s potentially useful in multiple scientific domains and it fits in the scope of existing `scipy` submodules. In principle new submodules can be added too, but this is far less common. For code that is specific to a single application, there may be an existing project that can use the code. Some `scikits` ([scikit-learn](#), [scikit-image](#), [statsmodels](#), etc.) are good examples here; they have a narrower focus and because of that more domain-specific code than SciPy.

Now if you have code that you would like to see included in SciPy, how do you go about it? After checking that your code can be distributed in SciPy under a compatible license (see FAQ for details), the first step is to discuss on the `scipy-dev` mailing list. All new features, as well as changes to existing code, are discussed and decided on there. You can, and probably should, already start this discussion before your code is finished.

Assuming the outcome of the discussion on the mailing list is positive and you have a function or piece of code that does what you need it to do, what next? Before code is added to SciPy, it at least has to have good documentation, unit tests and correct code style.

1. **Unit tests** In principle you should aim to create unit tests that exercise all the code that you are adding. This gives some degree of confidence that your code runs correctly, also on Python versions and hardware or OSes that you don’t have available yourself. An extensive description of how to write unit tests is given in the NumPy [testing guidelines](#).
2. **Documentation** Clear and complete documentation is essential in order for users to be able to find and understand the code. Documentation for individual functions and classes – which includes at least a basic description, type and meaning of all parameters and returns values, and usage examples in `doctest` format – is put in docstrings. Those docstrings can be read within the interpreter, and are compiled into a reference guide in html and pdf format. Higher-level documentation for key (areas of) functionality is provided in tutorial format and/or in module docstrings. A guide on how to write documentation is given in [how to document](#).
3. **Code style** Uniformity of style in which code is written is important to others trying to understand the code. SciPy follows the standard Python guidelines for code style, [PEP8](#). In order to check that your code conforms to PEP8, you can use the [pep8 package](#) style checker. Most IDEs and text editors have settings that can help you follow PEP8, for example by translating tabs by four spaces. Using [pyflakes](#) to check your code is also a good idea.

At the end of this document a checklist is given that may help to check if your code fulfills all requirements for inclusion in SciPy.

Another question you may have is: *where exactly do I put my code?* To answer this, it is useful to understand how the SciPy public API (application programming interface) is defined. For most modules the API is two levels deep, which means your new function should appear as `scipy.submodule.my_new_func`. `my_new_func` can be put in an existing or new file under `/scipy/<submodule>/`, its name is added to the `__all__` list in that file (which lists all public functions in the file), and those public functions are then imported in `/scipy/<submodule>/__init__.py`. Any private functions/classes should have a leading underscore (`_`) in their name. A more detailed description of what the public API of SciPy is, is given in [SciPy API](#).

Once you think your code is ready for inclusion in SciPy, you can send a pull request (PR) on Github. We won’t go into the details of how to work with git here, this is described well in the [git workflow](#) section of the NumPy

documentation and on the [Github help pages](#). When you send the PR for a new feature, be sure to also mention this on the `scipy-dev` mailing list. This can prompt interested people to help review your PR. Assuming that you already got positive feedback before on the general idea of your code/feature, the purpose of the code review is to ensure that the code is correct, efficient and meets the requirements outlined above. In many cases the code review happens relatively quickly, but it's possible that it stalls. If you have addressed all feedback already given, it's perfectly fine to ask on the mailing list again for review (after a reasonable amount of time, say a couple of weeks, has passed). Once the review is completed, the PR is merged into the “master” branch of SciPy.

The above describes the requirements and process for adding code to SciPy. It doesn't yet answer the question though how decisions are made exactly. The basic answer is: decisions are made by consensus, by everyone who chooses to participate in the discussion on the mailing list. This includes developers, other users and yourself. Aiming for consensus in the discussion is important – SciPy is a project by and for the scientific Python community. In those rare cases that agreement cannot be reached, the maintainers of the module in question can decide the issue.

## 4.2.2 Contributing by helping maintain existing code

The previous section talked specifically about adding new functionality to SciPy. A large part of that discussion also applies to maintenance of existing code. Maintenance means fixing bugs, improving code quality or style, documenting existing functionality better, adding missing unit tests, keeping build scripts up-to-date, etc. The [SciPy issue list](#) contains all reported bugs, build/documentation issues, etc. Fixing issues helps improve the overall quality of SciPy, and is also a good way of getting familiar with the project. You may also want to fix a bug because you ran into it and need the function in question to work correctly.

The discussion on code style and unit testing above applies equally to bug fixes. It is usually best to start by writing a unit test that shows the problem, i.e. it should pass but doesn't. Once you have that, you can fix the code so that the test does pass. That should be enough to send a PR for this issue. Unlike when adding new code, discussing this on the mailing list may not be necessary - if the old behavior of the code is clearly incorrect, no one will object to having it fixed. It may be necessary to add some warning or deprecation message for the changed behavior. This should be part of the review process.

## 4.2.3 Reviewing pull requests

Reviewing open pull requests (PRs) is very welcome, and a valuable way to help increase the speed at which the project moves forward. If you have specific knowledge/experience in a particular area (say “optimization algorithms” or “special functions”) then reviewing PRs in that area is especially valuable - sometimes PRs with technical code have to wait for a long time to get merged due to a shortage of appropriate reviewers.

We encourage everyone to get involved in the review process; it's also a great way to get familiar with the code base. Reviewers should ask themselves some or all of the following questions:

- Was this change adequately discussed (relevant for new features and changes in existing behavior)?
- Is the feature scientifically sound? Algorithms may be known to work based on literature; otherwise, closer look at correctness is valuable.
- Is the intended behavior clear under all conditions (e.g. unexpected inputs like empty arrays or nan/inf values)?
- Does the code meet the quality, test and documentation expectation outline under *Contributing new code*?

If we do not know you yet, consider introducing yourself.

## 4.2.4 Other ways to contribute

There are many ways to contribute other than contributing code.

Triaging issues (investigating bug reports for validity and possible actions to take) is also a useful activity. SciPy has many hundreds of open issues; closing invalid ones and correctly labeling valid ones (ideally with some first thoughts in a comment) allows prioritizing maintenance work and finding related issues easily when working on an existing function or submodule.

Participating in discussions on the `scipy-user` and `scipy-dev` [mailing lists](#) is a contribution in itself. Everyone who writes to those lists with a problem or an idea would like to get responses, and writing such responses makes the project and community function better and appear more welcoming.

The [scipy.org](#) website contains a lot of information on both SciPy the project and SciPy the community, and it can always use a new pair of hands. The sources for the website live in their own separate repo: <https://github.com/scipy/scipy.org>

### 4.2.5 Recommended development setup

Since Scipy contains parts written in C, C++, and Fortran that need to be compiled before use, make sure you have the necessary compilers and Python development headers installed. Having compiled code also means that importing Scipy from the development sources needs some additional steps, which are explained below.

First fork a copy of the main Scipy repository in Github onto your own account and then create your local repository via:

```
$ git clone git@github.com:YOURUSERNAME/scipy.git scipy
$ cd scipy
$ git remote add upstream git://github.com/scipy/scipy.git
```

To build the development version of Scipy and run tests, spawn interactive shells with the Python import paths properly set up etc., do one of:

```
$ python runtests.py -v
$ python runtests.py -v -s optimize
$ python runtests.py -v -t scipy.special.tests.test_basic::test_xlogy
$ python runtests.py --ipython
$ python runtests.py --python somescript.py
$ python runtests.py --bench
```

This builds Scipy first, so the first time it may take some time. If you specify `-n`, the tests are run against the version of Scipy (if any) found on current `PYTHONPATH`. *Note: if you run into a build issue, more detailed build documentation can be found at <http://scipy.org/scipylib/building/index.html>.*

Using `runtests.py` is the recommended approach to running tests. There are also a number of alternatives to it, for example in-place build or installing to a virtualenv. See the FAQ below for details.

Some of the tests in Scipy are very slow and need to be separately enabled. See the FAQ below for details.

### 4.2.6 SciPy structure

All SciPy modules should follow the following conventions. In the following, a *SciPy module* is defined as a Python package, say `yyy`, that is located in the `scipy/` directory.

- Ideally, each SciPy module should be as self-contained as possible. That is, it should have minimal dependencies on other packages or modules. Even dependencies on other SciPy modules should be kept to a minimum. A dependency on NumPy is of course assumed.
- Directory `yyy/` contains:

- A file `setup.py` that defines configuration (`parent_package='', top_path=None`) function for `numpy.distutils`.
- A directory `tests/` that contains files `test_<name>.py` corresponding to modules `yyy/<name>{.py, .so, /}`.
- Private modules should be prefixed with an underscore `_`, for instance `yyy/_somemodule.py`.
- User-visible functions should have good documentation following the Numpy documentation style, see [how to document](#)
- The `__init__.py` of the module should contain the main reference documentation in its docstring. This is connected to the Sphinx documentation under `doc/` via Sphinx's automodule directive.

The reference documentation should first give a categorized list of the contents of the module using `autosummary::` directives, and after that explain points essential for understanding the use of the module.

Tutorial-style documentation with extensive examples should be separate, and put under `doc/source/tutorial/`

See the existing Scipy submodules for guidance.

For further details on Numpy distutils, see:

<https://github.com/numpy/numpy/blob/master/doc/DISTUTILS.rst.txt>

## 4.2.7 Useful links, FAQ, checklist

### Checklist before submitting a PR

- Are there unit tests with good code coverage?
- Do all public function have docstrings including examples?
- Is the code style correct (PEP8, pyflakes)
- Is the commit message [formatted correctly](#)?
- Is the new functionality tagged with `.. versionadded:: X.Y.Z` (with X.Y.Z the version number of the next release - can be found in `setup.py`)?
- Is the new functionality mentioned in the release notes of the next release?
- Is the new functionality added to the reference guide?
- In case of larger additions, is there a tutorial or more extensive module-level description?
- In case compiled code is added, is it integrated correctly via `setup.py` (and preferably also Bento configuration files - `bento.info` and `bscript`)?
- If you are a first-time contributor, did you add yourself to `THANKS.txt`? Please note that this is perfectly normal and desirable - the aim is to give every single contributor credit, and if you don't add yourself it's simply extra work for the reviewer (or worse, the reviewer may forget).
- Did you check that the code can be distributed under a BSD license?

### Useful SciPy documents

- The [how to document guidelines](#)
- NumPy/SciPy [testing guidelines](#)
- [SciPy API](#)

- [The SciPy Roadmap](#)
- [NumPy/SciPy git workflow](#)
- [How to submit a good bug report](#)

### FAQ

*I based my code on existing Matlab/R/... code I found online, is this OK?*

It depends. SciPy is distributed under a BSD license, so if the code that you based your code on is also BSD licensed or has a BSD-compatible license (MIT, Apache, ...) then it's OK. Code which is GPL-licensed, has no clear license, requires citation or is free for academic use only can't be included in SciPy. Therefore if you copied existing code with such a license or made a direct translation to Python of it, your code can't be included. See also [license compatibility](#).

*Why is SciPy under the BSD license and not, say, the GPL?*

Like Python, SciPy uses a “permissive” open source license, which allows proprietary re-use. While this allows companies to use and modify the software without giving anything back, it is felt that the larger user base results in more contributions overall, and companies often publish their modifications anyway, without being required to. See John Hunter's [BSD pitch](#).

*How do I set up a development version of SciPy in parallel to a released version that I use to do my job/research?*

One simple way to achieve this is to install the released version in site-packages, by using a binary installer or pip for example, and set up the development version in a virtualenv. First install [virtualenv](#) (optionally use [virtualenvwrapper](#)), then create your virtualenv (named `scipy-dev` here) with:

```
$ virtualenv scipy-dev
```

Now, whenever you want to switch to the virtual environment, you can use the command `source scipy-dev/bin/activate`, and `deactivate` to exit from the virtual environment and back to your previous shell. With `scipy-dev` activated, install first SciPy's dependencies:

```
$ pip install Numpy pytest Cython
```

After that, you can install a development version of SciPy, for example via:

```
$ python setup.py install
```

The installation goes to the virtual environment.

*How do I set up an in-place build for development*

For development, you can set up an in-place build so that changes made to `.py` files have effect without rebuild. First, run:

```
$ python setup.py build_ext -i
```

Then you need to point your `PYTHONPATH` environment variable to this directory. Some IDEs (Spyder for example) have utilities to manage `PYTHONPATH`. On Linux and OSX, you can run the command:

```
$ export PYTHONPATH=$PWD
```

and on Windows

```
$ set PYTHONPATH=/path/to/scipy
```

Now editing a Python source file in SciPy allows you to immediately test and use your changes (in `.py` files), by simply restarting the interpreter.

*Can I use a programming language other than Python to speed up my code?*

Yes. The languages used in SciPy are Python, Cython, C, C++ and Fortran. All of these have their pros and cons. If Python really doesn't offer enough performance, one of those languages can be used. Important concerns when using compiled languages are maintainability and portability. For maintainability, Cython is clearly preferred over C/C++/Fortran. Cython and C are more portable than C++/Fortran. A lot of the existing C and Fortran code in SciPy is older, battle-tested code that was only wrapped in (but not specifically written for) Python/SciPy. Therefore the basic advice is: use Cython. If there's specific reasons why C/C++/Fortran should be preferred, please discuss those reasons first.

*How do I debug code written in C/C++/Fortran inside Scipy?*

The easiest way to do this is to first write a Python script that invokes the C code whose execution you want to debug. For instance `mytest.py`:

```
from scipy.special import hyp2f1
print(hyp2f1(5.0, 1.0, -1.8, 0.95))
```

Now, you can run:

```
gdb --args python runtests.py -g --python mytest.py
```

If you didn't compile with debug symbols enabled before, remove the `build` directory first. While in the debugger:

```
(gdb) break cephes_hyp2f1
(gdb) run
```

The execution will now stop at the corresponding C function and you can step through it as usual. Instead of plain `gdb` you can of course use your favourite alternative debugger; run it on the `python` binary with arguments `runtests.py -g --python mytest.py`.

*How do I enable additional tests in Scipy?*

Some of the tests in SciPy's test suite are very slow and not enabled by default. You can run the full suite via:

```
$ python runtests.py -g -m full
```

This invokes the test suite `import scipy; scipy.test("full")`, enabling also slow tests.

There is an additional level of very slow tests (several minutes), which are disabled also in this case. They can be enabled by setting the environment variable `SCIPY_XSLOW=1` before running the test suite.

## 4.3 SciPy Developer Guide

### 4.3.1 Decision making process

SciPy has a formal governance model, documented in *SciPy project governance*. The section below documents in an informal way what happens in practice for decision making about code and commit rights. The formal governance model is leading, the below is only provided for context.

### Code

Any significant decisions on adding (or not adding) new features, breaking backwards compatibility or making other significant changes to the codebase should be made on the `scipy-dev` mailing list after a discussion (preferably with full consensus).

Any non-trivial change (where trivial means a typo, or a one-liner maintenance commit) has to go in through a pull request (PR). It has to be reviewed by another developer. In case review doesn't happen quickly enough and it is important that the PR is merged quickly, the submitter of the PR should send a message to mailing list saying he/she intends to merge that PR without review at time X for reason Y unless someone reviews it before then.

Changes and new additions should be tested. Untested code is broken code.

### Commit rights

Who gets commit rights is decided by the SciPy Steering Council; changes in commit rights will then be announced on the `scipy-dev` mailing list.

## 4.3.2 Deciding on new features

The general decision rule to accept a proposed new feature has so far been conditional on:

1. The method is applicable in many fields and “generally agreed” to be useful,
2. Fits the topic of the submodule, and does not require extensive support frameworks to operate,
3. The implementation looks sound and unlikely to need much tweaking in the future (e.g., limited expected maintenance burden), and
4. Someone wants to do it.

Although it's difficult to give hard rules on what “generally useful and generally agreed to work” means, it may help to weigh the following against each other:

- Is the method used/useful in different domains in practice? How much domain-specific background knowledge is needed to use it properly?
- Consider the code already in the module. Is what you are adding an omission? Does it solve a problem that you'd expect the module be able to solve? Does it supplement an existing feature in a significant way?
- Consider the equivalence class of similar methods / features usually expected. Among them, what would in principle be the minimal set so that there's not a glaring omission in the offered features remaining? How much stuff would that be? Does including a representative one of them cover most use cases? Would it in principle sound reasonable to include everything from the minimal set in the module?
- Is what you are adding something that is well understood in the literature? If not, how sure are you that it will turn out well? Does the method perform well compared to other similar ones?
- Note that the twice-a-year release cycle and backward-compatibility policy makes correcting things later on more difficult.

The scopes of the submodules also vary, so it's probably best to consider each as if it's a separate project - “numerical evaluation of special functions” is relatively well-defined, but “commonly needed optimization algorithms” less so.

## 4.3.3 Development on GitHub

SciPy development largely takes place on GitHub; this section describes the expected way of working for issues, pull requests and managing the main `scipy` repository.

## Labels and Milestones

Each issue and pull request normally gets at least two labels: one for the topic or component (`scipy.stats`, `Documentation`, etc.), and one for the nature of the issue or pull request (`enhancement`, `maintenance`, `defect`, etc.). Other labels that may be added depending on the situation:

- `easy-fix`: for issues suitable to be tackled by new contributors.
- `needs-work`: for pull requests that have review comments that haven't been addressed for a while.
- `needs-decision`: for issues or pull requests that need a decision.
- `needs-champion`: for pull requests that were not finished by the original author, but are worth resurrecting.
- `backport-candidate`: bugfixes that should be considered for backporting by the release manager.

A milestone is created for each version number for which a release is planned. Issues that need to be addressed and pull requests that need to be merged for a particular release should be set to the corresponding milestone. After a pull request is merged, its milestone (and that of the issue it closes) should be set to the next upcoming release - this makes it easy to get an overview of changes and to add a complete list of those to the release notes.

## Dealing with pull requests

- When merging contributions, a committer is responsible for ensuring that those meet the requirements outlined in [Contributing to SciPy](#). Also check that new features and backwards compatibility breaks were discussed on the `scipy-dev` mailing list.
- New code goes in via a pull request (PR).
- Merge new code with the green button. In case of merge conflicts, ask the PR submitter to rebase (this may require providing some git instructions).
- Backports and trivial additions to finish a PR (really trivial, like a typo or PEP8 fix) can be pushed directly.
- For PRs that add new features or are in some way complex, wait at least a day or two before merging it. That way, others get a chance to comment before the code goes in.
- Squashing commits or cleaning up commit messages of a PR that you consider too messy is OK. Make sure though to retain the original author name when doing this.
- Make sure that the labels and milestone on a merged PR are set correctly.
- When you want to reject a PR: if it's very obvious you can just close it and explain why, if not obvious then it's a good idea to first explain why you think the PR is not suitable for inclusion in SciPy and then let a second committer comment or close.

## Backporting

All pull requests (whether they contain enhancements, bug fixes or something else), should be made against master. Only bug fixes are candidates for backporting to a maintenance branch. The backport strategy for SciPy is to (a) only backport fixes that are important, and (b) to only backport when it's reasonably sure that a new bugfix release on the relevant maintenance branch will be made. Typically, the developer who merges an important bugfix adds the `backport-candidate` label and pings the release manager, who decides on whether and when the backport is done. After the backport is completed, the `backport-candidate` label has to be removed again.

### Other

*PR status page:* When new commits get added to a pull request, GitHub doesn't send out any notifications. The `needs-work` label may not be justified anymore though. [This page](#) gives an overview of PRs that were updated, need review, need a decision, etc.

*Cross-referencing:* Cross-referencing issues and pull requests on GitHub is often useful. GitHub allows doing that by using `gh-xxxx` or `#xxxx` with `xxxx` the issue/PR number. The `gh-xxxx` format is strongly preferred, because it's clear that that is a GitHub link. Older issues contain `#xxxx` which is about Trac (what we used pre-GitHub) tickets.

*PR naming convention:* Pull requests, issues and commit messages usually start with a three-letter abbreviation like `ENH:` or `BUG:`. This is useful to quickly see what the nature of the commit/PR/issue is. For the full list of abbreviations, see [writing the commit message](#).

### 4.3.4 Licensing

Scipy is distributed under the modified (3-clause) BSD license. All code, documentation and other files added to Scipy by contributors is licensed under this license, unless another license is explicitly specified in the source code. Contributors keep the copyright for code they wrote and submit for inclusion to Scipy.

Other licenses that are compatible with the modified BSD license that Scipy uses are 2-clause BSD, MIT and PSF. Incompatible licenses are GPL, Apache and custom licenses that require attribution/citation or prohibit use for commercial purposes.

It regularly happens that PRs are submitted with content copied or derived from unlicensed code. Such contributions cannot be accepted for inclusion in Scipy. What is needed in such cases is to contact the original author and ask him to relicense his code under the modified BSD (or a compatible) license. If the original author agrees to this, add a comment saying so to the source files and forward the relevant email to the `scipy-dev` mailing list.

What also regularly happens is that code is translated or derived from code in R, Octave (both GPL-licensed) or a commercial application. Such code also cannot be included in Scipy. Simply implementing functionality with the same API as found in R/Octave/... is fine though, as long as the author doesn't look at the original incompatibly-licensed source code.

### 4.3.5 Version numbering

Scipy version numbering complies to [PEP 440](#). Released final versions, which are the only versions appearing on PyPI, are numbered `MAJOR.MINOR.MICRO` where:

- `MAJOR` is an integer indicating the major version. It changes very rarely; a change in `MAJOR` indicates large (possibly backwards-incompatible) changes.
- `MINOR` is an integer indicating the minor version. Minor versions are typically released twice a year and can contain new features, deprecations and bug-fixes.
- `MICRO` is an integer indicating a bug-fix version. Bug-fix versions are released when needed, typically one or two per minor version. They cannot contain new features or deprecations.

Released alpha, beta and rc (release candidate) versions are numbered like final versions but with postfixes `a#`, `b#` and `rc#` respectively, with `#` an integer. Development versions are postfixed with `.dev0+<git-commit-hash>`.

Examples of valid Scipy version strings are:

```
0.16.0
0.15.1
0.14.0a1
0.14.0b2
```

```
0.14.0rc1
0.17.0.dev0+ac53f09
```

An installed Scipy version contains these version identifiers:

```
scipy.__version__          # complete version string, including git commit hash for_
↳ dev versions
scipy.version.short_version # string, only major.minor.micro
scipy.version.version      # string, same as scipy.__version__
scipy.version.full_version # string, same as scipy.__version__
scipy.version.release      # bool, development or (alpha/beta/rc/final) released_
↳ version
scipy.version.git_revision # string, git commit hash from which scipy was built
```

### 4.3.6 Deprecations

There are various reasons for wanting to remove existing functionality: it's buggy, the API isn't understandable, it's superseded by functionality with better performance, it needs to be moved to another Scipy submodule, etc.

In general it's not a good idea to remove something without warning users about that removal first. Therefore this is what should be done before removing something from the public API:

1. Propose to deprecate the functionality on the scipy-dev mailing list and get agreement that that's OK.
2. Add a `DeprecationWarning` for it, which states that the functionality was deprecated, and in which release.
3. Mention the deprecation in the release notes for that release.
4. Wait till at least 6 months after the release date of the release that introduced the `DeprecationWarning` before removing the functionality.
5. Mention the removal of the functionality in the release notes.

The 6 months waiting period in practice usually means waiting two releases. When introducing the warning, also ensure that those warnings are filtered out when running the test suite so they don't pollute the output.

It's possible that there is reason to want to ignore this deprecation policy for a particular deprecation; this can always be discussed on the scipy-dev mailing list.

### 4.3.7 Distributing

Distributing Python packages is nontrivial - especially for a package with complex build requirements like Scipy - and subject to change. For an up-to-date overview of recommended tools and techniques, see the [Python Packaging User Guide](#). This document discusses some of the main issues and considerations for Scipy.

#### Dependencies

Dependencies are things that a user has to install in order to use (or build/test) a package. They usually cause trouble, especially if they're not optional. Scipy tries to keep its dependencies to a minimum; currently they are:

*Unconditional run-time dependencies:*

- [Numpy](#)

*Conditional run-time dependencies:*

- `nose` (to run the test suite)

- `asv` (to run the benchmarks)
- `matplotlib` (for some functions that can produce plots)
- `Pillow` (for image loading/saving)
- `scikits.umfpack` (optionally used in `sparse.linalg`)
- `mpmath` (for more extended tests in `special`)

*Unconditional build-time dependencies:*

- `Numpy`
- A BLAS and LAPACK implementation (reference BLAS/LAPACK, ATLAS, OpenBLAS, MKL, Accelerate are all known to work)
- (for development versions) `Cython`

*Conditional build-time dependencies:*

- `setuptools`
- `wheel` (`python setup.py bdist_wheel`)
- `Sphinx` (docs)
- `matplotlib` (docs)
- `LaTeX` (pdf docs)
- `Pillow` (docs)

Furthermore of course one needs C, C++ and Fortran compilers to build SciPy, but those we don't consider to be dependencies and are therefore not discussed here. For details, see <http://scipy.org/scipylib/building/index.html>.

When a package provides useful functionality and it's proposed as a new dependency, consider also if it makes sense to vendor (i.e. ship a copy of it with `scipy`) the package instead. For example, `six` and `decorator` are vendored in `scipy._lib`.

The only dependency that is reported to `pip` is `Numpy`, see `install_requires` in SciPy's main `setup.py`. The other dependencies aren't needed for SciPy to function correctly, and the one unconditional build dependency that `pip` knows how to install (`Cython`) we prefer to treat like a compiler rather than a Python package that `pip` is allowed to upgrade.

### ***Issues with dependency handling***

There are some serious issues with how Python packaging tools handle dependencies reported by projects. Because SciPy gets regular bug reports about this, we go in a bit of detail here.

SciPy only reports its dependency on `Numpy` via `install_requires` if `Numpy` isn't installed at all on a system. This will only change when there are either 32-bit and 64-bit Windows wheels for `Numpy` on PyPI or when `pip upgrade` becomes available (with sane behavior, unlike `pip install -U`, see [this PR](#)). For more details, see [this summary](#).

The situation with `setup_requires` is even worse; `pip` doesn't handle that keyword at all, while `setuptools` has issues (here's a [current one](#)) and invokes `easy_install` which comes with its own set of problems (note that SciPy doesn't support `easy_install` at all anymore; issues specific to it will be closed as "wontfix").

## **Supported Python and Numpy versions**

The `Python` versions that SciPy supports are listed in the list of PyPI classifiers in `setup.py`, and mentioned in the release notes for each release. All newly released Python versions will be supported as soon as possible. The general policy on dropping support for a Python version is that (a) usage of that version has to be quite low (say <5% of

users) and (b) the version isn't included in an active long-term support release of one of the main Linux distributions anymore. SciPy typically follows Numpy, which has a similar policy. The final decision on dropping support is always taken on the `scipy-dev` mailing list.

The lowest supported `Numpy` version for a SciPy version is mentioned in the release notes and is encoded in `scipy/___init__.py` and the `install_requires` field of `setup.py`. Typically the latest SciPy release supports 3 or 4 minor versions of Numpy. That may become more if the frequency of Numpy releases increases (it's about 1x/year at the time of writing). Support for a particular Numpy version is typically dropped if (a) that Numpy version is several years old, and (b) the maintenance cost of keeping support is starting to outweigh the benefits. The final decision on dropping support is always taken on the `scipy-dev` mailing list.

Supported versions of optional dependencies and compilers is less clearly documented, and also isn't tested well or at all by SciPy's Continuous Integration setup. Issues regarding this are dealt with as they come up in the issue tracker or mailing list.

## Building binary installers

---

**Note:** This section is only about building SciPy binary installers to *distribute*. For info on building SciPy on the same machine as where it will be used, see [this scipy.org](https://www.scipy.org) page.

---

There are a number of things to take into consideration when building binaries and distributing them on PyPI or elsewhere.

### General

- A binary is specific for a single Python version (because different Python versions aren't ABI-compatible, at least up to Python 3.4).
- Build against the lowest Numpy version that you need to support, then it will work for all Numpy versions with the same major version number (Numpy does maintain backwards ABI compatibility).

### Windows

- For 64-bit Windows installers built with a free toolchain, use the method documented at <https://github.com/numpy/numpy/wiki/Mingw-static-toolchain>. That method will likely be used for SciPy itself once it's clear that the maintenance of that toolchain is sustainable long-term. See the `MingwPy` project and [this thread](#) for details.
- The other way to produce 64-bit Windows installers is with `icc`, `ifort` plus MKL (or MSVC instead of `icc`). For Intel toolchain instructions see [this article](#) and for (partial) MSVC instructions see [this wiki page](#).
- Older SciPy releases contained a `.exe` "superpack" installer. Those contain 3 complete builds (no SSE, SSE2, SSE3), and were built with <https://github.com/numpy/numpy-vendor>. That build setup is known to not work well anymore and is no longer supported. It used `g77` instead of `gfortran`, due to complex DLL distribution issues (see [gh-2829](#)). Because the toolchain is no longer supported, `g77` support isn't needed anymore and SciPy can now include Fortran 90/95 code.

### OS X

- To produce OS X wheels that work with various Python versions (from `python.org`, Homebrew, MacPython), use the build method provided by <https://github.com/MacPython/scipy-wheels>.
- DMG installers for the Python from `python.org` on OS X can still be produced by `tools/scipy-macosx-installer/`. SciPy doesn't distribute those installers anymore though, now that there are binary wheels on PyPi.

### Linux

Besides PyPi not allowing Linux wheels (which is about to change with [PEP 513](#)), there are no specific issues with building binaries. To build a set of wheels for a Linux distribution and providing them in a [Wheelhouse](#), look at the wheel and [Wheelhouse](#) docs. A Wheelhouse for wheels compatible with TravisCI is <http://wheels.scipy.org>.

### 4.3.8 Making a SciPy release

At the highest level, this is what the release manager does to release a new Scipy version:

1. Propose a release schedule on the scipy-dev mailing list.
2. Create the maintenance branch for the release.
3. Tag the release.
4. Build all release artifacts (sources, installers, docs).
5. Upload the release artifacts.
6. Announce the release.
7. Port relevant changes to release notes and build scripts to master.

In this guide we attempt to describe in detail how to perform each of the above steps. In addition to those steps, which have to be performed by the release manager, here are descriptions of release-related activities and conventions of interest:

- *Backporting*
- *Labels and Milestones*
- versioning
- *Supported Python and Numpy versions*
- deprecations

#### Proposing a release schedule

A typical release cycle looks like:

- Create the maintenance branch
- Release a beta version
- Release a “release candidate” (RC)
- If needed, release one or more new RCs
- Release the final version once there are no issues with the last release candidate

There’s usually at least one week between each of the above steps. Experience shows that a cycle takes between 4 and 8 weeks for a new minor version. Bug-fix versions don’t need a beta or RC, and can be done much quicker.

Ideally the final release is identical to the last RC, however there may be minor difference - it’s up to the release manager to judge the risk of that. Typically, if compiled code or complex pure Python code changes then a new RC is needed, while a simple bug-fix that’s backported from master doesn’t require a new RC.

To propose a schedule, send a list with estimated dates for branching and beta/rc/final releases to scipy-dev. In the same email, ask everyone to check if there are important issues/PRs that need to be included and aren’t tagged with the Milestone for the release or the “backport-candidate” label.

## Creating the maintenance branch

Before branching, ensure that the release notes are updated as far as possible. Include the output of `tools/gh_lists.py` and `tools/authors.py` in the release notes.

Maintenance branches are named `maintenance/<major>.<minor>.x` (e.g. `0.19.x`). To create one, simply push a branch with the correct name to the `scipy` repo. Immediately after, push a commit where you increment the version number on the master branch and add release notes for that new version. Send an email to `scipy-dev` to let people know that you've done this.

## Tagging a release

First ensure that you have set up GPG correctly. See <https://github.com/scipy/scipy/issues/4919> for a discussion of signing release tags, and <http://keyring.debian.org/creating-key.html> for instructions on creating a GPG key if you do not have one.

To make your key more readily identifiable as you, consider sending your key to public key servers, with a command such as:

```
gpg --send-keys <yourkeyid>
```

Check that all relevant commits are in the branch. In particular, check issues and PRs under the Milestone for the release (<https://github.com/scipy/scipy/milestones>), PRs labeled “backport-candidate”, and that the release notes are up-to-date and included in the html docs.

Then edit `setup.py` to get the correct version number (set `ISRELEASED = True`) and commit it with a message like `REL: set version to <version-number>`. Don't push this commit to the SciPy repo yet.

Finally tag the release locally with `git tag -s <v0.x.y>` (the `-s` ensures the tag is signed). Continue with building release artifacts (next section). Only push the release commit and tag to the `scipy` repo once you have built the docs and Windows installers successfully. After that push, also push a second commit which increment the version number and sets `ISRELEASED` to `False` again.

## Building release artifacts

Here is a complete list of artifacts created for a release:

- source archives (`.tar.gz`, `.zip` and `.tar.xz` for GitHub Releases, only `.tar.gz` is uploaded to PyPI)
- Binary wheels for Windows, Linux and OS X
- Documentation (html, pdf)
- A README file
- A Changelog file

All of these except the wheels are built by running `paver release` in the repo root. Do this after you've created the signed tag. If this completes without issues, push the release tag to the `scipy` repo. This is needed because the `scipy-wheels` build scripts automatically build the last tag.

To build wheels, push a commit to the master branch of <https://github.com/MacPython/scipy-wheels>. This triggers builds for all needed Python versions on TravisCI. Check in the `.travis.yml` config file what version of Python and Numpy are used for the builds (it needs to be the lowest supported Numpy version for each Python version). See the README file in the `scipy-wheels` repo for more details.

The TravisCI builds run the tests from the built wheels and if they pass upload the wheels to <http://wheels.scipy.org/>. From there you can download them for uploading to PyPI. This can be done in an automated fashion with `terryfy`

(note the `-n` switch which makes it only download the wheels and skip the upload to PyPI step - we want to be able to check the wheels and put their checksums into README first):

```
$ python wheel-uploader -n -v -c -w ~/PATH_TO_STORE_WHEELS -t manylinux1 scipy 0.19.0
$ python wheel-uploader -n -v -c -w ~/PATH_TO_STORE_WHEELS -t macosx scipy 0.19.0
```

### Uploading release artifacts

For a release there are currently five places on the web to upload things to:

- PyPI (tarballs, wheels)
- Github releases (tarballs, release notes, Changelog)
- `scipy.org` (an announcement of the release)
- `docs.scipy.org` (html/pdf docs)

#### PyPI:

```
twine upload -s <tarballs or wheels to upload>
```

#### Github Releases:

Use GUI on <https://github.com/scipy/scipy/releases> to create release and upload all release artifacts.

#### scipy.org:

Sources for the site are in <https://github.com/scipy/scipy.org>. Update the News section in `www/index.rst` and then do `make upload USERNAME=yourusername`.

#### docs.scipy.org:

First build the scipy docs, by running `make dist` in `scipy/doc/`. Verify that they look OK, then upload them to the doc server with `make upload USERNAME=rgommers RELEASE=0.19.0`. Note that SSH access to the doc server is needed; ask `@pv` (server admin) or `@rgommers` (can upload) if you don't have that.

The sources for the website itself are maintained in <https://github.com/scipy/docs.scipy.org/>. Add the new Scipy version in the table of releases in `index.rst`. Push that commit, then do `make upload USERNAME=yourusername`.

### Wrapping up

Send an email announcing the release to the following mailing lists:

- `scipy-dev`
- `scipy-user`
- `numpy-discussion`
- `python-announce` (not for beta/rc releases)

For beta and rc versions, ask people in the email to test (run the scipy tests and test against their own code) and report issues on Github or `scipy-dev`.

After the final release is done, port relevant changes to release notes, build scripts, author name mapping in `tools/authors.py` and any other changes that were only made on the maintenance branch to master.

### 4.3.9 Module-Specific Instructions

Some SciPy modules have specific development workflows that it is useful to be aware of while contributing.

#### `scipy.special`

Many of the functions in `special` are vectorized versions of scalar functions. The scalar functions are written by hand and the necessary loops for vectorization are generated automatically. This section discusses the steps necessary to add a new vectorized special function.

The first step in adding a new vectorized function is writing the corresponding scalar function. This can be done in Cython, C, C++, or Fortran. If starting from scratch then Cython should be preferred because the code is easier to maintain for developers only familiar with Python. If the primary code is in Fortran then it is necessary to write a C wrapper around the code; for examples of such wrappers see `specfun_wrappers.c`.

After implementing the scalar function, register the new function by adding a line to the `FUNC` string in `generate_ufuncs.py`. The docstring for that file explains the format. Also add documentation for the new function by adding an entry to `add_newdocs.py`; look in the file for examples.

## 4.4 SciPy project governance

The purpose of this document is to formalize the governance process used by the SciPy project in both ordinary and extraordinary situations, and to clarify how decisions are made and how the various elements of our community interact, including the relationship between open source collaborative development and work that may be funded by for-profit or non-profit entities.

### 4.4.1 The Project

The SciPy Project (The Project) is an open source software project. The goal of The Project is to develop open source software for scientific computing in Python, and in particular the `scipy` package. The Software developed by The Project is released under the BSD (or similar) open source license, developed openly and hosted on public GitHub repositories under the `scipy` GitHub organization.

The Project is developed by a team of distributed developers, called Contributors. Contributors are individuals who have contributed code, documentation, designs or other work to the Project. Anyone can be a Contributor. Contributors can be affiliated with any legal entity or none. Contributors participate in the project by submitting, reviewing and discussing GitHub Pull Requests and Issues and participating in open and public Project discussions on GitHub, mailing lists, and other channels. The foundation of Project participation is openness and transparency.

The Project Community consists of all Contributors and Users of the Project. Contributors work on behalf of and are responsible to the larger Project Community and we strive to keep the barrier between Contributors and Users as low as possible.

The Project is not a legal entity, nor does it currently have any formal relationships with legal entities.

### 4.4.2 Governance

This section describes the governance and leadership model of The Project.

The foundations of Project governance are:

- Openness & Transparency
- Active Contribution

- Institutional Neutrality

Traditionally, Project leadership was provided by a subset of Contributors, called Core Developers, whose active and consistent contributions have been recognized by their receiving “commit rights” to the Project GitHub repositories. In general all Project decisions are made through consensus among the Core Developers with input from the Community.

While this approach has served us well, as the Project grows we see a need for a more formal governance model. The SciPy Core Developers expressed a preference for a leadership model which includes a BDFL (Benevolent Dictator for Life). Therefore, moving forward The Project leadership will consist of a BDFL and Steering Council.

### BDFL

The Project will have a BDFL (Benevolent Dictator for Life), who is currently Pauli Virtanen. As Dictator, the BDFL has the authority to make all final decisions for The Project. As Benevolent, the BDFL, in practice chooses to defer that authority to the consensus of the community discussion channels and the Steering Council (see below). It is expected, and in the past has been the case, that the BDFL will only rarely assert his/her final authority. Because rarely used, we refer to BDFL’s final authority as a “special” or “overriding” vote. When it does occur, the BDFL override typically happens in situations where there is a deadlock in the Steering Council or if the Steering Council asks the BDFL to make a decision on a specific matter. To ensure the benevolence of the BDFL, The Project encourages others to fork the project if they disagree with the overall direction the BDFL is taking. The BDFL may delegate his/her authority on a particular decision or set of decisions to any other Council member at his/her discretion.

The BDFL can appoint his/her successor, but it is expected that the Steering Council would be consulted on this decision. If the BDFL is unable to appoint a successor, the Steering Council will make this decision - preferably by consensus, but if needed by a majority vote.

Note that the BDFL can step down at any time, and acting in good faith, will also listen to serious calls to do so. Also note that the BDFL is more a role for fallback decision making rather than that of a director/CEO.

### Steering Council

The Project will have a Steering Council that consists of Project Contributors who have produced contributions that are substantial in quality and quantity, and sustained over at least one year. The overall role of the Council is to ensure, through working with the BDFL and taking input from the Community, the long-term well-being of the project, both technically and as a community.

The Council will have a Chair, who is tasked with keeping the organisational aspects of the functioning of the Council and the Project on track. The Council will also appoint a Release Manager for the Project, who has final responsibility for one or more releases.

During the everyday project activities, council members participate in all discussions, code review and other project activities as peers with all other Contributors and the Community. In these everyday activities, Council Members do not have any special power or privilege through their membership on the Council. However, it is expected that because of the quality and quantity of their contributions and their expert knowledge of the Project Software and Services that Council Members will provide useful guidance, both technical and in terms of project direction, to potentially less experienced contributors.

The Steering Council and its Members play a special role in certain situations. In particular, the Council may:

- Make decisions about the overall scope, vision and direction of the project.
- Make decisions about strategic collaborations with other organizations or individuals.
- Make decisions about specific technical issues, features, bugs and pull requests. They are the primary mechanism of guiding the code review process and merging pull requests.
- Make decisions about the Services that are run by The Project and manage those Services for the benefit of the Project and Community.

- Make decisions when regular community discussion does not produce consensus on an issue in a reasonable time frame.
- Update policy documents such as this one.

### ***Council membership***

To become eligible for being a Steering Council Member an individual must be a Project Contributor who has produced contributions that are substantial in quality and quantity, and sustained over at least one year. Potential Council Members are nominated by existing Council members and voted upon by the existing Council after asking if the potential Member is interested and willing to serve in that capacity. The Council will be initially formed from the set of existing Core Developers who, as of January 2017, have been significantly active over the last two years.

When considering potential Members, the Council will look at candidates with a comprehensive view of their contributions. This will include but is not limited to code, code review, infrastructure work, mailing list and chat participation, community help/building, education and outreach, design work, etc. We are deliberately not setting arbitrary quantitative metrics (like “100 commits in this repo”) to avoid encouraging behavior that plays to the metrics rather than the project’s overall well-being. We want to encourage a diverse array of backgrounds, viewpoints and talents in our team, which is why we explicitly do not define code as the sole metric on which council membership will be evaluated.

If a Council member becomes inactive in the project for a period of one year, they will be considered for removal from the Council. Before removal, inactive Member will be approached to see if they plan on returning to active participation. If not they will be removed immediately upon a Council vote. If they plan on returning to active participation soon, they will be given a grace period of one year. If they don’t return to active participation within that time period they will be removed by vote of the Council without further grace period. All former Council members can be considered for membership again at any time in the future, like any other Project Contributor. Retired Council members will be listed on the project website, acknowledging the period during which they were active in the Council.

The Council reserves the right to eject current Members, other than the BDFL, if they are deemed to be actively harmful to the project’s well-being, and attempts at communication and conflict resolution have failed.

A list of current Steering Council Members is maintained at the page [governance-people](#).

### ***Council Chair***

The Chair will be appointed by the Steering Council. The Chair can stay on as long as he/she wants, but may step down at any time and will listen to serious calls to do so (similar to the BDFL role). The Chair will be responsible for:

- Starting a review of the technical direction of the project (as captured by the *SciPy Roadmap*) bi-yearly, around mid-April and mid-October.
- At the same times of the year, summarizing any relevant organisational updates and issues in the preceding period, and asking for feedback/suggestions on the mailing list.
- Ensuring the composition of the Steering Council stays current.
- Ensuring matters discussed in private by the Steering Council get summarized on the mailing list to keep the Community informed.
- Ensuring other important organisational documents (e.g. Code of Conduct, Fiscal Sponsorship Agreement) stay current after they are added.

### ***Release Manager***

The Release Manager has final responsibility for making a release. This includes:

- Proposing of and deciding on the timing of a release.
- Determining the content of a release in case there is no consensus on a particular change or feature.
- Creating the release and announcing it on the relevant public channels.

For more details on what those responsibilities look like in practice, see [making-a-release](#).

### *Conflict of interest*

It is expected that the BDFL and Council Members will be employed at a wide range of companies, universities and non-profit organizations. Because of this, it is possible that Members will have conflict of interests. Such conflict of interests include, but are not limited to:

- Financial interests, such as investments, employment or contracting work, outside of The Project that may influence their work on The Project.
- Access to proprietary information of their employer that could potentially leak into their work with the Project.

All members of the Council, BDFL included, shall disclose to the rest of the Council any conflict of interest they may have. Members with a conflict of interest in a particular issue may participate in Council discussions on that issue, but must recuse themselves from voting on the issue. If the BDFL has recused his/herself for a particular decision, the Council will appoint a substitute BDFL for that decision.

### *Private communications of the Council*

Unless specifically required, all Council discussions and activities will be public and done in collaboration and discussion with the Project Contributors and Community. The Council will have a private mailing list that will be used sparingly and only when a specific matter requires privacy. When private communications and decisions are needed, the Council will do its best to summarize those to the Community after removing personal/private/sensitive information that should not be posted to the public internet.

### *Council decision making*

If it becomes necessary for the Steering Council to produce a formal decision, then they will use a form of the [Apache Foundation voting process](#). This is a formalized version of consensus, in which +1 votes indicate agreement, -1 votes are vetoes (and must be accompanied with a rationale, as above), and one can also vote fractionally (e.g. -0.5, +0.5) if one wishes to express an opinion without registering a full veto. These numeric votes are also often used informally as a way of getting a general sense of people's feelings on some issue, and should not normally be taken as formal votes. A formal vote only occurs if explicitly declared, and if this does occur then the vote should be held open for long enough to give all interested Council Members a chance to respond – at least one week.

In practice, we anticipate that for most Steering Council decisions (e.g., voting in new members) a more informal process will suffice.

## 4.4.3 Institutional Partners and Funding

The Steering Council is the primary leadership for the project. No outside institution, individual or legal entity has the ability to own, control, usurp or influence the project other than by participating in the Project as Contributors and Council Members. However, because institutions can be an important funding mechanism for the project, it is important to formally acknowledge institutional participation in the project. These are Institutional Partners.

An Institutional Contributor is any individual Project Contributor who contributes to the project as part of their official duties at an Institutional Partner. Likewise, an Institutional Council Member is any Project Steering Council Member who contributes to the project as part of their official duties at an Institutional Partner.

With these definitions, an Institutional Partner is any recognized legal entity in any country that employs at least 1 Institutional Contributor or Institutional Council Member. Institutional Partners can be for-profit or non-profit entities.

Institutions become eligible to become an Institutional Partner by employing individuals who actively contribute to The Project as part of their official duties. To state this another way, the only way for a Partner to influence the project is by actively contributing to the open development of the project, in equal terms to any other member of the community of Contributors and Council Members. Merely using Project Software in institutional context does not allow an entity to become an Institutional Partner. Financial gifts do not enable an entity to become an Institutional Partner. Once an institution becomes eligible for Institutional Partnership, the Steering Council must nominate and approve the Partnership.

If at some point an existing Institutional Partner stops having any contributing employees, then a one year grace period commences. If at the end of this one year period they continue not to have any contributing employees, then their Institutional Partnership will lapse, and resuming it will require going through the normal process for new Partnerships.

An Institutional Partner is free to pursue funding for their work on The Project through any legal means. This could involve a non-profit organization raising money from private foundations and donors or a for-profit company building proprietary products and services that leverage Project Software and Services. Funding acquired by Institutional Partners to work on The Project is called Institutional Funding. However, no funding obtained by an Institutional Partner can override the Steering Council. If a Partner has funding to do SciPy work and the Council decides to not pursue that work as a project, the Partner is free to pursue it on their own. However in this situation, that part of the Partner's work will not be under the SciPy umbrella and cannot use the Project trademarks in a way that suggests a formal relationship.

Institutional Partner benefits are:

- Acknowledgement on the SciPy website and in talks.
- Ability to acknowledge their own funding sources on the SciPy website and in talks.
- Ability to influence the project through the participation of their Council Member.
- Council Members invited to SciPy Developer Meetings.

A list of current Institutional Partners is maintained at the page [governance-people](#).

#### 4.4.4 Document history

<https://github.com/scipy/scipy/commits/master/doc/source/dev/governance/governance.rst>

#### 4.4.5 Acknowledgements

Substantial portions of this document were adapted from the [Jupyter/IPython project's governance document](#) and [NumPy's governance document](#).

#### 4.4.6 License

To the extent possible under law, the authors have waived all copyright and related or neighboring rights to the SciPy project governance document, as per the [CC-0 public domain dedication / license](#).

To get an overview of where help or new features are desired or planned, see the [roadmap](#):

### 4.5 SciPy Roadmap

Most of this roadmap is intended to provide a high-level view on what is most needed per SciPy submodule in terms of new functionality, bug fixes, etc. Besides important “business as usual” changes, it contains ideas for major new features - those are marked as such, and are expected to take significant dedicated effort. Things not mentioned in this roadmap are not necessarily unimportant or out of scope, however we (the SciPy developers) want to provide to our users and contributors a clear picture of where SciPy is going and where help is needed most.

#### 4.5.1 General

This roadmap will be evolving together with SciPy. Updates can be submitted as pull requests. For large or disruptive changes you may want to discuss those first on the [scipy-dev mailing list](#).

### API changes

In general, we want to evolve the API to remove known warts as much as possible, *however as much as possible without breaking backwards compatibility*.

Also, it should be made (even) more clear what is public and what is private in SciPy. Everything private should be named starting with an underscore as much as possible.

### Test coverage

Test coverage of code added in the last few years is quite good, and we aim for a high coverage for all new code that is added. However, there is still a significant amount of old code for which coverage is poor. Bringing that up to the current standard is probably not realistic, but we should plug the biggest holes.

Besides coverage there is also the issue of correctness - older code may have a few tests that provide decent statement coverage, but that doesn't necessarily say much about whether the code does what it says on the box. Therefore code review of some parts of the code (`stats`, `signal` and `ndimage` in particular) is necessary.

### Documentation

The documentation is in good shape. Expanding of current docstrings and putting them in the standard NumPy format should continue, so the number of reST errors and glitches in the html docs decreases. Most modules also have a tutorial in the reference guide that is a good introduction, however there are a few missing or incomplete tutorials - this should be fixed.

### Other

Regarding Cython code:

- It's not clear how much functionality can be Cythonized without making the .so files too large. This needs measuring.
- Cython's old syntax for using NumPy arrays should be removed and replaced with Cython memoryviews.

Regarding build environments:

- SciPy builds from source on Windows now with a MSVC + MinGW-w64 gfortran toolchain. This still needs to prove itself, but is looking good so far.
- Support for Accelerate will be dropped, likely in SciPy 1.1.0. If there is enough interest, we may want to write wrappers so the BLAS part of Accelerate can still be used.
- Bento development has stopped, so will remain having an experimental, use-at-your-own-risk status. Only the people that use it will be responsible for keeping the Bento build updated.

Continuous integration is in good shape, it covers Windows, macOS and Linux, as well as a range of versions of our dependencies and building release quality wheels.

## 4.5.2 Modules

### cluster

This module is in good shape.

## constants

This module is basically done, low-maintenance and without open issues.

## fftpack

Needed:

- solve issues with single precision: large errors, disabled for difficult sizes
- fix caching bug
- Bluestein algorithm (or chirp Z-transform)
- deprecate `fftpack.convolve` as public function (was not meant to be public)

There's a large overlap with `numpy.fft`. This duplication has to change (both are too widely used to deprecate one); in the documentation we should make clear that `scipy.fftpack` is preferred over `numpy.fft`. If there are differences in signature or functionality, the best version should be picked case by case (example: `numpy`'s `rfft` is preferred, see gh-2487).

## integrate

Needed for ODE solvers:

- Documentation is pretty bad, needs fixing
- A new ODE solver interface (`solve_ivp`) was added in SciPy 1.0.0. In the future we can consider (soft-)deprecating the older API.

The numerical integration functions are in good shape. Support for integrating complex-valued functions and integrating multiple intervals (see gh-3325) could be added.

## interpolate

Ideas for new features:

- Spline fitting routines with better user control.
- Integration and differentiation and arithmetic routines for splines
- Transparent tensor-product splines.
- NURBS support.
- Mesh refinement and coarsening of B-splines and corresponding tensor products.

## io

wavfile;

- PCM float will be supported, for anything else use `audiolab` or other specialized libraries.
- Raise errors instead of warnings if data not understood.

Other sub-modules (`matlab`, `netcdf`, `idl`, `harwell-boeing`, `arff`, `matrix market`) are in good shape.

### linalg

Needed:

- Remove functions that are duplicate with `numpy.linalg`
- `get_lapack_funcs` should always use `flapack`
- Wrap more LAPACK functions
- One too many funcs for LU decomposition, remove one

Ideas for new features:

- Add type-generic wrappers in the Cython BLAS and LAPACK
- Make many of the linear algebra routines into `gufuncs`

### misc

`scipy.misc` will be removed as a public module. Most functions in it have been moved to another submodule or deprecated. The few that are left:

- `doccer` : move to `scipy._lib` (making it private)
- `info`, `who` : these are NumPy functions
- `derivative`, `central_diff_weight` : remove, possibly replacing them with more extensive functionality for numerical differentiation.

### ndimage

Underlying `ndimage` is a powerful interpolation engine. Unfortunately, it was never decided whether to use a pixel model (`(1, 1)` elements with centers `(0.5, 0.5)`) or a data point model (values at points on a grid). Over time, it seems that the data point model is better defined and easier to implement. We therefore propose to move to this data representation for 1.0, and to vet all interpolation code to ensure that boundary values, transformations, etc. are correctly computed. Addressing this issue will close several issues, including #1323, #1903, #2045 and #2640.

The morphology interface needs to be standardized:

- binary dilation/erosion/opening/closing take a “structure” argument, whereas their grey equivalent take size (has to be a tuple, not a scalar), footprint, or structure.
- a scalar should be acceptable for size, equivalent to providing that same value for each axis.
- for binary dilation/erosion/opening/closing, the structuring element is optional, whereas it’s mandatory for grey. Grey morphology operations should get the same default.
- other filters should also take that default value where possible.

### odr

Rename the module to `regression` or `fitting`, include `optimize.curve_fit`. This module will then provide a home for other fitting functionality - what exactly needs to be worked out in more detail, a discussion can be found at <https://github.com/scipy/scipy/pull/448>.

## optimize

Overall this module is in reasonably good shape, however it is missing a few more good global optimizers as well as large-scale optimizers. These should be added. Other things that are needed:

- deprecate the `fmin_*` functions in the documentation, `minimize` is preferred.
- clearly define what's out of scope for this module.

## signal

*Convolution and correlation:* (Relevant functions are `convolve`, `correlate`, `fftconvolve`, `convolve2d`, `correlate2d`, and `sepfir2d`.) Eliminate the overlap with `ndimage` (and elsewhere). From `numpy`, `scipy.signal` and `scipy.ndimage` (and anywhere else we find them), pick the “best of class” for 1-D, 2-D and n-d convolution and correlation, put the implementation somewhere, and use that consistently throughout SciPy.

*B-splines:* (Relevant functions are `bspline`, `cubic`, `quadratic`, `gauss_spline`, `cspline1d`, `qspline1d`, `cspline2d`, `qspline2d`, `cspline1d_eval`, and `spline_filter`.) Move the good stuff to `interpolate` (with appropriate API changes to match how things are done in `interpolate`), and eliminate any duplication.

*Filter design:* merge `firwin` and `firwin2` so `firwin2` can be removed.

*Continuous-Time Linear Systems:* remove `lsim2`, `impulse2`, `step2`. The `lsim`, `impulse` and `step` functions now “just work” for any input system. Further improve the performance of `ltisys` (fewer internal transformations between different representations). Fill gaps in lti system conversion functions.

*Second Order Sections:* Make SOS filtering equally capable as existing methods. This includes `ltisys` objects, an *lfilter* equivalent, and numerically stable conversions to and from other filter representations. SOS filters could be considered as the default filtering method for `ltisys` objects, for their numerical stability.

*Wavelets:* what's there now doesn't make much sense. Continuous wavelets only at the moment - decide whether to completely rewrite or remove them. Discrete wavelet transforms are out of scope (PyWavelets does a good job for those).

## sparse

The sparse matrix formats are getting feature-complete but are slow ... reimplement parts in Cython?

- Small matrices are slower than PySparse, needs fixing

There are a lot of formats. These should be kept, but improvements/optimizations should go into CSR/CSC, which are the preferred formats. LIL may be the exception, it's inherently inefficient. It could be dropped if DOK is extended to support all the operations LIL currently provides. Alternatives are being worked on, see <https://github.com/ev-br/sparr> and <https://github.com/perimosocordiae/sparray>.

Ideas for new features:

- Sparse arrays now act like `np.matrix`. We want sparse *arrays*.

## sparse.csgraph

This module is in good shape.

### sparse.linalg

Arpack is in good shape.

isolve:

- callback keyword is inconsistent
- tol keyword is broken, should be relative tol
- Fortran code not re-entrant (but we don't solve, maybe re-use from PyKrilov)

dsolve:

- add sparse Cholesky or incomplete Cholesky
- look at CHOLMOD

Ideas for new features:

- Wrappers for PROPACK for faster sparse SVD computation.

### spatial

QHull wrappers are in good shape.

Needed:

- KDTree will be removed, and cKDTree will be renamed to KDTree in a backwards-compatible way.
- distance\_wrap.c needs to be cleaned up (maybe rewrite in Cython).

### special

Though there are still a lot of functions that need improvements in precision, probably the only show-stoppers are hypergeometric functions, parabolic cylinder functions, and spheroidal wave functions. Three possible ways to handle this:

1. Get good double-precision implementations. This is doable for parabolic cylinder functions (in progress). I think it's possible for hypergeometric functions, though maybe not in time. For spheroidal wavefunctions this is not possible with current theory.
2. Port Boost's arbitrary precision library and use it under the hood to get double precision accuracy. This might be necessary as a stopgap measure for hypergeometric functions; the idea of using arbitrary precision has been suggested before by @nmayorov and in gh-5349. Likely necessary for spheroidal wave functions, this could be reused: <https://github.com/radelman/scattering>.
3. Add clear warnings to the documentation about the limits of the existing implementations.

### stats

stats.distributions is in good shape.

gaussian\_kde is in good shape but limited. It should not be expanded probably, this fits better in Statsmodels (which already has a lot more KDE functionality).

### 4.5.3 New modules under discussion

#### diff

Currently Scipy doesn't provide much support for numerical differentiation. A new `scipy.diff` module for that is discussed in <https://github.com/scipy/scipy/issues/2035>. There's also a fairly detailed GSoC proposal to build on, see [here](#). There has been a second (unsuccessful) GSoC project in 2017. Recent discussion and the host of alternatives available make it unlikely that a new `scipy.diff` submodule will be added in the near future.

There is also `approx_derivative` in `optimize`, which is still private but could form a solid basis for this module.

#### transforms

This module was discussed previously, mainly to provide a home for discrete wavelet transform functionality. Other transforms could fit as well, for example there's a PR for a Hankel transform . *Note: this is on the back burner, because the plans to integrate PyWavelets DWT code has been put on hold.*



## API REFERENCE

The exact API of all functions and classes, as given by the docstrings. The API documents expected types and allowed features for all functions, and all parameters available for the algorithms.

### 5.1 Clustering package (`scipy.cluster`)

*scipy.cluster.vq*

Clustering algorithms are useful in information theory, target detection, communications, compression, and other areas. The *vq* module only supports vector quantization and the k-means algorithms.

*scipy.cluster.hierarchy*

The *hierarchy* module provides functions for hierarchical and agglomerative clustering. Its features include generating hierarchical clusters from distance matrices, calculating statistics on clusters, cutting linkages to generate flat clusters, and visualizing clusters with dendrograms.

### 5.2 K-means clustering and vector quantization (`scipy.cluster.vq`)

Provides routines for k-means clustering, generating code books from k-means models, and quantizing vectors by comparing them with centroids in a code book.

<code>whiten(obs[, check_finite])</code>	Normalize a group of observations on a per feature basis.
<code>vq(obs, code_book[, check_finite])</code>	Assign codes from a code book to observations.
<code>kmeans(obs, k_or_guess[, iter, thresh, ...])</code>	Performs k-means on a set of observation vectors forming k clusters.
<code>kmeans2(data, k[, iter, thresh, minit, ...])</code>	Classify a set of observations into k clusters using the k-means algorithm.

`scipy.cluster.vq.whiten` (*obs*, *check\_finite=True*)

Normalize a group of observations on a per feature basis.

Before running k-means, it is beneficial to rescale each feature dimension of the observation set with whitening. Each feature is divided by its standard deviation across all observations to give it unit variance.

**Parameters** `obs` : ndarray

Each row of the array is an observation. The columns are the features seen during each observation.

```

>>> #          f0      f1      f2
>>> obs = [[ 1.,    1.,    1.], #o0
...        [ 2.,    2.,    2.], #o1
...        [ 3.,    3.,    3.], #o2
...        [ 4.,    4.,    4.]] #o3
    
```

**check\_finite** : bool, optional

Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs. Default: True

**Returns**

**result** : ndarray

Contains the values in *obs* scaled by the standard deviation of each column.

### Examples

```

>>> from scipy.cluster.vq import whiten
>>> features = np.array([[1.9, 2.3, 1.7],
...                     [1.5, 2.5, 2.2],
...                     [0.8, 0.6, 1.7]])
>>> whiten(features)
array([[ 4.17944278,  2.69811351,  7.21248917],
       [ 3.29956009,  2.93273208,  9.33380951],
       [ 1.75976538,  0.70385557,  7.21248917]])
    
```

`scipy.cluster.vq.vq`(*obs*, *code\_book*, *check\_finite=True*)

Assign codes from a code book to observations.

Assigns a code from a code book to each observation. Each observation vector in the ‘M’ by ‘N’ *obs* array is compared with the centroids in the code book and assigned the code of the closest centroid.

The features in *obs* should have unit variance, which can be achieved by passing them through the `whiten` function. The code book can be created with the k-means algorithm or a different encoding algorithm.

**Parameters** **obs** : ndarray

Each row of the ‘M’ x ‘N’ array is an observation. The columns are the “features” seen during each observation. The features must be whitened first using the `whiten` function or something equivalent.

**code\_book** : ndarray

The code book is usually generated using the k-means algorithm. Each row of the array holds a different code, and the columns are the features of the code.

```

>>> #          f0      f1      f2      f3
>>> code_book = [
...             [ 1.,    2.,    3.,    4.], #c0
...             [ 1.,    2.,    3.,    4.], #c1
...             [ 1.,    2.,    3.,    4.]] #c2
    
```

**check\_finite** : bool, optional

Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs. Default: True

**Returns**

**code** : ndarray

A length M array holding the code book index for each observation.

**dist** : ndarray

The distortion (distance) between the observation and its nearest code.

*Examples*

```

>>> from numpy import array
>>> from scipy.cluster.vq import vq
>>> code_book = array([[1., 1., 1.],
...                   [2., 2., 2.]])
>>> features = array([[ 1.9, 2.3, 1.7],
...                  [ 1.5, 2.5, 2.2],
...                  [ 0.8, 0.6, 1.7]])
>>> vq(features, code_book)
(array([1, 1, 0], 'i'), array([ 0.43588989,  0.73484692,  0.83066239]))

```

`scipy.cluster.vq.kmeans` (*obs*, *k\_or\_guess*, *iter=20*, *thresh=1e-05*, *check\_finite=True*)

Performs k-means on a set of observation vectors forming k clusters.

The k-means algorithm adjusts the centroids until sufficient progress cannot be made, i.e. the change in distortion since the last iteration is less than some threshold. This yields a code book mapping centroids to codes and vice versa.

Distortion is defined as the sum of the squared differences between the observations and the corresponding centroid.

**Parameters** **obs** : ndarray

Each row of the M by N array is an observation vector. The columns are the features seen during each observation. The features must be whitened first with the *whiten* function.

**k\_or\_guess** : int or ndarray

The number of centroids to generate. A code is assigned to each centroid, which is also the row index of the centroid in the code\_book matrix generated.

The initial k centroids are chosen by randomly selecting observations from the observation matrix. Alternatively, passing a k by N array specifies the initial k centroids.

**iter** : int, optional

The number of times to run k-means, returning the codebook with the lowest distortion. This argument is ignored if initial centroids are specified with an array for the *k\_or\_guess* parameter. This parameter does not represent the number of iterations of the k-means algorithm.

**thresh** : float, optional

Terminates the k-means algorithm if the change in distortion since the last k-means iteration is less than or equal to thresh.

**check\_finite** : bool, optional

Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs. Default: True

**Returns****codebook** : ndarray

A k by N array of k centroids. The i'th centroid codebook[i] is represented with the code i. The centroids and codes generated represent the lowest distortion seen, not necessarily the globally minimal distortion.

**distortion** : float

The distortion between the observations passed and the centroids generated.

**See also:**

**kmeans2** a different implementation of k-means clustering with more methods for generating initial centroids but without using a distortion change threshold as a stopping criterion.

**whiten** must be called prior to passing an observation matrix to kmeans.

*Examples*

```

>>> from numpy import array
>>> from scipy.cluster.vq import vq, kmeans, whiten
>>> import matplotlib.pyplot as plt
>>> features = array([[ 1.9,2.3],
...                  [ 1.5,2.5],
...                  [ 0.8,0.6],
...                  [ 0.4,1.8],
...                  [ 0.1,0.1],
...                  [ 0.2,1.8],
...                  [ 2.0,0.5],
...                  [ 0.3,1.5],
...                  [ 1.0,1.0]])
>>> whitened = whiten(features)
>>> book = np.array((whitened[0],whitened[2]))
>>> kmeans(whitened,book)
(array([[ 2.3110306 ,  2.86287398],      # random
        [ 0.93218041,  1.24398691]]), 0.85684700941625547)

```

```

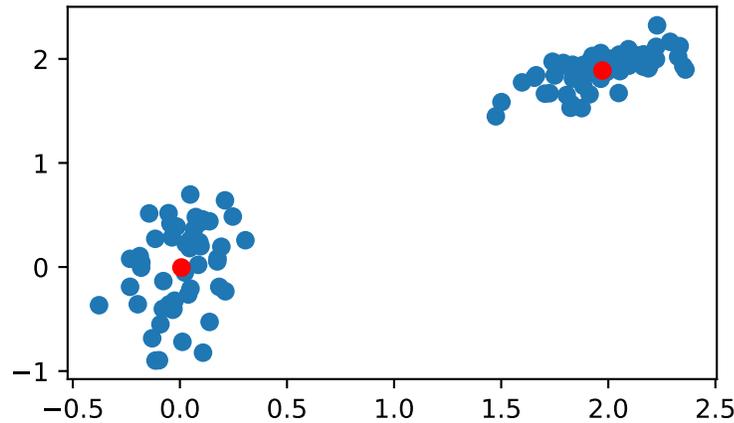
>>> from numpy import random
>>> random.seed((1000,2000))
>>> codes = 3
>>> kmeans(whitened,codes)
(array([[ 2.3110306 ,  2.86287398],      # random
        [ 1.32544402,  0.65607529],
        [ 0.40782893,  2.02786907]]), 0.5196582527686241)

```

```

>>> # Create 50 datapoints in two clusters a and b
>>> pts = 50
>>> a = np.random.multivariate_normal([0, 0], [[4, 1], [1, 4]], size=pts)
>>> b = np.random.multivariate_normal([30, 10],
...                                  [[10, 2], [2, 1]],
...                                  size=pts)
>>> features = np.concatenate((a, b))
>>> # Whiten data
>>> whitened = whiten(features)
>>> # Find 2 clusters in the data
>>> codebook, distortion = kmeans(whitened, 2)
>>> # Plot whitened data and cluster centers in red
>>> plt.scatter(whitened[:, 0], whitened[:, 1])
>>> plt.scatter(codebook[:, 0], codebook[:, 1], c='r')
>>> plt.show()

```



```
scipy.cluster.vq.kmeans2(data, k, iter=10, thresh=1e-05, minit='random', missing='warn',
                          check_finite=True)
```

Classify a set of observations into  $k$  clusters using the k-means algorithm.

The algorithm attempts to minimize the Euclidian distance between observations and centroids. Several initialization methods are included.

**Parameters**

**data** : ndarray  
A 'M' by 'N' array of 'M' observations in 'N' dimensions or a length 'M' array of 'M' one-dimensional observations.

**k** : int or ndarray  
The number of clusters to form as well as the number of centroids to generate. If *minit* initialization string is 'matrix', or if a ndarray is given instead, it is interpreted as initial cluster to use instead.

**iter** : int, optional  
Number of iterations of the k-means algorithm to run. Note that this differs in meaning from the *iters* parameter to the *kmeans* function.

**thresh** : float, optional  
(not used yet)

**minit** : str, optional  
Method for initialization. Available methods are 'random', 'points', and 'matrix':  
'random': generate  $k$  centroids from a Gaussian with mean and variance estimated from the data.  
'points': choose  $k$  observations (rows) at random from data for the initial centroids.  
'matrix': interpret the  $k$  parameter as a  $k$  by  $M$  (or length  $k$  array for one-dimensional data) array of initial centroids.

**missing** : str, optional  
Method to deal with empty clusters. Available methods are 'warn' and 'raise':  
'warn': give a warning and continue.  
'raise': raise an `ClusterError` and terminate the algorithm.

**check\_finite** : bool, optional  
Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs. Default: True

**Returns**

**centroid** : ndarray  
A 'k' by 'N' array of centroids found at the last iteration of k-means.

**label** : ndarray

label[i] is the code or index of the centroid the i'th observation is closest to.

### 5.2.1 Background information

The k-means algorithm takes as input the number of clusters to generate, *k*, and a set of observation vectors to cluster. It returns a set of centroids, one for each of the *k* clusters. An observation vector is classified with the cluster number or centroid index of the centroid closest to it.

A vector *v* belongs to cluster *i* if it is closer to centroid *i* than any other centroids. If *v* belongs to *i*, we say centroid *i* is the dominating centroid of *v*. The k-means algorithm tries to minimize distortion, which is defined as the sum of the squared distances between each observation vector and its dominating centroid. Each step of the k-means algorithm refines the choices of centroids to reduce distortion. The change in distortion is used as a stopping criterion: when the change is lower than a threshold, the k-means algorithm is not making sufficient progress and terminates. One can also define a maximum number of iterations.

Since vector quantization is a natural application for k-means, information theory terminology is often used. The centroid index or cluster index is also referred to as a “code” and the table mapping codes to centroids and vice versa is often referred as a “code book”. The result of k-means, a set of centroids, can be used to quantize vectors. Quantization aims to find an encoding of vectors that reduces the expected distortion.

All routines expect *obs* to be a *M* by *N* array where the rows are the observation vectors. The codebook is a *k* by *N* array where the *i*'th row is the centroid of code word *i*. The observation vectors and centroids have the same feature dimension.

As an example, suppose we wish to compress a 24-bit color image (each pixel is represented by one byte for red, one for blue, and one for green) before sending it over the web. By using a smaller 8-bit encoding, we can reduce the amount of data by two thirds. Ideally, the colors for each of the 256 possible 8-bit encoding values should be chosen to minimize distortion of the color. Running k-means with *k*=256 generates a code book of 256 codes, which fills up all possible 8-bit sequences. Instead of sending a 3-byte value for each pixel, the 8-bit centroid index (or code word) of the dominating centroid is transmitted. The code book is also sent over the wire so each 8-bit code can be translated back to a 24-bit pixel value representation. If the image of interest was of an ocean, we would expect many 24-bit blues to be represented by 8-bit codes. If it was an image of a human face, more flesh tone colors would be represented in the code book.

## 5.3 Hierarchical clustering (`scipy.cluster.hierarchy`)

These functions cut hierarchical clusterings into flat clusterings or find the roots of the forest formed by a cut by providing the flat cluster ids of each observation.

<code>fcluster(Z, t[, criterion, depth, R, monocrit])</code>	Form flat clusters from the hierarchical clustering defined by the given linkage matrix.
<code>fclusterdata(X, t[, criterion, metric, ...])</code>	Cluster observation data using a given metric.
<code>leaders(Z, T)</code>	Return the root nodes in a hierarchical clustering.

`scipy.cluster.hierarchy.fcluster` (*Z*, *t*, *criterion*='inconsistent', *depth*=2, *R*=None, *monocrit*=None)

Form flat clusters from the hierarchical clustering defined by the given linkage matrix.

**Parameters** **Z** : ndarray

The hierarchical clustering encoded with the matrix returned by the *linkage* function.

**t** : float

The threshold to apply when forming flat clusters.

**criterion** : str, optional

The criterion to use in forming flat clusters. This can be any of the following values:

***inconsistent***

[If a cluster node and all its] descendants have an inconsistent value less than or equal to  $t$  then all its leaf descendants belong to the same flat cluster. When no non-singleton cluster meets this criterion, every node is assigned to its own cluster. (Default)

***distance***

[Forms flat clusters so that the original] observations in each flat cluster have no greater a cophenetic distance than  $t$ .

***maxclust***

[Finds a minimum threshold  $r$  so that] the cophenetic distance between any two original observations in the same flat cluster is no more than  $r$  and no more than  $t$  flat clusters are formed.

***monocrit***

[Forms a flat cluster from a cluster node  $c$ ] with index  $i$  when  $\text{monocrit}[j] \leq t$ .

For example, to threshold on the maximum mean distance as computed in the inconsistency matrix  $R$  with a threshold of 0.8 do:

```
MR = maxRstat(Z, R, 3)
cluster(Z, t=0.8, criterion='monocrit',
        ↪monocrit=MR)
```

***maxclust\_monocrit***

[Forms a flat cluster from a] non-singleton cluster node  $c$  when  $\text{monocrit}[i] \leq r$  for all cluster indices  $i$  below and including  $c$ .  $r$  is minimized such that no more than  $t$  flat clusters are formed.  $\text{monocrit}$  must be monotonic. For example, to minimize the threshold  $t$  on maximum inconsistency values so that no more than 3 flat clusters are formed, do:

```
MI = maxinconsts(Z, R)
cluster(Z, t=3, criterion='maxclust_monocrit',
        ↪monocrit=MI)
```

**depth** : int, optional

The maximum depth to perform the inconsistency calculation. It has no meaning for the other criteria. Default is 2.

**R** : ndarray, optional

The inconsistency matrix to use for the 'inconsistent' criterion. This matrix is computed if not provided.

**monocrit** : ndarray, optional

An array of length  $n-1$ .  $\text{monocrit}[i]$  is the statistics upon which non-singleton  $i$  is thresholded. The  $\text{monocrit}$  vector must be monotonic, i.e. given a node  $c$  with index  $i$ , for all node indices  $j$  corresponding to nodes below  $c$ ,  $\text{monocrit}[i] \geq \text{monocrit}[j]$ .

**Returns**

**fcluster** : ndarray

An array of length  $n$ .  $T[i]$  is the flat cluster number to which original observation  $i$  belongs.

```
scipy.cluster.hierarchy.fclusterdata(X, t, criterion='inconsistent', metric='euclidean',
                                     depth=2, method='single', R=None)
```

Cluster observation data using a given metric.

Clusters the original observations in the  $n$ -by- $m$  data matrix  $X$  ( $n$  observations in  $m$  dimensions), using the euclidean distance metric to calculate distances between original observations, performs hierarchical clustering using the single linkage algorithm, and forms flat clusters using the inconsistency method with  $t$  as the cut-off threshold.

A one-dimensional array  $T$  of length  $n$  is returned.  $T[i]$  is the index of the flat cluster to which the original observation  $i$  belongs.

**Parameters**

- X** : (N, M) ndarray  
N by M data matrix with N observations in M dimensions.
- t** : float  
The threshold to apply when forming flat clusters.
- criterion** : str, optional  
Specifies the criterion for forming flat clusters. Valid values are ‘inconsistent’ (default), ‘distance’, or ‘maxclust’ cluster formation algorithms. See *fcluster* for descriptions.
- metric** : str, optional  
The distance metric for calculating pairwise distances. See *distance.pdist* for descriptions and linkage to verify compatibility with the linkage method.
- depth** : int, optional  
The maximum depth for the inconsistency calculation. See *inconsistent* for more information.
- method** : str, optional  
The linkage method to use (single, complete, average, weighted, median centroid, ward). See *linkage* for more information. Default is “single”.
- R** : ndarray, optional  
The inconsistency matrix. It will be computed if necessary if it is not passed.

**Returns**

- fclusterdata** : ndarray  
A vector of length  $n$ .  $T[i]$  is the flat cluster number to which original observation  $i$  belongs.

See also:

**scipy.spatial.distance.pdist**  
pairwise distance metrics

#### Notes

This function is similar to the MATLAB function *clusterdata*.

`scipy.cluster.hierarchy.leafs(Z, T)`

Return the root nodes in a hierarchical clustering.

Returns the root nodes in a hierarchical clustering corresponding to a cut defined by a flat cluster assignment vector  $T$ . See the *fcluster* function for more information on the format of  $T$ .

For each flat cluster  $j$  of the  $k$  flat clusters represented in the  $n$ -sized flat cluster assignment vector  $T$ , this function finds the lowest cluster node  $i$  in the linkage tree  $Z$  such that:

- leaf descendents belong only to flat cluster  $j$  (i.e.  $T[p] == j$  for all  $p$  in  $S(i)$  where  $S(i)$  is the set of leaf ids of leaf nodes descendent with cluster node  $i$ )
- there does not exist a leaf that is not descendent with  $i$  that also belongs to cluster  $j$  (i.e.  $T[q] != j$  for all  $q$  not in  $S(i)$ ). If this condition is violated,  $T$  is not a valid cluster assignment vector, and an exception will be thrown.

**Parameters**

- Z** : ndarray  
The hierarchical clustering encoded as a matrix. See *linkage* for more information.
- T** : ndarray  
The flat cluster assignment vector.

**Returns**

- L** : ndarray

The leader linkage node id's stored as a k-element 1-D array where k is the number of flat clusters found in T.

$L[j]=i$  is the linkage cluster node id that is the leader of flat cluster with id  $M[j]$ . If  $i < n$ , i corresponds to an original observation, otherwise it corresponds to a non-singleton cluster.

For example: if  $L[3]=2$  and  $M[3]=8$ , the flat cluster with id 8's leader is linkage node 2.

**M** : ndarray

The leader linkage node id's stored as a k-element 1-D array where k is the number of flat clusters found in T. This allows the set of flat cluster ids to be any arbitrary set of k integers.

These are routines for agglomerative clustering.

<i>linkage</i> (y[, method, metric, optimal_ordering])	Perform hierarchical/agglomerative clustering.
<i>single</i> (y)	Perform single/min/nearest linkage on the condensed distance matrix y.
<i>complete</i> (y)	Perform complete/max/farthest point linkage on a condensed distance matrix.
<i>average</i> (y)	Perform average/UPGMA linkage on a condensed distance matrix.
<i>weighted</i> (y)	Perform weighted/WPGMA linkage on the condensed distance matrix.
<i>centroid</i> (y)	Perform centroid/UPGMC linkage.
<i>median</i> (y)	Perform median/WPGMC linkage.
<i>ward</i> (y)	Perform Ward's linkage on a condensed distance matrix.

`scipy.cluster.hierarchy.linkage` (y, *method*='single', *metric*='euclidean', *optimal\_ordering*=False)

Perform hierarchical/agglomerative clustering.

The input y may be either a 1d compressed distance matrix or a 2d array of observation vectors.

If y is a 1d compressed distance matrix, then y must be a  $\binom{n}{2}$  sized vector where n is the number of original observations paired in the distance matrix. The behavior of this function is very similar to the MATLAB linkage function.

A  $(n - 1)$  by 4 matrix Z is returned. At the  $i$ -th iteration, clusters with indices  $Z[i, 0]$  and  $Z[i, 1]$  are combined to form cluster  $n + i$ . A cluster with an index less than  $n$  corresponds to one of the  $n$  original observations. The distance between clusters  $Z[i, 0]$  and  $Z[i, 1]$  is given by  $Z[i, 2]$ . The fourth value  $Z[i, 3]$  represents the number of original observations in the newly formed cluster.

The following linkage methods are used to compute the distance  $d(s, t)$  between two clusters  $s$  and  $t$ . The algorithm begins with a forest of clusters that have yet to be used in the hierarchy being formed. When two clusters  $s$  and  $t$  from this forest are combined into a single cluster  $u$ ,  $s$  and  $t$  are removed from the forest, and  $u$  is added to the forest. When only one cluster remains in the forest, the algorithm stops, and this cluster becomes the root.

A distance matrix is maintained at each iteration. The  $d[i, j]$  entry corresponds to the distance between cluster  $i$  and  $j$  in the original forest.

At each iteration, the algorithm must update the distance matrix to reflect the distance of the newly formed cluster  $u$  with the remaining clusters in the forest.

Suppose there are  $|u|$  original observations  $u[0], \dots, u[|u| - 1]$  in cluster  $u$  and  $|v|$  original objects  $v[0], \dots, v[|v| - 1]$  in cluster  $v$ . Recall  $s$  and  $t$  are combined to form cluster  $u$ . Let  $v$  be any remaining cluster in the forest that is not  $u$ .

The following are methods for calculating the distance between the newly formed cluster  $u$  and each  $v$ .

- method='single' assigns

$$d(u, v) = \min(\text{dist}(u[i], v[j]))$$

for all points  $i$  in cluster  $u$  and  $j$  in cluster  $v$ . This is also known as the Nearest Point Algorithm.

- method='complete' assigns

$$d(u, v) = \max(\text{dist}(u[i], v[j]))$$

for all points  $i$  in cluster  $u$  and  $j$  in cluster  $v$ . This is also known by the Farthest Point Algorithm or Voor Hees Algorithm.

- method='average' assigns

$$d(u, v) = \sum_{ij} \frac{d(u[i], v[j])}{(|u| * |v|)}$$

for all points  $i$  and  $j$  where  $|u|$  and  $|v|$  are the cardinalities of clusters  $u$  and  $v$ , respectively. This is also called the UPGMA algorithm.

- method='weighted' assigns

$$d(u, v) = (\text{dist}(s, v) + \text{dist}(t, v))/2$$

where cluster  $u$  was formed with cluster  $s$  and  $t$  and  $v$  is a remaining cluster in the forest. (also called WPGMA)

- method='centroid' assigns

$$\text{dist}(s, t) = \|c_s - c_t\|_2$$

where  $c_s$  and  $c_t$  are the centroids of clusters  $s$  and  $t$ , respectively. When two clusters  $s$  and  $t$  are combined into a new cluster  $u$ , the new centroid is computed over all the original objects in clusters  $s$  and  $t$ . The distance then becomes the Euclidean distance between the centroid of  $u$  and the centroid of a remaining cluster  $v$  in the forest. This is also known as the UPGMC algorithm.

- method='median' assigns  $d(s, t)$  like the `centroid` method. When two clusters  $s$  and  $t$  are combined into a new cluster  $u$ , the average of centroids  $s$  and  $t$  give the new centroid  $u$ . This is also known as the WPGMC algorithm.

- method='ward' uses the Ward variance minimization algorithm. The new entry  $d(u, v)$  is computed as follows,

$$d(u, v) = \sqrt{\frac{|v| + |s|}{T} d(v, s)^2 + \frac{|v| + |t|}{T} d(v, t)^2 - \frac{|v|}{T} d(s, t)^2}$$

where  $u$  is the newly joined cluster consisting of clusters  $s$  and  $t$ ,  $v$  is an unused cluster in the forest,  $T = |v| + |s| + |t|$ , and  $| * |$  is the cardinality of its argument. This is also known as the incremental algorithm.

Warning: When the minimum distance pair in the forest is chosen, there may be two or more pairs with the same minimum distance. This implementation may choose a different minimum than the MATLAB version.

**Parameters** `y` : ndarray

A condensed distance matrix. A condensed distance matrix is a flat array containing the upper triangular of the distance matrix. This is the form that `pdist` returns. Alternatively, a collection of  $m$  observation vectors in  $n$  dimensions may be passed as an  $m$  by  $n$  array. All elements of the condensed distance matrix must be finite, i.e. no NaNs or infs.

**method** : str, optional

The linkage algorithm to use. See the [Linkage Methods](#) section below for full descriptions.

**metric** : str or function, optional

The distance metric to use in the case that `y` is a collection of observation vectors; ignored otherwise. See the `pdist` function for a list of valid distance metrics. A custom distance function can also be used.

**optimal\_ordering** : bool, optional

If True, the linkage matrix will be reordered so that the distance between successive leaves is minimal. This results in a more intuitive tree structure when the data are visualized. defaults to False, because this algorithm can be slow, particularly on large datasets [R46]. See also the `optimal_leaf_ordering` function.

New in version 1.0.0.

**Returns** **Z** : ndarray

The hierarchical clustering encoded as a linkage matrix.

**See also:**

`scipy.spatial.distance.pdist`

pairwise distance metrics

**Notes**

1. For method 'single' an optimized algorithm based on minimum spanning tree is implemented. It has time complexity  $O(n^2)$ . For methods 'complete', 'average', 'weighted' and 'ward' an algorithm called nearest-neighbors chain is implemented. It also has time complexity  $O(n^2)$ . For other methods a naive algorithm is implemented with  $O(n^3)$  time complexity. All algorithms use  $O(n^2)$  memory. Refer to [R45] for details about the algorithms.
2. Methods 'centroid', 'median' and 'ward' are correctly defined only if Euclidean pairwise metric is used. If `y` is passed as precomputed pairwise distances, then it is a user responsibility to assure that these distances are in fact Euclidean, otherwise the produced result will be incorrect.

**References**

[R45], [R46]

**Examples**

```
>>> from scipy.cluster.hierarchy import dendrogram, linkage
>>> from matplotlib import pyplot as plt
>>> X = [[i] for i in [2, 8, 0, 4, 1, 9, 9, 0]]
```

```
>>> Z = linkage(X, 'ward')
>>> fig = plt.figure(figsize=(25, 10))
>>> dn = dendrogram(Z)
```

```
>>> Z = linkage(X, 'single')
>>> fig = plt.figure(figsize=(25, 10))
>>> dn = dendrogram(Z)
>>> plt.show()
```

`scipy.cluster.hierarchy.single`(`y`)

Perform single/min/nearest linkage on the condensed distance matrix `y`.

**Parameters** `y` : ndarray

The upper triangular of the distance matrix. The result of `pdist` is returned in this form.

**Returns** **Z** : ndarray  
The linkage matrix.

**See also:**

**linkage** for advanced creation of hierarchical clusterings.

**scipy.spatial.distance.pdist**  
pairwise distance metrics

`scipy.cluster.hierarchy.complete`(y)

Perform complete/max/farthest point linkage on a condensed distance matrix.

**Parameters** **y** : ndarray  
The upper triangular of the distance matrix. The result of `pdist` is returned in this form.

**Returns** **Z** : ndarray  
A linkage matrix containing the hierarchical clustering. See the `linkage` function documentation for more information on its structure.

**See also:**

**linkage** for advanced creation of hierarchical clusterings.

**scipy.spatial.distance.pdist**  
pairwise distance metrics

`scipy.cluster.hierarchy.average`(y)

Perform average/UPGMA linkage on a condensed distance matrix.

**Parameters** **y** : ndarray  
The upper triangular of the distance matrix. The result of `pdist` is returned in this form.

**Returns** **Z** : ndarray  
A linkage matrix containing the hierarchical clustering. See `linkage` for more information on its structure.

**See also:**

**linkage** for advanced creation of hierarchical clusterings.

**scipy.spatial.distance.pdist**  
pairwise distance metrics

`scipy.cluster.hierarchy.weighted`(y)

Perform weighted/WPGMA linkage on the condensed distance matrix.

See `linkage` for more information on the return structure and algorithm.

**Parameters** **y** : ndarray  
The upper triangular of the distance matrix. The result of `pdist` is returned in this form.

**Returns** **Z** : ndarray  
A linkage matrix containing the hierarchical clustering. See `linkage` for more information on its structure.

**See also:**

**linkage** for advanced creation of hierarchical clusterings.

**scipy.spatial.distance.pdist**  
pairwise distance metrics

`scipy.cluster.hierarchy.centroid(y)`

Perform centroid/UPGMC linkage.

See *linkage* for more information on the input matrix, return structure, and algorithm.

The following are common calling conventions:

1. `Z = centroid(y)`

Performs centroid/UPGMC linkage on the condensed distance matrix `y`.

2. `Z = centroid(X)`

Performs centroid/UPGMC linkage on the observation matrix `X` using Euclidean distance as the distance metric.

**Parameters** `y` : ndarray

A condensed distance matrix. A condensed distance matrix is a flat array containing the upper triangular of the distance matrix. This is the form that `pdist` returns. Alternatively, a collection of `m` observation vectors in `n` dimensions may be passed as a `m` by `n` array.

**Returns** `Z` : ndarray

A linkage matrix containing the hierarchical clustering. See the *linkage* function documentation for more information on its structure.

**See also:**

**linkage** for advanced creation of hierarchical clusterings.

`scipy.cluster.hierarchy.median(y)`

Perform median/WPGMC linkage.

See *linkage* for more information on the return structure and algorithm.

The following are common calling conventions:

1. `Z = median(y)`

Performs median/WPGMC linkage on the condensed distance matrix `y`. See *linkage* for more information on the return structure and algorithm.

2. `Z = median(X)`

Performs median/WPGMC linkage on the observation matrix `X` using Euclidean distance as the distance metric. See *linkage* for more information on the return structure and algorithm.

**Parameters** `y` : ndarray

A condensed distance matrix. A condensed distance matrix is a flat array containing the upper triangular of the distance matrix. This is the form that `pdist` returns. Alternatively, a collection of `m` observation vectors in `n` dimensions may be passed as a `m` by `n` array.

**Returns** `Z` : ndarray

The hierarchical clustering encoded as a linkage matrix.

**See also:**

**linkage** for advanced creation of hierarchical clusterings.

**scipy.spatial.distance.pdist**  
pairwise distance metrics

`scipy.cluster.hierarchy.ward(y)`  
Perform Ward's linkage on a condensed distance matrix.

See *linkage* for more information on the return structure and algorithm.

The following are common calling conventions:

1. `Z = ward(y)` Performs Ward's linkage on the condensed distance matrix `y`.
2. `Z = ward(X)` Performs Ward's linkage on the observation matrix `X` using Euclidean distance as the distance metric.

**Parameters** `y` : ndarray  
A condensed distance matrix. A condensed distance matrix is a flat array containing the upper triangular of the distance matrix. This is the form that `pdist` returns. Alternatively, a collection of `m` observation vectors in `n` dimensions may be passed as a `m` by `n` array.

**Returns** `Z` : ndarray  
The hierarchical clustering encoded as a linkage matrix. See *linkage* for more information on the return structure and algorithm.

**See also:**

**linkage** for advanced creation of hierarchical clusterings.

**scipy.spatial.distance.pdist**  
pairwise distance metrics

These routines compute statistics on hierarchies.

<code>cophenet(Z[, Y])</code>	Calculate the cophenetic distances between each observation in the hierarchical clustering defined by the linkage <code>Z</code> .
<code>from_mlab_linkage(Z)</code>	Convert a linkage matrix generated by MATLAB(TM) to a new linkage matrix compatible with this module.
<code>inconsistent(Z[, d])</code>	Calculate inconsistency statistics on a linkage matrix.
<code>maxinconsts(Z, R)</code>	Return the maximum inconsistency coefficient for each non-singleton cluster and its descendents.
<code>maxdists(Z)</code>	Return the maximum distance between any non-singleton cluster.
<code>maxRstat(Z, R, i)</code>	Return the maximum statistic for each non-singleton cluster and its descendents.
<code>to_mlab_linkage(Z)</code>	Convert a linkage matrix to a MATLAB(TM) compatible one.

`scipy.cluster.hierarchy.cophenet(Z, Y=None)`  
Calculate the cophenetic distances between each observation in the hierarchical clustering defined by the linkage `Z`.

Suppose `p` and `q` are original observations in disjoint clusters `s` and `t`, respectively and `s` and `t` are joined by a direct parent cluster `u`. The cophenetic distance between observations `i` and `j` is simply the distance between clusters `s` and `t`.

**Parameters** `Z` : ndarray  
The hierarchical clustering encoded as an array (see *linkage* function).

**Y** : ndarray (optional)

Calculates the cophenetic correlation coefficient  $c$  of a hierarchical clustering defined by the linkage matrix  $Z$  of a set of  $n$  observations in  $m$  dimensions.  $Y$  is the condensed distance matrix from which  $Z$  was generated.

**Returns**

**c** : ndarray

The cophenetic correlation distance (if  $Y$  is passed).

**d** : ndarray

The cophenetic distance matrix in condensed form. The  $ij$  th entry is the cophenetic distance between original observations  $i$  and  $j$ .

`scipy.cluster.hierarchy.from_mlab_linkage(Z)`

Convert a linkage matrix generated by MATLAB(TM) to a new linkage matrix compatible with this module.

The conversion does two things:

- the indices are converted from  $1 \dots N$  to  $0 \dots (N-1)$  form, and
- a fourth column  $Z[:, 3]$  is added where  $Z[i, 3]$  represents the number of original observations (leaves) in the non-singleton cluster  $i$ .

This function is useful when loading in linkages from legacy data files generated by MATLAB.

**Parameters** **Z** : ndarray

A linkage matrix generated by MATLAB(TM).

**Returns** **ZS** : ndarray

A linkage matrix compatible with `scipy.cluster.hierarchy`.

`scipy.cluster.hierarchy.inconsistent(Z, d=2)`

Calculate inconsistency statistics on a linkage matrix.

**Parameters** **Z** : ndarray

The  $(n - 1)$  by 4 matrix encoding the linkage (hierarchical clustering). See *linkage* documentation for more information on its form.

**d** : int, optional

The number of links up to  $d$  levels below each non-singleton cluster.

**Returns** **R** : ndarray

A  $(n - 1)$  by 5 matrix where the  $i$ 'th row contains the link statistics for the non-singleton cluster  $i$ . The link statistics are computed over the link heights for links  $d$  levels below the cluster  $i$ .  $R[i, 0]$  and  $R[i, 1]$  are the mean and standard deviation of the link heights, respectively;  $R[i, 2]$  is the number of links included in the calculation; and  $R[i, 3]$  is the inconsistency coefficient,

$$\frac{Z[i, 2] - R[i, 0]}{R[i, 1]}$$

### Notes

This function behaves similarly to the MATLAB(TM) `inconsistent` function.

### Examples

```
>>> from scipy.cluster.hierarchy import inconsistent, linkage
>>> from matplotlib import pyplot as plt
>>> X = [[i] for i in [2, 8, 0, 4, 1, 9, 9, 0]]
>>> Z = linkage(X, 'ward')
>>> print(Z)
[[ 5.         6.         0.         2.         ]
 [ 2.         7.         0.         2.         ]
 [ 0.         4.         1.         2.         ]
 [ 1.         8.         1.15470054  3.         ]
```

```
[ 9.          10.          2.12132034  4.          ]
[ 3.          12.          4.11096096  5.          ]
[ 11.         13.          14.07183949  8.          ]]
>>> inconsistent(Z)
array([[ 0.          ,  0.          ,  1.          ,  0.          ],
       [ 0.          ,  0.          ,  1.          ,  0.          ],
       [ 1.          ,  0.          ,  1.          ,  0.          ],
       [ 0.57735027,  0.81649658,  2.          ,  0.70710678],
       [ 1.04044011,  1.06123822,  3.          ,  1.01850858],
       [ 3.11614065,  1.40688837,  2.          ,  0.70710678],
       [ 6.44583366,  6.76770586,  3.          ,  1.12682288]])
```

`scipy.cluster.hierarchy.maxinconsts` (*Z*, *R*)

Return the maximum inconsistency coefficient for each non-singleton cluster and its descendents.

- Parameters**
- Z**: ndarray  
The hierarchical clustering encoded as a matrix. See *linkage* for more information.
  - R**: ndarray  
The inconsistency matrix.
- Returns**
- MI**: ndarray  
A monotonic (n-1)-sized numpy array of doubles.

`scipy.cluster.hierarchy.maxdists` (*Z*)

Return the maximum distance between any non-singleton cluster.

- Parameters**
- Z**: ndarray  
The hierarchical clustering encoded as a matrix. See *linkage* for more information.
- Returns**
- maxdists**: ndarray  
A (n-1) sized numpy array of doubles; MD[i] represents the maximum distance between any cluster (including singletons) below and including the node with index i. More specifically, MD[i] = Z[Q(i)-n, 2].max() where Q(i) is the set of all node indices below and including node i.

`scipy.cluster.hierarchy.maxRstat` (*Z*, *R*, *i*)

Return the maximum statistic for each non-singleton cluster and its descendents.

- Parameters**
- Z**: array\_like  
The hierarchical clustering encoded as a matrix. See *linkage* for more information.
  - R**: array\_like  
The inconsistency matrix.
  - i**: int  
The column of *R* to use as the statistic.
- Returns**
- MR**: ndarray  
Calculates the maximum statistic for the i'th column of the inconsistency matrix *R* for each non-singleton cluster node. MR[j] is the maximum over R[Q(j)-n, i] where Q(j) the set of all node ids corresponding to nodes below and including j.

`scipy.cluster.hierarchy.to_mlab_linkage` (*Z*)

Convert a linkage matrix to a MATLAB(TM) compatible one.

Converts a linkage matrix *Z* generated by the linkage function of this module to a MATLAB(TM) compatible one. The return linkage matrix has the last column removed and the cluster indices are converted to 1..N indexing.

- Parameters**
- Z**: ndarray  
A linkage matrix generated by `scipy.cluster.hierarchy`.
- Returns**
- to\_mlab\_linkage**: ndarray

A linkage matrix compatible with MATLAB(TM)'s hierarchical clustering functions. The return linkage matrix has the last column removed and the cluster indices are converted to 1 . . N indexing.

Routines for visualizing flat clusters.

---

`dendrogram(Z[, p, truncate_mode, ...])` Plot the hierarchical clustering as a dendrogram.

---

```
scipy.cluster.hierarchy.dendrogram(Z, p=30, truncate_mode=None, color_threshold=None,
                                   get_leaves=True, orientation='top', labels=None,
                                   count_sort=False, distance_sort=False,
                                   show_leaf_counts=True, no_plot=False,
                                   no_labels=False, leaf_font_size=None,
                                   leaf_rotation=None, leaf_label_func=None,
                                   show_contracted=False, link_color_func=None,
                                   ax=None, above_threshold_color='b')
```

Plot the hierarchical clustering as a dendrogram.

The dendrogram illustrates how each cluster is composed by drawing a U-shaped link between a non-singleton cluster and its children. The top of the U-link indicates a cluster merge. The two legs of the U-link indicate which clusters were merged. The length of the two legs of the U-link represents the distance between the child clusters. It is also the cophenetic distance between original observations in the two children clusters.

**Parameters** **Z** : ndarray

The linkage matrix encoding the hierarchical clustering to render as a dendrogram. See the `linkage` function for more information on the format of `Z`.

**p** : int, optional

The `p` parameter for `truncate_mode`.

**truncate\_mode** : str, optional

The dendrogram can be hard to read when the original observation matrix from which the linkage is derived is large. Truncation is used to condense the dendrogram. There are several modes:

**None** No truncation is performed (default). Note: 'none' is an alias for None that's kept for backward compatibility.

**'lastp'** The last `p` non-singleton clusters formed in the linkage are the only non-leaf nodes in the linkage; they correspond to rows `Z[n-p-2:end]` in `Z`. All other non-singleton clusters are contracted into leaf nodes.

**'level'** No more than `p` levels of the dendrogram tree are displayed. A "level" includes all nodes with `p` merges from the last merge.

Note: 'mtica' is an alias for 'level' that's kept for backward compatibility.

**color\_threshold** : double, optional

For brevity, let  $t$  be the `color_threshold`. Colors all the descendent links below a cluster node  $k$  the same color if  $k$  is the first node below the cut threshold  $t$ . All links connecting nodes with distances greater than or equal to the threshold are colored blue. If  $t$  is less than or equal to zero, all nodes are colored blue. If `color_threshold` is None or 'default', corresponding with MATLAB(TM) behavior, the threshold is set to  $0.7 * \max(Z[:, 2])$ .

**get\_leaves** : bool, optional

Includes a list `R['leaves'] = H` in the result dictionary. For each  $i$ , `H[i] == j`, cluster node  $j$  appears in position  $i$  in the left-to-right traversal of the leaves, where  $j < 2n - 1$  and  $i < n$ .

**orientation** : str, optional

The direction to plot the dendrogram, which can be any of the following strings:

**'top'** Plots the root at the top, and plot descendent links going downwards. (default).

**'bottom'** Plots the root at the bottom, and plot descendent links going upwards.

**'left'** Plots the root at the left, and plot descendent links going right.

**'right'** Plots the root at the right, and plot descendent links going left.

**labels** : ndarray, optional

By default `labels` is `None` so the index of the original observation is used to label the leaf nodes. Otherwise, this is an  $n$ -sized list (or tuple). The `labels[i]` value is the text to put under the  $i$ th leaf node only if it corresponds to an original observation and not a non-singleton cluster.

**count\_sort** : str or bool, optional

For each node  $n$ , the order (visually, from left-to-right)  $n$ 's two descendent links are plotted is determined by this parameter, which can be any of the following values:

**False** Nothing is done.

**'ascending' or True**

The child with the minimum number of original objects in its cluster is plotted first.

**'descendent'**

The child with the maximum number of original objects in its cluster is plotted first.

Note `distance_sort` and `count_sort` cannot both be `True`.

**distance\_sort** : str or bool, optional

For each node  $n$ , the order (visually, from left-to-right)  $n$ 's two descendent links are plotted is determined by this parameter, which can be any of the following values:

**False** Nothing is done.

**'ascending' or True**

The child with the minimum distance between its direct descendents is plotted first.

**'descending'**

The child with the maximum distance between its direct descendents is plotted first.

Note `distance_sort` and `count_sort` cannot both be `True`.

**show\_leaf\_counts** : bool, optional

When `True`, leaf nodes representing  $k > 1$  original observation are labeled with the number of observations they contain in parentheses.

**no\_plot** : bool, optional

When `True`, the final rendering is not performed. This is useful if only the data structures computed for the rendering are needed or if `matplotlib` is not available.

**no\_labels** : bool, optional

When `True`, no labels appear next to the leaf nodes in the rendering of the dendrogram.

**leaf\_rotation** : double, optional

Specifies the angle (in degrees) to rotate the leaf labels. When unspecified, the rotation is based on the number of nodes in the dendrogram (default is 0).

**leaf\_font\_size** : int, optional

Specifies the font size (in points) of the leaf labels. When unspecified, the size based on the number of nodes in the dendrogram.

**leaf\_label\_func** : lambda or function, optional

When `leaf_label_func` is a callable function, for each leaf with cluster index  $k < 2n - 1$ . The function is expected to return a string with the label for the leaf.

Indices  $k < n$  correspond to original observations while indices  $k \geq n$  correspond to non-singleton clusters.

For example, to label singletons with their node id and non-singletons with their id, count, and inconsistency coefficient, simply do:

```
# First define the leaf label function.
def llf(id):
    if id < n:
        return str(id)
    else:
        return "[%d %d %1.2f]" % (id, count, R[n-id,3])
# The text for the leaf nodes is going to be big so force
# a rotation of 90 degrees.
dendrogram(Z, leaf_label_func=llf, leaf_rotation=90)
```

**show\_contracted** : bool, optional

When True the heights of non-singleton nodes contracted into a leaf node are plotted as crosses along the link connecting that leaf node. This really is only useful when truncation is used (see `truncate_mode` parameter).

**link\_color\_func** : callable, optional

If given, `link_color_function` is called with each non-singleton id corresponding to each U-shaped link it will paint. The function is expected to return the color to paint the link, encoded as a matplotlib color string code. For example:

```
dendrogram(Z, link_color_func=lambda k: colors[k])
```

colors the direct links below each untruncated non-singleton node `k` using `colors[k]`.

**ax** : matplotlib Axes instance, optional

If None and `no_plot` is not True, the dendrogram will be plotted on the current axes. Otherwise if `no_plot` is not True the dendrogram will be plotted on the given Axes instance. This can be useful if the dendrogram is part of a more complex figure.

**above\_threshold\_color** : str, optional

This matplotlib color string sets the color of the links above the `color_threshold`. The default is 'b'.

#### Returns

**R** : dict

A dictionary of data structures computed to render the dendrogram. Its has the following keys:

**'color\_list'**

A list of color names. The `k`'th element represents the color of the `k`'th link.

**'icoord' and 'dcoord'**

Each of them is a list of lists. Let `icoord = [I1, I2, ..., Ip]` where `Ik = [xk1, xk2, xk3, xk4]` and `dcoord = [D1, D2, ..., Dp]` where `Dk = [yk1, yk2, yk3, yk4]`, then the `k`'th link painted is  $(xk1, yk1) - (xk2, yk2) - (xk3, yk3) - (xk4, yk4)$ .

**'ivl'**

A list of labels corresponding to the leaf nodes.

**'leaves'**

For each `i`, `H[i] == j`, cluster node `j` appears in position `i` in the left-to-right traversal of the leaves, where  $j < 2n - 1$  and  $i < n$ . If `j` is less than `n`, the `i`-th leaf node corresponds to an original observation. Otherwise, it corresponds to a non-singleton cluster.

#### See also:

`linkage`, `set_link_color_palette`

#### Notes

It is expected that the distances in `Z[:, 2]` be monotonic, otherwise crossings appear in the dendrogram.

*Examples*

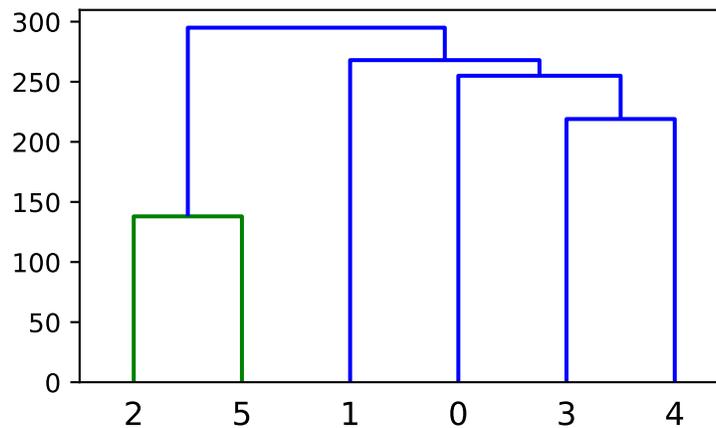
```
>>> from scipy.cluster import hierarchy
>>> import matplotlib.pyplot as plt
```

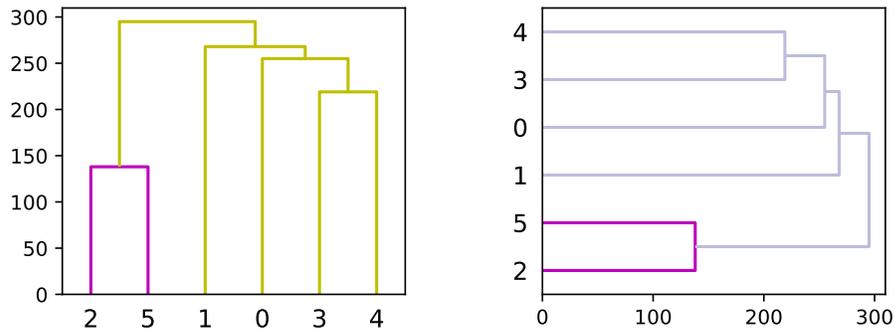
A very basic example:

```
>>> ytdist = np.array([662., 877., 255., 412., 996., 295., 468., 268.,
...                   400., 754., 564., 138., 219., 869., 669.])
>>> Z = hierarchy.linkage(ytdist, 'single')
>>> plt.figure()
>>> dn = hierarchy.dendrogram(Z)
```

Now plot in given axes, improve the color scheme and use both vertical and horizontal orientations:

```
>>> hierarchy.set_link_color_palette(['m', 'c', 'y', 'k'])
>>> fig, axes = plt.subplots(1, 2, figsize=(8, 3))
>>> dn1 = hierarchy.dendrogram(Z, ax=axes[0], above_threshold_color='y',
...                             orientation='top')
>>> dn2 = hierarchy.dendrogram(Z, ax=axes[1],
...                             above_threshold_color='#bcbddc',
...                             orientation='right')
>>> hierarchy.set_link_color_palette(None) # reset to default after use
>>> plt.show()
```





These are data structures and routines for representing hierarchies as tree objects.

<code>ClusterNode(id[, left, right, dist, count])</code>	A tree node class for representing a cluster.
<code>leaves_list(Z)</code>	Return a list of leaf node ids.
<code>to_tree(Z[, rd])</code>	Convert a linkage matrix into an easy-to-use tree object.
<code>cut_tree(Z[, n_clusters, height])</code>	Given a linkage matrix <i>Z</i> , return the cut tree.
<code>optimal_leaf_ordering(Z, y[, metric])</code>	Given a linkage matrix <i>Z</i> and distance, reorder the cut tree.

**class** `scipy.cluster.hierarchy.ClusterNode` (*id*, *left=None*, *right=None*, *dist=0*, *count=1*)  
 A tree node class for representing a cluster.

Leaf nodes correspond to original observations, while non-leaf nodes correspond to non-singleton clusters.

The `to_tree` function converts a matrix returned by the linkage function into an easy-to-use tree representation.

All parameter names are also attributes.

**Parameters**

- id** : int  
The node id.
- left** : ClusterNode instance, optional  
The left child tree node.
- right** : ClusterNode instance, optional  
The right child tree node.
- dist** : float, optional  
Distance for this cluster in the linkage matrix.
- count** : int, optional  
The number of samples in this cluster.

**See also:**

**to\_tree** for converting a linkage matrix *Z* into a tree object.

**Methods**

<code>get_count()</code>	The number of leaf nodes (original observations) belonging to the cluster node <i>nd</i> .
<code>get_id()</code>	The identifier of the target node.
<code>get_left()</code>	Return a reference to the left child tree object.
<code>get_right()</code>	Return a reference to the right child tree object.

Continued on next page

Table 5.7 – continued from previous page

<code>is_leaf()</code>	Return True if the target node is a leaf.
<code>pre_order([func])</code>	Perform pre-order traversal without recursive function calls.

`ClusterNode.get_count()`

The number of leaf nodes (original observations) belonging to the cluster node `nd`. If the target node is a leaf, 1 is returned.

**Returns**     **get\_count** : int  
The number of leaf nodes below the target node.

`ClusterNode.get_id()`

The identifier of the target node.

For  $0 \leq i < n$ ,  $i$  corresponds to original observation  $i$ . For  $n \leq i < 2n-1$ ,  $i$  corresponds to non-singleton cluster formed at iteration  $i-n$ .

**Returns**     **id** : int  
The identifier of the target node.

`ClusterNode.get_left()`

Return a reference to the left child tree object.

**Returns**     **left** : ClusterNode  
The left child of the target node. If the node is a leaf, None is returned.

`ClusterNode.get_right()`

Return a reference to the right child tree object.

**Returns**     **right** : ClusterNode  
The left child of the target node. If the node is a leaf, None is returned.

`ClusterNode.is_leaf()`

Return True if the target node is a leaf.

**Returns**     **leafness** : bool  
True if the target node is a leaf node.

`ClusterNode.pre_order(func=<function <lambda>>)`

Perform pre-order traversal without recursive function calls.

When a leaf node is first encountered, `func` is called with the leaf node as its argument, and its result is appended to the list.

For example, the statement:

```
ids = root.pre_order(lambda x: x.id)
```

returns a list of the node ids corresponding to the leaf nodes of the tree as they appear from left to right.

**Parameters**   **func** : function  
Applied to each leaf ClusterNode object in the pre-order traversal. Given the  $i$ -th leaf node in the pre-order traversal  $n[i]$ , the result of `func(n[i])` is stored in  $L[i]$ . If not provided, the index of the original observation to which the node corresponds is used.

**Returns**     **L** : list  
The pre-order traversal.

`scipy.cluster.hierarchy.leaves_list` (*Z*)

Return a list of leaf node ids.

The return corresponds to the observation vector index as it appears in the tree from left to right. *Z* is a linkage matrix.

**Parameters** *Z* : ndarray  
The hierarchical clustering encoded as a matrix. *Z* is a linkage matrix. See *linkage* for more information.

**Returns** `leaves_list` : ndarray  
The list of leaf node ids.

`scipy.cluster.hierarchy.to_tree` (*Z*, *rd=False*)

Convert a linkage matrix into an easy-to-use tree object.

The reference to the root *ClusterNode* object is returned (by default).

Each *ClusterNode* object has a `left`, `right`, `dist`, `id`, and `count` attribute. The left and right attributes point to *ClusterNode* objects that were combined to generate the cluster. If both are None then the *ClusterNode* object is a leaf node, its count must be 1, and its distance is meaningless but set to 0.

*Note: This function is provided for the convenience of the library user. ClusterNodes are not used as input to any of the functions in this library.*

**Parameters** *Z* : ndarray  
The linkage matrix in proper form (see the *linkage* function documentation).

*rd* : bool, optional  
When False (default), a reference to the root *ClusterNode* object is returned. Otherwise, a tuple (*r*, *d*) is returned. *r* is a reference to the root node while *d* is a list of *ClusterNode* objects - one per original entry in the linkage matrix plus entries for all clustering steps. If a cluster id is less than the number of samples *n* in the data that the linkage matrix describes, then it corresponds to a singleton cluster (leaf node). See *linkage* for more information on the assignment of cluster ids to clusters.

**Returns** `tree` : *ClusterNode* or tuple (*ClusterNode*, list of *ClusterNode*)  
If *rd* is False, a *ClusterNode*. If *rd* is True, a list of length  $2*n - 1$ , with *n* the number of samples. See the description of *rd* above for more details.

**See also:**

*linkage*, *is\_valid\_linkage*, *ClusterNode*

**Examples**

```
>>> from scipy.cluster import hierarchy
>>> x = np.random.rand(10).reshape(5, 2)
>>> Z = hierarchy.linkage(x)
>>> hierarchy.to_tree(Z)
<scipy.cluster.hierarchy.ClusterNode object at ...
>>> rootnode, nodelist = hierarchy.to_tree(Z, rd=True)
>>> rootnode
<scipy.cluster.hierarchy.ClusterNode object at ...
>>> len(nodelist)
9
```

`scipy.cluster.hierarchy.cut_tree` (*Z*, *n\_clusters=None*, *height=None*)

Given a linkage matrix *Z*, return the cut tree.

**Parameters** *Z* : `scipy.cluster.linkage` array  
The linkage matrix.

*n\_clusters* : array\_like, optional

Number of clusters in the tree at the cut point.

**height** : array\_like, optional

The height at which to cut the tree. Only possible for ultrametric trees.

**Returns**

**cutree** : array

An array indicating group membership at each agglomeration step. I.e., for a full cut tree, in the first column each data point is in its own cluster. At the next step, two nodes are merged. Finally all singleton and non-singleton clusters are in one group. If *n\_clusters* or *height* is given, the columns correspond to the columns of *n\_clusters* or *height*.

### Examples

```
>>> from scipy import cluster
>>> np.random.seed(23)
>>> X = np.random.randn(50, 4)
>>> Z = cluster.hierarchy.ward(X)
>>> cutree = cluster.hierarchy.cut_tree(Z, n_clusters=[5, 10])
>>> cutree[:10]
array([[0, 0],
       [1, 1],
       [2, 2],
       [3, 3],
       [3, 4],
       [2, 2],
       [0, 0],
       [1, 5],
       [3, 6],
       [4, 7]])
```

`scipy.cluster.hierarchy.optimal_leaf_ordering(Z, y, metric='euclidean')`

Given a linkage matrix *Z* and distance, reorder the cut tree.

**Parameters** **Z** : ndarray

The hierarchical clustering encoded as a linkage matrix. See *linkage* for more information on the return structure and algorithm.

**y** : ndarray

The condensed distance matrix from which *Z* was generated. Alternatively, a collection of *m* observation vectors in *n* dimensions may be passed as a *m* by *n* array.

**metric** : str or function, optional

The distance metric to use in the case that *y* is a collection of observation vectors; ignored otherwise. See the `pdist` function for a list of valid distance metrics. A custom distance function can also be used.

**Returns** **Z\_ordered** : ndarray

A copy of the linkage matrix *Z*, reordered to minimize the distance between adjacent leaves.

### Examples

```
>>> from scipy.cluster import hierarchy
>>> np.random.seed(23)
>>> X = np.random.randn(10, 10)
>>> Z = hierarchy.ward(X)
>>> hierarchy.leaves_list(Z)
array([0, 5, 3, 9, 6, 8, 1, 4, 2, 7], dtype=int32)
>>> hierarchy.leaves_list(hierarchy.optimal_leaf_ordering(Z, X))
array([3, 9, 0, 5, 8, 2, 7, 4, 1, 6], dtype=int32)
```

These are predicates for checking the validity of linkage and inconsistency matrices as well as for checking isomorphism of two flat cluster assignments.

<code>is_valid_im(R[, warning, throw, name])</code>	Return True if the inconsistency matrix passed is valid.
<code>is_valid_linkage(Z[, warning, throw, name])</code>	Check the validity of a linkage matrix.
<code>is_isomorphic(T1, T2)</code>	Determine if two different cluster assignments are equivalent.
<code>is_monotonic(Z)</code>	Return True if the linkage passed is monotonic.
<code>correspond(Z, Y)</code>	Check for correspondence between linkage and condensed distance matrices.
<code>num_obs_linkage(Z)</code>	Return the number of original observations of the linkage matrix passed.

`scipy.cluster.hierarchy.is_valid_im(R, warning=False, throw=False, name=None)`

Return True if the inconsistency matrix passed is valid.

It must be a  $n$  by 4 array of doubles. The standard deviations  $R[:, 1]$  must be nonnegative. The link counts  $R[:, 2]$  must be positive and no greater than  $n - 1$ .

**Parameters** **R** : ndarray  
 The inconsistency matrix to check for validity.  
**warning** : bool, optional  
 When True, issues a Python warning if the linkage matrix passed is invalid.  
**throw** : bool, optional  
 When True, throws a Python exception if the linkage matrix passed is invalid.  
**name** : str, optional  
 This string refers to the variable name of the invalid linkage matrix.

**Returns** **b** : bool  
 True if the inconsistency matrix is valid.

`scipy.cluster.hierarchy.is_valid_linkage(Z, warning=False, throw=False, name=None)`

Check the validity of a linkage matrix.

A linkage matrix is valid if it is a two dimensional array (type double) with  $n$  rows and 4 columns. The first two columns must contain indices between 0 and  $2n - 1$ . For a given row  $i$ , the following two expressions have to hold:

$$0 \leq Z[i, 0] \leq i + n - 10 \leq Z[i, 1] \leq i + n - 1$$

I.e. a cluster cannot join another cluster unless the cluster being joined has been generated.

**Parameters** **Z** : array\_like  
 Linkage matrix.  
**warning** : bool, optional  
 When True, issues a Python warning if the linkage matrix passed is invalid.  
**throw** : bool, optional  
 When True, throws a Python exception if the linkage matrix passed is invalid.  
**name** : str, optional  
 This string refers to the variable name of the invalid linkage matrix.

**Returns** **b** : bool  
 True if the inconsistency matrix is valid.

`scipy.cluster.hierarchy.is_isomorphic(T1, T2)`

Determine if two different cluster assignments are equivalent.

**Parameters** **T1** : array\_like  
 An assignment of singleton cluster ids to flat cluster ids.

**T2** : array\_like  
 An assignment of singleton cluster ids to flat cluster ids.

**Returns** **b** : bool  
 Whether the flat cluster assignments *T1* and *T2* are equivalent.

`scipy.cluster.hierarchy.is_monotonic` (*Z*)

Return True if the linkage passed is monotonic.

The linkage is monotonic if for every cluster *s* and *t* joined, the distance between them is no less than the distance between any previously joined clusters.

**Parameters** **Z** : ndarray  
 The linkage matrix to check for monotonicity.

**Returns** **b** : bool  
 A boolean indicating whether the linkage is monotonic.

`scipy.cluster.hierarchy.correspond` (*Z*, *Y*)

Check for correspondence between linkage and condensed distance matrices.

They must have the same number of original observations for the check to succeed.

This function is useful as a sanity check in algorithms that make extensive use of linkage and distance matrices that must correspond to the same set of original observations.

**Parameters** **Z** : array\_like  
 The linkage matrix to check for correspondence.

**Y** : array\_like  
 The condensed distance matrix to check for correspondence.

**Returns** **b** : bool  
 A boolean indicating whether the linkage matrix and distance matrix could possibly correspond to one another.

`scipy.cluster.hierarchy.num_obs_linkage` (*Z*)

Return the number of original observations of the linkage matrix passed.

**Parameters** **Z** : ndarray  
 The linkage matrix on which to perform the operation.

**Returns** **n** : int  
 The number of original observations in the linkage.

Utility routines for plotting:

---

`set_link_color_palette`(*palette*) Set list of matplotlib color codes for use by dendrogram.

---

`scipy.cluster.hierarchy.set_link_color_palette` (*palette*)

Set list of matplotlib color codes for use by dendrogram.

Note that this palette is global (i.e. setting it once changes the colors for all subsequent calls to `dendrogram`) and that it affects only the the colors below `color_threshold`.

Note that `dendrogram` also accepts a custom coloring function through its `link_color_func` keyword, which is more flexible and non-global.

**Parameters** **palette** : list of str or None  
 A list of matplotlib color codes. The order of the color codes is the order in which the colors are cycled through when color thresholding in the dendrogram.  
 If None, resets the palette to its default (which is ['g', 'r', 'c', 'm', 'y', 'k']).

**Returns** None

**See also:***dendrogram***Notes**Ability to reset the palette with `None` added in SciPy 0.17.0.**Examples**

```

>>> from scipy.cluster import hierarchy
>>> ytdist = np.array([662., 877., 255., 412., 996., 295., 468., 268.,
...                   400., 754., 564., 138., 219., 869., 669.])
>>> Z = hierarchy.linkage(ytdist, 'single')
>>> dn = hierarchy.dendrogram(Z, no_plot=True)
>>> dn['color_list']
['g', 'b', 'b', 'b', 'b']
>>> hierarchy.set_link_color_palette(['c', 'm', 'y', 'k'])
>>> dn = hierarchy.dendrogram(Z, no_plot=True)
>>> dn['color_list']
['c', 'b', 'b', 'b', 'b']
>>> dn = hierarchy.dendrogram(Z, no_plot=True, color_threshold=267,
...                           above_threshold_color='k')
>>> dn['color_list']
['c', 'm', 'm', 'k', 'k']

```

Now reset the color palette to its default:

```

>>> hierarchy.set_link_color_palette(None)

```

## 5.3.1 References

- MATLAB and MathWorks are registered trademarks of The MathWorks, Inc.
- Mathematica is a registered trademark of The Wolfram Research, Inc.

## 5.4 Constants (`scipy.constants`)

Physical and mathematical constants and units.

### 5.4.1 Mathematical constants

<code>pi</code>	Pi
<code>golden</code>	Golden ratio
<code>golden_ratio</code>	Golden ratio



Value in *physical\_constants* corresponding to *key*

**See also:**

**codata** Contains the description of *physical\_constants*, which, as a dictionary literal object, does not itself possess a docstring.

**Examples**

```
>>> from scipy import constants
>>> constants.value(u'elementary charge')
1.6021766208e-19
```

`scipy.constants.unit` (*key*)

Unit in *physical\_constants* indexed by *key*

**Parameters** **key** : Python string or unicode  
Key in dictionary *physical\_constants*

**Returns** **unit** : Python string  
Unit in *physical\_constants* corresponding to *key*

**See also:**

**codata** Contains the description of *physical\_constants*, which, as a dictionary literal object, does not itself possess a docstring.

**Examples**

```
>>> from scipy import constants
>>> constants.unit(u'proton mass')
'kg'
```

`scipy.constants.precision` (*key*)

Relative precision in *physical\_constants* indexed by *key*

**Parameters** **key** : Python string or unicode  
Key in dictionary *physical\_constants*

**Returns** **prec** : float  
Relative precision in *physical\_constants* corresponding to *key*

**See also:**

**codata** Contains the description of *physical\_constants*, which, as a dictionary literal object, does not itself possess a docstring.

**Examples**

```
>>> from scipy import constants
>>> constants.precision(u'proton mass')
1.2555138746605121e-08
```

`scipy.constants.find` (*sub=None, disp=False*)

Return list of *physical\_constant* keys containing a given string.

**Parameters** **sub** : str, unicode  
Sub-string to search keys for. By default, return all keys.

**disp** : bool

**Returns** If True, print the keys that are found, and return None. Otherwise, return the list of keys without printing anything.  
**keys** : list or None  
 If *disp* is False, the list of keys is returned. Otherwise, None is returned.

**See also:**

**codata** Contains the description of *physical\_constants*, which, as a dictionary literal object, does not itself possess a docstring.

**Examples**

```
>>> from scipy.constants import find, physical_constants
```

Which keys in the *physical\_constants* dictionary contain ‘boltzmann’?

```
>>> find('boltzmann')
['Boltzmann constant',
 'Boltzmann constant in Hz/K',
 'Boltzmann constant in eV/K',
 'Boltzmann constant in inverse meters per kelvin',
 'Stefan-Boltzmann constant']
```

Get the constant called ‘Boltzmann constant in Hz/K’:

```
>>> physical_constants['Boltzmann constant in Hz/K']
(20836612000.0, 'Hz K^-1', 12000.0)
```

Find constants with ‘radius’ in the key:

```
>>> find('radius')
['Bohr radius',
 'classical electron radius',
 'deuteron rms charge radius',
 'proton rms charge radius']
>>> physical_constants['classical electron radius']
(2.8179403227e-15, 'm', 1.9e-24)
```

**exception** `scipy.constants.ConstantWarning`  
 Accessing a constant no longer in current CODATA data set

`scipy.constants.physical_constants`  
 Dictionary of physical constants, of the format `physical_constants[name] = (value, unit, uncertainty)`.

Available constants:

alpha particle mass	6.64465723e-27 kg
alpha particle mass energy equivalent	5.971920097e-10 J
alpha particle mass energy equivalent in MeV	3727.379378 MeV
alpha particle mass in u	4.00150617913 u
alpha particle molar mass	0.00400150617913 kg mol <sup>-1</sup>
alpha particle-electron mass ratio	7294.29954136
alpha particle-proton mass ratio	3.97259968907
Angstrom star	1.00001495e-10 m
atomic mass constant	1.66053904e-27 kg

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atomic mass constant energy equivalent	1.492418062e-10 J
atomic mass constant energy equivalent in MeV	931.4940954 MeV
atomic mass unit-electron volt relationship	931494095.4 eV
atomic mass unit-hartree relationship	34231776.902 E_h
atomic mass unit-hertz relationship	2.2523427206e+23 Hz
atomic mass unit-inverse meter relationship	7.5130066166e+14 m <sup>-1</sup>
atomic mass unit-joule relationship	1.492418062e-10 J
atomic mass unit-kelvin relationship	1.08095438e+13 K
atomic mass unit-kilogram relationship	1.66053904e-27 kg
atomic unit of 1st hyperpolarizability	3.206361329e-53 C <sup>3</sup> m <sup>3</sup> J <sup>-2</sup>
atomic unit of 2nd hyperpolarizability	6.235380085e-65 C <sup>4</sup> m <sup>4</sup> J <sup>-3</sup>
atomic unit of action	1.0545718e-34 J s
atomic unit of charge	1.6021766208e-19 C
atomic unit of charge density	1.081202377e+12 C m <sup>-3</sup>
atomic unit of current	0.006623618183 A
atomic unit of electric dipole mom.	8.478353552e-30 C m
atomic unit of electric field	5.142206707e+11 V m <sup>-1</sup>
atomic unit of electric field gradient	9.717362356e+21 V m <sup>-2</sup>
atomic unit of electric polarizability	1.6487772731e-41 C <sup>2</sup> m <sup>2</sup> J <sup>-1</sup>
atomic unit of electric potential	27.21138602 V
atomic unit of electric quadrupole mom.	4.486551484e-40 C m <sup>2</sup>
atomic unit of energy	4.35974465e-18 J
atomic unit of force	8.23872336e-08 N
atomic unit of length	5.2917721067e-11 m
atomic unit of mag. dipole mom.	1.854801999e-23 J T <sup>-1</sup>
atomic unit of mag. flux density	235051.755 T
atomic unit of magnetizability	7.8910365886e-29 J T <sup>-2</sup>
atomic unit of mass	9.10938356e-31 kg
atomic unit of mom.um	1.992851882e-24 kg m s <sup>-1</sup>
atomic unit of permittivity	1.11265005605e-10 F m <sup>-1</sup>
atomic unit of time	2.41888432651e-17 s
atomic unit of velocity	2187691.26277 m s <sup>-1</sup>
Avogadro constant	6.022140857e+23 mol <sup>-1</sup>
Bohr magneton	9.274009994e-24 J T <sup>-1</sup>
Bohr magneton in eV/T	5.7883818012e-05 eV T <sup>-1</sup>
Bohr magneton in Hz/T	13996245042.0 Hz T <sup>-1</sup>
Bohr magneton in inverse meters per tesla	46.68644814 m <sup>-1</sup> T <sup>-1</sup>
Bohr magneton in K/T	0.67171405 K T <sup>-1</sup>
Bohr radius	5.2917721067e-11 m
Boltzmann constant	1.38064852e-23 J K <sup>-1</sup>
Boltzmann constant in eV/K	8.6173303e-05 eV K <sup>-1</sup>
Boltzmann constant in Hz/K	20836612000.0 Hz K <sup>-1</sup>
Boltzmann constant in inverse meters per kelvin	69.503457 m <sup>-1</sup> K <sup>-1</sup>
characteristic impedance of vacuum	376.730313462 ohm
classical electron radius	2.8179403227e-15 m
Compton wavelength	2.4263102367e-12 m
Compton wavelength over 2 pi	3.8615926764e-13 m
conductance quantum	7.748091731e-05 S
conventional value of Josephson constant	4.835979e+14 Hz V <sup>-1</sup>
conventional value of von Klitzing constant	25812.807 ohm

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Cu x unit	1.00207697e-13 m
deuteron g factor	0.8574382311
deuteron mag. mom.	4.33073504e-27 J T <sup>-1</sup>
deuteron mag. mom. to Bohr magneton ratio	0.0004669754554
deuteron mag. mom. to nuclear magneton ratio	0.8574382311
deuteron mass	3.343583719e-27 kg
deuteron mass energy equivalent	3.005063183e-10 J
deuteron mass energy equivalent in MeV	1875.612928 MeV
deuteron mass in u	2.01355321275 u
deuteron molar mass	0.00201355321274 kg mol <sup>-1</sup>
deuteron rms charge radius	2.1413e-15 m
deuteron-electron mag. mom. ratio	-0.0004664345535
deuteron-electron mass ratio	3670.48296785
deuteron-neutron mag. mom. ratio	-0.44820652
deuteron-proton mag. mom. ratio	0.3070122077
deuteron-proton mass ratio	1.99900750087
electric constant	8.85418781762e-12 F m <sup>-1</sup>
electron charge to mass quotient	-1.758820024e+11 C kg <sup>-1</sup>
electron g factor	-2.00231930436
electron gyromag. ratio	1.760859644e+11 s <sup>-1</sup> T <sup>-1</sup>
electron gyromag. ratio over 2 pi	28024.95164 MHz T <sup>-1</sup>
electron mag. mom.	-9.28476462e-24 J T <sup>-1</sup>
electron mag. mom. anomaly	0.00115965218091
electron mag. mom. to Bohr magneton ratio	-1.00115965218
electron mag. mom. to nuclear magneton ratio	-1838.28197234
electron mass	9.10938356e-31 kg
electron mass energy equivalent	8.18710565e-14 J
electron mass energy equivalent in MeV	0.5109989461 MeV
electron mass in u	0.00054857990907 u
electron molar mass	5.4857990907e-07 kg mol <sup>-1</sup>
electron to alpha particle mass ratio	0.00013709335548
electron to shielded helion mag. mom. ratio	864.058257
electron to shielded proton mag. mom. ratio	-658.2275971
electron volt	1.6021766208e-19 J
electron volt-atomic mass unit relationship	1.0735441105e-09 u
electron volt-hartree relationship	0.03674932248 E_h
electron volt-hertz relationship	2.417989262e+14 Hz
electron volt-inverse meter relationship	806554.4005 m <sup>-1</sup>
electron volt-joule relationship	1.6021766208e-19 J
electron volt-kelvin relationship	11604.5221 K
electron volt-kilogram relationship	1.782661907e-36 kg
electron-deuteron mag. mom. ratio	-2143.923499
electron-deuteron mass ratio	0.000272443710748
electron-helion mass ratio	0.000181954307485
electron-muon mag. mom. ratio	206.766988
electron-muon mass ratio	0.0048363317
electron-neutron mag. mom. ratio	960.9205
electron-neutron mass ratio	0.00054386734428
electron-proton mag. mom. ratio	-658.2106866
electron-proton mass ratio	0.000544617021352

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electron-tau mass ratio	0.000287592
electron-triton mass ratio	0.00018192000622
elementary charge	1.6021766208e-19 C
elementary charge over h	2.417989262e+14 A J <sup>-1</sup>
Faraday constant	96485.33289 C mol <sup>-1</sup>
Faraday constant for conventional electric current	96485.3251 C <sub>90</sub> mol <sup>-1</sup>
Fermi coupling constant	1.1663787e-05 GeV <sup>-2</sup>
fine-structure constant	0.0072973525664
first radiation constant	3.74177179e-16 W m <sup>2</sup>
first radiation constant for spectral radiance	1.191042953e-16 W m <sup>2</sup> sr <sup>-1</sup>
Hartree energy	4.35974465e-18 J
Hartree energy in eV	27.21138602 eV
hartree-atomic mass unit relationship	2.9212623197e-08 u
hartree-electron volt relationship	27.21138602 eV
hartree-hertz relationship	6.57968392071e+15 Hz
hartree-inverse meter relationship	21947463.137 m <sup>-1</sup>
hartree-joule relationship	4.35974465e-18 J
hartree-kelvin relationship	315775.13 K
hartree-kilogram relationship	4.850870129e-35 kg
helion g factor	-4.255250616
helion mag. mom.	-1.074617522e-26 J T <sup>-1</sup>
helion mag. mom. to Bohr magneton ratio	-0.001158740958
helion mag. mom. to nuclear magneton ratio	-2.127625308
helion mass	5.0064127e-27 kg
helion mass energy equivalent	4.499539341e-10 J
helion mass energy equivalent in MeV	2808.391586 MeV
helion mass in u	3.01493224673 u
helion molar mass	0.00301493224673 kg mol <sup>-1</sup>
helion-electron mass ratio	5495.88527922
helion-proton mass ratio	2.99315267046
hertz-atomic mass unit relationship	4.4398216616e-24 u
hertz-electron volt relationship	4.135667662e-15 eV
hertz-hartree relationship	1.51982984601e-16 E <sub>h</sub>
hertz-inverse meter relationship	3.33564095198e-09 m <sup>-1</sup>
hertz-joule relationship	6.62607004e-34 J
hertz-kelvin relationship	4.7992447e-11 K
hertz-kilogram relationship	7.372497201e-51 kg
inverse fine-structure constant	137.035999139
inverse meter-atomic mass unit relationship	1.331025049e-15 u
inverse meter-electron volt relationship	1.2398419739e-06 eV
inverse meter-hartree relationship	4.55633525277e-08 E <sub>h</sub>
inverse meter-hertz relationship	299792458.0 Hz
inverse meter-joule relationship	1.986445824e-25 J
inverse meter-kelvin relationship	0.0143877736 K
inverse meter-kilogram relationship	2.210219057e-42 kg
inverse of conductance quantum	12906.4037278 ohm
Josephson constant	4.835978525e+14 Hz V <sup>-1</sup>
joule-atomic mass unit relationship	6700535363.0 u
joule-electron volt relationship	6.241509126e+18 eV
joule-hartree relationship	2.293712317e+17 E <sub>h</sub>

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joule-hertz relationship	1.509190205e+33 Hz
joule-inverse meter relationship	5.034116651e+24 m <sup>-1</sup>
joule-kelvin relationship	7.2429731e+22 K
joule-kilogram relationship	1.11265005605e-17 kg
kelvin-atomic mass unit relationship	9.2510842e-14 u
kelvin-electron volt relationship	8.6173303e-05 eV
kelvin-hartree relationship	3.1668105e-06 E <sub>h</sub>
kelvin-hertz relationship	20836612000.0 Hz
kelvin-inverse meter relationship	69.503457 m <sup>-1</sup>
kelvin-joule relationship	1.38064852e-23 J
kelvin-kilogram relationship	1.53617865e-40 kg
kilogram-atomic mass unit relationship	6.022140857e+26 u
kilogram-electron volt relationship	5.60958865e+35 eV
kilogram-hartree relationship	2.061485823e+34 E <sub>h</sub>
kilogram-hertz relationship	1.356392512e+50 Hz
kilogram-inverse meter relationship	4.524438411e+41 m <sup>-1</sup>
kilogram-joule relationship	8.98755178737e+16 J
kilogram-kelvin relationship	6.5096595e+39 K
lattice parameter of silicon	5.431020504e-10 m
Loschmidt constant (273.15 K, 100 kPa)	2.6516467e+25 m <sup>-3</sup>
Loschmidt constant (273.15 K, 101.325 kPa)	2.6867811e+25 m <sup>-3</sup>
mag. constant	1.25663706144e-06 N A <sup>-2</sup>
mag. flux quantum	2.067833831e-15 Wb
Mo x unit	1.00209952e-13 m
molar gas constant	8.3144598 J mol <sup>-1</sup> K <sup>-1</sup>
molar mass constant	0.001 kg mol <sup>-1</sup>
molar mass of carbon-12	0.012 kg mol <sup>-1</sup>
molar Planck constant	3.990312711e-10 J s mol <sup>-1</sup>
molar Planck constant times c	0.119626565582 J m mol <sup>-1</sup>
molar volume of ideal gas (273.15 K, 100 kPa)	0.022710947 m <sup>3</sup> mol <sup>-1</sup>
molar volume of ideal gas (273.15 K, 101.325 kPa)	0.022413962 m <sup>3</sup> mol <sup>-1</sup>
molar volume of silicon	1.205883214e-05 m <sup>3</sup> mol <sup>-1</sup>
muon Compton wavelength	1.173444111e-14 m
muon Compton wavelength over 2 pi	1.867594308e-15 m
muon g factor	-2.0023318418
muon mag. mom.	-4.49044826e-26 J T <sup>-1</sup>
muon mag. mom. anomaly	0.00116592089
muon mag. mom. to Bohr magneton ratio	-0.00484197048
muon mag. mom. to nuclear magneton ratio	-8.89059705
muon mass	1.883531594e-28 kg
muon mass energy equivalent	1.692833774e-11 J
muon mass energy equivalent in MeV	105.6583745 MeV
muon mass in u	0.1134289257 u
muon molar mass	0.0001134289257 kg mol <sup>-1</sup>
muon-electron mass ratio	206.7682826
muon-neutron mass ratio	0.1124545167
muon-proton mag. mom. ratio	-3.183345142
muon-proton mass ratio	0.1126095262
muon-tau mass ratio	0.0594649
natural unit of action	1.0545718e-34 J s

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natural unit of action in eV s	6.582119514e-16 eV s
natural unit of energy	8.18710565e-14 J
natural unit of energy in MeV	0.5109989461 MeV
natural unit of length	3.8615926764e-13 m
natural unit of mass	9.10938356e-31 kg
natural unit of mom.um	2.730924488e-22 kg m s <sup>-1</sup>
natural unit of mom.um in MeV/c	0.5109989461 MeV/c
natural unit of time	1.28808866712e-21 s
natural unit of velocity	299792458.0 m s <sup>-1</sup>
neutron Compton wavelength	1.31959090481e-15 m
neutron Compton wavelength over 2 pi	2.1001941536e-16 m
neutron g factor	-3.82608545
neutron gyromag. ratio	183247172.0 s <sup>-1</sup> T <sup>-1</sup>
neutron gyromag. ratio over 2 pi	29.1646933 MHz T <sup>-1</sup>
neutron mag. mom.	-9.662365e-27 J T <sup>-1</sup>
neutron mag. mom. to Bohr magneton ratio	-0.00104187563
neutron mag. mom. to nuclear magneton ratio	-1.91304273
neutron mass	1.674927471e-27 kg
neutron mass energy equivalent	1.505349739e-10 J
neutron mass energy equivalent in MeV	939.5654133 MeV
neutron mass in u	1.00866491588 u
neutron molar mass	0.00100866491588 kg mol <sup>-1</sup>
neutron to shielded proton mag. mom. ratio	-0.68499694
neutron-electron mag. mom. ratio	0.00104066882
neutron-electron mass ratio	1838.68366158
neutron-muon mass ratio	8.89248408
neutron-proton mag. mom. ratio	-0.68497934
neutron-proton mass difference	2.30557377e-30
neutron-proton mass difference energy equivalent	2.07214637e-13
neutron-proton mass difference energy equivalent in MeV	1.29333205
neutron-proton mass difference in u	0.001388449
neutron-proton mass ratio	1.00137841898
neutron-tau mass ratio	0.52879
Newtonian constant of gravitation	6.67408e-11 m <sup>3</sup> kg <sup>-1</sup> s <sup>-2</sup>
Newtonian constant of gravitation over h-bar c	6.70861e-39 (GeV/c <sup>2</sup> ) <sup>-2</sup>
nuclear magneton	5.050783699e-27 J T <sup>-1</sup>
nuclear magneton in eV/T	3.152451255e-08 eV T <sup>-1</sup>
nuclear magneton in inverse meters per tesla	0.02542623432 m <sup>-1</sup> T <sup>-1</sup>
nuclear magneton in K/T	0.0003658269 K T <sup>-1</sup>
nuclear magneton in MHz/T	7.622593285 MHz T <sup>-1</sup>
Planck constant	6.62607004e-34 J s
Planck constant in eV s	4.135667662e-15 eV s
Planck constant over 2 pi	1.0545718e-34 J s
Planck constant over 2 pi in eV s	6.582119514e-16 eV s
Planck constant over 2 pi times c in MeV fm	197.3269788 MeV fm
Planck length	1.616229e-35 m
Planck mass	2.17647e-08 kg
Planck mass energy equivalent in GeV	1.22091e+19 GeV
Planck temperature	1.416808e+32 K
Planck time	5.39116e-44 s

Continued on next page

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proton charge to mass quotient	95788332.26 C kg <sup>-1</sup>
proton Compton wavelength	1.32140985396e-15 m
proton Compton wavelength over 2 pi	2.10308910109e-16 m
proton g factor	5.585694702
proton gyromag. ratio	267522190.0 s <sup>-1</sup> T <sup>-1</sup>
proton gyromag. ratio over 2 pi	42.57747892 MHz T <sup>-1</sup>
proton mag. mom.	1.4106067873e-26 J T <sup>-1</sup>
proton mag. mom. to Bohr magneton ratio	0.0015210322053
proton mag. mom. to nuclear magneton ratio	2.7928473508
proton mag. shielding correction	2.5691e-05
proton mass	1.672621898e-27 kg
proton mass energy equivalent	1.503277593e-10 J
proton mass energy equivalent in MeV	938.2720813 MeV
proton mass in u	1.00727646688 u
proton molar mass	0.00100727646688 kg mol <sup>-1</sup>
proton rms charge radius	8.751e-16 m
proton-electron mass ratio	1836.15267389
proton-muon mass ratio	8.88024338
proton-neutron mag. mom. ratio	-1.45989805
proton-neutron mass ratio	0.99862347844
proton-tau mass ratio	0.528063
quantum of circulation	0.00036369475486 m <sup>2</sup> s <sup>-1</sup>
quantum of circulation times 2	0.00072738950972 m <sup>2</sup> s <sup>-1</sup>
Rydberg constant	10973731.5685 m <sup>-1</sup>
Rydberg constant times c in Hz	3.28984196036e+15 Hz
Rydberg constant times hc in eV	13.605693009 eV
Rydberg constant times hc in J	2.179872325e-18 J
Sackur-Tetrode constant (1 K, 100 kPa)	-1.1517084
Sackur-Tetrode constant (1 K, 101.325 kPa)	-1.1648714
second radiation constant	0.0143877736 m K
shielded helion gyromag. ratio	203789458.5 s <sup>-1</sup> T <sup>-1</sup>
shielded helion gyromag. ratio over 2 pi	32.43409966 MHz T <sup>-1</sup>
shielded helion mag. mom.	-1.07455308e-26 J T <sup>-1</sup>
shielded helion mag. mom. to Bohr magneton ratio	-0.001158671471
shielded helion mag. mom. to nuclear magneton ratio	-2.12749772
shielded helion to proton mag. mom. ratio	-0.7617665603
shielded helion to shielded proton mag. mom. ratio	-0.7617861313
shielded proton gyromag. ratio	267515317.1 s <sup>-1</sup> T <sup>-1</sup>
shielded proton gyromag. ratio over 2 pi	42.57638507 MHz T <sup>-1</sup>
shielded proton mag. mom.	1.410570547e-26 J T <sup>-1</sup>
shielded proton mag. mom. to Bohr magneton ratio	0.001520993128
shielded proton mag. mom. to nuclear magneton ratio	2.7927756
speed of light in vacuum	299792458.0 m s <sup>-1</sup>
standard acceleration of gravity	9.80665 m s <sup>-2</sup>
standard atmosphere	101325.0 Pa
standard-state pressure	100000.0 Pa
Stefan-Boltzmann constant	5.670367e-08 W m <sup>-2</sup> K <sup>-4</sup>
tau Compton wavelength	6.97787e-16 m
tau Compton wavelength over 2 pi	1.11056e-16 m
tau mass	3.16747e-27 kg

Continued on next page

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tau mass energy equivalent	2.84678e-10 J
tau mass energy equivalent in MeV	1776.82 MeV
tau mass in u	1.90749 u
tau molar mass	0.00190749 kg mol <sup>-1</sup>
tau-electron mass ratio	3477.15
tau-muon mass ratio	16.8167
tau-neutron mass ratio	1.89111
tau-proton mass ratio	1.89372
Thomson cross section	6.6524587158e-29 m <sup>2</sup>
triton g factor	5.95792492
triton mag. mom.	1.504609503e-26 J T <sup>-1</sup>
triton mag. mom. to Bohr magneton ratio	0.0016223936616
triton mag. mom. to nuclear magneton ratio	2.97896246
triton mass	5.007356665e-27 kg
triton mass energy equivalent	4.500387735e-10 J
triton mass energy equivalent in MeV	2808.921112 MeV
triton mass in u	3.01550071632 u
triton molar mass	0.00301550071632 kg mol <sup>-1</sup>
triton-electron mass ratio	5496.92153588
triton-proton mass ratio	2.99371703348
unified atomic mass unit	1.66053904e-27 kg
von Klitzing constant	25812.8074555 ohm
weak mixing angle	0.2223
Wien frequency displacement law constant	58789238000.0 Hz K <sup>-1</sup>
Wien wavelength displacement law constant	0.0028977729 m K
{220} lattice spacing of silicon	1.920155714e-10 m

### 5.4.3 Units

#### SI prefixes

yotta	10 <sup>24</sup>
zetta	10 <sup>21</sup>
exa	10 <sup>18</sup>
peta	10 <sup>15</sup>
tera	10 <sup>12</sup>
giga	10 <sup>9</sup>
mega	10 <sup>6</sup>
kilo	10 <sup>3</sup>
hecto	10 <sup>2</sup>
deka	10 <sup>1</sup>
deci	10 <sup>-1</sup>
centi	10 <sup>-2</sup>
milli	10 <sup>-3</sup>
micro	10 <sup>-6</sup>
nano	10 <sup>-9</sup>
pico	10 <sup>-12</sup>
femto	10 <sup>-15</sup>
atto	10 <sup>-18</sup>
zepto	10 <sup>-21</sup>

## Binary prefixes

kibi	2 <sup>10</sup>
mebi	2 <sup>20</sup>
gibi	2 <sup>30</sup>
tebi	2 <sup>40</sup>
pebi	2 <sup>50</sup>
exbi	2 <sup>60</sup>
zebi	2 <sup>70</sup>
yobi	2 <sup>80</sup>

## Mass

gram	10 <sup>-3</sup> kg
metric_ton	10 <sup>3</sup> kg
grain	one grain in kg
lb	one pound (avoirdupois) in kg
pound	one pound (avoirdupois) in kg
blob	one inch version of a slug in kg (added in 1.0.0)
slinch	one inch version of a slug in kg (added in 1.0.0)
slug	one slug in kg (added in 1.0.0)
oz	one ounce in kg
ounce	one ounce in kg
stone	one stone in kg
grain	one grain in kg
long_ton	one long ton in kg
short_ton	one short ton in kg
troy_ounce	one Troy ounce in kg
troy_pound	one Troy pound in kg
carat	one carat in kg
m_u	atomic mass constant (in kg)
u	atomic mass constant (in kg)
atomic_mass	atomic mass constant (in kg)

## Angle

degree	degree in radians
arcmin	arc minute in radians
arcminute	arc minute in radians
arcsec	arc second in radians
arcsecond	arc second in radians

## Time

minute	one minute in seconds
hour	one hour in seconds
day	one day in seconds
week	one week in seconds
year	one year (365 days) in seconds
Julian_year	one Julian year (365.25 days) in seconds

## Length

inch	one inch in meters
foot	one foot in meters
yard	one yard in meters
mile	one mile in meters
mil	one mil in meters
pt	one point in meters
point	one point in meters
survey_foot	one survey foot in meters
survey_mile	one survey mile in meters
nautical_mile	one nautical mile in meters
fermi	one Fermi in meters
angstrom	one Angstrom in meters
micron	one micron in meters
au	one astronomical unit in meters
astronomical_unit	one astronomical unit in meters
light_year	one light year in meters
parsec	one parsec in meters

## Pressure

atm	standard atmosphere in pascals
atmosphere	standard atmosphere in pascals
bar	one bar in pascals
torr	one torr (mmHg) in pascals
mmHg	one torr (mmHg) in pascals
psi	one psi in pascals

## Area

hectare	one hectare in square meters
acre	one acre in square meters

## Volume

liter	one liter in cubic meters
litre	one liter in cubic meters
gallon	one gallon (US) in cubic meters
gallon_US	one gallon (US) in cubic meters
gallon_imp	one gallon (UK) in cubic meters
fluid_ounce	one fluid ounce (US) in cubic meters
fluid_ounce_US	one fluid ounce (US) in cubic meters
fluid_ounce_imp	one fluid ounce (UK) in cubic meters
bbl	one barrel in cubic meters
barrel	one barrel in cubic meters

## Speed

kmh	kilometers per hour in meters per second
mph	miles per hour in meters per second
mach	one Mach (approx., at 15 C, 1 atm) in meters per second
speed_of_sound	one Mach (approx., at 15 C, 1 atm) in meters per second
knot	one knot in meters per second

## Temperature

zero_Celsius	zero of Celsius scale in Kelvin
degree_Fahrenheit	one Fahrenheit (only differences) in Kelvins

`convert_temperature(val, old_scale, new_scale)` Convert from a temperature scale to another one among Celsius, Kelvin, Fahrenheit and Rankine scales.

---

`scipy.constants.convert_temperature` (*val, old\_scale, new\_scale*)

Convert from a temperature scale to another one among Celsius, Kelvin, Fahrenheit and Rankine scales.

**Parameters** **val** : array\_like

Value(s) of the temperature(s) to be converted expressed in the original scale.

**old\_scale**: str

Specifies as a string the original scale from which the temperature value(s) will be converted. Supported scales are Celsius ('Celsius', 'celsius', 'C' or 'c'), Kelvin ('Kelvin', 'kelvin', 'K', 'k'), Fahrenheit ('Fahrenheit', 'fahrenheit', 'F' or 'f') and Rankine ('Rankine', 'rankine', 'R', 'r').

**new\_scale**: str

Specifies as a string the new scale to which the temperature value(s) will be converted. Supported scales are Celsius ('Celsius', 'celsius', 'C' or 'c'), Kelvin ('Kelvin', 'kelvin', 'K', 'k'), Fahrenheit ('Fahrenheit', 'fahrenheit', 'F' or 'f') and Rankine ('Rankine', 'rankine', 'R', 'r').

**Returns** **res** : float or array of floats

Value(s) of the converted temperature(s) expressed in the new scale.

### Notes

New in version 0.18.0.

### Examples

```
>>> from scipy.constants import convert_temperature
>>> convert_temperature(np.array([-40, 40.0]), 'Celsius', 'Kelvin')
array([ 233.15,  313.15])
```

## Energy

eV	one electron volt in Joules
electron_volt	one electron volt in Joules
calorie	one calorie (thermochemical) in Joules
calorie_th	one calorie (thermochemical) in Joules
calorie_IT	one calorie (International Steam Table calorie, 1956) in Joules
erg	one erg in Joules
Btu	one British thermal unit (International Steam Table) in Joules
Btu_IT	one British thermal unit (International Steam Table) in Joules
Btu_th	one British thermal unit (thermochemical) in Joules
ton_TNT	one ton of TNT in Joules

## Power

hp	one horsepower in watts
horsepower	one horsepower in watts

## Force

dyn	one dyne in newtons
dyne	one dyne in newtons
lbf	one pound force in newtons
pound_force	one pound force in newtons
kgf	one kilogram force in newtons
kilogram_force	one kilogram force in newtons

## Optics

<code>lambda2nu(lambda_)</code>	Convert wavelength to optical frequency
<code>nu2lambda(nu)</code>	Convert optical frequency to wavelength.

`scipy.constants.lambda2nu(lambda_)`

Convert wavelength to optical frequency

**Parameters** **lambda\_** : array\_like  
Wavelength(s) to be converted.

**Returns** **nu** : float or array of floats  
Equivalent optical frequency.

### Notes

Computes  $\nu = c / \lambda$  where  $c = 299792458.0$ , i.e., the (vacuum) speed of light in meters/second.

### Examples

```
>>> from scipy.constants import lambda2nu, speed_of_light
>>> lambda2nu(np.array([1, speed_of_light]))
array([ 2.99792458e+08,  1.00000000e+00])
```

`scipy.constants.nu2lambda` (*nu*)

Convert optical frequency to wavelength.

**Parameters** `nu` : array\_like  
Optical frequency to be converted.

**Returns** `lambda` : float or array of floats  
Equivalent wavelength(s).

**Notes**

Computes  $\lambda = c / \nu$  where  $c = 299792458.0$ , i.e., the (vacuum) speed of light in meters/second.

**Examples**

```
>>> from scipy.constants import nu2lambda, speed_of_light
>>> nu2lambda(np.array((1, speed_of_light)))
array([ 2.99792458e+08,  1.00000000e+00])
```

## 5.4.4 References

## 5.5 Discrete Fourier transforms (`scipy.fftpack`)

### 5.5.1 Fast Fourier Transforms (FFTs)

<code>fft(x[, n, axis, overwrite_x])</code>	Return discrete Fourier transform of real or complex sequence.
<code>ifft(x[, n, axis, overwrite_x])</code>	Return discrete inverse Fourier transform of real or complex sequence.
<code>fft2(x[, shape, axes, overwrite_x])</code>	2-D discrete Fourier transform.
<code>ifft2(x[, shape, axes, overwrite_x])</code>	2-D discrete inverse Fourier transform of real or complex sequence.
<code>fftn(x[, shape, axes, overwrite_x])</code>	Return multidimensional discrete Fourier transform.
<code>ifftn(x[, shape, axes, overwrite_x])</code>	Return inverse multi-dimensional discrete Fourier transform of arbitrary type sequence <i>x</i> .
<code>rfft(x[, n, axis, overwrite_x])</code>	Discrete Fourier transform of a real sequence.
<code>irfft(x[, n, axis, overwrite_x])</code>	Return inverse discrete Fourier transform of real sequence <i>x</i> .
<code>dct(x[, type, n, axis, norm, overwrite_x])</code>	Return the Discrete Cosine Transform of arbitrary type sequence <i>x</i> .
<code>idct(x[, type, n, axis, norm, overwrite_x])</code>	Return the Inverse Discrete Cosine Transform of an arbitrary type sequence.
<code>dctn(x[, type, shape, axes, norm, overwrite_x])</code>	Return multidimensional Discrete Cosine Transform along the specified axes.
<code>idctn(x[, type, shape, axes, norm, overwrite_x])</code>	Return multidimensional Discrete Cosine Transform along the specified axes.
<code>dst(x[, type, n, axis, norm, overwrite_x])</code>	Return the Discrete Sine Transform of arbitrary type sequence <i>x</i> .
<code>idst(x[, type, n, axis, norm, overwrite_x])</code>	Return the Inverse Discrete Sine Transform of an arbitrary type sequence.
<code>dstn(x[, type, shape, axes, norm, overwrite_x])</code>	Return multidimensional Discrete Sine Transform along the specified axes.

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<code>idstn(x[, type, shape, axes, norm, overwrite_x])</code>	Return multidimensional Discrete Sine Transform along the specified axes.
---	---

`scipy.fftpack.fft(x, n=None, axis=-1, overwrite_x=False)`

Return discrete Fourier transform of real or complex sequence.

The returned complex array contains  $y(0), y(1), \dots, y(n-1)$  where

$$y(j) = (x * \exp(-2\pi i \sqrt{-1} * j * \text{np.arange}(n) / n)).\text{sum}()$$

**Parameters** `x`: array\_like

Array to Fourier transform.

`n`: int, optional

Length of the Fourier transform. If  $n < x.\text{shape}[\text{axis}]$ ,  $x$  is truncated. If  $n > x.\text{shape}[\text{axis}]$ ,  $x$  is zero-padded. The default results in  $n = x.\text{shape}[\text{axis}]$ .

`axis`: int, optional

Axis along which the fft's are computed; the default is over the last axis (i.e., `axis=-1`).

`overwrite_x`: bool, optional

If True, the contents of  $x$  can be destroyed; the default is False.

**Returns**

`z`: complex ndarray

with the elements:

$[y(0), y(1), \dots, y(n/2), y(1-n/2), \dots, y(-1)]$	<b>if <math>n</math> is even</b>
$[y(0), y(1), \dots, y((n-1)/2), y(-(n-1)/2), \dots, y(-1)]$	<b>if <math>n</math> is odd</b>

where:

$y(j) = \sum_{k=0}^{n-1} x[k] * \exp(-\sqrt{-1} * j * k * 2\pi / n), j = 0..$
$\leftarrow n-1$

**See also:**

**ifft** Inverse FFT

**rfft** FFT of a real sequence

**Notes**

The packing of the result is “standard”: If  $A = \text{fft}(a, n)$ , then  $A[0]$  contains the zero-frequency term,  $A[1:n/2]$  contains the positive-frequency terms, and  $A[n/2:]$  contains the negative-frequency terms, in order of decreasingly negative frequency. So for an 8-point transform, the frequencies of the result are  $[0, 1, 2, 3, -4, -3, -2, -1]$ . To rearrange the fft output so that the zero-frequency component is centered, like  $[-4, -3, -2, -1, 0, 1, 2, 3]$ , use `fftshift`.

Both single and double precision routines are implemented. Half precision inputs will be converted to single precision. Non floating-point inputs will be converted to double precision. Long-double precision inputs are not supported.

This function is most efficient when  $n$  is a power of two, and least efficient when  $n$  is prime.

Note that if  $x$  is real-valued then  $A[j] == A[n-j].\text{conjugate}()$ . If  $x$  is real-valued and  $n$  is even then  $A[n/2]$  is real.

If the data type of  $x$  is real, a “real FFT” algorithm is automatically used, which roughly halves the computation time. To increase efficiency a little further, use `rfft`, which does the same calculation, but only outputs half of the symmetrical spectrum. If the data is both real and symmetrical, the `dct` can again double the efficiency, by generating half of the spectrum from half of the signal.

### Examples

```
>>> from scipy.fftpack import fft, ifft
>>> x = np.arange(5)
>>> np.allclose(fft(ifft(x)), x, atol=1e-15) # within numerical accuracy.
True
```

`scipy.fftpack.ifft(x, n=None, axis=-1, overwrite_x=False)`

Return discrete inverse Fourier transform of real or complex sequence.

The returned complex array contains  $y(0), y(1), \dots, y(n-1)$  where

$$y(j) = (x * \exp(2\pi i \sqrt{-1} * j * \text{np.arange}(n) / n)) . \text{mean}().$$

**Parameters**

- x** : array\_like  
Transformed data to invert.
- n** : int, optional  
Length of the inverse Fourier transform. If  $n < x.\text{shape}[\text{axis}]$ ,  $x$  is truncated. If  $n > x.\text{shape}[\text{axis}]$ ,  $x$  is zero-padded. The default results in  $n = x.\text{shape}[\text{axis}]$ .
- axis** : int, optional  
Axis along which the ifft's are computed; the default is over the last axis (i.e.,  $\text{axis}=-1$ ).
- overwrite\_x** : bool, optional  
If True, the contents of  $x$  can be destroyed; the default is False.

**Returns**

- ifft** : ndarray of floats  
The inverse discrete Fourier transform.

**See also:**

**fft** Forward FFT

### Notes

Both single and double precision routines are implemented. Half precision inputs will be converted to single precision. Non floating-point inputs will be converted to double precision. Long-double precision inputs are not supported.

This function is most efficient when  $n$  is a power of two, and least efficient when  $n$  is prime.

If the data type of  $x$  is real, a “real IFFT” algorithm is automatically used, which roughly halves the computation time.

`scipy.fftpack.fft2(x, shape=None, axes=(-2, -1), overwrite_x=False)`

2-D discrete Fourier transform.

Return the two-dimensional discrete Fourier transform of the 2-D argument  $x$ .

**See also:**

**fftn** for detailed information.

`scipy.fftpack.ifft2(x, shape=None, axes=(-2, -1), overwrite_x=False)`

2-D discrete inverse Fourier transform of real or complex sequence.

Return inverse two-dimensional discrete Fourier transform of arbitrary type sequence  $x$ .

See `ifft` for more information.

**See also:**

*fft2, ifft*

`scipy.fftpack.fftn(x, shape=None, axes=None, overwrite_x=False)`

Return multidimensional discrete Fourier transform.

The returned array contains:

```
Y[j_1, ..., j_d] = sum[k_1=0..n_1-1, ..., k_d=0..n_d-1]
  x[k_1, ..., k_d] * prod[i=1..d] exp(-sqrt(-1)*2*pi/n_i * j_i * k_i)
```

where  $d = \text{len}(x.\text{shape})$  and  $n = x.\text{shape}$ .

**Parameters** **x** : array\_like

The (n-dimensional) array to transform.

**shape** : tuple of ints, optional

The shape of the result. If both *shape* and *axes* (see below) are None, *shape* is *x*.shape; if *shape* is None but *axes* is not None, then *shape* is `scipy.take(x.shape, axes, axis=0)`. If `shape[i] > x.shape[i]`, the *i*-th dimension is padded with zeros. If `shape[i] < x.shape[i]`, the *i*-th dimension is truncated to length `shape[i]`.

**axes** : array\_like of ints, optional

The axes of *x* (y if *shape* is not None) along which the transform is applied.

**overwrite\_x** : bool, optional

If True, the contents of *x* can be destroyed. Default is False.

**Returns** **y** : complex-valued n-dimensional numpy array

The (n-dimensional) DFT of the input array.

**See also:**

*ifftn*

**Notes**

If *x* is real-valued, then `y[..., j_i, ...] == y[..., n_i-j_i, ...].conjugate()`.

Both single and double precision routines are implemented. Half precision inputs will be converted to single precision. Non floating-point inputs will be converted to double precision. Long-double precision inputs are not supported.

**Examples**

```
>>> from scipy.fftpack import fftn, ifftn
>>> y = (-np.arange(16), 8 - np.arange(16), np.arange(16))
>>> np.allclose(y, fftn(ifftn(y)))
True
```

`scipy.fftpack.ifftn(x, shape=None, axes=None, overwrite_x=False)`

Return inverse multi-dimensional discrete Fourier transform of arbitrary type sequence *x*.

The returned array contains:

```
y[j_1, ..., j_d] = 1/p * sum[k_1=0..n_1-1, ..., k_d=0..n_d-1]
  x[k_1, ..., k_d] * prod[i=1..d] exp(sqrt(-1)*2*pi/n_i * j_i * k_i)
```

where  $d = \text{len}(x.\text{shape})$ ,  $n = x.\text{shape}$ , and  $p = \text{prod}[i=1..d] n_i$ .

For description of parameters see *fftn*.

**See also:**

**fftn** for detailed information.

`scipy.fftpack.rfft(x, n=None, axis=-1, overwrite_x=False)`

Discrete Fourier transform of a real sequence.

**Parameters**

- x** : array\_like, real-valued  
The data to transform.
- n** : int, optional  
Defines the length of the Fourier transform. If *n* is not specified (the default) then  $n = x.shape[axis]$ . If  $n < x.shape[axis]$ , *x* is truncated, if  $n > x.shape[axis]$ , *x* is zero-padded.
- axis** : int, optional  
The axis along which the transform is applied. The default is the last axis.
- overwrite\_x** : bool, optional  
If set to true, the contents of *x* can be overwritten. Default is False.

**Returns**

- z** : real ndarray  
The returned real array contains:

$[y(0), \text{Re}(y(1)), \text{Im}(y(1)), \dots, \text{Re}(y(n/2))]$	<b>if <i>n</i> is</b>
$\leftarrow \text{even}$	
$[y(0), \text{Re}(y(1)), \text{Im}(y(1)), \dots, \text{Re}(y(n/2)), \text{Im}(y(n/2))]$	<b>if <i>n</i> is odd</b>

where:

$y(j) = \sum_{k=0..n-1} x[k] * \exp(-\text{sqrt}(-1)*j*k*2*\text{pi}/n)$ $j = 0..n-1$
---

**See also:**

`fft`, `irfft`, `numpy.fft.rfft`

**Notes**

Within numerical accuracy,  $y == \text{rfft}(\text{irfft}(y))$ .

Both single and double precision routines are implemented. Half precision inputs will be converted to single precision. Non floating-point inputs will be converted to double precision. Long-double precision inputs are not supported.

To get an output with a complex datatype, consider using the related function `numpy.fft.rfft`.

**Examples**

```

>>> from scipy.fftpack import fft, rfft
>>> a = [9, -9, 1, 3]
>>> fft(a)
array([ 4.+0.j,  8.+12.j, 16.+0.j,  8.-12.j])
>>> rfft(a)
array([ 4.,  8., 12., 16.])
    
```

`scipy.fftpack.irfft(x, n=None, axis=-1, overwrite_x=False)`

Return inverse discrete Fourier transform of real sequence *x*.

The contents of *x* are interpreted as the output of the `rfft` function.

**Parameters**

- x** : array\_like  
Transformed data to invert.
- n** : int, optional  
Length of the inverse Fourier transform. If  $n < x.shape[axis]$ , *x* is truncated. If  $n > x.shape[axis]$ , *x* is zero-padded. The default results in  $n = x.shape[axis]$ .

**axis** : int, optional

Axis along which the `ifft`'s are computed; the default is over the last axis (i.e., `axis=-1`).

**overwrite\_x** : bool, optional

If True, the contents of `x` can be destroyed; the default is False.

**Returns** **irfft** : ndarray of floats

The inverse discrete Fourier transform.

**See also:**

`rfft`, `ifft`, `numpy.fft.irfft`

**Notes**

The returned real array contains:

$$[y(0), y(1), \dots, y(n-1)]$$

where for `n` is even:

$$y(j) = 1/n \left( \sum_{k=1..n/2-1} (x[2*k-1] + \sqrt{-1} * x[2*k]) * \exp(\sqrt{-1} * j * k * 2 * \pi / n) + \text{c.c.} + x[0] + (-1)**(j) * x[n-1] \right)$$

and for `n` is odd:

$$y(j) = 1/n \left( \sum_{k=1..(n-1)/2} (x[2*k-1] + \sqrt{-1} * x[2*k]) * \exp(\sqrt{-1} * j * k * 2 * \pi / n) + \text{c.c.} + x[0] \right)$$

`c.c.` denotes complex conjugate of preceding expression.

For details on input parameters, see `rfft`.

To process (conjugate-symmetric) frequency-domain data with a complex datatype, consider using the related function `numpy.fft.irfft`.

`scipy.fftpack.dct` (`x`, `type=2`, `n=None`, `axis=-1`, `norm=None`, `overwrite_x=False`)

Return the Discrete Cosine Transform of arbitrary type sequence `x`.

**Parameters** **x** : array\_like

The input array.

**type** : {1, 2, 3}, optional

Type of the DCT (see Notes). Default type is 2.

**n** : int, optional

Length of the transform. If `n < x.shape[axis]`, `x` is truncated. If `n > x.shape[axis]`, `x` is zero-padded. The default results in `n = x.shape[axis]`.

**axis** : int, optional

Axis along which the `dct` is computed; the default is over the last axis (i.e., `axis=-1`).

**norm** : {None, 'ortho'}, optional

Normalization mode (see Notes). Default is None.

**overwrite\_x** : bool, optional

If True, the contents of `x` can be destroyed; the default is False.

**Returns** **y** : ndarray of real

The transformed input array.

**See also:**

**idct** Inverse DCT

**Notes**

For a single dimension array  $x$ , `dct(x, norm='ortho')` is equal to MATLAB `dct(x)`.

There are theoretically 8 types of the DCT, only the first 3 types are implemented in `scipy`. ‘The’ DCT generally refers to DCT type 2, and ‘the’ Inverse DCT generally refers to DCT type 3.

**Type I**

There are several definitions of the DCT-I; we use the following (for `norm=None`):

$$y[k] = x[0] + (-1)^{**k} x[N-1] + 2 * \sum_{n=1}^{N-2} x[n] * \cos(\pi * k * n / (N-1))$$

Only `None` is supported as normalization mode for DCT-I. Note also that the DCT-I is only supported for input size  $> 1$

**Type II**

There are several definitions of the DCT-II; we use the following (for `norm=None`):

$$y[k] = 2 * \sum_{n=0}^{N-1} x[n] * \cos(\pi * k * (2n+1) / (2 * N)), \quad 0 \leq k < N.$$

If `norm='ortho'`,  $y[k]$  is multiplied by a scaling factor  $f$ :

$$f = \sqrt{1/(4 * N)} \quad \text{if } k = 0, \\ f = \sqrt{1/(2 * N)} \quad \text{otherwise.}$$

Which makes the corresponding matrix of coefficients orthonormal ( $OO^T = Id$ ).

**Type III**

There are several definitions, we use the following (for `norm=None`):

$$y[k] = x[0] + 2 * \sum_{n=1}^{N-1} x[n] * \cos(\pi * (k+0.5) * n / N), \quad 0 \leq k < N.$$

or, for `norm='ortho'` and  $0 \leq k < N$ :

$$y[k] = x[0] / \sqrt{N} + \sqrt{2/N} * \sum_{n=1}^{N-1} x[n] * \cos(\pi * (k+0.5) * n / N)$$

The (unnormalized) DCT-III is the inverse of the (unnormalized) DCT-II, up to a factor  $2N$ . The orthonormalized DCT-III is exactly the inverse of the orthonormalized DCT-II.

**References**

[R47], [R48]

**Examples**

The Type 1 DCT is equivalent to the FFT (though faster) for real, even-symmetrical inputs. The output is also real and even-symmetrical. Half of the FFT input is used to generate half of the FFT output:

```
>>> from scipy.fftpack import fft, dct
>>> fft(np.array([4., 3., 5., 10., 5., 3.])).real
array([ 30., -8.,  6., -2.,  6., -8.]
```

```
>>> dct(np.array([4., 3., 5., 10.]), 1)
array([ 30., -8.,  6., -2.]
```

`scipy.fftpack.idct(x, type=2, n=None, axis=-1, norm=None, overwrite_x=False)`

Return the Inverse Discrete Cosine Transform of an arbitrary type sequence.

**Parameters**

- x** : array\_like  
The input array.
- type** : {1, 2, 3}, optional  
Type of the DCT (see Notes). Default type is 2.
- n** : int, optional  
Length of the transform. If  $n < x.shape[axis]$ ,  $x$  is truncated. If  $n > x.shape[axis]$ ,  $x$  is zero-padded. The default results in  $n = x.shape[axis]$ .
- axis** : int, optional  
Axis along which the idct is computed; the default is over the last axis (i.e.,  $axis=-1$ ).
- norm** : {None, 'ortho'}, optional  
Normalization mode (see Notes). Default is None.
- overwrite\_x** : bool, optional  
If True, the contents of  $x$  can be destroyed; the default is False.

**Returns**

- idct** : ndarray of real  
The transformed input array.

See also:

**dct** Forward DCT

#### Notes

For a single dimension array  $x$ , `idct(x, norm='ortho')` is equal to MATLAB `idct(x)`.

'The' IDCT is the IDCT of type 2, which is the same as DCT of type 3.

IDCT of type 1 is the DCT of type 1, IDCT of type 2 is the DCT of type 3, and IDCT of type 3 is the DCT of type 2. For the definition of these types, see `dct`.

#### Examples

The Type 1 DCT is equivalent to the DFT for real, even-symmetrical inputs. The output is also real and even-symmetrical. Half of the IFFT input is used to generate half of the IFFT output:

```
>>> from scipy.fftpack import ifft, idct
>>> ifft(np.array([ 30., -8.,  6., -2.,  6., -8.])).real
array([ 4.,  3.,  5., 10.,  5.,  3.])
>>> idct(np.array([ 30., -8.,  6., -2.]), 1) / 6
array([ 4.,  3.,  5., 10.]
```

`scipy.fftpack.dctn(x, type=2, shape=None, axes=None, norm=None, overwrite_x=False)`

Return multidimensional Discrete Cosine Transform along the specified axes.

**Parameters**

- x** : array\_like  
The input array.
- type** : {1, 2, 3}, optional  
Type of the DCT (see Notes). Default type is 2.
- shape** : tuple of ints, optional  
The shape of the result. If both *shape* and *axes* (see below) are None, *shape* is  $x.shape$ ; if *shape* is None but *axes* is not None, then *shape* is `scipy.take(x.shape, axes, axis=0)`. If  $shape[i] > x.shape[i]$ , the  $i$ -th dimension is

padded with zeros. If `shape[i] < x.shape[i]`, the *i*-th dimension is truncated to length `shape[i]`.

**axes** : tuple or None, optional

Axes along which the DCT is computed; the default is over all axes.

**norm** : {None, 'ortho'}, optional

Normalization mode (see Notes). Default is None.

**overwrite\_x** : bool, optional

If True, the contents of *x* can be destroyed; the default is False.

**Returns** **y** : ndarray of real

The transformed input array.

**See also:**

**idctn**      Inverse multidimensional DCT

**Notes**

For full details of the DCT types and normalization modes, as well as references, see *dct*.

**Examples**

```
>>> from scipy.fftpack import dctn, idctn
>>> y = np.random.randn(16, 16)
>>> np.allclose(y, idctn(dctn(y, norm='ortho'), norm='ortho'))
True
```

`scipy.fftpack.idctn(x, type=2, shape=None, axes=None, norm=None, overwrite_x=False)`

Return multidimensional Discrete Cosine Transform along the specified axes.

**Parameters** **x** : array\_like

The input array.

**type** : {1, 2, 3}, optional

Type of the DCT (see Notes). Default type is 2.

**shape** : tuple of ints, optional

The shape of the result. If both *shape* and *axes* (see below) are None, *shape* is `x.shape`; if *shape* is None but *axes* is not None, then *shape* is `scipy.take(x.shape, axes, axis=0)`. If `shape[i] > x.shape[i]`, the *i*-th dimension is padded with zeros. If `shape[i] < x.shape[i]`, the *i*-th dimension is truncated to length `shape[i]`.

**axes** : tuple or None, optional

Axes along which the IDCT is computed; the default is over all axes.

**norm** : {None, 'ortho'}, optional

Normalization mode (see Notes). Default is None.

**overwrite\_x** : bool, optional

If True, the contents of *x* can be destroyed; the default is False.

**Returns** **y** : ndarray of real

The transformed input array.

**See also:**

**dctn**      multidimensional DCT

**Notes**

For full details of the IDCT types and normalization modes, as well as references, see *idct*.

**Examples**

```
>>> from scipy.fftpack import dctn, idctn
>>> y = np.random.randn(16, 16)
>>> np.allclose(y, idctn(dctn(y, norm='ortho'), norm='ortho'))
True
```

`scipy.fftpack.dst` (*x*, *type*=2, *n*=None, *axis*=-1, *norm*=None, *overwrite\_x*=False)  
Return the Discrete Sine Transform of arbitrary type sequence *x*.

**Parameters**

- x** : array\_like  
The input array.
- type** : {1, 2, 3}, optional  
Type of the DST (see Notes). Default type is 2.
- n** : int, optional  
Length of the transform. If  $n < x.shape[axis]$ , *x* is truncated. If  $n > x.shape[axis]$ , *x* is zero-padded. The default results in  $n = x.shape[axis]$ .
- axis** : int, optional  
Axis along which the `dst` is computed; the default is over the last axis (i.e., `axis=-1`).
- norm** : {None, 'ortho'}, optional  
Normalization mode (see Notes). Default is None.
- overwrite\_x** : bool, optional  
If True, the contents of *x* can be destroyed; the default is False.

**Returns**

- dst** : ndarray of reals  
The transformed input array.

**See also:**

**idst**      Inverse DST

**Notes**

For a single dimension array *x*.

There are theoretically 8 types of the DST for different combinations of even/odd boundary conditions and boundary off sets [R49], only the first 3 types are implemented in `scipy`.

**Type I**

There are several definitions of the DST-I; we use the following for `norm=None`. DST-I assumes the input is odd around  $n=-1$  and  $n=N$ .

$$y[k] = 2 * \sum_{n=0}^{N-1} x[n] * \sin(\pi * (k+1) * (n+1) / (N+1))$$

Only None is supported as normalization mode for DCT-I. Note also that the DCT-I is only supported for input size  $> 1$  The (unnormalized) DCT-I is its own inverse, up to a factor  $2(N+1)$ .

**Type II**

There are several definitions of the DST-II; we use the following for `norm=None`. DST-II assumes the input is odd around  $n=-1/2$  and  $n=N-1/2$ ; the output is odd around  $k=-1$  and even around  $k=N-1$

$$y[k] = 2 * \sum_{n=0}^{N-1} x[n] * \sin(\pi * (k+1) * (n+0.5) / N), \quad 0 \leq k < N.$$

if `norm='ortho'`,  $y[k]$  is multiplied by a scaling factor *f*

```
f = sqrt(1/(4*N)) if k == 0
f = sqrt(1/(2*N)) otherwise.
```

### Type III

There are several definitions of the DST-III, we use the following (for `norm=None`). DST-III assumes the input is odd around  $n=-1$  and even around  $n=N-1$

$$y[k] = x[N-1] * (-1)^{**k} + 2 * \sum_{n=0}^{N-2} x[n] * \sin(\pi * (k+0.5) * (n+1) / N), \quad 0 \leq k < N.$$

The (unnormalized) DCT-III is the inverse of the (unnormalized) DCT-II, up to a factor  $2N$ . The orthonormalized DST-III is exactly the inverse of the orthonormalized DST-II.

New in version 0.11.0.

### References

[R49]

`scipy.fftpack.idst(x, type=2, n=None, axis=-1, norm=None, overwrite_x=False)`

Return the Inverse Discrete Sine Transform of an arbitrary type sequence.

**Parameters**

- x** : array\_like  
The input array.
- type** : {1, 2, 3}, optional  
Type of the DST (see Notes). Default type is 2.
- n** : int, optional  
Length of the transform. If  $n < x.shape[axis]$ ,  $x$  is truncated. If  $n > x.shape[axis]$ ,  $x$  is zero-padded. The default results in  $n = x.shape[axis]$ .
- axis** : int, optional  
Axis along which the `idst` is computed; the default is over the last axis (i.e., `axis=-1`).
- norm** : {None, 'ortho'}, optional  
Normalization mode (see Notes). Default is None.
- overwrite\_x** : bool, optional  
If True, the contents of  $x$  can be destroyed; the default is False.

**Returns**

- idst** : ndarray of real  
The transformed input array.

See also:

**dst** Forward DST

### Notes

'The' IDST is the IDST of type 2, which is the same as DST of type 3.

IDST of type 1 is the DST of type 1, IDST of type 2 is the DST of type 3, and IDST of type 3 is the DST of type 2. For the definition of these types, see `dst`.

New in version 0.11.0.

`scipy.fftpack.dstn(x, type=2, shape=None, axes=None, norm=None, overwrite_x=False)`

Return multidimensional Discrete Sine Transform along the specified axes.

**Parameters**

- x** : array\_like  
The input array.
- type** : {1, 2, 3}, optional  
Type of the DCT (see Notes). Default type is 2.

**shape** : tuple of ints, optional

The shape of the result. If both *shape* and *axes* (see below) are None, *shape* is *x*.shape; if *shape* is None but *axes* is not None, then *shape* is `scipy.take(x.shape, axes, axis=0)`. If `shape[i] > x.shape[i]`, the *i*-th dimension is padded with zeros. If `shape[i] < x.shape[i]`, the *i*-th dimension is truncated to length `shape[i]`.

**axes** : tuple or None, optional

Axes along which the DCT is computed; the default is over all axes.

**norm** : {None, 'ortho'}, optional

Normalization mode (see Notes). Default is None.

**overwrite\_x** : bool, optional

If True, the contents of *x* can be destroyed; the default is False.

**Returns** *y* : ndarray of real

The transformed input array.

See also:

**idstn** Inverse multidimensional DST

**Notes**

For full details of the DST types and normalization modes, as well as references, see *dct*.

**Examples**

```
>>> from scipy.fftpack import dstn, idstn
>>> y = np.random.randn(16, 16)
>>> np.allclose(y, idstn(dstn(y, norm='ortho'), norm='ortho'))
True
```

`scipy.fftpack.idstn(x, type=2, shape=None, axes=None, norm=None, overwrite_x=False)`

Return multidimensional Discrete Sine Transform along the specified axes.

**Parameters** *x* : array\_like

The input array.

**type** : {1, 2, 3}, optional

Type of the DCT (see Notes). Default type is 2.

**shape** : tuple of ints, optional

The shape of the result. If both *shape* and *axes* (see below) are None, *shape* is *x*.shape; if *shape* is None but *axes* is not None, then *shape* is `scipy.take(x.shape, axes, axis=0)`. If `shape[i] > x.shape[i]`, the *i*-th dimension is padded with zeros. If `shape[i] < x.shape[i]`, the *i*-th dimension is truncated to length `shape[i]`.

**axes** : tuple or None, optional

Axes along which the IDCT is computed; the default is over all axes.

**norm** : {None, 'ortho'}, optional

Normalization mode (see Notes). Default is None.

**overwrite\_x** : bool, optional

If True, the contents of *x* can be destroyed; the default is False.

**Returns** *y* : ndarray of real

The transformed input array.

See also:

**dctn** multidimensional DST

*Notes*

For full details of the IDST types and normalization modes, as well as references, see *idst*.

*Examples*

```
>>> from scipy.fftpack import dstn, idstn
>>> y = np.random.randn(16, 16)
>>> np.allclose(y, idstn(dstn(y, norm='ortho'), norm='ortho'))
True
```

### 5.5.2 Differential and pseudo-differential operators

<code>diff(x[, order, period, _cache])</code>	Return k-th derivative (or integral) of a periodic sequence <i>x</i> .
<code>tilbert(x, h[, period, _cache])</code>	Return h-Tilbert transform of a periodic sequence <i>x</i> .
<code>itilbert(x, h[, period, _cache])</code>	Return inverse h-Tilbert transform of a periodic sequence <i>x</i> .
<code>hilbert(x[, _cache])</code>	Return Hilbert transform of a periodic sequence <i>x</i> .
<code>ihilbert(x)</code>	Return inverse Hilbert transform of a periodic sequence <i>x</i> .
<code>cs_diff(x, a, b[, period, _cache])</code>	Return (a,b)-cosh/sinh pseudo-derivative of a periodic sequence.
<code>sc_diff(x, a, b[, period, _cache])</code>	Return (a,b)-sinh/cosh pseudo-derivative of a periodic sequence <i>x</i> .
<code>ss_diff(x, a, b[, period, _cache])</code>	Return (a,b)-sinh/sinh pseudo-derivative of a periodic sequence <i>x</i> .
<code>cc_diff(x, a, b[, period, _cache])</code>	Return (a,b)-cosh/cosh pseudo-derivative of a periodic sequence.
<code>shift(x, a[, period, _cache])</code>	Shift periodic sequence <i>x</i> by <i>a</i> : $y(u) = x(u+a)$ .

`scipy.fftpack.diff(x, order=1, period=None, _cache={})`

Return k-th derivative (or integral) of a periodic sequence *x*.

If  $x_j$  and  $y_j$  are Fourier coefficients of periodic functions *x* and *y*, respectively, then:

```
y_j = pow(sqrt(-1)*j*2*pi/period, order) * x_j
y_0 = 0 if order is not 0.
```

- Parameters**
- x** : array\_like  
Input array.
  - order** : int, optional  
The order of differentiation. Default order is 1. If order is negative, then integration is carried out under the assumption that  $x_0 == 0$ .
  - period** : float, optional  
The assumed period of the sequence. Default is  $2*\pi$ .

*Notes*

If  $\text{sum}(x, \text{axis}=0) = 0$  then  $\text{diff}(\text{diff}(x, k), -k) == x$  (within numerical accuracy).

For odd order and even  $\text{len}(x)$ , the Nyquist mode is taken zero.

`scipy.fftpack.tilbert(x, h, period=None, _cache={})`

Return h-Tilbert transform of a periodic sequence *x*.

If  $x_j$  and  $y_j$  are Fourier coefficients of periodic functions  $x$  and  $y$ , respectively, then:

```
y_j = sqrt(-1)*coth(j*h*2*pi/period) * x_j
y_0 = 0
```

**Parameters**

- x** : array\_like  
The input array to transform.
- h** : float  
Defines the parameter of the Tilbert transform.
- period** : float, optional  
The assumed period of the sequence. Default period is  $2\pi$ .

**Returns**

- tilbert** : ndarray  
The result of the transform.

#### Notes

If  $\text{sum}(x, \text{axis}=0) == 0$  and  $n = \text{len}(x)$  is odd then  $\text{tilbert}(\text{itilbert}(x)) == x$ .

If  $2 * \pi * h / \text{period}$  is approximately 10 or larger, then numerically  $\text{tilbert} == \text{hilbert}$  (theoretically oo-Tilbert == Hilbert).

For even  $\text{len}(x)$ , the Nyquist mode of  $x$  is taken zero.

`scipy.fftpack.itilbert(x, h, period=None, _cache={})`  
Return inverse h-Tilbert transform of a periodic sequence  $x$ .

If  $x_j$  and  $y_j$  are Fourier coefficients of periodic functions  $x$  and  $y$ , respectively, then:

```
y_j = -sqrt(-1)*tanh(j*h*2*pi/period) * x_j
y_0 = 0
```

For more details, see `tilbert`.

`scipy.fftpack.hilbert(x, _cache={})`  
Return Hilbert transform of a periodic sequence  $x$ .

If  $x_j$  and  $y_j$  are Fourier coefficients of periodic functions  $x$  and  $y$ , respectively, then:

```
y_j = sqrt(-1)*sign(j) * x_j
y_0 = 0
```

**Parameters**

- x** : array\_like  
The input array, should be periodic.
- \_cache** : dict, optional  
Dictionary that contains the kernel used to do a convolution with.

**Returns**

- y** : ndarray  
The transformed input.

**See also:**

`scipy.signal.hilbert`  
Compute the analytic signal, using the Hilbert transform.

**Notes**

If `sum(x, axis=0) == 0` then `hilbert(ihilbert(x)) == x`.

For even `len(x)`, the Nyquist mode of `x` is taken zero.

The sign of the returned transform does not have a factor `-1` that is more often than not found in the definition of the Hilbert transform. Note also that `scipy.signal.hilbert` does have an extra `-1` factor compared to this function.

`scipy.fftpack.ihilbert(x)`

Return inverse Hilbert transform of a periodic sequence `x`.

If `x_j` and `y_j` are Fourier coefficients of periodic functions `x` and `y`, respectively, then:

$$\begin{aligned} y_j &= -\sqrt{-1} * \text{sign}(j) * x_j \\ y_0 &= 0 \end{aligned}$$

`scipy.fftpack.cs_diff(x, a, b, period=None, _cache={})`

Return (a,b)-cosh/sinh pseudo-derivative of a periodic sequence.

If `x_j` and `y_j` are Fourier coefficients of periodic functions `x` and `y`, respectively, then:

$$\begin{aligned} y_j &= -\sqrt{-1} * \cosh(j*a*2*\pi/\text{period}) / \sinh(j*b*2*\pi/\text{period}) * x_j \\ y_0 &= 0 \end{aligned}$$

- Parameters**
- x** : array\_like  
The array to take the pseudo-derivative from.
  - a, b** : float  
Defines the parameters of the cosh/sinh pseudo-differential operator.
  - period** : float, optional  
The period of the sequence. Default period is `2*pi`.
- Returns**
- cs\_diff** : ndarray  
Pseudo-derivative of periodic sequence `x`.

**Notes**

For even `len(x)`, the Nyquist mode of `x` is taken as zero.

`scipy.fftpack.sc_diff(x, a, b, period=None, _cache={})`

Return (a,b)-sinh/cosh pseudo-derivative of a periodic sequence `x`.

If `x_j` and `y_j` are Fourier coefficients of periodic functions `x` and `y`, respectively, then:

$$\begin{aligned} y_j &= \sqrt{-1} * \sinh(j*a*2*\pi/\text{period}) / \cosh(j*b*2*\pi/\text{period}) * x_j \\ y_0 &= 0 \end{aligned}$$

- Parameters**
- x** : array\_like  
Input array.
  - a, b** : float  
Defines the parameters of the sinh/cosh pseudo-differential operator.
  - period** : float, optional  
The period of the sequence `x`. Default is `2*pi`.

**Notes**

`sc_diff(cs_diff(x, a, b), b, a) == x` For even `len(x)`, the Nyquist mode of `x` is taken as zero.

`scipy.fftpack.ss_diff(x, a, b, period=None, _cache={})`

Return (a,b)-sinh/sinh pseudo-derivative of a periodic sequence x.

If  $x_j$  and  $y_j$  are Fourier coefficients of periodic functions x and y, respectively, then:

$$\begin{aligned} y_j &= \sinh(j*a*2*\pi/\text{period}) / \sinh(j*b*2*\pi/\text{period}) * x_j \\ y_0 &= a/b * x_0 \end{aligned}$$

**Parameters**

- x** : array\_like  
The array to take the pseudo-derivative from.
- a,b**  
Defines the parameters of the sinh/sinh pseudo-differential operator.
- period** : float, optional  
The period of the sequence x. Default is  $2*\pi$ .

**Notes**

$$\text{ss\_diff}(\text{ss\_diff}(x, a, b), b, a) == x$$

`scipy.fftpack.cc_diff(x, a, b, period=None, _cache={})`

Return (a,b)-cosh/cosh pseudo-derivative of a periodic sequence.

If  $x_j$  and  $y_j$  are Fourier coefficients of periodic functions x and y, respectively, then:

$$y_j = \cosh(j*a*2*\pi/\text{period}) / \cosh(j*b*2*\pi/\text{period}) * x_j$$

**Parameters**

- x** : array\_like  
The array to take the pseudo-derivative from.
- a,b** : float  
Defines the parameters of the sinh/sinh pseudo-differential operator.
- period** : float, optional  
The period of the sequence x. Default is  $2*\pi$ .

**Returns**

- cc\_diff** : ndarray  
Pseudo-derivative of periodic sequence x.

**Notes**

$$\text{cc\_diff}(\text{cc\_diff}(x, a, b), b, a) == x$$

`scipy.fftpack.shift(x, a, period=None, _cache={})`

Shift periodic sequence x by a:  $y(u) = x(u+a)$ .

If  $x_j$  and  $y_j$  are Fourier coefficients of periodic functions x and y, respectively, then:

$$y_j = \exp(j*a*2*\pi/\text{period}*sqrt(-1)) * x_f$$

**Parameters**

- x** : array\_like  
The array to take the pseudo-derivative from.
- a** : float  
Defines the parameters of the sinh/sinh pseudo-differential
- period** : float, optional  
The period of the sequences x and y. Default period is  $2*\pi$ .

### 5.5.3 Helper functions

<code>fftshift(x[, axes])</code>	Shift the zero-frequency component to the center of the spectrum.
<code>ifftshift(x[, axes])</code>	The inverse of <code>fftshift</code> .
<code>fftfreq(n[, d])</code>	Return the Discrete Fourier Transform sample frequencies.
<code>rfftfreq(n[, d])</code>	DFT sample frequencies (for usage with <code>rfft</code> , <code>irfft</code> ).
<code>next_fast_len(target)</code>	Find the next fast size of input data to <code>fft</code> , for zero-padding, etc.

`scipy.fftpack.fftshift(x, axes=None)`

Shift the zero-frequency component to the center of the spectrum.

This function swaps half-spaces for all axes listed (defaults to all). Note that `y[0]` is the Nyquist component only if `len(x)` is even.

**Parameters** `x` : array\_like  
 Input array.  
`axes` : int or shape tuple, optional  
 Axes over which to shift. Default is None, which shifts all axes.

**Returns** `y` : ndarray  
 The shifted array.

See also:

**ifftshift** The inverse of `fftshift`.

**Examples**

```
>>> freqs = np.fft.fftfreq(10, 0.1)
>>> freqs
array([ 0.,  1.,  2.,  3.,  4., -5., -4., -3., -2., -1.])
>>> np.fft.fftshift(freqs)
array([-5., -4., -3., -2., -1.,  0.,  1.,  2.,  3.,  4.])
```

Shift the zero-frequency component only along the second axis:

```
>>> freqs = np.fft.fftfreq(9, d=1./9).reshape(3, 3)
>>> freqs
array([[ 0.,  1.,  2.],
       [ 3.,  4., -4.],
       [-3., -2., -1.]])
>>> np.fft.fftshift(freqs, axes=(1,))
array([[ 2.,  0.,  1.],
       [-4.,  3.,  4.],
       [-1., -3., -2.]])
```

`scipy.fftpack.ifftshift(x, axes=None)`

The inverse of `fftshift`. Although identical for even-length `x`, the functions differ by one sample for odd-length `x`.

**Parameters** `x` : array\_like  
 Input array.  
`axes` : int or shape tuple, optional  
 Axes over which to calculate. Defaults to None, which shifts all axes.

**Returns** `y` : ndarray  
 The shifted array.

See also:

**fftshift** Shift zero-frequency component to the center of the spectrum.

*Examples*

```
>>> freqs = np.fft.fftfreq(9, d=1./9).reshape(3, 3)
>>> freqs
array([[ 0.,  1.,  2.],
       [ 3.,  4., -4.],
       [-3., -2., -1.]])
>>> np.fft.ifftshift(np.fft.fftshift(freqs))
array([[ 0.,  1.,  2.],
       [ 3.,  4., -4.],
       [-3., -2., -1.]])
```

`scipy.fftpack.fftfreq`(*n*, *d=1.0*)

Return the Discrete Fourier Transform sample frequencies.

The returned float array *f* contains the frequency bin centers in cycles per unit of the sample spacing (with zero at the start). For instance, if the sample spacing is in seconds, then the frequency unit is cycles/second.

Given a window length *n* and a sample spacing *d*:

```
f = [0, 1, ..., n/2-1, -n/2, ..., -1] / (d*n)   if n is even
f = [0, 1, ..., (n-1)/2, -(n-1)/2, ..., -1] / (d*n)   if n is odd
```

**Parameters**

- n** : int  
Window length.
- d** : scalar, optional  
Sample spacing (inverse of the sampling rate). Defaults to 1.

**Returns**

- f** : ndarray  
Array of length *n* containing the sample frequencies.

*Examples*

```
>>> signal = np.array([-2, 8, 6, 4, 1, 0, 3, 5], dtype=float)
>>> fourier = np.fft.fft(signal)
>>> n = signal.size
>>> timestep = 0.1
>>> freq = np.fft.fftfreq(n, d=timestep)
>>> freq
array([ 0. ,  1.25,  2.5 ,  3.75, -5. , -3.75, -2.5 , -1.25])
```

`scipy.fftpack.rfftfreq`(*n*, *d=1.0*)

DFT sample frequencies (for usage with rfft, irfft).

The returned float array contains the frequency bins in cycles/unit (with zero at the start) given a window length *n* and a sample spacing *d*:

```
f = [0, 1, 1, 2, 2, ..., n/2-1, n/2-1, n/2] / (d*n)   if n is even
f = [0, 1, 1, 2, 2, ..., n/2-1, n/2-1, n/2, n/2] / (d*n)   if n is odd
```

**Parameters**

- n** : int  
Window length.
- d** : scalar, optional  
Sample spacing. Default is 1.

**Returns**     **out** : ndarray  
                   The array of length  $n$ , containing the sample frequencies.

**Examples**

```
>>> from scipy import fftpack
>>> sig = np.array([-2, 8, 6, 4, 1, 0, 3, 5], dtype=float)
>>> sig_fft = fftpack.rfft(sig)
>>> n = sig_fft.size
>>> timestep = 0.1
>>> freq = fftpack.rfftfreq(n, d=timestep)
>>> freq
array([ 0. ,  1.25,  1.25,  2.5 ,  2.5 ,  3.75,  3.75,  5.  ])
```

`scipy.fftpack.next_fast_len(target)`  
 Find the next fast size of input data to *fft*, for zero-padding, etc.

SciPy's FFTPACK has efficient functions for radix {2, 3, 4, 5}, so this returns the next composite of the prime factors 2, 3, and 5 which is greater than or equal to *target*. (These are also known as 5-smooth numbers, regular numbers, or Hamming numbers.)

**Parameters**   **target** : int  
                   Length to start searching from. Must be a positive integer.  
**Returns**       **out** : int  
                   The first 5-smooth number greater than or equal to *target*.

**Notes**

New in version 0.18.0.

**Examples**

On a particular machine, an FFT of prime length takes 133 ms:

```
>>> from scipy import fftpack
>>> min_len = 10007 # prime length is worst case for speed
>>> a = np.random.randn(min_len)
>>> b = fftpack.fft(a)
```

Zero-padding to the next 5-smooth length reduces computation time to 211 us, a speedup of 630 times:

```
>>> fftpack.helper.next_fast_len(min_len)
10125
>>> b = fftpack.fft(a, 10125)
```

Rounding up to the next power of 2 is not optimal, taking 367 us to compute, 1.7 times as long as the 5-smooth size:

```
>>> b = fftpack.fft(a, 16384)
```

Note that `fftshift`, `ifftshift` and `fftfreq` are numpy functions exposed by `fftpack`; importing them from `numpy` should be preferred.

### 5.5.4 Convolutions (`scipy.fftpack.convolve`)

`convolve(x,omega,[swap_real_imag,overwrite_x])`     Wrapper for `convolve`.

Continued on next page

Table 5.17 – continued from previous page

<code>convolve_z(x,omega_real,omega_imag,[overwrite_x])</code>	Wrapper for <code>convolve_z</code> .
<code>init_convolution_kernel(...)</code>	Wrapper for <code>init_convolution_kernel</code> .
<code>destroy_convolve_cache()</code>	Wrapper for <code>destroy_convolve_cache</code> .

`scipy.fftpack.convolve.convolve(x, omega[, swap_real_imag, overwrite_x]) = <fortran object>`

Wrapper for `convolve`.

**Parameters** `x` : input rank-1 array('d') with bounds (n)  
**omega** : input rank-1 array('d') with bounds (n)  
**Returns** `y` : rank-1 array('d') with bounds (n) and x storage  
**Other Parameters**  
**overwrite\_x** : input int, optional  
Default: 0  
**swap\_real\_imag** : input int, optional  
Default: 0

`scipy.fftpack.convolve.convolve_z(x, omega_real, omega_imag[, overwrite_x]) = <fortran object>`

Wrapper for `convolve_z`.

**Parameters** `x` : input rank-1 array('d') with bounds (n)  
**omega\_real** : input rank-1 array('d') with bounds (n)  
**omega\_imag** : input rank-1 array('d') with bounds (n)  
**Returns** `y` : rank-1 array('d') with bounds (n) and x storage  
**Other Parameters**  
**overwrite\_x** : input int, optional  
Default: 0

`scipy.fftpack.convolve.init_convolution_kernel(n, kernel_func[, d, zero_nyquist, kernel_func_extra_args]) = <fortran object>`

Wrapper for `init_convolution_kernel`.

**Parameters** `n` : input int  
**kernel\_func** : call-back function  
**Returns** **omega** : rank-1 array('d') with bounds (n)  
**Other Parameters**  
**d** : input int, optional  
Default: 0  
**kernel\_func\_extra\_args** : input tuple, optional  
Default: ()  
**zero\_nyquist** : input int, optional  
Default: `d%2`

#### Notes

Call-back functions:

```
def kernel_func(k): return kernel_func
Required arguments:
  k : input int
Return objects:
  kernel_func : float
```

`scipy.fftpack.convolve.destroy_convolve_cache = <fortran object>`

Wrapper for `destroy_convolve_cache`.

## 5.6 Integration and ODEs (`scipy.integrate`)

### 5.6.1 Integrating functions, given function object

<code>quad(func, a, b[, args, full_output, ...])</code>	Compute a definite integral.
<code>dblquad(func, a, b, gfun, hfun[, args, ...])</code>	Compute a double integral.
<code>tplquad(func, a, b, gfun, hfun, qfun, rfun)</code>	Compute a triple (definite) integral.
<code>nquad(func, ranges[, args, opts, full_output])</code>	Integration over multiple variables.
<code>fixed_quad(func, a, b[, args, n])</code>	Compute a definite integral using fixed-order Gaussian quadrature.
<code>quadrature(func, a, b[, args, tol, rtol, ...])</code>	Compute a definite integral using fixed-tolerance Gaussian quadrature.
<code>romberg(function, a, b[, args, tol, rtol, ...])</code>	Romberg integration of a callable function or method.
<code>quad_explain([output])</code>	Print extra information about <code>integrate.quad()</code> parameters and returns.
<code>newton_cotes(m[, equal])</code>	Return weights and error coefficient for Newton-Cotes integration.
<code>IntegrationWarning</code>	Warning on issues during integration.

`scipy.integrate.quad` (*func*, *a*, *b*, *args*=(), *full\_output*=0, *epsabs*=1.49e-08, *epsrel*=1.49e-08, *limit*=50, *points*=None, *weight*=None, *wvar*=None, *wopts*=None, *maxpl*=50, *limlst*=50)  
 Compute a definite integral.

Integrate *func* from *a* to *b* (possibly infinite interval) using a technique from the Fortran library QUADPACK.

**Parameters** **func** : {function, `scipy.LowLevelCallable`}

A Python function or method to integrate. If *func* takes many arguments, it is integrated along the axis corresponding to the first argument.

If the user desires improved integration performance, then *f* may be a `scipy.LowLevelCallable` with one of the signatures:

```
double func(double x)
double func(double x, void *user_data)
double func(int n, double *xx)
double func(int n, double *xx, void *user_data)
```

The *user\_data* is the data contained in the `scipy.LowLevelCallable`. In the call forms with *xx*, *n* is the length of the *xx* array which contains `xx[0] == x` and the rest of the items are numbers contained in the *args* argument of `quad`.

In addition, certain ctypes call signatures are supported for backward compatibility, but those should not be used in new code.

**a** : float

Lower limit of integration (use `-numpy.inf` for -infinity).

**b** : float

Upper limit of integration (use `numpy.inf` for +infinity).

**args** : tuple, optional

Extra arguments to pass to *func*.

**full\_output** : int, optional

Non-zero to return a dictionary of integration information. If non-zero, warning messages are also suppressed and the message is appended to the output tuple.

**Returns**

**y** : float

The integral of *func* from *a* to *b*.

**abserr** : float

An estimate of the absolute error in the result.

**infodict** : dict

A dictionary containing additional information. Run `scipy.integrate.quad_explain()` for more information.

## message

A convergence message.

## explain

Appended only with 'cos' or 'sin' weighting and infinite integration limits, it contains an explanation of the codes in `infodict['ierlst']`

**Other Parameters****epsabs** : float or int, optional

Absolute error tolerance.

**epsrel** : float or int, optional

Relative error tolerance.

**limit** : float or int, optional

An upper bound on the number of subintervals used in the adaptive algorithm.

**points** : (sequence of floats,ints), optional

A sequence of break points in the bounded integration interval where local difficulties of the integrand may occur (e.g., singularities, discontinuities). The sequence does not have to be sorted.

**weight** : float or int, optional

String indicating weighting function. Full explanation for this and the remaining arguments can be found below.

**wvar** : optional

Variables for use with weighting functions.

**wopts** : optional

Optional input for reusing Chebyshev moments.

**maxp1** : float or int, optional

An upper bound on the number of Chebyshev moments.

**limlst** : int, optional

Upper bound on the number of cycles ( $\geq 3$ ) for use with a sinusoidal weighting and an infinite end-point.

**See also:**

**dblquad** double integral

**tplquad** triple integral

**nquad** n-dimensional integrals (uses *quad* recursively)

**fixed\_quad** fixed-order Gaussian quadrature

**quadrature** adaptive Gaussian quadrature

**odeint** ODE integrator

**ode** ODE integrator

**simps** integrator for sampled data

**romb** integrator for sampled data

**scipy.special**

for coefficients and roots of orthogonal polynomials

Notes

**Extra information for quad() inputs and outputs**

If full\_output is non-zero, then the third output argument (infodict) is a dictionary with entries as tabulated below. For infinite limits, the range is transformed to (0,1) and the optional outputs are given with respect to this transformed range. Let M be the input argument limit and let K be infodict['last']. The entries are:

- 'neval'      The number of function evaluations.
- 'last'        The number, K, of subintervals produced in the subdivision process.
- 'alist'       A rank-1 array of length M, the first K elements of which are the left end points of the subintervals in the partition of the integration range.
- 'blist'       A rank-1 array of length M, the first K elements of which are the right end points of the subintervals.
- 'rlist'       A rank-1 array of length M, the first K elements of which are the integral approximations on the subintervals.
- 'elist'       A rank-1 array of length M, the first K elements of which are the moduli of the absolute error estimates on the subintervals.
- 'iord'        A rank-1 integer array of length M, the first L elements of which are pointers to the error estimates over the subintervals with  $L=K$  if  $K \leq M/2+2$  or  $L=M+1-K$  otherwise. Let I be the sequence infodict['iord'] and let E be the sequence infodict['elist']. Then  $E[I[1]], \dots, E[I[L]]$  forms a decreasing sequence.

If the input argument points is provided (i.e. it is not None), the following additional outputs are placed in the output dictionary. Assume the points sequence is of length P.

- 'pts'        A rank-1 array of length P+2 containing the integration limits and the break points of the intervals in ascending order. This is an array giving the subintervals over which integration will occur.
- 'level'      A rank-1 integer array of length M (=limit), containing the subdivision levels of the subintervals, i.e., if (aa,bb) is a subinterval of (pts[1], pts[2]) where pts[0] and pts[2] are adjacent elements of infodict['pts'], then (aa,bb) has level l if  $|bb-aa| = |pts[2]-pts[1]| * 2^{l-1}$ .
- 'ndin'      A rank-1 integer array of length P+2. After the first integration over the intervals (pts[1], pts[2]), the error estimates over some of the intervals may have been increased artificially in order to put their subdivision forward. This array has ones in slots corresponding to the subintervals for which this happens.

**Weighting the integrand**

The input variables, weight and wvar, are used to weight the integrand by a select list of functions. Different integration methods are used to compute the integral with these weighting functions. The possible values of weight and the corresponding weighting functions are.

weight	Weight function used	wvar
'cos'	$\cos(w*x)$	wvar = w
'sin'	$\sin(w*x)$	wvar = w
'alg'	$g(x) = ((x-a)^{\alpha}) * ((b-x)^{\beta})$	wvar = (alpha, beta)
'alg-loga'	$g(x) * \log(x-a)$	wvar = (alpha, beta)
'alg-logb'	$g(x) * \log(b-x)$	wvar = (alpha, beta)
'alg-log'	$g(x) * \log(x-a) * \log(b-x)$	wvar = (alpha, beta)
'cauchy'	$1/(x-c)$	wvar = c

wvar holds the parameter w, (alpha, beta), or c depending on the weight selected. In these expressions, a and b are the integration limits.

For the ‘cos’ and ‘sin’ weighting, additional inputs and outputs are available.

For finite integration limits, the integration is performed using a Clenshaw-Curtis method which uses Chebyshev moments. For repeated calculations, these moments are saved in the output dictionary:

- ‘momcom’** The maximum level of Chebyshev moments that have been computed, i.e., if `M_c` is `infodict['momcom']` then the moments have been computed for intervals of length  $|b-a| * 2^{**(-l)}$ ,  $l=0, 1, \dots, M_c$ .
- ‘nnlog’** A rank-1 integer array of length `M(=limit)`, containing the subdivision levels of the subintervals, i.e., an element of this array is equal to `l` if the corresponding subinterval is  $|b-a| * 2^{**(-l)}$ .
- ‘chebmo’** A rank-2 array of shape `(25, maxp1)` containing the computed Chebyshev moments. These can be passed on to an integration over the same interval by passing this array as the second element of the sequence `wopts` and passing `infodict['momcom']` as the first element.

If one of the integration limits is infinite, then a Fourier integral is computed (assuming `w neq 0`). If `full_output` is 1 and a numerical error is encountered, besides the error message attached to the output tuple, a dictionary is also appended to the output tuple which translates the error codes in the array `info['ierlst']` to English messages. The output information dictionary contains the following entries instead of ‘last’, ‘alist’, ‘blist’, ‘rlist’, and ‘elist’:

- ‘lst’** The number of subintervals needed for the integration (call it `K_f`).
- ‘rslst’** A rank-1 array of length `M_f=limlst`, whose first `K_f` elements contain the integral contribution over the interval  $(a+(k-1)c, a+kc)$  where  $c = (2*\text{floor}(|w|) + 1) * \text{pi} / |w|$  and  $k=1, 2, \dots, K_f$ .
- ‘erlst’** A rank-1 array of length `M_f` containing the error estimate corresponding to the interval in the same position in `infodict['rslst']`.
- ‘ierlst’** A rank-1 integer array of length `M_f` containing an error flag corresponding to the interval in the same position in `infodict['rslst']`. See the explanation dictionary (last entry in the output tuple) for the meaning of the codes.

### Examples

Calculate  $\int_0^4 x^2 dx$  and compare with an analytic result

```
>>> from scipy import integrate
>>> x2 = lambda x: x**2
>>> integrate.quad(x2, 0, 4)
(21.333333333333332, 2.3684757858670003e-13)
>>> print(4**3 / 3.) # analytical result
21.3333333333
```

Calculate  $\int_0^\infty e^{-x} dx$

```
>>> invexp = lambda x: np.exp(-x)
>>> integrate.quad(invexp, 0, np.inf)
(1.0, 5.842605999138044e-11)
```

```
>>> f = lambda x,a : a*x
>>> y, err = integrate.quad(f, 0, 1, args=(1,))
>>> y
0.5
>>> y, err = integrate.quad(f, 0, 1, args=(3,))
>>> y
1.5
```

Calculate  $\int_0^1 x^2 + y^2 dx$  with ctypes, holding y parameter as 1:

```
testlib.c =>
    double func(int n, double args[n]){
        return args[0]*args[0] + args[1]*args[1];}
compile to library testlib.*
```

```
from scipy import integrate
import ctypes
lib = ctypes.CDLL('/home/.../testlib.*') #use absolute path
lib.func.restype = ctypes.c_double
lib.func.argtypes = (ctypes.c_int, ctypes.c_double)
integrate.quad(lib.func, 0, 1, (1))
#(1.3333333333333333, 1.4802973661668752e-14)
print((1.0**3/3.0 + 1.0) - (0.0**3/3.0 + 0.0)) #Analytic result
# 1.3333333333333333
```

`scipy.integrate.dblquad` (*func*, *a*, *b*, *gfun*, *hfun*, *args=()*, *epsabs=1.49e-08*, *epsrel=1.49e-08*)  
 Compute a double integral.

Return the double (definite) integral of `func(y, x)` from `x = a..b` and `y = gfun(x) ..hfun(x)`.

**Parameters**

- func** : callable  
 A Python function or method of at least two variables: *y* must be the first argument and *x* the second argument.
- a, b** : float  
 The limits of integration in *x*:  $a < b$
- gfun** : callable  
 The lower boundary curve in *y* which is a function taking a single floating point argument (*x*) and returning a floating point result: a lambda function can be useful here.
- hfun** : callable  
 The upper boundary curve in *y* (same requirements as *gfun*).
- args** : sequence, optional  
 Extra arguments to pass to *func*.
- epsabs** : float, optional  
 Absolute tolerance passed directly to the inner 1-D quadrature integration. Default is 1.49e-8.
- epsrel** : float, optional  
 Relative tolerance of the inner 1-D integrals. Default is 1.49e-8.

**Returns**

- y** : float  
 The resultant integral.
- abserr** : float  
 An estimate of the error.

See also:

- quad** single integral
- tplquad** triple integral
- nquad** N-dimensional integrals
- fixed\_quad** fixed-order Gaussian quadrature
- quadrature** adaptive Gaussian quadrature
- odeint** ODE integrator
- ode** ODE integrator

**simps** integrator for sampled data

**romb** integrator for sampled data

**scipy.special**

for coefficients and roots of orthogonal polynomials

`scipy.integrate.tplquad` (*func*, *a*, *b*, *gfun*, *hfun*, *qfun*, *rfun*, *args=()*, *epsabs=1.49e-08*, *epsrel=1.49e-08*)

Compute a triple (definite) integral.

Return the triple integral of `func(z, y, x)` from `x = a..b`, `y = gfun(x)..hfun(x)`, and `z = qfun(x, y)..rfun(x, y)`.

**Parameters** **func** : function

A Python function or method of at least three variables in the order (z, y, x).

**a, b** : float

The limits of integration in x:  $a < b$

**gfun** : function

The lower boundary curve in y which is a function taking a single floating point argument (x) and returning a floating point result: a lambda function can be useful here.

**hfun** : function

The upper boundary curve in y (same requirements as *gfun*).

**qfun** : function

The lower boundary surface in z. It must be a function that takes two floats in the order (x, y) and returns a float.

**rfun** : function

The upper boundary surface in z. (Same requirements as *qfun*.)

**args** : tuple, optional

Extra arguments to pass to *func*.

**epsabs** : float, optional

Absolute tolerance passed directly to the innermost 1-D quadrature integration. Default is 1.49e-8.

**epsrel** : float, optional

Relative tolerance of the innermost 1-D integrals. Default is 1.49e-8.

**Returns** **y** : float

The resultant integral.

**abserr** : float

An estimate of the error.

See also:

**quad** Adaptive quadrature using QUADPACK

**quadrature** Adaptive Gaussian quadrature

**fixed\_quad** Fixed-order Gaussian quadrature

**dblquad** Double integrals

**nquad** N-dimensional integrals

**romb** Integrators for sampled data

**simps** Integrators for sampled data

**ode** ODE integrators

**odeint** ODE integrators

**scipy.special**

For coefficients and roots of orthogonal polynomials

`scipy.integrate.nquad` (*func*, *ranges*, *args=None*, *opts=None*, *full\_output=False*)

Integration over multiple variables.

Wraps *quad* to enable integration over multiple variables. Various options allow improved integration of discontinuous functions, as well as the use of weighted integration, and generally finer control of the integration process.**Parameters** **func** : {callable, `scipy.LowLevelCallable`}The function to be integrated. Has arguments of  $x_0, \dots, x_n, t_0, t_m$ , where integration is carried out over  $x_0, \dots, x_n$ , which must be floats. Function signature should be `func(x0, x1, ..., xn, t0, t1, ..., tm)`. Integration is carried out in order. That is, integration over  $x_0$  is the innermost integral, and  $x_n$  is the outermost.If the user desires improved integration performance, then  $f$  may be a `scipy.LowLevelCallable` with one of the signatures:

```
double func(int n, double *xx)
double func(int n, double *xx, void *user_data)
```

where  $n$  is the number of extra parameters and *args* is an array of doubles of the additional parameters, the *xx* array contains the coordinates. The *user\_data* is the data contained in the `scipy.LowLevelCallable`.**ranges** : iterable objectEach element of *ranges* may be either a sequence of 2 numbers, or else a callable that returns such a sequence. `ranges[0]` corresponds to integration over  $x_0$ , and so on. If an element of *ranges* is a callable, then it will be called with all of the integration arguments available, as well as any parametric arguments. e.g. if  $func = f(x_0, x_1, x_2, t_0, t_1)$ , then `ranges[0]` may be defined as either  $(a, b)$  or else as  $(a, b) = range0(x_1, x_2, t_0, t_1)$ .**args** : iterable object, optionalAdditional arguments  $t_0, \dots, t_n$ , required by *func*, *ranges*, and *opts*.**opts** : iterable object or dict, optionalOptions to be passed to *quad*. May be empty, a dict, or a sequence of dicts or functions that return a dict. If empty, the default options from `scipy.integrate.quad` are used. If a dict, the same options are used for all levels of integration. If a sequence, then each element of the sequence corresponds to a particular integration. e.g. `opts[0]` corresponds to integration over  $x_0$ , and so on. If a callable, the signature must be the same as for *ranges*. The available options together with their default values are:

- `epsabs` = 1.49e-08
- `epsrel` = 1.49e-08
- `limit` = 50
- `points` = None
- `weight` = None
- `wvar` = None
- `wopts` = None

For more information on these options, see *quad* and *quad\_explain*.**full\_output** : bool, optionalPartial implementation of `full_output` from `scipy.integrate.quad`. The number of integrand function evaluations `neval` can be obtained by setting `full_output=True` when calling `nquad`.**Returns****result** : float

The result of the integration.

**abserr** : float

The maximum of the estimates of the absolute error in the various integration results.  
**out\_dict** : dict, optional  
 A dict containing additional information on the integration.

See also:

**quad** 1-dimensional numerical integration

*dblquad, tplquad*

**fixed\_quad** fixed-order Gaussian quadrature

**quadrature** adaptive Gaussian quadrature

*Examples*

```
>>> from scipy import integrate
>>> func = lambda x0,x1,x2,x3 : x0**2 + x1*x2 - x3**3 + np.sin(x0) + (
...     1 if (x0-.2*x3-.5-.25*x1>0) else 0)
>>> points = [[lambda x1,x2,x3 : 0.2*x3 + 0.5 + 0.25*x1], [], [], []]
>>> def opts0(*args, **kwargs):
...     return {'points':[0.2*args[2] + 0.5 + 0.25*args[0]]}
>>> integrate.nquad(func, [[0,1], [-1,1], [.13,.8], [-.15,1]],
...     opts=[opts0,{}, {}, {}], full_output=True)
(1.5267454070738633, 2.9437360001402324e-14, {'neval': 388962})
```

```
>>> scale = .1
>>> def func2(x0, x1, x2, x3, t0, t1):
...     return x0*x1*x3**2 + np.sin(x2) + 1 + (1 if x0+t1*x1-t0>0 else 0)
>>> def lim0(x1, x2, x3, t0, t1):
...     return [scale * (x1**2 + x2 + np.cos(x3)*t0*t1 + 1) - 1,
...             scale * (x1**2 + x2 + np.cos(x3)*t0*t1 + 1) + 1]
>>> def lim1(x2, x3, t0, t1):
...     return [scale * (t0*x2 + t1*x3) - 1,
...             scale * (t0*x2 + t1*x3) + 1]
>>> def lim2(x3, t0, t1):
...     return [scale * (x3 + t0**2*t1**3) - 1,
...             scale * (x3 + t0**2*t1**3) + 1]
>>> def lim3(t0, t1):
...     return [scale * (t0+t1) - 1, scale * (t0+t1) + 1]
>>> def opts0(x1, x2, x3, t0, t1):
...     return {'points' : [t0 - t1*x1]}
>>> def opts1(x2, x3, t0, t1):
...     return {}
>>> def opts2(x3, t0, t1):
...     return {}
>>> def opts3(t0, t1):
...     return {}
>>> integrate.nquad(func2, [lim0, lim1, lim2, lim3], args=(0,0),
...     opts=[opts0, opts1, opts2, opts3])
(25.066666666666666, 2.7829590483937256e-13)
```

`scipy.integrate.fixed_quad` (*func*, *a*, *b*, *args=()*, *n=5*)

Compute a definite integral using fixed-order Gaussian quadrature.

Integrate *func* from *a* to *b* using Gaussian quadrature of order *n*.

**Parameters** **func** : callable

A Python function or method to integrate (must accept vector inputs). If integrating a vector-valued function, the returned array must have shape  $(\dots, \text{len}(x))$ .

- a** : float  
Lower limit of integration.
- b** : float  
Upper limit of integration.
- args** : tuple, optional  
Extra arguments to pass to function, if any.
- n** : int, optional  
Order of quadrature integration. Default is 5.
- val** : float  
Gaussian quadrature approximation to the integral
- none** : None  
Statically returned value of None

**Returns**

**See also:**

- quad** adaptive quadrature using QUADPACK
- dblquad** double integrals
- tplquad** triple integrals
- romberg** adaptive Romberg quadrature
- quadrature** adaptive Gaussian quadrature
- romb** integrators for sampled data
- simps** integrators for sampled data
- cumtrapz** cumulative integration for sampled data
- ode** ODE integrator
- odeint** ODE integrator

`scipy.integrate.quadrature` (*func*, *a*, *b*, *args*=(), *tol*=1.49e-08, *rtol*=1.49e-08, *maxiter*=50, *vec\_func*=True, *miniter*=1)

Compute a definite integral using fixed-tolerance Gaussian quadrature.

Integrate *func* from *a* to *b* using Gaussian quadrature with absolute tolerance *tol*.

**Parameters**

- func** : function  
A Python function or method to integrate.
- a** : float  
Lower limit of integration.
- b** : float  
Upper limit of integration.
- args** : tuple, optional  
Extra arguments to pass to function.
- tol, rtol** : float, optional  
Iteration stops when error between last two iterates is less than *tol* OR the relative change is less than *rtol*.
- maxiter** : int, optional  
Maximum order of Gaussian quadrature.
- vec\_func** : bool, optional  
True or False if *func* handles arrays as arguments (is a “vector” function). Default is True.
- miniter** : int, optional

**Returns**

- val** : float  
Minimum order of Gaussian quadrature.
- Gaussian quadrature approximation (within tolerance) to integral.
- err** : float  
Difference between last two estimates of the integral.

See also:

**romberg** adaptive Romberg quadrature  
**fixed\_quad** fixed-order Gaussian quadrature  
**quad** adaptive quadrature using QUADPACK  
**dblquad** double integrals  
**tplquad** triple integrals  
**romb** integrator for sampled data  
**simps** integrator for sampled data  
**cumtrapz** cumulative integration for sampled data  
**ode** ODE integrator  
**odeint** ODE integrator

`scipy.integrate.romberg` (*function*, *a*, *b*, *args=()*, *tol=1.48e-08*, *rtol=1.48e-08*, *show=False*, *divmax=10*, *vec\_func=False*)

Romberg integration of a callable function or method.

Returns the integral of *function* (a function of one variable) over the interval (*a*, *b*).

If *show* is 1, the triangular array of the intermediate results will be printed. If *vec\_func* is True (default is False), then *function* is assumed to support vector arguments.

**Parameters**

- function** : callable  
Function to be integrated.
- a** : float  
Lower limit of integration.
- b** : float  
Upper limit of integration.

**Returns**

- results** : float  
Result of the integration.

**Other Parameters**

- args** : tuple, optional  
Extra arguments to pass to function. Each element of *args* will be passed as a single argument to *func*. Default is to pass no extra arguments.
- tol**, **rtol** : float, optional  
The desired absolute and relative tolerances. Defaults are 1.48e-8.
- show** : bool, optional  
Whether to print the results. Default is False.
- divmax** : int, optional  
Maximum order of extrapolation. Default is 10.
- vec\_func** : bool, optional  
Whether *func* handles arrays as arguments (i.e whether it is a “vector” function). Default is False.

See also:

- fixed\_quad** Fixed-order Gaussian quadrature.
- quad** Adaptive quadrature using QUADPACK.
- dblquad** Double integrals.
- tplquad** Triple integrals.
- romb** Integrators for sampled data.
- simps** Integrators for sampled data.
- cumtrapz** Cumulative integration for sampled data.
- ode** ODE integrator.
- odeint** ODE integrator.

**References**

[R63]

**Examples**

Integrate a gaussian from 0 to 1 and compare to the error function.

```
>>> from scipy import integrate
>>> from scipy.special import erf
>>> gaussian = lambda x: 1/np.sqrt(np.pi) * np.exp(-x**2)
>>> result = integrate.romberg(gaussian, 0, 1, show=True)
Romberg integration of <function vfunc at ...> from [0, 1]
```

Steps	StepSize	Results
1	1.000000	0.385872
2	0.500000	0.412631 0.421551
4	0.250000	0.419184 0.421368 0.421356
8	0.125000	0.420810 0.421352 0.421350 0.421350
16	0.062500	0.421215 0.421350 0.421350 0.421350 0.421350
32	0.031250	0.421317 0.421350 0.421350 0.421350 0.421350 0.421350

The final result is 0.421350396475 after 33 function evaluations.

```
>>> print("%g %g" % (2*result, erf(1)))
0.842701 0.842701
```

`scipy.integrate.quad_explain` (*output*=<open file '<stdout>', mode 'w'>)

Print extra information about `integrate.quad()` parameters and returns.

- Parameters** **output** : instance with “write” method, optional  
Information about `quad` is passed to `output.write()`. Default is `sys.stdout`.
- Returns** None

`scipy.integrate.newton_cotes` (*rn, equal=0*)

Return weights and error coefficient for Newton-Cotes integration.

Suppose we have (N+1) samples of f at the positions  $x_0, x_1, \dots, x_N$ . Then an N-point Newton-Cotes formula for the integral between  $x_0$  and  $x_N$  is:

$$\int_{x_0}^{x_N} f(x)dx = \Delta x \sum_{i=0}^N a_i f(x_i) + B_N(\Delta x)^{N+2} f^{N+1}(\xi)$$

where  $\xi \in [x_0, x_N]$  and  $\Delta x = \frac{x_N - x_0}{N}$  is the average samples spacing.

If the samples are equally-spaced and N is even, then the error term is  $B_N(\Delta x)^{N+3} f^{N+2}(\xi)$ .

**Parameters**

- rn** : int  
The integer order for equally-spaced data or the relative positions of the samples with the first sample at 0 and the last at N, where N+1 is the length of *m*. N is the order of the Newton-Cotes integration.
- equal** : int, optional  
Set to 1 to enforce equally spaced data.

**Returns**

- an** : ndarray  
1-D array of weights to apply to the function at the provided sample positions.
- B** : float  
Error coefficient.

**Notes**

Normally, the Newton-Cotes rules are used on smaller integration regions and a composite rule is used to return the total integral.

**exception** `scipy.integrate.IntegrationWarning`

Warning on issues during integration.

## 5.6.2 Integrating functions, given fixed samples

<code>trapz(y[, x, dx, axis])</code>	Integrate along the given axis using the composite trapezoidal rule.
<code>cumtrapz(y[, x, dx, axis, initial])</code>	Cumulatively integrate $y(x)$ using the composite trapezoidal rule.
<code>simps(y[, x, dx, axis, even])</code>	Integrate $y(x)$ using samples along the given axis and the composite Simpson's rule.
<code>romb(y[, dx, axis, show])</code>	Romberg integration using samples of a function.

`scipy.integrate.trapz` ( $y, x=None, dx=1.0, axis=-1$ )

Integrate along the given axis using the composite trapezoidal rule.

Integrate  $y(x)$  along given axis.

**Parameters**

- y** : array\_like  
Input array to integrate.
- x** : array\_like, optional  
The sample points corresponding to the  $y$  values. If  $x$  is None, the sample points are assumed to be evenly spaced  $dx$  apart. The default is None.
- dx** : scalar, optional  
The spacing between sample points when  $x$  is None. The default is 1.
- axis** : int, optional  
The axis along which to integrate.

**Returns**

- trapz** : float  
Definite integral as approximated by trapezoidal rule.

**See also:**

`sum`, `cumsum`

**Notes**

Image [R78] illustrates trapezoidal rule –  $y$ -axis locations of points will be taken from  $y$  array, by default  $x$ -axis distances between points will be 1.0, alternatively they can be provided with  $x$  array or with  $dx$  scalar. Return value will be equal to combined area under the red lines.

**References**

[R77], [R78]

**Examples**

```

>>> np.trapz([1,2,3])
4.0
>>> np.trapz([1,2,3], x=[4,6,8])
8.0
>>> np.trapz([1,2,3], dx=2)
8.0
>>> a = np.arange(6).reshape(2, 3)
>>> a
array([[0, 1, 2],
       [3, 4, 5]])
>>> np.trapz(a, axis=0)
array([ 1.5,  2.5,  3.5])
>>> np.trapz(a, axis=1)
array([ 2.,  8.])

```

`scipy.integrate.cumtrapz` (*y*, *x=None*, *dx=1.0*, *axis=-1*, *initial=None*)  
 Cumulatively integrate *y*(*x*) using the composite trapezoidal rule.

**Parameters**

- y** : array\_like  
Values to integrate.
- x** : array\_like, optional  
The coordinate to integrate along. If None (default), use spacing *dx* between consecutive elements in *y*.
- dx** : float, optional  
Spacing between elements of *y*. Only used if *x* is None.
- axis** : int, optional  
Specifies the axis to cumulate. Default is -1 (last axis).
- initial** : scalar, optional  
If given, uses this value as the first value in the returned result. Typically this value should be 0. Default is None, which means no value at  $x[0]$  is returned and *res* has one element less than *y* along the axis of integration.

**Returns**

- res** : ndarray  
The result of cumulative integration of *y* along *axis*. If *initial* is None, the shape is such that the axis of integration has one less value than *y*. If *initial* is given, the shape is equal to that of *y*.

**See also:**

`numpy.cumsum`, `numpy.cumprod`

**quad** adaptive quadrature using QUADPACK

**romberg** adaptive Romberg quadrature

**quadrature** adaptive Gaussian quadrature

**fixed\_quad** fixed-order Gaussian quadrature

**dblquad** double integrals

**tplquad** triple integrals

**romb** integrators for sampled data

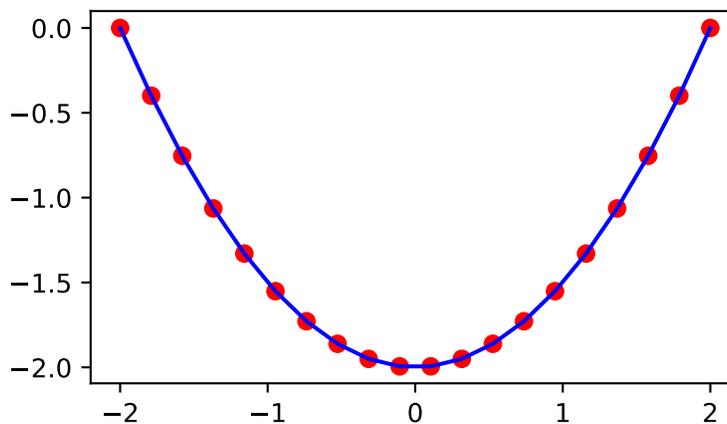
**ode** ODE integrators

**odeint** ODE integrators

### Examples

```
>>> from scipy import integrate
>>> import matplotlib.pyplot as plt
```

```
>>> x = np.linspace(-2, 2, num=20)
>>> y = x
>>> y_int = integrate.cumtrapz(y, x, initial=0)
>>> plt.plot(x, y_int, 'ro', x, y[0] + 0.5 * x**2, 'b-')
>>> plt.show()
```



`scipy.integrate.simps` ( $y$ ,  $x=None$ ,  $dx=1$ ,  $axis=-1$ ,  $even='avg'$ )

Integrate  $y(x)$  using samples along the given axis and the composite Simpson's rule. If  $x$  is `None`, spacing of  $dx$  is assumed.

If there are an even number of samples,  $N$ , then there are an odd number of intervals ( $N-1$ ), but Simpson's rule requires an even number of intervals. The parameter `'even'` controls how this is handled.

**Parameters**

- y** : array\_like  
Array to be integrated.
- x** : array\_like, optional  
If given, the points at which  $y$  is sampled.
- dx** : int, optional  
Spacing of integration points along axis of  $y$ . Only used when  $x$  is `None`. Default is 1.
- axis** : int, optional  
Axis along which to integrate. Default is the last axis.
- even** : str {'avg', 'first', 'last'}, optional
  - 'avg'** [Average two results: 1) use the first  $N-2$  intervals with] a trapezoidal rule on the last interval and 2) use the last  $N-2$  intervals with a trapezoidal rule on the first interval.
  - 'first'** [Use Simpson's rule for the first  $N-2$  intervals with] a trapezoidal rule on the last interval.
  - 'last'** [Use Simpson's rule for the last  $N-2$  intervals with] a trapezoidal rule on the first interval.

See also:

**quad** adaptive quadrature using QUADPACK  
**romberg** adaptive Romberg quadrature  
**quadrature** adaptive Gaussian quadrature  
**fixed\_quad** fixed-order Gaussian quadrature  
**dblquad** double integrals  
**tplquad** triple integrals  
**romb** integrators for sampled data  
**cumtrapz** cumulative integration for sampled data  
**ode** ODE integrators  
**odeint** ODE integrators

*Notes*

For an odd number of samples that are equally spaced the result is exact if the function is a polynomial of order 3 or less. If the samples are not equally spaced, then the result is exact only if the function is a polynomial of order 2 or less.

`scipy.integrate.romb(y, dx=1.0, axis=-1, show=False)`  
 Romberg integration using samples of a function.

**Parameters**

- y** : array\_like  
 A vector of  $2**k + 1$  equally-spaced samples of a function.
- dx** : float, optional  
 The sample spacing. Default is 1.
- axis** : int, optional  
 The axis along which to integrate. Default is -1 (last axis).
- show** : bool, optional  
 When y is a single 1-D array, then if this argument is True print the table showing Richardson extrapolation from the samples. Default is False.

**Returns**

- romb** : ndarray  
 The integrated result for *axis*.

See also:

**quad** adaptive quadrature using QUADPACK  
**romberg** adaptive Romberg quadrature  
**quadrature** adaptive Gaussian quadrature  
**fixed\_quad** fixed-order Gaussian quadrature  
**dblquad** double integrals  
**tplquad** triple integrals  
**simps** integrators for sampled data  
**cumtrapz** cumulative integration for sampled data  
**ode** ODE integrators  
**odeint** ODE integrators

**See also:**

`scipy.special` for orthogonal polynomials (special) for Gaussian quadrature roots and weights for other weighting factors and regions.

**5.6.3 Solving initial value problems for ODE systems**

The solvers are implemented as individual classes which can be used directly (low-level usage) or through a convenience function.

<code>solve_ivp(fun, t_span, y0[, method, t_eval, ...])</code>	Solve an initial value problem for a system of ODEs.
<code>RK23(fun, t0, y0, t_bound[, max_step, rtol, ...])</code>	Explicit Runge-Kutta method of order 3(2).
<code>RK45(fun, t0, y0, t_bound[, max_step, rtol, ...])</code>	Explicit Runge-Kutta method of order 5(4).
<code>Radau(fun, t0, y0, t_bound[, max_step, ...])</code>	Implicit Runge-Kutta method of Radau IIA family of order 5.
<code>BDF(fun, t0, y0, t_bound[, max_step, rtol, ...])</code>	Implicit method based on Backward Differentiation Formulas.
<code>LSODA(fun, t0, y0, t_bound[, first_step, ...])</code>	Adams/BDF method with automatic stiffness detection and switching.
<code>OdeSolver(fun, t0, y0, t_bound, vectorized)</code>	Base class for ODE solvers.
<code>DenseOutput(t_old, t)</code>	Base class for local interpolant over step made by an ODE solver.
<code>OdeSolution(ts, interpolants)</code>	Continuous ODE solution.

`scipy.integrate.solve_ivp` (*fun, t\_span, y0, method='RK45', t\_eval=None, dense\_output=False, events=None, vectorized=False, \*\*options*)

Solve an initial value problem for a system of ODEs.

This function numerically integrates a system of ordinary differential equations given an initial value:

$$\begin{aligned} dy / dt &= f(t, y) \\ y(t_0) &= y_0 \end{aligned}$$

Here  $t$  is a 1-dimensional independent variable (time),  $y(t)$  is an  $n$ -dimensional vector-valued function (state) and an  $n$ -dimensional vector-valued function  $f(t, y)$  determines the differential equations. The goal is to find  $y(t)$  approximately satisfying the differential equations, given an initial value  $y(t_0)=y_0$ .

Some of the solvers support integration in a complex domain, but note that for stiff ODE solvers the right hand side must be complex differentiable (satisfy Cauchy-Riemann equations<sup>11</sup>). To solve a problem in a complex domain, pass  $y_0$  with a complex data type. Another option always available is to rewrite your problem for real and imaginary parts separately.

**Parameters** **fun** : callable

Right-hand side of the system. The calling signature is `fun(t, y)`. Here  $t$  is a scalar and there are two options for ndarray  $y$ . It can either have shape  $(n)$ , then `fun` must return array\_like with shape  $(n)$ . Or alternatively it can have shape  $(n, k)$ , then `fun` must return array\_like with shape  $(n, k)$ , i.e. each column corresponds to a single column in  $y$ . The choice between the two options is determined by `vectorized` argument (see below). The vectorized implementation allows faster approximation of the Jacobian by finite differences (required for stiff solvers).

**t\_span** : 2-tuple of floats

Interval of integration  $(t_0, t_f)$ . The solver starts with  $t=t_0$  and integrates until it reaches  $t=t_f$ .

<sup>11</sup> Cauchy-Riemann equations on Wikipedia.

**y0** : array\_like, shape (n,)

Initial state. For problems in a complex domain pass *y0* with a complex data type (even if the initial guess is purely real).

**method** : string or *OdeSolver*, optional

Integration method to use:

- ‘RK45’ (default): Explicit Runge-Kutta method of order 5(4) [R68]. The error is controlled assuming 4th order accuracy, but steps are taken using a 5th order accurate formula (local extrapolation is done). A quartic interpolation polynomial is used for the dense output [R69]. Can be applied in a complex domain.
- ‘RK23’: Explicit Runge-Kutta method of order 3(2) [R70]. The error is controlled assuming 2nd order accuracy, but steps are taken using a 3rd order accurate formula (local extrapolation is done). A cubic Hermit polynomial is used for the dense output. Can be applied in a complex domain.
- ‘Radau’: Implicit Runge-Kutta method of Radau IIA family of order 5 [R71]. The error is controlled for a 3rd order accurate embedded formula. A cubic polynomial which satisfies the collocation conditions is used for the dense output.
- ‘BDF’: Implicit multi-step variable order (1 to 5) method based on a Backward Differentiation Formulas for the derivative approximation [R72]. An implementation approach follows the one described in [R73]. A quasi-constant step scheme is used and accuracy enhancement using NDF modification is also implemented. Can be applied in a complex domain.
- ‘LSODA’: Adams/BDF method with automatic stiffness detection and switching [R74], [R75]. This is a wrapper of the Fortran solver from ODEPACK.

You should use ‘RK45’ or ‘RK23’ methods for non-stiff problems and ‘Radau’ or ‘BDF’ for stiff problems [R76]. If not sure, first try to run ‘RK45’ and if it does unusual many iterations or diverges then your problem is likely to be stiff and you should use ‘Radau’ or ‘BDF’. ‘LSODA’ can also be a good universal choice, but it might be somewhat less convenient to work with as it wraps an old Fortran code.

You can also pass an arbitrary class derived from *OdeSolver* which implements the solver.

**dense\_output** : bool, optional

Whether to compute a continuous solution. Default is False.

**t\_eval** : array\_like or None, optional

Times at which to store the computed solution, must be sorted and lie within *t\_span*. If None (default), use points selected by a solver.

**events** : callable, list of callables or None, optional

Events to track. Events are defined by functions which take a zero value at a point of an event. Each function must have a signature *event(t, y)* and return float, the solver will find an accurate value of *t* at which *event(t, y(t)) = 0* using a root finding algorithm. Additionally each *event* function might have attributes:

- terminal**: bool, whether to terminate integration if this event occurs. Implicitly False if not assigned.
- direction**: float, direction of crossing a zero. If *direction* is positive then *event* must go from negative to positive, and vice-versa if *direction* is negative. If 0, then either way will count. Implicitly 0 if not assigned.

You can assign attributes like *event.terminal = True* to any function in Python. If None (default), events won’t be tracked.

**vectorized** : bool, optional

Whether *fun* is implemented in a vectorized fashion. Default is False.

**options**

Options passed to a chosen solver constructor. All options available for already implemented solvers are listed below.

**max\_step** : float, optional

Maximum allowed step size. Default is `np.inf`, i.e. step is not bounded and determined solely by the solver.

**rtol, atol** : float and array\_like, optional

Relative and absolute tolerances. The solver keeps the local error estimates less than  $atol + rtol * abs(y)$ . Here *rtol* controls a relative accuracy (number of correct digits). But if a component of *y* is approximately below *atol* then the error only needs to fall within the same *atol* threshold, and the number of correct digits is not guaranteed. If components of *y* have different scales, it might be beneficial to set different *atol* values for different components by passing array\_like with shape (n,) for *atol*. Default values are 1e-3 for *rtol* and 1e-6 for *atol*.

**jac** : {None, array\_like, sparse\_matrix, callable}, optional

Jacobian matrix of the right-hand side of the system with respect to *y*, required by ‘Radau’, ‘BDF’ and ‘LSODA’ methods. The Jacobian matrix has shape (n, n) and its element (i, j) is equal to  $d f_i / d y_j$ . There are 3 ways to define the Jacobian:

- If array\_like or sparse\_matrix, then the Jacobian is assumed to be constant. Not supported by ‘LSODA’.
- If callable, then the Jacobian is assumed to depend on both *t* and *y*, and will be called as `jac(t, y)` as necessary. For ‘Radau’ and ‘BDF’ methods the return value might be a sparse matrix.
- If None (default), then the Jacobian will be approximated by finite differences.

It is generally recommended to provide the Jacobian rather than relying on a finite difference approximation.

**jac\_sparsity** : {None, array\_like, sparse matrix}, optional

Defines a sparsity structure of the Jacobian matrix for a finite difference approximation, its shape must be (n, n). If the Jacobian has only few non-zero elements in *each* row, providing the sparsity structure will greatly speed up the computations<sup>10</sup>. A zero entry means that a corresponding element in the Jacobian is identically zero. If None (default), the Jacobian is assumed to be dense. Not supported by ‘LSODA’, see *lband* and *uband* instead.

**lband, uband** : int or None

Parameters defining the Jacobian matrix bandwidth for ‘LSODA’ method. The Jacobian bandwidth means that `jac[i, j] != 0` only for  $i - lband \leq j \leq i + uband$ . Setting these requires your `jac` routine to return the Jacobian in the packed format: the returned array must have *n* columns and `uband + lband + 1` rows in which Jacobian diagonals are written. Specifically `jac_packed[uband + i - j, j] = jac[i, j]`. The same format is used in `scipy.linalg.solve_banded` (check for an illustration). These parameters can be also used with `jac=None` to reduce the number of Jacobian elements estimated by finite differences.

**min\_step, first\_step** : float, optional

The minimum allowed step size and the initial step size respectively for ‘LSODA’ method. By default *min\_step* is zero and *first\_step* is selected automatically.

#### Returns

Bunch object with the following fields defined:

**t** : ndarray, shape (n\_points,)

Time points.

**y** : ndarray, shape (n, n\_points)

Solution values at *t*.

**sol** : *OdeSolution* or None

Found solution as *OdeSolution* instance, None if *dense\_output* was set to False.

**t\_events** : list of ndarray or None

Contains arrays with times at each a corresponding event was detected, the length of the list equals to the number of events. None if *events* was None.

**nfev** : int

<sup>10</sup> A. Curtis, M. J. D. Powell, and J. Reid, “On the estimation of sparse Jacobian matrices”, Journal of the Institute of Mathematics and its Applications, 13, pp. 117-120, 1974.

Number of the system rhs evaluations.  
**njev** : int  
 Number of the Jacobian evaluations.  
**nlu** : int  
 Number of LU decompositions.  
**status** : int  
 Reason for algorithm termination:  
 •-1: Integration step failed.  
 •0: The solver successfully reached the interval end.  
 •1: A termination event occurred.  
**message** : string  
 Verbal description of the termination reason.  
**success** : bool  
 True if the solver reached the interval end or a termination event occurred (`status >= 0`).

### References

[R68], [R69], [R70], [R71], [R72], [R73], [R74], [R75], [R76],<sup>10,11</sup>

### Examples

Basic exponential decay showing automatically chosen time points.

```

>>> from scipy.integrate import solve_ivp
>>> def exponential_decay(t, y): return -0.5 * y
>>> sol = solve_ivp(exponential_decay, [0, 10], [2, 4, 8])
>>> print(sol.t)
[ 0.          0.11487653  1.26364188  3.06061781  4.85759374
 6.65456967  8.4515456   10.         ]
>>> print(sol.y)
[[ 2.          1.88836035  1.06327177  0.43319312  0.17648948  0.0719045
 0.02929499  0.01350938]
 [ 4.          3.7767207   2.12654355  0.86638624  0.35297895  0.143809
 0.05858998  0.02701876]
 [ 8.          7.5534414   4.25308709  1.73277247  0.7059579   0.287618
 0.11717996  0.05403753]]
    
```

Specifying points where the solution is desired.

```

>>> sol = solve_ivp(exponential_decay, [0, 10], [2, 4, 8],
...                 t_eval=[0, 1, 2, 4, 10])
>>> print(sol.t)
[ 0  1  2  4 10]
>>> print(sol.y)
[[ 2.          1.21305369  0.73534021  0.27066736  0.01350938]
 [ 4.          2.42610739  1.47068043  0.54133472  0.02701876]
 [ 8.          4.85221478  2.94136085  1.08266944  0.05403753]]
    
```

Cannon fired upward with terminal event upon impact. The `terminal` and `direction` fields of an event are applied by monkey patching a function. Here `y[0]` is position and `y[1]` is velocity. The projectile starts at position 0 with velocity +10. Note that the integration never reaches `t=100` because the event is terminal.

```

>>> def upward_cannon(t, y): return [y[1], -0.5]
>>> def hit_ground(t, y): return y[1]
>>> hit_ground.terminal = True
>>> hit_ground.direction = -1
>>> sol = solve_ivp(upward_cannon, [0, 100], [0, 10], events=hit_ground)
    
```

```

>>> print(sol.t_events)
[array([ 20.]])
>>> print(sol.t)
[ 0.00000000e+00  9.99900010e-05  1.09989001e-03  1.10988901e-02
 1.11088891e-01  1.11098890e+00  1.11099890e+01  2.00000000e+01]

```

**class** `scipy.integrate.RK23` (*fun*, *t0*, *y0*, *t\_bound*, *max\_step=inf*, *rtol=0.001*, *atol=1e-06*, *vectorized=False*, *\*\*extraneous*)  
 Explicit Runge-Kutta method of order 3(2).

The Bogacki-Shampine pair of formulas is used [R58]. The error is controlled assuming 2nd order accuracy, but steps are taken using a 3rd order accurate formula (local extrapolation is done). A cubic Hermit polynomial is used for the dense output.

Can be applied in a complex domain.

**Parameters** **fun** : callable

Right-hand side of the system. The calling signature is `fun(t, y)`. Here `t` is a scalar and there are two options for ndarray `y`. It can either have shape `(n,)`, then `fun` must return `array_like` with shape `(n,)`. Or alternatively it can have shape `(n, k)`, then `fun` must return `array_like` with shape `(n, k)`, i.e. each column corresponds to a single column in `y`. The choice between the two options is determined by *vectorized* argument (see below). The vectorized implementation allows faster approximation of the Jacobian by finite differences.

**t0** : float

Initial time.

**y0** : `array_like`, shape `(n,)`

Initial state.

**t\_bound** : float

Boundary time — the integration won't continue beyond it. It also determines the direction of the integration.

**max\_step** : float, optional

Maximum allowed step size. Default is `np.inf`, i.e. the step is not bounded and determined solely by the solver.

**rtol, atol** : float and `array_like`, optional

Relative and absolute tolerances. The solver keeps the local error estimates less than `atol + rtol * abs(y)`. Here *rtol* controls a relative accuracy (number of correct digits). But if a component of `y` is approximately below *atol* then the error only needs to fall within the same *atol* threshold, and the number of correct digits is not guaranteed. If components of `y` have different scales, it might be beneficial to set different *atol* values for different components by passing `array_like` with shape `(n,)` for *atol*. Default values are `1e-3` for *rtol* and `1e-6` for *atol*.

**vectorized** : bool, optional

Whether *fun* is implemented in a vectorized fashion. Default is `False`.

## References

[R58]

**Attributes**

<code>n</code>	(int) Number of equations.
<code>status</code>	(string) Current status of the solver: 'running', 'finished' or 'failed'.
<code>t_bound</code>	(float) Boundary time.
<code>direction</code>	(float) Integration direction: +1 or -1.
<code>t</code>	(float) Current time.
<code>y</code>	(ndarray) Current state.
<code>t_old</code>	(float) Previous time. None if no steps were made yet.
<code>step_size</code>	(float) Size of the last successful step. None if no steps were made yet.
<code>nfev</code>	(int) Number of the system's rhs evaluations.
<code>njev</code>	(int) Number of the Jacobian evaluations.
<code>nlu</code>	(int) Number of LU decompositions.

**Methods**

---

<code>dense_output()</code>	Compute a local interpolant over the last successful step.
<code>step()</code>	Perform one integration step.

---

`RK23.dense_output()`

Compute a local interpolant over the last successful step.

**Returns** `sol`: *DenseOutput*  
Local interpolant over the last successful step.

`RK23.step()`

Perform one integration step.

**Returns** `message`: string or None  
Report from the solver. Typically a reason for a failure if *self.status* is 'failed' after the step was taken or None otherwise.

**class** `scipy.integrate.RK45` (*fun, t0, y0, t\_bound, max\_step=inf, rtol=0.001, atol=1e-06, vectorized=False, \*\*extraneous*)

Explicit Runge-Kutta method of order 5(4).

The Dormand-Prince pair of formulas is used [R59]. The error is controlled assuming 4th order accuracy, but steps are taken using a 5th order accurate formula (local extrapolation is done). A quartic interpolation polynomial is used for the dense output [R60].

Can be applied in a complex domain.

**Parameters** `fun`: callable  
Right-hand side of the system. The calling signature is `fun(t, y)`. Here `t` is a scalar and there are two options for ndarray `y`. It can either have shape `(n,)`, then `fun` must return array\_like with shape `(n,)`. Or alternatively it can have shape `(n, k)`, then `fun` must return array\_like with shape `(n, k)`, i.e. each column corresponds to a single column in `y`. The choice between the two options is determined by *vectorized* argument (see below). The vectorized implementation allows faster approximation of the Jacobian by finite differences.

`t0`: float  
Initial value of the independent variable.

`y0`: array\_like, shape `(n,)`  
Initial values of the dependent variable.

`t_bound`: float  
Boundary time — the integration won't continue beyond it. It also determines the direction of the integration.

**max\_step** : float, optional

Maximum allowed step size. Default is `np.inf`, i.e. the step is not bounded and determined solely by the solver.

**rtol, atol** : float and `array_like`, optional

Relative and absolute tolerances. The solver keeps the local error estimates less than  $atol + rtol * abs(y)$ . Here *rtol* controls a relative accuracy (number of correct digits). But if a component of *y* is approximately below *atol* then the error only needs to fall within the same *atol* threshold, and the number of correct digits is not guaranteed. If components of *y* have different scales, it might be beneficial to set different *atol* values for different components by passing `array_like` with shape `(n,)` for *atol*. Default values are  $1e-3$  for *rtol* and  $1e-6$  for *atol*.

**vectorized** : bool, optional

Whether *fun* is implemented in a vectorized fashion. Default is `False`.

### References

[R59], [R60]

### Attributes

<code>n</code>	(int) Number of equations.
<code>status</code>	(string) Current status of the solver: 'running', 'finished' or 'failed'.
<code>t_bound</code>	(float) Boundary time.
<code>direction</code>	(float) Integration direction: +1 or -1.
<code>t</code>	(float) Current time.
<code>y</code>	(ndarray) Current state.
<code>t_old</code>	(float) Previous time. None if no steps were made yet.
<code>step_size</code>	(float) Size of the last successful step. None if no steps were made yet.
<code>nfev</code>	(int) Number of the system's rhs evaluations.
<code>njev</code>	(int) Number of the Jacobian evaluations.
<code>nlu</code>	(int) Number of LU decompositions.

### Methods

<code>dense_output()</code>	Compute a local interpolant over the last successful step.
<code>step()</code>	Perform one integration step.

`RK45.dense_output()`

Compute a local interpolant over the last successful step.

**Returns** `sol` : `DenseOutput`  
Local interpolant over the last successful step.

`RK45.step()`

Perform one integration step.

**Returns** `message` : string or `None`  
Report from the solver. Typically a reason for a failure if `self.status` is 'failed' after the step was taken or `None` otherwise.

**class** `scipy.integrate.Radau` (*fun*, *t0*, *y0*, *t\_bound*, *max\_step=inf*, *rtol=0.001*, *atol=1e-06*, *jac=None*, *jac\_sparsity=None*, *vectorized=False*, *\*\*extraneous*)

Implicit Runge-Kutta method of Radau IIA family of order 5.

Implementation follows [R61]. The error is controlled for a 3rd order accurate embedded formula. A cubic polynomial which satisfies the collocation conditions is used for the dense output.

**Parameters**

**fun** : callable  
Right-hand side of the system. The calling signature is `fun(t, y)`. Here `t` is a scalar and there are two options for ndarray `y`. It can either have shape `(n,)`, then `fun` must return array\_like with shape `(n,)`. Or alternatively it can have shape `(n, k)`, then `fun` must return array\_like with shape `(n, k)`, i.e. each column corresponds to a single column in `y`. The choice between the two options is determined by *vectorized* argument (see below). The vectorized implementation allows faster approximation of the Jacobian by finite differences.

**t0** : float  
Initial time.

**y0** : array\_like, shape `(n,)`  
Initial state.

**t\_bound** : float  
Boundary time — the integration won't continue beyond it. It also determines the direction of the integration.

**max\_step** : float, optional  
Maximum allowed step size. Default is `np.inf`, i.e. the step is not bounded and determined solely by the solver.

**rtol, atol** : float and array\_like, optional  
Relative and absolute tolerances. The solver keeps the local error estimates less than `atol + rtol * abs(y)`. Here *rtol* controls a relative accuracy (number of correct digits). But if a component of `y` is approximately below *atol* then the error only needs to fall within the same *atol* threshold, and the number of correct digits is not guaranteed. If components of `y` have different scales, it might be beneficial to set different *atol* values for different components by passing array\_like with shape `(n,)` for *atol*. Default values are `1e-3` for *rtol* and `1e-6` for *atol*.

**jac** : {None, array\_like, sparse\_matrix, callable}, optional  
Jacobian matrix of the right-hand side of the system with respect to `y`, required only by 'Radau' and 'BDF' methods. The Jacobian matrix has shape `(n, n)` and its element `(i, j)` is equal to  $\frac{d f_i}{d y_j}$ . There are 3 ways to define the Jacobian:

- If array\_like or sparse\_matrix, then the Jacobian is assumed to be constant.
- If callable, then the Jacobian is assumed to depend on both `t` and `y`, and will be called as `jac(t, y)` as necessary. The return value might be a sparse matrix.
- If None (default), then the Jacobian will be approximated by finite differences.

It is generally recommended to provide the Jacobian rather than relying on a finite difference approximation.

**jac\_sparsity** : {None, array\_like, sparse matrix}, optional  
Defines a sparsity structure of the Jacobian matrix for a finite difference approximation, its shape must be `(n, n)`. If the Jacobian has only few non-zero elements in *each* row, providing the sparsity structure will greatly speed up the computations [R62]. A zero entry means that a corresponding element in the Jacobian is identically zero. If None (default), the Jacobian is assumed to be dense.

**vectorized** : bool, optional  
Whether *fun* is implemented in a vectorized fashion. Default is False.

## References

[R61], [R62]

**Attributes**

<b>n</b>	(int) Number of equations.
<b>status</b>	(string) Current status of the solver: 'running', 'finished' or 'failed'.
<b>t_bound</b>	(float) Boundary time.
<b>direction</b>	(float) Integration direction: +1 or -1.
<b>t</b>	(float) Current time.
<b>y</b>	(ndarray) Current state.
<b>t_old</b>	(float) Previous time. None if no steps were made yet.
<b>step_size</b>	(float) Size of the last successful step. None if no steps were made yet.
<b>nfev</b>	(int) Number of the system's rhs evaluations.
<b>njev</b>	(int) Number of the Jacobian evaluations.
<b>nlu</b>	(int) Number of LU decompositions.

**Methods**

<code>dense_output()</code>	Compute a local interpolant over the last successful step.
<code>step()</code>	Perform one integration step.

Radau.**dense\_output** ()

Compute a local interpolant over the last successful step.

**Returns** **sol** : *DenseOutput*  
Local interpolant over the last successful step.

Radau.**step** ()

Perform one integration step.

**Returns** **message** : string or None  
Report from the solver. Typically a reason for a failure if *self.status* is 'failed' after the step was taken or None otherwise.

**class** `scipy.integrate.BDF` (*fun*, *t0*, *y0*, *t\_bound*, *max\_step=inf*, *rtol=0.001*, *atol=1e-06*, *jac=None*,  
*jac\_sparsity=None*, *vectorized=False*, *\*\*extraneous*)

Implicit method based on Backward Differentiation Formulas.

This is a variable order method with the order varying automatically from 1 to 5. The general framework of the BDF algorithm is described in [R50]. This class implements a quasi-constant step size approach as explained in [R51]. The error estimation strategy for the constant step BDF is derived in [R52]. An accuracy enhancement using modified formulas (NDF) [R51] is also implemented.

Can be applied in a complex domain.

**Parameters** **fun** : callable  
Right-hand side of the system. The calling signature is `fun(t, y)`. Here `t` is a scalar and there are two options for ndarray `y`. It can either have shape `(n,)`, then `fun` must return `array_like` with shape `(n,)`. Or alternatively it can have shape `(n, k)`, then `fun` must return `array_like` with shape `(n, k)`, i.e. each column corresponds to a single column in `y`. The choice between the two options is determined by *vectorized* argument (see below). The vectorized implementation allows faster approximation of the Jacobian by finite differences.

**t0** : float  
Initial time.

**y0** : `array_like`, shape `(n,)`  
Initial state.

**t\_bound** : float

Boundary time — the integration won't continue beyond it. It also determines the direction of the integration.

**max\_step** : float, optional

Maximum allowed step size. Default is `np.inf`, i.e. the step is not bounded and determined solely by the solver.

**rtol, atol** : float and array\_like, optional

Relative and absolute tolerances. The solver keeps the local error estimates less than  $atol + rtol * abs(y)$ . Here *rtol* controls a relative accuracy (number of correct digits). But if a component of *y* is approximately below *atol* then the error only needs to fall within the same *atol* threshold, and the number of correct digits is not guaranteed. If components of *y* have different scales, it might be beneficial to set different *atol* values for different components by passing array\_like with shape (n,) for *atol*. Default values are 1e-3 for *rtol* and 1e-6 for *atol*.

**jac** : {None, array\_like, sparse\_matrix, callable}, optional

Jacobian matrix of the right-hand side of the system with respect to *y*, required only by 'Radau' and 'BDF' methods. The Jacobian matrix has shape (n, n) and its element (i, j) is equal to  $d f_i / d y_j$ . There are 3 ways to define the Jacobian:

- If array\_like or sparse\_matrix, then the Jacobian is assumed to be constant.
- If callable, then the Jacobian is assumed to depend on both *t* and *y*, and will be called as `jac(t, y)` as necessary. The return value might be a sparse matrix.
- If None (default), then the Jacobian will be approximated by finite differences.

It is generally recommended to provide the Jacobian rather than relying on a finite difference approximation.

**jac\_sparsity** : {None, array\_like, sparse matrix}, optional

Defines a sparsity structure of the Jacobian matrix for a finite difference approximation, its shape must be (n, n). If the Jacobian has only few non-zero elements in *each* row, providing the sparsity structure will greatly speed up the computations [R53]. A zero entry means that a corresponding element in the Jacobian is identically zero. If None (default), the Jacobian is assumed to be dense.

**vectorized** : bool, optional

Whether *fun* is implemented in a vectorized fashion. Default is False.

### References

[R50], [R51], [R52], [R53]

### Attributes

<code>n</code>	(int) Number of equations.
<code>status</code>	(string) Current status of the solver: 'running', 'finished' or 'failed'.
<code>t_bound</code>	(float) Boundary time.
<code>direction</code>	(float) Integration direction: +1 or -1.
<code>t</code>	(float) Current time.
<code>y</code>	(ndarray) Current state.
<code>t_old</code>	(float) Previous time. None if no steps were made yet.
<code>step_size</code>	(float) Size of the last successful step. None if no steps were made yet.
<code>nfev</code>	(int) Number of the system's rhs evaluations.
<code>njev</code>	(int) Number of the Jacobian evaluations.
<code>nlu</code>	(int) Number of LU decompositions.

### Methods

<code>dense_output()</code>	Compute a local interpolant over the last successful step.
<code>step()</code>	Perform one integration step.

`BDF.dense_output()`

Compute a local interpolant over the last successful step.

**Returns** `sol`: *DenseOutput*  
Local interpolant over the last successful step.

`BDF.step()`

Perform one integration step.

**Returns** `message`: string or None  
Report from the solver. Typically a reason for a failure if `self.status` is 'failed' after the step was taken or None otherwise.

`class scipy.integrate.LSODA` (*fun*, *t0*, *y0*, *t\_bound*, *first\_step=None*, *min\_step=0.0*, *max\_step=inf*, *rtol=0.001*, *atol=1e-06*, *jac=None*, *lband=None*, *uband=None*, *vectorized=False*, *\*\*extraneous*)

Adams/BDF method with automatic stiffness detection and switching.

This is a wrapper to the Fortran solver from ODEPACK [R56]. It switches automatically between the nonstiff Adams method and the stiff BDF method. The method was originally detailed in [R57].

**Parameters** `fun`: callable

Right-hand side of the system. The calling signature is `fun(t, y)`. Here `t` is a scalar and there are two options for ndarray `y`. It can either have shape `(n,)`, then `fun` must return array\_like with shape `(n,)`. Or alternatively it can have shape `(n, k)`, then `fun` must return array\_like with shape `(n, k)`, i.e. each column corresponds to a single column in `y`. The choice between the two options is determined by *vectorized* argument (see below). The vectorized implementation allows faster approximation of the Jacobian by finite differences.

`t0`: float

Initial time.

`y0`: array\_like, shape `(n,)`

Initial state.

`t_bound`: float

Boundary time — the integration won't continue beyond it. It also determines the direction of the integration.

`first_step`: float or None, optional

Initial step size. Default is None which means that the algorithm should choose.

`min_step`: float, optional

Minimum allowed step size. Default is 0.0, i.e. the step is not bounded and determined solely by the solver.

`max_step`: float, optional

Maximum allowed step size. Default is `np.inf`, i.e. the step is not bounded and determined solely by the solver.

`rtol`, `atol`: float and array\_like, optional

Relative and absolute tolerances. The solver keeps the local error estimates less than `atol + rtol * abs(y)`. Here *rtol* controls a relative accuracy (number of correct digits). But if a component of `y` is approximately below *atol* then the error only needs to fall within the same *atol* threshold, and the number of correct digits is not guaranteed. If components of `y` have different scales, it might be beneficial to set different *atol* values for different components by passing array\_like with shape `(n,)` for *atol*. Default values are 1e-3 for *rtol* and 1e-6 for *atol*.

`jac`: None or callable, optional

Jacobian matrix of the right-hand side of the system with respect to `y`. The Jacobian matrix has shape `(n, n)` and its element `(i, j)` is equal to  $\frac{d f_i}{d y_j}$ . The function will be called as `jac(t, y)`. If None (default), then the Jacobian will be ap-

proximated by finite differences. It is generally recommended to provide the Jacobian rather than relying on a finite difference approximation.

**lband, uband** : int or None, optional

Jacobian band width:  $\text{jac}[i, j] \neq 0$  only for  $i - \text{lband} \leq j \leq i + \text{uband}$ . Setting these requires your *jac* routine to return the Jacobian in the packed format: the returned array must have *n* columns and  $\text{uband} + \text{lband} + 1$  rows in which Jacobian diagonals are written. Specifically  $\text{jac\_packed}[\text{uband} + i - j, j] = \text{jac}[i, j]$ . The same format is used in *scipy.linalg.solve\_banded* (check for an illustration). These parameters can be also used with *jac=None* to reduce the number of Jacobian elements estimated by finite differences.

**vectorized** : bool, optional

Whether *fun* is implemented in a vectorized fashion. A vectorized implementation offers no advantages for this solver. Default is False.

**References**

[R56], [R57]

**Attributes**

<b>n</b>	(int) Number of equations.
<b>status</b>	(string) Current status of the solver: 'running', 'finished' or 'failed'.
<b>t_bound</b>	(float) Boundary time.
<b>direction</b>	(float) Integration direction: +1 or -1.
<b>t</b>	(float) Current time.
<b>y</b>	(ndarray) Current state.
<b>t_old</b>	(float) Previous time. None if no steps were made yet.
<b>nfev</b>	(int) Number of the system's rhs evaluations.
<b>njev</b>	(int) Number of the Jacobian evaluations.

**Methods**

<i>dense_output</i> ()	Compute a local interpolant over the last successful step.
<i>step</i> ()	Perform one integration step.

`LSODA.dense_output()`

Compute a local interpolant over the last successful step.

**Returns** `sol` : *DenseOutput*  
Local interpolant over the last successful step.

`LSODA.step()`

Perform one integration step.

**Returns** `message` : string or None  
Report from the solver. Typically a reason for a failure if *self.status* is 'failed' after the step was taken or None otherwise.

**class** `scipy.integrate.OdeSolver` (*fun, t0, y0, t\_bound, vectorized, support\_complex=False*)  
Base class for ODE solvers.

In order to implement a new solver you need to follow the guidelines:

- 1.A constructor must accept parameters presented in the base class (listed below) along with any other parameters specific to a solver.

2. A constructor must accept arbitrary extraneous arguments `**extraneous`, but warn that these arguments are irrelevant using `common.warn_extraneous` function. Do not pass these arguments to the base class.
3. A solver must implement a private method `_step_impl(self)` which propagates a solver one step further. It must return tuple `(success, message)`, where `success` is a boolean indicating whether a step was successful, and `message` is a string containing description of a failure if a step failed or `None` otherwise.
4. A solver must implement a private method `_dense_output_impl(self)` which returns a `DenseOutput` object covering the last successful step.
5. A solver must have attributes listed below in Attributes section. Note that `t_old` and `step_size` are updated automatically.
6. Use `fun(self, t, y)` method for the system rhs evaluation, this way the number of function evaluations (`nfev`) will be tracked automatically.
7. For convenience a base class provides `fun_single(self, t, y)` and `fun_vectorized(self, t, y)` for evaluating the rhs in non-vectorized and vectorized fashions respectively (regardless of how `fun` from the constructor is implemented). These calls don't increment `nfev`.
8. If a solver uses a Jacobian matrix and LU decompositions, it should track the number of Jacobian evaluations (`njev`) and the number of LU decompositions (`nlu`).
9. By convention the function evaluations used to compute a finite difference approximation of the Jacobian should not be counted in `nfev`, thus use `fun_single(self, t, y)` or `fun_vectorized(self, t, y)` when computing a finite difference approximation of the Jacobian.

**Parameters** `fun` : callable

Right-hand side of the system. The calling signature is `fun(t, y)`. Here `t` is a scalar and there are two options for ndarray `y`. It can either have shape `(n,)`, then `fun` must return array\_like with shape `(n,)`. Or alternatively it can have shape `(n, n_points)`, then `fun` must return array\_like with shape `(n, n_points)` (each column corresponds to a single column in `y`). The choice between the two options is determined by `vectorized` argument (see below).

**t0** : float

Initial time.

**y0** : array\_like, shape (n,)

Initial state.

**t\_bound** : float

Boundary time — the integration won't continue beyond it. It also determines the direction of the integration.

**vectorized** : bool

Whether `fun` is implemented in a vectorized fashion.

**support\_complex** : bool, optional

Whether integration in a complex domain should be supported. Generally determined by a derived solver class capabilities. Default is `False`.

**Attributes**

<code>n</code>	(int) Number of equations.
<code>status</code>	(string) Current status of the solver: 'running', 'finished' or 'failed'.
<code>t_bound</code>	(float) Boundary time.
<code>direction</code>	(float) Integration direction: +1 or -1.
<code>t</code>	(float) Current time.
<code>y</code>	(ndarray) Current state.
<code>t_old</code>	(float) Previous time. None if no steps were made yet.
<code>step_size</code>	(float) Size of the last successful step. None if no steps were made yet.
<code>nfev</code>	(int) Number of the system's rhs evaluations.
<code>njev</code>	(int) Number of the Jacobian evaluations.
<code>nlu</code>	(int) Number of LU decompositions.

**Methods**

---

<code>dense_output()</code>	Compute a local interpolant over the last successful step.
<code>step()</code>	Perform one integration step.

---

`OdeSolver.dense_output()`  
 Compute a local interpolant over the last successful step.

**Returns** `sol` : *DenseOutput*  
 Local interpolant over the last successful step.

`OdeSolver.step()`  
 Perform one integration step.

**Returns** `message` : string or None  
 Report from the solver. Typically a reason for a failure if `self.status` is 'failed' after the step was taken or None otherwise.

**class** `scipy.integrate.DenseOutput(t_old, t)`  
 Base class for local interpolant over step made by an ODE solver.

It interpolates between `t_min` and `t_max` (see Attributes below). Evaluation outside this interval is not forbidden, but the accuracy is not guaranteed.

**Attributes**

<code>t_min, t_max</code>	(float) Time range of the interpolation.
---------------------------	--

**Methods**

---

<code>__call__(t)</code>	Evaluate the interpolant.
--------------------------	---------------------------

---

`DenseOutput.__call__(t)`  
 Evaluate the interpolant.

**Parameters** `t` : float or array\_like with shape (n\_points,)  
 Points to evaluate the solution at.

**Returns** `y` : ndarray, shape (n,) or (n, n\_points)  
 Computed values. Shape depends on whether `t` was a scalar or a 1-d array.

**class** `scipy.integrate.OdeSolution(ts, interpolants)`  
 Continuous ODE solution.

It is organized as a collection of *DenseOutput* objects which represent local interpolants. It provides an algorithm to select a right interpolant for each given point.

The interpolants cover the range between *t\_min* and *t\_max* (see Attributes below). Evaluation outside this interval is not forbidden, but the accuracy is not guaranteed.

When evaluating at a breakpoint (one of the values in *ts*) a segment with the lower index is selected.

**Parameters** *ts* : array\_like, shape (n\_segments + 1,  
Time instants between which local interpolants are defined. Must be strictly increasing or decreasing (zero segment with two points is also allowed).

**interpolants** : list of DenseOutput with n\_segments elements  
Local interpolants. An i-th interpolant is assumed to be defined between *ts[i]* and *ts[i + 1]*.

#### Attributes

<i>t_min</i> , <i>t_max</i>	(float) Time range of the interpolation.
-----------------------------	--

#### Methods

<code>__call__(t)</code>	Evaluate the solution.
--------------------------	------------------------

`OdeSolution.__call__(t)`

Evaluate the solution.

**Parameters** *t* : float or array\_like with shape (n\_points,)
   
Points to evaluate at.

**Returns** *y* : ndarray, shape (n\_states,) or (n\_states, n\_points)
   
Computed values. Shape depends on whether *t* is a scalar or a 1-d array.

## Old API

These are the routines developed earlier for scipy. They wrap older solvers implemented in Fortran (mostly ODE-PACK). While the interface to them is not particularly convenient and certain features are missing compared to the new API, the solvers themselves are of good quality and work fast as compiled Fortran code. In some cases it might be worth using this old API.

<code>odeint(func, y0, t[, args, Dfun, col_deriv, ...])</code>	Integrate a system of ordinary differential equations.
<code>ode(f[, jac])</code>	A generic interface class to numeric integrators.
<code>complex_ode(f[, jac])</code>	A wrapper of ode for complex systems.

`scipy.integrate.odeint` (*func*, *y0*, *t*, *args=()*, *Dfun=None*, *col\_deriv=0*, *full\_output=0*, *ml=None*, *mu=None*, *rtol=None*, *atol=None*, *tcrit=None*, *h0=0.0*, *hmax=0.0*, *hmin=0.0*, *ixpr=0*, *mxstep=0*, *mxhnil=0*, *mxordn=12*, *mxords=5*, *printmessg=0*)

Integrate a system of ordinary differential equations.

Solve a system of ordinary differential equations using lsoda from the FORTRAN library odepack.

Solves the initial value problem for stiff or non-stiff systems of first order ode-s:

$dy/dt = \text{func}(y, t_0, \dots)$
--------------------------------------

where *y* can be a vector.

*Note:* The first two arguments of `func(y, t0, ...)` are in the opposite order of the arguments in the system definition function used by the `scipy.integrate.ode` class.

**Parameters**

- func** : callable(y, t0, ...)  
Computes the derivative of y at t0.
- y0** : array  
Initial condition on y (can be a vector).
- t** : array  
A sequence of time points for which to solve for y. The initial value point should be the first element of this sequence.
- args** : tuple, optional  
Extra arguments to pass to function.
- Dfun** : callable(y, t0, ...)  
Gradient (Jacobian) of *func*.
- col\_deriv** : bool, optional  
True if *Dfun* defines derivatives down columns (faster), otherwise *Dfun* should define derivatives across rows.
- full\_output** : bool, optional  
True if to return a dictionary of optional outputs as the second output
- printmessg** : bool, optional  
Whether to print the convergence message

**Returns**

- y** : array, shape (len(t), len(y0))  
Array containing the value of y for each desired time in t, with the initial value y0 in the first row.
- infodict** : dict, only returned if full\_output == True  
Dictionary containing additional output information

key	meaning
'hu'	vector of step sizes successfully used for each time step.
'tcur'	vector with the value of t reached for each time step. (will always be at least as large as the input times).
'tolstf'	vector of tolerance scale factors, greater than 1.0, computed when a request for too much accuracy was detected.
'tsw'	value of t at the time of the last method switch (given for each time step)
'nst'	cumulative number of time steps
'nfe'	cumulative number of function evaluations for each time step
'nje'	cumulative number of jacobian evaluations for each time step
'nqu'	a vector of method orders for each successful step.
'imxer'	index of the component of largest magnitude in the weighted local error vector (e / ewt) on an error return, -1 otherwise.
'lenrw'	the length of the double work array required.
'leniw'	the length of integer work array required.
'mused'	a vector of method indicators for each successful time step: 1: adams (nonstiff), 2: bdf (stiff)

**Other Parameters**

- ml, mu** : int, optional  
If either of these are not None or non-negative, then the Jacobian is assumed to be banded. These give the number of lower and upper non-zero diagonals in this banded matrix. For the banded case, *Dfun* should return a matrix whose rows contain the non-zero bands (starting with the lowest diagonal). Thus, the return matrix *jac* from *Dfun* should have shape `(ml + mu + 1, len(y0))` when `ml >= 0` or `mu >= 0`. The data in *jac* must be stored such that `jac[i - j + mu, j]` holds the derivative of the *i*'th equation with respect to the *j*'th state variable. If `'col_deriv` is True, the transpose of this *jac* must be returned.
- rtol, atol** : float, optional

The input parameters *rtol* and *atol* determine the error control performed by the solver. The solver will control the vector, *e*, of estimated local errors in *y*, according to an inequality of the form  $\max\text{-norm of } (e / \text{ewt}) \leq 1$ , where *ewt* is a vector of positive error weights computed as  $\text{ewt} = \text{rtol} * \text{abs}(y) + \text{atol}$ . *rtol* and *atol* can be either vectors the same length as *y* or scalars. Defaults to 1.49012e-8.

**tcrit** : ndarray, optional

Vector of critical points (e.g. singularities) where integration care should be taken.

**h0** : float, (0: solver-determined), optional

The step size to be attempted on the first step.

**hmax** : float, (0: solver-determined), optional

The maximum absolute step size allowed.

**hmin** : float, (0: solver-determined), optional

The minimum absolute step size allowed.

**ixpr** : bool, optional

Whether to generate extra printing at method switches.

**mxstep** : int, (0: solver-determined), optional

Maximum number of (internally defined) steps allowed for each integration point in *t*.

**mxhnil** : int, (0: solver-determined), optional

Maximum number of messages printed.

**mxordn** : int, (0: solver-determined), optional

Maximum order to be allowed for the non-stiff (Adams) method.

**mxords** : int, (0: solver-determined), optional

Maximum order to be allowed for the stiff (BDF) method.

#### See also:

**ode** a more object-oriented integrator based on VODE.

**quad** for finding the area under a curve.

#### Examples

The second order differential equation for the angle *theta* of a pendulum acted on by gravity with friction can be written:

```
theta''(t) + b*theta'(t) + c*sin(theta(t)) = 0
```

where *b* and *c* are positive constants, and a prime (') denotes a derivative. To solve this equation with *odeint*, we must first convert it to a system of first order equations. By defining the angular velocity  $\omega(t) = \text{theta}'(t)$ , we obtain the system:

```
theta'(t) = omega(t)
omega'(t) = -b*omega(t) - c*sin(theta(t))
```

Let *y* be the vector [*theta*, *omega*]. We implement this system in python as:

```
>>> def pend(y, t, b, c):
...     theta, omega = y
...     dydt = [omega, -b*omega - c*np.sin(theta)]
...     return dydt
... 
```

We assume the constants are *b* = 0.25 and *c* = 5.0:

```
>>> b = 0.25
>>> c = 5.0
```

For initial conditions, we assume the pendulum is nearly vertical with  $\theta(0) = \pi - 0.1$ , and it initially at rest, so  $\omega(0) = 0$ . Then the vector of initial conditions is

```
>>> y0 = [np.pi - 0.1, 0.0]
```

We generate a solution 101 evenly spaced samples in the interval  $0 \leq t \leq 10$ . So our array of times is:

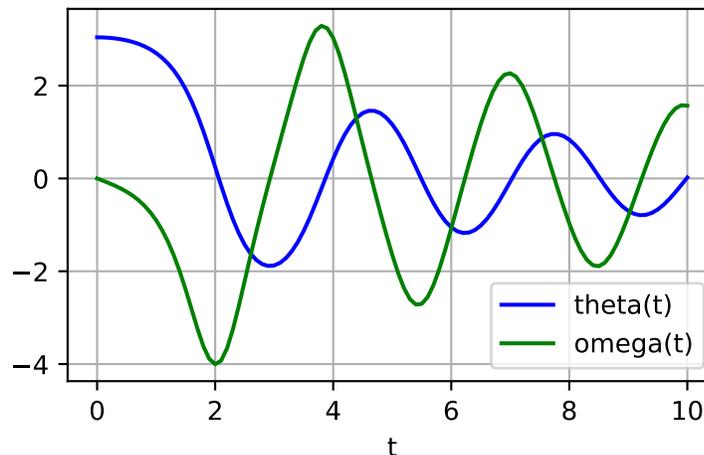
```
>>> t = np.linspace(0, 10, 101)
```

Call `odeint` to generate the solution. To pass the parameters  $b$  and  $c$  to `pend`, we give them to `odeint` using the `args` argument.

```
>>> from scipy.integrate import odeint
>>> sol = odeint(pend, y0, t, args=(b, c))
```

The solution is an array with shape (101, 2). The first column is  $\theta(t)$ , and the second is  $\omega(t)$ . The following code plots both components.

```
>>> import matplotlib.pyplot as plt
>>> plt.plot(t, sol[:, 0], 'b', label='theta(t)')
>>> plt.plot(t, sol[:, 1], 'g', label='omega(t)')
>>> plt.legend(loc='best')
>>> plt.xlabel('t')
>>> plt.grid()
>>> plt.show()
```



**class** `scipy.integrate.ode` ( $f, jac=None$ )

A generic interface class to numeric integrators.

Solve an equation system  $y'(t) = f(t, y)$  with (optional) `jac = df/dy`.

*Note:* The first two arguments of `f(t, y, ...)` are in the opposite order of the arguments in the system definition function used by `scipy.integrate.odeint`.

**Parameters** `f`: callable `f(t, y, *f_args)`

Right-hand side of the differential equation. `t` is a scalar, `y.shape == (n,)`. `f_args` is set by calling `set_f_params(*args)`. `f` should return a scalar, array or list (not a tuple).

`jac`: callable `jac(t, y, *jac_args)`, optional

Jacobian of the right-hand side,  $\text{jac}[i, j] = \text{d} f[i] / \text{d} y[j]$ . `jac_args` is set by calling `set_jac_params(*args)`.

**See also:**

**odeint** an integrator with a simpler interface based on `lsoda` from ODEPACK

**quad** for finding the area under a curve

**Notes**

Available integrators are listed below. They can be selected using the `set_integrator` method.

“vode”

Real-valued Variable-coefficient Ordinary Differential Equation solver, with fixed-leading-coefficient implementation. It provides implicit Adams method (for non-stiff problems) and a method based on backward differentiation formulas (BDF) (for stiff problems).

Source: <http://www.netlib.org/ode/vode.f>

**Warning:** This integrator is not re-entrant. You cannot have two `ode` instances using the “vode” integrator at the same time.

This integrator accepts the following parameters in `set_integrator` method of the `ode` class:

- `atol` : float or sequence absolute tolerance for solution
- `rtol` : float or sequence relative tolerance for solution
- `lband` : None or int
- `uband` : None or int Jacobian band width,  $\text{jac}[i, j] \neq 0$  for  $i - \text{lband} \leq j \leq i + \text{uband}$ . Setting these requires your `jac` routine to return the jacobian in packed format, `jac_packed[i-j+uband, j] = jac[i, j]`. The dimension of the matrix must be  $(\text{lband} + \text{uband} + 1, \text{len}(y))$ .
- `method`: ‘adams’ or ‘bdf’ Which solver to use, Adams (non-stiff) or BDF (stiff)
- `with_jacobian` : bool This option is only considered when the user has not supplied a Jacobian function and has not indicated (by setting either band) that the Jacobian is banded. In this case, `with_jacobian` specifies whether the iteration method of the ODE solver’s correction step is chord iteration with an internally generated full Jacobian or functional iteration with no Jacobian.
- `nsteps` : int Maximum number of (internally defined) steps allowed during one call to the solver.
- `first_step` : float
- `min_step` : float
- `max_step` : float Limits for the step sizes used by the integrator.
- `order` : int Maximum order used by the integrator, `order`  $\leq 12$  for Adams,  $\leq 5$  for BDF.

“zvode”

Complex-valued Variable-coefficient Ordinary Differential Equation solver, with fixed-leading-coefficient implementation. It provides implicit Adams method (for non-stiff problems) and a method based on backward differentiation formulas (BDF) (for stiff problems).

Source: <http://www.netlib.org/ode/zvode.f>

**Warning:** This integrator is not re-entrant. You cannot have two `ode` instances using the “zvode” integrator at the same time.

This integrator accepts the same parameters in `set_integrator` as the “vode” solver.

**Note:** When using ZVODE for a stiff system, it should only be used for the case in which the function `f` is analytic, that is, when each `f(i)` is an analytic function of each `y(j)`. Analyticity means that the partial derivative  $\text{d}f(i)/\text{d}y(j)$  is a unique complex number, and this fact is critical in the way ZVODE solves the dense or banded linear systems that arise in the stiff case. For a complex stiff ODE system in which `f` is

not analytic, ZVODE is likely to have convergence failures, and for this problem one should instead use DVODE on the equivalent real system (in the real and imaginary parts of  $y$ ).

---

“lsoda”

Real-valued Variable-coefficient Ordinary Differential Equation solver, with fixed-leading-coefficient implementation. It provides automatic method switching between implicit Adams method (for non-stiff problems) and a method based on backward differentiation formulas (BDF) (for stiff problems).

Source: <http://www.netlib.org/odepack>

**Warning:** This integrator is not re-entrant. You cannot have two *ode* instances using the “lsoda” integrator at the same time.

This integrator accepts the following parameters in *set\_integrator* method of the *ode* class:

- *atol* : float or sequence absolute tolerance for solution
- *rtol* : float or sequence relative tolerance for solution
- *lband* : None or int
- *uband* : None or int Jacobian band width,  $\text{jac}[i,j] \neq 0$  for  $i-\text{lband} \leq j \leq i+\text{uband}$ . Setting these requires your *jac* routine to return the jacobian in packed format,  $\text{jac\_packed}[i-j+\text{uband}, j] = \text{jac}[i,j]$ .
- *with\_jacobian* : bool *Not used*.
- *nsteps* : int Maximum number of (internally defined) steps allowed during one call to the solver.
- *first\_step* : float
- *min\_step* : float
- *max\_step* : float Limits for the step sizes used by the integrator.
- *max\_order\_ns* : int Maximum order used in the nonstiff case (default 12).
- *max\_order\_s* : int Maximum order used in the stiff case (default 5).
- *max\_hnil* : int Maximum number of messages reporting too small step size ( $t + h = t$ ) (default 0)
- *ixpr* : int Whether to generate extra printing at method switches (default False).

“dopri5”

This is an explicit runge-kutta method of order (4)5 due to Dormand & Prince (with stepsize control and dense output).

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This code is described in [*HNW93*].

This integrator accepts the following parameters in *set\_integrator()* method of the *ode* class:

- *atol* : float or sequence absolute tolerance for solution
- *rtol* : float or sequence relative tolerance for solution
- *nsteps* : int Maximum number of (internally defined) steps allowed during one call to the solver.
- *first\_step* : float
- *max\_step* : float
- *safety* : float Safety factor on new step selection (default 0.9)
- *ifactor* : float
- *dfactor* : float Maximum factor to increase/decrease step size by in one step
- *beta* : float Beta parameter for stabilised step size control.
- *verbosity* : int Switch for printing messages (< 0 for no messages).

“dop853”

This is an explicit runge-kutta method of order 8(5,3) due to Dormand & Prince (with stepsize control and dense output).

Options and references the same as “dopri5”.

## References

[HNW93]

## Examples

A problem to integrate and the corresponding jacobian:

```
>>> from scipy.integrate import ode
>>>
>>> y0, t0 = [1.0j, 2.0], 0
>>>
>>> def f(t, y, arg1):
...     return [1j*arg1*y[0] + y[1], -arg1*y[1]**2]
>>> def jac(t, y, arg1):
...     return [[1j*arg1, 1], [0, -arg1*2*y[1]]]
```

The integration:

```
>>> r = ode(f, jac).set_integrator('zvode', method='bdf')
>>> r.set_initial_value(y0, t0).set_f_params(2.0).set_jac_params(2.0)
>>> t1 = 10
>>> dt = 1
>>> while r.successful() and r.t < t1:
...     print(r.t+dt, r.integrate(r.t+dt))
1 [-0.71038232+0.23749653j  0.40000271+0.j          ]
2.0 [ 0.19098503-0.52359246j  0.22222356+0.j          ]
3.0 [ 0.47153208+0.52701229j  0.15384681+0.j          ]
4.0 [-0.61905937+0.30726255j  0.11764744+0.j          ]
5.0 [ 0.02340997-0.61418799j  0.09523835+0.j          ]
6.0 [ 0.58643071+0.339819j    0.08000018+0.j          ]
7.0 [-0.52070105+0.44525141j  0.06896565+0.j          ]
8.0 [-0.15986733-0.61234476j  0.06060616+0.j          ]
9.0 [ 0.64850462+0.15048982j  0.05405414+0.j          ]
10.0 [-0.38404699+0.56382299j  0.04878055+0.j          ]
```

## Attributes

t	(float) Current time.
y	(ndarray) Current variable values.

## Methods

<code>get_return_code()</code>	Extracts the return code for the integration to enable better control if the integration fails.
<code>integrate(t[, step, relax])</code>	Find $y=y(t)$ , set $y$ as an initial condition, and return $y$ .
<code>set_f_params(*args)</code>	Set extra parameters for user-supplied function $f$ .
<code>set_initial_value(y[, t])</code>	Set initial conditions $y(t) = y$ .
<code>set_integrator(name, **integrator_params)</code>	Set integrator by name.
<code>set_jac_params(*args)</code>	Set extra parameters for user-supplied function $jac$ .
<code>set_solout(solout)</code>	Set callable to be called at every successful integration step.
<code>successful()</code>	Check if integration was successful.

`ode.get_return_code()`

Extracts the return code for the integration to enable better control if the integration fails.

`ode.integrate(t, step=False, relax=False)`

Find  $y=y(t)$ , set  $y$  as an initial condition, and return  $y$ .

**Parameters** **t** : float

The endpoint of the integration step.

**step** : bool

If True, and if the integrator supports the `step` method, then perform a single integration step and return. This parameter is provided in order to expose internals of the implementation, and should not be changed from its default value in most cases.

**relax** : bool

If True and if the integrator supports the `run_relax` method, then integrate until  $t_1 \geq t$  and return. `relax` is not referenced if `step=True`. This parameter is provided in order to expose internals of the implementation, and should not be changed from its default value in most cases.

**Returns** **y** : float

The integrated value at  $t$

`ode.set_f_params(*args)`

Set extra parameters for user-supplied function  $f$ .

`ode.set_initial_value(y, t=0.0)`

Set initial conditions  $y(t) = y$ .

`ode.set_integrator(name, **integrator_params)`

Set integrator by name.

**Parameters** **name** : str

Name of the integrator.

**integrator\_params**

Additional parameters for the integrator.

`ode.set_jac_params(*args)`

Set extra parameters for user-supplied function  $jac$ .

`ode.set_solout(solout)`

Set callable to be called at every successful integration step.

**Parameters** **solout** : callable

`solout(t, y)` is called at each internal integrator step,  $t$  is a scalar providing the current independent position  $y$  is the current solution  $y.shape == (n,)$  `solout` should return -1 to stop integration otherwise it should return None or 0

`ode.successful()`

Check if integration was successful.

**class** `scipy.integrate.complex_ode(f, jac=None)`

A wrapper of `ode` for complex systems.

This functions similarly as `ode`, but re-maps a complex-valued equation system to a real-valued one before using the integrators.

**Parameters** **f** : callable  $f(t, y, *f_args)$

Rhs of the equation.  $t$  is a scalar,  $y.shape == (n,)$ . `f_args` is set by calling `set_f_params(*args)`.

**jac** : callable  $jac(t, y, *jac_args)$

Jacobian of the rhs,  $jac[i, j] = d f[i] / d y[j]$ . `jac_args` is set by calling `set_f_params(*args)`.

**Examples**

For usage examples, see `ode`.

**Attributes**

<code>t</code>	(float) Current time.
<code>y</code>	(ndarray) Current variable values.

**Methods**

<code>get_return_code()</code>	Extracts the return code for the integration to enable better control if the integration fails.
<code>integrate(t[, step, relax])</code>	Find $y=y(t)$ , set $y$ as an initial condition, and return $y$ .
<code>set_f_params(*args)</code>	Set extra parameters for user-supplied function $f$ .
<code>set_initial_value(y[, t])</code>	Set initial conditions $y(t) = y$ .
<code>set_integrator(name, **integrator_params)</code>	Set integrator by name.
<code>set_jac_params(*args)</code>	Set extra parameters for user-supplied function $jac$ .
<code>set_solout(solout)</code>	Set callable to be called at every successful integration step.
<code>successful()</code>	Check if integration was successful.

`complex_ode.get_return_code()`

Extracts the return code for the integration to enable better control if the integration fails.

`complex_ode.integrate(t, step=False, relax=False)`

Find  $y=y(t)$ , set  $y$  as an initial condition, and return  $y$ .

**Parameters** `t` : float

The endpoint of the integration step.

**step** : bool

If True, and if the integrator supports the `step` method, then perform a single integration step and return. This parameter is provided in order to expose internals of the implementation, and should not be changed from its default value in most cases.

**relax** : bool

If True and if the integrator supports the `run_relax` method, then integrate until `t_1`  $\geq t$  and return. `relax` is not referenced if `step=True`. This parameter is provided in order to expose internals of the implementation, and should not be changed from its default value in most cases.

**Returns** `y` : float

The integrated value at  $t$

`complex_ode.set_f_params(*args)`

Set extra parameters for user-supplied function  $f$ .

`complex_ode.set_initial_value(y, t=0.0)`

Set initial conditions  $y(t) = y$ .

`complex_ode.set_integrator(name, **integrator_params)`

Set integrator by name.

**Parameters** `name` : str

Name of the integrator

**integrator\_params**

Additional parameters for the integrator.

`complex_ode.set_jac_params(*args)`  
 Set extra parameters for user-supplied function `jac`.

`complex_ode.set_solout(solout)`  
 Set callable to be called at every successful integration step.

**Parameters** `solout` : callable  
`solout(t, y)` is called at each internal integrator step, `t` is a scalar providing the current independent position `y` is the current solution `y.shape == (n,)` `solout` should return -1 to stop integration otherwise it should return None or 0

`complex_ode.successful()`  
 Check if integration was successful.

## 5.6.4 Solving boundary value problems for ODE systems

---

`solve_bvp(fun, bc, x, y[, p, S, fun_jac, ...])` Solve a boundary-value problem for a system of ODEs.

---

`scipy.integrate.solve_bvp(fun, bc, x, y, p=None, S=None, fun_jac=None, bc_jac=None, tol=0.001, max_nodes=1000, verbose=0)`  
 Solve a boundary-value problem for a system of ODEs.

This function numerically solves a first order system of ODEs subject to two-point boundary conditions:

$dy / dx = f(x, y, p) + S * y / (x - a), \quad a \leq x \leq b$ $bc(y(a), y(b), p) = 0$
---

Here `x` is a 1-dimensional independent variable, `y(x)` is a `n`-dimensional vector-valued function and `p` is a `k`-dimensional vector of unknown parameters which is to be found along with `y(x)`. For the problem to be determined there must be `n + k` boundary conditions, i.e. `bc` must be `(n + k)`-dimensional function.

The last singular term in the right-hand side of the system is optional. It is defined by an `n`-by-`n` matrix `S`, such that the solution must satisfy `S y(a) = 0`. This condition will be forced during iterations, so it must not contradict boundary conditions. See [R65] for the explanation how this term is handled when solving BVPs numerically.

Problems in a complex domain can be solved as well. In this case `y` and `p` are considered to be complex, and `f` and `bc` are assumed to be complex-valued functions, but `x` stays real. Note that `f` and `bc` must be complex differentiable (satisfy Cauchy-Riemann equations [R67]), otherwise you should rewrite your problem for real and imaginary parts separately. To solve a problem in a complex domain, pass an initial guess for `y` with a complex data type (see below).

**Parameters** `fun` : callable  
 Right-hand side of the system. The calling signature is `fun(x, y)`, or `fun(x, y, p)` if parameters are present. All arguments are ndarray: `x` with shape `(m,)`, `y` with shape `(n, m)`, meaning that `y[:, i]` corresponds to `x[i]`, and `p` with shape `(k,)`. The return value must be an array with shape `(n, m)` and with the same layout as `y`.

`bc` : callable  
 Function evaluating residuals of the boundary conditions. The calling signature is `bc(ya, yb)`, or `bc(ya, yb, p)` if parameters are present. All arguments are ndarray: `ya` and `yb` with shape `(n,)`, and `p` with shape `(k,)`. The return value must be an array with shape `(n + k,)`.

`x` : array\_like, shape `(m,)`  
 Initial mesh. Must be a strictly increasing sequence of real numbers with `x[0]=a` and `x[-1]=b`.

`y` : array\_like, shape `(n, m)`

Initial guess for the function values at the mesh nodes,  $i$ -th column corresponds to  $x[i]$ . For problems in a complex domain pass  $y$  with a complex data type (even if the initial guess is purely real).

**p** : array\_like with shape (k,) or None, optional

Initial guess for the unknown parameters. If None (default), it is assumed that the problem doesn't depend on any parameters.

**S** : array\_like with shape (n, n) or None

Matrix defining the singular term. If None (default), the problem is solved without the singular term.

**fun\_jac** : callable or None, optional

Function computing derivatives of  $f$  with respect to  $y$  and  $p$ . The calling signature is `fun_jac(x, y)`, or `fun_jac(x, y, p)` if parameters are present. The return must contain 1 or 2 elements in the following order:

- **df\_dy** : array\_like with shape (n, n, m) where an element (i, j, q) equals to  $d f_i(x_q, y_q, p) / d (y_q)_j$ .
- **df\_dp** : array\_like with shape (n, k, m) where an element (i, j, q) equals to  $d f_i(x_q, y_q, p) / d p_j$ .

Here  $q$  numbers nodes at which  $x$  and  $y$  are defined, whereas  $i$  and  $j$  number vector components. If the problem is solved without unknown parameters **df\_dp** should not be returned.

If *fun\_jac* is None (default), the derivatives will be estimated by the forward finite differences.

**bc\_jac** : callable or None, optional

Function computing derivatives of  $bc$  with respect to  $y_a$ ,  $y_b$  and  $p$ . The calling signature is `bc_jac(ya, yb)`, or `bc_jac(ya, yb, p)` if parameters are present. The return must contain 2 or 3 elements in the following order:

- **dbc\_dya** : array\_like with shape (n, n) where an element (i, j) equals to  $d bc_i(y_a, y_b, p) / d y_{a_j}$ .
- **dbc\_dyb** : array\_like with shape (n, n) where an element (i, j) equals to  $d bc_i(y_a, y_b, p) / d y_{b_j}$ .
- **dbc\_dp** : array\_like with shape (n, k) where an element (i, j) equals to  $d bc_i(y_a, y_b, p) / d p_j$ .

If the problem is solved without unknown parameters **dbc\_dp** should not be returned.

If *bc\_jac* is None (default), the derivatives will be estimated by the forward finite differences.

**tol** : float, optional

Desired tolerance of the solution. If we define  $r = y' - f(x, y)$  where  $y$  is the found solution, then the solver tries to achieve on each mesh interval  $\text{norm}(r / (1 + \text{abs}(f))) < \text{tol}$ , where  $\text{norm}$  is estimated in a root mean squared sense (using a numerical quadrature formula). Default is  $1e-3$ .

**max\_nodes** : int, optional

Maximum allowed number of the mesh nodes. If exceeded, the algorithm terminates. Default is 1000.

**verbose** : {0, 1, 2}, optional

Level of algorithm's verbosity:

- 0 (default) : work silently.
- 1 : display a termination report.
- 2 : display progress during iterations.

### Returns

Bunch object with the following fields defined:

**sol** : PPoly

Found solution for  $y$  as `scipy.interpolate.PPoly` instance, a C1 continuous cubic spline.

**p** : ndarray or None, shape (k,)

Found parameters. None, if the parameters were not present in the problem.

**x** : ndarray, shape (m,)
   
Nodes of the final mesh.
   
**y** : ndarray, shape (n, m)
   
Solution values at the mesh nodes.
   
**yp** : ndarray, shape (n, m)
   
Solution derivatives at the mesh nodes.
   
**rms\_residuals** : ndarray, shape (m - 1,)
   
RMS values of the relative residuals over each mesh interval (see the description of *tol* parameter).
   
**niter** : int
   
Number of completed iterations.
   
**status** : int
   
Reason for algorithm termination:
 

- 0: The algorithm converged to the desired accuracy.
- 1: The maximum number of mesh nodes is exceeded.
- 2: A singular Jacobian encountered when solving the collocation system.

  
**message** : string
   
Verbal description of the termination reason.
   
**success** : bool
   
True if the algorithm converged to the desired accuracy (*status*=0).

### Notes

This function implements a 4-th order collocation algorithm with the control of residuals similar to [R64]. A collocation system is solved by a damped Newton method with an affine-invariant criterion function as described in [R66].

Note that in [R64] integral residuals are defined without normalization by interval lengths. So their definition is different by a multiplier of  $h^{*}0.5$  ( $h$  is an interval length) from the definition used here.

New in version 0.18.0.

### References

[R64], [R65], [R66], [R67]

### Examples

In the first example we solve Bratu's problem:

```

y'' + k * exp(y) = 0
y(0) = y(1) = 0
    
```

for  $k = 1$ .

We rewrite the equation as a first order system and implement its right-hand side evaluation:

```

y1' = y2
y2' = -exp(y1)
    
```

```

>>> def fun(x, y):
...     return np.vstack((y[1], -np.exp(y[0])))
    
```

Implement evaluation of the boundary condition residuals:

```

>>> def bc(ya, yb):
...     return np.array([ya[0], yb[0]])
    
```

Define the initial mesh with 5 nodes:

```
>>> x = np.linspace(0, 1, 5)
```

This problem is known to have two solutions. To obtain both of them we use two different initial guesses for  $y$ . We denote them by subscripts a and b.

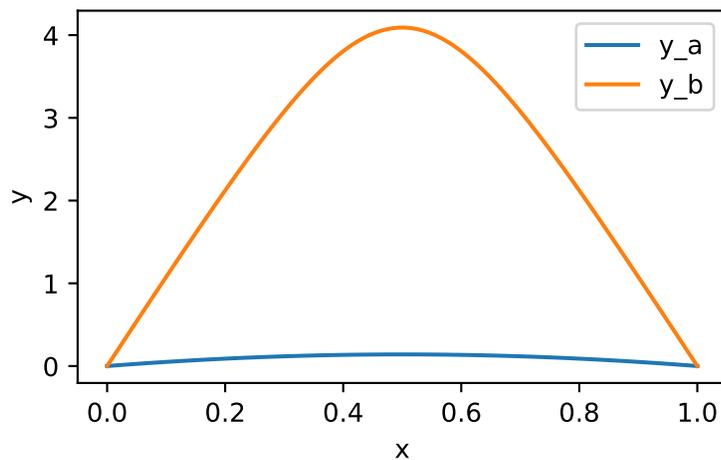
```
>>> y_a = np.zeros((2, x.size))
>>> y_b = np.zeros((2, x.size))
>>> y_b[0] = 3
```

Now we are ready to run the solver.

```
>>> from scipy.integrate import solve_bvp
>>> res_a = solve_bvp(fun, bc, x, y_a)
>>> res_b = solve_bvp(fun, bc, x, y_b)
```

Let's plot the two found solutions. We take an advantage of having the solution in a spline form to produce a smooth plot.

```
>>> x_plot = np.linspace(0, 1, 100)
>>> y_plot_a = res_a.sol(x_plot)[0]
>>> y_plot_b = res_b.sol(x_plot)[0]
>>> import matplotlib.pyplot as plt
>>> plt.plot(x_plot, y_plot_a, label='y_a')
>>> plt.plot(x_plot, y_plot_b, label='y_b')
>>> plt.legend()
>>> plt.xlabel("x")
>>> plt.ylabel("y")
>>> plt.show()
```



We see that the two solutions have similar shape, but differ in scale significantly.

In the second example we solve a simple Sturm-Liouville problem:

```
y'' + k**2 * y = 0
y(0) = y(1) = 0
```

It is known that a non-trivial solution  $y = A * \sin(k * x)$  is possible for  $k = \pi * n$ , where  $n$  is an integer. To establish the normalization constant  $A = 1$  we add a boundary condition:

```
y'(0) = k
```

Again we rewrite our equation as a first order system and implement its right-hand side evaluation:

```
y1' = y2
y2' = -k**2 * y1
```

```
>>> def fun(x, y, p):
...     k = p[0]
...     return np.vstack((y[1], -k**2 * y[0]))
```

Note that parameters  $p$  are passed as a vector (with one element in our case).

Implement the boundary conditions:

```
>>> def bc(ya, yb, p):
...     k = p[0]
...     return np.array([ya[0], yb[0], ya[1] - k])
```

Setup the initial mesh and guess for  $y$ . We aim to find the solution for  $k = 2 * \pi$ , to achieve that we set values of  $y$  to approximately follow  $\sin(2 * \pi * x)$ :

```
>>> x = np.linspace(0, 1, 5)
>>> y = np.zeros((2, x.size))
>>> y[0, 1] = 1
>>> y[0, 3] = -1
```

Run the solver with 6 as an initial guess for  $k$ .

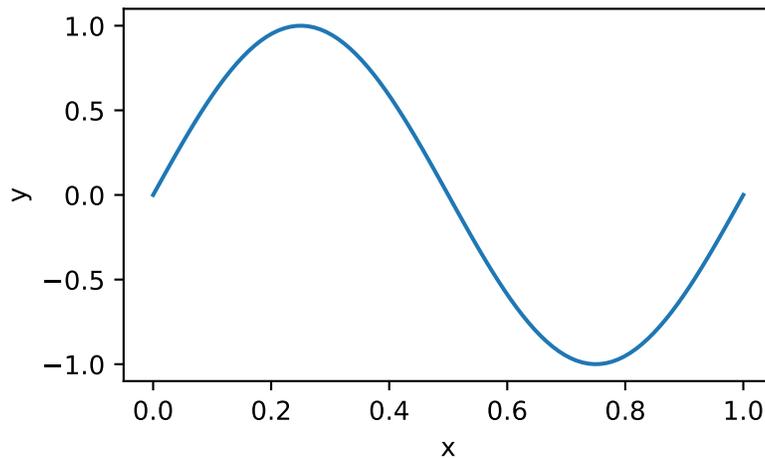
```
>>> sol = solve_bvp(fun, bc, x, y, p=[6])
```

We see that the found  $k$  is approximately correct:

```
>>> sol.p[0]
6.28329460046
```

And finally plot the solution to see the anticipated sinusoid:

```
>>> x_plot = np.linspace(0, 1, 100)
>>> y_plot = sol.sol(x_plot)[0]
>>> plt.plot(x_plot, y_plot)
>>> plt.xlabel("x")
>>> plt.ylabel("y")
>>> plt.show()
```



## 5.7 Interpolation (`scipy.interpolate`)

Sub-package for objects used in interpolation.

As listed below, this sub-package contains spline functions and classes, one-dimensional and multi-dimensional (univariate and multivariate) interpolation classes, Lagrange and Taylor polynomial interpolators, and wrappers for FITPACK and DFITPACK functions.

### 5.7.1 Univariate interpolation

<code>interp1d(x, y[, kind, axis, copy, ...])</code>	Interpolate a 1-D function.
<code>BarycentricInterpolator(xi[, yi, axis])</code>	The interpolating polynomial for a set of points
<code>KroghInterpolator(xi, yi[, axis])</code>	Interpolating polynomial for a set of points.
<code>PchipInterpolator(x, y[, axis, extrapolate])</code>	PCHIP 1-d monotonic cubic interpolation.
<code>barycentric_interpolate(xi, yi, x[, axis])</code>	Convenience function for polynomial interpolation.
<code>krogh_interpolate(xi, yi, x[, der, axis])</code>	Convenience function for polynomial interpolation.
<code>pchip_interpolate(xi, yi, x[, der, axis])</code>	Convenience function for pchip interpolation.
<code>Akima1DInterpolator(x, y[, axis])</code>	Akima interpolator
<code>CubicSpline(x, y[, axis, bc_type, extrapolate])</code>	Cubic spline data interpolator.
<code>PPoly(c, x[, extrapolate, axis])</code>	Piecewise polynomial in terms of coefficients and break-points
<code>BPPoly(c, x[, extrapolate, axis])</code>	Piecewise polynomial in terms of coefficients and break-points.

**class** `scipy.interpolate.interp1d(x, y, kind='linear', axis=-1, copy=True, bounds_error=None, fill_value=nan, assume_sorted=False)`

Interpolate a 1-D function.

$x$  and  $y$  are arrays of values used to approximate some function  $f$ :  $y = f(x)$ . This class returns a function whose call method uses interpolation to find the value of new points.

Note that calling `interp1d` with NaNs present in input values results in undefined behaviour.

**Parameters**

**x** : (N,) array\_like  
A 1-D array of real values.

**y** : (...,N,...) array\_like  
A N-D array of real values. The length of *y* along the interpolation axis must be equal to the length of *x*.

**kind** : str or int, optional  
Specifies the kind of interpolation as a string ('linear', 'nearest', 'zero', 'slinear', 'quadratic', 'cubic' where 'zero', 'slinear', 'quadratic' and 'cubic' refer to a spline interpolation of zeroth, first, second or third order) or as an integer specifying the order of the spline interpolator to use. Default is 'linear'.

**axis** : int, optional  
Specifies the axis of *y* along which to interpolate. Interpolation defaults to the last axis of *y*.

**copy** : bool, optional  
If True, the class makes internal copies of *x* and *y*. If False, references to *x* and *y* are used. The default is to copy.

**bounds\_error** : bool, optional  
If True, a ValueError is raised any time interpolation is attempted on a value outside of the range of *x* (where extrapolation is necessary). If False, out of bounds values are assigned *fill\_value*. By default, an error is raised unless *fill\_value*="extrapolate".

**fill\_value** : array-like or (array-like, array\_like) or "extrapolate", optional

- if a ndarray (or float), this value will be used to fill in for requested points outside of the data range. If not provided, then the default is NaN. The array-like must broadcast properly to the dimensions of the non-interpolation axes.
- If a two-element tuple, then the first element is used as a fill value for  $x_{\text{new}} < x[0]$  and the second element is used for  $x_{\text{new}} > x[-1]$ . Anything that is not a 2-element tuple (e.g., list or ndarray, regardless of shape) is taken to be a single array-like argument meant to be used for both bounds as below, above = *fill\_value*, *fill\_value*.  
New in version 0.17.0.
- If "extrapolate", then points outside the data range will be extrapolated.  
New in version 0.17.0.

**assume\_sorted** : bool, optional  
If False, values of *x* can be in any order and they are sorted first. If True, *x* has to be an array of monotonically increasing values.

See also:

*splrep*, *splev*

### **UnivariateSpline**

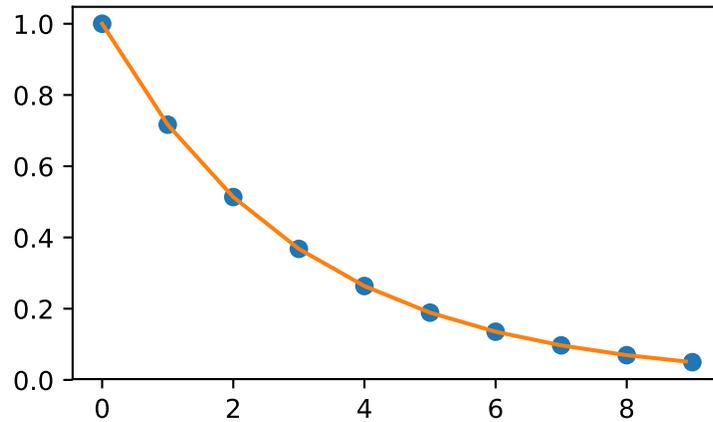
An object-oriented wrapper of the FITPACK routines.

**interp2d** 2-D interpolation

### **Examples**

```
>>> import matplotlib.pyplot as plt
>>> from scipy import interpolate
>>> x = np.arange(0, 10)
>>> y = np.exp(-x/3.0)
>>> f = interpolate.interpld(x, y)
```

```
>>> xnew = np.arange(0, 9, 0.1)
>>> ynew = f(xnew) # use interpolation function returned by `interpld`
>>> plt.plot(x, y, 'o', xnew, ynew, '-')
>>> plt.show()
```

**Attributes**`fill_value``interp1d.fill_value`**Methods**`__call__(x)`

Evaluate the interpolant

`interp1d.__call__(x)`

Evaluate the interpolant

**Parameters** `x` : array\_like  
Points to evaluate the interpolant at.

**Returns** `y` : array\_like  
Interpolated values. Shape is determined by replacing the interpolation axis in the original array with the shape of `x`.

**class** `scipy.interpolate.BarycentricInterpolator` (`xi`, `yi=None`, `axis=0`)

The interpolating polynomial for a set of points

Constructs a polynomial that passes through a given set of points. Allows evaluation of the polynomial, efficient changing of the `y` values to be interpolated, and updating by adding more `x` values. For reasons of numerical stability, this function does not compute the coefficients of the polynomial.

The values `yi` need to be provided before the function is evaluated, but none of the preprocessing depends on them, so rapid updates are possible.

**Parameters** `xi` : array\_like  
1-d array of `x` coordinates of the points the polynomial should pass through  
`yi` : array\_like, optional

The y coordinates of the points the polynomial should pass through. If None, the y values will be supplied later via the `set_y` method.

**axis** : int, optional

Axis in the yi array corresponding to the x-coordinate values.

**Notes**

This class uses a “barycentric interpolation” method that treats the problem as a special case of rational function interpolation. This algorithm is quite stable, numerically, but even in a world of exact computation, unless the x coordinates are chosen very carefully - Chebyshev zeros (e.g.  $\cos(i*\pi/n)$ ) are a good choice - polynomial interpolation itself is a very ill-conditioned process due to the Runge phenomenon.

Based on Berrut and Trefethen 2004, “Barycentric Lagrange Interpolation”.

**Methods**

<code>__call__(x)</code>	Evaluate the interpolating polynomial at the points x
<code>add_xi(xi[, yi])</code>	Add more x values to the set to be interpolated
<code>set_yi(yi[, axis])</code>	Update the y values to be interpolated

`BarycentricInterpolator.__call__(x)`

Evaluate the interpolating polynomial at the points x

**Parameters** **x** : array\_like

Points to evaluate the interpolant at.

**Returns** **y** : array\_like

Interpolated values. Shape is determined by replacing the interpolation axis in the original array with the shape of x.

**Notes**

Currently the code computes an outer product between x and the weights, that is, it constructs an intermediate array of size N by len(x), where N is the degree of the polynomial.

`BarycentricInterpolator.add_xi(xi, yi=None)`

Add more x values to the set to be interpolated

The barycentric interpolation algorithm allows easy updating by adding more points for the polynomial to pass through.

**Parameters** **xi** : array\_like

The x coordinates of the points that the polynomial should pass through.

**yi** : array\_like, optional

The y coordinates of the points the polynomial should pass through. Should have shape `(xi.size, R)`; if `R > 1` then the polynomial is vector-valued. If `yi` is not given, the y values will be supplied later. `yi` should be given if and only if the interpolator has y values specified.

`BarycentricInterpolator.set_yi(yi, axis=None)`

Update the y values to be interpolated

The barycentric interpolation algorithm requires the calculation of weights, but these depend only on the xi. The yi can be changed at any time.

**Parameters** **yi** : array\_like

The y coordinates of the points the polynomial should pass through. If None, the y values will be supplied later.

**axis** : int, optional

Axis in the `yi` array corresponding to the x-coordinate values.

**class** `scipy.interpolate.KroghInterpolator` (`xi, yi, axis=0`)  
Interpolating polynomial for a set of points.

The polynomial passes through all the pairs (`xi`,`yi`). One may additionally specify a number of derivatives at each point `xi`; this is done by repeating the value `xi` and specifying the derivatives as successive `yi` values.

Allows evaluation of the polynomial and all its derivatives. For reasons of numerical stability, this function does not compute the coefficients of the polynomial, although they can be obtained by evaluating all the derivatives.

**Parameters**

- xi** : array\_like, length N  
Known x-coordinates. Must be sorted in increasing order.
- yi** : array\_like  
Known y-coordinates. When an `xi` occurs two or more times in a row, the corresponding `yi`'s represent derivative values.
- axis** : int, optional  
Axis in the `yi` array corresponding to the x-coordinate values.

### Notes

Be aware that the algorithms implemented here are not necessarily the most numerically stable known. Moreover, even in a world of exact computation, unless the x coordinates are chosen very carefully - Chebyshev zeros (e.g.  $\cos(i\pi/n)$ ) are a good choice - polynomial interpolation itself is a very ill-conditioned process due to the Runge phenomenon. In general, even with well-chosen x values, degrees higher than about thirty cause problems with numerical instability in this code.

Based on [R87].

### References

[R87]

### Examples

To produce a polynomial that is zero at 0 and 1 and has derivative 2 at 0, call

```
>>> from scipy.interpolate import KroghInterpolator
>>> KroghInterpolator([0,0,1],[0,2,0])
```

This constructs the quadratic  $2X^2-2X$ . The derivative condition is indicated by the repeated zero in the `xi` array; the corresponding `yi` values are 0, the function value, and 2, the derivative value.

For another example, given `xi`, `yi`, and a derivative `ypi` for each point, appropriate arrays can be constructed as:

```
>>> xi = np.linspace(0, 1, 5)
>>> yi, ypi = np.random.rand(2, 5)
>>> xi_k, yi_k = np.repeat(xi, 2), np.ravel(np.dstack((yi, ypi)))
>>> KroghInterpolator(xi_k, yi_k)
```

To produce a vector-valued polynomial, supply a higher-dimensional array for `yi`:

```
>>> KroghInterpolator([0,1],[[2,3],[4,5]])
```

This constructs a linear polynomial giving (2,3) at 0 and (4,5) at 1.

### Methods

`__call__(x)`

Evaluate the interpolant

Continued on next page

Table 5.37 – continued from previous page

<code>derivative(x[, der])</code>	Evaluate one derivative of the polynomial at the point x
<code>derivatives(x[, der])</code>	Evaluate many derivatives of the polynomial at the point x

`KroghInterpolator.__call__(x)`

Evaluate the interpolant

**Parameters** `x` : array\_like  
Points to evaluate the interpolant at.

**Returns** `y` : array\_like  
Interpolated values. Shape is determined by replacing the interpolation axis in the original array with the shape of x.

`KroghInterpolator.derivative(x, der=1)`

Evaluate one derivative of the polynomial at the point x

**Parameters** `x` : array\_like  
Point or points at which to evaluate the derivatives  
`der` : integer, optional  
Which derivative to extract. This number includes the function value as 0th derivative.

**Returns** `d` : ndarray  
Derivative interpolated at the x-points. Shape of d is determined by replacing the interpolation axis in the original array with the shape of x.

**Notes**

This is computed by evaluating all derivatives up to the desired one (using `self.derivatives()`) and then discarding the rest.

`KroghInterpolator.derivatives(x, der=None)`

Evaluate many derivatives of the polynomial at the point x

Produce an array of all derivative values at the point x.

**Parameters** `x` : array\_like  
Point or points at which to evaluate the derivatives  
`der` : int or None, optional  
How many derivatives to extract; None for all potentially nonzero derivatives (that is a number equal to the number of points). This number includes the function value as 0th derivative.

**Returns** `d` : ndarray  
Array with derivatives; `d[j]` contains the j-th derivative. Shape of `d[j]` is determined by replacing the interpolation axis in the original array with the shape of x.

**Examples**

```
>>> from scipy.interpolate import KroghInterpolator
>>> KroghInterpolator([0,0,0],[1,2,3]).derivatives(0)
array([1.0, 2.0, 3.0])
>>> KroghInterpolator([0,0,0],[1,2,3]).derivatives([0,0])
array([[1.0, 1.0],
       [2.0, 2.0],
       [3.0, 3.0]])
```

**class** `scipy.interpolate.PchipInterpolator` (*x*, *y*, *axis=0*, *extrapolate=None*)  
 PCHIP 1-d monotonic cubic interpolation.

*x* and *y* are arrays of values used to approximate some function *f*, with  $y = f(x)$ . The interpolant uses monotonic cubic splines to find the value of new points. (PCHIP stands for Piecewise Cubic Hermite Interpolating Polynomial).

**Parameters**

- x** : ndarray  
 A 1-D array of monotonically increasing real values. *x* cannot include duplicate values (otherwise *f* is overspecified)
- y** : ndarray  
 A 1-D array of real values. *y*'s length along the interpolation axis must be equal to the length of *x*. If N-D array, use *axis* parameter to select correct axis.
- axis** : int, optional  
 Axis in the *y* array corresponding to the *x*-coordinate values.
- extrapolate** : bool, optional  
 Whether to extrapolate to out-of-bounds points based on first and last intervals, or to return NaNs.

**See also:**

*Akima1DInterpolator*, *CubicSpline*, *BPoly*

**Notes**

The interpolator preserves monotonicity in the interpolation data and does not overshoot if the data is not smooth.

The first derivatives are guaranteed to be continuous, but the second derivatives may jump at  $x_k$ .

Determines the derivatives at the points  $x_k$ ,  $f'_k$ , by using PCHIP algorithm [R89].

Let  $h_k = x_{k+1} - x_k$ , and  $d_k = (y_{k+1} - y_k)/h_k$  are the slopes at internal points  $x_k$ . If the signs of  $d_k$  and  $d_{k-1}$  are different or either of them equals zero, then  $f'_k = 0$ . Otherwise, it is given by the weighted harmonic mean

$$\frac{w_1 + w_2}{f'_k} = \frac{w_1}{d_{k-1}} + \frac{w_2}{d_k}$$

where  $w_1 = 2h_k + h_{k-1}$  and  $w_2 = h_k + 2h_{k-1}$ .

The end slopes are set using a one-sided scheme [R90].

**References**

[R89], [R90]

**Methods**

<code>__call__(x[, nu, extrapolate])</code>	Evaluate the piecewise polynomial or its derivative.
<code>derivative([nu])</code>	Construct a new piecewise polynomial representing the derivative.
<code>antiderivative([nu])</code>	Construct a new piecewise polynomial representing the antiderivative.
<code>roots()</code>	Return the roots of the interpolated function.

`PchipInterpolator.__call__(x, nu=0, extrapolate=None)`  
 Evaluate the piecewise polynomial or its derivative.

**Parameters**

- x** : array\_like  
 Points to evaluate the interpolant at.

**nu** : int, optional

Order of derivative to evaluate. Must be non-negative.

**extrapolate** : {bool, 'periodic', None}, optional

If bool, determines whether to extrapolate to out-of-bounds points based on first and last intervals, or to return NaNs. If 'periodic', periodic extrapolation is used. If None (default), use *self.extrapolate*.

**Returns** **y** : array\_like

Interpolated values. Shape is determined by replacing the interpolation axis in the original array with the shape of x.

**Notes**

Derivatives are evaluated piecewise for each polynomial segment, even if the polynomial is not differentiable at the breakpoints. The polynomial intervals are considered half-open,  $[a, b)$ , except for the last interval which is closed  $[a, b]$ .

`PchipInterpolator.derivative (nu=1)`

Construct a new piecewise polynomial representing the derivative.

**Parameters** **nu** : int, optional

Order of derivative to evaluate. Default is 1, i.e. compute the first derivative. If negative, the antiderivative is returned.

**Returns** **bp** : BPoly

Piecewise polynomial of order  $k - nu$  representing the derivative of this polynomial.

`PchipInterpolator.antiderivative (nu=1)`

Construct a new piecewise polynomial representing the antiderivative.

**Parameters** **nu** : int, optional

Order of antiderivative to evaluate. Default is 1, i.e. compute the first integral. If negative, the derivative is returned.

**Returns** **bp** : BPoly

Piecewise polynomial of order  $k + nu$  representing the antiderivative of this polynomial.

**Notes**

If antiderivative is computed and `self.extrapolate='periodic'`, it will be set to `False` for the returned instance. This is done because the antiderivative is no longer periodic and its correct evaluation outside of the initially given x interval is difficult.

`PchipInterpolator.roots ()`

Return the roots of the interpolated function.

`scipy.interpolate.barycentric_interpolate (xi, yi, x, axis=0)`

Convenience function for polynomial interpolation.

Constructs a polynomial that passes through a given set of points, then evaluates the polynomial. For reasons of numerical stability, this function does not compute the coefficients of the polynomial.

This function uses a “barycentric interpolation” method that treats the problem as a special case of rational function interpolation. This algorithm is quite stable, numerically, but even in a world of exact computation, unless the x coordinates are chosen very carefully - Chebyshev zeros (e.g.  $\cos(i*\pi/n)$ ) are a good choice - polynomial interpolation itself is a very ill-conditioned process due to the Runge phenomenon.

**Parameters** **xi** : array\_like

1-d array of x coordinates of the points the polynomial should pass through

**yi** : array\_like

The y coordinates of the points the polynomial should pass through.

**x** : scalar or array\_like

Points to evaluate the interpolator at.  
**axis** : int, optional  
 Axis in the `yi` array corresponding to the x-coordinate values.  
**Returns** **y** : scalar or array\_like  
 Interpolated values. Shape is determined by replacing the interpolation axis in the original array with the shape of `x`.

**See also:***BarycentricInterpolator***Notes**

Construction of the interpolation weights is a relatively slow process. If you want to call this many times with the same `xi` (but possibly varying `yi` or `x`) you should use the class *BarycentricInterpolator*. This is what this function uses internally.

`scipy.interpolate.krogh_interpolate` (`xi, yi, x, der=0, axis=0`)

Convenience function for polynomial interpolation.

See *KroghInterpolator* for more details.

**Parameters** **xi** : array\_like  
 Known x-coordinates.  
**yi** : array\_like  
 Known y-coordinates, of shape `(xi.size, R)`. Interpreted as vectors of length `R`, or scalars if `R=1`.  
**x** : array\_like  
 Point or points at which to evaluate the derivatives.  
**der** : int or list, optional  
 How many derivatives to extract; None for all potentially nonzero derivatives (that is a number equal to the number of points), or a list of derivatives to extract. This number includes the function value as 0th derivative.  
**axis** : int, optional  
 Axis in the `yi` array corresponding to the x-coordinate values.  
**Returns** **d** : ndarray  
 If the interpolator's values are `R`-dimensional then the returned array will be the number of derivatives by `N` by `R`. If `x` is a scalar, the middle dimension will be dropped; if the `yi` are scalars then the last dimension will be dropped.

**See also:***KroghInterpolator***Notes**

Construction of the interpolating polynomial is a relatively expensive process. If you want to evaluate it repeatedly consider using the class *KroghInterpolator* (which is what this function uses).

`scipy.interpolate.pchip_interpolate` (`xi, yi, x, der=0, axis=0`)

Convenience function for pchip interpolation. `xi` and `yi` are arrays of values used to approximate some function `f`, with `yi = f(xi)`. The interpolant uses monotonic cubic splines to find the value of new points `x` and the derivatives there.

See *PchipInterpolator* for details.

**Parameters** **xi** : array\_like  
 A sorted list of x-coordinates, of length `N`.  
**yi** : array\_like

A 1-D array of real values.  $y_i$ 's length along the interpolation axis must be equal to the length of  $x_i$ . If N-D array, use axis parameter to select correct axis.

**x** : scalar or array\_like  
Of length M.

**der** : int or list, optional  
Derivatives to extract. The 0-th derivative can be included to return the function value.

**axis** : int, optional  
Axis in the  $y_i$  array corresponding to the x-coordinate values.

**Returns** **y** : scalar or array\_like  
The result, of length R or length M or M by R,

**See also:**

*PchipInterpolator*

**class** `scipy.interpolate.Akima1DInterpolator` (*x*, *y*, *axis=0*)  
Akima interpolator

Fit piecewise cubic polynomials, given vectors *x* and *y*. The interpolation method by Akima uses a continuously differentiable sub-spline built from piecewise cubic polynomials. The resultant curve passes through the given data points and will appear smooth and natural.

**Parameters** **x** : ndarray, shape (m, )  
1-D array of monotonically increasing real values.  
**y** : ndarray, shape (m, ...)  
N-D array of real values. The length of *y* along the first axis must be equal to the length of *x*.  
**axis** : int, optional  
Specifies the axis of *y* along which to interpolate. Interpolation defaults to the first axis of *y*.

**See also:**

*PchipInterpolator*, *CubicSpline*, *PPoly*

**Notes**

New in version 0.14.

Use only for precise data, as the fitted curve passes through the given points exactly. This routine is useful for plotting a pleasingly smooth curve through a few given points for purposes of plotting.

**References**

[1] *A new method of interpolation and smooth curve fitting based on local procedures.* Hiroshi Akima, J. ACM, October 1970, 17(4), 589-602.

**Methods**

<code>__call__(x[, nu, extrapolate])</code>	Evaluate the piecewise polynomial or its derivative.
<code>derivative([nu])</code>	Construct a new piecewise polynomial representing the derivative.
<code>antiderivative([nu])</code>	Construct a new piecewise polynomial representing the antiderivative.
<code>roots([discontinuity, extrapolate])</code>	Find real roots of the the piecewise polynomial.

`Akima1DInterpolator.__call__(x, nu=0, extrapolate=None)`  
Evaluate the piecewise polynomial or its derivative.

**Parameters**

- x** : array\_like  
Points to evaluate the interpolant at.
- nu** : int, optional  
Order of derivative to evaluate. Must be non-negative.
- extrapolate** : {bool, 'periodic', None}, optional  
If bool, determines whether to extrapolate to out-of-bounds points based on first and last intervals, or to return NaNs. If 'periodic', periodic extrapolation is used. If None (default), use *self.extrapolate*.

**Returns**

- y** : array\_like  
Interpolated values. Shape is determined by replacing the interpolation axis in the original array with the shape of x.

**Notes**

Derivatives are evaluated piecewise for each polynomial segment, even if the polynomial is not differentiable at the breakpoints. The polynomial intervals are considered half-open,  $[a, b)$ , except for the last interval which is closed  $[a, b]$ .

`Akima1DInterpolator.derivative (nu=1)`

Construct a new piecewise polynomial representing the derivative.

**Parameters**

- nu** : int, optional  
Order of derivative to evaluate. Default is 1, i.e. compute the first derivative. If negative, the antiderivative is returned.

**Returns**

- pp** : PPoly  
Piecewise polynomial of order  $k_2 = k - n$  representing the derivative of this polynomial.

**Notes**

Derivatives are evaluated piecewise for each polynomial segment, even if the polynomial is not differentiable at the breakpoints. The polynomial intervals are considered half-open,  $[a, b)$ , except for the last interval which is closed  $[a, b]$ .

`Akima1DInterpolator.antiderivative (nu=1)`

Construct a new piecewise polynomial representing the antiderivative.

Antiderivative is also the indefinite integral of the function, and derivative is its inverse operation.

**Parameters**

- nu** : int, optional  
Order of antiderivative to evaluate. Default is 1, i.e. compute the first integral. If negative, the derivative is returned.

**Returns**

- pp** : PPoly  
Piecewise polynomial of order  $k_2 = k + n$  representing the antiderivative of this polynomial.

**Notes**

The antiderivative returned by this function is continuous and continuously differentiable to order  $n-1$ , up to floating point rounding error.

If antiderivative is computed and `self.extrapolate='periodic'`, it will be set to `False` for the returned instance. This is done because the antiderivative is no longer periodic and its correct evaluation outside of the initially given x interval is difficult.

`Akima1DInterpolator.roots (discontinuity=True, extrapolate=None)`

Find real roots of the the piecewise polynomial.

**Parameters**

- discontinuity** : bool, optional  
Whether to report sign changes across discontinuities at breakpoints as roots.

**extrapolate** : {bool, 'periodic', None}, optional

If bool, determines whether to return roots from the polynomial extrapolated based on first and last intervals, 'periodic' works the same as False. If None (default), use *self.extrapolate*.

**Returns**

**roots** : ndarray

Roots of the polynomial(s).

If the PPoly object describes multiple polynomials, the return value is an object array whose each element is an ndarray containing the roots.

**See also:**

*PPoly.solve*

**class** `scipy.interpolate.CubicSpline` (*x*, *y*, *axis=0*, *bc\_type='not-a-knot'*, *extrapolate=None*)

Cubic spline data interpolator.

Interpolate data with a piecewise cubic polynomial which is twice continuously differentiable [R85]. The result is represented as a *PPoly* instance with breakpoints matching the given data.

**Parameters**

**x** : array\_like, shape (n,)

1-d array containing values of the independent variable. Values must be real, finite and in strictly increasing order.

**y** : array\_like

Array containing values of the dependent variable. It can have arbitrary number of dimensions, but the length along *axis* (see below) must match the length of *x*. Values must be finite.

**axis** : int, optional

Axis along which *y* is assumed to be varying. Meaning that for  $x[i]$  the corresponding values are `np.take(y, i, axis=axis)`. Default is 0.

**bc\_type** : string or 2-tuple, optional

Boundary condition type. Two additional equations, given by the boundary conditions, are required to determine all coefficients of polynomials on each segment [R86].

If *bc\_type* is a string, then the specified condition will be applied at both ends of a spline. Available conditions are:

- 'not-a-knot' (default): The first and second segment at a curve end are the same polynomial. It is a good default when there is no information on boundary conditions.
- 'periodic': The interpolated functions is assumed to be periodic of period  $x[-1] - x[0]$ . The first and last value of *y* must be identical:  $y[0] == y[-1]$ . This boundary condition will result in  $y'[0] == y'[-1]$  and  $y''[0] == y''[-1]$ .
- 'clamped': The first derivative at curves ends are zero. Assuming a 1D *y*, *bc\_type*=((1, 0.0), (1, 0.0)) is the same condition.
- 'natural': The second derivative at curve ends are zero. Assuming a 1D *y*, *bc\_type*=((2, 0.0), (2, 0.0)) is the same condition.

If *bc\_type* is a 2-tuple, the first and the second value will be applied at the curve start and end respectively. The tuple values can be one of the previously mentioned strings (except 'periodic') or a tuple (*order*, *deriv\_values*) allowing to specify arbitrary derivatives at curve ends:

- *order*: the derivative order, 1 or 2.
- *deriv\_value*: array\_like containing derivative values, shape must be the same as *y*, excluding *axis* dimension. For example, if *y* is 1D, then *deriv\_value* must be a scalar. If *y* is 3D with the shape (n0, n1, n2) and *axis*=2, then *deriv\_value* must be 2D and have the shape (n0, n1).

**extrapolate** : {bool, 'periodic', None}, optional

If bool, determines whether to extrapolate to out-of-bounds points based on first and last intervals, or to return NaNs. If 'periodic', periodic extrapolation is used. If None

(default), `extrapolate` is set to 'periodic' for `bc_type='periodic'` and to `True` otherwise.

**See also:**

*Akima1DInterpolator*, *PchipInterpolator*, *PPoly*

**Notes**

Parameters `bc_type` and `interpolate` work independently, i.e. the former controls only construction of a spline, and the latter only evaluation.

When a boundary condition is 'not-a-knot' and `n = 2`, it is replaced by a condition that the first derivative is equal to the linear interpolant slope. When both boundary conditions are 'not-a-knot' and `n = 3`, the solution is sought as a parabola passing through given points.

When 'not-a-knot' boundary conditions is applied to both ends, the resulting spline will be the same as returned by `splrep` (with `s=0`) and `InterpolatedUnivariateSpline`, but these two methods use a representation in B-spline basis.

New in version 0.18.0.

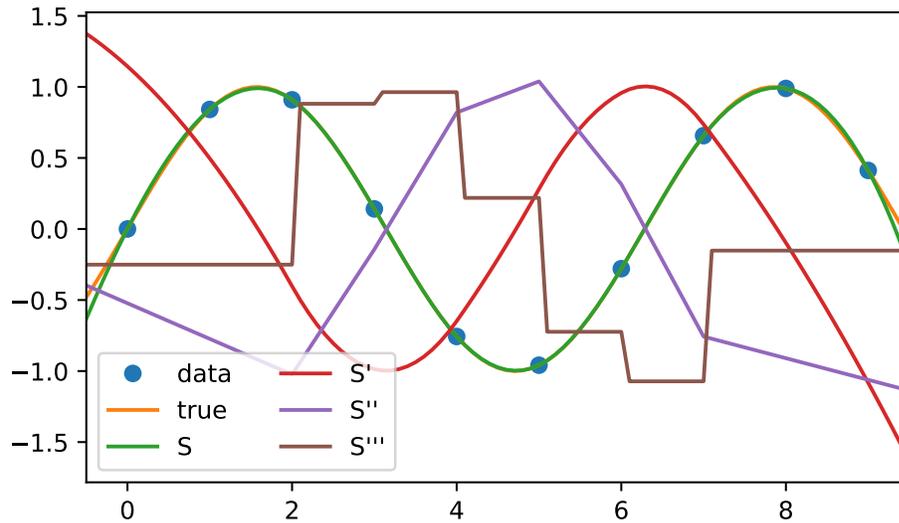
**References**

[R85], [R86]

**Examples**

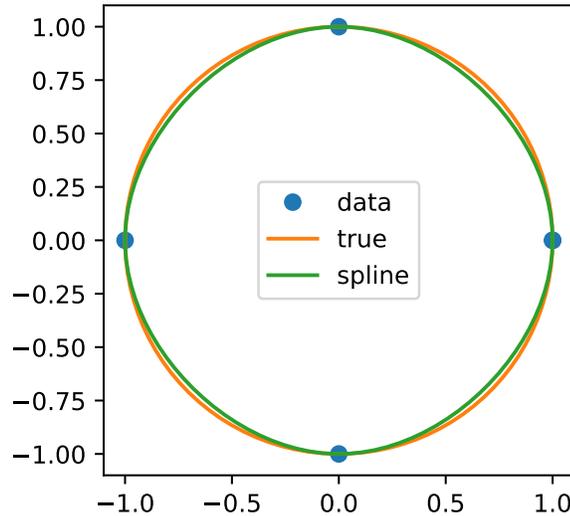
In this example the cubic spline is used to interpolate a sampled sinusoid. You can see that the spline continuity property holds for the first and second derivatives and violates only for the third derivative.

```
>>> from scipy.interpolate import CubicSpline
>>> import matplotlib.pyplot as plt
>>> x = np.arange(10)
>>> y = np.sin(x)
>>> cs = CubicSpline(x, y)
>>> xs = np.arange(-0.5, 9.6, 0.1)
>>> plt.figure(figsize=(6.5, 4))
>>> plt.plot(x, y, 'o', label='data')
>>> plt.plot(xs, np.sin(xs), label='true')
>>> plt.plot(xs, cs(xs), label="S")
>>> plt.plot(xs, cs(xs, 1), label="S'")
>>> plt.plot(xs, cs(xs, 2), label="S''")
>>> plt.plot(xs, cs(xs, 3), label="S'''")
>>> plt.xlim(-0.5, 9.5)
>>> plt.legend(loc='lower left', ncol=2)
>>> plt.show()
```



In the second example, the unit circle is interpolated with a spline. A periodic boundary condition is used. You can see that the first derivative values,  $ds/dx=0$ ,  $ds/dy=1$  at the periodic point  $(1, 0)$  are correctly computed. Note that a circle cannot be exactly represented by a cubic spline. To increase precision, more breakpoints would be required.

```
>>> theta = 2 * np.pi * np.linspace(0, 1, 5)
>>> y = np.c_[np.cos(theta), np.sin(theta)]
>>> cs = CubicSpline(theta, y, bc_type='periodic')
>>> print("ds/dx={:.1f} ds/dy={:.1f}".format(cs(0, 1)[0], cs(0, 1)[1]))
ds/dx=0.0 ds/dy=1.0
>>> xs = 2 * np.pi * np.linspace(0, 1, 100)
>>> plt.figure(figsize=(6.5, 4))
>>> plt.plot(y[:, 0], y[:, 1], 'o', label='data')
>>> plt.plot(np.cos(xs), np.sin(xs), label='true')
>>> plt.plot(cs(xs)[:, 0], cs(xs)[:, 1], label='spline')
>>> plt.axes().set_aspect('equal')
>>> plt.legend(loc='center')
>>> plt.show()
```



The third example is the interpolation of a polynomial  $y = x^{**3}$  on the interval  $0 \leq x \leq 1$ . A cubic spline can represent this function exactly. To achieve that we need to specify values and first derivatives at endpoints of the interval. Note that  $y' = 3 * x^{**2}$  and thus  $y'(0) = 0$  and  $y'(1) = 3$ .

```
>>> cs = CubicSpline([0, 1], [0, 1], bc_type=((1, 0), (1, 3)))
>>> x = np.linspace(0, 1)
>>> np.allclose(x**3, cs(x))
True
```

### Attributes

<code>x</code>	(ndarray, shape (n,)) Breakpoints. The same <code>x</code> which was passed to the constructor.
<code>c</code>	(ndarray, shape (4, n-1, ...)) Coefficients of the polynomials on each segment. The trailing dimensions match the dimensions of <code>y</code> , excluding <code>axis</code> . For example, if <code>y</code> is 1-d, then <code>c[k, i]</code> is a coefficient for $(x-x[i])^{(3-k)}$ on the segment between <code>x[i]</code> and <code>x[i+1]</code> .
<code>axis</code>	(int) Interpolation axis. The same <code>axis</code> which was passed to the constructor.

### Methods

<code>__call__(x[, nu, extrapolate])</code>	Evaluate the piecewise polynomial or its derivative.
<code>derivative([nu])</code>	Construct a new piecewise polynomial representing the derivative.
<code>antiderivative([nu])</code>	Construct a new piecewise polynomial representing the antiderivative.
<code>integrate(a, b[, extrapolate])</code>	Compute a definite integral over a piecewise polynomial.
<code>roots([discontinuity, extrapolate])</code>	Find real roots of the the piecewise polynomial.

```
CubicSpline.__call__(x, nu=0, extrapolate=None)
    Evaluate the piecewise polynomial or its derivative.
```

**Parameters** **x** : array\_like  
 Points to evaluate the interpolant at.  
**nu** : int, optional  
 Order of derivative to evaluate. Must be non-negative.  
**extrapolate** : {bool, 'periodic', None}, optional  
 If bool, determines whether to extrapolate to out-of-bounds points based on first and last intervals, or to return NaNs. If 'periodic', periodic extrapolation is used. If None (default), use *self.extrapolate*.

**Returns** **y** : array\_like  
 Interpolated values. Shape is determined by replacing the interpolation axis in the original array with the shape of x.

**Notes**

Derivatives are evaluated piecewise for each polynomial segment, even if the polynomial is not differentiable at the breakpoints. The polynomial intervals are considered half-open,  $[a, b)$ , except for the last interval which is closed  $[a, b]$ .

`CubicSpline.derivative(nu=1)`

Construct a new piecewise polynomial representing the derivative.

**Parameters** **nu** : int, optional  
 Order of derivative to evaluate. Default is 1, i.e. compute the first derivative. If negative, the antiderivative is returned.

**Returns** **pp** : PPoly  
 Piecewise polynomial of order  $k_2 = k - n$  representing the derivative of this polynomial.

**Notes**

Derivatives are evaluated piecewise for each polynomial segment, even if the polynomial is not differentiable at the breakpoints. The polynomial intervals are considered half-open,  $[a, b)$ , except for the last interval which is closed  $[a, b]$ .

`CubicSpline.antiderivative(nu=1)`

Construct a new piecewise polynomial representing the antiderivative.

Antiderivative is also the indefinite integral of the function, and derivative is its inverse operation.

**Parameters** **nu** : int, optional  
 Order of antiderivative to evaluate. Default is 1, i.e. compute the first integral. If negative, the derivative is returned.

**Returns** **pp** : PPoly  
 Piecewise polynomial of order  $k_2 = k + n$  representing the antiderivative of this polynomial.

**Notes**

The antiderivative returned by this function is continuous and continuously differentiable to order  $n-1$ , up to floating point rounding error.

If antiderivative is computed and `self.extrapolate='periodic'`, it will be set to `False` for the returned instance. This is done because the antiderivative is no longer periodic and its correct evaluation outside of the initially given x interval is difficult.

`CubicSpline.integrate(a, b, extrapolate=None)`

Compute a definite integral over a piecewise polynomial.

**Parameters** **a** : float  
 Lower integration bound

**b** : float

Upper integration bound

**extrapolate** : {bool, 'periodic', None}, optionalIf bool, determines whether to extrapolate to out-of-bounds points based on first and last intervals, or to return NaNs. If 'periodic', periodic extrapolation is used. If None (default), use *self.extrapolate*.**Returns** **ig** : array\_like

Definite integral of the piecewise polynomial over [a, b]

`CubicSpline.roots` (*discontinuity=True, extrapolate=None*)

Find real roots of the the piecewise polynomial.

**Parameters** **discontinuity** : bool, optional

Whether to report sign changes across discontinuities at breakpoints as roots.

**extrapolate** : {bool, 'periodic', None}, optionalIf bool, determines whether to return roots from the polynomial extrapolated based on first and last intervals, 'periodic' works the same as False. If None (default), use *self.extrapolate*.**Returns** **roots** : ndarray

Roots of the polynomial(s).

If the PPoly object describes multiple polynomials, the return value is an object array whose each element is an ndarray containing the roots.

**See also:***PPoly.solve***class** `scipy.interpolate.PPoly` (*c, x, extrapolate=None, axis=0*)

Piecewise polynomial in terms of coefficients and breakpoints

The polynomial between  $x[i]$  and  $x[i + 1]$  is written in the local power basis:

```
S = sum(c[m, i] * (xp - x[i])** (k-m) for m in range(k+1))
```

where  $k$  is the degree of the polynomial.**Parameters** **c** : ndarray, shape (k, m, ...)Polynomial coefficients, order  $k$  and  $m$  intervals**x** : ndarray, shape (m+1,)

Polynomial breakpoints. Must be sorted in either increasing or decreasing order.

**extrapolate** : bool or 'periodic', optional

If bool, determines whether to extrapolate to out-of-bounds points based on first and last intervals, or to return NaNs. If 'periodic', periodic extrapolation is used. Default is True.

**axis** : int, optional

Interpolation axis. Default is zero.

**See also:****BPoly** piecewise polynomials in the Bernstein basis**Notes**

High-order polynomials in the power basis can be numerically unstable. Precision problems can start to appear for orders larger than 20-30.

**Attributes**

<code>x</code>	(ndarray) Breakpoints.
<code>c</code>	(ndarray) Coefficients of the polynomials. They are reshaped to a 3-dimensional array with the last dimension representing the trailing dimensions of the original coefficient array.
<code>axis</code>	(int) Interpolation axis.

**Methods**

<code>__call__(x[, nu, extrapolate])</code>	Evaluate the piecewise polynomial or its derivative.
<code>derivative([nu])</code>	Construct a new piecewise polynomial representing the derivative.
<code>antiderivative([nu])</code>	Construct a new piecewise polynomial representing the antiderivative.
<code>integrate(a, b[, extrapolate])</code>	Compute a definite integral over a piecewise polynomial.
<code>solve([y, discontinuity, extrapolate])</code>	Find real solutions of the the equation $pp(x) == y$ .
<code>roots([discontinuity, extrapolate])</code>	Find real roots of the the piecewise polynomial.
<code>extend(c, x[, right])</code>	Add additional breakpoints and coefficients to the polynomial.
<code>from_spline(tck[, extrapolate])</code>	Construct a piecewise polynomial from a spline
<code>from_bernstein_basis(bp[, extrapolate])</code>	Construct a piecewise polynomial in the power basis from a polynomial in Bernstein basis.
<code>construct_fast(c, x[, extrapolate, axis])</code>	Construct the piecewise polynomial without making checks.

`PPoly.__call__(x, nu=0, extrapolate=None)`

Evaluate the piecewise polynomial or its derivative.

**Parameters** `x` : array\_like

Points to evaluate the interpolant at.

`nu` : int, optional

Order of derivative to evaluate. Must be non-negative.

**extrapolate** : {bool, 'periodic', None}, optional

If bool, determines whether to extrapolate to out-of-bounds points based on first and last intervals, or to return NaNs. If 'periodic', periodic extrapolation is used. If None (default), use *self.extrapolate*.

**Returns** `y` : array\_like

Interpolated values. Shape is determined by replacing the interpolation axis in the original array with the shape of `x`.

**Notes**

Derivatives are evaluated piecewise for each polynomial segment, even if the polynomial is not differentiable at the breakpoints. The polynomial intervals are considered half-open,  $[a, b)$ , except for the last interval which is closed  $[a, b]$ .

`PPoly.derivative(nu=1)`

Construct a new piecewise polynomial representing the derivative.

**Parameters** `nu` : int, optional

Order of derivative to evaluate. Default is 1, i.e. compute the first derivative. If negative, the antiderivative is returned.

**Returns** `pp` : PPoly

Piecewise polynomial of order  $k_2 = k - n$  representing the derivative of this polynomial.

### Notes

Derivatives are evaluated piecewise for each polynomial segment, even if the polynomial is not differentiable at the breakpoints. The polynomial intervals are considered half-open,  $[a, b)$ , except for the last interval which is closed  $[a, b]$ .

`PPoly.antiderivative (nu=1)`

Construct a new piecewise polynomial representing the antiderivative.

Antiderivative is also the indefinite integral of the function, and derivative is its inverse operation.

**Parameters** **nu** : int, optional  
Order of antiderivative to evaluate. Default is 1, i.e. compute the first integral. If negative, the derivative is returned.

**Returns** **pp** : PPoly  
Piecewise polynomial of order  $k_2 = k + n$  representing the antiderivative of this polynomial.

### Notes

The antiderivative returned by this function is continuous and continuously differentiable to order  $n-1$ , up to floating point rounding error.

If antiderivative is computed and `self.extrapolate='periodic'`, it will be set to `False` for the returned instance. This is done because the antiderivative is no longer periodic and its correct evaluation outside of the initially given  $x$  interval is difficult.

`PPoly.integrate (a, b, extrapolate=None)`

Compute a definite integral over a piecewise polynomial.

**Parameters** **a** : float  
Lower integration bound

**b** : float  
Upper integration bound

**extrapolate** : {bool, 'periodic', None}, optional  
If bool, determines whether to extrapolate to out-of-bounds points based on first and last intervals, or to return NaNs. If 'periodic', periodic extrapolation is used. If None (default), use `self.extrapolate`.

**Returns** **ig** : array\_like  
Definite integral of the piecewise polynomial over  $[a, b]$

`PPoly.solve (y=0.0, discontinuity=True, extrapolate=None)`

Find real solutions of the the equation  $pp(x) == y$ .

**Parameters** **y** : float, optional  
Right-hand side. Default is zero.

**discontinuity** : bool, optional  
Whether to report sign changes across discontinuities at breakpoints as roots.

**extrapolate** : {bool, 'periodic', None}, optional  
If bool, determines whether to return roots from the polynomial extrapolated based on first and last intervals, 'periodic' works the same as `False`. If None (default), use `self.extrapolate`.

**Returns** **roots** : ndarray  
Roots of the polynomial(s).  
If the PPoly object describes multiple polynomials, the return value is an object array whose each element is an ndarray containing the roots.

### Notes

This routine works only on real-valued polynomials.

If the piecewise polynomial contains sections that are identically zero, the root list will contain the start point of the corresponding interval, followed by a `nan` value.

If the polynomial is discontinuous across a breakpoint, and there is a sign change across the breakpoint, this is reported if the `discont` parameter is `True`.

### Examples

Finding roots of  $[x^2 - 1, (x - 1)^2]$  defined on intervals  $[-2, 1], [1, 2]$ :

```
>>> from scipy.interpolate import PPoly
>>> pp = PPoly(np.array([[1, -4, 3], [1, 0, 0]]).T, [-2, 1, 2])
>>> pp.roots()
array([-1.,  1.])
```

`PPoly.roots` (*discontinuity=True, extrapolate=None*)

Find real roots of the the piecewise polynomial.

**Parameters** **discontinuity** : bool, optional

Whether to report sign changes across discontinuities at breakpoints as roots.

**extrapolate** : {bool, 'periodic', None}, optional

If bool, determines whether to return roots from the polynomial extrapolated based on first and last intervals, 'periodic' works the same as False. If None (default), use *self.extrapolate*.

**Returns** **roots** : ndarray

Roots of the polynomial(s).

If the PPoly object describes multiple polynomials, the return value is an object array whose each element is an ndarray containing the roots.

### See also:

*PPoly.solve*

`PPoly.extend` (*c, x, right=None*)

Add additional breakpoints and coefficients to the polynomial.

**Parameters** **c** : ndarray, size (k, m, ...)

Additional coefficients for polynomials in intervals. Note that the first additional interval will be formed using one of the *self.x* end points.

**x** : ndarray, size (m,)

Additional breakpoints. Must be sorted in the same order as *self.x* and either to the right or to the left of the current breakpoints.

**right**

Deprecated argument. Has no effect.

Deprecated since version 0.19.

`classmethod PPoly.from_spline` (*tck, extrapolate=None*)

Construct a piecewise polynomial from a spline

**Parameters** **tck**

A spline, as returned by *splrep* or a BSpline object.

**extrapolate** : bool or 'periodic', optional

If bool, determines whether to extrapolate to out-of-bounds points based on first and last intervals, or to return NaNs. If 'periodic', periodic extrapolation is used. Default is True.

**classmethod** `PPoly.from_bernstein_basis` (*bp*, *extrapolate=None*)

Construct a piecewise polynomial in the power basis from a polynomial in Bernstein basis.

**Parameters** **bp** : BPoly

A Bernstein basis polynomial, as created by BPoly

**extrapolate** : bool or 'periodic', optional

If bool, determines whether to extrapolate to out-of-bounds points based on first and last intervals, or to return NaNs. If 'periodic', periodic extrapolation is used. Default is True.

`PPoly.construct_fast` (*c*, *x*, *extrapolate=None*, *axis=0*)

Construct the piecewise polynomial without making checks.

Takes the same parameters as the constructor. Input arguments *c* and *x* must be arrays of the correct shape and type. The *c* array can only be of dtype float and complex, and *x* array must have dtype float.

**class** `scipy.interpolate.BPoly` (*c*, *x*, *extrapolate=None*, *axis=0*)

Piecewise polynomial in terms of coefficients and breakpoints.

The polynomial between  $x[i]$  and  $x[i + 1]$  is written in the Bernstein polynomial basis:

```
S = sum(c[a, i] * b(a, k; x) for a in range(k+1)),
```

where *k* is the degree of the polynomial, and:

```
b(a, k; x) = binom(k, a) * t**a * (1 - t)**(k - a),
```

with  $t = (x - x[i]) / (x[i+1] - x[i])$  and `binom` is the binomial coefficient.

**Parameters** **c** : ndarray, shape (*k*, *m*, ...)

Polynomial coefficients, order *k* and *m* intervals

**x** : ndarray, shape (*m*+1,)

Polynomial breakpoints. Must be sorted in either increasing or decreasing order.

**extrapolate** : bool, optional

If bool, determines whether to extrapolate to out-of-bounds points based on first and last intervals, or to return NaNs. If 'periodic', periodic extrapolation is used. Default is True.

**axis** : int, optional

Interpolation axis. Default is zero.

**See also:**

**PPoly** piecewise polynomials in the power basis

**Notes**

Properties of Bernstein polynomials are well documented in the literature. Here's a non-exhaustive list:

**Examples**

```
>>> from scipy.interpolate import BPoly
>>> x = [0, 1]
>>> c = [[1], [2], [3]]
>>> bp = BPoly(c, x)
```

This creates a 2nd order polynomial

$$\begin{aligned} B(x) &= 1 \times b_{0,2}(x) + 2 \times b_{1,2}(x) + 3 \times b_{2,2}(x) \\ &= 1 \times (1 - x)^2 + 2 \times 2x(1 - x) + 3 \times x^2 \end{aligned}$$

**Attributes**

<code>x</code>	(ndarray) Breakpoints.
<code>c</code>	(ndarray) Coefficients of the polynomials. They are reshaped to a 3-dimensional array with the last dimension representing the trailing dimensions of the original coefficient array.
<code>axis</code>	(int) Interpolation axis.

**Methods**

<code>__call__(x[, nu, extrapolate])</code>	Evaluate the piecewise polynomial or its derivative.
<code>extend(c, x[, right])</code>	Add additional breakpoints and coefficients to the polynomial.
<code>derivative([nu])</code>	Construct a new piecewise polynomial representing the derivative.
<code>antiderivative([nu])</code>	Construct a new piecewise polynomial representing the antiderivative.
<code>integrate(a, b[, extrapolate])</code>	Compute a definite integral over a piecewise polynomial.
<code>construct_fast(c, x[, extrapolate, axis])</code>	Construct the piecewise polynomial without making checks.
<code>from_power_basis(pp[, extrapolate])</code>	Construct a piecewise polynomial in Bernstein basis from a power basis polynomial.
<code>from_derivatives(xi, yi[, orders, extrapolate])</code>	Construct a piecewise polynomial in the Bernstein basis, compatible with the specified values and derivatives at breakpoints.

`BPoly.__call__(x, nu=0, extrapolate=None)`

Evaluate the piecewise polynomial or its derivative.

**Parameters** `x` : array\_like

Points to evaluate the interpolant at.

`nu` : int, optional

Order of derivative to evaluate. Must be non-negative.

**extrapolate** : {bool, 'periodic', None}, optional

If bool, determines whether to extrapolate to out-of-bounds points based on first and last intervals, or to return NaNs. If 'periodic', periodic extrapolation is used. If None (default), use `self.extrapolate`.

**Returns** `y` : array\_like

Interpolated values. Shape is determined by replacing the interpolation axis in the original array with the shape of `x`.

**Notes**

Derivatives are evaluated piecewise for each polynomial segment, even if the polynomial is not differentiable at the breakpoints. The polynomial intervals are considered half-open,  $[a, b)$ , except for the last interval which is closed  $[a, b]$ .

`BPoly.extend(c, x, right=None)`

Add additional breakpoints and coefficients to the polynomial.

**Parameters** `c` : ndarray, size (k, m, ...)

Additional coefficients for polynomials in intervals. Note that the first additional interval will be formed using one of the `self.x` end points.

`x` : ndarray, size (m,)

Additional breakpoints. Must be sorted in the same order as *self.x* and either to the right or to the left of the current breakpoints.

**right**

Deprecated argument. Has no effect.  
Deprecated since version 0.19.

`BPoly.derivative (nu=1)`

Construct a new piecewise polynomial representing the derivative.

**Parameters** **nu** : int, optional

Order of derivative to evaluate. Default is 1, i.e. compute the first derivative. If negative, the antiderivative is returned.

**Returns** **bp** : BPoly

Piecewise polynomial of order  $k - nu$  representing the derivative of this polynomial.

`BPoly.antiderivative (nu=1)`

Construct a new piecewise polynomial representing the antiderivative.

**Parameters** **nu** : int, optional

Order of antiderivative to evaluate. Default is 1, i.e. compute the first integral. If negative, the derivative is returned.

**Returns** **bp** : BPoly

Piecewise polynomial of order  $k + nu$  representing the antiderivative of this polynomial.

**Notes**

If antiderivative is computed and `self.extrapolate='periodic'`, it will be set to `False` for the returned instance. This is done because the antiderivative is no longer periodic and its correct evaluation outside of the initially given  $x$  interval is difficult.

`BPoly.integrate (a, b, extrapolate=None)`

Compute a definite integral over a piecewise polynomial.

**Parameters** **a** : float

Lower integration bound

**b** : float

Upper integration bound

**extrapolate** : {bool, 'periodic', None}, optional

Whether to extrapolate to out-of-bounds points based on first and last intervals, or to return NaNs. If 'periodic', periodic extrapolation is used. If None (default), use `self.extrapolate`.

**Returns** array\_like

Definite integral of the piecewise polynomial over [a, b]

`BPoly.construct_fast (c, x, extrapolate=None, axis=0)`

Construct the piecewise polynomial without making checks.

Takes the same parameters as the constructor. Input arguments `c` and `x` must be arrays of the correct shape and type. The `c` array can only be of dtypes float and complex, and `x` array must have dtype float.

`classmethod BPoly.from_power_basis (pp, extrapolate=None)`

Construct a piecewise polynomial in Bernstein basis from a power basis polynomial.

**Parameters** **pp** : PPoly

A piecewise polynomial in the power basis

**extrapolate** : bool or 'periodic', optional

If `bool`, determines whether to extrapolate to out-of-bounds points based on first and last intervals, or to return NaNs. If 'periodic', periodic extrapolation is used. Default is `True`.

**classmethod** `BPoly.from_derivatives` (*xi, yi, orders=None, extrapolate=None*)

Construct a piecewise polynomial in the Bernstein basis, compatible with the specified values and derivatives at breakpoints.

**Parameters**

- xi** : array\_like  
sorted 1D array of x-coordinates
- yi** : array\_like or list of array\_likes  
`yi[i][j]` is the *j*-th derivative known at `xi[i]`
- orders** : None or int or array\_like of ints. Default: `None`.  
Specifies the degree of local polynomials. If not `None`, some derivatives are ignored.
- extrapolate** : bool or 'periodic', optional  
If bool, determines whether to extrapolate to out-of-bounds points based on first and last intervals, or to return NaNs. If 'periodic', periodic extrapolation is used. Default is `True`.

### Notes

If *k* derivatives are specified at a breakpoint *x*, the constructed polynomial is exactly *k* times continuously differentiable at *x*, unless the `order` is provided explicitly. In the latter case, the smoothness of the polynomial at the breakpoint is controlled by the `order`.

Deduces the number of derivatives to match at each end from `order` and the number of derivatives available. If possible it uses the same number of derivatives from each end; if the number is odd it tries to take the extra one from `y2`. In any case if not enough derivatives are available at one end or another it draws enough to make up the total from the other end.

If the `order` is too high and not enough derivatives are available, an exception is raised.

### Examples

```
>>> from scipy.interpolate import BPoly
>>> BPoly.from_derivatives([0, 1], [[1, 2], [3, 4]])
```

Creates a polynomial  $f(x)$  of degree 3, defined on  $[0, 1]$  such that  $f(0) = 1$ ,  $df/dx(0) = 2$ ,  $f(1) = 3$ ,  $df/dx(1) = 4$

```
>>> BPoly.from_derivatives([0, 1, 2], [[0, 1], [0], [2]])
```

Creates a piecewise polynomial  $f(x)$ , such that  $f(0) = f(1) = 0$ ,  $f(2) = 2$ , and  $df/dx(0) = 1$ . Based on the number of derivatives provided, the order of the local polynomials is 2 on  $[0, 1]$  and 1 on  $[1, 2]$ . Notice that no restriction is imposed on the derivatives at  $x = 1$  and  $x = 2$ .

Indeed, the explicit form of the polynomial is:

$$f(x) = \begin{cases} x * (1 - x), & 0 \leq x < 1 \\ 2 * (x - 1), & 1 \leq x \leq 2 \end{cases}$$

So that  $f'(1-0) = -1$  and  $f'(1+0) = 2$

## 5.7.2 Multivariate interpolation

Unstructured data:

<code>griddata(points, values, xi[, method, ...])</code>	Interpolate unstructured D-dimensional data.
<code>LinearNDInterpolator(points, values[, ...])</code>	Piecewise linear interpolant in N dimensions.
<code>NearestNDInterpolator(x, y)</code>	Nearest-neighbour interpolation in N dimensions.
<code>CloughTocher2DInterpolator(points, values[, tol])</code>	Piecewise cubic, C1 smooth, curvature-minimizing interpolant in 2D.
<code>Rbf(*args)</code>	A class for radial basis function approximation/interpolation of n-dimensional scattered data.
<code>interp2d(x, y, z[, kind, copy, ...])</code>	Interpolate over a 2-D grid.

`scipy.interpolate.griddata` (*points, values, xi, method='linear', fill\_value=nan, rescale=False*)  
Interpolate unstructured D-dimensional data.

**Parameters**

- points** : ndarray of floats, shape (n, D)  
Data point coordinates. Can either be an array of shape (n, D), or a tuple of *ndim* arrays.
- values** : ndarray of float or complex, shape (n,)
  - Data values.
- xi** : 2-D ndarray of float or tuple of 1-D array, shape (M, D)  
Points at which to interpolate data.
- method** : { 'linear', 'nearest', 'cubic' }, optional  
Method of interpolation. One of
  - nearest** return the value at the data point closest to the point of interpolation. See *NearestNDInterpolator* for more details.
  - linear** tessellate the input point set to n-dimensional simplices, and interpolate linearly on each simplex. See *LinearNDInterpolator* for more details.
  - cubic (1-D)** return the value determined from a cubic spline.
  - cubic (2-D)** return the value determined from a piecewise cubic, continuously differentiable (C1), and approximately curvature-minimizing polynomial surface. See *CloughTocher2DInterpolator* for more details.
- fill\_value** : float, optional  
Value used to fill in for requested points outside of the convex hull of the input points. If not provided, then the default is `nan`. This option has no effect for the 'nearest' method.
- rescale** : bool, optional  
Rescale points to unit cube before performing interpolation. This is useful if some of the input dimensions have incommensurable units and differ by many orders of magnitude.  
New in version 0.14.0.

#### Notes

New in version 0.9.

#### Examples

Suppose we want to interpolate the 2-D function

```
>>> def func(x, y):
...     return x*(1-x)*np.cos(4*np.pi*x) * np.sin(4*np.pi*y**2)**2
```

on a grid in [0, 1]x[0, 1]

```
>>> grid_x, grid_y = np.mgrid[0:1:100j, 0:1:200j]
```

but we only know its values at 1000 data points:

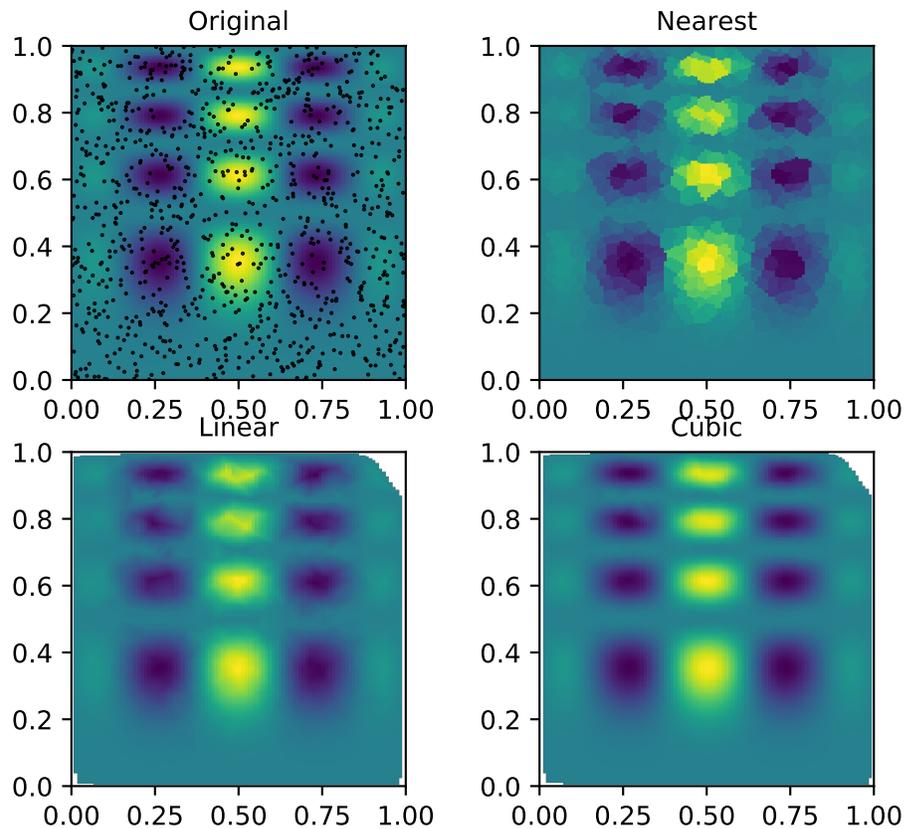
```
>>> points = np.random.rand(1000, 2)
>>> values = func(points[:,0], points[:,1])
```

This can be done with *griddata* – below we try out all of the interpolation methods:

```
>>> from scipy.interpolate import griddata
>>> grid_z0 = griddata(points, values, (grid_x, grid_y), method='nearest')
>>> grid_z1 = griddata(points, values, (grid_x, grid_y), method='linear')
>>> grid_z2 = griddata(points, values, (grid_x, grid_y), method='cubic')
```

One can see that the exact result is reproduced by all of the methods to some degree, but for this smooth function the piecewise cubic interpolant gives the best results:

```
>>> import matplotlib.pyplot as plt
>>> plt.subplot(221)
>>> plt.imshow(func(grid_x, grid_y).T, extent=(0,1,0,1), origin='lower')
>>> plt.plot(points[:,0], points[:,1], 'k.', ms=1)
>>> plt.title('Original')
>>> plt.subplot(222)
>>> plt.imshow(grid_z0.T, extent=(0,1,0,1), origin='lower')
>>> plt.title('Nearest')
>>> plt.subplot(223)
>>> plt.imshow(grid_z1.T, extent=(0,1,0,1), origin='lower')
>>> plt.title('Linear')
>>> plt.subplot(224)
>>> plt.imshow(grid_z2.T, extent=(0,1,0,1), origin='lower')
>>> plt.title('Cubic')
>>> plt.gcf().set_size_inches(6, 6)
>>> plt.show()
```



**class** `scipy.interpolate.LinearNDInterpolator` (*points*, *values*, *fill\_value=np.nan*, *rescale=False*)

Piecewise linear interpolant in N dimensions.

New in version 0.9.

**Parameters**

- points** : ndarray of floats, shape (npoints, ndims); or Delaunay  
Data point coordinates, or a precomputed Delaunay triangulation.
- values** : ndarray of float or complex, shape (npoints, ...)  
Data values.
- fill\_value** : float, optional  
Value used to fill in for requested points outside of the convex hull of the input points.  
If not provided, then the default is `nan`.
- rescale** : bool, optional  
Rescale points to unit cube before performing interpolation. This is useful if some of  
the input dimensions have incommensurable units and differ by many orders of magnitude.

*Notes*

The interpolant is constructed by triangulating the input data with Qhull [R88], and on each triangle performing linear barycentric interpolation.

*References*

[R88]

*Methods*

---

<code>__call__(xi)</code>	Evaluate interpolator at given points.
---------------------------	--

---

`LinearNDInterpolator.__call__(xi)`

Evaluate interpolator at given points.

**Parameters** **xi** : ndarray of float, shape (... , ndim)  
Points where to interpolate data at.

**class** `scipy.interpolate.NearestNDInterpolator(x, y)`

Nearest-neighbour interpolation in N dimensions.

New in version 0.9.

**Parameters** **x** : (Npoints, Ndims) ndarray of floats  
Data point coordinates.  
**y** : (Npoints,) ndarray of float or complex  
Data values.  
**rescale** : boolean, optional  
Rescale points to unit cube before performing interpolation. This is useful if some of the input dimensions have incommensurable units and differ by many orders of magnitude.  
New in version 0.14.0.  
**tree\_options** : dict, optional  
Options passed to the underlying cKDTree.  
New in version 0.17.0.

*Notes*

Uses `scipy.spatial.cKDTree`

*Methods*

---

<code>__call__(*args)</code>	Evaluate interpolator at given points.
------------------------------	--

---

`NearestNDInterpolator.__call__(*args)`

Evaluate interpolator at given points.

**Parameters** **xi** : ndarray of float, shape (... , ndim)  
Points where to interpolate data at.

**class** `scipy.interpolate.CloughTocher2DInterpolator(points, values, tol=1e-6)`

Piecewise cubic, C1 smooth, curvature-minimizing interpolant in 2D.

New in version 0.9.

**Parameters** **points** : ndarray of floats, shape (npoints, ndims); or Delaunay  
Data point coordinates, or a precomputed Delaunay triangulation.

**values** : ndarray of float or complex, shape (npoints, ...)  
Data values.

**fill\_value** : float, optional  
Value used to fill in for requested points outside of the convex hull of the input points. If not provided, then the default is `nan`.

**tol** : float, optional  
Absolute/relative tolerance for gradient estimation.

**maxiter** : int, optional  
Maximum number of iterations in gradient estimation.

**rescale** : bool, optional  
Rescale points to unit cube before performing interpolation. This is useful if some of the input dimensions have incommensurable units and differ by many orders of magnitude.

### Notes

The interpolant is constructed by triangulating the input data with Qhull [R84], and constructing a piecewise cubic interpolating Bezier polynomial on each triangle, using a Clough-Tocher scheme [CT]. The interpolant is guaranteed to be continuously differentiable.

The gradients of the interpolant are chosen so that the curvature of the interpolating surface is approximately minimized. The gradients necessary for this are estimated using the global algorithm described in [Nielson83, Renka84].

### References

[R84], [CT], [Nielson83], [Renka84]

### Methods

---

`__call__(xi)` Evaluate interpolator at given points.

---

`CloughTocher2DInterpolator.__call__(xi)`

Evaluate interpolator at given points.

**Parameters** **xi** : ndarray of float, shape (... , ndim)  
Points where to interpolate data at.

**class** `scipy.interpolate.Rbf(*args)`

A class for radial basis function approximation/interpolation of n-dimensional scattered data.

**Parameters** **\*args** : arrays

x, y, z, ..., d, where x, y, z, ... are the coordinates of the nodes and d is the array of values at the nodes

**function** : str or callable, optional

The radial basis function, based on the radius, r, given by the norm (default is Euclidean distance); the default is 'multiquadric':

```
'multiquadric': sqrt((r/self.epsilon)**2 + 1)
'inverse': 1.0/sqrt((r/self.epsilon)**2 + 1)
'gaussian': exp(-(r/self.epsilon)**2)
'linear': r
'cubic': r**3
'quintic': r**5
'thin_plate': r**2 * log(r)
```

If callable, then it must take 2 arguments (self, r). The epsilon parameter will be available as `self.epsilon`. Other keyword arguments passed in will be available as well.

**epsilon** : float, optional

Adjustable constant for gaussian or multiquadrics functions - defaults to approximate average distance between nodes (which is a good start).

**smooth** : float, optional

Values greater than zero increase the smoothness of the approximation. 0 is for interpolation (default), the function will always go through the nodal points in this case.

**norm** : callable, optional

A function that returns the 'distance' between two points, with inputs as arrays of positions (x, y, z, ...), and an output as an array of distance. E.g, the default:

```
def euclidean_norm(x1, x2):
    return sqrt( ((x1 - x2)**2).sum(axis=0) )
```

which is called with `x1 = x1[ndims, newaxis, :]` and `x2 = x2[ndims, :, newaxis]` such that the result is a matrix of the distances from each point in `x1` to each point in `x2`.

### Examples

```
>>> from scipy.interpolate import Rbf
>>> x, y, z, d = np.random.rand(4, 50)
>>> rbfi = Rbf(x, y, z, d) # radial basis function interpolator instance
>>> xi = yi = zi = np.linspace(0, 1, 20)
>>> di = rbfi(xi, yi, zi) # interpolated values
>>> di.shape
(20,)
```

### Attributes

A

---

Rbf.**A**

### Methods

`__call__`(\*args)

---

Rbf.`__call__`(\*args)

**class** `scipy.interpolate.interp2d`(*x, y, z, kind='linear', copy=True, bounds\_error=False, fill\_value=nan*)

Interpolate over a 2-D grid.

*x, y* and *z* are arrays of values used to approximate some function *f*:  $z = f(x, y)$ . This class returns a function whose call method uses spline interpolation to find the value of new points.

If *x* and *y* represent a regular grid, consider using `RectBivariateSpline`.

Note that calling `interp2d` with NaNs present in input values results in undefined behaviour.

**Parameters** *x, y* : array\_like

Arrays defining the data point coordinates.

If the points lie on a regular grid, *x* can specify the column coordinates and *y* the row coordinates, for example:

```
>>> x = [0,1,2]; y = [0,3]; z = [[1,2,3], [4,5,6]]
```

Otherwise,  $x$  and  $y$  must specify the full coordinates for each point, for example:

```
>>> x = [0,1,2,0,1,2]; y = [0,0,0,3,3,3]; z = [1,2,3,4,5,6]
```

If  $x$  and  $y$  are multi-dimensional, they are flattened before use.

**z** : array\_like

The values of the function to interpolate at the data points. If  $z$  is a multi-dimensional array, it is flattened before use. The length of a flattened  $z$  array is either  $\text{len}(x)*\text{len}(y)$  if  $x$  and  $y$  specify the column and row coordinates or  $\text{len}(z) == \text{len}(x) == \text{len}(y)$  if  $x$  and  $y$  specify coordinates for each point.

**kind** : { 'linear', 'cubic', 'quintic' }, optional

The kind of spline interpolation to use. Default is 'linear'.

**copy** : bool, optional

If True, the class makes internal copies of  $x$ ,  $y$  and  $z$ . If False, references may be used. The default is to copy.

**bounds\_error** : bool, optional

If True, when interpolated values are requested outside of the domain of the input data ( $x,y$ ), a `ValueError` is raised. If False, then *fill\_value* is used.

**fill\_value** : number, optional

If provided, the value to use for points outside of the interpolation domain. If omitted (None), values outside the domain are extrapolated.

See also:

#### **RectBivariateSpline**

Much faster 2D interpolation if your input data is on a grid

*bisplrep*, *bisplev*

#### **BivariateSpline**

a more recent wrapper of the FITPACK routines

**interp1d** one dimension version of this function

#### *Notes*

The minimum number of data points required along the interpolation axis is  $(k+1)**2$ , with  $k=1$  for linear,  $k=3$  for cubic and  $k=5$  for quintic interpolation.

The interpolator is constructed by *bisplrep*, with a smoothing factor of 0. If more control over smoothing is needed, *bisplrep* should be used directly.

#### *Examples*

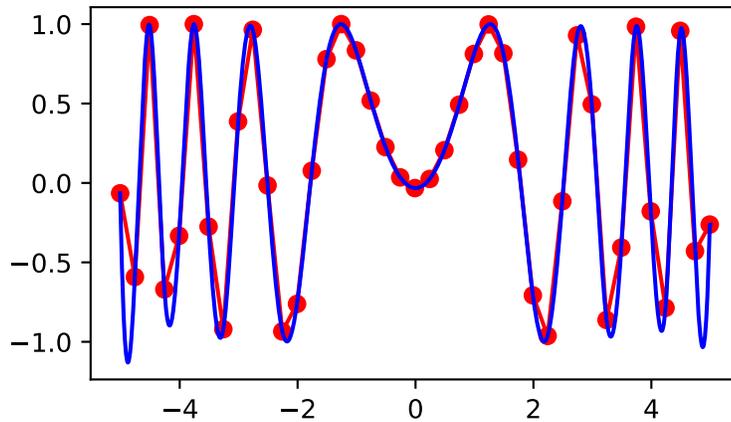
Construct a 2-D grid and interpolate on it:

```
>>> from scipy import interpolate
>>> x = np.arange(-5.01, 5.01, 0.25)
>>> y = np.arange(-5.01, 5.01, 0.25)
>>> xx, yy = np.meshgrid(x, y)
>>> z = np.sin(xx**2+yy**2)
>>> f = interpolate.interp2d(x, y, z, kind='cubic')
```

Now use the obtained interpolation function and plot the result:

```

>>> import matplotlib.pyplot as plt
>>> xnew = np.arange(-5.01, 5.01, 1e-2)
>>> ynew = np.arange(-5.01, 5.01, 1e-2)
>>> znew = f(xnew, ynew)
>>> plt.plot(x, z[0, :], 'ro-', xnew, znew[0, :], 'b-')
>>> plt.show()
    
```



### Methods

---

`__call__(x, y[, dx, dy, assume_sorted])` Interpolate the function.

---

`interp2d.__call__(x, y, dx=0, dy=0, assume_sorted=False)`  
 Interpolate the function.

**Parameters**

- x** : 1D array  
x-coordinates of the mesh on which to interpolate.
- y** : 1D array  
y-coordinates of the mesh on which to interpolate.
- dx** : int  $\geq 0$ ,  $< k_x$   
Order of partial derivatives in x.
- dy** : int  $\geq 0$ ,  $< k_y$   
Order of partial derivatives in y.
- assume\_sorted** : bool, optional  
If False, values of x and y can be in any order and they are sorted first. If True, x and y have to be arrays of monotonically increasing values.

**Returns**

- z** : 2D array with shape (len(y), len(x))  
The interpolated values.

For data on a grid:

<code>interpn(points, values, xi[, method, ...])</code>	Multidimensional interpolation on regular grids.
<code>RegularGridInterpolator(points, values[, ...])</code>	Interpolation on a regular grid in arbitrary dimensions
<code>RectBivariateSpline(x, y, z[, bbox, kx, ky, s])</code>	Bivariate spline approximation over a rectangular mesh.

`scipy.interpolate.interpn` (*points*, *values*, *xi*, *method='linear'*, *bounds\_error=True*,  
*fill\_value=nan*)

Multidimensional interpolation on regular grids.

**Parameters**

- points** : tuple of ndarray of float, with shapes (m1, ), ..., (mn, )  
The points defining the regular grid in n dimensions.
- values** : array\_like, shape (m1, ..., mn, ...)  
The data on the regular grid in n dimensions.
- xi** : ndarray of shape (... , ndim)  
The coordinates to sample the gridded data at
- method** : str, optional  
The method of interpolation to perform. Supported are “linear” and “nearest”, and “splinef2d”. “splinef2d” is only supported for 2-dimensional data.
- bounds\_error** : bool, optional  
If True, when interpolated values are requested outside of the domain of the input data, a `ValueError` is raised. If False, then *fill\_value* is used.
- fill\_value** : number, optional  
If provided, the value to use for points outside of the interpolation domain. If None, values outside the domain are extrapolated. Extrapolation is not supported by method “splinef2d”.

**Returns**

- values\_x** : ndarray, shape xi.shape[:-1] + values.shape[ndim:]  
Interpolated values at input coordinates.

See also:

#### **NearestNDInterpolator**

Nearest neighbour interpolation on unstructured data in N dimensions

#### **LinearNDInterpolator**

Piecewise linear interpolant on unstructured data in N dimensions

#### **RegularGridInterpolator**

Linear and nearest-neighbor Interpolation on a regular grid in arbitrary dimensions

#### **RectBivariateSpline**

Bivariate spline approximation over a rectangular mesh

#### *Notes*

New in version 0.14.

**class** `scipy.interpolate.RegularGridInterpolator` (*points*, *values*, *method='linear'*,  
*bounds\_error=True*, *fill\_value=nan*)

Interpolation on a regular grid in arbitrary dimensions

The data must be defined on a regular grid; the grid spacing however may be uneven. Linear and nearest-neighbour interpolation are supported. After setting up the interpolator object, the interpolation method (*linear* or *nearest*) may be chosen at each evaluation.

**Parameters**

- points** : tuple of ndarray of float, with shapes (m1, ), ..., (mn, )  
The points defining the regular grid in n dimensions.
- values** : array\_like, shape (m1, ..., mn, ...)  
The data on the regular grid in n dimensions.
- method** : str, optional  
The method of interpolation to perform. Supported are “linear” and “nearest”. This parameter will become the default for the object’s `__call__` method. Default is “linear”.
- bounds\_error** : bool, optional

If True, when interpolated values are requested outside of the domain of the input data, a `ValueError` is raised. If False, then `fill_value` is used.

**fill\_value** : number, optional

If provided, the value to use for points outside of the interpolation domain. If None, values outside the domain are extrapolated.

**See also:**

**NearestNDInterpolator**

Nearest neighbour interpolation on unstructured data in N dimensions

**LinearNDInterpolator**

Piecewise linear interpolant on unstructured data in N dimensions

*Notes*

Contrary to `LinearNDInterpolator` and `NearestNDInterpolator`, this class avoids expensive triangulation of the input data by taking advantage of the regular grid structure.

If any of *points* have a dimension of size 1, linear interpolation will return an array of *nan* values. Nearest-neighbor interpolation will work as usual in this case.

New in version 0.14.

*References*

[R91], [R92], [R93]

*Examples*

Evaluate a simple example function on the points of a 3D grid:

```
>>> from scipy.interpolate import RegularGridInterpolator
>>> def f(x, y, z):
...     return 2 * x**3 + 3 * y**2 - z
>>> x = np.linspace(1, 4, 11)
>>> y = np.linspace(4, 7, 22)
>>> z = np.linspace(7, 9, 33)
>>> data = f(*np.meshgrid(x, y, z, indexing='ij', sparse=True))
```

`data` is now a 3D array with `data[i, j, k] = f(x[i], y[j], z[k])`. Next, define an interpolating function from this data:

```
>>> my_interpolating_function = RegularGridInterpolator((x, y, z), data)
```

Evaluate the interpolating function at the two points  $(x, y, z) = (2.1, 6.2, 8.3)$  and  $(3.3, 5.2, 7.1)$ :

```
>>> pts = np.array([[2.1, 6.2, 8.3], [3.3, 5.2, 7.1]])
>>> my_interpolating_function(pts)
array([ 125.80469388,  146.30069388])
```

which is indeed a close approximation to `[f(2.1, 6.2, 8.3), f(3.3, 5.2, 7.1)]`.

*Methods*

---

<code>__call__(xi[, method])</code>	Interpolation at coordinates
-------------------------------------	------------------------------

RegularGridInterpolator.\_\_call\_\_(xi, method=None)

Interpolation at coordinates

**Parameters** **xi** : ndarray of shape (... , ndim)  
The coordinates to sample the gridded data at  
**method** : str  
The method of interpolation to perform. Supported are “linear” and “nearest”.

**class** scipy.interpolate.RectBivariateSpline(x, y, z, bbox=[None, None, None, None], kx=3, ky=3, s=0)

Bivariate spline approximation over a rectangular mesh.

Can be used for both smoothing and interpolating data.

**Parameters** **x,y** : array\_like  
1-D arrays of coordinates in strictly ascending order.  
**z** : array\_like  
2-D array of data with shape (x.size,y.size).  
**bbox** : array\_like, optional  
Sequence of length 4 specifying the boundary of the rectangular approximation domain.  
By default, `bbox=[min(x,tx), max(x,tx), min(y,ty), max(y,ty)]`.  
**kx, ky** : ints, optional  
Degrees of the bivariate spline. Default is 3.  
**s** : float, optional  
Positive smoothing factor defined for estimation condition:  
`sum((w[i]*(z[i]-s(x[i], y[i])))**2, axis=0) <= s` Default is `s=0`, which is for interpolation.

See also:

**SmoothBivariateSpline**  
a smoothing bivariate spline for scattered data

**bisplrep** an older wrapping of FITPACK

**bisplev** an older wrapping of FITPACK

**UnivariateSpline**  
a similar class for univariate spline interpolation

### Methods

<code>__call__(x, y[, dx, dy, grid])</code>	Evaluate the spline or its derivatives at given positions.
<code>ev(xi, yi[, dx, dy])</code>	Evaluate the spline at points
<code>get_coeffs()</code>	Return spline coefficients.
<code>get_knots()</code>	Return a tuple (tx,ty) where tx,ty contain knots positions of the spline with respect to x-, y-variable, respectively.
<code>get_residual()</code>	Return weighted sum of squared residuals of the spline
<code>integral(xa, xb, ya, yb)</code>	Evaluate the integral of the spline over area [xa,xb] x [ya,yb].

RectBivariateSpline.\_\_call\_\_(x, y, dx=0, dy=0, grid=True)

Evaluate the spline or its derivatives at given positions.

**Parameters** **x,y** : array\_like  
Input coordinates.  
If `grid` is False, evaluate the spline at points `(x[i], y[i])`, `i=0, ..., len(x)-1`. Standard Numpy broadcasting is obeyed.

If *grid* is True: evaluate spline at the grid points defined by the coordinate arrays *x*, *y*. The arrays must be sorted to increasing order.

**dx** : int  
Order of x-derivative  
New in version 0.14.0.

**dy** : int  
Order of y-derivative  
New in version 0.14.0.

**grid** : bool  
Whether to evaluate the results on a grid spanned by the input arrays, or at points specified by the input arrays.  
New in version 0.14.0.

`RectBivariateSpline.ev(xi, yi, dx=0, dy=0)`

Evaluate the spline at points

Returns the interpolated value at  $(xi[i], yi[i])$ ,  $i=0, \dots, len(xi)-1$ .

**Parameters** **xi, yi** : array\_like  
Input coordinates. Standard Numpy broadcasting is obeyed.

**dx** : int, optional  
Order of x-derivative  
New in version 0.14.0.

**dy** : int, optional  
Order of y-derivative  
New in version 0.14.0.

`RectBivariateSpline.get_coeffs()`

Return spline coefficients.

`RectBivariateSpline.get_knots()`

Return a tuple (tx,ty) where tx,ty contain knots positions of the spline with respect to x-, y-variable, respectively. The position of interior and additional knots are given as  $t[k+1:-k-1]$  and  $t[:k+1]=b$ ,  $t[-k-1:]=e$ , respectively.

`RectBivariateSpline.get_residual()`

Return weighted sum of squared residuals of the spline approximation:  $\sum ((w[i]*(z[i]-s(x[i],y[i])))**2,axis=0)$

`RectBivariateSpline.integral(xa, xb, ya, yb)`

Evaluate the integral of the spline over area  $[xa,xb] \times [ya,yb]$ .

**Parameters** **xa, xb** : float  
The end-points of the x integration interval.

**ya, yb** : float  
The end-points of the y integration interval.

**Returns** **integ** : float  
The value of the resulting integral.

See also:

`scipy.ndimage.map_coordinates`

Tensor product polynomials:

---

`NdPPoly(c, x[, extrapolate])`

Piecewise tensor product polynomial

---

**class** `scipy.interpolate.NdPPoly(c, x, extrapolate=None)`

Piecewise tensor product polynomial

The value at point  $xp = (x', y', z', \dots)$  is evaluated by first computing the interval indices  $i$  such that:

```
x[0][i[0]] <= x' < x[0][i[0]+1]
x[1][i[1]] <= y' < x[1][i[1]+1]
...
```

and then computing:

```
S = sum(c[k0-m0-1, ..., kn-mn-1, i[0], ..., i[n]]
        * (xp[0] - x[0][i[0]])**m0
        * ...
        * (xp[n] - x[n][i[n]])**mn
        for m0 in range(k[0]+1)
        ...
        for mn in range(k[n]+1))
```

where  $k[j]$  is the degree of the polynomial in dimension  $j$ . This representation is the piecewise multivariate power basis.

**Parameters**

- c** : ndarray, shape (k0, ..., kn, m0, ..., mn, ...)  
Polynomial coefficients, with polynomial order  $k_j$  and  $m_j+1$  intervals for each dimension  $j$ .
- x** : ndim-tuple of ndarrays, shapes (mj+1,)  
Polynomial breakpoints for each dimension. These must be sorted in increasing order.
- extrapolate** : bool, optional  
Whether to extrapolate to out-of-bounds points based on first and last intervals, or to return NaNs. Default: True.

**See also:**

**PPoly** piecewise polynomials in 1D

**Notes**

High-order polynomials in the power basis can be numerically unstable.

**Attributes**

x	(tuple of ndarrays) Breakpoints.
c	(ndarray) Coefficients of the polynomials.

**Methods**

<code>__call__(x[, nu, extrapolate])</code>	Evaluate the piecewise polynomial or its derivative
<code>construct_fast(c, x[, extrapolate])</code>	Construct the piecewise polynomial without making checks.

`NdPPoly.__call__(x, nu=None, extrapolate=None)`

Evaluate the piecewise polynomial or its derivative

**Parameters**

- x** : array-like  
Points to evaluate the interpolant at.
- nu** : tuple, optional  
Orders of derivatives to evaluate. Each must be non-negative.
- extrapolate** : bool, optional  
Whether to extrapolate to out-of-bounds points based on first and last intervals, or to return NaNs.

**Returns** `y` : array-like  
 Interpolated values. Shape is determined by replacing the interpolation axis in the original array with the shape of `x`.

**Notes**

Derivatives are evaluated piecewise for each polynomial segment, even if the polynomial is not differentiable at the breakpoints. The polynomial intervals are considered half-open,  $[a, b)$ , except for the last interval which is closed  $[a, b]$ .

**classmethod** `NdPPoly.construct_fast` (*c*, *x*, *extrapolate=None*)  
 Construct the piecewise polynomial without making checks.

Takes the same parameters as the constructor. Input arguments *c* and *x* must be arrays of the correct shape and type. The *c* array can only be of dtypes float and complex, and *x* array must have dtype float.

### 5.7.3 1-D Splines

<code>BSpline(t, c, k[, extrapolate, axis])</code>	Univariate spline in the B-spline basis.
<code>make_interp_spline(x, y[, k, t, bc_type, ...])</code>	Compute the (coefficients of) interpolating B-spline.
<code>make_lsq_spline(x, y, t[, k, w, axis, ...])</code>	Compute the (coefficients of) an LSQ B-spline.

**class** `scipy.interpolate.BSpline` (*t*, *c*, *k*, *extrapolate=True*, *axis=0*)  
 Univariate spline in the B-spline basis.

$$S(x) = \sum_{j=0}^{n-1} c_j B_{j,k;t}(x)$$

where  $B_{j,k;t}$  are B-spline basis functions of degree *k* and knots *t*.

**Parameters**

- t** : ndarray, shape (n+k+1,)  
 knots
- c** : ndarray, shape (>=n, ...)  
 spline coefficients
- k** : int  
 B-spline order
- extrapolate** : bool or 'periodic', optional  
 whether to extrapolate beyond the base interval,  $t[k] \dots t[n]$ , or to return nans. If True, extrapolates the first and last polynomial pieces of b-spline functions active on the base interval. If 'periodic', periodic extrapolation is used. Default is True.
- axis** : int, optional  
 Interpolation axis. Default is zero.

**Notes**

B-spline basis elements are defined via

$$B_{i,0}(x) = 1, \text{ if } t_i \leq x < t_{i+1}, \text{ otherwise } 0,$$

$$B_{i,k}(x) = \frac{x - t_i}{t_{i+k} - t_i} B_{i,k-1}(x) + \frac{t_{i+k+1} - x}{t_{i+k+1} - t_{i+1}} B_{i+1,k-1}(x)$$

**Implementation details**

- At least *k*+1 coefficients are required for a spline of degree *k*, so that  $n \geq k+1$ . Additional coefficients, `c[j]` with  $j > n$ , are ignored.

- B-spline basis elements of degree  $k$  form a partition of unity on the *base interval*,  $t[k] \leq x \leq t[n]$ .

### References

[R82], [R83]

### Examples

Translating the recursive definition of B-splines into Python code, we have:

```
>>> def B(x, k, i, t):
...     if k == 0:
...         return 1.0 if t[i] <= x < t[i+1] else 0.0
...     if t[i+k] == t[i]:
...         c1 = 0.0
...     else:
...         c1 = (x - t[i]) / (t[i+k] - t[i]) * B(x, k-1, i, t)
...     if t[i+k+1] == t[i+1]:
...         c2 = 0.0
...     else:
...         c2 = (t[i+k+1] - x) / (t[i+k+1] - t[i+1]) * B(x, k-1, i+1, t)
...     return c1 + c2
```

```
>>> def bspline(x, t, c, k):
...     n = len(t) - k - 1
...     assert (n >= k+1) and (len(c) >= n)
...     return sum(c[i] * B(x, k, i, t) for i in range(n))
```

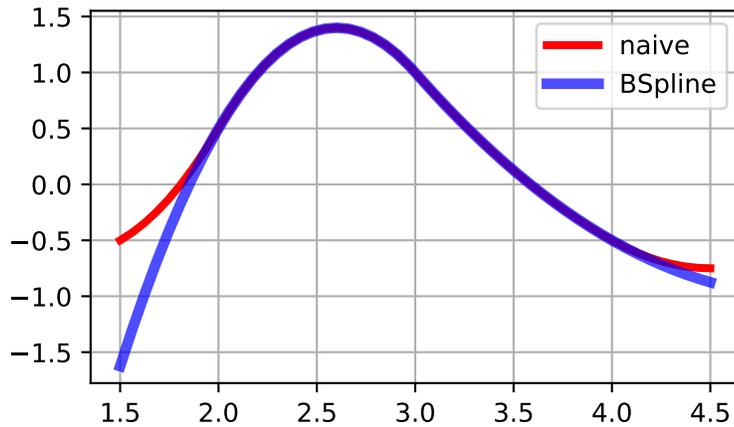
Note that this is an inefficient (if straightforward) way to evaluate B-splines — this spline class does it in an equivalent, but much more efficient way.

Here we construct a quadratic spline function on the base interval  $2 \leq x \leq 4$  and compare with the naive way of evaluating the spline:

```
>>> from scipy.interpolate import BSpline
>>> k = 2
>>> t = [0, 1, 2, 3, 4, 5, 6]
>>> c = [-1, 2, 0, -1]
>>> spl = BSpline(t, c, k)
>>> spl(2.5)
array(1.375)
>>> bspline(2.5, t, c, k)
1.375
```

Note that outside of the base interval results differ. This is because *BSpline* extrapolates the first and last polynomial pieces of b-spline functions active on the base interval.

```
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots()
>>> xx = np.linspace(1.5, 4.5, 50)
>>> ax.plot(xx, [bspline(x, t, c, k) for x in xx], 'r-', lw=3, label='naive')
>>> ax.plot(xx, spl(xx), 'b-', lw=4, alpha=0.7, label='BSpline')
>>> ax.grid(True)
>>> ax.legend(loc='best')
>>> plt.show()
```



### Attributes

`tck` Equivalent to `(self.t, self.c, self.k)` (read-only).

### BSpline.tck

Equivalent to `(self.t, self.c, self.k)` (read-only).

<code>t</code>	(ndarray) knot vector
<code>c</code>	(ndarray) spline coefficients
<code>k</code>	(int) spline degree
<code>extrapolate</code>	(bool) If True, extrapolates the first and last polynomial pieces of b-spline functions active on the base interval.
<code>axis</code>	(int) Interpolation axis.

### Methods

<code>__call__(x[, nu, extrapolate])</code>	Evaluate a spline function.
<code>basis_element(t[, extrapolate])</code>	Return a B-spline basis element $B(x   t[0], \dots, t[k+1])$ .
<code>derivative([nu])</code>	Return a b-spline representing the derivative.
<code>antiderivative([nu])</code>	Return a b-spline representing the antiderivative.
<code>integrate(a, b[, extrapolate])</code>	Compute a definite integral of the spline.
<code>construct_fast(t, c, k[, extrapolate, axis])</code>	Construct a spline without making checks.

BSpline.**\_\_call\_\_**(*x*, *nu*=0, *extrapolate*=None)

Evaluate a spline function.

**Parameters**

- `x`: array\_like  
points to evaluate the spline at.
- `nu`: int, optional  
derivative to evaluate (default is 0).
- `extrapolate`: bool or 'periodic', optional

whether to extrapolate based on the first and last intervals or return nans. If ‘periodic’, periodic extrapolation is used. Default is *self.extrapolate*.

**Returns** `y`: array\_like

Shape is determined by replacing the interpolation axis in the coefficient array with the shape of *x*.

**classmethod** `BSpline.basis_element` (*t*, *extrapolate=True*)

Return a B-spline basis element  $B(x | t[0], \dots, t[k+1])$ .

**Parameters** `t`: ndarray, shape (k+1,)  
internal knots

**extrapolate**: bool or ‘periodic’, optional  
whether to extrapolate beyond the base interval,  $t[0] \dots t[k+1]$ , or to return nans. If ‘periodic’, periodic extrapolation is used. Default is True.

**Returns** **basis\_element**: callable

A callable representing a B-spline basis element for the knot vector *t*.

### Notes

The order of the b-spline, *k*, is inferred from the length of *t* as  $\text{len}(t) - 2$ . The knot vector is constructed by appending and prepending *k*+1 elements to internal knots *t*.

### Examples

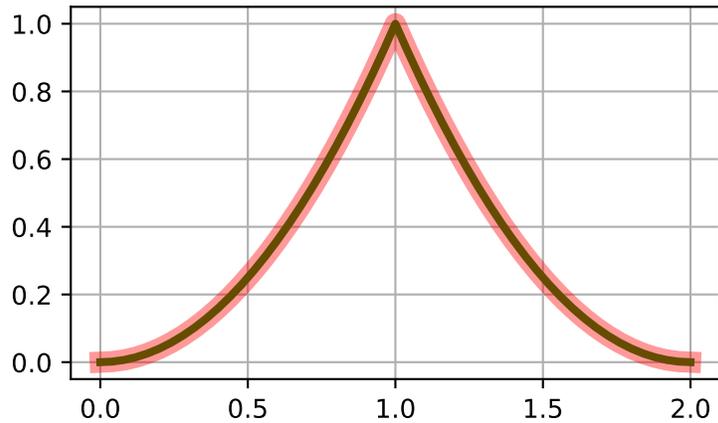
Construct a cubic b-spline:

```
>>> from scipy.interpolate import BSpline
>>> b = BSpline.basis_element([0, 1, 2, 3, 4])
>>> k = b.k
>>> b.t[k:-k]
array([ 0.,  1.,  2.,  3.,  4.])
>>> k
3
```

Construct a second order b-spline on  $[0, 1, 1, 2]$ , and compare to its explicit form:

```
>>> t = [-1, 0, 1, 1, 2]
>>> b = BSpline.basis_element(t[1:])
>>> def f(x):
...     return np.where(x < 1, x*x, (2. - x)**2)
```

```
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots()
>>> x = np.linspace(0, 2, 51)
>>> ax.plot(x, b(x), 'g', lw=3)
>>> ax.plot(x, f(x), 'r', lw=8, alpha=0.4)
>>> ax.grid(True)
>>> plt.show()
```



`BSpline.derivative (nu=1)`

Return a b-spline representing the derivative.

**Parameters** **nu** : int, optional  
Derivative order. Default is 1.

**Returns** **b** : BSpline object  
A new instance representing the derivative.

**See also:**

*splder, splantider*

`BSpline.antiderivative (nu=1)`

Return a b-spline representing the antiderivative.

**Parameters** **nu** : int, optional  
Antiderivative order. Default is 1.

**Returns** **b** : BSpline object  
A new instance representing the antiderivative.

**See also:**

*splder, splantider*

**Notes**

If antiderivative is computed and `self.extrapolate='periodic'`, it will be set to `False` for the returned instance. This is done because the antiderivative is no longer periodic and its correct evaluation outside of the initially given `x` interval is difficult.

`BSpline.integrate (a, b, extrapolate=None)`

Compute a definite integral of the spline.

**Parameters** **a** : float  
Lower limit of integration.  
**b** : float  
Upper limit of integration.  
**extrapolate** : bool or 'periodic', optional

whether to extrapolate beyond the base interval,  $t[k] \dots t[-k-1]$ , or take the spline to be zero outside of the base interval. If ‘periodic’, periodic extrapolation is used. If None (default), use *self.extrapolate*.

**Returns** **I**: array\_like  
Definite integral of the spline over the interval  $[a, b]$ .

### Examples

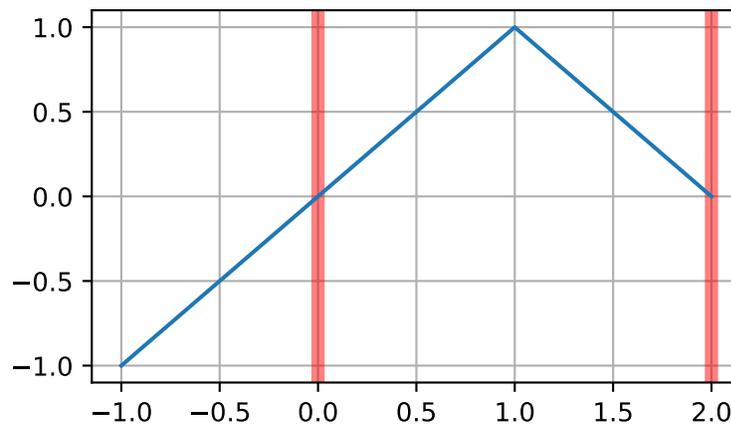
Construct the linear spline  $x$  if  $x < 1$  else  $2 - x$  on the base interval  $[0, 2]$ , and integrate it

```
>>> from scipy.interpolate import BSpline
>>> b = BSpline.basis_element([0, 1, 2])
>>> b.integrate(0, 1)
array(0.5)
```

If the integration limits are outside of the base interval, the result is controlled by the *extrapolate* parameter

```
>>> b.integrate(-1, 1)
array(0.0)
>>> b.integrate(-1, 1, extrapolate=False)
array(0.5)
```

```
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots()
>>> ax.grid(True)
>>> ax.axvline(0, c='r', lw=5, alpha=0.5) # base interval
>>> ax.axvline(2, c='r', lw=5, alpha=0.5)
>>> xx = [-1, 1, 2]
>>> ax.plot(xx, b(xx))
>>> plt.show()
```



**classmethod** `BSpline.construct_fast` (*t, c, k, extrapolate=True, axis=0*)

Construct a spline without making checks.

Accepts same parameters as the regular constructor. Input arrays *t* and *c* must of correct shape and dtype.

`scipy.interpolate.make_interp_spline` (*x, y, k=3, t=None, bc\_type=None, axis=0, check\_finite=True*)

Compute the (coefficients of) interpolating B-spline.

**Parameters**

- x** : array\_like, shape (n,)
  - Abscissas.
- y** : array\_like, shape (n, ...)
  - Ordinates.
- k** : int, optional
  - B-spline degree. Default is cubic, k=3.
- t** : array\_like, shape (nt + k + 1,), optional.
  - Knots. The number of knots needs to agree with the number of datapoints and the number of derivatives at the edges. Specifically,  $nt - n$  must equal  $\text{len}(\text{deriv}_l) + \text{len}(\text{deriv}_r)$ .
- bc\_type** : 2-tuple or None
  - Boundary conditions. Default is None, which means choosing the boundary conditions automatically. Otherwise, it must be a length-two tuple where the first element sets the boundary conditions at  $x[0]$  and the second element sets the boundary conditions at  $x[-1]$ . Each of these must be an iterable of pairs (*order*, *value*) which gives the values of derivatives of specified orders at the given edge of the interpolation interval.
- axis** : int, optional
  - Interpolation axis. Default is 0.
- check\_finite** : bool, optional
  - Whether to check that the input arrays contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs. Default is True.

**Returns**

- b** : a BSpline object of the degree *k* and with knots *t*.

See also:

**BSpline** base class representing the B-spline objects

**CubicSpline**  
a cubic spline in the polynomial basis

**make\_lsq\_spline**  
a similar factory function for spline fitting

**UnivariateSpline**  
a wrapper over FITPACK spline fitting routines

**splrep** a wrapper over FITPACK spline fitting routines

**Examples**

Use cubic interpolation on Chebyshev nodes:

```
>>> def cheb_nodes(N):
...     jj = 2.*np.arange(N) + 1
...     x = np.cos(np.pi * jj / 2 / N)[::-1]
...     return x
```

```
>>> x = cheb_nodes(20)
>>> y = np.sqrt(1 - x**2)
```

```
>>> from scipy.interpolate import BSpline, make_interp_spline
>>> b = make_interp_spline(x, y)
>>> np.allclose(b(x), y)
True
```

Note that the default is a cubic spline with a not-a-knot boundary condition

```
>>> b.k
3
```

Here we use a ‘natural’ spline, with zero 2nd derivatives at edges:

```
>>> l, r = [(2, 0)], [(2, 0)]
>>> b_n = make_interp_spline(x, y, bc_type=(l, r))
>>> np.allclose(b_n(x), y)
True
>>> x0, x1 = x[0], x[-1]
>>> np.allclose([b_n(x0, 2), b_n(x1, 2)], [0, 0])
True
```

Interpolation of parametric curves is also supported. As an example, we compute a discretization of a snail curve in polar coordinates

```
>>> phi = np.linspace(0, 2.*np.pi, 40)
>>> r = 0.3 + np.cos(phi)
>>> x, y = r*np.cos(phi), r*np.sin(phi) # convert to Cartesian coordinates
```

Build an interpolating curve, parameterizing it by the angle

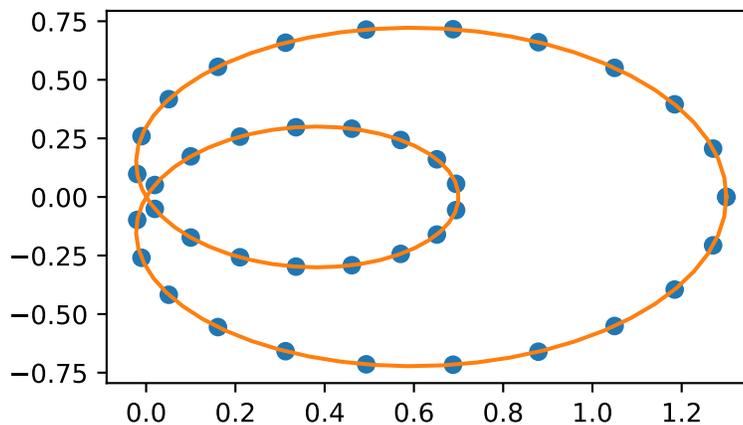
```
>>> from scipy.interpolate import make_interp_spline
>>> spl = make_interp_spline(phi, np.c_[x, y])
```

Evaluate the interpolant on a finer grid (note that we transpose the result to unpack it into a pair of x- and y-arrays)

```
>>> phi_new = np.linspace(0, 2.*np.pi, 100)
>>> x_new, y_new = spl(phi_new).T
```

Plot the result

```
>>> import matplotlib.pyplot as plt
>>> plt.plot(x, y, 'o')
>>> plt.plot(x_new, y_new, '-')
>>> plt.show()
```



`scipy.interpolate.make_lsq_spline(x, y, t, k=3, w=None, axis=0, check_finite=True)`  
 Compute the (coefficients of) an LSQ B-spline.

The result is a linear combination

$$S(x) = \sum_j c_j B_j(x; t)$$

of the B-spline basis elements,  $B_j(x; t)$ , which minimizes

$$\sum_j (w_j \times (S(x_j) - y_j))^2$$

**Parameters**

- x** : array\_like, shape (m,)
  - Abscissas.
- y** : array\_like, shape (m, ...)
  - Ordinates.
- t** : array\_like, shape (n + k + 1,).
  - Knots. Knots and data points must satisfy Schoenberg-Whitney conditions.
- k** : int, optional
  - B-spline degree. Default is cubic, k=3.
- w** : array\_like, shape (n,), optional
  - Weights for spline fitting. Must be positive. If `None`, then weights are all equal. Default is `None`.
- axis** : int, optional
  - Interpolation axis. Default is zero.
- check\_finite** : bool, optional
  - Whether to check that the input arrays contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs. Default is `True`.

**Returns**

- b** : a `BSpline` object of the degree  $k$  with knots  $t$ .

See also:

- BSpline** base class representing the B-spline objects
- make\_interp\_spline** a similar factory function for interpolating splines
- LSQUnivariateSpline** a FITPACK-based spline fitting routine
- splrep** a FITPACK-based fitting routine

**Notes**

The number of data points must be larger than the spline degree  $k$ .

Knots  $t$  must satisfy the Schoenberg-Whitney conditions, i.e., there must be a subset of data points  $x[j]$  such that  $t[j] < x[j] < t[j+k+1]$ , for  $j=0, 1, \dots, n-k-2$ .

**Examples**

Generate some noisy data:

```

>>> x = np.linspace(-3, 3, 50)
>>> y = np.exp(-x**2) + 0.1 * np.random.randn(50)
```

Now fit a smoothing cubic spline with a pre-defined internal knots. Here we make the knot vector (k+1)-regular by adding boundary knots:

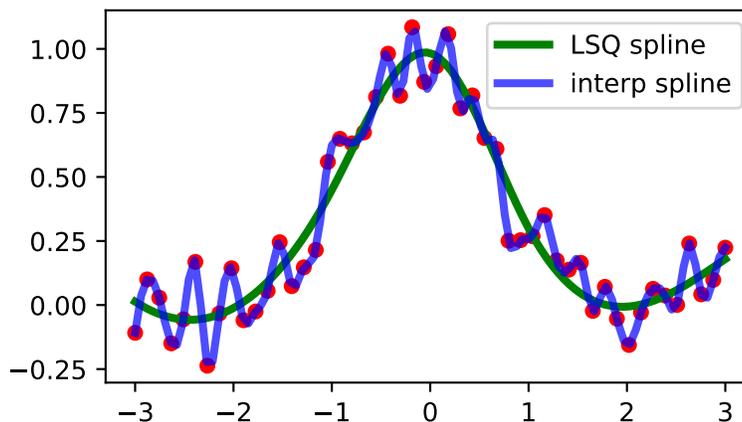
```
>>> from scipy.interpolate import make_lsq_spline, BSpline
>>> t = [-1, 0, 1]
>>> k = 3
>>> t = np.r_[(x[0],)*(k+1),
...          t,
...          (x[-1],)*(k+1)]
>>> spl = make_lsq_spline(x, y, t, k)
```

For comparison, we also construct an interpolating spline for the same set of data:

```
>>> from scipy.interpolate import make_interp_spline
>>> spl_i = make_interp_spline(x, y)
```

Plot both:

```
>>> import matplotlib.pyplot as plt
>>> xs = np.linspace(-3, 3, 100)
>>> plt.plot(x, y, 'ro', ms=5)
>>> plt.plot(xs, spl(xs), 'g-', lw=3, label='LSQ spline')
>>> plt.plot(xs, spl_i(xs), 'b-', lw=3, alpha=0.7, label='interp spline')
>>> plt.legend(loc='best')
>>> plt.show()
```



**NaN handling:** If the input arrays contain `nan` values, the result is not useful since the underlying spline fitting routines cannot deal with `nan`. A workaround is to use zero weights for not-a-number data points:

```
>>> y[8] = np.nan
>>> w = np.isnan(y)
>>> y[w] = 0.
>>> tck = make_lsq_spline(x, y, t, w=~w)
```

Notice the need to replace a `nan` by a numerical value (precise value does not matter as long as the corresponding weight is zero.)

Functional interface to FITPACK routines:

`splrep(x, y[, w, xb, xe, k, task, s, t, ...])`

Find the B-spline representation of 1-D curve.

Continued on next page

Table 5.58 – continued from previous page

<code>splprep(x[, w, u, ub, ue, k, task, s, t, ...])</code>	Find the B-spline representation of an N-dimensional curve.
<code>splev(x, tck[, der, ext])</code>	Evaluate a B-spline or its derivatives.
<code>splint(a, b, tck[, full_output])</code>	Evaluate the definite integral of a B-spline between two given points.
<code>sproot(tck[, mest])</code>	Find the roots of a cubic B-spline.
<code>spalde(x, tck)</code>	Evaluate all derivatives of a B-spline.
<code>splder(tck[, n])</code>	Compute the spline representation of the derivative of a given spline
<code>splantider(tck[, n])</code>	Compute the spline for the antiderivative (integral) of a given spline.
<code>insert(x, tck[, m, per])</code>	Insert knots into a B-spline.

`scipy.interpolate.splrep(x, y, w=None, xb=None, xe=None, k=3, task=0, s=None, t=None, full_output=0, per=0, quiet=1)`

Find the B-spline representation of 1-D curve.

Given the set of data points  $(x[i], y[i])$  determine a smooth spline approximation of degree  $k$  on the interval  $x_b \leq x \leq x_e$ .

- Parameters**
- x, y** : array\_like  
The data points defining a curve  $y = f(x)$ .
  - w** : array\_like, optional  
Strictly positive rank-1 array of weights the same length as  $x$  and  $y$ . The weights are used in computing the weighted least-squares spline fit. If the errors in the  $y$  values have standard-deviation given by the vector  $d$ , then  $w$  should be  $1/d$ . Default is `ones(len(x))`.
  - xb, xe** : float, optional  
The interval to fit. If `None`, these default to  $x[0]$  and  $x[-1]$  respectively.
  - k** : int, optional  
The degree of the spline fit. It is recommended to use cubic splines. Even values of  $k$  should be avoided especially with small  $s$  values.  $1 \leq k \leq 5$
  - task** : {1, 0, -1}, optional  
If `task==0` find  $t$  and  $c$  for a given smoothing factor,  $s$ .  
If `task==1` find  $t$  and  $c$  for another value of the smoothing factor,  $s$ . There must have been a previous call with `task=0` or `task=1` for the same set of data ( $t$  will be stored and used internally)  
If `task=-1` find the weighted least square spline for a given set of knots,  $t$ . These should be interior knots as knots on the ends will be added automatically.
  - s** : float, optional  
A smoothing condition. The amount of smoothness is determined by satisfying the conditions:  $\sum((w * (y - g))^2, axis=0) \leq s$  where  $g(x)$  is the smoothed interpolation of  $(x,y)$ . The user can use  $s$  to control the tradeoff between closeness and smoothness of fit. Larger  $s$  means more smoothing while smaller values of  $s$  indicate less smoothing. Recommended values of  $s$  depend on the weights,  $w$ . If the weights represent the inverse of the standard-deviation of  $y$ , then a good  $s$  value should be found in the range  $(m - \sqrt{2*m}, m + \sqrt{2*m})$  where  $m$  is the number of datapoints in  $x, y$ , and  $w$ .  
default :  $s = m - \sqrt{2*m}$  if weights are supplied.  $s = 0.0$  (interpolating) if no weights are supplied.
  - t** : array\_like, optional  
The knots needed for `task=-1`. If given then `task` is automatically set to `-1`.
  - full\_output** : bool, optional  
If non-zero, then return optional outputs.
  - per** : bool, optional

If non-zero, data points are considered periodic with period  $x[m-1] - x[0]$  and a smooth periodic spline approximation is returned. Values of  $y[m-1]$  and  $w[m-1]$  are not used.

**quiet** : bool, optional

Non-zero to suppress messages. This parameter is deprecated; use standard Python warning filters instead.

**Returns**

**tck** : tuple

A tuple (t,c,k) containing the vector of knots, the B-spline coefficients, and the degree of the spline.

**fp** : array, optional

The weighted sum of squared residuals of the spline approximation.

**ier** : int, optional

An integer flag about splrep success. Success is indicated if  $ier \leq 0$ . If  $ier$  in [1,2,3] an error occurred but was not raised. Otherwise an error is raised.

**msg** : str, optional

A message corresponding to the integer flag,  $ier$ .

**See also:**

UnivariateSpline, BivariateSpline, splprep, splev, sproot, spalde, splint, bisplrep, bisplev, BSpline, make\_interp\_spline

**Notes**

See *splev* for evaluation of the spline and its derivatives. Uses the FORTRAN routine *curfit* from FITPACK.

The user is responsible for assuring that the values of  $x$  are unique. Otherwise, *splrep* will not return sensible results.

If provided, knots  $t$  must satisfy the Schoenberg-Whitney conditions, i.e., there must be a subset of data points  $x[j]$  such that  $t[j] < x[j] < t[j+k+1]$ , for  $j=0, 1, \dots, n-k-2$ .

This routine zero-pads the coefficients array  $c$  to have the same length as the array of knots  $t$  (the trailing  $k + 1$  coefficients are ignored by the evaluation routines, *splev* and *BSpline*.) This is in contrast with *splprep*, which does not zero-pad the coefficients.

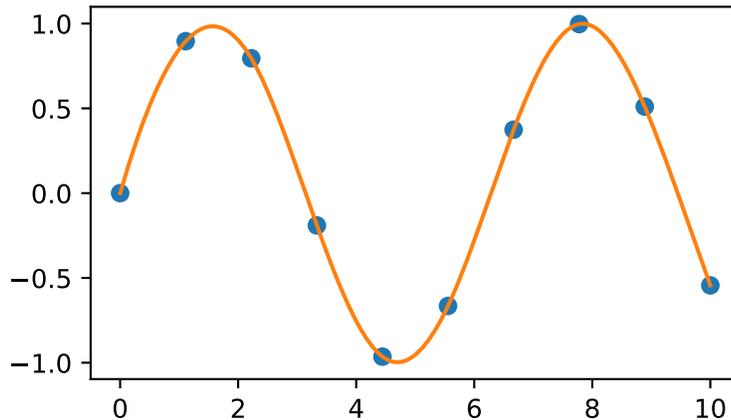
**References**

Based on algorithms described in [R113], [R114], [R115], and [R116]:

[R113], [R114], [R115], [R116]

**Examples**

```
>>> import matplotlib.pyplot as plt
>>> from scipy.interpolate import splev, splrep
>>> x = np.linspace(0, 10, 10)
>>> y = np.sin(x)
>>> spl = splrep(x, y)
>>> x2 = np.linspace(0, 10, 200)
>>> y2 = splev(x2, spl)
>>> plt.plot(x, y, 'o', x2, y2)
>>> plt.show()
```



```
scipy.interpolate.splprep(x, w=None, u=None, ub=None, ue=None, k=3, task=0, s=None,
                          t=None, full_output=0, nest=None, per=0, quiet=1)
```

Find the B-spline representation of an N-dimensional curve.

Given a list of N rank-1 arrays,  $x$ , which represent a curve in N-dimensional space parametrized by  $u$ , find a smooth approximating spline curve  $g(u)$ . Uses the FORTRAN routine `parcur` from FITPACK.

**Parameters**  $x$  : array\_like

A list of sample vector arrays representing the curve.

$w$  : array\_like, optional

Strictly positive rank-1 array of weights the same length as  $x[0]$ . The weights are used in computing the weighted least-squares spline fit. If the errors in the  $x$  values have standard-deviation given by the vector  $d$ , then  $w$  should be  $1/d$ . Default is `ones(len(x[0]))`.

$u$  : array\_like, optional

An array of parameter values. If not given, these values are calculated automatically as  $M = \text{len}(x[0])$ , where

$$v[0] = 0$$

$$v[i] = v[i-1] + \text{distance}(x[i], x[i-1])$$

$$u[i] = v[i] / v[M-1]$$

$ub, ue$  : int, optional

The end-points of the parameters interval. Defaults to  $u[0]$  and  $u[-1]$ .

$k$  : int, optional

Degree of the spline. Cubic splines are recommended. Even values of  $k$  should be avoided especially with a small  $s$ -value.  $1 \leq k \leq 5$ , default is 3.

$task$  : int, optional

If  $task==0$  (default), find  $t$  and  $c$  for a given smoothing factor,  $s$ . If  $task==1$ , find  $t$  and  $c$  for another value of the smoothing factor,  $s$ . There must have been a previous call with  $task=0$  or  $task=1$  for the same set of data. If  $task=-1$  find the weighted least square spline for a given set of knots,  $t$ .

$s$  : float, optional

A smoothing condition. The amount of smoothness is determined by satisfying the conditions:  $\text{sum}((w * (y - g))**2, \text{axis}=0) \leq s$ , where  $g(x)$  is the smoothed interpolation of  $(x,y)$ . The user can use  $s$  to control the trade-off between closeness and smoothness of fit. Larger  $s$  means more smoothing while smaller values of  $s$  indicate less smoothing. Recommended values of  $s$  depend on the weights,  $w$ . If the

weights represent the inverse of the standard-deviation of  $y$ , then a good  $s$  value should be found in the range  $(m - \sqrt{2 * m}, m + \sqrt{2 * m})$ , where  $m$  is the number of data points in  $x$ ,  $y$ , and  $w$ .

**t** : int, optional

The knots needed for `task=-1`.

**full\_output** : int, optional

If non-zero, then return optional outputs.

**nest** : int, optional

An over-estimate of the total number of knots of the spline to help in determining the storage space. By default `nest=m/2`. Always large enough is `nest=m+k+1`.

**per** : int, optional

If non-zero, data points are considered periodic with period  $x[m-1] - x[0]$  and a smooth periodic spline approximation is returned. Values of  $y[m-1]$  and  $w[m-1]$  are not used.

**quiet** : int, optional

Non-zero to suppress messages. This parameter is deprecated; use standard Python warning filters instead.

### Returns

**tck** : tuple

( $t, c, k$ ) a tuple containing the vector of knots, the B-spline coefficients, and the degree of the spline.

**u** : array

An array of the values of the parameter.

**fp** : float

The weighted sum of squared residuals of the spline approximation.

**ier** : int

An integer flag about `splrep` success. Success is indicated if `ier <= 0`. If `ier` in `[1,2,3]` an error occurred but was not raised. Otherwise an error is raised.

**msg** : str

A message corresponding to the integer flag, `ier`.

### See also:

`splrep`, `splev`, `sproot`, `spalde`, `splint`, `bisplrep`, `bisplev`, `UnivariateSpline`, `BivariateSpline`, `BSpline`, `make_interp_spline`

### Notes

See `splev` for evaluation of the spline and its derivatives. The number of dimensions  $N$  must be smaller than 11.

The number of coefficients in the  $c$  array is  $k+1$  less than the number of knots, `len(t)`. This is in contrast with `splrep`, which zero-pads the array of coefficients to have the same length as the array of knots. These additional coefficients are ignored by evaluation routines, `splev` and `BSpline`.

### References

[R110], [R111], [R112]

### Examples

Generate a discretization of a limaçon curve in the polar coordinates:

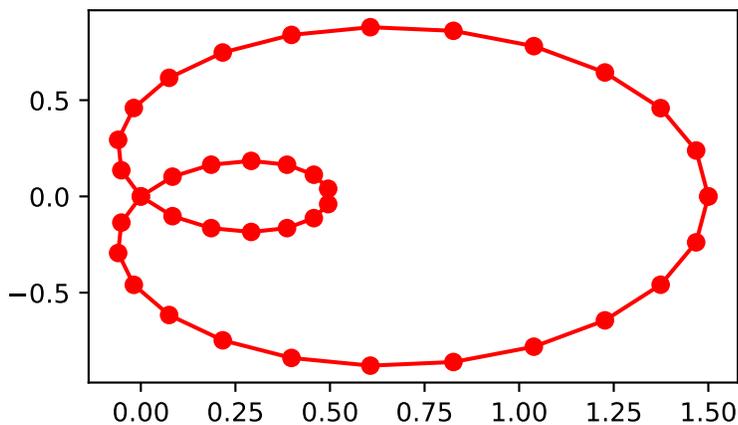
```
>>> phi = np.linspace(0, 2.*np.pi, 40)
>>> r = 0.5 + np.cos(phi)           # polar coords
>>> x, y = r * np.cos(phi), r * np.sin(phi)   # convert to cartesian
```

And interpolate:

```
>>> from scipy.interpolate import splprep, splev
>>> tck, u = splprep([x, y], s=0)
>>> new_points = splev(u, tck)
```

Notice that (i) we force interpolation by using  $s=0$ , (ii) the parameterization,  $u$ , is generated automatically. Now plot the result:

```
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots()
>>> ax.plot(x, y, 'ro')
>>> ax.plot(new_points[0], new_points[1], 'r-')
>>> plt.show()
```



`scipy.interpolate.splev` ( $x, tck, der=0, ext=0$ )  
Evaluate a B-spline or its derivatives.

Given the knots and coefficients of a B-spline representation, evaluate the value of the smoothing polynomial and its derivatives. This is a wrapper around the FORTRAN routines `splev` and `splder` of FITPACK.

**Parameters**  $x$  : array\_like

An array of points at which to return the value of the smoothed spline or its derivatives. If  $tck$  was returned from `splprep`, then the parameter values,  $u$  should be given.

**tck** : 3-tuple or a BSpline object

If a tuple, then it should be a sequence of length 3 returned by `splprep` or `splprep` containing the knots, coefficients, and degree of the spline. (Also see Notes.)

**der** : int, optional

The order of derivative of the spline to compute (must be less than or equal to  $k$ ).

**ext** : int, optional

Controls the value returned for elements of  $x$  not in the interval defined by the knot sequence.

- if  $ext=0$ , return the extrapolated value.
- if  $ext=1$ , return 0
- if  $ext=2$ , raise a `ValueError`
- if  $ext=3$ , return the boundary value.

The default value is 0.

**Returns**  $y$  : ndarray or list of ndarrays

An array of values representing the spline function evaluated at the points in  $x$ . If  $tck$  was returned from `splprep`, then this is a list of arrays representing the curve in  $N$ -dimensional space.

**See also:**

`splprep`, `splrep`, `sproot`, `spalde`, `splint`, `bisplrep`, `bisplev`, `BSpline`

**Notes**

Manipulating the `tck`-tuples directly is not recommended. In new code, prefer using `BSpline` objects.

**References**

[R105], [R106], [R107]

`scipy.interpolate.splint` ( $a$ ,  $b$ ,  $tck$ ,  $full\_output=0$ )

Evaluate the definite integral of a B-spline between two given points.

**Parameters**

- a, b** : float  
The end-points of the integration interval.
- tck** : tuple or a `BSpline` instance  
If a tuple, then it should be a sequence of length 3, containing the vector of knots, the B-spline coefficients, and the degree of the spline (see `splev`).
- full\_output** : int, optional  
Non-zero to return optional output.

**Returns**

- integral** : float  
The resulting integral.
- wrk** : ndarray  
An array containing the integrals of the normalized B-splines defined on the set of knots. (Only returned if `full_output` is non-zero)

**See also:**

`splprep`, `splrep`, `sproot`, `spalde`, `splev`, `bisplrep`, `bisplev`, `BSpline`

**Notes**

`splint` silently assumes that the spline function is zero outside the data interval ( $a$ ,  $b$ ).

Manipulating the `tck`-tuples directly is not recommended. In new code, prefer using the `BSpline` objects.

**References**

[R108], [R109]

`scipy.interpolate.sproot` ( $tck$ ,  $mest=10$ )

Find the roots of a cubic B-spline.

Given the knots ( $\geq 8$ ) and coefficients of a cubic B-spline return the roots of the spline.

**Parameters**

- tck** : tuple or a `BSpline` object  
If a tuple, then it should be a sequence of length 3, containing the vector of knots, the B-spline coefficients, and the degree of the spline. The number of knots must be  $\geq 8$ , and the degree must be 3. The knots must be a monotonically increasing sequence.
- mest** : int, optional  
An estimate of the number of zeros (Default is 10).

**Returns**

- zeros** : ndarray  
An array giving the roots of the spline.

**See also:**

*splprep, splrep, splint, spalde, splev, bisplrep, bisplev, BSpline*

**Notes**

Manipulating the *tck*-tuples directly is not recommended. In new code, prefer using the *BSpline* objects.

**References**

[R117], [R118], [R119]

`scipy.interpolate.spalde` (*x, tck*)

Evaluate all derivatives of a B-spline.

Given the knots and coefficients of a cubic B-spline compute all derivatives up to order *k* at a point (or set of points).

**Parameters** *x* : array\_like

A point or a set of points at which to evaluate the derivatives. Note that  $t(k) \leq x \leq t(n-k+1)$  must hold for each *x*.

**tck** : tuple

A tuple (*t, c, k*), containing the vector of knots, the B-spline coefficients, and the degree of the spline (see *splev*).

**Returns** **results** : {ndarray, list of ndarrays}

An array (or a list of arrays) containing all derivatives up to order *k* inclusive for each point *x*.

**See also:**

*splprep, splrep, splint, sproot, splev, bisplrep, bisplev, BSpline*

**References**

[R102], [R103], [R104]

`scipy.interpolate.splder` (*tck, n=1*)

Compute the spline representation of the derivative of a given spline

**Parameters** **tck** : BSpline instance or a tuple of (*t, c, k*)

Spline whose derivative to compute

**n** : int, optional

Order of derivative to evaluate. Default: 1

**Returns** *BSpline* instance or tuple

Spline of order  $k_2=k-n$  representing the derivative of the input spline. A tuple is returned iff the input argument *tck* is a tuple, otherwise a BSpline object is constructed and returned.

**See also:**

*splantider, splev, spalde, BSpline*

**Notes**

New in version 0.13.0.

**Examples**

This can be used for finding maxima of a curve:

```
>>> from scipy.interpolate import splrep, splder, sproot
>>> x = np.linspace(0, 10, 70)
>>> y = np.sin(x)
>>> spl = splrep(x, y, k=4)
```

Now, differentiate the spline and find the zeros of the derivative. (NB: *sproot* only works for order 3 splines, so we fit an order 4 spline):

```
>>> dspl = splder(spl)
>>> sproot(dspl) / np.pi
array([ 0.50000001,  1.5          ,  2.49999998])
```

This agrees well with roots  $\pi/2 + n\pi$  of  $\cos(x) = \sin'(x)$ .

`scipy.interpolate.splantider` (*tck*, *n=1*)

Compute the spline for the antiderivative (integral) of a given spline.

**Parameters** **tck** : BSpline instance or a tuple of (t, c, k)  
 Spline whose antiderivative to compute  
**n** : int, optional  
 Order of antiderivative to evaluate. Default: 1

**Returns** BSpline instance or a tuple of (t2, c2, k2)  
 Spline of order  $k2=k+n$  representing the antiderivative of the input spline. A tuple is returned iff the input argument *tck* is a tuple, otherwise a BSpline object is constructed and returned.

**See also:**

*splder*, *splev*, *spalde*, *BSpline*

**Notes**

The *splder* function is the inverse operation of this function. Namely, `splder(splantider(tck))` is identical to *tck*, modulo rounding error.

New in version 0.13.0.

**Examples**

```
>>> from scipy.interpolate import splrep, splder, splantider, splev
>>> x = np.linspace(0, np.pi/2, 70)
>>> y = 1 / np.sqrt(1 - 0.8*np.sin(x)**2)
>>> spl = splrep(x, y)
```

The derivative is the inverse operation of the antiderivative, although some floating point error accumulates:

```
>>> splev(1.7, spl), splev(1.7, splder(splantider(spl)))
(array(2.1565429877197317), array(2.1565429877201865))
```

Antiderivative can be used to evaluate definite integrals:

```
>>> ispl = splantider(spl)
>>> splev(np.pi/2, ispl) - splev(0, ispl)
2.2572053588768486
```

This is indeed an approximation to the complete elliptic integral  $K(m) = \int_0^{\pi/2} [1 - m \sin^2 x]^{-1/2} dx$ :

```
>>> from scipy.special import ellipk
>>> ellipk(0.8)
2.2572053268208538
```

`scipy.interpolate.insert(x, tck, m=1, per=0)`

Insert knots into a B-spline.

Given the knots and coefficients of a B-spline representation, create a new B-spline with a knot inserted  $m$  times at point  $x$ . This is a wrapper around the FORTRAN routine `insert` of FITPACK.

**Parameters**

- x (u)** : array\_like  
A 1-D point at which to insert a new knot(s). If `tck` was returned from `splprep`, then the parameter values, `u` should be given.
- tck** : a *BSpline* instance or a tuple  
If tuple, then it is expected to be a tuple (t,c,k) containing the vector of knots, the B-spline coefficients, and the degree of the spline.
- m** : int, optional  
The number of times to insert the given knot (its multiplicity). Default is 1.
- per** : int, optional  
If non-zero, the input spline is considered periodic.

**Returns**

BSpline instance or a tuple  
A new B-spline with knots `t`, coefficients `c`, and degree `k`.  $t_{(k+1)} \leq x \leq t_{(n-k)}$ , where `k` is the degree of the spline. In case of a periodic spline (`per != 0`) there must be either at least `k` interior knots `t(j)` satisfying  $t_{(k+1)} < t_{(j)} \leq x$  or at least `k` interior knots `t(j)` satisfying  $x \leq t_{(j)} < t_{(n-k)}$ . A tuple is returned iff the input argument `tck` is a tuple, otherwise a BSpline object is constructed and returned.

**Notes**

Based on algorithms from [R100] and [R101].

Manipulating the `tck`-tuples directly is not recommended. In new code, prefer using the *BSpline* objects.

**References**

[R100], [R101]

Object-oriented FITPACK interface:

<code>UnivariateSpline(x, y[, w, bbox, k, s, ext, ...])</code>	One-dimensional smoothing spline fit to a given set of data points.
<code>InterpolatedUnivariateSpline(x, y[, w, ...])</code>	One-dimensional interpolating spline for a given set of data points.
<code>LSQUnivariateSpline(x, y, t[, w, bbox, k, ...])</code>	One-dimensional spline with explicit internal knots.

### 5.7.4 2-D Splines

For data on a grid:

<code>RectBivariateSpline(x, y, z[, bbox, kx, ky, s])</code>	Bivariate spline approximation over a rectangular mesh.
<code>RectSphereBivariateSpline(u, v, r[, s, ...])</code>	Bivariate spline approximation over a rectangular mesh on a sphere.

**class** `scipy.interpolate.RectSphereBivariateSpline` (*u, v, r, s=0.0, pole\_continuity=False, pole\_values=None, pole\_exact=False, pole\_flat=False*)

Bivariate spline approximation over a rectangular mesh on a sphere.

Can be used for smoothing data.

New in version 0.11.0.

**Parameters**

- u** : array\_like  
1-D array of latitude coordinates in strictly ascending order. Coordinates must be given in radians and lie within the interval (0, pi).
- v** : array\_like  
1-D array of longitude coordinates in strictly ascending order. Coordinates must be given in radians. First element (`v[0]`) must lie within the interval `[-pi, pi)`. Last element (`v[-1]`) must satisfy `v[-1] <= v[0] + 2*pi`.
- r** : array\_like  
2-D array of data with shape (`u.size, v.size`).
- s** : float, optional  
Positive smoothing factor defined for estimation condition (`s=0` is for interpolation).
- pole\_continuity** : bool or (bool, bool), optional  
Order of continuity at the poles `u=0` (`pole_continuity[0]`) and `u=pi` (`pole_continuity[1]`). The order of continuity at the pole will be 1 or 0 when this is True or False, respectively. Defaults to False.
- pole\_values** : float or (float, float), optional  
Data values at the poles `u=0` and `u=pi`. Either the whole parameter or each individual element can be None. Defaults to None.
- pole\_exact** : bool or (bool, bool), optional  
Data value exactness at the poles `u=0` and `u=pi`. If True, the value is considered to be the right function value, and it will be fitted exactly. If False, the value will be considered to be a data value just like the other data values. Defaults to False.
- pole\_flat** : bool or (bool, bool), optional  
For the poles at `u=0` and `u=pi`, specify whether or not the approximation has vanishing derivatives. Defaults to False.

See also:

### **RectBivariateSpline**

bivariate spline approximation over a rectangular mesh

### **Notes**

Currently, only the smoothing spline approximation (`iopt[0] = 0` and `iopt[0] = 1` in the FITPACK routine) is supported. The exact least-squares spline approximation is not implemented yet.

When actually performing the interpolation, the requested `v` values must lie within the same length `2pi` interval that the original `v` values were chosen from.

For more information, see the [FITPACK](#) site about this function.

### **Examples**

Suppose we have global data on a coarse grid

```
>>> lats = np.linspace(10, 170, 9) * np.pi / 180.
>>> lons = np.linspace(0, 350, 18) * np.pi / 180.
>>> data = np.dot(np.atleast_2d(90. - np.linspace(-80., 80., 18)).T,
...               np.atleast_2d(180. - np.abs(np.linspace(0., 350., 9)))).T
```

We want to interpolate it to a global one-degree grid

```
>>> new_lats = np.linspace(1, 180, 180) * np.pi / 180
>>> new_lons = np.linspace(1, 360, 360) * np.pi / 180
>>> new_lats, new_lons = np.meshgrid(new_lats, new_lons)
```

We need to set up the interpolator object

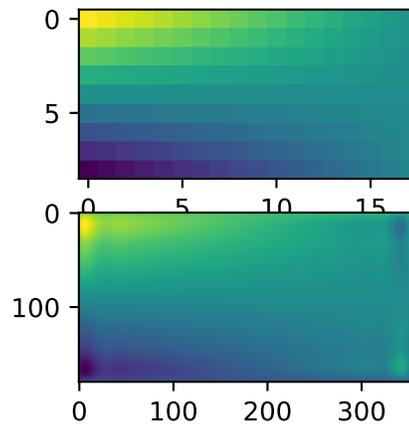
```
>>> from scipy.interpolate import RectSphereBivariateSpline
>>> lut = RectSphereBivariateSpline(lats, lons, data)
```

Finally we interpolate the data. The *RectSphereBivariateSpline* object only takes 1-D arrays as input, therefore we need to do some reshaping.

```
>>> data_interp = lut.ev(new_lats.ravel(),
...                      new_lons.ravel()).reshape((360, 180)).T
```

Looking at the original and the interpolated data, one can see that the interpolant reproduces the original data very well:

```
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> ax1 = fig.add_subplot(211)
>>> ax1.imshow(data, interpolation='nearest')
>>> ax2 = fig.add_subplot(212)
>>> ax2.imshow(data_interp, interpolation='nearest')
>>> plt.show()
```



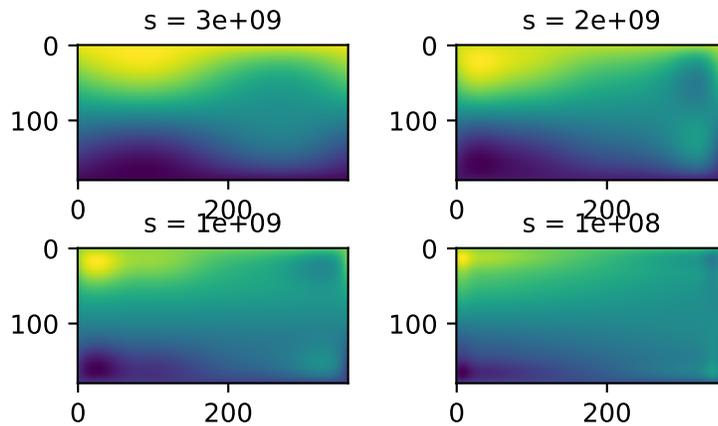
Choosing the optimal value of  $s$  can be a delicate task. Recommended values for  $s$  depend on the accuracy of the data values. If the user has an idea of the statistical errors on the data, she can also find a proper estimate for  $s$ . By assuming that, if she specifies the right  $s$ , the interpolator will use a spline  $f(u, v)$  which exactly reproduces the function underlying the data, she can evaluate  $\sum ((r(i, j) - s(u(i), v(j)))^2)$  to find a good estimate for this  $s$ . For example, if she knows that the statistical errors on her  $r(i, j)$ -values are not greater than 0.1, she may expect that a good  $s$  should have a value not larger than  $u.size * v.size * (0.1)^2$ .

If nothing is known about the statistical error in  $r(i, j)$ ,  $s$  must be determined by trial and error. The best is then to start with a very large value of  $s$  (to determine the least-squares polynomial and the corresponding

upper bound  $fp_0$  for  $s$ ) and then to progressively decrease the value of  $s$  (say by a factor 10 in the beginning, i.e.  $s = fp_0 / 10, fp_0 / 100, \dots$  and more carefully as the approximation shows more detail) to obtain closer fits.

The interpolation results for different values of  $s$  give some insight into this process:

```
>>> fig2 = plt.figure()
>>> s = [3e9, 2e9, 1e9, 1e8]
>>> for ii in range(len(s)):
...     lut = RectSphereBivariateSpline(lats, lons, data, s=s[ii])
...     data_interp = lut.ev(new_lats.ravel(),
...                           new_lons.ravel()).reshape((360, 180)).T
...     ax = fig2.add_subplot(2, 2, ii+1)
...     ax.imshow(data_interp, interpolation='nearest')
...     ax.set_title("s = %g" % s[ii])
>>> plt.show()
```



### Methods

<code>__call__(theta, phi[, dtheta, dphi, grid])</code>	Evaluate the spline or its derivatives at given positions.
<code>ev(theta, phi[, dtheta, dphi])</code>	Evaluate the spline at points
<code>get_coeffs()</code>	Return spline coefficients.
<code>get_knots()</code>	Return a tuple (tx,ty) where tx,ty contain knots positions of the spline with respect to x-, y-variable, respectively.
<code>get_residual()</code>	Return weighted sum of squared residuals of the spline

`RectSphereBivariateSpline.__call__(theta, phi, dtheta=0, dphi=0, grid=True)`  
Evaluate the spline or its derivatives at given positions.

**Parameters** **theta, phi** : array\_like  
Input coordinates.  
If *grid* is False, evaluate the spline at points  $(\text{theta}[i], \text{phi}[i])$ ,  $i=0, \dots, \text{len}(x)-1$ . Standard Numpy broadcasting is obeyed.  
If *grid* is True: evaluate spline at the grid points defined by the coordinate arrays *theta*, *phi*. The arrays must be sorted to increasing order.  
**dtheta** : int, optional

Order of theta-derivative  
New in version 0.14.0.

**dphi** : int  
Order of phi-derivative  
New in version 0.14.0.

**grid** : bool  
Whether to evaluate the results on a grid spanned by the input arrays, or at points specified by the input arrays.  
New in version 0.14.0.

`RectSphereBivariateSpline.ev(theta, phi, dtheta=0, dphi=0)`

Evaluate the spline at points

Returns the interpolated value at  $(\text{theta}[i], \text{phi}[i])$ ,  $i=0, \dots, \text{len}(\text{theta})-1$ .

**Parameters** **theta, phi** : array\_like  
Input coordinates. Standard Numpy broadcasting is obeyed.  
**dtheta** : int, optional  
Order of theta-derivative  
New in version 0.14.0.  
**dphi** : int, optional  
Order of phi-derivative  
New in version 0.14.0.

`RectSphereBivariateSpline.get_coeffs()`

Return spline coefficients.

`RectSphereBivariateSpline.get_knots()`

Return a tuple (tx,ty) where tx,ty contain knots positions of the spline with respect to x-, y-variable, respectively. The position of interior and additional knots are given as  $t[k+1:-k-1]$  and  $t[:k+1]=b$ ,  $t[-k-1:] = e$ , respectively.

`RectSphereBivariateSpline.get_residual()`

Return weighted sum of squared residuals of the spline approximation:  $\text{sum}((w[i]*(z[i]-s(x[i],y[i])))**2,axis=0)$

For unstructured data:

<i>BivariateSpline</i>	Base class for bivariate splines.
<i>SmoothBivariateSpline</i> (x, y, z[, w, bbox, ...])	Smooth bivariate spline approximation.
<i>SmoothSphereBivariateSpline</i> (theta, phi, r[, ...])	Smooth bivariate spline approximation in spherical coordinates.
<i>LSQBivariateSpline</i> (x, y, z, tx, ty[, w, ...])	Weighted least-squares bivariate spline approximation.
<i>LSQSphereBivariateSpline</i> (theta, phi, r, tt, tp)	Weighted least-squares bivariate spline approximation in spherical coordinates.

**class** `scipy.interpolate.BivariateSpline`

Base class for bivariate splines.

This describes a spline  $s(x, y)$  of degrees  $k_x$  and  $k_y$  on the rectangle  $[x_b, x_e] * [y_b, y_e]$  calculated from a given set of data points  $(x, y, z)$ .

This class is meant to be subclassed, not instantiated directly. To construct these splines, call either *SmoothBivariateSpline* or *LSQBivariateSpline*.

**See also:**

*UnivariateSpline*

a similar class for univariate spline interpolation

**SmoothBivariateSpline**

to create a BivariateSpline through the given points

**LSQBivariateSpline**

to create a BivariateSpline using weighted least-squares fitting

**SphereBivariateSpline**

bivariate spline interpolation in spherical coordinates

**bisplrep** older wrapping of FITPACK

**bisplev** older wrapping of FITPACK

*Methods*

<code>__call__(x, y[, dx, dy, grid])</code>	Evaluate the spline or its derivatives at given positions.
<code>ev(xi, yi[, dx, dy])</code>	Evaluate the spline at points
<code>get_coeffs()</code>	Return spline coefficients.
<code>get_knots()</code>	Return a tuple (tx,ty) where tx,ty contain knots positions of the spline with respect to x-, y-variable, respectively.
<code>get_residual()</code>	Return weighted sum of squared residuals of the spline
<code>integral(xa, xb, ya, yb)</code>	Evaluate the integral of the spline over area [xa,xb] x [ya,yb].

`BivariateSpline.__call__(x, y, dx=0, dy=0, grid=True)`

Evaluate the spline or its derivatives at given positions.

**Parameters** **x, y** : array\_like

Input coordinates.

If *grid* is False, evaluate the spline at points  $(x[i], y[i])$ ,  $i=0, \dots, \text{len}(x)-1$ . Standard Numpy broadcasting is obeyed.

If *grid* is True: evaluate spline at the grid points defined by the coordinate arrays *x*, *y*. The arrays must be sorted to increasing order.

**dx** : int

Order of x-derivative

New in version 0.14.0.

**dy** : int

Order of y-derivative

New in version 0.14.0.

**grid** : bool

Whether to evaluate the results on a grid spanned by the input arrays, or at points specified by the input arrays.

New in version 0.14.0.

`BivariateSpline.ev(xi, yi, dx=0, dy=0)`

Evaluate the spline at points

Returns the interpolated value at  $(xi[i], yi[i])$ ,  $i=0, \dots, \text{len}(xi)-1$ .

**Parameters** **xi, yi** : array\_like

Input coordinates. Standard Numpy broadcasting is obeyed.

**dx** : int, optional

Order of x-derivative

New in version 0.14.0.

**dy** : int, optional

Order of y-derivative  
 New in version 0.14.0.

`BivariateSpline.get_coeffs()`

Return spline coefficients.

`BivariateSpline.get_knots()`

Return a tuple (tx,ty) where tx,ty contain knots positions of the spline with respect to x-, y-variable, respectively. The position of interior and additional knots are given as `t[k+1:-k-1]` and `t[:k+1]=b`, `t[-k-1]=e`, respectively.

`BivariateSpline.get_residual()`

Return weighted sum of squared residuals of the spline approximation: `sum((w[i]*(z[i]-s(x[i],y[i])))**2,axis=0)`

`BivariateSpline.integral(xa,xb,ya,yb)`

Evaluate the integral of the spline over area [xa,xb] x [ya,yb].

**Parameters** `xa, xb` : float  
 The end-points of the x integration interval.  
`ya, yb` : float  
 The end-points of the y integration interval.  
**Returns** `integ` : float  
 The value of the resulting integral.

`class scipy.interpolate.SmoothBivariateSpline(x, y, z, w=None, bbox=[None, None, None, None], kx=3, ky=3, s=None, eps=None)`

Smooth bivariate spline approximation.

**Parameters** `x, y, z` : array\_like  
 1-D sequences of data points (order is not important).  
`w` : array\_like, optional  
 Positive 1-D sequence of weights, of same length as x, y and z.  
`bbox` : array\_like, optional  
 Sequence of length 4 specifying the boundary of the rectangular approximation domain.  
 By default, `bbox=[min(x,tx), max(x,tx), min(y,ty), max(y,ty)]`.  
`kx, ky` : ints, optional  
 Degrees of the bivariate spline. Default is 3.  
`s` : float, optional  
 Positive smoothing factor defined for estimation condition:  
`sum((w[i]*(z[i]-s(x[i],y[i])))**2,axis=0) <= s` Default  
`s=len(w)` which should be a good value if `1/w[i]` is an estimate of the standard deviation of `z[i]`.  
`eps` : float, optional  
 A threshold for determining the effective rank of an over-determined linear system of equations. `eps` should have a value between 0 and 1, the default is 1e-16.

See also:

`bisplrep` an older wrapping of FITPACK

`bisplev` an older wrapping of FITPACK

**UnivariateSpline**

a similar class for univariate spline interpolation

**LSQUnivariateSpline**

to create a BivariateSpline using weighted

**Notes**

The length of  $x$ ,  $y$  and  $z$  should be at least  $(k_x+1) * (k_y+1)$ .

**Methods**

<code>__call__(x, y[, dx, dy, grid])</code>	Evaluate the spline or its derivatives at given positions.
<code>ev(xi, yi[, dx, dy])</code>	Evaluate the spline at points
<code>get_coeffs()</code>	Return spline coefficients.
<code>get_knots()</code>	Return a tuple (tx,ty) where tx,ty contain knots positions of the spline with respect to x-, y-variable, respectively.
<code>get_residual()</code>	Return weighted sum of squared residuals of the spline
<code>integral(xa, xb, ya, yb)</code>	Evaluate the integral of the spline over area [xa,xb] x [ya,yb].

`SmoothBivariateSpline.__call__(x, y, dx=0, dy=0, grid=True)`

Evaluate the spline or its derivatives at given positions.

**Parameters** **x, y** : array\_like

Input coordinates.

If *grid* is False, evaluate the spline at points  $(x[i], y[i])$ ,  $i=0, \dots, \text{len}(x)-1$ . Standard Numpy broadcasting is obeyed.

If *grid* is True: evaluate spline at the grid points defined by the coordinate arrays *x*, *y*. The arrays must be sorted to increasing order.

**dx** : int

Order of x-derivative

New in version 0.14.0.

**dy** : int

Order of y-derivative

New in version 0.14.0.

**grid** : bool

Whether to evaluate the results on a grid spanned by the input arrays, or at points specified by the input arrays.

New in version 0.14.0.

`SmoothBivariateSpline.ev(xi, yi, dx=0, dy=0)`

Evaluate the spline at points

Returns the interpolated value at  $(xi[i], yi[i])$ ,  $i=0, \dots, \text{len}(xi)-1$ .

**Parameters** **xi, yi** : array\_like

Input coordinates. Standard Numpy broadcasting is obeyed.

**dx** : int, optional

Order of x-derivative

New in version 0.14.0.

**dy** : int, optional

Order of y-derivative

New in version 0.14.0.

`SmoothBivariateSpline.get_coeffs()`

Return spline coefficients.

`SmoothBivariateSpline.get_knots()`

Return a tuple (tx,ty) where tx,ty contain knots positions of the spline with respect to x-, y-variable, respectively. The position of interior and additional knots are given as  $t[k+1:-k-1]$  and  $t[:k+1]=b$ ,  $t[-k-1]=e$ , respectively.

`SmoothBivariateSpline.get_residual()`

Return weighted sum of squared residuals of the spline approximation:  $\sum ((w[i]*(z[i]-s(x[i],y[i])))^2, \text{axis}=0)$

`SmoothBivariateSpline.integral(xa, xb, ya, yb)`

Evaluate the integral of the spline over area  $[xa,xb] \times [ya,yb]$ .

**Parameters** `xa, xb` : float  
The end-points of the x integration interval.  
`ya, yb` : float  
The end-points of the y integration interval.  
**Returns** `integ` : float  
The value of the resulting integral.

`class scipy.interpolate.SmoothSphereBivariateSpline(theta, phi, r, w=None, s=0.0, eps=1e-16)`

Smooth bivariate spline approximation in spherical coordinates.

New in version 0.11.0.

**Parameters** `theta, phi, r` : array\_like  
1-D sequences of data points (order is not important). Coordinates must be given in radians. Theta must lie within the interval (0, pi), and phi must lie within the interval (0, 2pi).  
`w` : array\_like, optional  
Positive 1-D sequence of weights.  
`s` : float, optional  
Positive smoothing factor defined for estimation condition:  $\sum ((w(i)*(r(i) - s(\theta(i), \phi(i))))^2, \text{axis}=0) \leq s$  Default  $s=\text{len}(w)$  which should be a good value if  $1/w[i]$  is an estimate of the standard deviation of  $r[i]$ .  
`eps` : float, optional  
A threshold for determining the effective rank of an over-determined linear system of equations. *eps* should have a value between 0 and 1, the default is 1e-16.

### Notes

For more information, see the [FITPACK](#) site about this function.

### Examples

Suppose we have global data on a coarse grid (the input data does not have to be on a grid):

```
>>> theta = np.linspace(0., np.pi, 7)
>>> phi = np.linspace(0., 2*np.pi, 9)
>>> data = np.empty((theta.shape[0], phi.shape[0]))
>>> data[:,0], data[0,:], data[-1,:] = 0., 0., 0.
>>> data[1:-1,1], data[1:-1,-1] = 1., 1.
>>> data[1,1:-1], data[-2,1:-1] = 1., 1.
>>> data[2:-2,2], data[2:-2,-2] = 2., 2.
>>> data[2,2:-2], data[-3,2:-2] = 2., 2.
>>> data[3,3:-2] = 3.
>>> data = np.roll(data, 4, 1)
```

We need to set up the interpolator object

```
>>> lats, lons = np.meshgrid(theta, phi)
>>> from scipy.interpolate import SmoothSphereBivariateSpline
>>> lut = SmoothSphereBivariateSpline(lats.ravel(), lons.ravel(),
...                                  data.T.ravel(), s=3.5)
```

As a first test, we'll see what the algorithm returns when run on the input coordinates

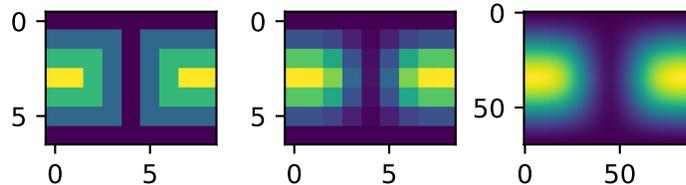
```
>>> data_orig = lut(theta, phi)
```

Finally we interpolate the data to a finer grid

```
>>> fine_lats = np.linspace(0., np.pi, 70)
>>> fine_lons = np.linspace(0., 2 * np.pi, 90)
```

```
>>> data_smth = lut(fine_lats, fine_lons)
```

```
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> ax1 = fig.add_subplot(131)
>>> ax1.imshow(data, interpolation='nearest')
>>> ax2 = fig.add_subplot(132)
>>> ax2.imshow(data_orig, interpolation='nearest')
>>> ax3 = fig.add_subplot(133)
>>> ax3.imshow(data_smth, interpolation='nearest')
>>> plt.show()
```



### Methods

<code>__call__(theta, phi[, dtheta, dphi, grid])</code>	Evaluate the spline or its derivatives at given positions.
<code>ev(theta, phi[, dtheta, dphi])</code>	Evaluate the spline at points
<code>get_coeffs()</code>	Return spline coefficients.
<code>get_knots()</code>	Return a tuple (tx,ty) where tx,ty contain knots positions of the spline with respect to x-, y-variable, respectively.
<code>get_residual()</code>	Return weighted sum of squared residuals of the spline

`SmoothSphereBivariateSpline.__call__(theta, phi, dtheta=0, dphi=0, grid=True)`  
 Evaluate the spline or its derivatives at given positions.

**Parameters** **theta, phi** : array\_like  
 Input coordinates.

If *grid* is False, evaluate the spline at points  $(\text{theta}[i], \text{phi}[i])$ ,  $i=0, \dots, \text{len}(x)-1$ . Standard Numpy broadcasting is obeyed.

If *grid* is True: evaluate spline at the grid points defined by the coordinate arrays *theta*, *phi*. The arrays must be sorted to increasing order.

**dtheta** : int, optional

Order of theta-derivative

New in version 0.14.0.

**dphi** : int

Order of phi-derivative

New in version 0.14.0.

**grid** : bool

Whether to evaluate the results on a grid spanned by the input arrays, or at points specified by the input arrays.

New in version 0.14.0.

`SmoothSphereBivariateSpline.ev(theta, phi, dtheta=0, dphi=0)`

Evaluate the spline at points

Returns the interpolated value at  $(\text{theta}[i], \text{phi}[i])$ ,  $i=0, \dots, \text{len}(\text{theta})-1$ .

**Parameters** **theta, phi** : array\_like

Input coordinates. Standard Numpy broadcasting is obeyed.

**dtheta** : int, optional

Order of theta-derivative

New in version 0.14.0.

**dphi** : int, optional

Order of phi-derivative

New in version 0.14.0.

`SmoothSphereBivariateSpline.get_coeffs()`

Return spline coefficients.

`SmoothSphereBivariateSpline.get_knots()`

Return a tuple (tx,ty) where tx,ty contain knots positions of the spline with respect to x-, y-variable, respectively. The position of interior and additional knots are given as  $t[k+1:-k-1]$  and  $t[:k+1]=b$ ,  $t[-k-1:]=e$ , respectively.

`SmoothSphereBivariateSpline.get_residual()`

Return weighted sum of squared residuals of the spline approximation:  $\text{sum}((w[i]*(z[i]-s(x[i],y[i])))**2,axis=0)$

**class** `scipy.interpolate.LSQBivariateSpline` (*x, y, z, tx, ty, w=None, bbox=[None, None, None, None], kx=3, ky=3, eps=None*)

Weighted least-squares bivariate spline approximation.

**Parameters** **x, y, z** : array\_like

1-D sequences of data points (order is not important).

**tx, ty** : array\_like

Strictly ordered 1-D sequences of knots coordinates.

**w** : array\_like, optional

Positive 1-D array of weights, of the same length as *x*, *y* and *z*.

**bbox** : (4,) array\_like, optional

Sequence of length 4 specifying the boundary of the rectangular approximation domain.

By default, `bbox=[min(x,tx), max(x,tx), min(y,ty), max(y,ty)]`.

**kx, ky** : ints, optional

Degrees of the bivariate spline. Default is 3.

**eps** : float, optional

A threshold for determining the effective rank of an over-determined linear system of equations. *eps* should have a value between 0 and 1, the default is 1e-16.

**See also:**

**bisplrep** an older wrapping of FITPACK

**bisplev** an older wrapping of FITPACK

**UnivariateSpline**

a similar class for univariate spline interpolation

**SmoothBivariateSpline**

create a smoothing BivariateSpline

**Notes**

The length of *x*, *y* and *z* should be at least  $(k_x+1) * (k_y+1)$ .

**Methods**

<code>__call__(x, y[, dx, dy, grid])</code>	Evaluate the spline or its derivatives at given positions.
<code>ev(xi, yi[, dx, dy])</code>	Evaluate the spline at points
<code>get_coeffs()</code>	Return spline coefficients.
<code>get_knots()</code>	Return a tuple (tx,ty) where tx,ty contain knots positions of the spline with respect to x-, y-variable, respectively.
<code>get_residual()</code>	Return weighted sum of squared residuals of the spline
<code>integral(xa, xb, ya, yb)</code>	Evaluate the integral of the spline over area [xa,xb] x [ya,yb].

`LSQBivariateSpline.__call__(x, y, dx=0, dy=0, grid=True)`

Evaluate the spline or its derivatives at given positions.

**Parameters** **x, y** : array\_like

Input coordinates.

If *grid* is False, evaluate the spline at points  $(x[i], y[i])$ ,  $i=0, \dots, \text{len}(x)-1$ . Standard Numpy broadcasting is obeyed.

If *grid* is True: evaluate spline at the grid points defined by the coordinate arrays *x*, *y*. The arrays must be sorted to increasing order.

**dx** : int

Order of x-derivative

New in version 0.14.0.

**dy** : int

Order of y-derivative

New in version 0.14.0.

**grid** : bool

Whether to evaluate the results on a grid spanned by the input arrays, or at points specified by the input arrays.

New in version 0.14.0.

`LSQBivariateSpline.ev(xi, yi, dx=0, dy=0)`

Evaluate the spline at points

Returns the interpolated value at  $(xi[i], yi[i])$ ,  $i=0, \dots, \text{len}(xi)-1$ .

**Parameters** **xi, yi** : array\_like

Input coordinates. Standard Numpy broadcasting is obeyed.

**dx** : int, optional  
 Order of x-derivative  
 New in version 0.14.0.  
**dy** : int, optional  
 Order of y-derivative  
 New in version 0.14.0.

`LSQBivariateSpline.get_coeffs()`  
 Return spline coefficients.

`LSQBivariateSpline.get_knots()`  
 Return a tuple (tx,ty) where tx,ty contain knots positions of the spline with respect to x-, y-variable, respectively. The position of interior and additional knots are given as `t[k+1:-k-1]` and `t[:k+1]=b`, `t[-k-1]=e`, respectively.

`LSQBivariateSpline.get_residual()`  
 Return weighted sum of squared residuals of the spline approximation:  $\sum ((w[i]*(z[i]-s(x[i],y[i])))^2, axis=0)$

`LSQBivariateSpline.integral(xa, xb, ya, yb)`  
 Evaluate the integral of the spline over area [xa,xb] x [ya,yb].

**Parameters** **xa, xb** : float  
 The end-points of the x integration interval.  
**ya, yb** : float  
 The end-points of the y integration interval.  
**Returns** **integ** : float  
 The value of the resulting integral.

**class** `scipy.interpolate.LSQSphereBivariateSpline(theta, phi, r, tt, tp, w=None, eps=1e-16)`  
 Weighted least-squares bivariate spline approximation in spherical coordinates.

New in version 0.11.0.

**Parameters** **theta, phi, r** : array\_like  
 1-D sequences of data points (order is not important). Coordinates must be given in radians. Theta must lie within the interval (0, pi), and phi must lie within the interval (0, 2pi).  
**tt, tp** : array\_like  
 Strictly ordered 1-D sequences of knots coordinates. Coordinates must satisfy  $0 < tt[i] < pi, 0 < tp[i] < 2*pi$ .  
**w** : array\_like, optional  
 Positive 1-D sequence of weights, of the same length as *theta*, *phi* and *r*.  
**eps** : float, optional  
 A threshold for determining the effective rank of an over-determined linear system of equations. *eps* should have a value between 0 and 1, the default is 1e-16.

**Notes**

For more information, see the [FITPACK](#) site about this function.

**Examples**

Suppose we have global data on a coarse grid (the input data does not have to be on a grid):

```
>>> theta = np.linspace(0., np.pi, 7)
>>> phi = np.linspace(0., 2*np.pi, 9)
>>> data = np.empty((theta.shape[0], phi.shape[0]))
>>> data[:,0], data[0,:], data[-1,:] = 0., 0., 0.
>>> data[1:-1,1], data[1:-1,-1] = 1., 1.
```

```
>>> data[1,1:-1], data[-2,1:-1] = 1., 1.
>>> data[2:-2,2], data[2:-2,-2] = 2., 2.
>>> data[2,2:-2], data[-3,2:-2] = 2., 2.
>>> data[3,3:-2] = 3.
>>> data = np.roll(data, 4, 1)
```

We need to set up the interpolator object. Here, we must also specify the coordinates of the knots to use.

```
>>> lats, lons = np.meshgrid(theta, phi)
>>> knotst, knotsp = theta.copy(), phi.copy()
>>> knotst[0] += .0001
>>> knotst[-1] -= .0001
>>> knotsp[0] += .0001
>>> knotsp[-1] -= .0001
>>> from scipy.interpolate import LSQSphereBivariateSpline
>>> lut = LSQSphereBivariateSpline(lats.ravel(), lons.ravel(),
...                               data.T.ravel(), knotst, knotsp)
```

As a first test, we'll see what the algorithm returns when run on the input coordinates

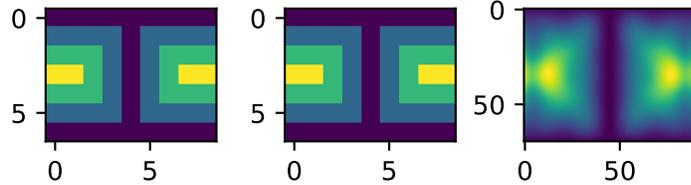
```
>>> data_orig = lut(theta, phi)
```

Finally we interpolate the data to a finer grid

```
>>> fine_lats = np.linspace(0., np.pi, 70)
>>> fine_lons = np.linspace(0., 2*np.pi, 90)
```

```
>>> data_lsq = lut(fine_lats, fine_lons)
```

```
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> ax1 = fig.add_subplot(131)
>>> ax1.imshow(data, interpolation='nearest')
>>> ax2 = fig.add_subplot(132)
>>> ax2.imshow(data_orig, interpolation='nearest')
>>> ax3 = fig.add_subplot(133)
>>> ax3.imshow(data_lsq, interpolation='nearest')
>>> plt.show()
```



**Methods**

<code>__call__(theta, phi[, dtheta, dphi, grid])</code>	Evaluate the spline or its derivatives at given positions.
<code>ev(theta, phi[, dtheta, dphi])</code>	Evaluate the spline at points
<code>get_coeffs()</code>	Return spline coefficients.
<code>get_knots()</code>	Return a tuple (tx,ty) where tx,ty contain knots positions of the spline with respect to x-, y-variable, respectively.
<code>get_residual()</code>	Return weighted sum of squared residuals of the spline

`LSQSphereBivariateSpline.__call__(theta, phi, dtheta=0, dphi=0, grid=True)`  
 Evaluate the spline or its derivatives at given positions.

**Parameters** **theta, phi** : array\_like  
 Input coordinates.  
 If *grid* is False, evaluate the spline at points  $(\text{theta}[i], \text{phi}[i])$ ,  $i=0, \dots, \text{len}(x)-1$ . Standard Numpy broadcasting is obeyed.  
 If *grid* is True: evaluate spline at the grid points defined by the coordinate arrays *theta*, *phi*. The arrays must be sorted to increasing order.

**dtheta** : int, optional  
 Order of theta-derivative  
 New in version 0.14.0.

**dphi** : int  
 Order of phi-derivative  
 New in version 0.14.0.

**grid** : bool  
 Whether to evaluate the results on a grid spanned by the input arrays, or at points specified by the input arrays.  
 New in version 0.14.0.

`LSQSphereBivariateSpline.ev(theta, phi, dtheta=0, dphi=0)`  
 Evaluate the spline at points  
 Returns the interpolated value at  $(\text{theta}[i], \text{phi}[i])$ ,  $i=0, \dots, \text{len}(\text{theta})-1$ .

**Parameters** **theta, phi** : array\_like  
 Input coordinates. Standard Numpy broadcasting is obeyed.

**dtheta** : int, optional  
Order of theta-derivative  
New in version 0.14.0.

**dphi** : int, optional  
Order of phi-derivative  
New in version 0.14.0.

`LSQSphereBivariateSpline.get_coeffs()`  
Return spline coefficients.

`LSQSphereBivariateSpline.get_knots()`  
Return a tuple (tx,ty) where tx,ty contain knots positions of the spline with respect to x-, y-variable, respectively. The position of interior and additional knots are given as `t[k+1:-k-1]` and `t[:k+1]=b`, `t[-k-1]=e`, respectively.

`LSQSphereBivariateSpline.get_residual()`  
Return weighted sum of squared residuals of the spline approximation:  $\sum ((w[i]*(z[i]-s(x[i],y[i])))^2, \text{axis}=0)$

Low-level interface to FITPACK functions:

<code>bisplrep(x, y, z[, w, xb, xe, yb, ye, kx, ...])</code>	Find a bivariate B-spline representation of a surface.
<code>bisplev(x, y, tck[, dx, dy])</code>	Evaluate a bivariate B-spline and its derivatives.

`scipy.interpolate.bisplrep(x, y, z, w=None, xb=None, xe=None, yb=None, ye=None, kx=3, ky=3, task=0, s=None, eps=1e-16, tx=None, ty=None, full_output=0, nvest=None, nyest=None, quiet=1)`

Find a bivariate B-spline representation of a surface.

Given a set of data points  $(x[i], y[i], z[i])$  representing a surface  $z=f(x,y)$ , compute a B-spline representation of the surface. Based on the routine SURFIT from FITPACK.

**Parameters**

- x, y, z** : ndarray  
Rank-1 arrays of data points.
- w** : ndarray, optional  
Rank-1 array of weights. By default `w=np.ones(len(x))`.
- xb, xe** : float, optional  
End points of approximation interval in x. By default `xb = x.min()`, `xe=x.max()`.
- yb, ye** : float, optional  
End points of approximation interval in y. By default `yb=y.min()`, `ye = y.max()`.
- kx, ky** : int, optional  
The degrees of the spline ( $1 \leq kx, ky \leq 5$ ). Third order ( $kx=ky=3$ ) is recommended.
- task** : int, optional  
If `task=0`, find knots in x and y and coefficients for a given smoothing factor, s. If `task=1`, find knots and coefficients for another value of the smoothing factor, s. `bisplrep` must have been previously called with `task=0` or `task=1`. If `task=-1`, find coefficients for a given set of knots tx, ty.
- s** : float, optional  
A non-negative smoothing factor. If weights correspond to the inverse of the standard-deviation of the errors in z, then a good s-value should be found in the range  $(m-\sqrt{2*m}, m+\sqrt{2*m})$  where  $m=\text{len}(x)$ .
- eps** : float, optional  
A threshold for determining the effective rank of an over-determined linear system of equations ( $0 < \text{eps} < 1$ ). `eps` is not likely to need changing.

**tx, ty** : ndarray, optional  
 Rank-1 arrays of the knots of the spline for task=-1

**full\_output** : int, optional  
 Non-zero to return optional outputs.

**nxest, nyest** : int, optional  
 Over-estimates of the total number of knots. If None then  $nxest = \max(kx + \sqrt{m/2}, 2 * kx + 3)$ ,  $nyest = \max(ky + \sqrt{m/2}, 2 * ky + 3)$ .

**quiet** : int, optional  
 Non-zero to suppress printing of messages. This parameter is deprecated; use standard Python warning filters instead.

**Returns**

**tck** : array\_like  
 A list [tx, ty, c, kx, ky] containing the knots (tx, ty) and coefficients (c) of the bivariate B-spline representation of the surface along with the degree of the spline.

**fp** : ndarray  
 The weighted sum of squared residuals of the spline approximation.

**ier** : int  
 An integer flag about splrep success. Success is indicated if  $ier \leq 0$ . If  $ier$  in [1,2,3] an error occurred but was not raised. Otherwise an error is raised.

**msg** : str  
 A message corresponding to the integer flag,  $ier$ .

**See also:**

*splprep, splrep, splint, sproot, splev, UnivariateSpline, BivariateSpline*

**Notes**

See *bisplev* to evaluate the value of the B-spline given its tck representation.

**References**

[R97], [R98], [R99]

`scipy.interpolate.bisplev(x, y, tck, dx=0, dy=0)`

Evaluate a bivariate B-spline and its derivatives.

Return a rank-2 array of spline function values (or spline derivative values) at points given by the cross-product of the rank-1 arrays  $x$  and  $y$ . In special cases, return an array or just a float if either  $x$  or  $y$  or both are floats. Based on BISPEV from FITPACK.

**Parameters**

**x, y** : ndarray  
 Rank-1 arrays specifying the domain over which to evaluate the spline or its derivative.

**tck** : tuple  
 A sequence of length 5 returned by *bisplprep* containing the knot locations, the coefficients, and the degree of the spline: [tx, ty, c, kx, ky].

**dx, dy** : int, optional  
 The orders of the partial derivatives in  $x$  and  $y$  respectively.

**Returns**

**vals** : ndarray  
 The B-spline or its derivative evaluated over the set formed by the cross-product of  $x$  and  $y$ .

**See also:**

*splprep, splrep, splint, sproot, splev, UnivariateSpline, BivariateSpline*

**Notes**

See *bisplprep* to generate the *tck* representation.

**References**

[R94], [R95], [R96]

**5.7.5 Additional tools**

<code>lagrange(x, w)</code>	Return a Lagrange interpolating polynomial.
<code>approximate_taylor_polynomial(f, x, degree, ...)</code>	Estimate the Taylor polynomial of $f$ at $x$ by polynomial fitting.
<code>pade(an, m)</code>	Return Pade approximation to a polynomial as the ratio of two polynomials.

`scipy.interpolate.lagrange(x, w)`

Return a Lagrange interpolating polynomial.

Given two 1-D arrays  $x$  and  $w$ , returns the Lagrange interpolating polynomial through the points  $(x, w)$ .

Warning: This implementation is numerically unstable. Do not expect to be able to use more than about 20 points even if they are chosen optimally.

**Parameters**  $x$ : array\_like  
 $x$  represents the x-coordinates of a set of datapoints.  
 $w$ : array\_like  
 $w$  represents the y-coordinates of a set of datapoints, i.e.  $f(x)$ .

**Returns** **lagrange**: `numpy.poly1d` instance  
The Lagrange interpolating polynomial.

**Examples**

Interpolate  $f(x) = x^3$  by 3 points.

```
>>> from scipy.interpolate import lagrange
>>> x = np.array([0, 1, 2])
>>> y = x**3
>>> poly = lagrange(x, y)
```

Since there are only 3 points, Lagrange polynomial has degree 2. Explicitly, it is given by

$$L(x) = 1 \times \frac{x(x-2)}{-1} + 8 \times \frac{x(x-1)}{2} \\ = x(-2 + 3x)$$

```
>>> from numpy.polynomial.polynomial import Polynomial
>>> Polynomial(poly).coef
array([ 3., -2.,  0.]
```

`scipy.interpolate.approximate_taylor_polynomial(f, x, degree, scale, order=None)`

Estimate the Taylor polynomial of  $f$  at  $x$  by polynomial fitting.

**Parameters**  $f$ : callable  
The function whose Taylor polynomial is sought. Should accept a vector of  $x$  values.  
 $x$ : scalar  
The point at which the polynomial is to be evaluated.  
**degree**: int  
The degree of the Taylor polynomial

**scale** : scalar

The width of the interval to use to evaluate the Taylor polynomial. Function values spread over a range this wide are used to fit the polynomial. Must be chosen carefully.

**order** : int or None, optional

The order of the polynomial to be used in the fitting;  $f$  will be evaluated  $\text{order}+1$  times. If None, use *degree*.

**Returns**

**p** : poly1d instance

The Taylor polynomial (translated to the origin, so that for example  $p(0)=f(x)$ ).

### Notes

The appropriate choice of “scale” is a trade-off; too large and the function differs from its Taylor polynomial too much to get a good answer, too small and round-off errors overwhelm the higher-order terms. The algorithm used becomes numerically unstable around order 30 even under ideal circumstances.

Choosing order somewhat larger than degree may improve the higher-order terms.

`scipy.interpolate.pade` (*an*, *m*)

Return Pade approximation to a polynomial as the ratio of two polynomials.

**Parameters**

**an** : (N,) array\_like

Taylor series coefficients.

**m** : int

The order of the returned approximating polynomials.

**Returns**

**p, q** : Polynomial class

The Pade approximation of the polynomial defined by *an* is  $p(x)/q(x)$ .

### Examples

```
>>> from scipy.interpolate import pade
>>> e_exp = [1.0, 1.0, 1.0/2.0, 1.0/6.0, 1.0/24.0, 1.0/120.0]
>>> p, q = pade(e_exp, 2)
```

```
>>> e_exp.reverse()
>>> e_poly = np.poly1d(e_exp)
```

Compare `e_poly(x)` and the Pade approximation  $p(x)/q(x)$

```
>>> e_poly(1)
2.7166666666666668
```

```
>>> p(1)/q(1)
2.7179487179487181
```

### See also:

`scipy.ndimage.map_coordinates`, `scipy.ndimage.spline_filter`, `scipy.signal.resample`, `scipy.signal.bspline`, `scipy.signal.gauss_spline`, `scipy.signal.qspline1d`, `scipy.signal.cspline1d`, `scipy.signal.qspline1d_eval`, `scipy.signal.cspline1d_eval`, `scipy.signal.qspline2d`, `scipy.signal.cspline2d`.

Functions existing for backward compatibility (should not be used in new code):

`spleval(*args, **kwargs)`

`spleval` is deprecated!

`spline(*args, **kwargs)`

`spline` is deprecated!

`splmake(*args, **kwargs)`

`splmake` is deprecated!

Continued on next page

Table 5.70 – continued from previous page

<code>spltopp(*args, **kwargs)</code>	<code>spltopp</code> is deprecated!
<code>pchip</code>	alias of <code>PchipInterpolator</code>

`scipy.interpolate.spleval(*args, **kwargs)`

`spleval` is deprecated! `spleval` is deprecated in scipy 0.19.0, use `BSpline` instead.

Evaluate a fixed spline represented by the given tuple at the new x-values

The  $x_j$  values are the interior knot points. The approximation region is  $x_j[0]$  to  $x_j[-1]$ . If  $N+1$  is the length of  $x_j$ , then  $cvals$  should have length  $N+k$  where  $k$  is the order of the spline.

**Parameters** `(xj, cvals, k)` : tuple

Parameters that define the fixed spline

<code>xj</code>	[array_like] Interior knot points
<code>cvals</code>	[array_like] Curvature
<code>k</code>	[int] Order of the spline
<code>xnew</code>	[array_like] Locations to calculate spline
<code>deriv</code>	[int] Deriv

**Returns** `spleval` : ndarray

If `cvals` represents more than one curve (`cvals.ndim > 1`) and/or `xnew` is N-d, then the result is `xnew.shape + cvals.shape[1:]` providing the interpolation of multiple curves.

#### Notes

Internally, an additional  $k-1$  knot points are added on either side of the spline.

`scipy.interpolate.spline(*args, **kwargs)`

`spline` is deprecated! `spline` is deprecated in scipy 0.19.0, use `Bspline` class instead.

Interpolate a curve at new points using a spline fit

**Parameters** `xk, yk` : array\_like

The x and y values that define the curve.

<code>xnew</code>	[array_like] The x values where spline should estimate the y values.
<code>order</code>	[int] Default is 3.
<code>kind</code>	[string] One of {'smoothest'}
<code>conds</code>	[Don't know] Don't know

**Returns** `spline` : ndarray

An array of y values; the spline evaluated at the positions `xnew`.

`scipy.interpolate.splmake(*args, **kwargs)`

`splmake` is deprecated! `splmake` is deprecated in scipy 0.19.0, use `make_interp_spline` instead.

Return a representation of a spline given data-points at internal knots

**Parameters** `xk` : array\_like

The input array of x values of rank 1

<code>yk</code>	[array_like] The input array of y values of rank N. <code>yk</code> can be an N-d array to represent more than one curve, through the same <code>xk</code> points. The first dimension is assumed to be the interpolating dimension and is the same length of <code>xk</code> .
<code>order</code>	[int, optional] Order of the spline

**kind** [str, optional] Can be 'smoothest', 'not\_a\_knot', 'fixed', 'clamped', 'natural', 'periodic', 'symmetric', 'user', 'mixed' and it is ignored if order < 2

**conds** [optional] Conds

**Returns** **splmake** : tuple  
Return a  $(xk, cvals, k)$  representation of a spline given data-points where the (internal) knots are at the data-points.

`scipy.interpolate.spltopp(*args, **kwargs)`  
*spltopp* is deprecated! *spltopp* is deprecated in scipy 0.19.0, use `PPoly.from_spline` instead.

Return a piece-wise polynomial object from a fixed-spline tuple.

`scipy.interpolate.pchip`  
alias of `PchipInterpolator`

## 5.8 Input and output (`scipy.io`)

SciPy has many modules, classes, and functions available to read data from and write data to a variety of file formats.

**See also:**

`numpy-reference.routines.io` (in Numpy)

### 5.8.1 MATLAB® files

<code>loadmat(file_name[, mdict, appendmat])</code>	Load MATLAB file.
<code>savemat(file_name, mdict[, appendmat, ...])</code>	Save a dictionary of names and arrays into a MATLAB-style .mat file.
<code>whosmat(file_name[, appendmat])</code>	List variables inside a MATLAB file.

`scipy.io.loadmat(file_name, mdict=None, appendmat=True, **kwargs)`  
Load MATLAB file.

**Parameters**

- file\_name** : str  
Name of the mat file (do not need .mat extension if `appendmat==True`). Can also pass open file-like object.
- mdict** : dict, optional  
Dictionary in which to insert matfile variables.
- appendmat** : bool, optional  
True to append the .mat extension to the end of the given filename, if not already present.
- byte\_order** : str or None, optional  
None by default, implying byte order guessed from mat file. Otherwise can be one of ('native', '=', 'little', '<', 'BIG', '>').
- mat\_dtype** : bool, optional  
If True, return arrays in same dtype as would be loaded into MATLAB (instead of the dtype with which they are saved).
- squeeze\_me** : bool, optional  
Whether to squeeze unit matrix dimensions or not.
- chars\_as\_strings** : bool, optional  
Whether to convert char arrays to string arrays.

**matlab\_compatible** : bool, optional

Returns matrices as would be loaded by MATLAB (implies `squeeze_me=False`, `chars_as_strings=False`, `mat_dtype=True`, `struct_as_record=True`).

**struct\_as\_record** : bool, optional

Whether to load MATLAB structs as numpy record arrays, or as old-style numpy arrays with `dtype=object`. Setting this flag to False replicates the behavior of scipy version 0.7.x (returning numpy object arrays). The default setting is True, because it allows easier round-trip load and save of MATLAB files.

**verify\_compressed\_data\_integrity** : bool, optional

Whether the length of compressed sequences in the MATLAB file should be checked, to ensure that they are not longer than we expect. It is advisable to enable this (the default) because overlong compressed sequences in MATLAB files generally indicate that the files have experienced some sort of corruption.

**variable\_names** : None or sequence

If None (the default) - read all variables in file. Otherwise `variable_names` should be a sequence of strings, giving names of the matlab variables to read from the file. The reader will skip any variable with a name not in this sequence, possibly saving some read processing.

**Returns**

**mat\_dict** : dict

dictionary with variable names as keys, and loaded matrices as values.

**Notes**

v4 (Level 1.0), v6 and v7 to 7.2 matfiles are supported.

You will need an HDF5 python library to read matlab 7.3 format mat files. Because scipy does not supply one, we do not implement the HDF5 / 7.3 interface here.

`scipy.io.savemat` (`file_name`, `mdict`, `appendmat=True`, `format='5'`, `long_field_names=False`, `do_compression=False`, `oned_as='row'`)

Save a dictionary of names and arrays into a MATLAB-style .mat file.

This saves the array objects in the given dictionary to a MATLAB- style .mat file.

**Parameters**

**file\_name** : str or file-like object

Name of the .mat file (.mat extension not needed if `appendmat == True`). Can also pass open file\_like object.

**mdict** : dict

Dictionary from which to save matfile variables.

**appendmat** : bool, optional

True (the default) to append the .mat extension to the end of the given filename, if not already present.

**format** : {'5', '4'}, string, optional

'5' (the default) for MATLAB 5 and up (to 7.2), '4' for MATLAB 4 .mat files.

**long\_field\_names** : bool, optional

False (the default) - maximum field name length in a structure is 31 characters which is the documented maximum length. True - maximum field name length in a structure is 63 characters which works for MATLAB 7.6+.

**do\_compression** : bool, optional

Whether or not to compress matrices on write. Default is False.

**oned\_as** : {'row', 'column'}, optional

If 'column', write 1-D numpy arrays as column vectors. If 'row', write 1-D numpy arrays as row vectors.

**See also:**

`mio4.MatFile4Writer`, `mio5.MatFile5Writer`

`scipy.io.whosmat` (*file\_name*, *appendmat=True*, *\*\*kwargs*)

List variables inside a MATLAB file.

**Parameters**

- file\_name** : str  
Name of the mat file (do not need .mat extension if `appendmat==True`) Can also pass open file-like object.
- appendmat** : bool, optional  
True to append the .mat extension to the end of the given filename, if not already present.
- byte\_order** : str or None, optional  
None by default, implying byte order guessed from mat file. Otherwise can be one of ('native', '=', 'little', '<', 'BIG', '>').
- mat\_dtype** : bool, optional  
If True, return arrays in same dtype as would be loaded into MATLAB (instead of the dtype with which they are saved).
- squeeze\_me** : bool, optional  
Whether to squeeze unit matrix dimensions or not.
- chars\_as\_strings** : bool, optional  
Whether to convert char arrays to string arrays.
- matlab\_compatible** : bool, optional  
Returns matrices as would be loaded by MATLAB (implies `squeeze_me=False`, `chars_as_strings=False`, `mat_dtype=True`, `struct_as_record=True`).
- struct\_as\_record** : bool, optional  
Whether to load MATLAB structs as numpy record arrays, or as old-style numpy arrays with `dtype=object`. Setting this flag to False replicates the behavior of scipy version 0.7.x (returning numpy object arrays). The default setting is True, because it allows easier round-trip load and save of MATLAB files.

**Returns**

- variables** : list of tuples  
A list of tuples, where each tuple holds the matrix name (a string), its shape (tuple of ints), and its data class (a string). Possible data classes are: int8, uint8, int16, uint16, int32, uint32, int64, uint64, single, double, cell, struct, object, char, sparse, function, opaque, logical, unknown.

**Notes**

v4 (Level 1.0), v6 and v7 to 7.2 matfiles are supported.

You will need an HDF5 python library to read matlab 7.3 format mat files. Because scipy does not supply one, we do not implement the HDF5 / 7.3 interface here.

New in version 0.12.0.

## 5.8.2 IDL® files

---

`readsav`(*file\_name*[, *idict*, *python\_dict*, ...])                      Read an IDL .sav file.

---

`scipy.io.readsav` (*file\_name*, *idict=None*, *python\_dict=False*, *uncompressed\_file\_name=None*, *verbose=False*)

Read an IDL .sav file.

**Parameters**

- file\_name** : str  
Name of the IDL save file.
- idict** : dict, optional  
Dictionary in which to insert .sav file variables.
- python\_dict** : bool, optional

By default, the object return is not a Python dictionary, but a case-insensitive dictionary with item, attribute, and call access to variables. To get a standard Python dictionary, set this option to True.

**uncompressed\_file\_name** : str, optional

This option only has an effect for .sav files written with the /compress option. If a file name is specified, compressed .sav files are uncompressed to this file. Otherwise, readsav will use the `tempfile` module to determine a temporary filename automatically, and will remove the temporary file upon successfully reading it in.

**verbose** : bool, optional

Whether to print out information about the save file, including the records read, and available variables.

**Returns** **idl\_dict** : AttrDict or dict

If `python_dict` is set to False (default), this function returns a case-insensitive dictionary with item, attribute, and call access to variables. If `python_dict` is set to True, this function returns a Python dictionary with all variable names in lowercase. If `idict` was specified, then variables are written to the dictionary specified, and the updated dictionary is returned.

### 5.8.3 Matrix Market files

<code>mminfo(source)</code>	Return size and storage parameters from Matrix Market file-like 'source'.
<code>mmread(source)</code>	Reads the contents of a Matrix Market file-like 'source' into a matrix.
<code>mmwrite(target, a[, comment, field, ...])</code>	Writes the sparse or dense array <i>a</i> to Matrix Market file-like <i>target</i> .

`scipy.io.mminfo(source)`

Return size and storage parameters from Matrix Market file-like 'source'.

**Parameters** **source** : str or file-like

Matrix Market filename (extension .mtx) or open file-like object

**Returns** **rows** : int

Number of matrix rows.

**cols** : int

Number of matrix columns.

**entries** : int

Number of non-zero entries of a sparse matrix or rows\*cols for a dense matrix.

**format** : str

Either 'coordinate' or 'array'.

**field** : str

Either 'real', 'complex', 'pattern', or 'integer'.

**symmetry** : str

Either 'general', 'symmetric', 'skew-symmetric', or 'hermitian'.

`scipy.io.mmread(source)`

Reads the contents of a Matrix Market file-like 'source' into a matrix.

**Parameters** **source** : str or file-like

Matrix Market filename (extensions .mtx, .mtz.gz) or open file-like object.

**Returns** **a** : ndarray or coo\_matrix

Dense or sparse matrix depending on the matrix format in the Matrix Market file.

`scipy.io.mmwrite` (*target*, *a*, *comment*='', *field*=None, *precision*=None, *symmetry*=None)  
 Writes the sparse or dense array *a* to Matrix Market file-like *target*.

**Parameters**

- target** : str or file-like  
 Matrix Market filename (extension .mtx) or open file-like object.
- a** : array like  
 Sparse or dense 2D array.
- comment** : str, optional  
 Comments to be prepended to the Matrix Market file.
- field** : None or str, optional  
 Either 'real', 'complex', 'pattern', or 'integer'.
- precision** : None or int, optional  
 Number of digits to display for real or complex values.
- symmetry** : None or str, optional  
 Either 'general', 'symmetric', 'skew-symmetric', or 'hermitian'. If symmetry is None the symmetry type of 'a' is determined by its values.

## 5.8.4 Unformatted Fortran files

<code>FortranFile</code> (filename[, mode, header_dtype])	A file object for unformatted sequential files from Fortran code.
---	---

---

**class** `scipy.io.FortranFile` (*filename*, *mode*='r', *header\_dtype*=<type 'numpy.uint32'>)  
 A file object for unformatted sequential files from Fortran code.

**Parameters**

- filename** : file or str  
 Open file object or filename.
- mode** : {'r', 'w'}, optional  
 Read-write mode, default is 'r'.
- header\_dtype** : dtype, optional  
 Data type of the header. Size and endianness must match the input/output file.

### Notes

These files are broken up into records of unspecified types. The size of each record is given at the start (although the size of this header is not standard) and the data is written onto disk without any formatting. Fortran compilers supporting the BACKSPACE statement will write a second copy of the size to facilitate backwards seeking.

This class only supports files written with both sizes for the record. It also does not support the subrecords used in Intel and gfortran compilers for records which are greater than 2GB with a 4-byte header.

An example of an unformatted sequential file in Fortran would be written as:

```
OPEN(1, FILE=myfilename, FORM='unformatted')

WRITE(1) myvariable
```

Since this is a non-standard file format, whose contents depend on the compiler and the endianness of the machine, caution is advised. Files from gfortran 4.8.0 and gfortran 4.1.2 on x86\_64 are known to work.

Consider using Fortran direct-access files or files from the newer Stream I/O, which can be easily read by `numpy.fromfile`.

### Examples

To create an unformatted sequential Fortran file:

```
>>> from scipy.io import FortranFile
>>> f = FortranFile('test.unf', 'w')
>>> f.write_record(np.array([1,2,3,4,5], dtype=np.int32))
>>> f.write_record(np.linspace(0,1,20).reshape((5,4)).T)
>>> f.close()
```

To read this file:

```
>>> f = FortranFile('test.unf', 'r')
>>> print(f.read_ints(np.int32))
[1 2 3 4 5]
>>> print(f.read_reals(float).reshape((5,4), order="F"))
[[ 0.          0.05263158  0.10526316  0.15789474]
 [ 0.21052632  0.26315789  0.31578947  0.36842105]
 [ 0.42105263  0.47368421  0.52631579  0.57894737]
 [ 0.63157895  0.68421053  0.73684211  0.78947368]
 [ 0.84210526  0.89473684  0.94736842  1.          ]]
>>> f.close()
```

Or, in Fortran:

```
integer :: a(5), i
double precision :: b(5,4)
open(1, file='test.unf', form='unformatted')
read(1) a
read(1) b
close(1)
write(*,*) a
do i = 1, 5
    write(*,*) b(i,:)
end do
```

### Methods

<code>close()</code>	Closes the file.
<code>read_ints([dtype])</code>	Reads a record of a given type from the file, defaulting to an integer type (INTEGER*4 in Fortran).
<code>read_reals([dtype])</code>	Reads a record of a given type from the file, defaulting to a floating point number (real*8 in Fortran).
<code>read_record(*dtypes, **kwargs)</code>	Reads a record of a given type from the file.
<code>write_record(*items)</code>	Write a record (including sizes) to the file.

`FortranFile.close()`

Closes the file. It is unsupported to call any other methods off this object after closing it. Note that this class supports the 'with' statement in modern versions of Python, to call this automatically

`FortranFile.read_ints(dtype='i4')`

Reads a record of a given type from the file, defaulting to an integer type (INTEGER\*4 in Fortran).

**Parameters** `dtype` : dtype, optional  
Data type specifying the size and endianness of the data.

**Returns** `data` : ndarray  
A one-dimensional array object.

**See also:**

`read_reals`, `read_record`

FortranFile.**read\_reals** (*dtype='f8'*)

Reads a record of a given type from the file, defaulting to a floating point number (`real*8` in Fortran).

**Parameters** **dtype** : dtype, optional  
Data type specifying the size and endianness of the data.

**Returns** **data** : ndarray  
A one-dimensional array object.

**See also:**

`read_ints`, `read_record`

FortranFile.**read\_record** (*\*dtypes, \*\*kwargs*)

Reads a record of a given type from the file.

**Parameters** **\*dtypes** : dtypes, optional  
Data type(s) specifying the size and endianness of the data.

**Returns** **data** : ndarray  
A one-dimensional array object.

**See also:**

`read_reals`, `read_ints`

**Notes**

If the record contains a multi-dimensional array, you can specify the size in the dtype. For example:

```
INTEGER var(5,4)
```

can be read with:

```
read_record('(4,5)i4').T
```

Note that this function does **not** assume the file data is in Fortran column major order, so you need to (i) swap the order of dimensions when reading and (ii) transpose the resulting array.

Alternatively, you can read the data as a 1D array and handle the ordering yourself. For example:

```
read_record('i4').reshape(5, 4, order='F')
```

For records that contain several variables or mixed types (as opposed to single scalar or array types), give them as separate arguments:

```
double precision :: a
integer :: b
write(1) a, b

record = f.read_record('<f4', '<i4')
a = record[0] # first number
b = record[1] # second number
```

and if any of the variables are arrays, the shape can be specified as the third item in the relevant dtype:

```
double precision :: a
integer :: b(3,4)
write(1) a, b

record = f.read_record('<f4', np.dtype('<i4', (4, 3)))
a = record[0]
b = record[1].T
```

Numpy also supports a short syntax for this kind of type:

```
record = f.read_record('<f4', '(3,3)<i4')
```

FortranFile.**write\_record**(\*items)

Write a record (including sizes) to the file.

**Parameters** \*items : array\_like  
The data arrays to write.

#### Notes

Writes data items to a file:

```
write_record(a.T, b.T, c.T, ...)
write(1) a, b, c, ...
```

Note that data in multidimensional arrays is written in row-major order — to make them read correctly by Fortran programs, you need to transpose the arrays yourself when writing them.

## 5.8.5 Netcdf

<code>netcdf_file(filename[, mode, mmap, version, ...])</code>	A file object for NetCDF data.
<code>netcdf_variable(data, typecode, size, shape, ...)</code>	A data object for the <code>netcdf</code> module.

**class** `scipy.io.netcdf_file` (*filename, mode='r', mmap=None, version=1, maskandscale=False*)  
A file object for NetCDF data.

A `netcdf_file` object has two standard attributes: *dimensions* and *variables*. The values of both are dictionaries, mapping dimension names to their associated lengths and variable names to variables, respectively. Application programs should never modify these dictionaries.

All other attributes correspond to global attributes defined in the NetCDF file. Global file attributes are created by assigning to an attribute of the `netcdf_file` object.

**Parameters**

- filename** : string or file-like  
string -> filename
- mode** : {'r', 'w', 'a'}, optional  
read-write-append mode, default is 'r'
- mmap** : None or bool, optional  
Whether to mmap *filename* when reading. Default is True when *filename* is a file name, False when *filename* is a file-like object. Note that when mmap is in use, data arrays returned refer directly to the mmapped data on disk, and the file cannot be closed as long as references to it exist.
- version** : {1, 2}, optional  
version of netcdf to read / write, where 1 means *Classic format* and 2 means *64-bit offset format*. Default is 1. See [here](#) for more info.
- maskandscale** : bool, optional  
Whether to automatically scale and/or mask data based on attributes. Default is False.

#### Notes

The major advantage of this module over other modules is that it doesn't require the code to be linked to the NetCDF libraries. This module is derived from `pupynere`.

NetCDF files are a self-describing binary data format. The file contains metadata that describes the dimensions and variables in the file. More details about NetCDF files can be found [here](#). There are three main sections to a NetCDF data structure:

1. Dimensions
2. Variables
3. Attributes

The dimensions section records the name and length of each dimension used by the variables. The variables would then indicate which dimensions it uses and any attributes such as data units, along with containing the data values for the variable. It is good practice to include a variable that is the same name as a dimension to provide the values for that axes. Lastly, the attributes section would contain additional information such as the name of the file creator or the instrument used to collect the data.

When writing data to a NetCDF file, there is often the need to indicate the ‘record dimension’. A record dimension is the unbounded dimension for a variable. For example, a temperature variable may have dimensions of latitude, longitude and time. If one wants to add more temperature data to the NetCDF file as time progresses, then the temperature variable should have the time dimension flagged as the record dimension.

In addition, the NetCDF file header contains the position of the data in the file, so access can be done in an efficient manner without loading unnecessary data into memory. It uses the `mmap` module to create Numpy arrays mapped to the data on disk, for the same purpose.

Note that when `netcdf_file` is used to open a file with `mmap=True` (default for read-only), arrays returned by it refer to data directly on the disk. The file should not be closed, and cannot be cleanly closed when asked, if such arrays are alive. You may want to copy data arrays obtained from mmapped Netcdf file if they are to be processed after the file is closed, see the example below.

### Examples

To create a NetCDF file:

```
>>> from scipy.io import netcdf
>>> f = netcdf.netcdf_file('simple.nc', 'w')
>>> f.history = 'Created for a test'
>>> f.createDimension('time', 10)
>>> time = f.createVariable('time', 'i', ('time',))
>>> time[:] = np.arange(10)
>>> time.units = 'days since 2008-01-01'
>>> f.close()
```

Note the assignment of `range(10)` to `time[:]`. Exposing the slice of the time variable allows for the data to be set in the object, rather than letting `range(10)` overwrite the `time` variable.

To read the NetCDF file we just created:

```
>>> from scipy.io import netcdf
>>> f = netcdf.netcdf_file('simple.nc', 'r')
>>> print(f.history)
b'Created for a test'
>>> time = f.variables['time']
>>> print(time.units)
b'days since 2008-01-01'
>>> print(time.shape)
(10,)
>>> print(time[-1])
9
```

NetCDF files, when opened read-only, return arrays that refer directly to memory-mapped data on disk:

```
>>> data = time[:]
>>> data.base.base
<mmap.mmap object at 0x7fe753763180>
```

If the data is to be processed after the file is closed, it needs to be copied to main memory:

```
>>> data = time[:].copy()
>>> f.close()
>>> data.mean()
4.5
```

A NetCDF file can also be used as context manager:

```
>>> from scipy.io import netcdf
>>> with netcdf.netcdf_file('simple.nc', 'r') as f:
...     print(f.history)
b'Created for a test'
```

### Methods

<code>close()</code>	Closes the NetCDF file.
<code>createDimension(name, length)</code>	Adds a dimension to the Dimension section of the NetCDF data structure.
<code>createVariable(name, type, dimensions)</code>	Create an empty variable for the <code>netcdf_file</code> object, specifying its data type and the dimensions it uses.
<code>flush()</code>	Perform a sync-to-disk flush if the <code>netcdf_file</code> object is in write mode.
<code>sync()</code>	Perform a sync-to-disk flush if the <code>netcdf_file</code> object is in write mode.

`netcdf_file.close()`  
Closes the NetCDF file.

`netcdf_file.createDimension(name, length)`  
Adds a dimension to the Dimension section of the NetCDF data structure.

Note that this function merely adds a new dimension that the variables can reference. The values for the dimension, if desired, should be added as a variable using `createVariable`, referring to this dimension.

**Parameters**

- name** : str  
Name of the dimension (Eg, 'lat' or 'time').
- length** : int  
Length of the dimension.

#### See also:

`createVariable`

`netcdf_file.createVariable(name, type, dimensions)`

Create an empty variable for the `netcdf_file` object, specifying its data type and the dimensions it uses.

**Parameters**

- name** : str  
Name of the new variable.

**type** : dtype or str

Data type of the variable.

**dimensions** : sequence of str

List of the dimension names used by the variable, in the desired order.

**Returns** **variable** : netcdf\_variable

The newly created `netcdf_variable` object. This object has also been added to the `netcdf_file` object as well.

**See also:**

`createDimension`

**Notes**

Any dimensions to be used by the variable should already exist in the NetCDF data structure or should be created by `createDimension` prior to creating the NetCDF variable.

`netcdf_file.flush()`

Perform a sync-to-disk flush if the `netcdf_file` object is in write mode.

**See also:**

**sync** Identical function

`netcdf_file.sync()`

Perform a sync-to-disk flush if the `netcdf_file` object is in write mode.

**See also:**

**sync** Identical function

**class** `scipy.io.netcdf_variable` (*data, typecode, size, shape, dimensions, attributes=None, maskand-scale=False*)

A data object for the `netcdf` module.

`netcdf_variable` objects are constructed by calling the method `netcdf_file.createVariable` on the `netcdf_file` object. `netcdf_variable` objects behave much like array objects defined in `numpy`, except that their data resides in a file. Data is read by indexing and written by assigning to an indexed subset; the entire array can be accessed by the index `[:]` or (for scalars) by using the methods `getValue` and `assignValue`. `netcdf_variable` objects also have attribute `shape` with the same meaning as for arrays, but the shape cannot be modified. There is another read-only attribute `dimensions`, whose value is the tuple of dimension names.

All other attributes correspond to variable attributes defined in the NetCDF file. Variable attributes are created by assigning to an attribute of the `netcdf_variable` object.

**Parameters** **data** : array\_like

The data array that holds the values for the variable. Typically, this is initialized as empty, but with the proper shape.

**typecode** : dtype character code

Desired data-type for the data array.

**size** : int

Desired element size for the data array.

**shape** : sequence of ints

The shape of the array. This should match the lengths of the variable's dimensions.

**dimensions** : sequence of strings

The names of the dimensions used by the variable. Must be in the same order of the dimension lengths given by `shape`.

**attributes** : dict, optional

Attribute values (any type) keyed by string names. These attributes become attributes for the `netcdf_variable` object.

**maskandscale** : bool, optional

Whether to automatically scale and/or mask data based on attributes. Default is False.

**See also:**

`isrec`, `shape`

**Attributes**

<code>dimensions</code>	(list of str) List of names of dimensions used by the variable object.
<code>isrec</code> , <code>shape</code>	Properties

**Methods**

<code>assignValue(value)</code>	Assign a scalar value to a <code>netcdf_variable</code> of length one.
<code>getValue()</code>	Retrieve a scalar value from a <code>netcdf_variable</code> of length one.
<code>itemsize()</code>	Return the itemsize of the variable.
<code>typecode()</code>	Return the typecode of the variable.

`netcdf_variable.assignValue(value)`

Assign a scalar value to a `netcdf_variable` of length one.

**Parameters** **value** : scalar

Scalar value (of compatible type) to assign to a length-one netcdf variable. This value will be written to file.

**Raises** **ValueError**

If the input is not a scalar, or if the destination is not a length-one netcdf variable.

`netcdf_variable.getValue()`

Retrieve a scalar value from a `netcdf_variable` of length one.

**Raises** **ValueError**

If the netcdf variable is an array of length greater than one, this exception will be raised.

`netcdf_variable.itemsize()`

Return the itemsize of the variable.

**Returns** **itemsize** : int

The element size of the variable (eg, 8 for float64).

`netcdf_variable.typecode()`

Return the typecode of the variable.

**Returns** **typecode** : char

The character typecode of the variable (eg, 'i' for int).

## 5.8.6 Harwell-Boeing files

<code>hb_read(path_or_open_file)</code>	Read HB-format file.
<code>hb_write(path_or_open_file, m[, hb_info])</code>	Write HB-format file.

`scipy.io.hb_read(path_or_open_file)`

Read HB-format file.

**Parameters** **path\_or\_open\_file** : path-like or file-like  
 If a file-like object, it is used as-is. Otherwise it is opened before reading.

**Returns** **data** : `scipy.sparse.csc_matrix` instance  
 The data read from the HB file as a sparse matrix.

**Notes**

At the moment not the full Harwell-Boeing format is supported. Supported features are:

- assembled, non-symmetric, real matrices
- integer for pointer/indices
- exponential format for float values, and int format

`scipy.io.hb_write(path_or_open_file, m, hb_info=None)`

Write HB-format file.

**Parameters** **path\_or\_open\_file** : path-like or file-like  
 If a file-like object, it is used as-is. Otherwise it is opened before writing.

**m** : sparse-matrix  
 the sparse matrix to write

**hb\_info** : `HBInfo`  
 contains the meta-data for write

**Returns** `None`

**Notes**

At the moment not the full Harwell-Boeing format is supported. Supported features are:

- assembled, non-symmetric, real matrices
- integer for pointer/indices
- exponential format for float values, and int format

### 5.8.7 Wav sound files (`scipy.io.wavfile`)

<code>read(filename[, mmap])</code>	Open a WAV file
<code>write(filename, rate, data)</code>	Write a numpy array as a WAV file.
<code>WavFileWarning</code>	

`scipy.io.wavfile.read(filename, mmap=False)`

Open a WAV file

Return the sample rate (in samples/sec) and data from a WAV file.

**Parameters** **filename** : string or open file handle  
 Input wav file.

**mmap** : bool, optional  
 Whether to read data as memory-mapped. Only to be used on real files (Default: False).  
 New in version 0.12.0.

**Returns** **rate** : int  
 Sample rate of wav file.

**data** : numpy array

Data read from wav file. Data-type is determined from the file; see Notes.

### Notes

This function cannot read wav files with 24-bit data.

Common data types: [R120]

WAV format	Min	Max	NumPy dtype
32-bit floating-point	-1.0	+1.0	float32
32-bit PCM	-2147483648	+2147483647	int32
16-bit PCM	-32768	+32767	int16
8-bit PCM	0	255	uint8

Note that 8-bit PCM is unsigned.

### References

[R120]

`scipy.io.wavfile.write` (*filename*, *rate*, *data*)

Write a numpy array as a WAV file.

**Parameters**

- filename** : string or open file handle  
Output wav file.
- rate** : int  
The sample rate (in samples/sec).
- data** : ndarray  
A 1-D or 2-D numpy array of either integer or float data-type.

### Notes

- Writes a simple uncompressed WAV file.
- To write multiple-channels, use a 2-D array of shape (Nsamples, Nchannels).
- The bits-per-sample and PCM/float will be determined by the data-type.

Common data types: [R121]

WAV format	Min	Max	NumPy dtype
32-bit floating-point	-1.0	+1.0	float32
32-bit PCM	-2147483648	+2147483647	int32
16-bit PCM	-32768	+32767	int16
8-bit PCM	0	255	uint8

Note that 8-bit PCM is unsigned.

### References

[R121]

exception `scipy.io.wavfile.WavFileWarning`

## 5.8.8 Arff files (`scipy.io.arff`)

`loadarff`(f)

Read an arff file.

Continued on next page

Table 5.81 – continued from previous page

<i>MetaData</i> (rel, attr)	Small container to keep useful informations on a ARFF dataset.
<i>ArffError</i>	
<i>ParseArffError</i>	

`scipy.io.arff.loadarff(f)`

Read an arff file.

The data is returned as a record array, which can be accessed much like a dictionary of numpy arrays. For example, if one of the attributes is called ‘pressure’, then its first 10 data points can be accessed from the data record array like so: `data['pressure'][0:10]`

- Parameters** **f**: file-like or str  
File-like object to read from, or filename to open.
- Returns** **data**: record array  
The data of the arff file, accessible by attribute names.  
**meta**: *MetaData*  
Contains information about the arff file such as name and type of attributes, the relation (name of the dataset), etc...
- Raises** **ParseArffError**  
This is raised if the given file is not ARFF-formatted.  
**NotImplementedError**  
The ARFF file has an attribute which is not supported yet.

**Notes**

This function should be able to read most arff files. Not implemented functionality include:

- date type attributes
- string type attributes

It can read files with numeric and nominal attributes. It cannot read files with sparse data ({} in the file). However, this function can read files with missing data (? in the file), representing the data points as NaNs.

**Examples**

```
>>> from scipy.io import arff
>>> from io import StringIO
>>> content = """
... @relation foo
... @attribute width numeric
... @attribute height numeric
... @attribute color {red,green,blue,yellow,black}
... @data
... 5.0,3.25,blue
... 4.5,3.75,green
... 3.0,4.00,red
... """
>>> f = StringIO(content)
>>> data, meta = arff.loadarff(f)
>>> data
array([(5.0, 3.25, 'blue'), (4.5, 3.75, 'green'), (3.0, 4.0, 'red')],
      dtype=[('width', '<f8'), ('height', '<f8'), ('color', '|S6')])
>>> meta
Dataset: foo
width's type is numeric
```

```
height's type is numeric
color's type is nominal, range is ('red', 'green', 'blue', 'yellow', 'black')
```

**class** `scipy.io.arff.MetaData` (*rel, attr*)  
Small container to keep useful informations on a ARFF dataset.

Knows about attributes names and types.

### Notes

Also maintains the list of attributes in order, i.e. doing for *i* in *meta*, where *meta* is an instance of `MetaData`, will return the different attribute names in the order they were defined.

### Examples

```
data, meta = loadarff('iris.arff')
# This will print the attributes names of the iris.arff dataset
for i in meta:
    print(i)
# This works too
meta.names()
# Getting attribute type
types = meta.types()
```

### Methods

<code>names()</code>	Return the list of attribute names.
<code>types()</code>	Return the list of attribute types.

`MetaData.names()`  
Return the list of attribute names.

`MetaData.types()`  
Return the list of attribute types.

**exception** `scipy.io.arff.ArffError`

**exception** `scipy.io.arff.ParseArffError`

## 5.9 Linear algebra (`scipy.linalg`)

Linear algebra functions.

### See also:

`numpy.linalg` for more linear algebra functions. Note that although `scipy.linalg` imports most of them, identically named functions from `scipy.linalg` may offer more or slightly differing functionality.

### 5.9.1 Basics

<code>inv(a[, overwrite_a, check_finite])</code>	Compute the inverse of a matrix.
--	----------------------------------

Continued on next page

Table 5.83 – continued from previous page

<code>solve(a, b[, sym_pos, lower, overwrite_a, ...])</code>	Solves the linear equation set $a * x = b$ for the unknown $x$ for square $a$ matrix.
<code>solve_banded(l_and_u, ab, b[, overwrite_ab, ...])</code>	Solve the equation $a x = b$ for $x$ , assuming $a$ is banded matrix.
<code>solveh_banded(ab, b[, overwrite_ab, ...])</code>	Solve equation $a x = b$ .
<code>solve_circulant(c, b[, singular, tol, ...])</code>	Solve $C x = b$ for $x$ , where $C$ is a circulant matrix.
<code>solve_triangular(a, b[, trans, lower, ...])</code>	Solve the equation $a x = b$ for $x$ , assuming $a$ is a triangular matrix.
<code>solve_toeplitz(c_or_cr, b[, check_finite])</code>	Solve a Toeplitz system using Levinson Recursion
<code>det(a[, overwrite_a, check_finite])</code>	Compute the determinant of a matrix
<code>norm(a[, ord, axis, keepdims])</code>	Matrix or vector norm.
<code>lstsq(a, b[, cond, overwrite_a, ...])</code>	Compute least-squares solution to equation $Ax = b$ .
<code>pinv(a[, cond, rcond, return_rank, check_finite])</code>	Compute the (Moore-Penrose) pseudo-inverse of a matrix.
<code>pinv2(a[, cond, rcond, return_rank, ...])</code>	Compute the (Moore-Penrose) pseudo-inverse of a matrix.
<code>pinvh(a[, cond, rcond, lower, return_rank, ...])</code>	Compute the (Moore-Penrose) pseudo-inverse of a Hermitian matrix.
<code>kron(a, b)</code>	Kronecker product.
<code>tril(m[, k])</code>	Make a copy of a matrix with elements above the $k$ -th diagonal zeroed.
<code>triu(m[, k])</code>	Make a copy of a matrix with elements below the $k$ -th diagonal zeroed.
<code>orthogonal_procrustes(A, B[, check_finite])</code>	Compute the matrix solution of the orthogonal Procrustes problem.
<code>matrix_balance(A[, permute, scale, ...])</code>	Compute a diagonal similarity transformation for row/column balancing.
<code>subspace_angles(A, B)</code>	Compute the subspace angles between two matrices.
<code>LinAlgError</code>	Generic Python-exception-derived object raised by linalg functions.

`scipy.linalg.inv(a, overwrite_a=False, check_finite=True)`

Compute the inverse of a matrix.

**Parameters** **a** : array\_like

Square matrix to be inverted.

**overwrite\_a** : bool, optional

Discard data in  $a$  (may improve performance). Default is False.

**check\_finite** : bool, optional

Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns** **ainv** : ndarray

Inverse of the matrix  $a$ .

**Raises** **LinAlgError**

If  $a$  is singular.

**ValueError**

If  $a$  is not square, or not 2-dimensional.

### Examples

```
>>> from scipy import linalg
>>> a = np.array([[1., 2.], [3., 4.]])
>>> linalg.inv(a)
array([[ -2. ,  1. ],
```

```
[ 1.5, -0.5]])
>>> np.dot(a, linalg.inv(a))
array([[ 1.,  0.],
       [ 0.,  1.]])
```

`scipy.linalg.solve(a, b, sym_pos=False, lower=False, overwrite_a=False, overwrite_b=False, debug=None, check_finite=True, assume_a='gen', transposed=False)`  
Solves the linear equation set  $a * x = b$  for the unknown  $x$  for square  $a$  matrix.

If the data matrix is known to be a particular type then supplying the corresponding string to `assume_a` key chooses the dedicated solver. The available options are

generic matrix	'gen'
symmetric	'sym'
hermitian	'her'
positive definite	'pos'

If omitted, 'gen' is the default structure.

The datatype of the arrays define which solver is called regardless of the values. In other words, even when the complex array entries have precisely zero imaginary parts, the complex solver will be called based on the data type of the array.

**Parameters**

- a** : (N, N) array\_like  
Square input data
- b** : (N, NRHS) array\_like  
Input data for the right hand side.
- sym\_pos** : bool, optional  
Assume  $a$  is symmetric and positive definite. This key is deprecated and `assume_a = 'pos'` keyword is recommended instead. The functionality is the same. It will be removed in the future.
- lower** : bool, optional  
If True, only the data contained in the lower triangle of  $a$ . Default is to use upper triangle. (ignored for 'gen')
- overwrite\_a** : bool, optional  
Allow overwriting data in  $a$  (may enhance performance). Default is False.
- overwrite\_b** : bool, optional  
Allow overwriting data in  $b$  (may enhance performance). Default is False.
- check\_finite** : bool, optional  
Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.
- assume\_a** : str, optional  
Valid entries are explained above.
- transposed**: bool, optional  
If True,  $a^T x = b$  for real matrices, raises *NotImplementedError* for complex matrices (only for True).

**Returns**

- x** : (N, NRHS) ndarray  
The solution array.

**Raises**

- ValueError**  
If size mismatches detected or input  $a$  is not square.
- LinAlgError**  
If the matrix is singular.
- RuntimeWarning**  
If an ill-conditioned input  $a$  is detected.
- NotImplementedError**

If `transposed` is `True` and input `a` is a complex matrix.

**Notes**

If the input `b` matrix is a 1D array with `N` elements, when supplied together with an `NxN` input `a`, it is assumed as a valid column vector despite the apparent size mismatch. This is compatible with the `numpy.dot()` behavior and the returned result is still 1D array.

The generic, symmetric, hermitian and positive definite solutions are obtained via calling `?GESV`, `?SYSV`, `?HESV`, and `?POSV` routines of LAPACK respectively.

**Examples**

Given `a` and `b`, solve for `x`:

```
>>> a = np.array([[3, 2, 0], [1, -1, 0], [0, 5, 1]])
>>> b = np.array([2, 4, -1])
>>> from scipy import linalg
>>> x = linalg.solve(a, b)
>>> x
array([ 2., -2.,  9.])
>>> np.dot(a, x) == b
array([ True,  True,  True], dtype=bool)
```

`scipy.linalg.solve_banded(l_and_u, ab, b, overwrite_ab=False, overwrite_b=False, debug=None, check_finite=True)`

Solve the equation  $a x = b$  for `x`, assuming `a` is banded matrix.

The matrix `a` is stored in `ab` using the matrix diagonal ordered form:

```
ab[u + i - j, j] == a[i, j]
```

Example of `ab` (shape of `a` is (6,6), `u`=1, `l`=2):

```
*      a01  a12  a23  a34  a45
a00  a11  a22  a33  a44  a55
a10  a21  a32  a43  a54  *
a20  a31  a42  a53  *   *
```

- Parameters**
- (l, u)** : (integer, integer)  
Number of non-zero lower and upper diagonals
  - ab** : ( $l + u + 1, M$ ) array\_like  
Banded matrix
  - b** : (M,) or (M, K) array\_like  
Right-hand side
  - overwrite\_ab** : bool, optional  
Discard data in `ab` (may enhance performance)
  - overwrite\_b** : bool, optional  
Discard data in `b` (may enhance performance)
  - check\_finite** : bool, optional  
Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.
- Returns**
- x** : (M,) or (M, K) ndarray  
The solution to the system  $a x = b$ . Returned shape depends on the shape of `b`.

**Examples**

Solve the banded system  $a x = b$ , where:

$$a = \begin{bmatrix} 5 & 2 & -1 & 0 & 0 \\ 1 & 4 & 2 & -1 & 0 \\ 0 & 1 & 3 & 2 & -1 \\ 0 & 0 & 1 & 2 & 2 \\ 0 & 0 & 0 & 1 & 1 \end{bmatrix} \quad b = \begin{bmatrix} 0 \\ 1 \\ 2 \\ 2 \\ 3 \end{bmatrix}$$

There is one nonzero diagonal below the main diagonal ( $l = 1$ ), and two above ( $u = 2$ ). The diagonal banded form of the matrix is:

$$ab = \begin{bmatrix} * & * & -1 & -1 & -1 \\ * & 2 & 2 & 2 & 2 \\ 5 & 4 & 3 & 2 & 1 \\ 1 & 1 & 1 & 1 & * \end{bmatrix}$$

```
>>> from scipy.linalg import solve_banded
>>> ab = np.array([[0, 0, -1, -1, -1],
...               [0, 2, 2, 2, 2],
...               [5, 4, 3, 2, 1],
...               [1, 1, 1, 1, 0]])
>>> b = np.array([0, 1, 2, 2, 3])
>>> x = solve_banded((1, 2), ab, b)
>>> x
array([-2.37288136,  3.93220339, -4.          ,  4.3559322 , -1.3559322 ])
```

`scipy.linalg.solveh_banded`(*ab*, *b*, *overwrite\_ab=False*, *overwrite\_b=False*, *lower=False*, *check\_finite=True*)

Solve equation  $a x = b$ . *a* is Hermitian positive-definite banded matrix.

The matrix *a* is stored in *ab* either in lower diagonal or upper diagonal ordered form:

$$ab[u + i - j, j] == a[i, j] \text{ (if upper form; } i \leq j) \quad ab[i - j, j] == a[i, j] \text{ (if lower form; } i \geq j)$$

Example of *ab* (shape of *a* is (6, 6),  $u = 2$ ):

```
upper form:
*   *   a02 a13 a24 a35
*   a01 a12 a23 a34 a45
a00 a11 a22 a33 a44 a55

lower form:
a00 a11 a22 a33 a44 a55
a10 a21 a32 a43 a54 *
a20 a31 a42 a53 *   *
```

Cells marked with \* are not used.

**Parameters**

- ab** : ( $u + 1$ , *M*) array\_like  
Banded matrix
- b** : (*M*,) or (*M*, *K*) array\_like  
Right-hand side
- overwrite\_ab** : bool, optional  
Discard data in *ab* (may enhance performance)
- overwrite\_b** : bool, optional  
Discard data in *b* (may enhance performance)
- lower** : bool, optional

Is the matrix in the lower form. (Default is upper form)

**check\_finite** : bool, optional

Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns** **x** : (M,) or (M, K) ndarray

The solution to the system  $ax = b$ . Shape of return matches shape of  $b$ .

### Examples

Solve the banded system  $Ax = b$ , where:

```
A = [ 4  2 -1  0  0  0]
     [ 2  5  2 -1  0  0]
     [-1  2  6  2 -1  0]
     [ 0 -1  2  7  2 -1]
     [ 0  0 -1  2  8  2]
     [ 0  0  0 -1  2  9]
b = [1]
     [2]
     [2]
     [3]
     [3]
     [3]
```

```
>>> from scipy.linalg import solveh_banded
```

$ab$  contains the main diagonal and the nonzero diagonals below the main diagonal. That is, we use the lower form:

```
>>> ab = np.array([[ 4,  5,  6,  7,  8,  9],
...               [ 2,  2,  2,  2,  2,  0],
...               [-1, -1, -1, -1,  0,  0]])
>>> b = np.array([1, 2, 2, 3, 3, 3])
>>> x = solveh_banded(ab, b, lower=True)
>>> x
array([ 0.03431373,  0.45938375,  0.05602241,  0.47759104,  0.17577031,
        0.34733894])
```

Solve the Hermitian banded system  $Hx = b$ , where:

```
H = [ 8  2-1j  0  0 ]
     [2+1j  5  1j  0 ]
     [ 0  -1j  9 -2-1j]
     [ 0  0  -2+1j  6 ]
b = [ 1 ]
     [1+1j]
     [1-2j]
     [ 0 ]
```

In this example, we put the upper diagonals in the array  $hb$ :

```
>>> hb = np.array([[0, 2-1j, 1j, -2-1j],
...               [8,  5,  9,  6 ]])
>>> b = np.array([1, 1+1j, 1-2j, 0])
>>> x = solveh_banded(hb, b)
>>> x
array([ 0.07318536-0.02939412j,  0.11877624+0.17696461j,
        0.10077984-0.23035393j, -0.00479904-0.09358128j])
```

`scipy.linalg.solve_circulant` ( $c, b, singular='raise', tol=None, caxis=-1, baxis=0, outaxis=0$ )

Solve  $Cx = b$  for  $x$ , where  $C$  is a circulant matrix.

$C$  is the circulant matrix associated with the vector  $c$ .

The system is solved by doing division in Fourier space. The calculation is:

```
x = ifft(fft(b) / fft(c))
```

where *fft* and *ifft* are the fast Fourier transform and its inverse, respectively. For a large vector *c*, this is *much* faster than solving the system with the full circulant matrix.

- Parameters**
- c** : array\_like  
The coefficients of the circulant matrix.
  - b** : array\_like  
Right-hand side matrix in  $a x = b$ .
  - singular** : str, optional  
This argument controls how a near singular circulant matrix is handled. If *singular* is “raise” and the circulant matrix is near singular, a *LinAlgError* is raised. If *singular* is “lstsq”, the least squares solution is returned. Default is “raise”.
  - tol** : float, optional  
If any eigenvalue of the circulant matrix has an absolute value that is less than or equal to *tol*, the matrix is considered to be near singular. If not given, *tol* is set to:
 

```
tol = abs_eigs.max() * abs_eigs.size * np.finfo(np.float64).eps
```

 where *abs\_eigs* is the array of absolute values of the eigenvalues of the circulant matrix.
  - caxis** : int  
When *c* has dimension greater than 1, it is viewed as a collection of circulant vectors. In this case, *caxis* is the axis of *c* that holds the vectors of circulant coefficients.
  - baxis** : int  
When *b* has dimension greater than 1, it is viewed as a collection of vectors. In this case, *baxis* is the axis of *b* that holds the right-hand side vectors.
  - outaxis** : int  
When *c* or *b* are multidimensional, the value returned by *solve\_circulant* is multidimensional. In this case, *outaxis* is the axis of the result that holds the solution vectors.
- Returns**
- x** : ndarray  
Solution to the system  $C x = b$ .
- Raises**
- LinAlgError**  
If the circulant matrix associated with *c* is near singular.

See also:

**circulant** circulant matrix

**Notes**

For a one-dimensional vector *c* with length *m*, and an array *b* with shape  $(m, \dots)$ ,

```
solve_circulant(c, b)
```

returns the same result as

```
solve(circulant(c), b)
```

where *solve* and *circulant* are from *scipy.linalg*.

New in version 0.16.0.

**Examples**

```
>>> from scipy.linalg import solve_circulant, solve, circulant, lstsq
```

```
>>> c = np.array([2, 2, 4])
>>> b = np.array([1, 2, 3])
>>> solve_circulant(c, b)
array([ 0.75, -0.25,  0.25])
```

Compare that result to solving the system with `scipy.linalg.solve`:

```
>>> solve(circulant(c), b)
array([ 0.75, -0.25,  0.25])
```

A singular example:

```
>>> c = np.array([1, 1, 0, 0])
>>> b = np.array([1, 2, 3, 4])
```

Calling `solve_circulant(c, b)` will raise a `LinAlgError`. For the least square solution, use the option `singular='lstsq'`:

```
>>> solve_circulant(c, b, singular='lstsq')
array([ 0.25,  1.25,  2.25,  1.25])
```

Compare to `scipy.linalg.lstsq`:

```
>>> x, resid, rnk, s = lstsq(circulant(c), b)
>>> x
array([ 0.25,  1.25,  2.25,  1.25])
```

A broadcasting example:

Suppose we have the vectors of two circulant matrices stored in an array with shape (2, 5), and three *b* vectors stored in an array with shape (3, 5). For example,

```
>>> c = np.array([[1.5, 2, 3, 0, 0], [1, 1, 4, 3, 2]])
>>> b = np.arange(15).reshape(-1, 5)
```

We want to solve all combinations of circulant matrices and *b* vectors, with the result stored in an array with shape (2, 3, 5). When we disregard the axes of *c* and *b* that hold the vectors of coefficients, the shapes of the collections are (2,) and (3,), respectively, which are not compatible for broadcasting. To have a broadcast result with shape (2, 3), we add a trivial dimension to *c*: `c[:, np.newaxis, :]` has shape (2, 1, 5). The last dimension holds the coefficients of the circulant matrices, so when we call `solve_circulant`, we can use the default `caxis=-1`. The coefficients of the *b* vectors are in the last dimension of the array *b*, so we use `baxis=-1`. If we use the default `outaxis`, the result will have shape (5, 2, 3), so we'll use `outaxis=-1` to put the solution vectors in the last dimension.

```
>>> x = solve_circulant(c[:, np.newaxis, :], b, baxis=-1, outaxis=-1)
>>> x.shape
(2, 3, 5)
>>> np.set_printoptions(precision=3) # For compact output of numbers.
>>> x
array([[[-0.118,  0.22 ,  1.277, -0.142,  0.302],
        [ 0.651,  0.989,  2.046,  0.627,  1.072],
        [ 1.42 ,  1.758,  2.816,  1.396,  1.841]],
       [[ 0.401,  0.304,  0.694, -0.867,  0.377],
        [ 0.856,  0.758,  1.149, -0.412,  0.831],
        [ 1.31 ,  1.213,  1.603,  0.042,  1.286]]])
```

Check by solving one pair of *c* and *b* vectors (cf. `x[1, 1, :]`):

```
>>> solve_circulant(c[1], b[1, :])
array([ 0.856,  0.758,  1.149, -0.412,  0.831])
```

`scipy.linalg.solve_triangular(a, b, trans=0, lower=False, unit_diagonal=False, overwrite_b=False, debug=None, check_finite=True)`

Solve the equation  $ax = b$  for  $x$ , assuming  $a$  is a triangular matrix.

**Parameters**

- a** : (M, M) array\_like  
A triangular matrix
- b** : (M,) or (M, N) array\_like  
Right-hand side matrix in  $ax = b$
- lower** : bool, optional  
Use only data contained in the lower triangle of  $a$ . Default is to use upper triangle.
- trans** : {0, 1, 2, 'N', 'T', 'C'}, optional  
Type of system to solve:

trans	system
0 or 'N'	$ax = b$
1 or 'T'	$a^T x = b$
2 or 'C'	$a^H x = b$

- unit\_diagonal** : bool, optional  
If True, diagonal elements of  $a$  are assumed to be 1 and will not be referenced.
- overwrite\_b** : bool, optional  
Allow overwriting data in  $b$  (may enhance performance)
- check\_finite** : bool, optional  
Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns** **x** : (M,) or (M, N) ndarray  
Solution to the system  $ax = b$ . Shape of return matches  $b$ .

**Raises** **LinAlgError**  
If  $a$  is singular

### Notes

New in version 0.9.0.

### Examples

Solve the lower triangular system  $ax = b$ , where:

```
a = [[3  0  0  0]
      [2  1  0  0]
      [1  0  1  0]
      [1  1  1  1]]
b = [4]
     [2]
     [4]
     [2]
```

```
>>> from scipy.linalg import solve_triangular
>>> a = np.array([[3, 0, 0, 0], [2, 1, 0, 0], [1, 0, 1, 0], [1, 1, 1, 1]])
>>> b = np.array([4, 2, 4, 2])
>>> x = solve_triangular(a, b, lower=True)
>>> x
array([ 1.33333333, -0.66666667,  2.66666667, -1.33333333])
>>> a.dot(x) # Check the result
array([ 4.,  2.,  4.,  2.]
```

`scipy.linalg.solve_toeplitz(c_or_cr, b, check_finite=True)`

Solve a Toeplitz system using Levinson Recursion

The Toeplitz matrix has constant diagonals, with  $c$  as its first column and  $r$  as its first row. If  $r$  is not given,  $r == \text{conjugate}(c)$  is assumed.

**Parameters**

- c\_or\_cr** : array\_like or tuple of (array\_like, array\_like)  
The vector  $c$ , or a tuple of arrays  $(c, r)$ . Whatever the actual shape of  $c$ , it will be converted to a 1-D array. If not supplied,  $r = \text{conjugate}(c)$  is assumed; in this case, if  $c[0]$  is real, the Toeplitz matrix is Hermitian.  $r[0]$  is ignored; the first row of the Toeplitz matrix is  $[c[0], r[1:]]$ . Whatever the actual shape of  $r$ , it will be converted to a 1-D array.
- b** : (M,) or (M, K) array\_like  
Right-hand side in  $T x = b$ .
- check\_finite** : bool, optional  
Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (result entirely NaNs) if the inputs do contain infinities or NaNs.

**Returns**

- x** : (M,) or (M, K) ndarray  
The solution to the system  $T x = b$ . Shape of return matches shape of  $b$ .

**See also:**

**toeplitz** Toeplitz matrix

**Notes**

The solution is computed using Levinson-Durbin recursion, which is faster than generic least-squares methods, but can be less numerically stable.

**Examples**

Solve the Toeplitz system  $T x = b$ , where:

```
T = [ 1 -1 -2 -3]
     [ 3  1 -1 -2]
     [ 6  3  1 -1]
     [10  6  3  1]
b = [1]
     [2]
     [2]
     [5]
```

To specify the Toeplitz matrix, only the first column and the first row are needed.

```
>>> c = np.array([1, 3, 6, 10]) # First column of T
>>> r = np.array([1, -1, -2, -3]) # First row of T
>>> b = np.array([1, 2, 2, 5])
```

```
>>> from scipy.linalg import solve_toeplitz, toeplitz
>>> x = solve_toeplitz((c, r), b)
>>> x
array([ 1.66666667, -1.          , -2.66666667,  2.33333333])
```

Check the result by creating the full Toeplitz matrix and multiplying it by  $x$ . We should get  $b$ .

```
>>> T = toeplitz(c, r)
>>> T.dot(x)
array([ 1.,  2.,  2.,  5.])
```

`scipy.linalg.det` ( $a$ , *overwrite\_a=False*, *check\_finite=True*)

Compute the determinant of a matrix

The determinant of a square matrix is a value derived arithmetically from the coefficients of the matrix.

The determinant for a 3x3 matrix, for example, is computed as follows:

```

a   b   c
d   e   f = A
g   h   i

det(A) = a*e*i + b*f*g + c*d*h - c*e*g - b*d*i - a*f*h

```

**Parameters**

- a** : (M, M) array\_like  
A square matrix.
- overwrite\_a** : bool, optional  
Allow overwriting data in a (may enhance performance).
- check\_finite** : bool, optional  
Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns**

- det** : float or complex  
Determinant of *a*.

**Notes**

The determinant is computed via LU factorization, LAPACK routine `z/dgetrf`.

**Examples**

```

>>> from scipy import linalg
>>> a = np.array([[1,2,3], [4,5,6], [7,8,9]])
>>> linalg.det(a)
0.0
>>> a = np.array([[0,2,3], [4,5,6], [7,8,9]])
>>> linalg.det(a)
3.0

```

`scipy.linalg.norm(a, ord=None, axis=None, keepdims=False)`  
Matrix or vector norm.

This function is able to return one of seven different matrix norms, or one of an infinite number of vector norms (described below), depending on the value of the `ord` parameter.

**Parameters**

- a** : (M,) or (M, N) array\_like  
Input array. If *axis* is `None`, *a* must be 1-D or 2-D.
- ord** : {non-zero int, inf, -inf, 'fro'}, optional  
Order of the norm (see table under `Notes`). `inf` means numpy's `inf` object
- axis** : {int, 2-tuple of ints, None}, optional  
If *axis* is an integer, it specifies the axis of *a* along which to compute the vector norms.  
If *axis* is a 2-tuple, it specifies the axes that hold 2-D matrices, and the matrix norms of these matrices are computed. If *axis* is `None` then either a vector norm (when *a* is 1-D) or a matrix norm (when *a* is 2-D) is returned.
- keepdims** : bool, optional  
If this is set to `True`, the axes which are normed over are left in the result as dimensions with size one. With this option the result will broadcast correctly against the original *a*.

**Returns**

- n** : float or ndarray  
Norm of the matrix or vector(s).

**Notes**

For values of `ord`  $\leq 0$ , the result is, strictly speaking, not a mathematical 'norm', but it may still be useful for various numerical purposes.

The following norms can be calculated:

ord	norm for matrices	norm for vectors
None	Frobenius norm	2-norm
'fro'	Frobenius norm	-
inf	max(sum(abs(x), axis=1))	max(abs(x))
-inf	min(sum(abs(x), axis=1))	min(abs(x))
0	-	sum(x != 0)
1	max(sum(abs(x), axis=0))	as below
-1	min(sum(abs(x), axis=0))	as below
2	2-norm (largest sing. value)	as below
-2	smallest singular value	as below
other	-	sum(abs(x)**ord)**(1./ord)

The Frobenius norm is given by [R139]:

$$\|A\|_F = [\sum_{i,j} \text{abs}(a_{i,j})^2]^{1/2}$$

The `axis` and `keepdims` arguments are passed directly to `numpy.linalg.norm` and are only usable if they are supported by the version of `numpy` in use.

### References

[R139]

### Examples

```
>>> from scipy.linalg import norm
>>> a = np.arange(9) - 4.0
>>> a
array([-4., -3., -2., -1.,  0.,  1.,  2.,  3.,  4.])
>>> b = a.reshape((3, 3))
>>> b
array([[ -4.,  -3.,  -2.],
       [ -1.,   0.,   1.],
       [  2.,   3.,   4.]])
```

```
>>> norm(a)
7.745966692414834
>>> norm(b)
7.745966692414834
>>> norm(b, 'fro')
7.745966692414834
>>> norm(a, np.inf)
4
>>> norm(b, np.inf)
9
>>> norm(a, -np.inf)
0
>>> norm(b, -np.inf)
2
```

```
>>> norm(a, 1)
20
>>> norm(b, 1)
7
>>> norm(a, -1)
-4.6566128774142013e-010
```

```
>>> norm(b, -1)
6
>>> norm(a, 2)
7.745966692414834
>>> norm(b, 2)
7.3484692283495345
```

```
>>> norm(a, -2)
0
>>> norm(b, -2)
1.8570331885190563e-016
>>> norm(a, 3)
5.8480354764257312
>>> norm(a, -3)
0
```

`scipy.linalg.lstsq(a, b, cond=None, overwrite_a=False, overwrite_b=False, check_finite=True, lapack_driver=None)`

Compute least-squares solution to equation  $Ax = b$ .

Compute a vector  $x$  such that the 2-norm  $\|b - Ax\|$  is minimized.

**Parameters**

- a** : (M, N) array\_like  
Left hand side matrix (2-D array).
- b** : (M,) or (M, K) array\_like  
Right hand side matrix or vector (1-D or 2-D array).
- cond** : float, optional  
Cutoff for 'small' singular values; used to determine effective rank of  $a$ . Singular values smaller than  $\text{rcond} * \text{largest\_singular\_value}$  are considered zero.
- overwrite\_a** : bool, optional  
Discard data in  $a$  (may enhance performance). Default is False.
- overwrite\_b** : bool, optional  
Discard data in  $b$  (may enhance performance). Default is False.
- check\_finite** : bool, optional  
Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.
- lapack\_driver** : str, optional  
Which LAPACK driver is used to solve the least-squares problem. Options are 'gelsd', 'gelsy', 'gelss'. Default ('gelsd') is a good choice. However, 'gelsy' can be slightly faster on many problems. 'gelss' was used historically. It is generally slow but uses less memory.  
New in version 0.17.0.

**Returns**

- x** : (N,) or (N, K) ndarray  
Least-squares solution. Return shape matches shape of  $b$ .
- residues** : (0,) or () or (K,) ndarray  
Sums of residues, squared 2-norm for each column in  $b - ax$ . If rank of matrix  $a$  is  $< N$  or  $N > M$ , or 'gelsy' is used, this is a length zero array. If  $b$  was 1-D, this is a () shape array (numpy scalar), otherwise the shape is (K,).
- rank** : int  
Effective rank of matrix  $a$ .
- s** : (min(M,N),) ndarray or None  
Singular values of  $a$ . The condition number of  $a$  is  $\text{abs}(s[0] / s[-1])$ . None is returned when 'gelsy' is used.

**Raises**

- LinAlgError**

If computation does not converge.  
**ValueError**  
When parameters are wrong.

See also:

**`optimize.nnls`**  
linear least squares with non-negativity constraint

*Examples*

```
>>> from scipy.linalg import lstsq
>>> import matplotlib.pyplot as plt
```

Suppose we have the following data:

```
>>> x = np.array([1, 2.5, 3.5, 4, 5, 7, 8.5])
>>> y = np.array([0.3, 1.1, 1.5, 2.0, 3.2, 6.6, 8.6])
```

We want to fit a quadratic polynomial of the form  $y = a + b*x**2$  to this data. We first form the “design matrix”  $M$ , with a constant column of 1s and a column containing  $x**2$ :

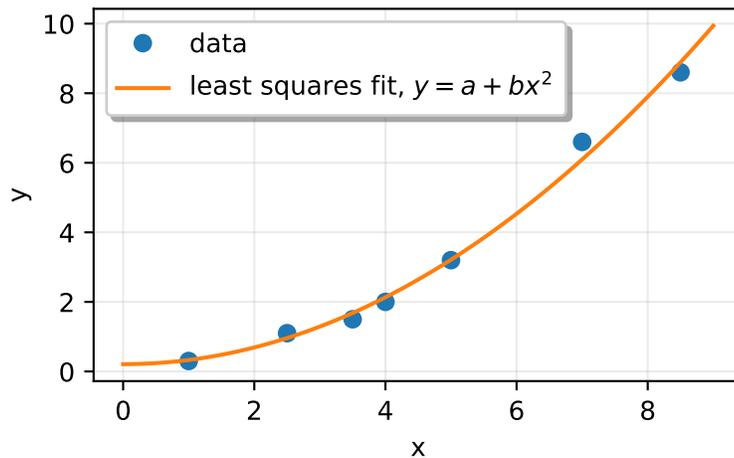
```
>>> M = x[:, np.newaxis]**[0, 2]
>>> M
array([[ 1.  ,  1.  ],
       [ 1.  ,  6.25],
       [ 1.  , 12.25],
       [ 1.  , 16.  ],
       [ 1.  , 25.  ],
       [ 1.  , 49.  ],
       [ 1.  , 72.25]])
```

We want to find the least-squares solution to  $M \cdot p = y$ , where  $p$  is a vector with length 2 that holds the parameters  $a$  and  $b$ .

```
>>> p, res, rnk, s = lstsq(M, y)
>>> p
array([ 0.20925829,  0.12013861])
```

Plot the data and the fitted curve.

```
>>> plt.plot(x, y, 'o', label='data')
>>> xx = np.linspace(0, 9, 101)
>>> yy = p[0] + p[1]*xx**2
>>> plt.plot(xx, yy, label='least squares fit, $y = a + bx^2$')
>>> plt.xlabel('x')
>>> plt.ylabel('y')
>>> plt.legend(framealpha=1, shadow=True)
>>> plt.grid(alpha=0.25)
>>> plt.show()
```



`scipy.linalg.pinv(a, cond=None, rcond=None, return_rank=False, check_finite=True)`  
 Compute the (Moore-Penrose) pseudo-inverse of a matrix.

Calculate a generalized inverse of a matrix using a least-squares solver.

**Parameters**

- a** : (M, N) array\_like  
Matrix to be pseudo-inverted.
- cond, rcond** : float, optional  
Cutoff for ‘small’ singular values in the least-squares solver. Singular values smaller than `rcond * largest_singular_value` are considered zero.
- return\_rank** : bool, optional  
if True, return the effective rank of the matrix
- check\_finite** : bool, optional  
Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns**

- B** : (N, M) ndarray  
The pseudo-inverse of matrix *a*.
- rank** : int  
The effective rank of the matrix. Returned if `return_rank == True`

**Raises**

- LinAlgError**  
If computation does not converge.

### Examples

```
>>> from scipy import linalg
>>> a = np.random.randn(9, 6)
>>> B = linalg.pinv(a)
>>> np.allclose(a, np.dot(a, np.dot(B, a)))
True
>>> np.allclose(B, np.dot(B, np.dot(a, B)))
True
```

`scipy.linalg.pinv2(a, cond=None, rcond=None, return_rank=False, check_finite=True)`  
 Compute the (Moore-Penrose) pseudo-inverse of a matrix.

Calculate a generalized inverse of a matrix using its singular-value decomposition and including all ‘large’ singular values.

**Parameters**

- a** : (M, N) array\_like  
Matrix to be pseudo-inverted.
- cond, rcond** : float or None  
Cutoff for ‘small’ singular values. Singular values smaller than  $rcond * largest\_singular\_value$  are considered zero. If None or -1, suitable machine precision is used.
- return\_rank** : bool, optional  
if True, return the effective rank of the matrix
- check\_finite** : bool, optional  
Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns**

- B** : (N, M) ndarray  
The pseudo-inverse of matrix *a*.
- rank** : int  
The effective rank of the matrix. Returned if `return_rank == True`

**Raises**

- LinAlgError**  
If SVD computation does not converge.

### Examples

```

>>> from scipy import linalg
>>> a = np.random.randn(9, 6)
>>> B = linalg.pinv2(a)
>>> np.allclose(a, np.dot(a, np.dot(B, a)))
True
>>> np.allclose(B, np.dot(B, np.dot(a, B)))
True
    
```

`scipy.linalg.pinvh(a, cond=None, rcond=None, lower=True, return_rank=False, check_finite=True)`  
 Compute the (Moore-Penrose) pseudo-inverse of a Hermitian matrix.

Calculate a generalized inverse of a Hermitian or real symmetric matrix using its eigenvalue decomposition and including all eigenvalues with ‘large’ absolute value.

**Parameters**

- a** : (N, N) array\_like  
Real symmetric or complex hermetian matrix to be pseudo-inverted
- cond, rcond** : float or None  
Cutoff for ‘small’ eigenvalues. Singular values smaller than  $rcond * largest\_eigenvalue$  are considered zero. If None or -1, suitable machine precision is used.
- lower** : bool, optional  
Whether the pertinent array data is taken from the lower or upper triangle of *a*. (Default: lower)
- return\_rank** : bool, optional  
if True, return the effective rank of the matrix
- check\_finite** : bool, optional  
Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns**

- B** : (N, N) ndarray  
The pseudo-inverse of matrix *a*.
- rank** : int  
The effective rank of the matrix. Returned if `return_rank == True`

**Raises**

- LinAlgError**  
If eigenvalue does not converge

**Examples**

```
>>> from scipy.linalg import pinvh
>>> a = np.random.randn(9, 6)
>>> a = np.dot(a, a.T)
>>> B = pinvh(a)
>>> np.allclose(a, np.dot(a, np.dot(B, a)))
True
>>> np.allclose(B, np.dot(B, np.dot(a, B)))
True
```

`scipy.linalg.kron(a, b)`

Kronecker product.

The result is the block matrix:

```
a[0,0]*b   a[0,1]*b   ... a[0,-1]*b
a[1,0]*b   a[1,1]*b   ... a[1,-1]*b
...
a[-1,0]*b  a[-1,1]*b  ... a[-1,-1]*b
```

**Parameters**

- a** : (M, N) ndarray  
Input array
- b** : (P, Q) ndarray  
Input array

**Returns**

- A** : (M\*P, N\*Q) ndarray  
Kronecker product of *a* and *b*.

**Examples**

```
>>> from numpy import array
>>> from scipy.linalg import kron
>>> kron(array([[1,2],[3,4]]), array([[1,1,1]]))
array([[1, 1, 1, 2, 2, 2],
       [3, 3, 3, 4, 4, 4]])
```

`scipy.linalg.tril(m, k=0)`

Make a copy of a matrix with elements above the k-th diagonal zeroed.

**Parameters**

- m** : array\_like  
Matrix whose elements to return
- k** : int, optional  
Diagonal above which to zero elements.  $k == 0$  is the main diagonal,  $k < 0$  subdiagonal and  $k > 0$  superdiagonal.

**Returns**

- tril** : ndarray  
Return is the same shape and type as *m*.

**Examples**

```
>>> from scipy.linalg import tril
>>> tril([[1,2,3],[4,5,6],[7,8,9],[10,11,12]], -1)
array([[ 0,  0,  0],
       [ 4,  0,  0],
       [ 7,  8,  0],
       [10, 11, 12]])
```

`scipy.linalg.triu(m, k=0)`

Make a copy of a matrix with elements below the k-th diagonal zeroed.

**Parameters** **m** : array\_like  
 Matrix whose elements to return  
**k** : int, optional  
 Diagonal below which to zero elements.  $k == 0$  is the main diagonal,  $k < 0$  subdiagonal and  $k > 0$  superdiagonal.

**Returns** **triu** : ndarray  
 Return matrix with zeroed elements below the k-th diagonal and has same shape and type as *m*.

**Examples**

```
>>> from scipy.linalg import triu
>>> triu([[1,2,3],[4,5,6],[7,8,9],[10,11,12]], -1)
array([[ 1,  2,  3],
       [ 4,  5,  6],
       [ 0,  8,  9],
       [ 0,  0, 12]])
```

`scipy.linalg.orthogonal_procrustes(A, B, check_finite=True)`

Compute the matrix solution of the orthogonal Procrustes problem.

Given matrices A and B of equal shape, find an orthogonal matrix R that most closely maps A to B [R140]. Note that unlike higher level Procrustes analyses of spatial data, this function only uses orthogonal transformations like rotations and reflections, and it does not use scaling or translation.

**Parameters** **A** : (M, N) array\_like  
 Matrix to be mapped.  
**B** : (M, N) array\_like  
 Target matrix.  
**check\_finite** : bool, optional  
 Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns** **R** : (N, N) ndarray  
 The matrix solution of the orthogonal Procrustes problem. Minimizes the Frobenius norm of  $\text{dot}(A, R) - B$ , subject to  $\text{dot}(R.T, R) == I$ .  
**scale** : float  
 Sum of the singular values of  $\text{dot}(A.T, B)$ .

**Raises** **ValueError**  
 If the input arrays are incompatibly shaped. This may also be raised if matrix A or B contains an inf or nan and check\_finite is True, or if the matrix product AB contains an inf or nan.

**Notes**

New in version 0.15.0.

**References**

[R140]

`scipy.linalg.matrix_balance(A, permute=True, scale=True, separate=False, overwrite_a=False)`

Compute a diagonal similarity transformation for row/column balancing.

The balancing tries to equalize the row and column 1-norms by applying a similarity transformation such that the magnitude variation of the matrix entries is reflected to the scaling matrices.

Moreover, if enabled, the matrix is first permuted to isolate the upper triangular parts of the matrix and, again if scaling is also enabled, only the remaining subblocks are subjected to scaling.

The balanced matrix satisfies the following equality

$$B = T^{-1}AT$$

The scaling coefficients are approximated to the nearest power of 2 to avoid round-off errors.

**Parameters**

- A** : (n, n) array\_like  
Square data matrix for the balancing.
- permute** : bool, optional  
The selector to define whether permutation of A is also performed prior to scaling.
- scale** : bool, optional  
The selector to turn on and off the scaling. If False, the matrix will not be scaled.
- separate** : bool, optional  
This switches from returning a full matrix of the transformation to a tuple of two separate 1D permutation and scaling arrays.
- overwrite\_a** : bool, optional  
This is passed to xGEBAL directly. Essentially, overwrites the result to the data. It might increase the space efficiency. See LAPACK manual for details. This is False by default.

**Returns**

- B** : (n, n) ndarray  
Balanced matrix
- T** : (n, n) ndarray  
A possibly permuted diagonal matrix whose nonzero entries are integer powers of 2 to avoid numerical truncation errors.
- scale, perm** : (n,) ndarray  
If `separate` keyword is set to True then instead of the array T above, the scaling and the permutation vectors are given separately as a tuple without allocating the full array T.

New in version 0.19.0.

### Notes

This algorithm is particularly useful for eigenvalue and matrix decompositions and in many cases it is already called by various LAPACK routines.

The algorithm is based on the well-known technique of [R136] and has been modified to account for special cases. See [R137] for details which have been implemented since LAPACK v3.5.0. Before this version there are corner cases where balancing can actually worsen the conditioning. See [R138] for such examples.

The code is a wrapper around LAPACK's xGEBAL routine family for matrix balancing.

### References

[R136], [R137], [R138]

### Examples

```
>>> from scipy import linalg
>>> x = np.array([[1,2,0], [9,1,0.01], [1,2,10*np.pi]])
```

```
>>> y, permscale = linalg.matrix_balance(x)
>>> np.abs(x).sum(axis=0) / np.abs(x).sum(axis=1)
array([ 3.66666667,  0.4995005 ,  0.91312162])
```

```
>>> np.abs(y).sum(axis=0) / np.abs(y).sum(axis=1)
array([ 1.2          ,  1.27041742,  0.92658316]) # may vary
```

```
>>> permscale # only powers of 2 (0.5 == 2^(-1))
array([[ 0.5,  0. ,  0. ], # may vary
       [ 0. ,  1. ,  0. ],
       [ 0. ,  0. ,  1. ]])
```

`scipy.linalg.subspace_angles(A, B)`

Compute the subspace angles between two matrices.

**Parameters**

- A** : (M, N) array\_like  
The first input array.
- B** : (M, K) array\_like  
The second input array.

**Returns**

- angles** : ndarray, shape (min(N, K),)  
The subspace angles between the column spaces of *A* and *B*.

**See also:**

*orth, svd*

**Notes**

This computes the subspace angles according to the formula provided in [R161]. For equivalence with MATLAB and Octave behavior, use `angles[0]`.

New in version 1.0.

**References**

[R161]

**Examples**

A Hadamard matrix, which has orthogonal columns, so we expect that the subspace angle to be  $\frac{\pi}{2}$ :

```
>>> from scipy.linalg import hadamard, subspace_angles
>>> H = hadamard(4)
>>> print(H)
[[ 1  1  1  1]
 [ 1 -1  1 -1]
 [ 1  1 -1 -1]
 [ 1 -1 -1  1]]
>>> np.rad2deg(subspace_angles(H[:, :2], H[:, 2:]))
array([ 90.,  90.])
```

And the subspace angle of a matrix to itself should be zero:

```
>>> subspace_angles(H[:, :2], H[:, :2]) <= 2 * np.finfo(float).eps
array([ True,  True], dtype=bool)
```

The angles between non-orthogonal subspaces are in between these extremes:

```
>>> x = np.random.RandomState(0).randn(4, 3)
>>> np.rad2deg(subspace_angles(x[:, :2], x[:, [2]]))
array([ 55.832])
```

**exception** `scipy.linalg.LinAlgError`

Generic Python-exception-derived object raised by linalg functions.

General purpose exception class, derived from Python's exception.Exception class, programmatically raised in linalg functions when a Linear Algebra-related condition would prevent further correct execution of the function.

**Parameters** None

**Examples**

```
>>> from numpy import linalg as LA
>>> LA.inv(np.zeros((2,2)))
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "...linalg.py", line 350,
    in inv return wrap(solve(a, identity(a.shape[0], dtype=a.dtype)))
  File "...linalg.py", line 249,
    in solve
    raise LinAlgError('Singular matrix')
numpy.linalg.LinAlgError: Singular matrix
```

## 5.9.2 Eigenvalue Problems

<code>eig(a[, b, left, right, overwrite_a, ...])</code>	Solve an ordinary or generalized eigenvalue problem of a square matrix.
<code>eigvals(a[, b, overwrite_a, check_finite, ...])</code>	Compute eigenvalues from an ordinary or generalized eigenvalue problem.
<code>eigh(a[, b, lower, eigvals_only, ...])</code>	Solve an ordinary or generalized eigenvalue problem for a complex Hermitian or real symmetric matrix.
<code>eigvalsh(a[, b, lower, overwrite_a, ...])</code>	Solve an ordinary or generalized eigenvalue problem for a complex Hermitian or real symmetric matrix.
<code>eig_banded(a_band[, lower, eigvals_only, ...])</code>	Solve real symmetric or complex hermitian band matrix eigenvalue problem.
<code>eigvals_banded(a_band[, lower, ...])</code>	Solve real symmetric or complex hermitian band matrix eigenvalue problem.
<code>eigh_tridiagonal(d, e[, eigvals_only, ...])</code>	Solve eigenvalue problem for a real symmetric tridiagonal matrix.
<code>eigvalsh_tridiagonal(d, e[, select, ...])</code>	Solve eigenvalue problem for a real symmetric tridiagonal matrix.

`scipy.linalg.eig(a, b=None, left=False, right=True, overwrite_a=False, overwrite_b=False, check_finite=True, homogeneous_eigvals=False)`

Solve an ordinary or generalized eigenvalue problem of a square matrix.

Find eigenvalues  $w$  and right or left eigenvectors of a general matrix:

```
a   vr[:,i] = w[i]           b   vr[:,i]
a.H vl[:,i] = w[i].conj()  b.H vl[:,i]
```

where `.H` is the Hermitian conjugation.

**Parameters**

- a** : (M, M) array\_like  
A complex or real matrix whose eigenvalues and eigenvectors will be computed.
- b** : (M, M) array\_like, optional  
Right-hand side matrix in a generalized eigenvalue problem. Default is None, identity matrix is assumed.
- left** : bool, optional  
Whether to calculate and return left eigenvectors. Default is False.
- right** : bool, optional  
Whether to calculate and return right eigenvectors. Default is True.
- overwrite\_a** : bool, optional  
Whether to overwrite *a*; may improve performance. Default is False.
- overwrite\_b** : bool, optional  
Whether to overwrite *b*; may improve performance. Default is False.
- check\_finite** : bool, optional  
Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.
- homogeneous\_eigvals** : bool, optional  
If True, return the eigenvalues in homogeneous coordinates. In this case *w* is a (2, M) array so that:

$$w[1, i] \ a \ vr[:, i] = w[0, i] \ b \ vr[:, i]$$

Default is False.

**Returns**

- w** : (M,) or (2, M) double or complex ndarray  
The eigenvalues, each repeated according to its multiplicity. The shape is (M,) unless `homogeneous_eigvals=True`.
- vl** : (M, M) double or complex ndarray  
The normalized left eigenvector corresponding to the eigenvalue `w[i]` is the column `vl[:,i]`. Only returned if `left=True`.
- vr** : (M, M) double or complex ndarray  
The normalized right eigenvector corresponding to the eigenvalue `w[i]` is the column `vr[:,i]`. Only returned if `right=True`.

**Raises**

- LinAlgError**  
If eigenvalue computation does not converge.

See also:

**eigvals** eigenvalues of general arrays

**eigh** Eigenvalues and right eigenvectors for symmetric/Hermitian arrays.

**eig\_banded** eigenvalues and right eigenvectors for symmetric/Hermitian band matrices

**eigh\_tridiagonal**  
eigenvalues and right eigenvectors for symmetric/Hermitian tridiagonal matrices

`scipy.linalg.eigvals` (*a*, *b=None*, *overwrite\_a=False*, *check\_finite=True*, *homogeneous\_eigvals=False*)

Compute eigenvalues from an ordinary or generalized eigenvalue problem.

Find eigenvalues of a general matrix:

$$a \quad vr[:, i] = w[i] \quad b \quad vr[:, i]$$

**Parameters**

- a** : (M, M) array\_like  
A complex or real matrix whose eigenvalues and eigenvectors will be computed.

**b** : (M, M) array\_like, optional  
Right-hand side matrix in a generalized eigenvalue problem. If omitted, identity matrix is assumed.

**overwrite\_a** : bool, optional  
Whether to overwrite data in a (may improve performance)

**check\_finite** : bool, optional  
Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**homogeneous\_eigvals** : bool, optional  
If True, return the eigenvalues in homogeneous coordinates. In this case *w* is a (2, M) array so that:

$$w[1, i] \ a \ v[:, i] = w[0, i] \ b \ v[:, i]$$

Default is False.

**Returns** **w** : (M,) or (2, M) double or complex ndarray  
The eigenvalues, each repeated according to its multiplicity but not in any specific order. The shape is (M,) unless `homogeneous_eigvals=True`.

**Raises** **LinAlgError**  
If eigenvalue computation does not converge

See also:

**eig** eigenvalues and right eigenvectors of general arrays.

**eigvalsh** eigenvalues of symmetric or Hermitian arrays

**eigvals\_banded**  
eigenvalues for symmetric/Hermitian band matrices

**eigvalsh\_tridiagonal**  
eigenvalues of symmetric/Hermitian tridiagonal matrices

`scipy.linalg.eigh(a, b=None, lower=True, eigvals_only=False, overwrite_a=False, overwrite_b=False, turbo=True, eigvals=None, type=1, check_finite=True)`  
Solve an ordinary or generalized eigenvalue problem for a complex Hermitian or real symmetric matrix.

Find eigenvalues *w* and optionally eigenvectors *v* of matrix *a*, where *b* is positive definite:

$$\begin{aligned} a \ v[:, i] &= w[i] \ b \ v[:, i] \\ v[i, :].conj() \ a \ v[:, i] &= w[i] \\ v[i, :].conj() \ b \ v[:, i] &= 1 \end{aligned}$$

**Parameters** **a** : (M, M) array\_like  
A complex Hermitian or real symmetric matrix whose eigenvalues and eigenvectors will be computed.

**b** : (M, M) array\_like, optional  
A complex Hermitian or real symmetric definite positive matrix in. If omitted, identity matrix is assumed.

**lower** : bool, optional  
Whether the pertinent array data is taken from the lower or upper triangle of *a*. (Default: lower)

**eigvals\_only** : bool, optional  
Whether to calculate only eigenvalues and no eigenvectors. (Default: both are calculated)

**turbo** : bool, optional

Use divide and conquer algorithm (faster but expensive in memory, only for generalized eigenvalue problem and if eigvals=None)

**eigvals** : tuple (lo, hi), optional

Indexes of the smallest and largest (in ascending order) eigenvalues and corresponding eigenvectors to be returned:  $0 \leq lo \leq hi \leq M-1$ . If omitted, all eigenvalues and eigenvectors are returned.

**type** : int, optional

Specifies the problem type to be solved:

type = 1:  $a v[:,i] = w[i] b v[:,i]$

type = 2:  $a b v[:,i] = w[i] v[:,i]$

type = 3:  $b a v[:,i] = w[i] v[:,i]$

**overwrite\_a** : bool, optional

Whether to overwrite data in *a* (may improve performance)

**overwrite\_b** : bool, optional

Whether to overwrite data in *b* (may improve performance)

**check\_finite** : bool, optional

Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns**

**w** : (N,) float ndarray

The N ( $1 \leq N \leq M$ ) selected eigenvalues, in ascending order, each repeated according to its multiplicity.

**v** : (M, N) complex ndarray

(if eigvals\_only == False)

The normalized selected eigenvector corresponding to the eigenvalue  $w[i]$  is the column  $v[:,i]$ .

Normalization:

type 1 and 3:  $v.conj() a v = w$

type 2:  $inv(v).conj() a inv(v) = w$

type = 1 or 2:  $v.conj() b v = I$

type = 3:  $v.conj() inv(b) v = I$

**Raises**

**LinAlgError**

If eigenvalue computation does not converge, an error occurred, or *b* matrix is not definite positive. Note that if input matrices are not symmetric or hermitian, no error is reported but results will be wrong.

**See also:**

**eigvalsh** eigenvalues of symmetric or Hermitian arrays

**eig** eigenvalues and right eigenvectors for non-symmetric arrays

**eigh** eigenvalues and right eigenvectors for symmetric/Hermitian arrays

**eigh\_tridiagonal**

eigenvalues and right eigenvectors for symmetric/Hermitian tridiagonal matrices

`scipy.linalg.eigvalsh` (*a*, *b=None*, *lower=True*, *overwrite\_a=False*, *overwrite\_b=False*, *turbo=True*, *eigvals=None*, *type=1*, *check\_finite=True*)

Solve an ordinary or generalized eigenvalue problem for a complex Hermitian or real symmetric matrix.

Find eigenvalues *w* of matrix *a*, where *b* is positive definite:

```

                a v[:,i] = w[i] b v[:,i]
v[i, :].conj() a v[:,i] = w[i]
v[i, :].conj() b v[:,i] = 1
    
```

**Parameters**

- a** : (M, M) array\_like  
A complex Hermitian or real symmetric matrix whose eigenvalues and eigenvectors will be computed.
- b** : (M, M) array\_like, optional  
A complex Hermitian or real symmetric definite positive matrix in. If omitted, identity matrix is assumed.
- lower** : bool, optional  
Whether the pertinent array data is taken from the lower or upper triangle of *a*. (Default: lower)
- turbo** : bool, optional  
Use divide and conquer algorithm (faster but expensive in memory, only for generalized eigenvalue problem and if eigvals=None)
- eigvals** : tuple (lo, hi), optional  
Indexes of the smallest and largest (in ascending order) eigenvalues and corresponding eigenvectors to be returned:  $0 \leq lo < hi \leq M-1$ . If omitted, all eigenvalues and eigenvectors are returned.
- type** : int, optional  
Specifies the problem type to be solved:  
  - type = 1:  $a v[:,i] = w[i] b v[:,i]$
  - type = 2:  $a b v[:,i] = w[i] v[:,i]$
  - type = 3:  $b a v[:,i] = w[i] v[:,i]$
- overwrite\_a** : bool, optional  
Whether to overwrite data in *a* (may improve performance)
- overwrite\_b** : bool, optional  
Whether to overwrite data in *b* (may improve performance)
- check\_finite** : bool, optional  
Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns**

- w** : (N,) float ndarray  
The N ( $1 \leq N \leq M$ ) selected eigenvalues, in ascending order, each repeated according to its multiplicity.

**Raises**

- LinAlgError**  
If eigenvalue computation does not converge, an error occurred, or *b* matrix is not definite positive. Note that if input matrices are not symmetric or hermitian, no error is reported but results will be wrong.

See also:

**eigh** eigenvalues and right eigenvectors for symmetric/Hermitian arrays

**eigvals** eigenvalues of general arrays

**eigvals\_banded**  
eigenvalues for symmetric/Hermitian band matrices

**eigvalsh\_tridiagonal**  
eigenvalues of symmetric/Hermitian tridiagonal matrices

`scipy.linalg.eig_banded`(*a\_band*, *lower=False*, *eigvals\_only=False*, *overwrite\_a\_band=False*, *select='a'*, *select\_range=None*, *max\_ev=0*, *check\_finite=True*)

Solve real symmetric or complex hermitian band matrix eigenvalue problem.

Find eigenvalues *w* and optionally right eigenvectors *v* of *a*:

```
a v[:,i] = w[i] v[:,i]
v.H v    = identity
```

The matrix `a` is stored in `a_band` either in lower diagonal or upper diagonal ordered form:

`a_band[u + i - j, j] == a[i,j]` (if upper form;  $i \leq j$ ) `a_band[ i - j, j] == a[i,j]` (if lower form;  $i \geq j$ )

where `u` is the number of bands above the diagonal.

Example of `a_band` (shape of `a` is (6,6), `u=2`):

```
upper form:
*   *   a02 a13 a24 a35
*   a01 a12 a23 a34 a45
a00 a11 a22 a33 a44 a55

lower form:
a00 a11 a22 a33 a44 a55
a10 a21 a32 a43 a54 *
a20 a31 a42 a53 *   *
```

Cells marked with `*` are not used.

- Parameters**
- a\_band** : (u+1, M) array\_like  
The bands of the M by M matrix `a`.
  - lower** : bool, optional  
Is the matrix in the lower form. (Default is upper form)
  - eigvals\_only** : bool, optional  
Compute only the eigenvalues and no eigenvectors. (Default: calculate also eigenvectors)
  - overwrite\_a\_band** : bool, optional  
Discard data in `a_band` (may enhance performance)
  - select** : {'a', 'v', 'i'}, optional  
Which eigenvalues to calculate
 

select	calculated
'a'	All eigenvalues
'v'	Eigenvalues in the interval (min, max]
'i'	Eigenvalues with indices $\text{min} \leq i \leq \text{max}$
  - select\_range** : (min, max), optional  
Range of selected eigenvalues
  - max\_ev** : int, optional  
For `select=='v'`, maximum number of eigenvalues expected. For other values of `select`, has no meaning.  
In doubt, leave this parameter untouched.
  - check\_finite** : bool, optional  
Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.
- Returns**
- w** : (M,) ndarray  
The eigenvalues, in ascending order, each repeated according to its multiplicity.
  - v** : (M, M) float or complex ndarray  
The normalized eigenvector corresponding to the eigenvalue `w[i]` is the column `v[:,i]`.
- Raises**
- LinAlgError**  
If eigenvalue computation does not converge.

See also:

**eigvals\_banded**

eigenvalues for symmetric/Hermitian band matrices

**eig**

eigenvalues and right eigenvectors of general arrays.

**eigh**

eigenvalues and right eigenvectors for symmetric/Hermitian arrays

**eigh\_tridiagonal**

eigenvalues and right eigenvectors for symmetric/Hermitian tridiagonal matrices

`scipy.linalg.eigvals_banded(a_band, lower=False, overwrite_a_band=False, select='a', select_range=None, check_finite=True)`

Solve real symmetric or complex hermitian band matrix eigenvalue problem.

Find eigenvalues  $w$  of  $a$ :

```
a v[:,i] = w[i] v[:,i]
v.H v    = identity
```

The matrix  $a$  is stored in  $a\_band$  either in lower diagonal or upper diagonal ordered form:
$$a\_band[u + i - j, j] == a[i, j] \text{ (if upper form; } i \leq j) \quad a\_band[i - j, j] == a[i, j] \text{ (if lower form; } i \geq j)$$
where  $u$  is the number of bands above the diagonal.Example of  $a\_band$  (shape of  $a$  is (6,6),  $u=2$ ):

```
upper form:
*   *   a02 a13 a24 a35
*   a01 a12 a23 a34 a45
a00 a11 a22 a33 a44 a55

lower form:
a00 a11 a22 a33 a44 a55
a10 a21 a32 a43 a54 *
a20 a31 a42 a53 *   *
```

Cells marked with \* are not used.

**Parameters****a\_band** : (u+1, M) array\_likeThe bands of the M by M matrix  $a$ .**lower** : bool, optional

Is the matrix in the lower form. (Default is upper form)

**overwrite\_a\_band** : bool, optionalDiscard data in  $a\_band$  (may enhance performance)**select** : {'a', 'v', 'i'}, optional

Which eigenvalues to calculate

select	calculated
'a'	All eigenvalues
'v'	Eigenvalues in the interval (min, max]
'i'	Eigenvalues with indices $\min \leq i \leq \max$

**select\_range** : (min, max), optional

Range of selected eigenvalues

**check\_finite** : bool, optional

Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns****w** : (M,) ndarray

The eigenvalues, in ascending order, each repeated according to its multiplicity.

**Raises** **LinAlgError**

If eigenvalue computation does not converge.

**See also:**

**eig\_banded** eigenvalues and right eigenvectors for symmetric/Hermitian band matrices

**eigvalsh\_tridiagonal** eigenvalues of symmetric/Hermitian tridiagonal matrices

**eigvals** eigenvalues of general arrays

**eigh** eigenvalues and right eigenvectors for symmetric/Hermitian arrays

**eig** eigenvalues and right eigenvectors for non-symmetric arrays

`scipy.linalg.eigh_tridiagonal(d, e, eigvals_only=False, select='a', select_range=None, check_finite=True, tol=0.0, lapack_driver='auto')`

Solve eigenvalue problem for a real symmetric tridiagonal matrix.

Find eigenvalues  $w$  and optionally right eigenvectors  $v$  of  $a$ :

$$a v[:,i] = w[i] v[:,i]$$

$$v.H v = \text{identity}$$

For a real symmetric matrix  $a$  with diagonal elements  $d$  and off-diagonal elements  $e$ .

**Parameters**

**d** : ndarray, shape (ndim,)

The diagonal elements of the array.

**e** : ndarray, shape (ndim-1,)

The off-diagonal elements of the array.

**select** : {'a', 'v', 'i'}, optional

Which eigenvalues to calculate

select	calculated
'a'	All eigenvalues
'v'	Eigenvalues in the interval (min, max]
'i'	Eigenvalues with indices $\text{min} \leq i \leq \text{max}$

**select\_range** : (min, max), optional

Range of selected eigenvalues

**check\_finite** : bool, optional

Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**tol** : float

The absolute tolerance to which each eigenvalue is required (only used when 'stebz' is the *lapack\_driver*). An eigenvalue (or cluster) is considered to have converged if it lies in an interval of this width. If  $\leq 0$ . (default), the value  $\text{eps} * |a|$  is used where  $\text{eps}$  is the machine precision, and  $|a|$  is the 1-norm of the matrix  $a$ .

**lapack\_driver** : str

LAPACK function to use, can be 'auto', 'stemr', 'stebz', 'sterf', or 'stev'. When 'auto' (default), it will use 'stemr' if  $\text{select}='a'$  and 'stebz' otherwise. When 'stebz' is used to find the eigenvalues and  $\text{eigvals\_only}=\text{False}$ , then a second LAPACK call (to ?STEIN) is used to find the corresponding eigenvectors. 'sterf' can only be used when  $\text{eigvals\_only}=\text{True}$  and  $\text{select}='a'$ . 'stev' can only be used when  $\text{select}='a'$ .

**Returns**

**w** : (M,) ndarray

The eigenvalues, in ascending order, each repeated according to its multiplicity.

**v** : (M, M) ndarray

The normalized eigenvector corresponding to the eigenvalue  $w[i]$  is the column  $v[:, i]$ .

**Raises** **LinAlgError**

If eigenvalue computation does not converge.

See also:

**eigvalsh\_tridiagonal**

eigenvalues of symmetric/Hermitian tridiagonal matrices

**eig** eigenvalues and right eigenvectors for non-symmetric arrays

**eigh** eigenvalues and right eigenvectors for symmetric/Hermitian arrays

**eig\_banded** eigenvalues and right eigenvectors for symmetric/Hermitian band matrices

**Notes**

This function makes use of LAPACK *S/DSTEMR* routines.

```
scipy.linalg.eigvalsh_tridiagonal(d, e, select='a', select_range=None, check_finite=True,
                                  tol=0.0, lapack_driver='auto')
```

Solve eigenvalue problem for a real symmetric tridiagonal matrix.

Find eigenvalues  $w$  of  $a$ :

```
a v[:,i] = w[i] v[:,i]
v.H v    = identity
```

For a real symmetric matrix  $a$  with diagonal elements  $d$  and off-diagonal elements  $e$ .

**Parameters** **d** : ndarray, shape (ndim,)

The diagonal elements of the array.

**e** : ndarray, shape (ndim-1,)

The off-diagonal elements of the array.

**select** : {'a', 'v', 'i'}, optional

Which eigenvalues to calculate

select	calculated
'a'	All eigenvalues
'v'	Eigenvalues in the interval (min, max]
'i'	Eigenvalues with indices $\min \leq i \leq \max$

**select\_range** : (min, max), optional

Range of selected eigenvalues

**check\_finite** : bool, optional

Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**tol** : float

The absolute tolerance to which each eigenvalue is required (only used when `lapack_driver='stebz'`). An eigenvalue (or cluster) is considered to have converged if it lies in an interval of this width. If  $\leq 0$ . (default), the value  $\text{eps} * |a|$  is used where  $\text{eps}$  is the machine precision, and  $|a|$  is the 1-norm of the matrix  $a$ .

**lapack\_driver** : str

LAPACK function to use, can be 'auto', 'stemr', 'stebz', 'sterf', or 'stev'. When 'auto' (default), it will use 'stemr' if `select='a'` and 'stebz' otherwise. 'sterf' and 'stev' can only be used when `select='a'`.

**Returns** **w** : (M,) ndarray

The eigenvalues, in ascending order, each repeated according to its multiplicity.

**Raises**

**LinAlgError**

If eigenvalue computation does not converge.

See also:

**eigh\_tridiagonal**

eigenvalues and right eigenvectors for symmetric/Hermitian tridiagonal matrices

### 5.9.3 Decompositions

<code>lu(a[, permute_l, overwrite_a, check_finite])</code>	Compute pivoted LU decomposition of a matrix.
<code>lu_factor(a[, overwrite_a, check_finite])</code>	Compute pivoted LU decomposition of a matrix.
<code>lu_solve(lu_and_piv, b[, trans, ...])</code>	Solve an equation system, $a x = b$ , given the LU factorization of $a$
<code>svd(a[, full_matrices, compute_uv, ...])</code>	Singular Value Decomposition.
<code>svdvals(a[, overwrite_a, check_finite])</code>	Compute singular values of a matrix.
<code>diagsvd(s, M, N)</code>	Construct the sigma matrix in SVD from singular values and size $M, N$ .
<code>orth(A)</code>	Construct an orthonormal basis for the range of $A$ using SVD
<code>cholesky(a[, lower, overwrite_a, check_finite])</code>	Compute the Cholesky decomposition of a matrix.
<code>cholesky_banded(ab[, overwrite_ab, lower, ...])</code>	Cholesky decompose a banded Hermitian positive-definite matrix
<code>cho_factor(a[, lower, overwrite_a, check_finite])</code>	Compute the Cholesky decomposition of a matrix, to use in <code>cho_solve</code>
<code>cho_solve(c_and_lower, b[, overwrite_b, ...])</code>	Solve the linear equations $A x = b$ , given the Cholesky factorization of $A$ .
<code>cho_solve_banded(cb_and_lower, b[, ...])</code>	Solve the linear equations $A x = b$ , given the Cholesky factorization of $A$ .
<code>polar(a[, side])</code>	Compute the polar decomposition.
<code>qr(a[, overwrite_a, lwork, mode, pivoting, ...])</code>	Compute QR decomposition of a matrix.
<code>qr_multiply(a, c[, mode, pivoting, ...])</code>	Calculate the QR decomposition and multiply $Q$ with a matrix.
<code>qr_update(Q, R, u, v[, overwrite_qruv, ...])</code>	Rank- $k$ QR update
<code>qr_delete(Q, R, k, int p=1[, which, ...])</code>	QR downdate on row or column deletions
<code>qr_insert(Q, R, u, k[, which, rcond, ...])</code>	QR update on row or column insertions
<code>rq(a[, overwrite_a, lwork, mode, check_finite])</code>	Compute RQ decomposition of a matrix.
<code>qz(A, B[, output, lwork, sort, overwrite_a, ...])</code>	QZ decomposition for generalized eigenvalues of a pair of matrices.
<code>ordqz(A, B[, sort, output, overwrite_a, ...])</code>	QZ decomposition for a pair of matrices with reordering.
<code>schur(a[, output, lwork, overwrite_a, sort, ...])</code>	Compute Schur decomposition of a matrix.
<code>rsf2csf(T, Z[, check_finite])</code>	Convert real Schur form to complex Schur form.
<code>hessenberg(a[, calc_q, overwrite_a, ...])</code>	Compute Hessenberg form of a matrix.

`scipy.linalg.lu(a, permute_l=False, overwrite_a=False, check_finite=True)`

Compute pivoted LU decomposition of a matrix.

The decomposition is:

$$A = P L U$$

where  $P$  is a permutation matrix,  $L$  lower triangular with unit diagonal elements, and  $U$  upper triangular.

**Parameters**

- a** : (M, N) array\_like  
Array to decompose
- permute\_l** : bool, optional  
Perform the multiplication P\*L (Default: do not permute)
- overwrite\_a** : bool, optional  
Whether to overwrite data in a (may improve performance)
- check\_finite** : bool, optional  
Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns**

**(If permute\_l == False)**

- p** : (M, M) ndarray  
Permutation matrix
- l** : (M, K) ndarray  
Lower triangular or trapezoidal matrix with unit diagonal.  $K = \min(M, N)$
- u** : (K, N) ndarray  
Upper triangular or trapezoidal matrix

**(If permute\_l == True)**

- pl** : (M, K) ndarray  
Permuted L matrix.  $K = \min(M, N)$
- u** : (K, N) ndarray  
Upper triangular or trapezoidal matrix

**Notes**

This is a LU factorization routine written for Scipy.

`scipy.linalg.lu_factor(a, overwrite_a=False, check_finite=True)`  
Compute pivoted LU decomposition of a matrix.

The decomposition is:

$$A = P L U$$

where P is a permutation matrix, L lower triangular with unit diagonal elements, and U upper triangular.

**Parameters**

- a** : (M, M) array\_like  
Matrix to decompose
- overwrite\_a** : bool, optional  
Whether to overwrite data in A (may increase performance)
- check\_finite** : bool, optional  
Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns**

- lu** : (N, N) ndarray  
Matrix containing U in its upper triangle, and L in its lower triangle. The unit diagonal elements of L are not stored.
- piv** : (N,) ndarray  
Pivot indices representing the permutation matrix P: row i of matrix was interchanged with row piv[i].

**See also:**

**lu\_solve** solve an equation system using the LU factorization of a matrix

*Notes*

This is a wrapper to the \*GETRF routines from LAPACK.

`scipy.linalg.lu_solve(lu_and_piv, b, trans=0, overwrite_b=False, check_finite=True)`

Solve an equation system,  $a x = b$ , given the LU factorization of  $a$

**Parameters** (lu, piv)

Factorization of the coefficient matrix  $a$ , as given by `lu_factor`

**b** : array  
Right-hand side

**trans** : {0, 1, 2}, optional  
Type of system to solve:

trans	system
0	$a x = b$
1	$a^T x = b$
2	$a^H x = b$

**overwrite\_b** : bool, optional  
Whether to overwrite data in  $b$  (may increase performance)

**check\_finite** : bool, optional  
Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns** **x** : array  
Solution to the system

**See also:**

**lu\_factor** LU factorize a matrix

`scipy.linalg.svd(a, full_matrices=True, compute_uv=True, overwrite_a=False, check_finite=True, lapack_driver='gesdd')`

Singular Value Decomposition.

Factorizes the matrix  $a$  into two unitary matrices  $U$  and  $Vh$ , and a 1-D array  $s$  of singular values (real, non-negative) such that  $a == U @ S @ Vh$ , where  $S$  is a suitably shaped matrix of zeros with main diagonal  $s$ .

**Parameters** **a** : (M, N) array\_like  
Matrix to decompose.

**full\_matrices** : bool, optional  
If True (default),  $U$  and  $Vh$  are of shape  $(M, M)$ ,  $(N, N)$ . If False, the shapes are  $(M, K)$  and  $(K, N)$ , where  $K = \min(M, N)$ .

**compute\_uv** : bool, optional  
Whether to compute also  $U$  and  $Vh$  in addition to  $s$ . Default is True.

**overwrite\_a** : bool, optional  
Whether to overwrite  $a$ ; may improve performance. Default is False.

**check\_finite** : bool, optional  
Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**lapack\_driver** : {'gesdd', 'gesvd'}, optional  
Whether to use the more efficient divide-and-conquer approach ('gesdd') or general rectangular approach ('gesvd') to compute the SVD. MATLAB and Octave use the 'gesvd' approach. Default is 'gesdd'.  
New in version 0.18.

**Returns** **U** : ndarray

Unitary matrix having left singular vectors as columns. Of shape  $(M, M)$  or  $(M, K)$ , depending on *full\_matrices*.

**s** : ndarray

The singular values, sorted in non-increasing order. Of shape  $(K,)$ , with  $K = \min(M, N)$ .

**Vh** : ndarray

Unitary matrix having right singular vectors as rows. Of shape  $(N, N)$  or  $(K, N)$  depending on *full\_matrices*.

For *compute\_uv=False*, only *s* is returned.

**Raises**

**LinAlgError**

If SVD computation does not converge.

**See also:**

**svdvals** Compute singular values of a matrix.

**diagsvd** Construct the Sigma matrix, given the vector *s*.

**Examples**

```
>>> from scipy import linalg
>>> m, n = 9, 6
>>> a = np.random.randn(m, n) + 1.j*np.random.randn(m, n)
>>> U, s, Vh = linalg.svd(a)
>>> U.shape, s.shape, Vh.shape
((9, 9), (6,), (6, 6))
```

Reconstruct the original matrix from the decomposition:

```
>>> sigma = np.zeros((m, n))
>>> for i in range(min(m, n)):
...     sigma[i, i] = s[i]
>>> a1 = np.dot(U, np.dot(sigma, Vh))
>>> np.allclose(a, a1)
True
```

Alternatively, use *full\_matrices=False* (notice that the shape of *U* is then  $(m, n)$  instead of  $(m, m)$ ):

```
>>> U, s, Vh = linalg.svd(a, full_matrices=False)
>>> U.shape, s.shape, Vh.shape
((9, 6), (6,), (6, 6))
>>> S = np.diag(s)
>>> np.allclose(a, np.dot(U, np.dot(S, Vh)))
True
```

```
>>> s2 = linalg.svd(a, compute_uv=False)
>>> np.allclose(s, s2)
True
```

`scipy.linalg.svdvals` (*a*, *overwrite\_a=False*, *check\_finite=True*)

Compute singular values of a matrix.

**Parameters** **a** :  $(M, N)$  array\_like

Matrix to decompose.

**overwrite\_a** : bool, optional

Whether to overwrite *a*; may improve performance. Default is False.

**check\_finite** : bool, optional

Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns** `s` : ( $\min(M, N)$ ,) ndarray  
The singular values, sorted in decreasing order.

**Raises** **LinAlgError**  
If SVD computation does not converge.

**See also:**

**svd** Compute the full singular value decomposition of a matrix.

**diagsvd** Construct the Sigma matrix, given the vector `s`.

**Notes**

`svdvals(a)` only differs from `svd(a, compute_uv=False)` by its handling of the edge case of empty `a`, where it returns an empty sequence:

```
>>> a = np.empty((0, 2))
>>> from scipy.linalg import svdvals
>>> svdvals(a)
array([], dtype=float64)
```

**Examples**

```
>>> from scipy.linalg import svdvals
>>> m = np.array([[1.0, 0.0],
...              [2.0, 3.0],
...              [1.0, 1.0],
...              [0.0, 2.0],
...              [1.0, 0.0]])
>>> svdvals(m)
array([ 4.28091555,  1.63516424])
```

We can verify the maximum singular value of  $m$  by computing the maximum length of  $m \cdot \text{dot}(u)$  over all the unit vectors  $u$  in the (x,y) plane. We approximate “all” the unit vectors with a large sample. Because of linearity, we only need the unit vectors with angles in  $[0, \pi]$ .

```
>>> t = np.linspace(0, np.pi, 2000)
>>> u = np.array([np.cos(t), np.sin(t)])
>>> np.linalg.norm(m.dot(u), axis=0).max()
4.2809152422538475
```

$p$  is a projection matrix with rank 1. With exact arithmetic, its singular values would be  $[1, 0, 0, 0]$ .

```
>>> v = np.array([0.1, 0.3, 0.9, 0.3])
>>> p = np.outer(v, v)
>>> svdvals(p)
array([ 1.00000000e+00,  2.02021698e-17,  1.56692500e-17,
        8.15115104e-34])
```

The singular values of an orthogonal matrix are all 1. Here we create a random orthogonal matrix by using the `rvs()` method of `scipy.stats.ortho_group`.

```
>>> from scipy.stats import ortho_group
>>> np.random.seed(123)
>>> orth = ortho_group.rvs(4)
```

```
>>> svdvals(orth)
array([ 1.,  1.,  1.,  1.]
```

`scipy.linalg.diagsvd`(*s*, *M*, *N*)

Construct the sigma matrix in SVD from singular values and size *M*, *N*.

**Parameters** *s* : (M,) or (N,) array\_like  
Singular values  
*M* : int  
Size of the matrix whose singular values are *s*.  
*N* : int  
Size of the matrix whose singular values are *s*.  
**Returns** *S* : (M, N) ndarray  
The S-matrix in the singular value decomposition

`scipy.linalg.orth`(*A*)

Construct an orthonormal basis for the range of *A* using SVD

**Parameters** *A* : (M, N) array\_like  
Input array  
**Returns** *Q* : (M, K) ndarray  
Orthonormal basis for the range of *A*. *K* = effective rank of *A*, as determined by automatic cutoff

**See also:**

**svd** Singular value decomposition of a matrix

`scipy.linalg.cholesky`(*a*, *lower=False*, *overwrite\_a=False*, *check\_finite=True*)

Compute the Cholesky decomposition of a matrix.

Returns the Cholesky decomposition,  $A = LL^*$  or  $A = U^*U$  of a Hermitian positive-definite matrix *A*.

**Parameters** *a* : (M, M) array\_like  
Matrix to be decomposed  
**lower** : bool, optional  
Whether to compute the upper or lower triangular Cholesky factorization. Default is upper-triangular.  
**overwrite\_a** : bool, optional  
Whether to overwrite data in *a* (may improve performance).  
**check\_finite** : bool, optional  
Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.  
**Returns** *c* : (M, M) ndarray  
Upper- or lower-triangular Cholesky factor of *a*.  
**Raises** **LinAlgError** : if decomposition fails.

**Examples**

```
>>> from scipy import array, linalg, dot
>>> a = array([[1, -2j], [2j, 5]])
>>> L = linalg.cholesky(a, lower=True)
>>> L
array([[ 1.+0.j,  0.+0.j],
       [ 0.+2.j,  1.+0.j]])
>>> dot(L, L.T.conj())
```

```
array([[ 1.+0.j,  0.-2.j],
       [ 0.+2.j,  5.+0.j]])
```

`scipy.linalg.cholesky_banded` (*ab*, *overwrite\_ab=False*, *lower=False*, *check\_finite=True*)  
 Cholesky decompose a banded Hermitian positive-definite matrix

The matrix *a* is stored in *ab* either in lower diagonal or upper diagonal ordered form:

```
ab[u + i - j, j] == a[i, j]      (if upper form; i <= j)
ab[    i - j, j] == a[i, j]      (if lower form; i >= j)
```

Example of *ab* (shape of *a* is (6,6), *u*=2):

```
upper form:
*   *   a02 a13 a24 a35
*   a01 a12 a23 a34 a45
a00 a11 a22 a33 a44 a55

lower form:
a00 a11 a22 a33 a44 a55
a10 a21 a32 a43 a54 *
a20 a31 a42 a53 *   *
```

**Parameters**

- ab** : (u + 1, M) array\_like  
Banded matrix
- overwrite\_ab** : bool, optional  
Discard data in *ab* (may enhance performance)
- lower** : bool, optional  
Is the matrix in the lower form. (Default is upper form)
- check\_finite** : bool, optional  
Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns**

- c** : (u + 1, M) ndarray  
Cholesky factorization of *a*, in the same banded format as *ab*

`scipy.linalg.cho_factor` (*a*, *lower=False*, *overwrite\_a=False*, *check\_finite=True*)  
 Compute the Cholesky decomposition of a matrix, to use in `cho_solve`

Returns a matrix containing the Cholesky decomposition,  $A = L L^*$  or  $A = U^* U$  of a Hermitian positive-definite matrix *a*. The return value can be directly used as the first parameter to `cho_solve`.

**Warning:** The returned matrix also contains random data in the entries not used by the Cholesky decomposition. If you need to zero these entries, use the function `cholesky` instead.

**Parameters**

- a** : (M, M) array\_like  
Matrix to be decomposed
- lower** : bool, optional  
Whether to compute the upper or lower triangular Cholesky factorization (Default: upper-triangular)
- overwrite\_a** : bool, optional  
Whether to overwrite data in *a* (may improve performance)
- check\_finite** : bool, optional

Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns** **c** : (M, M) ndarray  
Matrix whose upper or lower triangle contains the Cholesky factor of *a*. Other parts of the matrix contain random data.

**lower** : bool  
Flag indicating whether the factor is in the lower or upper triangle

**Raises** **LinAlgError**  
Raised if decomposition fails.

**See also:**

**cho\_solve** Solve a linear set equations using the Cholesky factorization of a matrix.

`scipy.linalg.cho_solve(c_and_lower, b, overwrite_b=False, check_finite=True)`

Solve the linear equations  $Ax = b$ , given the Cholesky factorization of *A*.

**Parameters** **(c, lower)** : tuple, (array, bool)  
Cholesky factorization of *a*, as given by `cho_factor`

**b** : array  
Right-hand side

**overwrite\_b** : bool, optional  
Whether to overwrite data in *b* (may improve performance)

**check\_finite** : bool, optional  
Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns** **x** : array  
The solution to the system  $Ax = b$

**See also:**

**cho\_factor** Cholesky factorization of a matrix

`scipy.linalg.cho_solve_banded(cb_and_lower, b, overwrite_b=False, check_finite=True)`

Solve the linear equations  $Ax = b$ , given the Cholesky factorization of *A*.

**Parameters** **(cb, lower)** : tuple, (array, bool)  
*cb* is the Cholesky factorization of *A*, as given by `cholesky_banded`. *lower* must be the same value that was given to `cholesky_banded`.

**b** : array  
Right-hand side

**overwrite\_b** : bool, optional  
If True, the function will overwrite the values in *b*.

**check\_finite** : bool, optional  
Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns** **x** : array  
The solution to the system  $Ax = b$

**See also:**

**cholesky\_banded**

Cholesky factorization of a banded matrix

**Notes**

New in version 0.8.0.

`scipy.linalg.polar(a, side='right')`

Compute the polar decomposition.

Returns the factors of the polar decomposition [R141]  $u$  and  $p$  such that  $a = up$  (if *side* is “right”) or  $a = pu$  (if *side* is “left”), where  $p$  is positive semidefinite. Depending on the shape of  $a$ , either the rows or columns of  $u$  are orthonormal. When  $a$  is a square array,  $u$  is a square unitary array. When  $a$  is not square, the “canonical polar decomposition” [R142] is computed.

**Parameters** **a** : (m, n) array\_like

The array to be factored.

**side** : {‘left’, ‘right’}, optional

Determines whether a right or left polar decomposition is computed. If *side* is “right”, then  $a = up$ . If *side* is “left”, then  $a = pu$ . The default is “right”.

**Returns** **u** : (m, n) ndarray

If  $a$  is square, then  $u$  is unitary. If  $m > n$ , then the columns of  $a$  are orthonormal, and if  $m < n$ , then the rows of  $u$  are orthonormal.

**p** : ndarray

$p$  is Hermitian positive semidefinite. If  $a$  is nonsingular,  $p$  is positive definite. The shape of  $p$  is (n, n) or (m, m), depending on whether *side* is “right” or “left”, respectively.

**References**

[R141], [R142]

**Examples**

```
>>> from scipy.linalg import polar
>>> a = np.array([[1, -1], [2, 4]])
>>> u, p = polar(a)
>>> u
array([[ 0.85749293, -0.51449576],
       [ 0.51449576,  0.85749293]])
>>> p
array([[ 1.88648444,  1.2004901 ],
       [ 1.2004901 ,  3.94446746]])
```

A non-square example, with  $m < n$ :

```
>>> b = np.array([[0.5, 1, 2], [1.5, 3, 4]])
>>> u, p = polar(b)
>>> u
array([[ -0.21196618, -0.42393237,  0.88054056],
       [  0.39378971,  0.78757942,  0.4739708 ]])
>>> p
array([[ 0.48470147,  0.96940295,  1.15122648],
       [ 0.96940295,  1.9388059 ,  2.30245295],
       [ 1.15122648,  2.30245295,  3.65696431]])
>>> u.dot(p) # Verify the decomposition.
array([[ 0.5,  1. ,  2. ],
       [ 1.5,  3. ,  4. ]])
>>> u.dot(u.T) # The rows of u are orthonormal.
array([[ 1.00000000e+00, -2.07353665e-17],
       [-2.07353665e-17,  1.00000000e+00]])
```

Another non-square example, with  $m > n$ :

```

>>> c = b.T
>>> u, p = polar(c)
>>> u
array([[ -0.21196618,  0.39378971],
       [ -0.42393237,  0.78757942],
       [  0.88054056,  0.4739708 ]])
>>> p
array([[ 1.23116567,  1.93241587],
       [ 1.93241587,  4.84930602]])
>>> u.dot(p) # Verify the decomposition.
array([[ 0.5,  1.5],
       [ 1. ,  3. ],
       [ 2. ,  4. ]])
>>> u.T.dot(u) # The columns of u are orthonormal.
array([[ 1.00000000e+00, -1.26363763e-16],
       [-1.26363763e-16,  1.00000000e+00]])

```

`scipy.linalg.qr` (*a*, *overwrite\_a=False*, *lwork=None*, *mode='full'*, *pivoting=False*, *check\_finite=True*)  
 Compute QR decomposition of a matrix.

Calculate the decomposition  $A = Q R$  where  $Q$  is unitary/orthogonal and  $R$  upper triangular.

**Parameters**

- a** : (M, N) array\_like  
Matrix to be decomposed
- overwrite\_a** : bool, optional  
Whether data in a is overwritten (may improve performance)
- lwork** : int, optional  
Work array size, `lwork >= a.shape[1]`. If None or -1, an optimal size is computed.
- mode** : {'full', 'r', 'economic', 'raw'}, optional  
Determines what information is to be returned: either both  $Q$  and  $R$  ('full', default), only  $R$  ('r') or both  $Q$  and  $R$  but computed in economy-size ('economic', see Notes). The final option 'raw' (added in SciPy 0.11) makes the function return two matrices ( $Q$ ,  $\tau$ ) in the internal format used by LAPACK.
- pivoting** : bool, optional  
Whether or not factorization should include pivoting for rank-revealing qr decomposition. If pivoting, compute the decomposition  $A P = Q R$  as above, but where  $P$  is chosen such that the diagonal of  $R$  is non-increasing.
- check\_finite** : bool, optional  
Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns**

- Q** : float or complex ndarray  
Of shape (M, M), or (M, K) for `mode='economic'`. Not returned if `mode='r'`.
- R** : float or complex ndarray  
Of shape (M, N), or (K, N) for `mode='economic'`.  $K = \min(M, N)$ .
- P** : int ndarray  
Of shape (N,) for `pivoting=True`. Not returned if `pivoting=False`.

**Raises**

- LinAlgError**  
Raised if decomposition fails

### Notes

This is an interface to the LAPACK routines `dgeqrf`, `zgeqrf`, `dorgqr`, `zungqr`, `dgeqp3`, and `zgeqp3`.

If `mode=economic`, the shapes of  $Q$  and  $R$  are (M, K) and (K, N) instead of (M,M) and (M,N), with  $K=\min(M, N)$ .

*Examples*

```
>>> from scipy import random, linalg, dot, diag, all, allclose
>>> a = random.randn(9, 6)
```

```
>>> q, r = linalg.qr(a)
>>> allclose(a, np.dot(q, r))
True
>>> q.shape, r.shape
((9, 9), (9, 6))
```

```
>>> r2 = linalg.qr(a, mode='r')
>>> allclose(r, r2)
True
```

```
>>> q3, r3 = linalg.qr(a, mode='economic')
>>> q3.shape, r3.shape
((9, 6), (6, 6))
```

```
>>> q4, r4, p4 = linalg.qr(a, pivoting=True)
>>> d = abs(diag(r4))
>>> all(d[1:] <= d[:-1])
True
>>> allclose(a[:, p4], dot(q4, r4))
True
>>> q4.shape, r4.shape, p4.shape
((9, 9), (9, 6), (6,))
```

```
>>> q5, r5, p5 = linalg.qr(a, mode='economic', pivoting=True)
>>> q5.shape, r5.shape, p5.shape
((9, 6), (6, 6), (6,))
```

`scipy.linalg.qr_multiply(a, c, mode='right', pivoting=False, conjugate=False, overwrite_a=False, overwrite_c=False)`

Calculate the QR decomposition and multiply Q with a matrix.

Calculate the decomposition  $A = QR$  where Q is unitary/orthogonal and R upper triangular. Multiply Q with a vector or a matrix c.

- Parameters**
- a** : array\_like, shape (M, N)  
Matrix to be decomposed
  - c** : array\_like, one- or two-dimensional  
calculate the product of c and q, depending on the mode:
  - mode** : {'left', 'right'}, optional  
dot(Q, c) is returned if mode is 'left', dot(c, Q) is returned if mode is 'right'.  
The shape of c must be appropriate for the matrix multiplications, if mode is 'left', `min(a.shape) == c.shape[0]`, if mode is 'right', `a.shape[0] == c.shape[1]`.
  - pivoting** : bool, optional  
Whether or not factorization should include pivoting for rank-revealing qr decomposition, see the documentation of qr.
  - conjugate** : bool, optional  
Whether Q should be complex-conjugated. This might be faster than explicit conjugation.
  - overwrite\_a** : bool, optional  
Whether data in a is overwritten (may improve performance)

**overwrite\_c** : bool, optional  
Whether data in *c* is overwritten (may improve performance). If this is used, *c* must be big enough to keep the result, i.e.  $c.shape[0] = a.shape[0]$  if mode is 'left'.

**Returns**

**CQ** : float or complex ndarray  
the product of *Q* and *c*, as defined in mode

**R** : float or complex ndarray  
Of shape (K, N),  $K = \min(M, N)$ .

**P** : ndarray of ints  
Of shape (N,) for `pivoting=True`. Not returned if `pivoting=False`.

**Raises**

**LinAlgError**  
Raised if decomposition fails

**Notes**

This is an interface to the LAPACK routines `dgeqrf`, `zgeqrf`, `dormqr`, `zunmqr`, `dgeqp3`, and `zgeqp3`.

New in version 0.11.0.

`scipy.linalg.qr_update` (*Q*, *R*, *u*, *v*, *overwrite\_qruv=False*, *check\_finite=True*)

Rank-k QR update

If  $A = QR$  is the QR factorization of *A*, return the QR factorization of  $A + uv^T$  for real *A* or  $A + uv^H$  for complex *A*.

**Parameters**

**Q** : (M, M) or (M, N) array\_like  
Unitary/orthogonal matrix from the qr decomposition of *A*.

**R** : (M, N) or (N, N) array\_like  
Upper triangular matrix from the qr decomposition of *A*.

**u** : (M,) or (M, k) array\_like  
Left update vector

**v** : (N,) or (N, k) array\_like  
Right update vector

**overwrite\_qruv** : bool, optional  
If True, consume *Q*, *R*, *u*, and *v*, if possible, while performing the update, otherwise make copies as necessary. Defaults to False.

**check\_finite** : bool, optional  
Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs. Default is True.

**Returns**

**Q1** : ndarray  
Updated unitary/orthogonal factor

**R1** : ndarray  
Updated upper triangular factor

**See also:**

`qr`, `qr_multiply`, `qr_delete`, `qr_insert`

**Notes**

This routine does not guarantee that the diagonal entries of *R1* are real or positive.

New in version 0.16.0.

**References**

[R149], [R150], [R151]

*Examples*

```
>>> from scipy import linalg
>>> a = np.array([[ 3., -2., -2.],
...              [ 6., -9., -3.],
...              [-3., 10.,  1.],
...              [ 6., -7.,  4.],
...              [ 7.,  8., -6.]])
>>> q, r = linalg.qr(a)
```

Given this q, r decomposition, perform a rank 1 update.

```
>>> u = np.array([7., -2., 4., 3., 5.])
>>> v = np.array([1., 3., -5.])
>>> q_up, r_up = linalg.qr_update(q, r, u, v, False)
>>> q_up
array([[ 0.54073807,  0.18645997,  0.81707661, -0.02136616,  0.06902409], # may vary (signs)
       [ 0.21629523, -0.63257324,  0.06567893,  0.34125904, -0.65749222],
       [ 0.05407381,  0.64757787, -0.12781284, -0.20031219, -0.72198188],
       [ 0.48666426, -0.30466718, -0.27487277, -0.77079214,  0.0256951 ],
       [ 0.64888568,  0.23001   , -0.4859845 ,  0.49883891,  0.20253783]])
>>> r_up
array([[ 18.49324201,  24.11691794, -44.98940746], # may vary (signs)
       [  0.          , 31.95894662, -27.40998201],
       [  0.          ,  0.          , -9.25451794],
       [  0.          ,  0.          ,  0.          ],
       [  0.          ,  0.          ,  0.          ]])
```

The update is equivalent, but faster than the following.

```
>>> a_up = a + np.outer(u, v)
>>> q_direct, r_direct = linalg.qr(a_up)
```

Check that we have equivalent results:

```
>>> np.allclose(np.dot(q_up, r_up), a_up)
True
```

And the updated Q is still unitary:

```
>>> np.allclose(np.dot(q_up.T, q_up), np.eye(5))
True
```

Updating economic (reduced, thin) decompositions is also possible:

```
>>> qe, re = linalg.qr(a, mode='economic')
>>> qe_up, re_up = linalg.qr_update(qe, re, u, v, False)
>>> qe_up
array([[ 0.54073807,  0.18645997,  0.81707661], # may vary (signs)
       [ 0.21629523, -0.63257324,  0.06567893],
       [ 0.05407381,  0.64757787, -0.12781284],
       [ 0.48666426, -0.30466718, -0.27487277],
       [ 0.64888568,  0.23001   , -0.4859845 ]])
>>> re_up
array([[ 18.49324201,  24.11691794, -44.98940746], # may vary (signs)
       [  0.          , 31.95894662, -27.40998201],
       [  0.          ,  0.          , -9.25451794]])
```

```
>>> np.allclose(np.dot(qe_up, re_up), a_up)
True
>>> np.allclose(np.dot(qe_up.T, qe_up), np.eye(3))
True
```

Similarly to the above, perform a rank 2 update.

```
>>> u2 = np.array([[ 7., -1.],
...               [-2.,  4.],
...               [ 4.,  2.],
...               [ 3., -6.],
...               [ 5.,  3.]])
>>> v2 = np.array([[ 1.,  2.],
...               [ 3.,  4.],
...               [-5.,  2.]])
>>> q_up2, r_up2 = linalg.qr_update(q, r, u2, v2, False)
>>> q_up2
array([[ -0.33626508, -0.03477253,  0.61956287, -0.64352987, -0.29618884], # may vary
      [-0.50439762,  0.58319694, -0.43010077, -0.33395279,  0.33008064],
      [-0.21016568, -0.63123106,  0.0582249 , -0.13675572,  0.73163206],
      [ 0.12609941,  0.49694436,  0.64590024,  0.31191919,  0.47187344],
      [-0.75659643, -0.11517748,  0.10284903,  0.5986227 , -0.21299983]])
>>> r_up2
array([[ -23.79075451, -41.1084062 ,  24.71548348], # may vary (signs)
      [  0.          , -33.83931057,  11.02226551],
      [  0.          ,  0.          ,  48.91476811],
      [  0.          ,  0.          ,  0.          ],
      [  0.          ,  0.          ,  0.          ]])
```

This update is also a valid qr decomposition of  $A + U V^* T$ .

```
>>> a_up2 = a + np.dot(u2, v2.T)
>>> np.allclose(a_up2, np.dot(q_up2, r_up2))
True
>>> np.allclose(np.dot(q_up2.T, q_up2), np.eye(5))
True
```

`scipy.linalg.qr_delete(Q, R, k, int p=1, which='row', overwrite_qr=False, check_finite=True)`

QR downdate on row or column deletions

If  $A = Q R$  is the QR factorization of  $A$ , return the QR factorization of  $A$  where  $p$  rows or columns have been removed starting at row or column  $k$ .

- Parameters**
- Q** : (M, M) or (M, N) array\_like  
Unitary/orthogonal matrix from QR decomposition.
  - R** : (M, N) or (N, N) array\_like  
Upper triangular matrix from QR decomposition.
  - k** : int  
Index of the first row or column to delete.
  - p** : int, optional  
Number of rows or columns to delete, defaults to 1.
  - which** : {'row', 'col'}, optional  
Determines if rows or columns will be deleted, defaults to 'row'
  - overwrite\_qr** : bool, optional  
If True, consume Q and R, overwriting their contents with their downdated versions, and returning appropriately sized views. Defaults to False.

**check\_finite** : bool, optional

Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs. Default is True.

**Returns**

**Q1** : ndarray  
Updated unitary/orthogonal factor

**R1** : ndarray  
Updated upper triangular factor

**See also:**

`qr`, `qr_multiply`, `qr_insert`, `qr_update`

**Notes**

This routine does not guarantee that the diagonal entries of R1 are positive.

New in version 0.16.0.

**References**

[R143], [R144], [R145]

**Examples**

```
>>> from scipy import linalg
>>> a = np.array([[ 3., -2., -2.],
...              [ 6., -9., -3.],
...              [-3., 10.,  1.],
...              [ 6., -7.,  4.],
...              [ 7.,  8., -6.]])
>>> q, r = linalg.qr(a)
```

Given this QR decomposition, update q and r when 2 rows are removed.

```
>>> q1, r1 = linalg.qr_delete(q, r, 2, 2, 'row', False)
>>> q1
array([[ 0.30942637,  0.15347579,  0.93845645], # may vary (signs)
       [ 0.61885275,  0.71680171, -0.32127338],
       [ 0.72199487, -0.68017681, -0.12681844]])
>>> r1
array([[ 9.69535971, -0.4125685 , -6.80738023], # may vary (signs)
       [ 0.          , -12.19958144,  1.62370412],
       [ 0.          ,  0.          , -0.15218213]])
```

The update is equivalent, but faster than the following.

```
>>> a1 = np.delete(a, slice(2,4), 0)
>>> a1
array([[ 3., -2., -2.],
       [ 6., -9., -3.],
       [ 7.,  8., -6.]])
>>> q_direct, r_direct = linalg.qr(a1)
```

Check that we have equivalent results:

```
>>> np.dot(q1, r1)
array([[ 3., -2., -2.],
       [ 6., -9., -3.],
       [ 7.,  8., -6.]])
```

```
>>> np.allclose(np.dot(q1, r1), a1)
True
```

And the updated Q is still unitary:

```
>>> np.allclose(np.dot(q1.T, q1), np.eye(3))
True
```

```
scipy.linalg.qr_insert(Q, R, u, k, which='row', rcond=None, overwrite_qru=False,
                      check_finite=True)
```

QR update on row or column insertions

If  $A = QR$  is the QR factorization of  $A$ , return the QR factorization of  $A$  where rows or columns have been inserted starting at row or column  $k$ .

**Parameters**

- Q** : (M, M) array\_like  
Unitary/orthogonal matrix from the QR decomposition of  $A$ .
- R** : (M, N) array\_like  
Upper triangular matrix from the QR decomposition of  $A$ .
- u** : (N,), (p, N), (M,), or (M, p) array\_like  
Rows or columns to insert
- k** : int  
Index before which  $u$  is to be inserted.
- which** : {'row', 'col'}, optional  
Determines if rows or columns will be inserted, defaults to 'row'
- rcond** : float  
Lower bound on the reciprocal condition number of  $Q$  augmented with  $u/||u||$ . Only used when updating economic mode (thin, (M,N) (N,N)) decompositions. If None, machine precision is used. Defaults to None.
- overwrite\_qru** : bool, optional  
If True, consume  $Q$ ,  $R$ , and  $u$ , if possible, while performing the update, otherwise make copies as necessary. Defaults to False.
- check\_finite** : bool, optional  
Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs. Default is True.

**Returns**

- Q1** : ndarray  
Updated unitary/orthogonal factor
- R1** : ndarray  
Updated upper triangular factor

**Raises**

- LinAlgError** :  
If updating a (M,N) (N,N) factorization and the reciprocal condition number of  $Q$  augmented with  $u/||u||$  is smaller than  $rcond$ .

**See also:**

`qr`, `qr_multiply`, `qr_delete`, `qr_update`

**Notes**

This routine does not guarantee that the diagonal entries of  $R1$  are positive.

New in version 0.16.0.

**References**

[R146], [R147], [R148]

*Examples*

```
>>> from scipy import linalg
>>> a = np.array([[ 3., -2., -2.],
...              [ 6., -7.,  4.],
...              [ 7.,  8., -6.]])
>>> q, r = linalg.qr(a)
```

Given this QR decomposition, update q and r when 2 rows are inserted.

```
>>> u = np.array([[ 6., -9., -3.],
...              [-3., 10.,  1.]])
>>> q1, r1 = linalg.qr_insert(q, r, u, 2, 'row')
>>> q1
array([[ -0.25445668,  0.02246245,  0.18146236, -0.72798806,  0.60979671], # may vary (signs)
       [-0.50891336,  0.23226178, -0.82836478, -0.02837033, -0.00828114],
       [-0.50891336,  0.35715302,  0.38937158,  0.58110733,  0.35235345],
       [ 0.25445668, -0.52202743, -0.32165498,  0.36263239,  0.65404509],
       [-0.59373225, -0.73856549,  0.16065817, -0.0063658 , -0.27595554]])
>>> r1
array([[ -11.78982612,  6.44623587,  3.81685018], # may vary (signs)
       [  0.          , -16.01393278,  3.72202865],
       [  0.          ,  0.          , -6.13010256],
       [  0.          ,  0.          ,  0.          ],
       [  0.          ,  0.          ,  0.          ]])
```

The update is equivalent, but faster than the following.

```
>>> a1 = np.insert(a, 2, u, 0)
>>> a1
array([[ 3., -2., -2.],
       [ 6., -7.,  4.],
       [ 6., -9., -3.],
       [-3., 10.,  1.],
       [ 7.,  8., -6.]])
>>> q_direct, r_direct = linalg.qr(a1)
```

Check that we have equivalent results:

```
>>> np.dot(q1, r1)
array([[ 3., -2., -2.],
       [ 6., -7.,  4.],
       [ 6., -9., -3.],
       [-3., 10.,  1.],
       [ 7.,  8., -6.]])
```

```
>>> np.allclose(np.dot(q1, r1), a1)
True
```

And the updated Q is still unitary:

```
>>> np.allclose(np.dot(q1.T, q1), np.eye(5))
True
```

`scipy.linalg.rq(a, overwrite_a=False, lwork=None, mode='full', check_finite=True)`

Compute RQ decomposition of a matrix.

Calculate the decomposition  $A = R Q$  where Q is unitary/orthogonal and R upper triangular.

**Parameters**

- a** : (M, N) array\_like  
Matrix to be decomposed
- overwrite\_a** : bool, optional  
Whether data in a is overwritten (may improve performance)
- lwork** : int, optional  
Work array size, lwork >= a.shape[1]. If None or -1, an optimal size is computed.
- mode** : {'full', 'r', 'economic'}, optional  
Determines what information is to be returned: either both Q and R ('full', default), only R ('r') or both Q and R but computed in economy-size ('economic', see Notes).
- check\_finite** : bool, optional  
Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns**

- R** : float or complex ndarray  
Of shape (M, N) or (M, K) for mode='economic'.  $K = \min(M, N)$ .
- Q** : float or complex ndarray  
Of shape (N, N) or (K, N) for mode='economic'. Not returned if mode='r'.

**Raises**

- LinAlgError**  
If decomposition fails.

### Notes

This is an interface to the LAPACK routines sgerqf, dgerqf, cgerqf, zgerqf, sorgqr, dorgqr, cungrq and zungrq. If mode=economic, the shapes of Q and R are (K, N) and (M, K) instead of (N,N) and (M,N), with  $K=\min(M, N)$ .

### Examples

```
>>> from scipy import linalg
>>> from numpy import random, dot, allclose
>>> a = random.randn(6, 9)
>>> r, q = linalg.rq(a)
>>> allclose(a, dot(r, q))
True
>>> r.shape, q.shape
((6, 9), (9, 9))
>>> r2 = linalg.rq(a, mode='r')
>>> allclose(r, r2)
True
>>> r3, q3 = linalg.rq(a, mode='economic')
>>> r3.shape, q3.shape
((6, 6), (6, 9))
```

`scipy.linalg.qz(A, B, output='real', lwork=None, sort=None, overwrite_a=False, overwrite_b=False, check_finite=True)`

QZ decomposition for generalized eigenvalues of a pair of matrices.

The QZ, or generalized Schur, decomposition for a pair of  $N \times N$  nonsymmetric matrices (A,B) is:

$$(A, B) = (Q * AA * Z', Q * BB * Z')$$

where AA, BB is in generalized Schur form if BB is upper-triangular with non-negative diagonal and AA is upper-triangular, or for real QZ decomposition (output='real') block upper triangular with 1x1 and 2x2 blocks. In this case, the 1x1 blocks correspond to real generalized eigenvalues and 2x2 blocks are 'standardized' by making the corresponding elements of BB have the form:

```
[ a 0 ]
[ 0 b ]
```

and the pair of corresponding 2x2 blocks in **AA** and **BB** will have a complex conjugate pair of generalized eigenvalues. If (`output='complex'`) or **A** and **B** are complex matrices, **Z**' denotes the conjugate-transpose of **Z**. **Q** and **Z** are unitary matrices.

**Parameters**

- A** : (N, N) array\_like  
2d array to decompose
- B** : (N, N) array\_like  
2d array to decompose
- output** : {'real', 'complex'}, optional  
Construct the real or complex QZ decomposition for real matrices. Default is 'real'.
- lwork** : int, optional  
Work array size. If None or -1, it is automatically computed.
- sort** : {None, callable, 'lhp', 'rhp', 'iuc', 'ouc'}, optional  
NOTE: THIS INPUT IS DISABLED FOR NOW. Use `ordqz` instead.  
Specifies whether the upper eigenvalues should be sorted. A callable may be passed that, given a eigenvalue, returns a boolean denoting whether the eigenvalue should be sorted to the top-left (True). For real matrix pairs, the sort function takes three real arguments (`alphan`, `alpha`, `beta`). The eigenvalue  $x = (\text{alphan} + \text{alpha} \cdot 1j) / \text{beta}$ . For complex matrix pairs or `output='complex'`, the sort function takes two complex arguments (`alpha`, `beta`). The eigenvalue  $x = (\text{alpha} / \text{beta})$ . Alternatively, string parameters may be used:
  - 'lhp' Left-hand plane (`x.real < 0.0`)
  - 'rhp' Right-hand plane (`x.real > 0.0`)
  - 'iuc' Inside the unit circle (`x*x.conjugate() < 1.0`)
  - 'ouc' Outside the unit circle (`x*x.conjugate() > 1.0`)
 Defaults to None (no sorting).
- overwrite\_a** : bool, optional  
Whether to overwrite data in **a** (may improve performance)
- overwrite\_b** : bool, optional  
Whether to overwrite data in **b** (may improve performance)
- check\_finite** : bool, optional  
If true checks the elements of **A** and **B** are finite numbers. If false does no checking and passes matrix through to underlying algorithm.

**Returns**

- AA** : (N, N) ndarray  
Generalized Schur form of **A**.
- BB** : (N, N) ndarray  
Generalized Schur form of **B**.
- Q** : (N, N) ndarray  
The left Schur vectors.
- Z** : (N, N) ndarray  
The right Schur vectors.

**See also:**

`ordqz`

**Notes**

**Q** is transposed versus the equivalent function in Matlab.

New in version 0.11.0.

**Examples**

```

>>> from scipy import linalg
>>> np.random.seed(1234)
>>> A = np.arange(9).reshape((3, 3))
>>> B = np.random.randn(3, 3)

>>> AA, BB, Q, Z = linalg.qz(A, B)
>>> AA
array([[ -13.40928183,  -4.62471562,   1.09215523],
       [  0.          ,   0.          ,  1.22805978],
       [  0.          ,   0.          ,  0.31973817]])
>>> BB
array([[ 0.33362547, -1.37393632,  0.02179805],
       [ 0.          ,  1.68144922,  0.74683866],
       [ 0.          ,  0.          ,  0.9258294 ]])
>>> Q
array([[ 0.14134727, -0.97562773,  0.16784365],
       [ 0.49835904, -0.07636948, -0.86360059],
       [ 0.85537081,  0.20571399,  0.47541828]])
>>> Z
array([[ -0.24900855, -0.51772687,  0.81850696],
       [ -0.79813178,  0.58842606,  0.12938478],
       [ -0.54861681, -0.6210585 , -0.55973739]])

```

`scipy.linalg.ordqz(A, B, sort='lhp', output='real', overwrite_a=False, overwrite_b=False, check_finite=True)`  
 QZ decomposition for a pair of matrices with reordering.

New in version 0.17.0.

**Parameters**

- A** : (N, N) array\_like  
2d array to decompose
- B** : (N, N) array\_like  
2d array to decompose
- sort** : {callable, 'lhp', 'rhp', 'iuc', 'ouc'}, optional  
Specifies whether the upper eigenvalues should be sorted. A callable may be passed that, given an ordered pair (alpha, beta) representing the eigenvalue  $x = (\alpha/\beta)$ , returns a boolean denoting whether the eigenvalue should be sorted to the top-left (True). For the real matrix pairs beta is real while alpha can be complex, and for complex matrix pairs both alpha and beta can be complex. The callable must be able to accept a numpy array. Alternatively, string parameters may be used:
  - 'lhp' Left-hand plane ( $x.\text{real} < 0.0$ )
  - 'rhp' Right-hand plane ( $x.\text{real} > 0.0$ )
  - 'iuc' Inside the unit circle ( $x*x.\text{conjugate}() < 1.0$ )
  - 'ouc' Outside the unit circle ( $x*x.\text{conjugate}() > 1.0$ )

With the predefined sorting functions, an infinite eigenvalue (i.e.  $\alpha \neq 0$  and  $\beta = 0$ ) is considered to lie in neither the left-hand nor the right-hand plane, but it is considered to lie outside the unit circle. For the eigenvalue  $(\alpha, \beta) = (0, 0)$  the predefined sorting functions all return *False*.

- output** : str {'real', 'complex'}, optional  
Construct the real or complex QZ decomposition for real matrices. Default is 'real'.
- overwrite\_a** : bool, optional  
If True, the contents of A are overwritten.
- overwrite\_b** : bool, optional  
If True, the contents of B are overwritten.

**check\_finite** : bool, optional  
 If true checks the elements of *A* and *B* are finite numbers. If false does no checking and passes matrix through to underlying algorithm.

**Returns**

- AA** : (N, N) ndarray  
 Generalized Schur form of *A*.
- BB** : (N, N) ndarray  
 Generalized Schur form of *B*.
- alpha** : (N,) ndarray  
 $\alpha = \alpha_{\text{real}} + \alpha_{\text{imag}} * 1j$ . See notes.
- beta** : (N,) ndarray  
 See notes.
- Q** : (N, N) ndarray  
 The left Schur vectors.
- Z** : (N, N) ndarray  
 The right Schur vectors.

**See also:**

*qz*

**Notes**

On exit,  $(\text{ALPHAR}(j) + \text{ALPHAI}(j) * i) / \text{BETA}(j)$ ,  $j=1, \dots, N$ , will be the generalized eigenvalues.  $\text{ALPHAR}(j) + \text{ALPHAI}(j) * i$  and  $\text{BETA}(j)$ ,  $j=1, \dots, N$  are the diagonals of the complex Schur form (S,T) that would result if the 2-by-2 diagonal blocks of the real generalized Schur form of (A,B) were further reduced to triangular form using complex unitary transformations. If  $\text{ALPHAI}(j)$  is zero, then the *j*-th eigenvalue is real; if positive, then the *j*-th and (*j*+1)-st eigenvalues are a complex conjugate pair, with  $\text{ALPHAI}(j+1)$  negative.

`scipy.linalg.schur(a, output='real', lwork=None, overwrite_a=False, sort=None, check_finite=True)`  
 Compute Schur decomposition of a matrix.

The Schur decomposition is:

$$A = Z T Z^H$$

where *Z* is unitary and *T* is either upper-triangular, or for real Schur decomposition (output='real'), quasi-upper triangular. In the quasi-triangular form, 2x2 blocks describing complex-valued eigenvalue pairs may extrude from the diagonal.

**Parameters**

- a** : (M, M) array\_like  
 Matrix to decompose
- output** : {'real', 'complex'}, optional  
 Construct the real or complex Schur decomposition (for real matrices).
- lwork** : int, optional  
 Work array size. If None or -1, it is automatically computed.
- overwrite\_a** : bool, optional  
 Whether to overwrite data in *a* (may improve performance).
- sort** : {None, callable, 'lhp', 'rhp', 'iuc', 'ouc'}, optional  
 Specifies whether the upper eigenvalues should be sorted. A callable may be passed that, given a eigenvalue, returns a boolean denoting whether the eigenvalue should be sorted to the top-left (True). Alternatively, string parameters may be used:

```
'lhp' Left-hand plane (x.real < 0.0)
'rhp' Right-hand plane (x.real > 0.0)
'iuc' Inside the unit circle (x*x.conjugate() <= 1.0)
'ouc' Outside the unit circle (x*x.conjugate() > 1.0)
```

Defaults to None (no sorting).

**check\_finite** : bool, optional

Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns**

**T** : (M, M) ndarray

Schur form of A. It is real-valued for the real Schur decomposition.

**Z** : (M, M) ndarray

An unitary Schur transformation matrix for A. It is real-valued for the real Schur decomposition.

**sdim** : int

If and only if sorting was requested, a third return value will contain the number of eigenvalues satisfying the sort condition.

**Raises**

**LinAlgError**

Error raised under three conditions:

- 1.The algorithm failed due to a failure of the QR algorithm to compute all eigenvalues
- 2.If eigenvalue sorting was requested, the eigenvalues could not be reordered due to a failure to separate eigenvalues, usually because of poor conditioning
- 3.If eigenvalue sorting was requested, roundoff errors caused the leading eigenvalues to no longer satisfy the sorting condition

**See also:**

**rsf2csf** Convert real Schur form to complex Schur form

`scipy.linalg.rsf2csf(T, Z, check_finite=True)`

Convert real Schur form to complex Schur form.

Convert a quasi-diagonal real-valued Schur form to the upper triangular complex-valued Schur form.

**Parameters** **T** : (M, M) array\_like

Real Schur form of the original matrix

**Z** : (M, M) array\_like

Schur transformation matrix

**check\_finite** : bool, optional

Whether to check that the input matrices contain only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns**

**T** : (M, M) ndarray

Complex Schur form of the original matrix

**Z** : (M, M) ndarray

Schur transformation matrix corresponding to the complex form

**See also:**

**schur** Schur decompose a matrix

`scipy.linalg.hessenberg(a, calc_q=False, overwrite_a=False, check_finite=True)`

Compute Hessenberg form of a matrix.

The Hessenberg decomposition is:

$$A = Q H Q^H$$

where  $Q$  is unitary/orthogonal and  $H$  has only zero elements below the first sub-diagonal.

**Parameters** **a** : (M, M) array\_like

Matrix to bring into Hessenberg form.

**calc\_q** : bool, optional

Whether to compute the transformation matrix. Default is False.

**overwrite\_a** : bool, optional

Whether to overwrite *a*; may improve performance. Default is False.

**check\_finite** : bool, optional

Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns**

**H** : (M, M) ndarray

Hessenberg form of *a*.

**Q** : (M, M) ndarray

Unitary/orthogonal similarity transformation matrix  $A = Q H Q^H$ . Only returned if `calc_q=True`.

**See also:**

`scipy.linalg.interpolative` – Interpolative matrix decompositions

## 5.9.4 Matrix Functions

<code>expm(A)</code>	Compute the matrix exponential using Pade approximation.
<code>logm(A[, disp])</code>	Compute matrix logarithm.
<code>cosm(A)</code>	Compute the matrix cosine.
<code>sinm(A)</code>	Compute the matrix sine.
<code>tanm(A)</code>	Compute the matrix tangent.
<code>coshm(A)</code>	Compute the hyperbolic matrix cosine.
<code>sinhm(A)</code>	Compute the hyperbolic matrix sine.
<code>tanhm(A)</code>	Compute the hyperbolic matrix tangent.
<code>signm(A[, disp])</code>	Matrix sign function.
<code>sqrtn(A[, disp, blocksize])</code>	Matrix square root.
<code>funm(A, func[, disp])</code>	Evaluate a matrix function specified by a callable.
<code>expm_frechet(A, E[, method, compute_expm, ...])</code>	Frechet derivative of the matrix exponential of A in the direction E.
<code>expm_cond(A[, check_finite])</code>	Relative condition number of the matrix exponential in the Frobenius norm.
<code>fractional_matrix_power(A, t)</code>	Compute the fractional power of a matrix.

`scipy.linalg.expm(A)`

Compute the matrix exponential using Pade approximation.

**Parameters** **A** : (N, N) array\_like or sparse matrix  
Matrix to be exponentiated.

**Returns** **expm** : (N, N) ndarray  
Matrix exponential of A.

**References**

[R125]

**Examples**

```
>>> from scipy.linalg import expm, sinm, cosm
```

Matrix version of the formula  $\exp(0) = 1$ :

```
>>> expm(np.zeros((2,2)))
array([[ 1.,  0.],
       [ 0.,  1.]])
```

Euler's identity ( $\exp(i*\theta) = \cos(\theta) + i*\sin(\theta)$ ) applied to a matrix:

```
>>> a = np.array([[1.0, 2.0], [-1.0, 3.0]])
>>> expm(1j*a)
array([[ 0.42645930+1.89217551j, -2.13721484-0.97811252j],
       [ 1.06860742+0.48905626j, -1.71075555+0.91406299j]])
>>> cosm(a) + 1j*sinm(a)
array([[ 0.42645930+1.89217551j, -2.13721484-0.97811252j],
       [ 1.06860742+0.48905626j, -1.71075555+0.91406299j]])
```

`scipy.linalg.logm(A, disp=True)`

Compute matrix logarithm.

The matrix logarithm is the inverse of `expm`: `expm(logm(A)) == A`

**Parameters** **A** : (N, N) array\_like  
Matrix whose logarithm to evaluate  
**disp** : bool, optional  
Print warning if error in the result is estimated large instead of returning estimated error.  
(Default: True)

**Returns** **logm** : (N, N) ndarray  
Matrix logarithm of A  
**errest** : float  
(if `disp == False`)  
1-norm of the estimated error, `||err||_1 / ||A||_1`

### References

[R133], [R134], [R135]

### Examples

```
>>> from scipy.linalg import logm, expm
>>> a = np.array([[1.0, 3.0], [1.0, 4.0]])
>>> b = logm(a)
>>> b
array([[ -1.02571087,  2.05142174],
       [ 0.68380725,  1.02571087]])
>>> expm(b) # Verify expm(logm(a)) returns a
array([[ 1.,  3.],
       [ 1.,  4.]])
```

`scipy.linalg.cosm(A)`

Compute the matrix cosine.

This routine uses `expm` to compute the matrix exponentials.

**Parameters** **A** : (N, N) array\_like  
Input array

**Returns** **cosm** : (N, N) ndarray  
Matrix cosine of A

*Examples*

```
>>> from scipy.linalg import expm, sinm, cosm
```

Euler's identity ( $\exp(i*\theta) = \cos(\theta) + i*\sin(\theta)$ ) applied to a matrix:

```
>>> a = np.array([[1.0, 2.0], [-1.0, 3.0]])
>>> expm(1j*a)
array([[ 0.42645930+1.89217551j, -2.13721484-0.97811252j],
       [ 1.06860742+0.48905626j, -1.71075555+0.91406299j]])
>>> cosm(a) + 1j*sinm(a)
array([[ 0.42645930+1.89217551j, -2.13721484-0.97811252j],
       [ 1.06860742+0.48905626j, -1.71075555+0.91406299j]])
```

`scipy.linalg.sinm(A)`

Compute the matrix sine.

This routine uses `expm` to compute the matrix exponentials.

**Parameters** **A** : (N, N) array\_like  
Input array.

**Returns** **sinm** : (N, N) ndarray  
Matrix sine of A

*Examples*

```
>>> from scipy.linalg import expm, sinm, cosm
```

Euler's identity ( $\exp(i*\theta) = \cos(\theta) + i*\sin(\theta)$ ) applied to a matrix:

```
>>> a = np.array([[1.0, 2.0], [-1.0, 3.0]])
>>> expm(1j*a)
array([[ 0.42645930+1.89217551j, -2.13721484-0.97811252j],
       [ 1.06860742+0.48905626j, -1.71075555+0.91406299j]])
>>> cosm(a) + 1j*sinm(a)
array([[ 0.42645930+1.89217551j, -2.13721484-0.97811252j],
       [ 1.06860742+0.48905626j, -1.71075555+0.91406299j]])
```

`scipy.linalg.tanm(A)`

Compute the matrix tangent.

This routine uses `expm` to compute the matrix exponentials.

**Parameters** **A** : (N, N) array\_like  
Input array.

**Returns** **tanm** : (N, N) ndarray  
Matrix tangent of A

*Examples*

```
>>> from scipy.linalg import tanm, sinm, cosm
>>> a = np.array([[1.0, 3.0], [1.0, 4.0]])
>>> t = tanm(a)
>>> t
array([[ -2.00876993,  -8.41880636],
       [ -2.80626879, -10.42757629]])
```

Verify  $\tanm(a) = \sinm(a).\text{dot}(\text{inv}(\text{cosm}(a)))$

```

>>> s = sinm(a)
>>> c = cosm(a)
>>> s.dot(np.linalg.inv(c))
array([[ -2.00876993,  -8.41880636],
       [ -2.80626879, -10.42757629]])

```

`scipy.linalg.coshm(A)`

Compute the hyperbolic matrix cosine.

This routine uses `expm` to compute the matrix exponentials.

**Parameters** **A** : (N, N) array\_like  
Input array.

**Returns** **coshm** : (N, N) ndarray  
Hyperbolic matrix cosine of *A*

### Examples

```

>>> from scipy.linalg import tanhm, sinhm, coshm
>>> a = np.array([[1.0, 3.0], [1.0, 4.0]])
>>> c = coshm(a)
>>> c
array([[ 11.24592233,  38.76236492],
       [ 12.92078831,  50.00828725]])

```

Verify  $\tanhm(a) = \sinhm(a).dot(inv(\coshm(a)))$

```

>>> t = tanhm(a)
>>> s = sinhm(a)
>>> t - s.dot(np.linalg.inv(c))
array([[ 2.72004641e-15,  4.55191440e-15],
       [ 0.00000000e+00, -5.55111512e-16]])

```

`scipy.linalg.sinhm(A)`

Compute the hyperbolic matrix sine.

This routine uses `expm` to compute the matrix exponentials.

**Parameters** **A** : (N, N) array\_like  
Input array.

**Returns** **sinhm** : (N, N) ndarray  
Hyperbolic matrix sine of *A*

### Examples

```

>>> from scipy.linalg import tanhm, sinhm, coshm
>>> a = np.array([[1.0, 3.0], [1.0, 4.0]])
>>> s = sinhm(a)
>>> s
array([[ 10.57300653,  39.28826594],
       [ 13.09608865,  49.86127247]])

```

Verify  $\tanhm(a) = \sinhm(a).dot(inv(\coshm(a)))$

```

>>> t = tanhm(a)
>>> c = coshm(a)
>>> t - s.dot(np.linalg.inv(c))
array([[ 2.72004641e-15,  4.55191440e-15],
       [ 0.00000000e+00, -5.55111512e-16]])

```

`scipy.linalg.tanhm(A)`

Compute the hyperbolic matrix tangent.

This routine uses `expm` to compute the matrix exponentials.

**Parameters** **A** : (N, N) array\_like  
 Input array

**Returns** **tanhm** : (N, N) ndarray  
 Hyperbolic matrix tangent of A

**Examples**

```
>>> from scipy.linalg import tanhm, sinhm, coshm
>>> a = np.array([[1.0, 3.0], [1.0, 4.0]])
>>> t = tanhm(a)
>>> t
array([[ 0.3428582 ,  0.51987926],
       [ 0.17329309,  0.86273746]])
```

Verify `tanhm(a) = sinhm(a).dot(inv(coshm(a)))`

```
>>> s = sinhm(a)
>>> c = coshm(a)
>>> t - s.dot(np.linalg.inv(c))
array([[ 2.72004641e-15,  4.55191440e-15],
       [ 0.00000000e+00, -5.55111512e-16]])
```

`scipy.linalg.signm(A, disp=True)`

Matrix sign function.

Extension of the scalar `sign(x)` to matrices.

**Parameters** **A** : (N, N) array\_like  
 Matrix at which to evaluate the sign function

**disp** : bool, optional  
 Print warning if error in the result is estimated large instead of returning estimated error.  
 (Default: True)

**Returns** **signm** : (N, N) ndarray  
 Value of the sign function at A

**errest** : float  
 (if `disp == False`)  
 1-norm of the estimated error, `||err||_1 / ||A||_1`

**Examples**

```
>>> from scipy.linalg import signm, eigvals
>>> a = [[1,2,3], [1,2,1], [1,1,1]]
>>> eigvals(a)
array([ 4.12488542+0.j, -0.76155718+0.j,  0.63667176+0.j])
>>> eigvals(signm(a))
array([-1.+0.j,  1.+0.j,  1.+0.j])
```

`scipy.linalg.sqrtm(A, disp=True, blocksize=64)`

Matrix square root.

**Parameters** **A** : (N, N) array\_like  
 Matrix whose square root to evaluate

**disp** : bool, optional  
Print warning if error in the result is estimated large instead of returning estimated error.  
(Default: True)

**blocksize** : integer, optional  
If the blocksize is not degenerate with respect to the size of the input array, then use a blocked algorithm. (Default: 64)

**Returns** **sqrtnm** : (N, N) ndarray  
Value of the sqrt function at  $A$   
**errest** : float  
(if `disp == False`)  
Frobenius norm of the estimated error,  $\|err\|_F / \|A\|_F$

### References

[R160]

### Examples

```
>>> from scipy.linalg import sqrtnm
>>> a = np.array([[1.0, 3.0], [1.0, 4.0]])
>>> r = sqrtnm(a)
>>> r
array([[ 0.75592895,  1.13389342],
       [ 0.37796447,  1.88982237]])
>>> r.dot(r)
array([[ 1.,  3.],
       [ 1.,  4.]])
```

`scipy.linalg.funm`( $A$ , *func*, *disp=True*)

Evaluate a matrix function specified by a callable.

Returns the value of matrix-valued function  $f$  at  $A$ . The function  $f$  is an extension of the scalar-valued function *func* to matrices.

**Parameters** **A** : (N, N) array\_like  
Matrix at which to evaluate the function  
**func** : callable  
Callable object that evaluates a scalar function  $f$ . Must be vectorized (eg. using `vectorize`).  
**disp** : bool, optional  
Print warning if error in the result is estimated large instead of returning estimated error.  
(Default: True)

**Returns** **funm** : (N, N) ndarray  
Value of the matrix function specified by *func* evaluated at  $A$   
**errest** : float  
(if `disp == False`)  
1-norm of the estimated error,  $\|err\|_1 / \|A\|_1$

### Notes

This function implements the general algorithm based on Schur decomposition (Algorithm 9.1.1. in [R128]).

If the input matrix is known to be diagonalizable, then relying on the eigendecomposition is likely to be faster. For example, if your matrix is Hermitian, you can do

```
>>> from scipy.linalg import eigh
>>> def funm_herm(a, func, check_finite=False):
...     w, v = eigh(a, check_finite=check_finite)
```

```

...     ## if you further know that your matrix is positive semidefinite,
...     ## you can optionally guard against precision errors by doing
...     # w = np.maximum(w, 0)
...     w = func(w)
...     return (v * w).dot(v.conj()).T
    
```

## References

[R128]

## Examples

```

>>> from scipy.linalg import funm
>>> a = np.array([[1.0, 3.0], [1.0, 4.0]])
>>> funm(a, lambda x: x*x)
array([[ 4., 15.],
       [ 5., 19.]])
>>> a.dot(a)
array([[ 4., 15.],
       [ 5., 19.]])
    
```

`scipy.linalg.expm_frechet` (*A*, *E*, *method=None*, *compute\_expm=True*, *check\_finite=True*)  
 Frechet derivative of the matrix exponential of *A* in the direction *E*.

**Parameters**

- A** : (N, N) array\_like  
 Matrix of which to take the matrix exponential.
- E** : (N, N) array\_like  
 Matrix direction in which to take the Frechet derivative.
- method** : str, optional  
 Choice of algorithm. Should be one of
  - *SPS* (default)
  - *blockEnlarge*
- compute\_expm** : bool, optional  
 Whether to compute also *expm\_A* in addition to *expm\_frechet\_AE*. Default is True.
- check\_finite** : bool, optional  
 Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns**

- expm\_A** : ndarray  
 Matrix exponential of *A*.
- expm\_frechet\_AE** : ndarray  
 Frechet derivative of the matrix exponential of *A* in the direction *E*.  
 For `compute_expm = False`, only *expm\_frechet\_AE* is returned.

## See also:

**expm**      Compute the exponential of a matrix.

## Notes

This section describes the available implementations that can be selected by the *method* parameter. The default method is *SPS*.

Method *blockEnlarge* is a naive algorithm.

Method *SPS* is Scaling-Pade-Squaring [R126]. It is a sophisticated implementation which should take only about 3/8 as much time as the naive implementation. The asymptotics are the same.

New in version 0.13.0.

### References

[R126]

### Examples

```
>>> import scipy.linalg
>>> A = np.random.randn(3, 3)
>>> E = np.random.randn(3, 3)
>>> expm_A, expm_frechet_AE = scipy.linalg.expm_frechet(A, E)
>>> expm_A.shape, expm_frechet_AE.shape
((3, 3), (3, 3))
```

```
>>> import scipy.linalg
>>> A = np.random.randn(3, 3)
>>> E = np.random.randn(3, 3)
>>> expm_A, expm_frechet_AE = scipy.linalg.expm_frechet(A, E)
>>> M = np.zeros((6, 6))
>>> M[:3, :3] = A; M[:3, 3:] = E; M[3:, 3:] = A
>>> expm_M = scipy.linalg.expm(M)
>>> np.allclose(expm_A, expm_M[:3, :3])
True
>>> np.allclose(expm_frechet_AE, expm_M[:3, 3:])
True
```

`scipy.linalg.expm_cond(A, check_finite=True)`

Relative condition number of the matrix exponential in the Frobenius norm.

**Parameters** **A** : 2d array\_like

Square input matrix with shape (N, N).

**check\_finite** : bool, optional

Whether to check that the input matrix contains only finite numbers. Disabling may give a performance gain, but may result in problems (crashes, non-termination) if the inputs do contain infinities or NaNs.

**Returns** **kappa** : float

The relative condition number of the matrix exponential in the Frobenius norm

**See also:**

**expm** Compute the exponential of a matrix.

**expm\_frechet** Compute the Frechet derivative of the matrix exponential.

### Notes

A faster estimate for the condition number in the 1-norm has been published but is not yet implemented in scipy.

New in version 0.14.0.

`scipy.linalg.fractional_matrix_power(A, t)`

Compute the fractional power of a matrix.

Proceeds according to the discussion in section (6) of [R127].

**Parameters** **A** : (N, N) array\_like

Matrix whose fractional power to evaluate.

**t** : float

**Returns** Fractional power.  
**X** : (N, N) array\_like  
 The fractional power of the matrix.

**References**

[R127]

**Examples**

```
>>> from scipy.linalg import fractional_matrix_power
>>> a = np.array([[1.0, 3.0], [1.0, 4.0]])
>>> b = fractional_matrix_power(a, 0.5)
>>> b
array([[ 0.75592895,  1.13389342],
       [ 0.37796447,  1.88982237]])
>>> np.dot(b, b)      # Verify square root
array([[ 1.,  3.],
       [ 1.,  4.]])
```

### 5.9.5 Matrix Equation Solvers

<code>solve_sylvester(a, b, q)</code>	Computes a solution (X) to the Sylvester equation $AX + XB = Q$ .
<code>solve_continuous_are(a, b, q, r[, e, s, ...])</code>	Solves the continuous-time algebraic Riccati equation (CARE).
<code>solve_discrete_are(a, b, q, r[, e, s, balanced])</code>	Solves the discrete-time algebraic Riccati equation (DARE).
<code>solve_continuous_lyapunov(a, q)</code>	Solves the continuous Lyapunov equation $AX + XA^H = Q$ .
<code>solve_discrete_lyapunov(a, q[, method])</code>	Solves the discrete Lyapunov equation $AXA^H - X + Q = 0$ .

`scipy.linalg.solve_sylvester(a, b, q)`  
 Computes a solution (X) to the Sylvester equation  $AX + XB = Q$ .

**Parameters** **a** : (M, M) array\_like  
 Leading matrix of the Sylvester equation  
**b** : (N, N) array\_like  
 Trailing matrix of the Sylvester equation  
**q** : (M, N) array\_like  
 Right-hand side  
**Returns** **x** : (M, N) ndarray  
 The solution to the Sylvester equation.  
**Raises** **LinAlgError**  
 If solution was not found

**Notes**

Computes a solution to the Sylvester matrix equation via the Bartels- Stewart algorithm. The A and B matrices first undergo Schur decompositions. The resulting matrices are used to construct an alternative Sylvester equation  $(RY + YS^T = F)$  where the R and S matrices are in quasi-triangular form (or, when R, S or F are complex, triangular form). The simplified equation is then solved using \*TRSYL from LAPACK directly.

New in version 0.11.0.

**Examples**

Given  $a$ ,  $b$ , and  $q$  solve for  $x$ :

```
>>> from scipy import linalg
>>> a = np.array([[ -3, -2,  0], [-1, -1,  3], [ 3, -5, -1]])
>>> b = np.array([[1]])
>>> q = np.array([[1], [2], [3]])
>>> x = linalg.solve_sylvester(a, b, q)
>>> x
array([[ 0.0625],
       [-0.5625],
       [ 0.6875]])
>>> np.allclose(a.dot(x) + x.dot(b), q)
True
```

`scipy.linalg.solve_continuous_are` ( $a, b, q, r, e=None, s=None, balanced=True$ )

Solves the continuous-time algebraic Riccati equation (CARE).

The CARE is defined as

$$XA + A^H X - XBR^{-1}B^H X + Q = 0$$

The limitations for a solution to exist are :

- All eigenvalues of  $A$  on the right half plane, should be controllable.
- The associated hamiltonian pencil (See Notes), should have eigenvalues sufficiently away from the imaginary axis.

Moreover, if  $e$  or  $s$  is not precisely `None`, then the generalized version of CARE

$$E^H X A + A^H X E - (E^H X B + S)R^{-1}(B^H X E + S^H) + Q = 0$$

is solved. When omitted,  $e$  is assumed to be the identity and  $s$  is assumed to be the zero matrix with sizes compatible with  $a$  and  $b$  respectively.

**Parameters** **a** : (M, M) array\_like  
Square matrix

**b** : (M, N) array\_like  
Input

**q** : (M, M) array\_like  
Input

**r** : (N, N) array\_like  
Nonsingular square matrix

**e** : (M, M) array\_like, optional  
Nonsingular square matrix

**s** : (M, N) array\_like, optional  
Input

**balanced** : bool, optional

The boolean that indicates whether a balancing step is performed on the data. The default is set to `True`.

**Returns** **x** : (M, M) ndarray

Solution to the continuous-time algebraic Riccati equation.

**Raises** **LinAlgError**

For cases where the stable subspace of the pencil could not be isolated. See Notes section and the references for details.

See also:

**solve\_discrete\_are**

Solves the discrete-time algebraic Riccati equation

**Notes**

The equation is solved by forming the extended hamiltonian matrix pencil, as described in [R152],  $H - \lambda J$  given by the block matrices

$$\begin{bmatrix} A & 0 & B \\ -Q & -A^H & -S \\ S^H & B^H & R \end{bmatrix} - \lambda * \begin{bmatrix} E & 0 & 0 \\ 0 & E^H & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

and using a QZ decomposition method.

In this algorithm, the fail conditions are linked to the symmetry of the product  $U_2 U_1^{-1}$  and condition number of  $U_1$ . Here,  $U$  is the  $2m$ -by- $m$  matrix that holds the eigenvectors spanning the stable subspace with  $2m$  rows and partitioned into two  $m$ -row matrices. See [R152] and [R153] for more details.

In order to improve the QZ decomposition accuracy, the pencil goes through a balancing step where the sum of absolute values of  $H$  and  $J$  entries (after removing the diagonal entries of the sum) is balanced following the recipe given in [R154].

New in version 0.11.0.

**References**

[R152], [R153], [R154]

**Examples**

Given  $a$ ,  $b$ ,  $q$ , and  $r$  solve for  $x$ :

```
>>> from scipy import linalg
>>> a = np.array([[4, 3], [-4.5, -3.5]])
>>> b = np.array([[1], [-1]])
>>> q = np.array([[9, 6], [6, 4.]])
>>> r = 1
>>> x = linalg.solve_continuous_are(a, b, q, r)
>>> x
array([[ 21.72792206,  14.48528137],
       [ 14.48528137,   9.65685425]])
>>> np.allclose(a.T.dot(x) + x.dot(a) - x.dot(b).dot(b.T).dot(x), -q)
True
```

`scipy.linalg.solve_discrete_are` ( $a, b, q, r, e=None, s=None, balanced=True$ )

Solves the discrete-time algebraic Riccati equation (DARE).

The DARE is defined as

$$A^H X A - X - (A^H X B)(R + B^H X B)^{-1}(B^H X A) + Q = 0$$

The limitations for a solution to exist are :

- All eigenvalues of  $A$  outside the unit disc, should be controllable.
- The associated symplectic pencil (See Notes), should have eigenvalues sufficiently away from the unit circle.

Moreover, if  $e$  and  $s$  are not both precisely `None`, then the generalized version of DARE

$$A^H X A - E^H X E - (A^H X B + S)(R + B^H X B)^{-1}(B^H X A + S^H) + Q = 0$$

is solved. When omitted,  $e$  is assumed to be the identity and  $s$  is assumed to be the zero matrix.

**Parameters**

- a** : (M, M) array\_like  
Square matrix
- b** : (M, N) array\_like  
Input
- q** : (M, M) array\_like  
Input
- r** : (N, N) array\_like  
Square matrix
- e** : (M, M) array\_like, optional  
Nonsingular square matrix
- s** : (M, N) array\_like, optional  
Input
- balanced** : bool  
The boolean that indicates whether a balancing step is performed on the data. The default is set to True.

**Returns**

- x** : (M, M) ndarray  
Solution to the discrete algebraic Riccati equation.

**Raises**

- LinAlgError**  
For cases where the stable subspace of the pencil could not be isolated. See Notes section and the references for details.

See also:

#### `solve_continuous_are`

Solves the continuous algebraic Riccati equation

#### Notes

The equation is solved by forming the extended symplectic matrix pencil, as described in [R155],  $H - \lambda J$  given by the block matrices

$$\begin{bmatrix} A & 0 & B \\ -Q & E^H & -S \\ S^H & 0 & R \end{bmatrix} - \lambda * \begin{bmatrix} E & 0 & B \\ 0 & A^H & 0 \\ 0 & -B^H & 0 \end{bmatrix}$$

and using a QZ decomposition method.

In this algorithm, the fail conditions are linked to the symmetry of the product  $U_2 U_1^{-1}$  and condition number of  $U_1$ . Here,  $U$  is the  $2m$ -by- $m$  matrix that holds the eigenvectors spanning the stable subspace with  $2m$  rows and partitioned into two  $m$ -row matrices. See [R155] and [R156] for more details.

In order to improve the QZ decomposition accuracy, the pencil goes through a balancing step where the sum of absolute values of  $H$  and  $J$  rows/cols (after removing the diagonal entries) is balanced following the recipe given in [R157]. If the data has small numerical noise, balancing may amplify their effects and some clean up is required.

New in version 0.11.0.

#### References

[R155], [R156], [R157]

#### Examples

Given  $a$ ,  $b$ ,  $q$ , and  $r$  solve for  $x$ :

```

>>> from scipy import linalg as la
>>> a = np.array([[0, 1], [0, -1]])
>>> b = np.array([[1, 0], [2, 1]])
>>> q = np.array([[ -4, -4], [-4, 7]])
>>> r = np.array([[9, 3], [3, 1]])
>>> x = la.solve_discrete_are(a, b, q, r)
>>> x
array([[ -4., -4.],
       [ -4.,  7.]])
>>> R = la.solve(r + b.T.dot(x).dot(b), b.T.dot(x).dot(a))
>>> np.allclose(a.T.dot(x).dot(a) - x - a.T.dot(x).dot(b).dot(R), -q)
True
    
```

`scipy.linalg.solve_continuous_lyapunov(a, q)`  
 Solves the continuous Lyapunov equation  $AX + XA^H = Q$ .

Uses the Bartels-Stewart algorithm to find  $X$ .

**Parameters**

- a** : array\_like  
A square matrix
- q** : array\_like  
Right-hand side square matrix

**Returns**

- x** : ndarray  
Solution to the continuous Lyapunov equation

See also:

**solve\_discrete\_lyapunov**  
 computes the solution to the discrete-time Lyapunov equation

**solve\_sylvester**  
 computes the solution to the Sylvester equation

**Notes**

The continuous Lyapunov equation is a special form of the Sylvester equation, hence this solver relies on LAPACK routine ?TRSYL.

New in version 0.11.0.

**Examples**

Given  $a$  and  $q$  solve for  $x$ :

```

>>> from scipy import linalg
>>> a = np.array([[ -3, -2,  0], [-1, -1,  0], [ 0, -5, -1]])
>>> b = np.array([2, 4, -1])
>>> q = np.eye(3)
>>> x = linalg.solve_continuous_lyapunov(a, q)
>>> x
array([[ -0.75 ,  0.875 , -3.75  ],
       [  0.875 , -1.375 ,  5.3125],
       [ -3.75 ,  5.3125, -27.0625]])
>>> np.allclose(a.dot(x) + x.dot(a.T), q)
True
    
```

`scipy.linalg.solve_discrete_lyapunov(a, q, method=None)`  
 Solves the discrete Lyapunov equation  $AXA^H - X + Q = 0$ .

**Parameters**

- a, q** : (M, M) array\_like

Square matrices corresponding to  $A$  and  $Q$  in the equation above respectively. Must have the same shape.

**method** : {'direct', 'bilinear'}, optional

Type of solver.

If not given, chosen to be `direct` if  $M$  is less than 10 and `bilinear` otherwise.

**Returns**  $x$  : ndarray

Solution to the discrete Lyapunov equation

**See also:**

**`solve_continuous_lyapunov`**

computes the solution to the continuous-time Lyapunov equation

**Notes**

This section describes the available solvers that can be selected by the 'method' parameter. The default method is `direct` if  $M$  is less than 10 and `bilinear` otherwise.

Method `direct` uses a direct analytical solution to the discrete Lyapunov equation. The algorithm is given in, for example, [R158]. However it requires the linear solution of a system with dimension  $M^2$  so that performance degrades rapidly for even moderately sized matrices.

Method `bilinear` uses a bilinear transformation to convert the discrete Lyapunov equation to a continuous Lyapunov equation ( $BX + XB' = -C$ ) where  $B = (A - I)(A + I)^{-1}$  and  $C = 2(A' + I)^{-1}Q(A + I)^{-1}$ . The continuous equation can be efficiently solved since it is a special case of a Sylvester equation. The transformation algorithm is from Popov (1964) as described in [R159].

New in version 0.11.0.

**References**

[R158], [R159]

**Examples**

Given  $a$  and  $q$  solve for  $x$ :

```
>>> from scipy import linalg
>>> a = np.array([[0.2, 0.5], [0.7, -0.9]])
>>> q = np.eye(2)
>>> x = linalg.solve_discrete_lyapunov(a, q)
>>> x
array([[ 0.70872893,  1.43518822],
       [ 1.43518822, -2.4266315 ]])
>>> np.allclose(a.dot(x).dot(a.T)-x, -q)
True
```

## 5.9.6 Sketches and Random Projections

`clarkson_woodruff_transform(input_matrix, ...)` “

`scipy.linalg.clarkson_woodruff_transform(input_matrix, sketch_size, seed=None)`

” Find low-rank matrix approximation via the Clarkson-Woodruff Transform.

Given an input\_matrix  $A$  of size  $(n, d)$ , compute a matrix  $A'$  of size  $(\text{sketch\_size}, d)$  which holds:

$$\|Ax\| = (1 \pm \epsilon)\|A'x\|$$

with high probability.

The error is related to the number of rows of the sketch and it is bounded

$$\text{poly}(r(\epsilon^{-1}))$$

**Parameters**

- input\_matrix: array\_like**  
Input matrix, of shape  $(n, d)$ .
- sketch\_size: int**  
Number of rows for the sketch.
- seed**: None or int or `numpy.random.RandomState` instance, optional  
This parameter defines the `RandomState` object to use for drawing random variates. If None (or `np.random`), the global `np.random` state is used. If integer, it is used to seed the local `RandomState` instance. Default is None.

**Returns**

- A'**: array\_like  
Sketch of the input matrix  $A$ , of size  $(\text{sketch\_size}, d)$ .

### Notes

This is an implementation of the Clarkson-Woodruff Transform (CountSketch).  $A'$  can be computed in principle in  $O(\text{nnz}(A))$  (with `nnz` meaning the number of nonzero entries), however we don't take advantage of sparse matrices in this implementation.

### References

[R122]

### Examples

Given a big dense matrix  $A$ :

```
>>> from scipy import linalg
>>> n_rows, n_columns, sketch_n_rows = (2000, 100, 100)
>>> threshold = 0.1
>>> tmp = np.random.normal(0, 0.1, n_rows*n_columns)
>>> A = np.reshape(tmp, (n_rows, n_columns))
>>> sketch = linalg.clarkson_woodruff_transform(A, sketch_n_rows)
>>> sketch.shape
(100, 100)
>>> normA = linalg.norm(A)
>>> norm_sketch = linalg.norm(sketch)
```

Now with high probability, the condition `abs(normA - normSketch) < threshold` holds.

## 5.9.7 Special Matrices

<code>block_diag(*arrs)</code>	Create a block diagonal matrix from provided arrays.
<code>circulant(c)</code>	Construct a circulant matrix.
<code>companion(a)</code>	Create a companion matrix.
<code>dft(n[, scale])</code>	Discrete Fourier transform matrix.
<code>hadamard(n[, dtype])</code>	Construct a Hadamard matrix.

Continued on next page

Table 5.89 – continued from previous page

<code>hankel(c[, r])</code>	Construct a Hankel matrix.
<code>helmert(n[, full])</code>	Create a Helmert matrix of order $n$ .
<code>hilbert(n)</code>	Create a Hilbert matrix of order $n$ .
<code>invhilbert(n[, exact])</code>	Compute the inverse of the Hilbert matrix of order $n$ .
<code>leslie(f, s)</code>	Create a Leslie matrix.
<code>pascal(n[, kind, exact])</code>	Returns the $n \times n$ Pascal matrix.
<code>invpascal(n[, kind, exact])</code>	Returns the inverse of the $n \times n$ Pascal matrix.
<code>toeplitz(c[, r])</code>	Construct a Toeplitz matrix.
<code>tri(N[, M, k, dtype])</code>	Construct $(N, M)$ matrix filled with ones at and below the $k$ -th diagonal.

`scipy.linalg.block_diag(*arrs)`

Create a block diagonal matrix from provided arrays.

Given the inputs  $A$ ,  $B$  and  $C$ , the output will have these arrays arranged on the diagonal:

```
[A, 0, 0],
 [0, B, 0],
 [0, 0, C]]
```

**Parameters**  $A, B, C, \dots$  : array\_like, up to 2-D

Input arrays. A 1-D array or array\_like sequence of length  $n$  is treated as a 2-D array with shape  $(1, n)$ .

**Returns**  $D$  : ndarray

Array with  $A, B, C, \dots$  on the diagonal.  $D$  has the same dtype as  $A$ .

#### Notes

If all the input arrays are square, the output is known as a block diagonal matrix.

Empty sequences (i.e., array-likes of zero size) will not be ignored. Noteworthy, both `[]` and  `[[] ]` are treated as matrices with shape  $(1, 0)$ .

#### Examples

```
>>> from scipy.linalg import block_diag
>>> A = [[1, 0],
...      [0, 1]]
>>> B = [[3, 4, 5],
...      [6, 7, 8]]
>>> C = [[7]]
>>> P = np.zeros((2, 0), dtype='int32')
>>> block_diag(A, B, C)
array([[1, 0, 0, 0, 0, 0],
       [0, 1, 0, 0, 0, 0],
       [0, 0, 3, 4, 5, 0],
       [0, 0, 6, 7, 8, 0],
       [0, 0, 0, 0, 0, 7]])
>>> block_diag(A, P, B, C)
array([[1, 0, 0, 0, 0, 0],
       [0, 1, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0],
       [0, 0, 3, 4, 5, 0],
       [0, 0, 6, 7, 8, 0],
```

```
[0, 0, 0, 0, 0, 7]])
>>> block_diag(1.0, [2, 3], [[4, 5], [6, 7]])
array([[ 1.,  0.,  0.,  0.,  0.],
       [ 0.,  2.,  3.,  0.,  0.],
       [ 0.,  0.,  0.,  4.,  5.],
       [ 0.,  0.,  0.,  6.,  7.]])
```

`scipy.linalg.circulant(c)`

Construct a circulant matrix.

**Parameters** `c` : (N,) array\_like  
 1-D array, the first column of the matrix.

**Returns** `A` : (N, N) ndarray  
 A circulant matrix whose first column is `c`.

**See also:**

**toeplitz** Toeplitz matrix

**hankel** Hankel matrix

**solve\_circulant**  
 Solve a circulant system.

**Notes**

New in version 0.8.0.

**Examples**

```
>>> from scipy.linalg import circulant
>>> circulant([1, 2, 3])
array([[1, 3, 2],
       [2, 1, 3],
       [3, 2, 1]])
```

`scipy.linalg.companion(a)`

Create a companion matrix.

Create the companion matrix  $[R123]$  associated with the polynomial whose coefficients are given in `a`.

**Parameters** `a` : (N,) array\_like  
 1-D array of polynomial coefficients. The length of `a` must be at least two, and `a[0]` must not be zero.

**Returns** `c` : (N-1, N-1) ndarray  
 The first row of `c` is  $-a[1:]/a[0]$ , and the first sub-diagonal is all ones. The data-type of the array is the same as the data-type of `1.0*a[0]`.

**Raises** **ValueError**  
 If any of the following are true: a) `a.ndim != 1`; b) `a.size < 2`; c) `a[0] == 0`.

**Notes**

New in version 0.8.0.

**References**

$[R123]$

### Examples

```
>>> from scipy.linalg import companion
>>> companion([1, -10, 31, -30])
array([[ 10., -31.,  30.],
       [  1.,   0.,   0.],
       [  0.,   1.,   0.]])
```

`scipy.linalg.dft` (*n*, *scale=None*)

Discrete Fourier transform matrix.

Create the matrix that computes the discrete Fourier transform of a sequence [R124]. The *n*-th primitive root of unity used to generate the matrix is  $\exp(-2\pi i/n)$ , where  $i = \sqrt{-1}$ .

**Parameters**    **n** : int  
                     Size the matrix to create.

**scale** : str, optional  
                     Must be None, 'sqrtn', or 'n'. If *scale* is 'sqrtn', the matrix is divided by  $\sqrt{n}$ . If *scale* is 'n', the matrix is divided by *n*. If *scale* is None (the default), the matrix is not normalized, and the return value is simply the Vandermonde matrix of the roots of unity.

**Returns**        **m** : (n, n) ndarray  
                     The DFT matrix.

### Notes

When *scale* is None, multiplying a vector by the matrix returned by *dft* is mathematically equivalent to (but much less efficient than) the calculation performed by `scipy.fftpack.fft`.

New in version 0.14.0.

### References

[R124]

### Examples

```
>>> from scipy.linalg import dft
>>> np.set_printoptions(precision=5, suppress=True)
>>> x = np.array([1, 2, 3, 0, 3, 2, 1, 0])
>>> m = dft(8)
>>> m.dot(x)    # Compute the DFT of x
array([ 12.+0.j,  -2.-2.j,   0.-4.j,  -2.+2.j,   4.+0.j,  -2.-2.j,
        -0.+4.j,  -2.+2.j])
```

Verify that `m.dot(x)` is the same as `fft(x)`.

```
>>> from scipy.fftpack import fft
>>> fft(x)    # Same result as m.dot(x)
array([ 12.+0.j,  -2.-2.j,   0.-4.j,  -2.+2.j,   4.+0.j,  -2.-2.j,
        0.+4.j,  -2.+2.j])
```

`scipy.linalg.hadamard` (*n*, *dtype=<type 'int'>*)

Construct a Hadamard matrix.

Constructs an *n*-by-*n* Hadamard matrix, using Sylvester's construction. *n* must be a power of 2.

**Parameters**    **n** : int  
                     The order of the matrix. *n* must be a power of 2.

**dtype** : dtype, optional

**Returns**            **H**: (n, n) ndarray  
                          The Hadamard matrix.

**Notes**

New in version 0.8.0.

**Examples**

```
>>> from scipy.linalg import hadamard
>>> hadamard(2, dtype=complex)
array([[ 1.+0.j,  1.+0.j],
       [ 1.+0.j, -1.-0.j]])
>>> hadamard(4)
array([[ 1,  1,  1,  1],
       [ 1, -1,  1, -1],
       [ 1,  1, -1, -1],
       [ 1, -1, -1,  1]])
```

`scipy.linalg.hankel` (*c*, *r=None*)

Construct a Hankel matrix.

The Hankel matrix has constant anti-diagonals, with *c* as its first column and *r* as its last row. If *r* is not given, then *r* = `zeros_like(c)` is assumed.

**Parameters**    **c**: array\_like  
                          First column of the matrix. Whatever the actual shape of *c*, it will be converted to a 1-D array.  
                          **r**: array\_like, optional  
                          Last row of the matrix. If None, *r* = `zeros_like(c)` is assumed. *r*[0] is ignored; the last row of the returned matrix is [*c*[-1], *r*[1:]]. Whatever the actual shape of *r*, it will be converted to a 1-D array.

**Returns**            **A**: (len(*c*), len(*r*)) ndarray  
                          The Hankel matrix. Dtype is the same as (*c*[0] + *r*[0]).dtype.

See also:

**toeplitz**    Toeplitz matrix

**circulant**    circulant matrix

**Examples**

```
>>> from scipy.linalg import hankel
>>> hankel([1, 17, 99])
array([[ 1, 17, 99],
       [17, 99,  0],
       [99,  0,  0]])
>>> hankel([1, 2, 3, 4], [4, 7, 7, 8, 9])
array([[1, 2, 3, 4, 7],
       [2, 3, 4, 7, 7],
       [3, 4, 7, 7, 8],
       [4, 7, 7, 8, 9]])
```

`scipy.linalg.helmert` (*n*, *full=False*)

Create a Helmert matrix of order *n*.

This has applications in statistics, compositional or simplicial analysis, and in Aitchison geometry.

**Parameters** **n** : int  
The size of the array to create.

**full** : bool, optional  
If True the (n, n) ndarray will be returned. Otherwise the submatrix that does not include the first row will be returned. Default: False.

**Returns** **M** : ndarray  
The Helmert matrix. The shape is (n, n) or (n-1, n) depending on the *full* argument.

**Examples**

```
>>> from scipy.linalg import helmert
>>> helmert(5, full=True)
array([[ 0.4472136 ,  0.4472136 ,  0.4472136 ,  0.4472136 ,  0.4472136 ],
       [ 0.70710678, -0.70710678,  0.          ,  0.          ,  0.          ],
       [ 0.40824829,  0.40824829, -0.81649658,  0.          ,  0.          ],
       [ 0.28867513,  0.28867513,  0.28867513, -0.8660254 ,  0.          ],
       [ 0.2236068 ,  0.2236068 ,  0.2236068 ,  0.2236068 , -0.89442719]])
```

`scipy.linalg.hilbert(n)`

Create a Hilbert matrix of order *n*.

Returns the *n* by *n* array with entries  $h[i,j] = 1 / (i + j + 1)$ .

**Parameters** **n** : int  
The size of the array to create.

**Returns** **h** : (n, n) ndarray  
The Hilbert matrix.

**See also:**

**invhilbert** Compute the inverse of a Hilbert matrix.

**Notes**

New in version 0.10.0.

**Examples**

```
>>> from scipy.linalg import hilbert
>>> hilbert(3)
array([[ 1.          ,  0.5          ,  0.33333333],
       [ 0.5          ,  0.33333333,  0.25         ],
       [ 0.33333333,  0.25         ,  0.2          ]])
```

`scipy.linalg.invhilbert(n, exact=False)`

Compute the inverse of the Hilbert matrix of order *n*.

The entries in the inverse of a Hilbert matrix are integers. When *n* is greater than 14, some entries in the inverse exceed the upper limit of 64 bit integers. The *exact* argument provides two options for dealing with these large integers.

**Parameters** **n** : int  
The order of the Hilbert matrix.

**exact** : bool, optional  
If False, the data type of the array that is returned is np.float64, and the array is an approximation of the inverse. If True, the array is the exact integer inverse array. To represent the exact inverse when *n* > 14, the returned array is an object array of long integers. For *n* ≤ 14, the exact inverse is returned as an array with data type np.int64.

**Returns** **invh** : (n, n) ndarray

The data type of the array is `np.float64` if `exact` is `False`. If `exact` is `True`, the data type is either `np.int64` (for  $n \leq 14$ ) or `object` (for  $n > 14$ ). In the latter case, the objects in the array will be long integers.

**See also:**

**hilbert** Create a Hilbert matrix.

**Notes**

New in version 0.10.0.

**Examples**

```
>>> from scipy.linalg import invhilbert
>>> invhilbert(4)
array([[ 16., -120., 240., -140.],
       [-120., 1200., -2700., 1680.],
       [ 240., -2700., 6480., -4200.],
       [-140., 1680., -4200., 2800.]])
>>> invhilbert(4, exact=True)
array([[ 16, -120, 240, -140],
       [-120, 1200, -2700, 1680],
       [ 240, -2700, 6480, -4200],
       [-140, 1680, -4200, 2800]], dtype=int64)
>>> invhilbert(16)[7,7]
4.2475099528537506e+19
>>> invhilbert(16, exact=True)[7,7]
42475099528537378560L
```

`scipy.linalg.leslie` (*f*, *s*)

Create a Leslie matrix.

Given the length *n* array of fecundity coefficients *f* and the length *n*-1 array of survival coefficients *s*, return the associated Leslie matrix.

**Parameters**

- f** : (N,) array\_like  
The “fecundity” coefficients.
- s** : (N-1,) array\_like  
The “survival” coefficients, has to be 1-D. The length of *s* must be one less than the length of *f*, and it must be at least 1.

**Returns**

- L** : (N, N) ndarray  
The array is zero except for the first row, which is *f*, and the first sub-diagonal, which is *s*. The data-type of the array will be the data-type of `f[0]+s[0]`.

**Notes**

New in version 0.8.0.

The Leslie matrix is used to model discrete-time, age-structured population growth [R131] [R132]. In a population with *n* age classes, two sets of parameters define a Leslie matrix: the *n* “fecundity coefficients”, which give the number of offspring per-capita produced by each age class, and the *n* - 1 “survival coefficients”, which give the per-capita survival rate of each age class.

**References**

[R131], [R132]

**Examples**

```
>>> from scipy.linalg import leslie
>>> leslie([0.1, 2.0, 1.0, 0.1], [0.2, 0.8, 0.7])
array([[ 0.1,  2. ,  1. ,  0.1],
       [ 0.2,  0. ,  0. ,  0. ],
       [ 0. ,  0.8,  0. ,  0. ],
       [ 0. ,  0. ,  0.7,  0. ]])
```

`scipy.linalg.pascal` (*n*, *kind*='symmetric', *exact*=True)

Returns the *n* x *n* Pascal matrix.

The Pascal matrix is a matrix containing the binomial coefficients as its elements.

**Parameters** **n** : int

The size of the matrix to create; that is, the result is an *n* x *n* matrix.

**kind** : str, optional

Must be one of 'symmetric', 'lower', or 'upper'. Default is 'symmetric'.

**exact** : bool, optional

If *exact* is True, the result is either an array of type `numpy.uint64` (if *n* < 35) or an object array of Python long integers. If *exact* is False, the coefficients in the matrix are computed using `scipy.special.comb` with *exact*=False. The result will be a floating point array, and the values in the array will not be the exact coefficients, but this version is much faster than *exact*=True.

**Returns** **p** : (n, n) ndarray

The Pascal matrix.

**See also:**

`invpascal`

**Notes**

See [http://en.wikipedia.org/wiki/Pascal\\_matrix](http://en.wikipedia.org/wiki/Pascal_matrix) for more information about Pascal matrices.

New in version 0.11.0.

**Examples**

```
>>> from scipy.linalg import pascal
>>> pascal(4)
array([[ 1,  1,  1,  1],
       [ 1,  2,  3,  4],
       [ 1,  3,  6, 10],
       [ 1,  4, 10, 20]], dtype=uint64)
>>> pascal(4, kind='lower')
array([[1, 0, 0, 0],
       [1, 1, 0, 0],
       [1, 2, 1, 0],
       [1, 3, 3, 1]], dtype=uint64)
>>> pascal(50)[-1, -1]
25477612258980856902730428600L
>>> from scipy.special import comb
>>> comb(98, 49, exact=True)
25477612258980856902730428600L
```

`scipy.linalg.invpascal` (*n*, *kind*='symmetric', *exact*=True)

Returns the inverse of the *n* x *n* Pascal matrix.

The Pascal matrix is a matrix containing the binomial coefficients as its elements.

**Parameters**

- n** : int  
The size of the matrix to create; that is, the result is an  $n \times n$  matrix.
- kind** : str, optional  
Must be one of 'symmetric', 'lower', or 'upper'. Default is 'symmetric'.
- exact** : bool, optional  
If *exact* is True, the result is either an array of type `numpy.int64` (if  $n \leq 35$ ) or an object array of Python integers. If *exact* is False, the coefficients in the matrix are computed using `scipy.special.comb` with *exact=False*. The result will be a floating point array, and for large  $n$ , the values in the array will not be the exact coefficients.

**Returns**

- invp** : (n, n) ndarray  
The inverse of the Pascal matrix.

**See also:**`pascal`**Notes**

New in version 0.16.0.

**References**[\[R129\]](#), [\[R130\]](#)**Examples**

```
>>> from scipy.linalg import invpascal, pascal
>>> invp = invpascal(5)
>>> invp
array([[ 5, -10, 10, -5,  1],
       [-10, 30, -35, 19, -4],
       [ 10, -35, 46, -27,  6],
       [-5, 19, -27, 17, -4],
       [ 1, -4,  6, -4,  1]])
```

```
>>> p = pascal(5)
>>> p.dot(invp)
array([[ 1.,  0.,  0.,  0.,  0.],
       [ 0.,  1.,  0.,  0.,  0.],
       [ 0.,  0.,  1.,  0.,  0.],
       [ 0.,  0.,  0.,  1.,  0.],
       [ 0.,  0.,  0.,  0.,  1.]])
```

An example of the use of *kind* and *exact*:

```
>>> invpascal(5, kind='lower', exact=False)
array([[ 1., -0.,  0., -0.,  0.],
       [-1.,  1., -0.,  0., -0.],
       [ 1., -2.,  1., -0.,  0.],
       [-1.,  3., -3.,  1., -0.],
       [ 1., -4.,  6., -4.,  1.]])
```

`scipy.linalg.toeplitz` (*c*, *r=None*)

Construct a Toeplitz matrix.

The Toeplitz matrix has constant diagonals, with *c* as its first column and *r* as its first row. If *r* is not given, `r == conjugate(c)` is assumed.

**Parameters**

- c** : array\_like  
First column of the matrix. Whatever the actual shape of *c*, it will be converted to a 1-D array.
- r** : array\_like, optional  
First row of the matrix. If *None*,  $r = \text{conjugate}(c)$  is assumed; in this case, if *c*[0] is real, the result is a Hermitian matrix. *r*[0] is ignored; the first row of the returned matrix is  $[c[0], r[1:]]$ . Whatever the actual shape of *r*, it will be converted to a 1-D array.

**Returns**

- A** : (len(c), len(r)) ndarray  
The Toeplitz matrix. Dtype is the same as  $(c[0] + r[0]).\text{dtype}$ .

**See also:**

**circulant** circulant matrix

**hankel** Hankel matrix

**solve\_toeplitz**  
Solve a Toeplitz system.

**Notes**

The behavior when *c* or *r* is a scalar, or when *c* is complex and *r* is *None*, was changed in version 0.8.0. The behavior in previous versions was undocumented and is no longer supported.

**Examples**

```
>>> from scipy.linalg import toeplitz
>>> toeplitz([1,2,3], [1,4,5,6])
array([[1, 4, 5, 6],
       [2, 1, 4, 5],
       [3, 2, 1, 4]])
>>> toeplitz([1.0, 2+3j, 4-1j])
array([[ 1.+0.j,  2.-3.j,  4.+1.j],
       [ 2.+3.j,  1.+0.j,  2.-3.j],
       [ 4.-1.j,  2.+3.j,  1.+0.j]])
```

`scipy.linalg.tri` (*N*, *M=None*, *k=0*, *dtype=None*)

Construct (*N*, *M*) matrix filled with ones at and below the *k*-th diagonal.

The matrix has  $A[i,j] == 1$  for  $i \leq j + k$

**Parameters**

- N** : int  
The size of the first dimension of the matrix.
- M** : int or *None*, optional  
The size of the second dimension of the matrix. If *M* is *None*,  $M = N$  is assumed.
- k** : int, optional  
Number of subdiagonal below which matrix is filled with ones.  $k = 0$  is the main diagonal,  $k < 0$  subdiagonal and  $k > 0$  superdiagonal.
- dtype** : dtype, optional  
Data type of the matrix.

**Returns**

- tri** : (*N*, *M*) ndarray  
Tri matrix.

**Examples**

```

>>> from scipy.linalg import tri
>>> tri(3, 5, 2, dtype=int)
array([[1, 1, 1, 0, 0],
       [1, 1, 1, 1, 0],
       [1, 1, 1, 1, 1]])
>>> tri(3, 5, -1, dtype=int)
array([[0, 0, 0, 0, 0],
       [1, 0, 0, 0, 0],
       [1, 1, 0, 0, 0]])
    
```

## 5.9.8 Low-level routines

<code>get_blas_funcs(names[, arrays, dtype])</code>	Return available BLAS function objects from names.
<code>get_lapack_funcs(names[, arrays, dtype])</code>	Return available LAPACK function objects from names.
<code>find_best_blas_type([arrays, dtype])</code>	Find best-matching BLAS/LAPACK type.

`scipy.linalg.get_blas_funcs` (*names*, *arrays*=(), *dtype*=None)

Return available BLAS function objects from names.

Arrays are used to determine the optimal prefix of BLAS routines.

**Parameters**

- names** : str or sequence of str  
Name(s) of BLAS functions without type prefix.
- arrays** : sequence of ndarrays, optional  
Arrays can be given to determine optimal prefix of BLAS routines. If not given, double-precision routines will be used, otherwise the most generic type in arrays will be used.
- dtype** : str or dtype, optional  
Data-type specifier. Not used if *arrays* is non-empty.

**Returns**

- funcs** : list  
List containing the found function(s).

### Notes

This routine automatically chooses between Fortran/C interfaces. Fortran code is used whenever possible for arrays with column major order. In all other cases, C code is preferred.

In BLAS, the naming convention is that all functions start with a type prefix, which depends on the type of the principal matrix. These can be one of {'s', 'd', 'c', 'z'} for the numpy types {float32, float64, complex64, complex128} respectively. The code and the dtype are stored in attributes *typecode* and *dtype* of the returned functions.

### Examples

```

>>> import scipy.linalg as LA
>>> a = np.random.rand(3, 2)
>>> x_gemv = LA.get_blas_funcs('gemv', (a,))
>>> x_gemv.typecode
'd'
>>> x_gemv = LA.get_blas_funcs('gemv', (a*1j,))
>>> x_gemv.typecode
'z'
    
```

`scipy.linalg.get_lapack_funcs` (*names*, *arrays*=(), *dtype*=None)

Return available LAPACK function objects from names.

Arrays are used to determine the optimal prefix of LAPACK routines.

**Parameters**

- names** : str or sequence of str  
Name(s) of LAPACK functions without type prefix.
- arrays** : sequence of ndarrays, optional  
Arrays can be given to determine optimal prefix of LAPACK routines. If not given, double-precision routines will be used, otherwise the most generic type in arrays will be used.
- dtype** : str or dtype, optional  
Data-type specifier. Not used if *arrays* is non-empty.

**Returns**

- funcs** : list  
List containing the found function(s).

### Notes

This routine automatically chooses between Fortran/C interfaces. Fortran code is used whenever possible for arrays with column major order. In all other cases, C code is preferred.

In LAPACK, the naming convention is that all functions start with a type prefix, which depends on the type of the principal matrix. These can be one of {'s', 'd', 'c', 'z'} for the numpy types {float32, float64, complex64, complex128} respectively, and are stored in attribute `typecode` of the returned functions.

### Examples

Suppose we would like to use 'lange' routine which computes the selected norm of an array. We pass our array in order to get the correct 'lange' flavor.

```
>>> import scipy.linalg as LA
>>> a = np.random.rand(3,2)
>>> x_lange = LA.get_lapack_funcs('lange', (a,))
>>> x_lange.typecode
'd'
>>> x_lange = LA.get_lapack_funcs('lange', (a*1j,))
>>> x_lange.typecode
'z'
```

Several LAPACK routines work best when its internal WORK array has the optimal size (big enough for fast computation and small enough to avoid waste of memory). This size is determined also by a dedicated query to the function which is often wrapped as a standalone function and commonly denoted as `###_lwork`. Below is an example for `?sysv`

```
>>> import scipy.linalg as LA
>>> a = np.random.rand(1000,1000)
>>> b = np.random.rand(1000,1)*1j
>>> # We pick up zsysv and zsysv_lwork due to b array
... xsysv, xlwork = LA.get_lapack_funcs(('sysv', 'sysv_lwork'), (a, b))
>>> opt_lwork, _ = xlwork(a.shape[0]) # returns a complex for 'z' prefix
>>> udut, ipiv, x, info = xsysv(a, b, lwork=int(opt_lwork.real))
```

`scipy.linalg.find_best_blas_type` (*arrays=()*, *dtype=None*)

Find best-matching BLAS/LAPACK type.

Arrays are used to determine the optimal prefix of BLAS routines.

**Parameters**

- arrays** : sequence of ndarrays, optional  
Arrays can be given to determine optimal prefix of BLAS routines. If not given, double-precision routines will be used, otherwise the most generic type in arrays will be used.
- dtype** : str or dtype, optional  
Data-type specifier. Not used if *arrays* is non-empty.

**Returns**

- prefix** : str  
BLAS/LAPACK prefix character.
- dtype** : dtype  
Inferred Numpy data type.
- prefer\_fortran** : bool  
Whether to prefer Fortran order routines over C order.

**Examples**

```
>>> import scipy.linalg.blas as bla
>>> a = np.random.rand(10,15)
>>> b = np.asfortranarray(a) # Change the memory layout order
>>> bla.find_best_blas_type((a,))
('d', dtype('float64'), False)
>>> bla.find_best_blas_type((a*1j,))
('z', dtype('complex128'), False)
>>> bla.find_best_blas_type((b,))
('d', dtype('float64'), True)
```

**See also:**

- scipy.linalg.blas* – Low-level BLAS functions
- scipy.linalg.lapack* – Low-level LAPACK functions
- scipy.linalg.cython\_blas* – Low-level BLAS functions for Cython
- scipy.linalg.cython\_lapack* – Low-level LAPACK functions for Cython

## 5.10 Low-level BLAS functions (*scipy.linalg.blas*)

This module contains low-level functions from the BLAS library.

New in version 0.12.0.

**Warning:** These functions do little to no error checking. It is possible to cause crashes by mis-using them, so prefer using the higher-level routines in *scipy.linalg*.

### 5.10.1 Finding functions

<i>get_blas_funcs</i> (names[, arrays, dtype])	Return available BLAS function objects from names.
<i>find_best_blas_type</i> ([arrays, dtype])	Find best-matching BLAS/LAPACK type.

*scipy.linalg.blas.get\_blas\_funcs* (names, arrays=(), dtype=None)

Return available BLAS function objects from names.

Arrays are used to determine the optimal prefix of BLAS routines.

**Parameters**

- names** : str or sequence of str  
Name(s) of BLAS functions without type prefix.
- arrays** : sequence of ndarrays, optional  
Arrays can be given to determine optimal prefix of BLAS routines. If not given, double-precision routines will be used, otherwise the most generic type in arrays will be used.

**dtype** : str or dtype, optional  
Data-type specifier. Not used if *arrays* is non-empty.

**Returns** **funcs** : list  
List containing the found function(s).

**Notes**

This routine automatically chooses between Fortran/C interfaces. Fortran code is used whenever possible for arrays with column major order. In all other cases, C code is preferred.

In BLAS, the naming convention is that all functions start with a type prefix, which depends on the type of the principal matrix. These can be one of {'s', 'd', 'c', 'z'} for the numpy types {float32, float64, complex64, complex128} respectively. The code and the dtype are stored in attributes *typecode* and *dtype* of the returned functions.

**Examples**

```
>>> import scipy.linalg as LA
>>> a = np.random.rand(3,2)
>>> x_gemv = LA.get_blas_funcs('gemv', (a,))
>>> x_gemv.typecode
'd'
>>> x_gemv = LA.get_blas_funcs('gemv', (a*1j,))
>>> x_gemv.typecode
'z'
```

`scipy.linalg.blas.find_best_blas_type` (*arrays=()*, *dtype=None*)  
Find best-matching BLAS/LAPACK type.

Arrays are used to determine the optimal prefix of BLAS routines.

**Parameters** **arrays** : sequence of ndarrays, optional  
Arrays can be given to determine optimal prefix of BLAS routines. If not given, double-precision routines will be used, otherwise the most generic type in arrays will be used.

**dtype** : str or dtype, optional  
Data-type specifier. Not used if *arrays* is non-empty.

**Returns** **prefix** : str  
BLAS/LAPACK prefix character.

**dtype** : dtype  
Inferred Numpy data type.

**prefer\_fortran** : bool  
Whether to prefer Fortran order routines over C order.

**Examples**

```
>>> import scipy.linalg.blas as bla
>>> a = np.random.rand(10,15)
>>> b = np.asfortranarray(a) # Change the memory layout order
>>> bla.find_best_blas_type((a,))
('d', dtype('float64'), False)
>>> bla.find_best_blas_type((a*1j,))
('z', dtype('complex128'), False)
>>> bla.find_best_blas_type((b,))
('d', dtype('float64'), True)
```

**5.10.2 BLAS Level 1 functions**

<i>caxpy</i> (x,y,[n,a,offx,incx,offy,incy])	Wrapper for <i>caxpy</i> .
<i>ccopy</i> (x,y,[n,offx,incx,offy,incy])	Wrapper for <i>ccopy</i> .
<i>cdotc</i> (x,y,[n,offx,incx,offy,incy])	Wrapper for <i>cdotc</i> .
<i>cdotu</i> (x,y,[n,offx,incx,offy,incy])	Wrapper for <i>cdotu</i> .
<i>crotg</i> (a,b)	Wrapper for <i>crotg</i> .
<i>cscal</i> (a,x,[n,offx,incx])	Wrapper for <i>cscal</i> .
<i>csrot</i> (...)	Wrapper for <i>csrot</i> .
<i>csscal</i> (a,x,[n,offx,incx,overwrite_x])	Wrapper for <i>csscal</i> .
<i>cswap</i> (x,y,[n,offx,incx,offy,incy])	Wrapper for <i>cswap</i> .
<i>dasum</i> (x,[n,offx,incx])	Wrapper for <i>dasum</i> .
<i>daxpy</i> (x,y,[n,a,offx,incx,offy,incy])	Wrapper for <i>daxpy</i> .
<i>dcopy</i> (x,y,[n,offx,incx,offy,incy])	Wrapper for <i>dcopy</i> .
<i>ddot</i> (x,y,[n,offx,incx,offy,incy])	Wrapper for <i>ddot</i> .
<i>dnrm2</i> (x,[n,offx,incx])	Wrapper for <i>dnrm2</i> .
<i>drot</i> (...)	Wrapper for <i>drot</i> .
<i>drotg</i> (a,b)	Wrapper for <i>drotg</i> .
<i>drotm</i> (...)	Wrapper for <i>drotm</i> .
<i>drotmg</i> (d1,d2,x1,y1)	Wrapper for <i>drotmg</i> .
<i>dscal</i> (a,x,[n,offx,incx])	Wrapper for <i>dscal</i> .
<i>dswap</i> (x,y,[n,offx,incx,offy,incy])	Wrapper for <i>dswap</i> .
<i>dzasum</i> (x,[n,offx,incx])	Wrapper for <i>dzasum</i> .
<i>dznrm2</i> (x,[n,offx,incx])	Wrapper for <i>dznrm2</i> .
<i>icamax</i> (x,[n,offx,incx])	Wrapper for <i>icamax</i> .
<i>idamax</i> (x,[n,offx,incx])	Wrapper for <i>idamax</i> .
<i>isamax</i> (x,[n,offx,incx])	Wrapper for <i>isamax</i> .
<i>izamax</i> (x,[n,offx,incx])	Wrapper for <i>izamax</i> .
<i>sasum</i> (x,[n,offx,incx])	Wrapper for <i>sasum</i> .
<i>saxpy</i> (x,y,[n,a,offx,incx,offy,incy])	Wrapper for <i>saxpy</i> .
<i>scasum</i> (x,[n,offx,incx])	Wrapper for <i>scasum</i> .
<i>scnrm2</i> (x,[n,offx,incx])	Wrapper for <i>scnrm2</i> .
<i>scopy</i> (x,y,[n,offx,incx,offy,incy])	Wrapper for <i>scopy</i> .
<i>sdot</i> (x,y,[n,offx,incx,offy,incy])	Wrapper for <i>sdot</i> .
<i>snrm2</i> (x,[n,offx,incx])	Wrapper for <i>snrm2</i> .
<i>srot</i> (...)	Wrapper for <i>srot</i> .
<i>srotg</i> (a,b)	Wrapper for <i>srotg</i> .
<i>srotm</i> (...)	Wrapper for <i>srotm</i> .
<i>srotmg</i> (d1,d2,x1,y1)	Wrapper for <i>srotmg</i> .
<i>sscal</i> (a,x,[n,offx,incx])	Wrapper for <i>sscal</i> .
<i>sswap</i> (x,y,[n,offx,incx,offy,incy])	Wrapper for <i>sswap</i> .
<i>zaxpy</i> (x,y,[n,a,offx,incx,offy,incy])	Wrapper for <i>zaxpy</i> .
<i>zcopy</i> (x,y,[n,offx,incx,offy,incy])	Wrapper for <i>zcopy</i> .
<i>zdotc</i> (x,y,[n,offx,incx,offy,incy])	Wrapper for <i>zdotc</i> .
<i>zdotu</i> (x,y,[n,offx,incx,offy,incy])	Wrapper for <i>zdotu</i> .
<i>zdrot</i> (...)	Wrapper for <i>zdrot</i> .
<i>zdscal</i> (a,x,[n,offx,incx,overwrite_x])	Wrapper for <i>zdscal</i> .
<i>zrotg</i> (a,b)	Wrapper for <i>zrotg</i> .
<i>zscal</i> (a,x,[n,offx,incx])	Wrapper for <i>zscal</i> .
<i>zswap</i> (x,y,[n,offx,incx,offy,incy])	Wrapper for <i>zswap</i> .

`scipy.linalg.blas.caxpy(x, y[, n, a, offx, incx, offy, incy]) = <fortran object>`  
 Wrapper for *caxpy*.

**Parameters** **x** : input rank-1 array('F') with bounds (\*)  
**y** : input rank-1 array('F') with bounds (\*)

**Returns** **z** : rank-1 array('F') with bounds (\*) and y storage

**Other Parameters**

**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$

**a** : input complex, optional  
 Default: (1.0, 0.0)

**offx** : input int, optional  
 Default: 0

**incx** : input int, optional  
 Default: 1

**offy** : input int, optional  
 Default: 0

**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.ccopy(x, y[, n, offx, incx, offy, incy]) = <fortran object>`  
 Wrapper for `ccopy`.

**Parameters** **x** : input rank-1 array('F') with bounds (\*)  
**y** : input rank-1 array('F') with bounds (\*)

**Returns** **y** : rank-1 array('F') with bounds (\*)

**Other Parameters**

**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$

**offx** : input int, optional  
 Default: 0

**incx** : input int, optional  
 Default: 1

**offy** : input int, optional  
 Default: 0

**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.cdotc(x, y[, n, offx, incx, offy, incy]) = <fortran cdotc>`  
 Wrapper for `cdotc`.

**Parameters** **x** : input rank-1 array('F') with bounds (\*)  
**y** : input rank-1 array('F') with bounds (\*)

**Returns** **xy** : complex

**Other Parameters**

**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$

**offx** : input int, optional  
 Default: 0

**incx** : input int, optional  
 Default: 1

**offy** : input int, optional  
 Default: 0

**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.cdotu(x, y[, n, offx, incx, offy, incy]) = <fortran cdotu>`  
 Wrapper for `cdotu`.

**Parameters** **x** : input rank-1 array('F') with bounds (\*)  
**y** : input rank-1 array('F') with bounds (\*)

**Returns** **xy** : complex

**Other Parameters**  
**n** : input int, optional  
 Default: (len(x)-offx)/abs(incx)  
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1

scipy.linalg.blas.**crotdg**(*a, b*) = <fortran object>  
 Wrapper for crotdg.

**Parameters** **a** : input complex  
**b** : input complex

**Returns** **c** : complex  
**s** : complex

scipy.linalg.blas.**csca1**(*a, x*[, *n, offx, incx* ]) = <fortran object>  
 Wrapper for csca1.

**Parameters** **a** : input complex  
**x** : input rank-1 array('F') with bounds (\*)

**Returns** **x** : rank-1 array('F') with bounds (\*)

**Other Parameters**  
**n** : input int, optional  
 Default: (len(x)-offx)/abs(incx)  
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1

scipy.linalg.blas.**csrot**(*x, y, c, s*[, *n, offx, incx, offy, incy, overwrite\_x, overwrite\_y* ]) = <fortran object>

Wrapper for csrot.

**Parameters** **x** : input rank-1 array('F') with bounds (\*)  
**y** : input rank-1 array('F') with bounds (\*)  
**c** : input float  
**s** : input float

**Returns** **x** : rank-1 array('F') with bounds (\*)  
**y** : rank-1 array('F') with bounds (\*)

**Other Parameters**  
**n** : input int, optional  
 Default: (len(x)-1-offx)/abs(incx)+1  
**overwrite\_x** : input int, optional  
 Default: 0  
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**overwrite\_y** : input int, optional

Default: 0  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.csscal(a, x[, n, offx, incx, overwrite_x]) = <fortran object>`  
 Wrapper for `csscal`.

**Parameters** **a** : input float  
**x** : input rank-1 array('F') with bounds (\*)  
**Returns** **x** : rank-1 array('F') with bounds (\*)  
**Other Parameters**  
**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**overwrite\_x** : input int, optional  
 Default: 0  
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1

`scipy.linalg.blas.cswap(x, y[, n, offx, incx, offy, incy]) = <fortran object>`  
 Wrapper for `cswap`.

**Parameters** **x** : input rank-1 array('F') with bounds (\*)  
**y** : input rank-1 array('F') with bounds (\*)  
**Returns** **x** : rank-1 array('F') with bounds (\*)  
**y** : rank-1 array('F') with bounds (\*)  
**Other Parameters**  
**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.dasum(x[, n, offx, incx]) = <fortran dasum>`  
 Wrapper for `dasum`.

**Parameters** **x** : input rank-1 array('d') with bounds (\*)  
**Returns** **s** : float  
**Other Parameters**  
**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1

`scipy.linalg.blas.daxpy(x, y[, n, a, offx, incx, offy, incy]) = <fortran object>`  
 Wrapper for `daxpy`.

**Parameters** **x** : input rank-1 array('d') with bounds (\*)  
**y** : input rank-1 array('d') with bounds (\*)

**Returns** **z** : rank-1 array('d') with bounds (\*) and y storage

**Other Parameters**

**n** : input int, optional  
 Default: (len(x)-offx)/abs(incx)

**a** : input float, optional  
 Default: 1.0

**offx** : input int, optional  
 Default: 0

**incx** : input int, optional  
 Default: 1

**offy** : input int, optional  
 Default: 0

**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.dcopy(x, y[, n, offx, incx, offy, incy]) = <fortran object>`  
 Wrapper for dcopy.

**Parameters** **x** : input rank-1 array('d') with bounds (\*)  
**y** : input rank-1 array('d') with bounds (\*)

**Returns** **y** : rank-1 array('d') with bounds (\*)

**Other Parameters**

**n** : input int, optional  
 Default: (len(x)-offx)/abs(incx)

**offx** : input int, optional  
 Default: 0

**incx** : input int, optional  
 Default: 1

**offy** : input int, optional  
 Default: 0

**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.ddot(x, y[, n, offx, incx, offy, incy]) = <fortran ddot>`  
 Wrapper for ddot.

**Parameters** **x** : input rank-1 array('d') with bounds (\*)  
**y** : input rank-1 array('d') with bounds (\*)

**Returns** **xy** : float

**Other Parameters**

**n** : input int, optional  
 Default: (len(x)-offx)/abs(incx)

**offx** : input int, optional  
 Default: 0

**incx** : input int, optional  
 Default: 1

**offy** : input int, optional  
 Default: 0

**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.dnrm2(x[, n, offx, incx]) = <fortran dnrm2>`  
 Wrapper for dnrm2.

**Parameters** **x** : input rank-1 array('d') with bounds (\*)

**Returns** **n2** : float  
**Other Parameters**  
**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1

`scipy.linalg.blas.drot(x, y, c, s[, n, offx, incx, offy, incy, overwrite_x, overwrite_y]) = <fortran object>`

Wrapper for drot.

**Parameters** **x** : input rank-1 array('d') with bounds (\*)  
**y** : input rank-1 array('d') with bounds (\*)  
**c** : input float  
**s** : input float  
**Returns** **x** : rank-1 array('d') with bounds (\*)  
**y** : rank-1 array('d') with bounds (\*)  
**Other Parameters**  
**n** : input int, optional  
 Default:  $(\text{len}(x) - 1 - \text{offx}) / \text{abs}(\text{incx}) + 1$   
**overwrite\_x** : input int, optional  
 Default: 0  
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**overwrite\_y** : input int, optional  
 Default: 0  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.drotg(a, b) = <fortran object>`

Wrapper for drotg.

**Parameters** **a** : input float  
**b** : input float  
**Returns** **c** : float  
**s** : float

`scipy.linalg.blas.drotm(x, y, param[, n, offx, incx, offy, incy, overwrite_x, overwrite_y]) = <fortran object>`

Wrapper for drotm.

**Parameters** **x** : input rank-1 array('d') with bounds (\*)  
**y** : input rank-1 array('d') with bounds (\*)  
**param** : input rank-1 array('d') with bounds (5)  
**Returns** **x** : rank-1 array('d') with bounds (\*)  
**y** : rank-1 array('d') with bounds (\*)  
**Other Parameters**  
**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**overwrite\_x** : input int, optional  
 Default: 0

**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**overwrite\_y** : input int, optional  
 Default: 0  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.drotmg(d1, d2, x1, y1) = <fortran object>`

Wrapper for `drotmg`.

**Parameters** **d1** : input float  
**d2** : input float  
**x1** : input float  
**y1** : input float  
**Returns** **param** : rank-1 array('d') with bounds (5)

`scipy.linalg.blas.dsca1(a, x[, n, offx, incx]) = <fortran object>`

Wrapper for `dscal`.

**Parameters** **a** : input float  
**x** : input rank-1 array('d') with bounds (\*)  
**Returns** **x** : rank-1 array('d') with bounds (\*)  
**Other Parameters**  
**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1

`scipy.linalg.blas.dswap(x, y[, n, offx, incx, offy, incy]) = <fortran object>`

Wrapper for `dswap`.

**Parameters** **x** : input rank-1 array('d') with bounds (\*)  
**y** : input rank-1 array('d') with bounds (\*)  
**Returns** **x** : rank-1 array('d') with bounds (\*)  
**y** : rank-1 array('d') with bounds (\*)  
**Other Parameters**  
**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.dzasum(x[, n, offx, incx]) = <fortran dzasum>`

Wrapper for `dzasum`.

**Parameters** **x** : input rank-1 array('D') with bounds (\*)  
**Returns** **s** : float

**Other Parameters**

**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1

`scipy.linalg.blas.dznrm2(x[, n, offx, incx]) = <fortran dznrm2>`  
 Wrapper for `dznrm2`.

**Parameters** **x** : input rank-1 array('D') with bounds (\*)

**Returns** **n2** : float

**Other Parameters**

**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1

`scipy.linalg.blas.icamax(x[, n, offx, incx]) = <fortran object>`  
 Wrapper for `icamax`.

**Parameters** **x** : input rank-1 array('F') with bounds (\*)

**Returns** **k** : int

**Other Parameters**

**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1

`scipy.linalg.blas.idamax(x[, n, offx, incx]) = <fortran object>`  
 Wrapper for `idamax`.

**Parameters** **x** : input rank-1 array('d') with bounds (\*)

**Returns** **k** : int

**Other Parameters**

**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1

`scipy.linalg.blas.isamax(x[, n, offx, incx]) = <fortran object>`  
 Wrapper for `isamax`.

**Parameters** **x** : input rank-1 array('f') with bounds (\*)

**Returns** **k** : int

**Other Parameters**

**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional

Default: 1

`scipy.linalg.blas.izamax(x[, n, offx, incx]) = <fortran object>`  
 Wrapper for `izamax`.

**Parameters** `x` : input rank-1 array('D') with bounds (\*)  
**Returns** `k` : int  
**Other Parameters**  
`n` : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
`offx` : input int, optional  
 Default: 0  
`incx` : input int, optional  
 Default: 1

`scipy.linalg.blas.sasum(x[, n, offx, incx]) = <fortran sasum>`  
 Wrapper for `sasum`.

**Parameters** `x` : input rank-1 array('f') with bounds (\*)  
**Returns** `s` : float  
**Other Parameters**  
`n` : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
`offx` : input int, optional  
 Default: 0  
`incx` : input int, optional  
 Default: 1

`scipy.linalg.blas.saxpy(x, y[, n, a, offx, incx, offy, incy]) = <fortran object>`  
 Wrapper for `saxpy`.

**Parameters** `x` : input rank-1 array('f') with bounds (\*)  
`y` : input rank-1 array('f') with bounds (\*)  
**Returns** `z` : rank-1 array('f') with bounds (\*) and y storage  
**Other Parameters**  
`n` : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
`a` : input float, optional  
 Default: 1.0  
`offx` : input int, optional  
 Default: 0  
`incx` : input int, optional  
 Default: 1  
`offy` : input int, optional  
 Default: 0  
`incy` : input int, optional  
 Default: 1

`scipy.linalg.blas.scasum(x[, n, offx, incx]) = <fortran scasum>`  
 Wrapper for `scasum`.

**Parameters** `x` : input rank-1 array('F') with bounds (\*)  
**Returns** `s` : float  
**Other Parameters**  
`n` : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
`offx` : input int, optional  
 Default: 0

**incx** : input int, optional  
Default: 1

`scipy.linalg.blas.scnrm2(x[, n, offx, incx]) = <fortran scnrm2>`

Wrapper for `scnrm2`.

**Parameters** **x** : input rank-1 array('F') with bounds (\*)

**Returns** **n2** : float

**Other Parameters**

**n** : input int, optional  
Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$

**offx** : input int, optional  
Default: 0

**incx** : input int, optional  
Default: 1

`scipy.linalg.blas.scopy(x, y[, n, offx, incx, offy, incy]) = <fortran object>`

Wrapper for `scopy`.

**Parameters** **x** : input rank-1 array('f') with bounds (\*)

**y** : input rank-1 array('f') with bounds (\*)

**Returns** **y** : rank-1 array('f') with bounds (\*)

**Other Parameters**

**n** : input int, optional  
Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$

**offx** : input int, optional  
Default: 0

**incx** : input int, optional  
Default: 1

**offy** : input int, optional  
Default: 0

**incy** : input int, optional  
Default: 1

`scipy.linalg.blas.sdot(x, y[, n, offx, incx, offy, incy]) = <fortran sdot>`

Wrapper for `sdot`.

**Parameters** **x** : input rank-1 array('f') with bounds (\*)

**y** : input rank-1 array('f') with bounds (\*)

**Returns** **xy** : float

**Other Parameters**

**n** : input int, optional  
Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$

**offx** : input int, optional  
Default: 0

**incx** : input int, optional  
Default: 1

**offy** : input int, optional  
Default: 0

**incy** : input int, optional  
Default: 1

`scipy.linalg.blas.snrm2(x[, n, offx, incx]) = <fortran snrm2>`

Wrapper for `snrm2`.

**Parameters** **x** : input rank-1 array('f') with bounds (\*)

**Returns** **n2** : float

**Other Parameters**

**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1

`scipy.linalg.blas.srot(x, y, c, s[, n, offx, incx, offy, incy, overwrite_x, overwrite_y]) = <fortran object>`

Wrapper for `srot`.

**Parameters** **x** : input rank-1 array('f') with bounds (\*)  
**y** : input rank-1 array('f') with bounds (\*)  
**c** : input float  
**s** : input float  
**Returns** **x** : rank-1 array('f') with bounds (\*)  
**y** : rank-1 array('f') with bounds (\*)

**Other Parameters**

**n** : input int, optional  
 Default:  $(\text{len}(x) - 1 - \text{offx}) / \text{abs}(\text{incx}) + 1$   
**overwrite\_x** : input int, optional  
 Default: 0  
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**overwrite\_y** : input int, optional  
 Default: 0  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.srotg(a, b) = <fortran object>`

Wrapper for `srotg`.

**Parameters** **a** : input float  
**b** : input float  
**Returns** **c** : float  
**s** : float

`scipy.linalg.blas.srotm(x, y, param[, n, offx, incx, offy, incy, overwrite_x, overwrite_y]) = <fortran object>`

Wrapper for `srotm`.

**Parameters** **x** : input rank-1 array('f') with bounds (\*)  
**y** : input rank-1 array('f') with bounds (\*)  
**param** : input rank-1 array('f') with bounds (5)  
**Returns** **x** : rank-1 array('f') with bounds (\*)  
**y** : rank-1 array('f') with bounds (\*)

**Other Parameters**

**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**overwrite\_x** : input int, optional  
 Default: 0  
**offx** : input int, optional

Default: 0  
**incx** : input int, optional  
 Default: 1  
**overwrite\_y** : input int, optional  
 Default: 0  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.srotmg(d1, d2, x1, y1) = <fortran object>`

Wrapper for `srotmg`.

**Parameters** **d1** : input float  
**d2** : input float  
**x1** : input float  
**y1** : input float  
**Returns** **param** : rank-1 array('f') with bounds (5)

`scipy.linalg.blas.sscal(a, x[, n, offx, incx]) = <fortran object>`

Wrapper for `sscal`.

**Parameters** **a** : input float  
**x** : input rank-1 array('f') with bounds (\*)  
**Returns** **x** : rank-1 array('f') with bounds (\*)  
**Other Parameters**  
**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1

`scipy.linalg.blas.sswap(x, y[, n, offx, incx, offy, incy]) = <fortran object>`

Wrapper for `sswap`.

**Parameters** **x** : input rank-1 array('f') with bounds (\*)  
**y** : input rank-1 array('f') with bounds (\*)  
**Returns** **x** : rank-1 array('f') with bounds (\*)  
**y** : rank-1 array('f') with bounds (\*)  
**Other Parameters**  
**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.zaxpy(x, y[, n, a, offx, incx, offy, incy]) = <fortran object>`

Wrapper for `zaxpy`.

**Parameters** **x** : input rank-1 array('D') with bounds (\*)  
**y** : input rank-1 array('D') with bounds (\*)  
**Returns** **z** : rank-1 array('D') with bounds (\*) and y storage

*Other Parameters*

**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**a** : input complex, optional  
 Default: (1.0, 0.0)  
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.zcopy(x, y[, n, offx, incx, offy, incy]) = <fortran object>`  
 Wrapper for `zcopy`.

**Parameters** **x** : input rank-1 array('D') with bounds (\*)  
**y** : input rank-1 array('D') with bounds (\*)

**Returns** **y** : rank-1 array('D') with bounds (\*)

*Other Parameters*

**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.zdotc(x, y[, n, offx, incx, offy, incy]) = <fortran zdotc>`  
 Wrapper for `zdotc`.

**Parameters** **x** : input rank-1 array('D') with bounds (\*)  
**y** : input rank-1 array('D') with bounds (\*)

**Returns** **xy** : complex

*Other Parameters*

**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.zdotu(x, y[, n, offx, incx, offy, incy]) = <fortran zdotu>`  
 Wrapper for `zdotu`.

**Parameters** **x** : input rank-1 array('D') with bounds (\*)  
**y** : input rank-1 array('D') with bounds (\*)

**Returns** **xy** : complex

**Other Parameters**

**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.zdrot(x, y, c, s[, n, offx, incx, offy, incy, overwrite_x, overwrite_y]) = <fortran object>`

Wrapper for `zdrot`.

**Parameters** **x** : input rank-1 array('D') with bounds (\*)  
**y** : input rank-1 array('D') with bounds (\*)  
**c** : input float  
**s** : input float  
**Returns** **x** : rank-1 array('D') with bounds (\*)  
**y** : rank-1 array('D') with bounds (\*)

**Other Parameters**

**n** : input int, optional  
 Default:  $(\text{len}(x) - 1 - \text{offx}) / \text{abs}(\text{incx}) + 1$   
**overwrite\_x** : input int, optional  
 Default: 0  
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**overwrite\_y** : input int, optional  
 Default: 0  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1

`scipy.linalg.blas.zdscal(a, x[, n, offx, incx, overwrite_x]) = <fortran object>`

Wrapper for `zdscal`.

**Parameters** **a** : input float  
**x** : input rank-1 array('D') with bounds (\*)  
**Returns** **x** : rank-1 array('D') with bounds (\*)

**Other Parameters**

**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**overwrite\_x** : input int, optional  
 Default: 0  
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1

`scipy.linalg.blas.zrotg(a, b) = <fortran object>`

Wrapper for `zrotg`.

**Parameters** **a** : input complex  
**b** : input complex  
**Returns** **c** : complex  
**s** : complex

`scipy.linalg.blas.zscal(a, x[, n, offx, incx]) = <fortran object>`  
 Wrapper for `zscal`.

**Parameters** **a** : input complex  
**x** : input rank-1 array('D') with bounds (\*)  
**Returns** **x** : rank-1 array('D') with bounds (\*)  
**Other Parameters**  
**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1

`scipy.linalg.blas.zswap(x, y[, n, offx, incx, offy, incy]) = <fortran object>`  
 Wrapper for `zswap`.

**Parameters** **x** : input rank-1 array('D') with bounds (\*)  
**y** : input rank-1 array('D') with bounds (\*)  
**Returns** **x** : rank-1 array('D') with bounds (\*)  
**y** : rank-1 array('D') with bounds (\*)  
**Other Parameters**  
**n** : input int, optional  
 Default:  $(\text{len}(x) - \text{offx}) / \text{abs}(\text{incx})$   
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1

### 5.10.3 BLAS Level 2 functions

<code>sgbmv(...)</code>	Wrapper for <code>sgbmv</code> .
<code>sgemv(...)</code>	Wrapper for <code>sgemv</code> .
<code>sger(...)</code>	Wrapper for <code>sger</code> .
<code>ssbmv(...)</code>	Wrapper for <code>ssbmv</code> .
<code>sspr(n,alpha,x,ap,[incx,offx,lower,overwrite_ap])</code>	Wrapper for <code>sspr</code> .
<code>sspr2(...)</code>	Wrapper for <code>sspr2</code> .
<code>ssymv(...)</code>	Wrapper for <code>ssymv</code> .
<code>ssyr(alpha,x,[lower,incx,offx,n,a,overwrite_a])</code>	Wrapper for <code>ssyr</code> .
<code>ssyr2(...)</code>	Wrapper for <code>ssyr2</code> .
<code>stbmv(...)</code>	Wrapper for <code>stbmv</code> .
<code>stpsv(...)</code>	Wrapper for <code>stpsv</code> .
<code>strmv(...)</code>	Wrapper for <code>strmv</code> .
<code>strsv(...)</code>	Wrapper for <code>strsv</code> .

Continued on next page

Table 5.93 – continued from previous page

<i>dgbmv(...)</i>	Wrapper for <i>dgbmv</i> .
<i>dgemv(...)</i>	Wrapper for <i>dgemv</i> .
<i>dger(...)</i>	Wrapper for <i>dger</i> .
<i>dsbmv(...)</i>	Wrapper for <i>dsbmv</i> .
<i>dspr(n,alpha,x,ap,[incx,offx,lower,overwrite_ap])</i>	Wrapper for <i>dspr</i> .
<i>dspr2(...)</i>	Wrapper for <i>dspr2</i> .
<i>dsymv(...)</i>	Wrapper for <i>dsymv</i> .
<i>dsyr(alpha,x,[lower,incx,offx,n,a,overwrite_a])</i>	Wrapper for <i>dsyr</i> .
<i>dsyr2(...)</i>	Wrapper for <i>dsyr2</i> .
<i>dtbmv(...)</i>	Wrapper for <i>dtbmv</i> .
<i>dtpsv(...)</i>	Wrapper for <i>dtpsv</i> .
<i>dtrmv(...)</i>	Wrapper for <i>dtrmv</i> .
<i>dtrsv(...)</i>	Wrapper for <i>dtrsv</i> .
<i>cgbmv(...)</i>	Wrapper for <i>cgbmv</i> .
<i>cgemv(...)</i>	Wrapper for <i>cgemv</i> .
<i>cgerc(...)</i>	Wrapper for <i>cgerc</i> .
<i>cgeru(...)</i>	Wrapper for <i>cgeru</i> .
<i>chbmv(...)</i>	Wrapper for <i>chbmv</i> .
<i>chemv(...)</i>	Wrapper for <i>chemv</i> .
<i>cher(alpha,x,[lower,incx,offx,n,a,overwrite_a])</i>	Wrapper for <i>cher</i> .
<i>cher2(...)</i>	Wrapper for <i>cher2</i> .
<i>chpmv(...)</i>	Wrapper for <i>chpmv</i> .
<i>chpr(n,alpha,x,ap,[incx,offx,lower,overwrite_ap])</i>	Wrapper for <i>chpr</i> .
<i>chpr2(...)</i>	Wrapper for <i>chpr2</i> .
<i>ctbmv(...)</i>	Wrapper for <i>ctbmv</i> .
<i>ctbsv(...)</i>	Wrapper for <i>ctbsv</i> .
<i>ctpmv(...)</i>	Wrapper for <i>ctpmv</i> .
<i>ctpsv(...)</i>	Wrapper for <i>ctpsv</i> .
<i>ctrmv(...)</i>	Wrapper for <i>ctrmv</i> .
<i>ctrsv(...)</i>	Wrapper for <i>ctrsv</i> .
<i>csyr(alpha,x,[lower,incx,offx,n,a,overwrite_a])</i>	Wrapper for <i>csyr</i> .
<i>zgbmv(...)</i>	Wrapper for <i>zgbmv</i> .
<i>zgemv(...)</i>	Wrapper for <i>zgemv</i> .
<i>zgerc(...)</i>	Wrapper for <i>zgerc</i> .
<i>zgeru(...)</i>	Wrapper for <i>zgeru</i> .
<i>zhbmv(...)</i>	Wrapper for <i>zhbmv</i> .
<i>zhemv(...)</i>	Wrapper for <i>zhemv</i> .
<i>zher(alpha,x,[lower,incx,offx,n,a,overwrite_a])</i>	Wrapper for <i>zher</i> .
<i>zher2(...)</i>	Wrapper for <i>zher2</i> .
<i>zhpmv(...)</i>	Wrapper for <i>zhpmv</i> .
<i>zhpr(n,alpha,x,ap,[incx,offx,lower,overwrite_ap])</i>	Wrapper for <i>zhpr</i> .
<i>zhpr2(...)</i>	Wrapper for <i>zhpr2</i> .
<i>ztbmv(...)</i>	Wrapper for <i>ztbmv</i> .
<i>ztbsv(...)</i>	Wrapper for <i>ztbsv</i> .
<i>ztpmv(...)</i>	Wrapper for <i>ztpmv</i> .
<i>ztrmv(...)</i>	Wrapper for <i>ztrmv</i> .
<i>ztrsv(...)</i>	Wrapper for <i>ztrsv</i> .
<i>zsyr(alpha,x,[lower,incx,offx,n,a,overwrite_a])</i>	Wrapper for <i>zsyr</i> .

`scipy.linalg.blas.sgbmv` (*m*, *n*, *kl*, *ku*, *alpha*, *a*, *x*[, *incx*, *offx*, *beta*, *y*, *incy*, *offy*, *trans*, *overwrite\_y*])  
 = <fortran object>

Wrapper for `sgbmv`.

**Parameters**    **m** : input int  
                   **n** : input int  
                   **kl** : input int  
                   **ku** : input int  
                   **alpha** : input float  
                   **a** : input rank-2 array('f') with bounds (lda,n)  
                   **x** : input rank-1 array('f') with bounds (\*)  
**Returns**        **yout** : rank-1 array('f') with bounds (ly) and y storage  
**Other Parameters**  
                   **incx** : input int, optional  
                             Default: 1  
                   **offx** : input int, optional  
                             Default: 0  
                   **beta** : input float, optional  
                             Default: 0.0  
                   **y** : input rank-1 array('f') with bounds (ly)  
                   **overwrite\_y** : input int, optional  
                             Default: 0  
                   **incy** : input int, optional  
                             Default: 1  
                   **offy** : input int, optional  
                             Default: 0  
                   **trans** : input int, optional  
                             Default: 0

`scipy.linalg.blas.sgemv` (*alpha*, *a*, *x*[, *beta*, *y*, *offx*, *incx*, *offy*, *incy*, *trans*, *overwrite\_y*]) = <fortran  
 object>

Wrapper for `sgemv`.

**Parameters**    **alpha** : input float  
                   **a** : input rank-2 array('f') with bounds (m,n)  
                   **x** : input rank-1 array('f') with bounds (\*)  
**Returns**        **y** : rank-1 array('f') with bounds (ly)  
**Other Parameters**  
                   **beta** : input float, optional  
                             Default: 0.0  
                   **y** : input rank-1 array('f') with bounds (ly)  
                   **overwrite\_y** : input int, optional  
                             Default: 0  
                   **offx** : input int, optional  
                             Default: 0  
                   **incx** : input int, optional  
                             Default: 1  
                   **offy** : input int, optional  
                             Default: 0  
                   **incy** : input int, optional  
                             Default: 1  
                   **trans** : input int, optional  
                             Default: 0

`scipy.linalg.blas.sger(alpha, x, y[, incx, incy, a, overwrite_x, overwrite_y, overwrite_a]) = <fortran object>`

Wrapper for `sger`.

**Parameters** **alpha** : input float  
**x** : input rank-1 array('f') with bounds (m)  
**y** : input rank-1 array('f') with bounds (n)  
**Returns** **a** : rank-2 array('f') with bounds (m,n)  
**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 1  
**incx** : input int, optional  
 Default: 1  
**overwrite\_y** : input int, optional  
 Default: 1  
**incy** : input int, optional  
 Default: 1  
**a** : input rank-2 array('f') with bounds (m,n), optional  
 Default: 0.0  
**overwrite\_a** : input int, optional  
 Default: 0

`scipy.linalg.blas.ssbmv(k, alpha, a, x[, incx, offx, beta, y, incy, offy, lower, overwrite_y]) = <fortran object>`

Wrapper for `ssbmv`.

**Parameters** **k** : input int  
**alpha** : input float  
**a** : input rank-2 array('f') with bounds (lda,n)  
**x** : input rank-1 array('f') with bounds (\*)  
**Returns** **yout** : rank-1 array('f') with bounds (ly) and y storage  
**Other Parameters**  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**beta** : input float, optional  
 Default: 0.0  
**y** : input rank-1 array('f') with bounds (ly)  
**overwrite\_y** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.sspr(n, alpha, x, ap[, incx, offx, lower, overwrite_ap]) = <fortran object>`

Wrapper for `sspr`.

**Parameters** **n** : input int  
**alpha** : input float  
**x** : input rank-1 array('f') with bounds (\*)  
**ap** : input rank-1 array('f') with bounds (\*)  
**Returns** **apu** : rank-1 array('f') with bounds (\*) and ap storage

*Other Parameters*

**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**overwrite\_ap** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

scipy.linalg.blas.**sspr2**(*n, alpha, x, y, ap*[, *incx, offx, incy, offy, lower, overwrite\_ap*]) = <fortran object>

Wrapper for `sspr2`.

*Parameters* **n** : input int  
**alpha** : input float  
**x** : input rank-1 array('f') with bounds (\*)  
**y** : input rank-1 array('f') with bounds (\*)  
**ap** : input rank-1 array('f') with bounds (\*)  
*Returns* **apu** : rank-1 array('f') with bounds (\*) and ap storage

*Other Parameters*

**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**overwrite\_ap** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

scipy.linalg.blas.**ssymv**(*alpha, a, x*[, *beta, y, offx, incx, offy, incy, lower, overwrite\_y*]) = <fortran object>

Wrapper for `ssymv`.

*Parameters* **alpha** : input float  
**a** : input rank-2 array('f') with bounds (n,n)  
**x** : input rank-1 array('f') with bounds (\*)  
*Returns* **y** : rank-1 array('f') with bounds (ly)

*Other Parameters*

**beta** : input float, optional  
 Default: 0.0  
**y** : input rank-1 array('f') with bounds (ly)  
**overwrite\_y** : input int, optional  
 Default: 0  
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1

**lower** : input int, optional  
Default: 0

`scipy.linalg.blas.ssyrr` (*alpha*, *x*[, *lower*, *incx*, *offx*, *n*, *a*, *overwrite\_a* ]) = <fortran object>

Wrapper for `ssyr`.

**Parameters** **alpha** : input float  
**x** : input rank-1 array('f') with bounds (\*)

**Returns** **a** : rank-2 array('f') with bounds (n,n)

**Other Parameters**  
**lower** : input int, optional  
Default: 0  
**incx** : input int, optional  
Default: 1  
**offx** : input int, optional  
Default: 0  
**n** : input int, optional  
Default:  $(\text{len}(x)-1-\text{offx})/\text{abs}(\text{incx})+1$   
**a** : input rank-2 array('f') with bounds (n,n)  
**overwrite\_a** : input int, optional  
Default: 0

`scipy.linalg.blas.ssyrr2` (*alpha*, *x*, *y*[, *lower*, *incx*, *offx*, *incy*, *offy*, *n*, *a*, *overwrite\_a* ]) = <fortran object>

Wrapper for `ssyr2`.

**Parameters** **alpha** : input float  
**x** : input rank-1 array('f') with bounds (\*)  
**y** : input rank-1 array('f') with bounds (\*)

**Returns** **a** : rank-2 array('f') with bounds (n,n)

**Other Parameters**  
**lower** : input int, optional  
Default: 0  
**incx** : input int, optional  
Default: 1  
**offx** : input int, optional  
Default: 0  
**incy** : input int, optional  
Default: 1  
**offy** : input int, optional  
Default: 0  
**n** : input int, optional  
Default:  $((\text{len}(x)-1-\text{offx})/\text{abs}(\text{incx})+1 \leq (\text{len}(y)-1-\text{offy})/\text{abs}(\text{incy})+1 ? (\text{len}(x)-1-\text{offx})/\text{abs}(\text{incx})+1 : (\text{len}(y)-1-\text{offy})/\text{abs}(\text{incy})+1)$   
**a** : input rank-2 array('f') with bounds (n,n)  
**overwrite\_a** : input int, optional  
Default: 0

`scipy.linalg.blas.stbmv` (*k*, *a*, *x*[, *incx*, *offx*, *lower*, *trans*, *diag*, *overwrite\_x* ]) = <fortran object>

Wrapper for `stbmv`.

**Parameters** **k** : input int  
**a** : input rank-2 array('f') with bounds (lda,n)  
**x** : input rank-1 array('f') with bounds (\*)

**Returns** **xout** : rank-1 array('f') with bounds (\*) and x storage

**Other Parameters**  
**overwrite\_x** : input int, optional

Default: 0  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.stpsv(n, ap, x[, incx, offx, lower, trans, diag, overwrite_x]) = <fortran object>`  
 Wrapper for `stpsv`.

**Parameters** **n** : input int  
**ap** : input rank-1 array('f') with bounds (\*)  
**x** : input rank-1 array('f') with bounds (\*)  
**Returns** **xout** : rank-1 array('f') with bounds (\*) and x storage  
**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.strmv(a, x[, offx, incx, lower, trans, diag, overwrite_x]) = <fortran object>`  
 Wrapper for `strmv`.

**Parameters** **a** : input rank-2 array('f') with bounds (n,n)  
**x** : input rank-1 array('f') with bounds (\*)  
**Returns** **x** : rank-1 array('f') with bounds (\*)  
**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0  
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**lower** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.strsv(a, x[, incx, offx, lower, trans, diag, overwrite_x]) = <fortran object>`  
 Wrapper for `strsv`.

**Parameters** **a** : input rank-2 array('f') with bounds (n,n)  
**x** : input rank-1 array('f') with bounds (\*)

**Returns** **xout** : rank-1 array('f') with bounds (\*) and x storage

**Other Parameters**

**overwrite\_x** : input int, optional  
 Default: 0

**incx** : input int, optional  
 Default: 1

**offx** : input int, optional  
 Default: 0

**lower** : input int, optional  
 Default: 0

**trans** : input int, optional  
 Default: 0

**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.dgbmv(m, n, kl, ku, alpha, a, x[, incx, offx, beta, y, incy, offy, trans, overwrite_y])`  
 = <fortran object>

Wrapper for dgbmv.

**Parameters** **m** : input int  
**n** : input int  
**kl** : input int  
**ku** : input int  
**alpha** : input float  
**a** : input rank-2 array('d') with bounds (lda,n)  
**x** : input rank-1 array('d') with bounds (\*)

**Returns** **yout** : rank-1 array('d') with bounds (ly) and y storage

**Other Parameters**

**incx** : input int, optional  
 Default: 1

**offx** : input int, optional  
 Default: 0

**beta** : input float, optional  
 Default: 0.0

**y** : input rank-1 array('d') with bounds (ly)

**overwrite\_y** : input int, optional  
 Default: 0

**incy** : input int, optional  
 Default: 1

**offy** : input int, optional  
 Default: 0

**trans** : input int, optional  
 Default: 0

`scipy.linalg.blas.dgemv(alpha, a, x[, beta, y, offx, incx, offy, incy, trans, overwrite_y])` = <fortran object>

Wrapper for dgemv.

**Parameters** **alpha** : input float  
**a** : input rank-2 array('d') with bounds (m,n)  
**x** : input rank-1 array('d') with bounds (\*)

**Returns** **y** : rank-1 array('d') with bounds (ly)

**Other Parameters**

**beta** : input float, optional

Default: 0.0  
**y** : input rank-1 array('d') with bounds (ly)  
**overwrite\_y** : input int, optional  
 Default: 0  
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1  
**trans** : input int, optional  
 Default: 0

`scipy.linalg.blas.dger(alpha, x, y[, incx, incy, a, overwrite_x, overwrite_y, overwrite_a]) = <fortran object>`

Wrapper for dger.

**Parameters** **alpha** : input float  
**x** : input rank-1 array('d') with bounds (m)  
**y** : input rank-1 array('d') with bounds (n)  
**Returns** **a** : rank-2 array('d') with bounds (m,n)  
**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 1  
**incx** : input int, optional  
 Default: 1  
**overwrite\_y** : input int, optional  
 Default: 1  
**incy** : input int, optional  
 Default: 1  
**a** : input rank-2 array('d') with bounds (m,n), optional  
 Default: 0.0  
**overwrite\_a** : input int, optional  
 Default: 0

`scipy.linalg.blas.dsblmv(k, alpha, a, x[, incx, offx, beta, y, incy, offy, lower, overwrite_y]) = <fortran object>`

Wrapper for dsblmv.

**Parameters** **k** : input int  
**alpha** : input float  
**a** : input rank-2 array('d') with bounds (lda,n)  
**x** : input rank-1 array('d') with bounds (\*)  
**Returns** **yout** : rank-1 array('d') with bounds (ly) and y storage  
**Other Parameters**  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**beta** : input float, optional  
 Default: 0.0  
**y** : input rank-1 array('d') with bounds (ly)  
**overwrite\_y** : input int, optional  
 Default: 0

**incy** : input int, optional  
Default: 1  
**offy** : input int, optional  
Default: 0  
**lower** : input int, optional  
Default: 0

`scipy.linalg.blas.dspr` (*n*, *alpha*, *x*, *ap*[, *incx*, *offx*, *lower*, *overwrite\_ap* ]) = <fortran object>  
Wrapper for dspr.

**Parameters** **n** : input int  
**alpha** : input float  
**x** : input rank-1 array('d') with bounds (\*)  
**ap** : input rank-1 array('d') with bounds (\*)  
**Returns** **apu** : rank-1 array('d') with bounds (\*) and ap storage  
**Other Parameters**  
**incx** : input int, optional  
Default: 1  
**offx** : input int, optional  
Default: 0  
**overwrite\_ap** : input int, optional  
Default: 0  
**lower** : input int, optional  
Default: 0

`scipy.linalg.blas.dspr2` (*n*, *alpha*, *x*, *y*, *ap*[, *incx*, *offx*, *incy*, *offy*, *lower*, *overwrite\_ap* ]) = <fortran object>  
Wrapper for dspr2.

**Parameters** **n** : input int  
**alpha** : input float  
**x** : input rank-1 array('d') with bounds (\*)  
**y** : input rank-1 array('d') with bounds (\*)  
**ap** : input rank-1 array('d') with bounds (\*)  
**Returns** **apu** : rank-1 array('d') with bounds (\*) and ap storage  
**Other Parameters**  
**incx** : input int, optional  
Default: 1  
**offx** : input int, optional  
Default: 0  
**incy** : input int, optional  
Default: 1  
**offy** : input int, optional  
Default: 0  
**overwrite\_ap** : input int, optional  
Default: 0  
**lower** : input int, optional  
Default: 0

`scipy.linalg.blas.dsymv` (*alpha*, *a*, *x*[, *beta*, *y*, *offx*, *incx*, *offy*, *incy*, *lower*, *overwrite\_y* ]) = <fortran object>  
Wrapper for dsymv.

**Parameters** **alpha** : input float  
**a** : input rank-2 array('d') with bounds (n,n)  
**x** : input rank-1 array('d') with bounds (\*)  
**Returns** **y** : rank-1 array('d') with bounds (ly)

*Other Parameters*

**beta** : input float, optional  
 Default: 0.0  
**y** : input rank-1 array('d') with bounds (ly)  
**overwrite\_y** : input int, optional  
 Default: 0  
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1  
**lower** : input int, optional  
 Default: 0

scipy.linalg.blas.**dsyr** (*alpha*, *x*[, *lower*, *incx*, *offx*, *n*, *a*, *overwrite\_a* ]) = <fortran object>  
 Wrapper for dsyr.

*Parameters*    **alpha** : input float  
                   **x** : input rank-1 array('d') with bounds (\*)  
*Returns*        **a** : rank-2 array('d') with bounds (n,n)

*Other Parameters*

**lower** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**n** : input int, optional  
 Default: (len(x)-1-offx)/abs(incx)+1  
**a** : input rank-2 array('d') with bounds (n,n)  
**overwrite\_a** : input int, optional  
 Default: 0

scipy.linalg.blas.**dsyr2** (*alpha*, *x*, *y*[, *lower*, *incx*, *offx*, *incy*, *offy*, *n*, *a*, *overwrite\_a* ]) = <fortran object>

Wrapper for dsyr2.

*Parameters*    **alpha** : input float  
                   **x** : input rank-1 array('d') with bounds (\*)  
                   **y** : input rank-1 array('d') with bounds (\*)  
*Returns*        **a** : rank-2 array('d') with bounds (n,n)

*Other Parameters*

**lower** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**n** : input int, optional

Default:  $((\text{len}(x)-1-\text{offx})/\text{abs}(\text{incx})+1 \leq (\text{len}(y)-1-\text{offy})/\text{abs}(\text{incy})+1 \text{ ?}(\text{len}(x)-1-\text{offx})/\text{abs}(\text{incx})+1 : (\text{len}(y)-1-\text{offy})/\text{abs}(\text{incy})+1)$   
**a** : input rank-2 array('d') with bounds (n,n)  
**overwrite\_a** : input int, optional  
 Default: 0

`scipy.linalg.blas.dtbmv(k, a, x[, incx, offx, lower, trans, diag, overwrite_x]) = <fortran object>`

Wrapper for dtbmv.

**Parameters** **k** : input int  
**a** : input rank-2 array('d') with bounds (lda,n)  
**x** : input rank-1 array('d') with bounds (\*)  
**Returns** **xout** : rank-1 array('d') with bounds (\*) and x storage  
**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.dtpsv(n, ap, x[, incx, offx, lower, trans, diag, overwrite_x]) = <fortran object>`

Wrapper for dtpsv.

**Parameters** **n** : input int  
**ap** : input rank-1 array('d') with bounds (\*)  
**x** : input rank-1 array('d') with bounds (\*)  
**Returns** **xout** : rank-1 array('d') with bounds (\*) and x storage  
**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.dtrmv(a, x[, offx, incx, lower, trans, diag, overwrite_x]) = <fortran object>`

Wrapper for dtrmv.

**Parameters** **a** : input rank-2 array('d') with bounds (n,n)  
**x** : input rank-1 array('d') with bounds (\*)  
**Returns** **x** : rank-1 array('d') with bounds (\*)  
**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0

**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**lower** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.dtrsv(a, x[, incx, offx, lower, trans, diag, overwrite_x]) = <fortran object>`  
 Wrapper for `dtrsv`.

**Parameters** **a** : input rank-2 array('d') with bounds (n,n)  
**x** : input rank-1 array('d') with bounds (\*)  
**Returns** **xout** : rank-1 array('d') with bounds (\*) and x storage  
**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.cgbmv(m, n, kl, ku, alpha, a, x[, incx, offx, beta, y, incy, offy, trans, overwrite_y])`  
 = <fortran object>

Wrapper for `cgbmv`.

**Parameters** **m** : input int  
**n** : input int  
**kl** : input int  
**ku** : input int  
**alpha** : input complex  
**a** : input rank-2 array('F') with bounds (lda,n)  
**x** : input rank-1 array('F') with bounds (\*)  
**Returns** **yout** : rank-1 array('F') with bounds (ly) and y storage  
**Other Parameters**  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**beta** : input complex, optional  
 Default: (0.0, 0.0)  
**y** : input rank-1 array('F') with bounds (ly)  
**overwrite\_y** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1  
**offy** : input int, optional

Default: 0  
**trans** : input int, optional  
 Default: 0

`scipy.linalg.blas.cgemv(alpha, a, x[, beta, y, offx, incx, offy, incy, trans, overwrite_y]) = <fortran object>`

Wrapper for cgemv.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('F') with bounds (m,n)  
**x** : input rank-1 array('F') with bounds (\*)  
**Returns** **y** : rank-1 array('F') with bounds (ly)  
**Other Parameters**  
**beta** : input complex, optional  
 Default: (0.0, 0.0)  
**y** : input rank-1 array('F') with bounds (ly)  
**overwrite\_y** : input int, optional  
 Default: 0  
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1  
**trans** : input int, optional  
 Default: 0

`scipy.linalg.blas.cgerc(alpha, x, y[, incx, incy, a, overwrite_x, overwrite_y, overwrite_a]) = <fortran object>`

Wrapper for cgerc.

**Parameters** **alpha** : input complex  
**x** : input rank-1 array('F') with bounds (m)  
**y** : input rank-1 array('F') with bounds (n)  
**Returns** **a** : rank-2 array('F') with bounds (m,n)  
**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 1  
**incx** : input int, optional  
 Default: 1  
**overwrite\_y** : input int, optional  
 Default: 1  
**incy** : input int, optional  
 Default: 1  
**a** : input rank-2 array('F') with bounds (m,n), optional  
 Default: (0.0,0.0)  
**overwrite\_a** : input int, optional  
 Default: 0

`scipy.linalg.blas.cgeru(alpha, x, y[, incx, incy, a, overwrite_x, overwrite_y, overwrite_a]) = <fortran object>`

Wrapper for cgeru.

**Parameters** **alpha** : input complex  
**x** : input rank-1 array('F') with bounds (m)

**Returns** **y** : input rank-1 array('F') with bounds (n)  
**a** : rank-2 array('F') with bounds (m,n)

**Other Parameters**

**overwrite\_x** : input int, optional  
 Default: 1

**incx** : input int, optional  
 Default: 1

**overwrite\_y** : input int, optional  
 Default: 1

**incy** : input int, optional  
 Default: 1

**a** : input rank-2 array('F') with bounds (m,n), optional  
 Default: (0.0,0.0)

**overwrite\_a** : input int, optional  
 Default: 0

`scipy.linalg.blas.chbmv(k, alpha, a, x[, incx, offx, beta, y, incy, offy, lower, overwrite_y]) = <fortran object>`

Wrapper for chbmv.

**Parameters** **k** : input int  
**alpha** : input complex  
**a** : input rank-2 array('F') with bounds (lda,n)  
**x** : input rank-1 array('F') with bounds (\*)

**Returns** **yout** : rank-1 array('F') with bounds (ly) and y storage

**Other Parameters**

**incx** : input int, optional  
 Default: 1

**offx** : input int, optional  
 Default: 0

**beta** : input complex, optional  
 Default: (0.0, 0.0)

**y** : input rank-1 array('F') with bounds (ly)

**overwrite\_y** : input int, optional  
 Default: 0

**incy** : input int, optional  
 Default: 1

**offy** : input int, optional  
 Default: 0

**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.chemv(alpha, a, x[, beta, y, offx, incx, offy, incy, lower, overwrite_y]) = <fortran object>`

Wrapper for chemv.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('F') with bounds (n,n)  
**x** : input rank-1 array('F') with bounds (\*)

**Returns** **y** : rank-1 array('F') with bounds (ly)

**Other Parameters**

**beta** : input complex, optional  
 Default: (0.0, 0.0)

**y** : input rank-1 array('F') with bounds (ly)

**overwrite\_y** : input int, optional  
 Default: 0

**offx** : input int, optional  
Default: 0  
**incx** : input int, optional  
Default: 1  
**offy** : input int, optional  
Default: 0  
**incy** : input int, optional  
Default: 1  
**lower** : input int, optional  
Default: 0

`scipy.linalg.blas.cher(alpha, x[, lower, incx, offx, n, a, overwrite_a]) = <fortran object>`  
 Wrapper for cher.

**Parameters** **alpha** : input complex  
**x** : input rank-1 array('F') with bounds (\*)  
**Returns** **a** : rank-2 array('F') with bounds (n,n)  
**Other Parameters**  
**lower** : input int, optional  
Default: 0  
**incx** : input int, optional  
Default: 1  
**offx** : input int, optional  
Default: 0  
**n** : input int, optional  
Default: (len(x)-1-offx)/abs(incx)+1  
**a** : input rank-2 array('F') with bounds (n,n)  
**overwrite\_a** : input int, optional  
Default: 0

`scipy.linalg.blas.cher2(alpha, x, y[, lower, incx, offx, incy, offy, n, a, overwrite_a]) = <fortran object>`

Wrapper for cher2.

**Parameters** **alpha** : input complex  
**x** : input rank-1 array('F') with bounds (\*)  
**y** : input rank-1 array('F') with bounds (\*)  
**Returns** **a** : rank-2 array('F') with bounds (n,n)  
**Other Parameters**  
**lower** : input int, optional  
Default: 0  
**incx** : input int, optional  
Default: 1  
**offx** : input int, optional  
Default: 0  
**incy** : input int, optional  
Default: 1  
**offy** : input int, optional  
Default: 0  
**n** : input int, optional  
Default: ((len(x)-1-offx)/abs(incx)+1 <=(len(y)-1-offy)/abs(incy)+1 ?(len(x)-1-offx)/abs(incx)+1 :(len(y)-1-offy)/abs(incy)+1)  
**a** : input rank-2 array('F') with bounds (n,n)  
**overwrite\_a** : input int, optional  
Default: 0

`scipy.linalg.blas.chpmv` (*n*, *alpha*, *ap*, *x*[, *incx*, *offx*, *beta*, *y*, *incy*, *offy*, *lower*, *overwrite\_y* ]) = <fortran object>

Wrapper for `chpmv`.

**Parameters**

- n** : input int
- alpha** : input complex
- ap** : input rank-1 array('F') with bounds (\*)
- x** : input rank-1 array('F') with bounds (\*)

**Returns**

- yout** : rank-1 array('F') with bounds (ly) and y storage

**Other Parameters**

- incx** : input int, optional  
Default: 1
- offx** : input int, optional  
Default: 0
- beta** : input complex, optional  
Default: (0.0, 0.0)
- y** : input rank-1 array('F') with bounds (ly)
- overwrite\_y** : input int, optional  
Default: 0
- incy** : input int, optional  
Default: 1
- offy** : input int, optional  
Default: 0
- lower** : input int, optional  
Default: 0

`scipy.linalg.blas.chpr` (*n*, *alpha*, *x*, *ap*[, *incx*, *offx*, *lower*, *overwrite\_ap* ]) = <fortran object>

Wrapper for `chpr`.

**Parameters**

- n** : input int
- alpha** : input float
- x** : input rank-1 array('F') with bounds (\*)
- ap** : input rank-1 array('F') with bounds (\*)

**Returns**

- apu** : rank-1 array('F') with bounds (\*) and ap storage

**Other Parameters**

- incx** : input int, optional  
Default: 1
- offx** : input int, optional  
Default: 0
- overwrite\_ap** : input int, optional  
Default: 0
- lower** : input int, optional  
Default: 0

`scipy.linalg.blas.chpr2` (*n*, *alpha*, *x*, *y*, *ap*[, *incx*, *offx*, *incy*, *offy*, *lower*, *overwrite\_ap* ]) = <fortran object>

Wrapper for `chpr2`.

**Parameters**

- n** : input int
- alpha** : input complex
- x** : input rank-1 array('F') with bounds (\*)
- y** : input rank-1 array('F') with bounds (\*)
- ap** : input rank-1 array('F') with bounds (\*)

**Returns**

- apu** : rank-1 array('F') with bounds (\*) and ap storage

**Other Parameters**

- incx** : input int, optional  
Default: 1

**offx** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**overwrite\_ap** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.ctbmv(k, a, x[, incx, offx, lower, trans, diag, overwrite_x]) = <fortran object>`  
 Wrapper for `ctbmv`.

**Parameters** **k** : input int  
**a** : input rank-2 array('F') with bounds (lda,n)  
**x** : input rank-1 array('F') with bounds (\*)  
**Returns** **xout** : rank-1 array('F') with bounds (\*) and x storage  
**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.ctbsv(k, a, x[, incx, offx, lower, trans, diag, overwrite_x]) = <fortran object>`  
 Wrapper for `ctbsv`.

**Parameters** **k** : input int  
**a** : input rank-2 array('F') with bounds (lda,n)  
**x** : input rank-1 array('F') with bounds (\*)  
**Returns** **xout** : rank-1 array('F') with bounds (\*) and x storage  
**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.ctpmv(n, ap, x[, incx, offx, lower, trans, diag, overwrite_x]) = <fortran object>`  
 Wrapper for `ctpmv`.

**Parameters** **n** : input int  
**ap** : input rank-1 array('F') with bounds (\*)  
**x** : input rank-1 array('F') with bounds (\*)  
**Returns** **xout** : rank-1 array('F') with bounds (\*) and x storage

**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.ctpsv(n, ap, x[, incx, offx, lower, trans, diag, overwrite_x]) = <fortran object>`  
 Wrapper for `ctpsv`.

**Parameters** **n** : input int  
**ap** : input rank-1 array('F') with bounds (\*)  
**x** : input rank-1 array('F') with bounds (\*)  
**Returns** **xout** : rank-1 array('F') with bounds (\*) and x storage

**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.ctrmv(a, x[, offx, incx, lower, trans, diag, overwrite_x]) = <fortran object>`  
 Wrapper for `ctrmv`.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)  
**x** : input rank-1 array('F') with bounds (\*)  
**Returns** **x** : rank-1 array('F') with bounds (\*)

**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0  
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**lower** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0

**diag** : input int, optional  
Default: 0

`scipy.linalg.blas.ctrsv(a, x[, incx, offx, lower, trans, diag, overwrite_x]) = <fortran object>`

Wrapper for `ctrsv`.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)  
**x** : input rank-1 array('F') with bounds (\*)

**Returns** **xout** : rank-1 array('F') with bounds (\*) and x storage

**Other Parameters**  
**overwrite\_x** : input int, optional  
Default: 0  
**incx** : input int, optional  
Default: 1  
**offx** : input int, optional  
Default: 0  
**lower** : input int, optional  
Default: 0  
**trans** : input int, optional  
Default: 0  
**diag** : input int, optional  
Default: 0

`scipy.linalg.blas.csyr(alpha, x[, lower, incx, offx, n, a, overwrite_a]) = <fortran object>`

Wrapper for `csyr`.

**Parameters** **alpha** : input complex  
**x** : input rank-1 array('F') with bounds (\*)

**Returns** **a** : rank-2 array('F') with bounds (n,n)

**Other Parameters**  
**lower** : input int, optional  
Default: 0  
**incx** : input int, optional  
Default: 1  
**offx** : input int, optional  
Default: 0  
**n** : input int, optional  
Default: (len(x)-1-offx)/abs(incx)+1  
**a** : input rank-2 array('F') with bounds (n,n)  
**overwrite\_a** : input int, optional  
Default: 0

`scipy.linalg.blas.zgbmv(m, n, kl, ku, alpha, a, x[, incx, offx, beta, y, incy, offy, trans, overwrite_y]) = <fortran object>`

Wrapper for `zgbmv`.

**Parameters** **m** : input int  
**n** : input int  
**kl** : input int  
**ku** : input int  
**alpha** : input complex  
**a** : input rank-2 array('D') with bounds (lda,n)  
**x** : input rank-1 array('D') with bounds (\*)

**Returns** **yout** : rank-1 array('D') with bounds (ly) and y storage

**Other Parameters**  
**incx** : input int, optional  
Default: 1

**offx** : input int, optional  
 Default: 0  
**beta** : input complex, optional  
 Default: (0.0, 0.0)  
**y** : input rank-1 array('D') with bounds (ly)  
**overwrite\_y** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0

`scipy.linalg.blas.zgemv(alpha, a, x[, beta, y, offx, incx, offy, incy, trans, overwrite_y]) = <fortran object>`

Wrapper for zgemv.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('D') with bounds (m,n)  
**x** : input rank-1 array('D') with bounds (\*)  
**Returns** **y** : rank-1 array('D') with bounds (ly)

**Other Parameters**  
**beta** : input complex, optional  
 Default: (0.0, 0.0)  
**y** : input rank-1 array('D') with bounds (ly)  
**overwrite\_y** : input int, optional  
 Default: 0  
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1  
**trans** : input int, optional  
 Default: 0

`scipy.linalg.blas.zgerc(alpha, x, y[, incx, incy, a, overwrite_x, overwrite_y, overwrite_a]) = <fortran object>`

Wrapper for zgerc.

**Parameters** **alpha** : input complex  
**x** : input rank-1 array('D') with bounds (m)  
**y** : input rank-1 array('D') with bounds (n)  
**Returns** **a** : rank-2 array('D') with bounds (m,n)

**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 1  
**incx** : input int, optional  
 Default: 1  
**overwrite\_y** : input int, optional  
 Default: 1  
**incy** : input int, optional  
 Default: 1

**a** : input rank-2 array('D') with bounds (m,n), optional  
 Default: (0,0,0.0)  
**overwrite\_a** : input int, optional  
 Default: 0

`scipy.linalg.blas.zgeru(alpha, x, y[, incx, incy, a, overwrite_x, overwrite_y, overwrite_a]) = <fortran object>`

Wrapper for zgeru.

**Parameters** **alpha** : input complex  
**x** : input rank-1 array('D') with bounds (m)  
**y** : input rank-1 array('D') with bounds (n)  
**Returns** **a** : rank-2 array('D') with bounds (m,n)  
**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 1  
**incx** : input int, optional  
 Default: 1  
**overwrite\_y** : input int, optional  
 Default: 1  
**incy** : input int, optional  
 Default: 1  
**a** : input rank-2 array('D') with bounds (m,n), optional  
 Default: (0,0,0.0)  
**overwrite\_a** : input int, optional  
 Default: 0

`scipy.linalg.blas.zhbmvm(k, alpha, a, x[, incx, offx, beta, y, incy, offy, lower, overwrite_y]) = <fortran object>`

Wrapper for zhbmvm.

**Parameters** **k** : input int  
**alpha** : input complex  
**a** : input rank-2 array('D') with bounds (lda,n)  
**x** : input rank-1 array('D') with bounds (\*)  
**Returns** **yout** : rank-1 array('D') with bounds (ly) and y storage  
**Other Parameters**  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**beta** : input complex, optional  
 Default: (0.0, 0.0)  
**y** : input rank-1 array('D') with bounds (ly)  
**overwrite\_y** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.zhemv(alpha, a, x[, beta, y, offx, incx, offy, incy, lower, overwrite_y]) = <fortran object>`

Wrapper for zhemv.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('D') with bounds (n,n)  
**x** : input rank-1 array('D') with bounds (\*)

**Returns** **y** : rank-1 array('D') with bounds (ly)

**Other Parameters**  
**beta** : input complex, optional  
 Default: (0.0, 0.0)  
**y** : input rank-1 array('D') with bounds (ly)  
**overwrite\_y** : input int, optional  
 Default: 0  
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1  
**lower** : input int, optional  
 Default: 0

scipy.linalg.blas.**zher** (*alpha, x*[, *lower, incx, offx, n, a, overwrite\_a* ]) = <fortran object>  
 Wrapper for zher.

**Parameters** **alpha** : input complex  
**x** : input rank-1 array('D') with bounds (\*)

**Returns** **a** : rank-2 array('D') with bounds (n,n)

**Other Parameters**  
**lower** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**n** : input int, optional  
 Default: (len(x)-1-offx)/abs(incx)+1  
**a** : input rank-2 array('D') with bounds (n,n)  
**overwrite\_a** : input int, optional  
 Default: 0

scipy.linalg.blas.**zher2** (*alpha, x, y*[, *lower, incx, offx, incy, offy, n, a, overwrite\_a* ]) = <fortran object>  
 Wrapper for zher2.

**Parameters** **alpha** : input complex  
**x** : input rank-1 array('D') with bounds (\*)  
**y** : input rank-1 array('D') with bounds (\*)

**Returns** **a** : rank-2 array('D') with bounds (n,n)

**Other Parameters**  
**lower** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**incy** : input int, optional

Default: 1  
**offy** : input int, optional  
 Default: 0  
**n** : input int, optional  
 Default:  $((\text{len}(x)-1-\text{offx})/\text{abs}(\text{incx})+1 \leq (\text{len}(y)-1-\text{offy})/\text{abs}(\text{incy})+1 \text{ ?}(\text{len}(x)-1-\text{offx})/\text{abs}(\text{incx})+1 : (\text{len}(y)-1-\text{offy})/\text{abs}(\text{incy})+1)$   
**a** : input rank-2 array('D') with bounds (n,n)  
**overwrite\_a** : input int, optional  
 Default: 0

`scipy.linalg.blas.zhpmv(n, alpha, ap, x[, incx, offx, beta, y, incy, offy, lower, overwrite_y]) = <fortran object>`

Wrapper for zhpmv.

**Parameters** **n** : input int  
**alpha** : input complex  
**ap** : input rank-1 array('D') with bounds (\*)  
**x** : input rank-1 array('D') with bounds (\*)  
**Returns** **yout** : rank-1 array('D') with bounds (ly) and y storage  
**Other Parameters**  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**beta** : input complex, optional  
 Default: (0.0, 0.0)  
**y** : input rank-1 array('D') with bounds (ly)  
**overwrite\_y** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.zhpr(n, alpha, x, ap[, incx, offx, lower, overwrite_ap]) = <fortran object>`

Wrapper for zhpr.

**Parameters** **n** : input int  
**alpha** : input float  
**x** : input rank-1 array('D') with bounds (\*)  
**ap** : input rank-1 array('D') with bounds (\*)  
**Returns** **apu** : rank-1 array('D') with bounds (\*) and ap storage  
**Other Parameters**  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**overwrite\_ap** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.zhpr2(n, alpha, x, y, ap[, incx, offx, incy, offy, lower, overwrite_ap]) = <fortran object>`

Wrapper for zhpr2.

**Parameters** **n** : input int  
**alpha** : input complex  
**x** : input rank-1 array('D') with bounds (\*)  
**y** : input rank-1 array('D') with bounds (\*)  
**ap** : input rank-1 array('D') with bounds (\*)

**Returns** **apu** : rank-1 array('D') with bounds (\*) and ap storage

**Other Parameters**  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1  
**offy** : input int, optional  
 Default: 0  
**overwrite\_ap** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.ztbmv(k, a, x[, incx, offx, lower, trans, diag, overwrite_x]) = <fortran object>`  
 Wrapper for ztbmv.

**Parameters** **k** : input int  
**a** : input rank-2 array('D') with bounds (lda,n)  
**x** : input rank-1 array('D') with bounds (\*)

**Returns** **xout** : rank-1 array('D') with bounds (\*) and x storage

**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.ztbsv(k, a, x[, incx, offx, lower, trans, diag, overwrite_x]) = <fortran object>`  
 Wrapper for ztbsv.

**Parameters** **k** : input int  
**a** : input rank-2 array('D') with bounds (lda,n)  
**x** : input rank-1 array('D') with bounds (\*)

**Returns** **xout** : rank-1 array('D') with bounds (\*) and x storage

**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**lower** : input int, optional

Default: 0  
**trans** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.ztpmv(n, ap, x[, incx, offx, lower, trans, diag, overwrite_x]) = <fortran object>`

Wrapper for ztpmv.

**Parameters** **n** : input int  
**ap** : input rank-1 array('D') with bounds (\*)  
**x** : input rank-1 array('D') with bounds (\*)  
**Returns** **xout** : rank-1 array('D') with bounds (\*) and x storage  
**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.ztrmv(a, x[, offx, incx, lower, trans, diag, overwrite_x]) = <fortran object>`

Wrapper for ztrmv.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**x** : input rank-1 array('D') with bounds (\*)  
**Returns** **x** : rank-1 array('D') with bounds (\*)  
**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0  
**offx** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**lower** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.ztrsv(a, x[, incx, offx, lower, trans, diag, overwrite_x]) = <fortran object>`

Wrapper for ztrsv.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**x** : input rank-1 array('D') with bounds (\*)  
**Returns** **xout** : rank-1 array('D') with bounds (\*) and x storage  
**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0  
**incx** : input int, optional

Default: 1  
**offx** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.zsyr(alpha, x[, lower, incx, offx, n, a, overwrite_a]) = <fortran object>`  
 Wrapper for zsyr.

**Parameters** **alpha** : input complex  
**x** : input rank-1 array('D') with bounds (\*)  
**Returns** **a** : rank-2 array('D') with bounds (n,n)  
**Other Parameters**  
**lower** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1  
**offx** : input int, optional  
 Default: 0  
**n** : input int, optional  
 Default: (len(x)-1-offx)/abs(incx)+1  
**a** : input rank-2 array('D') with bounds (n,n)  
**overwrite\_a** : input int, optional  
 Default: 0

### 5.10.4 BLAS Level 3 functions

<code>sgemm(...)</code>	Wrapper for <code>sgemm</code> .
<code>ssymm(alpha,a,b,[beta,c,side,lower,overwrite_c])</code>	Wrapper for <code>ssymm</code> .
<code>ssyr2k(...)</code>	Wrapper for <code>ssyr2k</code> .
<code>ssyrk(alpha,a,[beta,c,trans,lower,overwrite_c])</code>	Wrapper for <code>ssyrk</code> .
<code>strmm(...)</code>	Wrapper for <code>strmm</code> .
<code>strsm(...)</code>	Wrapper for <code>strsm</code> .
<code>dgemm(...)</code>	Wrapper for <code>dgemm</code> .
<code>dsymm(alpha,a,b,[beta,c,side,lower,overwrite_c])</code>	Wrapper for <code>dsymm</code> .
<code>dsyr2k(...)</code>	Wrapper for <code>dsyr2k</code> .
<code>dsyrk(alpha,a,[beta,c,trans,lower,overwrite_c])</code>	Wrapper for <code>dsyrk</code> .
<code>dtrmm(...)</code>	Wrapper for <code>dtrmm</code> .
<code>dtrsm(...)</code>	Wrapper for <code>dtrsm</code> .
<code>cgemm(...)</code>	Wrapper for <code>cgemm</code> .
<code>chemm(alpha,a,b,[beta,c,side,lower,overwrite_c])</code>	Wrapper for <code>chemm</code> .
<code>cher2k(...)</code>	Wrapper for <code>cher2k</code> .
<code>cherk(alpha,a,[beta,c,trans,lower,overwrite_c])</code>	Wrapper for <code>cherk</code> .
<code>csymm(alpha,a,b,[beta,c,side,lower,overwrite_c])</code>	Wrapper for <code>csymm</code> .
<code>csyr2k(...)</code>	Wrapper for <code>csyr2k</code> .
<code>csyrk(alpha,a,[beta,c,trans,lower,overwrite_c])</code>	Wrapper for <code>csyrk</code> .
<code>ctrmm(...)</code>	Wrapper for <code>ctrmm</code> .

Continued on next page

Table 5.94 – continued from previous page

<code>ctrsm(...)</code>	Wrapper for <code>ctrsm</code> .
<code>zgemm(...)</code>	Wrapper for <code>zgemm</code> .
<code>zhemm(alpha,a,b,[beta,c,side,lower,overwrite_c])</code>	Wrapper for <code>zhemm</code> .
<code>zher2k(...)</code>	Wrapper for <code>zher2k</code> .
<code>zherk(alpha,a,[beta,c,trans,lower,overwrite_c])</code>	Wrapper for <code>zherk</code> .
<code>zsymm(alpha,a,b,[beta,c,side,lower,overwrite_c])</code>	Wrapper for <code>zsymm</code> .
<code>zsyr2k(...)</code>	Wrapper for <code>zsyr2k</code> .
<code>zsyrk(alpha,a,[beta,c,trans,lower,overwrite_c])</code>	Wrapper for <code>zsyrk</code> .
<code>ztrmm(...)</code>	Wrapper for <code>ztrmm</code> .
<code>ztrsm(...)</code>	Wrapper for <code>ztrsm</code> .

`scipy.linalg.blas.sgemm(alpha, a, b[, beta, c, trans_a, trans_b, overwrite_c]) = <fortran object>`  
 Wrapper for `sgemm`.

**Parameters** **alpha** : input float  
**a** : input rank-2 array('f') with bounds (lda,ka)  
**b** : input rank-2 array('f') with bounds (ldb,kb)  
**Returns** **c** : rank-2 array('f') with bounds (m,n)  
**Other Parameters**  
**beta** : input float, optional  
 Default: 0.0  
**c** : input rank-2 array('f') with bounds (m,n)  
**overwrite\_c** : input int, optional  
 Default: 0  
**trans\_a** : input int, optional  
 Default: 0  
**trans\_b** : input int, optional  
 Default: 0

`scipy.linalg.blas.ssymm(alpha, a, b[, beta, c, side, lower, overwrite_c]) = <fortran object>`  
 Wrapper for `ssymm`.

**Parameters** **alpha** : input float  
**a** : input rank-2 array('f') with bounds (lda,ka)  
**b** : input rank-2 array('f') with bounds (ldb,kb)  
**Returns** **c** : rank-2 array('f') with bounds (m,n)  
**Other Parameters**  
**beta** : input float, optional  
 Default: 0.0  
**c** : input rank-2 array('f') with bounds (m,n)  
**overwrite\_c** : input int, optional  
 Default: 0  
**side** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.ssyrr2k(alpha, a, b[, beta, c, trans, lower, overwrite_c]) = <fortran object>`  
 Wrapper for `ssyr2k`.

**Parameters** **alpha** : input float  
**a** : input rank-2 array('f') with bounds (lda,ka)  
**b** : input rank-2 array('f') with bounds (ldb,kb)  
**Returns** **c** : rank-2 array('f') with bounds (n,n)

*Other Parameters*

**beta** : input float, optional  
 Default: 0.0  
**c** : input rank-2 array('f') with bounds (n,n)  
**overwrite\_c** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.ssyrk(alpha, a[, beta, c, trans, lower, overwrite_c]) = <fortran object>`  
 Wrapper for `ssyrk`.

*Parameters* **alpha** : input float  
**a** : input rank-2 array('f') with bounds (lda,ka)  
*Returns* **c** : rank-2 array('f') with bounds (n,n)

*Other Parameters*

**beta** : input float, optional  
 Default: 0.0  
**c** : input rank-2 array('f') with bounds (n,n)  
**overwrite\_c** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.strrmm(alpha, a, b[, side, lower, trans_a, diag, overwrite_b]) = <fortran object>`  
 Wrapper for `strmm`.

*Parameters* **alpha** : input float  
**a** : input rank-2 array('f') with bounds (lda,k)  
**b** : input rank-2 array('f') with bounds (ldb,n)  
*Returns* **b** : rank-2 array('f') with bounds (ldb,n)

*Other Parameters*

**overwrite\_b** : input int, optional  
 Default: 0  
**side** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**trans\_a** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.strsm(alpha, a, b[, side, lower, trans_a, diag, overwrite_b]) = <fortran object>`  
 Wrapper for `strsm`.

*Parameters* **alpha** : input float  
**a** : input rank-2 array('f') with bounds (lda,\*)  
**b** : input rank-2 array('f') with bounds (ldb,n)  
*Returns* **x** : rank-2 array('f') with bounds (ldb,n) and b storage

*Other Parameters*

**overwrite\_b** : input int, optional  
 Default: 0

**side** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**trans\_a** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.dgemm(alpha, a, b[, beta, c, trans_a, trans_b, overwrite_c]) = <fortran object>`  
 Wrapper for dgemm.

**Parameters** **alpha** : input float  
**a** : input rank-2 array('d') with bounds (lda,ka)  
**b** : input rank-2 array('d') with bounds (ldb,kb)  
**Returns** **c** : rank-2 array('d') with bounds (m,n)  
**Other Parameters**  
**beta** : input float, optional  
 Default: 0.0  
**c** : input rank-2 array('d') with bounds (m,n)  
**overwrite\_c** : input int, optional  
 Default: 0  
**trans\_a** : input int, optional  
 Default: 0  
**trans\_b** : input int, optional  
 Default: 0

`scipy.linalg.blas.dsymm(alpha, a, b[, beta, c, side, lower, overwrite_c]) = <fortran object>`  
 Wrapper for dsymm.

**Parameters** **alpha** : input float  
**a** : input rank-2 array('d') with bounds (lda,ka)  
**b** : input rank-2 array('d') with bounds (ldb,kb)  
**Returns** **c** : rank-2 array('d') with bounds (m,n)  
**Other Parameters**  
**beta** : input float, optional  
 Default: 0.0  
**c** : input rank-2 array('d') with bounds (m,n)  
**overwrite\_c** : input int, optional  
 Default: 0  
**side** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.dsyr2k(alpha, a, b[, beta, c, trans, lower, overwrite_c]) = <fortran object>`  
 Wrapper for dsyr2k.

**Parameters** **alpha** : input float  
**a** : input rank-2 array('d') with bounds (lda,ka)  
**b** : input rank-2 array('d') with bounds (ldb,kb)  
**Returns** **c** : rank-2 array('d') with bounds (n,n)  
**Other Parameters**  
**beta** : input float, optional  
 Default: 0.0  
**c** : input rank-2 array('d') with bounds (n,n)  
**overwrite\_c** : input int, optional

Default: 0  
**trans** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.dsyrk(alpha, a[, beta, c, trans, lower, overwrite_c]) = <fortran object>`  
 Wrapper for dsyrk.

**Parameters** **alpha** : input float  
**a** : input rank-2 array('d') with bounds (lda,ka)  
**Returns** **c** : rank-2 array('d') with bounds (n,n)  
**Other Parameters**  
**beta** : input float, optional  
 Default: 0.0  
**c** : input rank-2 array('d') with bounds (n,n)  
**overwrite\_c** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.dtrmm(alpha, a, b[, side, lower, trans_a, diag, overwrite_b]) = <fortran object>`  
 Wrapper for dtrmm.

**Parameters** **alpha** : input float  
**a** : input rank-2 array('d') with bounds (lda,k)  
**b** : input rank-2 array('d') with bounds (ldb,n)  
**Returns** **b** : rank-2 array('d') with bounds (ldb,n)  
**Other Parameters**  
**overwrite\_b** : input int, optional  
 Default: 0  
**side** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**trans\_a** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.dtrsm(alpha, a, b[, side, lower, trans_a, diag, overwrite_b]) = <fortran object>`  
 Wrapper for dtrsm.

**Parameters** **alpha** : input float  
**a** : input rank-2 array('d') with bounds (lda,\*)  
**b** : input rank-2 array('d') with bounds (ldb,n)  
**Returns** **x** : rank-2 array('d') with bounds (ldb,n) and b storage  
**Other Parameters**  
**overwrite\_b** : input int, optional  
 Default: 0  
**side** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**trans\_a** : input int, optional

Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.cgemm(alpha, a, b[, beta, c, trans_a, trans_b, overwrite_c]) = <fortran object>`  
 Wrapper for `cgemm`.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('F') with bounds (lda,ka)  
**b** : input rank-2 array('F') with bounds (ldb,kb)  
**Returns** **c** : rank-2 array('F') with bounds (m,n)  
**Other Parameters**  
**beta** : input complex, optional  
 Default: (0.0, 0.0)  
**c** : input rank-2 array('F') with bounds (m,n)  
**overwrite\_c** : input int, optional  
 Default: 0  
**trans\_a** : input int, optional  
 Default: 0  
**trans\_b** : input int, optional  
 Default: 0

`scipy.linalg.blas.chemm(alpha, a, b[, beta, c, side, lower, overwrite_c]) = <fortran object>`  
 Wrapper for `chemm`.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('F') with bounds (lda,ka)  
**b** : input rank-2 array('F') with bounds (ldb,kb)  
**Returns** **c** : rank-2 array('F') with bounds (m,n)  
**Other Parameters**  
**beta** : input complex, optional  
 Default: (0.0, 0.0)  
**c** : input rank-2 array('F') with bounds (m,n)  
**overwrite\_c** : input int, optional  
 Default: 0  
**side** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.cher2k(alpha, a, b[, beta, c, trans, lower, overwrite_c]) = <fortran object>`  
 Wrapper for `cher2k`.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('F') with bounds (lda,ka)  
**b** : input rank-2 array('F') with bounds (ldb,kb)  
**Returns** **c** : rank-2 array('F') with bounds (n,n)  
**Other Parameters**  
**beta** : input complex, optional  
 Default: (0.0, 0.0)  
**c** : input rank-2 array('F') with bounds (n,n)  
**overwrite\_c** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.cherk` (*alpha*, *a*[, *beta*, *c*, *trans*, *lower*, *overwrite\_c*]) = <fortran object>  
 Wrapper for `cherk`.

**Parameters**    **alpha** : input complex  
                   **a** : input rank-2 array('F') with bounds (lda,ka)  
**Returns**        **c** : rank-2 array('F') with bounds (n,n)  
**Other Parameters**  
                   **beta** : input complex, optional  
                           Default: (0.0, 0.0)  
                   **c** : input rank-2 array('F') with bounds (n,n)  
                   **overwrite\_c** : input int, optional  
                           Default: 0  
                   **trans** : input int, optional  
                           Default: 0  
                   **lower** : input int, optional  
                           Default: 0

`scipy.linalg.blas.csymm` (*alpha*, *a*, *b*[, *beta*, *c*, *side*, *lower*, *overwrite\_c*]) = <fortran object>  
 Wrapper for `csymm`.

**Parameters**    **alpha** : input complex  
                   **a** : input rank-2 array('F') with bounds (lda,ka)  
                   **b** : input rank-2 array('F') with bounds (ldb,kb)  
**Returns**        **c** : rank-2 array('F') with bounds (m,n)  
**Other Parameters**  
                   **beta** : input complex, optional  
                           Default: (0.0, 0.0)  
                   **c** : input rank-2 array('F') with bounds (m,n)  
                   **overwrite\_c** : input int, optional  
                           Default: 0  
                   **side** : input int, optional  
                           Default: 0  
                   **lower** : input int, optional  
                           Default: 0

`scipy.linalg.blas.csyr2k` (*alpha*, *a*, *b*[, *beta*, *c*, *trans*, *lower*, *overwrite\_c*]) = <fortran object>  
 Wrapper for `csyr2k`.

**Parameters**    **alpha** : input complex  
                   **a** : input rank-2 array('F') with bounds (lda,ka)  
                   **b** : input rank-2 array('F') with bounds (ldb,kb)  
**Returns**        **c** : rank-2 array('F') with bounds (n,n)  
**Other Parameters**  
                   **beta** : input complex, optional  
                           Default: (0.0, 0.0)  
                   **c** : input rank-2 array('F') with bounds (n,n)  
                   **overwrite\_c** : input int, optional  
                           Default: 0  
                   **trans** : input int, optional  
                           Default: 0  
                   **lower** : input int, optional  
                           Default: 0

`scipy.linalg.blas.csyrk` (*alpha*, *a*[, *beta*, *c*, *trans*, *lower*, *overwrite\_c*]) = <fortran object>  
 Wrapper for `csyrk`.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('F') with bounds (lda,ka)  
**Returns** **c** : rank-2 array('F') with bounds (n,n)  
**Other Parameters**  
**beta** : input complex, optional  
Default: (0.0, 0.0)  
**c** : input rank-2 array('F') with bounds (n,n)  
**overwrite\_c** : input int, optional  
Default: 0  
**trans** : input int, optional  
Default: 0  
**lower** : input int, optional  
Default: 0

`scipy.linalg.blas.ctrrmm(alpha, a, b[, side, lower, trans_a, diag, overwrite_b]) = <fortran object>`  
 Wrapper for `ctrrmm`.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('F') with bounds (lda,k)  
**b** : input rank-2 array('F') with bounds (ldb,n)  
**Returns** **b** : rank-2 array('F') with bounds (ldb,n)  
**Other Parameters**  
**overwrite\_b** : input int, optional  
Default: 0  
**side** : input int, optional  
Default: 0  
**lower** : input int, optional  
Default: 0  
**trans\_a** : input int, optional  
Default: 0  
**diag** : input int, optional  
Default: 0

`scipy.linalg.blas.ctrsm(alpha, a, b[, side, lower, trans_a, diag, overwrite_b]) = <fortran object>`  
 Wrapper for `ctrsm`.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('F') with bounds (lda,\*)  
**b** : input rank-2 array('F') with bounds (ldb,n)  
**Returns** **x** : rank-2 array('F') with bounds (ldb,n) and b storage  
**Other Parameters**  
**overwrite\_b** : input int, optional  
Default: 0  
**side** : input int, optional  
Default: 0  
**lower** : input int, optional  
Default: 0  
**trans\_a** : input int, optional  
Default: 0  
**diag** : input int, optional  
Default: 0

`scipy.linalg.blas.zgemm(alpha, a, b[, beta, c, trans_a, trans_b, overwrite_c]) = <fortran object>`  
 Wrapper for `zgemm`.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('D') with bounds (lda,ka)  
**b** : input rank-2 array('D') with bounds (ldb,kb)

**Returns** **c** : rank-2 array('D') with bounds (m,n)

**Other Parameters**  
**beta** : input complex, optional  
 Default: (0.0, 0.0)  
**c** : input rank-2 array('D') with bounds (m,n)  
**overwrite\_c** : input int, optional  
 Default: 0  
**trans\_a** : input int, optional  
 Default: 0  
**trans\_b** : input int, optional  
 Default: 0

`scipy.linalg.blas.zhemm(alpha, a, b[, beta, c, side, lower, overwrite_c]) = <fortran object>`  
 Wrapper for zhemm.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('D') with bounds (lda,ka)  
**b** : input rank-2 array('D') with bounds (ldb,kb)

**Returns** **c** : rank-2 array('D') with bounds (m,n)

**Other Parameters**  
**beta** : input complex, optional  
 Default: (0.0, 0.0)  
**c** : input rank-2 array('D') with bounds (m,n)  
**overwrite\_c** : input int, optional  
 Default: 0  
**side** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.zher2k(alpha, a, b[, beta, c, trans, lower, overwrite_c]) = <fortran object>`  
 Wrapper for zher2k.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('D') with bounds (lda,ka)  
**b** : input rank-2 array('D') with bounds (ldb,kb)

**Returns** **c** : rank-2 array('D') with bounds (n,n)

**Other Parameters**  
**beta** : input complex, optional  
 Default: (0.0, 0.0)  
**c** : input rank-2 array('D') with bounds (n,n)  
**overwrite\_c** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.zherk(alpha, a[, beta, c, trans, lower, overwrite_c]) = <fortran object>`  
 Wrapper for zherk.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('D') with bounds (lda,ka)

**Returns** **c** : rank-2 array('D') with bounds (n,n)

**Other Parameters**

**beta** : input complex, optional  
 Default: (0.0, 0.0)  
**c** : input rank-2 array('D') with bounds (n,n)  
**overwrite\_c** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.zsymm(alpha, a, b[, beta, c, side, lower, overwrite_c]) = <fortran object>`  
 Wrapper for `zsymm`.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('D') with bounds (lda,ka)  
**b** : input rank-2 array('D') with bounds (ldb,kb)  
**Returns** **c** : rank-2 array('D') with bounds (m,n)

**Other Parameters**

**beta** : input complex, optional  
 Default: (0.0, 0.0)  
**c** : input rank-2 array('D') with bounds (m,n)  
**overwrite\_c** : input int, optional  
 Default: 0  
**side** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.zsyr2k(alpha, a, b[, beta, c, trans, lower, overwrite_c]) = <fortran object>`  
 Wrapper for `zsyr2k`.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('D') with bounds (lda,ka)  
**b** : input rank-2 array('D') with bounds (ldb,kb)  
**Returns** **c** : rank-2 array('D') with bounds (n,n)

**Other Parameters**

**beta** : input complex, optional  
 Default: (0.0, 0.0)  
**c** : input rank-2 array('D') with bounds (n,n)  
**overwrite\_c** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.zsyrk(alpha, a[, beta, c, trans, lower, overwrite_c]) = <fortran object>`  
 Wrapper for `zsyrk`.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('D') with bounds (lda,ka)  
**Returns** **c** : rank-2 array('D') with bounds (n,n)

**Other Parameters**

**beta** : input complex, optional  
 Default: (0.0, 0.0)

**c** : input rank-2 array('D') with bounds (n,n)  
**overwrite\_c** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.blas.ztrmm(alpha, a, b[, side, lower, trans_a, diag, overwrite_b]) = <fortran object>`  
 Wrapper for `ztrmm`.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('D') with bounds (lda,k)  
**b** : input rank-2 array('D') with bounds (ldb,n)

**Returns** **b** : rank-2 array('D') with bounds (ldb,n)

**Other Parameters**  
**overwrite\_b** : input int, optional  
 Default: 0  
**side** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**trans\_a** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

`scipy.linalg.blas.ztrsm(alpha, a, b[, side, lower, trans_a, diag, overwrite_b]) = <fortran object>`  
 Wrapper for `ztrsm`.

**Parameters** **alpha** : input complex  
**a** : input rank-2 array('D') with bounds (lda,\*)  
**b** : input rank-2 array('D') with bounds (ldb,n)

**Returns** **x** : rank-2 array('D') with bounds (ldb,n) and b storage

**Other Parameters**  
**overwrite\_b** : input int, optional  
 Default: 0  
**side** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**trans\_a** : input int, optional  
 Default: 0  
**diag** : input int, optional  
 Default: 0

## 5.11 Low-level LAPACK functions (`scipy.linalg.lapack`)

This module contains low-level functions from the LAPACK library.

The *\*gegv* family of routines have been removed from LAPACK 3.6.0 and have been deprecated in SciPy 0.17.0. They will be removed in a future release.

New in version 0.12.0.

**Warning:** These functions do little to no error checking. It is possible to cause crashes by mis-using them, so prefer using the higher-level routines in `scipy.linalg`.

### 5.11.1 Finding functions

`get_lapack_funcs(names[, arrays, dtype])` Return available LAPACK function objects from names.

### 5.11.2 All functions

<code>sgbsv(kl,ku,ab,b,[overwrite_ab,overwrite_b])</code>	Wrapper for <code>sgbsv</code> .
<code>dgbsv(kl,ku,ab,b,[overwrite_ab,overwrite_b])</code>	Wrapper for <code>dgbsv</code> .
<code>cgbsv(kl,ku,ab,b,[overwrite_ab,overwrite_b])</code>	Wrapper for <code>cgbsv</code> .
<code>zgbsv(kl,ku,ab,b,[overwrite_ab,overwrite_b])</code>	Wrapper for <code>zgbsv</code> .
<code>sgbtrf(ab,kl,ku,[m,n,ldab,overwrite_ab])</code>	Wrapper for <code>sgbtrf</code> .
<code>dgbtrf(ab,kl,ku,[m,n,ldab,overwrite_ab])</code>	Wrapper for <code>dgbtrf</code> .
<code>cgbtrf(ab,kl,ku,[m,n,ldab,overwrite_ab])</code>	Wrapper for <code>cgbtrf</code> .
<code>zgbtrf(ab,kl,ku,[m,n,ldab,overwrite_ab])</code>	Wrapper for <code>zgbtrf</code> .
<code>sgbtrs(...)</code>	Wrapper for <code>sgbtrs</code> .
<code>dgbtrs(...)</code>	Wrapper for <code>dgbtrs</code> .
<code>cgbtrs(...)</code>	Wrapper for <code>cgbtrs</code> .
<code>zgbtrs(...)</code>	Wrapper for <code>zgbtrs</code> .
<code>sgebal(a,[scale,permute,overwrite_a])</code>	Wrapper for <code>sgebal</code> .
<code>dgebal(a,[scale,permute,overwrite_a])</code>	Wrapper for <code>dgebal</code> .
<code>cgebal(a,[scale,permute,overwrite_a])</code>	Wrapper for <code>cgebal</code> .
<code>zgebal(a,[scale,permute,overwrite_a])</code>	Wrapper for <code>zgebal</code> .
<code>sgees(...)</code>	Wrapper for <code>sgees</code> .
<code>dgees(...)</code>	Wrapper for <code>dgees</code> .
<code>cgees(...)</code>	Wrapper for <code>cgees</code> .
<code>zgees(...)</code>	Wrapper for <code>zgees</code> .
<code>sgeev(...)</code>	Wrapper for <code>sgeev</code> .
<code>dgeev(...)</code>	Wrapper for <code>dgeev</code> .
<code>cgeev(...)</code>	Wrapper for <code>cgeev</code> .
<code>zgeev(...)</code>	Wrapper for <code>zgeev</code> .
<code>sgeev_lwork(n,[compute_vl,compute_vr])</code>	Wrapper for <code>sgeev_lwork</code> .
<code>dgeev_lwork(n,[compute_vl,compute_vr])</code>	Wrapper for <code>dgeev_lwork</code> .
<code>cgeev_lwork(n,[compute_vl,compute_vr])</code>	Wrapper for <code>cgeev_lwork</code> .
<code>zgeev_lwork(n,[compute_vl,compute_vr])</code>	Wrapper for <code>zgeev_lwork</code> .
<code>sgegv(*args, **kwds)</code>	<code>sgegv</code> is deprecated!
<code>dgegv(*args, **kwds)</code>	<code>dgegv</code> is deprecated!
<code>cgegv(*args, **kwds)</code>	<code>cgegv</code> is deprecated!
<code>zgegv(*args, **kwds)</code>	<code>zgegv</code> is deprecated!
<code>sgehrd(a,[lo,hi,lwork,overwrite_a])</code>	Wrapper for <code>sgehrd</code> .
<code>dgehrd(a,[lo,hi,lwork,overwrite_a])</code>	Wrapper for <code>dgehrd</code> .
<code>cgehrd(a,[lo,hi,lwork,overwrite_a])</code>	Wrapper for <code>cgehrd</code> .
<code>zgehrd(a,[lo,hi,lwork,overwrite_a])</code>	Wrapper for <code>zgehrd</code> .
<code>sgehrd_lwork(n,[lo,hi])</code>	Wrapper for <code>sgehrd_lwork</code> .
<code>dgehrd_lwork(n,[lo,hi])</code>	Wrapper for <code>dgehrd_lwork</code> .

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<i>cgehrd_lwork</i> (n,[lo,hi])	Wrapper for <i>cgehrd_lwork</i> .
<i>zgehrd_lwork</i> (n,[lo,hi])	Wrapper for <i>zgehrd_lwork</i> .
<i>sgelss</i> (a,b,[cond,lwork,overwrite_a,overwrite_b])	Wrapper for <i>sgelss</i> .
<i>dgelss</i> (a,b,[cond,lwork,overwrite_a,overwrite_b])	Wrapper for <i>dgelss</i> .
<i>cgelss</i> (a,b,[cond,lwork,overwrite_a,overwrite_b])	Wrapper for <i>cgelss</i> .
<i>zgelss</i> (a,b,[cond,lwork,overwrite_a,overwrite_b])	Wrapper for <i>zgelss</i> .
<i>sgelss_lwork</i> (m,n,nrhs,[cond,lwork])	Wrapper for <i>sgelss_lwork</i> .
<i>dgelss_lwork</i> (m,n,nrhs,[cond,lwork])	Wrapper for <i>dgelss_lwork</i> .
<i>cgelss_lwork</i> (m,n,nrhs,[cond,lwork])	Wrapper for <i>cgelss_lwork</i> .
<i>zgelss_lwork</i> (m,n,nrhs,[cond,lwork])	Wrapper for <i>zgelss_lwork</i> .
<i>sgelsd</i> (...)	Wrapper for <i>sgelsd</i> .
<i>dgelsd</i> (...)	Wrapper for <i>dgelsd</i> .
<i>cgelsd</i> (...)	Wrapper for <i>cgelsd</i> .
<i>zgelsd</i> (...)	Wrapper for <i>zgelsd</i> .
<i>sgelsd_lwork</i> (m,n,nrhs,[cond,lwork])	Wrapper for <i>sgelsd_lwork</i> .
<i>dgelsd_lwork</i> (m,n,nrhs,[cond,lwork])	Wrapper for <i>dgelsd_lwork</i> .
<i>cgelsd_lwork</i> (m,n,nrhs,[cond,lwork])	Wrapper for <i>cgelsd_lwork</i> .
<i>zgelsd_lwork</i> (m,n,nrhs,[cond,lwork])	Wrapper for <i>zgelsd_lwork</i> .
<i>sgelsy</i> (...)	Wrapper for <i>sgelsy</i> .
<i>dgelsy</i> (...)	Wrapper for <i>dgelsy</i> .
<i>cgelsy</i> (...)	Wrapper for <i>cgelsy</i> .
<i>zgelsy</i> (...)	Wrapper for <i>zgelsy</i> .
<i>sgelsy_lwork</i> (m,n,nrhs,cond,[lwork])	Wrapper for <i>sgelsy_lwork</i> .
<i>dgelsy_lwork</i> (m,n,nrhs,cond,[lwork])	Wrapper for <i>dgelsy_lwork</i> .
<i>cgelsy_lwork</i> (m,n,nrhs,cond,[lwork])	Wrapper for <i>cgelsy_lwork</i> .
<i>zgelsy_lwork</i> (m,n,nrhs,cond,[lwork])	Wrapper for <i>zgelsy_lwork</i> .
<i>sgeqp3</i> (a,[lwork,overwrite_a])	Wrapper for <i>sgeqp3</i> .
<i>dgeqp3</i> (a,[lwork,overwrite_a])	Wrapper for <i>dgeqp3</i> .
<i>cgeqp3</i> (a,[lwork,overwrite_a])	Wrapper for <i>cgeqp3</i> .
<i>zgeqp3</i> (a,[lwork,overwrite_a])	Wrapper for <i>zgeqp3</i> .
<i>sgeqrf</i> (a,[lwork,overwrite_a])	Wrapper for <i>sgeqrf</i> .
<i>dgeqrf</i> (a,[lwork,overwrite_a])	Wrapper for <i>dgeqrf</i> .
<i>cg eqrf</i> (a,[lwork,overwrite_a])	Wrapper for <i>cg eqrf</i> .
<i>zgeqrf</i> (a,[lwork,overwrite_a])	Wrapper for <i>zgeqrf</i> .
<i>sgerqf</i> (a,[lwork,overwrite_a])	Wrapper for <i>sgerqf</i> .
<i>dgerqf</i> (a,[lwork,overwrite_a])	Wrapper for <i>dgerqf</i> .
<i>cgerqf</i> (a,[lwork,overwrite_a])	Wrapper for <i>cgerqf</i> .
<i>zgerqf</i> (a,[lwork,overwrite_a])	Wrapper for <i>zgerqf</i> .
<i>sgesdd</i> (...)	Wrapper for <i>sgesdd</i> .
<i>dgesdd</i> (...)	Wrapper for <i>dgesdd</i> .
<i>cg esdd</i> (...)	Wrapper for <i>cg esdd</i> .
<i>zgesdd</i> (...)	Wrapper for <i>zgesdd</i> .
<i>sgesdd_lwork</i> (m,n,[compute_uv,full_matrices])	Wrapper for <i>sgesdd_lwork</i> .
<i>dgesdd_lwork</i> (m,n,[compute_uv,full_matrices])	Wrapper for <i>dgesdd_lwork</i> .
<i>cg esdd_lwork</i> (m,n,[compute_uv,full_matrices])	Wrapper for <i>cg esdd_lwork</i> .
<i>zgesdd_lwork</i> (m,n,[compute_uv,full_matrices])	Wrapper for <i>zgesdd_lwork</i> .
<i>sgesvd</i> (...)	Wrapper for <i>sgesvd</i> .
<i>dgesvd</i> (...)	Wrapper for <i>dgesvd</i> .
<i>cg esvd</i> (...)	Wrapper for <i>cg esvd</i> .
<i>zgesvd</i> (...)	Wrapper for <i>zgesvd</i> .

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<i>sge</i> svd_lwork(m,n,[compute_uv,full_matrices])	Wrapper for <i>sge</i> svd_lwork.
<i>dge</i> svd_lwork(m,n,[compute_uv,full_matrices])	Wrapper for <i>dge</i> svd_lwork.
<i>cge</i> svd_lwork(m,n,[compute_uv,full_matrices])	Wrapper for <i>cge</i> svd_lwork.
<i>zge</i> svd_lwork(m,n,[compute_uv,full_matrices])	Wrapper for <i>zge</i> svd_lwork.
<i>sge</i> sv(a,b,[overwrite_a,overwrite_b])	Wrapper for <i>sge</i> sv.
<i>dge</i> sv(a,b,[overwrite_a,overwrite_b])	Wrapper for <i>dge</i> sv.
<i>cge</i> sv(a,b,[overwrite_a,overwrite_b])	Wrapper for <i>cge</i> sv.
<i>zge</i> sv(a,b,[overwrite_a,overwrite_b])	Wrapper for <i>zge</i> sv.
<i>sge</i> svx(...)	Wrapper for <i>sge</i> svx.
<i>dge</i> svx(...)	Wrapper for <i>dge</i> svx.
<i>cge</i> svx(...)	Wrapper for <i>cge</i> svx.
<i>zge</i> svx(...)	Wrapper for <i>zge</i> svx.
<i>sge</i> con(a,anorm,[norm])	Wrapper for <i>sge</i> con.
<i>dge</i> con(a,anorm,[norm])	Wrapper for <i>dge</i> con.
<i>cge</i> con(a,anorm,[norm])	Wrapper for <i>cge</i> con.
<i>zge</i> con(a,anorm,[norm])	Wrapper for <i>zge</i> con.
<i>ssys</i> sv(a,b,[lwork,lower,overwrite_a,overwrite_b])	Wrapper for <i>ssys</i> sv.
<i>dsys</i> sv(a,b,[lwork,lower,overwrite_a,overwrite_b])	Wrapper for <i>dsys</i> sv.
<i>csys</i> sv(a,b,[lwork,lower,overwrite_a,overwrite_b])	Wrapper for <i>csys</i> sv.
<i>zsys</i> sv(a,b,[lwork,lower,overwrite_a,overwrite_b])	Wrapper for <i>zsys</i> sv.
<i>ssys</i> sv_lwork(n,[lower])	Wrapper for <i>ssys</i> sv_lwork.
<i>dsys</i> sv_lwork(n,[lower])	Wrapper for <i>dsys</i> sv_lwork.
<i>csys</i> sv_lwork(n,[lower])	Wrapper for <i>csys</i> sv_lwork.
<i>zsys</i> sv_lwork(n,[lower])	Wrapper for <i>zsys</i> sv_lwork.
<i>ssys</i> svx(...)	Wrapper for <i>ssys</i> svx.
<i>dsys</i> svx(...)	Wrapper for <i>dsys</i> svx.
<i>csys</i> svx(...)	Wrapper for <i>csys</i> svx.
<i>zsys</i> svx(...)	Wrapper for <i>zsys</i> svx.
<i>ssys</i> svx_lwork(n,[lower])	Wrapper for <i>ssys</i> svx_lwork.
<i>dsys</i> svx_lwork(n,[lower])	Wrapper for <i>dsys</i> svx_lwork.
<i>csys</i> svx_lwork(n,[lower])	Wrapper for <i>csys</i> svx_lwork.
<i>zsys</i> svx_lwork(n,[lower])	Wrapper for <i>zsys</i> svx_lwork.
<i>ssy</i> trd(a,[lower,lwork,overwrite_a])	Wrapper for <i>ssy</i> trd.
<i>dsy</i> trd(a,[lower,lwork,overwrite_a])	Wrapper for <i>dsy</i> trd.
<i>ssy</i> trd_lwork(n,[lower])	Wrapper for <i>ssy</i> trd_lwork.
<i>dsy</i> trd_lwork(n,[lower])	Wrapper for <i>dsy</i> trd_lwork.
<i>chet</i> rd(a,[lower,lwork,overwrite_a])	Wrapper for <i>chet</i> rd.
<i>zhet</i> rd(a,[lower,lwork,overwrite_a])	Wrapper for <i>zhet</i> rd.
<i>chet</i> rd_lwork(n,[lower])	Wrapper for <i>chet</i> rd_lwork.
<i>zhet</i> rd_lwork(n,[lower])	Wrapper for <i>zhet</i> rd_lwork.
<i>ches</i> v(a,b,[lwork,lower,overwrite_a,overwrite_b])	Wrapper for <i>ches</i> v.
<i>zhes</i> v(a,b,[lwork,lower,overwrite_a,overwrite_b])	Wrapper for <i>zhes</i> v.
<i>ches</i> v_lwork(n,[lower])	Wrapper for <i>ches</i> v_lwork.
<i>zhes</i> v_lwork(n,[lower])	Wrapper for <i>zhes</i> v_lwork.
<i>ches</i> vx(...)	Wrapper for <i>ches</i> vx.
<i>zhes</i> vx(...)	Wrapper for <i>zhes</i> vx.
<i>ches</i> vx_lwork(n,[lower])	Wrapper for <i>ches</i> vx_lwork.
<i>zhes</i> vx_lwork(n,[lower])	Wrapper for <i>zhes</i> vx_lwork.
<i>sget</i> rf(a,[overwrite_a])	Wrapper for <i>sget</i> rf.
<i>dget</i> rf(a,[overwrite_a])	Wrapper for <i>dget</i> rf.

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<i>cgetrf</i> (a,[overwrite_a])	Wrapper for <i>cgetrf</i> .
<i>zgetrf</i> (a,[overwrite_a])	Wrapper for <i>zgetrf</i> .
<i>sgetri</i> (lu,piv,[lwork,overwrite_lu])	Wrapper for <i>sgetri</i> .
<i>dgetri</i> (lu,piv,[lwork,overwrite_lu])	Wrapper for <i>dgetri</i> .
<i>cgetri</i> (lu,piv,[lwork,overwrite_lu])	Wrapper for <i>cgetri</i> .
<i>zgetri</i> (lu,piv,[lwork,overwrite_lu])	Wrapper for <i>zgetri</i> .
<i>sgetri_lwork</i> (n)	Wrapper for <i>sgetri_lwork</i> .
<i>dgetri_lwork</i> (n)	Wrapper for <i>dgetri_lwork</i> .
<i>cgetri_lwork</i> (n)	Wrapper for <i>cgetri_lwork</i> .
<i>zgetri_lwork</i> (n)	Wrapper for <i>zgetri_lwork</i> .
<i>sgetrs</i> (lu,piv,b,[trans,overwrite_b])	Wrapper for <i>sgetrs</i> .
<i>dgetrs</i> (lu,piv,b,[trans,overwrite_b])	Wrapper for <i>dgetrs</i> .
<i>cgetrs</i> (lu,piv,b,[trans,overwrite_b])	Wrapper for <i>cgetrs</i> .
<i>zgetrs</i> (lu,piv,b,[trans,overwrite_b])	Wrapper for <i>zgetrs</i> .
<i>sgges</i> (...)	Wrapper for <i>sgges</i> .
<i>dgges</i> (...)	Wrapper for <i>dgges</i> .
<i>cgges</i> (...)	Wrapper for <i>cgges</i> .
<i>zgges</i> (...)	Wrapper for <i>zgges</i> .
<i>sggev</i> (...)	Wrapper for <i>sggev</i> .
<i>dggev</i> (...)	Wrapper for <i>dggev</i> .
<i>cggev</i> (...)	Wrapper for <i>cggev</i> .
<i>zggev</i> (...)	Wrapper for <i>zggev</i> .
<i>chbevd</i> (...)	Wrapper for <i>chbevd</i> .
<i>zhbevd</i> (...)	Wrapper for <i>zhbevd</i> .
<i>chbevz</i> (...)	Wrapper for <i>chbevz</i> .
<i>zhbevz</i> (...)	Wrapper for <i>zhbevz</i> .
<i>cheev</i> (a,[compute_v,lower,lwork,overwrite_a])	Wrapper for <i>cheev</i> .
<i>zheev</i> (a,[compute_v,lower,lwork,overwrite_a])	Wrapper for <i>zheev</i> .
<i>cheevd</i> (a,[compute_v,lower,lwork,overwrite_a])	Wrapper for <i>cheevd</i> .
<i>zheevd</i> (a,[compute_v,lower,lwork,overwrite_a])	Wrapper for <i>zheevd</i> .
<i>cheevr</i> (...)	Wrapper for <i>cheevr</i> .
<i>zheevr</i> (...)	Wrapper for <i>zheevr</i> .
<i>chegv</i> (...)	Wrapper for <i>chegv</i> .
<i>zhhev</i> (...)	Wrapper for <i>zhhev</i> .
<i>chegvd</i> (...)	Wrapper for <i>chegvd</i> .
<i>zhhev</i> (...)	Wrapper for <i>zhhev</i> .
<i>chegvx</i> (...)	Wrapper for <i>chegvx</i> .
<i>zhhev</i> (...)	Wrapper for <i>zhhev</i> .
<i>slarf</i> (v,tau,c,work,[side,incv,overwrite_c])	Wrapper for <i>slarf</i> .
<i>dlarf</i> (v,tau,c,work,[side,incv,overwrite_c])	Wrapper for <i>dlarf</i> .
<i>clarf</i> (v,tau,c,work,[side,incv,overwrite_c])	Wrapper for <i>clarf</i> .
<i>zlarf</i> (v,tau,c,work,[side,incv,overwrite_c])	Wrapper for <i>zlarf</i> .
<i>slarfg</i> (n,alpha,x,[incx,overwrite_x])	Wrapper for <i>slarfg</i> .
<i>dlarfg</i> (n,alpha,x,[incx,overwrite_x])	Wrapper for <i>dlarfg</i> .
<i>clarfg</i> (n,alpha,x,[incx,overwrite_x])	Wrapper for <i>clarfg</i> .
<i>zlarfg</i> (n,alpha,x,[incx,overwrite_x])	Wrapper for <i>zlarfg</i> .
<i>slartg</i> (f,g)	Wrapper for <i>slartg</i> .
<i>dlartg</i> (f,g)	Wrapper for <i>dlartg</i> .
<i>clartg</i> (f,g)	Wrapper for <i>clartg</i> .
<i>zartg</i> (f,g)	Wrapper for <i>zartg</i> .

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<i>slasd4</i> (i,d,z,[rho])	Wrapper for <i>slasd4</i> .
<i>dlsasd4</i> (i,d,z,[rho])	Wrapper for <i>dlsasd4</i> .
<i>slaswp</i> (a,piv,[k1,k2,off,inc,overwrite_a])	Wrapper for <i>slaswp</i> .
<i>dlsaswp</i> (a,piv,[k1,k2,off,inc,overwrite_a])	Wrapper for <i>dlsaswp</i> .
<i>claswp</i> (a,piv,[k1,k2,off,inc,overwrite_a])	Wrapper for <i>claswp</i> .
<i>zlaswp</i> (a,piv,[k1,k2,off,inc,overwrite_a])	Wrapper for <i>zlaswp</i> .
<i>slauum</i> (c,[lower,overwrite_c])	Wrapper for <i>slauum</i> .
<i>dlsauum</i> (c,[lower,overwrite_c])	Wrapper for <i>dlsauum</i> .
<i>clauum</i> (c,[lower,overwrite_c])	Wrapper for <i>clauum</i> .
<i>zlsauum</i> (c,[lower,overwrite_c])	Wrapper for <i>zlsauum</i> .
<i>spbsv</i> (ab,b,[lower,ldab,overwrite_ab,overwrite_b])	Wrapper for <i>spbsv</i> .
<i>dpbsv</i> (ab,b,[lower,ldab,overwrite_ab,overwrite_b])	Wrapper for <i>dpbsv</i> .
<i>cpbsv</i> (ab,b,[lower,ldab,overwrite_ab,overwrite_b])	Wrapper for <i>cpbsv</i> .
<i>zpbsv</i> (ab,b,[lower,ldab,overwrite_ab,overwrite_b])	Wrapper for <i>zpbsv</i> .
<i>spbtrf</i> (ab,[lower,ldab,overwrite_ab])	Wrapper for <i>spbtrf</i> .
<i>dpbtrf</i> (ab,[lower,ldab,overwrite_ab])	Wrapper for <i>dpbtrf</i> .
<i>cpbtrf</i> (ab,[lower,ldab,overwrite_ab])	Wrapper for <i>cpbtrf</i> .
<i>zpbtrf</i> (ab,[lower,ldab,overwrite_ab])	Wrapper for <i>zpbtrf</i> .
<i>spbtrs</i> (ab,b,[lower,ldab,overwrite_b])	Wrapper for <i>spbtrs</i> .
<i>dpbtrs</i> (ab,b,[lower,ldab,overwrite_b])	Wrapper for <i>dpbtrs</i> .
<i>cpbtrs</i> (ab,b,[lower,ldab,overwrite_b])	Wrapper for <i>cpbtrs</i> .
<i>zpbtrs</i> (ab,b,[lower,ldab,overwrite_b])	Wrapper for <i>zpbtrs</i> .
<i>sposv</i> (a,b,[lower,overwrite_a,overwrite_b])	Wrapper for <i>sposv</i> .
<i>dpovs</i> (a,b,[lower,overwrite_a,overwrite_b])	Wrapper for <i>dpovs</i> .
<i>cpovs</i> (a,b,[lower,overwrite_a,overwrite_b])	Wrapper for <i>cpovs</i> .
<i>zposv</i> (a,b,[lower,overwrite_a,overwrite_b])	Wrapper for <i>zposv</i> .
<i>sposvx</i> (...)	Wrapper for <i>sposvx</i> .
<i>dpovsx</i> (...)	Wrapper for <i>dpovsx</i> .
<i>cpovsx</i> (...)	Wrapper for <i>cpovsx</i> .
<i>zposvx</i> (...)	Wrapper for <i>zposvx</i> .
<i>spocon</i> (a,anorm,[uplo])	Wrapper for <i>spocon</i> .
<i>dpocon</i> (a,anorm,[uplo])	Wrapper for <i>dpocon</i> .
<i>cpocon</i> (a,anorm,[uplo])	Wrapper for <i>cpocon</i> .
<i>zpocon</i> (a,anorm,[uplo])	Wrapper for <i>zpocon</i> .
<i>spotrf</i> (a,[lower,clean,overwrite_a])	Wrapper for <i>spotrf</i> .
<i>dpotrf</i> (a,[lower,clean,overwrite_a])	Wrapper for <i>dpotrf</i> .
<i>cpotrf</i> (a,[lower,clean,overwrite_a])	Wrapper for <i>cpotrf</i> .
<i>zpotrf</i> (a,[lower,clean,overwrite_a])	Wrapper for <i>zpotrf</i> .
<i>spotri</i> (c,[lower,overwrite_c])	Wrapper for <i>spotri</i> .
<i>dpotri</i> (c,[lower,overwrite_c])	Wrapper for <i>dpotri</i> .
<i>cpotri</i> (c,[lower,overwrite_c])	Wrapper for <i>cpotri</i> .
<i>zpotri</i> (c,[lower,overwrite_c])	Wrapper for <i>zpotri</i> .
<i>spotrs</i> (c,b,[lower,overwrite_b])	Wrapper for <i>spotrs</i> .
<i>dpotrs</i> (c,b,[lower,overwrite_b])	Wrapper for <i>dpotrs</i> .
<i>cpotrs</i> (c,b,[lower,overwrite_b])	Wrapper for <i>cpotrs</i> .
<i>zpotrs</i> (c,b,[lower,overwrite_b])	Wrapper for <i>zpotrs</i> .
<i>crot</i> (...)	Wrapper for <i>crot</i> .
<i>zrot</i> (...)	Wrapper for <i>zrot</i> .
<i>strsyl</i> (a,b,c,[trana,tranb,isgn,overwrite_c])	Wrapper for <i>strsyl</i> .
<i>dtrsyl</i> (a,b,c,[trana,tranb,isgn,overwrite_c])	Wrapper for <i>dtrsyl</i> .

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<i>ctrsyl</i> (a,b,c,[trana,tranb,isgn,overwrite_c])	Wrapper for <i>ctrsyl</i> .
<i>ztrsyl</i> (a,b,c,[trana,tranb,isgn,overwrite_c])	Wrapper for <i>ztrsyl</i> .
<i>strtri</i> (c,[lower,unitdiag,overwrite_c])	Wrapper for <i>strtri</i> .
<i>dtrtri</i> (c,[lower,unitdiag,overwrite_c])	Wrapper for <i>dtrtri</i> .
<i>ctrtri</i> (c,[lower,unitdiag,overwrite_c])	Wrapper for <i>ctrtri</i> .
<i>ztrtri</i> (c,[lower,unitdiag,overwrite_c])	Wrapper for <i>ztrtri</i> .
<i>strtrs</i> (...)	Wrapper for <i>strtrs</i> .
<i>dtrtrs</i> (...)	Wrapper for <i>dtrtrs</i> .
<i>ctrtrs</i> (...)	Wrapper for <i>ctrtrs</i> .
<i>ztrtrs</i> (...)	Wrapper for <i>ztrtrs</i> .
<i>cunghr</i> (a,tau,[lo,hi,lwork,overwrite_a])	Wrapper for <i>cunghr</i> .
<i>zunghr</i> (a,tau,[lo,hi,lwork,overwrite_a])	Wrapper for <i>zunghr</i> .
<i>cungqr</i> (a,tau,[lwork,overwrite_a])	Wrapper for <i>cungqr</i> .
<i>zungqr</i> (a,tau,[lwork,overwrite_a])	Wrapper for <i>zungqr</i> .
<i>cungrq</i> (a,tau,[lwork,overwrite_a])	Wrapper for <i>cungrq</i> .
<i>zungrq</i> (a,tau,[lwork,overwrite_a])	Wrapper for <i>zungrq</i> .
<i>cunmqr</i> (side,trans,a,tau,c,lwork,[overwrite_c])	Wrapper for <i>cunmqr</i> .
<i>zunmqr</i> (side,trans,a,tau,c,lwork,[overwrite_c])	Wrapper for <i>zunmqr</i> .
<i>sgtsv</i> (...)	Wrapper for <i>sgtsv</i> .
<i>dgtsv</i> (...)	Wrapper for <i>dgtsv</i> .
<i>cgtsv</i> (...)	Wrapper for <i>cgtsv</i> .
<i>zgtsv</i> (...)	Wrapper for <i>zgtsv</i> .
<i>sptsv</i> (...)	Wrapper for <i>sptsv</i> .
<i>dptsv</i> (...)	Wrapper for <i>dptsv</i> .
<i>cptsv</i> (...)	Wrapper for <i>cptsv</i> .
<i>zptsv</i> (...)	Wrapper for <i>zptsv</i> .
<i>slamch</i> (cmach)	Wrapper for <i>slamch</i> .
<i>dlamch</i> (cmach)	Wrapper for <i>dlamch</i> .
<i>sorghr</i> (a,tau,[lo,hi,lwork,overwrite_a])	Wrapper for <i>sorghr</i> .
<i>dorghr</i> (a,tau,[lo,hi,lwork,overwrite_a])	Wrapper for <i>dorghr</i> .
<i>sorgqr</i> (a,tau,[lwork,overwrite_a])	Wrapper for <i>sorgqr</i> .
<i>dorgqr</i> (a,tau,[lwork,overwrite_a])	Wrapper for <i>dorgqr</i> .
<i>sorgrq</i> (a,tau,[lwork,overwrite_a])	Wrapper for <i>sorgrq</i> .
<i>dorgrq</i> (a,tau,[lwork,overwrite_a])	Wrapper for <i>dorgrq</i> .
<i>sormqr</i> (side,trans,a,tau,c,lwork,[overwrite_c])	Wrapper for <i>sormqr</i> .
<i>dormqr</i> (side,trans,a,tau,c,lwork,[overwrite_c])	Wrapper for <i>dormqr</i> .
<i>ssbev</i> (ab,[compute_v,lower,ldab,overwrite_ab])	Wrapper for <i>ssbev</i> .
<i>dsbev</i> (ab,[compute_v,lower,ldab,overwrite_ab])	Wrapper for <i>dsbev</i> .
<i>ssbevd</i> (...)	Wrapper for <i>ssbevd</i> .
<i>dsbevd</i> (...)	Wrapper for <i>dsbevd</i> .
<i>ssbevz</i> (...)	Wrapper for <i>ssbevz</i> .
<i>dsbevz</i> (...)	Wrapper for <i>dsbevz</i> .
<i>sstebz</i> (d,e,range,vl,vu,il,iu,tol,order)	Wrapper for <i>sstebz</i> .
<i>dstebz</i> (d,e,range,vl,vu,il,iu,tol,order)	Wrapper for <i>dstebz</i> .
<i>sstemr</i> (...)	Wrapper for <i>sstemr</i> .
<i>dstemr</i> (...)	Wrapper for <i>dstemr</i> .
<i>ssterf</i> (d,e,[overwrite_d,overwrite_e])	Wrapper for <i>ssterf</i> .
<i>dsterf</i> (d,e,[overwrite_d,overwrite_e])	Wrapper for <i>dsterf</i> .
<i>sstein</i> (d,e,w,iblock,isplit)	Wrapper for <i>sstein</i> .
<i>dstein</i> (d,e,w,iblock,isplit)	Wrapper for <i>dstein</i> .

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<code>sstev(d,e,[compute_v,overwrite_d,overwrite_e])</code>	Wrapper for <code>sstev</code> .
<code>dstev(d,e,[compute_v,overwrite_d,overwrite_e])</code>	Wrapper for <code>dstev</code> .
<code>ssyev(a,[compute_v,lower,lwork,overwrite_a])</code>	Wrapper for <code>ssyev</code> .
<code>dsyev(a,[compute_v,lower,lwork,overwrite_a])</code>	Wrapper for <code>dsyev</code> .
<code>ssyevd(a,[compute_v,lower,lwork,overwrite_a])</code>	Wrapper for <code>ssyevd</code> .
<code>dsyevd(a,[compute_v,lower,lwork,overwrite_a])</code>	Wrapper for <code>dsyevd</code> .
<code>ssyevr(...)</code>	Wrapper for <code>ssyevr</code> .
<code>dsyevr(...)</code>	Wrapper for <code>dsyevr</code> .
<code>ssygv(...)</code>	Wrapper for <code>ssygv</code> .
<code>dsygv(...)</code>	Wrapper for <code>dsygv</code> .
<code>ssygvd(...)</code>	Wrapper for <code>ssygvd</code> .
<code>dsygvd(...)</code>	Wrapper for <code>dsygvd</code> .
<code>ssygvx(...)</code>	Wrapper for <code>ssygvx</code> .
<code>dsygvx(...)</code>	Wrapper for <code>dsygvx</code> .
<code>slange(norm,a)</code>	Wrapper for <code>slange</code> .
<code>dlange(norm,a)</code>	Wrapper for <code>dlange</code> .
<code>clange(norm,a)</code>	Wrapper for <code>clange</code> .
<code>zlange(norm,a)</code>	Wrapper for <code>zlange</code> .
<code>ilaver()</code>	Wrapper for <code>ilaver</code> .

`scipy.linalg.lapack.sgbsv(kl, ku, ab, b[, overwrite_ab, overwrite_b]) = <fortran object>`  
 Wrapper for `sgbsv`.

**Parameters** **kl** : input int  
**ku** : input int  
**ab** : input rank-2 array('f') with bounds (2\*kl+ku+1,n)  
**b** : input rank-2 array('f') with bounds (n,nrhs)

**Returns** **lub** : rank-2 array('f') with bounds (2\*kl+ku+1,n) and ab storage  
**piv** : rank-1 array('i') with bounds (n)  
**x** : rank-2 array('f') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**  
**overwrite\_ab** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.dgbsv(kl, ku, ab, b[, overwrite_ab, overwrite_b]) = <fortran object>`  
 Wrapper for `dgbsv`.

**Parameters** **kl** : input int  
**ku** : input int  
**ab** : input rank-2 array('d') with bounds (2\*kl+ku+1,n)  
**b** : input rank-2 array('d') with bounds (n,nrhs)

**Returns** **lub** : rank-2 array('d') with bounds (2\*kl+ku+1,n) and ab storage  
**piv** : rank-1 array('i') with bounds (n)  
**x** : rank-2 array('d') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**  
**overwrite\_ab** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.cgbsv(kl, ku, ab, b[, overwrite_ab, overwrite_b]) = <fortran object>`  
 Wrapper for cgbsv.

**Parameters** **kl** : input int  
**ku** : input int  
**ab** : input rank-2 array('F') with bounds (2\*kl+ku+1,n)  
**b** : input rank-2 array('F') with bounds (n,nrhs)

**Returns** **lub** : rank-2 array('F') with bounds (2\*kl+ku+1,n) and ab storage  
**piv** : rank-1 array('i') with bounds (n)  
**x** : rank-2 array('F') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**  
**overwrite\_ab** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.zgbsv(kl, ku, ab, b[, overwrite_ab, overwrite_b]) = <fortran object>`  
 Wrapper for zgbsv.

**Parameters** **kl** : input int  
**ku** : input int  
**ab** : input rank-2 array('D') with bounds (2\*kl+ku+1,n)  
**b** : input rank-2 array('D') with bounds (n,nrhs)

**Returns** **lub** : rank-2 array('D') with bounds (2\*kl+ku+1,n) and ab storage  
**piv** : rank-1 array('i') with bounds (n)  
**x** : rank-2 array('D') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**  
**overwrite\_ab** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.sgbtrf(ab, kl, ku[, m, n, ldab, overwrite_ab]) = <fortran object>`  
 Wrapper for sgbtrf.

**Parameters** **ab** : input rank-2 array('f') with bounds (ldab,\*)  
**kl** : input int  
**ku** : input int

**Returns** **lu** : rank-2 array('f') with bounds (ldab,\*) and ab storage  
**ipiv** : rank-1 array('i') with bounds (MIN(m,n))  
**info** : int

**Other Parameters**  
**m** : input int, optional  
 Default: shape(ab,1)  
**n** : input int, optional  
 Default: shape(ab,1)  
**overwrite\_ab** : input int, optional  
 Default: 0  
**ldab** : input int, optional  
 Default: shape(ab,0)

`scipy.linalg.lapack.dgbtrf(ab, kl, ku[, m, n, ldab, overwrite_ab]) = <fortran object>`  
 Wrapper for dgbtrf.

**Parameters** **ab** : input rank-2 array('d') with bounds (ldab,\*)  
**kl** : input int  
**ku** : input int

**Returns** **lu** : rank-2 array('d') with bounds (ldab,\*) and ab storage  
**ipiv** : rank-1 array('i') with bounds (MIN(m,n))  
**info** : int

**Other Parameters**  
**m** : input int, optional  
Default: shape(ab,1)  
**n** : input int, optional  
Default: shape(ab,1)  
**overwrite\_ab** : input int, optional  
Default: 0  
**ldab** : input int, optional  
Default: shape(ab,0)

`scipy.linalg.lapack.cgbtrf(ab, kl, ku[, m, n, ldab, overwrite_ab]) = <fortran object>`  
Wrapper for cgbtrf.

**Parameters** **ab** : input rank-2 array('F') with bounds (ldab,\*)  
**kl** : input int  
**ku** : input int

**Returns** **lu** : rank-2 array('F') with bounds (ldab,\*) and ab storage  
**ipiv** : rank-1 array('i') with bounds (MIN(m,n))  
**info** : int

**Other Parameters**  
**m** : input int, optional  
Default: shape(ab,1)  
**n** : input int, optional  
Default: shape(ab,1)  
**overwrite\_ab** : input int, optional  
Default: 0  
**ldab** : input int, optional  
Default: shape(ab,0)

`scipy.linalg.lapack.zgbtrf(ab, kl, ku[, m, n, ldab, overwrite_ab]) = <fortran object>`  
Wrapper for zgbtrf.

**Parameters** **ab** : input rank-2 array('D') with bounds (ldab,\*)  
**kl** : input int  
**ku** : input int

**Returns** **lu** : rank-2 array('D') with bounds (ldab,\*) and ab storage  
**ipiv** : rank-1 array('i') with bounds (MIN(m,n))  
**info** : int

**Other Parameters**  
**m** : input int, optional  
Default: shape(ab,1)  
**n** : input int, optional  
Default: shape(ab,1)  
**overwrite\_ab** : input int, optional  
Default: 0  
**ldab** : input int, optional  
Default: shape(ab,0)

`scipy.linalg.lapack.sgbtrs(ab, kl, ku, b, ipiv[, trans, n, ldab, ldb, overwrite_b]) = <fortran object>`  
Wrapper for sgbtrs.

**Parameters** **ab** : input rank-2 array('f') with bounds (ldab,n)  
**kl** : input int  
**ku** : input int  
**b** : input rank-2 array('f') with bounds (ldb,nrhs)  
**ipiv** : input rank-1 array('i') with bounds (n)  
**Returns** **x** : rank-2 array('f') with bounds (ldb,nrhs) and b storage  
**info** : int

**Other Parameters**  
**overwrite\_b** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**n** : input int, optional  
 Default: shape(ab,1)  
**ldab** : input int, optional  
 Default: shape(ab,0)  
**ldb** : input int, optional  
 Default: shape(b,0)

`scipy.linalg.lapack.dgbtrs (ab, kl, ku, b, ipiv[, trans, n, ldab, ldb, overwrite_b]) = <fortran object>`

Wrapper for `dgbtrs`.

**Parameters** **ab** : input rank-2 array('d') with bounds (ldab,n)  
**kl** : input int  
**ku** : input int  
**b** : input rank-2 array('d') with bounds (ldb,nrhs)  
**ipiv** : input rank-1 array('i') with bounds (n)  
**Returns** **x** : rank-2 array('d') with bounds (ldb,nrhs) and b storage  
**info** : int

**Other Parameters**  
**overwrite\_b** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**n** : input int, optional  
 Default: shape(ab,1)  
**ldab** : input int, optional  
 Default: shape(ab,0)  
**ldb** : input int, optional  
 Default: shape(b,0)

`scipy.linalg.lapack.cgbtrs (ab, kl, ku, b, ipiv[, trans, n, ldab, ldb, overwrite_b]) = <fortran object>`

Wrapper for `cgbtrs`.

**Parameters** **ab** : input rank-2 array('F') with bounds (ldab,n)  
**kl** : input int  
**ku** : input int  
**b** : input rank-2 array('F') with bounds (ldb,nrhs)  
**ipiv** : input rank-1 array('i') with bounds (n)  
**Returns** **x** : rank-2 array('F') with bounds (ldb,nrhs) and b storage  
**info** : int

**Other Parameters**  
**overwrite\_b** : input int, optional  
 Default: 0

**trans** : input int, optional  
 Default: 0  
**n** : input int, optional  
 Default: shape(ab,1)  
**ldab** : input int, optional  
 Default: shape(ab,0)  
**ldb** : input int, optional  
 Default: shape(b,0)

`scipy.linalg.lapack.zgbtrs` (*ab*, *kl*, *ku*, *b*, *ipiv*[, *trans*, *n*, *ldab*, *ldb*, *overwrite\_b* ]) = <fortran object>

Wrapper for zgbtrs.

**Parameters** **ab** : input rank-2 array('D') with bounds (ldab,n)  
**kl** : input int  
**ku** : input int  
**b** : input rank-2 array('D') with bounds (ldb,nrhs)  
**ipiv** : input rank-1 array('i') with bounds (n)  
**Returns** **x** : rank-2 array('D') with bounds (ldb,nrhs) and b storage  
**info** : int  
**Other Parameters**  
**overwrite\_b** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**n** : input int, optional  
 Default: shape(ab,1)  
**ldab** : input int, optional  
 Default: shape(ab,0)  
**ldb** : input int, optional  
 Default: shape(b,0)

`scipy.linalg.lapack.sgebal` (*a*[, *scale*, *permute*, *overwrite\_a* ]) = <fortran object>

Wrapper for sgebal.

**Parameters** **a** : input rank-2 array('f') with bounds (m,n)  
**Returns** **ba** : rank-2 array('f') with bounds (m,n) and a storage  
**lo** : int  
**hi** : int  
**pivscale** : rank-1 array('f') with bounds (n)  
**info** : int  
**Other Parameters**  
**scale** : input int, optional  
 Default: 0  
**permute** : input int, optional  
 Default: 0  
**overwrite\_a** : input int, optional  
 Default: 0

`scipy.linalg.lapack.dgebal` (*a*[, *scale*, *permute*, *overwrite\_a* ]) = <fortran object>

Wrapper for dgebal.

**Parameters** **a** : input rank-2 array('d') with bounds (m,n)  
**Returns** **ba** : rank-2 array('d') with bounds (m,n) and a storage  
**lo** : int  
**hi** : int  
**pivscale** : rank-1 array('d') with bounds (n)

**info** : int

**Other Parameters**

**scale** : input int, optional

Default: 0

**permute** : input int, optional

Default: 0

**overwrite\_a** : input int, optional

Default: 0

`scipy.linalg.lapack.cgebal(a[, scale, permute, overwrite_a]) = <fortran object>`

Wrapper for cgebal.

**Parameters** **a** : input rank-2 array('F') with bounds (m,n)

**Returns** **ba** : rank-2 array('F') with bounds (m,n) and a storage

**lo** : int

**hi** : int

**pivscale** : rank-1 array('f') with bounds (n)

**info** : int

**Other Parameters**

**scale** : input int, optional

Default: 0

**permute** : input int, optional

Default: 0

**overwrite\_a** : input int, optional

Default: 0

`scipy.linalg.lapack.zgebal(a[, scale, permute, overwrite_a]) = <fortran object>`

Wrapper for zgebal.

**Parameters** **a** : input rank-2 array('D') with bounds (m,n)

**Returns** **ba** : rank-2 array('D') with bounds (m,n) and a storage

**lo** : int

**hi** : int

**pivscale** : rank-1 array('d') with bounds (n)

**info** : int

**Other Parameters**

**scale** : input int, optional

Default: 0

**permute** : input int, optional

Default: 0

**overwrite\_a** : input int, optional

Default: 0

`scipy.linalg.lapack.sgees(sselect, a[, compute_v, sort_t, lwork, sselect_extra_args, overwrite_a]) = <fortran object>`

Wrapper for sgees.

**Parameters** **sselect** : call-back function

**a** : input rank-2 array('f') with bounds (n,n)

**Returns** **t** : rank-2 array('f') with bounds (n,n) and a storage

**sdim** : int

**wr** : rank-1 array('f') with bounds (n)

**wi** : rank-1 array('f') with bounds (n)

**vs** : rank-2 array('f') with bounds (ldvs,n)

**work** : rank-1 array('f') with bounds (MAX(lwork,1))

**info** : int

**Other Parameters**

**compute\_v** : input int, optional  
Default: 1

**sort\_t** : input int, optional  
Default: 0

**sselect\_extra\_args** : input tuple, optional  
Default: ()

**overwrite\_a** : input int, optional  
Default: 0

**lwork** : input int, optional  
Default: 3\*n

**Notes**

Call-back functions:

```
def sselect(arg1, arg2): return sselect
Required arguments:
  arg1 : input float
  arg2 : input float
Return objects:
  sselect : int
```

`scipy.linalg.lapack.dgees` (*dselect*, *a*[, *compute\_v*, *sort\_t*, *lwork*, *dselect\_extra\_args*, *overwrite\_a* ] ) = <fortran object>

Wrapper for `dgees`.

**Parameters** **dselect** : call-back function

**a** : input rank-2 array('d') with bounds (n,n)

**Returns** **t** : rank-2 array('d') with bounds (n,n) and a storage

**sdim** : int

**wr** : rank-1 array('d') with bounds (n)

**wi** : rank-1 array('d') with bounds (n)

**vs** : rank-2 array('d') with bounds (ldvs,n)

**work** : rank-1 array('d') with bounds (MAX(lwork,1))

**info** : int

**Other Parameters**

**compute\_v** : input int, optional  
Default: 1

**sort\_t** : input int, optional  
Default: 0

**dselect\_extra\_args** : input tuple, optional  
Default: ()

**overwrite\_a** : input int, optional  
Default: 0

**lwork** : input int, optional  
Default: 3\*n

**Notes**

Call-back functions:

```
def dselect(arg1, arg2): return dselect
Required arguments:
  arg1 : input float
  arg2 : input float
```

```
Return objects:
dselect : int
```

`scipy.linalg.lapack.cgees` (*cselect*, *a*[, *compute\_v*, *sort\_t*, *lwork*, *cselect\_extra\_args*, *overwrite\_a* ] ) = <fortran object>

Wrapper for `cgees`.

**Parameters** **cselect** : call-back function  
**a** : input rank-2 array('F') with bounds (n,n)  
**Returns** **t** : rank-2 array('F') with bounds (n,n) and a storage  
**sdim** : int  
**w** : rank-1 array('F') with bounds (n)  
**vs** : rank-2 array('F') with bounds (ldvs,n)  
**work** : rank-1 array('F') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**compute\_v** : input int, optional  
 Default: 1  
**sort\_t** : input int, optional  
 Default: 0  
**cselect\_extra\_args** : input tuple, optional  
 Default: ()  
**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*n

**Notes**

Call-back functions:

```
def cselect(arg): return cselect
Required arguments:
arg : input complex
Return objects:
cselect : int
```

`scipy.linalg.lapack.zgees` (*zselect*, *a*[, *compute\_v*, *sort\_t*, *lwork*, *zselect\_extra\_args*, *overwrite\_a* ] ) = <fortran object>

Wrapper for `zgees`.

**Parameters** **zselect** : call-back function  
**a** : input rank-2 array('D') with bounds (n,n)  
**Returns** **t** : rank-2 array('D') with bounds (n,n) and a storage  
**sdim** : int  
**w** : rank-1 array('D') with bounds (n)  
**vs** : rank-2 array('D') with bounds (ldvs,n)  
**work** : rank-1 array('D') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**compute\_v** : input int, optional  
 Default: 1  
**sort\_t** : input int, optional  
 Default: 0  
**zselect\_extra\_args** : input tuple, optional  
 Default: ()

**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*n

**Notes**

Call-back functions:

```
def zselect(arg): return zselect
Required arguments:
  arg : input complex
Return objects:
  zselect : int
```

`scipy.linalg.lapack.sgeev(a[, compute_vl, compute_vr, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for sgeev.

**Parameters** **a** : input rank-2 array('f') with bounds (n,n)  
**Returns** **wr** : rank-1 array('f') with bounds (n)  
**wi** : rank-1 array('f') with bounds (n)  
**vl** : rank-2 array('f') with bounds (ldvl,n)  
**vr** : rank-2 array('f') with bounds (ldvr,n)  
**info** : int

**Other Parameters**

**compute\_vl** : input int, optional  
 Default: 1  
**compute\_vr** : input int, optional  
 Default: 1  
**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 4\*n

`scipy.linalg.lapack.dgeev(a[, compute_vl, compute_vr, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for dgeev.

**Parameters** **a** : input rank-2 array('d') with bounds (n,n)  
**Returns** **wr** : rank-1 array('d') with bounds (n)  
**wi** : rank-1 array('d') with bounds (n)  
**vl** : rank-2 array('d') with bounds (ldvl,n)  
**vr** : rank-2 array('d') with bounds (ldvr,n)  
**info** : int

**Other Parameters**

**compute\_vl** : input int, optional  
 Default: 1  
**compute\_vr** : input int, optional  
 Default: 1  
**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 4\*n

`scipy.linalg.lapack.cgeev(a[, compute_vl, compute_vr, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for cgeev.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)

**Returns**     **w** : rank-1 array('F') with bounds (n)  
               **vl** : rank-2 array('F') with bounds (ldvl,n)  
               **vr** : rank-2 array('F') with bounds (ldvr,n)  
               **info** : int

**Other Parameters**

**compute\_vl** : input int, optional  
               Default: 1  
**compute\_vr** : input int, optional  
               Default: 1  
**overwrite\_a** : input int, optional  
               Default: 0  
**lwork** : input int, optional  
            Default: 2\*n

`scipy.linalg.lapack.zgeev(a[, compute_vl, compute_vr, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for zgeev.

**Parameters**   **a** : input rank-2 array('D') with bounds (n,n)  
**Returns**       **w** : rank-1 array('D') with bounds (n)  
               **vl** : rank-2 array('D') with bounds (ldvl,n)  
               **vr** : rank-2 array('D') with bounds (ldvr,n)  
               **info** : int

**Other Parameters**

**compute\_vl** : input int, optional  
               Default: 1  
**compute\_vr** : input int, optional  
               Default: 1  
**overwrite\_a** : input int, optional  
               Default: 0  
**lwork** : input int, optional  
            Default: 2\*n

`scipy.linalg.lapack.sgeev_lwork(n[, compute_vl, compute_vr]) = <fortran object>`  
 Wrapper for sgeev\_lwork.

**Parameters**   **n** : input int  
**Returns**       **work** : float  
               **info** : int

**Other Parameters**

**compute\_vl** : input int, optional  
               Default: 1  
**compute\_vr** : input int, optional  
               Default: 1

`scipy.linalg.lapack.dgeev_lwork(n[, compute_vl, compute_vr]) = <fortran object>`  
 Wrapper for dgeev\_lwork.

**Parameters**   **n** : input int  
**Returns**       **work** : float  
               **info** : int

**Other Parameters**

**compute\_vl** : input int, optional  
               Default: 1  
**compute\_vr** : input int, optional  
               Default: 1

`scipy.linalg.lapack.cgeev_lwork` ( $n$ [, *compute\_vl*, *compute\_vr* ]) = <fortran object>  
 Wrapper for `cgeev_lwork`.

**Parameters** **n** : input int

**Returns** **work** : complex  
**info** : int

**Other Parameters**

**compute\_vl** : input int, optional  
 Default: 1

**compute\_vr** : input int, optional  
 Default: 1

`scipy.linalg.lapack.zgeev_lwork` ( $n$ [, *compute\_vl*, *compute\_vr* ]) = <fortran object>  
 Wrapper for `zgeev_lwork`.

**Parameters** **n** : input int

**Returns** **work** : complex  
**info** : int

**Other Parameters**

**compute\_vl** : input int, optional  
 Default: 1

**compute\_vr** : input int, optional  
 Default: 1

`scipy.linalg.lapack.sgegv` (*\*args*, *\*\*kws*)

*sgegv* is deprecated! The *\*gegv* family of routines has been deprecated in LAPACK 3.6.0 in favor of the *\*ggev* family of routines. The corresponding wrappers will be removed from SciPy in a future release.

`alphar, alphai, beta, vl, vr, info = sgegv(a, b, [compute_vl, compute_vr, lwork, overwrite_a, overwrite_b])`

Wrapper for `sgegv`.

**Parameters** **a** : input rank-2 array('f') with bounds (n,n)  
**b** : input rank-2 array('f') with bounds (n,n)

**Returns** **alphar** : rank-1 array('f') with bounds (n)  
**alphai** : rank-1 array('f') with bounds (n)  
**beta** : rank-1 array('f') with bounds (n)  
**vl** : rank-2 array('f') with bounds (ldvl,n)  
**vr** : rank-2 array('f') with bounds (ldvr,n)  
**info** : int

**Other Parameters**

**compute\_vl** : input int, optional  
 Default: 1

**compute\_vr** : input int, optional  
 Default: 1

**overwrite\_a** : input int, optional  
 Default: 0

**overwrite\_b** : input int, optional  
 Default: 0

**lwork** : input int, optional  
 Default: 8\*n

`scipy.linalg.lapack.dgegv` (*\*args*, *\*\*kws*)

*dgegv* is deprecated! The *\*gegv* family of routines has been deprecated in LAPACK 3.6.0 in favor of the *\*ggev* family of routines. The corresponding wrappers will be removed from SciPy in a future release.

`alphar, alphai, beta, vl, vr, info = dgegv(a, b, [compute_vl, compute_vr, lwork, overwrite_a, overwrite_b])`

Wrapper for `dgegv`.

**Parameters** **a** : input rank-2 array('d') with bounds (n,n)  
**b** : input rank-2 array('d') with bounds (n,n)

**Returns** **alphar** : rank-1 array('d') with bounds (n)  
**alpha** : rank-1 array('d') with bounds (n)  
**beta** : rank-1 array('d') with bounds (n)  
**vl** : rank-2 array('d') with bounds (ldvl,n)  
**vr** : rank-2 array('d') with bounds (ldvr,n)  
**info** : int

**Other Parameters**  
**compute\_vl** : input int, optional  
Default: 1  
**compute\_vr** : input int, optional  
Default: 1  
**overwrite\_a** : input int, optional  
Default: 0  
**overwrite\_b** : input int, optional  
Default: 0  
**lwork** : input int, optional  
Default: 8\*n

`scipy.linalg.lapack.cgegv(*args, **kwargs)`

*cgegv* is deprecated! The *\*gegv* family of routines has been deprecated in LAPACK 3.6.0 in favor of the *\*ggev* family of routines. The corresponding wrappers will be removed from SciPy in a future release.

`alpha,beta,vl,vr,info = cgegv(a,b,[compute_vl,compute_vr,lwork,overwrite_a,overwrite_b])`

Wrapper for *cgegv*.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)  
**b** : input rank-2 array('F') with bounds (n,n)

**Returns** **alpha** : rank-1 array('F') with bounds (n)  
**beta** : rank-1 array('F') with bounds (n)  
**vl** : rank-2 array('F') with bounds (ldvl,n)  
**vr** : rank-2 array('F') with bounds (ldvr,n)  
**info** : int

**Other Parameters**  
**compute\_vl** : input int, optional  
Default: 1  
**compute\_vr** : input int, optional  
Default: 1  
**overwrite\_a** : input int, optional  
Default: 0  
**overwrite\_b** : input int, optional  
Default: 0  
**lwork** : input int, optional  
Default: 2\*n

`scipy.linalg.lapack.zgegv(*args, **kwargs)`

*zgegv* is deprecated! The *\*gegv* family of routines has been deprecated in LAPACK 3.6.0 in favor of the *\*ggev* family of routines. The corresponding wrappers will be removed from SciPy in a future release.

`alpha,beta,vl,vr,info = zgegv(a,b,[compute_vl,compute_vr,lwork,overwrite_a,overwrite_b])`

Wrapper for *zgegv*.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**b** : input rank-2 array('D') with bounds (n,n)

**Returns**     **alpha** : rank-1 array('D') with bounds (n)  
                  **beta** : rank-1 array('D') with bounds (n)  
                  **vl** : rank-2 array('D') with bounds (ldvl,n)  
                  **vr** : rank-2 array('D') with bounds (ldvr,n)  
                  **info** : int

**Other Parameters**

**compute\_vl** : input int, optional  
               Default: 1  
**compute\_vr** : input int, optional  
               Default: 1  
**overwrite\_a** : input int, optional  
               Default: 0  
**overwrite\_b** : input int, optional  
               Default: 0  
**lwork** : input int, optional  
           Default: 2\*n

`scipy.linalg.lapack.sgehrd(a[, lo, hi, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for sgehrd.

**Parameters**   **a** : input rank-2 array('f') with bounds (n,n)  
**Returns**       **ht** : rank-2 array('f') with bounds (n,n) and a storage  
                  **tau** : rank-1 array('f') with bounds (n - 1)  
                  **info** : int

**Other Parameters**

**lo** : input int, optional  
       Default: 0  
**hi** : input int, optional  
       Default: n-1  
**overwrite\_a** : input int, optional  
       Default: 0  
**lwork** : input int, optional  
       Default: MAX(n,1)

`scipy.linalg.lapack.dgehrd(a[, lo, hi, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for dgehrd.

**Parameters**   **a** : input rank-2 array('d') with bounds (n,n)  
**Returns**       **ht** : rank-2 array('d') with bounds (n,n) and a storage  
                  **tau** : rank-1 array('d') with bounds (n - 1)  
                  **info** : int

**Other Parameters**

**lo** : input int, optional  
       Default: 0  
**hi** : input int, optional  
       Default: n-1  
**overwrite\_a** : input int, optional  
       Default: 0  
**lwork** : input int, optional  
       Default: MAX(n,1)

`scipy.linalg.lapack.cgehrd(a[, lo, hi, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for cgehrd.

**Parameters**   **a** : input rank-2 array('F') with bounds (n,n)

**Returns**     **ht** : rank-2 array('F') with bounds (n,n) and a storage  
                   **tau** : rank-1 array('F') with bounds (n - 1)  
                   **info** : int

**Other Parameters**

**lo** : input int, optional  
           Default: 0  
    **hi** : input int, optional  
           Default: n-1  
    **overwrite\_a** : input int, optional  
           Default: 0  
    **lwork** : input int, optional  
           Default: MAX(n,1)

`scipy.linalg.lapack.zgehrd(a[, lo, hi, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for zgehrd.

**Parameters**   **a** : input rank-2 array('D') with bounds (n,n)  
**Returns**       **ht** : rank-2 array('D') with bounds (n,n) and a storage  
                   **tau** : rank-1 array('D') with bounds (n - 1)  
                   **info** : int

**Other Parameters**

**lo** : input int, optional  
           Default: 0  
    **hi** : input int, optional  
           Default: n-1  
    **overwrite\_a** : input int, optional  
           Default: 0  
    **lwork** : input int, optional  
           Default: MAX(n,1)

`scipy.linalg.lapack.sgehrd_lwork(n[, lo, hi]) = <fortran object>`  
 Wrapper for sgehrd\_lwork.

**Parameters**   **n** : input int  
**Returns**       **work** : float  
                   **info** : int

**Other Parameters**

**lo** : input int, optional  
           Default: 0  
    **hi** : input int, optional  
           Default: n-1

`scipy.linalg.lapack.dgehrd_lwork(n[, lo, hi]) = <fortran object>`  
 Wrapper for dgehrd\_lwork.

**Parameters**   **n** : input int  
**Returns**       **work** : float  
                   **info** : int

**Other Parameters**

**lo** : input int, optional  
           Default: 0  
    **hi** : input int, optional  
           Default: n-1

`scipy.linalg.lapack.cgehrd_lwork(n[, lo, hi]) = <fortran object>`  
 Wrapper for cgehrd\_lwork.

**Parameters**   **n** : input int

**Returns**     **work** : complex  
                   **info** : int

**Other Parameters**

**lo** : input int, optional  
       Default: 0  
**hi** : input int, optional  
       Default: n-1

`scipy.linalg.lapack.zgehrd_lwork` ( $n$ [,  $lo$ ,  $hi$ ]) = <fortran object>  
 Wrapper for `zgehrd_lwork`.

**Parameters**   **n** : input int  
**Returns**       **work** : complex  
                   **info** : int

**Other Parameters**

**lo** : input int, optional  
       Default: 0  
**hi** : input int, optional  
       Default: n-1

`scipy.linalg.lapack.sgelss` ( $a$ ,  $b$ [,  $cond$ ,  $lwork$ ,  $overwrite_a$ ,  $overwrite_b$ ]) = <fortran object>  
 Wrapper for `sgelss`.

**Parameters**   **a** : input rank-2 array('f') with bounds (m,n)  
                   **b** : input rank-2 array('f') with bounds (maxmn,nrhs)  
**Returns**       **v** : rank-2 array('f') with bounds (m,n) and a storage  
                   **x** : rank-2 array('f') with bounds (maxmn,nrhs) and b storage  
                   **s** : rank-1 array('f') with bounds (minmn)  
                   **rank** : int  
                   **work** : rank-1 array('f') with bounds (MAX(lwork,1))  
                   **info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
                Default: 0  
**overwrite\_b** : input int, optional  
                Default: 0  
**cond** : input float, optional  
           Default: -1.0  
**lwork** : input int, optional  
           Default: 3\*minmn+MAX(2\*minmn,MAX(maxmn,nrhs))

`scipy.linalg.lapack.dgelss` ( $a$ ,  $b$ [,  $cond$ ,  $lwork$ ,  $overwrite_a$ ,  $overwrite_b$ ]) = <fortran object>  
 Wrapper for `dgelss`.

**Parameters**   **a** : input rank-2 array('d') with bounds (m,n)  
                   **b** : input rank-2 array('d') with bounds (maxmn,nrhs)  
**Returns**       **v** : rank-2 array('d') with bounds (m,n) and a storage  
                   **x** : rank-2 array('d') with bounds (maxmn,nrhs) and b storage  
                   **s** : rank-1 array('d') with bounds (minmn)  
                   **rank** : int  
                   **work** : rank-1 array('d') with bounds (MAX(lwork,1))  
                   **info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
                Default: 0  
**overwrite\_b** : input int, optional  
                Default: 0

**cond** : input float, optional  
 Default: -1.0  
**lwork** : input int, optional  
 Default: 3\*minmn+MAX(2\*minmn,MAX(maxmn,nrhs))

`scipy.linalg.lapack.cgels`(*a*, *b*[, *cond*, *lwork*, *overwrite\_a*, *overwrite\_b*]) = <fortran object>  
 Wrapper for `cgels`.

**Parameters** **a** : input rank-2 array('F') with bounds (m,n)  
**b** : input rank-2 array('F') with bounds (maxmn,nrhs)  
**Returns** **v** : rank-2 array('F') with bounds (m,n) and a storage  
**x** : rank-2 array('F') with bounds (maxmn,nrhs) and b storage  
**s** : rank-1 array('f') with bounds (minmn)  
**rank** : int  
**work** : rank-1 array('F') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**cond** : input float, optional  
 Default: -1.0  
**lwork** : input int, optional  
 Default: 2\*minmn+MAX(maxmn,nrhs)

`scipy.linalg.lapack.zgels`(*a*, *b*[, *cond*, *lwork*, *overwrite\_a*, *overwrite\_b*]) = <fortran object>  
 Wrapper for `zgels`.

**Parameters** **a** : input rank-2 array('D') with bounds (m,n)  
**b** : input rank-2 array('D') with bounds (maxmn,nrhs)  
**Returns** **v** : rank-2 array('D') with bounds (m,n) and a storage  
**x** : rank-2 array('D') with bounds (maxmn,nrhs) and b storage  
**s** : rank-1 array('d') with bounds (minmn)  
**rank** : int  
**work** : rank-1 array('D') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**cond** : input float, optional  
 Default: -1.0  
**lwork** : input int, optional  
 Default: 2\*minmn+MAX(maxmn,nrhs)

`scipy.linalg.lapack.sgels_lwork`(*m*, *n*, *nrhs*[, *cond*, *lwork*]) = <fortran object>  
 Wrapper for `sgels_lwork`.

**Parameters** **m** : input int  
**n** : input int  
**nrhs** : input int  
**Returns** **work** : float  
**info** : int  
**Other Parameters**  
**cond** : input float, optional

Default: -1.0  
**lwork** : input int, optional  
 Default: -1

`scipy.linalg.lapack.dgelss_lwork(m, n, nrhs[, cond, lwork]) = <fortran object>`  
 Wrapper for `dgelss_lwork`.

**Parameters** **m** : input int  
**n** : input int  
**nrhs** : input int  
**Returns** **work** : float  
**info** : int  
**Other Parameters**  
**cond** : input float, optional  
 Default: -1.0  
**lwork** : input int, optional  
 Default: -1

`scipy.linalg.lapack.cgelss_lwork(m, n, nrhs[, cond, lwork]) = <fortran object>`  
 Wrapper for `cgelss_lwork`.

**Parameters** **m** : input int  
**n** : input int  
**nrhs** : input int  
**Returns** **work** : complex  
**info** : int  
**Other Parameters**  
**cond** : input float, optional  
 Default: -1.0  
**lwork** : input int, optional  
 Default: -1

`scipy.linalg.lapack.zgelss_lwork(m, n, nrhs[, cond, lwork]) = <fortran object>`  
 Wrapper for `zgelss_lwork`.

**Parameters** **m** : input int  
**n** : input int  
**nrhs** : input int  
**Returns** **work** : complex  
**info** : int  
**Other Parameters**  
**cond** : input float, optional  
 Default: -1.0  
**lwork** : input int, optional  
 Default: -1

`scipy.linalg.lapack.sgelsd(a, b, lwork, size_iwork[, cond, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for `sgelsd`.

**Parameters** **a** : input rank-2 array('f') with bounds (m,n)  
**b** : input rank-2 array('f') with bounds (maxmn,nrhs)  
**lwork** : input int  
**size\_iwork** : input int  
**Returns** **x** : rank-2 array('f') with bounds (maxmn,nrhs) and b storage  
**s** : rank-1 array('f') with bounds (minmn)  
**rank** : int  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**cond** : input float, optional  
 Default: -1.0

`scipy.linalg.lapack.dgelsd(a, b, lwork, size_iwork[, cond, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for dgelsd.

**Parameters** **a** : input rank-2 array('d') with bounds (m,n)  
**b** : input rank-2 array('d') with bounds (maxmn,nrhs)  
**lwork** : input int  
**size\_iwork** : input int  
**Returns** **x** : rank-2 array('d') with bounds (maxmn,nrhs) and b storage  
**s** : rank-1 array('d') with bounds (minmn)  
**rank** : int  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**cond** : input float, optional  
 Default: -1.0

`scipy.linalg.lapack.cgelsd(a, b, lwork, size_rwork, size_iwork[, cond, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for cgelsd.

**Parameters** **a** : input rank-2 array('F') with bounds (m,n)  
**b** : input rank-2 array('F') with bounds (maxmn,nrhs)  
**lwork** : input int  
**size\_rwork** : input int  
**size\_iwork** : input int  
**Returns** **x** : rank-2 array('F') with bounds (maxmn,nrhs) and b storage  
**s** : rank-1 array('f') with bounds (minmn)  
**rank** : int  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**cond** : input float, optional  
 Default: -1.0

`scipy.linalg.lapack.zgelsd(a, b, lwork, size_rwork, size_iwork[, cond, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for zgelsd.

**Parameters** **a** : input rank-2 array('D') with bounds (m,n)  
**b** : input rank-2 array('D') with bounds (maxmn,nrhs)  
**lwork** : input int  
**size\_rwork** : input int

**Returns** **size\_iwork** : input int  
**x** : rank-2 array('D') with bounds (maxmn,nrhs) and b storage  
**s** : rank-1 array('d') with bounds (minmn)  
**rank** : int  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
Default: 0  
**overwrite\_b** : input int, optional  
Default: 0  
**cond** : input float, optional  
Default: -1.0

`scipy.linalg.lapack.sgelsd_lwork(m, n, nrhs[, cond, lwork]) = <fortran object>`  
Wrapper for `sgelsd_lwork`.

**Parameters** **m** : input int  
**n** : input int  
**nrhs** : input int  
**Returns** **work** : float  
**iwork** : int  
**info** : int

**Other Parameters**

**cond** : input float, optional  
Default: -1.0  
**lwork** : input int, optional  
Default: -1

`scipy.linalg.lapack.dgelsd_lwork(m, n, nrhs[, cond, lwork]) = <fortran object>`  
Wrapper for `dgelsd_lwork`.

**Parameters** **m** : input int  
**n** : input int  
**nrhs** : input int  
**Returns** **work** : float  
**iwork** : int  
**info** : int

**Other Parameters**

**cond** : input float, optional  
Default: -1.0  
**lwork** : input int, optional  
Default: -1

`scipy.linalg.lapack.cgelsd_lwork(m, n, nrhs[, cond, lwork]) = <fortran object>`  
Wrapper for `cgelsd_lwork`.

**Parameters** **m** : input int  
**n** : input int  
**nrhs** : input int  
**Returns** **work** : complex  
**rwork** : float  
**iwork** : int  
**info** : int

**Other Parameters**

**cond** : input float, optional  
Default: -1.0  
**lwork** : input int, optional

Default: -1

`scipy.linalg.lapack.zgelsd_lwork(m, n, nrhs[, cond, lwork]) = <fortran object>`

Wrapper for zgelsd\_lwork.

**Parameters** **m** : input int  
**n** : input int  
**nrhs** : input int

**Returns** **work** : complex  
**rwork** : float  
**iwork** : int  
**info** : int

**Other Parameters**  
**cond** : input float, optional  
 Default: -1.0  
**lwork** : input int, optional  
 Default: -1

`scipy.linalg.lapack.sgelsy(a, b, jptv, cond, lwork[, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for sgelsy.

**Parameters** **a** : input rank-2 array('f') with bounds (m,n)  
**b** : input rank-2 array('f') with bounds (maxmn,nrhs)  
**jptv** : input rank-1 array('i') with bounds (n)  
**cond** : input float  
**lwork** : input int

**Returns** **v** : rank-2 array('f') with bounds (m,n) and a storage  
**x** : rank-2 array('f') with bounds (maxmn,nrhs) and b storage  
**j** : rank-1 array('i') with bounds (n) and jptv storage  
**rank** : int  
**info** : int

**Other Parameters**  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.dgelsy(a, b, jptv, cond, lwork[, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for dgelsy.

**Parameters** **a** : input rank-2 array('d') with bounds (m,n)  
**b** : input rank-2 array('d') with bounds (maxmn,nrhs)  
**jptv** : input rank-1 array('i') with bounds (n)  
**cond** : input float  
**lwork** : input int

**Returns** **v** : rank-2 array('d') with bounds (m,n) and a storage  
**x** : rank-2 array('d') with bounds (maxmn,nrhs) and b storage  
**j** : rank-1 array('i') with bounds (n) and jptv storage  
**rank** : int  
**info** : int

**Other Parameters**  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.cgelsy(a, b, jptv, cond, lwork[, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for cgelsy.

**Parameters**

- a** : input rank-2 array('F') with bounds (m,n)
- b** : input rank-2 array('F') with bounds (maxmn,nrhs)
- jptv** : input rank-1 array('i') with bounds (n)
- cond** : input float
- lwork** : input int

**Returns**

- v** : rank-2 array('F') with bounds (m,n) and a storage
- x** : rank-2 array('F') with bounds (maxmn,nrhs) and b storage
- j** : rank-1 array('i') with bounds (n) and jptv storage
- rank** : int
- info** : int

**Other Parameters**

- overwrite\_a** : input int, optional  
Default: 0
- overwrite\_b** : input int, optional  
Default: 0

`scipy.linalg.lapack.zgelsy(a, b, jptv, cond, lwork[, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for zgelsy.

**Parameters**

- a** : input rank-2 array('D') with bounds (m,n)
- b** : input rank-2 array('D') with bounds (maxmn,nrhs)
- jptv** : input rank-1 array('i') with bounds (n)
- cond** : input float
- lwork** : input int

**Returns**

- v** : rank-2 array('D') with bounds (m,n) and a storage
- x** : rank-2 array('D') with bounds (maxmn,nrhs) and b storage
- j** : rank-1 array('i') with bounds (n) and jptv storage
- rank** : int
- info** : int

**Other Parameters**

- overwrite\_a** : input int, optional  
Default: 0
- overwrite\_b** : input int, optional  
Default: 0

`scipy.linalg.lapack.sgelsy_lwork(m, n, nrhs, cond[, lwork]) = <fortran object>`

Wrapper for sgelsy\_lwork.

**Parameters**

- m** : input int
- n** : input int
- nrhs** : input int
- cond** : input float

**Returns**

- work** : float
- info** : int

**Other Parameters**

- lwork** : input int, optional  
Default: -1

`scipy.linalg.lapack.dgelsy_lwork(m, n, nrhs, cond[, lwork]) = <fortran object>`

Wrapper for dgelsy\_lwork.

**Parameters** **m** : input int  
**n** : input int  
**nrhs** : input int  
**cond** : input float

**Returns** **work** : float  
**info** : int

**Other Parameters**

**lwork** : input int, optional  
 Default: -1

`scipy.linalg.lapack.cgelsy_lwork(m, n, nrhs, cond[, lwork]) = <fortran object>`  
 Wrapper for cgelsy\_lwork.

**Parameters** **m** : input int  
**n** : input int  
**nrhs** : input int  
**cond** : input float

**Returns** **work** : complex  
**info** : int

**Other Parameters**

**lwork** : input int, optional  
 Default: -1

`scipy.linalg.lapack.zgelsy_lwork(m, n, nrhs, cond[, lwork]) = <fortran object>`  
 Wrapper for zgelsy\_lwork.

**Parameters** **m** : input int  
**n** : input int  
**nrhs** : input int  
**cond** : input float

**Returns** **work** : complex  
**info** : int

**Other Parameters**

**lwork** : input int, optional  
 Default: -1

`scipy.linalg.lapack.sgeqp3(a[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for sgeqp3.

**Parameters** **a** : input rank-2 array('f') with bounds (m,n)  
**Returns** **qr** : rank-2 array('f') with bounds (m,n) and a storage  
**jpvt** : rank-1 array('i') with bounds (n)  
**tau** : rank-1 array('f') with bounds (MIN(m,n))  
**work** : rank-1 array('f') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*(n+1)

`scipy.linalg.lapack.dgeqp3(a[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for dgeqp3.

**Parameters** **a** : input rank-2 array('d') with bounds (m,n)  
**Returns** **qr** : rank-2 array('d') with bounds (m,n) and a storage  
**jpvt** : rank-1 array('i') with bounds (n)  
**tau** : rank-1 array('d') with bounds (MIN(m,n))

**work** : rank-1 array('d') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*(n+1)

`scipy.linalg.lapack.cgeqp3(a[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for cgeqp3.

**Parameters** **a** : input rank-2 array('F') with bounds (m,n)  
**Returns** **qr** : rank-2 array('F') with bounds (m,n) and a storage  
**jpvt** : rank-1 array('i') with bounds (n)  
**tau** : rank-1 array('F') with bounds (MIN(m,n))  
**work** : rank-1 array('F') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*(n+1)

`scipy.linalg.lapack.zgeqp3(a[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for zgeqp3.

**Parameters** **a** : input rank-2 array('D') with bounds (m,n)  
**Returns** **qr** : rank-2 array('D') with bounds (m,n) and a storage  
**jpvt** : rank-1 array('i') with bounds (n)  
**tau** : rank-1 array('D') with bounds (MIN(m,n))  
**work** : rank-1 array('D') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*(n+1)

`scipy.linalg.lapack.sgeqrf(a[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for sgeqrf.

**Parameters** **a** : input rank-2 array('f') with bounds (m,n)  
**Returns** **qr** : rank-2 array('f') with bounds (m,n) and a storage  
**tau** : rank-1 array('f') with bounds (MIN(m,n))  
**work** : rank-1 array('f') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*n

`scipy.linalg.lapack.dgeqrf(a[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for dgeqrf.

**Parameters** **a** : input rank-2 array('d') with bounds (m,n)

**Returns**     **qr** : rank-2 array('d') with bounds (m,n) and a storage  
                   **tau** : rank-1 array('d') with bounds (MIN(m,n))  
                   **work** : rank-1 array('d') with bounds (MAX(lwork,1))  
                   **info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
                                   Default: 0  
                   **lwork** : input int, optional  
                                   Default: 3\*n

`scipy.linalg.lapack.cgeqrf(a[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for `cgeqrf`.

**Parameters**   **a** : input rank-2 array('F') with bounds (m,n)  
**Returns**       **qr** : rank-2 array('F') with bounds (m,n) and a storage  
                   **tau** : rank-1 array('F') with bounds (MIN(m,n))  
                   **work** : rank-1 array('F') with bounds (MAX(lwork,1))  
                   **info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
                                   Default: 0  
                   **lwork** : input int, optional  
                                   Default: 3\*n

`scipy.linalg.lapack.zgeqrf(a[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for `zgeqrf`.

**Parameters**   **a** : input rank-2 array('D') with bounds (m,n)  
**Returns**       **qr** : rank-2 array('D') with bounds (m,n) and a storage  
                   **tau** : rank-1 array('D') with bounds (MIN(m,n))  
                   **work** : rank-1 array('D') with bounds (MAX(lwork,1))  
                   **info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
                                   Default: 0  
                   **lwork** : input int, optional  
                                   Default: 3\*n

`scipy.linalg.lapack.sgerqf(a[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for `sgerqf`.

**Parameters**   **a** : input rank-2 array('f') with bounds (m,n)  
**Returns**       **qr** : rank-2 array('f') with bounds (m,n) and a storage  
                   **tau** : rank-1 array('f') with bounds (MIN(m,n))  
                   **work** : rank-1 array('f') with bounds (MAX(lwork,1))  
                   **info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
                                   Default: 0  
                   **lwork** : input int, optional  
                                   Default: 3\*m

`scipy.linalg.lapack.dgerqf(a[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for `dgerqf`.

**Parameters**   **a** : input rank-2 array('d') with bounds (m,n)

**Returns** **qr** : rank-2 array('d') with bounds (m,n) and a storage  
**tau** : rank-1 array('d') with bounds (MIN(m,n))  
**work** : rank-1 array('d') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*m

`scipy.linalg.lapack.cgerqf(a[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for `cgerqf`.

**Parameters** **a** : input rank-2 array('F') with bounds (m,n)  
**Returns** **qr** : rank-2 array('F') with bounds (m,n) and a storage  
**tau** : rank-1 array('F') with bounds (MIN(m,n))  
**work** : rank-1 array('F') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*m

`scipy.linalg.lapack.zgerqf(a[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for `zgerqf`.

**Parameters** **a** : input rank-2 array('D') with bounds (m,n)  
**Returns** **qr** : rank-2 array('D') with bounds (m,n) and a storage  
**tau** : rank-1 array('D') with bounds (MIN(m,n))  
**work** : rank-1 array('D') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*m

`scipy.linalg.lapack.sgesdd(a[, compute_uv, full_matrices, lwork, overwrite_a]) = <fortran object>`

Wrapper for `sgesdd`.

**Parameters** **a** : input rank-2 array('f') with bounds (m,n)  
**Returns** **u** : rank-2 array('f') with bounds (u0,u1)  
**s** : rank-1 array('f') with bounds (minmn)  
**vt** : rank-2 array('f') with bounds (vt0,vt1)  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**compute\_uv** : input int, optional  
 Default: 1  
**full\_matrices** : input int, optional  
 Default: 1  
**lwork** : input int, optional  
 Default: (compute\_uv?4\*minmn\*minmn+MAX(m,n)+9\*minmn:MAX(14\*minmn+4,10\*minmn+2+25\*

`scipy.linalg.lapack.dgesdd(a[, compute_uv, full_matrices, lwork, overwrite_a]) = <fortran object>`

Wrapper for dgesdd.

**Parameters** **a** : input rank-2 array('d') with bounds (m,n)

**Returns** **u** : rank-2 array('d') with bounds (u0,u1)  
**s** : rank-1 array('d') with bounds (minmn)  
**vt** : rank-2 array('d') with bounds (vt0,vt1)  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0

**compute\_uv** : input int, optional  
 Default: 1

**full\_matrices** : input int, optional  
 Default: 1

**lwork** : input int, optional  
 Default: (compute\_uv?4\*minmn\*minmn+MAX(m,n)+9\*minmn:MAX(14\*minmn+4,10\*minmn+2+25\*

`scipy.linalg.lapack.cgesdd(a[, compute_uv, full_matrices, lwork, overwrite_a]) = <fortran object>`

Wrapper for cgesdd.

**Parameters** **a** : input rank-2 array('F') with bounds (m,n)

**Returns** **u** : rank-2 array('F') with bounds (u0,u1)  
**s** : rank-1 array('f') with bounds (minmn)  
**vt** : rank-2 array('F') with bounds (vt0,vt1)  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0

**compute\_uv** : input int, optional  
 Default: 1

**full\_matrices** : input int, optional  
 Default: 1

**lwork** : input int, optional  
 Default: (compute\_uv?2\*minmn\*minmn+MAX(m,n)+2\*minmn:2\*minmn+MAX(m,n))

`scipy.linalg.lapack.zgesdd(a[, compute_uv, full_matrices, lwork, overwrite_a]) = <fortran object>`

Wrapper for zgesdd.

**Parameters** **a** : input rank-2 array('D') with bounds (m,n)

**Returns** **u** : rank-2 array('D') with bounds (u0,u1)  
**s** : rank-1 array('d') with bounds (minmn)  
**vt** : rank-2 array('D') with bounds (vt0,vt1)  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0

**compute\_uv** : input int, optional  
 Default: 1

**full\_matrices** : input int, optional  
 Default: 1

**lwork** : input int, optional  
 Default: (compute\_uv?2\*minmn\*minmn+MAX(m,n)+2\*minmn:2\*minmn+MAX(m,n))

`scipy.linalg.lapack.sgesdd_lwork` ( $m, n$  [,  $compute_uv, full_matrices$  ]) = <fortran object>  
 Wrapper for `sgesdd_lwork`.

**Parameters**    **m** : input int  
                   **n** : input int  
**Returns**        **work** : float  
                   **info** : int  
**Other Parameters**  
                   **compute\_uv** : input int, optional  
                                   Default: 1  
                   **full\_matrices** : input int, optional  
                                   Default: 1

`scipy.linalg.lapack.dgesdd_lwork` ( $m, n$  [,  $compute_uv, full_matrices$  ]) = <fortran object>  
 Wrapper for `dgesdd_lwork`.

**Parameters**    **m** : input int  
                   **n** : input int  
**Returns**        **work** : float  
                   **info** : int  
**Other Parameters**  
                   **compute\_uv** : input int, optional  
                                   Default: 1  
                   **full\_matrices** : input int, optional  
                                   Default: 1

`scipy.linalg.lapack.cgesdd_lwork` ( $m, n$  [,  $compute_uv, full_matrices$  ]) = <fortran object>  
 Wrapper for `cgesdd_lwork`.

**Parameters**    **m** : input int  
                   **n** : input int  
**Returns**        **work** : complex  
                   **info** : int  
**Other Parameters**  
                   **compute\_uv** : input int, optional  
                                   Default: 1  
                   **full\_matrices** : input int, optional  
                                   Default: 1

`scipy.linalg.lapack.zgesdd_lwork` ( $m, n$  [,  $compute_uv, full_matrices$  ]) = <fortran object>  
 Wrapper for `zgesdd_lwork`.

**Parameters**    **m** : input int  
                   **n** : input int  
**Returns**        **work** : complex  
                   **info** : int  
**Other Parameters**  
                   **compute\_uv** : input int, optional  
                                   Default: 1  
                   **full\_matrices** : input int, optional  
                                   Default: 1

`scipy.linalg.lapack.sgesvd` ( $a$  [,  $compute_uv, full_matrices, lwork, overwrite_a$  ]) = <fortran object>

Wrapper for `sgesvd`.

**Parameters**    **a** : input rank-2 array('f') with bounds (m,n)

**Returns** **u** : rank-2 array('f') with bounds (u0,u1)  
**s** : rank-1 array('f') with bounds (minmn)  
**vt** : rank-2 array('f') with bounds (vt0,vt1)  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**compute\_uv** : input int, optional  
 Default: 1  
**full\_matrices** : input int, optional  
 Default: 1  
**lwork** : input int, optional  
 Default: MAX(1,MAX(3\*minmn+MAX(m,n),5\*minmn))

scipy.linalg.lapack.dgesvd(*a*[, *compute\_uv*, *full\_matrices*, *lwork*, *overwrite\_a*]) = <fortran object>

Wrapper for dgesvd.

**Parameters** **a** : input rank-2 array('d') with bounds (m,n)  
**Returns** **u** : rank-2 array('d') with bounds (u0,u1)  
**s** : rank-1 array('d') with bounds (minmn)  
**vt** : rank-2 array('d') with bounds (vt0,vt1)  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**compute\_uv** : input int, optional  
 Default: 1  
**full\_matrices** : input int, optional  
 Default: 1  
**lwork** : input int, optional  
 Default: MAX(1,MAX(3\*minmn+MAX(m,n),5\*minmn))

scipy.linalg.lapack.cgesvd(*a*[, *compute\_uv*, *full\_matrices*, *lwork*, *overwrite\_a*]) = <fortran object>

Wrapper for cgesvd.

**Parameters** **a** : input rank-2 array('F') with bounds (m,n)  
**Returns** **u** : rank-2 array('F') with bounds (u0,u1)  
**s** : rank-1 array('f') with bounds (minmn)  
**vt** : rank-2 array('F') with bounds (vt0,vt1)  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**compute\_uv** : input int, optional  
 Default: 1  
**full\_matrices** : input int, optional  
 Default: 1  
**lwork** : input int, optional  
 Default: MAX(1,2\*minmn+MAX(m,n))

scipy.linalg.lapack.zgesvd(*a*[, *compute\_uv*, *full\_matrices*, *lwork*, *overwrite\_a*]) = <fortran object>

Wrapper for zgesvd.

**Parameters** **a** : input rank-2 array('D') with bounds (m,n)

**Returns** **u** : rank-2 array('D') with bounds (u0,u1)  
**s** : rank-1 array('d') with bounds (minmn)  
**vt** : rank-2 array('D') with bounds (vt0,vt1)  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**compute\_uv** : input int, optional  
 Default: 1  
**full\_matrices** : input int, optional  
 Default: 1  
**lwork** : input int, optional  
 Default: MAX(1,2\*minmn+MAX(m,n))

`scipy.linalg.lapack.sgesvd_lwork(m, n[, compute_uv, full_matrices]) = <fortran object>`  
 Wrapper for `sgesvd_lwork`.

**Parameters** **m** : input int  
**n** : input int  
**Returns** **work** : float  
**info** : int

**Other Parameters**

**compute\_uv** : input int, optional  
 Default: 1  
**full\_matrices** : input int, optional  
 Default: 1

`scipy.linalg.lapack.dgesvd_lwork(m, n[, compute_uv, full_matrices]) = <fortran object>`  
 Wrapper for `dgesvd_lwork`.

**Parameters** **m** : input int  
**n** : input int  
**Returns** **work** : float  
**info** : int

**Other Parameters**

**compute\_uv** : input int, optional  
 Default: 1  
**full\_matrices** : input int, optional  
 Default: 1

`scipy.linalg.lapack.cgesvd_lwork(m, n[, compute_uv, full_matrices]) = <fortran object>`  
 Wrapper for `cgesvd_lwork`.

**Parameters** **m** : input int  
**n** : input int  
**Returns** **work** : complex  
**info** : int

**Other Parameters**

**compute\_uv** : input int, optional  
 Default: 1  
**full\_matrices** : input int, optional  
 Default: 1

`scipy.linalg.lapack.zgesvd_lwork(m, n[, compute_uv, full_matrices]) = <fortran object>`  
 Wrapper for `zgesvd_lwork`.

**Parameters** **m** : input int  
**n** : input int

**Returns**     **work** : complex  
                   **info** : int

**Other Parameters**

**compute\_uv** : input int, optional  
                   Default: 1  
       **full\_matrices** : input int, optional  
                   Default: 1

`scipy.linalg.lapack.sgesv(a, b[, overwrite_a, overwrite_b]) = <fortran object>`  
 Wrapper for `sgesv`.

**Parameters**   **a** : input rank-2 array('f') with bounds (n,n)  
                   **b** : input rank-2 array('f') with bounds (n,nrhs)  
**Returns**       **lu** : rank-2 array('f') with bounds (n,n) and a storage  
                   **piv** : rank-1 array('i') with bounds (n)  
                   **x** : rank-2 array('f') with bounds (n,nrhs) and b storage  
                   **info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
                   Default: 0  
       **overwrite\_b** : input int, optional  
                   Default: 0

`scipy.linalg.lapack.dgesv(a, b[, overwrite_a, overwrite_b]) = <fortran object>`  
 Wrapper for `dgesv`.

**Parameters**   **a** : input rank-2 array('d') with bounds (n,n)  
                   **b** : input rank-2 array('d') with bounds (n,nrhs)  
**Returns**       **lu** : rank-2 array('d') with bounds (n,n) and a storage  
                   **piv** : rank-1 array('i') with bounds (n)  
                   **x** : rank-2 array('d') with bounds (n,nrhs) and b storage  
                   **info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
                   Default: 0  
       **overwrite\_b** : input int, optional  
                   Default: 0

`scipy.linalg.lapack.cgesv(a, b[, overwrite_a, overwrite_b]) = <fortran object>`  
 Wrapper for `cgesv`.

**Parameters**   **a** : input rank-2 array('F') with bounds (n,n)  
                   **b** : input rank-2 array('F') with bounds (n,nrhs)  
**Returns**       **lu** : rank-2 array('F') with bounds (n,n) and a storage  
                   **piv** : rank-1 array('i') with bounds (n)  
                   **x** : rank-2 array('F') with bounds (n,nrhs) and b storage  
                   **info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
                   Default: 0  
       **overwrite\_b** : input int, optional  
                   Default: 0

`scipy.linalg.lapack.zgesv(a, b[, overwrite_a, overwrite_b]) = <fortran object>`  
 Wrapper for `zgesv`.

**Parameters**   **a** : input rank-2 array('D') with bounds (n,n)  
                   **b** : input rank-2 array('D') with bounds (n,nrhs)

**Returns** **lu** : rank-2 array('D') with bounds (n,n) and a storage  
**piv** : rank-1 array('i') with bounds (n)  
**x** : rank-2 array('D') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.sgesvx(a, b[, fact, trans, af, ipiv, equed, r, c, overwrite_a, overwrite_b]) =`  
**<fortran object>**

Wrapper for sgesvx.

**Parameters** **a** : input rank-2 array('f') with bounds (n,n)  
**b** : input rank-2 array('f') with bounds (n,nrhs)  
**Returns** **as** : rank-2 array('f') with bounds (n,n) and a storage  
**lu** : rank-2 array('f') with bounds (n,n) and af storage  
**ipiv** : rank-1 array('i') with bounds (n)  
**equed** : string(len=1)  
**rs** : rank-1 array('f') with bounds (n) and r storage  
**cs** : rank-1 array('f') with bounds (n) and c storage  
**bs** : rank-2 array('f') with bounds (n,nrhs) and b storage  
**x** : rank-2 array('f') with bounds (n,nrhs)  
**rcond** : float  
**ferr** : rank-1 array('f') with bounds (nrhs)  
**berr** : rank-1 array('f') with bounds (nrhs)  
**info** : int

**Other Parameters**

**fact** : input string(len=1), optional  
 Default: 'E'  
**trans** : input string(len=1), optional  
 Default: 'N'  
**overwrite\_a** : input int, optional  
 Default: 0  
**af** : input rank-2 array('f') with bounds (n,n)  
**ipiv** : input rank-1 array('i') with bounds (n)  
**equed** : input string(len=1), optional  
 Default: 'B'  
**r** : input rank-1 array('f') with bounds (n)  
**c** : input rank-1 array('f') with bounds (n)  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.dgesvx(a, b[, fact, trans, af, ipiv, equed, r, c, overwrite_a, overwrite_b]) =`  
**<fortran object>**

Wrapper for dgesvx.

**Parameters** **a** : input rank-2 array('d') with bounds (n,n)  
**b** : input rank-2 array('d') with bounds (n,nrhs)  
**Returns** **as** : rank-2 array('d') with bounds (n,n) and a storage  
**lu** : rank-2 array('d') with bounds (n,n) and af storage  
**ipiv** : rank-1 array('i') with bounds (n)  
**equed** : string(len=1)  
**rs** : rank-1 array('d') with bounds (n) and r storage  
**cs** : rank-1 array('d') with bounds (n) and c storage

**bs** : rank-2 array('d') with bounds (n,nrhs) and b storage  
**x** : rank-2 array('d') with bounds (n,nrhs)  
**rcond** : float  
**ferr** : rank-1 array('d') with bounds (nrhs)  
**berr** : rank-1 array('d') with bounds (nrhs)  
**info** : int

*Other Parameters*

**fact** : input string(len=1), optional  
 Default: 'E'  
**trans** : input string(len=1), optional  
 Default: 'N'  
**overwrite\_a** : input int, optional  
 Default: 0  
**af** : input rank-2 array('d') with bounds (n,n)  
**ipiv** : input rank-1 array('i') with bounds (n)  
**equed** : input string(len=1), optional  
 Default: 'B'  
**r** : input rank-1 array('d') with bounds (n)  
**c** : input rank-1 array('d') with bounds (n)  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.cgesvx(a, b[, fact, trans, af, ipiv, equed, r, c, overwrite_a, overwrite_b]) =`  
**<fortran object>**

Wrapper for cgesvx.

*Parameters*    **a** : input rank-2 array('F') with bounds (n,n)  
                   **b** : input rank-2 array('F') with bounds (n,nrhs)  
*Returns*        **as** : rank-2 array('F') with bounds (n,n) and a storage  
                   **lu** : rank-2 array('F') with bounds (n,n) and af storage  
                   **ipiv** : rank-1 array('i') with bounds (n)  
                   **equed** : string(len=1)  
                   **rs** : rank-1 array('f') with bounds (n) and r storage  
                   **cs** : rank-1 array('f') with bounds (n) and c storage  
                   **bs** : rank-2 array('F') with bounds (n,nrhs) and b storage  
                   **x** : rank-2 array('F') with bounds (n,nrhs)  
                   **rcond** : float  
                   **ferr** : rank-1 array('f') with bounds (nrhs)  
                   **berr** : rank-1 array('f') with bounds (nrhs)  
                   **info** : int

*Other Parameters*

**fact** : input string(len=1), optional  
 Default: 'E'  
**trans** : input string(len=1), optional  
 Default: 'N'  
**overwrite\_a** : input int, optional  
 Default: 0  
**af** : input rank-2 array('F') with bounds (n,n)  
**ipiv** : input rank-1 array('i') with bounds (n)  
**equed** : input string(len=1), optional  
 Default: 'B'  
**r** : input rank-1 array('f') with bounds (n)  
**c** : input rank-1 array('f') with bounds (n)  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.zgesvx(a, b[, fact, trans, af, ipiv, equed, r, c, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for zgesvx.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**b** : input rank-2 array('D') with bounds (n,nrhs)  
**Returns** **as** : rank-2 array('D') with bounds (n,n) and a storage  
**lu** : rank-2 array('D') with bounds (n,n) and af storage  
**ipiv** : rank-1 array('i') with bounds (n)  
**equed** : string(len=1)  
**rs** : rank-1 array('d') with bounds (n) and r storage  
**cs** : rank-1 array('d') with bounds (n) and c storage  
**bs** : rank-2 array('D') with bounds (n,nrhs) and b storage  
**x** : rank-2 array('D') with bounds (n,nrhs)  
**rcond** : float  
**ferr** : rank-1 array('d') with bounds (nrhs)  
**berr** : rank-1 array('d') with bounds (nrhs)  
**info** : int

**Other Parameters**

**fact** : input string(len=1), optional  
 Default: 'E'  
**trans** : input string(len=1), optional  
 Default: 'N'  
**overwrite\_a** : input int, optional  
 Default: 0  
**af** : input rank-2 array('D') with bounds (n,n)  
**ipiv** : input rank-1 array('i') with bounds (n)  
**equed** : input string(len=1), optional  
 Default: 'B'  
**r** : input rank-1 array('d') with bounds (n)  
**c** : input rank-1 array('d') with bounds (n)  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.sgecon(a, anorm[, norm]) = <fortran object>`

Wrapper for sgecon.

**Parameters** **a** : input rank-2 array('f') with bounds (n,n)  
**anorm** : input float  
**Returns** **rcond** : float  
**info** : int

**Other Parameters**

**norm** : input string(len=1), optional  
 Default: '1'

`scipy.linalg.lapack.dgecon(a, anorm[, norm]) = <fortran object>`

Wrapper for dgecon.

**Parameters** **a** : input rank-2 array('d') with bounds (n,n)  
**anorm** : input float  
**Returns** **rcond** : float  
**info** : int

**Other Parameters**

**norm** : input string(len=1), optional  
 Default: '1'

`scipy.linalg.lapack.cgecon(a, anorm[, norm]) = <fortran object>`  
 Wrapper for cgecon.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)  
**anorm** : input float

**Returns** **rcond** : float  
**info** : int

**Other Parameters**  
**norm** : input string(len=1), optional  
 Default: '1'

`scipy.linalg.lapack.zgecon(a, anorm[, norm]) = <fortran object>`  
 Wrapper for zgecon.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**anorm** : input float

**Returns** **rcond** : float  
**info** : int

**Other Parameters**  
**norm** : input string(len=1), optional  
 Default: '1'

`scipy.linalg.lapack.ssysv(a, b[, lwork, lower, overwrite_a, overwrite_b]) = <fortran object>`  
 Wrapper for ssysv.

**Parameters** **a** : input rank-2 array('f') with bounds (n,n)  
**b** : input rank-2 array('f') with bounds (n,nrhs)

**Returns** **udut** : rank-2 array('f') with bounds (n,n) and a storage  
**ipiv** : rank-1 array('i') with bounds (n)  
**x** : rank-2 array('f') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: n  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.dsysv(a, b[, lwork, lower, overwrite_a, overwrite_b]) = <fortran object>`  
 Wrapper for dsysv.

**Parameters** **a** : input rank-2 array('d') with bounds (n,n)  
**b** : input rank-2 array('d') with bounds (n,nrhs)

**Returns** **udut** : rank-2 array('d') with bounds (n,n) and a storage  
**ipiv** : rank-1 array('i') with bounds (n)  
**x** : rank-2 array('d') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: n

**lower** : input int, optional  
Default: 0

`scipy.linalg.lapack.csysv(a, b[, lwork, lower, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for `csysv`.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)  
**b** : input rank-2 array('F') with bounds (n,nrhs)  
**Returns** **udut** : rank-2 array('F') with bounds (n,n) and a storage  
**ipiv** : rank-1 array('i') with bounds (n)  
**x** : rank-2 array('F') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
Default: 0  
**overwrite\_b** : input int, optional  
Default: 0  
**lwork** : input int, optional  
Default: n  
**lower** : input int, optional  
Default: 0

`scipy.linalg.lapack.zsysv(a, b[, lwork, lower, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for `zsysv`.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**b** : input rank-2 array('D') with bounds (n,nrhs)  
**Returns** **udut** : rank-2 array('D') with bounds (n,n) and a storage  
**ipiv** : rank-1 array('i') with bounds (n)  
**x** : rank-2 array('D') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
Default: 0  
**overwrite\_b** : input int, optional  
Default: 0  
**lwork** : input int, optional  
Default: n  
**lower** : input int, optional  
Default: 0

`scipy.linalg.lapack.ssysv_lwork(n[, lower]) = <fortran object>`

Wrapper for `ssysv_lwork`.

**Parameters** **n** : input int  
**Returns** **work** : float  
**info** : int

**Other Parameters**

**lower** : input int, optional  
Default: 0

`scipy.linalg.lapack.dsysv_lwork(n[, lower]) = <fortran object>`

Wrapper for `dsysv_lwork`.

**Parameters** **n** : input int  
**Returns** **work** : float  
**info** : int

*Other Parameters*

**lower** : input int, optional  
Default: 0

`scipy.linalg.lapack.csysv_lwork` (*n*[, *lower*]) = <fortran object>  
Wrapper for `csysv_lwork`.

*Parameters*    **n** : input int  
*Returns*        **work** : complex  
                  **info** : int

*Other Parameters*

**lower** : input int, optional  
Default: 0

`scipy.linalg.lapack.zsysv_lwork` (*n*[, *lower*]) = <fortran object>  
Wrapper for `zsysv_lwork`.

*Parameters*    **n** : input int  
*Returns*        **work** : complex  
                  **info** : int

*Other Parameters*

**lower** : input int, optional  
Default: 0

`scipy.linalg.lapack.ssysvx` (*a*, *b*[, *af*, *ipiv*, *lwork*, *factored*, *lower*, *overwrite\_a*, *overwrite\_b*]) = <fortran object>

Wrapper for `ssysvx`.

*Parameters*    **a** : input rank-2 array('f') with bounds (n,n)  
                  **b** : input rank-2 array('f') with bounds (n,nrhs)  
*Returns*        **a\_s** : rank-2 array('f') with bounds (n,n) and a storage  
                  **udut** : rank-2 array('f') with bounds (n,n) and af storage  
                  **ipiv** : rank-1 array('i') with bounds (n)  
                  **b\_s** : rank-2 array('f') with bounds (n,nrhs) and b storage  
                  **x** : rank-2 array('f') with bounds (n,nrhs)  
                  **rcond** : float  
                  **ferr** : rank-1 array('f') with bounds (nrhs)  
                  **berr** : rank-1 array('f') with bounds (nrhs)  
                  **info** : int

*Other Parameters*

**overwrite\_a** : input int, optional  
Default: 0  
**af** : input rank-2 array('f') with bounds (n,n)  
**ipiv** : input rank-1 array('i') with bounds (n)  
**overwrite\_b** : input int, optional  
Default: 0  
**lwork** : input int, optional  
Default: 3\*n  
**factored** : input int, optional  
Default: 0  
**lower** : input int, optional  
Default: 0

`scipy.linalg.lapack.dsysvx` (*a*, *b*[, *af*, *ipiv*, *lwork*, *factored*, *lower*, *overwrite\_a*, *overwrite\_b*]) = <fortran object>

Wrapper for `dsysvx`.

**Parameters** **a** : input rank-2 array('d') with bounds (n,n)  
**b** : input rank-2 array('d') with bounds (n,nrhs)

**Returns** **a\_s** : rank-2 array('d') with bounds (n,n) and a storage  
**udut** : rank-2 array('d') with bounds (n,n) and af storage  
**ipiv** : rank-1 array('i') with bounds (n)  
**b\_s** : rank-2 array('d') with bounds (n,nrhs) and b storage  
**x** : rank-2 array('d') with bounds (n,nrhs)  
**rcond** : float  
**ferr** : rank-1 array('d') with bounds (nrhs)  
**berr** : rank-1 array('d') with bounds (nrhs)  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
Default: 0  
**af** : input rank-2 array('d') with bounds (n,n)  
**ipiv** : input rank-1 array('i') with bounds (n)  
**overwrite\_b** : input int, optional  
Default: 0  
**lwork** : input int, optional  
Default: 3\*n  
**factored** : input int, optional  
Default: 0  
**lower** : input int, optional  
Default: 0

`scipy.linalg.lapack.csysvx(a, b[, af, ipiv, lwork, factored, lower, overwrite_a, overwrite_b]) =`  
**<fortran object>**

Wrapper for csysvx.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)  
**b** : input rank-2 array('F') with bounds (n,nrhs)

**Returns** **a\_s** : rank-2 array('F') with bounds (n,n) and a storage  
**udut** : rank-2 array('F') with bounds (n,n) and af storage  
**ipiv** : rank-1 array('i') with bounds (n)  
**b\_s** : rank-2 array('F') with bounds (n,nrhs) and b storage  
**x** : rank-2 array('F') with bounds (n,nrhs)  
**rcond** : float  
**ferr** : rank-1 array('f') with bounds (nrhs)  
**berr** : rank-1 array('f') with bounds (nrhs)  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
Default: 0  
**af** : input rank-2 array('F') with bounds (n,n)  
**ipiv** : input rank-1 array('i') with bounds (n)  
**overwrite\_b** : input int, optional  
Default: 0  
**lwork** : input int, optional  
Default: 3\*n  
**factored** : input int, optional  
Default: 0  
**lower** : input int, optional  
Default: 0

`scipy.linalg.lapack.zsysvx(a, b[, af, ipiv, lwork, factored, lower, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for zsysvx.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**b** : input rank-2 array('D') with bounds (n,nrhs)  
**Returns** **a\_s** : rank-2 array('D') with bounds (n,n) and a storage  
**udut** : rank-2 array('D') with bounds (n,n) and af storage  
**ipiv** : rank-1 array('i') with bounds (n)  
**b\_s** : rank-2 array('D') with bounds (n,nrhs) and b storage  
**x** : rank-2 array('D') with bounds (n,nrhs)  
**rcond** : float  
**ferr** : rank-1 array('d') with bounds (nrhs)  
**berr** : rank-1 array('d') with bounds (nrhs)  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**af** : input rank-2 array('D') with bounds (n,n)  
**ipiv** : input rank-1 array('i') with bounds (n)  
**overwrite\_b** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*n  
**factored** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.ssysvx_lwork(n[, lower]) = <fortran object>`

Wrapper for ssysvx\_lwork.

**Parameters** **n** : input int  
**Returns** **work** : float  
**info** : int

**Other Parameters**

**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.dsysvx_lwork(n[, lower]) = <fortran object>`

Wrapper for dsysvx\_lwork.

**Parameters** **n** : input int  
**Returns** **work** : float  
**info** : int

**Other Parameters**

**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.csysvx_lwork(n[, lower]) = <fortran object>`

Wrapper for csysvx\_lwork.

**Parameters** **n** : input int  
**Returns** **work** : complex  
**info** : int

**Other Parameters**

**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.zsysvx_lwork` ( $n$ [,  $lower$ ]) = <fortran object>

Wrapper for `zsysvx_lwork`.

**Parameters**  $n$  : input int

**Returns**  $work$  : complex

$info$  : int

**Other Parameters**

$lower$  : input int, optional

Default: 0

`scipy.linalg.lapack.ssytrd` ( $a$ [,  $lower$ ,  $lwork$ ,  $overwrite_a$ ]) = <fortran object>

Wrapper for `ssytrd`.

**Parameters**  $a$  : input rank-2 array('f') with bounds (lda,n)

**Returns**  $c$  : rank-2 array('f') with bounds (lda,n) and a storage

$d$  : rank-1 array('f') with bounds (n)

$e$  : rank-1 array('f') with bounds (n - 1)

$\tau$  : rank-1 array('f') with bounds (n - 1)

$info$  : int

**Other Parameters**

$lower$  : input int, optional

Default: 0

$overwrite_a$  : input int, optional

Default: 0

$lwork$  : input int, optional

Default: MAX(n,1)

`scipy.linalg.lapack.dsytrd` ( $a$ [,  $lower$ ,  $lwork$ ,  $overwrite_a$ ]) = <fortran object>

Wrapper for `dsytrd`.

**Parameters**  $a$  : input rank-2 array('d') with bounds (lda,n)

**Returns**  $c$  : rank-2 array('d') with bounds (lda,n) and a storage

$d$  : rank-1 array('d') with bounds (n)

$e$  : rank-1 array('d') with bounds (n - 1)

$\tau$  : rank-1 array('d') with bounds (n - 1)

$info$  : int

**Other Parameters**

$lower$  : input int, optional

Default: 0

$overwrite_a$  : input int, optional

Default: 0

$lwork$  : input int, optional

Default: MAX(n,1)

`scipy.linalg.lapack.ssytrd_lwork` ( $n$ [,  $lower$ ]) = <fortran object>

Wrapper for `ssytrd_lwork`.

**Parameters**  $n$  : input int

**Returns**  $work$  : float

$info$  : int

**Other Parameters**

$lower$  : input int, optional

Default: 0

`scipy.linalg.lapack.dsytrd_lwork` ( $n$ [,  $lower$ ]) = <fortran object>

Wrapper for `dsytrd_lwork`.

**Parameters**  $n$  : input int

**Returns**     **work** : float  
                   **info** : int

**Other Parameters**

**lower** : input int, optional  
           Default: 0

`scipy.linalg.lapack.chetrd(a[, lower, lwork, overwrite_a]) = <fortran object>`

Wrapper for `chetrd`.

**Parameters**   **a** : input rank-2 array('F') with bounds (lda,n)  
**Returns**       **c** : rank-2 array('F') with bounds (lda,n) and a storage  
                   **d** : rank-1 array('f') with bounds (n)  
                   **e** : rank-1 array('f') with bounds (n - 1)  
                   **tau** : rank-1 array('F') with bounds (n - 1)  
                   **info** : int

**Other Parameters**

**lower** : input int, optional  
           Default: 0  
       **overwrite\_a** : input int, optional  
           Default: 0  
       **lwork** : input int, optional  
           Default: MAX(n,1)

`scipy.linalg.lapack.zhetrd(a[, lower, lwork, overwrite_a]) = <fortran object>`

Wrapper for `zhetrd`.

**Parameters**   **a** : input rank-2 array('D') with bounds (lda,n)  
**Returns**       **c** : rank-2 array('D') with bounds (lda,n) and a storage  
                   **d** : rank-1 array('d') with bounds (n)  
                   **e** : rank-1 array('d') with bounds (n - 1)  
                   **tau** : rank-1 array('D') with bounds (n - 1)  
                   **info** : int

**Other Parameters**

**lower** : input int, optional  
           Default: 0  
       **overwrite\_a** : input int, optional  
           Default: 0  
       **lwork** : input int, optional  
           Default: MAX(n,1)

`scipy.linalg.lapack.chetrd_lwork(n[, lower]) = <fortran object>`

Wrapper for `chetrd_lwork`.

**Parameters**   **n** : input int  
**Returns**       **work** : complex  
                   **info** : int

**Other Parameters**

**lower** : input int, optional  
           Default: 0

`scipy.linalg.lapack.zhetrd_lwork(n[, lower]) = <fortran object>`

Wrapper for `zhetrd_lwork`.

**Parameters**   **n** : input int  
**Returns**       **work** : complex  
                   **info** : int

**Other Parameters**

**lower** : input int, optional

Default: 0

`scipy.linalg.lapack.chesv(a, b[, lwork, lower, overwrite_a, overwrite_b]) = <fortran object>`  
 Wrapper for `chesv`.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)  
**b** : input rank-2 array('F') with bounds (n,nrhs)

**Returns** **uduh** : rank-2 array('F') with bounds (n,n) and a storage  
**ipiv** : rank-1 array('i') with bounds (n)  
**x** : rank-2 array('F') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: n  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.zhesv(a, b[, lwork, lower, overwrite_a, overwrite_b]) = <fortran object>`  
 Wrapper for `zhesv`.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**b** : input rank-2 array('D') with bounds (n,nrhs)

**Returns** **uduh** : rank-2 array('D') with bounds (n,n) and a storage  
**ipiv** : rank-1 array('i') with bounds (n)  
**x** : rank-2 array('D') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: n  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.chesv_lwork(n[, lower]) = <fortran object>`  
 Wrapper for `chesv_lwork`.

**Parameters** **n** : input int

**Returns** **work** : complex  
**info** : int

**Other Parameters**  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.zhesv_lwork(n[, lower]) = <fortran object>`  
 Wrapper for `zhesv_lwork`.

**Parameters** **n** : input int

**Returns** **work** : complex  
**info** : int

**Other Parameters**  
**lower** : input int, optional

Default: 0

`scipy.linalg.lapack.chesvx` (*a*, *b*[, *af*, *ipiv*, *lwork*, *factored*, *lower*, *overwrite\_a*, *overwrite\_b*]) =  
 <fortran object>

Wrapper for `chesvx`.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)  
**b** : input rank-2 array('F') with bounds (n,nrhs)  
**Returns** **uduh** : rank-2 array('F') with bounds (n,n) and *af* storage  
**ipiv** : rank-1 array('i') with bounds (n)  
**x** : rank-2 array('F') with bounds (n,nrhs)  
**rcond** : float  
**ferr** : rank-1 array('f') with bounds (nrhs)  
**berr** : rank-1 array('f') with bounds (nrhs)  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**af** : input rank-2 array('F') with bounds (n,n)  
**ipiv** : input rank-1 array('i') with bounds (n)  
**overwrite\_b** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 2\*n  
**factored** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.zhesvx` (*a*, *b*[, *af*, *ipiv*, *lwork*, *factored*, *lower*, *overwrite\_a*, *overwrite\_b*]) =  
 <fortran object>

Wrapper for `zhesvx`.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**b** : input rank-2 array('D') with bounds (n,nrhs)  
**Returns** **uduh** : rank-2 array('D') with bounds (n,n) and *af* storage  
**ipiv** : rank-1 array('i') with bounds (n)  
**x** : rank-2 array('D') with bounds (n,nrhs)  
**rcond** : float  
**ferr** : rank-1 array('d') with bounds (nrhs)  
**berr** : rank-1 array('d') with bounds (nrhs)  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**af** : input rank-2 array('D') with bounds (n,n)  
**ipiv** : input rank-1 array('i') with bounds (n)  
**overwrite\_b** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 2\*n  
**factored** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0



**Returns** **lu** : rank-2 array('D') with bounds (m,n) and a storage  
**piv** : rank-1 array('i') with bounds (MIN(m,n))  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0

`scipy.linalg.lapack.sgetri(lu, piv[, lwork, overwrite_lu]) = <fortran object>`  
 Wrapper for sgetri.

**Parameters** **lu** : input rank-2 array('f') with bounds (n,n)  
**piv** : input rank-1 array('i') with bounds (n)

**Returns** **inv\_a** : rank-2 array('f') with bounds (n,n) and lu storage  
**info** : int

**Other Parameters**

**overwrite\_lu** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*n

`scipy.linalg.lapack.dgetri(lu, piv[, lwork, overwrite_lu]) = <fortran object>`  
 Wrapper for dgetri.

**Parameters** **lu** : input rank-2 array('d') with bounds (n,n)  
**piv** : input rank-1 array('i') with bounds (n)

**Returns** **inv\_a** : rank-2 array('d') with bounds (n,n) and lu storage  
**info** : int

**Other Parameters**

**overwrite\_lu** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*n

`scipy.linalg.lapack.cgetri(lu, piv[, lwork, overwrite_lu]) = <fortran object>`  
 Wrapper for cgetri.

**Parameters** **lu** : input rank-2 array('F') with bounds (n,n)  
**piv** : input rank-1 array('i') with bounds (n)

**Returns** **inv\_a** : rank-2 array('F') with bounds (n,n) and lu storage  
**info** : int

**Other Parameters**

**overwrite\_lu** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*n

`scipy.linalg.lapack.zgetri(lu, piv[, lwork, overwrite_lu]) = <fortran object>`  
 Wrapper for zgetri.

**Parameters** **lu** : input rank-2 array('D') with bounds (n,n)  
**piv** : input rank-1 array('i') with bounds (n)

**Returns** **inv\_a** : rank-2 array('D') with bounds (n,n) and lu storage  
**info** : int

**Other Parameters**

**overwrite\_lu** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*n

`scipy.linalg.lapack.sgetri_lwork(n) = <fortran object>`

Wrapper for `sgetri_lwork`.

**Parameters** `n` : input int  
**Returns** `work` : float  
`info` : int

`scipy.linalg.lapack.dgetri_lwork(n) = <fortran object>`

Wrapper for `dgetri_lwork`.

**Parameters** `n` : input int  
**Returns** `work` : float  
`info` : int

`scipy.linalg.lapack.cgetri_lwork(n) = <fortran object>`

Wrapper for `cgetri_lwork`.

**Parameters** `n` : input int  
**Returns** `work` : complex  
`info` : int

`scipy.linalg.lapack.zgetri_lwork(n) = <fortran object>`

Wrapper for `zgetri_lwork`.

**Parameters** `n` : input int  
**Returns** `work` : complex  
`info` : int

`scipy.linalg.lapack.sgetrs(lu, piv, b[, trans, overwrite_b]) = <fortran object>`

Wrapper for `sgetrs`.

**Parameters** `lu` : input rank-2 array('f') with bounds (n,n)  
`piv` : input rank-1 array('i') with bounds (n)  
`b` : input rank-2 array('f') with bounds (n,nrhs)  
**Returns** `x` : rank-2 array('f') with bounds (n,nrhs) and b storage  
`info` : int

**Other Parameters**

`overwrite_b` : input int, optional  
Default: 0  
`trans` : input int, optional  
Default: 0

`scipy.linalg.lapack.dgetrs(lu, piv, b[, trans, overwrite_b]) = <fortran object>`

Wrapper for `dgetrs`.

**Parameters** `lu` : input rank-2 array('d') with bounds (n,n)  
`piv` : input rank-1 array('i') with bounds (n)  
`b` : input rank-2 array('d') with bounds (n,nrhs)  
**Returns** `x` : rank-2 array('d') with bounds (n,nrhs) and b storage  
`info` : int

**Other Parameters**

`overwrite_b` : input int, optional  
Default: 0  
`trans` : input int, optional  
Default: 0

`scipy.linalg.lapack.cgetrs(lu, piv, b[, trans, overwrite_b]) = <fortran object>`

Wrapper for `cgetrs`.

**Parameters** **lu** : input rank-2 array('F') with bounds (n,n)  
**piv** : input rank-1 array('i') with bounds (n)  
**b** : input rank-2 array('F') with bounds (n,nrhs)  
**Returns** **x** : rank-2 array('F') with bounds (n,nrhs) and b storage  
**info** : int  
**Other Parameters**  
**overwrite\_b** : input int, optional  
Default: 0  
**trans** : input int, optional  
Default: 0

`scipy.linalg.lapack.zgetrs (lu, piv, b[, trans, overwrite_b ]) = <fortran object>`  
Wrapper for zgetrs.

**Parameters** **lu** : input rank-2 array('D') with bounds (n,n)  
**piv** : input rank-1 array('i') with bounds (n)  
**b** : input rank-2 array('D') with bounds (n,nrhs)  
**Returns** **x** : rank-2 array('D') with bounds (n,nrhs) and b storage  
**info** : int  
**Other Parameters**  
**overwrite\_b** : input int, optional  
Default: 0  
**trans** : input int, optional  
Default: 0

`scipy.linalg.lapack.sgges (sselect, a, b[, jobvsl, jobvsr, sort_t, ldvsl, ldvsr, lwork, sselect_extra_args, overwrite_a, overwrite_b ]) = <fortran object>`  
Wrapper for sgges.

**Parameters** **sselect** : call-back function  
**a** : input rank-2 array('f') with bounds (lda,n)  
**b** : input rank-2 array('f') with bounds (ldb,n)  
**Returns** **a** : rank-2 array('f') with bounds (lda,n)  
**b** : rank-2 array('f') with bounds (ldb,n)  
**sdim** : int  
**alphar** : rank-1 array('f') with bounds (n)  
**alpha** : rank-1 array('f') with bounds (n)  
**beta** : rank-1 array('f') with bounds (n)  
**vsl** : rank-2 array('f') with bounds (ldvsl,n)  
**vsr** : rank-2 array('f') with bounds (ldvsr,n)  
**work** : rank-1 array('f') with bounds (MAX(lwork,1))  
**info** : int  
**Other Parameters**  
**jobvsl** : input int, optional  
Default: 1  
**jobvsr** : input int, optional  
Default: 1  
**sort\_t** : input int, optional  
Default: 0  
**sselect\_extra\_args** : input tuple, optional  
Default: ()  
**overwrite\_a** : input int, optional  
Default: 0  
**overwrite\_b** : input int, optional  
Default: 0  
**ldvsl** : input int, optional

Default: ((jobvsl==1)?n:1)  
**ldvsr** : input int, optional  
 Default: ((jobvsr==1)?n:1)  
**lwork** : input int, optional  
 Default: 8\*n+16

**Notes**

Call-back functions:

```
def sselect(alphar, alphai, beta): return sselect
Required arguments:
  alphar : input float
  alphai : input float
  beta   : input float
Return objects:
  sselect : int
```

`scipy.linalg.lapack.dgges` (*dselect*, *a*, *b*[, *jobvsl*, *jobvsr*, *sort\_t*, *ldvsl*, *ldvsr*, *lwork*, *dselect\_extra\_args*, *overwrite\_a*, *overwrite\_b*]) = **<fortran object>**

Wrapper for dgges.

**Parameters** **dselect** : call-back function  
**a** : input rank-2 array('d') with bounds (lda,n)  
**b** : input rank-2 array('d') with bounds (ldb,n)  
**Returns** **a** : rank-2 array('d') with bounds (lda,n)  
**b** : rank-2 array('d') with bounds (ldb,n)  
**sdim** : int  
**alphar** : rank-1 array('d') with bounds (n)  
**alphai** : rank-1 array('d') with bounds (n)  
**beta** : rank-1 array('d') with bounds (n)  
**vsl** : rank-2 array('d') with bounds (ldvsl,n)  
**vsr** : rank-2 array('d') with bounds (ldvsr,n)  
**work** : rank-1 array('d') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**jobvsl** : input int, optional  
 Default: 1  
**jobvsr** : input int, optional  
 Default: 1  
**sort\_t** : input int, optional  
 Default: 0  
**dselect\_extra\_args** : input tuple, optional  
 Default: ()  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**ldvsl** : input int, optional  
 Default: ((jobvsl==1)?n:1)  
**ldvsr** : input int, optional  
 Default: ((jobvsr==1)?n:1)  
**lwork** : input int, optional  
 Default: 8\*n+16

*Notes*

Call-back functions:

```
def dselect(alpha, alpha_i, beta): return dselect
Required arguments:
  alpha : input float
  alpha_i : input float
  beta : input float
Return objects:
  dselect : int
```

scipy.linalg.lapack.**cgges**(*cselect*, *a*, *b*[, *jobvsl*, *jobvsr*, *sort\_t*, *ldvsl*, *ldvsr*, *lwork*, *cselect\_extra\_args*, *overwrite\_a*, *overwrite\_b*]) = <fortran object>

Wrapper for cgges.

**Parameters** **cselect** : call-back function  
**a** : input rank-2 array('F') with bounds (lda,n)  
**b** : input rank-2 array('F') with bounds (ldb,n)

**Returns** **a** : rank-2 array('F') with bounds (lda,n)  
**b** : rank-2 array('F') with bounds (ldb,n)  
**sdim** : int  
**alpha** : rank-1 array('F') with bounds (n)  
**beta** : rank-1 array('F') with bounds (n)  
**vsl** : rank-2 array('F') with bounds (ldvsl,n)  
**vsr** : rank-2 array('F') with bounds (ldvsr,n)  
**work** : rank-1 array('F') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**jobvsl** : input int, optional  
 Default: 1  
**jobvsr** : input int, optional  
 Default: 1  
**sort\_t** : input int, optional  
 Default: 0  
**cselect\_extra\_args** : input tuple, optional  
 Default: ()  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**ldvsl** : input int, optional  
 Default: ((jobvsl==1)?n:1)  
**ldvsr** : input int, optional  
 Default: ((jobvsr==1)?n:1)  
**lwork** : input int, optional  
 Default: 2\*n

*Notes*

Call-back functions:

```
def cselect(alpha, beta): return cselect
Required arguments:
  alpha : input complex
  beta : input complex
```

```
Return objects:
  cselect : int
```

`scipy.linalg.lapack.zgges` (`zselect`, `a`, `b`[, `jobvsl`, `jobvsr`, `sort_t`, `ldvsl`, `ldvsr`, `lwork`, `zselect_extra_args`, `overwrite_a`, `overwrite_b`]) = **<fortran object>**

Wrapper for zgges.

**Parameters** `zselect` : call-back function  
**a** : input rank-2 array('D') with bounds (lda,n)  
**b** : input rank-2 array('D') with bounds (ldb,n)  
**Returns** **a** : rank-2 array('D') with bounds (lda,n)  
**b** : rank-2 array('D') with bounds (ldb,n)  
**sdim** : int  
**alpha** : rank-1 array('D') with bounds (n)  
**beta** : rank-1 array('D') with bounds (n)  
**vsl** : rank-2 array('D') with bounds (ldvsl,n)  
**vsr** : rank-2 array('D') with bounds (ldvsr,n)  
**work** : rank-1 array('D') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**jobvsl** : input int, optional  
 Default: 1  
**jobvsr** : input int, optional  
 Default: 1  
**sort\_t** : input int, optional  
 Default: 0  
**zselect\_extra\_args** : input tuple, optional  
 Default: ()  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**ldvsl** : input int, optional  
 Default: ((jobvsl==1)?n:1)  
**ldvsr** : input int, optional  
 Default: ((jobvsr==1)?n:1)  
**lwork** : input int, optional  
 Default: 2\*n

**Notes**

Call-back functions:

```
def zselect(alpha,beta): return zselect
Required arguments:
  alpha : input complex
  beta  : input complex
Return objects:
  zselect : int
```

`scipy.linalg.lapack.sggev` (`a`, `b`[, `compute_vl`, `compute_vr`, `lwork`, `overwrite_a`, `overwrite_b`]) = **<fortran object>**

Wrapper for sggev.

**Parameters** **a** : input rank-2 array('f') with bounds (n,n)  
**b** : input rank-2 array('f') with bounds (n,n)

**Returns**

- alphar** : rank-1 array('f') with bounds (n)
- alpha** : rank-1 array('f') with bounds (n)
- beta** : rank-1 array('f') with bounds (n)
- vl** : rank-2 array('f') with bounds (ldvl,n)
- vr** : rank-2 array('f') with bounds (ldvr,n)
- work** : rank-1 array('f') with bounds (MAX(lwork,1))
- info** : int

**Other Parameters**

- compute\_vl** : input int, optional  
Default: 1
- compute\_vr** : input int, optional  
Default: 1
- overwrite\_a** : input int, optional  
Default: 0
- overwrite\_b** : input int, optional  
Default: 0
- lwork** : input int, optional  
Default: 8\*n

`scipy.linalg.lapack.dggeev(a, b[, compute_vl, compute_vr, lwork, overwrite_a, overwrite_b]) =`  
**<fortran object>**

Wrapper for dggev.

**Parameters**

- a** : input rank-2 array('d') with bounds (n,n)
- b** : input rank-2 array('d') with bounds (n,n)

**Returns**

- alphar** : rank-1 array('d') with bounds (n)
- alpha** : rank-1 array('d') with bounds (n)
- beta** : rank-1 array('d') with bounds (n)
- vl** : rank-2 array('d') with bounds (ldvl,n)
- vr** : rank-2 array('d') with bounds (ldvr,n)
- work** : rank-1 array('d') with bounds (MAX(lwork,1))
- info** : int

**Other Parameters**

- compute\_vl** : input int, optional  
Default: 1
- compute\_vr** : input int, optional  
Default: 1
- overwrite\_a** : input int, optional  
Default: 0
- overwrite\_b** : input int, optional  
Default: 0
- lwork** : input int, optional  
Default: 8\*n

`scipy.linalg.lapack.cggev(a, b[, compute_vl, compute_vr, lwork, overwrite_a, overwrite_b]) =`  
**<fortran object>**

Wrapper for cggev.

**Parameters**

- a** : input rank-2 array('F') with bounds (n,n)
- b** : input rank-2 array('F') with bounds (n,n)

**Returns**

- alpha** : rank-1 array('F') with bounds (n)
- beta** : rank-1 array('F') with bounds (n)
- vl** : rank-2 array('F') with bounds (ldvl,n)
- vr** : rank-2 array('F') with bounds (ldvr,n)
- work** : rank-1 array('F') with bounds (MAX(lwork,1))
- info** : int

**Other Parameters**

**compute\_vl** : input int, optional  
Default: 1  
**compute\_vr** : input int, optional  
Default: 1  
**overwrite\_a** : input int, optional  
Default: 0  
**overwrite\_b** : input int, optional  
Default: 0  
**lwork** : input int, optional  
Default: 2\*n

`scipy.linalg.lapack.zggev(a, b[, compute_vl, compute_vr, lwork, overwrite_a, overwrite_b]) =`  
**<fortran object>**

Wrapper for zggev.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**b** : input rank-2 array('D') with bounds (n,n)  
**Returns** **alpha** : rank-1 array('D') with bounds (n)  
**beta** : rank-1 array('D') with bounds (n)  
**vl** : rank-2 array('D') with bounds (ldvl,n)  
**vr** : rank-2 array('D') with bounds (ldvr,n)  
**work** : rank-1 array('D') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**compute\_vl** : input int, optional  
Default: 1  
**compute\_vr** : input int, optional  
Default: 1  
**overwrite\_a** : input int, optional  
Default: 0  
**overwrite\_b** : input int, optional  
Default: 0  
**lwork** : input int, optional  
Default: 2\*n

`scipy.linalg.lapack.chbevd(ab[, compute_v, lower, ldab, lrwork, liwork, overwrite_ab]) =`  
**<fortran object>**

Wrapper for chbevd.

**Parameters** **ab** : input rank-2 array('F') with bounds (ldab,n)  
**Returns** **w** : rank-1 array('f') with bounds (n)  
**z** : rank-2 array('F') with bounds (ldz,ldz)  
**info** : int

**Other Parameters**

**overwrite\_ab** : input int, optional  
Default: 1  
**compute\_v** : input int, optional  
Default: 1  
**lower** : input int, optional  
Default: 0  
**ldab** : input int, optional  
Default: shape(ab,0)  
**lrwork** : input int, optional  
Default: (compute\_v?1+5\*n+2\*n\*n:n)  
**liwork** : input int, optional

Default: (compute\_v?3+5\*n:1)

scipy.linalg.lapack.**zhbevd**(*ab*[, *compute\_v*, *lower*, *ldab*, *lrwork*, *liwork*, *overwrite\_ab* ]) = <fortran object>

Wrapper for zhbevd.

**Parameters** **ab** : input rank-2 array('D') with bounds (ldab,n)  
**Returns** **w** : rank-1 array('d') with bounds (n)  
**z** : rank-2 array('D') with bounds (ldz,ldz)  
**info** : int

**Other Parameters**

**overwrite\_ab** : input int, optional  
 Default: 1  
**compute\_v** : input int, optional  
 Default: 1  
**lower** : input int, optional  
 Default: 0  
**ldab** : input int, optional  
 Default: shape(ab,0)  
**lrwork** : input int, optional  
 Default: (compute\_v?1+5\*n+2\*n\*n:n)  
**liwork** : input int, optional  
 Default: (compute\_v?3+5\*n:1)

scipy.linalg.lapack.**chbevz**(*ab*, *vl*, *vu*, *il*, *iu*[, *ldab*, *compute\_v*, *range*, *lower*, *abstol*, *mmax*, *overwrite\_ab* ]) = <fortran object>

Wrapper for chbevz.

**Parameters** **ab** : input rank-2 array('F') with bounds (ldab,n)  
**vl** : input float  
**vu** : input float  
**il** : input int  
**iu** : input int  
**Returns** **w** : rank-1 array('f') with bounds (n)  
**z** : rank-2 array('F') with bounds (ldz,mmax)  
**m** : int  
**ifail** : rank-1 array('i') with bounds ((compute\_v?n:1))  
**info** : int

**Other Parameters**

**overwrite\_ab** : input int, optional  
 Default: 1  
**ldab** : input int, optional  
 Default: shape(ab,0)  
**compute\_v** : input int, optional  
 Default: 1  
**range** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**abstol** : input float, optional  
 Default: 0.0  
**mmax** : input int, optional  
 Default: (compute\_v?(range==2?(iu-il+1):n):1)

scipy.linalg.lapack.**zhbevz**(*ab*, *vl*, *vu*, *il*, *iu*[, *ldab*, *compute\_v*, *range*, *lower*, *abstol*, *mmax*, *overwrite\_ab* ]) = <fortran object>

Wrapper for zhbevz.

**Parameters** **ab** : input rank-2 array('D') with bounds (ldab,n)  
**vl** : input float  
**vu** : input float  
**il** : input int  
**iu** : input int

**Returns** **w** : rank-1 array('d') with bounds (n)  
**z** : rank-2 array('D') with bounds (ldz,mmax)  
**m** : int  
**ifail** : rank-1 array('i') with bounds ((compute\_v?n:1))  
**info** : int

**Other Parameters**

**overwrite\_ab** : input int, optional  
Default: 1

**ldab** : input int, optional  
Default: shape(ab,0)

**compute\_v** : input int, optional  
Default: 1

**range** : input int, optional  
Default: 0

**lower** : input int, optional  
Default: 0

**abstol** : input float, optional  
Default: 0.0

**mmax** : input int, optional  
Default: (compute\_v?(range==2?(iu-il+1):n):1)

`scipy.linalg.lapack.cheev(a[, compute_v, lower, lwork, overwrite_a]) = <fortran object>`  
Wrapper for cheev.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)

**Returns** **w** : rank-1 array('f') with bounds (n)  
**v** : rank-2 array('F') with bounds (n,n) and a storage  
**info** : int

**Other Parameters**

**compute\_v** : input int, optional  
Default: 1

**lower** : input int, optional  
Default: 0

**overwrite\_a** : input int, optional  
Default: 0

**lwork** : input int, optional  
Default: 2\*n-1

`scipy.linalg.lapack.zheev(a[, compute_v, lower, lwork, overwrite_a]) = <fortran object>`  
Wrapper for zheev.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)

**Returns** **w** : rank-1 array('d') with bounds (n)  
**v** : rank-2 array('D') with bounds (n,n) and a storage  
**info** : int

**Other Parameters**

**compute\_v** : input int, optional  
Default: 1

**lower** : input int, optional  
Default: 0

**overwrite\_a** : input int, optional

Default: 0  
**lwork** : input int, optional  
 Default: 2\*n-1

`scipy.linalg.lapack.cheevd(a[, compute_v, lower, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for cheevd.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)  
**Returns** **w** : rank-1 array('f') with bounds (n)  
**v** : rank-2 array('F') with bounds (n,n) and a storage  
**info** : int

**Other Parameters**  
**compute\_v** : input int, optional  
 Default: 1  
**lower** : input int, optional  
 Default: 0  
**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: (compute\_v?2\*n+n\*n:n+1)

`scipy.linalg.lapack.zheevd(a[, compute_v, lower, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for zheevd.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**Returns** **w** : rank-1 array('d') with bounds (n)  
**v** : rank-2 array('D') with bounds (n,n) and a storage  
**info** : int

**Other Parameters**  
**compute\_v** : input int, optional  
 Default: 1  
**lower** : input int, optional  
 Default: 0  
**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: (compute\_v?2\*n+n\*n:n+1)

`scipy.linalg.lapack.cheevr(a[, jobz, range, uplo, il, iu, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for cheevr.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)  
**Returns** **w** : rank-1 array('f') with bounds (n)  
**z** : rank-2 array('F') with bounds (n,m)  
**info** : int

**Other Parameters**  
**jobz** : input string(len=1), optional  
 Default: 'V'  
**range** : input string(len=1), optional  
 Default: 'A'  
**uplo** : input string(len=1), optional  
 Default: 'L'  
**overwrite\_a** : input int, optional  
 Default: 0  
**il** : input int, optional  
 Default: 1  
**iu** : input int, optional

Default: n  
**lwork** : input int, optional  
 Default: 18\*n

`scipy.linalg.lapack.zheevr(a[, jobz, range, uplo, il, iu, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for zheevr.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**Returns** **w** : rank-1 array('d') with bounds (n)  
**z** : rank-2 array('D') with bounds (n,m)  
**info** : int

**Other Parameters**

**jobz** : input string(len=1), optional  
 Default: 'V'  
**range** : input string(len=1), optional  
 Default: 'A'  
**uplo** : input string(len=1), optional  
 Default: 'L'  
**overwrite\_a** : input int, optional  
 Default: 0  
**il** : input int, optional  
 Default: 1  
**iu** : input int, optional  
 Default: n  
**lwork** : input int, optional  
 Default: 18\*n

`scipy.linalg.lapack.chegv(a, b[, itype, jobz, uplo, overwrite_a, overwrite_b]) = <fortran object>`  
 Wrapper for chegv.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)  
**b** : input rank-2 array('F') with bounds (n,n)  
**Returns** **a** : rank-2 array('F') with bounds (n,n)  
**w** : rank-1 array('f') with bounds (n)  
**info** : int

**Other Parameters**

**itype** : input int, optional  
 Default: 1  
**jobz** : input string(len=1), optional  
 Default: 'V'  
**uplo** : input string(len=1), optional  
 Default: 'L'  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.zhegv(a, b[, itype, jobz, uplo, overwrite_a, overwrite_b]) = <fortran object>`  
 Wrapper for zhegv.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**b** : input rank-2 array('D') with bounds (n,n)  
**Returns** **a** : rank-2 array('D') with bounds (n,n)  
**w** : rank-1 array('d') with bounds (n)  
**info** : int

**Other Parameters**

**itype** : input int, optional

Default: 1  
**jobz** : input string(len=1), optional  
 Default: 'V'  
**uplo** : input string(len=1), optional  
 Default: 'L'  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.chegvd(a, b[, itype, jobz, uplo, lwork, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for `chegvd`.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)  
**b** : input rank-2 array('F') with bounds (n,n)  
**Returns** **a** : rank-2 array('F') with bounds (n,n)  
**w** : rank-1 array('f') with bounds (n)  
**info** : int

**Other Parameters**  
**itype** : input int, optional  
 Default: 1  
**jobz** : input string(len=1), optional  
 Default: 'V'  
**uplo** : input string(len=1), optional  
 Default: 'L'  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 2\*n+n\*n

`scipy.linalg.lapack.zhegvd(a, b[, itype, jobz, uplo, lwork, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for `zhegvd`.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**b** : input rank-2 array('D') with bounds (n,n)  
**Returns** **a** : rank-2 array('D') with bounds (n,n)  
**w** : rank-1 array('d') with bounds (n)  
**info** : int

**Other Parameters**  
**itype** : input int, optional  
 Default: 1  
**jobz** : input string(len=1), optional  
 Default: 'V'  
**uplo** : input string(len=1), optional  
 Default: 'L'  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 2\*n+n\*n

`scipy.linalg.lapack.chegvx(a, b, iu[, itype, jobz, uplo, il, lwork, overwrite_a, overwrite_b]) =`  
**<fortran object>**

Wrapper for `chegvx`.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)  
**b** : input rank-2 array('F') with bounds (n,n)  
**iu** : input int

**Returns** **w** : rank-1 array('F') with bounds (n)  
**z** : rank-2 array('F') with bounds (n,m)  
**ifail** : rank-1 array('i') with bounds (n)  
**info** : int

**Other Parameters**

**itype** : input int, optional  
 Default: 1  
**jobz** : input string(len=1), optional  
 Default: 'V'  
**uplo** : input string(len=1), optional  
 Default: 'L'  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**il** : input int, optional  
 Default: 1  
**lwork** : input int, optional  
 Default: 18\*n-1

`scipy.linalg.lapack.zhegvx(a, b, iu[, itype, jobz, uplo, il, lwork, overwrite_a, overwrite_b]) =`  
**<fortran object>**

Wrapper for `zhegvx`.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**b** : input rank-2 array('D') with bounds (n,n)  
**iu** : input int

**Returns** **w** : rank-1 array('d') with bounds (n)  
**z** : rank-2 array('D') with bounds (n,m)  
**ifail** : rank-1 array('i') with bounds (n)  
**info** : int

**Other Parameters**

**itype** : input int, optional  
 Default: 1  
**jobz** : input string(len=1), optional  
 Default: 'V'  
**uplo** : input string(len=1), optional  
 Default: 'L'  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**il** : input int, optional  
 Default: 1  
**lwork** : input int, optional  
 Default: 18\*n-1

`scipy.linalg.lapack.slarf(v, tau, c, work[, side, incv, overwrite_c]) = <fortran object>`

Wrapper for `slarf`.

**Parameters** **v** : input rank-1 array('f') with bounds (\*)  
**tau** : input float  
**c** : input rank-2 array('f') with bounds (m,n)  
**work** : input rank-1 array('f') with bounds (\*)

**Returns** **c** : rank-2 array('f') with bounds (m,n)

**Other Parameters**  
**side** : input string(len=1), optional  
 Default: 'L'  
**incv** : input int, optional  
 Default: 1  
**overwrite\_c** : input int, optional  
 Default: 0

`scipy.linalg.lapack.dlarf(v, tau, c, work[, side, incv, overwrite_c]) = <fortran object>`  
 Wrapper for dlarf.

**Parameters** **v** : input rank-1 array('d') with bounds (\*)  
**tau** : input float  
**c** : input rank-2 array('d') with bounds (m,n)  
**work** : input rank-1 array('d') with bounds (\*)

**Returns** **c** : rank-2 array('d') with bounds (m,n)

**Other Parameters**  
**side** : input string(len=1), optional  
 Default: 'L'  
**incv** : input int, optional  
 Default: 1  
**overwrite\_c** : input int, optional  
 Default: 0

`scipy.linalg.lapack.clarf(v, tau, c, work[, side, incv, overwrite_c]) = <fortran object>`  
 Wrapper for clarf.

**Parameters** **v** : input rank-1 array('F') with bounds (\*)  
**tau** : input complex  
**c** : input rank-2 array('F') with bounds (m,n)  
**work** : input rank-1 array('F') with bounds (\*)

**Returns** **c** : rank-2 array('F') with bounds (m,n)

**Other Parameters**  
**side** : input string(len=1), optional  
 Default: 'L'  
**incv** : input int, optional  
 Default: 1  
**overwrite\_c** : input int, optional  
 Default: 0

`scipy.linalg.lapack.zlarf(v, tau, c, work[, side, incv, overwrite_c]) = <fortran object>`  
 Wrapper for zlarf.

**Parameters** **v** : input rank-1 array('D') with bounds (\*)  
**tau** : input complex  
**c** : input rank-2 array('D') with bounds (m,n)  
**work** : input rank-1 array('D') with bounds (\*)

**Returns** **c** : rank-2 array('D') with bounds (m,n)

**Other Parameters**  
**side** : input string(len=1), optional  
 Default: 'L'  
**incv** : input int, optional

Default: 1  
**overwrite\_c** : input int, optional  
 Default: 0

`scipy.linalg.lapack.slarfg(n, alpha, x[, incx, overwrite_x]) = <fortran object>`  
 Wrapper for slarfg.

**Parameters** **n** : input int  
**alpha** : input float  
**x** : input rank-1 array('f') with bounds (\*)

**Returns** **alpha** : float  
**x** : rank-1 array('f') with bounds (\*)  
**tau** : float

**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1

`scipy.linalg.lapack.dlarfg(n, alpha, x[, incx, overwrite_x]) = <fortran object>`  
 Wrapper for dlarfg.

**Parameters** **n** : input int  
**alpha** : input float  
**x** : input rank-1 array('d') with bounds (\*)

**Returns** **alpha** : float  
**x** : rank-1 array('d') with bounds (\*)  
**tau** : float

**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1

`scipy.linalg.lapack.clarfg(n, alpha, x[, incx, overwrite_x]) = <fortran object>`  
 Wrapper for clarfg.

**Parameters** **n** : input int  
**alpha** : input complex  
**x** : input rank-1 array('F') with bounds (\*)

**Returns** **alpha** : complex  
**x** : rank-1 array('F') with bounds (\*)  
**tau** : complex

**Other Parameters**  
**overwrite\_x** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1

`scipy.linalg.lapack.zlarfg(n, alpha, x[, incx, overwrite_x]) = <fortran object>`  
 Wrapper for zlarfg.

**Parameters** **n** : input int  
**alpha** : input complex  
**x** : input rank-1 array('D') with bounds (\*)

**Returns** **alpha** : complex  
**x** : rank-1 array('D') with bounds (\*)  
**tau** : complex

*Other Parameters*

**overwrite\_x** : input int, optional  
 Default: 0  
**incx** : input int, optional  
 Default: 1

`scipy.linalg.lapack.slartg(f, g) = <fortran object>`  
 Wrapper for slartg.

**Parameters** **f** : input float  
**g** : input float  
**Returns** **cs** : float  
**sn** : float  
**r** : float

`scipy.linalg.lapack.dlartg(f, g) = <fortran object>`  
 Wrapper for dlartg.

**Parameters** **f** : input float  
**g** : input float  
**Returns** **cs** : float  
**sn** : float  
**r** : float

`scipy.linalg.lapack.clartg(f, g) = <fortran object>`  
 Wrapper for clartg.

**Parameters** **f** : input complex  
**g** : input complex  
**Returns** **cs** : float  
**sn** : complex  
**r** : complex

`scipy.linalg.lapack.zlartg(f, g) = <fortran object>`  
 Wrapper for zlartg.

**Parameters** **f** : input complex  
**g** : input complex  
**Returns** **cs** : float  
**sn** : complex  
**r** : complex

`scipy.linalg.lapack.slasd4(i, d, z[, rho]) = <fortran object>`  
 Wrapper for slasd4.

**Parameters** **i** : input int  
**d** : input rank-1 array('f') with bounds (n)  
**z** : input rank-1 array('f') with bounds (n)  
**Returns** **delta** : rank-1 array('f') with bounds (n)  
**sigma** : float  
**work** : rank-1 array('f') with bounds (n)  
**info** : int

*Other Parameters*

**rho** : input float, optional  
 Default: 1.0

`scipy.linalg.lapack.dlasd4(i, d, z[, rho]) = <fortran object>`  
 Wrapper for dlasd4.

**Parameters** **i** : input int  
**d** : input rank-1 array('d') with bounds (n)  
**z** : input rank-1 array('d') with bounds (n)

**Returns** **delta** : rank-1 array('d') with bounds (n)  
**sigma** : float  
**work** : rank-1 array('d') with bounds (n)  
**info** : int

**Other Parameters**  
**rho** : input float, optional  
Default: 1.0

`scipy.linalg.lapack.slaswp(a, piv[, k1, k2, off, inc, overwrite_a]) = <fortran object>`  
Wrapper for `slaswp`.

**Parameters** **a** : input rank-2 array('f') with bounds (nrows,n)  
**piv** : input rank-1 array('i') with bounds (\*)

**Returns** **a** : rank-2 array('f') with bounds (nrows,n)

**Other Parameters**  
**overwrite\_a** : input int, optional  
Default: 0  
**k1** : input int, optional  
Default: 0  
**k2** : input int, optional  
Default: len(piv)-1  
**off** : input int, optional  
Default: 0  
**inc** : input int, optional  
Default: 1

`scipy.linalg.lapack.dlaswp(a, piv[, k1, k2, off, inc, overwrite_a]) = <fortran object>`  
Wrapper for `dlaswp`.

**Parameters** **a** : input rank-2 array('d') with bounds (nrows,n)  
**piv** : input rank-1 array('i') with bounds (\*)

**Returns** **a** : rank-2 array('d') with bounds (nrows,n)

**Other Parameters**  
**overwrite\_a** : input int, optional  
Default: 0  
**k1** : input int, optional  
Default: 0  
**k2** : input int, optional  
Default: len(piv)-1  
**off** : input int, optional  
Default: 0  
**inc** : input int, optional  
Default: 1

`scipy.linalg.lapack.claswp(a, piv[, k1, k2, off, inc, overwrite_a]) = <fortran object>`  
Wrapper for `claswp`.

**Parameters** **a** : input rank-2 array('F') with bounds (nrows,n)  
**piv** : input rank-1 array('i') with bounds (\*)

**Returns** **a** : rank-2 array('F') with bounds (nrows,n)

**Other Parameters**  
**overwrite\_a** : input int, optional  
Default: 0  
**k1** : input int, optional

Default: 0  
**k2** : input int, optional  
 Default: len(piv)-1  
**off** : input int, optional  
 Default: 0  
**inc** : input int, optional  
 Default: 1

`scipy.linalg.lapack.zlaswp(a, piv[, k1, k2, off, inc, overwrite_a]) = <fortran object>`  
 Wrapper for zlaswp.

**Parameters** **a** : input rank-2 array('D') with bounds (nrows,n)  
**piv** : input rank-1 array('i') with bounds (\*)  
**Returns** **a** : rank-2 array('D') with bounds (nrows,n)  
**Other Parameters**  
**overwrite\_a** : input int, optional  
 Default: 0  
**k1** : input int, optional  
 Default: 0  
**k2** : input int, optional  
 Default: len(piv)-1  
**off** : input int, optional  
 Default: 0  
**inc** : input int, optional  
 Default: 1

`scipy.linalg.lapack.slauum(c[, lower, overwrite_c]) = <fortran object>`  
 Wrapper for slauum.

**Parameters** **c** : input rank-2 array('f') with bounds (n,n)  
**Returns** **a** : rank-2 array('f') with bounds (n,n) and c storage  
**info** : int  
**Other Parameters**  
**overwrite\_c** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.dlauum(c[, lower, overwrite_c]) = <fortran object>`  
 Wrapper for dlauum.

**Parameters** **c** : input rank-2 array('d') with bounds (n,n)  
**Returns** **a** : rank-2 array('d') with bounds (n,n) and c storage  
**info** : int  
**Other Parameters**  
**overwrite\_c** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.clauum(c[, lower, overwrite_c]) = <fortran object>`  
 Wrapper for clauum.

**Parameters** **c** : input rank-2 array('F') with bounds (n,n)  
**Returns** **a** : rank-2 array('F') with bounds (n,n) and c storage  
**info** : int  
**Other Parameters**  
**overwrite\_c** : input int, optional

Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.zlauum(c[, lower, overwrite_c]) = <fortran object>`  
 Wrapper for zlauum.

**Parameters** **c** : input rank-2 array('D') with bounds (n,n)  
**Returns** **a** : rank-2 array('D') with bounds (n,n) and c storage  
**info** : int  
**Other Parameters**  
**overwrite\_c** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.spbsv(ab, b[, lower, ldab, overwrite_ab, overwrite_b]) = <fortran object>`  
 Wrapper for spbsv.

**Parameters** **ab** : input rank-2 array('f') with bounds (ldab,n)  
**b** : input rank-2 array('f') with bounds (ldb,nrhs)  
**Returns** **c** : rank-2 array('f') with bounds (ldab,n) and ab storage  
**x** : rank-2 array('f') with bounds (ldb,nrhs) and b storage  
**info** : int  
**Other Parameters**  
**lower** : input int, optional  
 Default: 0  
**overwrite\_ab** : input int, optional  
 Default: 0  
**ldab** : input int, optional  
 Default: shape(ab,0)  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.dpbsv(ab, b[, lower, ldab, overwrite_ab, overwrite_b]) = <fortran object>`  
 Wrapper for dpbsv.

**Parameters** **ab** : input rank-2 array('d') with bounds (ldab,n)  
**b** : input rank-2 array('d') with bounds (ldb,nrhs)  
**Returns** **c** : rank-2 array('d') with bounds (ldab,n) and ab storage  
**x** : rank-2 array('d') with bounds (ldb,nrhs) and b storage  
**info** : int  
**Other Parameters**  
**lower** : input int, optional  
 Default: 0  
**overwrite\_ab** : input int, optional  
 Default: 0  
**ldab** : input int, optional  
 Default: shape(ab,0)  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.cpbsv(ab, b[, lower, ldab, overwrite_ab, overwrite_b]) = <fortran object>`  
 Wrapper for cpbsv.

**Parameters** **ab** : input rank-2 array('F') with bounds (ldab,n)  
**b** : input rank-2 array('F') with bounds (ldb,nrhs)

**Returns** **c** : rank-2 array('F') with bounds (ldab,n) and ab storage  
**x** : rank-2 array('F') with bounds (ldb,nrhs) and b storage  
**info** : int

**Other Parameters**

**lower** : input int, optional  
 Default: 0  
**overwrite\_ab** : input int, optional  
 Default: 0  
**ldab** : input int, optional  
 Default: shape(ab,0)  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.zpbsv(ab, b[, lower, ldab, overwrite_ab, overwrite_b]) = <fortran object>`  
 Wrapper for zpbsv.

**Parameters** **ab** : input rank-2 array('D') with bounds (ldab,n)

**b** : input rank-2 array('D') with bounds (ldb,nrhs)

**Returns** **c** : rank-2 array('D') with bounds (ldab,n) and ab storage  
**x** : rank-2 array('D') with bounds (ldb,nrhs) and b storage  
**info** : int

**Other Parameters**

**lower** : input int, optional  
 Default: 0  
**overwrite\_ab** : input int, optional  
 Default: 0  
**ldab** : input int, optional  
 Default: shape(ab,0)  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.spbtrf(ab[, lower, ldab, overwrite_ab]) = <fortran object>`  
 Wrapper for spbtrf.

**Parameters** **ab** : input rank-2 array('f') with bounds (ldab,n)

**Returns** **c** : rank-2 array('f') with bounds (ldab,n) and ab storage  
**info** : int

**Other Parameters**

**lower** : input int, optional  
 Default: 0  
**overwrite\_ab** : input int, optional  
 Default: 0  
**ldab** : input int, optional  
 Default: shape(ab,0)

`scipy.linalg.lapack.dpbtrf(ab[, lower, ldab, overwrite_ab]) = <fortran object>`  
 Wrapper for dpbtrf.

**Parameters** **ab** : input rank-2 array('d') with bounds (ldab,n)

**Returns** **c** : rank-2 array('d') with bounds (ldab,n) and ab storage  
**info** : int

**Other Parameters**

**lower** : input int, optional  
 Default: 0  
**overwrite\_ab** : input int, optional  
 Default: 0  
**ldab** : input int, optional

Default: shape(ab,0)

`scipy.linalg.lapack.cpbtrfs(ab[, lower, ldab, overwrite_ab]) = <fortran object>`  
 Wrapper for `cpbtrfs`.

**Parameters** **ab** : input rank-2 array('F') with bounds (ldab,n)  
**Returns** **c** : rank-2 array('F') with bounds (ldab,n) and ab storage  
**info** : int  
**Other Parameters**  
**lower** : input int, optional  
 Default: 0  
**overwrite\_ab** : input int, optional  
 Default: 0  
**ldab** : input int, optional  
 Default: shape(ab,0)

`scipy.linalg.lapack.zpbtrfs(ab[, lower, ldab, overwrite_ab]) = <fortran object>`  
 Wrapper for `zpbtrfs`.

**Parameters** **ab** : input rank-2 array('D') with bounds (ldab,n)  
**Returns** **c** : rank-2 array('D') with bounds (ldab,n) and ab storage  
**info** : int  
**Other Parameters**  
**lower** : input int, optional  
 Default: 0  
**overwrite\_ab** : input int, optional  
 Default: 0  
**ldab** : input int, optional  
 Default: shape(ab,0)

`scipy.linalg.lapack.spbtrs(ab, b[, lower, ldab, overwrite_b]) = <fortran object>`  
 Wrapper for `spbtrs`.

**Parameters** **ab** : input rank-2 array('f') with bounds (ldab,n)  
**b** : input rank-2 array('f') with bounds (ldb,nrhs)  
**Returns** **x** : rank-2 array('f') with bounds (ldb,nrhs) and b storage  
**info** : int  
**Other Parameters**  
**lower** : input int, optional  
 Default: 0  
**ldab** : input int, optional  
 Default: shape(ab,0)  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.dpbtrs(ab, b[, lower, ldab, overwrite_b]) = <fortran object>`  
 Wrapper for `dpbtrs`.

**Parameters** **ab** : input rank-2 array('d') with bounds (ldab,n)  
**b** : input rank-2 array('d') with bounds (ldb,nrhs)  
**Returns** **x** : rank-2 array('d') with bounds (ldb,nrhs) and b storage  
**info** : int  
**Other Parameters**  
**lower** : input int, optional  
 Default: 0  
**ldab** : input int, optional  
 Default: shape(ab,0)  
**overwrite\_b** : input int, optional

Default: 0

`scipy.linalg.lapack.cpbtrs` (*ab*, *b*[, *lower*, *ldab*, *overwrite\_b*]) = <fortran object>  
 Wrapper for `cpbtrs`.

**Parameters** **ab** : input rank-2 array('F') with bounds (ldab,n)  
**b** : input rank-2 array('F') with bounds (ldb,nrhs)  
**Returns** **x** : rank-2 array('F') with bounds (ldb,nrhs) and b storage  
**info** : int  
**Other Parameters**  
**lower** : input int, optional  
 Default: 0  
**ldab** : input int, optional  
 Default: shape(ab,0)  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.zpbtrs` (*ab*, *b*[, *lower*, *ldab*, *overwrite\_b*]) = <fortran object>  
 Wrapper for `zpbtrs`.

**Parameters** **ab** : input rank-2 array('D') with bounds (ldab,n)  
**b** : input rank-2 array('D') with bounds (ldb,nrhs)  
**Returns** **x** : rank-2 array('D') with bounds (ldb,nrhs) and b storage  
**info** : int  
**Other Parameters**  
**lower** : input int, optional  
 Default: 0  
**ldab** : input int, optional  
 Default: shape(ab,0)  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.sposv` (*a*, *b*[, *lower*, *overwrite\_a*, *overwrite\_b*]) = <fortran object>  
 Wrapper for `sposv`.

**Parameters** **a** : input rank-2 array('f') with bounds (n,n)  
**b** : input rank-2 array('f') with bounds (n,nrhs)  
**Returns** **c** : rank-2 array('f') with bounds (n,n) and a storage  
**x** : rank-2 array('f') with bounds (n,nrhs) and b storage  
**info** : int  
**Other Parameters**  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.dposv` (*a*, *b*[, *lower*, *overwrite\_a*, *overwrite\_b*]) = <fortran object>  
 Wrapper for `dposv`.

**Parameters** **a** : input rank-2 array('d') with bounds (n,n)  
**b** : input rank-2 array('d') with bounds (n,nrhs)  
**Returns** **c** : rank-2 array('d') with bounds (n,n) and a storage  
**x** : rank-2 array('d') with bounds (n,nrhs) and b storage  
**info** : int  
**Other Parameters**  
**overwrite\_a** : input int, optional

Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.cposv(a, b[, lower, overwrite_a, overwrite_b]) = <fortran object>`  
 Wrapper for `cposv`.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)  
**b** : input rank-2 array('F') with bounds (n,nrhs)  
**Returns** **c** : rank-2 array('F') with bounds (n,n) and a storage  
**x** : rank-2 array('F') with bounds (n,nrhs) and b storage  
**info** : int  
**Other Parameters**  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.zposv(a, b[, lower, overwrite_a, overwrite_b]) = <fortran object>`  
 Wrapper for `zposv`.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**b** : input rank-2 array('D') with bounds (n,nrhs)  
**Returns** **c** : rank-2 array('D') with bounds (n,n) and a storage  
**x** : rank-2 array('D') with bounds (n,nrhs) and b storage  
**info** : int  
**Other Parameters**  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.sposvx(a, b[, fact, af, equed, s, lower, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for `sposvx`.

**Parameters** **a** : input rank-2 array('f') with bounds (n,n)  
**b** : input rank-2 array('f') with bounds (n,nrhs)  
**Returns** **a\_s** : rank-2 array('f') with bounds (n,n) and a storage  
**lu** : rank-2 array('f') with bounds (n,n) and af storage  
**equed** : string(len=1)  
**s** : rank-1 array('f') with bounds (n)  
**b\_s** : rank-2 array('f') with bounds (n,nrhs) and b storage  
**x** : rank-2 array('f') with bounds (n,nrhs)  
**rcond** : float  
**ferr** : rank-1 array('f') with bounds (nrhs)  
**berr** : rank-1 array('f') with bounds (nrhs)  
**info** : int  
**Other Parameters**  
**fact** : input string(len=1), optional  
 Default: 'E'

**overwrite\_a** : input int, optional  
 Default: 0  
**af** : input rank-2 array('f') with bounds (n,n)  
**equed** : input string(len=1), optional  
 Default: 'Y'  
**s** : input rank-1 array('f') with bounds (n)  
**overwrite\_b** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.dposvx(a, b[, fact, af, equed, s, lower, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for `dposvx`.

**Parameters** **a** : input rank-2 array('d') with bounds (n,n)  
**b** : input rank-2 array('d') with bounds (n,nrhs)  
**Returns** **a\_s** : rank-2 array('d') with bounds (n,n) and a storage  
**lu** : rank-2 array('d') with bounds (n,n) and af storage  
**equed** : string(len=1)  
**s** : rank-1 array('d') with bounds (n)  
**b\_s** : rank-2 array('d') with bounds (n,nrhs) and b storage  
**x** : rank-2 array('d') with bounds (n,nrhs)  
**rcond** : float  
**ferr** : rank-1 array('d') with bounds (nrhs)  
**berr** : rank-1 array('d') with bounds (nrhs)  
**info** : int

**Other Parameters**

**fact** : input string(len=1), optional  
 Default: 'E'  
**overwrite\_a** : input int, optional  
 Default: 0  
**af** : input rank-2 array('d') with bounds (n,n)  
**equed** : input string(len=1), optional  
 Default: 'Y'  
**s** : input rank-1 array('d') with bounds (n)  
**overwrite\_b** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.cposvx(a, b[, fact, af, equed, s, lower, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for `cpovsx`.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)  
**b** : input rank-2 array('F') with bounds (n,nrhs)  
**Returns** **a\_s** : rank-2 array('F') with bounds (n,n) and a storage  
**lu** : rank-2 array('F') with bounds (n,n) and af storage  
**equed** : string(len=1)  
**s** : rank-1 array('f') with bounds (n)  
**b\_s** : rank-2 array('F') with bounds (n,nrhs) and b storage  
**x** : rank-2 array('F') with bounds (n,nrhs)  
**rcond** : float  
**ferr** : rank-1 array('f') with bounds (nrhs)  
**berr** : rank-1 array('f') with bounds (nrhs)

**info** : int

**Other Parameters**

**fact** : input string(len=1), optional

Default: 'E'

**overwrite\_a** : input int, optional

Default: 0

**af** : input rank-2 array('F') with bounds (n,n)

**equed** : input string(len=1), optional

Default: 'Y'

**s** : input rank-1 array('f') with bounds (n)

**overwrite\_b** : input int, optional

Default: 0

**lower** : input int, optional

Default: 0

`scipy.linalg.lapack.zposvx(a, b[, fact, af, equed, s, lower, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for zposvx.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)

**b** : input rank-2 array('D') with bounds (n,nrhs)

**Returns** **a\_s** : rank-2 array('D') with bounds (n,n) and a storage

**lu** : rank-2 array('D') with bounds (n,n) and af storage

**equed** : string(len=1)

**s** : rank-1 array('d') with bounds (n)

**b\_s** : rank-2 array('D') with bounds (n,nrhs) and b storage

**x** : rank-2 array('D') with bounds (n,nrhs)

**rcond** : float

**ferr** : rank-1 array('d') with bounds (nrhs)

**berr** : rank-1 array('d') with bounds (nrhs)

**info** : int

**Other Parameters**

**fact** : input string(len=1), optional

Default: 'E'

**overwrite\_a** : input int, optional

Default: 0

**af** : input rank-2 array('D') with bounds (n,n)

**equed** : input string(len=1), optional

Default: 'Y'

**s** : input rank-1 array('d') with bounds (n)

**overwrite\_b** : input int, optional

Default: 0

**lower** : input int, optional

Default: 0

`scipy.linalg.lapack.spocon(a, anorm[, uplo]) = <fortran object>`

Wrapper for spocon.

**Parameters** **a** : input rank-2 array('f') with bounds (n,n)

**anorm** : input float

**Returns** **rcond** : float

**info** : int

**Other Parameters**

**uplo** : input string(len=1), optional

Default: 'U'

`scipy.linalg.lapack.dpocon(a, anorm[, uplo]) = <fortran object>`  
 Wrapper for `dpocon`.

**Parameters** **a** : input rank-2 array('d') with bounds (n,n)  
**anorm** : input float  
**Returns** **rcond** : float  
**info** : int  
**Other Parameters**  
**uplo** : input string(len=1), optional  
 Default: 'U'

`scipy.linalg.lapack.cpocon(a, anorm[, uplo]) = <fortran object>`  
 Wrapper for `cpocon`.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)  
**anorm** : input float  
**Returns** **rcond** : float  
**info** : int  
**Other Parameters**  
**uplo** : input string(len=1), optional  
 Default: 'U'

`scipy.linalg.lapack.zpocon(a, anorm[, uplo]) = <fortran object>`  
 Wrapper for `zpocon`.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**anorm** : input float  
**Returns** **rcond** : float  
**info** : int  
**Other Parameters**  
**uplo** : input string(len=1), optional  
 Default: 'U'

`scipy.linalg.lapack.spotrf(a[, lower, clean, overwrite_a]) = <fortran object>`  
 Wrapper for `spotrf`.

**Parameters** **a** : input rank-2 array('f') with bounds (n,n)  
**Returns** **c** : rank-2 array('f') with bounds (n,n) and a storage  
**info** : int  
**Other Parameters**  
**overwrite\_a** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**clean** : input int, optional  
 Default: 1

`scipy.linalg.lapack.dpotrf(a[, lower, clean, overwrite_a]) = <fortran object>`  
 Wrapper for `dpotrf`.

**Parameters** **a** : input rank-2 array('d') with bounds (n,n)  
**Returns** **c** : rank-2 array('d') with bounds (n,n) and a storage  
**info** : int  
**Other Parameters**  
**overwrite\_a** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

**clean** : input int, optional  
Default: 1

`scipy.linalg.lapack.cpotrf(a[, lower, clean, overwrite_a]) = <fortran object>`

Wrapper for `cpotrf`.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)  
**Returns** **c** : rank-2 array('F') with bounds (n,n) and a storage  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
Default: 0  
**lower** : input int, optional  
Default: 0  
**clean** : input int, optional  
Default: 1

`scipy.linalg.lapack.zpotrf(a[, lower, clean, overwrite_a]) = <fortran object>`

Wrapper for `zpotrf`.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**Returns** **c** : rank-2 array('D') with bounds (n,n) and a storage  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
Default: 0  
**lower** : input int, optional  
Default: 0  
**clean** : input int, optional  
Default: 1

`scipy.linalg.lapack.spotri(c[, lower, overwrite_c]) = <fortran object>`

Wrapper for `spotri`.

**Parameters** **c** : input rank-2 array('f') with bounds (n,n)  
**Returns** **inv\_a** : rank-2 array('f') with bounds (n,n) and c storage  
**info** : int

**Other Parameters**

**overwrite\_c** : input int, optional  
Default: 0  
**lower** : input int, optional  
Default: 0

`scipy.linalg.lapack.dpotri(c[, lower, overwrite_c]) = <fortran object>`

Wrapper for `dpotri`.

**Parameters** **c** : input rank-2 array('d') with bounds (n,n)  
**Returns** **inv\_a** : rank-2 array('d') with bounds (n,n) and c storage  
**info** : int

**Other Parameters**

**overwrite\_c** : input int, optional  
Default: 0  
**lower** : input int, optional  
Default: 0

`scipy.linalg.lapack.cpotri(c[, lower, overwrite_c]) = <fortran object>`

Wrapper for `cpotri`.

**Parameters** **c** : input rank-2 array('F') with bounds (n,n)

**Returns** **inv\_a** : rank-2 array('F') with bounds (n,n) and c storage  
**info** : int

**Other Parameters**

**overwrite\_c** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.zpotri(c[, lower, overwrite_c]) = <fortran object>`  
 Wrapper for `zpotri`.

**Parameters** **c** : input rank-2 array('D') with bounds (n,n)

**Returns** **inv\_a** : rank-2 array('D') with bounds (n,n) and c storage  
**info** : int

**Other Parameters**

**overwrite\_c** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.spotrs(c, b[, lower, overwrite_b]) = <fortran object>`  
 Wrapper for `spotrs`.

**Parameters** **c** : input rank-2 array('f') with bounds (n,n)

**b** : input rank-2 array('f') with bounds (n,nrhs)

**Returns** **x** : rank-2 array('f') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**

**overwrite\_b** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.dpotrs(c, b[, lower, overwrite_b]) = <fortran object>`  
 Wrapper for `dpotrs`.

**Parameters** **c** : input rank-2 array('d') with bounds (n,n)

**b** : input rank-2 array('d') with bounds (n,nrhs)

**Returns** **x** : rank-2 array('d') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**

**overwrite\_b** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.cpotrs(c, b[, lower, overwrite_b]) = <fortran object>`  
 Wrapper for `cpotrs`.

**Parameters** **c** : input rank-2 array('F') with bounds (n,n)

**b** : input rank-2 array('F') with bounds (n,nrhs)

**Returns** **x** : rank-2 array('F') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**

**overwrite\_b** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0

`scipy.linalg.lapack.zpotrs(c, b[, lower, overwrite_b]) = <fortran object>`  
 Wrapper for `zpotrs`.

**Parameters** `c` : input rank-2 array('D') with bounds (n,n)  
`b` : input rank-2 array('D') with bounds (n,nrhs)  
**Returns** `x` : rank-2 array('D') with bounds (n,nrhs) and b storage  
`info` : int  
**Other Parameters**  
`overwrite_b` : input int, optional  
 Default: 0  
`lower` : input int, optional  
 Default: 0

`scipy.linalg.lapack.crot(x, y, c, s[, n, offx, incx, offy, incy, overwrite_x, overwrite_y]) = <fortran object>`

Wrapper for `crot`.

**Parameters** `x` : input rank-1 array('F') with bounds (\*)  
`y` : input rank-1 array('F') with bounds (\*)  
`c` : input float  
`s` : input complex  
**Returns** `x` : rank-1 array('F') with bounds (\*)  
`y` : rank-1 array('F') with bounds (\*)  
**Other Parameters**  
`n` : input int, optional  
 Default: (len(x)-1-offx)/abs(incx)+1  
`overwrite_x` : input int, optional  
 Default: 0  
`offx` : input int, optional  
 Default: 0  
`incx` : input int, optional  
 Default: 1  
`overwrite_y` : input int, optional  
 Default: 0  
`offy` : input int, optional  
 Default: 0  
`incy` : input int, optional  
 Default: 1

`scipy.linalg.lapack.zrot(x, y, c, s[, n, offx, incx, offy, incy, overwrite_x, overwrite_y]) = <fortran object>`

Wrapper for `zrot`.

**Parameters** `x` : input rank-1 array('D') with bounds (\*)  
`y` : input rank-1 array('D') with bounds (\*)  
`c` : input float  
`s` : input complex  
**Returns** `x` : rank-1 array('D') with bounds (\*)  
`y` : rank-1 array('D') with bounds (\*)  
**Other Parameters**  
`n` : input int, optional  
 Default: (len(x)-1-offx)/abs(incx)+1  
`overwrite_x` : input int, optional  
 Default: 0  
`offx` : input int, optional  
 Default: 0  
`incx` : input int, optional

Default: 1  
**overwrite\_y** : input int, optional  
 Default: 0  
**offy** : input int, optional  
 Default: 0  
**incy** : input int, optional  
 Default: 1

`scipy.linalg.lapack.strsyl(a, b, c[, trana, tranb, isgn, overwrite_c]) = <fortran object>`  
 Wrapper for `strsyl`.

**Parameters** **a** : input rank-2 array('f') with bounds (m,m)  
**b** : input rank-2 array('f') with bounds (n,n)  
**c** : input rank-2 array('f') with bounds (m,n)

**Returns** **x** : rank-2 array('f') with bounds (m,n) and c storage  
**scale** : float  
**info** : int

**Other Parameters**  
**trana** : input string(len=1), optional  
 Default: 'N'  
**tranb** : input string(len=1), optional  
 Default: 'N'  
**isgn** : input int, optional  
 Default: 1  
**overwrite\_c** : input int, optional  
 Default: 0

`scipy.linalg.lapack.dtrsyl(a, b, c[, trana, tranb, isgn, overwrite_c]) = <fortran object>`  
 Wrapper for `dtrsyl`.

**Parameters** **a** : input rank-2 array('d') with bounds (m,m)  
**b** : input rank-2 array('d') with bounds (n,n)  
**c** : input rank-2 array('d') with bounds (m,n)

**Returns** **x** : rank-2 array('d') with bounds (m,n) and c storage  
**scale** : float  
**info** : int

**Other Parameters**  
**trana** : input string(len=1), optional  
 Default: 'N'  
**tranb** : input string(len=1), optional  
 Default: 'N'  
**isgn** : input int, optional  
 Default: 1  
**overwrite\_c** : input int, optional  
 Default: 0

`scipy.linalg.lapack.ctrsyl(a, b, c[, trana, tranb, isgn, overwrite_c]) = <fortran object>`  
 Wrapper for `ctrsyl`.

**Parameters** **a** : input rank-2 array('F') with bounds (m,m)  
**b** : input rank-2 array('F') with bounds (n,n)  
**c** : input rank-2 array('F') with bounds (m,n)

**Returns** **x** : rank-2 array('F') with bounds (m,n) and c storage  
**scale** : float  
**info** : int

**Other Parameters**  
**trana** : input string(len=1), optional

Default: 'N'  
**tranb** : input string(len=1), optional  
 Default: 'N'  
**isgn** : input int, optional  
 Default: 1  
**overwrite\_c** : input int, optional  
 Default: 0

`scipy.linalg.lapack.ztrsyl(a, b, c[, trana, tranb, isgn, overwrite_c]) = <fortran object>`  
 Wrapper for ztrsyl.

**Parameters** **a** : input rank-2 array('D') with bounds (m,m)  
**b** : input rank-2 array('D') with bounds (n,n)  
**c** : input rank-2 array('D') with bounds (m,n)  
**Returns** **x** : rank-2 array('D') with bounds (m,n) and c storage  
**scale** : float  
**info** : int

**Other Parameters**  
**trana** : input string(len=1), optional  
 Default: 'N'  
**tranb** : input string(len=1), optional  
 Default: 'N'  
**isgn** : input int, optional  
 Default: 1  
**overwrite\_c** : input int, optional  
 Default: 0

`scipy.linalg.lapack.strtri(c[, lower, unitdiag, overwrite_c]) = <fortran object>`  
 Wrapper for strtri.

**Parameters** **c** : input rank-2 array('f') with bounds (n,n)  
**Returns** **inv\_c** : rank-2 array('f') with bounds (n,n) and c storage  
**info** : int

**Other Parameters**  
**overwrite\_c** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**unitdiag** : input int, optional  
 Default: 0

`scipy.linalg.lapack.dtrtri(c[, lower, unitdiag, overwrite_c]) = <fortran object>`  
 Wrapper for dtrtri.

**Parameters** **c** : input rank-2 array('d') with bounds (n,n)  
**Returns** **inv\_c** : rank-2 array('d') with bounds (n,n) and c storage  
**info** : int

**Other Parameters**  
**overwrite\_c** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**unitdiag** : input int, optional  
 Default: 0

`scipy.linalg.lapack.ctrtri(c[, lower, unitdiag, overwrite_c]) = <fortran object>`  
 Wrapper for ctrtri.

**Parameters** `c` : input rank-2 array('F') with bounds (n,n)  
**Returns** `inv_c` : rank-2 array('F') with bounds (n,n) and c storage  
`info` : int

**Other Parameters**  
`overwrite_c` : input int, optional  
 Default: 0  
`lower` : input int, optional  
 Default: 0  
`unitdiag` : input int, optional  
 Default: 0

`scipy.linalg.lapack.ztrtri(c[, lower, unitdiag, overwrite_c]) = <fortran object>`  
 Wrapper for `ztrtri`.

**Parameters** `c` : input rank-2 array('D') with bounds (n,n)  
**Returns** `inv_c` : rank-2 array('D') with bounds (n,n) and c storage  
`info` : int

**Other Parameters**  
`overwrite_c` : input int, optional  
 Default: 0  
`lower` : input int, optional  
 Default: 0  
`unitdiag` : input int, optional  
 Default: 0

`scipy.linalg.lapack.strtrs(a, b[, lower, trans, unitdiag, lda, overwrite_b]) = <fortran object>`  
 Wrapper for `strtrs`.

**Parameters** `a` : input rank-2 array('f') with bounds (lda,n)  
`b` : input rank-2 array('f') with bounds (ldb,nrhs)  
**Returns** `x` : rank-2 array('f') with bounds (ldb,nrhs) and b storage  
`info` : int

**Other Parameters**  
`lower` : input int, optional  
 Default: 0  
`trans` : input int, optional  
 Default: 0  
`unitdiag` : input int, optional  
 Default: 0  
`lda` : input int, optional  
 Default: `shape(a,0)`  
`overwrite_b` : input int, optional  
 Default: 0

`scipy.linalg.lapack.dtrtrs(a, b[, lower, trans, unitdiag, lda, overwrite_b]) = <fortran object>`  
 Wrapper for `dtrtrs`.

**Parameters** `a` : input rank-2 array('d') with bounds (lda,n)  
`b` : input rank-2 array('d') with bounds (ldb,nrhs)  
**Returns** `x` : rank-2 array('d') with bounds (ldb,nrhs) and b storage  
`info` : int

**Other Parameters**  
`lower` : input int, optional  
 Default: 0  
`trans` : input int, optional  
 Default: 0  
`unitdiag` : input int, optional

Default: 0  
**lda** : input int, optional  
 Default: shape(a,0)  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.ctrtrs(a, b[, lower, trans, unitdiag, lda, overwrite_b]) = <fortran object>`  
 Wrapper for `ctrtrs`.

**Parameters** **a** : input rank-2 array('F') with bounds (lda,n)  
**b** : input rank-2 array('F') with bounds (ldb,nrhs)  
**Returns** **x** : rank-2 array('F') with bounds (ldb,nrhs) and b storage  
**info** : int  
**Other Parameters**  
**lower** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**unitdiag** : input int, optional  
 Default: 0  
**lda** : input int, optional  
 Default: shape(a,0)  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.ztrtrs(a, b[, lower, trans, unitdiag, lda, overwrite_b]) = <fortran object>`  
 Wrapper for `ztrtrs`.

**Parameters** **a** : input rank-2 array('D') with bounds (lda,n)  
**b** : input rank-2 array('D') with bounds (ldb,nrhs)  
**Returns** **x** : rank-2 array('D') with bounds (ldb,nrhs) and b storage  
**info** : int  
**Other Parameters**  
**lower** : input int, optional  
 Default: 0  
**trans** : input int, optional  
 Default: 0  
**unitdiag** : input int, optional  
 Default: 0  
**lda** : input int, optional  
 Default: shape(a,0)  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.cunghr(a, tau[, lo, hi, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for `cunghr`.

**Parameters** **a** : input rank-2 array('F') with bounds (n,n)  
**tau** : input rank-1 array('F') with bounds (n - 1)  
**Returns** **ht** : rank-2 array('F') with bounds (n,n) and a storage  
**info** : int  
**Other Parameters**  
**lo** : input int, optional  
 Default: 0  
**hi** : input int, optional  
 Default: n-1  
**overwrite\_a** : input int, optional

Default: 0  
**lwork** : input int, optional  
 Default: hi-lo

`scipy.linalg.lapack.zunghr(a, tau[, lo, hi, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for zunghr.

**Parameters** **a** : input rank-2 array('D') with bounds (n,n)  
**tau** : input rank-1 array('D') with bounds (n - 1)  
**Returns** **ht** : rank-2 array('D') with bounds (n,n) and a storage  
**info** : int  
**Other Parameters**  
**lo** : input int, optional  
 Default: 0  
**hi** : input int, optional  
 Default: n-1  
**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: hi-lo

`scipy.linalg.lapack.cungqr(a, tau[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for cungqr.

**Parameters** **a** : input rank-2 array('F') with bounds (m,n)  
**tau** : input rank-1 array('F') with bounds (k)  
**Returns** **q** : rank-2 array('F') with bounds (m,n) and a storage  
**work** : rank-1 array('F') with bounds (MAX(lwork,1))  
**info** : int  
**Other Parameters**  
**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*n

`scipy.linalg.lapack.zungqr(a, tau[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for zungqr.

**Parameters** **a** : input rank-2 array('D') with bounds (m,n)  
**tau** : input rank-1 array('D') with bounds (k)  
**Returns** **q** : rank-2 array('D') with bounds (m,n) and a storage  
**work** : rank-1 array('D') with bounds (MAX(lwork,1))  
**info** : int  
**Other Parameters**  
**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*n

`scipy.linalg.lapack.cungrq(a, tau[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for cungrq.

**Parameters** **a** : input rank-2 array('F') with bounds (m,n)  
**tau** : input rank-1 array('F') with bounds (k)  
**Returns** **q** : rank-2 array('F') with bounds (m,n) and a storage  
**work** : rank-1 array('F') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
Default: 0  
**lwork** : input int, optional  
Default: 3\*m

`scipy.linalg.lapack.zungqr(a, tau[, lwork, overwrite_a]) = <fortran object>`

Wrapper for zungqr.

**Parameters** **a** : input rank-2 array('D') with bounds (m,n)  
**tau** : input rank-1 array('D') with bounds (k)  
**Returns** **q** : rank-2 array('D') with bounds (m,n) and a storage  
**work** : rank-1 array('D') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
Default: 0  
**lwork** : input int, optional  
Default: 3\*m

`scipy.linalg.lapack.cunmqr(side, trans, a, tau, c, lwork[, overwrite_c]) = <fortran object>`

Wrapper for cunmqr.

**Parameters** **side** : input string(len=1)  
**trans** : input string(len=1)  
**a** : input rank-2 array('F') with bounds (lda,k)  
**tau** : input rank-1 array('F') with bounds (k)  
**c** : input rank-2 array('F') with bounds (ldc,n)  
**lwork** : input int  
**Returns** **cq** : rank-2 array('F') with bounds (ldc,n) and c storage  
**work** : rank-1 array('F') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**overwrite\_c** : input int, optional  
Default: 0

`scipy.linalg.lapack.zunmqr(side, trans, a, tau, c, lwork[, overwrite_c]) = <fortran object>`

Wrapper for zunmqr.

**Parameters** **side** : input string(len=1)  
**trans** : input string(len=1)  
**a** : input rank-2 array('D') with bounds (lda,k)  
**tau** : input rank-1 array('D') with bounds (k)  
**c** : input rank-2 array('D') with bounds (ldc,n)  
**lwork** : input int  
**Returns** **cq** : rank-2 array('D') with bounds (ldc,n) and c storage  
**work** : rank-1 array('D') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**overwrite\_c** : input int, optional  
Default: 0

`scipy.linalg.lapack.sgtsv(dl, d, du, b[, overwrite_dl, overwrite_d, overwrite_du, overwrite_b]) = <fortran object>`

Wrapper for sgtsv.

**Parameters** **dl** : input rank-1 array('f') with bounds (n - 1)  
**d** : input rank-1 array('f') with bounds (n)  
**du** : input rank-1 array('f') with bounds (n - 1)  
**b** : input rank-2 array('f') with bounds (n,nrhs)

**Returns** **du2** : rank-1 array('f') with bounds (n - 1) and dl storage  
**d** : rank-1 array('f') with bounds (n)  
**du** : rank-1 array('f') with bounds (n - 1)  
**x** : rank-2 array('f') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**  
**overwrite\_dl** : input int, optional  
Default: 0  
**overwrite\_d** : input int, optional  
Default: 0  
**overwrite\_du** : input int, optional  
Default: 0  
**overwrite\_b** : input int, optional  
Default: 0

`scipy.linalg.lapack.dgtsv(dl, d, du, b[, overwrite_dl, overwrite_d, overwrite_du, overwrite_b]) =`  
**<fortran object>**

Wrapper for dgtsv.

**Parameters** **dl** : input rank-1 array('d') with bounds (n - 1)  
**d** : input rank-1 array('d') with bounds (n)  
**du** : input rank-1 array('d') with bounds (n - 1)  
**b** : input rank-2 array('d') with bounds (n,nrhs)

**Returns** **du2** : rank-1 array('d') with bounds (n - 1) and dl storage  
**d** : rank-1 array('d') with bounds (n)  
**du** : rank-1 array('d') with bounds (n - 1)  
**x** : rank-2 array('d') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**  
**overwrite\_dl** : input int, optional  
Default: 0  
**overwrite\_d** : input int, optional  
Default: 0  
**overwrite\_du** : input int, optional  
Default: 0  
**overwrite\_b** : input int, optional  
Default: 0

`scipy.linalg.lapack.cgtsv(dl, d, du, b[, overwrite_dl, overwrite_d, overwrite_du, overwrite_b]) =`  
**<fortran object>**

Wrapper for cgtsv.

**Parameters** **dl** : input rank-1 array('F') with bounds (n - 1)  
**d** : input rank-1 array('F') with bounds (n)  
**du** : input rank-1 array('F') with bounds (n - 1)  
**b** : input rank-2 array('F') with bounds (n,nrhs)

**Returns** **du2** : rank-1 array('F') with bounds (n - 1) and dl storage  
**d** : rank-1 array('F') with bounds (n)  
**du** : rank-1 array('F') with bounds (n - 1)  
**x** : rank-2 array('F') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**

**overwrite\_dl** : input int, optional  
Default: 0  
**overwrite\_d** : input int, optional  
Default: 0  
**overwrite\_du** : input int, optional  
Default: 0  
**overwrite\_b** : input int, optional  
Default: 0

`scipy.linalg.lapack.zgtsv` (*dl, d, du, b*[, *overwrite\_dl, overwrite\_d, overwrite\_du, overwrite\_b*]) = **<fortran object>**

Wrapper for zgtsv.

**Parameters** **dl** : input rank-1 array('D') with bounds (n - 1)  
**d** : input rank-1 array('D') with bounds (n)  
**du** : input rank-1 array('D') with bounds (n - 1)  
**b** : input rank-2 array('D') with bounds (n,nrhs)  
**Returns** **du2** : rank-1 array('D') with bounds (n - 1) and dl storage  
**d** : rank-1 array('D') with bounds (n)  
**du** : rank-1 array('D') with bounds (n - 1)  
**x** : rank-2 array('D') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**

**overwrite\_dl** : input int, optional  
Default: 0  
**overwrite\_d** : input int, optional  
Default: 0  
**overwrite\_du** : input int, optional  
Default: 0  
**overwrite\_b** : input int, optional  
Default: 0

`scipy.linalg.lapack.sptsv` (*d, e, b*[, *overwrite\_d, overwrite\_e, overwrite\_b*]) = **<fortran object>**

Wrapper for sptsv.

**Parameters** **d** : input rank-1 array('f') with bounds (n)  
**e** : input rank-1 array('f') with bounds (n - 1)  
**b** : input rank-2 array('f') with bounds (n,nrhs)  
**Returns** **d** : rank-1 array('f') with bounds (n)  
**du** : rank-1 array('f') with bounds (n - 1) and e storage  
**x** : rank-2 array('f') with bounds (n,nrhs) and b storage  
**info** : int

**Other Parameters**

**overwrite\_d** : input int, optional  
Default: 0  
**overwrite\_e** : input int, optional  
Default: 0  
**overwrite\_b** : input int, optional  
Default: 0

`scipy.linalg.lapack.dptsv` (*d, e, b*[, *overwrite\_d, overwrite\_e, overwrite\_b*]) = **<fortran object>**

Wrapper for dptsv.

**Parameters** **d** : input rank-1 array('d') with bounds (n)  
**e** : input rank-1 array('d') with bounds (n - 1)  
**b** : input rank-2 array('d') with bounds (n,nrhs)

**Returns**     **d** : rank-1 array('d') with bounds (n)  
                   **du** : rank-1 array('d') with bounds (n - 1) and e storage  
                   **x** : rank-2 array('d') with bounds (n,nrhs) and b storage  
                   **info** : int

**Other Parameters**

**overwrite\_d** : input int, optional  
                   Default: 0  
**overwrite\_e** : input int, optional  
                   Default: 0  
**overwrite\_b** : input int, optional  
                   Default: 0

`scipy.linalg.lapack.cptsv(d, e, b[, overwrite_d, overwrite_e, overwrite_b]) = <fortran object>`  
 Wrapper for `cptsv`.

**Parameters**   **d** : input rank-1 array('f') with bounds (n)  
                   **e** : input rank-1 array('F') with bounds (n - 1)  
                   **b** : input rank-2 array('F') with bounds (n,nrhs)  
**Returns**        **d** : rank-1 array('f') with bounds (n)  
                   **du** : rank-1 array('F') with bounds (n - 1) and e storage  
                   **x** : rank-2 array('F') with bounds (n,nrhs) and b storage  
                   **info** : int

**Other Parameters**

**overwrite\_d** : input int, optional  
                   Default: 0  
**overwrite\_e** : input int, optional  
                   Default: 0  
**overwrite\_b** : input int, optional  
                   Default: 0

`scipy.linalg.lapack.zptsv(d, e, b[, overwrite_d, overwrite_e, overwrite_b]) = <fortran object>`  
 Wrapper for `zptsv`.

**Parameters**   **d** : input rank-1 array('d') with bounds (n)  
                   **e** : input rank-1 array('D') with bounds (n - 1)  
                   **b** : input rank-2 array('D') with bounds (n,nrhs)  
**Returns**        **d** : rank-1 array('d') with bounds (n)  
                   **du** : rank-1 array('D') with bounds (n - 1) and e storage  
                   **x** : rank-2 array('D') with bounds (n,nrhs) and b storage  
                   **info** : int

**Other Parameters**

**overwrite\_d** : input int, optional  
                   Default: 0  
**overwrite\_e** : input int, optional  
                   Default: 0  
**overwrite\_b** : input int, optional  
                   Default: 0

`scipy.linalg.lapack.slamch(cmach) = <fortran slamch>`  
 Wrapper for `slamch`.

**Parameters**   **cmach** : input string(len=1)  
**Returns**        **slamch** : float

`scipy.linalg.lapack.dlamch(cmach) = <fortran dlamch>`  
 Wrapper for `dlamch`.

**Parameters**   **cmach** : input string(len=1)

**Returns** **dlamch** : float

`scipy.linalg.lapack.sorghr(a, tau[, lo, hi, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for `sorghr`.

**Parameters** **a** : input rank-2 array('f') with bounds (n,n)  
**tau** : input rank-1 array('f') with bounds (n - 1)  
**Returns** **ht** : rank-2 array('f') with bounds (n,n) and a storage  
**info** : int

**Other Parameters**

**lo** : input int, optional  
 Default: 0  
**hi** : input int, optional  
 Default: n-1  
**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: hi-lo

`scipy.linalg.lapack.dorghr(a, tau[, lo, hi, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for `dorghr`.

**Parameters** **a** : input rank-2 array('d') with bounds (n,n)  
**tau** : input rank-1 array('d') with bounds (n - 1)  
**Returns** **ht** : rank-2 array('d') with bounds (n,n) and a storage  
**info** : int

**Other Parameters**

**lo** : input int, optional  
 Default: 0  
**hi** : input int, optional  
 Default: n-1  
**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: hi-lo

`scipy.linalg.lapack.sorgqr(a, tau[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for `sorgqr`.

**Parameters** **a** : input rank-2 array('f') with bounds (m,n)  
**tau** : input rank-1 array('f') with bounds (k)  
**Returns** **q** : rank-2 array('f') with bounds (m,n) and a storage  
**work** : rank-1 array('f') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*n

`scipy.linalg.lapack.dorgqr(a, tau[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for `dorgqr`.

**Parameters** **a** : input rank-2 array('d') with bounds (m,n)  
**tau** : input rank-1 array('d') with bounds (k)  
**Returns** **q** : rank-2 array('d') with bounds (m,n) and a storage  
**work** : rank-1 array('d') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*n

`scipy.linalg.lapack.sorgqr(a, tau[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for sorgqr.

**Parameters** **a** : input rank-2 array('f') with bounds (m,n)  
**tau** : input rank-1 array('f') with bounds (k)  
**Returns** **q** : rank-2 array('f') with bounds (m,n) and a storage  
**work** : rank-1 array('f') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*m

`scipy.linalg.lapack.dorgqr(a, tau[, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for dorgqr.

**Parameters** **a** : input rank-2 array('d') with bounds (m,n)  
**tau** : input rank-1 array('d') with bounds (k)  
**Returns** **q** : rank-2 array('d') with bounds (m,n) and a storage  
**work** : rank-1 array('d') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*m

`scipy.linalg.lapack.sormqr(side, trans, a, tau, c, lwork[, overwrite_c]) = <fortran object>`  
 Wrapper for sormqr.

**Parameters** **side** : input string(len=1)  
**trans** : input string(len=1)  
**a** : input rank-2 array('f') with bounds (lda,k)  
**tau** : input rank-1 array('f') with bounds (k)  
**c** : input rank-2 array('f') with bounds (ldc,n)  
**lwork** : input int  
**Returns** **cq** : rank-2 array('f') with bounds (ldc,n) and c storage  
**work** : rank-1 array('f') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**overwrite\_c** : input int, optional  
 Default: 0

`scipy.linalg.lapack.dormqr(side, trans, a, tau, c, lwork[, overwrite_c]) = <fortran object>`  
 Wrapper for dormqr.

**Parameters** **side** : input string(len=1)  
**trans** : input string(len=1)  
**a** : input rank-2 array('d') with bounds (lda,k)  
**tau** : input rank-1 array('d') with bounds (k)  
**c** : input rank-2 array('d') with bounds (ldc,n)

**Returns** **lwork** : input int  
**cq** : rank-2 array('d') with bounds (ldc,n) and c storage  
**work** : rank-1 array('d') with bounds (MAX(lwork,1))  
**info** : int

**Other Parameters**

**overwrite\_c** : input int, optional  
 Default: 0

`scipy.linalg.lapack.ssbev(ab[, compute_v, lower, ldab, overwrite_ab]) = <fortran object>`  
 Wrapper for `ssbev`.

**Parameters** **ab** : input rank-2 array('f') with bounds (ldab,n)

**Returns** **w** : rank-1 array('f') with bounds (n)  
**z** : rank-2 array('f') with bounds (ldz,ldz)  
**info** : int

**Other Parameters**

**overwrite\_ab** : input int, optional  
 Default: 1  
**compute\_v** : input int, optional  
 Default: 1  
**lower** : input int, optional  
 Default: 0  
**ldab** : input int, optional  
 Default: `shape(ab,0)`

`scipy.linalg.lapack.dsbev(ab[, compute_v, lower, ldab, overwrite_ab]) = <fortran object>`  
 Wrapper for `dsbev`.

**Parameters** **ab** : input rank-2 array('d') with bounds (ldab,n)

**Returns** **w** : rank-1 array('d') with bounds (n)  
**z** : rank-2 array('d') with bounds (ldz,ldz)  
**info** : int

**Other Parameters**

**overwrite\_ab** : input int, optional  
 Default: 1  
**compute\_v** : input int, optional  
 Default: 1  
**lower** : input int, optional  
 Default: 0  
**ldab** : input int, optional  
 Default: `shape(ab,0)`

`scipy.linalg.lapack.ssbevd(ab[, compute_v, lower, ldab, liwork, overwrite_ab]) = <fortran object>`

Wrapper for `ssbevd`.

**Parameters** **ab** : input rank-2 array('f') with bounds (ldab,n)

**Returns** **w** : rank-1 array('f') with bounds (n)  
**z** : rank-2 array('f') with bounds (ldz,ldz)  
**info** : int

**Other Parameters**

**overwrite\_ab** : input int, optional  
 Default: 1  
**compute\_v** : input int, optional  
 Default: 1  
**lower** : input int, optional  
 Default: 0

**ldab** : input int, optional  
 Default: shape(ab,0)  
**liwork** : input int, optional  
 Default: (compute\_v?3+5\*n:1)

scipy.linalg.lapack.**dsbevd**(*ab*[, *compute\_v*, *lower*, *ldab*, *liwork*, *overwrite\_ab*]) = <fortran object>

Wrapper for dsbevd.

**Parameters** **ab** : input rank-2 array('d') with bounds (ldab,n)  
**Returns** **w** : rank-1 array('d') with bounds (n)  
**z** : rank-2 array('d') with bounds (ldz,ldz)  
**info** : int

**Other Parameters**

**overwrite\_ab** : input int, optional  
 Default: 1  
**compute\_v** : input int, optional  
 Default: 1  
**lower** : input int, optional  
 Default: 0  
**ldab** : input int, optional  
 Default: shape(ab,0)  
**liwork** : input int, optional  
 Default: (compute\_v?3+5\*n:1)

scipy.linalg.lapack.**ssbevx**(*ab*, *vl*, *vu*, *il*, *iu*[, *ldab*, *compute\_v*, *range*, *lower*, *abstol*, *mmax*, *overwrite\_ab*]) = <fortran object>

Wrapper for ssbevx.

**Parameters** **ab** : input rank-2 array('f') with bounds (ldab,n)  
**vl** : input float  
**vu** : input float  
**il** : input int  
**iu** : input int  
**Returns** **w** : rank-1 array('f') with bounds (n)  
**z** : rank-2 array('f') with bounds (ldz,mmax)  
**m** : int  
**ifail** : rank-1 array('i') with bounds ((compute\_v?n:1))  
**info** : int

**Other Parameters**

**overwrite\_ab** : input int, optional  
 Default: 1  
**ldab** : input int, optional  
 Default: shape(ab,0)  
**compute\_v** : input int, optional  
 Default: 1  
**range** : input int, optional  
 Default: 0  
**lower** : input int, optional  
 Default: 0  
**abstol** : input float, optional  
 Default: 0.0  
**mmax** : input int, optional  
 Default: (compute\_v?(range==2?(iu-il+1):n):1)

`scipy.linalg.lapack.dsbevx` (*ab*, *vl*, *vu*, *il*, *iu*[, *ldab*, *compute\_v*, *range*, *lower*, *abstol*, *mmax*, *overwrite\_ab*]) = <fortran object>

Wrapper for dsbevx.

**Parameters**

- ab** : input rank-2 array('d') with bounds (ldab,n)
- vl** : input float
- vu** : input float
- il** : input int
- iu** : input int

**Returns**

- w** : rank-1 array('d') with bounds (n)
- z** : rank-2 array('d') with bounds (ldz,mmax)
- m** : int
- ifail** : rank-1 array('i') with bounds ((compute\_v?n:1))
- info** : int

**Other Parameters**

- overwrite\_ab** : input int, optional  
Default: 1
- ldab** : input int, optional  
Default: shape(ab,0)
- compute\_v** : input int, optional  
Default: 1
- range** : input int, optional  
Default: 0
- lower** : input int, optional  
Default: 0
- abstol** : input float, optional  
Default: 0.0
- mmax** : input int, optional  
Default: (compute\_v?(range==2?(iu-il+1):n):1)

`scipy.linalg.lapack.sstebz` (*d*, *e*, *range*, *vl*, *vu*, *il*, *iu*, *tol*, *order*) = <fortran object>

Wrapper for sstebz.

**Parameters**

- d** : input rank-1 array('f') with bounds (n)
- e** : input rank-1 array('f') with bounds (n - 1)
- range** : input int
- vl** : input float
- vu** : input float
- il** : input int
- iu** : input int
- tol** : input float
- order** : input string(len=1)

**Returns**

- m** : int
- w** : rank-1 array('f') with bounds (n)
- iblock** : rank-1 array('i') with bounds (n)
- isplit** : rank-1 array('i') with bounds (n)
- info** : int

`scipy.linalg.lapack.dstebz` (*d*, *e*, *range*, *vl*, *vu*, *il*, *iu*, *tol*, *order*) = <fortran object>

Wrapper for dstebz.

**Parameters**

- d** : input rank-1 array('d') with bounds (n)
- e** : input rank-1 array('d') with bounds (n - 1)
- range** : input int
- vl** : input float
- vu** : input float
- il** : input int

**iu** : input int  
**tol** : input float  
**order** : input string(len=1)  
**Returns** **m** : int  
**w** : rank-1 array('d') with bounds (n)  
**iblock** : rank-1 array('i') with bounds (n)  
**isplit** : rank-1 array('i') with bounds (n)  
**info** : int

scipy.linalg.lapack.**sstemr**(*d, e, range, vl, vu, il, iu*[, *compute\_v, lwork, liwork, overwrite\_d*]) =  
 <fortran object>

Wrapper for sstemr.

**Parameters** **d** : input rank-1 array('f') with bounds (n)  
**e** : input rank-1 array('f') with bounds (n)  
**range** : input int  
**vl** : input float  
**vu** : input float  
**il** : input int  
**iu** : input int  
**Returns** **m** : int  
**w** : rank-1 array('f') with bounds (n)  
**z** : rank-2 array('f') with bounds (n,n)  
**info** : int

**Other Parameters**

**overwrite\_d** : input int, optional  
 Default: 0  
**compute\_v** : input int, optional  
 Default: 1  
**lwork** : input int, optional  
 Default: (compute\_v?18\*n:12\*n)  
**liwork** : input int, optional  
 Default: (compute\_v?10\*n:8\*n)

scipy.linalg.lapack.**dstemr**(*d, e, range, vl, vu, il, iu*[, *compute\_v, lwork, liwork, overwrite\_d*]) =  
 <fortran object>

Wrapper for dstemr.

**Parameters** **d** : input rank-1 array('d') with bounds (n)  
**e** : input rank-1 array('d') with bounds (n)  
**range** : input int  
**vl** : input float  
**vu** : input float  
**il** : input int  
**iu** : input int  
**Returns** **m** : int  
**w** : rank-1 array('d') with bounds (n)  
**z** : rank-2 array('d') with bounds (n,n)  
**info** : int

**Other Parameters**

**overwrite\_d** : input int, optional  
 Default: 0  
**compute\_v** : input int, optional  
 Default: 1  
**lwork** : input int, optional  
 Default: (compute\_v?18\*n:12\*n)

**liwork** : input int, optional  
 Default: (compute\_v?10\*n:8\*n)

`scipy.linalg.lapack.ssterf(d, e[, overwrite_d, overwrite_e]) = <fortran object>`

Wrapper for `ssterf`.

**Parameters** **d** : input rank-1 array('f') with bounds (n)  
**e** : input rank-1 array('f') with bounds (n - 1)  
**Returns** **vals** : rank-1 array('f') with bounds (n) and d storage  
**info** : int  
**Other Parameters**  
**overwrite\_d** : input int, optional  
 Default: 0  
**overwrite\_e** : input int, optional  
 Default: 0

`scipy.linalg.lapack.dsterf(d, e[, overwrite_d, overwrite_e]) = <fortran object>`

Wrapper for `dsterf`.

**Parameters** **d** : input rank-1 array('d') with bounds (n)  
**e** : input rank-1 array('d') with bounds (n - 1)  
**Returns** **vals** : rank-1 array('d') with bounds (n) and d storage  
**info** : int  
**Other Parameters**  
**overwrite\_d** : input int, optional  
 Default: 0  
**overwrite\_e** : input int, optional  
 Default: 0

`scipy.linalg.lapack.sstein(d, e, w, iblock, isplit) = <fortran object>`

Wrapper for `sstein`.

**Parameters** **d** : input rank-1 array('f') with bounds (n)  
**e** : input rank-1 array('f') with bounds (n - 1)  
**w** : input rank-1 array('f') with bounds (m)  
**iblock** : input rank-1 array('i') with bounds (n)  
**isplit** : input rank-1 array('i') with bounds (n)  
**Returns** **z** : rank-2 array('f') with bounds (ldz,m)  
**info** : int

`scipy.linalg.lapack.dstein(d, e, w, iblock, isplit) = <fortran object>`

Wrapper for `dstein`.

**Parameters** **d** : input rank-1 array('d') with bounds (n)  
**e** : input rank-1 array('d') with bounds (n - 1)  
**w** : input rank-1 array('d') with bounds (m)  
**iblock** : input rank-1 array('i') with bounds (n)  
**isplit** : input rank-1 array('i') with bounds (n)  
**Returns** **z** : rank-2 array('d') with bounds (ldz,m)  
**info** : int

`scipy.linalg.lapack.sstev(d, e[, compute_v, overwrite_d, overwrite_e]) = <fortran object>`

Wrapper for `sstev`.

**Parameters** **d** : input rank-1 array('f') with bounds (n)  
**e** : input rank-1 array('f') with bounds (MAX(n-1,1))  
**Returns** **vals** : rank-1 array('f') with bounds (n) and d storage  
**z** : rank-2 array('f') with bounds (ldz,(compute\_v?n:1))  
**info** : int

*Other Parameters*

**overwrite\_d** : input int, optional  
 Default: 0  
**overwrite\_e** : input int, optional  
 Default: 0  
**compute\_v** : input int, optional  
 Default: 1

`scipy.linalg.lapack.dstev(d, e[, compute_v, overwrite_d, overwrite_e]) = <fortran object>`  
 Wrapper for `dstev`.

**Parameters** **d** : input rank-1 array('d') with bounds (n)  
**e** : input rank-1 array('d') with bounds (MAX(n-1,1))  
**Returns** **vals** : rank-1 array('d') with bounds (n) and d storage  
**z** : rank-2 array('d') with bounds (ldz,(compute\_v?n:1))  
**info** : int

*Other Parameters*

**overwrite\_d** : input int, optional  
 Default: 0  
**overwrite\_e** : input int, optional  
 Default: 0  
**compute\_v** : input int, optional  
 Default: 1

`scipy.linalg.lapack.ssyev(a[, compute_v, lower, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for `ssyev`.

**Parameters** **a** : input rank-2 array('f') with bounds (n,n)  
**Returns** **w** : rank-1 array('f') with bounds (n)  
**v** : rank-2 array('f') with bounds (n,n) and a storage  
**info** : int

*Other Parameters*

**compute\_v** : input int, optional  
 Default: 1  
**lower** : input int, optional  
 Default: 0  
**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*n-1

`scipy.linalg.lapack.dsyev(a[, compute_v, lower, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for `dsyev`.

**Parameters** **a** : input rank-2 array('d') with bounds (n,n)  
**Returns** **w** : rank-1 array('d') with bounds (n)  
**v** : rank-2 array('d') with bounds (n,n) and a storage  
**info** : int

*Other Parameters*

**compute\_v** : input int, optional  
 Default: 1  
**lower** : input int, optional  
 Default: 0  
**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 3\*n-1

`scipy.linalg.lapack.ssyevd(a[, compute_v, lower, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for `ssyevd`.

**Parameters** **a** : input rank-2 array('f') with bounds (n,n)  
**Returns** **w** : rank-1 array('f') with bounds (n)  
**v** : rank-2 array('f') with bounds (n,n) and a storage  
**info** : int

**Other Parameters**

**compute\_v** : input int, optional  
 Default: 1  
**lower** : input int, optional  
 Default: 0  
**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: (compute\_v?1+6\*n+2\*n\*n:2\*n+1)

`scipy.linalg.lapack.dsyevd(a[, compute_v, lower, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for `dsyevd`.

**Parameters** **a** : input rank-2 array('d') with bounds (n,n)  
**Returns** **w** : rank-1 array('d') with bounds (n)  
**v** : rank-2 array('d') with bounds (n,n) and a storage  
**info** : int

**Other Parameters**

**compute\_v** : input int, optional  
 Default: 1  
**lower** : input int, optional  
 Default: 0  
**overwrite\_a** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: (compute\_v?1+6\*n+2\*n\*n:2\*n+1)

`scipy.linalg.lapack.ssyevr(a[, jobz, range, uplo, il, iu, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for `ssyevr`.

**Parameters** **a** : input rank-2 array('f') with bounds (n,n)  
**Returns** **w** : rank-1 array('f') with bounds (n)  
**z** : rank-2 array('f') with bounds (n,m)  
**info** : int

**Other Parameters**

**jobz** : input string(len=1), optional  
 Default: 'V'  
**range** : input string(len=1), optional  
 Default: 'A'  
**uplo** : input string(len=1), optional  
 Default: 'L'  
**overwrite\_a** : input int, optional  
 Default: 0  
**il** : input int, optional  
 Default: 1  
**iu** : input int, optional  
 Default: n  
**lwork** : input int, optional  
 Default: 26\*n

`scipy.linalg.lapack.dsyevr(a[, jobz, range, uplo, il, iu, lwork, overwrite_a]) = <fortran object>`  
 Wrapper for dsyevr.

**Parameters** **a** : input rank-2 array('d') with bounds (n,n)

**Returns** **w** : rank-1 array('d') with bounds (n)

**z** : rank-2 array('d') with bounds (n,m)

**info** : int

**Other Parameters**

**jobz** : input string(len=1), optional  
 Default: 'V'

**range** : input string(len=1), optional  
 Default: 'A'

**uplo** : input string(len=1), optional  
 Default: 'L'

**overwrite\_a** : input int, optional  
 Default: 0

**il** : input int, optional  
 Default: 1

**iu** : input int, optional  
 Default: n

**lwork** : input int, optional  
 Default: 26\*n

`scipy.linalg.lapack.ssygv(a, b[, itype, jobz, uplo, overwrite_a, overwrite_b]) = <fortran object>`  
 Wrapper for ssygv.

**Parameters** **a** : input rank-2 array('f') with bounds (n,n)

**b** : input rank-2 array('f') with bounds (n,n)

**Returns** **a** : rank-2 array('f') with bounds (n,n)

**w** : rank-1 array('f') with bounds (n)

**info** : int

**Other Parameters**

**itype** : input int, optional  
 Default: 1

**jobz** : input string(len=1), optional  
 Default: 'V'

**uplo** : input string(len=1), optional  
 Default: 'L'

**overwrite\_a** : input int, optional  
 Default: 0

**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.dsygv(a, b[, itype, jobz, uplo, overwrite_a, overwrite_b]) = <fortran object>`  
 Wrapper for dsygv.

**Parameters** **a** : input rank-2 array('d') with bounds (n,n)

**b** : input rank-2 array('d') with bounds (n,n)

**Returns** **a** : rank-2 array('d') with bounds (n,n)

**w** : rank-1 array('d') with bounds (n)

**info** : int

**Other Parameters**

**itype** : input int, optional  
 Default: 1

**jobz** : input string(len=1), optional  
 Default: 'V'

**uplo** : input string(len=1), optional  
 Default: 'L'  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0

`scipy.linalg.lapack.ssygvd(a, b[, itype, jobz, uplo, lwork, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for ssygvd.

**Parameters** **a** : input rank-2 array('f') with bounds (n,n)  
**b** : input rank-2 array('f') with bounds (n,n)  
**Returns** **a** : rank-2 array('f') with bounds (n,n)  
**w** : rank-1 array('f') with bounds (n)  
**info** : int

**Other Parameters**

**itype** : input int, optional  
 Default: 1  
**jobz** : input string(len=1), optional  
 Default: 'V'  
**uplo** : input string(len=1), optional  
 Default: 'L'  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 1+6\*n+2\*n\*n

`scipy.linalg.lapack.dsygvd(a, b[, itype, jobz, uplo, lwork, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for dsygvd.

**Parameters** **a** : input rank-2 array('d') with bounds (n,n)  
**b** : input rank-2 array('d') with bounds (n,n)  
**Returns** **a** : rank-2 array('d') with bounds (n,n)  
**w** : rank-1 array('d') with bounds (n)  
**info** : int

**Other Parameters**

**itype** : input int, optional  
 Default: 1  
**jobz** : input string(len=1), optional  
 Default: 'V'  
**uplo** : input string(len=1), optional  
 Default: 'L'  
**overwrite\_a** : input int, optional  
 Default: 0  
**overwrite\_b** : input int, optional  
 Default: 0  
**lwork** : input int, optional  
 Default: 1+6\*n+2\*n\*n

`scipy.linalg.lapack.ssygvx(a, b, iu[, itype, jobz, uplo, il, lwork, overwrite_a, overwrite_b]) = <fortran object>`

Wrapper for ssygvx.



`scipy.linalg.lapack.dlange` (*norm*, *a*) = <fortran dlange>  
 Wrapper for dlange.

**Parameters** **norm** : input string(len=1)  
**a** : input rank-2 array('d') with bounds (m,n)  
**Returns** **n2** : float

`scipy.linalg.lapack.clange` (*norm*, *a*) = <fortran clange>  
 Wrapper for clange.

**Parameters** **norm** : input string(len=1)  
**a** : input rank-2 array('F') with bounds (m,n)  
**Returns** **n2** : float

`scipy.linalg.lapack.zlange` (*norm*, *a*) = <fortran zlange>  
 Wrapper for zlange.

**Parameters** **norm** : input string(len=1)  
**a** : input rank-2 array('D') with bounds (m,n)  
**Returns** **n2** : float

`scipy.linalg.lapack.ilaver` = <fortran object>  
 Wrapper for ilaver.

**Returns** **major** : int  
**minor** : int  
**patch** : int

## 5.12 BLAS Functions for Cython

Usable from Cython via:

```
cimport scipy.linalg.cython_blas
```

These wrappers do not check for alignment of arrays. Alignment should be checked before these wrappers are used.

Raw function pointers (Fortran-style pointer arguments):

- caxpy
- ccopy
- cdotc
- cdotu
- cgbmv
- cgemm
- cgemv
- cgerc
- cgeru
- chbmv
- chemm
- chemv
- cher

- cher2
- cher2k
- cherk
- chpmv
- chpr
- chpr2
- crotg
- cscal
- csrot
- csscal
- cswap
- csymm
- csyr2k
- csyrk
- ctbmv
- ctbsv
- ctpmv
- ctpsv
- ctrmm
- ctrmv
- ctrsm
- ctrsv
- dasum
- daxpy
- dcabs1
- dcopy
- ddot
- dgbmv
- dgemm
- dgemv
- dger
- dnorm2
- drot
- drotg
- drotm
- drotmg

- dsbmv
- dscal
- dsdot
- dspmv
- dspr
- dspr2
- dswap
- dsymm
- dsymv
- dsyr
- dsyr2
- dsyr2k
- dsyrk
- dtbmv
- dtbsv
- dtpmv
- dtpsv
- dtrmm
- dtrmv
- dtrsm
- dtrsv
- dzasum
- dznrm2
- icamax
- idamax
- isamax
- izamax
- lsame
- sasum
- saxpy
- scasum
- scnrm2
- scopy
- sdot
- sdsdot
- sgbmv

- `sgemm`
- `sgemv`
- `sger`
- `snrm2`
- `srot`
- `srotg`
- `srotm`
- `srotmg`
- `ssbmv`
- `sscal`
- `sspmv`
- `sspr`
- `sspr2`
- `sswap`
- `ssymm`
- `ssymv`
- `ssyr`
- `ssyr2`
- `ssyr2k`
- `ssyrk`
- `stbmv`
- `stbsv`
- `stpmv`
- `stpsv`
- `strmm`
- `strmv`
- `strsm`
- `strsv`
- `zaxpy`
- `zcopy`
- `zdotc`
- `zdotu`
- `zdrot`
- `zdscal`
- `zgbmv`
- `zgemm`

- zgemv
- zgerc
- zgeru
- zhbmvm
- zhemm
- zhemv
- zher
- zher2
- zher2k
- zherk
- zhpmv
- zhpr
- zhpr2
- zrotg
- zscal
- zswap
- zsymm
- zsyr2k
- zsyrok
- ztbmv
- ztbsv
- ztpmv
- ztpsv
- ztrmm
- ztrmv
- ztrsm
- ztrsv

## 5.13 LAPACK functions for Cython

Usable from Cython via:

```
cimport scipy.linalg.cython_lapack
```

This module provides Cython-level wrappers for all primary routines included in LAPACK 3.1.0 except for `zcgessv` since its interface is not consistent from LAPACK 3.1.0 to 3.6.0. It also provides some of the fixed-api auxiliary routines.

These wrappers do not check for alignment of arrays. Alignment should be checked before these wrappers are used.

Raw function pointers (Fortran-style pointer arguments):

- `cbdsqr`
- `cgbbrd`
- `cgbcon`
- `cgbequ`
- `cgbrfs`
- `cgbsv`
- `cgbsvx`
- `cgbt2`
- `cgbtrf`
- `cgbtrs`
- `cgebak`
- `cgebal`
- `cgebd2`
- `cgebrd`
- `cgecon`
- `cgeequ`
- `cgees`
- `cgeesx`
- `cgeev`
- `cgeevx`
- `cgehd2`
- `cgehrd`
- `cgelq2`
- `cgelqf`
- `cgels`
- `cgelsd`
- `cgelss`
- `cgelsy`
- `cgeql2`
- `cgeqlf`
- `cgeqp3`
- `cgeqr2`
- `cgeqrf`
- `cgerfs`
- `cgerq2`
- `cgerqf`

- cgesc2
- cgesdd
- cgesv
- cgesvd
- cgesvx
- cgetc2
- cgetf2
- cgetrf
- cgetri
- cgetrs
- cggbak
- cggbal
- cgges
- cggesx
- cggev
- cggevx
- cggglm
- cgghrd
- cgglse
- cggqrf
- cggrqf
- cgtcon
- cgtrfs
- cgtsv
- cgtsvx
- cgtrfs
- cgttrs
- cgtts2
- chbev
- chbevd
- chbevz
- chbgst
- chbgv
- chbgvd
- chbgvx
- chbtrd

- checon
- cheev
- cheevd
- cheevr
- cheevx
- chegs2
- chegst
- chegv
- chegvd
- chegvx
- cherfs
- chesv
- chesvx
- chetd2
- chetf2
- chetrd
- chetrf
- chetri
- chetrs
- chgeqz
- chpcon
- chpev
- chpevd
- chpevx
- chpgst
- chpgv
- chpgvd
- chpgvx
- chprfs
- chpsv
- chpsvx
- chptrd
- chptrf
- chptri
- chptrs
- chsein

- chseqr
- clabrd
- clacgv
- clacn2
- clacon
- clacp2
- clacpy
- clacrm
- clacrt
- cladiv
- claed0
- claed7
- claed8
- claein
- claesy
- claev2
- clag2z
- clags2
- clagtm
- clahef
- clahqr
- clahr2
- claic1
- clals0
- clalsa
- clalsd
- clangb
- clange
- clangt
- clanhb
- clanhe
- clanhp
- clanhs
- clanht
- clansb
- clansp

- `clansy`
- `clantb`
- `clantp`
- `clantr`
- `clapll`
- `clapmt`
- `claqgb`
- `claqge`
- `claqhb`
- `claqhe`
- `claqhp`
- `claqp2`
- `claqps`
- `claqr0`
- `claqr1`
- `claqr2`
- `claqr3`
- `claqr4`
- `claqr5`
- `claqsb`
- `claqsp`
- `claqsy`
- `clar1v`
- `clar2v`
- `clarcn`
- `clarf`
- `clarfb`
- `clarfg`
- `clarft`
- `clarfx`
- `clargv`
- `clarnv`
- `clarrv`
- `clartg`
- `clartv`
- `clarz`

- clarzb
- clarzt
- clascl
- claset
- clasr
- classq
- claswp
- clasyf
- clatbs
- clatdf
- clatps
- clatrd
- clatrs
- clatz
- clauu2
- clauum
- cpbcon
- cpbequ
- cpbrfs
- cpbstf
- cpbsv
- cpbsvx
- cpbtf2
- cpbtrf
- cpbtrs
- cpocon
- cpoequ
- cporfs
- cposv
- cposvx
- cpotf2
- cpotrf
- cpotri
- cpotrs
- cppcon
- cppequ

- cprfs
- cppsv
- cppsvx
- cpptrf
- cpptri
- cpptrs
- cptcon
- cpteqr
- cptrfs
- cptsv
- cptsvx
- cpttrf
- cpttrs
- cptts2
- crot
- cspcon
- cspmv
- cspr
- csprfs
- cspsv
- cspsvx
- csptrf
- csptri
- csptrs
- csrscl
- cstedc
- csteqr
- cstein
- cstemr
- csteqr
- csycon
- csymv
- csyr
- csyrfs
- csysv
- csysvx

- csytf2
- csytrf
- csytri
- csytrs
- ctbcon
- ctbrfs
- ctbtrs
- ctgevc
- ctgex2
- ctgexc
- ctgsen
- ctgsja
- ctgsna
- ctgsy2
- ctgsyl
- ctpcon
- ctptrfs
- ctptri
- ctptrs
- ctrcon
- ctrevc
- ctrex
- ctrrfs
- ctrsen
- ctrsna
- ctrsyl
- ctrti2
- ctrtri
- ctrtrs
- ctzrzf
- cun2l
- cun2r
- cun2br
- cunghr
- cun2l2
- cun2lq

- `cungql`
- `cungqr`
- `cungr2`
- `cungrq`
- `cungtr`
- `cunm2l`
- `cunm2r`
- `cunmbr`
- `cunmhr`
- `cunml2`
- `cunmlq`
- `cunmql`
- `cunmqr`
- `cunmr2`
- `cunmr3`
- `cunmrq`
- `cunmrz`
- `cunmtr`
- `cupgtr`
- `cupmtr`
- `dbdsdc`
- `dbdsqr`
- `ddisna`
- `dgbbrd`
- `dgbcon`
- `dgbequ`
- `dgbrfs`
- `dgbsv`
- `dgbsvx`
- `dgbtf2`
- `dgbtrf`
- `dgbtrs`
- `dgebak`
- `dgebal`
- `dgebd2`
- `dgebrd`

- dgecon
- dgeequ
- dgees
- dgeesx
- dgeev
- dgeevx
- dgehd2
- dgehrd
- dgelq2
- dgelqf
- dgels
- dgelsd
- dgelss
- dgelsy
- dgeql2
- dgeqlf
- dgeqp3
- dgeqr2
- dgeqrf
- dgerfs
- dgerq2
- dgerqf
- dgesc2
- dgesdd
- dgesv
- dgesvd
- dgesvx
- dgetc2
- dgetf2
- dgetrf
- dgetri
- dgetrs
- dggbak
- dggbal
- dgges
- dggesx

- `dggev`
- `dggevx`
- `dggglm`
- `dgghrd`
- `dgglse`
- `dggqrf`
- `dggqrqf`
- `dgtcon`
- `dgtrfs`
- `dgtsv`
- `dgtsvx`
- `dgtrfs`
- `dgtrrs`
- `dgts2`
- `dhgeqz`
- `dhsein`
- `dhseqr`
- `disnan`
- `dlabad`
- `dlabrd`
- `dlacn2`
- `dlacon`
- `dlacpy`
- `dladiv`
- `dlae2`
- `dlaeبز`
- `dlaed0`
- `dlaed1`
- `dlaed2`
- `dlaed3`
- `dlaed4`
- `dlaed5`
- `dlaed6`
- `dlaed7`
- `dlaed8`
- `dlaed9`

- dlaeda
- dlaein
- dlaev2
- dlaexc
- dlag2
- dlag2s
- dlags2
- dlagtf
- dlagtm
- dlagts
- dlagv2
- dlahqr
- dlahr2
- dlaic1
- dlaln2
- dlals0
- dlalsa
- dlalsd
- dlamch
- dlamrg
- dlaneg
- dlangb
- dlange
- dlangt
- dlanhs
- dlansb
- dlansp
- dlanst
- dlansy
- dlantb
- dlantp
- dlantr
- dlanv2
- dlapll
- dlapmt
- dlapy2

- `dlapy3`
- `dlaqgb`
- `dlaqge`
- `dlaqp2`
- `dlaqps`
- `dlaqr0`
- `dlaqr1`
- `dlaqr2`
- `dlaqr3`
- `dlaqr4`
- `dlaqr5`
- `dlaqsb`
- `dlaqsp`
- `dlaqsy`
- `dlaqtr`
- `dlar1v`
- `dlar2v`
- `dlarf`
- `dlarfb`
- `dlarfg`
- `dlarft`
- `dlarfx`
- `dlargv`
- `dlarnv`
- `dlarra`
- `dlarrb`
- `dlarrc`
- `dlarrd`
- `dlarre`
- `dlarrf`
- `dlarrj`
- `dlarrk`
- `dlarrl`
- `dlarrv`
- `dlartg`
- `dlartv`

- dlaruv
- dlarz
- dlarzb
- dlarzt
- dlas2
- dlascl
- dlasd0
- dlasd1
- dlasd2
- dlasd3
- dlasd4
- dlasd5
- dlasd6
- dlasd7
- dlasd8
- dlasda
- dlasdq
- dlasdt
- dlaset
- dlasq1
- dlasq2
- dlasq6
- dlasr
- dlasrt
- dlassq
- dlasv2
- dlaswp
- dlasv2
- dlasvf
- dlatbs
- dlatdf
- dlatps
- dlatrd
- dlatrs
- dlatrz
- dlauu2

- dlauum
- dopgtr
- dopmtr
- dorg2l
- dorg2r
- dorgbr
- dorghr
- dorgl2
- dorglq
- dorgql
- dorgqr
- dorg2
- dorgq
- dorgtr
- dorm2l
- dorm2r
- dormbr
- dormhr
- dorml2
- dormlq
- dormql
- dormqr
- dormr2
- dormr3
- dormrq
- dormrz
- dormtr
- dpbcon
- dpbequ
- dpbrfs
- dpbstf
- dpbsv
- dpbsvx
- dpbtf2
- dpbtrf
- dpbtrs

- dpocon
- dpoequ
- dporfs
- dposv
- dposvx
- dpotf2
- dpotrf
- dpotri
- dpotrs
- dppcon
- dppequ
- dpprfs
- dppsv
- dppsvx
- dpptrf
- dpptri
- dpptrs
- dptcon
- dpteqr
- dptrfs
- dptsv
- dptsvx
- dpttrf
- dpttrs
- dptts2
- drscl
- dsbev
- dsbevd
- dsbevx
- dsbgst
- dsbgv
- dsbgvd
- dsbgvx
- dsbtrd
- dsgesv
- dspcon

- dspev
- dspevd
- dspevx
- dspgst
- dspgv
- dspgvd
- dspgvx
- dsprfs
- dspsv
- dspsvx
- dsptrd
- dsptrf
- dsptri
- dsptrs
- dstebz
- dstedc
- dstegr
- dstein
- dstemr
- dsteqr
- dsterf
- dstev
- dstevd
- dstevr
- dstevx
- dsycon
- dsyev
- dsyevd
- dsyevr
- dsyevx
- dsygs2
- dsygst
- dsygv
- dsygvd
- dsygvx
- dsyrfs

- dsysv
- dsysvx
- dsytd2
- dsytf2
- dsytrd
- dsytrf
- dsytri
- dsytrs
- dtbcon
- dtbrfs
- dtbtrs
- dtgevc
- dtgex2
- dtgexc
- dtgsen
- dtgsja
- dtgsna
- dtgsy2
- dtgsyl
- dtpcon
- dtprfs
- dtptri
- dtptrs
- dtrcon
- dtrevc
- dtrexc
- dtrrfs
- dtrsen
- dtrsna
- dtrsyl
- dtrti2
- dtrtri
- dtrtrs
- dtzrzf
- dzsum1
- icmax1

- ieeck
- ilaver
- izmax1
- sbdsdc
- sbdsqr
- scsum1
- sdisna
- sgbbdd
- sgbccon
- sgbequ
- sgbrfs
- sgbsv
- sgbsvx
- sgbtf2
- sgbtrf
- sgbtrs
- sgebak
- sgebal
- sgebd2
- sgebrd
- sgecon
- sgeequ
- sgees
- sgeesx
- sgeev
- sgeevx
- sgehd2
- sgehrd
- sgelq2
- sgelqf
- sgels
- sgelsd
- sgelss
- sgelsy
- sgeql2
- sgeqlf

- sgeqp3
- sgeqr2
- sgeqrf
- sgerfs
- sgerq2
- sgerqf
- sgesc2
- sgesdd
- sgesv
- sgesvd
- sgesvx
- sgetc2
- sgetf2
- sgetrf
- sgetri
- sgetrs
- sggbak
- sggbal
- sgges
- sggesx
- sggev
- sggevx
- sgglm
- sgghrd
- sgglse
- sggqrf
- sggrqf
- sgtcon
- sgttrfs
- sgtsv
- sgtsvx
- sgttrf
- sgttrs
- sgts2
- shgeqz
- shsein

- shseqr
- slabad
- slabrd
- slacn2
- slacon
- slacpy
- sladiv
- slae2
- slaebz
- slaed0
- slaed1
- slaed2
- slaed3
- slaed4
- slaed5
- slaed6
- slaed7
- slaed8
- slaed9
- slaeda
- slaein
- slaev2
- slaexc
- slag2
- slag2d
- slags2
- slagtf
- slagtm
- slagts
- slagv2
- slahqr
- slahr2
- slaic1
- slaln2
- slals0
- slalsa

- slalsd
- slamch
- slamrg
- slangb
- slange
- slangt
- slanhs
- slansb
- slansp
- slanst
- slansy
- slantb
- slantp
- slantr
- slanv2
- slapll
- slapmt
- slapy2
- slapy3
- slaqgb
- slaqge
- slaqp2
- slaqps
- slaqr0
- slaqr1
- slaqr2
- slaqr3
- slaqr4
- slaqr5
- slaqsb
- slaqsp
- slaqsy
- slaqtr
- slar1v
- slar2v
- slarf

- slarfb
- slarfg
- slarft
- slarfx
- slargv
- slarnv
- slarra
- slarrb
- slarrc
- slarrd
- slarre
- slarrf
- slarrj
- slarrk
- slarrl
- slarrv
- slartg
- slartv
- slaruv
- slarz
- slarzb
- slarzt
- slas2
- slascl
- slasd0
- slasd1
- slasd2
- slasd3
- slasd4
- slasd5
- slasd6
- slasd7
- slasd8
- slasda
- slasdq
- slasdt

- slaset
- slasq1
- slasq2
- slasq6
- slasr
- slasrt
- slassq
- slasv2
- slaswp
- slasy2
- slasyf
- slatbs
- slatdf
- slatps
- slatrd
- slatrs
- slatz
- slauu2
- slauum
- sopgtr
- sopmtr
- sorg2l
- sorg2r
- sorgbr
- sorgbr
- sorgbr
- sorgl2
- sorglq
- sorgql
- sorgqr
- sorgqr
- sorgqr2
- sorgqr
- sorgtr
- sorm2l
- sorm2r
- sormbr
- sormhr

- sorml2
- sormlq
- sormql
- sormqr
- sormr2
- sormr3
- sormrq
- sormrz
- sormtr
- spbcon
- spbequ
- spbrfs
- spbstf
- spbsv
- spbsvx
- spbtf2
- spbtrf
- spbtrs
- spocon
- spoequ
- sporfs
- sposv
- sposvx
- spotf2
- spotrf
- spotri
- spotrs
- sppcon
- sppequ
- spprfs
- sppsv
- sppsvx
- spptrf
- spptri
- spptrs
- sptcon

- `spteqr`
- `sptrfs`
- `sptsv`
- `sptsvx`
- `spttrf`
- `spttrs`
- `sptts2`
- `srscl`
- `ssbev`
- `ssbevd`
- `ssbevx`
- `ssbgst`
- `ssbgv`
- `ssbgvd`
- `ssbgvx`
- `ssbtrd`
- `sspcon`
- `sspev`
- `sspevd`
- `sspevx`
- `sspgst`
- `sspgv`
- `sspgvd`
- `sspgvx`
- `ssprfs`
- `sspsv`
- `sspsvx`
- `ssptrd`
- `ssptrf`
- `ssptri`
- `ssptrs`
- `sstebz`
- `sstedc`
- `sstegr`
- `sstein`
- `sstemr`

- ssteqr
- ssterf
- sstev
- sstevd
- sstevr
- sstevx
- ssycon
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- ssyevr
- ssyevx
- ssygs2
- ssygst
- ssygv
- ssygvd
- ssygvx
- ssyrfs
- ssysv
- ssysvx
- ssytd2
- ssytf2
- ssytrd
- ssytrf
- ssytri
- ssytrs
- stbcon
- stbrfs
- stbtrs
- stgevc
- stgex2
- stgexc
- stgsen
- stgsja
- stgsna
- stgsy2
- stgsyl

- stpcon
- stprfs
- stptri
- stptrs
- strcon
- strevc
- strexc
- strfs
- strsen
- strсна
- strsyl
- strti2
- strtri
- strtrs
- stzrzf
- zbdsqr
- zdrscl
- zgbbnd
- zgbccon
- zgbequ
- zgbrfs
- zgbsv
- zgbsvx
- zgbtf2
- zgbtrf
- zgbtrs
- zgebak
- zgebal
- zgebd2
- zgebrd
- zgecon
- zgeequ
- zgees
- zgeesx
- zgeev
- zgeevx

- zgehd2
- zgehrd
- zgelq2
- zgelqf
- zgels
- zgelsd
- zgelsx
- zgelsy
- zgeql2
- zgeqlf
- zgeqp3
- zgeqr2
- zgeqrf
- zgerfs
- zgerq2
- zgerqf
- zgesc2
- zgesdd
- zgesv
- zgesvd
- zgesvx
- zgetc2
- zgetf2
- zgetrf
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- zggrqf
- zgtcon
- zgtrfs
- zgtsv
- zgtsvx
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- zgtrfs
- zgts2
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- zhbevz
- zhbgst
- zhbgv
- zhbgvd
- zhbgvx
- zhbtrd
- zhecon
- zheev
- zheevd
- zheevr
- zheevz
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- zhegst
- zhegv
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- zhesvx
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- zhetrd
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- zhetri
- zhetrs
- zhgeqz

- zhpcon
- zhpev
- zhpevd
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- zhpgst
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- zhpgvd
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- zhptri
- zhptrs
- zhsein
- zhseqr
- zlabrd
- zlacgv
- zlacn2
- zlacon
- zlap2
- zlapy
- zlacrm
- zlact
- zladv
- zlaed0
- zlaed7
- zlaed8
- zlaein
- zlaesy
- zlaev2
- zlag2c
- zlags2
- zlagtm
- zlahef

- zlahqr
- zlahr2
- zlaic1
- zlals0
- zlalsa
- zlalsd
- zlangb
- zlange
- zlangt
- zlanhb
- zlanhe
- zlanhp
- zlanhs
- zlanht
- zlansb
- zlansp
- zlansy
- zlantb
- zlantp
- zlantr
- zlapll
- zlapmt
- zlaqgb
- zlaqge
- zlaqhb
- zlaqhe
- zlaqhp
- zlaqp2
- zlaqps
- zlaqr0
- zlaqr1
- zlaqr2
- zlaqr3
- zlaqr4
- zlaqr5
- zlaqsb

- zlaqsp
- zlaqsy
- zlar1v
- zlar2v
- zlarcml
- zlarf
- zlarfb
- zlarfg
- zlarft
- zlarfx
- zlargv
- zlarnv
- zlarrv
- zlarg
- zlargv
- zlarz
- zlarzb
- zlarzt
- zlascl
- zlaset
- zlasr
- zlassq
- zlaswp
- zlasyf
- zlatbs
- zlatdf
- zlatps
- zlatrd
- zlatrs
- zlatrz
- zlauu2
- zlauum
- zpbcon
- zpbequ
- zpbrfs
- zpbstf

- `zpbsv`
- `zpbsvx`
- `zpbtf2`
- `zpbtrf`
- `zpbtrs`
- `zpocon`
- `zpoequ`
- `zporfs`
- `zposv`
- `zposvx`
- `zpotf2`
- `zpotrf`
- `zpotri`
- `zpotrs`
- `zppcon`
- `zppequ`
- `zpprfs`
- `zppsv`
- `zppsvx`
- `zpptrf`
- `zpptri`
- `zpptrs`
- `zptcon`
- `zpteqr`
- `zptrfs`
- `zptsv`
- `zptsvx`
- `zpttrf`
- `zpttrs`
- `zptts2`
- `zrot`
- `zspcon`
- `zspmv`
- `zspr`
- `zsprfs`
- `zspsv`

- zpsvx
- zsptrf
- zsptri
- zsptrs
- zstedc
- zstegr
- zstein
- zstemr
- zsteqr
- zsycon
- zsymv
- zsyr
- zsyrf
- zsysv
- zsysvx
- zsytf2
- zsytrf
- zsytri
- zsytrs
- ztbcon
- ztbrfs
- ztbtrs
- ztgevc
- ztgex2
- ztgexc
- ztgsen
- ztgsja
- ztgsna
- ztgsy2
- ztgsyl
- ztpcon
- ztprfs
- ztptri
- ztptrs
- ztrcon
- ztrevc

- ztrexc
- ztrrfs
- ztrsen
- ztrsna
- ztrsyl
- ztrti2
- ztrtri
- ztrtrs
- ztzrf
- zung2l
- zung2r
- zungbr
- zunghr
- zungl2
- zunglq
- zungql
- zungqr
- zungr2
- zungrq
- zungtr
- zunm2l
- zunm2r
- zunmbr
- zunmhr
- zunml2
- zunmlq
- zunmql
- zunmqr
- zunmr2
- zunmr3
- zunmrq
- zunmrz
- zunmtr
- zupgtr
- zupmtr

## 5.14 Interpolative matrix decomposition (scipy.linalg.interpolative)

New in version 0.13.

An interpolative decomposition (ID) of a matrix  $A \in \mathbb{C}^{m \times n}$  of rank  $k \leq \min\{m, n\}$  is a factorization

$$A\Pi = [A\Pi_1 \quad A\Pi_2] = A\Pi_1 [I \quad T],$$

where  $\Pi = [\Pi_1, \Pi_2]$  is a permutation matrix with  $\Pi_1 \in \{0, 1\}^{n \times k}$ , i.e.,  $A\Pi_2 = A\Pi_1 T$ . This can equivalently be written as  $A = BP$ , where  $B = A\Pi_1$  and  $P = [I, T]\Pi^T$  are the *skeleton* and *interpolation matrices*, respectively.

If  $A$  does not have exact rank  $k$ , then there exists an approximation in the form of an ID such that  $A = BP + E$ , where  $\|E\| \sim \sigma_{k+1}$  is on the order of the  $(k + 1)$ -th largest singular value of  $A$ . Note that  $\sigma_{k+1}$  is the best possible error for a rank- $k$  approximation and, in fact, is achieved by the singular value decomposition (SVD)  $A \approx USV^*$ , where  $U \in \mathbb{C}^{m \times k}$  and  $V \in \mathbb{C}^{n \times k}$  have orthonormal columns and  $S = \text{diag}(\sigma_i) \in \mathbb{C}^{k \times k}$  is diagonal with nonnegative entries. The principal advantages of using an ID over an SVD are that:

- it is cheaper to construct;
- it preserves the structure of  $A$ ; and
- it is more efficient to compute with in light of the identity submatrix of  $P$ .

### 5.14.1 Routines

Main functionality:

<code>interp_decomp(A, eps_or_k[, rand])</code>	Compute ID of a matrix.
<code>reconstruct_matrix_from_id(B, idx, proj)</code>	Reconstruct matrix from its ID.
<code>reconstruct_interp_matrix(idx, proj)</code>	Reconstruct interpolation matrix from ID.
<code>reconstruct_skel_matrix(A, k, idx)</code>	Reconstruct skeleton matrix from ID.
<code>id_to_svd(B, idx, proj)</code>	Convert ID to SVD.
<code>svd(A, eps_or_k[, rand])</code>	Compute SVD of a matrix via an ID.
<code>estimate_spectral_norm(A[, its])</code>	Estimate spectral norm of a matrix by the randomized power method.
<code>estimate_spectral_norm_diff(A, B[, its])</code>	Estimate spectral norm of the difference of two matrices by the randomized power method.
<code>estimate_rank(A, eps)</code>	Estimate matrix rank to a specified relative precision using randomized methods.

`scipy.linalg.interpolative.interp_decomp(A, eps_or_k, rand=True)`

Compute ID of a matrix.

An ID of a matrix  $A$  is a factorization defined by a rank  $k$ , a column index array  $idx$ , and interpolation coefficients  $proj$  such that:

```
numpy.dot(A[:, idx[:k]], proj) = A[:, idx[k:]]
```

The original matrix can then be reconstructed as:

```
numpy.hstack([A[:, idx[:k]],
              numpy.dot(A[:, idx[k:]], proj)]
             )[:, numpy.argsort(idx)]
```

or via the routine `reconstruct_matrix_from_id`. This can equivalently be written as:

```
numpy.dot(A[:,idx[:k]],
          numpy.hstack([numpy.eye(k), proj])
          )[:,np.argsort(idx)]
```

in terms of the skeleton and interpolation matrices:

```
B = A[:,idx[:k]]
```

and:

```
P = numpy.hstack([numpy.eye(k), proj])[:,np.argsort(idx)]
```

respectively. See also `reconstruct_interp_matrix` and `reconstruct_skel_matrix`.

The ID can be computed to any relative precision or rank (depending on the value of `eps_or_k`). If a precision is specified (`eps_or_k < 1`), then this function has the output signature:

```
k, idx, proj = interp_decomp(A, eps_or_k)
```

Otherwise, if a rank is specified (`eps_or_k >= 1`), then the output signature is:

```
idx, proj = interp_decomp(A, eps_or_k)
```

**Parameters**

- A**: `numpy.ndarray` or `scipy.sparse.linalg.LinearOperator` with `rmatvec` Matrix to be factored
- eps\_or\_k**: float or int  
Relative error (if `eps_or_k < 1`) or rank (if `eps_or_k >= 1`) of approximation.
- rand**: bool, optional  
Whether to use random sampling if `A` is of type `numpy.ndarray` (randomized algorithms are always used if `A` is of type `scipy.sparse.linalg.LinearOperator`).

**Returns**

- k**: int  
Rank required to achieve specified relative precision if `eps_or_k < 1`.
- idx**: `numpy.ndarray`  
Column index array.
- proj**: `numpy.ndarray`  
Interpolation coefficients.

`scipy.linalg.interpolative.reconstruct_matrix_from_id(B, idx, proj)`

Reconstruct matrix from its ID.

A matrix `A` with skeleton matrix `B` and ID indices and coefficients `idx` and `proj`, respectively, can be reconstructed as:

```
numpy.hstack([B, numpy.dot(B, proj)])[:,np.argsort(idx)]
```

See also `reconstruct_interp_matrix` and `reconstruct_skel_matrix`.

**Parameters**

- B**: `numpy.ndarray`  
Skeleton matrix.
- idx**: `numpy.ndarray`  
Column index array.
- proj**: `numpy.ndarray`  
Interpolation coefficients.

**Returns**

- `numpy.ndarray`

Reconstructed matrix.

`scipy.linalg.interpolative.reconstruct_interp_matrix`(*idx*, *proj*)  
 Reconstruct interpolation matrix from ID.

The interpolation matrix can be reconstructed from the ID indices and coefficients *idx* and *proj*, respectively, as:

```
P = numpy.hstack([numpy.eye(proj.shape[0]), proj])[ :, numpy.argsort(idx) ]
```

The original matrix can then be reconstructed from its skeleton matrix *B* via:

```
numpy.dot(B, P)
```

See also `reconstruct_matrix_from_id` and `reconstruct_skel_matrix`.

**Parameters** **idx**: `numpy.ndarray`  
 Column index array.  
**proj**: `numpy.ndarray`  
 Interpolation coefficients.  
**Returns** `numpy.ndarray`  
 Interpolation matrix.

`scipy.linalg.interpolative.reconstruct_skel_matrix`(*A*, *k*, *idx*)  
 Reconstruct skeleton matrix from ID.

The skeleton matrix can be reconstructed from the original matrix *A* and its ID rank and indices *k* and *idx*, respectively, as:

```
B = A[:, idx[:k]]
```

The original matrix can then be reconstructed via:

```
numpy.hstack([B, numpy.dot(B, proj)])[ :, numpy.argsort(idx) ]
```

See also `reconstruct_matrix_from_id` and `reconstruct_interp_matrix`.

**Parameters** **A**: `numpy.ndarray`  
 Original matrix.  
**k**: `int`  
 Rank of ID.  
**idx**: `numpy.ndarray`  
 Column index array.  
**Returns** `numpy.ndarray`  
 Skeleton matrix.

`scipy.linalg.interpolative.id_to_svd`(*B*, *idx*, *proj*)  
 Convert ID to SVD.

The SVD reconstruction of a matrix with skeleton matrix *B* and ID indices and coefficients *idx* and *proj*, respectively, is:

```
U, S, V = id_to_svd(B, idx, proj)
A = numpy.dot(U, numpy.dot(numpy.diag(S), V.conj().T))
```

See also `svd`.

**Parameters** **B**: `numpy.ndarray`  
 Skeleton matrix.  
**idx**: `numpy.ndarray`  
 Column index array.

**Returns**

- proj**: `numpy.ndarray`  
Interpolation coefficients.
- U**: `numpy.ndarray`  
Left singular vectors.
- S**: `numpy.ndarray`  
Singular values.
- V**: `numpy.ndarray`  
Right singular vectors.

`scipy.linalg.interpolative.svd(A, eps_or_k, rand=True)`  
Compute SVD of a matrix via an ID.

An SVD of a matrix  $A$  is a factorization:

```
A = numpy.dot(U, numpy.dot(numpy.diag(S), V.conj().T))
```

where  $U$  and  $V$  have orthonormal columns and  $S$  is nonnegative.

The SVD can be computed to any relative precision or rank (depending on the value of `eps_or_k`).

See also `interp_decomp` and `id_to_svd`.

**Parameters**

- A**: `numpy.ndarray` or `scipy.sparse.linalg.LinearOperator`  
Matrix to be factored, given as either a `numpy.ndarray` or a `scipy.sparse.linalg.LinearOperator` with the `matvec` and `rmatvec` methods (to apply the matrix and its adjoint).
- eps\_or\_k**: float or int  
Relative error (if `eps_or_k < 1`) or rank (if `eps_or_k >= 1`) of approximation.
- rand**: bool, optional  
Whether to use random sampling if  $A$  is of type `numpy.ndarray` (randomized algorithms are always used if  $A$  is of type `scipy.sparse.linalg.LinearOperator`).

**Returns**

- U**: `numpy.ndarray`  
Left singular vectors.
- S**: `numpy.ndarray`  
Singular values.
- V**: `numpy.ndarray`  
Right singular vectors.

`scipy.linalg.interpolative.estimate_spectral_norm(A, its=20)`  
Estimate spectral norm of a matrix by the randomized power method.

**Parameters**

- A**: `scipy.sparse.linalg.LinearOperator`  
Matrix given as a `scipy.sparse.linalg.LinearOperator` with the `matvec` and `rmatvec` methods (to apply the matrix and its adjoint).
- its**: int, optional  
Number of power method iterations.

**Returns**

- float  
Spectral norm estimate.

`scipy.linalg.interpolative.estimate_spectral_norm_diff(A, B, its=20)`  
Estimate spectral norm of the difference of two matrices by the randomized power method.

**Parameters**

- A**: `scipy.sparse.linalg.LinearOperator`  
First matrix given as a `scipy.sparse.linalg.LinearOperator` with the `matvec` and `rmatvec` methods (to apply the matrix and its adjoint).
- B**: `scipy.sparse.linalg.LinearOperator`  
Second matrix given as a `scipy.sparse.linalg.LinearOperator` with the `matvec` and `rmatvec` methods (to apply the matrix and its adjoint).

**Returns** **its** : int, optional  
 Number of power method iterations.  
**float**  
 Spectral norm estimate of matrix difference.

`scipy.linalg.interpolative.estimate_rank(A, eps)`  
 Estimate matrix rank to a specified relative precision using randomized methods.

The matrix *A* can be given as either a `numpy.ndarray` or a `scipy.sparse.linalg.LinearOperator`, with different algorithms used for each case. If *A* is of type `numpy.ndarray`, then the output rank is typically about 8 higher than the actual numerical rank.

**Parameters** **A** : `numpy.ndarray` or `scipy.sparse.linalg.LinearOperator`  
 Matrix whose rank is to be estimated, given as either a `numpy.ndarray` or a `scipy.sparse.linalg.LinearOperator` with the `rmatvec` method (to apply the matrix adjoint).  
**eps** : float  
 Relative error for numerical rank definition.  
**Returns** **int**  
 Estimated matrix rank.

Support functions:

<code>seed([seed])</code>	Seed the internal random number generator used in this ID package.
<code>rand(*shape)</code>	Generate standard uniform pseudorandom numbers via a very efficient lagged Fibonacci method.

`scipy.linalg.interpolative.seed(seed=None)`  
 Seed the internal random number generator used in this ID package.

The generator is a lagged Fibonacci method with 55-element internal state.

**Parameters** **seed** : int, sequence, 'default', optional  
 If 'default', the random seed is reset to a default value.  
 If *seed* is a sequence containing 55 floating-point numbers in range [0,1], these are used to set the internal state of the generator.  
 If the value is an integer, the internal state is obtained from `numpy.random.RandomState` (MT19937) with the integer used as the initial seed.  
 If *seed* is omitted (None), `numpy.random` is used to initialize the generator.

`scipy.linalg.interpolative.rand(*shape)`  
 Generate standard uniform pseudorandom numbers via a very efficient lagged Fibonacci method.

This routine is used for all random number generation in this package and can affect ID and SVD results.

**Parameters** **shape**  
 Shape of output array

## 5.14.2 References

This module uses the ID software package [R830] by Martinsson, Rokhlin, Shkolnisky, and Tygert, which is a Fortran library for computing IDs using various algorithms, including the rank-revealing QR approach of [R831] and the more recent randomized methods described in [R832], [R833], and [R834]. This module exposes its functionality in a way convenient for Python users. Note that this module does not add any functionality beyond that of organizing a simpler and more consistent interface.

We advise the user to consult also the [documentation](#) for the ID package.

### 5.14.3 Tutorial

#### Initializing

The first step is to import `scipy.linalg.interpolative` by issuing the command:

```
>>> import scipy.linalg.interpolative as sli
```

Now let's build a matrix. For this, we consider a Hilbert matrix, which is well know to have low rank:

```
>>> from scipy.linalg import hilbert
>>> n = 1000
>>> A = hilbert(n)
```

We can also do this explicitly via:

```
>>> import numpy as np
>>> n = 1000
>>> A = np.empty((n, n), order='F')
>>> for j in range(n):
>>>     for i in range(m):
>>>         A[i, j] = 1. / (i + j + 1)
```

Note the use of the flag `order='F'` in `numpy.empty`. This instantiates the matrix in Fortran-contiguous order and is important for avoiding data copying when passing to the backend.

We then define multiplication routines for the matrix by regarding it as a `scipy.sparse.linalg.LinearOperator`:

```
>>> from scipy.sparse.linalg import aslinearoperator
>>> L = aslinearoperator(A)
```

This automatically sets up methods describing the action of the matrix and its adjoint on a vector.

#### Computing an ID

We have several choices of algorithm to compute an ID. These fall largely according to two dichotomies:

1. how the matrix is represented, i.e., via its entries or via its action on a vector; and
2. whether to approximate it to a fixed relative precision or to a fixed rank.

We step through each choice in turn below.

In all cases, the ID is represented by three parameters:

1. a rank `k`;
2. an index array `idx`; and
3. interpolation coefficients `proj`.

The ID is specified by the relation `np.dot(A[:,idx[:k]], proj) == A[:,idx[k:]]`.

***From matrix entries***

We first consider a matrix given in terms of its entries.

To compute an ID to a fixed precision, type:

```
>>> k, idx, proj = sli.interp_decomp(A, eps)
```

where `eps < 1` is the desired precision.

To compute an ID to a fixed rank, use:

```
>>> idx, proj = sli.interp_decomp(A, k)
```

where `k >= 1` is the desired rank.

Both algorithms use random sampling and are usually faster than the corresponding older, deterministic algorithms, which can be accessed via the commands:

```
>>> k, idx, proj = sli.interp_decomp(A, eps, rand=False)
```

and:

```
>>> idx, proj = sli.interp_decomp(A, k, rand=False)
```

respectively.

***From matrix action***

Now consider a matrix given in terms of its action on a vector as a `scipy.sparse.linalg.LinearOperator`.

To compute an ID to a fixed precision, type:

```
>>> k, idx, proj = sli.interp_decomp(L, eps)
```

To compute an ID to a fixed rank, use:

```
>>> idx, proj = sli.interp_decomp(L, k)
```

These algorithms are randomized.

**Reconstructing an ID**

The ID routines above do not output the skeleton and interpolation matrices explicitly but instead return the relevant information in a more compact (and sometimes more useful) form. To build these matrices, write:

```
>>> B = sli.reconstruct_skel_matrix(A, k, idx)
```

for the skeleton matrix and:

```
>>> P = sli.reconstruct_interp_matrix(idx, proj)
```

for the interpolation matrix. The ID approximation can then be computed as:

```
>>> C = np.dot(B, P)
```

This can also be constructed directly using:

```
>>> C = sli.reconstruct_matrix_from_id(B, idx, proj)
```

without having to first compute P.

Alternatively, this can be done explicitly as well using:

```
>>> B = A[:, idx[:k]]
>>> P = np.hstack([np.eye(k), proj])[:, np.argsort(idx)]
>>> C = np.dot(B, P)
```

## Computing an SVD

An ID can be converted to an SVD via the command:

```
>>> U, S, V = sli.id_to_svd(B, idx, proj)
```

The SVD approximation is then:

```
>>> C = np.dot(U, np.dot(np.diag(S), np.dot(V.conj().T)))
```

The SVD can also be computed “fresh” by combining both the ID and conversion steps into one command. Following the various ID algorithms above, there are correspondingly various SVD algorithms that one can employ.

### *From matrix entries*

We consider first SVD algorithms for a matrix given in terms of its entries.

To compute an SVD to a fixed precision, type:

```
>>> U, S, V = sli.svd(A, eps)
```

To compute an SVD to a fixed rank, use:

```
>>> U, S, V = sli.svd(A, k)
```

Both algorithms use random sampling; for the deterministic versions, issue the keyword `rand=False` as above.

### *From matrix action*

Now consider a matrix given in terms of its action on a vector.

To compute an SVD to a fixed precision, type:

```
>>> U, S, V = sli.svd(L, eps)
```

To compute an SVD to a fixed rank, use:

```
>>> U, S, V = sli.svd(L, k)
```

## Utility routines

Several utility routines are also available.

To estimate the spectral norm of a matrix, use:

```
>>> snorm = sli.estimate_spectral_norm(A)
```

This algorithm is based on the randomized power method and thus requires only matrix-vector products. The number of iterations to take can be set using the keyword `its` (default: `its=20`). The matrix is interpreted as a `scipy.sparse.linalg.LinearOperator`, but it is also valid to supply it as a `numpy.ndarray`, in which case it is trivially converted using `scipy.sparse.linalg.aslinearoperator`.

The same algorithm can also estimate the spectral norm of the difference of two matrices `A1` and `A2` as follows:

```
>>> diff = sli.estimate_spectral_norm_diff(A1, A2)
```

This is often useful for checking the accuracy of a matrix approximation.

Some routines in `scipy.linalg.interpolative` require estimating the rank of a matrix as well. This can be done with either:

```
>>> k = sli.estimate_rank(A, eps)
```

or:

```
>>> k = sli.estimate_rank(L, eps)
```

depending on the representation. The parameter `eps` controls the definition of the numerical rank.

Finally, the random number generation required for all randomized routines can be controlled via `scipy.linalg.interpolative.seed`. To reset the seed values to their original values, use:

```
>>> sli.seed('default')
```

To specify the seed values, use:

```
>>> sli.seed(s)
```

where `s` must be an integer or array of 55 floats. If an integer, the array of floats is obtained by using `np.random.rand` with the given integer seed.

To simply generate some random numbers, type:

```
>>> sli.rand(n)
```

where `n` is the number of random numbers to generate.

## Remarks

The above functions all automatically detect the appropriate interface and work with both real and complex data types, passing input arguments to the proper backend routine.

## 5.15 Miscellaneous routines (`scipy.misc`)

Various utilities that don't have another home.

Note that Pillow (<https://python-pillow.org/>) is not a dependency of SciPy, but the image manipulation functions indicated in the list below are not available without it.

<code>ascent()</code>	Get an 8-bit grayscale bit-depth, 512 x 512 derived image for easy use in demos
<code>central_diff_weights(Np[, ndiv])</code>	Return weights for an <code>Np</code> -point central derivative.

Continued on next page

Table 5.99 – continued from previous page

<code>derivative(func, x0[, dx, n, args, order])</code>	Find the n-th derivative of a function at a point.
<code>face([gray])</code>	Get a 1024 x 768, color image of a raccoon face.

`scipy.misc.ascent()`

Get an 8-bit grayscale bit-depth, 512 x 512 derived image for easy use in demos

The image is derived from `accent-to-the-top.jpg` at <http://www.public-domain-image.com/people-public-domain-images-pictures/>

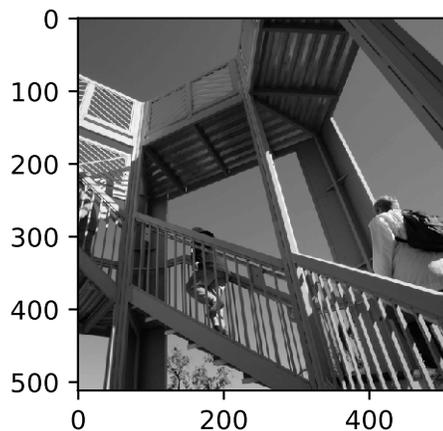
**Parameters** None

**Returns** `ascent` : ndarray  
convenient image to use for testing and demonstration

### Examples

```
>>> import scipy.misc
>>> ascent = scipy.misc.ascent()
>>> ascent.shape
(512, 512)
>>> ascent.max()
255
```

```
>>> import matplotlib.pyplot as plt
>>> plt.gray()
>>> plt.imshow(ascent)
>>> plt.show()
```



`scipy.misc.central_diff_weights(Np, ndiv=1)`

Return weights for an  $N_p$ -point central derivative.

Assumes equally-spaced function points.

If weights are in the vector  $w$ , then derivative is  $w[0] * f(x-h_0*dx) + \dots + w[-1] * f(x+h_0*dx)$

**Parameters** `Np` : int  
Number of points for the central derivative.  
`ndiv` : int, optional

Number of divisions. Default is 1.

**Notes**

Can be inaccurate for large number of points.

`scipy.misc.derivative` (*func*, *x0*, *dx=1.0*, *n=1*, *args=()*, *order=3*)

Find the *n*-th derivative of a function at a point.

Given a function, use a central difference formula with spacing *dx* to compute the *n*-th derivative at *x0*.

**Parameters**

- func** : function  
Input function.
- x0** : float  
The point at which *n*-th derivative is found.
- dx** : float, optional  
Spacing.
- n** : int, optional  
Order of the derivative. Default is 1.
- args** : tuple, optional  
Arguments
- order** : int, optional  
Number of points to use, must be odd.

**Notes**

Decreasing the step size too small can result in round-off error.

**Examples**

```
>>> from scipy.misc import derivative
>>> def f(x):
...     return x**3 + x**2
>>> derivative(f, 1.0, dx=1e-6)
4.9999999999217337
```

`scipy.misc.face` (*gray=False*)

Get a 1024 x 768, color image of a raccoon face.

raccoon-procyon-lotor.jpg at <http://www.public-domain-image.com>

**Parameters**

- gray** : bool, optional  
If True return 8-bit grey-scale image, otherwise return a color image

**Returns**

- face** : ndarray  
image of a racoon face

**Examples**

```
>>> import scipy.misc
>>> face = scipy.misc.face()
>>> face.shape
(768, 1024, 3)
>>> face.max()
255
>>> face.dtype
dtype('uint8')
```

```
>>> import matplotlib.pyplot as plt
>>> plt.gray()
>>> plt.imshow(face)
>>> plt.show()
```



Deprecated functions:

<code>bytescale(*args, **kwargs)</code>	<code>bytescale</code> is deprecated!
<code>fromimage(*args, **kwargs)</code>	<code>fromimage</code> is deprecated!
<code>imfilter(*args, **kwargs)</code>	<code>imfilter</code> is deprecated!
<code>imread(*args, **kwargs)</code>	<code>imread</code> is deprecated!
<code>imresize(*args, **kwargs)</code>	<code>imresize</code> is deprecated!
<code>imrotate(*args, **kwargs)</code>	<code>imrotate</code> is deprecated!
<code>imsave(*args, **kwargs)</code>	<code>imsave</code> is deprecated!
<code>imshow(*args, **kwargs)</code>	<code>imshow</code> is deprecated!
<code>toimage(*args, **kwargs)</code>	<code>toimage</code> is deprecated!

`scipy.misc.bytescale(*args, **kwargs)`

`bytescale` is deprecated! `bytescale` is deprecated in SciPy 1.0.0, and will be removed in 1.2.0.

Byte scales an array (image).

Byte scaling means converting the input image to uint8 dtype and scaling the range to `(low, high)` (default 0-255). If the input image already has dtype uint8, no scaling is done.

This function is only available if Python Imaging Library (PIL) is installed.

**Parameters** `data` : ndarray

PIL image data array.

**`cmin`** [scalar, optional] Bias scaling of small values. Default is `data.min()`.

**`cmax`** [scalar, optional] Bias scaling of large values. Default is `data.max()`.

**`high`** [scalar, optional] Scale max value to `high`. Default is 255.

**`low`** [scalar, optional] Scale min value to `low`. Default is 0.

**Returns** `img_array` : uint8 ndarray

The byte-scaled array.

*Examples*

```

>>> from scipy.misc import bytescale
>>> img = np.array([[ 91.06794177,   3.39058326,   84.4221549 ],
...                [ 73.88003259,   80.91433048,   4.88878881],
...                [ 51.53875334,   34.45808177,   27.5873488 ]])
>>> bytescale(img)
array([[255,   0, 236],
       [205, 225,   4],
       [140,  90,  70]], dtype=uint8)
>>> bytescale(img, high=200, low=100)
array([[200, 100, 192],
       [180, 188, 102],
       [155, 135, 128]], dtype=uint8)
>>> bytescale(img, cmin=0, cmax=255)
array([[91,   3, 84],
       [74, 81,  5],
       [52, 34, 28]], dtype=uint8)

```

`scipy.misc.fromimage(*args, **kwargs)`

*fromimage* is deprecated! *fromimage* is deprecated in SciPy 1.0.0. and will be removed in 1.2.0. Use `np.asarray(im)` instead.

Return a copy of a PIL image as a numpy array.

This function is only available if Python Imaging Library (PIL) is installed.

**Parameters** **im** : PIL image

Input image.

**flatten**

[bool] If true, convert the output to grey-scale.

**mode**

[str, optional] Mode to convert image to, e.g. 'RGB'. See the Notes of the *imread* docstring for more details.

**Returns** **fromimage** : ndarray

The different colour bands/channels are stored in the third dimension, such that a grey-image is MxN, an RGB-image MxNx3 and an RGBA-image MxNx4.

`scipy.misc.imfilter(*args, **kwargs)`

*imfilter* is deprecated! *imfilter* is deprecated in SciPy 1.0.0, and will be removed in 1.2.0. Use Pillow filtering functionality directly.

Simple filtering of an image.

This function is only available if Python Imaging Library (PIL) is installed.

**Warning:** This function uses *bytescale* under the hood to rescale images to use the full (0, 255) range if mode is one of None, 'L', 'P', '1'. It will also cast data for 2-D images to uint32 for mode=None (which is the default).

**Parameters** **arr** : ndarray

The array of Image in which the filter is to be applied.

**ftype**

[str] The filter that has to be applied. Legal values are: 'blur', 'contour', 'detail', 'edge\_enhance', 'edge\_enhance\_more', 'emboss', 'find\_edges', 'smooth', 'smooth\_more', 'sharpen'.

**Returns** **imfilter** : ndarray

The array with filter applied.

**Raises**      **ValueError**

*Unknown filter type.* If the filter you are trying to apply is unsupported.

`scipy.misc.imread(*args, **kwargs)`

*imread* is deprecated! *imread* is deprecated in SciPy 1.0.0, and will be removed in 1.2.0. Use `imageio.imread` instead.

Read an image from a file as an array.

This function is only available if Python Imaging Library (PIL) is installed.

**Parameters**

**name** : str or file object

The file name or file object to be read.

**flatten**

[bool, optional] If True, flattens the color layers into a single gray-scale layer.

**mode**

[str, optional] Mode to convert image to, e.g. 'RGB'. See the Notes for more details.

**Returns**

**imread** : ndarray

The array obtained by reading the image.

**Notes**

*imread* uses the Python Imaging Library (PIL) to read an image. The following notes are from the PIL documentation.

*mode* can be one of the following strings:

- 'L' (8-bit pixels, black and white)
- 'P' (8-bit pixels, mapped to any other mode using a color palette)
- 'RGB' (3x8-bit pixels, true color)
- 'RGBA' (4x8-bit pixels, true color with transparency mask)
- 'CMYK' (4x8-bit pixels, color separation)
- 'YCbCr' (3x8-bit pixels, color video format)
- 'I' (32-bit signed integer pixels)
- 'F' (32-bit floating point pixels)

PIL also provides limited support for a few special modes, including 'LA' ('L' with alpha), 'RGBX' (true color with padding) and 'RGBA' (true color with premultiplied alpha).

When translating a color image to black and white (mode 'L', 'I' or 'F'), the library uses the ITU-R 601-2 luma transform:

$$L = R * 299/1000 + G * 587/1000 + B * 114/1000$$

When *flatten* is True, the image is converted using mode 'F'. When *mode* is not None and *flatten* is True, the image is first converted according to *mode*, and the result is then flattened using mode 'F'.

`scipy.misc.imresize(*args, **kwargs)`

*imresize* is deprecated! *imresize* is deprecated in SciPy 1.0.0, and will be removed in 1.2.0. Use `skimage.transform.resize` instead.

Resize an image.

This function is only available if Python Imaging Library (PIL) is installed.

**Warning:** This function uses *bytescale* under the hood to rescale images to use the full (0, 255) range if mode is one of None, 'L', 'P', 'l'. It will also cast data for 2-D images to `uint32` for mode=None (which is the default).

**Parameters**

**arr** : ndarray  
The array of image to be resized.

**size** : [int, float or tuple]  

- int - Percentage of current size.
- float - Fraction of current size.
- tuple - Size of the output image (height, width).

**interp** : [str, optional] Interpolation to use for re-sizing ('nearest', 'lanczos', 'bilinear', 'bicubic' or 'cubic').

**mode** : [str, optional] The PIL image mode ('P', 'L', etc.) to convert *arr* before resizing. If mode=None (the default), 2-D images will be treated like mode='L', i.e. casting to long integer. For 3-D and 4-D arrays, mode will be set to 'RGB' and 'RGBA' respectively.

**Returns**

**imresize** : ndarray  
The resized array of image.

See also:

**toimage** Implicitly used to convert *arr* according to *mode*.

**scipy.ndimage.zoom**  
More generic implementation that does not use PIL.

`scipy.misc.imrotate(*args, **kws)`

*imrotate* is deprecated! *imrotate* is deprecated in SciPy 1.0.0, and will be removed in 1.2.0. Use `skimage.transform.rotate` instead.

Rotate an image counter-clockwise by angle degrees.  
This function is only available if Python Imaging Library (PIL) is installed.

**Warning:** This function uses *bytescale* under the hood to rescale images to use the full (0, 255) range if mode is one of None, 'L', 'P', 'l'. It will also cast data for 2-D images to `uint32` for mode=None (which is the default).

**Parameters**

**arr** : ndarray  
Input array of image to be rotated.

**angle** : [float] The angle of rotation.

**interp** : [str, optional] Interpolation  

- 'nearest' : for nearest neighbor
- 'bilinear' : for bilinear
- 'lanczos' : for lanczos
- 'cubic' : for bicubic
- 'bicubic' : for bicubic

**Returns**

**imrotate** : ndarray  
The rotated array of image.

`scipy.misc.imsave(*args, **kwargs)`

*imsave* is deprecated! *imsave* is deprecated in SciPy 1.0.0, and will be removed in 1.2.0. Use `imageio.imwrite` instead.

Save an array as an image.

This function is only available if Python Imaging Library (PIL) is installed.

**Warning:** This function uses *bytescale* under the hood to rescale images to use the full (0, 255) range if mode is one of `None`, `'L'`, `'P'`, `'1'`. It will also cast data for 2-D images to `uint32` for mode=`None` (which is the default).

**Parameters** **name** : str or file object

Output file name or file object.

**arr** [ndarray, MxN or MxNx3 or MxNx4] Array containing image values. If the shape is MxN, the array represents a grey-level image. Shape MxNx3 stores the red, green and blue bands along the last dimension. An alpha layer may be included, specified as the last colour band of an MxNx4 array.

**format** [str] Image format. If omitted, the format to use is determined from the file name extension. If a file object was used instead of a file name, this parameter should always be used.

### Examples

Construct an array of gradient intensity values and save to file:

```
>>> from scipy.misc import imsave
>>> x = np.zeros((255, 255))
>>> x = np.zeros((255, 255), dtype=np.uint8)
>>> x[:] = np.arange(255)
>>> imsave('gradient.png', x)
```

Construct an array with three colour bands (R, G, B) and store to file:

```
>>> rgb = np.zeros((255, 255, 3), dtype=np.uint8)
>>> rgb[..., 0] = np.arange(255)
>>> rgb[..., 1] = 55
>>> rgb[..., 2] = 1 - np.arange(255)
>>> imsave('rgb_gradient.png', rgb)
```

`scipy.misc.imshow(*args, **kwargs)`

*imshow* is deprecated! *imshow* is deprecated in SciPy 1.0.0, and will be removed in 1.2.0. Use `matplotlib.pyplot.imshow` instead.

Simple showing of an image through an external viewer.

This function is only available if Python Imaging Library (PIL) is installed.

Uses the image viewer specified by the environment variable `SCIPY_PIL_IMAGE_VIEWER`, or if that is not defined then *see*, to view a temporary file generated from array data.

**Warning:** This function uses *bytescale* under the hood to rescale images to use the full (0, 255) range if mode is one of `None`, `'L'`, `'P'`, `'1'`. It will also cast data for 2-D images to `uint32` for mode=`None` (which is the default).

**Parameters** **arr** : ndarray

**Returns** Array of image data to show.  
None

**Examples**

```
>>> a = np.tile(np.arange(255), (255,1))
>>> from scipy import misc
>>> misc.imshow(a)
```

`scipy.misc.toimage(*args, **kws)`  
*toimage* is deprecated! *toimage* is deprecated in SciPy 1.0.0, and will be removed in 1.2.0. Use Pillow’s `Image.fromarray` directly instead.

Takes a numpy array and returns a PIL image.

This function is only available if Python Imaging Library (PIL) is installed.  
 The mode of the PIL image depends on the array shape and the *pal* and *mode* keywords.  
 For 2-D arrays, if *pal* is a valid (N,3) byte-array giving the RGB values (from 0 to 255) then *mode*=‘P’, otherwise *mode*=‘L’, unless *mode* is given as ‘F’ or ‘I’ in which case a float and/or integer array is made.

**Warning:** This function uses *bytescale* under the hood to rescale images to use the full (0, 255) range if *mode* is one of None, ‘L’, ‘P’, ‘l’. It will also cast data for 2-D images to `uint32` for *mode*=None (which is the default).

**Notes**

For 3-D arrays, the *channel\_axis* argument tells which dimension of the array holds the channel data.

For 3-D arrays if one of the dimensions is 3, the *mode* is ‘RGB’ by default or ‘YCbCr’ if selected.

The numpy array must be either 2 dimensional or 3 dimensional.

Deprecated aliases:

<code>comb(*args, **kws)</code>	<code>comb</code> is deprecated!
<code>factorial(*args, **kws)</code>	<code>factorial</code> is deprecated!
<code>factorial2(*args, **kws)</code>	<code>factorial2</code> is deprecated!
<code>factorialk(*args, **kws)</code>	<code>factorialk</code> is deprecated!
<code>logsumexp(*args, **kws)</code>	<code>logsumexp</code> is deprecated!
<code>pade(*args, **kws)</code>	<code>pade</code> is deprecated!
<code>info(*args, **kws)</code>	Get help information for a function, class, or module.
<code>source(*args, **kws)</code>	<code>source</code> is deprecated!
<code>who(*args, **kws)</code>	<code>who</code> is deprecated!

`scipy.misc.comb(*args, **kws)`  
*comb* is deprecated! Importing *comb* from `scipy.misc` is deprecated in `scipy 1.0.0`. Use `scipy.special.comb` instead.

The number of combinations of N things taken k at a time.

This is often expressed as “N choose k”.

**Parameters** **N** : int, ndarray  
 Number of things.  
**k** [int, ndarray] Number of elements taken.

**exact** [bool, optional] If *exact* is False, then floating point precision is used, otherwise exact long integer is computed.

**repetition** [bool, optional] If *repetition* is True, then the number of combinations with repetition is computed.

**Returns** **val** : int, float, ndarray  
The total number of combinations.

**See also:**

**binom** Binomial coefficient ufunc

**Notes**

- Array arguments accepted only for *exact=False* case.
- If  $k > N$ ,  $N < 0$ , or  $k < 0$ , then a 0 is returned.

**Examples**

```
>>> from scipy.special import comb
>>> k = np.array([3, 4])
>>> n = np.array([10, 10])
>>> comb(n, k, exact=False)
array([ 120.,  210.])
>>> comb(10, 3, exact=True)
120L
>>> comb(10, 3, exact=True, repetition=True)
220L
```

`scipy.misc.factorial(*args, **kws)`

*factorial* is deprecated! Importing *factorial* from `scipy.misc` is deprecated in `scipy 1.0.0`. Use `scipy.special.factorial` instead.

The factorial of a number or array of numbers.

The factorial of non-negative integer  $n$  is the product of all positive integers less than or equal to  $n$ :

$$n! = n * (n - 1) * (n - 2) * \dots * 1$$

**Parameters** **n** : int or array\_like of ints  
Input values. If  $n < 0$ , the return value is 0.

**exact** [bool, optional] If True, calculate the answer exactly using long integer arithmetic. If False, result is approximated in floating point rapidly using the *gamma* function. Default is False.

**Returns** **nf** : float or int or ndarray  
Factorial of  $n$ , as integer or float depending on *exact*.

**Notes**

For arrays with *exact=True*, the factorial is computed only once, for the largest input, with each other result computed in the process. The output dtype is increased to `int64` or `object` if necessary.

With *exact=False* the factorial is approximated using the gamma function:

$$n! = \Gamma(n + 1)$$

*Examples*

```
>>> from scipy.special import factorial
>>> arr = np.array([3, 4, 5])
>>> factorial(arr, exact=False)
array([ 6., 24., 120.])
>>> factorial(arr, exact=True)
array([ 6, 24, 120])
>>> factorial(5, exact=True)
120L
```

scipy.misc.**factorial2**(\*args, \*\*kwargs)  
*factorial2* is deprecated! Importing *factorial2* from *scipy.misc* is deprecated in *scipy 1.0.0*. Use *scipy.special.factorial2* instead.

Double factorial.

This is the factorial with every second value skipped. E.g.,  $7!! = 7 * 5 * 3 * 1$ . It can be approximated numerically as:

$$n!! = \begin{cases} \text{special.gamma}(n/2+1) * 2^{*(m+1)/2} / \text{sqrt}(\pi) & n \text{ odd} \\ 2^{*(n/2)} * (n/2)! & n \text{ even} \end{cases}$$

**Parameters** **n** : int or array\_like  
 Calculate  $n!!$ . Arrays are only supported with *exact* set to *False*. If  $n < 0$ , the return value is 0.  
**exact** [bool, optional] The result can be approximated rapidly using the gamma-formula above (default). If *exact* is set to *True*, calculate the answer exactly using integer arithmetic.

**Returns** **nff** : float or int  
 Double factorial of  $n$ , as an int or a float depending on *exact*.

*Examples*

```
>>> from scipy.special import factorial2
>>> factorial2(7, exact=False)
array(105.00000000000001)
>>> factorial2(7, exact=True)
105L
```

scipy.misc.**factorialk**(\*args, \*\*kwargs)  
*factorialk* is deprecated! Importing *factorialk* from *scipy.misc* is deprecated in *scipy 1.0.0*. Use *scipy.special.factorialk* instead.

Multifactorial of  $n$  of order  $k$ ,  $n(!...!)$ .

This is the multifactorial of  $n$  skipping  $k$  values. For example,  
 $factorialk(17, 4) = 17!!!! = 17 * 13 * 9 * 5 * 1$

In particular, for any integer  $n$ , we have  
 $factorialk(n, 1) = factorial(n)$   
 $factorialk(n, 2) = factorial2(n)$

**Parameters** **n** : int  
 Calculate multifactorial. If  $n < 0$ , the return value is 0.  
**k** [int] Order of multifactorial.

**exact** [bool, optional] If exact is set to True, calculate the answer exactly using integer arithmetic.

**Returns** **val** : int  
Multifactorial of  $n$ .

**Raises** **NotImplementedError**  
Raises when exact is False

**Examples**

```
>>> from scipy.special import factorialk
>>> factorialk(5, 1, exact=True)
120L
>>> factorialk(5, 3, exact=True)
10L
```

`scipy.misc.logsumexp(*args, **kwargs)`

*logsumexp* is deprecated! Importing *logsumexp* from *scipy.misc* is deprecated in *scipy* 1.0.0. Use *scipy.special.logsumexp* instead.

Compute the log of the sum of exponentials of input elements.

**Parameters**

- a** : array\_like  
Input array.
- axis** [None or int or tuple of ints, optional] Axis or axes over which the sum is taken. By default *axis* is None, and all elements are summed. New in version 0.11.0.
- keepdims** [bool, optional] If this is set to True, the axes which are reduced are left in the result as dimensions with size one. With this option, the result will broadcast correctly against the original array. New in version 0.15.0.
- b** [array-like, optional] Scaling factor for  $\exp(a)$  must be of the same shape as *a* or broadcastable to *a*. These values may be negative in order to implement subtraction. New in version 0.12.0.
- return\_sign** [bool, optional] If this is set to True, the result will be a pair containing sign information; if False, results that are negative will be returned as NaN. Default is False (no sign information). New in version 0.16.0.
- res** [ndarray] The result,  $\text{np.log}(\text{np.sum}(\text{np.exp}(a)))$  calculated in a numerically more stable way. If *b* is given then  $\text{np.log}(\text{np.sum}(b * \text{np.exp}(a)))$  is returned.
- sgn** [ndarray] If *return\_sign* is True, this will be an array of floating-point numbers matching *res* and +1, 0, or -1 depending on the sign of the result. If False, only one result is returned.

**Notes**

Numpy has a `logaddexp` function which is very similar to *logsumexp*, but only handles two arguments. *logaddexp.reduce* is similar to this function, but may be less stable.

**Examples**

```
>>> from scipy.special import logsumexp
>>> a = np.arange(10)
>>> np.log(np.sum(np.exp(a)))
```

```
9.4586297444267107
>>> logsumexp(a)
9.4586297444267107
```

With weights

```
>>> a = np.arange(10)
>>> b = np.arange(10, 0, -1)
>>> logsumexp(a, b=b)
9.9170178533034665
>>> np.log(np.sum(b*np.exp(a)))
9.9170178533034647
```

Returning a sign flag

```
>>> logsumexp([1,2],b=[1,-1],return_sign=True)
(1.5413248546129181, -1.0)
```

Notice that `logsumexp` does not directly support masked arrays. To use it on a masked array, convert the mask into zero weights:

```
>>> a = np.ma.array([np.log(2), 2, np.log(3)],
...                 mask=[False, True, False])
>>> b = (~a.mask).astype(int)
>>> logsumexp(a.data, b=b), np.log(5)
1.6094379124341005, 1.6094379124341005
```

`scipy.misc.pade(*args, **kws)`

`pade` is deprecated! Importing `pade` from `scipy.misc` is deprecated in `scipy 1.0.0`. Use `scipy.interpolate.pade` instead.

Return Pade approximation to a polynomial as the ratio of two polynomials.

**Parameters** `an` : (N,) array\_like  
Taylor series coefficients.

`m` [int] The order of the returned approximating polynomials.

**Returns** `p, q` : Polynomial class

The Pade approximation of the polynomial defined by `an` is  $p(x)/q(x)$ .

**Examples**

```
>>> from scipy.interpolate import pade
>>> e_exp = [1.0, 1.0, 1.0/2.0, 1.0/6.0, 1.0/24.0, 1.0/120.0]
>>> p, q = pade(e_exp, 2)
```

```
>>> e_exp.reverse()
>>> e_poly = np.poly1d(e_exp)
```

Compare `e_poly(x)` and the Pade approximation  $p(x)/q(x)$

```
>>> e_poly(1)
2.7166666666666668
```

```
>>> p(1)/q(1)
2.7179487179487181
```

`scipy.misc.info(*args, **kwargs)`

Get help information for a function, class, or module.

**Parameters** **object** : object or str, optional  
 Input object or name to get information about. If *object* is a numpy object, its docstring is given. If it is a string, available modules are searched for matching objects. If None, information about *info* itself is returned.

**maxwidth** : int, optional  
 Printing width.

**output** : file like object, optional  
 File like object that the output is written to, default is `stdout`. The object has to be opened in 'w' or 'a' mode.

**toplevel** : str, optional  
 Start search at this level.

**See also:**

`source`, `lookfor`

**Notes**

When used interactively with an object, `np.info(obj)` is equivalent to `help(obj)` on the Python prompt or `obj?` on the IPython prompt.

**Examples**

```
>>> np.info(np.polyval)
polyval(p, x)
  Evaluate the polynomial p at x.
  ...
```

When using a string for *object* it is possible to get multiple results.

```
>>> np.info('fft')
*** Found in numpy ***
Core FFT routines
...
*** Found in numpy.fft ***
fft(a, n=None, axis=-1)
...
*** Repeat reference found in numpy.fft.fftpack ***
*** Total of 3 references found. ***
```

`scipy.misc.source(*args, **kwargs)`

*source* is deprecated! Importing *source* from `scipy.misc` is deprecated in `scipy 1.0.0`. Use `numpy.source` instead.

Print or write to a file the source code for a NumPy object.

The source code is only returned for objects written in Python. Many functions and classes are defined in C and will therefore not return useful information.

**Parameters** **object** : numpy object  
 Input object. This can be any object (function, class, module, ...).

**output** [file object, optional] If *output* not supplied then source code is printed to screen (`sys.stdout`). File object must be created with either write 'w' or append 'a' modes.



### 5.16.1 Filters

<code>convolve(input, weights[, output, mode, ...])</code>	Multidimensional convolution.
<code>convolve1d(input, weights[, axis, output, ...])</code>	Calculate a one-dimensional convolution along the given axis.
<code>correlate(input, weights[, output, mode, ...])</code>	Multi-dimensional correlation.
<code>correlate1d(input, weights[, axis, output, ...])</code>	Calculate a one-dimensional correlation along the given axis.
<code>gaussian_filter(input, sigma[, order, ...])</code>	Multidimensional Gaussian filter.
<code>gaussian_filter1d(input, sigma[, axis, ...])</code>	One-dimensional Gaussian filter.
<code>gaussian_gradient_magnitude(input, sigma[, ...])</code>	Multidimensional gradient magnitude using Gaussian derivatives.
<code>gaussian_laplace(input, sigma[, output, ...])</code>	Multidimensional Laplace filter using gaussian second derivatives.
<code>generic_filter(input, function[, size, ...])</code>	Calculate a multi-dimensional filter using the given function.
<code>generic_filter1d(input, function, filter_size)</code>	Calculate a one-dimensional filter along the given axis.
<code>generic_gradient_magnitude(input, derivative)</code>	Gradient magnitude using a provided gradient function.
<code>generic_laplace(input, derivative2[, ...])</code>	N-dimensional Laplace filter using a provided second derivative function.
<code>laplace(input[, output, mode, cval])</code>	N-dimensional Laplace filter based on approximate second derivatives.
<code>maximum_filter(input[, size, footprint, ...])</code>	Calculate a multi-dimensional maximum filter.
<code>maximum_filter1d(input, size[, axis, ...])</code>	Calculate a one-dimensional maximum filter along the given axis.
<code>median_filter(input[, size, footprint, ...])</code>	Calculate a multidimensional median filter.
<code>minimum_filter(input[, size, footprint, ...])</code>	Calculate a multi-dimensional minimum filter.
<code>minimum_filter1d(input, size[, axis, ...])</code>	Calculate a one-dimensional minimum filter along the given axis.
<code>percentile_filter(input, percentile[, size, ...])</code>	Calculate a multi-dimensional percentile filter.
<code>prewitt(input[, axis, output, mode, cval])</code>	Calculate a Prewitt filter.
<code>rank_filter(input, rank[, size, footprint, ...])</code>	Calculate a multi-dimensional rank filter.
<code>sobel(input[, axis, output, mode, cval])</code>	Calculate a Sobel filter.
<code>uniform_filter(input[, size, output, mode, ...])</code>	Multi-dimensional uniform filter.
<code>uniform_filter1d(input, size[, axis, ...])</code>	Calculate a one-dimensional uniform filter along the given axis.

`scipy.ndimage.convolve` (*input, weights, output=None, mode='reflect', cval=0.0, origin=0*)  
Multidimensional convolution.

The array is convolved with the given kernel.

**Parameters**

- input** : array\_like  
Input array to filter.
- weights** : array\_like  
Array of weights, same number of dimensions as input
- output** : ndarray, optional  
The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.
- mode** : {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}, optional  
the *mode* parameter determines how the array borders are handled. For 'constant' mode, values beyond borders are set to be *cval*. Default is 'reflect'.
- cval** : scalar, optional

Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

**origin** : array\_like, optional

The *origin* parameter controls the placement of the filter, relative to the centre of the current element of the input. Default of 0 is equivalent to  $(0, ) * \text{input}.\text{ndim}$ .

**Returns** **result** : ndarray

The result of convolution of *input* with *weights*.

**See also:**

**correlate** Correlate an image with a kernel.

**Notes**

Each value in result is  $C_i = \sum_j I_{i+k-j} W_j$ , where  $W$  is the *weights* kernel,  $j$  is the n-D spatial index over  $W$ ,  $I$  is the *input* and  $k$  is the coordinate of the center of  $W$ , specified by *origin* in the input parameters.

**Examples**

Perhaps the simplest case to understand is `mode='constant'`, `cval=0.0`, because in this case borders (i.e. where the *weights* kernel, centered on any one value, extends beyond an edge of *input*).

```
>>> a = np.array([[1, 2, 0, 0],
...              [5, 3, 0, 4],
...              [0, 0, 0, 7],
...              [9, 3, 0, 0]])
>>> k = np.array([[1, 1, 1], [1, 1, 0], [1, 0, 0]])
>>> from scipy import ndimage
>>> ndimage.convolve(a, k, mode='constant', cval=0.0)
array([[11, 10, 7, 4],
       [10, 3, 11, 11],
       [15, 12, 14, 7],
       [12, 3, 7, 0]])
```

Setting `cval=1.0` is equivalent to padding the outer edge of *input* with 1.0's (and then extracting only the original region of the result).

```
>>> ndimage.convolve(a, k, mode='constant', cval=1.0)
array([[13, 11, 8, 7],
       [11, 3, 11, 14],
       [16, 12, 14, 10],
       [15, 6, 10, 5]])
```

With `mode='reflect'` (the default), outer values are reflected at the edge of *input* to fill in missing values.

```
>>> b = np.array([[2, 0, 0],
...              [1, 0, 0],
...              [0, 0, 0]])
>>> k = np.array([[0, 1, 0], [0, 1, 0], [0, 1, 0]])
>>> ndimage.convolve(b, k, mode='reflect')
array([[5, 0, 0],
       [3, 0, 0],
       [1, 0, 0]])
```

This includes diagonally at the corners.

```
>>> k = np.array([[1, 0, 0], [0, 1, 0], [0, 0, 1]])
>>> ndimage.convolve(b, k)
array([[4, 2, 0],
```

```
[3, 2, 0],
 [1, 1, 0]])
```

With `mode='nearest'`, the single nearest value in to an edge in *input* is repeated as many times as needed to match the overlapping *weights*.

```
>>> c = np.array([[2, 0, 1],
...              [1, 0, 0],
...              [0, 0, 0]])
>>> k = np.array([[0, 1, 0],
...              [0, 1, 0],
...              [0, 1, 0],
...              [0, 1, 0]])
>>> ndimage.convolve(c, k, mode='nearest')
array([[7, 0, 3],
       [5, 0, 2],
       [3, 0, 1]])
```

`scipy.ndimage.convolve1d(input, weights, axis=-1, output=None, mode='reflect', cval=0.0, origin=0)`

Calculate a one-dimensional convolution along the given axis.

The lines of the array along the given axis are convolved with the given weights.

**Parameters**

- input** : array\_like  
Input array to filter.
- weights** : ndarray  
One-dimensional sequence of numbers.
- axis** : int, optional  
The axis of *input* along which to calculate. Default is -1.
- output** : array, optional  
The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.
- mode** : {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}, optional  
The *mode* parameter determines how the array borders are handled, where *cval* is the value when mode is equal to 'constant'. Default is 'reflect'
- cval** : scalar, optional  
Value to fill past edges of input if *mode* is 'constant'. Default is 0.0
- origin** : scalar, optional  
The *origin* parameter controls the placement of the filter. Default 0.0.

**Returns**

- convolve1d** : ndarray  
Convolved array with same shape as input

### Examples

```
>>> from scipy.ndimage import convolve1d
>>> convolve1d([2, 8, 0, 4, 1, 9, 9, 0], weights=[1, 3])
array([14, 24, 4, 13, 12, 36, 27, 0])
```

`scipy.ndimage.correlate(input, weights, output=None, mode='reflect', cval=0.0, origin=0)`

Multi-dimensional correlation.

The array is correlated with the given kernel.

**Parameters**

- input** : array-like  
input array to filter

**weights** : ndarray  
array of weights, same number of dimensions as input

**output** : array, optional  
The `output` parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.

**mode** : {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}, optional  
The `mode` parameter determines how the array borders are handled, where `cval` is the value when mode is equal to 'constant'. Default is 'reflect'

**cval** : scalar, optional  
Value to fill past edges of input if `mode` is 'constant'. Default is 0.0

**origin** : scalar, optional  
The `origin` parameter controls the placement of the filter. Default 0

**See also:**

**convolve** Convolve an image with a kernel.

`scipy.ndimage.correlate1d`(*input*, *weights*, *axis=-1*, *output=None*, *mode='reflect'*, *cval=0.0*, *origin=0*)

Calculate a one-dimensional correlation along the given axis.

The lines of the array along the given axis are correlated with the given weights.

**Parameters**

**input** : array\_like  
Input array to filter.

**weights** : array  
One-dimensional sequence of numbers.

**axis** : int, optional  
The axis of *input* along which to calculate. Default is -1.

**output** : array, optional  
The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.

**mode** : {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}, optional  
The *mode* parameter determines how the array borders are handled, where *cval* is the value when mode is equal to 'constant'. Default is 'reflect'

**cval** : scalar, optional  
Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

**origin** : scalar, optional  
The *origin* parameter controls the placement of the filter. Default 0.0.

**Examples**

```
>>> from scipy.ndimage import correlate1d
>>> correlate1d([2, 8, 0, 4, 1, 9, 9, 0], weights=[1, 3])
array([ 8, 26,  8, 12,  7, 28, 36,  9])
```

`scipy.ndimage.gaussian_filter`(*input*, *sigma*, *order=0*, *output=None*, *mode='reflect'*, *cval=0.0*, *truncate=4.0*)

Multidimensional Gaussian filter.

**Parameters**

**input** : array\_like  
Input array to filter.

**sigma** : scalar or sequence of scalars  
Standard deviation for Gaussian kernel. The standard deviations of the Gaussian filter are given for each axis as a sequence, or as a single number, in which case it is equal for all axes.

**order** : int or sequence of ints, optional

The order of the filter along each axis is given as a sequence of integers, or as a single number. An order of 0 corresponds to convolution with a Gaussian kernel. A positive order corresponds to convolution with that derivative of a Gaussian.

**output** : array, optional

The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.

**mode** : str or sequence, optional

The *mode* parameter determines how the array borders are handled. Valid modes are {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}. *cval* is the value used when mode is equal to 'constant'. A list of modes with length equal to the number of axes can be provided to specify different modes for different axes. Default is 'reflect'

**cval** : scalar, optional

Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

**truncate** : float

Truncate the filter at this many standard deviations. Default is 4.0.

**Returns**

**gaussian\_filter** : ndarray

Returned array of same shape as *input*.

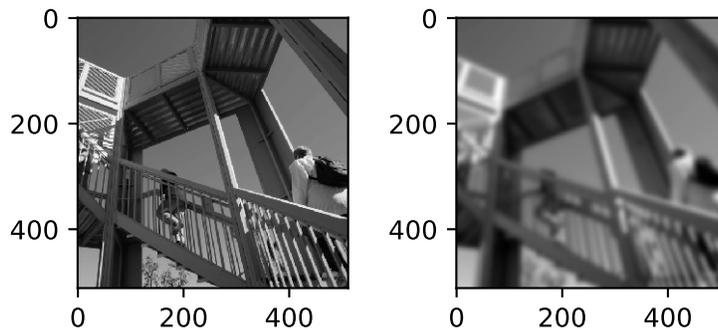
### Notes

The multidimensional filter is implemented as a sequence of one-dimensional convolution filters. The intermediate arrays are stored in the same data type as the output. Therefore, for output types with a limited precision, the results may be imprecise because intermediate results may be stored with insufficient precision.

### Examples

```
>>> from scipy.ndimage import gaussian_filter
>>> a = np.arange(50, step=2).reshape((5,5))
>>> a
array([[ 0,  2,  4,  6,  8],
       [10, 12, 14, 16, 18],
       [20, 22, 24, 26, 28],
       [30, 32, 34, 36, 38],
       [40, 42, 44, 46, 48]])
>>> gaussian_filter(a, sigma=1)
array([[ 4,  6,  8,  9, 11],
       [10, 12, 14, 15, 17],
       [20, 22, 24, 25, 27],
       [29, 31, 33, 34, 36],
       [35, 37, 39, 40, 42]])
```

```
>>> from scipy import misc
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> plt.gray() # show the filtered result in grayscale
>>> ax1 = fig.add_subplot(121) # left side
>>> ax2 = fig.add_subplot(122) # right side
>>> ascent = misc.ascent()
>>> result = gaussian_filter(ascent, sigma=5)
>>> ax1.imshow(ascent)
>>> ax2.imshow(result)
>>> plt.show()
```



`scipy.ndimage.gaussian_filter1d` (*input*, *sigma*, *axis=-1*, *order=0*, *output=None*, *mode='reflect'*, *cval=0.0*, *truncate=4.0*)

One-dimensional Gaussian filter.

**Parameters**

- input** : array\_like  
Input array to filter.
- sigma** : scalar  
standard deviation for Gaussian kernel
- axis** : int, optional  
The axis of *input* along which to calculate. Default is -1.
- order** : int, optional  
An order of 0 corresponds to convolution with a Gaussian kernel. A positive order corresponds to convolution with that derivative of a Gaussian.
- output** : array, optional  
The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.
- mode** : {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}, optional  
The *mode* parameter determines how the array borders are handled, where *cval* is the value when mode is equal to 'constant'. Default is 'reflect'
- cval** : scalar, optional  
Value to fill past edges of input if *mode* is 'constant'. Default is 0.0
- truncate** : float, optional  
Truncate the filter at this many standard deviations. Default is 4.0.

**Returns**

**gaussian\_filter1d** : ndarray

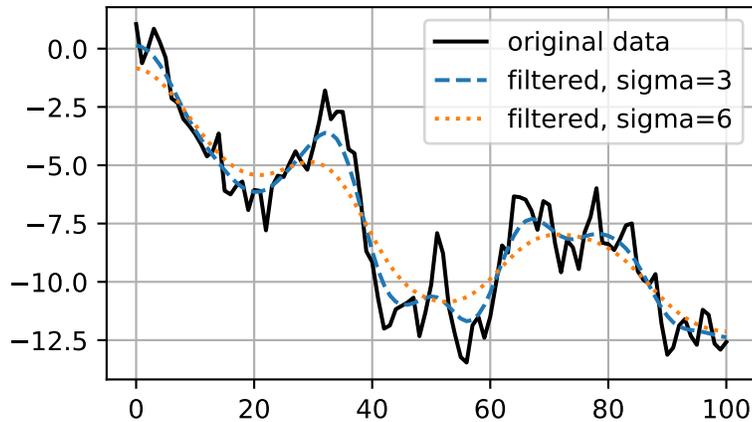
### Examples

```
>>> from scipy.ndimage import gaussian_filter1d
>>> gaussian_filter1d([1.0, 2.0, 3.0, 4.0, 5.0], 1)
array([ 1.42704095,  2.06782203,  3.          ,  3.93217797,  4.57295905])
>>> gaussian_filter1d([1.0, 2.0, 3.0, 4.0, 5.0], 4)
array([ 2.91948343,  2.95023502,  3.          ,  3.04976498,  3.08051657])
>>> import matplotlib.pyplot as plt
>>> np.random.seed(280490)
>>> x = np.random.randn(101).cumsum()
>>> y3 = gaussian_filter1d(x, 3)
>>> y6 = gaussian_filter1d(x, 6)
```

```

>>> plt.plot(x, 'k', label='original data')
>>> plt.plot(y3, '--', label='filtered, sigma=3')
>>> plt.plot(y6, ':', label='filtered, sigma=6')
>>> plt.legend()
>>> plt.grid()
>>> plt.show()

```



`scipy.ndimage.gaussian_gradient_magnitude` (*input*, *sigma*, *output=None*, *mode='reflect'*, *cval=0.0*, *\*\*kwargs*)  
 Multidimensional gradient magnitude using Gaussian derivatives.

**Parameters**

- input** : array\_like  
Input array to filter.
- sigma** : scalar or sequence of scalars  
The standard deviations of the Gaussian filter are given for each axis as a sequence, or as a single number, in which case it is equal for all axes..
- output** : array, optional  
The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.
- mode** : str or sequence, optional  
The *mode* parameter determines how the array borders are handled. Valid modes are {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}. *cval* is the value used when mode is equal to 'constant'. A list of modes with length equal to the number of axes can be provided to specify different modes for different axes. Default is 'reflect'
- cval** : scalar, optional  
Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

**Extra keyword arguments will be passed to `gaussian_filter()`.**

**Returns**

- gaussian\_gradient\_magnitude** : ndarray  
Filtered array. Has the same shape as *input*.

### Examples

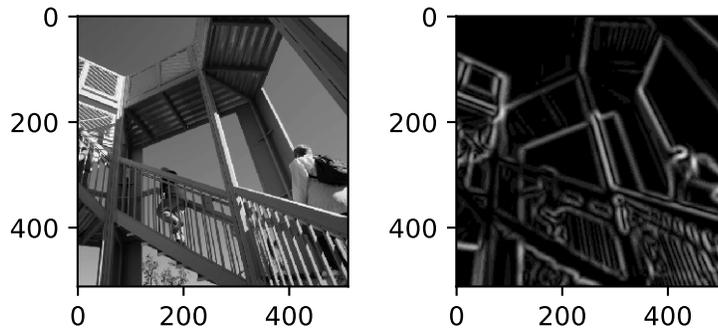
```

>>> from scipy import ndimage, misc
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> plt.gray() # show the filtered result in grayscale

```

```

>>> ax1 = fig.add_subplot(121) # left side
>>> ax2 = fig.add_subplot(122) # right side
>>> ascent = misc.ascent()
>>> result = ndimage.gaussian_gradient_magnitude(ascent, sigma=5)
>>> ax1.imshow(ascent)
>>> ax2.imshow(result)
>>> plt.show()
    
```



`scipy.ndimage.gaussian_laplace` (*input*, *sigma*, *output=None*, *mode='reflect'*, *cval=0.0*, *\*\*kwargs*)

Multidimensional Laplace filter using gaussian second derivatives.

**Parameters** **input** : array\_like

Input array to filter.

**sigma** : scalar or sequence of scalars

The standard deviations of the Gaussian filter are given for each axis as a sequence, or as a single number, in which case it is equal for all axes.

**output** : array, optional

The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.

**mode** : str or sequence, optional

The *mode* parameter determines how the array borders are handled. Valid modes are {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}. *cval* is the value used when mode is equal to 'constant'. A list of modes with length equal to the number of axes can be provided to specify different modes for different axes. Default is 'reflect'

**cval** : scalar, optional

Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

**Extra keyword arguments will be passed to `gaussian_filter()`.**

### Examples

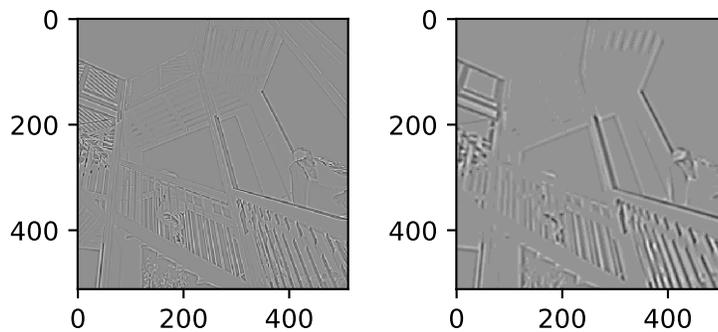
```

>>> from scipy import ndimage, misc
>>> import matplotlib.pyplot as plt
>>> ascent = misc.ascent()
    
```

```
>>> fig = plt.figure()
>>> plt.gray() # show the filtered result in grayscale
>>> ax1 = fig.add_subplot(121) # left side
>>> ax2 = fig.add_subplot(122) # right side
```

```
>>> result = ndimage.gaussian_laplace(ascent, sigma=1)
>>> ax1.imshow(result)
```

```
>>> result = ndimage.gaussian_laplace(ascent, sigma=3)
>>> ax2.imshow(result)
>>> plt.show()
```



`scipy.ndimage.generic_filter` (*input*, *function*, *size=None*, *footprint=None*, *output=None*, *mode='reflect'*, *cval=0.0*, *origin=0*, *extra\_arguments=()*, *extra\_keywords=None*)

Calculate a multi-dimensional filter using the given function.

At each element the provided function is called. The input values within the filter footprint at that element are passed to the function as a 1D array of double values.

**Parameters** **input** : array\_like

Input array to filter.

**function** : {callable, `scipy.LowLevelCallable`}

Function to apply at each element.

**size** : scalar or tuple, optional

See footprint, below

**footprint** : array, optional

Either *size* or *footprint* must be defined. *size* gives the shape that is taken from the input array, at every element position, to define the input to the filter function. *footprint* is a boolean array that specifies (implicitly) a shape, but also which of the elements within this shape will get passed to the filter function. Thus *size*=(*n*,*m*) is equivalent to *footprint*=`np.ones((n,m))`. We adjust *size* to the number of dimensions of the input array, so that, if the input array is shape (10,10,10), and *size* is 2, then the actual size used is (2,2,2).

**output** : array, optional

The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.

**mode** : {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}, optional

The *mode* parameter determines how the array borders are handled, where *cval* is the value when mode is equal to 'constant'. Default is 'reflect'

**cval** : scalar, optional

Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

**origin** : scalar, optional

The *origin* parameter controls the placement of the filter. Default 0.0.

**extra\_arguments** : sequence, optional

Sequence of extra positional arguments to pass to passed function

**extra\_keywords** : dict, optional

dict of extra keyword arguments to pass to passed function

### Notes

This function also accepts low-level callback functions with one of the following signatures and wrapped in *scipy.LowLevelCallable*:

```
int callback(double *buffer, npy_intp filter_size,
             double *return_value, void *user_data)
int callback(double *buffer, intptr_t filter_size,
             double *return_value, void *user_data)
```

The calling function iterates over the elements of the input and output arrays, calling the callback function at each element. The elements within the footprint of the filter at the current element are passed through the *buffer* parameter, and the number of elements within the footprint through *filter\_size*. The calculated value is returned in *return\_value*. *user\_data* is the data pointer provided to *scipy.LowLevelCallable* as-is.

The callback function must return an integer error status that is zero if something went wrong and one otherwise. If an error occurs, you should normally set the python error status with an informative message before returning, otherwise a default error message is set by the calling function.

In addition, some other low-level function pointer specifications are accepted, but these are for backward compatibility only and should not be used in new code.

```
scipy.ndimage.generic_filter1d(input, function, filter_size, axis=-1, output=None,
                              mode='reflect', cval=0.0, origin=0, extra_arguments=(),
                              extra_keywords=None)
```

Calculate a one-dimensional filter along the given axis.

*generic\_filter1d* iterates over the lines of the array, calling the given function at each line. The arguments of the line are the input line, and the output line. The input and output lines are 1D double arrays. The input line is extended appropriately according to the filter size and origin. The output line must be modified in-place with the result.

**Parameters** **input** : array\_like

Input array to filter.

**function** : {callable, *scipy.LowLevelCallable*}

Function to apply along given axis.

**filter\_size** : scalar

Length of the filter.

**axis** : int, optional

The axis of *input* along which to calculate. Default is -1.

**output** : array, optional

The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.

**mode** : {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}, optional  
 The *mode* parameter determines how the array borders are handled, where *cval* is the value when mode is equal to 'constant'. Default is 'reflect'

**cval** : scalar, optional  
 Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

**origin** : scalar, optional  
 The *origin* parameter controls the placement of the filter. Default 0.0.

**extra\_arguments** : sequence, optional  
 Sequence of extra positional arguments to pass to passed function

**extra\_keywords** : dict, optional  
 dict of extra keyword arguments to pass to passed function

### Notes

This function also accepts low-level callback functions with one of the following signatures and wrapped in `scipy.LowLevelCallable`:

```
int function(double *input_line, npy_intp input_length,
             double *output_line, npy_intp output_length,
             void *user_data)
int function(double *input_line, intp_t input_length,
             double *output_line, intp_t output_length,
             void *user_data)
```

The calling function iterates over the lines of the input and output arrays, calling the callback function at each line. The current line is extended according to the border conditions set by the calling function, and the result is copied into the array that is passed through `input_line`. The length of the input line (after extension) is passed through `input_length`. The callback function should apply the filter and store the result in the array passed through `output_line`. The length of the output line is passed through `output_length`. `user_data` is the data pointer provided to `scipy.LowLevelCallable` as-is.

The callback function must return an integer error status that is zero if something went wrong and one otherwise. If an error occurs, you should normally set the python error status with an informative message before returning, otherwise a default error message is set by the calling function.

In addition, some other low-level function pointer specifications are accepted, but these are for backward compatibility only and should not be used in new code.

```
scipy.ndimage.generic_gradient_magnitude(input, derivative, output=None, mode='reflect',
                                         cval=0.0, extra_arguments=(), extra_keywords=None)
```

Gradient magnitude using a provided gradient function.

**Parameters**

**input** : array\_like  
 Input array to filter.

**derivative** : callable  
 Callable with the following signature:

```
derivative(input, axis, output, mode, cval,
           *extra_arguments, **extra_keywords)
```

See *extra\_arguments*, *extra\_keywords* below. *derivative* can assume that *input* and *output* are ndarrays. Note that the output from *derivative* is modified inplace; be careful to copy important inputs before returning them.

**output** : array, optional  
 The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.

**mode** : str or sequence, optional

The *mode* parameter determines how the array borders are handled. Valid modes are {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}. *cval* is the value used when mode is equal to 'constant'. A list of modes with length equal to the number of axes can be provided to specify different modes for different axes. Default is 'reflect'

**cval** : scalar, optional

Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

**extra\_keywords** : dict, optional

dict of extra keyword arguments to pass to passed function

**extra\_arguments** : sequence, optional

Sequence of extra positional arguments to pass to passed function

`scipy.ndimage.generic_laplace` (*input*, *derivative2*, *output=None*, *mode='reflect'*, *cval=0.0*, *extra\_arguments=()*, *extra\_keywords=None*)

N-dimensional Laplace filter using a provided second derivative function.

**Parameters** **input** : array\_like

Input array to filter.

**derivative2** : callable

Callable with the following signature:

```

derivative2(input, axis, output, mode, cval,
            *extra_arguments, **extra_keywords)
    
```

See *extra\_arguments*, *extra\_keywords* below.

**output** : array, optional

The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.

**mode** : str or sequence, optional

The *mode* parameter determines how the array borders are handled. Valid modes are {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}. *cval* is the value used when mode is equal to 'constant'. A list of modes with length equal to the number of axes can be provided to specify different modes for different axes. Default is 'reflect'

**cval** : scalar, optional

Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

**extra\_keywords** : dict, optional

dict of extra keyword arguments to pass to passed function

**extra\_arguments** : sequence, optional

Sequence of extra positional arguments to pass to passed function

`scipy.ndimage.laplace` (*input*, *output=None*, *mode='reflect'*, *cval=0.0*)

N-dimensional Laplace filter based on approximate second derivatives.

**Parameters** **input** : array\_like

Input array to filter.

**output** : array, optional

The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.

**mode** : str or sequence, optional

The *mode* parameter determines how the array borders are handled. Valid modes are {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}. *cval* is the value used when mode is equal to 'constant'. A list of modes with length equal to the number of axes can be provided to specify different modes for different axes. Default is 'reflect'

**cval** : scalar, optional

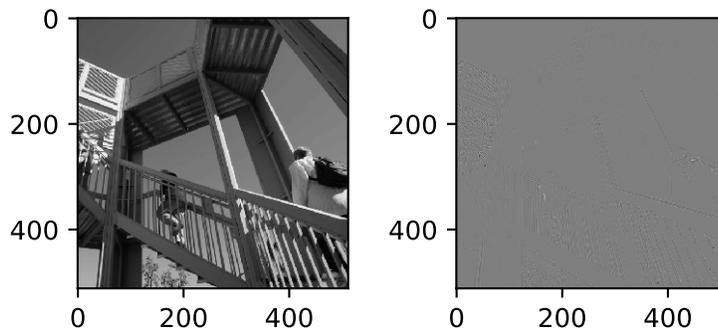
Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

**Examples**

```

>>> from scipy import ndimage, misc
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> plt.gray() # show the filtered result in grayscale
>>> ax1 = fig.add_subplot(121) # left side
>>> ax2 = fig.add_subplot(122) # right side
>>> ascent = misc.ascent()
>>> result = ndimage.laplace(ascent)
>>> ax1.imshow(ascent)
>>> ax2.imshow(result)
>>> plt.show()

```



`scipy.ndimage.maximum_filter` (*input*, *size=None*, *footprint=None*, *output=None*, *mode='reflect'*, *cval=0.0*, *origin=0*)

Calculate a multi-dimensional maximum filter.

**Parameters** **input** : array\_like

Input array to filter.

**size** : scalar or tuple, optional

See footprint, below

**footprint** : array, optional

Either *size* or *footprint* must be defined. *size* gives the shape that is taken from the input array, at every element position, to define the input to the filter function. *footprint* is a boolean array that specifies (implicitly) a shape, but also which of the elements within this shape will get passed to the filter function. Thus *size*=(*n*,*m*) is equivalent to *footprint*=`np.ones((n,m))`. We adjust *size* to the number of dimensions of the input array, so that, if the input array is shape (10,10,10), and *size* is 2, then the actual size used is (2,2,2).

**output** : array, optional

The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.

**mode** : str or sequence, optional

The *mode* parameter determines how the array borders are handled. Valid modes are {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}. *cval* is the value used when mode

is equal to 'constant'. A list of modes with length equal to the number of axes can be provided to specify different modes for different axes. Default is 'reflect'

**cval** : scalar, optional

Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

**origin** : scalar, optional

The *origin* parameter controls the placement of the filter. Default 0.0.

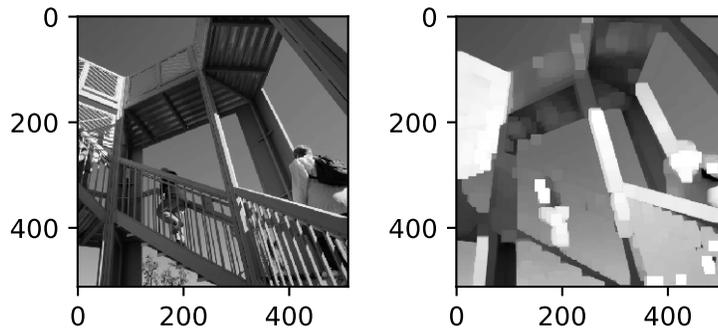
**Returns**

**maximum\_filter** : ndarray

Filtered array. Has the same shape as *input*.

### Examples

```
>>> from scipy import ndimage, misc
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> plt.gray() # show the filtered result in grayscale
>>> ax1 = fig.add_subplot(121) # left side
>>> ax2 = fig.add_subplot(122) # right side
>>> ascent = misc.ascent()
>>> result = ndimage.maximum_filter(ascent, size=20)
>>> ax1.imshow(ascent)
>>> ax2.imshow(result)
>>> plt.show()
```



`scipy.ndimage.maximum_filter1d` (*input*, *size*, *axis=-1*, *output=None*, *mode='reflect'*, *cval=0.0*, *origin=0*)

Calculate a one-dimensional maximum filter along the given axis.

The lines of the array along the given axis are filtered with a maximum filter of given size.

**Parameters**

**input** : array\_like

Input array to filter.

**size** : int

Length along which to calculate the 1-D maximum.

**axis** : int, optional

The axis of *input* along which to calculate. Default is -1.

**output** : array, optional

The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.

**mode** : { 'reflect', 'constant', 'nearest', 'mirror', 'wrap' }, optional  
 The *mode* parameter determines how the array borders are handled, where *cval* is the value when mode is equal to 'constant'. Default is 'reflect'

**cval** : scalar, optional  
 Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

**origin** : scalar, optional  
 The *origin* parameter controls the placement of the filter. Default 0.0.

**Returns** **maximum1d** : ndarray, None  
 Maximum-filtered array with same shape as input. None if *output* is not None

#### Notes

This function implements the MAXLIST algorithm [R181], as described by Richard Harter [R182], and has a guaranteed O(n) performance, *n* being the *input* length, regardless of filter size.

#### References

[R181], [R182]

#### Examples

```
>>> from scipy.ndimage import maximum_filter1d
>>> maximum_filter1d([2, 8, 0, 4, 1, 9, 9, 0], size=3)
array([8, 8, 8, 4, 9, 9, 9, 9])
```

`scipy.ndimage.median_filter` (*input*, *size=None*, *footprint=None*, *output=None*, *mode='reflect'*, *cval=0.0*, *origin=0*)

Calculate a multidimensional median filter.

**Parameters** **input** : array\_like  
 Input array to filter.

**size** : scalar or tuple, optional  
 See footprint, below

**footprint** : array, optional  
 Either *size* or *footprint* must be defined. *size* gives the shape that is taken from the input array, at every element position, to define the input to the filter function. *footprint* is a boolean array that specifies (implicitly) a shape, but also which of the elements within this shape will get passed to the filter function. Thus *size=(n,m)* is equivalent to *footprint=np.ones((n,m))*. We adjust *size* to the number of dimensions of the input array, so that, if the input array is shape (10,10,10), and *size* is 2, then the actual size used is (2,2,2).

**output** : array, optional  
 The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.

**mode** : { 'reflect', 'constant', 'nearest', 'mirror', 'wrap' }, optional  
 The *mode* parameter determines how the array borders are handled, where *cval* is the value when mode is equal to 'constant'. Default is 'reflect'

**cval** : scalar, optional  
 Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

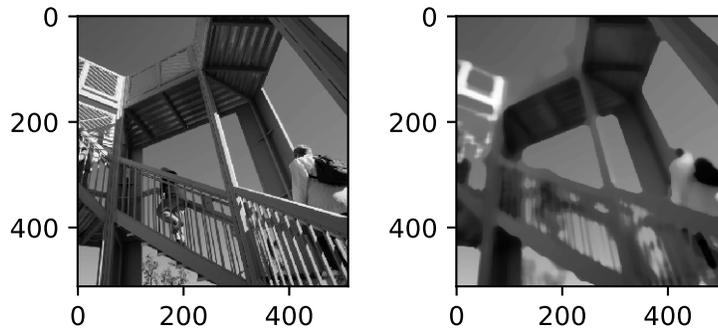
**origin** : scalar, optional  
 The *origin* parameter controls the placement of the filter. Default 0.0.

**Returns** **median\_filter** : ndarray  
 Filtered array. Has the same shape as *input*.

### Examples

```

>>> from scipy import ndimage, misc
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> plt.gray() # show the filtered result in grayscale
>>> ax1 = fig.add_subplot(121) # left side
>>> ax2 = fig.add_subplot(122) # right side
>>> ascent = misc.ascent()
>>> result = ndimage.median_filter(ascent, size=20)
>>> ax1.imshow(ascent)
>>> ax2.imshow(result)
>>> plt.show()
    
```



`scipy.ndimage.minimum_filter` (*input*, *size=None*, *footprint=None*, *output=None*, *mode='reflect'*, *cval=0.0*, *origin=0*)

Calculate a multi-dimensional minimum filter.

**Parameters** **input** : array\_like

Input array to filter.

**size** : scalar or tuple, optional

See footprint, below

**footprint** : array, optional

Either *size* or *footprint* must be defined. *size* gives the shape that is taken from the input array, at every element position, to define the input to the filter function. *footprint* is a boolean array that specifies (implicitly) a shape, but also which of the elements within this shape will get passed to the filter function. Thus *size*=(*n*,*m*) is equivalent to *footprint*=`np.ones((n,m))`. We adjust *size* to the number of dimensions of the input array, so that, if the input array is shape (10,10,10), and *size* is 2, then the actual size used is (2,2,2).

**output** : array, optional

The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.

**mode** : str or sequence, optional

The *mode* parameter determines how the array borders are handled. Valid modes are {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}. *cval* is the value used when mode

is equal to 'constant'. A list of modes with length equal to the number of axes can be provided to specify different modes for different axes. Default is 'reflect'

**cval** : scalar, optional

Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

**origin** : scalar, optional

The *origin* parameter controls the placement of the filter. Default 0.0.

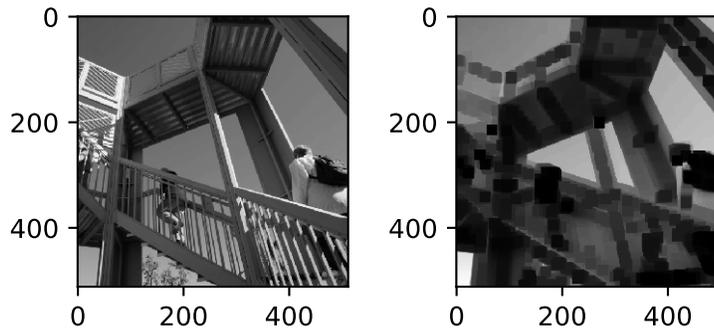
**Returns**

**minimum\_filter** : ndarray

Filtered array. Has the same shape as *input*.

### Examples

```
>>> from scipy import ndimage, misc
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> plt.gray() # show the filtered result in grayscale
>>> ax1 = fig.add_subplot(121) # left side
>>> ax2 = fig.add_subplot(122) # right side
>>> ascent = misc.ascent()
>>> result = ndimage.minimum_filter(ascent, size=20)
>>> ax1.imshow(ascent)
>>> ax2.imshow(result)
>>> plt.show()
```



`scipy.ndimage.minimum_filter1d(input, size, axis=-1, output=None, mode='reflect', cval=0.0, origin=0)`

Calculate a one-dimensional minimum filter along the given axis.

The lines of the array along the given axis are filtered with a minimum filter of given size.

#### Parameters

**input** : array\_like

Input array to filter.

**size** : int

length along which to calculate 1D minimum

**axis** : int, optional

The axis of *input* along which to calculate. Default is -1.

**output** : array, optional

The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.

**mode** : { 'reflect', 'constant', 'nearest', 'mirror', 'wrap' }, optional

The *mode* parameter determines how the array borders are handled, where *cval* is the value when mode is equal to 'constant'. Default is 'reflect'

**cval** : scalar, optional

Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

**origin** : scalar, optional

The *origin* parameter controls the placement of the filter. Default 0.0.

### Notes

This function implements the MINLIST algorithm [R183], as described by Richard Harter [R184], and has a guaranteed O(n) performance, *n* being the *input* length, regardless of filter size.

### References

[R183], [R184]

### Examples

```
>>> from scipy.ndimage import minimum_filter1d
>>> minimum_filter1d([2, 8, 0, 4, 1, 9, 9, 0], size=3)
array([2, 0, 0, 0, 1, 1, 0, 0])
```

`scipy.ndimage.percentile_filter` (*input*, *percentile*, *size=None*, *footprint=None*, *output=None*, *mode='reflect'*, *cval=0.0*, *origin=0*)

Calculate a multi-dimensional percentile filter.

#### Parameters

**input** : array\_like

Input array to filter.

**percentile** : scalar

The percentile parameter may be less than zero, i.e., percentile = -20 equals percentile = 80

**size** : scalar or tuple, optional

See footprint, below

**footprint** : array, optional

Either *size* or *footprint* must be defined. *size* gives the shape that is taken from the input array, at every element position, to define the input to the filter function. *footprint* is a boolean array that specifies (implicitly) a shape, but also which of the elements within this shape will get passed to the filter function. Thus *size*=(*n*,*m*) is equivalent to *footprint*=`np.ones((n,m))`. We adjust *size* to the number of dimensions of the input array, so that, if the input array is shape (10,10,10), and *size* is 2, then the actual size used is (2,2,2).

**output** : array, optional

The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.

**mode** : { 'reflect', 'constant', 'nearest', 'mirror', 'wrap' }, optional

The *mode* parameter determines how the array borders are handled, where *cval* is the value when mode is equal to 'constant'. Default is 'reflect'

**cval** : scalar, optional

Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

**origin** : scalar, optional

The *origin* parameter controls the placement of the filter. Default 0.0.

#### Returns

**percentile\_filter** : ndarray

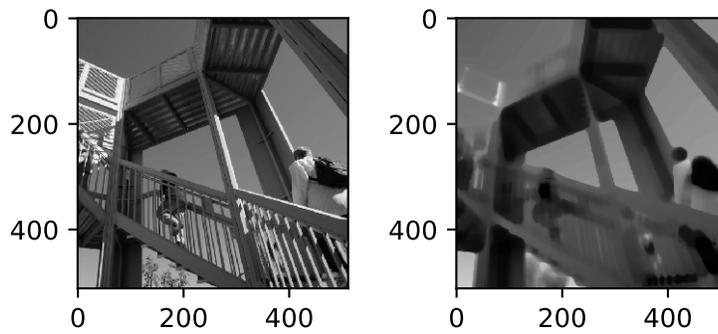
Filtered array. Has the same shape as *input*.

**Examples**

```

>>> from scipy import ndimage, misc
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> plt.gray() # show the filtered result in grayscale
>>> ax1 = fig.add_subplot(121) # left side
>>> ax2 = fig.add_subplot(122) # right side
>>> ascent = misc.ascent()
>>> result = ndimage.percentile_filter(ascent, percentile=20, size=20)
>>> ax1.imshow(ascent)
>>> ax2.imshow(result)
>>> plt.show()

```



`scipy.ndimage.prewitt` (*input*, *axis=-1*, *output=None*, *mode='reflect'*, *cval=0.0*)

Calculate a Prewitt filter.

**Parameters**

- input** : array\_like  
Input array to filter.
- axis** : int, optional  
The axis of *input* along which to calculate. Default is -1.
- output** : array, optional  
The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.
- mode** : str or sequence, optional  
The *mode* parameter determines how the array borders are handled. Valid modes are {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}. *cval* is the value used when mode is equal to 'constant'. A list of modes with length equal to the number of axes can be provided to specify different modes for different axes. Default is 'reflect'
- cval** : scalar, optional  
Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

**Examples**

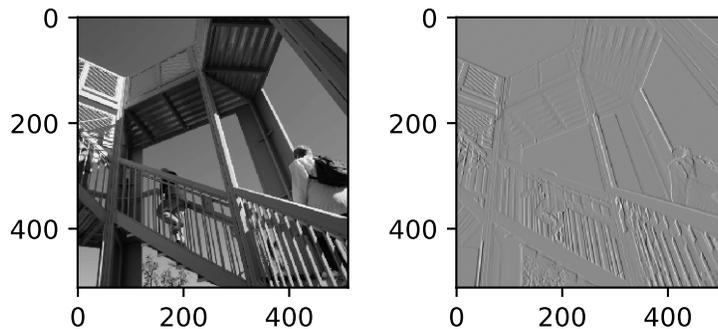
```

>>> from scipy import ndimage, misc
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()

```

```

>>> plt.gray() # show the filtered result in grayscale
>>> ax1 = fig.add_subplot(121) # left side
>>> ax2 = fig.add_subplot(122) # right side
>>> ascent = misc.ascent()
>>> result = ndimage.prewitt(ascent)
>>> ax1.imshow(ascent)
>>> ax2.imshow(result)
>>> plt.show()
    
```



`scipy.ndimage.rank_filter` (*input*, *rank*, *size=None*, *footprint=None*, *output=None*, *mode='reflect'*, *cval=0.0*, *origin=0*)

Calculate a multi-dimensional rank filter.

**Parameters**

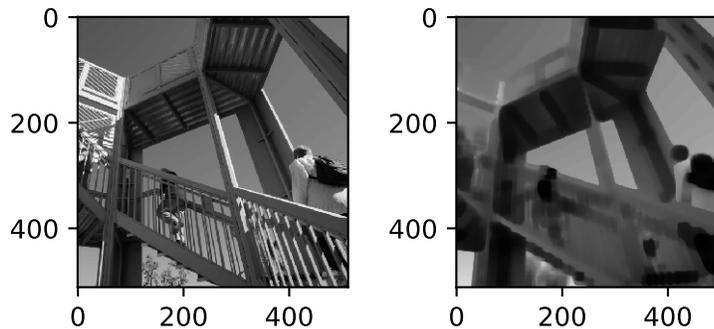
- input** : array\_like  
Input array to filter.
- rank** : int  
The rank parameter may be less than zero, i.e., `rank = -1` indicates the largest element.
- size** : scalar or tuple, optional  
See footprint, below
- footprint** : array, optional  
Either *size* or *footprint* must be defined. *size* gives the shape that is taken from the input array, at every element position, to define the input to the filter function. *footprint* is a boolean array that specifies (implicitly) a shape, but also which of the elements within this shape will get passed to the filter function. Thus `size=(n,m)` is equivalent to `footprint=np.ones((n,m))`. We adjust *size* to the number of dimensions of the input array, so that, if the input array is shape (10,10,10), and *size* is 2, then the actual size used is (2,2,2).
- output** : array, optional  
The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.
- mode** : {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}, optional  
The *mode* parameter determines how the array borders are handled, where *cval* is the value when mode is equal to 'constant'. Default is 'reflect'
- cval** : scalar, optional  
Value to fill past edges of input if *mode* is 'constant'. Default is 0.0
- origin** : scalar, optional

The *origin* parameter controls the placement of the filter. Default 0.0.

**Returns** **rank\_filter** : ndarray  
Filtered array. Has the same shape as *input*.

### Examples

```
>>> from scipy import ndimage, misc
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> plt.gray() # show the filtered result in grayscale
>>> ax1 = fig.add_subplot(121) # left side
>>> ax2 = fig.add_subplot(122) # right side
>>> ascent = misc.ascent()
>>> result = ndimage.rank_filter(ascent, rank=42, size=20)
>>> ax1.imshow(ascent)
>>> ax2.imshow(result)
>>> plt.show()
```



`scipy.ndimage.sobel` (*input*, *axis=-1*, *output=None*, *mode='reflect'*, *cval=0.0*)  
Calculate a Sobel filter.

**Parameters**

**input** : array\_like  
Input array to filter.

**axis** : int, optional  
The axis of *input* along which to calculate. Default is -1.

**output** : array, optional  
The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.

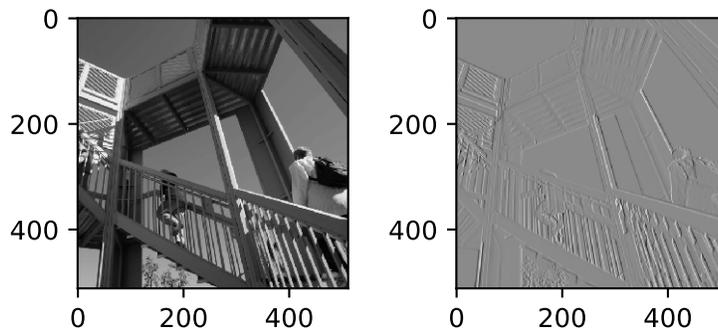
**mode** : str or sequence, optional  
The *mode* parameter determines how the array borders are handled. Valid modes are {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}. *cval* is the value used when mode is equal to 'constant'. A list of modes with length equal to the number of axes can be provided to specify different modes for different axes. Default is 'reflect'

**cval** : scalar, optional  
Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

### Examples

```

>>> from scipy import ndimage, misc
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> plt.gray() # show the filtered result in grayscale
>>> ax1 = fig.add_subplot(121) # left side
>>> ax2 = fig.add_subplot(122) # right side
>>> ascent = misc.ascent()
>>> result = ndimage.sobel(ascent)
>>> ax1.imshow(ascent)
>>> ax2.imshow(result)
>>> plt.show()
    
```



`scipy.ndimage.uniform_filter` (*input*, *size=3*, *output=None*, *mode='reflect'*, *cval=0.0*, *origin=0*)  
 Multi-dimensional uniform filter.

**Parameters**

- input** : array\_like  
Input array to filter.
- size** : int or sequence of ints, optional  
The sizes of the uniform filter are given for each axis as a sequence, or as a single number, in which case the size is equal for all axes.
- output** : array, optional  
The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.
- mode** : str or sequence, optional  
The *mode* parameter determines how the array borders are handled. Valid modes are {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}. *cval* is the value used when mode is equal to 'constant'. A list of modes with length equal to the number of axes can be provided to specify different modes for different axes. Default is 'reflect'
- cval** : scalar, optional  
Value to fill past edges of input if *mode* is 'constant'. Default is 0.0
- origin** : scalar, optional  
The *origin* parameter controls the placement of the filter. Default 0.0.

**Returns**

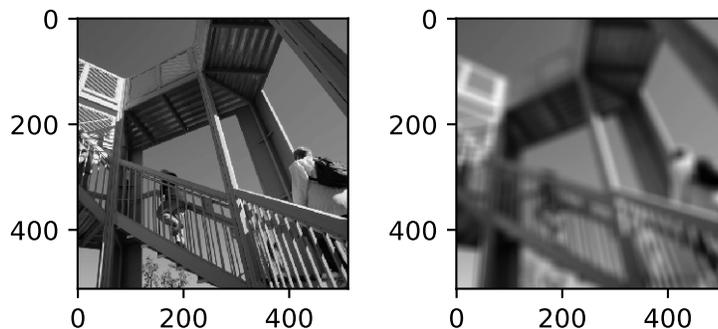
- uniform\_filter** : ndarray  
Filtered array. Has the same shape as *input*.

### Notes

The multi-dimensional filter is implemented as a sequence of one-dimensional uniform filters. The intermediate arrays are stored in the same data type as the output. Therefore, for output types with a limited precision, the results may be imprecise because intermediate results may be stored with insufficient precision.

### Examples

```
>>> from scipy import ndimage, misc
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> plt.gray() # show the filtered result in grayscale
>>> ax1 = fig.add_subplot(121) # left side
>>> ax2 = fig.add_subplot(122) # right side
>>> ascent = misc.ascent()
>>> result = ndimage.uniform_filter(ascent, size=20)
>>> ax1.imshow(ascent)
>>> ax2.imshow(result)
>>> plt.show()
```



`scipy.ndimage.uniform_filter1d` (*input*, *size*, *axis=-1*, *output=None*, *mode='reflect'*, *cval=0.0*, *origin=0*)

Calculate a one-dimensional uniform filter along the given axis.

The lines of the array along the given axis are filtered with a uniform filter of given size.

**Parameters** **input** : array\_like

Input array to filter.

**size** : int

length of uniform filter

**axis** : int, optional

The axis of *input* along which to calculate. Default is -1.

**output** : array, optional

The *output* parameter passes an array in which to store the filter output. Output array should have different name as compared to input array to avoid aliasing errors.

**mode** : {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}, optional

The *mode* parameter determines how the array borders are handled, where *cval* is the value when mode is equal to 'constant'. Default is 'reflect'

**eval** : scalar, optional  
 Value to fill past edges of input if *mode* is 'constant'. Default is 0.0

**origin** : scalar, optional  
 The *origin* parameter controls the placement of the filter. Default 0.0.

### Examples

```
>>> from scipy.ndimage import uniform_filter1d
>>> uniform_filter1d([2, 8, 0, 4, 1, 9, 9, 0], size=3)
array([4, 3, 4, 1, 4, 6, 6, 3])
```

## 5.16.2 Fourier filters

<code>fourier_ellipsoid(input, size[, n, axis, output])</code>	Multi-dimensional ellipsoid fourier filter.
<code>fourier_gaussian(input, sigma[, n, axis, output])</code>	Multi-dimensional Gaussian fourier filter.
<code>fourier_shift(input, shift[, n, axis, output])</code>	Multi-dimensional fourier shift filter.
<code>fourier_uniform(input, size[, n, axis, output])</code>	Multi-dimensional uniform fourier filter.

`scipy.ndimage.fourier_ellipsoid(input, size, n=-1, axis=-1, output=None)`  
 Multi-dimensional ellipsoid fourier filter.

The array is multiplied with the fourier transform of a ellipsoid of given sizes.

**Parameters**

- input** : array\_like  
 The input array.
- size** : float or sequence  
 The size of the box used for filtering. If a float, *size* is the same for all axes. If a sequence, *size* has to contain one value for each axis.
- n** : int, optional  
 If *n* is negative (default), then the input is assumed to be the result of a complex fft. If *n* is larger than or equal to zero, the input is assumed to be the result of a real fft, and *n* gives the length of the array before transformation along the real transform direction.
- axis** : int, optional  
 The axis of the real transform.
- output** : ndarray, optional  
 If given, the result of filtering the input is placed in this array. None is returned in this case.

**Returns**

- fourier\_ellipsoid** : ndarray or None  
 The filtered input. If *output* is given as a parameter, None is returned.

### Notes

This function is implemented for arrays of rank 1, 2, or 3.

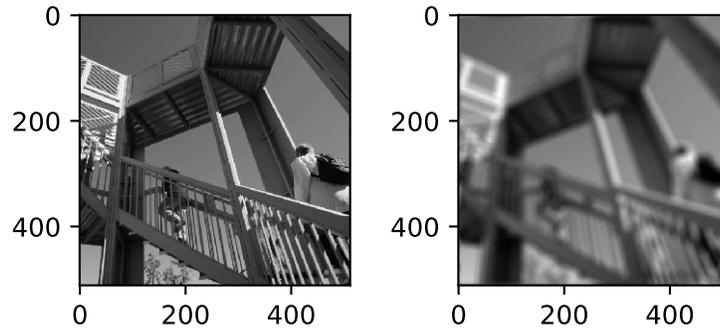
### Examples

```
>>> from scipy import ndimage, misc
>>> import numpy.fft
>>> import matplotlib.pyplot as plt
>>> fig, (ax1, ax2) = plt.subplots(1, 2)
>>> plt.gray() # show the filtered result in grayscale
>>> ascent = misc.ascent()
>>> input_ = numpy.fft.fft2(ascent)
>>> result = ndimage.fourier_ellipsoid(input_, size=20)
```

```

>>> result = numpy.fft.ifft2(result)
>>> ax1.imshow(ascent)
>>> ax2.imshow(result.real) # the imaginary part is an artifact
>>> plt.show()

```



`scipy.ndimage.fourier_gaussian` (*input*, *sigma*, *n=-1*, *axis=-1*, *output=None*)  
Multi-dimensional Gaussian Fourier filter.

The array is multiplied with the Fourier transform of a Gaussian kernel.

**Parameters**

- input** : array\_like  
The input array.
- sigma** : float or sequence  
The sigma of the Gaussian kernel. If a float, *sigma* is the same for all axes. If a sequence, *sigma* has to contain one value for each axis.
- n** : int, optional  
If *n* is negative (default), then the input is assumed to be the result of a complex fft. If *n* is larger than or equal to zero, the input is assumed to be the result of a real fft, and *n* gives the length of the array before transformation along the real transform direction.
- axis** : int, optional  
The axis of the real transform.
- output** : ndarray, optional  
If given, the result of filtering the input is placed in this array. None is returned in this case.

**Returns**

- fourier\_gaussian** : ndarray or None  
The filtered input. If *output* is given as a parameter, None is returned.

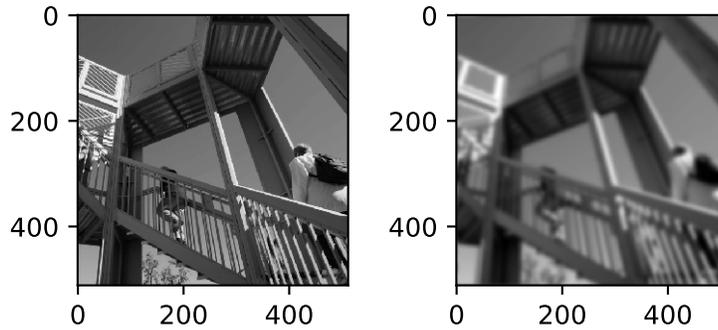
### Examples

```

>>> from scipy import ndimage, misc
>>> import numpy.fft
>>> import matplotlib.pyplot as plt
>>> fig, (ax1, ax2) = plt.subplots(1, 2)
>>> plt.gray() # show the filtered result in grayscale
>>> ascent = misc.ascent()
>>> input_ = numpy.fft.fft2(ascent)
>>> result = ndimage.fourier_gaussian(input_, sigma=4)

```

```
>>> result = numpy.fft.ifft2(result)
>>> ax1.imshow(ascent)
>>> ax2.imshow(result.real) # the imaginary part is an artifact
>>> plt.show()
```



`scipy.ndimage.fourier_shift` (*input*, *shift*, *n=-1*, *axis=-1*, *output=None*)  
 Multi-dimensional fourier shift filter.

The array is multiplied with the fourier transform of a shift operation.

**Parameters**

- input** : array\_like  
The input array.
- shift** : float or sequence  
The size of the box used for filtering. If a float, *shift* is the same for all axes. If a sequence, *shift* has to contain one value for each axis.
- n** : int, optional  
If *n* is negative (default), then the input is assumed to be the result of a complex fft. If *n* is larger than or equal to zero, the input is assumed to be the result of a real fft, and *n* gives the length of the array before transformation along the real transform direction.
- axis** : int, optional  
The axis of the real transform.
- output** : ndarray, optional  
If given, the result of shifting the input is placed in this array. None is returned in this case.

**Returns**

- fourier\_shift** : ndarray or None  
The shifted input. If *output* is given as a parameter, None is returned.

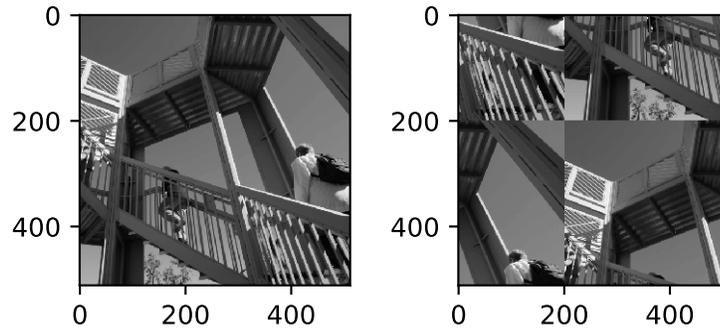
### Examples

```
>>> from scipy import ndimage, misc
>>> import matplotlib.pyplot as plt
>>> import numpy.fft
>>> fig, (ax1, ax2) = plt.subplots(1, 2)
>>> plt.gray() # show the filtered result in grayscale
>>> ascent = misc.ascent()
>>> input_ = numpy.fft.fft2(ascent)
>>> result = ndimage.fourier_shift(input_, shift=200)
```

```

>>> result = numpy.fft.ifft2(result)
>>> ax1.imshow(ascent)
>>> ax2.imshow(result.real) # the imaginary part is an artifact
>>> plt.show()

```



`scipy.ndimage.fourier_uniform` (*input, size, n=-1, axis=-1, output=None*)  
Multi-dimensional uniform fourier filter.

The array is multiplied with the fourier transform of a box of given size.

**Parameters**

- input** : array\_like  
The input array.
- size** : float or sequence  
The size of the box used for filtering. If a float, *size* is the same for all axes. If a sequence, *size* has to contain one value for each axis.
- n** : int, optional  
If *n* is negative (default), then the input is assumed to be the result of a complex fft. If *n* is larger than or equal to zero, the input is assumed to be the result of a real fft, and *n* gives the length of the array before transformation along the real transform direction.
- axis** : int, optional  
The axis of the real transform.
- output** : ndarray, optional  
If given, the result of filtering the input is placed in this array. None is returned in this case.

**Returns**

- fourier\_uniform** : ndarray or None  
The filtered input. If *output* is given as a parameter, None is returned.

### Examples

```

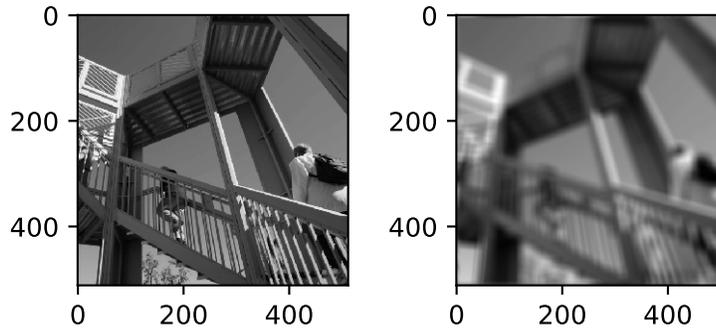
>>> from scipy import ndimage, misc
>>> import numpy.fft
>>> import matplotlib.pyplot as plt
>>> fig, (ax1, ax2) = plt.subplots(1, 2)
>>> plt.gray() # show the filtered result in grayscale
>>> ascent = misc.ascent()
>>> input_ = numpy.fft.fft2(ascent)
>>> result = ndimage.fourier_uniform(input_, size=20)

```

```

>>> result = numpy.fft.ifft2(result)
>>> ax1.imshow(ascent)
>>> ax2.imshow(result.real) # the imaginary part is an artifact
>>> plt.show()

```



### 5.16.3 Interpolation

<code>affine_transform(input, matrix[, offset, ...])</code>	Apply an affine transformation.
<code>geometric_transform(input, mapping[, ...])</code>	Apply an arbitrary geometric transform.
<code>map_coordinates(input, coordinates[, ...])</code>	Map the input array to new coordinates by interpolation.
<code>rotate(input, angle[, axes, reshape, ...])</code>	Rotate an array.
<code>shift(input, shift[, output, order, mode, ...])</code>	Shift an array.
<code>spline_filter(input[, order, output])</code>	Multi-dimensional spline filter.
<code>spline_filter1d(input[, order, axis, output])</code>	Calculates a one-dimensional spline filter along the given axis.
<code>zoom(input, zoom[, output, order, mode, ...])</code>	Zoom an array.

`scipy.ndimage.affine_transform` (*input, matrix, offset=0.0, output\_shape=None, output=None, order=3, mode='constant', cval=0.0, prefilter=True*)

Apply an affine transformation.

Given an output image pixel index vector `o`, the pixel value is determined from the input image at position `np.dot(matrix, o) + offset`.

**Parameters** **input** : ndarray

The input array.

**matrix** : ndarray

The inverse coordinate transformation matrix, mapping output coordinates to input coordinates. If `ndim` is the number of dimensions of `input`, the given matrix must have one of the following shapes:

- `(ndim, ndim)`: the linear transformation matrix for each output coordinate.
- `(ndim, )`: assume that the 2D transformation matrix is diagonal, with the diagonal specified by the given value. A more efficient algorithm is then used that exploits the

separability of the problem.

- $(\text{ndim} + 1, \text{ndim} + 1)$ : assume that the transformation is specified using homogeneous coordinates [R162]. In this case, any value passed to `offset` is ignored.
- $(\text{ndim}, \text{ndim} + 1)$ : as above, but the bottom row of a homogeneous transformation matrix is always  $[0, 0, \dots, 1]$ , and may be omitted.

**offset** : float or sequence, optional

The offset into the array where the transform is applied. If a float, *offset* is the same for each axis. If a sequence, *offset* should contain one value for each axis.

**output\_shape** : tuple of ints, optional

Shape tuple.

**output** : ndarray or dtype, optional

The array in which to place the output, or the dtype of the returned array.

**order** : int, optional

The order of the spline interpolation, default is 3. The order has to be in the range 0-5.

**mode** : str, optional

Points outside the boundaries of the input are filled according to the given mode ('constant', 'nearest', 'reflect', 'mirror' or 'wrap'). Default is 'constant'.

**cval** : scalar, optional

Value used for points outside the boundaries of the input if `mode='constant'`. Default is 0.0

**prefilter** : bool, optional

The parameter `prefilter` determines if the input is pre-filtered with `spline_filter` before interpolation (necessary for spline interpolation of order  $> 1$ ). If `False`, it is assumed that the input is already filtered. Default is `True`.

**Returns**

**affine\_transform** : ndarray or None

The transformed input. If *output* is given as a parameter, `None` is returned.

### Notes

The given matrix and offset are used to find for each point in the output the corresponding coordinates in the input by an affine transformation. The value of the input at those coordinates is determined by spline interpolation of the requested order. Points outside the boundaries of the input are filled according to the given mode.

Changed in version 0.18.0: Previously, the exact interpretation of the affine transformation depended on whether the matrix was supplied as a one-dimensional or two-dimensional array. If a one-dimensional array was supplied to the matrix parameter, the output pixel value at index `o` was determined from the input image at position `matrix * (o + offset)`.

### References

[R162]

`scipy.ndimage.geometric_transform` (*input*, *mapping*, *output\_shape=None*, *output=None*, *order=3*, *mode='constant'*, *cval=0.0*, *prefilter=True*, *extra\_arguments=()*, *extra\_keywords={}*)

Apply an arbitrary geometric transform.

The given mapping function is used to find, for each point in the output, the corresponding coordinates in the input. The value of the input at those coordinates is determined by spline interpolation of the requested order.

**Parameters** **input** : array\_like

The input array.

**mapping** : {callable, `scipy.LowLevelCallable`}

A callable object that accepts a tuple of length equal to the output array rank, and returns the corresponding input coordinates as a tuple of length equal to the input array rank.

**output\_shape** : tuple of ints, optional

Shape tuple.

**output** : ndarray or dtype, optional

The array in which to place the output, or the dtype of the returned array.

**order** : int, optional

The order of the spline interpolation, default is 3. The order has to be in the range 0-5.

**mode** : str, optional

Points outside the boundaries of the input are filled according to the given mode ('constant', 'nearest', 'reflect', 'mirror' or 'wrap'). Default is 'constant'.

**cval** : scalar, optional

Value used for points outside the boundaries of the input if mode='constant'. Default is 0.0

**prefilter** : bool, optional

The parameter prefilter determines if the input is pre-filtered with *spline\_filter* before interpolation (necessary for spline interpolation of order > 1). If False, it is assumed that the input is already filtered. Default is True.

**extra\_arguments** : tuple, optional

Extra arguments passed to *mapping*.

**extra\_keywords** : dict, optional

Extra keywords passed to *mapping*.

**Returns**

**return\_value** : ndarray or None

The filtered input. If *output* is given as a parameter, None is returned.

**See also:**

*map\_coordinates*, *affine\_transform*, *spline\_filter1d*

**Notes**

This function also accepts low-level callback functions with one the following signatures and wrapped in *scipy.LowLevelCallable*:

```
int mapping(npyptr_t *output_coordinates, double *input_coordinates,
            int output_rank, int input_rank, void *user_data)
int mapping(intptr_t *output_coordinates, double *input_coordinates,
            int output_rank, int input_rank, void *user_data)
```

The calling function iterates over the elements of the output array, calling the callback function at each element. The coordinates of the current output element are passed through *output\_coordinates*. The callback function must return the coordinates at which the input must be interpolated in *input\_coordinates*. The rank of the input and output arrays are given by *input\_rank* and *output\_rank* respectively. *user\_data* is the data pointer provided to *scipy.LowLevelCallable* as-is.

The callback function must return an integer error status that is zero if something went wrong and one otherwise. If an error occurs, you should normally set the python error status with an informative message before returning, otherwise a default error message is set by the calling function.

In addition, some other low-level function pointer specifications are accepted, but these are for backward compatibility only and should not be used in new code.

**Examples**

```
>>> from scipy import ndimage
>>> a = np.arange(12.).reshape((4, 3))
>>> def shift_func(output_coords):
...     return (output_coords[0] - 0.5, output_coords[1] - 0.5)
...
>>> ndimage.geometric_transform(a, shift_func)
array([[ 0.  ,  0.  ,  0.  ],
```

```
[ 0. ,  1.362,  2.738],
 [ 0. ,  4.812,  6.187],
 [ 0. ,  8.263,  9.637]])
```

`scipy.ndimage.map_coordinates` (*input*, *coordinates*, *output=None*, *order=3*, *mode='constant'*, *cval=0.0*, *prefilter=True*)

Map the input array to new coordinates by interpolation.

The array of coordinates is used to find, for each point in the output, the corresponding coordinates in the input. The value of the input at those coordinates is determined by spline interpolation of the requested order.

The shape of the output is derived from that of the coordinate array by dropping the first axis. The values of the array along the first axis are the coordinates in the input array at which the output value is found.

**Parameters**

- input** : ndarray  
The input array.
- coordinates** : array\_like  
The coordinates at which *input* is evaluated.
- output** : ndarray or dtype, optional  
The array in which to place the output, or the dtype of the returned array.
- order** : int, optional  
The order of the spline interpolation, default is 3. The order has to be in the range 0-5.
- mode** : str, optional  
Points outside the boundaries of the input are filled according to the given mode ('constant', 'nearest', 'reflect', 'mirror' or 'wrap'). Default is 'constant'.
- cval** : scalar, optional  
Value used for points outside the boundaries of the input if *mode='constant'*. Default is 0.0
- prefilter** : bool, optional  
The parameter *prefilter* determines if the input is pre-filtered with *spline\_filter* before interpolation (necessary for spline interpolation of order > 1). If False, it is assumed that the input is already filtered. Default is True.

**Returns**

- map\_coordinates** : ndarray  
The result of transforming the input. The shape of the output is derived from that of *coordinates* by dropping the first axis.

**See also:**

*spline\_filter*, *geometric\_transform*, *scipy.interpolate*

**Examples**

```
>>> from scipy import ndimage
>>> a = np.arange(12.).reshape((4, 3))
>>> a
array([[ 0.,  1.,  2.],
       [ 3.,  4.,  5.],
       [ 6.,  7.,  8.],
       [ 9., 10., 11.]])
>>> ndimage.map_coordinates(a, [[0.5, 2], [0.5, 1]], order=1)
array([ 2.,  7.])
```

Above, the interpolated value of `a[0.5, 0.5]` gives `output[0]`, while `a[2, 1]` is `output[1]`.

```
>>> inds = np.array([[0.5, 2], [0.5, 4]])
>>> ndimage.map_coordinates(a, inds, order=1, cval=-33.3)
array([ 2. , -33.3])
>>> ndimage.map_coordinates(a, inds, order=1, mode='nearest')
```

```
array([ 2.,  8.])
>>> ndimage.map_coordinates(a, inds, order=1, cval=0, output=bool)
array([ True, False], dtype=bool)
```

`scipy.ndimage.rotate` (*input*, *angle*, *axes*=(1, 0), *reshape*=True, *output*=None, *order*=3, *mode*='constant', *cval*=0.0, *prefilter*=True)

Rotate an array.

The array is rotated in the plane defined by the two axes given by the *axes* parameter using spline interpolation of the requested order.

**Parameters**

- input** : ndarray  
The input array.
- angle** : float  
The rotation angle in degrees.
- axes** : tuple of 2 ints, optional  
The two axes that define the plane of rotation. Default is the first two axes.
- reshape** : bool, optional  
If *reshape* is true, the output shape is adapted so that the input array is contained completely in the output. Default is True.
- output** : ndarray or dtype, optional  
The array in which to place the output, or the dtype of the returned array.
- order** : int, optional  
The order of the spline interpolation, default is 3. The order has to be in the range 0-5.
- mode** : str, optional  
Points outside the boundaries of the input are filled according to the given mode ('constant', 'nearest', 'reflect', 'mirror' or 'wrap'). Default is 'constant'.
- cval** : scalar, optional  
Value used for points outside the boundaries of the input if *mode*='constant'. Default is 0.0
- prefilter** : bool, optional  
The parameter *prefilter* determines if the input is pre-filtered with *spline\_filter* before interpolation (necessary for spline interpolation of order > 1). If False, it is assumed that the input is already filtered. Default is True.

**Returns**

- rotate** : ndarray or None  
The rotated input. If *output* is given as a parameter, None is returned.

`scipy.ndimage.shift` (*input*, *shift*, *output*=None, *order*=3, *mode*='constant', *cval*=0.0, *prefilter*=True)

Shift an array.

The array is shifted using spline interpolation of the requested order. Points outside the boundaries of the input are filled according to the given mode.

**Parameters**

- input** : ndarray  
The input array.
- shift** : float or sequence  
The shift along the axes. If a float, *shift* is the same for each axis. If a sequence, *shift* should contain one value for each axis.
- output** : ndarray or dtype, optional  
The array in which to place the output, or the dtype of the returned array.
- order** : int, optional  
The order of the spline interpolation, default is 3. The order has to be in the range 0-5.
- mode** : str, optional  
Points outside the boundaries of the input are filled according to the given mode ('constant', 'nearest', 'reflect', 'mirror' or 'wrap'). Default is 'constant'.
- cval** : scalar, optional

Value used for points outside the boundaries of the input if `mode='constant'`.  
Default is 0.0

**prefilter** : bool, optional

The parameter `prefilter` determines if the input is pre-filtered with `spline_filter` before interpolation (necessary for spline interpolation of order  $> 1$ ). If `False`, it is assumed that the input is already filtered. Default is `True`.

**Returns** **shift** : ndarray or None

The shifted input. If `output` is given as a parameter, `None` is returned.

`scipy.ndimage.spline_filter` (*input*, *order*=3, *output*=<type 'numpy.float64'>)

Multi-dimensional spline filter.

For more details, see `spline_filter1d`.

**See also:**

`spline_filter1d`

**Notes**

The multi-dimensional filter is implemented as a sequence of one-dimensional spline filters. The intermediate arrays are stored in the same data type as the output. Therefore, for output types with a limited precision, the results may be imprecise because intermediate results may be stored with insufficient precision.

`scipy.ndimage.spline_filter1d` (*input*, *order*=3, *axis*=-1, *output*=<type 'numpy.float64'>)

Calculates a one-dimensional spline filter along the given axis.

The lines of the array along the given axis are filtered by a spline filter. The order of the spline must be  $\geq 2$  and  $\leq 5$ .

**Parameters** **input** : array\_like

The input array.

**order** : int, optional

The order of the spline, default is 3.

**axis** : int, optional

The axis along which the spline filter is applied. Default is the last axis.

**output** : ndarray or dtype, optional

The array in which to place the output, or the dtype of the returned array. Default is `numpy.float64`.

**Returns** **spline\_filter1d** : ndarray or None

The filtered input. If `output` is given as a parameter, `None` is returned.

`scipy.ndimage.zoom` (*input*, *zoom*, *output*=None, *order*=3, *mode*='constant', *cval*=0.0, *prefilter*=True)

Zoom an array.

The array is zoomed using spline interpolation of the requested order.

**Parameters** **input** : ndarray

The input array.

**zoom** : float or sequence

The zoom factor along the axes. If a float, `zoom` is the same for each axis. If a sequence, `zoom` should contain one value for each axis.

**output** : ndarray or dtype, optional

The array in which to place the output, or the dtype of the returned array.

**order** : int, optional

The order of the spline interpolation, default is 3. The order has to be in the range 0-5.

**mode** : str, optional

Points outside the boundaries of the input are filled according to the given mode ('constant', 'nearest', 'reflect', 'mirror' or 'wrap'). Default is 'constant'.

**cval** : scalar, optional  
 Value used for points outside the boundaries of the input if `mode='constant'`.  
 Default is 0.0

**prefilter** : bool, optional  
 The parameter `prefilter` determines if the input is pre-filtered with `spline_filter` before interpolation (necessary for spline interpolation of order > 1). If False, it is assumed that the input is already filtered. Default is True.

**Returns** **zoom** : ndarray or None  
 The zoomed input. If `output` is given as a parameter, None is returned.

## 5.16.4 Measurements

<code>center_of_mass(input[, labels, index])</code>	Calculate the center of mass of the values of an array at labels.
<code>extrema(input[, labels, index])</code>	Calculate the minimums and maximums of the values of an array at labels, along with their positions.
<code>find_objects(input[, max_label])</code>	Find objects in a labeled array.
<code>histogram(input, min, max, bins[, labels, index])</code>	Calculate the histogram of the values of an array, optionally at labels.
<code>label(input[, structure, output])</code>	Label features in an array.
<code>labeled_comprehension(input, labels, index, ...)</code>	Roughly equivalent to <code>[func(input[labels == i]) for i in index]</code> .
<code>maximum(input[, labels, index])</code>	Calculate the maximum of the values of an array over labeled regions.
<code>maximum_position(input[, labels, index])</code>	Find the positions of the maximums of the values of an array at labels.
<code>mean(input[, labels, index])</code>	Calculate the mean of the values of an array at labels.
<code>median(input[, labels, index])</code>	Calculate the median of the values of an array over labeled regions.
<code>minimum(input[, labels, index])</code>	Calculate the minimum of the values of an array over labeled regions.
<code>minimum_position(input[, labels, index])</code>	Find the positions of the minimums of the values of an array at labels.
<code>standard_deviation(input[, labels, index])</code>	Calculate the standard deviation of the values of an n-D image array, optionally at specified sub-regions.
<code>sum(input[, labels, index])</code>	Calculate the sum of the values of the array.
<code>variance(input[, labels, index])</code>	Calculate the variance of the values of an n-D image array, optionally at specified sub-regions.
<code>watershed_ift(input, markers[, structure, ...])</code>	Apply watershed from markers using image foresting transform algorithm.

`scipy.ndimage.center_of_mass` (*input*, *labels=None*, *index=None*)

Calculate the center of mass of the values of an array at labels.

**Parameters** **input** : ndarray  
 Data from which to calculate center-of-mass. The masses can either be positive or negative.

**labels** : ndarray, optional  
 Labels for objects in *input*, as generated by `ndimage.label`. Only used with *index*. Dimensions must be the same as *input*.

**index** : int or sequence of ints, optional

**Returns** Labels for which to calculate centers-of-mass. If not specified, all labels greater than zero are used. Only used with *labels*.  
**center\_of\_mass** : tuple, or list of tuples  
 Coordinates of centers-of-mass.

**Examples**

```
>>> a = np.array([[0, 0, 0, 0],
...               [0, 1, 1, 0],
...               [0, 1, 1, 0],
...               [0, 1, 1, 0]])
>>> from scipy import ndimage
>>> ndimage.measurements.center_of_mass(a)
(2.0, 1.5)
```

Calculation of multiple objects in an image

```
>>> b = np.array([[0, 1, 1, 0],
...               [0, 1, 0, 0],
...               [0, 0, 0, 0],
...               [0, 0, 1, 1],
...               [0, 0, 1, 1]])
>>> lbl = ndimage.label(b)[0]
>>> ndimage.measurements.center_of_mass(b, lbl, [1, 2])
[(0.33333333333333331, 1.3333333333333333), (3.5, 2.5)]
```

Negative masses are also accepted, which can occur for example when bias is removed from measured data due to random noise.

```
>>> c = np.array([[-1, 0, 0, 0],
...               [0, -1, -1, 0],
...               [0, 1, -1, 0],
...               [0, 1, 1, 0]])
>>> ndimage.measurements.center_of_mass(c)
(-4.0, 1.0)
```

If there are division by zero issues, the function does not raise an error but rather issues a `RuntimeWarning` before returning `inf` and/or `NaN`.

```
>>> d = np.array([-1, 1])
>>> ndimage.measurements.center_of_mass(d)
(inf,)
```

`scipy.ndimage.extrema` (*input*, *labels=None*, *index=None*)

Calculate the minimums and maximums of the values of an array at labels, along with their positions.

**Parameters**

- input** : ndarray  
Nd-image data to process.
- labels** : ndarray, optional  
Labels of features in input. If not `None`, must be same shape as *input*.
- index** : int or sequence of ints, optional  
Labels to include in output. If `None` (default), all values where non-zero *labels* are used.

**Returns**

- minimums, maximums** : int or ndarray  
Values of minimums and maximums in each feature.
- min\_positions, max\_positions** : tuple or list of tuples  
Each tuple gives the n-D coordinates of the corresponding minimum or maximum.

**See also:**

*maximum, minimum, maximum\_position, minimum\_position, center\_of\_mass*

**Examples**

```
>>> a = np.array([[1, 2, 0, 0],
...              [5, 3, 0, 4],
...              [0, 0, 0, 7],
...              [9, 3, 0, 0]])
>>> from scipy import ndimage
>>> ndimage.extrema(a)
(0, 9, (0, 2), (3, 0))
```

Features to process can be specified using *labels* and *index*:

```
>>> lbl, nlbl = ndimage.label(a)
>>> ndimage.extrema(a, lbl, index=np.arange(1, nlbl+1))
(array([1, 4, 3]),
 array([5, 7, 9]),
 [(0, 0), (1, 3), (3, 1)],
 [(1, 0), (2, 3), (3, 0)])
```

If no index is given, non-zero *labels* are processed:

```
>>> ndimage.extrema(a, lbl)
(1, 9, (0, 0), (3, 0))
```

`scipy.ndimage.find_objects` (*input*, *max\_label=0*)

Find objects in a labeled array.

**Parameters** **input** : ndarray of ints  
 Array containing objects defined by different labels. Labels with value 0 are ignored.

**max\_label** : int, optional  
 Maximum label to be searched for in *input*. If *max\_label* is not given, the positions of all objects are returned.

**Returns** **object\_slices** : list of tuples  
 A list of tuples, with each tuple containing N slices (with N the dimension of the input array). Slices correspond to the minimal parallelepiped that contains the object. If a number is missing, None is returned instead of a slice.

**See also:**

*label, center\_of\_mass*

**Notes**

This function is very useful for isolating a volume of interest inside a 3-D array, that cannot be “seen through”.

**Examples**

```
>>> from scipy import ndimage
>>> a = np.zeros((6,6), dtype=int)
>>> a[2:4, 2:4] = 1
>>> a[4, 4] = 1
>>> a[:2, :3] = 2
>>> a[0, 5] = 3
>>> a
array([[2, 2, 2, 0, 0, 3],
```

```

    [2, 2, 2, 0, 0, 0],
    [0, 0, 1, 1, 0, 0],
    [0, 0, 1, 1, 0, 0],
    [0, 0, 0, 0, 1, 0],
    [0, 0, 0, 0, 0, 0]])
>>> ndimage.find_objects(a)
[(slice(2, 5, None), slice(2, 5, None)), (slice(0, 2, None), slice(0, 3, None)),
 →(slice(0, 1, None), slice(5, 6, None))]
>>> ndimage.find_objects(a, max_label=2)
[(slice(2, 5, None), slice(2, 5, None)), (slice(0, 2, None), slice(0, 3, None))]
>>> ndimage.find_objects(a == 1, max_label=2)
[(slice(2, 5, None), slice(2, 5, None)), None]

```

```

>>> loc = ndimage.find_objects(a)[0]
>>> a[loc]
array([[1, 1, 0],
       [1, 1, 0],
       [0, 0, 1]])

```

`scipy.ndimage.histogram` (*input*, *min*, *max*, *bins*, *labels=None*, *index=None*)

Calculate the histogram of the values of an array, optionally at labels.

Histogram calculates the frequency of values in an array within bins determined by *min*, *max*, and *bins*. The *labels* and *index* keywords can limit the scope of the histogram to specified sub-regions within the array.

**Parameters**

- input** : array\_like  
Data for which to calculate histogram.
- min, max** : int  
Minimum and maximum values of range of histogram bins.
- bins** : int  
Number of bins.
- labels** : array\_like, optional  
Labels for objects in *input*. If not None, must be same shape as *input*.
- index** : int or sequence of ints, optional  
Label or labels for which to calculate histogram. If None, all values where label is greater than zero are used

**Returns**

- hist** : ndarray  
Histogram counts.

### Examples

```

>>> a = np.array([[ 0.    ,  0.2146,  0.5962,  0.    ],
...              [ 0.    ,  0.7778,  0.    ,  0.    ],
...              [ 0.    ,  0.    ,  0.    ,  0.    ],
...              [ 0.    ,  0.    ,  0.7181,  0.2787],
...              [ 0.    ,  0.    ,  0.6573,  0.3094]])
>>> from scipy import ndimage
>>> ndimage.measurements.histogram(a, 0, 1, 10)
array([13,  0,  2,  1,  0,  1,  1,  2,  0,  0])

```

With labels and no indices, non-zero elements are counted:

```

>>> lbl, nlbl = ndimage.label(a)
>>> ndimage.measurements.histogram(a, 0, 1, 10, lbl)
array([0, 0, 2, 1, 0, 1, 1, 2, 0, 0])

```

Indices can be used to count only certain objects:

```
>>> ndimage.measurements.histogram(a, 0, 1, 10, lbl, 2)
array([0, 0, 1, 1, 0, 0, 1, 1, 0, 0])
```

`scipy.ndimage.label` (*input*, *structure=None*, *output=None*)

Label features in an array.

**Parameters** **input** : array\_like

An array-like object to be labeled. Any non-zero values in *input* are counted as features and zero values are considered the background.

**structure** : array\_like, optional

A structuring element that defines feature connections. *structure* must be symmetric. If no structuring element is provided, one is automatically generated with a squared connectivity equal to one. That is, for a 2-D *input* array, the default structuring element is:

```
[[0, 1, 0],
 [1, 1, 1],
 [0, 1, 0]]
```

**output** : (None, data-type, array\_like), optional

If *output* is a data type, it specifies the type of the resulting labeled feature array. If *output* is an array-like object, then *output* will be updated with the labeled features from this function. This function can operate in-place, by passing *output=input*. Note that the output must be able to store the largest label, or this function will raise an Exception.

**Returns** **label** : ndarray or int

An integer ndarray where each unique feature in *input* has a unique label in the returned array.

**num\_features** : int

How many objects were found.

If *output* is None, this function returns a tuple of (*labeled\_array*, *num\_features*).

If *output* is a ndarray, then it will be updated with values in *labeled\_array* and only *num\_features* will be returned by this function.

See also:

**find\_objects**

generate a list of slices for the labeled features (or objects); useful for finding features' position or dimensions

**Examples**

Create an image with some features, then label it using the default (cross-shaped) structuring element:

```
>>> from scipy.ndimage import label, generate_binary_structure
>>> a = np.array([[0, 0, 1, 1, 0, 0],
...              [0, 0, 0, 1, 0, 0],
...              [1, 1, 0, 0, 1, 0],
...              [0, 0, 0, 1, 0, 0]])
>>> labeled_array, num_features = label(a)
```

Each of the 4 features are labeled with a different integer:

```
>>> num_features
4
>>> labeled_array
array([[0, 0, 1, 1, 0, 0],
```

```
[0, 0, 0, 1, 0, 0],
[2, 2, 0, 0, 3, 0],
[0, 0, 0, 4, 0, 0]])
```

Generate a structuring element that will consider features connected even if they touch diagonally:

```
>>> s = generate_binary_structure(2,2)
```

or,

```
>>> s = [[1,1,1],
...      [1,1,1],
...      [1,1,1]]
```

Label the image using the new structuring element:

```
>>> labeled_array, num_features = label(a, structure=s)
```

Show the 2 labeled features (note that features 1, 3, and 4 from above are now considered a single feature):

```
>>> num_features
2
>>> labeled_array
array([[0, 0, 1, 1, 0, 0],
       [0, 0, 0, 1, 0, 0],
       [2, 2, 0, 0, 1, 0],
       [0, 0, 0, 1, 0, 0]])
```

`scipy.ndimage.labeled_comprehension` (*input*, *labels*, *index*, *func*, *out\_dtype*, *default*, *pass\_positions=False*)

Roughly equivalent to `[func(input[labels == i]) for i in index]`.

Sequentially applies an arbitrary function (that works on `array_like` input) to subsets of an n-D image array specified by *labels* and *index*. The option exists to provide the function with positional parameters as the second argument.

**Parameters**

- input** : `array_like`  
Data from which to select *labels* to process.
- labels** : `array_like` or `None`  
Labels to objects in *input*. If not `None`, array must be same shape as *input*. If `None`, *func* is applied to raveled *input*.
- index** : `int`, sequence of `ints` or `None`  
Subset of *labels* to which to apply *func*. If a scalar, a single value is returned. If `None`, *func* is applied to all non-zero values of *labels*.
- func** : callable  
Python function to apply to *labels* from *input*.
- out\_dtype** : `dtype`  
Dtype to use for *result*.
- default** : `int`, `float` or `None`  
Default return value when a element of *index* does not exist in *labels*.
- pass\_positions** : `bool`, optional  
If `True`, pass linear indices to *func* as a second argument. Default is `False`.

**Returns**

- result** : `ndarray`  
Result of applying *func* to each of *labels* to *input* in *index*.

**Examples**

```
>>> a = np.array([[1, 2, 0, 0],
...              [5, 3, 0, 4],
...              [0, 0, 0, 7],
...              [9, 3, 0, 0]])
>>> from scipy import ndimage
>>> lbl, nlbl = ndimage.label(a)
>>> lbls = np.arange(1, nlbl+1)
>>> ndimage.labeled_comprehension(a, lbl, lbls, np.mean, float, 0)
array([ 2.75,  5.5 ,  6.  ])
```

Falling back to *default*:

```
>>> lbls = np.arange(1, nlbl+2)
>>> ndimage.labeled_comprehension(a, lbl, lbls, np.mean, float, -1)
array([ 2.75,  5.5 ,  6.  , -1.  ])
```

Passing positions:

```
>>> def fn(val, pos):
...     print("fn says: %s : %s" % (val, pos))
...     return (val.sum()) if (pos.sum() % 2 == 0) else (-val.sum())
...
>>> ndimage.labeled_comprehension(a, lbl, lbls, fn, float, 0, True)
fn says: [1 2 5 3] : [0 1 4 5]
fn says: [4 7] : [ 7 11]
fn says: [9 3] : [12 13]
array([ 11.,  11., -12.,  0.])
```

`scipy.ndimage.maximum` (*input*, *labels=None*, *index=None*)

Calculate the maximum of the values of an array over labeled regions.

**Parameters** **input** : array\_like

Array\_like of values. For each region specified by *labels*, the maximal values of *input* over the region is computed.

**labels** : array\_like, optional

An array of integers marking different regions over which the maximum value of *input* is to be computed. *labels* must have the same shape as *input*. If *labels* is not specified, the maximum over the whole array is returned.

**index** : array\_like, optional

A list of region labels that are taken into account for computing the maxima. If *index* is None, the maximum over all elements where *labels* is non-zero is returned.

**Returns** **output** : float or list of floats

List of maxima of *input* over the regions determined by *labels* and whose index is in *index*. If *index* or *labels* are not specified, a float is returned: the maximal value of *input* if *labels* is None, and the maximal value of elements where *labels* is greater than zero if *index* is None.

**See also:**

*label*, *minimum*, *median*, *maximum\_position*, *extrema*, *sum*, *mean*, *variance*, *standard\_deviation*

**Notes**

The function returns a Python list and not a Numpy array, use *np.array* to convert the list to an array.

**Examples**

```

>>> a = np.arange(16).reshape((4,4))
>>> a
array([[ 0,  1,  2,  3],
       [ 4,  5,  6,  7],
       [ 8,  9, 10, 11],
       [12, 13, 14, 15]])
>>> labels = np.zeros_like(a)
>>> labels[:2,:2] = 1
>>> labels[2:, 1:3] = 2
>>> labels
array([[1, 1, 0, 0],
       [1, 1, 0, 0],
       [0, 2, 2, 0],
       [0, 2, 2, 0]])
>>> from scipy import ndimage
>>> ndimage.maximum(a)
15.0
>>> ndimage.maximum(a, labels=labels, index=[1,2])
[5.0, 14.0]
>>> ndimage.maximum(a, labels=labels)
14.0

```

```

>>> b = np.array([[1, 2, 0, 0],
...              [5, 3, 0, 4],
...              [0, 0, 0, 7],
...              [9, 3, 0, 0]])
>>> labels, labels_nb = ndimage.label(b)
>>> labels
array([[1, 1, 0, 0],
       [1, 1, 0, 2],
       [0, 0, 0, 2],
       [3, 3, 0, 0]])
>>> ndimage.maximum(b, labels=labels, index=np.arange(1, labels_nb + 1))
[5.0, 7.0, 9.0]

```

`scipy.ndimage.maximum_position` (*input*, *labels=None*, *index=None*)

Find the positions of the maximums of the values of an array at labels.

For each region specified by *labels*, the position of the maximum value of *input* within the region is returned.

**Parameters** **input** : array\_like

Array\_like of values.

**labels** : array\_like, optional

An array of integers marking different regions over which the position of the maximum value of *input* is to be computed. *labels* must have the same shape as *input*. If *labels* is not specified, the location of the first maximum over the whole array is returned.

The *labels* argument only works when *index* is specified.

**index** : array\_like, optional

A list of region labels that are taken into account for finding the location of the maxima. If *index* is None, the first maximum over all elements where *labels* is non-zero is returned.

The *index* argument only works when *labels* is specified.

**Returns** **output** : list of tuples of ints

List of tuples of ints that specify the location of maxima of *input* over the regions determined by *labels* and whose index is in *index*.

If *index* or *labels* are not specified, a tuple of ints is returned specifying the location of the first maximal value of *input*.

**See also:**

*label*, *minimum*, *median*, *maximum\_position*, *extrema*, *sum*, *mean*, *variance*, *standard\_deviation*

`scipy.ndimage.mean` (*input*, *labels=None*, *index=None*)

Calculate the mean of the values of an array at labels.

**Parameters**

- input** : array\_like  
Array on which to compute the mean of elements over distinct regions.
- labels** : array\_like, optional  
Array of labels of same shape, or broadcastable to the same shape as *input*. All elements sharing the same label form one region over which the mean of the elements is computed.
- index** : int or sequence of ints, optional  
Labels of the objects over which the mean is to be computed. Default is None, in which case the mean for all values where label is greater than 0 is calculated.

**Returns**

- out** : list  
Sequence of same length as *index*, with the mean of the different regions labeled by the labels in *index*.

**See also:**

`ndimage.variance`, `ndimage.standard_deviation`, `ndimage.minimum`, `ndimage.maximum`, `ndimage.sum`, `ndimage.label`

**Examples**

```
>>> from scipy import ndimage
>>> a = np.arange(25).reshape((5, 5))
>>> labels = np.zeros_like(a)
>>> labels[3:5, 3:5] = 1
>>> index = np.unique(labels)
>>> labels
array([[0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0],
       [0, 0, 0, 1, 1],
       [0, 0, 0, 1, 1]])
>>> index
array([0, 1])
>>> ndimage.mean(a, labels=labels, index=index)
[10.285714285714286, 21.0]
```

`scipy.ndimage.median` (*input*, *labels=None*, *index=None*)

Calculate the median of the values of an array over labeled regions.

**Parameters**

- input** : array\_like  
Array\_like of values. For each region specified by *labels*, the median value of *input* over the region is computed.
- labels** : array\_like, optional  
An array\_like of integers marking different regions over which the median value of *input* is to be computed. *labels* must have the same shape as *input*. If *labels* is not specified, the median over the whole array is returned.
- index** : array\_like, optional

A list of region labels that are taken into account for computing the medians. If *index* is *None*, the median over all elements where *labels* is non-zero is returned.

**Returns** **median** : float or list of floats  
List of medians of *input* over the regions determined by *labels* and whose index is in *index*. If *index* or *labels* are not specified, a float is returned: the median value of *input* if *labels* is *None*, and the median value of elements where *labels* is greater than zero if *index* is *None*.

**See also:**

*label*, *minimum*, *maximum*, *extrema*, *sum*, *mean*, *variance*, *standard\_deviation*

**Notes**

The function returns a Python list and not a Numpy array, use *np.array* to convert the list to an array.

**Examples**

```
>>> from scipy import ndimage
>>> a = np.array([[1, 2, 0, 1],
...              [5, 3, 0, 4],
...              [0, 0, 0, 7],
...              [9, 3, 0, 0]])
>>> labels, labels_nb = ndimage.label(a)
>>> labels
array([[1, 1, 0, 2],
       [1, 1, 0, 2],
       [0, 0, 0, 2],
       [3, 3, 0, 0]])
>>> ndimage.median(a, labels=labels, index=np.arange(1, labels_nb + 1))
[2.5, 4.0, 6.0]
>>> ndimage.median(a)
1.0
>>> ndimage.median(a, labels=labels)
3.0
```

`scipy.ndimage.minimum` (*input*, *labels=None*, *index=None*)

Calculate the minimum of the values of an array over labeled regions.

**Parameters** **input** : array\_like  
Array\_like of values. For each region specified by *labels*, the minimal values of *input* over the region is computed.  
**labels** : array\_like, optional  
An array\_like of integers marking different regions over which the minimum value of *input* is to be computed. *labels* must have the same shape as *input*. If *labels* is not specified, the minimum over the whole array is returned.  
**index** : array\_like, optional  
A list of region labels that are taken into account for computing the minima. If *index* is *None*, the minimum over all elements where *labels* is non-zero is returned.

**Returns** **minimum** : float or list of floats  
List of minima of *input* over the regions determined by *labels* and whose index is in *index*. If *index* or *labels* are not specified, a float is returned: the minimal value of *input* if *labels* is *None*, and the minimal value of elements where *labels* is greater than zero if *index* is *None*.

**See also:**

*label*, *maximum*, *median*, *minimum\_position*, *extrema*, *sum*, *mean*, *variance*, *standard\_deviation*

**Notes**

The function returns a Python list and not a Numpy array, use *np.array* to convert the list to an array.

**Examples**

```
>>> from scipy import ndimage
>>> a = np.array([[1, 2, 0, 0],
...              [5, 3, 0, 4],
...              [0, 0, 0, 7],
...              [9, 3, 0, 0]])
>>> labels, labels_nb = ndimage.label(a)
>>> labels
array([[1, 1, 0, 0],
       [1, 1, 0, 2],
       [0, 0, 0, 2],
       [3, 3, 0, 0]])
>>> ndimage.minimum(a, labels=labels, index=np.arange(1, labels_nb + 1))
[1.0, 4.0, 3.0]
>>> ndimage.minimum(a)
0.0
>>> ndimage.minimum(a, labels=labels)
1.0
```

`scipy.ndimage.minimum_position` (*input*, *labels=None*, *index=None*)

Find the positions of the minimums of the values of an array at labels.

- Parameters**
- input** : array\_like  
Array\_like of values.
  - labels** : array\_like, optional  
An array of integers marking different regions over which the position of the minimum value of *input* is to be computed. *labels* must have the same shape as *input*. If *labels* is not specified, the location of the first minimum over the whole array is returned. The *labels* argument only works when *index* is specified.
  - index** : array\_like, optional  
A list of region labels that are taken into account for finding the location of the minima. If *index* is None, the first minimum over all elements where *labels* is non-zero is returned. The *index* argument only works when *labels* is specified.
- Returns**
- output** : list of tuples of ints  
Tuple of ints or list of tuples of ints that specify the location of minima of *input* over the regions determined by *labels* and whose index is in *index*. If *index* or *labels* are not specified, a tuple of ints is returned specifying the location of the first minimal value of *input*.

**See also:**

*label*, *minimum*, *median*, *maximum\_position*, *extrema*, *sum*, *mean*, *variance*, *standard\_deviation*

`scipy.ndimage.standard_deviation` (*input*, *labels=None*, *index=None*)

Calculate the standard deviation of the values of an n-D image array, optionally at specified sub-regions.

- Parameters**
- input** : array\_like  
Nd-image data to process.
  - labels** : array\_like, optional  
Labels to identify sub-regions in *input*. If not None, must be same shape as *input*.
  - index** : int or sequence of ints, optional

*labels* to include in output. If None (default), all values where *labels* is non-zero are used.

**Returns** **standard\_deviation** : float or ndarray  
Values of standard deviation, for each sub-region if *labels* and *index* are specified.

**See also:**

*label, variance, maximum, minimum, extrema*

**Examples**

```
>>> a = np.array([[1, 2, 0, 0],
...              [5, 3, 0, 4],
...              [0, 0, 0, 7],
...              [9, 3, 0, 0]])
>>> from scipy import ndimage
>>> ndimage.standard_deviation(a)
2.7585095613392387
```

Features to process can be specified using *labels* and *index*:

```
>>> lbl, nlbl = ndimage.label(a)
>>> ndimage.standard_deviation(a, lbl, index=np.arange(1, nlbl+1))
array([ 1.479,  1.5   ,  3.   ])
```

If no index is given, non-zero *labels* are processed:

```
>>> ndimage.standard_deviation(a, lbl)
2.4874685927665499
```

`scipy.ndimage.sum(input, labels=None, index=None)`

Calculate the sum of the values of the array.

**Parameters** **input** : array\_like  
Values of *input* inside the regions defined by *labels* are summed together.  
**labels** : array\_like of ints, optional  
Assign labels to the values of the array. Has to have the same shape as *input*.  
**index** : array\_like, optional  
A single label number or a sequence of label numbers of the objects to be measured.

**Returns** **sum** : ndarray or scalar  
An array of the sums of values of *input* inside the regions defined by *labels* with the same shape as *index*. If 'index' is None or scalar, a scalar is returned.

**See also:**

*mean, median*

**Examples**

```
>>> from scipy import ndimage
>>> input = [0,1,2,3]
>>> labels = [1,1,2,2]
>>> ndimage.sum(input, labels, index=[1,2])
[1.0, 5.0]
>>> ndimage.sum(input, labels, index=1)
1
>>> ndimage.sum(input, labels)
6
```

`scipy.ndimage.variance` (*input*, *labels=None*, *index=None*)

Calculate the variance of the values of an n-D image array, optionally at specified sub-regions.

**Parameters**

- input** : array\_like  
Nd-image data to process.
- labels** : array\_like, optional  
Labels defining sub-regions in *input*. If not None, must be same shape as *input*.
- index** : int or sequence of ints, optional  
*labels* to include in output. If None (default), all values where *labels* is non-zero are used.

**Returns**

- variance** : float or ndarray  
Values of variance, for each sub-region if *labels* and *index* are specified.

**See also:**

*label*, *standard\_deviation*, *maximum*, *minimum*, *extrema*

**Examples**

```
>>> a = np.array([[1, 2, 0, 0],
...              [5, 3, 0, 4],
...              [0, 0, 0, 7],
...              [9, 3, 0, 0]])
>>> from scipy import ndimage
>>> ndimage.variance(a)
7.609375
```

Features to process can be specified using *labels* and *index*:

```
>>> lbl, nlbl = ndimage.label(a)
>>> ndimage.variance(a, lbl, index=np.arange(1, nlbl+1))
array([ 2.1875,  2.25 ,  9.   ])
```

If no *index* is given, all non-zero *labels* are processed:

```
>>> ndimage.variance(a, lbl)
6.1875
```

`scipy.ndimage.watershed_ift` (*input*, *markers*, *structure=None*, *output=None*)

Apply watershed from markers using image foresting transform algorithm.

**Parameters**

- input** : array\_like  
Input.
- markers** : array\_like  
Markers are points within each watershed that form the beginning of the process. Negative markers are considered background markers which are processed after the other markers.
- structure** : structure element, optional  
A structuring element defining the connectivity of the object can be provided. If None, an element is generated with a squared connectivity equal to one.
- output** : ndarray, optional  
An output array can optionally be provided. The same shape as input.

**Returns**

- watershed\_ift** : ndarray  
Output. Same shape as *input*.

**References**

[R186]

## 5.16.5 Morphology

<code>binary_closing(input[, structure, ...])</code>	Multi-dimensional binary closing with the given structuring element.
<code>binary_dilation(input[, structure, ...])</code>	Multi-dimensional binary dilation with the given structuring element.
<code>binary_erosion(input[, structure, ...])</code>	Multi-dimensional binary erosion with a given structuring element.
<code>binary_fill_holes(input[, structure, ...])</code>	Fill the holes in binary objects.
<code>binary_hit_or_miss(input[, structure1, ...])</code>	Multi-dimensional binary hit-or-miss transform.
<code>binary_opening(input[, structure, ...])</code>	Multi-dimensional binary opening with the given structuring element.
<code>binary_propagation(input[, structure, mask, ...])</code>	Multi-dimensional binary propagation with the given structuring element.
<code>black_tophat(input[, size, footprint, ...])</code>	Multi-dimensional black tophat filter.
<code>distance_transform_bf(input[, metric, ...])</code>	Distance transform function by a brute force algorithm.
<code>distance_transform_cdt(input[, metric, ...])</code>	Distance transform for chamfer type of transforms.
<code>distance_transform_edt(input[, sampling, ...])</code>	Exact euclidean distance transform.
<code>generate_binary_structure(rank, connectivity)</code>	Generate a binary structure for binary morphological operations.
<code>grey_closing(input[, size, footprint, ...])</code>	Multi-dimensional greyscale closing.
<code>grey_dilation(input[, size, footprint, ...])</code>	Calculate a greyscale dilation, using either a structuring element, or a footprint corresponding to a flat structuring element.
<code>grey_erosion(input[, size, footprint, ...])</code>	Calculate a greyscale erosion, using either a structuring element, or a footprint corresponding to a flat structuring element.
<code>grey_opening(input[, size, footprint, ...])</code>	Multi-dimensional greyscale opening.
<code>iterate_structure(structure, iterations[, ...])</code>	Iterate a structure by dilating it with itself.
<code>morphological_gradient(input[, size, ...])</code>	Multi-dimensional morphological gradient.
<code>morphological_laplace(input[, size, ...])</code>	Multi-dimensional morphological laplace.
<code>white_tophat(input[, size, footprint, ...])</code>	Multi-dimensional white tophat filter.

`scipy.ndimage.binary_closing(input, structure=None, iterations=1, output=None, origin=0)`

Multi-dimensional binary closing with the given structuring element.

The *closing* of an input image by a structuring element is the *erosion* of the *dilation* of the image by the structuring element.

**Parameters** **input** : array\_like

Binary array\_like to be closed. Non-zero (True) elements form the subset to be closed.

**structure** : array\_like, optional

Structuring element used for the closing. Non-zero elements are considered True. If no structuring element is provided an element is generated with a square connectivity equal to one (i.e., only nearest neighbors are connected to the center, diagonally-connected elements are not considered neighbors).

**iterations** : {int, float}, optional

The dilation step of the closing, then the erosion step are each repeated *iterations* times (one, by default). If iterations is less than 1, each operations is repeated until the result does not change anymore.

**output** : ndarray, optional

Array of the same shape as input, into which the output is placed. By default, a new array is created.

**origin** : int or tuple of ints, optional  
Placement of the filter, by default 0.

**Returns** **binary\_closing** : ndarray of bools  
Closing of the input by the structuring element.

**See also:**

*grey\_closing*, *binary\_opening*, *binary\_dilation*, *binary\_erosion*,  
*generate\_binary\_structure*

**Notes**

*Closing* [R163] is a mathematical morphology operation [R164] that consists in the succession of a dilation and an erosion of the input with the same structuring element. Closing therefore fills holes smaller than the structuring element.

Together with *opening* (*binary\_opening*), closing can be used for noise removal.

**References**

[R163], [R164]

**Examples**

```
>>> from scipy import ndimage
>>> a = np.zeros((5,5), dtype=int)
>>> a[1:-1, 1:-1] = 1; a[2,2] = 0
>>> a
array([[0, 0, 0, 0, 0],
       [0, 1, 1, 1, 0],
       [0, 1, 0, 1, 0],
       [0, 1, 1, 1, 0],
       [0, 0, 0, 0, 0]])
>>> # Closing removes small holes
>>> ndimage.binary_closing(a).astype(int)
array([[0, 0, 0, 0, 0],
       [0, 1, 1, 1, 0],
       [0, 1, 1, 1, 0],
       [0, 1, 1, 1, 0],
       [0, 0, 0, 0, 0]])
>>> # Closing is the erosion of the dilation of the input
>>> ndimage.binary_dilation(a).astype(int)
array([[0, 1, 1, 1, 0],
       [1, 1, 1, 1, 1],
       [1, 1, 1, 1, 1],
       [1, 1, 1, 1, 1],
       [0, 1, 1, 1, 0]])
>>> ndimage.binary_erosion(ndimage.binary_dilation(a)).astype(int)
array([[0, 0, 0, 0, 0],
       [0, 1, 1, 1, 0],
       [0, 1, 1, 1, 0],
       [0, 1, 1, 1, 0],
       [0, 0, 0, 0, 0]])
```

```
>>> a = np.zeros((7,7), dtype=int)
>>> a[1:6, 2:5] = 1; a[1:3,3] = 0
>>> a
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 0, 1, 0, 1, 0, 0],
```

```

    [0, 0, 1, 0, 1, 0, 0],
    [0, 0, 1, 1, 1, 0, 0],
    [0, 0, 1, 1, 1, 0, 0],
    [0, 0, 1, 1, 1, 0, 0],
    [0, 0, 0, 0, 0, 0, 0]])
>>> # In addition to removing holes, closing can also
>>> # coarsen boundaries with fine hollows.
>>> ndimage.binary_closing(a).astype(int)
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 0, 1, 0, 1, 0, 0],
       [0, 0, 1, 1, 1, 0, 0],
       [0, 0, 1, 1, 1, 0, 0],
       [0, 0, 1, 1, 1, 0, 0],
       [0, 0, 1, 1, 1, 0, 0],
       [0, 0, 0, 0, 0, 0, 0]])
>>> ndimage.binary_closing(a, structure=np.ones((2,2))).astype(int)
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 0, 1, 1, 1, 0, 0],
       [0, 0, 1, 1, 1, 0, 0],
       [0, 0, 1, 1, 1, 0, 0],
       [0, 0, 1, 1, 1, 0, 0],
       [0, 0, 1, 1, 1, 0, 0],
       [0, 0, 0, 0, 0, 0, 0]])

```

`scipy.ndimage.binary_dilation` (*input*, *structure=None*, *iterations=1*, *mask=None*, *output=None*, *border\_value=0*, *origin=0*, *brute\_force=False*)  
 Multi-dimensional binary dilation with the given structuring element.

**Parameters**

- input** : array\_like  
Binary array\_like to be dilated. Non-zero (True) elements form the subset to be dilated.
- structure** : array\_like, optional  
Structuring element used for the dilation. Non-zero elements are considered True. If no structuring element is provided an element is generated with a square connectivity equal to one.
- iterations** : {int, float}, optional  
The dilation is repeated *iterations* times (one, by default). If iterations is less than 1, the dilation is repeated until the result does not change anymore.
- mask** : array\_like, optional  
If a mask is given, only those elements with a True value at the corresponding mask element are modified at each iteration.
- output** : ndarray, optional  
Array of the same shape as input, into which the output is placed. By default, a new array is created.
- origin** : int or tuple of ints, optional  
Placement of the filter, by default 0.
- border\_value** : int (cast to 0 or 1), optional  
Value at the border in the output array.

**Returns**

- binary\_dilation** : ndarray of bools  
Dilation of the input by the structuring element.

**See also:**

`grey_dilation`, `binary_erosion`, `binary_closing`, `binary_opening`,  
`generate_binary_structure`

**Notes**

Dilation [R165] is a mathematical morphology operation [R166] that uses a structuring element for expanding the shapes in an image. The binary dilation of an image by a structuring element is the locus of the points covered by the structuring element, when its center lies within the non-zero points of the image.

**References**

[R165], [R166]

**Examples**

```

>>> from scipy import ndimage
>>> a = np.zeros((5, 5))
>>> a[2, 2] = 1
>>> a
array([[ 0.,  0.,  0.,  0.,  0.],
       [ 0.,  0.,  0.,  0.,  0.],
       [ 0.,  0.,  1.,  0.,  0.],
       [ 0.,  0.,  0.,  0.,  0.],
       [ 0.,  0.,  0.,  0.,  0.]])
>>> ndimage.binary_dilation(a)
array([[False, False, False, False, False],
       [False, False, True, False, False],
       [False, True, True, True, False],
       [False, False, True, False, False],
       [False, False, False, False, False]], dtype=bool)
>>> ndimage.binary_dilation(a).astype(a.dtype)
array([[ 0.,  0.,  0.,  0.,  0.],
       [ 0.,  0.,  1.,  0.,  0.],
       [ 0.,  1.,  1.,  1.,  0.],
       [ 0.,  0.,  1.,  0.,  0.],
       [ 0.,  0.,  0.,  0.,  0.]])
>>> # 3x3 structuring element with connectivity 1, used by default
>>> struct1 = ndimage.generate_binary_structure(2, 1)
>>> struct1
array([[False, True, False],
       [ True, True, True],
       [False, True, False]], dtype=bool)
>>> # 3x3 structuring element with connectivity 2
>>> struct2 = ndimage.generate_binary_structure(2, 2)
>>> struct2
array([[ True,  True,  True],
       [ True,  True,  True],
       [ True,  True,  True]], dtype=bool)
>>> ndimage.binary_dilation(a, structure=struct1).astype(a.dtype)
array([[ 0.,  0.,  0.,  0.,  0.],
       [ 0.,  0.,  1.,  0.,  0.],
       [ 0.,  1.,  1.,  1.,  0.],
       [ 0.,  0.,  1.,  0.,  0.],
       [ 0.,  0.,  0.,  0.,  0.]])
>>> ndimage.binary_dilation(a, structure=struct2).astype(a.dtype)
array([[ 0.,  0.,  0.,  0.,  0.],
       [ 0.,  1.,  1.,  1.,  0.],
       [ 0.,  1.,  1.,  1.,  0.],
       [ 0.,  1.,  1.,  1.,  0.],
       [ 0.,  0.,  0.,  0.,  0.]])
>>> ndimage.binary_dilation(a, structure=struct1, \
... iterations=2).astype(a.dtype)

```

```
array([[ 0.,  0.,  1.,  0.,  0.],
       [ 0.,  1.,  1.,  1.,  0.],
       [ 1.,  1.,  1.,  1.,  1.],
       [ 0.,  1.,  1.,  1.,  0.],
       [ 0.,  0.,  1.,  0.,  0.]])
```

`scipy.ndimage.binary_erosion` (*input*, *structure=None*, *iterations=1*, *mask=None*, *output=None*, *border\_value=0*, *origin=0*, *brute\_force=False*)

Multi-dimensional binary erosion with a given structuring element.

Binary erosion is a mathematical morphology operation used for image processing.

**Parameters**

- input** : array\_like  
Binary image to be eroded. Non-zero (True) elements form the subset to be eroded.
- structure** : array\_like, optional  
Structuring element used for the erosion. Non-zero elements are considered True. If no structuring element is provided, an element is generated with a square connectivity equal to one.
- iterations** : {int, float}, optional  
The erosion is repeated *iterations* times (one, by default). If *iterations* is less than 1, the erosion is repeated until the result does not change anymore.
- mask** : array\_like, optional  
If a mask is given, only those elements with a True value at the corresponding mask element are modified at each iteration.
- output** : ndarray, optional  
Array of the same shape as input, into which the output is placed. By default, a new array is created.
- origin** : int or tuple of ints, optional  
Placement of the filter, by default 0.
- border\_value** : int (cast to 0 or 1), optional  
Value at the border in the output array.

**Returns**

- binary\_erosion** : ndarray of bools  
Erosion of the input by the structuring element.

**See also:**

`grey_erosion`, `binary_dilation`, `binary_closing`, `binary_opening`,  
`generate_binary_structure`

**Notes**

Erosion [R167] is a mathematical morphology operation [R168] that uses a structuring element for shrinking the shapes in an image. The binary erosion of an image by a structuring element is the locus of the points where a superimposition of the structuring element centered on the point is entirely contained in the set of non-zero elements of the image.

**References**

[R167], [R168]

**Examples**

```
>>> from scipy import ndimage
>>> a = np.zeros((7,7), dtype=int)
>>> a[1:6, 2:5] = 1
>>> a
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 0, 1, 1, 1, 0, 0],
```

```

    [0, 0, 1, 1, 1, 0, 0],
    [0, 0, 1, 1, 1, 0, 0],
    [0, 0, 1, 1, 1, 0, 0],
    [0, 0, 1, 1, 1, 0, 0],
    [0, 0, 0, 0, 0, 0, 0]])
>>> ndimage.binary_erosion(a).astype(a.dtype)
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 1, 0, 0, 0],
       [0, 0, 0, 1, 0, 0, 0],
       [0, 0, 0, 1, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0]])
>>> #Erosion removes objects smaller than the structure
>>> ndimage.binary_erosion(a, structure=np.ones((5,5)).astype(a.dtype)
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0]])

```

`scipy.ndimage.binary_fill_holes` (*input*, *structure=None*, *output=None*, *origin=0*)

Fill the holes in binary objects.

**Parameters**

- input** : array\_like  
n-dimensional binary array with holes to be filled
- structure** : array\_like, optional  
Structuring element used in the computation; large-size elements make computations faster but may miss holes separated from the background by thin regions. The default element (with a square connectivity equal to one) yields the intuitive result where all holes in the input have been filled.
- output** : ndarray, optional  
Array of the same shape as input, into which the output is placed. By default, a new array is created.
- origin** : int, tuple of ints, optional  
Position of the structuring element.

**Returns**

- out** : ndarray  
Transformation of the initial image *input* where holes have been filled.

**See also:**

*binary\_dilation*, *binary\_propagation*, *label*

**Notes**

The algorithm used in this function consists in invading the complementary of the shapes in *input* from the outer boundary of the image, using binary dilations. Holes are not connected to the boundary and are therefore not invaded. The result is the complementary subset of the invaded region.

**References**

[R169]

**Examples**

```

>>> from scipy import ndimage
>>> a = np.zeros((5, 5), dtype=int)
>>> a[1:4, 1:4] = 1
>>> a[2,2] = 0
>>> a
array([[0, 0, 0, 0, 0],
       [0, 1, 1, 1, 0],
       [0, 1, 0, 1, 0],
       [0, 1, 1, 1, 0],
       [0, 0, 0, 0, 0]])
>>> ndimage.binary_fill_holes(a).astype(int)
array([[0, 0, 0, 0, 0],
       [0, 1, 1, 1, 0],
       [0, 1, 1, 1, 0],
       [0, 1, 1, 1, 0],
       [0, 0, 0, 0, 0]])
>>> # Too big structuring element
>>> ndimage.binary_fill_holes(a, structure=np.ones((5,5))).astype(int)
array([[0, 0, 0, 0, 0],
       [0, 1, 1, 1, 0],
       [0, 1, 0, 1, 0],
       [0, 1, 1, 1, 0],
       [0, 0, 0, 0, 0]])

```

`scipy.ndimage.binary_hit_or_miss` (*input*, *structure1=None*, *structure2=None*, *output=None*, *origin1=0*, *origin2=None*)

Multi-dimensional binary hit-or-miss transform.

The hit-or-miss transform finds the locations of a given pattern inside the input image.

**Parameters**

- input** : array\_like (cast to booleans)  
Binary image where a pattern is to be detected.
- structure1** : array\_like (cast to booleans), optional  
Part of the structuring element to be fitted to the foreground (non-zero elements) of *input*. If no value is provided, a structure of square connectivity 1 is chosen.
- structure2** : array\_like (cast to booleans), optional  
Second part of the structuring element that has to miss completely the foreground. If no value is provided, the complementary of *structure1* is taken.
- output** : ndarray, optional  
Array of the same shape as *input*, into which the output is placed. By default, a new array is created.
- origin1** : int or tuple of ints, optional  
Placement of the first part of the structuring element *structure1*, by default 0 for a centered structure.
- origin2** : int or tuple of ints, optional  
Placement of the second part of the structuring element *structure2*, by default 0 for a centered structure. If a value is provided for *origin1* and not for *origin2*, then *origin2* is set to *origin1*.

**Returns**

- binary\_hit\_or\_miss** : ndarray  
Hit-or-miss transform of *input* with the given structuring element (*structure1*, *structure2*).

See also:

`ndimage.morphology`, `binary_erosion`

**References**

[R170]

**Examples**

```

>>> from scipy import ndimage
>>> a = np.zeros((7,7), dtype=int)
>>> a[1, 1] = 1; a[2:4, 2:4] = 1; a[4:6, 4:6] = 1
>>> a
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 1, 0, 0, 0, 0, 0],
       [0, 0, 1, 1, 0, 0, 0],
       [0, 0, 1, 1, 0, 0, 0],
       [0, 0, 0, 0, 1, 1, 0],
       [0, 0, 0, 0, 1, 1, 0],
       [0, 0, 0, 0, 0, 0, 0]])
>>> structure1 = np.array([[1, 0, 0], [0, 1, 1], [0, 1, 1]])
>>> structure1
array([[1, 0, 0],
       [0, 1, 1],
       [0, 1, 1]])
>>> # Find the matches of structure1 in the array a
>>> ndimage.binary_hit_or_miss(a, structure1=structure1).astype(int)
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 1, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 1, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0]])
>>> # Change the origin of the filter
>>> # origin1=1 is equivalent to origin1=(1,1) here
>>> ndimage.binary_hit_or_miss(a, structure1=structure1, \
... origin1=1).astype(int)
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 1, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 1, 0],
       [0, 0, 0, 0, 0, 0, 0]])

```

`scipy.ndimage.binary_opening` (*input*, *structure=None*, *iterations=1*, *output=None*, *origin=0*)  
 Multi-dimensional binary opening with the given structuring element.

The *opening* of an input image by a structuring element is the *dilation* of the *erosion* of the image by the structuring element.

**Parameters** **input** : array\_like

Binary array\_like to be opened. Non-zero (True) elements form the subset to be opened.

**structure** : array\_like, optional

Structuring element used for the opening. Non-zero elements are considered True. If no structuring element is provided an element is generated with a square connectivity equal to one (i.e., only nearest neighbors are connected to the center, diagonally-connected elements are not considered neighbors).

**iterations** : {int, float}, optional

The erosion step of the opening, then the dilation step are each repeated *iterations* times (one, by default). If *iterations* is less than 1, each operation is repeated until the result

does not change anymore.

**output** : ndarray, optional

Array of the same shape as input, into which the output is placed. By default, a new array is created.

**origin** : int or tuple of ints, optional

Placement of the filter, by default 0.

**Returns**

**binary\_opening** : ndarray of bools

Opening of the input by the structuring element.

**See also:**

`grey_opening`, `binary_closing`, `binary_erosion`, `binary_dilation`,  
`generate_binary_structure`

**Notes**

*Opening* [R171] is a mathematical morphology operation [R172] that consists in the succession of an erosion and a dilation of the input with the same structuring element. Opening therefore removes objects smaller than the structuring element.

Together with *closing* (`binary_closing`), opening can be used for noise removal.

**References**

[R171], [R172]

**Examples**

```
>>> from scipy import ndimage
>>> a = np.zeros((5,5), dtype=int)
>>> a[1:4, 1:4] = 1; a[4, 4] = 1
>>> a
array([[0, 0, 0, 0, 0],
       [0, 1, 1, 1, 0],
       [0, 1, 1, 1, 0],
       [0, 1, 1, 1, 0],
       [0, 0, 0, 0, 1]])
>>> # Opening removes small objects
>>> ndimage.binary_opening(a, structure=np.ones((3,3)).astype(int))
array([[0, 0, 0, 0, 0],
       [0, 1, 1, 1, 0],
       [0, 1, 1, 1, 0],
       [0, 1, 1, 1, 0],
       [0, 0, 0, 0, 0]])
>>> # Opening can also smooth corners
>>> ndimage.binary_opening(a).astype(int)
array([[0, 0, 0, 0, 0],
       [0, 0, 1, 0, 0],
       [0, 1, 1, 1, 0],
       [0, 0, 1, 0, 0],
       [0, 0, 0, 0, 0]])
>>> # Opening is the dilation of the erosion of the input
>>> ndimage.binary_erosion(a).astype(int)
array([[0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0],
       [0, 0, 1, 0, 0],
       [0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0]])
>>> ndimage.binary_dilation(ndimage.binary_erosion(a)).astype(int)
```

```
array([[0, 0, 0, 0, 0],
       [0, 0, 1, 0, 0],
       [0, 1, 1, 1, 0],
       [0, 0, 1, 0, 0],
       [0, 0, 0, 0, 0]])
```

`scipy.ndimage.binary_propagation` (*input*, *structure=None*, *mask=None*, *output=None*, *border\_value=0*, *origin=0*)

Multi-dimensional binary propagation with the given structuring element.

**Parameters** **input** : array\_like

Binary image to be propagated inside *mask*.

**structure** : array\_like, optional

Structuring element used in the successive dilations. The output may depend on the structuring element, especially if *mask* has several connex components. If no structuring element is provided, an element is generated with a squared connectivity equal to one.

**mask** : array\_like, optional

Binary mask defining the region into which *input* is allowed to propagate.

**output** : ndarray, optional

Array of the same shape as input, into which the output is placed. By default, a new array is created.

**border\_value** : int (cast to 0 or 1), optional

Value at the border in the output array.

**origin** : int or tuple of ints, optional

Placement of the filter, by default 0.

**Returns** **binary\_propagation** : ndarray

Binary propagation of *input* inside *mask*.

### Notes

This function is functionally equivalent to calling `binary_dilation` with the number of iterations less than one: iterative dilation until the result does not change anymore.

The succession of an erosion and propagation inside the original image can be used instead of an *opening* for deleting small objects while keeping the contours of larger objects untouched.

### References

[R173], [R174]

### Examples

```
>>> from scipy import ndimage
>>> input = np.zeros((8, 8), dtype=int)
>>> input[2, 2] = 1
>>> mask = np.zeros((8, 8), dtype=int)
>>> mask[1:4, 1:4] = mask[4, 4] = mask[6:8, 6:8] = 1
>>> input
array([[0, 0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0, 0],
       [0, 0, 1, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0, 0]])
>>> mask
```

```

array([[0, 0, 0, 0, 0, 0, 0, 0],
       [0, 1, 1, 1, 0, 0, 0, 0],
       [0, 1, 1, 1, 0, 0, 0, 0],
       [0, 1, 1, 1, 0, 0, 0, 0],
       [0, 0, 0, 0, 1, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 1, 1],
       [0, 0, 0, 0, 0, 0, 1, 1]])
>>> ndimage.binary_propagation(input, mask=mask).astype(int)
array([[0, 0, 0, 0, 0, 0, 0, 0],
       [0, 1, 1, 1, 0, 0, 0, 0],
       [0, 1, 1, 1, 0, 0, 0, 0],
       [0, 1, 1, 1, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0, 0]])
>>> ndimage.binary_propagation(input, mask=mask, \
... structure=np.ones((3,3)).astype(int)
array([[0, 0, 0, 0, 0, 0, 0, 0],
       [0, 1, 1, 1, 0, 0, 0, 0],
       [0, 1, 1, 1, 0, 0, 0, 0],
       [0, 1, 1, 1, 0, 0, 0, 0],
       [0, 0, 0, 0, 1, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0, 0]])

```

```

>>> # Comparison between opening and erosion+propagation
>>> a = np.zeros((6,6), dtype=int)
>>> a[2:5, 2:5] = 1; a[0, 0] = 1; a[5, 5] = 1
>>> a
array([[1, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0],
       [0, 0, 1, 1, 1, 0],
       [0, 0, 1, 1, 1, 0],
       [0, 0, 1, 1, 1, 0],
       [0, 0, 0, 0, 0, 1]])
>>> ndimage.binary_opening(a).astype(int)
array([[0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0],
       [0, 0, 0, 1, 0, 0],
       [0, 0, 1, 1, 1, 0],
       [0, 0, 0, 1, 0, 0],
       [0, 0, 0, 0, 0, 0]])
>>> b = ndimage.binary_erosion(a)
>>> b.astype(int)
array([[0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0],
       [0, 0, 0, 1, 0, 0],
       [0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0]])
>>> ndimage.binary_propagation(b, mask=a).astype(int)
array([[0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0],
       [0, 0, 1, 1, 1, 0],
       [0, 0, 1, 1, 1, 0],

```

```
[0, 0, 1, 1, 1, 0],
 [0, 0, 0, 0, 0, 0]])
```

`scipy.ndimage.black_tophat` (*input*, *size=None*, *footprint=None*, *structure=None*, *output=None*, *mode='reflect'*, *cval=0.0*, *origin=0*)

Multi-dimensional black tophat filter.

**Parameters**

- input** : array\_like  
Input.
- size** : tuple of ints, optional  
Shape of a flat and full structuring element used for the filter. Optional if *footprint* or *structure* is provided.
- footprint** : array of ints, optional  
Positions of non-infinite elements of a flat structuring element used for the black tophat filter.
- structure** : array of ints, optional  
Structuring element used for the filter. *structure* may be a non-flat structuring element.
- output** : array, optional  
An array used for storing the output of the filter may be provided.
- mode** : {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}, optional  
The *mode* parameter determines how the array borders are handled, where *cval* is the value when mode is equal to 'constant'. Default is 'reflect'
- cval** : scalar, optional  
Value to fill past edges of input if *mode* is 'constant'. Default is 0.0.
- origin** : scalar, optional  
The *origin* parameter controls the placement of the filter. Default 0

**Returns**

- black\_tophat** : ndarray  
Result of the filter of *input* with *structure*.

**See also:**

`white_tophat`, `grey_opening`, `grey_closing`

`scipy.ndimage.distance_transform_bf` (*input*, *metric='euclidean'*, *sampling=None*, *return\_distances=True*, *return\_indices=False*, *distances=None*, *indices=None*)

Distance transform function by a brute force algorithm.

This function calculates the distance transform of the *input*, by replacing each foreground (non-zero) element, with its shortest distance to the background (any zero-valued element).

In addition to the distance transform, the feature transform can be calculated. In this case the index of the closest background element is returned along the first axis of the result.

**Parameters**

- input** : array\_like  
Input
- metric** : str, optional  
Three types of distance metric are supported: 'euclidean', 'taxicab' and 'chessboard'.
- sampling** : {int, sequence of ints}, optional  
This parameter is only used in the case of the euclidean *metric* distance transform.  
The sampling along each axis can be given by the *sampling* parameter which should be a sequence of length equal to the input rank, or a single number in which the *sampling* is assumed to be equal along all axes.
- return\_distances** : bool, optional  
The *return\_distances* flag can be used to indicate if the distance transform is returned.  
The default is True.
- return\_indices** : bool, optional

The *return\_indices* flags can be used to indicate if the feature transform is returned. The default is False.

**distances** : float64 ndarray, optional  
Optional output array to hold distances (if *return\_distances* is True).  
**indices** : int64 ndarray, optional  
Optional output array to hold indices (if *return\_indices* is True).

**Returns** **distances** : ndarray  
Distance array if *return\_distances* is True.  
**indices** : ndarray  
Indices array if *return\_indices* is True.

### Notes

This function employs a slow brute force algorithm, see also the function `distance_transform_cdt` for more efficient taxicab and chessboard algorithms.

`scipy.ndimage.distance_transform_cdt` (*input*, *metric*='chessboard', *return\_distances*=True, *return\_indices*=False, *distances*=None, *indices*=None)

Distance transform for chamfer type of transforms.

**Parameters** **input** : array\_like  
Input  
**metric** : {'chessboard', 'taxicab'}, optional  
The *metric* determines the type of chamfering that is done. If the *metric* is equal to 'taxicab' a structure is generated using `generate_binary_structure` with a squared distance equal to 1. If the *metric* is equal to 'chessboard', a *metric* is generated using `generate_binary_structure` with a squared distance equal to the dimensionality of the array. These choices correspond to the common interpretations of the 'taxicab' and the 'chessboard' distance metrics in two dimensions.  
The default for *metric* is 'chessboard'.  
**return\_distances, return\_indices** : bool, optional  
The *return\_distances*, and *return\_indices* flags can be used to indicate if the distance transform, the feature transform, or both must be returned.  
If the feature transform is returned (*return\_indices*=True), the index of the closest background element is returned along the first axis of the result.  
The *return\_distances* default is True, and the *return\_indices* default is False.  
**distances, indices** : ndarrays of int32, optional  
The *distances* and *indices* arguments can be used to give optional output arrays that must be the same shape as *input*.

`scipy.ndimage.distance_transform_edt` (*input*, *sampling*=None, *return\_distances*=True, *return\_indices*=False, *distances*=None, *indices*=None)

Exact euclidean distance transform.

In addition to the distance transform, the feature transform can be calculated. In this case the index of the closest background element is returned along the first axis of the result.

**Parameters** **input** : array\_like  
Input data to transform. Can be any type but will be converted into binary: 1 wherever input equates to True, 0 elsewhere.  
**sampling** : float or int, or sequence of same, optional  
Spacing of elements along each dimension. If a sequence, must be of length equal to the input rank; if a single number, this is used for all axes. If not specified, a grid spacing of unity is implied.  
**return\_distances** : bool, optional  
Whether to return distance matrix. At least one of *return\_distances*/*return\_indices* must be True. Default is True.

**return\_indices** : bool, optional  
 Whether to return indices matrix. Default is False.

**distances** : ndarray, optional  
 Used for output of distance array, must be of type float64.

**indices** : ndarray, optional  
 Used for output of indices, must be of type int32.

**Returns** **distance\_transform\_edt** : ndarray or list of ndarrays  
 Either distance matrix, index matrix, or a list of the two, depending on *return\_x* flags and *distance* and *indices* input parameters.

### Notes

The euclidean distance transform gives values of the euclidean distance:

$$y_i = \sqrt{\sum_i^n (x[i]-b[i])**2}$$

where  $b[i]$  is the background point (value 0) with the smallest Euclidean distance to input points  $x[i]$ , and  $n$  is the number of dimensions.

### Examples

```
>>> from scipy import ndimage
>>> a = np.array([[0,1,1,1,1],
...              [0,0,1,1,1],
...              [0,1,1,1,1],
...              [0,1,1,1,0],
...              [0,1,1,0,0]])
>>> ndimage.distance_transform_edt(a)
array([[ 0.   ,  1.   ,  1.4142,  2.2361,  3.   ],
       [ 0.   ,  0.   ,  1.   ,  2.   ,  2.   ],
       [ 0.   ,  1.   ,  1.4142,  1.4142,  1.   ],
       [ 0.   ,  1.   ,  1.4142,  1.   ,  0.   ],
       [ 0.   ,  1.   ,  1.   ,  0.   ,  0.   ]])
```

With a sampling of 2 units along x, 1 along y:

```
>>> ndimage.distance_transform_edt(a, sampling=[2,1])
array([[ 0.   ,  1.   ,  2.   ,  2.8284,  3.6056],
       [ 0.   ,  0.   ,  1.   ,  2.   ,  3.   ],
       [ 0.   ,  1.   ,  2.   ,  2.2361,  2.   ],
       [ 0.   ,  1.   ,  2.   ,  1.   ,  0.   ],
       [ 0.   ,  1.   ,  1.   ,  0.   ,  0.   ]])
```

Asking for indices as well:

```
>>> edt, inds = ndimage.distance_transform_edt(a, return_indices=True)
>>> inds
array([[0, 0, 1, 1, 3],
       [1, 1, 1, 1, 3],
       [2, 2, 1, 3, 3],
       [3, 3, 4, 4, 3],
       [4, 4, 4, 4, 4]],
      [[0, 0, 1, 1, 4],
       [0, 1, 1, 1, 4],
       [0, 0, 1, 4, 4],
```

```
[0, 0, 3, 3, 4],
 [0, 0, 3, 3, 4]])
```

With arrays provided for inplace outputs:

```
>>> indices = np.zeros((np.ndim(a,) + a.shape), dtype=np.int32)
>>> ndimage.distance_transform_edt(a, return_indices=True, indices=indices)
array([[ 0.   ,  1.   ,  1.4142,  2.2361,  3.   ],
       [ 0.   ,  0.   ,  1.   ,  2.   ,  2.   ],
       [ 0.   ,  1.   ,  1.4142,  1.4142,  1.   ],
       [ 0.   ,  1.   ,  1.4142,  1.   ,  0.   ],
       [ 0.   ,  1.   ,  1.   ,  0.   ,  0.   ]])
>>> indices
array([[ [0, 0, 1, 1, 3],
        [1, 1, 1, 1, 3],
        [2, 2, 1, 3, 3],
        [3, 3, 4, 4, 3],
        [4, 4, 4, 4, 4]],
       [ [0, 0, 1, 1, 4],
        [0, 1, 1, 1, 4],
        [0, 0, 1, 4, 4],
        [0, 0, 3, 3, 4],
        [0, 0, 3, 3, 4]]])
```

`scipy.ndimage.generate_binary_structure` (*rank, connectivity*)

Generate a binary structure for binary morphological operations.

**Parameters** **rank** : int

Number of dimensions of the array to which the structuring element will be applied, as returned by `np.ndim`.

**connectivity** : int

`connectivity` determines which elements of the output array belong to the structure, i.e. are considered as neighbors of the central element. Elements up to a squared distance of `connectivity` from the center are considered neighbors. `connectivity` may range from 1 (no diagonal elements are neighbors) to `rank` (all elements are neighbors).

**Returns** **output** : ndarray of bools

Structuring element which may be used for binary morphological operations, with `rank` dimensions and all dimensions equal to 3.

**See also:**

`iterate_structure`, `binary_dilation`, `binary_erosion`

**Notes**

`generate_binary_structure` can only create structuring elements with dimensions equal to 3, i.e. minimal dimensions. For larger structuring elements, that are useful e.g. for eroding large objects, one may either use `iterate_structure`, or create directly custom arrays with numpy functions such as `numpy.ones`.

**Examples**

```
>>> from scipy import ndimage
>>> struct = ndimage.generate_binary_structure(2, 1)
>>> struct
array([[False,  True,  False],
       [ True,  True,  True],
       [False,  True,  False]], dtype=bool)
>>> a = np.zeros((5,5))
```

```

>>> a[2, 2] = 1
>>> a
array([[ 0.,  0.,  0.,  0.,  0.],
       [ 0.,  0.,  0.,  0.,  0.],
       [ 0.,  0.,  1.,  0.,  0.],
       [ 0.,  0.,  0.,  0.,  0.],
       [ 0.,  0.,  0.,  0.,  0.]])
>>> b = ndimage.binary_dilation(a, structure=struct).astype(a.dtype)
>>> b
array([[ 0.,  0.,  0.,  0.,  0.],
       [ 0.,  0.,  1.,  0.,  0.],
       [ 0.,  1.,  1.,  1.,  0.],
       [ 0.,  0.,  1.,  0.,  0.],
       [ 0.,  0.,  0.,  0.,  0.]])
>>> ndimage.binary_dilation(b, structure=struct).astype(a.dtype)
array([[ 0.,  0.,  1.,  0.,  0.],
       [ 0.,  1.,  1.,  1.,  0.],
       [ 1.,  1.,  1.,  1.,  1.],
       [ 0.,  1.,  1.,  1.,  0.],
       [ 0.,  0.,  1.,  0.,  0.]])
>>> struct = ndimage.generate_binary_structure(2, 2)
>>> struct
array([[ True,  True,  True],
       [ True,  True,  True],
       [ True,  True,  True]], dtype=bool)
>>> struct = ndimage.generate_binary_structure(3, 1)
>>> struct # no diagonal elements
array([[ [False, False, False],
        [False,  True, False],
        [False, False, False]],
       [[False,  True, False],
        [ True,  True,  True],
        [False,  True, False]],
       [[False, False, False],
        [False,  True, False],
        [False, False, False]]], dtype=bool)

```

`scipy.ndimage.grey_closing` (*input*, *size=None*, *footprint=None*, *structure=None*, *output=None*, *mode='reflect'*, *cval=0.0*, *origin=0*)

Multi-dimensional greyscale closing.

A greyscale closing consists in the succession of a greyscale dilation, and a greyscale erosion.

**Parameters** **input** : array\_like

Array over which the grayscale closing is to be computed.

**size** : tuple of ints

Shape of a flat and full structuring element used for the grayscale closing. Optional if *footprint* or *structure* is provided.

**footprint** : array of ints, optional

Positions of non-infinite elements of a flat structuring element used for the grayscale closing.

**structure** : array of ints, optional

Structuring element used for the grayscale closing. *structure* may be a non-flat structuring element.

**output** : array, optional

An array used for storing the output of the closing may be provided.

**mode** : {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}, optional

The *mode* parameter determines how the array borders are handled, where *cval* is the value when mode is equal to 'constant'. Default is 'reflect'

**cval** : scalar, optional

Value to fill past edges of input if *mode* is 'constant'. Default is 0.0.

**origin** : scalar, optional

The *origin* parameter controls the placement of the filter. Default 0

**Returns**

**grey\_closing** : ndarray

Result of the grayscale closing of *input* with *structure*.

**See also:**

*binary\_closing*, *grey\_dilation*, *grey\_erosion*, *grey\_opening*,  
*generate\_binary\_structure*

**Notes**

The action of a grayscale closing with a flat structuring element amounts to smoothen deep local minima, whereas binary closing fills small holes.

**References**

[R175]

**Examples**

```
>>> from scipy import ndimage
>>> a = np.arange(36).reshape((6, 6))
>>> a[3,3] = 0
>>> a
array([[ 0,  1,  2,  3,  4,  5],
       [ 6,  7,  8,  9, 10, 11],
       [12, 13, 14, 15, 16, 17],
       [18, 19, 20,  0, 22, 23],
       [24, 25, 26, 27, 28, 29],
       [30, 31, 32, 33, 34, 35]])
>>> ndimage.grey_closing(a, size=(3,3))
array([[ 7,  7,  8,  9, 10, 11],
       [ 7,  7,  8,  9, 10, 11],
       [13, 13, 14, 15, 16, 17],
       [19, 19, 20, 20, 22, 23],
       [25, 25, 26, 27, 28, 29],
       [31, 31, 32, 33, 34, 35]])
>>> # Note that the local minimum a[3,3] has disappeared
```

`scipy.ndimage.grey_dilation`(*input*, *size=None*, *footprint=None*, *structure=None*, *output=None*,  
*mode='reflect'*, *cval=0.0*, *origin=0*)

Calculate a greyscale dilation, using either a structuring element, or a footprint corresponding to a flat structuring element.

Grayscale dilation is a mathematical morphology operation. For the simple case of a full and flat structuring element, it can be viewed as a maximum filter over a sliding window.

**Parameters** **input** : array\_like

Array over which the grayscale dilation is to be computed.

**size** : tuple of ints

Shape of a flat and full structuring element used for the grayscale dilation. Optional if *footprint* or *structure* is provided.

**footprint** : array of ints, optional

Positions of non-infinite elements of a flat structuring element used for the grayscale dilation. Non-zero values give the set of neighbors of the center over which the maximum is chosen.

**structure** : array of ints, optional

Structuring element used for the grayscale dilation. *structure* may be a non-flat structuring element.

**output** : array, optional

An array used for storing the output of the dilation may be provided.

**mode** : {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}, optional

The *mode* parameter determines how the array borders are handled, where *cval* is the value when mode is equal to 'constant'. Default is 'reflect'

**cval** : scalar, optional

Value to fill past edges of input if *mode* is 'constant'. Default is 0.0.

**origin** : scalar, optional

The *origin* parameter controls the placement of the filter. Default 0

**Returns** **grey\_dilation** : ndarray

Grayscale dilation of *input*.

**See also:**

*binary\_dilation*, *grey\_erosion*, *grey\_closing*, *grey\_opening*,  
*generate\_binary\_structure*, *ndimage.maximum\_filter*

**Notes**

The grayscale dilation of an image input by a structuring element *s* defined over a domain *E* is given by:

$$(\text{input}+s)(x) = \max \{ \text{input}(y) + s(x-y), \text{ for } y \text{ in } E \}$$

In particular, for structuring elements defined as  $s(y) = 0$  for  $y$  in  $E$ , the grayscale dilation computes the maximum of the input image inside a sliding window defined by  $E$ .

Grayscale dilation [R176] is a *mathematical morphology* operation [R177].

**References**

[R176], [R177]

**Examples**

```
>>> from scipy import ndimage
>>> a = np.zeros((7,7), dtype=int)
>>> a[2:5, 2:5] = 1
>>> a[4,4] = 2; a[2,3] = 3
>>> a
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 1, 3, 1, 0, 0],
       [0, 0, 1, 1, 1, 0, 0],
       [0, 0, 1, 1, 2, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0]])
>>> ndimage.grey_dilation(a, size=(3,3))
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 1, 3, 3, 3, 1, 0],
       [0, 1, 3, 3, 3, 1, 0],
       [0, 1, 3, 3, 3, 2, 0],
       [0, 1, 1, 2, 2, 2, 0],
       [0, 1, 1, 2, 2, 2, 0],
```

```

    [0, 0, 0, 0, 0, 0, 0])
>>> ndimage.grey_dilation(a, footprint=np.ones((3,3)))
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 1, 3, 3, 3, 1, 0],
       [0, 1, 3, 3, 3, 1, 0],
       [0, 1, 3, 3, 3, 2, 0],
       [0, 1, 1, 2, 2, 2, 0],
       [0, 1, 1, 2, 2, 2, 0],
       [0, 0, 0, 0, 0, 0, 0]])
>>> s = ndimage.generate_binary_structure(2,1)
>>> s
array([[False,  True, False],
       [ True,  True,  True],
       [False,  True, False]], dtype=bool)
>>> ndimage.grey_dilation(a, footprint=s)
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 0, 1, 3, 1, 0, 0],
       [0, 1, 3, 3, 3, 1, 0],
       [0, 1, 1, 3, 2, 1, 0],
       [0, 1, 1, 2, 2, 2, 0],
       [0, 0, 1, 1, 2, 0, 0],
       [0, 0, 0, 0, 0, 0, 0]])
>>> ndimage.grey_dilation(a, size=(3,3), structure=np.ones((3,3)))
array([[1, 1, 1, 1, 1, 1, 1],
       [1, 2, 4, 4, 4, 2, 1],
       [1, 2, 4, 4, 4, 2, 1],
       [1, 2, 4, 4, 4, 3, 1],
       [1, 2, 2, 3, 3, 3, 1],
       [1, 2, 2, 3, 3, 3, 1],
       [1, 1, 1, 1, 1, 1, 1]])

```

`scipy.ndimage.grey_erosion` (*input*, *size=None*, *footprint=None*, *structure=None*, *output=None*, *mode='reflect'*, *cval=0.0*, *origin=0*)

Calculate a grayscale erosion, using either a structuring element, or a footprint corresponding to a flat structuring element.

Grayscale erosion is a mathematical morphology operation. For the simple case of a full and flat structuring element, it can be viewed as a minimum filter over a sliding window.

**Parameters** **input** : array\_like

Array over which the grayscale erosion is to be computed.

**size** : tuple of ints

Shape of a flat and full structuring element used for the grayscale erosion. Optional if *footprint* or *structure* is provided.

**footprint** : array of ints, optional

Positions of non-infinite elements of a flat structuring element used for the grayscale erosion. Non-zero values give the set of neighbors of the center over which the minimum is chosen.

**structure** : array of ints, optional

Structuring element used for the grayscale erosion. *structure* may be a non-flat structuring element.

**output** : array, optional

An array used for storing the output of the erosion may be provided.

**mode** : {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}, optional

The *mode* parameter determines how the array borders are handled, where *cval* is the value when mode is equal to 'constant'. Default is 'reflect'

**cval** : scalar, optional

Value to fill past edges of input if *mode* is 'constant'. Default is 0.0.

**origin** : scalar, optional

The *origin* parameter controls the placement of the filter. Default 0

**Returns**

**output** : ndarray

Grayscale erosion of *input*.

**See also:**

*binary\_erosion*, *grey\_dilation*, *grey\_opening*, *grey\_closing*,  
*generate\_binary\_structure*, *ndimage.minimum\_filter*

**Notes**

The grayscale erosion of an image input by a structuring element *s* defined over a domain *E* is given by:

$$(\text{input}+s)(x) = \min \{ \text{input}(y) - s(x-y), \text{ for } y \text{ in } E \}$$

In particular, for structuring elements defined as  $s(y) = 0$  for  $y$  in  $E$ , the grayscale erosion computes the minimum of the input image inside a sliding window defined by  $E$ .

Grayscale erosion [R178] is a *mathematical morphology* operation [R179].

**References**

[R178], [R179]

**Examples**

```
>>> from scipy import ndimage
>>> a = np.zeros((7,7), dtype=int)
>>> a[1:6, 1:6] = 3
>>> a[4,4] = 2; a[2,3] = 1
>>> a
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 3, 3, 3, 3, 3, 0],
       [0, 3, 3, 1, 3, 3, 0],
       [0, 3, 3, 3, 3, 3, 0],
       [0, 3, 3, 3, 2, 3, 0],
       [0, 3, 3, 3, 3, 3, 0],
       [0, 0, 0, 0, 0, 0, 0]])
>>> ndimage.grey_erosion(a, size=(3,3))
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 1, 1, 1, 0, 0],
       [0, 0, 1, 1, 1, 0, 0],
       [0, 0, 3, 2, 2, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0]])
>>> footprint = ndimage.generate_binary_structure(2, 1)
>>> footprint
array([[False,  True,  False],
       [ True,  True,  True],
       [False,  True,  False]], dtype=bool)
>>> # Diagonally-connected elements are not considered neighbors
>>> ndimage.grey_erosion(a, size=(3,3), footprint=footprint)
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 1, 1, 1, 0, 0],
       [0, 0, 3, 1, 2, 0, 0],
       [0, 0, 3, 2, 2, 0, 0],
```

```
[0, 0, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0, 0]])
```

`scipy.ndimage.grey_opening` (*input*, *size=None*, *footprint=None*, *structure=None*, *output=None*, *mode='reflect'*, *cval=0.0*, *origin=0*)

Multi-dimensional greyscale opening.

A greyscale opening consists in the succession of a greyscale erosion, and a greyscale dilation.

**Parameters**

- input** : array\_like  
Array over which the grayscale opening is to be computed.
- size** : tuple of ints  
Shape of a flat and full structuring element used for the grayscale opening. Optional if *footprint* or *structure* is provided.
- footprint** : array of ints, optional  
Positions of non-infinite elements of a flat structuring element used for the grayscale opening.
- structure** : array of ints, optional  
Structuring element used for the grayscale opening. *structure* may be a non-flat structuring element.
- output** : array, optional  
An array used for storing the output of the opening may be provided.
- mode** : {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}, optional  
The *mode* parameter determines how the array borders are handled, where *cval* is the value when mode is equal to 'constant'. Default is 'reflect'
- cval** : scalar, optional  
Value to fill past edges of input if *mode* is 'constant'. Default is 0.0.
- origin** : scalar, optional  
The *origin* parameter controls the placement of the filter. Default 0

**Returns**

- grey\_opening** : ndarray  
Result of the grayscale opening of *input* with *structure*.

**See also:**

*binary\_opening*, *grey\_dilation*, *grey\_erosion*, *grey\_closing*,  
*generate\_binary\_structure*

**Notes**

The action of a grayscale opening with a flat structuring element amounts to smoothen high local maxima, whereas binary opening erases small objects.

**References**

[R180]

**Examples**

```
>>> from scipy import ndimage
>>> a = np.arange(36).reshape((6, 6))
>>> a[3, 3] = 50
>>> a
array([[ 0,  1,  2,  3,  4,  5],
       [ 6,  7,  8,  9, 10, 11],
       [12, 13, 14, 15, 16, 17],
       [18, 19, 20, 50, 22, 23],
       [24, 25, 26, 27, 28, 29],
       [30, 31, 32, 33, 34, 35]])
```

```
>>> ndimage.grey_opening(a, size=(3,3))
array([[ 0,  1,  2,  3,  4,  4],
       [ 6,  7,  8,  9, 10, 10],
       [12, 13, 14, 15, 16, 16],
       [18, 19, 20, 22, 22, 22],
       [24, 25, 26, 27, 28, 28],
       [24, 25, 26, 27, 28, 28]])
>>> # Note that the local maximum a[3,3] has disappeared
```

`scipy.ndimage.iterate_structure` (*structure, iterations, origin=None*)

Iterate a structure by dilating it with itself.

**Parameters**    **structure** : array\_like  
                   Structuring element (an array of bools, for example), to be dilated with itself.

**iterations** : int  
                   number of dilations performed on the structure with itself

**origin** : optional  
                   If origin is None, only the iterated structure is returned. If not, a tuple of the iterated structure and the modified origin is returned.

**Returns**        **iterate\_structure** : ndarray of bools  
                   A new structuring element obtained by dilating *structure* (*iterations* - 1) times with itself.

See also:

`generate_binary_structure`

**Examples**

```
>>> from scipy import ndimage
>>> struct = ndimage.generate_binary_structure(2, 1)
>>> struct.astype(int)
array([[0, 1, 0],
       [1, 1, 1],
       [0, 1, 0]])
>>> ndimage.iterate_structure(struct, 2).astype(int)
array([[0, 0, 1, 0, 0],
       [0, 1, 1, 1, 0],
       [1, 1, 1, 1, 1],
       [0, 1, 1, 1, 0],
       [0, 0, 1, 0, 0]])
>>> ndimage.iterate_structure(struct, 3).astype(int)
array([[0, 0, 0, 1, 0, 0, 0],
       [0, 0, 1, 1, 1, 0, 0],
       [0, 1, 1, 1, 1, 1, 0],
       [1, 1, 1, 1, 1, 1, 1],
       [0, 1, 1, 1, 1, 1, 0],
       [0, 0, 1, 1, 1, 0, 0],
       [0, 0, 0, 1, 0, 0, 0]])
```

`scipy.ndimage.morphological_gradient` (*input, size=None, footprint=None, structure=None, output=None, mode='reflect', cval=0.0, origin=0*)

Multi-dimensional morphological gradient.

The morphological gradient is calculated as the difference between a dilation and an erosion of the input with a given structuring element.

**Parameters**    **input** : array\_like  
                   Array over which to compute the morphological gradient.

**size** : tuple of ints

Shape of a flat and full structuring element used for the mathematical morphology operations. Optional if *footprint* or *structure* is provided. A larger *size* yields a more blurred gradient.

**footprint** : array of ints, optional

Positions of non-infinite elements of a flat structuring element used for the morphology operations. Larger footprints give a more blurred morphological gradient.

**structure** : array of ints, optional

Structuring element used for the morphology operations. *structure* may be a non-flat structuring element.

**output** : array, optional

An array used for storing the output of the morphological gradient may be provided.

**mode** : {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}, optional

The *mode* parameter determines how the array borders are handled, where *cval* is the value when mode is equal to 'constant'. Default is 'reflect'

**cval** : scalar, optional

Value to fill past edges of input if *mode* is 'constant'. Default is 0.0.

**origin** : scalar, optional

The *origin* parameter controls the placement of the filter. Default 0

**Returns** **morphological\_gradient** : ndarray

Morphological gradient of *input*.

**See also:**

*grey\_dilation*, *grey\_erosion*, *ndimage.gaussian\_gradient\_magnitude*

**Notes**

For a flat structuring element, the morphological gradient computed at a given point corresponds to the maximal difference between elements of the input among the elements covered by the structuring element centered on the point.

**References**

[R185]

**Examples**

```
>>> from scipy import ndimage
>>> a = np.zeros((7,7), dtype=int)
>>> a[2:5, 2:5] = 1
>>> ndimage.morphological_gradient(a, size=(3,3))
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 1, 1, 1, 1, 1, 0],
       [0, 1, 1, 1, 1, 1, 0],
       [0, 1, 1, 0, 1, 1, 0],
       [0, 1, 1, 1, 1, 1, 0],
       [0, 1, 1, 1, 1, 1, 0],
       [0, 0, 0, 0, 0, 0, 0]])
>>> # The morphological gradient is computed as the difference
>>> # between a dilation and an erosion
>>> ndimage.grey_dilation(a, size=(3,3)) -\
... ndimage.grey_erosion(a, size=(3,3))
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 1, 1, 1, 1, 1, 0],
       [0, 1, 1, 1, 1, 1, 0],
       [0, 1, 1, 0, 1, 1, 0],
       [0, 1, 1, 1, 1, 1, 0],
```

```

        [0, 1, 1, 1, 1, 1, 0],
        [0, 0, 0, 0, 0, 0, 0]])
>>> a = np.zeros((7,7), dtype=int)
>>> a[2:5, 2:5] = 1
>>> a[4,4] = 2; a[2,3] = 3
>>> a
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 1, 3, 1, 0, 0],
       [0, 0, 1, 1, 1, 0, 0],
       [0, 0, 1, 1, 2, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0]])
>>> ndimage.morphological_gradient(a, size=(3,3))
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 1, 3, 3, 3, 1, 0],
       [0, 1, 3, 3, 3, 1, 0],
       [0, 1, 3, 2, 3, 2, 0],
       [0, 1, 1, 2, 2, 2, 0],
       [0, 1, 1, 2, 2, 2, 0],
       [0, 0, 0, 0, 0, 0, 0]])
    
```

`scipy.ndimage.morphological_laplace` (*input*, *size=None*, *footprint=None*, *structure=None*, *output=None*, *mode='reflect'*, *cval=0.0*, *origin=0*)

Multi-dimensional morphological laplace.

**Parameters**

- input** : array\_like  
Input.
- size** : int or sequence of ints, optional  
See *structure*.
- footprint** : bool or ndarray, optional  
See *structure*.
- structure** : structure, optional  
Either *size*, *footprint*, or the *structure* must be provided.
- output** : ndarray, optional  
An output array can optionally be provided.
- mode** : {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}, optional  
The mode parameter determines how the array borders are handled. For 'constant' mode, values beyond borders are set to be *cval*. Default is 'reflect'.
- cval** : scalar, optional  
Value to fill past edges of input if mode is 'constant'. Default is 0.0
- origin** : origin, optional  
The origin parameter controls the placement of the filter.

**Returns**

- morphological\_laplace** : ndarray  
Output

`scipy.ndimage.white_tophat` (*input*, *size=None*, *footprint=None*, *structure=None*, *output=None*, *mode='reflect'*, *cval=0.0*, *origin=0*)

Multi-dimensional white tophat filter.

**Parameters**

- input** : array\_like  
Input.
- size** : tuple of ints  
Shape of a flat and full structuring element used for the filter. Optional if *footprint* or *structure* is provided.
- footprint** : array of ints, optional  
Positions of elements of a flat structuring element used for the white tophat filter.

**structure** : array of ints, optional

Structuring element used for the filter. *structure* may be a non-flat structuring element.

**output** : array, optional

An array used for storing the output of the filter may be provided.

**mode** : {'reflect', 'constant', 'nearest', 'mirror', 'wrap'}, optional

The *mode* parameter determines how the array borders are handled, where *cval* is the value when mode is equal to 'constant'. Default is 'reflect'

**cval** : scalar, optional

Value to fill past edges of input if *mode* is 'constant'. Default is 0.0.

**origin** : scalar, optional

The *origin* parameter controls the placement of the filter. Default is 0.

**Returns**

**output** : ndarray

Result of the filter of *input* with *structure*.

**See also:**

`black_tophat`

## 5.16.6 Utility

`imread(*args, **kwds)`

*imread* is deprecated!

`scipy.ndimage.imread(*args, **kwds)`

*imread* is deprecated! *imread* is deprecated in SciPy 1.0.0, and will be removed in 1.2.0. Use `imageio.imread` instead.

Read an image from a file as an array.

This function is only available if Python Imaging Library (PIL) is installed.

**Parameters** **fname** : str or file object

The file name or file object to be read.

**flatten** [bool, optional] If True, flattens the color layers into a single gray-scale layer.

**mode** [str, optional] Mode to convert image to, e.g. 'RGB'. See the Notes for more details.

**Returns** **imread** : ndarray

The array obtained by reading the image.

**Notes**

*imread* uses the Python Imaging Library (PIL) to read an image. The following notes are from the PIL documentation.

*mode* can be one of the following strings:

- 'L' (8-bit pixels, black and white)
- 'P' (8-bit pixels, mapped to any other mode using a color palette)
- 'RGB' (3x8-bit pixels, true color)
- 'RGBA' (4x8-bit pixels, true color with transparency mask)
- 'CMYK' (4x8-bit pixels, color separation)
- 'YCbCr' (3x8-bit pixels, color video format)

- ‘I’ (32-bit signed integer pixels)
- ‘F’ (32-bit floating point pixels)

PIL also provides limited support for a few special modes, including ‘LA’ (‘L’ with alpha), ‘RGBX’ (true color with padding) and ‘RGBA’ (true color with premultiplied alpha).

When translating a color image to black and white (mode ‘L’, ‘I’ or ‘F’), the library uses the ITU-R 601-2 luma transform:

$$L = R * 299/1000 + G * 587/1000 + B * 114/1000$$

When *flatten* is True, the image is converted using mode ‘F’. When *mode* is not None and *flatten* is True, the image is first converted according to *mode*, and the result is then flattened using mode ‘F’.

## 5.17 Orthogonal distance regression (`scipy.odr`)

### 5.17.1 Package Content

<code>Data(x[, y, we, wd, fix, meta])</code>	The data to fit.
<code>RealData(x[, y, sx, sy, covx, covy, fix, meta])</code>	The data, with weightings as actual standard deviations and/or covariances.
<code>Model(fcn[, fjacb, fjacd, extra_args, ...])</code>	The Model class stores information about the function you wish to fit.
<code>ODR(data, model[, beta0, delta0, ifixb, ...])</code>	The ODR class gathers all information and coordinates the running of the main fitting routine.
<code>Output(output)</code>	The Output class stores the output of an ODR run.
<code>odr(fcn, beta0, y, x[, we, wd, fjacb, ...])</code>	Low-level function for ODR.
<code>OdrWarning</code>	Warning indicating that the data passed into ODR will cause problems when passed into ‘odr’ that the user should be aware of.
<code>OdrError</code>	Exception indicating an error in fitting.
<code>OdrStop</code>	Exception stopping fitting.
<code>odr_error</code>	alias of <code>OdrError</code>
<code>odr_stop</code>	alias of <code>OdrStop</code>

**class** `scipy.odr.Data` (*x*, *y=None*, *we=None*, *wd=None*, *fix=None*, *meta={}*)

The data to fit.

**Parameters**

- x** : array\_like  
Observed data for the independent variable of the regression
- y** : array\_like, optional  
If array-like, observed data for the dependent variable of the regression. A scalar input implies that the model to be used on the data is implicit.
- we** : array\_like, optional  
If *we* is a scalar, then that value is used for all data points (and all dimensions of the response variable). If *we* is a rank-1 array of length *q* (the dimensionality of the response variable), then this vector is the diagonal of the covariant weighting matrix for all data points. If *we* is a rank-1 array of length *n* (the number of data points), then the *i*’th element is the weight for the *i*’th response variable observation (single-dimensional only). If *we* is a rank-2 array of shape (*q*, *q*), then this is the full covariant weighting matrix broadcast to each observation. If *we* is a rank-2 array of shape (*q*, *n*),

then  $we[:,i]$  is the diagonal of the covariant weighting matrix for the  $i$ 'th observation. If  $we$  is a rank-3 array of shape  $(q, q, n)$ , then  $we[:, :, i]$  is the full specification of the covariant weighting matrix for each observation. If the fit is implicit, then only a positive scalar value is used.

**wd** : array\_like, optional

If  $wd$  is a scalar, then that value is used for all data points (and all dimensions of the input variable). If  $wd = 0$ , then the covariant weighting matrix for each observation is set to the identity matrix (so each dimension of each observation has the same weight). If  $wd$  is a rank-1 array of length  $m$  (the dimensionality of the input variable), then this vector is the diagonal of the covariant weighting matrix for all data points. If  $wd$  is a rank-1 array of length  $n$  (the number of data points), then the  $i$ 'th element is the weight for the  $i$ 'th input variable observation (single-dimensional only). If  $wd$  is a rank-2 array of shape  $(m, m)$ , then this is the full covariant weighting matrix broadcast to each observation. If  $wd$  is a rank-2 array of shape  $(m, n)$ , then  $wd[:, i]$  is the diagonal of the covariant weighting matrix for the  $i$ 'th observation. If  $wd$  is a rank-3 array of shape  $(m, m, n)$ , then  $wd[:, :, i]$  is the full specification of the covariant weighting matrix for each observation.

**fix** : array\_like of ints, optional

The *fix* argument is the same as *ifix* in the class ODR. It is an array of integers with the same shape as *data.x* that determines which input observations are treated as fixed. One can use a sequence of length  $m$  (the dimensionality of the input observations) to fix some dimensions for all observations. A value of 0 fixes the observation, a value  $> 0$  makes it free.

**meta** : dict, optional

Free-form dictionary for metadata.

### Notes

Each argument is attached to the member of the instance of the same name. The structures of  $x$  and  $y$  are described in the Model class docstring. If  $y$  is an integer, then the Data instance can only be used to fit with implicit models where the dimensionality of the response is equal to the specified value of  $y$ .

The *we* argument weights the effect a deviation in the response variable has on the fit. The *wd* argument weights the effect a deviation in the input variable has on the fit. To handle multidimensional inputs and responses easily, the structure of these arguments has the  $n$ 'th dimensional axis first. These arguments heavily use the structured arguments feature of ODRPACK to conveniently and flexibly support all options. See the ODRPACK User's Guide for a full explanation of how these weights are used in the algorithm. Basically, a higher value of the weight for a particular data point makes a deviation at that point more detrimental to the fit.

### Methods

<code>set_meta(**kws)</code>	Update the metadata dictionary with the keywords and data provided by keywords.
------------------------------	---

---

`Data.set_meta(**kws)`  
Update the metadata dictionary with the keywords and data provided by keywords.

### Examples

```
data.set_meta(lab="Ph 7; Lab 26", title="Ag110 + Ag108 Decay")
```

```
class scipy.odr.RealData(x, y=None, sx=None, sy=None, covx=None, covy=None, fix=None,
                        meta={})
```

The data, with weightings as actual standard deviations and/or covariances.

**Parameters** `x` : array\_like

Observed data for the independent variable of the regression

**y** : array\_like, optional  
 If array-like, observed data for the dependent variable of the regression. A scalar input implies that the model to be used on the data is implicit.

**sx** : array\_like, optional  
 Standard deviations of  $x$ .  $sx$  are standard deviations of  $x$  and are converted to weights by dividing 1.0 by their squares.

**sy** : array\_like, optional  
 Standard deviations of  $y$ .  $sy$  are standard deviations of  $y$  and are converted to weights by dividing 1.0 by their squares.

**covx** : array\_like, optional  
 Covariance of  $x$   $covx$  is an array of covariance matrices of  $x$  and are converted to weights by performing a matrix inversion on each observation's covariance matrix.

**covy** : array\_like, optional  
 Covariance of  $y$   $covy$  is an array of covariance matrices and are converted to weights by performing a matrix inversion on each observation's covariance matrix.

**fix** : array\_like, optional  
 The argument and member `fix` is the same as `Data.fix` and `ODR.ifixx`: It is an array of integers with the same shape as  $x$  that determines which input observations are treated as fixed. One can use a sequence of length  $m$  (the dimensionality of the input observations) to fix some dimensions for all observations. A value of 0 fixes the observation, a value  $> 0$  makes it free.

**meta** : dict, optional  
 Free-form dictionary for metadata.

**Notes**

The weights  $wd$  and  $we$  are computed from provided values as follows:

$sx$  and  $sy$  are converted to weights by dividing 1.0 by their squares. For example, `wd = 1./numpy.power(`sx`, 2)`.

$covx$  and  $covy$  are arrays of covariance matrices and are converted to weights by performing a matrix inversion on each observation's covariance matrix. For example, `we[i] = numpy.linalg.inv(covy[i])`.

These arguments follow the same structured argument conventions as  $wd$  and  $we$  only restricted by their natures:  $sx$  and  $sy$  can't be rank-3, but  $covx$  and  $covy$  can be.

Only set *either*  $sx$  or  $covx$  (not both). Setting both will raise an exception. Same with  $sy$  and  $covy$ .

**Methods**

<code>set_meta(**kwds)</code>	Update the metadata dictionary with the keywords and data provided by keywords.
-------------------------------	---

---

`RealData.set_meta(**kwds)`  
 Update the metadata dictionary with the keywords and data provided by keywords.

**Examples**

```
data.set_meta(lab="Ph 7; Lab 26", title="Ag110 + Ag108 Decay")
```

**class** `scipy.odr.Model` (*fcn*, *fjacb=None*, *fjacd=None*, *extra\_args=None*, *estimate=None*, *implicit=0*, *meta=None*)

The `Model` class stores information about the function you wish to fit.

It stores the function itself, at the least, and optionally stores functions which compute the Jacobians used

during fitting. Also, one can provide a function that will provide reasonable starting values for the fit parameters possibly given the set of data.

**Parameters**

- fcn** : function  
fcn(beta, x) -> y
- fjacb** : function  
Jacobian of fcn wrt the fit parameters beta.  
fjacb(beta, x) -> @f\_i(x,B)/@B\_j
- fjacd** : function  
Jacobian of fcn wrt the (possibly multidimensional) input variable.  
fjacd(beta, x) -> @f\_i(x,B)/@x\_j
- extra\_args** : tuple, optional  
If specified, *extra\_args* should be a tuple of extra arguments to pass to *fcn*, *fjacb*, and *fjacd*. Each will be called by *apply(fcn, (beta, x) + extra\_args)*
- estimate** : array\_like of rank-1  
Provides estimates of the fit parameters from the data  
estimate(data) -> estbeta
- implicit** : boolean  
If TRUE, specifies that the model is implicit; i.e. *fcn(beta, x) ~ 0* and there is no *y* data to fit against
- meta** : dict, optional  
freeform dictionary of metadata for the model

### Notes

Note that the *fcn*, *fjacb*, and *fjacd* operate on NumPy arrays and return a NumPy array. The *estimate* object takes an instance of the Data class.

Here are the rules for the shapes of the argument and return arrays of the callback functions:

**x** if the input data is single-dimensional, then *x* is rank-1 array; i.e. *x* = array([1, 2, 3, ...]); *x*.shape = (n,) If the input data is multi-dimensional, then *x* is a rank-2 array; i.e., *x* = array([[1, 2, ...], [2, 4, ...]]); *x*.shape = (m, n). In all cases, it has the same shape as the input data array passed to *odr*. *m* is the dimensionality of the input data, *n* is the number of observations.

**y** if the response variable is single-dimensional, then *y* is a rank-1 array, i.e., *y* = array([2, 4, ...]); *y*.shape = (n,). If the response variable is multi-dimensional, then *y* is a rank-2 array, i.e., *y* = array([[2, 4, ...], [3, 6, ...]]); *y*.shape = (q, n) where *q* is the dimensionality of the response variable.

**beta** rank-1 array of length *p* where *p* is the number of parameters; i.e. *beta* = array([B\_1, B\_2, ..., B\_p])

**fjacb** if the response variable is multi-dimensional, then the return array's shape is (*q*, *p*, *n*) such that *fjacb*(*x*, *beta*) [*i*, *k*, *i*] = d f\_*i*(*X*, *B*) / d B\_*k* evaluated at the *i*'th data point. If *q* == 1, then the return array is only rank-2 and with shape (*p*, *n*).

**fjacd** as with *fjacb*, only the return array's shape is (*q*, *m*, *n*) such that *fjacd*(*x*, *beta*) [*i*, *j*, *i*] = d f\_*i*(*X*, *B*) / d X\_*j* at the *i*'th data point. If *q* == 1, then the return array's shape is (*m*, *n*). If *m* == 1, the shape is (*q*, *n*). If *m* == *q* == 1, the shape is (*n*).

### Methods

*set\_meta*(\*\*kwds)

Update the metadata dictionary with the keywords and data provided here.

`Model.set_meta (**kws)`

Update the metadata dictionary with the keywords and data provided here.

**Examples**

```
set_meta(name="Exponential", equation="y = a exp(b x) + c")
```

```
class scipy.odr.ODR (data, model, beta0=None, delta0=None, ifixb=None, ifixx=None, job=None,
                    iprint=None, errfile=None, rptfile=None, ndigit=None, taufac=None, sstol=None,
                    partol=None, maxit=None, stpb=None, stpd=None, sclb=None, scld=None,
                    work=None, iwork=None)
```

The ODR class gathers all information and coordinates the running of the main fitting routine.

Members of instances of the ODR class have the same names as the arguments to the initialization routine.

**Parameters**

- data** : Data class instance  
instance of the Data class
- model** : Model class instance  
instance of the Model class

**Other Parameters**

- beta0** : array\_like of rank-1  
a rank-1 sequence of initial parameter values. Optional if model provides an “estimate” function to estimate these values.
- delta0** : array\_like of floats of rank-1, optional  
a (double-precision) float array to hold the initial values of the errors in the input variables. Must be same shape as data.x
- ifixb** : array\_like of ints of rank-1, optional  
sequence of integers with the same length as beta0 that determines which parameters are held fixed. A value of 0 fixes the parameter, a value > 0 makes the parameter free.
- ifixx** : array\_like of ints with same shape as data.x, optional  
an array of integers with the same shape as data.x that determines which input observations are treated as fixed. One can use a sequence of length m (the dimensionality of the input observations) to fix some dimensions for all observations. A value of 0 fixes the observation, a value > 0 makes it free.
- job** : int, optional  
an integer telling ODRPACK what tasks to perform. See p. 31 of the ODRPACK User’s Guide if you absolutely must set the value here. Use the method `set_job` post-initialization for a more readable interface.
- iprint** : int, optional  
an integer telling ODRPACK what to print. See pp. 33-34 of the ODRPACK User’s Guide if you absolutely must set the value here. Use the method `set_iprint` post-initialization for a more readable interface.
- errfile** : str, optional  
string with the filename to print ODRPACK errors to. *Do Not Open This File Yourself!*
- rptfile** : str, optional  
string with the filename to print ODRPACK summaries to. *Do Not Open This File Yourself!*
- ndigit** : int, optional  
integer specifying the number of reliable digits in the computation of the function.
- taufac** : float, optional  
float specifying the initial trust region. The default value is 1. The initial trust region is equal to taufac times the length of the first computed Gauss-Newton step. taufac must be less than 1.
- sstol** : float, optional

float specifying the tolerance for convergence based on the relative change in the sum-of-squares. The default value is  $\text{eps}^{**}(1/2)$  where  $\text{eps}$  is the smallest value such that  $1 + \text{eps} > 1$  for double precision computation on the machine. `sstol` must be less than 1.

**partol** : float, optional

float specifying the tolerance for convergence based on the relative change in the estimated parameters. The default value is  $\text{eps}^{**}(2/3)$  for explicit models and  $\text{eps}^{**}(1/3)$  for implicit models. `partol` must be less than 1.

**maxit** : int, optional

integer specifying the maximum number of iterations to perform. For first runs, `maxit` is the total number of iterations performed and defaults to 50. For restarts, `maxit` is the number of additional iterations to perform and defaults to 10.

**stpb** : array\_like, optional

sequence ( $\text{len}(\text{stpb}) == \text{len}(\text{beta0})$ ) of relative step sizes to compute finite difference derivatives wrt the parameters.

**stpd** : optional

array ( $\text{stpd.shape} == \text{data.x.shape}$  or  $\text{stpd.shape} == (m,)$ ) of relative step sizes to compute finite difference derivatives wrt the input variable errors. If `stpd` is a rank-1 array with length  $m$  (the dimensionality of the input variable), then the values are broadcast to all observations.

**scfb** : array\_like, optional

sequence ( $\text{len}(\text{stpb}) == \text{len}(\text{beta0})$ ) of scaling factors for the parameters. The purpose of these scaling factors are to scale all of the parameters to around unity. Normally appropriate scaling factors are computed if this argument is not specified. Specify them yourself if the automatic procedure goes awry.

**sclb** : array\_like, optional

array ( $\text{sclb.shape} == \text{data.x.shape}$  or  $\text{sclb.shape} == (m,)$ ) of scaling factors for the *errors* in the input variables. Again, these factors are automatically computed if you do not provide them. If  $\text{sclb.shape} == (m,)$ , then the scaling factors are broadcast to all observations.

**work** : ndarray, optional

array to hold the double-valued working data for ODRPACK. When restarting, takes the value of `self.output.work`.

**iwork** : ndarray, optional

array to hold the integer-valued working data for ODRPACK. When restarting, takes the value of `self.output.iwork`.

### Attributes

<code>data</code>	(Data) The data for this fit
<code>model</code>	(Model) The model used in fit
<code>output</code>	(Output) An instance if the Output class containing all of the returned data from an invocation of <code>ODR.run()</code> or <code>ODR.restart()</code>

### Methods

<code>restart([iter])</code>	Restarts the run with <code>iter</code> more iterations.
<code>run()</code>	Run the fitting routine with all of the information given and with <code>full_output=1</code> .
<code>set_iprint([init, so_init, iter, so_iter, ...])</code>	Set the <code>iprint</code> parameter for the printing of computation reports.
<code>set_job([fit_type, deriv, var_calc, ...])</code>	Sets the “job” parameter in a hopefully comprehensible way.

ODR.**restart** (*iter=None*)

Restarts the run with *iter* more iterations.

**Parameters** **iter** : int, optional  
 ODRPACK's default for the number of new iterations is 10.

**Returns** **output** : Output instance  
 This object is also assigned to the attribute `.output`.

ODR.**run** ()

Run the fitting routine with all of the information given and with `full_output=1`.

**Returns** **output** : Output instance  
 This object is also assigned to the attribute `.output`.

ODR.**set\_iprint** (*init=None, so\_init=None, iter=None, so\_iter=None, iter\_step=None, final=None, so\_final=None*)

Set the `iprint` parameter for the printing of computation reports.

If any of the arguments are specified here, then they are set in the `iprint` member. If `iprint` is not set manually or with this method, then ODRPACK defaults to no printing. If no filename is specified with the member `rptfile`, then ODRPACK prints to `stdout`. One can tell ODRPACK to print to `stdout` in addition to the specified filename by setting the `so_*` arguments to this function, but one cannot specify to print to `stdout` but not a file since one can do that by not specifying a `rptfile` filename.

There are three reports: initialization, iteration, and final reports. They are represented by the arguments `init`, `iter`, and `final` respectively. The permissible values are 0, 1, and 2 representing "no report", "short report", and "long report" respectively.

The argument `iter_step` ( $0 \leq \text{iter\_step} \leq 9$ ) specifies how often to make the iteration report; the report will be made for every `iter_step`'th iteration starting with iteration one. If `iter_step == 0`, then no iteration report is made, regardless of the other arguments.

If the `rptfile` is `None`, then any `so_*` arguments supplied will raise an exception.

ODR.**set\_job** (*fit\_type=None, deriv=None, var\_calc=None, del\_init=None, restart=None*)

Sets the "job" parameter in a hopefully comprehensible way.

If an argument is not specified, then the value is left as is. The default value from class initialization is for all of these options set to 0.

**Parameters** **fit\_type** : {0, 1, 2} int  
 0 -> explicit ODR  
 1 -> implicit ODR  
 2 -> ordinary least-squares  
**deriv** : {0, 1, 2, 3} int  
 0 -> forward finite differences  
 1 -> central finite differences  
 2 -> *user-supplied derivatives (Jacobians) with results*  
     checked by ODRPACK  
 3 -> user-supplied derivatives, no checking  
**var\_calc** : {0, 1, 2} int  
 0 -> *calculate asymptotic covariance matrix and fit*  
     parameter uncertainties (`V_B`, `s_B`) using derivatives recomputed at  
     the final solution  
 1 -> calculate `V_B` and `s_B` using derivatives from last iteration  
 2 -> do not calculate `V_B` and `s_B`  
**del\_init** : {0, 1} int  
 0 -> initial input variable offsets set to 0  
 1 -> initial offsets provided by user in variable "work"  
**restart** : {0, 1} int

0 -> fit is not a restart  
 1 -> fit is a restart

**Notes**

The permissible values are different from those given on pg. 31 of the ODRPACK User’s Guide only in that one cannot specify numbers greater than the last value for each variable.

If one does not supply functions to compute the Jacobians, the fitting procedure will change deriv to 0, finite differences, as a default. To initialize the input variable offsets by yourself, set del\_init to 1 and put the offsets into the “work” variable correctly.

**class** `scipy.odr.Output` (*output*)

The Output class stores the output of an ODR run.

**Notes**

Takes one argument for initialization, the return value from the function `odr`. The attributes listed as “optional” above are only present if `odr` was run with `full_output=1`.

**Attributes**

beta	(ndarray) Estimated parameter values, of shape (q,).
sd_beta	(ndarray) Standard errors of the estimated parameters, of shape (p,).
cov_beta	(ndarray) Covariance matrix of the estimated parameters, of shape (p,p).
delta	(ndarray, optional) Array of estimated errors in input variables, of same shape as <i>x</i> .
eps	(ndarray, optional) Array of estimated errors in response variables, of same shape as <i>y</i> .
xplus	(ndarray, optional) Array of $x + \text{delta}$ .
y	(ndarray, optional) Array $y = \text{fcn}(x + \text{delta})$ .
res_var	(float, optional) Residual variance.
sum_square	(float, optional) Sum of squares error.
sum_square_delta	(float, optional) Sum of squares of delta error.
sum_square_eps	(float, optional) Sum of squares of eps error.
inv_condnum	(float, optional) Inverse condition number (cf. ODRPACK UG p. 77).
rel_error	(float, optional) Relative error in function values computed within fcn.
work	(ndarray, optional) Final work array.
work_ind	(dict, optional) Indices into work for drawing out values (cf. ODRPACK UG p. 83).
info	(int, optional) Reason for returning, as output by ODRPACK (cf. ODRPACK UG p. 38).
stopreason	(list of str, optional) <i>info</i> interpreted into English.

**Methods**

`pprint()` Pretty-print important results.

Output `.pprint()`  
 Pretty-print important results.

`scipy.odr.odr` (*fcn, beta0, y, x, we=None, wd=None, fjacb=None, fjacd=None, extra\_args=None, ifixx=None, ifixb=None, job=0, iprint=0, errfile=None, rptfile=None, ndigit=0, tau-fac=0.0, sstol=-1.0, partol=-1.0, maxit=-1, stpb=None, stpd=None, sclb=None, scld=None, work=None, iwork=None, full\_output=0*)

Low-level function for ODR.

**See also:**

*ODR, Model, Data, RealData*

*Notes*

This is a function performing the same operation as the *ODR*, *Model* and *Data* classes together. The parameters of this function are explained in the class documentation.

**exception** `scipy.odr.OdrWarning`

Warning indicating that the data passed into ODR will cause problems when passed into ‘odr’ that the user should be aware of.

**exception** `scipy.odr.OdrError`

Exception indicating an error in fitting.

This is raised by `scipy.odr` if an error occurs during fitting.

**exception** `scipy.odr.OdrStop`

Exception stopping fitting.

You can raise this exception in your objective function to tell `scipy.odr` to stop fitting.

`scipy.odr.odr_error`

alias of `OdrError`

`scipy.odr.odr_stop`

alias of `OdrStop`

Prebuilt models:

`polynomial(order)`

Factory function for a general polynomial model.

---

`scipy.odr.polynomial` (*order*)

Factory function for a general polynomial model.

**Parameters**    **order** : int or sequence

If an integer, it becomes the order of the polynomial to fit. If a sequence of numbers, then these are the explicit powers in the polynomial. A constant term (power 0) is always included, so don’t include 0. Thus, `polynomial(n)` is equivalent to `polynomial(range(1, n+1))`.

**Returns**        **polynomial** : Model instance  
                   Model instance.

`scipy.odr.exponential`

`scipy.odr.multilinear`

`scipy.odr.unilinear`

`scipy.odr.quadratic`

`scipy.odr.polynomial`

## 5.17.2 Usage information

### Introduction

Why Orthogonal Distance Regression (ODR)? Sometimes one has measurement errors in the explanatory (a.k.a., “independent”) variable(s), not just the response (a.k.a., “dependent”) variable(s). Ordinary Least Squares (OLS) fitting procedures treat the data for explanatory variables as fixed, i.e., not subject to error of any kind. Furthermore, OLS procedures require that the response variables be an explicit function of the explanatory variables; sometimes making the equation explicit is impractical and/or introduces errors. ODR can handle both of these cases with ease, and can even reduce to the OLS case if that is sufficient for the problem.

ODRPACK is a FORTRAN-77 library for performing ODR with possibly non-linear fitting functions. It uses a modified trust-region Levenberg-Marquardt-type algorithm [R860] to estimate the function parameters. The fitting functions are provided by Python functions operating on NumPy arrays. The required derivatives may be provided by Python functions as well, or may be estimated numerically. ODRPACK can do explicit or implicit ODR fits, or it can do OLS. Input and output variables may be multi-dimensional. Weights can be provided to account for different variances of the observations, and even covariances between dimensions of the variables.

The `scipy.odr` package offers an object-oriented interface to ODRPACK, in addition to the low-level `odr` function.

Additional background information about ODRPACK can be found in the [ODRPACK User’s Guide](#), reading which is recommended.

### Basic usage

1. Define the function you want to fit against.:

```
def f(B, x):
    '''Linear function y = m*x + b'''
    # B is a vector of the parameters.
    # x is an array of the current x values.
    # x is in the same format as the x passed to Data or RealData.
    #
    # Return an array in the same format as y passed to Data or RealData.
    return B[0]*x + B[1]
```

2. Create a Model.:

```
linear = Model(f)
```

3. Create a Data or RealData instance.:

```
mydata = Data(x, y, wd=1./power(sx,2), we=1./power(sy,2))
```

or, when the actual covariances are known:

```
mydata = RealData(x, y, sx=sx, sy=sy)
```

4. Instantiate ODR with your data, model and initial parameter estimate.:

```
myodr = ODR(mydata, linear, beta0=[1., 2.])
```

5. Run the fit.:

```
myoutput = myodr.run()
```

6. Examine output.:

```
myoutput.pprint()
```

## References

# 5.18 Optimization and root finding (`scipy.optimize`)

## 5.18.1 Optimization

### Local Optimization

<code>minimize</code> ( <code>fun</code> , <code>x0</code> [, <code>args</code> , <code>method</code> , <code>jac</code> , <code>hess</code> , ...])	Minimization of scalar function of one or more variables.
<code>minimize_scalar</code> ( <code>fun</code> [, <code>bracket</code> , <code>bounds</code> , ...])	Minimization of scalar function of one variable.
<code>OptimizeResult</code>	Represents the optimization result.
<code>OptimizeWarning</code>	

`scipy.optimize.minimize` (`fun`, `x0`, `args=()`, `method=None`, `jac=None`, `hess=None`, `hessp=None`, `bounds=None`, `constraints=()`, `tol=None`, `callback=None`, `options=None`)  
 Minimization of scalar function of one or more variables.

In general, the optimization problems are of the form:

```
minimize f(x) subject to
g_i(x) >= 0,  i = 1, ..., m
h_j(x) = 0,   j = 1, ..., p
```

where `x` is a vector of one or more variables. `g_i(x)` are the inequality constraints. `h_j(x)` are the equality constraints.

Optionally, the lower and upper bounds for each element in `x` can also be specified using the `bounds` argument.

**Parameters** `fun` : callable

The objective function to be minimized. Must be in the form `f(x, *args)`. The optimizing argument, `x`, is a 1-D array of points, and `args` is a tuple of any additional fixed parameters needed to completely specify the function.

`x0` : ndarray

Initial guess. `len(x0)` is the dimensionality of the minimization problem.

`args` : tuple, optional

Extra arguments passed to the objective function and its derivatives (Jacobian, Hessian).

`method` : str or callable, optional

Type of solver. Should be one of

- ‘Nelder-Mead’ (*see here*)
- ‘Powell’ (*see here*)
- ‘CG’ (*see here*)
- ‘BFGS’ (*see here*)
- ‘Newton-CG’ (*see here*)
- ‘L-BFGS-B’ (*see here*)
- ‘TNC’ (*see here*)
- ‘COBYLA’ (*see here*)
- ‘SLSQP’ (*see here*)
- ‘dogleg’ (*see here*)

- ‘trust-ncg’ (*see here*)
- ‘trust-exact’ (*see here*)
- ‘trust-krylov’ (*see here*)
- custom - a callable object (added in version 0.14.0), see below for description.

If not given, chosen to be one of BFGS, L-BFGS-B, SLSQP, depending if the problem has constraints or bounds.

**jac** : bool or callable, optional

Jacobian (gradient) of objective function. Only for CG, BFGS, Newton-CG, L-BFGS-B, TNC, SLSQP, dogleg, trust-ncg, trust-krylov, trust-region-exact. If *jac* is a Boolean and is True, *fun* is assumed to return the gradient along with the objective function. If False, the gradient will be estimated numerically. *jac* can also be a callable returning the gradient of the objective. In this case, it must accept the same arguments as *fun*.

**hess, hessp** : callable, optional

Hessian (matrix of second-order derivatives) of objective function or Hessian of objective function times an arbitrary vector *p*. Only for Newton-CG, dogleg, trust-ncg, trust-krylov, trust-region-exact. Only one of *hessp* or *hess* needs to be given. If *hess* is provided, then *hessp* will be ignored. If neither *hess* nor *hessp* is provided, then the Hessian product will be approximated using finite differences on *jac*. *hessp* must compute the Hessian times an arbitrary vector.

**bounds** : sequence, optional

Bounds for variables (only for L-BFGS-B, TNC and SLSQP). (*min*, *max*) pairs for each element in *x*, defining the bounds on that parameter. Use None for one of *min* or *max* when there is no bound in that direction.

**constraints** : dict or sequence of dict, optional

Constraints definition (only for COBYLA and SLSQP). Each constraint is defined in a dictionary with fields:

<i>type</i>	[str] Constraint type: ‘eq’ for equality, ‘ineq’ for inequality.
<i>fun</i>	[callable] The function defining the constraint.
<i>jac</i>	[callable, optional] The Jacobian of <i>fun</i> (only for SLSQP).
<i>args</i>	[sequence, optional] Extra arguments to be passed to the function and Jacobian.

Equality constraint means that the constraint function result is to be zero whereas inequality means that it is to be non-negative. Note that COBYLA only supports inequality constraints.

**tol** : float, optional

Tolerance for termination. For detailed control, use solver-specific options.

**options** : dict, optional

A dictionary of solver options. All methods accept the following generic options:

<i>maxiter</i>	[int] Maximum number of iterations to perform.
<i>disp</i>	[bool] Set to True to print convergence messages.

For method-specific options, see *show\_options*.

**callback** : callable, optional

Called after each iteration, as `callback(xk)`, where *xk* is the current parameter vector.

### Returns

**res** : OptimizeResult

The optimization result represented as a `OptimizeResult` object. Important attributes are: *x* the solution array, *success* a Boolean flag indicating if the optimizer exited successfully and *message* which describes the cause of the termination. See `OptimizeResult` for a description of other attributes.

See also:

### `minimize_scalar`

Interface to minimization algorithms for scalar univariate functions

**show\_options**

Additional options accepted by the solvers

**Notes**

This section describes the available solvers that can be selected by the ‘method’ parameter. The default method is *BFGS*.

**Unconstrained minimization**

Method *Nelder-Mead* uses the Simplex algorithm [R210], [R211]. This algorithm is robust in many applications. However, if numerical computation of derivative can be trusted, other algorithms using the first and/or second derivatives information might be preferred for their better performance in general.

Method *Powell* is a modification of Powell’s method [R212], [R213] which is a conjugate direction method. It performs sequential one-dimensional minimizations along each vector of the directions set (*direc* field in *options* and *info*), which is updated at each iteration of the main minimization loop. The function need not be differentiable, and no derivatives are taken.

Method *CG* uses a nonlinear conjugate gradient algorithm by Polak and Ribiere, a variant of the Fletcher-Reeves method described in [R214] pp. 120-122. Only the first derivatives are used.

Method *BFGS* uses the quasi-Newton method of Broyden, Fletcher, Goldfarb, and Shanno (BFGS) [R214] pp. 136. It uses the first derivatives only. BFGS has proven good performance even for non-smooth optimizations. This method also returns an approximation of the Hessian inverse, stored as *hess\_inv* in the *OptimizeResult* object.

Method *Newton-CG* uses a Newton-CG algorithm [R214] pp. 168 (also known as the truncated Newton method). It uses a CG method to compute the search direction. See also *TNC* method for a box-constrained minimization with a similar algorithm. Suitable for large-scale problems.

Method *dogleg* uses the dog-leg trust-region algorithm [R214] for unconstrained minimization. This algorithm requires the gradient and Hessian; furthermore the Hessian is required to be positive definite.

Method *trust-ncg* uses the Newton conjugate gradient trust-region algorithm [R214] for unconstrained minimization. This algorithm requires the gradient and either the Hessian or a function that computes the product of the Hessian with a given vector. Suitable for large-scale problems.

Method *trust-krylov* uses the Newton GLTR trust-region algorithm<sup>14, 15</sup> for unconstrained minimization. This algorithm requires the gradient and either the Hessian or a function that computes the product of the Hessian with a given vector. Suitable for large-scale problems. On indefinite problems it requires usually less iterations than the *trust-ncg* method and is recommended for medium and large-scale problems.

Method *trust-exact* is a trust-region method for unconstrained minimization in which quadratic subproblems are solved almost exactly<sup>13</sup>. This algorithm requires the gradient and the Hessian (which is *not* required to be positive definite). It is, in many situations, the Newton method to converge in fewer interaction and the most recommended for small and medium-size problems.

**Constrained minimization**

Method *L-BFGS-B* uses the L-BFGS-B algorithm [R215], [R216] for bound constrained minimization.

Method *TNC* uses a truncated Newton algorithm [R214], [R217] to minimize a function with variables subject to bounds. This algorithm uses gradient information; it is also called Newton Conjugate-Gradient. It differs from the *Newton-CG* method described above as it wraps a C implementation and allows each variable to be given upper and lower bounds.

---

<sup>14</sup> F. Lenders, C. Kirches, A. Potschka: “trlib: A vector-free implementation of the GLTR method for iterative solution of the trust region problem”, <https://arxiv.org/abs/1611.04718>

<sup>15</sup> N. Gould, S. Lucidi, M. Roma, P. Toint: “Solving the Trust-Region Subproblem using the Lanczos Method”, *SIAM J. Optim.*, 9(2), 504–525, (1999).

<sup>13</sup> Conn, A. R., Gould, N. I., and Toint, P. L. Trust region methods. 2000. Siam. pp. 169-200.

Method *COBYLA* uses the Constrained Optimization BY Linear Approximation (COBYLA) method [R218],<sup>10,11</sup>. The algorithm is based on linear approximations to the objective function and each constraint. The method wraps a FORTRAN implementation of the algorithm. The constraints functions ‘fun’ may return either a single number or an array or list of numbers.

Method *SLSQP* uses Sequential Least Squares Programming to minimize a function of several variables with any combination of bounds, equality and inequality constraints. The method wraps the SLSQP Optimization subroutine originally implemented by Dieter Kraft<sup>12</sup>. Note that the wrapper handles infinite values in bounds by converting them into large floating values.

### Custom minimizers

It may be useful to pass a custom minimization method, for example when using a frontend to this method such as `scipy.optimize.basinhopping` or a different library. You can simply pass a callable as the `method` parameter.

The callable is called as `method(fun, x0, args, **kwargs, **options)` where `kwargs` corresponds to any other parameters passed to `minimize` (such as `callback`, `hess`, etc.), except the `options` dict, which has its contents also passed as `method` parameters pair by pair. Also, if `jac` has been passed as a bool type, `jac` and `fun` are mangled so that `fun` returns just the function values and `jac` is converted to a function returning the Jacobian. The method shall return an `OptimizeResult` object.

The provided `method` callable must be able to accept (and possibly ignore) arbitrary parameters; the set of parameters accepted by `minimize` may expand in future versions and then these parameters will be passed to the method. You can find an example in the `scipy.optimize` tutorial.

New in version 0.11.0.

### References

[R210], [R211], [R212], [R213], [R214], [R215], [R216], [R217], [R218],<sup>10,11,12,13,14,15</sup>

### Examples

Let us consider the problem of minimizing the Rosenbrock function. This function (and its respective derivatives) is implemented in `rosen` (resp. `rosen_der`, `rosen_hess`) in the `scipy.optimize`.

```
>>> from scipy.optimize import minimize, rosen, rosen_der
```

A simple application of the *Nelder-Mead* method is:

```
>>> x0 = [1.3, 0.7, 0.8, 1.9, 1.2]
>>> res = minimize(rosen, x0, method='Nelder-Mead', tol=1e-6)
>>> res.x
array([ 1.,  1.,  1.,  1.,  1.]
```

Now using the *BFGS* algorithm, using the first derivative and a few options:

```
>>> res = minimize(rosen, x0, method='BFGS', jac=rosen_der,
...               options={'gtol': 1e-6, 'disp': True})
Optimization terminated successfully.
    Current function value: 0.000000
    Iterations: 26
    Function evaluations: 31
    Gradient evaluations: 31
>>> res.x
```

<sup>10</sup> Powell M J D. Direct search algorithms for optimization calculations. 1998. Acta Numerica 7: 287-336.

<sup>11</sup> Powell M J D. A view of algorithms for optimization without derivatives. 2007. Cambridge University Technical Report DAMTP 2007/NA03

<sup>12</sup> Kraft, D. A software package for sequential quadratic programming. 1988. Tech. Rep. DFVLR-FB 88-28, DLR German Aerospace Center – Institute for Flight Mechanics, Koln, Germany.

```

array([ 1.,  1.,  1.,  1.,  1.])
>>> print(res.message)
Optimization terminated successfully.
>>> res.hess_inv
array([[ 0.00749589,  0.01255155,  0.02396251,  0.04750988,  0.09495377], # may_
↪ vary
       [ 0.01255155,  0.02510441,  0.04794055,  0.09502834,  0.18996269],
       [ 0.02396251,  0.04794055,  0.09631614,  0.19092151,  0.38165151],
       [ 0.04750988,  0.09502834,  0.19092151,  0.38341252,  0.7664427 ],
       [ 0.09495377,  0.18996269,  0.38165151,  0.7664427,  1.53713523]])
    
```

Next, consider a minimization problem with several constraints (namely Example 16.4 from [R214]). The objective function is:

```
>>> fun = lambda x: (x[0] - 1)**2 + (x[1] - 2.5)**2
```

There are three constraints defined as:

```
>>> cons = ({'type': 'ineq', 'fun': lambda x: x[0] - 2 * x[1] + 2},
...         {'type': 'ineq', 'fun': lambda x: -x[0] - 2 * x[1] + 6},
...         {'type': 'ineq', 'fun': lambda x: -x[0] + 2 * x[1] + 2})
```

And variables must be positive, hence the following bounds:

```
>>> bnds = ((0, None), (0, None))
```

The optimization problem is solved using the SLSQP method as:

```
>>> res = minimize(fun, (2, 0), method='SLSQP', bounds=bnds,
...               constraints=cons)
```

It should converge to the theoretical solution (1.4,1.7).

```
scipy.optimize.minimize_scalar(fun, bracket=None, bounds=None, args=(), method='brent',
                              tol=None, options=None)
```

Minimization of scalar function of one variable.

**Parameters** **fun** : callable

Objective function. Scalar function, must return a scalar.

**bracket** : sequence, optional

For methods 'brent' and 'golden', *bracket* defines the bracketing interval and can either have three items (*a*, *b*, *c*) so that  $a < b < c$  and  $\text{fun}(b) < \text{fun}(a)$ ,  $\text{fun}(c)$  or two items *a* and *c* which are assumed to be a starting interval for a downhill bracket search (see *bracket*); it doesn't always mean that the obtained solution will satisfy  $a \leq x \leq c$ .

**bounds** : sequence, optional

For method 'bounded', *bounds* is mandatory and must have two items corresponding to the optimization bounds.

**args** : tuple, optional

Extra arguments passed to the objective function.

**method** : str or callable, optional

Type of solver. Should be one of:

- 'Brent' (see here)
- 'Bounded' (see here)
- 'Golden' (see here)
- custom - a callable object (added in version 0.14.0), see below

**tol** : float, optional

Tolerance for termination. For detailed control, use solver-specific options.

**options** : dict, optional

A dictionary of solver options.

**maxiter** [int] Maximum number of iterations to perform.

**disp** [bool] Set to True to print convergence messages.

See `show_options` for solver-specific options.

**Returns** **res** : OptimizeResult

The optimization result represented as a `OptimizeResult` object. Important attributes are: `x` the solution array, `success` a Boolean flag indicating if the optimizer exited successfully and `message` which describes the cause of the termination. See `OptimizeResult` for a description of other attributes.

**See also:**

**minimize** Interface to minimization algorithms for scalar multivariate functions

**show\_options**

Additional options accepted by the solvers

**Notes**

This section describes the available solvers that can be selected by the ‘method’ parameter. The default method is *Brent*.

Method *Brent* uses Brent’s algorithm to find a local minimum. The algorithm uses inverse parabolic interpolation when possible to speed up convergence of the golden section method.

Method *Golden* uses the golden section search technique. It uses analog of the bisection method to decrease the bracketed interval. It is usually preferable to use the *Brent* method.

Method *Bounded* can perform bounded minimization. It uses the Brent method to find a local minimum in the interval  $x_1 < x_{opt} < x_2$ .

**Custom minimizers**

It may be useful to pass a custom minimization method, for example when using some library frontend to `minimize_scalar`. You can simply pass a callable as the `method` parameter.

The callable is called as `method(fun, args, **kwargs, **options)` where `kwargs` corresponds to any other parameters passed to `minimize` (such as `bracket`, `tol`, etc.), except the `options` dict, which has its contents also passed as `method` parameters pair by pair. The method shall return an `OptimizeResult` object.

The provided `method` callable must be able to accept (and possibly ignore) arbitrary parameters; the set of parameters accepted by `minimize` may expand in future versions and then these parameters will be passed to the method. You can find an example in the `scipy.optimize` tutorial.

New in version 0.11.0.

**Examples**

Consider the problem of minimizing the following function.

```
>>> def f(x):
...     return (x - 2) * x * (x + 2)**2
```

Using the *Brent* method, we find the local minimum as:

```
>>> from scipy.optimize import minimize_scalar
>>> res = minimize_scalar(f)
>>> res.x
1.28077640403
```

Using the *Bounded* method, we find a local minimum with specified bounds as:

```
>>> res = minimize_scalar(f, bounds=(-3, -1), method='bounded')
>>> res.x
-2.0000002026
```

**class** `scipy.optimize.OptimizeResult`

Represents the optimization result.

*Notes*

There may be additional attributes not listed above depending of the specific solver. Since this class is essentially a subclass of dict with attribute accessors, one can see which attributes are available using the *keys()* method.

*Attributes*

x	(ndarray) The solution of the optimization.
success	(bool) Whether or not the optimizer exited successfully.
status	(int) Termination status of the optimizer. Its value depends on the underlying solver. Refer to <i>message</i> for details.
message	(str) Description of the cause of the termination.
fun, jac, hess:	Values of objective function, its Jacobian and its Hessian (if available). The Hessians may be approximations, see the documentation of the function in question.
ndarray	
hess_inv	(object) Inverse of the objective function's Hessian; may be an approximation. Not available for all solvers. The type of this attribute may be either <code>np.ndarray</code> or <code>scipy.sparse.linalg.LinearOperator</code> .
nfev, njev, nhev	(int) Number of evaluations of the objective functions and of its Jacobian and Hessian.
nit	(int) Number of iterations performed by the optimizer.
maxcv	(float) The maximum constraint violation.

*Methods*

<code>clear()</code>	-> None. Remove all items from D.)
<code>copy()</code>	-> a shallow copy of D)
<code>fromkeys(...)</code>	v defaults to None.
<code>get((k[,d])</code>	-> D[k] if k in D, ...)
<code>has_key((k)</code>	-> True if D has a key k, else False)
<code>items()</code>	-> list of D's (key, value) pairs, ...)
<code>iteritems()</code>	-> an iterator over the (key, ...)
<code>iterkeys()</code>	-> an iterator over the keys of D)
<code>itervalues(...)</code>	
<code>keys()</code>	-> list of D's keys)
<code>pop((k[,d])</code>	-> v, ...)
	If key is not found, d is returned if given, otherwise Key-Error is raised
<code>popitem()</code>	-> (k, v), ...)
	2-tuple; but raise KeyError if D is empty.
<code>setdefault((k[,d])</code>	-> D.get(k,d), ...)

Continued on next page

Table 5.116 – continued from previous page

<code>update((E, ...)</code>	If E present and has a <code>.keys()</code> method, does: for k in E: D[k] = E[k]
<code>values()</code> -> list of D's values)	
<code>viewitems(...)</code>	
<code>viewkeys(...)</code>	
<code>viewvalues(...)</code>	

`OptimizeResult.clear()` → None. Remove all items from D.

`OptimizeResult.copy()` → a shallow copy of D

`OptimizeResult.fromkeys(S, v)` → New dict with keys from S and values equal to v.  
v defaults to None.

`OptimizeResult.get(k, d)` → D[k] if k in D, else d. d defaults to None.

`OptimizeResult.has_key(k)` → True if D has a key k, else False

`OptimizeResult.items()` → list of D's (key, value) pairs, as 2-tuples

`OptimizeResult.iteritems()` → an iterator over the (key, value) items of D

`OptimizeResult.iterkeys()` → an iterator over the keys of D

`OptimizeResult.itervalues()` → an iterator over the values of D

`OptimizeResult.keys()` → list of D's keys

`OptimizeResult.pop(k, d)` → v, remove specified key and return the corresponding value.  
If key is not found, d is returned if given, otherwise `KeyError` is raised

`OptimizeResult.popitem()` → (k, v), remove and return some (key, value) pair as a  
2-tuple; but raise `KeyError` if D is empty.

`OptimizeResult.setdefault(k, d)` → D.get(k,d), also set D[k]=d if k not in D

`OptimizeResult.update([E], **F)` → None. Update D from dict/iterable E and F.  
If E present and has a `.keys()` method, does: for k in E: D[k] = E[k] If E present and lacks `.keys()` method,  
does: for (k, v) in E: D[k] = v In either case, this is followed by: for k in F: D[k] = F[k]

`OptimizeResult.values()` → list of D's values

`OptimizeResult.viewitems()` → a set-like object providing a view on D's items

`OptimizeResult.viewkeys()` → a set-like object providing a view on D's keys

`OptimizeResult.viewvalues()` → an object providing a view on D's values

**exception** `scipy.optimize.OptimizeWarning`

The `minimize` function supports the following methods:

**`minimize(method='Nelder-Mead')`**

```
scipy.optimize.minimize (fun, x0, args=(), method='Nelder-Mead', tol=None, callback=None, options={'disp': False, 'initial_simplex': None, 'maxiter': None, 'xatol': 0.0001, 'return_all': False, 'fatol': 0.0001, 'func': None, 'maxfev': None})
```

Minimization of scalar function of one or more variables using the Nelder-Mead algorithm.

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.minimize`

<b>Options</b>	<p><b>disp</b> : bool Set to True to print convergence messages.</p> <p><b>maxiter, maxfev</b> : int Maximum allowed number of iterations and function evaluations. Will default to <math>N*200</math>, where <math>N</math> is the number of variables, if neither <code>maxiter</code> or <code>maxfev</code> is set. If both <code>maxiter</code> and <code>maxfev</code> are set, minimization will stop at the first reached.</p> <p><b>initial_simplex</b> : array_like of shape <math>(N + 1, N)</math> Initial simplex. If given, overrides <code>x0</code>. <code>initial_simplex[j, :]</code> should contain the coordinates of the <math>j</math>-th vertex of the <math>N+1</math> vertices in the simplex, where <math>N</math> is the dimension.</p> <p><b>xatol</b> : float, optional Absolute error in <code>xopt</code> between iterations that is acceptable for convergence.</p> <p><b>fatol</b> : number, optional Absolute error in <code>func(xopt)</code> between iterations that is acceptable for convergence.</p>
----------------	---

**`minimize(method='Powell')`**

```
scipy.optimize.minimize (fun, x0, args=(), method='Powell', tol=None, callback=None, options={'disp': False, 'return_all': False, 'maxiter': None, 'direc': None, 'func': None, 'maxfev': None, 'xtol': 0.0001, 'ftol': 0.0001})
```

Minimization of scalar function of one or more variables using the modified Powell algorithm.

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.minimize`

<b>Options</b>	<p><b>disp</b> : bool Set to True to print convergence messages.</p> <p><b>xtol</b> : float Relative error in solution <code>xopt</code> acceptable for convergence.</p> <p><b>ftol</b> : float Relative error in <code>fun(xopt)</code> acceptable for convergence.</p> <p><b>maxiter, maxfev</b> : int Maximum allowed number of iterations and function evaluations. Will default to <math>N*1000</math>, where <math>N</math> is the number of variables, if neither <code>maxiter</code> or <code>maxfev</code> is set. If both <code>maxiter</code> and <code>maxfev</code> are set, minimization will stop at the first reached.</p> <p><b>direc</b> : ndarray Initial set of direction vectors for the Powell method.</p>
----------------	---

***minimize(method='CG')***

```
scipy.optimize.minimize (fun, x0, args=(), method='CG', jac=None, tol=None, callback=None, options={'disp': False, 'gtol': 1e-05, 'eps': 1.4901161193847656e-08, 'return_all': False, 'maxiter': None, 'norm': inf})
```

Minimization of scalar function of one or more variables using the conjugate gradient algorithm.

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.minimize`

<b>Options</b>	<b>disp</b> : bool Set to True to print convergence messages. <b>maxiter</b> : int Maximum number of iterations to perform. <b>gtol</b> : float Gradient norm must be less than <i>gtol</i> before successful termination. <b>norm</b> : float Order of norm (Inf is max, -Inf is min). <b>eps</b> : float or ndarray If <i>jac</i> is approximated, use this value for the step size.
----------------	---

***minimize(method='BFGS')***

```
scipy.optimize.minimize (fun, x0, args=(), method='BFGS', jac=None, tol=None, callback=None, options={'disp': False, 'gtol': 1e-05, 'eps': 1.4901161193847656e-08, 'return_all': False, 'maxiter': None, 'norm': inf})
```

Minimization of scalar function of one or more variables using the BFGS algorithm.

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.minimize`

<b>Options</b>	<b>disp</b> : bool Set to True to print convergence messages. <b>maxiter</b> : int Maximum number of iterations to perform. <b>gtol</b> : float Gradient norm must be less than <i>gtol</i> before successful termination. <b>norm</b> : float Order of norm (Inf is max, -Inf is min). <b>eps</b> : float or ndarray If <i>jac</i> is approximated, use this value for the step size.
----------------	---

***minimize(method='Newton-CG')***

```
scipy.optimize.minimize (fun, x0, args=(), method='Newton-CG', jac=None, hess=None, hessp=None, tol=None, callback=None, options={'disp': False, 'xtol': 1e-05, 'eps': 1.4901161193847656e-08, 'return_all': False, 'maxiter': None})
```

Minimization of scalar function of one or more variables using the Newton-CG algorithm.

Note that the *jac* parameter (Jacobian) is required.

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.minimize`

<b>Options</b>	<b>disp</b> : bool
----------------	--------------------

Set to True to print convergence messages.  
**xtol** : float  
 Average relative error in solution *xopt* acceptable for convergence.  
**maxiter** : int  
 Maximum number of iterations to perform.  
**eps** : float or ndarray  
 If *jac* is approximated, use this value for the step size.

***minimize(method='L-BFGS-B')***

```
scipy.optimize.minimize(fun, x0, args=(), method='L-BFGS-B', jac=None, bounds=None,
                        tol=None, callback=None, options={'disp': None, 'maxls': 20,
                        'iprint': -1, 'gtol': 1e-05, 'eps': 1e-08, 'maxiter': 15000, 'ftol':
                        2.220446049250313e-09, 'maxcor': 10, 'maxfun': 15000})
```

Minimize a scalar function of one or more variables using the L-BFGS-B algorithm.

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.minimize`

**Options**

**disp** : bool  
 Set to True to print convergence messages.  
**maxcor** : int  
 The maximum number of variable metric corrections used to define the limited memory matrix. (The limited memory BFGS method does not store the full hessian but uses this many terms in an approximation to it.)  
**ftol** : float  
 The iteration stops when  $(f^k - f^{k+1}) / \max\{|f^k|, |f^{k+1}|, 1\} \leq ftol$ .  
**gtol** : float  
 The iteration will stop when  $\max\{|proj\ g_i| \mid i = 1, \dots, n\} \leq gtol$  where *pg<sub>i</sub>* is the *i*-th component of the projected gradient.  
**eps** : float  
 Step size used for numerical approximation of the jacobian.  
**disp** : int  
 Set to True to print convergence messages.  
**maxfun** : int  
 Maximum number of function evaluations.  
**maxiter** : int  
 Maximum number of iterations.  
**maxls** : int, optional  
 Maximum number of line search steps (per iteration). Default is 20.

**Notes**

The option *ftol* is exposed via the `scipy.optimize.minimize` interface, but calling `scipy.optimize.fmin_l_bfgs_b` directly exposes *factr*. The relationship between the two is  $ftol = factr * \text{numpy.finfo(float)}.eps$ . I.e., *factr* multiplies the default machine floating-point precision to arrive at *ftol*.

***minimize(method='TNC')***

```
scipy.optimize.minimize(fun, x0, args=(), method='TNC', jac=None, bounds=None, tol=None,
                        callback=None, options={'disp': False, 'minfev': 0, 'scale': None, 'rescale':
                        -1, 'offset': None, 'gtol': -1, 'eps': 1e-08, 'eta': -1, 'maxiter': None, 'max-
                        CGit': -1, 'msg_num': None, 'ftol': -1, 'xtol': -1, 'stepmx': 0, 'accuracy':
                        0})
```

Minimize a scalar function of one or more variables using a truncated Newton (TNC) algorithm.

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.minimize`

<b>Options</b>	<p><b>eps</b> : float Step size used for numerical approximation of the jacobian.</p> <p><b>scale</b> : list of floats Scaling factors to apply to each variable. If None, the factors are up-low for interval bounded variables and 1+ x  for the others. Defaults to None</p> <p><b>offset</b> : float Value to subtract from each variable. If None, the offsets are (up+low)/2 for interval bounded variables and x for the others.</p> <p><b>disp</b> : bool Set to True to print convergence messages.</p> <p><b>maxCGit</b> : int Maximum number of hessian*vector evaluations per main iteration. If maxCGit == 0, the direction chosen is -gradient if maxCGit &lt; 0, maxCGit is set to max(1,min(50,n/2)). Defaults to -1.</p> <p><b>maxiter</b> : int Maximum number of function evaluation. if None, <i>maxiter</i> is set to max(100, 10*len(x0)). Defaults to None.</p> <p><b>eta</b> : float Severity of the line search. if &lt; 0 or &gt; 1, set to 0.25. Defaults to -1.</p> <p><b>stepmx</b> : float Maximum step for the line search. May be increased during call. If too small, it will be set to 10.0. Defaults to 0.</p> <p><b>accuracy</b> : float Relative precision for finite difference calculations. If &lt;= machine_precision, set to sqrt(machine_precision). Defaults to 0.</p> <p><b>minfev</b> : float Minimum function value estimate. Defaults to 0.</p> <p><b>ftol</b> : float Precision goal for the value of f in the stopping criterion. If ftol &lt; 0.0, ftol is set to 0.0 defaults to -1.</p> <p><b>xtol</b> : float Precision goal for the value of x in the stopping criterion (after applying x scaling factors). If xtol &lt; 0.0, xtol is set to sqrt(machine_precision). Defaults to -1.</p> <p><b>gtol</b> : float Precision goal for the value of the projected gradient in the stopping criterion (after applying x scaling factors). If gtol &lt; 0.0, gtol is set to 1e-2 * sqrt(accuracy). Setting it to 0.0 is not recommended. Defaults to -1.</p> <p><b>rescale</b> : float Scaling factor (in log10) used to trigger f value rescaling. If 0, rescale at each iteration. If a large value, never rescale. If &lt; 0, rescale is set to 1.3.</p>
----------------	--

***minimize(method='COBYLA')***

```
scipy.optimize.minimize(fun, x0, args=(), method='COBYLA', constraints=(), tol=None, call-
                        back=None, options={'disp': False, 'catol': 0.0002, 'maxiter': 1000,
                        'rhobeg': 1.0})
```

Minimize a scalar function of one or more variables using the Constrained Optimization BY Linear Approximation (COBYLA) algorithm.

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.minimize`

**Options**

- rhobeg** : float  
Reasonable initial changes to the variables.
- tol** : float  
Final accuracy in the optimization (not precisely guaranteed). This is a lower bound on the size of the trust region.
- disp** : bool  
Set to True to print convergence messages. If False, *verbosity* is ignored as set to 0.
- maxiter** : int  
Maximum number of function evaluations.
- catol** : float  
Tolerance (absolute) for constraint violations

***minimize(method='SLSQP')***

```
scipy.optimize.minimize(fun, x0, args=(), method='SLSQP', jac=None, bounds=None, constraints=(), tol=None, callback=None, options={'disp': False, 'iprint': 1, 'eps': 1.4901161193847656e-08, 'func': None, 'maxiter': 100, 'ftol': 1e-06})
```

Minimize a scalar function of one or more variables using Sequential Least Squares Programming (SLSQP).

**See also:**

For documentation for the rest of the parameters, see *scipy.optimize.minimize*

**Options**

- ftol** : float  
Precision goal for the value of f in the stopping criterion.
- eps** : float  
Step size used for numerical approximation of the Jacobian.
- disp** : bool  
Set to True to print convergence messages. If False, *verbosity* is ignored and set to 0.
- maxiter** : int  
Maximum number of iterations.

***minimize(method='dogleg')***

```
scipy.optimize.minimize(fun, x0, args=(), method='dogleg', jac=None, hess=None, tol=None, callback=None, options={})
```

Minimization of scalar function of one or more variables using the dog-leg trust-region algorithm.

**See also:**

For documentation for the rest of the parameters, see *scipy.optimize.minimize*

**Options**

- initial\_trust\_radius** : float  
Initial trust-region radius.
- max\_trust\_radius** : float  
Maximum value of the trust-region radius. No steps that are longer than this value will be proposed.
- eta** : float  
Trust region related acceptance stringency for proposed steps.
- gtol** : float  
Gradient norm must be less than *gtol* before successful termination.

***minimize(method='trust-ncg')***

`scipy.optimize.minimize` (*fun*, *x0*, *args=()*, *method='trust-ncg'*, *jac=None*, *hess=None*, *hessp=None*, *tol=None*, *callback=None*, *options={}*)

Minimization of scalar function of one or more variables using the Newton conjugate gradient trust-region algorithm.

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.minimize`

**Options**

- initial\_trust\_radius** : float  
Initial trust-region radius.
- max\_trust\_radius** : float  
Maximum value of the trust-region radius. No steps that are longer than this value will be proposed.
- eta** : float  
Trust region related acceptance stringency for proposed steps.
- gtol** : float  
Gradient norm must be less than *gtol* before successful termination.

***minimize(method='trust-krylov')***

`scipy.optimize.minimize` (*fun*, *x0*, *args=()*, *method='trust-krylov'*, *jac=None*, *hess=None*, *hessp=None*, *tol=None*, *callback=None*, *options={'inexact': True}*)

Minimization of a scalar function of one or more variables using a nearly exact trust-region algorithm that only requires matrix vector products with the hessian matrix.

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.minimize`

**Options**

- inexact** : bool, optional  
Accuracy to solve subproblems. If True requires less nonlinear iterations, but more vector products.
- .. versionadded:: 1.0.0**

***minimize(method='trust-exact')***

`scipy.optimize.minimize` (*fun*, *x0*, *args=()*, *method='trust-exact'*, *jac=None*, *hess=None*, *tol=None*, *callback=None*, *options={}*)

Minimization of scalar function of one or more variables using a nearly exact trust-region algorithm.

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.minimize`

**Options**

- initial\_tr\_radius** : float  
Initial trust-region radius.
- max\_tr\_radius** : float  
Maximum value of the trust-region radius. No steps that are longer than this value will be proposed.
- eta** : float  
Trust region related acceptance stringency for proposed steps.
- gtol** : float  
Gradient norm must be less than *gtol* before successful termination.

The `minimize_scalar` function supports the following methods:

*minimize\_scalar(method='brent')*

`scipy.optimize.minimize_scalar` (*fun*, *args*=(), *method*='brent', *tol*=None, *options*={'xtol': 1.48e-08, 'brack': None, 'func': None, 'maxiter': 500})

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.minimize_scalar`

**Options**      **maxiter** : int  
                   Maximum number of iterations to perform.  
                   **xtol** : float  
                   Relative error in solution *xopt* acceptable for convergence.

**Notes**

Uses inverse parabolic interpolation when possible to speed up convergence of golden section method.

*minimize\_scalar(method='bounded')*

`scipy.optimize.minimize_scalar` (*fun*, *bounds*=None, *args*=(), *method*='bounded', *tol*=None, *options*={'disp': 0, 'maxiter': 500, 'func': None, 'xatol': 1e-05})

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.minimize_scalar`

**Options**      **maxiter** : int  
                   Maximum number of iterations to perform.  
                   **disp** : bool  
                   Set to True to print convergence messages.  
                   **xatol** : float  
                   Absolute error in solution *xopt* acceptable for convergence.

*minimize\_scalar(method='golden')*

`scipy.optimize.minimize_scalar` (*fun*, *args*=(), *method*='golden', *tol*=None, *options*={'xtol': 1.4901161193847656e-08, 'brack': None, 'func': None, 'maxiter': 5000})

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.minimize_scalar`

**Options**      **maxiter** : int  
                   Maximum number of iterations to perform.  
                   **xtol** : float  
                   Relative error in solution *xopt* acceptable for convergence.

The specific optimization method interfaces below in this subsection are not recommended for use in new scripts; all of these methods are accessible via a newer, more consistent interface provided by the functions above.

General-purpose multivariate methods:

<code>fmin</code> ( <i>func</i> , <i>x0</i> [], <i>args</i> , <i>xtol</i> , <i>ftol</i> , <i>maxiter</i> , ...)	Minimize a function using the downhill simplex algorithm.
<code>fmin_powell</code> ( <i>func</i> , <i>x0</i> [], <i>args</i> , <i>xtol</i> , <i>ftol</i> , ...)	Minimize a function using modified Powell's method.

Continued on next page

Table 5.117 – continued from previous page

<code>fmin_cg(f, x0[, fprime, args, gtol, norm, ...])</code>	Minimize a function using a nonlinear conjugate gradient algorithm.
<code>fmin_bfgs(f, x0[, fprime, args, gtol, norm, ...])</code>	Minimize a function using the BFGS algorithm.
<code>fmin_ncg(f, x0, fprime[, fhess_p, fhess, ...])</code>	Unconstrained minimization of a function using the Newton-CG method.

`scipy.optimize.fmin` (*func*, *x0*, *args*=(), *xtol*=0.0001, *ftol*=0.0001, *maxiter*=None, *maxfun*=None, *full\_output*=0, *disp*=1, *retall*=0, *callback*=None, *initial\_simplex*=None)  
 Minimize a function using the downhill simplex algorithm.

This algorithm only uses function values, not derivatives or second derivatives.

**Parameters**

- func** : callable `func(x,*args)`  
The objective function to be minimized.
- x0** : ndarray  
Initial guess.
- args** : tuple, optional  
Extra arguments passed to `func`, i.e. `f(x,*args)`.
- xtol** : float, optional  
Absolute error in `xopt` between iterations that is acceptable for convergence.
- ftol** : number, optional  
Absolute error in `func(xopt)` between iterations that is acceptable for convergence.
- maxiter** : int, optional  
Maximum number of iterations to perform.
- maxfun** : number, optional  
Maximum number of function evaluations to make.
- full\_output** : bool, optional  
Set to True if `fopt` and `warnflag` outputs are desired.
- disp** : bool, optional  
Set to True to print convergence messages.
- retall** : bool, optional  
Set to True to return list of solutions at each iteration.
- callback** : callable, optional  
Called after each iteration, as `callback(xk)`, where `xk` is the current parameter vector.
- initial\_simplex** : array\_like of shape (N + 1, N), optional  
Initial simplex. If given, overrides `x0`. `initial_simplex[j, :]` should contain the coordinates of the `j`-th vertex of the N+1 vertices in the simplex, where N is the dimension.

**Returns**

- xopt** : ndarray  
Parameter that minimizes function.
- fopt** : float  
Value of function at minimum: `fopt = func(xopt)`.
- iter** : int  
Number of iterations performed.
- funcalls** : int  
Number of function calls made.
- warnflag** : int  
1 : Maximum number of function evaluations made. 2 : Maximum number of iterations reached.
- allvecs** : list  
Solution at each iteration.

See also:

**minimize** Interface to minimization algorithms for multivariate functions. See the ‘Nelder-Mead’ *method* in particular.

*Notes*

Uses a Nelder-Mead simplex algorithm to find the minimum of function of one or more variables.

This algorithm has a long history of successful use in applications. But it will usually be slower than an algorithm that uses first or second derivative information. In practice it can have poor performance in high-dimensional problems and is not robust to minimizing complicated functions. Additionally, there currently is no complete theory describing when the algorithm will successfully converge to the minimum, or how fast it will if it does. Both the *ftol* and *xtol* criteria must be met for convergence.

*References*

[R198], [R199]

*Examples*

```
>>> def f(x):
...     return x**2

>>> from scipy import optimize

>>> minimum = optimize.fmin(f, 1)
Optimization terminated successfully.
    Current function value: 0.000000
    Iterations: 17
    Function evaluations: 34
>>> minimum[0]
-8.8817841970012523e-16
```

`scipy.optimize.fmin_powell` (*func*, *x0*, *args=()*, *xtol=0.0001*, *ftol=0.0001*, *maxiter=None*, *maxfun=None*, *full\_output=0*, *disp=1*, *retall=0*, *callback=None*, *direc=None*)

Minimize a function using modified Powell’s method. This method only uses function values, not derivatives.

- Parameters**
- func** : callable f(x,\*args)  
Objective function to be minimized.
  - x0** : ndarray  
Initial guess.
  - args** : tuple, optional  
Extra arguments passed to func.
  - callback** : callable, optional  
An optional user-supplied function, called after each iteration. Called as `callback(xk)`, where `xk` is the current parameter vector.
  - direc** : ndarray, optional  
Initial direction set.
  - xtol** : float, optional  
Line-search error tolerance.
  - ftol** : float, optional  
Relative error in `func(xopt)` acceptable for convergence.
  - maxiter** : int, optional  
Maximum number of iterations to perform.
  - maxfun** : int, optional  
Maximum number of function evaluations to make.
  - full\_output** : bool, optional

If True, `fopt`, `xi`, `direc`, `iter`, `funcalls`, and `warnflag` are returned.

**disp** : bool, optional  
If True, print convergence messages.

**retall** : bool, optional  
If True, return a list of the solution at each iteration.

**Returns** **xopt** : ndarray  
Parameter which minimizes *func*.

**fopt** : number  
Value of function at minimum: `fopt = func(xopt)`.

**direc** : ndarray  
Current direction set.

**iter** : int  
Number of iterations.

**funcalls** : int  
Number of function calls made.

**warnflag** : int  
*Integer warning flag:*  
1 : Maximum number of function evaluations. 2 : Maximum number of iterations.

**allvecs** : list  
List of solutions at each iteration.

**See also:**

**minimize** Interface to unconstrained minimization algorithms for multivariate functions. See the ‘Powell’ *method* in particular.

**Notes**

Uses a modification of Powell’s method to find the minimum of a function of N variables. Powell’s method is a conjugate direction method.

The algorithm has two loops. The outer loop merely iterates over the inner loop. The inner loop minimizes over each current direction in the direction set. At the end of the inner loop, if certain conditions are met, the direction that gave the largest decrease is dropped and replaced with the difference between the current estimated  $x$  and the estimated  $x$  from the beginning of the inner-loop.

The technical conditions for replacing the direction of greatest increase amount to checking that

- 1.No further gain can be made along the direction of greatest increase from that iteration.
- 2.The direction of greatest increase accounted for a large sufficient fraction of the decrease in the function value from that iteration of the inner loop.

**References**

Powell M.J.D. (1964) An efficient method for finding the minimum of a function of several variables without calculating derivatives, *Computer Journal*, 7 (2):155-162.

Press W., Teukolsky S.A., Vetterling W.T., and Flannery B.P.: *Numerical Recipes* (any edition), Cambridge University Press

**Examples**

```
>>> def f(x):
...     return x**2
```

```
>>> from scipy import optimize
```

```
>>> minimum = optimize.fmin_powell(f, -1)
Optimization terminated successfully.
      Current function value: 0.000000
      Iterations: 2
      Function evaluations: 18
>>> minimum
array(0.0)
```

```
scipy.optimize.fmin_cg(f, x0, fprime=None, args=(), gtol=1e-05, norm=inf,
                      epsilon=1.4901161193847656e-08, maxiter=None, full_output=0, disp=1,
                      retall=0, callback=None)
```

Minimize a function using a nonlinear conjugate gradient algorithm.

**Parameters**

- f** : callable,  $f(x, *args)$   
Objective function to be minimized. Here  $x$  must be a 1-D array of the variables that are to be changed in the search for a minimum, and  $args$  are the other (fixed) parameters of  $f$ .
- x0** : ndarray  
A user-supplied initial estimate of  $x_{opt}$ , the optimal value of  $x$ . It must be a 1-D array of values.
- fprime** : callable,  $fprime(x, *args)$ , optional  
A function that returns the gradient of  $f$  at  $x$ . Here  $x$  and  $args$  are as described above for  $f$ . The returned value must be a 1-D array. Defaults to None, in which case the gradient is approximated numerically (see *epsilon*, below).
- args** : tuple, optional  
Parameter values passed to  $f$  and  $fprime$ . Must be supplied whenever additional fixed parameters are needed to completely specify the functions  $f$  and  $fprime$ .
- gtol** : float, optional  
Stop when the norm of the gradient is less than  $gtol$ .
- norm** : float, optional  
Order to use for the norm of the gradient ( $-np.Inf$  is min,  $np.Inf$  is max).
- epsilon** : float or ndarray, optional  
Step size(s) to use when  $fprime$  is approximated numerically. Can be a scalar or a 1-D array. Defaults to  $\sqrt{eps}$ , with  $eps$  the floating point machine precision. Usually  $\sqrt{eps}$  is about  $1.5e-8$ .
- maxiter** : int, optional  
Maximum number of iterations to perform. Default is  $200 * \text{len}(x0)$ .
- full\_output** : bool, optional  
If True, return  $f_{opt}$ ,  $func\_calls$ ,  $grad\_calls$ , and  $warnflag$  in addition to  $x_{opt}$ . See the Returns section below for additional information on optional return values.
- disp** : bool, optional  
If True, return a convergence message, followed by  $x_{opt}$ .
- retall** : bool, optional  
If True, add to the returned values the results of each iteration.
- callback** : callable, optional  
An optional user-supplied function, called after each iteration. Called as  $callback(xk)$ , where  $xk$  is the current value of  $x0$ .

**Returns**

- xopt** : ndarray  
Parameters which minimize  $f$ , i.e.  $f(x_{opt}) == f_{opt}$ .
- fopt** : float, optional  
Minimum value found,  $f(x_{opt})$ . Only returned if *full\_output* is True.
- func\_calls** : int, optional

The number of function\_calls made. Only returned if *full\_output* is True.

**grad\_calls** : int, optional  
The number of gradient calls made. Only returned if *full\_output* is True.

**warnflag** : int, optional  
Integer value with warning status, only returned if *full\_output* is True.  
0 : Success.  
1 : The maximum number of iterations was exceeded.  
2 [Gradient and/or function calls were not changing. May indicate] that precision was lost, i.e., the routine did not converge.

**allvecs** : list of ndarray, optional  
List of arrays, containing the results at each iteration. Only returned if *retall* is True.

**See also:**

**minimize** common interface to all *scipy.optimize* algorithms for unconstrained and constrained minimization of multivariate functions. It provides an alternative way to call `fmin_cg`, by specifying `method='CG'`.

**Notes**

This conjugate gradient algorithm is based on that of Polak and Ribiere [R200].

Conjugate gradient methods tend to work better when:

1.  $f$  has a unique global minimizing point, and no local minima or other stationary points,
2.  $f$  is, at least locally, reasonably well approximated by a quadratic function of the variables,
3.  $f$  is continuous and has a continuous gradient,
4.  $f_{\text{prime}}$  is not too large, e.g., has a norm less than 1000,
5. The initial guess,  $x_0$ , is reasonably close to  $f$ 's global minimizing point,  $x_{\text{opt}}$ .

**References**

[R200]

**Examples**

Example 1: seek the minimum value of the expression  $a*u**2 + b*u*v + c*v**2 + d*u + e*v + f$  for given values of the parameters and an initial guess  $(u, v) = (0, 0)$ .

```
>>> args = (2, 3, 7, 8, 9, 10) # parameter values
>>> def f(x, *args):
...     u, v = x
...     a, b, c, d, e, f = args
...     return a*u**2 + b*u*v + c*v**2 + d*u + e*v + f
>>> def gradf(x, *args):
...     u, v = x
...     a, b, c, d, e, f = args
...     gu = 2*a*u + b*v + d # u-component of the gradient
...     gv = b*u + 2*c*v + e # v-component of the gradient
...     return np.asarray((gu, gv))
>>> x0 = np.asarray((0, 0)) # Initial guess.
>>> from scipy import optimize
>>> res1 = optimize.fmin_cg(f, x0, fprime=gradf, args=args)
Optimization terminated successfully.
Current function value: 1.617021
Iterations: 4
Function evaluations: 8
```

```

        Gradient evaluations: 8
>>> res1
array([-1.80851064, -0.25531915])
    
```

Example 2: solve the same problem using the `minimize` function. (This `myopts` dictionary shows all of the available options, although in practice only non-default values would be needed. The returned value will be a dictionary.)

```

>>> opts = {'maxiter' : None,      # default value.
...         'disp' : True,        # non-default value.
...         'gtol' : 1e-5,       # default value.
...         'norm' : np.inf,     # default value.
...         'eps' : 1.4901161193847656e-08} # default value.
>>> res2 = optimize.minimize(f, x0, jac=gradf, args=args,
...                          method='CG', options=opts)
Optimization terminated successfully.
    Current function value: 1.617021
    Iterations: 4
    Function evaluations: 8
    Gradient evaluations: 8
>>> res2.x # minimum found
array([-1.80851064, -0.25531915])
    
```

```

scipy.optimize.fmin_bfgs(f, x0, fprime=None, args=(), gtol=1e-05, norm=inf,
                        epsilon=1.4901161193847656e-08, maxiter=None, full_output=0,
                        disp=1, retall=0, callback=None)
    
```

Minimize a function using the BFGS algorithm.

**Parameters**

- f** : callable f(x,\*args)  
Objective function to be minimized.
- x0** : ndarray  
Initial guess.
- fprime** : callable f'(x,\*args), optional  
Gradient of f.
- args** : tuple, optional  
Extra arguments passed to f and fprime.
- gtol** : float, optional  
Gradient norm must be less than gtol before successful termination.
- norm** : float, optional  
Order of norm (Inf is max, -Inf is min)
- epsilon** : int or ndarray, optional  
If fprime is approximated, use this value for the step size.
- callback** : callable, optional  
An optional user-supplied function to call after each iteration. Called as callback(xk), where xk is the current parameter vector.
- maxiter** : int, optional  
Maximum number of iterations to perform.
- full\_output** : bool, optional  
If True, return foft, func\_calls, grad\_calls, and warnflag in addition to xopt.
- disp** : bool, optional  
Print convergence message if True.
- retall** : bool, optional  
Return a list of results at each iteration if True.

**Returns**

- xopt** : ndarray  
Parameters which minimize f, i.e. f(xopt) == foft.
- foft** : float

Minimum value.  
**gopt** : ndarray  
 Value of gradient at minimum,  $f'(x_{opt})$ , which should be near 0.  
**Bopt** : ndarray  
 Value of  $1/f''(x_{opt})$ , i.e. the inverse hessian matrix.  
**func\_calls** : int  
 Number of function\_calls made.  
**grad\_calls** : int  
 Number of gradient calls made.  
**warnflag** : integer  
 1 : Maximum number of iterations exceeded. 2 : Gradient and/or function calls not changing.  
**allvecs** : list  
*OptimizeResult* at each iteration. Only returned if `retall` is True.

**See also:**

**minimize** Interface to minimization algorithms for multivariate functions. See the ‘BFGS’ *method* in particular.

**Notes**

Optimize the function,  $f$ , whose gradient is given by  $fprime$  using the quasi-Newton method of Broyden, Fletcher, Goldfarb, and Shanno (BFGS)

**References**

Wright, and Nocedal ‘Numerical Optimization’, 1999, pg. 198.

```
scipy.optimize.fmin_ncg(f, x0, fprime, fhess_p=None, fhess=None, args=(), avextol=1e-05,
                        epsilon=1.4901161193847656e-08, maxiter=None, full_output=0, disp=1,
                        retall=0, callback=None)
```

Unconstrained minimization of a function using the Newton-CG method.

**Parameters**

- f** : callable  $f(x, *args)$   
Objective function to be minimized.
- x0** : ndarray  
Initial guess.
- fprime** : callable  $f'(x, *args)$   
Gradient of  $f$ .
- fhess\_p** : callable  $fhess_p(x, p, *args)$ , optional  
Function which computes the Hessian of  $f$  times an arbitrary vector,  $p$ .
- fhess** : callable  $fhess(x, *args)$ , optional  
Function to compute the Hessian matrix of  $f$ .
- args** : tuple, optional  
Extra arguments passed to  $f$ ,  $fprime$ ,  $fhess_p$ , and  $fhess$  (the same set of extra arguments is supplied to all of these functions).
- epsilon** : float or ndarray, optional  
If  $fhess$  is approximated, use this value for the step size.
- callback** : callable, optional  
An optional user-supplied function which is called after each iteration. Called as `callback(xk)`, where  $xk$  is the current parameter vector.
- avextol** : float, optional  
Convergence is assumed when the average relative error in the minimizer falls below this amount.
- maxiter** : int, optional  
Maximum number of iterations to perform.

**full\_output** : bool, optional  
 If True, return the optional outputs.

**disp** : bool, optional  
 If True, print convergence message.

**retall** : bool, optional  
 If True, return a list of results at each iteration.

**Returns**

**xopt** : ndarray  
 Parameters which minimize  $f$ , i.e.  $f(x_{opt}) == f_{opt}$ .

**fopt** : float  
 Value of the function at  $x_{opt}$ , i.e.  $f_{opt} = f(x_{opt})$ .

**fcalls** : int  
 Number of function calls made.

**gcalls** : int  
 Number of gradient calls made.

**hcalls** : int  
 Number of hessian calls made.

**warnflag** : int  
 Warnings generated by the algorithm. 1 : Maximum number of iterations exceeded.

**allvecs** : list  
 The result at each iteration, if `retall` is True (see below).

**See also:**

**minimize** Interface to minimization algorithms for multivariate functions. See the ‘Newton-CG’ *method* in particular.

**Notes**

Only one of `f_hess_p` or `f_hess` need to be given. If `f_hess` is provided, then `f_hess_p` will be ignored. If neither `f_hess` nor `f_hess_p` is provided, then the hessian product will be approximated using finite differences on `f_prime`. `f_hess_p` must compute the hessian times an arbitrary vector. If it is not given, finite-differences on `f_prime` are used to compute it.

Newton-CG methods are also called truncated Newton methods. This function differs from `scipy.optimize.fmin_tnc` because

1. `scipy.optimize.fmin_ncg` is written purely in python using `numpy` and `scipy` while `scipy.optimize.fmin_tnc` calls a C function.
2. `scipy.optimize.fmin_ncg` is only for unconstrained minimization while `scipy.optimize.fmin_tnc` is for unconstrained minimization or box constrained minimization. (Box constraints give lower and upper bounds for each variable separately.)

**References**

Wright & Nocedal, ‘Numerical Optimization’, 1999, pg. 140.

Constrained multivariate methods:

<code>fmin_l_bfgs_b(func, x0[, fprime, args, ...])</code>	Minimize a function <code>func</code> using the L-BFGS-B algorithm.
<code>fmin_tnc(func, x0[, fprime, args, ...])</code>	Minimize a function with variables subject to bounds, using gradient information in a truncated Newton algorithm.
<code>fmin_cobyla(func, x0, cons[, args, ...])</code>	Minimize a function using the Constrained Optimization BY Linear Approximation (COBYLA) method.
<code>fmin_slsqp(func, x0[, eqcons, f_eqcons, ...])</code>	Minimize a function using Sequential Least Squares Programming
<code>differential_evolution(func, bounds[, args, ...])</code>	Finds the global minimum of a multivariate function.

```
scipy.optimize.fmin_l_bfgs_b(func, x0, fprime=None, args=(), approx_grad=0, bounds=None,
                             m=10, factr=10000000.0, pgtol=1e-05, epsilon=1e-08, iprint=-
                             1, maxfun=15000, maxiter=15000, disp=None, callback=None,
                             maxls=20)
```

Minimize a function `func` using the L-BFGS-B algorithm.

**Parameters**

- func** : callable `f(x,*args)`  
Function to minimise.
- x0** : ndarray  
Initial guess.
- fprime** : callable `fprime(x,*args)`, optional  
The gradient of `func`. If `None`, then `func` returns the function value and the gradient (`f`, `g = func(x, *args)`), unless `approx_grad` is `True` in which case `func` returns only `f`.
- args** : sequence, optional  
Arguments to pass to `func` and `fprime`.
- approx\_grad** : bool, optional  
Whether to approximate the gradient numerically (in which case `func` returns only the function value).
- bounds** : list, optional  
(`min`, `max`) pairs for each element in `x`, defining the bounds on that parameter. Use `None` or `+inf` for one of `min` or `max` when there is no bound in that direction.
- m** : int, optional  
The maximum number of variable metric corrections used to define the limited memory matrix. (The limited memory BFGS method does not store the full hessian but uses this many terms in an approximation to it.)
- factr** : float, optional  
The iteration stops when  $(f^k - f^{k+1}) / \max\{|f^k|, |f^{k+1}|, 1\} \leq \text{factr} * \text{eps}$ , where `eps` is the machine precision, which is automatically generated by the code. Typical values for `factr` are: `1e12` for low accuracy; `1e7` for moderate accuracy; `10.0` for extremely high accuracy. See Notes for relationship to `ftol`, which is exposed (instead of `factr`) by the `scipy.optimize.minimize` interface to L-BFGS-B.
- pgtol** : float, optional  
The iteration will stop when  $\max\{|\text{proj } g_i| \mid i = 1, \dots, n\} \leq \text{pgtol}$  where `pg_i` is the *i*-th component of the projected gradient.
- epsilon** : float, optional  
Step size used when `approx_grad` is `True`, for numerically calculating the gradient
- iprint** : int, optional  
Controls the frequency of output. `iprint < 0` means no output; `iprint = 0` print only one line at the last iteration; `0 < iprint < 99` print also `f` and `|\text{proj } g|` every `iprint` iterations; `iprint = 99` print details of every iteration except `n`-vectors; `iprint = 100` print also the changes of active set and final `x`; `iprint > 100` print details of every iteration including `x` and `g`.
- disp** : int, optional  
If zero, then no output. If a positive number, then this over-rides `iprint` (i.e., `iprint` gets the value of `disp`).
- maxfun** : int, optional  
Maximum number of function evaluations.
- maxiter** : int, optional  
Maximum number of iterations.
- callback** : callable, optional  
Called after each iteration, as `callback(xk)`, where `xk` is the current parameter vector.
- maxls** : int, optional

**Returns**

- x** : array\_like  
Estimated position of the minimum.
- f** : float  
Value of *func* at the minimum.
- d** : dict  
Information dictionary.
  - d['warnflag'] is
    - 0 if converged,
    - 1 if too many function evaluations or too many iterations,
    - 2 if stopped for another reason, given in d['task']
  - d['grad'] is the gradient at the minimum (should be 0 ish)
  - d['funcalls'] is the number of function calls made.
  - d['nit'] is the number of iterations.

**See also:**

**minimize** Interface to minimization algorithms for multivariate functions. See the 'L-BFGS-B' *method* in particular. Note that the *ftol* option is made available via that interface, while *factr* is provided via this interface, where *factr* is the factor multiplying the default machine floating-point precision to arrive at *ftol*: `ftol = factr * numpy.finfo(float).eps`.

**Notes**

License of L-BFGS-B (FORTRAN code):

The version included here (in fortran code) is 3.0 (released April 25, 2011). It was written by Ciyou Zhu, Richard Byrd, and Jorge Nocedal <[nocedal@ece.nwu.edu](mailto:nocedal@ece.nwu.edu)>. It carries the following condition for use:

This software is freely available, but we expect that all publications describing work using this software, or all commercial products using it, quote at least one of the references given below. This software is released under the BSD License.

**References**

- R. H. Byrd, P. Lu and J. Nocedal. A Limited Memory Algorithm for Bound Constrained Optimization, (1995), SIAM Journal on Scientific and Statistical Computing, 16, 5, pp. 1190-1208.
- C. Zhu, R. H. Byrd and J. Nocedal. L-BFGS-B: Algorithm 778: L-BFGS-B, FORTRAN routines for large scale bound constrained optimization (1997), ACM Transactions on Mathematical Software, 23, 4, pp. 550 - 560.
- J.L. Morales and J. Nocedal. L-BFGS-B: Remark on Algorithm 778: L-BFGS-B, FORTRAN routines for large scale bound constrained optimization (2011), ACM Transactions on Mathematical Software, 38, 1.

`scipy.optimize.fmin_tnc`(*func*, *x0*, *fprime=None*, *args=()*, *approx\_grad=0*, *bounds=None*, *epsilon=1e-08*, *scale=None*, *offset=None*, *messages=15*, *maxCGit=-1*, *maxfun=None*, *eta=-1*, *stepmx=0*, *accuracy=0*, *fmin=0*, *ftol=-1*, *xtol=-1*, *pgtol=-1*, *rescale=-1*, *disp=None*, *callback=None*)

Minimize a function with variables subject to bounds, using gradient information in a truncated Newton algorithm. This method wraps a C implementation of the algorithm.

**Parameters**

- func** : callable `func(x, *args)`  
Function to minimize. Must do one of:
  - 1.Return f and g, where f is the value of the function and g its gradient (a list of floats).
  - 2.Return the function value but supply gradient function separately as *fprime*.
  - 3.Return the function value and set `approx_grad=True`.
 If the function returns None, the minimization is aborted.

**x0** : array\_like  
Initial estimate of minimum.

**fprime** : callable `fprime(x, *args)`, optional  
Gradient of *func*. If None, then either *func* must return the function value and the gradient (`f, g = func(x, *args)`) or *approx\_grad* must be True.

**args** : tuple, optional  
Arguments to pass to function.

**approx\_grad** : bool, optional  
If true, approximate the gradient numerically.

**bounds** : list, optional  
(min, max) pairs for each element in x0, defining the bounds on that parameter. Use None or +/-inf for one of min or max when there is no bound in that direction.

**epsilon** : float, optional  
Used if *approx\_grad* is True. The stepsize in a finite difference approximation for *fprime*.

**scale** : array\_like, optional  
Scaling factors to apply to each variable. If None, the factors are up-low for interval bounded variables and  $1+|x|$  for the others. Defaults to None.

**offset** : array\_like, optional  
Value to subtract from each variable. If None, the offsets are  $(\text{up}+\text{low})/2$  for interval bounded variables and *x* for the others.

**messages** : int, optional  
Bit mask used to select messages display during minimization values defined in the MSGS dict. Defaults to MGS\_ALL.

**disp** : int, optional  
Integer interface to messages. 0 = no message, 5 = all messages

**maxCGit** : int, optional  
Maximum number of hessian\*vector evaluations per main iteration. If `maxCGit == 0`, the direction chosen is -gradient if `maxCGit < 0`, `maxCGit` is set to  $\max(1, \min(50, n/2))$ . Defaults to -1.

**maxfun** : int, optional  
Maximum number of function evaluation. if None, `maxfun` is set to  $\max(100, 10*\text{len}(x0))$ . Defaults to None.

**eta** : float, optional  
Severity of the line search. if  $< 0$  or  $> 1$ , set to 0.25. Defaults to -1.

**stepmx** : float, optional  
Maximum step for the line search. May be increased during call. If too small, it will be set to 10.0. Defaults to 0.

**accuracy** : float, optional  
Relative precision for finite difference calculations. If  $\leq \text{machine\_precision}$ , set to  $\sqrt{\text{machine\_precision}}$ . Defaults to 0.

**fmin** : float, optional  
Minimum function value estimate. Defaults to 0.

**ftol** : float, optional  
Precision goal for the value of *f* in the stopping criterion. If `ftol < 0.0`, `ftol` is set to 0.0 defaults to -1.

**xtol** : float, optional  
Precision goal for the value of *x* in the stopping criterion (after applying *x* scaling factors). If `xtol < 0.0`, `xtol` is set to  $\sqrt{\text{machine\_precision}}$ . Defaults to -1.

**pgtol** : float, optional  
Precision goal for the value of the projected gradient in the stopping criterion (after applying *x* scaling factors). If `pgtol < 0.0`, `pgtol` is set to  $1e-2 * \sqrt{\text{accuracy}}$ . Setting it to 0.0 is not recommended. Defaults to -1.

**rescale** : float, optional

Scaling factor (in log10) used to trigger f value rescaling. If 0, rescale at each iteration. If a large value, never rescale. If < 0, rescale is set to 1.3.

**callback** : callable, optional

Called after each iteration, as `callback(xk)`, where `xk` is the current parameter vector.

**Returns**

**x** : ndarray

The solution.

**nfeval** : int

The number of function evaluations.

**rc** : int

Return code, see below

**See also:**

**minimize** Interface to minimization algorithms for multivariate functions. See the ‘TNC’ *method* in particular.

**Notes**

The underlying algorithm is truncated Newton, also called Newton Conjugate-Gradient. This method differs from `scipy.optimize.fmin_ncg` in that

- 1.It wraps a C implementation of the algorithm
- 2.It allows each variable to be given an upper and lower bound.

The algorithm incorporates the bound constraints by determining the descent direction as in an unconstrained truncated Newton, but never taking a step-size large enough to leave the space of feasible `x`'s. The algorithm keeps track of a set of currently active constraints, and ignores them when computing the minimum allowable step size. (The `x`'s associated with the active constraint are kept fixed.) If the maximum allowable step size is zero then a new constraint is added. At the end of each iteration one of the constraints may be deemed no longer active and removed. A constraint is considered no longer active is if it is currently active but the gradient for that variable points inward from the constraint. The specific constraint removed is the one associated with the variable of largest index whose constraint is no longer active.

Return codes are defined as follows:

```

-1 : Infeasible (lower bound > upper bound)
 0 : Local minimum reached (|pg| ~= 0)
 1 : Converged (|f_n-f_(n-1)| ~= 0)
 2 : Converged (|x_n-x_(n-1)| ~= 0)
 3 : Max. number of function evaluations reached
 4 : Linear search failed
 5 : All lower bounds are equal to the upper bounds
 6 : Unable to progress
 7 : User requested end of minimization
```

**References**

Wright S., Nocedal J. (2006), ‘Numerical Optimization’

Nash S.G. (1984), “Newton-Type Minimization Via the Lanczos Method”, SIAM Journal of Numerical Analysis 21, pp. 770-778

`scipy.optimize.fmin_cobyla` (*func*, *x0*, *cons*, *args=()*, *consargs=None*, *rhobeg=1.0*, *rhoend=0.0001*, *maxfun=1000*, *disp=None*, *catol=0.0002*)

Minimize a function using the Constrained Optimization BY Linear Approximation (COBYLA) method. This method wraps a FORTRAN implementation of the algorithm.

**Parameters**

**func** : callable

Function to minimize. In the form `func(x, *args)`.

**x0** : ndarray  
Initial guess.

**cons** : sequence  
Constraint functions; must all be  $\geq 0$  (a single function if only 1 constraint). Each function takes the parameters  $x$  as its first argument, and it can return either a single number or an array or list of numbers.

**args** : tuple, optional  
Extra arguments to pass to function.

**consargs** : tuple, optional  
Extra arguments to pass to constraint functions (default of None means use same extra arguments as those passed to func). Use () for no extra arguments.

**rhobeg** : float, optional  
Reasonable initial changes to the variables.

**rhoend** : float, optional  
Final accuracy in the optimization (not precisely guaranteed). This is a lower bound on the size of the trust region.

**disp** : {0, 1, 2, 3}, optional  
Controls the frequency of output; 0 implies no output.

**maxfun** : int, optional  
Maximum number of function evaluations.

**catol** : float, optional  
Absolute tolerance for constraint violations.

**Returns** **x** : ndarray  
The argument that minimises  $f$ .

**See also:**

**minimize** Interface to minimization algorithms for multivariate functions. See the ‘COBYLA’ *method* in particular.

**Notes**

This algorithm is based on linear approximations to the objective function and each constraint. We briefly describe the algorithm.

Suppose the function is being minimized over  $k$  variables. At the  $j$ th iteration the algorithm has  $k+1$  points  $v_1, \dots, v_{k+1}$ , an approximate solution  $x_j$ , and a radius  $RHO_j$ . (i.e. linear plus a constant) approximations to the objective function and constraint functions such that their function values agree with the linear approximation on the  $k+1$  points  $v_1, \dots, v_{k+1}$ . This gives a linear program to solve (where the linear approximations of the constraint functions are constrained to be non-negative).

However the linear approximations are likely only good approximations near the current simplex, so the linear program is given the further requirement that the solution, which will become  $x_{j+1}$ , must be within  $RHO_j$  from  $x_j$ .  $RHO_j$  only decreases, never increases. The initial  $RHO_j$  is `rhobeg` and the final  $RHO_j$  is `rhoend`. In this way COBYLA’s iterations behave like a trust region algorithm.

Additionally, the linear program may be inconsistent, or the approximation may give poor improvement. For details about how these issues are resolved, as well as how the points  $v_i$  are updated, refer to the source code or the references below.

**References**

Powell M.J.D. (1994), “A direct search optimization method that models the objective and constraint functions by linear interpolation.”, in *Advances in Optimization and Numerical Analysis*, eds. S. Gomez and J-P Hennart, Kluwer Academic (Dordrecht), pp. 51-67

Powell M.J.D. (1998), “Direct search algorithms for optimization calculations”, *Acta Numerica* 7, 287-336

Powell M.J.D. (2007), "A view of algorithms for optimization without derivatives", Cambridge University Technical Report DAMTP 2007/NA03

**Examples**

Minimize the objective function  $f(x,y) = x*y$  subject to the constraints  $x**2 + y**2 < 1$  and  $y > 0$ :

```
>>> def objective(x):
...     return x[0]*x[1]
...
>>> def constr1(x):
...     return 1 - (x[0]**2 + x[1]**2)
...
>>> def constr2(x):
...     return x[1]
...
>>> from scipy.optimize import fmin_cobyla
>>> fmin_cobyla(objective, [0.0, 0.1], [constr1, constr2], rhoend=1e-7)
array([-0.70710685,  0.70710671])
```

The exact solution is  $(-\sqrt{2}/2, \sqrt{2}/2)$ .

`scipy.optimize.fmin_slsqp` (*func*, *x0*, *eqcons*=(), *f\_eqcons*=None, *ieqcons*=(), *f\_ieqcons*=None, *bounds*=(), *fprime*=None, *fprime\_eqcons*=None, *fprime\_ieqcons*=None, *args*=(), *iter*=100, *acc*=1e-06, *iprint*=1, *disp*=None, *full\_output*=0, *epsilon*=1.4901161193847656e-08, *callback*=None)

Minimize a function using Sequential Least Squares Programming

Python interface function for the SLSQP Optimization subroutine originally implemented by Dieter Kraft.

- Parameters**
- func** : callable  $f(x,*args)$   
Objective function. Must return a scalar.
  - x0** : 1-D ndarray of float  
Initial guess for the independent variable(s).
  - eqcons** : list, optional  
A list of functions of length  $n$  such that  $eqcons[j](x,*args) == 0.0$  in a successfully optimized problem.
  - f\_eqcons** : callable  $f(x,*args)$ , optional  
Returns a 1-D array in which each element must equal 0.0 in a successfully optimized problem. If *f\_eqcons* is specified, *eqcons* is ignored.
  - ieqcons** : list, optional  
A list of functions of length  $n$  such that  $ieqcons[j](x,*args) >= 0.0$  in a successfully optimized problem.
  - f\_ieqcons** : callable  $f(x,*args)$ , optional  
Returns a 1-D ndarray in which each element must be greater or equal to 0.0 in a successfully optimized problem. If *f\_ieqcons* is specified, *ieqcons* is ignored.
  - bounds** : list, optional  
A list of tuples specifying the lower and upper bound for each independent variable [(x10, xu0),(x11, xu1),...] Infinite values will be interpreted as large floating values.
  - fprime** : callable  $f(x,*args)$ , optional  
A function that evaluates the partial derivatives of *func*.
  - fprime\_eqcons** : callable  $f(x,*args)$ , optional  
A function of the form  $f(x,*args)$  that returns the  $m$  by  $n$  array of equality constraint normals. If not provided, the normals will be approximated. The array returned by *fprime\_eqcons* should be sized as  $(\text{len}(eqcons), \text{len}(x0))$ .
  - fprime\_ieqcons** : callable  $f(x,*args)$ , optional

A function of the form  $f(x, *args)$  that returns the  $m$  by  $n$  array of inequality constraint normals. If not provided, the normals will be approximated. The array returned by `fprime_ieqcons` should be sized as `( len(ieqcons), len(x0) )`.

**args** : sequence, optional

Additional arguments passed to `func` and `fprime`.

**iter** : int, optional

The maximum number of iterations.

**acc** : float, optional

Requested accuracy.

**iprint** : int, optional

The verbosity of `fmin_slsqp` :

- `iprint <= 0` : Silent operation
- `iprint == 1` : Print summary upon completion (default)
- `iprint >= 2` : Print status of each iterate and summary

**disp** : int, optional

Over-rides the `iprint` interface (preferred).

**full\_output** : bool, optional

If False, return only the minimizer of `func` (default). Otherwise, output final objective function and summary information.

**epsilon** : float, optional

The step size for finite-difference derivative estimates.

**callback** : callable, optional

Called after each iteration, as `callback(x)`, where `x` is the current parameter vector.

#### Returns

**out** : ndarray of float

The final minimizer of `func`.

**fx** : ndarray of float, if `full_output` is true

The final value of the objective function.

**its** : int, if `full_output` is true

The number of iterations.

**imode** : int, if `full_output` is true

The exit mode from the optimizer (see below).

**smode** : string, if `full_output` is true

Message describing the exit mode from the optimizer.

#### See also:

**minimize** Interface to minimization algorithms for multivariate functions. See the ‘SLSQP’ *method* in particular.

#### Notes

Exit modes are defined as follows

```
-1 : Gradient evaluation required (g & a)
0 : Optimization terminated successfully.
1 : Function evaluation required (f & c)
2 : More equality constraints than independent variables
3 : More than 3*n iterations in LSQ subproblem
4 : Inequality constraints incompatible
5 : Singular matrix E in LSQ subproblem
6 : Singular matrix C in LSQ subproblem
7 : Rank-deficient equality constraint subproblem HFTI
8 : Positive directional derivative for linesearch
9 : Iteration limit exceeded
```

### Examples

Examples are given *in the tutorial*.

```
scipy.optimize.differential_evolution(func, bounds, args=(), strategy='best1bin', max-  
iter=1000, popsize=15, tol=0.01, mutation=(0.5,  
1), recombination=0.7, seed=None, callback=None,  
disp=False, polish=True, init='latinhypercube',  
atol=0)
```

Finds the global minimum of a multivariate function. Differential Evolution is stochastic in nature (does not use gradient methods) to find the minimum, and can search large areas of candidate space, but often requires larger numbers of function evaluations than conventional gradient based techniques.

The algorithm is due to Storn and Price [R194].

**Parameters** **func** : callable

The objective function to be minimized. Must be in the form  $f(x, *args)$ , where  $x$  is the argument in the form of a 1-D array and  $args$  is a tuple of any additional fixed parameters needed to completely specify the function.

**bounds** : sequence

Bounds for variables.  $(min, max)$  pairs for each element in  $x$ , defining the lower and upper bounds for the optimizing argument of *func*. It is required to have  $len(bounds) == len(x)$ .  $len(bounds)$  is used to determine the number of parameters in  $x$ .

**args** : tuple, optional

Any additional fixed parameters needed to completely specify the objective function.

**strategy** : str, optional

The differential evolution strategy to use. Should be one of:

- 'best1bin'
- 'best1exp'
- 'rand1exp'
- 'randtobest1exp'
- 'best2exp'
- 'rand2exp'
- 'randtobest1bin'
- 'best2bin'
- 'rand2bin'
- 'rand1bin'

The default is 'best1bin'.

**maxiter** : int, optional

The maximum number of generations over which the entire population is evolved. The maximum number of function evaluations (with no polishing) is:  $(maxiter + 1) * popsize * len(x)$

**popsize** : int, optional

A multiplier for setting the total population size. The population has  $popsize * len(x)$  individuals.

**tol** : float, optional

Relative tolerance for convergence, the solving stops when  $np.std(pop) \leq atol + tol * np.abs(np.mean(population_energies))$ , where  $atol$  and  $tol$  are the absolute and relative tolerance respectively.

**mutation** : float or tuple(float, float), optional

The mutation constant. In the literature this is also known as differential weight, being denoted by  $F$ . If specified as a float it should be in the range  $[0, 2]$ . If specified as a tuple  $(min, max)$  dithering is employed. Dithering randomly changes the mutation constant on a generation by generation basis. The mutation constant for that generation is taken from  $U[min, max)$ . Dithering can help speed convergence significantly.

Increasing the mutation constant increases the search radius, but will slow down convergence.

**recombination** : float, optional

The recombination constant, should be in the range [0, 1]. In the literature this is also known as the crossover probability, being denoted by CR. Increasing this value allows a larger number of mutants to progress into the next generation, but at the risk of population stability.

**seed** : int or `np.random.RandomState`, optional

If *seed* is not specified the `np.RandomState` singleton is used. If *seed* is an int, a new `np.random.RandomState` instance is used, seeded with *seed*. If *seed* is already a `np.random.RandomState` instance, then that `np.random.RandomState` instance is used. Specify *seed* for repeatable minimizations.

**disp** : bool, optional

Display status messages

**callback** : callable, `callback(xk, convergence=val)`, optional

A function to follow the progress of the minimization. *xk* is the current value of *x0*. *val* represents the fractional value of the population convergence. When *val* is greater than one the function halts. If callback returns `True`, then the minimization is halted (any polishing is still carried out).

**polish** : bool, optional

If `True` (default), then `scipy.optimize.minimize` with the *L-BFGS-B* method is used to polish the best population member at the end, which can improve the minimization slightly.

**init** : string, optional

Specify how the population initialization is performed. Should be one of:

- 'latinhypercube'
- 'random'

The default is 'latinhypercube'. Latin Hypercube sampling tries to maximize coverage of the available parameter space. 'random' initializes the population randomly - this has the drawback that clustering can occur, preventing the whole of parameter space being covered.

**atol** : float, optional

Absolute tolerance for convergence, the solving stops when `np.std(pop) <= atol + tol * np.abs(np.mean(population_energies))`, where *atol* and *tol* are the absolute and relative tolerance respectively.

### Returns

**res** : `OptimizeResult`

The optimization result represented as a `OptimizeResult` object. Important attributes are: *x* the solution array, *success* a Boolean flag indicating if the optimizer exited successfully and *message* which describes the cause of the termination. See `OptimizeResult` for a description of other attributes. If *polish* was employed, and a lower minimum was obtained by the polishing, then `OptimizeResult` also contains the *jac* attribute.

### Notes

Differential evolution is a stochastic population based method that is useful for global optimization problems. At each pass through the population the algorithm mutates each candidate solution by mixing with other candidate solutions to create a trial candidate. There are several strategies [R195] for creating trial candidates, which suit some problems more than others. The 'best1bin' strategy is a good starting point for many systems. In this strategy two members of the population are randomly chosen. Their difference is used to mutate the best member (the *best* in *best1bin*), *b<sub>0</sub>*, so far:

$$b' = b_0 + \text{mutation} * (\text{population}[\text{rand0}] - \text{population}[\text{rand1}])$$

A trial vector is then constructed. Starting with a randomly chosen 'i'th parameter the trial is sequentially filled (in modulo) with parameters from *b'* or the original candidate. The choice of whether to use *b'* or the original candidate is made with a binomial distribution (the 'bin' in 'best1bin') - a random number in [0, 1) is generated. If this number is less than the *recombination* constant then the parameter is loaded from *b'*, otherwise it is loaded from the original candidate. The final parameter is always loaded from *b'*. Once the trial candidate is built its fitness is assessed. If the trial is better than the original candidate then it takes its place. If it is also better than the best overall candidate it also replaces that. To improve your chances of finding a global minimum use higher *popsize* values, with higher *mutation* and (dithering), but lower *recombination* values. This has the effect of widening the search radius, but slowing convergence.

New in version 0.15.0.

### References

[R194], [R195], [R196]

### Examples

Let us consider the problem of minimizing the Rosenbrock function. This function is implemented in *rosen* in *scipy.optimize*.

```
>>> from scipy.optimize import rosen, differential_evolution
>>> bounds = [(0,2), (0, 2), (0, 2), (0, 2), (0, 2)]
>>> result = differential_evolution(rosen, bounds)
>>> result.x, result.fun
(array([1., 1., 1., 1., 1.]), 1.9216496320061384e-19)
```

Next find the minimum of the Ackley function ([http://en.wikipedia.org/wiki/Test\\_functions\\_for\\_optimization](http://en.wikipedia.org/wiki/Test_functions_for_optimization)).

```
>>> from scipy.optimize import differential_evolution
>>> import numpy as np
>>> def ackley(x):
...     arg1 = -0.2 * np.sqrt(0.5 * (x[0] ** 2 + x[1] ** 2))
...     arg2 = 0.5 * (np.cos(2. * np.pi * x[0]) + np.cos(2. * np.pi * x[1]))
...     return -20. * np.exp(arg1) - np.exp(arg2) + 20. + np.e
>>> bounds = [(-5, 5), (-5, 5)]
>>> result = differential_evolution(ackley, bounds)
>>> result.x, result.fun
(array([ 0.,  0.]), 4.4408920985006262e-16)
```

Univariate (scalar) minimization methods:

<i>fminbound</i> (func, x1, x2[, args, xtol, ...])	Bounded minimization for scalar functions.
<i>brent</i> (func[, args, brack, tol, full_output, ...])	Given a function of one-variable and a possible bracket, return the local minimum of the function isolated to a fractional precision of tol.
<i>golden</i> (func[, args, brack, tol, ...])	Return the minimum of a function of one variable using golden section method.

`scipy.optimize.fminbound` (*func*, *x1*, *x2*, *args*=(), *xtol*=1e-05, *maxfun*=500, *full\_output*=0, *disp*=1)  
Bounded minimization for scalar functions.

**Parameters**

- func** : callable f(x,\*args)  
Objective function to be minimized (must accept and return scalars).
- x1, x2** : float or array scalar  
The optimization bounds.
- args** : tuple, optional

Extra arguments passed to function.

**xtol** : float, optional  
The convergence tolerance.

**maxfun** : int, optional  
Maximum number of function evaluations allowed.

**full\_output** : bool, optional  
If True, return optional outputs.

**disp** : int, optional  
*If non-zero, print messages.*  
0 : no message printing. 1 : non-convergence notification messages only. 2 : print a message on convergence too. 3 : print iteration results.

**Returns**

**xopt** : ndarray  
Parameters (over given interval) which minimize the objective function.

**fval** : number  
The function value at the minimum point.

**ierr** : int  
An error flag (0 if converged, 1 if maximum number of function calls reached).

**numfunc** : int  
The number of function calls made.

**See also:**

**minimize\_scalar**

Interface to minimization algorithms for scalar univariate functions. See the ‘Bounded’ *method* in particular.

**Notes**

Finds a local minimizer of the scalar function *func* in the interval  $x_1 < x_{opt} < x_2$  using Brent’s method. (See *brent* for auto-bracketing).

**Examples**

*fminbound* finds the minimum of the function in the given range. The following examples illustrate the same

```
>>> def f(x):
...     return x**2
```

```
>>> from scipy import optimize
```

```
>>> minimum = optimize.fminbound(f, -1, 2)
>>> minimum
0.0
>>> minimum = optimize.fminbound(f, 1, 2)
>>> minimum
1.0000059608609866
```

`scipy.optimize.brent` (*func*, *args*=(), *brack*=None, *tol*=1.48e-08, *full\_output*=0, *maxiter*=500)

Given a function of one-variable and a possible bracket, return the local minimum of the function isolated to a fractional precision of *tol*.

**Parameters**

**func** : callable f(x,\*args)  
Objective function.

**args** : tuple, optional  
Additional arguments (if present).

**brack** : tuple, optional

Either a triple  $(x_a, x_b, x_c)$  where  $x_a < x_b < x_c$  and  $\text{func}(x_b) < \text{func}(x_a)$ ,  $\text{func}(x_c)$  or a pair  $(x_a, x_b)$  which are used as a starting interval for a downhill bracket search (see *bracket*). Providing the pair  $(x_a, x_b)$  does not always mean the obtained solution will satisfy  $x_a \leq x \leq x_b$ .

**tol** : float, optional  
 Stop if between iteration change is less than *tol*.  
**full\_output** : bool, optional  
 If True, return all output args (*xmin*, *fval*, *iter*, *funcalls*).  
**maxiter** : int, optional  
 Maximum number of iterations in solution.

**Returns**

**xmin** : ndarray  
 Optimum point.  
**fval** : float  
 Optimum value.  
**iter** : int  
 Number of iterations.  
**funcalls** : int  
 Number of objective function evaluations made.

**See also:**

**minimize\_scalar**

Interface to minimization algorithms for scalar univariate functions. See the ‘Brent’ *method* in particular.

**Notes**

Uses inverse parabolic interpolation when possible to speed up convergence of golden section method.

Does not ensure that the minimum lies in the range specified by *brack*. See *fminbound*.

**Examples**

We illustrate the behaviour of the function when *brack* is of size 2 and 3 respectively. In the case where *brack* is of the form  $(x_a, x_b)$ , we can see for the given values, the output need not necessarily lie in the range  $(x_a, x_b)$ .

```
>>> def f(x):
...     return x**2
```

```
>>> from scipy import optimize
```

```
>>> minimum = optimize.brent(f, brack=(1, 2))
>>> minimum
0.0
>>> minimum = optimize.brent(f, brack=(-1, 0.5, 2))
>>> minimum
-2.7755575615628914e-17
```

`scipy.optimize.golden` (*func*, *args=()*, *brack=None*, *tol=1.4901161193847656e-08*, *full\_output=0*, *maxiter=5000*)

Return the minimum of a function of one variable using golden section method.

Given a function of one variable and a possible bracketing interval, return the minimum of the function isolated to a fractional precision of *tol*.

**Parameters** **func** : callable `func(x,*args)`  
 Objective function to minimize.  
**args** : tuple, optional

Additional arguments (if present), passed to `func`.

**brack** : tuple, optional

Triple (a,b,c), where (a<b<c) and `func(b) < func(a),func(c)`. If bracket consists of two numbers (a, c), then they are assumed to be a starting interval for a downhill bracket search (see `bracket`); it doesn't always mean that obtained solution will satisfy `a<=x<=c`.

**tol** : float, optional

x tolerance stop criterion

**full\_output** : bool, optional

If True, return optional outputs.

**maxiter** : int

Maximum number of iterations to perform.

See also:

**minimize\_scalar**

Interface to minimization algorithms for scalar univariate functions. See the 'Golden' *method* in particular.

*Notes*

Uses analog of bisection method to decrease the bracketed interval.

*Examples*

We illustrate the behaviour of the function when `brack` is of size 2 and 3 respectively. In the case where `brack` is of the form (xa,xb), we can see for the given values, the output need not necessarily lie in the range (xa, xb).

```
>>> def f(x):
...     return x**2
```

```
>>> from scipy import optimize
```

```
>>> minimum = optimize.golden(f, brack=(1, 2))
>>> minimum
1.5717277788484873e-162
>>> minimum = optimize.golden(f, brack=(-1, 0.5, 2))
>>> minimum
-1.5717277788484873e-162
```

## Equation (Local) Minimizers

<code>leastsq(func, x0[, args, Dfun, full_output, ...])</code>	Minimize the sum of squares of a set of equations.
<code>least_squares(fun, x0[, jac, bounds, ...])</code>	Solve a nonlinear least-squares problem with bounds on the variables.
<code>nnls(A, b)</code>	Solve $\operatorname{argmin}_x   Ax - b  _2$ for $x \geq 0$ .
<code>lsq_linear(A, b[, bounds, method, tol, ...])</code>	Solve a linear least-squares problem with bounds on the variables.

`scipy.optimize.leastsq` (`func, x0, args=()`, `Dfun=None`, `full_output=0`, `col_deriv=0`, `ftol=1.49012e-08`, `xtol=1.49012e-08`, `gtol=0.0`, `maxfev=0`, `epsfcn=None`, `factor=100`, `diag=None`)

Minimize the sum of squares of a set of equations.

```
x = arg min(sum(func(y)**2,axis=0))
           y
```

- Parameters**
- func** : callable  
should take at least one (possibly length N vector) argument and returns M floating point numbers. It must not return NaNs or fitting might fail.
  - x0** : ndarray  
The starting estimate for the minimization.
  - args** : tuple, optional  
Any extra arguments to func are placed in this tuple.
  - Dfun** : callable, optional  
A function or method to compute the Jacobian of func with derivatives across the rows. If this is None, the Jacobian will be estimated.
  - full\_output** : bool, optional  
non-zero to return all optional outputs.
  - col\_deriv** : bool, optional  
non-zero to specify that the Jacobian function computes derivatives down the columns (faster, because there is no transpose operation).
  - ftol** : float, optional  
Relative error desired in the sum of squares.
  - xtol** : float, optional  
Relative error desired in the approximate solution.
  - gtol** : float, optional  
Orthogonality desired between the function vector and the columns of the Jacobian.
  - maxfev** : int, optional  
The maximum number of calls to the function. If *Dfun* is provided then the default *maxfev* is 100\*(N+1) where N is the number of elements in x0, otherwise the default *maxfev* is 200\*(N+1).
  - epsfcn** : float, optional  
A variable used in determining a suitable step length for the forward- difference approximation of the Jacobian (for Dfun=None). Normally the actual step length will be sqrt(epsfcn)\*x. If epsfcn is less than the machine precision, it is assumed that the relative errors are of the order of the machine precision.
  - factor** : float, optional  
A parameter determining the initial step bound (`factor * || diag * x||`). Should be in interval (0.1, 100).
  - diag** : sequence, optional  
N positive entries that serve as a scale factors for the variables.
- Returns**
- x** : ndarray  
The solution (or the result of the last iteration for an unsuccessful call).
  - cov\_x** : ndarray  
Uses the *fjac* and *ipvt* optional outputs to construct an estimate of the jacobian around the solution. None if a singular matrix encountered (indicates very flat curvature in some direction). This matrix must be multiplied by the residual variance to get the covariance of the parameter estimates – see `curve_fit`.
  - infodict** : dict  
a dictionary of optional outputs with the key s:
    - nfev**        The number of function calls
    - fvec**        The function evaluated at the output
    - fjac**        A permutation of the R matrix of a QR factorization of the final approximate Jacobian matrix, stored column wise. Together with *ipvt*, the covariance of the estimate can be approximated.

**ipvt** An integer array of length N which defines a permutation matrix, p, such that  $fjac * p = q * r$ , where r is upper triangular with diagonal elements of nonincreasing magnitude. Column j of p is column ipvt(j) of the identity matrix.

**qtf** The vector  $(\text{transpose}(q) * \text{fvec})$ .

**mesg** : str  
A string message giving information about the cause of failure.

**ier** : int  
An integer flag. If it is equal to 1, 2, 3 or 4, the solution was found. Otherwise, the solution was not found. In either case, the optional output variable 'mesg' gives more information.

### Notes

"leastsq" is a wrapper around MINPACK's lmdif and lmdcr algorithms.

cov\_x is a Jacobian approximation to the Hessian of the least squares objective function. This approximation assumes that the objective function is based on the difference between some observed target data (ydata) and a (non-linear) function of the parameters  $f(xdata, params)$

```
func(params) = ydata - f(xdata, params)
```

so that the objective function is

```
min sum((ydata - f(xdata, params))**2, axis=0)
params
```

```
scipy.optimize.least_squares(fun, x0, jac='2-point', bounds=(-inf, inf), method='trf',
                             ftol=1e-08, xtol=1e-08, gtol=1e-08, x_scale=1.0, loss='linear',
                             f_scale=1.0, diff_step=None, tr_solver=None, tr_options={},
                             jac_sparsity=None, max_nfev=None, verbose=0, args=(),
                             kwargs={})
```

Solve a nonlinear least-squares problem with bounds on the variables.

Given the residuals  $f(x)$  (an m-dimensional real function of n real variables) and the loss function  $\rho(s)$  (a scalar function), `least_squares` finds a local minimum of the cost function  $F(x)$ :

```
minimize F(x) = 0.5 * sum(rho(f_i(x)**2), i = 0, ..., m - 1)
subject to lb <= x <= ub
```

The purpose of the loss function  $\rho(s)$  is to reduce the influence of outliers on the solution.

**Parameters** **fun** : callable

Function which computes the vector of residuals, with the signature `fun(x, *args, **kwargs)`, i.e., the minimization proceeds with respect to its first argument. The argument `x` passed to this function is an ndarray of shape (n,) (never a scalar, even for  $n=1$ ). It must return a 1-d array\_like of shape (m,) or a scalar. If the argument `x` is complex or the function `fun` returns complex residuals, it must be wrapped in a real function of real arguments, as shown at the end of the Examples section.

**x0** : array\_like with shape (n,) or float

Initial guess on independent variables. If float, it will be treated as a 1-d array with one element.

**jac** : {'2-point', '3-point', 'cs', callable}, optional

Method of computing the Jacobian matrix (an m-by-n matrix, where element (i, j) is the partial derivative of  $f[i]$  with respect to  $x[j]$ ). The keywords select a finite difference scheme for numerical estimation. The scheme '3-point' is more accurate, but requires twice as much operations compared to '2-point' (default). The scheme 'cs'

uses complex steps, and while potentially the most accurate, it is applicable only when *fun* correctly handles complex inputs and can be analytically continued to the complex plane. Method 'lm' always uses the '2-point' scheme. If callable, it is used as `jac(x, *args, **kwargs)` and should return a good approximation (or the exact value) for the Jacobian as an `array_like` (`np.atleast_2d` is applied), a sparse matrix or a `scipy.sparse.linalg.LinearOperator`.

**bounds** : 2-tuple of `array_like`, optional

Lower and upper bounds on independent variables. Defaults to no bounds. Each array must match the size of `x0` or be a scalar, in the latter case a bound will be the same for all variables. Use `np.inf` with an appropriate sign to disable bounds on all or some variables.

**method** : {'trf', 'dogbox', 'lm'}, optional

Algorithm to perform minimization.

- 'trf' : Trust Region Reflective algorithm, particularly suitable for large sparse problems with bounds. Generally robust method.
- 'dogbox' : dogleg algorithm with rectangular trust regions, typical use case is small problems with bounds. Not recommended for problems with rank-deficient Jacobian.
- 'lm' : Levenberg-Marquardt algorithm as implemented in MINPACK. Doesn't handle bounds and sparse Jacobians. Usually the most efficient method for small unconstrained problems.

Default is 'trf'. See Notes for more information.

**ftol** : float, optional

Tolerance for termination by the change of the cost function. Default is 1e-8. The optimization process is stopped when  $dF < ftol * F$ , and there was an adequate agreement between a local quadratic model and the true model in the last step.

**xtol** : float, optional

Tolerance for termination by the change of the independent variables. Default is 1e-8. The exact condition depends on the *method* used:

- For 'trf' and 'dogbox':  $\text{norm}(dx) < xtol * (xtol + \text{norm}(x))$
- For 'lm':  $\Delta < xtol * \text{norm}(xs)$ , where  $\Delta$  is a trust-region radius and  $xs$  is the value of  $x$  scaled according to `x_scale` parameter (see below).

**gtol** : float, optional

Tolerance for termination by the norm of the gradient. Default is 1e-8. The exact condition depends on a *method* used:

- For 'trf':  $\text{norm}(g\_scaled, \text{ord}=\text{np.inf}) < gtol$ , where `g_scaled` is the value of the gradient scaled to account for the presence of the bounds [STIR].
- For 'dogbox':  $\text{norm}(g\_free, \text{ord}=\text{np.inf}) < gtol$ , where `g_free` is the gradient with respect to the variables which are not in the optimal state on the boundary.
- For 'lm': the maximum absolute value of the cosine of angles between columns of the Jacobian and the residual vector is less than `gtol`, or the residual vector is zero.

**x\_scale** : `array_like` or 'jac', optional

Characteristic scale of each variable. Setting `x_scale` is equivalent to reformulating the problem in scaled variables  $xs = x / x\_scale$ . An alternative view is that the size of a trust region along *j*-th dimension is proportional to `x_scale[j]`. Improved convergence may be achieved by setting `x_scale` such that a step of a given size along any of the scaled variables has a similar effect on the cost function. If set to 'jac', the scale is iteratively updated using the inverse norms of the columns of the Jacobian matrix (as described in [JJMore]).

**loss** : str or callable, optional

Determines the loss function. The following keyword values are allowed:

- 'linear' (default):  $\rho(z) = z$ . Gives a standard least-squares problem.

- ‘soft\_l1’:  $\rho(z) = 2 * ((1 + z)**0.5 - 1)$ . The smooth approximation of l1 (absolute value) loss. Usually a good choice for robust least squares.
- ‘huber’:  $\rho(z) = z$  if  $z \leq 1$  else  $2*z**0.5 - 1$ . Works similarly to ‘soft\_l1’.
- ‘cauchy’:  $\rho(z) = \ln(1 + z)$ . Severely weakens outliers influence, but may cause difficulties in optimization process.
- ‘arctan’:  $\rho(z) = \arctan(z)$ . Limits a maximum loss on a single residual, has properties similar to ‘cauchy’.

If callable, it must take a 1-d ndarray  $z=f**2$  and return an array\_like with shape (3, m) where row 0 contains function values, row 1 contains first derivatives and row 2 contains second derivatives. Method ‘lm’ supports only ‘linear’ loss.

**f\_scale** : float, optional

Value of soft margin between inlier and outlier residuals, default is 1.0. The loss function is evaluated as follows  $\rho_-(f**2) = C**2 * \rho(f**2 / C**2)$ , where C is *f\_scale*, and  $\rho$  is determined by *loss* parameter. This parameter has no effect with *loss*='linear', but for other *loss* values it is of crucial importance.

**max\_nfev** : None or int, optional

Maximum number of function evaluations before the termination. If None (default), the value is chosen automatically:

- For ‘trf’ and ‘dogbox’:  $100 * n$ .
- For ‘lm’:  $100 * n$  if *jac* is callable and  $100 * n * (n + 1)$  otherwise (because ‘lm’ counts function calls in Jacobian estimation).

**diff\_step** : None or array\_like, optional

Determines the relative step size for the finite difference approximation of the Jacobian. The actual step is computed as  $x * \text{diff\_step}$ . If None (default), then *diff\_step* is taken to be a conventional “optimal” power of machine epsilon for the finite difference scheme used [NR].

**tr\_solver** : {None, ‘exact’, ‘lsmr’}, optional

Method for solving trust-region subproblems, relevant only for ‘trf’ and ‘dogbox’ methods.

- ‘exact’ is suitable for not very large problems with dense Jacobian matrices. The computational complexity per iteration is comparable to a singular value decomposition of the Jacobian matrix.
- ‘lsmr’ is suitable for problems with sparse and large Jacobian matrices. It uses the iterative procedure `scipy.sparse.linalg.lsmr` for finding a solution of a linear least-squares problem and only requires matrix-vector product evaluations.

If None (default) the solver is chosen based on the type of Jacobian returned on the first iteration.

**tr\_options** : dict, optional

Keyword options passed to trust-region solver.

- tr\_solver*='exact': *tr\_options* are ignored.
- tr\_solver*='lsmr': options for `scipy.sparse.linalg.lsmr`. Additionally *method*='trf' supports ‘regularize’ option (bool, default is True) which adds a regularization term to the normal equation, which improves convergence if the Jacobian is rank-deficient [Byrd] (eq. 3.4).

**jac\_sparsity** : {None, array\_like, sparse matrix}, optional

Defines the sparsity structure of the Jacobian matrix for finite difference estimation, its shape must be (m, n). If the Jacobian has only few non-zero elements in *each* row, providing the sparsity structure will greatly speed up the computations [Curtis]. A zero entry means that a corresponding element in the Jacobian is identically zero. If provided, forces the use of ‘lsmr’ trust-region solver. If None (default) then dense differencing will be used. Has no effect for ‘lm’ method.

**verbose** : {0, 1, 2}, optional

Level of algorithm’s verbosity:

- 0 (default) : work silently.
- 1 : display a termination report.
- 2 : display progress during iterations (not supported by ‘lm’ method).

**args, kwargs** : tuple and dict, optional

Additional arguments passed to *fun* and *jac*. Both empty by default. The calling signature is *fun*(*x*, \**args*, \*\**kwargs*) and the same for *jac*.

**Returns** *OptimizeResult* with the following fields defined:

**x** : ndarray, shape (n,)

Solution found.

**cost** : float

Value of the cost function at the solution.

**fun** : ndarray, shape (m,)

Vector of residuals at the solution.

**jac** : ndarray, sparse matrix or LinearOperator, shape (m, n)

Modified Jacobian matrix at the solution, in the sense that  $J^T J$  is a Gauss-Newton approximation of the Hessian of the cost function. The type is the same as the one used by the algorithm.

**grad** : ndarray, shape (m,)

Gradient of the cost function at the solution.

**optimality** : float

First-order optimality measure. In unconstrained problems, it is always the uniform norm of the gradient. In constrained problems, it is the quantity which was compared with *gtol* during iterations.

**active\_mask** : ndarray of int, shape (n,)

Each component shows whether a corresponding constraint is active (that is, whether a variable is at the bound):

- 0 : a constraint is not active.
- 1 : a lower bound is active.
- 1 : an upper bound is active.

Might be somewhat arbitrary for ‘trf’ method as it generates a sequence of strictly feasible iterates and *active\_mask* is determined within a tolerance threshold.

**nfev** : int

Number of function evaluations done. Methods ‘trf’ and ‘dogbox’ do not count function calls for numerical Jacobian approximation, as opposed to ‘lm’ method.

**njev** : int or None

Number of Jacobian evaluations done. If numerical Jacobian approximation is used in ‘lm’ method, it is set to None.

**status** : int

The reason for algorithm termination:

- 1 : improper input parameters status returned from MINPACK.
- 0 : the maximum number of function evaluations is exceeded.
- 1 : *gtol* termination condition is satisfied.
- 2 : *ftol* termination condition is satisfied.
- 3 : *xtol* termination condition is satisfied.
- 4 : Both *ftol* and *xtol* termination conditions are satisfied.

**message** : str

Verbal description of the termination reason.

**success** : bool

True if one of the convergence criteria is satisfied (*status* > 0).

See also:

**leastsq** A legacy wrapper for the MINPACK implementation of the Levenberg-Marquadt algorithm.

**curve\_fit** Least-squares minimization applied to a curve fitting problem.

### Notes

Method ‘lm’ (Levenberg-Marquardt) calls a wrapper over least-squares algorithms implemented in MINPACK (lmdcr, lmdif). It runs the Levenberg-Marquardt algorithm formulated as a trust-region type algorithm. The implementation is based on paper [JJMore], it is very robust and efficient with a lot of smart tricks. It should be your first choice for unconstrained problems. Note that it doesn’t support bounds. Also it doesn’t work when  $m < n$ .

Method ‘trf’ (Trust Region Reflective) is motivated by the process of solving a system of equations, which constitute the first-order optimality condition for a bound-constrained minimization problem as formulated in [STIR]. The algorithm iteratively solves trust-region subproblems augmented by a special diagonal quadratic term and with trust-region shape determined by the distance from the bounds and the direction of the gradient. This enhancements help to avoid making steps directly into bounds and efficiently explore the whole space of variables. To further improve convergence, the algorithm considers search directions reflected from the bounds. To obey theoretical requirements, the algorithm keeps iterates strictly feasible. With dense Jacobians trust-region subproblems are solved by an exact method very similar to the one described in [JJMore] (and implemented in MINPACK). The difference from the MINPACK implementation is that a singular value decomposition of a Jacobian matrix is done once per iteration, instead of a QR decomposition and series of Givens rotation eliminations. For large sparse Jacobians a 2-d subspace approach of solving trust-region subproblems is used [STIR], [Byrd]. The subspace is spanned by a scaled gradient and an approximate Gauss-Newton solution delivered by `scipy.sparse.linalg.lsmr`. When no constraints are imposed the algorithm is very similar to MINPACK and has generally comparable performance. The algorithm works quite robust in unbounded and bounded problems, thus it is chosen as a default algorithm.

Method ‘dogbox’ operates in a trust-region framework, but considers rectangular trust regions as opposed to conventional ellipsoids [Voglis]. The intersection of a current trust region and initial bounds is again rectangular, so on each iteration a quadratic minimization problem subject to bound constraints is solved approximately by Powell’s dogleg method [NumOpt]. The required Gauss-Newton step can be computed exactly for dense Jacobians or approximately by `scipy.sparse.linalg.lsmr` for large sparse Jacobians. The algorithm is likely to exhibit slow convergence when the rank of Jacobian is less than the number of variables. The algorithm often outperforms ‘trf’ in bounded problems with a small number of variables.

Robust loss functions are implemented as described in [BA]. The idea is to modify a residual vector and a Jacobian matrix on each iteration such that computed gradient and Gauss-Newton Hessian approximation match the true gradient and Hessian approximation of the cost function. Then the algorithm proceeds in a normal way, i.e. robust loss functions are implemented as a simple wrapper over standard least-squares algorithms.

New in version 0.17.0.

### References

[STIR], [NR], [Byrd], [Curtis], [JJMore], [Voglis], [NumOpt], [BA]

### Examples

In this example we find a minimum of the Rosenbrock function without bounds on independent variables.

```
>>> def fun_rosenbrock(x):
...     return np.array([10 * (x[1] - x[0]**2), (1 - x[0])])
```

Notice that we only provide the vector of the residuals. The algorithm constructs the cost function as a sum of squares of the residuals, which gives the Rosenbrock function. The exact minimum is at  $x = [1.0, 1.0]$ .

```
>>> from scipy.optimize import least_squares
>>> x0_rosenbrock = np.array([2, 2])
>>> res_1 = least_squares(fun_rosenbrock, x0_rosenbrock)
>>> res_1.x
array([ 1.,  1.]
```

```
>>> res_1.cost
9.8669242910846867e-30
>>> res_1.optimality
8.8928864934219529e-14
```

We now constrain the variables, in such a way that the previous solution becomes infeasible. Specifically, we require that  $x[1] \geq 1.5$ , and  $x[0]$  left unconstrained. To this end, we specify the *bounds* parameter to *least\_squares* in the form `bounds=(-np.inf, 1.5], np.inf)`.

We also provide the analytic Jacobian:

```
>>> def jac_rosenbrock(x):
...     return np.array([
...         [-20 * x[0], 10],
...         [-1, 0]])
```

Putting this all together, we see that the new solution lies on the bound:

```
>>> res_2 = least_squares(fun_rosenbrock, x0_rosenbrock, jac_rosenbrock,
...                       bounds=(-np.inf, 1.5], np.inf))
>>> res_2.x
array([ 1.22437075,  1.5          ])
>>> res_2.cost
0.025213093946805685
>>> res_2.optimality
1.5885401433157753e-07
```

Now we solve a system of equations (i.e., the cost function should be zero at a minimum) for a Broyden tridiagonal vector-valued function of 100000 variables:

```
>>> def fun_broyden(x):
...     f = (3 - x) * x + 1
...     f[1:] -= x[:-1]
...     f[:-1] -= 2 * x[1:]
...     return f
```

The corresponding Jacobian matrix is sparse. We tell the algorithm to estimate it by finite differences and provide the sparsity structure of Jacobian to significantly speed up this process.

```
>>> from scipy.sparse import lil_matrix
>>> def sparsity_broyden(n):
...     sparsity = lil_matrix((n, n), dtype=int)
...     i = np.arange(n)
...     sparsity[i, i] = 1
...     i = np.arange(1, n)
...     sparsity[i, i - 1] = 1
...     i = np.arange(n - 1)
...     sparsity[i, i + 1] = 1
...     return sparsity
...
>>> n = 100000
>>> x0_broyden = -np.ones(n)
...
>>> res_3 = least_squares(fun_broyden, x0_broyden,
...                       jac_sparsity=sparsity_broyden(n))
>>> res_3.cost
4.5687069299604613e-23
```

```
>>> res_3.optimality
1.1650454296851518e-11
```

Let's also solve a curve fitting problem using robust loss function to take care of outliers in the data. Define the model function as  $y = a + b * \exp(c * t)$ , where  $t$  is a predictor variable,  $y$  is an observation and  $a$ ,  $b$ ,  $c$  are parameters to estimate.

First, define the function which generates the data with noise and outliers, define the model parameters, and generate data:

```
>>> def gen_data(t, a, b, c, noise=0, n_outliers=0, random_state=0):
...     y = a + b * np.exp(t * c)
...
...     rnd = np.random.RandomState(random_state)
...     error = noise * rnd.randn(t.size)
...     outliers = rnd.randint(0, t.size, n_outliers)
...     error[outliers] *= 10
...
...     return y + error
...
>>> a = 0.5
>>> b = 2.0
>>> c = -1
>>> t_min = 0
>>> t_max = 10
>>> n_points = 15
...
>>> t_train = np.linspace(t_min, t_max, n_points)
>>> y_train = gen_data(t_train, a, b, c, noise=0.1, n_outliers=3)
```

Define function for computing residuals and initial estimate of parameters.

```
>>> def fun(x, t, y):
...     return x[0] + x[1] * np.exp(x[2] * t) - y
...
>>> x0 = np.array([1.0, 1.0, 0.0])
```

Compute a standard least-squares solution:

```
>>> res_lsq = least_squares(fun, x0, args=(t_train, y_train))
```

Now compute two solutions with two different robust loss functions. The parameter *f\_scale* is set to 0.1, meaning that inlier residuals should not significantly exceed 0.1 (the noise level used).

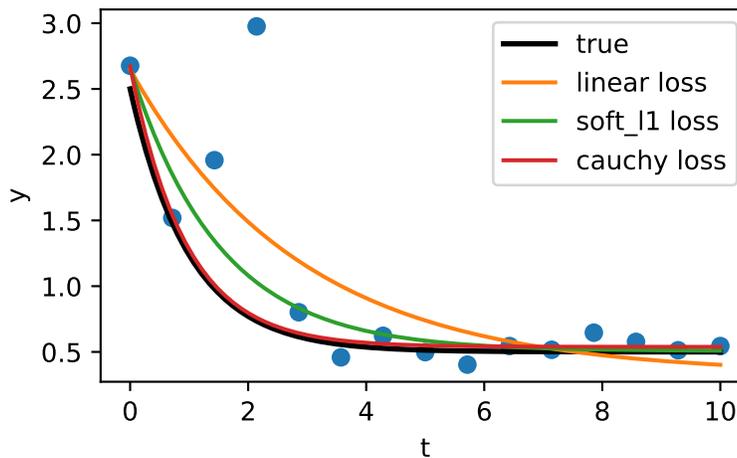
```
>>> res_soft_l1 = least_squares(fun, x0, loss='soft_l1', f_scale=0.1,
...                             args=(t_train, y_train))
>>> res_log = least_squares(fun, x0, loss='cauchy', f_scale=0.1,
...                          args=(t_train, y_train))
```

And finally plot all the curves. We see that by selecting an appropriate *loss* we can get estimates close to optimal even in the presence of strong outliers. But keep in mind that generally it is recommended to try 'soft\_l1' or 'huber' losses first (if at all necessary) as the other two options may cause difficulties in optimization process.

```
>>> t_test = np.linspace(t_min, t_max, n_points * 10)
>>> y_true = gen_data(t_test, a, b, c)
>>> y_lsq = gen_data(t_test, *res_lsq.x)
>>> y_soft_l1 = gen_data(t_test, *res_soft_l1.x)
>>> y_log = gen_data(t_test, *res_log.x)
```

```

...
>>> import matplotlib.pyplot as plt
>>> plt.plot(t_train, y_train, 'o')
>>> plt.plot(t_test, y_true, 'k', linewidth=2, label='true')
>>> plt.plot(t_test, y_lsq, label='linear loss')
>>> plt.plot(t_test, y_soft_l1, label='soft_l1 loss')
>>> plt.plot(t_test, y_log, label='cauchy loss')
>>> plt.xlabel("t")
>>> plt.ylabel("y")
>>> plt.legend()
>>> plt.show()
    
```



In the next example, we show how complex-valued residual functions of complex variables can be optimized with `least_squares()`. Consider the following function:

```

>>> def f(z):
...     return z - (0.5 + 0.5j)
    
```

We wrap it into a function of real variables that returns real residuals by simply handling the real and imaginary parts as independent variables:

```

>>> def f_wrap(x):
...     fx = f(x[0] + 1j*x[1])
...     return np.array([fx.real, fx.imag])
    
```

Thus, instead of the original  $m$ -dimensional complex function of  $n$  complex variables we optimize a  $2m$ -dimensional real function of  $2n$  real variables:

```

>>> from scipy.optimize import least_squares
>>> res_wrapped = least_squares(f_wrap, (0.1, 0.1), bounds=([0, 0], [1, 1]))
>>> z = res_wrapped.x[0] + res_wrapped.x[1]*1j
>>> z
(0.49999999999925893+0.49999999999925893j)
    
```

`scipy.optimize.nnls(A, b)`

Solve  $\operatorname{argmin}_x ||Ax - b||_2$  for  $x \geq 0$ . This is a wrapper for a FORTRAN non-negative least squares solver.

**Parameters** **A** : ndarray  
Matrix **A** as shown above.

**b** : ndarray  
Right-hand side vector.

**Returns** **x** : ndarray  
Solution vector.

**rnorm** : float  
The residual,  $\|Ax - b\|_2$ .

**Notes**

The FORTRAN code was published in the book below. The algorithm is an active set method. It solves the KKT (Karush-Kuhn-Tucker) conditions for the non-negative least squares problem.

**References**

Lawson C., Hanson R.J., (1987) Solving Least Squares Problems, SIAM

`scipy.optimize.lsq_linear` (*A*, *b*, *bounds*=(-inf, inf), *method*='trf', *tol*=1e-10, *lsq\_solver*=None, *lsnr\_tol*=None, *max\_iter*=None, *verbose*=0)

Solve a linear least-squares problem with bounds on the variables.

Given a *m*-by-*n* design matrix *A* and a target vector *b* with *m* elements, *lsq\_linear* solves the following optimization problem:

```
minimize 0.5 * ||A x - b||**2
subject to lb <= x <= ub
```

This optimization problem is convex, hence a found minimum (if iterations have converged) is guaranteed to be global.

**Parameters** **A** : array\_like, sparse matrix of LinearOperator, shape (*m*, *n*)  
Design matrix. Can be `scipy.sparse.linalg.LinearOperator`.

**b** : array\_like, shape (*m*,)  
Target vector.

**bounds** : 2-tuple of array\_like, optional  
Lower and upper bounds on independent variables. Defaults to no bounds. Each array must have shape (*n*,) or be a scalar, in the latter case a bound will be the same for all variables. Use `np.inf` with an appropriate sign to disable bounds on all or some variables.

**method** : 'trf' or 'bvls', optional  
Method to perform minimization.

- 'trf' : Trust Region Reflective algorithm adapted for a linear least-squares problem. This is an interior-point-like method and the required number of iterations is weakly correlated with the number of variables.
- 'bvls' : Bounded-Variable Least-Squares algorithm. This is an active set method, which requires the number of iterations comparable to the number of variables. Can't be used when *A* is sparse or LinearOperator.

Default is 'trf'.

**tol** : float, optional  
Tolerance parameter. The algorithm terminates if a relative change of the cost function is less than *tol* on the last iteration. Additionally the first-order optimality measure is considered:

- `method='trf'` terminates if the uniform norm of the gradient, scaled to account for the presence of the bounds, is less than *tol*.
- `method='bvls'` terminates if Karush-Kuhn-Tucker conditions are satisfied within *tol* tolerance.

**lsq\_solver** : {None, 'exact', 'lsmr'}, optional  
 Method of solving unbounded least-squares problems throughout iterations:

- 'exact' : Use dense QR or SVD decomposition approach. Can't be used when *A* is sparse or `LinearOperator`.
- 'lsmr' : Use `scipy.sparse.linalg.lsmr` iterative procedure which requires only matrix-vector product evaluations. Can't be used with `method='bvls'`.

If None (default) the solver is chosen based on type of *A*.

**lsmr\_tol** : None, float or 'auto', optional  
 Tolerance parameters 'atol' and 'btol' for `scipy.sparse.linalg.lsmr` If None (default), it is set to  $1e-2 * tol$ . If 'auto', the tolerance will be adjusted based on the optimality of the current iterate, which can speed up the optimization process, but is not always reliable.

**max\_iter** : None or int, optional  
 Maximum number of iterations before termination. If None (default), it is set to 100 for `method='trf'` or to the number of variables for `method='bvls'` (not counting iterations for 'bvls' initialization).

**verbose** : {0, 1, 2}, optional  
 Level of algorithm's verbosity:

- 0 : work silently (default).
- 1 : display a termination report.
- 2 : display progress during iterations.

**Returns** `OptimizeResult` with the following fields defined:

**x** : ndarray, shape (n,)
   
Solution found.

**cost** : float
   
Value of the cost function at the solution.

**fun** : ndarray, shape (m,)
   
Vector of residuals at the solution.

**optimality** : float
   
First-order optimality measure. The exact meaning depends on *method*, refer to the description of *tol* parameter.

**active\_mask** : ndarray of int, shape (n,)
   
Each component shows whether a corresponding constraint is active (that is, whether a variable is at the bound):

- 0 : a constraint is not active.
- -1 : a lower bound is active.
- 1 : an upper bound is active.

Might be somewhat arbitrary for the *trf* method as it generates a sequence of strictly feasible iterates and `active_mask` is determined within a tolerance threshold.

**nit** : int
   
Number of iterations. Zero if the unconstrained solution is optimal.

**status** : int
   
Reason for algorithm termination:

- -1 : the algorithm was not able to make progress on the last iteration.
- 0 : the maximum number of iterations is exceeded.
- 1 : the first-order optimality measure is less than *tol*.
- 2 : the relative change of the cost function is less than *tol*.
- 3 : the unconstrained solution is optimal.

**message** : str
   
Verbal description of the termination reason.

**success** : bool
   
True if one of the convergence criteria is satisfied (*status* > 0).

See also:

**nnls** Linear least squares with non-negativity constraint.

**least\_squares**  
Nonlinear least squares with bounds on the variables.

### Notes

The algorithm first computes the unconstrained least-squares solution by `numpy.linalg.lstsq` or `scipy.sparse.linalg.lsmr` depending on `lsq_solver`. This solution is returned as optimal if it lies within the bounds.

Method 'trf' runs the adaptation of the algorithm described in [STIR] for a linear least-squares problem. The iterations are essentially the same as in the nonlinear least-squares algorithm, but as the quadratic function model is always accurate, we don't need to track or modify the radius of a trust region. The line search (backtracking) is used as a safety net when a selected step does not decrease the cost function. Read more detailed description of the algorithm in `scipy.optimize.least_squares`.

Method 'bvls' runs a Python implementation of the algorithm described in [BVLS]. The algorithm maintains active and free sets of variables, on each iteration chooses a new variable to move from the active set to the free set and then solves the unconstrained least-squares problem on free variables. This algorithm is guaranteed to give an accurate solution eventually, but may require up to  $n$  iterations for a problem with  $n$  variables. Additionally, an ad-hoc initialization procedure is implemented, that determines which variables to set free or active initially. It takes some number of iterations before actual BVLS starts, but can significantly reduce the number of further iterations.

### References

[STIR], [BVLS]

### Examples

In this example a problem with a large sparse matrix and bounds on the variables is solved.

```
>>> from scipy.sparse import rand
>>> from scipy.optimize import lsq_linear
...
>>> np.random.seed(0)
...
>>> m = 20000
>>> n = 10000
...
>>> A = rand(m, n, density=1e-4)
>>> b = np.random.randn(m)
...
>>> lb = np.random.randn(n)
>>> ub = lb + 1
...
>>> res = lsq_linear(A, b, bounds=(lb, ub), lsmr_tol='auto', verbose=1)
# may vary
The relative change of the cost function is less than `tol`.
Number of iterations 16, initial cost 1.5039e+04, final cost 1.1112e+04,
first-order optimality 4.66e-08.
```

## Global Optimization

<code>basinhopping(func, x0[, niter, T, stepsize, ...])</code>	Find the global minimum of a function using the basin-hopping algorithm
<code>brute(func, ranges[, args, Ns, full_output, ...])</code>	Minimize a function over a given range by brute force.
<code>differential_evolution(func, bounds[, args, ...])</code>	Finds the global minimum of a multivariate function.

`scipy.optimize.basinhopping` (*func*, *x0*, *niter*=100, *T*=1.0, *stepsize*=0.5, *minimizer\_kwargs*=None, *take\_step*=None, *accept\_test*=None, *callback*=None, *interval*=50, *disp*=False, *niter\_success*=None, *seed*=None)

Find the global minimum of a function using the basin-hopping algorithm

**Parameters**

- func** : callable `f(x, *args)`  
Function to be optimized. `args` can be passed as an optional item in the dict `minimizer_kwargs`
- x0** : ndarray  
Initial guess.
- niter** : integer, optional  
The number of basin hopping iterations
- T** : float, optional  
The “temperature” parameter for the accept or reject criterion. Higher “temperatures” mean that larger jumps in function value will be accepted. For best results `T` should be comparable to the separation (in function value) between local minima.
- stepsize** : float, optional  
initial step size for use in the random displacement.
- minimizer\_kwargs** : dict, optional  
Extra keyword arguments to be passed to the minimizer `scipy.optimize.minimize()` Some important options could be:
  - method** [str] The minimization method (e.g. "L-BFGS-B")
  - args** [tuple] Extra arguments passed to the objective function (`func`) and its derivatives (Jacobian, Hessian).
- take\_step** : callable `take_step(x)`, optional  
Replace the default step taking routine with this routine. The default step taking routine is a random displacement of the coordinates, but other step taking algorithms may be better for some systems. `take_step` can optionally have the attribute `take_step.stepsize`. If this attribute exists, then `basinhopping` will adjust `take_step.stepsize` in order to try to optimize the global minimum search.
- accept\_test** : callable, `accept_test(f_new=f_new, x_new=x_new, f_old=fold, x_old=x_old)`, optional  
Define a test which will be used to judge whether or not to accept the step. This will be used in addition to the Metropolis test based on “temperature” `T`. The acceptable return values are `True`, `False`, or "force accept". If any of the tests return `False` then the step is rejected. If the latter, then this will override any other tests in order to accept the step. This can be used, for example, to forcefully escape from a local minimum that `basinhopping` is trapped in.
- callback** : callable, `callback(x, f, accept)`, optional  
A callback function which will be called for all minima found. `x` and `f` are the coordinates and function value of the trial minimum, and `accept` is whether or not that minimum was accepted. This can be used, for example, to save the lowest `N` minima found. Also, `callback` can be used to specify a user defined stop criterion by optionally returning `True` to stop the `basinhopping` routine.
- interval** : integer, optional  
interval for how often to update the `stepsize`
- disp** : bool, optional  
Set to `True` to print status messages

**niter\_success** : integer, optional

Stop the run if the global minimum candidate remains the same for this number of iterations.

**seed** : int or *np.random.RandomState*, optional

If *seed* is not specified the *np.RandomState* singleton is used. If *seed* is an int, a new *np.random.RandomState* instance is used, seeded with *seed*. If *seed* is already a *np.random.RandomState* instance, then that *np.random.RandomState* instance is used. Specify *seed* for repeatable minimizations. The random numbers generated with this seed only affect the default Metropolis *accept\_test* and the default *take\_step*. If you supply your own *take\_step* and *accept\_test*, and these functions use random number generation, then those functions are responsible for the state of their random number generator.

**Returns** **res** : *OptimizeResult*

The optimization result represented as a *OptimizeResult* object. Important attributes are: *x* the solution array, *fun* the value of the function at the solution, and *message* which describes the cause of the termination. The *OptimizeResult* object returned by the selected minimizer at the lowest minimum is also contained within this object and can be accessed through the *lowest\_optimization\_result* attribute. See *OptimizeResult* for a description of other attributes.

**See also:**

**minimize** The local minimization function called once for each basin-hopping step. *minimizer\_kwargs* is passed to this routine.

**Notes**

Basin-hopping is a stochastic algorithm which attempts to find the global minimum of a smooth scalar function of one or more variables [R188] [R189] [R190] [R191]. The algorithm in its current form was described by David Wales and Jonathan Doye [R189] <http://www-wales.ch.cam.ac.uk/>.

The algorithm is iterative with each cycle composed of the following features

- 1.random perturbation of the coordinates
- 2.local minimization
- 3.accept or reject the new coordinates based on the minimized function value

The acceptance test used here is the Metropolis criterion of standard Monte Carlo algorithms, although there are many other possibilities [R190].

This global minimization method has been shown to be extremely efficient for a wide variety of problems in physics and chemistry. It is particularly useful when the function has many minima separated by large barriers. See the Cambridge Cluster Database <http://www-wales.ch.cam.ac.uk/CCD.html> for databases of molecular systems that have been optimized primarily using basin-hopping. This database includes minimization problems exceeding 300 degrees of freedom.

See the free software program GMIN (<http://www-wales.ch.cam.ac.uk/GMIN>) for a Fortran implementation of basin-hopping. This implementation has many different variations of the procedure described above, including more advanced step taking algorithms and alternate acceptance criterion.

For stochastic global optimization there is no way to determine if the true global minimum has actually been found. Instead, as a consistency check, the algorithm can be run from a number of different random starting points to ensure the lowest minimum found in each example has converged to the global minimum. For this reason *basinhopping* will by default simply run for the number of iterations *niter* and return the lowest minimum found. It is left to the user to ensure that this is in fact the global minimum.

Choosing `stepsize`: This is a crucial parameter in `basinhopping` and depends on the problem being solved. Ideally it should be comparable to the typical separation between local minima of the function being optimized. `basinhopping` will, by default, adjust `stepsize` to find an optimal value, but this may take many iterations. You will get quicker results if you set a sensible value for `stepsize`.

Choosing `T`: The parameter `T` is the temperature used in the metropolis criterion. Basinhopping steps are accepted with probability 1 if `func(xnew) < func(xold)`, or otherwise with probability:

$$\exp(-(\text{func}(\text{xnew}) - \text{func}(\text{xold})) / T)$$

So, for best results, `T` should be comparable to the typical difference in function values between local minima. New in version 0.12.0.

### References

[R188], [R189], [R190], [R191]

### Examples

The following example is a one-dimensional minimization problem, with many local minima superimposed on a parabola.

```
>>> from scipy.optimize import basinhopping
>>> func = lambda x: np.cos(14.5 * x - 0.3) + (x + 0.2) * x
>>> x0=[1.]
```

`Basinhopping`, internally, uses a local minimization algorithm. We will use the parameter `minimizer_kwargs` to tell `basinhopping` which algorithm to use and how to set up that minimizer. This parameter will be passed to `scipy.optimize.minimize()`.

```
>>> minimizer_kwargs = {"method": "BFGS"}
>>> ret = basinhopping(func, x0, minimizer_kwargs=minimizer_kwargs,
...                   niter=200)
>>> print("global minimum: x = %.4f, f(x0) = %.4f" % (ret.x, ret.fun))
global minimum: x = -0.1951, f(x0) = -1.0009
```

Next consider a two-dimensional minimization problem. Also, this time we will use gradient information to significantly speed up the search.

```
>>> def func2d(x):
...     f = np.cos(14.5 * x[0] - 0.3) + (x[1] + 0.2) * x[1] + (x[0] +
...                                                         0.2) * x[0]
...     df = np.zeros(2)
...     df[0] = -14.5 * np.sin(14.5 * x[0] - 0.3) + 2. * x[0] + 0.2
...     df[1] = 2. * x[1] + 0.2
...     return f, df
```

We'll also use a different local minimization algorithm. Also we must tell the minimizer that our function returns both energy and gradient (jacobian)

```
>>> minimizer_kwargs = {"method": "L-BFGS-B", "jac": True}
>>> x0 = [1.0, 1.0]
>>> ret = basinhopping(func2d, x0, minimizer_kwargs=minimizer_kwargs,
...                   niter=200)
>>> print("global minimum: x = [%.4f, %.4f], f(x0) = %.4f" % (ret.x[0],
...                                                         ret.x[1],
...                                                         ret.fun))
global minimum: x = [-0.1951, -0.1000], f(x0) = -1.0109
```

Here is an example using a custom step taking routine. Imagine you want the first coordinate to take larger steps than the rest of the coordinates. This can be implemented like so:

```
>>> class MyTakeStep(object):
...     def __init__(self, stepsize=0.5):
...         self.stepsize = stepsize
...     def __call__(self, x):
...         s = self.stepsize
...         x[0] += np.random.uniform(-2.*s, 2.*s)
...         x[1:] += np.random.uniform(-s, s, x[1:].shape)
...         return x
```

Since `MyTakeStep.stepsize` exists `basinhopping` will adjust the magnitude of `stepsize` to optimize the search. We'll use the same 2-D function as before

```
>>> mytakestep = MyTakeStep()
>>> ret = basinhopping(func2d, x0, minimizer_kwargs=minimizer_kwargs,
...                   niter=200, take_step=mytakestep)
>>> print("global minimum: x = [%.4f, %.4f], f(x0) = %.4f" % (ret.x[0],
...                                                         ret.x[1],
...                                                         ret.fun))
global minimum: x = [-0.1951, -0.1000], f(x0) = -1.0109
```

Now let's do an example using a custom callback function which prints the value of every minimum found

```
>>> def print_fun(x, f, accepted):
...     print("at minimum %.4f accepted %d" % (f, int(accepted)))
```

We'll run it for only 10 `basinhopping` steps this time.

```
>>> np.random.seed(1)
>>> ret = basinhopping(func2d, x0, minimizer_kwargs=minimizer_kwargs,
...                   niter=10, callback=print_fun)
at minimum 0.4159 accepted 1
at minimum -0.9073 accepted 1
at minimum -0.1021 accepted 1
at minimum -0.1021 accepted 1
at minimum 0.9102 accepted 1
at minimum 0.9102 accepted 1
at minimum 2.2945 accepted 0
at minimum -0.1021 accepted 1
at minimum -1.0109 accepted 1
at minimum -1.0109 accepted 1
```

The minimum at `-1.0109` is actually the global minimum, found already on the 8th iteration.

Now let's implement bounds on the problem using a custom `accept_test`:

```
>>> class MyBounds(object):
...     def __init__(self, xmax=[1.1,1.1], xmin=[-1.1,-1.1]):
...         self.xmax = np.array(xmax)
...         self.xmin = np.array(xmin)
...     def __call__(self, **kwargs):
...         x = kwargs["x_new"]
...         tmax = bool(np.all(x <= self.xmax))
...         tmin = bool(np.all(x >= self.xmin))
...         return tmax and tmin
```

```
>>> mybounds = MyBounds()
>>> ret = basinhopping(func2d, x0, minimizer_kwargs=minimizer_kwargs,
...                   niter=10, accept_test=mybounds)
```

`scipy.optimize.brute` (*func*, *ranges*, *args=()*, *Ns=20*, *full\_output=0*, *finish=<function fmin>*, *disp=False*)

Minimize a function over a given range by brute force.

Uses the “brute force” method, i.e. computes the function’s value at each point of a multidimensional grid of points, to find the global minimum of the function.

The function is evaluated everywhere in the range with the datatype of the first call to the function, as enforced by the `vectorize` NumPy function. The value and type of the function evaluation returned when `full_output=True` are affected in addition by the `finish` argument (see Notes).

**Parameters** **func** : callable

The objective function to be minimized. Must be in the form `f(x, *args)`, where `x` is the argument in the form of a 1-D array and `args` is a tuple of any additional fixed parameters needed to completely specify the function.

**ranges** : tuple

Each component of the `ranges` tuple must be either a “slice object” or a range tuple of the form `(low, high)`. The program uses these to create the grid of points on which the objective function will be computed. See *Note 2* for more detail.

**args** : tuple, optional

Any additional fixed parameters needed to completely specify the function.

**Ns** : int, optional

Number of grid points along the axes, if not otherwise specified. See *Note 2*.

**full\_output** : bool, optional

If True, return the evaluation grid and the objective function’s values on it.

**finish** : callable, optional

An optimization function that is called with the result of brute force minimization as initial guess. `finish` should take `func` and the initial guess as positional arguments, and take `args` as keyword arguments. It may additionally take `full_output` and/or `disp` as keyword arguments. Use None if no “polishing” function is to be used. See Notes for more details.

**disp** : bool, optional

Set to True to print convergence messages.

**Returns** **x0** : ndarray

A 1-D array containing the coordinates of a point at which the objective function had its minimum value. (See *Note 1* for which point is returned.)

**fval** : float

Function value at the point `x0`. (Returned when `full_output` is True.)

**grid** : tuple

Representation of the evaluation grid. It has the same length as `x0`. (Returned when `full_output` is True.)

**Jout** : ndarray

Function values at each point of the evaluation grid, i.e., `Jout = func(*grid)`. (Returned when `full_output` is True.)

**See also:**

`basinhopping`, `differential_evolution`

**Notes**

*Note 1:* The program finds the gridpoint at which the lowest value of the objective function occurs. If `finish` is None, that is the point returned. When the global minimum occurs within (or not very far outside) the grid’s

boundaries, and the grid is fine enough, that point will be in the neighborhood of the global minimum.

However, users often employ some other optimization program to “polish” the gridpoint values, *i.e.*, to seek a more precise (local) minimum near *brute*’s best gridpoint. The *brute* function’s *finish* option provides a convenient way to do that. Any polishing program used must take *brute*’s output as its initial guess as a positional argument, and take *brute*’s input values for *args* as keyword arguments, otherwise an error will be raised. It may additionally take *full\_output* and/or *disp* as keyword arguments.

*brute* assumes that the *finish* function returns either an *OptimizeResult* object or a tuple in the form:  $(x_{\min}, J_{\min}, \dots, \text{statuscode})$ , where  $x_{\min}$  is the minimizing value of the argument,  $J_{\min}$  is the minimum value of the objective function, “...” may be some other returned values (which are not used by *brute*), and *statuscode* is the status code of the *finish* program.

Note that when *finish* is not *None*, the values returned are those of the *finish* program, *not* the gridpoint ones. Consequently, while *brute* confines its search to the input grid points, the *finish* program’s results usually will not coincide with any gridpoint, and may fall outside the grid’s boundary. Thus, if a minimum only needs to be found over the provided grid points, make sure to pass in *finish=None*.

*Note 2:* The grid of points is a `numpy.mgrid` object. For *brute* the *ranges* and *Ns* inputs have the following effect. Each component of the *ranges* tuple can be either a slice object or a two-tuple giving a range of values, such as  $(0, 5)$ . If the component is a slice object, *brute* uses it directly. If the component is a two-tuple range, *brute* internally converts it to a slice object that interpolates *Ns* points from its low-value to its high-value, inclusive.

### Examples

We illustrate the use of *brute* to seek the global minimum of a function of two variables that is given as the sum of a positive-definite quadratic and two deep “Gaussian-shaped” craters. Specifically, define the objective function *f* as the sum of three other functions,  $f = f_1 + f_2 + f_3$ . We suppose each of these has a signature  $(z, \text{*params})$ , where  $z = (x, y)$ , and *params* and the functions are as defined below.

```
>>> params = (2, 3, 7, 8, 9, 10, 44, -1, 2, 26, 1, -2, 0.5)
>>> def f1(z, *params):
...     x, y = z
...     a, b, c, d, e, f, g, h, i, j, k, l, scale = params
...     return (a * x**2 + b * x * y + c * y**2 + d*x + e*y + f)
```

```
>>> def f2(z, *params):
...     x, y = z
...     a, b, c, d, e, f, g, h, i, j, k, l, scale = params
...     return (-g*np.exp(-((x-h)**2 + (y-i)**2) / scale))
```

```
>>> def f3(z, *params):
...     x, y = z
...     a, b, c, d, e, f, g, h, i, j, k, l, scale = params
...     return (-j*np.exp(-((x-k)**2 + (y-l)**2) / scale))
```

```
>>> def f(z, *params):
...     return f1(z, *params) + f2(z, *params) + f3(z, *params)
```

Thus, the objective function may have local minima near the minimum of each of the three functions of which it is composed. To use *fmin* to polish its gridpoint result, we may then continue as follows:

```
>>> rranges = (slice(-4, 4, 0.25), slice(-4, 4, 0.25))
>>> from scipy import optimize
>>> resbrute = optimize.brute(f, rranges, args=params, full_output=True,
...                          finish=optimize.fmin)
>>> resbrute[0] # global minimum
```

```
array([-1.05665192,  1.80834843])
>>> resbrute[1] # function value at global minimum
-3.4085818767
```

Note that if *finish* had been set to `None`, we would have gotten the gridpoint `[-1.0 1.75]` where the rounded function value is `-2.892`.

## Rosenbrock function

<code>rosen(x)</code>	The Rosenbrock function.
<code>rosen_der(x)</code>	The derivative (i.e.
<code>rosen_hess(x)</code>	The Hessian matrix of the Rosenbrock function.
<code>rosen_hess_prod(x, p)</code>	Product of the Hessian matrix of the Rosenbrock function with a vector.

`scipy.optimize.rosen(x)`

The Rosenbrock function.

The function computed is:

```
sum(100.0*(x[1:] - x[:-1])**2.0)**2.0 + (1 - x[:-1])**2.0)
```

**Parameters** `x` : array\_like  
 1-D array of points at which the Rosenbrock function is to be computed.

**Returns** `f` : float  
 The value of the Rosenbrock function.

**See also:**

`rosen_der`, `rosen_hess`, `rosen_hess_prod`

`scipy.optimize.rosen_der(x)`

The derivative (i.e. gradient) of the Rosenbrock function.

**Parameters** `x` : array\_like  
 1-D array of points at which the derivative is to be computed.

**Returns** `rosen_der` : (N,) ndarray  
 The gradient of the Rosenbrock function at *x*.

**See also:**

`rosen`, `rosen_hess`, `rosen_hess_prod`

`scipy.optimize.rosen_hess(x)`

The Hessian matrix of the Rosenbrock function.

**Parameters** `x` : array\_like  
 1-D array of points at which the Hessian matrix is to be computed.

**Returns** `rosen_hess` : ndarray  
 The Hessian matrix of the Rosenbrock function at *x*.

**See also:**

`rosen`, `rosen_der`, `rosen_hess_prod`

`scipy.optimize.rosen_hess_prod(x, p)`

Product of the Hessian matrix of the Rosenbrock function with a vector.

**Parameters** **x** : array\_like  
 1-D array of points at which the Hessian matrix is to be computed.  
**p** : array\_like  
 1-D array, the vector to be multiplied by the Hessian matrix.

**Returns** **rosen\_hess\_prod** : ndarray  
 The Hessian matrix of the Rosenbrock function at  $x$  multiplied by the vector  $p$ .

**See also:**

`rosen`, `rosen_der`, `rosen_hess`

## 5.18.2 Fitting

---

`curve_fit(f, xdata, ydata[, p0, sigma, ...])` Use non-linear least squares to fit a function,  $f$ , to data.

---

`scipy.optimize.curve_fit(f, xdata, ydata, p0=None, sigma=None, absolute_sigma=False, check_finite=True, bounds=(-inf, inf), method=None, jac=None, **kwargs)`

Use non-linear least squares to fit a function,  $f$ , to data.

Assumes  $ydata = f(xdata, *params) + \epsilon$

**Parameters** **f** : callable  
 The model function,  $f(x, \dots)$ . It must take the independent variable as the first argument and the parameters to fit as separate remaining arguments.

**xdata** : An M-length sequence or an (k,M)-shaped array for functions with k predictors  
 The independent variable where the data is measured.

**ydata** : M-length sequence  
 The dependent data — nominally  $f(xdata, \dots)$

**p0** : None, scalar, or N-length sequence, optional  
 Initial guess for the parameters. If None, then the initial values will all be 1 (if the number of parameters for the function can be determined using introspection, otherwise a ValueError is raised).

**sigma** : None or M-length sequence or MxM array, optional  
 Determines the uncertainty in  $ydata$ . If we define residuals as  $r = ydata - f(xdata, *popt)$ , then the interpretation of  $\sigma$  depends on its number of dimensions:

- A 1-d  $\sigma$  should contain values of standard deviations of errors in  $ydata$ . In this case, the optimized function is  $chisq = \sum((r / \sigma) ** 2)$ .
- A 2-d  $\sigma$  should contain the covariance matrix of errors in  $ydata$ . In this case, the optimized function is  $chisq = r.T @ \text{inv}(\sigma) @ r$ .

New in version 0.19.  
 None (default) is equivalent of 1-d  $\sigma$  filled with ones.

**absolute\_sigma** : bool, optional  
 If True,  $\sigma$  is used in an absolute sense and the estimated parameter covariance  $pcov$  reflects these absolute values.  
 If False, only the relative magnitudes of the  $\sigma$  values matter. The returned parameter covariance matrix  $pcov$  is based on scaling  $\sigma$  by a constant factor. This constant is set by demanding that the reduced  $chisq$  for the optimal parameters  $popt$  when using the *scaled*  $\sigma$  equals unity. In other words,  $\sigma$  is scaled to match the sample variance of the residuals after the fit. Mathematically,  $pcov(\text{absolute\_sigma}=\text{False}) = pcov(\text{absolute\_sigma}=\text{True}) * chisq(popt) / (M-N)$

**check\_finite** : bool, optional

If True, check that the input arrays do not contain nans or infs, and raise a `ValueError` if they do. Setting this parameter to False may silently produce nonsensical results if the input arrays do contain nans. Default is True.

**bounds** : 2-tuple of array\_like, optional

Lower and upper bounds on independent variables. Defaults to no bounds. Each element of the tuple must be either an array with the length equal to the number of parameters, or a scalar (in which case the bound is taken to be the same for all parameters.) Use `np.inf` with an appropriate sign to disable bounds on all or some parameters.

New in version 0.17.

**method** : {'lm', 'trf', 'dogbox'}, optional

Method to use for optimization. See `least_squares` for more details. Default is 'lm' for unconstrained problems and 'trf' if `bounds` are provided. The method 'lm' won't work when the number of observations is less than the number of variables, use 'trf' or 'dogbox' in this case.

New in version 0.17.

**jac** : callable, string or None, optional

Function with signature `jac(x, ...)` which computes the Jacobian matrix of the model function with respect to parameters as a dense array\_like structure. It will be scaled according to provided `sigma`. If None (default), the Jacobian will be estimated numerically. String keywords for 'trf' and 'dogbox' methods can be used to select a finite difference scheme, see `least_squares`.

New in version 0.18.

**kwargs**

Keyword arguments passed to `leastsq` for `method='lm'` or `least_squares` otherwise.

**Returns**

**popt** : array

Optimal values for the parameters so that the sum of the squared residuals of  $f(xdata, *popt) - ydata$  is minimized

**pcov** : 2d array

The estimated covariance of `popt`. The diagonals provide the variance of the parameter estimate. To compute one standard deviation errors on the parameters use `perr = np.sqrt(np.diag(pcov))`.

How the `sigma` parameter affects the estimated covariance depends on `absolute_sigma` argument, as described above.

If the Jacobian matrix at the solution doesn't have a full rank, then 'lm' method returns a matrix filled with `np.inf`, on the other hand 'trf' and 'dogbox' methods use Moore-Penrose pseudoinverse to compute the covariance matrix.

**Raises**

**ValueError**

if either `ydata` or `xdata` contain NaNs, or if incompatible options are used.

**RuntimeError**

if the least-squares minimization fails.

**OptimizeWarning**

if covariance of the parameters can not be estimated.

See also:

**least\_squares**

Minimize the sum of squares of nonlinear functions.

**scipy.stats.linregress**

Calculate a linear least squares regression for two sets of measurements.

### Notes

With `method='lm'`, the algorithm uses the Levenberg-Marquardt algorithm through `leastsq`. Note that this algorithm can only deal with unconstrained problems.

Box constraints can be handled by methods `'trf'` and `'dogbox'`. Refer to the docstring of `least_squares` for more information.

### Examples

```
>>> import numpy as np
>>> import matplotlib.pyplot as plt
>>> from scipy.optimize import curve_fit
```

```
>>> def func(x, a, b, c):
...     return a * np.exp(-b * x) + c
```

Define the data to be fit with some noise:

```
>>> xdata = np.linspace(0, 4, 50)
>>> y = func(xdata, 2.5, 1.3, 0.5)
>>> np.random.seed(1729)
>>> y_noise = 0.2 * np.random.normal(size=xdata.size)
>>> ydata = y + y_noise
>>> plt.plot(xdata, ydata, 'b-', label='data')
```

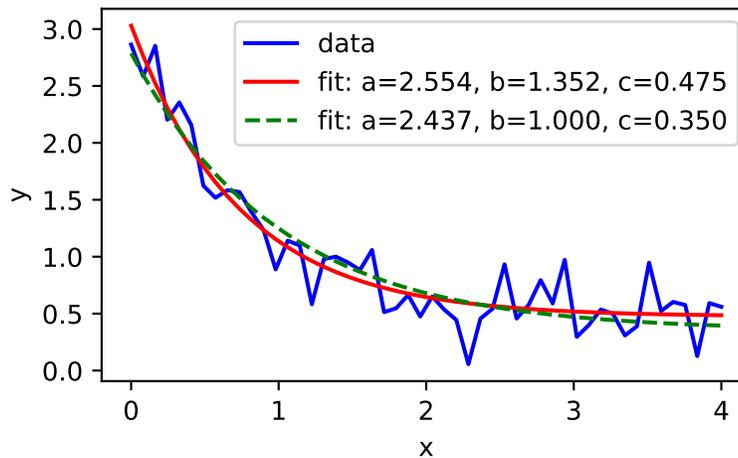
Fit for the parameters `a`, `b`, `c` of the function `func`:

```
>>> popt, pcov = curve_fit(func, xdata, ydata)
>>> popt
array([ 2.55423706,  1.35190947,  0.47450618])
>>> plt.plot(xdata, func(xdata, *popt), 'r-',
...         label='fit: a=%5.3f, b=%5.3f, c=%5.3f' % tuple(popt))
```

Constrain the optimization to the region of  $0 \leq a \leq 3, 0 \leq b \leq 1$  and  $0 \leq c \leq 0.5$ :

```
>>> popt, pcov = curve_fit(func, xdata, ydata, bounds=(0, [3., 1., 0.5]))
>>> popt
array([ 2.43708906,  1.          ,  0.35015434])
>>> plt.plot(xdata, func(xdata, *popt), 'g--',
...         label='fit: a=%5.3f, b=%5.3f, c=%5.3f' % tuple(popt))
```

```
>>> plt.xlabel('x')
>>> plt.ylabel('y')
>>> plt.legend()
>>> plt.show()
```



### 5.18.3 Root finding

#### Scalar functions

<code>brentq(f, a, b[, args, xtol, rtol, maxiter, ...])</code>	Find a root of a function in a bracketing interval using Brent's method.
<code>brenth(f, a, b[, args, xtol, rtol, maxiter, ...])</code>	Find root of $f$ in $[a, b]$ .
<code>ridder(f, a, b[, args, xtol, rtol, maxiter, ...])</code>	Find a root of a function in an interval.
<code>bisect(f, a, b[, args, xtol, rtol, maxiter, ...])</code>	Find root of a function within an interval.
<code>newton(func, x0[, fprime, args, tol, ...])</code>	Find a zero using the Newton-Raphson or secant method.

`scipy.optimize.brentq(f, a, b, args=(), xtol=2e-12, rtol=8.8817841970012523e-16, maxiter=100, full_output=False, disp=True)`

Find a root of a function in a bracketing interval using Brent's method.

Uses the classic Brent's method to find a zero of the function  $f$  on the sign changing interval  $[a, b]$ . Generally considered the best of the rootfinding routines here. It is a safe version of the secant method that uses inverse quadratic extrapolation. Brent's method combines root bracketing, interval bisection, and inverse quadratic interpolation. It is sometimes known as the van Wijngaarden-Dekker-Brent method. Brent (1973) claims convergence is guaranteed for functions computable within  $[a, b]$ .

[Brent1973] provides the classic description of the algorithm. Another description can be found in a recent edition of Numerical Recipes, including [PressEtal1992]. Another description is at <http://mathworld.wolfram.com/BrentsMethod.html>. It should be easy to understand the algorithm just by reading our code. Our code diverges a bit from standard presentations: we choose a different formula for the extrapolation step.

**Parameters**

- f** : function  
Python function returning a number. The function  $f$  must be continuous, and  $f(a)$  and  $f(b)$  must have opposite signs.
- a** : number  
One end of the bracketing interval  $[a, b]$ .
- b** : number  
The other end of the bracketing interval  $[a, b]$ .
- xtol** : number, optional

The computed root  $x_0$  will satisfy `np.allclose(x, x0, atol=xtol, rtol=rtol)`, where  $x$  is the exact root. The parameter must be nonnegative. For nice functions, Brent's method will often satisfy the above condition with  $xtol/2$  and  $rtol/2$ . [Brent1973]

**rtol** : number, optional

The computed root  $x_0$  will satisfy `np.allclose(x, x0, atol=xtol, rtol=rtol)`, where  $x$  is the exact root. The parameter cannot be smaller than its default value of `4*np.finfo(float).eps`. For nice functions, Brent's method will often satisfy the above condition with  $xtol/2$  and  $rtol/2$ . [Brent1973]

**maxiter** : number, optional

if convergence is not achieved in `maxiter` iterations, an error is raised. Must be  $\geq 0$ .

**args** : tuple, optional

containing extra arguments for the function  $f$ .  $f$  is called by `apply(f, (x)+args)`.

**full\_output** : bool, optional

If `full_output` is `False`, the root is returned. If `full_output` is `True`, the return value is  $(x, r)$ , where  $x$  is the root, and  $r$  is a `RootResults` object.

**disp** : bool, optional

If `True`, raise `RuntimeError` if the algorithm didn't converge.

#### Returns

**x0** : float

Zero of  $f$  between  $a$  and  $b$ .

**r** : `RootResults` (present if `full_output = True`)

Object containing information about the convergence. In particular, `r.converged` is `True` if the routine converged.

See also:

#### **multivariate**

`fmin`, `fmin_powell`, `fmin_cg`, `fmin_bfgs`, `fmin_ncg`

#### **nonlinear** `leastsq`

#### **constrained**

`fmin_l_bfgs_b`, `fmin_tnc`, `fmin_cobyla`

#### **global** `basinhopping`, `brute`, `differential_evolution`

#### **local** `fminbound`, `brent`, `golden`, `bracket`

#### **n-dimensional**

`fsolve`

#### **one-dimensional**

`brenth`, `ridder`, `bisect`, `newton`

#### **scalar** `fixed_point`

#### Notes

$f$  must be continuous.  $f(a)$  and  $f(b)$  must have opposite signs.

#### References

[Brent1973], [PressEtal1992]

#### Examples

```
>>> def f(x):
...     return (x**2 - 1)
```

```
>>> from scipy import optimize
```

```
>>> root = optimize.brentq(f, -2, 0)
>>> root
-1.0
```

```
>>> root = optimize.brentq(f, 0, 2)
>>> root
1.0
```

`scipy.optimize.brenth`(*f*, *a*, *b*, *args*=(), *xtol*= $2e-12$ , *rtol*= $8.8817841970012523e-16$ , *maxiter*=100, *full\_output*=False, *disp*=True)

Find root of *f* in [*a*,*b*].

A variation on the classic Brent routine to find a zero of the function *f* between the arguments *a* and *b* that uses hyperbolic extrapolation instead of inverse quadratic extrapolation. There was a paper back in the 1980's ... *f*(*a*) and *f*(*b*) cannot have the same signs. Generally on a par with the *brent* routine, but not as heavily tested. It is a safe version of the secant method that uses hyperbolic extrapolation. The version here is by Chuck Harris.

**Parameters**

- f** : function  
Python function returning a number. *f* must be continuous, and *f*(*a*) and *f*(*b*) must have opposite signs.
- a** : number  
One end of the bracketing interval [*a*,*b*].
- b** : number  
The other end of the bracketing interval [*a*,*b*].
- xtol** : number, optional  
The computed root *x0* will satisfy `np.allclose(x, x0, atol=xtol, rtol=rtol)`, where *x* is the exact root. The parameter must be nonnegative. As with *brentq*, for nice functions the method will often satisfy the above condition with *xtol*/2 and *rtol*/2.
- rtol** : number, optional  
The computed root *x0* will satisfy `np.allclose(x, x0, atol=xtol, rtol=rtol)`, where *x* is the exact root. The parameter cannot be smaller than its default value of `4*np.finfo(float).eps`. As with *brentq*, for nice functions the method will often satisfy the above condition with *xtol*/2 and *rtol*/2.
- maxiter** : number, optional  
if convergence is not achieved in *maxiter* iterations, an error is raised. Must be  $\geq 0$ .
- args** : tuple, optional  
containing extra arguments for the function *f*. *f* is called by `apply(f, (x)+args)`.
- full\_output** : bool, optional  
If *full\_output* is False, the root is returned. If *full\_output* is True, the return value is (*x*, *r*), where *x* is the root, and *r* is a RootResults object.
- disp** : bool, optional  
If True, raise RuntimeError if the algorithm didn't converge.

**Returns**

- x0** : float  
Zero of *f* between *a* and *b*.
- r** : RootResults (present if *full\_output* = True)  
Object containing information about the convergence. In particular, *r.converged* is True if the routine converged.

**See also:**

*fmin*, *fmin\_powell*, *fmin\_cg*

**leastsq** nonlinear least squares minimizer

*fmin\_l\_bfgs\_b*, *fmin\_tnc*, *fmin\_cobyla*, *basinhopping*, *differential\_evolution*, *brute*, *fminbound*, *brent*, *golden*, *bracket*

**fsolve** n-dimensional root-finding

*brentq*, *brenth*, *ridder*, *bisect*, *newton*

**fixed\_point**

scalar fixed-point finder

### Examples

```
>>> def f(x):
...     return (x**2 - 1)
```

```
>>> from scipy import optimize
```

```
>>> root = optimize.brenth(f, -2, 0)
>>> root
-1.0
```

```
>>> root = optimize.brenth(f, 0, 2)
>>> root
1.0
```

`scipy.optimize.ridder(f, a, b, args=(), xtol=2e-12, rtol=8.8817841970012523e-16, maxiter=100, full_output=False, disp=True)`

Find a root of a function in an interval.

**Parameters**

- f**: function  
Python function returning a number. *f* must be continuous, and *f*(*a*) and *f*(*b*) must have opposite signs.
- a**: number  
One end of the bracketing interval [*a*,*b*].
- b**: number  
The other end of the bracketing interval [*a*,*b*].
- xtol**: number, optional  
The computed root *x0* will satisfy `np.allclose(x, x0, atol=xtol, rtol=rtol)`, where *x* is the exact root. The parameter must be nonnegative.
- rtol**: number, optional  
The computed root *x0* will satisfy `np.allclose(x, x0, atol=xtol, rtol=rtol)`, where *x* is the exact root. The parameter cannot be smaller than its default value of `4*np.finfo(float).eps`.
- maxiter**: number, optional  
if convergence is not achieved in *maxiter* iterations, an error is raised. Must be  $\geq 0$ .
- args**: tuple, optional  
containing extra arguments for the function *f*. *f* is called by `apply(f, (x)+args)`.
- full\_output**: bool, optional  
If *full\_output* is False, the root is returned. If *full\_output* is True, the return value is (*x*, *r*), where *x* is the root, and *r* is a RootResults object.
- disp**: bool, optional  
If True, raise RuntimeError if the algorithm didn't converge.

**Returns**

- x0**: float  
Zero of *f* between *a* and *b*.
- r**: RootResults (present if `full_output = True`)

Object containing information about the convergence. In particular, `r.converged` is True if the routine converged.

**See also:**

`brentq`, `brenth`, `bisect`, `newton`

**fixed\_point**

scalar fixed-point finder

**Notes**

Uses [Ridders1979] method to find a zero of the function  $f$  between the arguments  $a$  and  $b$ . Ridders' method is faster than bisection, but not generally as fast as the Brent routines. [Ridders1979] provides the classic description and source of the algorithm. A description can also be found in any recent edition of Numerical Recipes.

The routine used here diverges slightly from standard presentations in order to be a bit more careful of tolerance.

**References**

[Ridders1979]

**Examples**

```
>>> def f(x):
...     return (x**2 - 1)
```

```
>>> from scipy import optimize
```

```
>>> root = optimize.ridder(f, 0, 2)
>>> root
1.0
```

```
>>> root = optimize.ridder(f, -2, 0)
>>> root
-1.0
```

`scipy.optimize.bisect` ( $f$ ,  $a$ ,  $b$ ,  $args=()$ ,  $xtol=2e-12$ ,  $rtol=8.8817841970012523e-16$ ,  $maxiter=100$ ,  $full_output=False$ ,  $disp=True$ )

Find root of a function within an interval.

Basic bisection routine to find a zero of the function  $f$  between the arguments  $a$  and  $b$ .  $f(a)$  and  $f(b)$  cannot have the same signs. Slow but sure.

**Parameters**

- f**: function  
Python function returning a number.  $f$  must be continuous, and  $f(a)$  and  $f(b)$  must have opposite signs.
- a**: number  
One end of the bracketing interval  $[a,b]$ .
- b**: number  
The other end of the bracketing interval  $[a,b]$ .
- xtol**: number, optional  
The computed root  $x_0$  will satisfy `np.allclose(x, x0, atol=xtol, rtol=rtol)`, where  $x$  is the exact root. The parameter must be nonnegative.
- rtol**: number, optional  
The computed root  $x_0$  will satisfy `np.allclose(x, x0, atol=xtol, rtol=rtol)`, where  $x$  is the exact root. The parameter cannot be smaller than its default value of `4*np.finfo(float).eps`.

**maxiter** : number, optional  
if convergence is not achieved in *maxiter* iterations, an error is raised. Must be  $\geq 0$ .

**args** : tuple, optional  
containing extra arguments for the function *f*. *f* is called by `apply(f, (x)+args)`.

**full\_output** : bool, optional  
If *full\_output* is False, the root is returned. If *full\_output* is True, the return value is `(x, r)`, where *x* is the root, and *r* is a *RootResults* object.

**disp** : bool, optional  
If True, raise RuntimeError if the algorithm didn't converge.

**Returns**

**x0** : float  
Zero of *f* between *a* and *b*.

**r** : RootResults (present if `full_output = True`)  
Object containing information about the convergence. In particular, `r.converged` is True if the routine converged.

**See also:**

*brentq*, *brenth*, *bisect*, *newton*

**fixed\_point**

scalar fixed-point finder

**fsolve** n-dimensional root-finding

**Examples**

```
>>> def f(x):
...     return (x**2 - 1)
```

```
>>> from scipy import optimize
```

```
>>> root = optimize.bisect(f, 0, 2)
>>> root
1.0
```

```
>>> root = optimize.bisect(f, -2, 0)
>>> root
-1.0
```

`scipy.optimize.newton` (*func*, *x0*, *fprime*=None, *args*=(), *tol*=1.48e-08, *maxiter*=50, *fprime2*=None)

Find a zero using the Newton-Raphson or secant method.

Find a zero of the function *func* given a nearby starting point *x0*. The Newton-Raphson method is used if the derivative *fprime* of *func* is provided, otherwise the secant method is used. If the second order derivate *fprime2* of *func* is provided, parabolic Halley's method is used.

**Parameters**

**func** : function

The function whose zero is wanted. It must be a function of a single variable of the form `f(x,a,b,c,...)`, where `a,b,c...` are extra arguments that can be passed in the `args` parameter.

**x0** : float

An initial estimate of the zero that should be somewhere near the actual zero.

**fprime** : function, optional

The derivative of the function when available and convenient. If it is None (default), then the secant method is used.

**args** : tuple, optional

Extra arguments to be used in the function call.

**tol** : float, optional  
The allowable error of the zero value.

**maxiter** : int, optional  
Maximum number of iterations.

**fprime2** : function, optional  
The second order derivative of the function when available and convenient. If it is None (default), then the normal Newton-Raphson or the secant method is used. If it is given, parabolic Halley's method is used.

**Returns** **zero** : float  
Estimated location where function is zero.

**See also:**

*brentq, brenth, ridder, bisect*

**fsolve** find zeroes in n dimensions.

**Notes**

The convergence rate of the Newton-Raphson method is quadratic, the Halley method is cubic, and the secant method is sub-quadratic. This means that if the function is well behaved the actual error in the estimated zero is approximately the square (cube for Halley) of the requested tolerance up to roundoff error. However, the stopping criterion used here is the step size and there is no guarantee that a zero has been found. Consequently the result should be verified. Safer algorithms are *brentq*, *brenth*, *ridder*, and *bisect*, but they all require that the root first be bracketed in an interval where the function changes sign. The *brentq* algorithm is recommended for general use in one dimensional problems when such an interval has been found.

**Examples**

```
>>> def f(x):
...     return (x**3 - 1) # only one real root at x = 1
```

```
>>> from scipy import optimize
```

fprime and fprime2 not provided, use secant method

```
>>> root = optimize.newton(f, 1.5)
>>> root
1.00000000000000016
```

Only fprime provided, use Newton Raphson method

```
>>> root = optimize.newton(f, 1.5, fprime=lambda x: 3 * x**2)
>>> root
1.0
```

fprime2 provided, fprime provided/not provided use parabolic Halley's method

```
>>> root = optimize.newton(f, 1.5, fprime2=lambda x: 6 * x)
>>> root
1.00000000000000016
>>> root = optimize.newton(f, 1.5, fprime=lambda x: 3 * x**2,
...                          fprime2=lambda x: 6 * x)
>>> root
1.0
```

Fixed point finding:

---

<code>fixed_point(func, x0[, args, xtol, maxiter, ...])</code>	Find a fixed point of the function.
--	-------------------------------------

---

`scipy.optimize.fixed_point` (*func*, *x0*, *args*=(), *xtol*=1e-08, *maxiter*=500, *method*='del2')

Find a fixed point of the function.

Given a function of one or more variables and a starting point, find a fixed-point of the function: i.e. where `func(x0) == x0`.

**Parameters**

- func** : function  
Function to evaluate.
- x0** : array\_like  
Fixed point of function.
- args** : tuple, optional  
Extra arguments to *func*.
- xtol** : float, optional  
Convergence tolerance, defaults to 1e-08.
- maxiter** : int, optional  
Maximum number of iterations, defaults to 500.
- method** : {"del2", "iteration"}, optional  
Method of finding the fixed-point, defaults to "del2" which uses Steffensen's Method with Aitken's Del<sup>2</sup> convergence acceleration [R197]. The "iteration" method simply iterates the function until convergence is detected, without attempting to accelerate the convergence.

### References

[R197]

### Examples

```
>>> from scipy import optimize
>>> def func(x, c1, c2):
...     return np.sqrt(c1/(x+c2))
>>> c1 = np.array([10, 12.])
>>> c2 = np.array([3, 5.])
>>> optimize.fixed_point(func, [1.2, 1.3], args=(c1, c2))
array([ 1.4920333 ,  1.37228132])
```

## Multidimensional

General nonlinear solvers:

<code>root(func, x0[, args, method, jac, tol, ...])</code>	Find a root of a vector function.
<code>fsolve(func, x0[, args, fprime, ...])</code>	Find the roots of a function.
<code>broyden1(F, xin[, iter, alpha, ...])</code>	Find a root of a function, using Broyden's first Jacobian approximation.
<code>broyden2(F, xin[, iter, alpha, ...])</code>	Find a root of a function, using Broyden's second Jacobian approximation.

---

`scipy.optimize.root` (*fun*, *x0*, *args*=(), *method*='hybr', *jac*=None, *tol*=None, *callback*=None, *options*=None)

Find a root of a vector function.

**Parameters** **fun** : callable

A vector function to find a root of.

**x0** : ndarray

Initial guess.

**args** : tuple, optional

Extra arguments passed to the objective function and its Jacobian.

**method** : str, optional

Type of solver. Should be one of

- 'hybr' (*see here*)
- 'lm' (*see here*)
- 'broyden1' (*see here*)
- 'broyden2' (*see here*)
- 'anderson' (*see here*)
- 'linearmixing' (*see here*)
- 'diagbroyden' (*see here*)
- 'excitingmixing' (*see here*)
- 'krylov' (*see here*)
- 'df-sane' (*see here*)

**jac** : bool or callable, optional

If *jac* is a Boolean and is True, *fun* is assumed to return the value of Jacobian along with the objective function. If False, the Jacobian will be estimated numerically. *jac* can also be a callable returning the Jacobian of *fun*. In this case, it must accept the same arguments as *fun*.

**tol** : float, optional

Tolerance for termination. For detailed control, use solver-specific options.

**callback** : function, optional

Optional callback function. It is called on every iteration as `callback(x, f)` where *x* is the current solution and *f* the corresponding residual. For all methods but 'hybr' and 'lm'.

**options** : dict, optional

A dictionary of solver options. E.g. *xtol* or *maxiter*, see `show_options()` for details.

**Returns**

**sol** : OptimizeResult

The solution represented as a `OptimizeResult` object. Important attributes are: *x* the solution array, *success* a Boolean flag indicating if the algorithm exited successfully and *message* which describes the cause of the termination. See `OptimizeResult` for a description of other attributes.

**See also:**

**show\_options**

Additional options accepted by the solvers

**Notes**

This section describes the available solvers that can be selected by the 'method' parameter. The default method is *hybr*.

Method *hybr* uses a modification of the Powell hybrid method as implemented in MINPACK [R221].

Method *lm* solves the system of nonlinear equations in a least squares sense using a modification of the Levenberg-Marquardt algorithm as implemented in MINPACK [R221].

Method *df-sane* is a derivative-free spectral method. [R223]

Methods *broyden1*, *broyden2*, *anderson*, *linearmixing*, *diagbroyden*, *excitingmixing*, *krylov* are inexact Newton methods, with backtracking or full line searches [R222]. Each method corresponds to a particular Jacobian approximations. See *nonlin* for details.

- Method *broyden1* uses Broyden's first Jacobian approximation, it is known as Broyden's good method.
- Method *broyden2* uses Broyden's second Jacobian approximation, it is known as Broyden's bad method.
- Method *anderson* uses (extended) Anderson mixing.
- Method *Krylov* uses Krylov approximation for inverse Jacobian. It is suitable for large-scale problem.
- Method *diagbroyden* uses diagonal Broyden Jacobian approximation.
- Method *linearmixing* uses a scalar Jacobian approximation.
- Method *excitingmixing* uses a tuned diagonal Jacobian approximation.

**Warning:** The algorithms implemented for methods *diagbroyden*, *linearmixing* and *excitingmixing* may be useful for specific problems, but whether they will work may depend strongly on the problem.

New in version 0.11.0.

### References

[R221], [R222], [R223]

### Examples

The following functions define a system of nonlinear equations and its jacobian.

```
>>> def fun(x):
...     return [x[0] + 0.5 * (x[0] - x[1])**3 - 1.0,
...            0.5 * (x[1] - x[0])**3 + x[1]]
```

```
>>> def jac(x):
...     return np.array([[1 + 1.5 * (x[0] - x[1])**2,
...                      -1.5 * (x[0] - x[1])**2],
...                     [-1.5 * (x[1] - x[0])**2,
...                      1 + 1.5 * (x[1] - x[0])**2]])
```

A solution can be obtained as follows.

```
>>> from scipy import optimize
>>> sol = optimize.root(fun, [0, 0], jac=jac, method='hybr')
>>> sol.x
array([ 0.8411639,  0.1588361])
```

`scipy.optimize.fsolve` (*func*, *x0*, *args=()*, *fprime=None*, *full\_output=0*, *col\_deriv=0*, *xtol=1.49012e-08*, *maxfev=0*, *band=None*, *epsfcn=None*, *factor=100*, *diag=None*)

Find the roots of a function.

Return the roots of the (non-linear) equations defined by  $\text{func}(x) = 0$  given a starting estimate.

- Parameters**
- func** : callable  $f(x, *args)$   
A function that takes at least one (possibly vector) argument.
  - x0** : ndarray  
The starting estimate for the roots of  $\text{func}(x) = 0$ .
  - args** : tuple, optional  
Any extra arguments to *func*.
  - fprime** : callable  $f(x, *args)$ , optional  
A function to compute the Jacobian of *func* with derivatives across the rows. By default, the Jacobian will be estimated.

**full\_output** : bool, optional  
 If True, return optional outputs.

**col\_deriv** : bool, optional  
 Specify whether the Jacobian function computes derivatives down the columns (faster, because there is no transpose operation).

**xtol** : float, optional  
 The calculation will terminate if the relative error between two consecutive iterates is at most *xtol*.

**maxfev** : int, optional  
 The maximum number of calls to the function. If zero, then  $100 * (N+1)$  is the maximum where N is the number of elements in *x0*.

**band** : tuple, optional  
 If set to a two-sequence containing the number of sub- and super-diagonals within the band of the Jacobi matrix, the Jacobi matrix is considered banded (only for *fprime=None*).

**epsfcn** : float, optional  
 A suitable step length for the forward-difference approximation of the Jacobian (for *fprime=None*). If *epsfcn* is less than the machine precision, it is assumed that the relative errors in the functions are of the order of the machine precision.

**factor** : float, optional  
 A parameter determining the initial step bound ( $factor * ||diag * x||$ ). Should be in the interval (0.1, 100).

**diag** : sequence, optional  
 N positive entries that serve as a scale factors for the variables.

**Returns**

**x** : ndarray  
 The solution (or the result of the last iteration for an unsuccessful call).

**infodict** : dict  
 A dictionary of optional outputs with the keys:

<b>nfev</b>	number of function calls
<b>njev</b>	number of Jacobian calls
<b>fvec</b>	function evaluated at the output
<b>fjac</b>	the orthogonal matrix, q, produced by the QR factorization of the final approximate Jacobian matrix, stored column wise
<b>r</b>	upper triangular matrix produced by QR factorization of the same matrix
<b>qtf</b>	the vector ( $transpose(q) * fvec$ )

**ier** : int  
 An integer flag. Set to 1 if a solution was found, otherwise refer to *mesg* for more information.

**mesg** : str  
 If no solution is found, *mesg* details the cause of failure.

**See also:**

**root**      Interface to root finding algorithms for multivariate functions.

**Notes**

*fsolve* is a wrapper around MINPACK's *hybrd* and *hybrj* algorithms.

```
scipy.optimize.broyden1(F, xin, iter=None, alpha=None, reduction_method='restart',
                        max_rank=None, verbose=False, maxiter=None, f_tol=None,
                        f_rtol=None, x_tol=None, x_rtol=None, tol_norm=None,
                        line_search='armijo', callback=None, **kw)
```

Find a root of a function, using Broyden's first Jacobian approximation.

This method is also known as “Broyden’s good method”.

<b>Parameters</b>	<p><b>F</b> : function(x) -&gt; f Function whose root to find; should take and return an array-like object.</p> <p><b>xin</b> : array_like Initial guess for the solution</p> <p><b>alpha</b> : float, optional Initial guess for the Jacobian is <math>(-1/\text{alpha})</math>.</p> <p><b>reduction_method</b> : str or tuple, optional Method used in ensuring that the rank of the Broyden matrix stays low. Can either be a string giving the name of the method, or a tuple of the form (method, param1, param2, ...) that gives the name of the method and values for additional parameters. Methods available:</p> <ul style="list-style-type: none"> <li>•restart: drop all matrix columns. Has no extra parameters.</li> <li>•simple: drop oldest matrix column. Has no extra parameters.</li> <li>•svd: keep only the most significant SVD components. Takes an extra parameter, to_retain, which determines the number of SVD components to retain when rank reduction is done. Default is <code>max_rank - 2</code>.</li> </ul> <p><b>max_rank</b> : int, optional Maximum rank for the Broyden matrix. Default is infinity (ie., no rank reduction).</p> <p><b>iter</b> : int, optional Number of iterations to make. If omitted (default), make as many as required to meet tolerances.</p> <p><b>verbose</b> : bool, optional Print status to stdout on every iteration.</p> <p><b>maxiter</b> : int, optional Maximum number of iterations to make. If more are needed to meet convergence, <i>NoConvergence</i> is raised.</p> <p><b>f_tol</b> : float, optional Absolute tolerance (in max-norm) for the residual. If omitted, default is 6e-6.</p> <p><b>f_rtol</b> : float, optional Relative tolerance for the residual. If omitted, not used.</p> <p><b>x_tol</b> : float, optional Absolute minimum step size, as determined from the Jacobian approximation. If the step size is smaller than this, optimization is terminated as successful. If omitted, not used.</p> <p><b>x_rtol</b> : float, optional Relative minimum step size. If omitted, not used.</p> <p><b>tol_norm</b> : function(vector) -&gt; scalar, optional Norm to use in convergence check. Default is the maximum norm.</p> <p><b>line_search</b> : {None, ‘armijo’ (default), ‘wolfe’}, optional Which type of a line search to use to determine the step size in the direction given by the Jacobian approximation. Defaults to ‘armijo’.</p> <p><b>callback</b> : function, optional Optional callback function. It is called on every iteration as <code>callback(x, f)</code> where <i>x</i> is the current solution and <i>f</i> the corresponding residual.</p>
<b>Returns</b>	<p><b>sol</b> : ndarray An array (of similar array type as <i>x0</i>) containing the final solution.</p>
<b>Raises</b>	<p><b>NoConvergence</b> When a solution was not found.</p>

**Notes**

This algorithm implements the inverse Jacobian Quasi-Newton update

$$H_+ = H + (dx - Hdf)dx^\dagger H / (dx^\dagger Hdf)$$

which corresponds to Broyden's first Jacobian update

$$J_+ = J + (df - Jdx)dx^\dagger / dx^\dagger dx$$

**References**

[R192]

```
scipy.optimize.broyden2(F, xin, iter=None, alpha=None, reduction_method='restart',
                        max_rank=None, verbose=False, maxiter=None, f_tol=None,
                        f_rtol=None, x_tol=None, x_rtol=None, tol_norm=None,
                        line_search='armijo', callback=None, **kw)
```

Find a root of a function, using Broyden's second Jacobian approximation.

This method is also known as "Broyden's bad method".

**Parameters**

**F** : function(x) -> f

Function whose root to find; should take and return an array-like object.

**xin** : array\_like

Initial guess for the solution

**alpha** : float, optional

Initial guess for the Jacobian is  $(-1/\alpha)$ .

**reduction\_method** : str or tuple, optional

Method used in ensuring that the rank of the Broyden matrix stays low. Can either be a string giving the name of the method, or a tuple of the form (method, param1, param2, ...) that gives the name of the method and values for additional parameters.

Methods available:

- restart: drop all matrix columns. Has no extra parameters.
- simple: drop oldest matrix column. Has no extra parameters.
- svd: keep only the most significant SVD components. Takes an extra parameter, to\_retain, which determines the number of SVD components to retain when rank reduction is done. Default is max\_rank - 2.

**max\_rank** : int, optional

Maximum rank for the Broyden matrix. Default is infinity (ie., no rank reduction).

**iter** : int, optional

Number of iterations to make. If omitted (default), make as many as required to meet tolerances.

**verbose** : bool, optional

Print status to stdout on every iteration.

**maxiter** : int, optional

Maximum number of iterations to make. If more are needed to meet convergence, *NoConvergence* is raised.

**f\_tol** : float, optional

Absolute tolerance (in max-norm) for the residual. If omitted, default is 6e-6.

**f\_rtol** : float, optional

Relative tolerance for the residual. If omitted, not used.

**x\_tol** : float, optional

Absolute minimum step size, as determined from the Jacobian approximation. If the step size is smaller than this, optimization is terminated as successful. If omitted, not used.

**x\_rtol** : float, optional  
Relative minimum step size. If omitted, not used.

**tol\_norm** : function(vector) -> scalar, optional  
Norm to use in convergence check. Default is the maximum norm.

**line\_search** : {None, 'armijo' (default), 'wolfe'}, optional  
Which type of a line search to use to determine the step size in the direction given by the Jacobian approximation. Defaults to 'armijo'.

**callback** : function, optional  
Optional callback function. It is called on every iteration as `callback(x, f)` where `x` is the current solution and `f` the corresponding residual.

**Returns** **sol** : ndarray  
An array (of similar array type as `x0`) containing the final solution.

**Raises** **NoConvergence**  
When a solution was not found.

### Notes

This algorithm implements the inverse Jacobian Quasi-Newton update

$$H_+ = H + (dx - Hdf)df^\dagger / (df^\dagger df)$$

corresponding to Broyden's second method.

### References

[R193]

The `root` function supports the following methods:

#### `root(method='hybr')`

`scipy.optimize.root` (*fun*, *x0*, *args=()*, *method='hybr'*, *jac=None*, *tol=None*, *callback=None*, *options={'col\_deriv': 0, 'diag': None, 'factor': 100, 'eps': None, 'band': None, 'func': None, 'maxfev': 0, 'xtol': 1.49012e-08}*)

Find the roots of a multivariate function using MINPACK's `hybrd` and `hybrj` routines (modified Powell method).

#### See also:

For documentation for the rest of the parameters, see `scipy.optimize.root`

**Options** **col\_deriv** : bool  
Specify whether the Jacobian function computes derivatives down the columns (faster, because there is no transpose operation).

**xtol** : float  
The calculation will terminate if the relative error between two consecutive iterates is at most `xtol`.

**maxfev** : int  
The maximum number of calls to the function. If zero, then `100 * (N+1)` is the maximum where `N` is the number of elements in `x0`.

**band** : tuple  
If set to a two-sequence containing the number of sub- and super-diagonals within the band of the Jacobi matrix, the Jacobi matrix is considered banded (only for `fprime=None`).

**eps** : float  
A suitable step length for the forward-difference approximation of the Jacobian (for `fprime=None`). If `eps` is less than the machine precision, it is assumed that the relative errors in the functions are of the order of the machine precision.

**factor** : float

A parameter determining the initial step bound (`factor * ||diag * x||`). Should be in the interval  $(0.1, 100)$ .

**diag** : sequence  
N positive entries that serve as a scale factors for the variables.

***root(method='lm')***

`scipy.optimize.root` (*fun*, *x0*, *args=()*, *method='lm'*, *jac=None*, *tol=None*, *callback=None*, *options={'col\_deriv': 0, 'diag': None, 'factor': 100, 'gtol': 0.0, 'eps': 0.0, 'func': None, 'maxiter': 0, 'xtol': 1.49012e-08, 'ftol': 1.49012e-08}*)

Solve for least squares with Levenberg-Marquardt

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.root`

**Options**

- col\_deriv** : bool  
non-zero to specify that the Jacobian function computes derivatives down the columns (faster, because there is no transpose operation).
- ftol** : float  
Relative error desired in the sum of squares.
- xtol** : float  
Relative error desired in the approximate solution.
- gtol** : float  
Orthogonality desired between the function vector and the columns of the Jacobian.
- maxiter** : int  
The maximum number of calls to the function. If zero, then  $100*(N+1)$  is the maximum where N is the number of elements in *x0*.
- epsfcn** : float  
A suitable step length for the forward-difference approximation of the Jacobian (for *Dfun=None*). If *epsfcn* is less than the machine precision, it is assumed that the relative errors in the functions are of the order of the machine precision.
- factor** : float  
A parameter determining the initial step bound (`factor * ||diag * x||`). Should be in interval  $(0.1, 100)$ .
- diag** : sequence  
N positive entries that serve as a scale factors for the variables.

***root(method='broyden1')***

`scipy.optimize.root` (*fun*, *x0*, *args=()*, *method='broyden1'*, *tol=None*, *callback=None*, *options={}*)

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.root`

**Options**

- nit** : int, optional  
Number of iterations to make. If omitted (default), make as many as required to meet tolerances.
- disp** : bool, optional  
Print status to stdout on every iteration.
- maxiter** : int, optional  
Maximum number of iterations to make. If more are needed to meet convergence, *NoConvergence* is raised.
- ftol** : float, optional  
Relative tolerance for the residual. If omitted, not used.

**fatol** : float, optional  
 Absolute tolerance (in max-norm) for the residual. If omitted, default is 6e-6.

**xtol** : float, optional  
 Relative minimum step size. If omitted, not used.

**xatol** : float, optional  
 Absolute minimum step size, as determined from the Jacobian approximation. If the step size is smaller than this, optimization is terminated as successful. If omitted, not used.

**tol\_norm** : function(vector) -> scalar, optional  
 Norm to use in convergence check. Default is the maximum norm.

**line\_search** : {None, 'armijo' (default), 'wolfe'}, optional  
 Which type of a line search to use to determine the step size in the direction given by the Jacobian approximation. Defaults to 'armijo'.

**jac\_options** : dict, optional  
*Options for the respective Jacobian approximation.*

**alpha** [float, optional] Initial guess for the Jacobian is (-1/alpha).

**reduction\_method** [str or tuple, optional] Method used in ensuring that the rank of the Broyden matrix stays low. Can either be a string giving the name of the method, or a tuple of the form (method, param1, param2, ...) that gives the name of the method and values for additional parameters.

*Methods available:*

• **restart**: drop all matrix columns. Has no

extra parameters.

• **simple**: drop oldest matrix column. Has no

extra parameters.

• **svd**: keep only the most significant SVD

components.

*Extra parameters:*

**-to\_retain**: number of SVD compon

retain when rank reduction is done. Default is max\_rank - 2.

**max\_rank** [int, optional] Maximum rank for the Broyden matrix. Default is infinity (ie., no rank reduction).

*root(method='broyden2')*

`scipy.optimize.root` (*fun*, *x0*, *args=()*, *method='broyden2'*, *tol=None*, *callback=None*, *options={}*)

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.root`

**Options**

- nit** : int, optional  
Number of iterations to make. If omitted (default), make as many as required to meet tolerances.
- disp** : bool, optional  
Print status to stdout on every iteration.
- maxiter** : int, optional  
Maximum number of iterations to make. If more are needed to meet convergence, *NoConvergence* is raised.
- ftol** : float, optional  
Relative tolerance for the residual. If omitted, not used.
- fatol** : float, optional  
Absolute tolerance (in max-norm) for the residual. If omitted, default is 6e-6.
- xtol** : float, optional  
Relative minimum step size. If omitted, not used.
- xatol** : float, optional  
Absolute minimum step size, as determined from the Jacobian approximation. If the step size is smaller than this, optimization is terminated as successful. If omitted, not used.
- tol\_norm** : function(vector) -> scalar, optional  
Norm to use in convergence check. Default is the maximum norm.
- line\_search** : {None, 'armijo' (default), 'wolfe' }, optional  
Which type of a line search to use to determine the step size in the direction given by the Jacobian approximation. Defaults to 'armijo'.
- jac\_options** : dict, optional  
Options for the respective Jacobian approximation.
  - alpha** [float, optional] Initial guess for the Jacobian is (-1/alpha).
  - reduction\_method** [str or tuple, optional] Method used in ensuring that the rank of the Broyden matrix stays low. Can either be a string giving the name of the method, or a tuple of the form (method, param1, param2, ...) that gives the name of the method and values for additional parameters.

**Methods available:**

- **restart**: drop all matrix columns. Has no extra parameters.
- **simple**: drop oldest matrix column. Has no extra parameters.
- **svd**: keep only the most significant SVD components.

**Extra parameters:**

*-to\_retain: number of SVD compo*

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De-  
fault  
is  
max\_rank

*max\_rank* [int, optional] Maximum rank for the Broyden matrix. De-  
fault is infinity (ie., no rank reduction).

*root(method='anderson')*

`scipy.optimize.root` (*fun*, *x0*, *args=()*, *method='anderson'*, *tol=None*, *callback=None*, *options={}*)

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.root`

- Options**
- nit** : int, optional  
Number of iterations to make. If omitted (default), make as many as required to meet tolerances.
  - disp** : bool, optional  
Print status to stdout on every iteration.
  - maxiter** : int, optional  
Maximum number of iterations to make. If more are needed to meet convergence, *NoConvergence* is raised.
  - ftol** : float, optional  
Relative tolerance for the residual. If omitted, not used.
  - fatol** : float, optional  
Absolute tolerance (in max-norm) for the residual. If omitted, default is 6e-6.
  - xtol** : float, optional  
Relative minimum step size. If omitted, not used.
  - xatol** : float, optional  
Absolute minimum step size, as determined from the Jacobian approximation. If the step size is smaller than this, optimization is terminated as successful. If omitted, not used.
  - tol\_norm** : function(vector) -> scalar, optional  
Norm to use in convergence check. Default is the maximum norm.
  - line\_search** : {None, 'armijo' (default), 'wolfe'}, optional  
Which type of a line search to use to determine the step size in the direction given by the Jacobian approximation. Defaults to 'armijo'.
  - jac\_options** : dict, optional  
Options for the respective Jacobian approximation.
  - alpha** : [float, optional] Initial guess for the Jacobian is (-1/alpha).
  - M** : [float, optional] Number of previous vectors to retain. Defaults to 5.

**w0** [float, optional] Regularization parameter for numerical stability. Compared to unity, good values of the order of 0.01.

*root(method='linear mixing')*

`scipy.optimize.root` (*fun*, *x0*, *args=()*, *method='linear mixing'*, *tol=None*, *callback=None*, *options={}*)

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.root`

**Options**

- nit** : int, optional  
Number of iterations to make. If omitted (default), make as many as required to meet tolerances.
- disp** : bool, optional  
Print status to stdout on every iteration.
- maxiter** : int, optional  
Maximum number of iterations to make. If more are needed to meet convergence, `NoConvergence` is raised.
- ftol** : float, optional  
Relative tolerance for the residual. If omitted, not used.
- fatol** : float, optional  
Absolute tolerance (in max-norm) for the residual. If omitted, default is 6e-6.
- xtol** : float, optional  
Relative minimum step size. If omitted, not used.
- xatol** : float, optional  
Absolute minimum step size, as determined from the Jacobian approximation. If the step size is smaller than this, optimization is terminated as successful. If omitted, not used.
- tol\_norm** : function(vector) -> scalar, optional  
Norm to use in convergence check. Default is the maximum norm.
- line\_search** : {None, 'armijo' (default), 'wolfe' }, optional  
Which type of a line search to use to determine the step size in the direction given by the Jacobian approximation. Defaults to 'armijo'.
- jac\_options** : dict, optional  
Options for the respective Jacobian approximation.
  - alpha** [float, optional] initial guess for the jacobian is (-1/alpha).

*root(method='diagbroyden')*

`scipy.optimize.root` (*fun*, *x0*, *args=()*, *method='diagbroyden'*, *tol=None*, *callback=None*, *options={}*)

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.root`

**Options**

- nit** : int, optional  
Number of iterations to make. If omitted (default), make as many as required to meet tolerances.
- disp** : bool, optional  
Print status to stdout on every iteration.
- maxiter** : int, optional  
Maximum number of iterations to make. If more are needed to meet convergence, `NoConvergence` is raised.

**ftol** : float, optional  
Relative tolerance for the residual. If omitted, not used.

**fatol** : float, optional  
Absolute tolerance (in max-norm) for the residual. If omitted, default is 6e-6.

**xtol** : float, optional  
Relative minimum step size. If omitted, not used.

**xatol** : float, optional  
Absolute minimum step size, as determined from the Jacobian approximation. If the step size is smaller than this, optimization is terminated as successful. If omitted, not used.

**tol\_norm** : function(vector) -> scalar, optional  
Norm to use in convergence check. Default is the maximum norm.

**line\_search** : {None, 'armijo' (default), 'wolfe'}, optional  
Which type of a line search to use to determine the step size in the direction given by the Jacobian approximation. Defaults to 'armijo'.

**jac\_options** : dict, optional  
Options for the respective Jacobian approximation.  
*alpha* [float, optional] initial guess for the jacobian is (-1/alpha).

*root(method='excitingmixing')*

`scipy.optimize.root` (*fun*, *x0*, *args=()*, *method='excitingmixing'*, *tol=None*, *callback=None*, *options={}*)

#### See also:

For documentation for the rest of the parameters, see `scipy.optimize.root`

**Options**

**nit** : int, optional  
Number of iterations to make. If omitted (default), make as many as required to meet tolerances.

**disp** : bool, optional  
Print status to stdout on every iteration.

**maxiter** : int, optional  
Maximum number of iterations to make. If more are needed to meet convergence, *NoConvergence* is raised.

**ftol** : float, optional  
Relative tolerance for the residual. If omitted, not used.

**fatol** : float, optional  
Absolute tolerance (in max-norm) for the residual. If omitted, default is 6e-6.

**xtol** : float, optional  
Relative minimum step size. If omitted, not used.

**xatol** : float, optional  
Absolute minimum step size, as determined from the Jacobian approximation. If the step size is smaller than this, optimization is terminated as successful. If omitted, not used.

**tol\_norm** : function(vector) -> scalar, optional  
Norm to use in convergence check. Default is the maximum norm.

**line\_search** : {None, 'armijo' (default), 'wolfe'}, optional  
Which type of a line search to use to determine the step size in the direction given by the Jacobian approximation. Defaults to 'armijo'.

**jac\_options** : dict, optional  
Options for the respective Jacobian approximation.

***alpha*** [float, optional] Initial Jacobian approximation is  $(-1/\alpha)$ ,  
***alphamax*** [float, optional] The entries of the diagonal Jacobian are kept  
in the range  $[\alpha, \text{alphamax}]$ .

***root(method='krylov')***

`scipy.optimize.root` (*fun*, *x0*, *args=()*, *method='krylov'*, *tol=None*, *callback=None*, *options={}*)

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.root`

**Options**

- nit** : int, optional  
Number of iterations to make. If omitted (default), make as many as required to meet tolerances.
- disp** : bool, optional  
Print status to stdout on every iteration.
- maxiter** : int, optional  
Maximum number of iterations to make. If more are needed to meet convergence, *NoConvergence* is raised.
- ftol** : float, optional  
Relative tolerance for the residual. If omitted, not used.
- fatol** : float, optional  
Absolute tolerance (in max-norm) for the residual. If omitted, default is  $6e-6$ .
- xtol** : float, optional  
Relative minimum step size. If omitted, not used.
- xatol** : float, optional  
Absolute minimum step size, as determined from the Jacobian approximation. If the step size is smaller than this, optimization is terminated as successful. If omitted, not used.
- tol\_norm** : function(vector) -> scalar, optional  
Norm to use in convergence check. Default is the maximum norm.
- line\_search** : {None, 'armijo' (default), 'wolfe'}, optional  
Which type of a line search to use to determine the step size in the direction given by the Jacobian approximation. Defaults to 'armijo'.
- jac\_options** : dict, optional  
Options for the respective Jacobian approximation.
- rdiff*** [float, optional] Relative step size to use in numerical differentiation.
- method*** [{ 'lgmres', 'gmres', 'bicgstab', 'cgs', 'minres' } or function]  
Krylov method to use to approximate the Jacobian. Can be a string, or a function implementing the same interface as the iterative solvers in `scipy.sparse.linalg`.
- inner\_M*** [LinearOperator or InverseJacobian]  
The default is `scipy.sparse.linalg.lgmres`.  
Preconditioner for the inner Krylov iteration. Note that you can use also inverse Jacobians as (adaptive) preconditioners. For example,

```

>>> jac = BroydenFirst()
>>> kjac = KrylovJacobian(inner_M=jac.
    ↪inverse).
```

If the preconditioner has a method named 'update', it will be called as `update(x, f)` after each nonlinear step, with `x` giving the current point, and `f` the current function value.

*inner\_tol, inner\_maxiter, ...*

Parameters to pass on to the “inner” Krylov solver. See

*outer\_k* `scipy.sparse.linalg.gmres` for details.  
[int, optional] Size of the subspace kept across LGMRES  
nonlinear iterations.

See `scipy.sparse.linalg.lgmres` for details.

***root(method='df-sane')***

`scipy.optimize.root` (*fun*, *x0*, *args=()*, *method='df-sane'*, *tol=None*, *callback=None*, *options={ 'disp': False, 'fnorm': None, 'sigma\_0': 1.0, 'eta\_strategy': None, 'sigma\_eps': 1e-10, 'M': 10, 'line\_search': 'cruz', 'fatol': 1e-300, 'func': None, 'maxfev': 1000, 'ftol': 1e-08}*)

Solve nonlinear equation with the DF-SANE method

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.root`

**Options**

**ftol** : float, optional  
Relative norm tolerance.

**fatol** : float, optional  
Absolute norm tolerance. Algorithm terminates when  $\|func(x)\| < fatol + ftol \|func(x_0)\|$ .

**fnorm** : callable, optional  
Norm to use in the convergence check. If None, 2-norm is used.

**maxfev** : int, optional  
Maximum number of function evaluations.

**disp** : bool, optional  
Whether to print convergence process to stdout.

**eta\_strategy** : callable, optional  
Choice of the `eta_k` parameter, which gives slack for growth of  $\|F\|^{**2}$ . Called as `eta_k = eta_strategy(k, x, F)` with `k` the iteration number, `x` the current iterate and `F` the current residual. Should satisfy `eta_k > 0` and `sum(eta, k=0..inf) < inf`. Default:  $\|F\|^{**2} / (1 + k)^{**2}$ .

**sigma\_eps** : float, optional  
The spectral coefficient is constrained to  $sigma\_eps < sigma < 1/sigma\_eps$ . Default: 1e-10

**sigma\_0** : float, optional  
Initial spectral coefficient. Default: 1.0

**M** : int, optional  
Number of iterates to include in the nonmonotonic line search. Default: 10

**line\_search** : {'cruz', 'cheng'}  
Type of line search to employ. 'cruz' is the original one defined in [Martinez & Raydan. Math. Comp. 75, 1429 (2006)], 'cheng' is a modified search defined in [Cheng & Li. IMA J. Numer. Anal. 29, 814 (2009)]. Default: 'cruz'

## References

[R915], [R916], [R917]

Large-scale nonlinear solvers:

Continued on next page

Table 5.127 – continued from previous page

<code>newton_krylov(F, xin[, iter, rdiff, method, ...])</code>	Find a root of a function, using Krylov approximation for inverse Jacobian.
<code>anderson(F, xin[, iter, alpha, w0, M, ...])</code>	Find a root of a function, using (extended) Anderson mixing.

```
scipy.optimize.newton_krylov(F, xin, iter=None, rdiff=None, method='lgmres',
                             inner_maxiter=20, inner_M=None, outer_k=10, verbose=False,
                             maxiter=None, f_tol=None, f_rtol=None, x_tol=None,
                             x_rtol=None, tol_norm=None, line_search='armijo',
                             callback=None, **kw)
```

Find a root of a function, using Krylov approximation for inverse Jacobian.

This method is suitable for solving large-scale problems.

**Parameters**

- F** : function(x) -> f  
Function whose root to find; should take and return an array-like object.
- xin** : array\_like  
Initial guess for the solution
- rdiff** : float, optional  
Relative step size to use in numerical differentiation.
- method** : {'lgmres', 'gmres', 'bicgstab', 'cgs', 'minres'} or function  
Krylov method to use to approximate the Jacobian. Can be a string, or a function implementing the same interface as the iterative solvers in `scipy.sparse.linalg`. The default is `scipy.sparse.linalg.lgmres`.
- inner\_M** : LinearOperator or InverseJacobian  
Preconditioner for the inner Krylov iteration. Note that you can use also inverse Jacobians as (adaptive) preconditioners. For example,

```
>>> from scipy.optimize.nonlin import BroydenFirst, \
↳KrylovJacobian
>>> from scipy.optimize.nonlin import InverseJacobian
>>> jac = BroydenFirst()
>>> kjac = KrylovJacobian(inner_M=InverseJacobian(jac))
```

If the preconditioner has a method named 'update', it will be called as `update(x, f)` after each nonlinear step, with `x` giving the current point, and `f` the current function value.

**inner\_tol, inner\_maxiter, ...**

Parameters to pass on to the "inner" Krylov solver. See `scipy.sparse.linalg.gmres` for details.

**outer\_k** : int, optional

Size of the subspace kept across LGMRES nonlinear iterations. See `scipy.sparse.linalg.lgmres` for details.

**iter** : int, optional

Number of iterations to make. If omitted (default), make as many as required to meet tolerances.

**verbose** : bool, optional

Print status to stdout on every iteration.

**maxiter** : int, optional

Maximum number of iterations to make. If more are needed to meet convergence, `NoConvergence` is raised.

**f\_tol** : float, optional

Absolute tolerance (in max-norm) for the residual. If omitted, default is 6e-6.

**f\_rtol** : float, optional  
Relative tolerance for the residual. If omitted, not used.

**x\_tol** : float, optional  
Absolute minimum step size, as determined from the Jacobian approximation. If the step size is smaller than this, optimization is terminated as successful. If omitted, not used.

**x\_rtol** : float, optional  
Relative minimum step size. If omitted, not used.

**tol\_norm** : function(vector) -> scalar, optional  
Norm to use in convergence check. Default is the maximum norm.

**line\_search** : {None, 'armijo' (default), 'wolfe'}, optional  
Which type of a line search to use to determine the step size in the direction given by the Jacobian approximation. Defaults to 'armijo'.

**callback** : function, optional  
Optional callback function. It is called on every iteration as `callback(x, f)` where  $x$  is the current solution and  $f$  the corresponding residual.

**Returns** **sol** : ndarray  
An array (of similar array type as  $x_0$ ) containing the final solution.

**Raises** **NoConvergence**  
When a solution was not found.

**See also:**

`scipy.sparse.linalg.gmres`, `scipy.sparse.linalg.lgmres`

**Notes**

This function implements a Newton-Krylov solver. The basic idea is to compute the inverse of the Jacobian with an iterative Krylov method. These methods require only evaluating the Jacobian-vector products, which are conveniently approximated by a finite difference:

$$Jv \approx (f(x + \omega * v/|v|) - f(x))/\omega$$

Due to the use of iterative matrix inverses, these methods can deal with large nonlinear problems.

Scipy's `scipy.sparse.linalg` module offers a selection of Krylov solvers to choose from. The default here is `lgmres`, which is a variant of restarted GMRES iteration that reuses some of the information obtained in the previous Newton steps to invert Jacobians in subsequent steps.

For a review on Newton-Krylov methods, see for example [R219], and for the LGMRES sparse inverse method, see [R220].

**References**

[R219], [R220]

```
scipy.optimize.anderson(F, xin, iter=None, alpha=None, w0=0.01, M=5, verbose=False,
                        maxiter=None, f_tol=None, f_rtol=None, x_tol=None, x_rtol=None,
                        tol_norm=None, line_search='armijo', callback=None, **kw)
```

Find a root of a function, using (extended) Anderson mixing.

The Jacobian is formed by for a 'best' solution in the space spanned by last  $M$  vectors. As a result, only a  $M \times M$  matrix inversions and  $M \times N$  multiplications are required. [Ey]

**Parameters** **F** : function(x) -> f  
Function whose root to find; should take and return an array-like object.

**xin** : array\_like

Initial guess for the solution

**alpha** : float, optional  
Initial guess for the Jacobian is (-1/alpha).

**M** : float, optional  
Number of previous vectors to retain. Defaults to 5.

**w0** : float, optional  
Regularization parameter for numerical stability. Compared to unity, good values of the order of 0.01.

**iter** : int, optional  
Number of iterations to make. If omitted (default), make as many as required to meet tolerances.

**verbose** : bool, optional  
Print status to stdout on every iteration.

**maxiter** : int, optional  
Maximum number of iterations to make. If more are needed to meet convergence, *NoConvergence* is raised.

**f\_tol** : float, optional  
Absolute tolerance (in max-norm) for the residual. If omitted, default is 6e-6.

**f\_rtol** : float, optional  
Relative tolerance for the residual. If omitted, not used.

**x\_tol** : float, optional  
Absolute minimum step size, as determined from the Jacobian approximation. If the step size is smaller than this, optimization is terminated as successful. If omitted, not used.

**x\_rtol** : float, optional  
Relative minimum step size. If omitted, not used.

**tol\_norm** : function(vector) -> scalar, optional  
Norm to use in convergence check. Default is the maximum norm.

**line\_search** : {None, 'armijo' (default), 'wolfe'}, optional  
Which type of a line search to use to determine the step size in the direction given by the Jacobian approximation. Defaults to 'armijo'.

**callback** : function, optional  
Optional callback function. It is called on every iteration as `callback(x, f)` where  $x$  is the current solution and  $f$  the corresponding residual.

**Returns** **sol** : ndarray  
An array (of similar array type as  $x0$ ) containing the final solution.

**Raises** **NoConvergence**  
When a solution was not found.

### References

[Ey]

Simple iterations:

<code>excitingmixing(F, xin[, iter, alpha, ...])</code>	Find a root of a function, using a tuned diagonal Jacobian approximation.
<code>linearmixing(F, xin[, iter, alpha, verbose, ...])</code>	Find a root of a function, using a scalar Jacobian approximation.
<code>diagbroyden(F, xin[, iter, alpha, verbose, ...])</code>	Find a root of a function, using diagonal Broyden Jacobian approximation.

`scipy.optimize.excitingmixing` (*F*, *xin*, *iter=None*, *alpha=None*, *alphamax=1.0*, *verbose=False*, *maxiter=None*, *f\_tol=None*, *f\_rtol=None*, *x\_tol=None*, *x\_rtol=None*, *tol\_norm=None*, *line\_search='armijo'*, *callback=None*, *\*\*kw*)

Find a root of a function, using a tuned diagonal Jacobian approximation.

The Jacobian matrix is diagonal and is tuned on each iteration.

**Warning:** This algorithm may be useful for specific problems, but whether it will work may depend strongly on the problem.

**Parameters**

- F** : function(*x*) -> *f*  
Function whose root to find; should take and return an array-like object.
- xin** : array\_like  
Initial guess for the solution
- alpha** : float, optional  
Initial Jacobian approximation is (-1/alpha).
- alphamax** : float, optional  
The entries of the diagonal Jacobian are kept in the range [*alpha*, *alphamax*].
- iter** : int, optional  
Number of iterations to make. If omitted (default), make as many as required to meet tolerances.
- verbose** : bool, optional  
Print status to stdout on every iteration.
- maxiter** : int, optional  
Maximum number of iterations to make. If more are needed to meet convergence, *NoConvergence* is raised.
- f\_tol** : float, optional  
Absolute tolerance (in max-norm) for the residual. If omitted, default is 6e-6.
- f\_rtol** : float, optional  
Relative tolerance for the residual. If omitted, not used.
- x\_tol** : float, optional  
Absolute minimum step size, as determined from the Jacobian approximation. If the step size is smaller than this, optimization is terminated as successful. If omitted, not used.
- x\_rtol** : float, optional  
Relative minimum step size. If omitted, not used.
- tol\_norm** : function(vector) -> scalar, optional  
Norm to use in convergence check. Default is the maximum norm.
- line\_search** : {None, 'armijo' (default), 'wolfe'}, optional  
Which type of a line search to use to determine the step size in the direction given by the Jacobian approximation. Defaults to 'armijo'.
- callback** : function, optional  
Optional callback function. It is called on every iteration as `callback(x, f)` where *x* is the current solution and *f* the corresponding residual.

**Returns**

- sol** : ndarray  
An array (of similar array type as *x0*) containing the final solution.

**Raises**

- NoConvergence**  
When a solution was not found.

`scipy.optimize.linearminimize` (*F*, *xin*, *iter=None*, *alpha=None*, *verbose=False*, *max-iter=None*, *f\_tol=None*, *f\_rtol=None*, *x\_tol=None*, *x\_rtol=None*, *tol\_norm=None*, *line\_search='armijo'*, *callback=None*, *\*\*kw*)

Find a root of a function, using a scalar Jacobian approximation.

**Warning:** This algorithm may be useful for specific problems, but whether it will work may depend strongly on the problem.

**Parameters**

- F** : function(x) -> f  
Function whose root to find; should take and return an array-like object.
- xin** : array\_like  
Initial guess for the solution
- alpha** : float, optional  
The Jacobian approximation is (-1/alpha).
- iter** : int, optional  
Number of iterations to make. If omitted (default), make as many as required to meet tolerances.
- verbose** : bool, optional  
Print status to stdout on every iteration.
- maxiter** : int, optional  
Maximum number of iterations to make. If more are needed to meet convergence, *NoConvergence* is raised.
- f\_tol** : float, optional  
Absolute tolerance (in max-norm) for the residual. If omitted, default is 6e-6.
- f\_rtol** : float, optional  
Relative tolerance for the residual. If omitted, not used.
- x\_tol** : float, optional  
Absolute minimum step size, as determined from the Jacobian approximation. If the step size is smaller than this, optimization is terminated as successful. If omitted, not used.
- x\_rtol** : float, optional  
Relative minimum step size. If omitted, not used.
- tol\_norm** : function(vector) -> scalar, optional  
Norm to use in convergence check. Default is the maximum norm.
- line\_search** : {None, 'armijo' (default), 'wolfe'}, optional  
Which type of a line search to use to determine the step size in the direction given by the Jacobian approximation. Defaults to 'armijo'.
- callback** : function, optional  
Optional callback function. It is called on every iteration as `callback(x, f)` where *x* is the current solution and *f* the corresponding residual.

**Returns**

- sol** : ndarray  
An array (of similar array type as *x0*) containing the final solution.

**Raises**

- NoConvergence**  
When a solution was not found.

`scipy.optimize.diagbroyden` (*F*, *xin*, *iter=None*, *alpha=None*, *verbose=False*, *maxiter=None*, *f\_tol=None*, *f\_rtol=None*, *x\_tol=None*, *x\_rtol=None*, *tol\_norm=None*, *line\_search='armijo'*, *callback=None*, *\*\*kw*)

Find a root of a function, using diagonal Broyden Jacobian approximation.

The Jacobian approximation is derived from previous iterations, by retaining only the diagonal of Broyden matrices.

**Warning:** This algorithm may be useful for specific problems, but whether it will work may depend strongly on the problem.

**Parameters**

- F** : function(x) -> f  
Function whose root to find; should take and return an array-like object.
- xin** : array\_like  
Initial guess for the solution
- alpha** : float, optional  
Initial guess for the Jacobian is (-1/alpha).
- iter** : int, optional  
Number of iterations to make. If omitted (default), make as many as required to meet tolerances.
- verbose** : bool, optional  
Print status to stdout on every iteration.
- maxiter** : int, optional  
Maximum number of iterations to make. If more are needed to meet convergence, *NoConvergence* is raised.
- f\_tol** : float, optional  
Absolute tolerance (in max-norm) for the residual. If omitted, default is 6e-6.
- f\_rtol** : float, optional  
Relative tolerance for the residual. If omitted, not used.
- x\_tol** : float, optional  
Absolute minimum step size, as determined from the Jacobian approximation. If the step size is smaller than this, optimization is terminated as successful. If omitted, not used.
- x\_rtol** : float, optional  
Relative minimum step size. If omitted, not used.
- tol\_norm** : function(vector) -> scalar, optional  
Norm to use in convergence check. Default is the maximum norm.
- line\_search** : {None, 'armijo' (default), 'wolfe'}, optional  
Which type of a line search to use to determine the step size in the direction given by the Jacobian approximation. Defaults to 'armijo'.
- callback** : function, optional  
Optional callback function. It is called on every iteration as `callback(x, f)` where  $x$  is the current solution and  $f$  the corresponding residual.

**Returns**

- sol** : ndarray  
An array (of similar array type as  $x0$ ) containing the final solution.

**Raises**

- NoConvergence**  
When a solution was not found.

*Additional information on the nonlinear solvers*

## 5.18.4 Linear Programming

General linear programming solver:

`linprog(c[, A_ub, b_ub, A_eq, b_eq, bounds, ...])`      Minimize a linear objective function subject to linear equality and inequality constraints.

`scipy.optimize.linprog(c, A_ub=None, b_ub=None, A_eq=None, b_eq=None, bounds=None, method='simplex', callback=None, options=None)`

Minimize a linear objective function subject to linear equality and inequality constraints.

Linear Programming is intended to solve the following problem form:

```
Minimize:      c^T * x
Subject to:    A_ub * x <= b_ub
               A_eq * x == b_eq
```

**Parameters** **c** : array\_like

Coefficients of the linear objective function to be minimized.

**A\_ub** : array\_like, optional

2-D array which, when matrix-multiplied by *x*, gives the values of the upper-bound inequality constraints at *x*.

**b\_ub** : array\_like, optional

1-D array of values representing the upper-bound of each inequality constraint (row) in *A\_ub*.

**A\_eq** : array\_like, optional

2-D array which, when matrix-multiplied by *x*, gives the values of the equality constraints at *x*.

**b\_eq** : array\_like, optional

1-D array of values representing the RHS of each equality constraint (row) in *A\_eq*.

**bounds** : sequence, optional

(*min*, *max*) pairs for each element in *x*, defining the bounds on that parameter. Use *None* for one of *min* or *max* when there is no bound in that direction. By default bounds are (0, *None*) (non-negative) If a sequence containing a single tuple is provided, then *min* and *max* will be applied to all variables in the problem.

**method** : str, optional

Type of solver. 'simplex' and 'interior-point' are supported.

**callback** : callable, optional (simplex only)

If a callback function is provide, it will be called within each iteration of the simplex algorithm. The callback must have the signature `callback(xk, **kwargs)` where *xk* is the current solution vector and *kwargs* is a dictionary containing the following:

```
"tableau" : The current Simplex algorithm tableau
"nit" : The current iteration.
"pivot" : The pivot (row, column) used for the next_
↪iteration.
"phase" : Whether the algorithm is in Phase 1 or Phase_
↪2.
"basis" : The indices of the columns of the basic_
↪variables.
```

**options** : dict, optional

A dictionary of solver options. All methods accept the following generic options:

**maxiter** [int] Maximum number of iterations to perform.

**disp** [bool] Set to True to print convergence messages.

For method-specific options, see `show_options('linprog')`.

**Returns** A `scipy.optimize.OptimizeResult` consisting of the following fields:

<b><i>x</i></b>	[ndarray] The independent variable vector which optimizes the linear programming problem.
<b><i>fun</i></b>	[float] Value of the objective function.
<b><i>slack</i></b>	[ndarray] The values of the slack variables. Each slack variable corresponds to an inequality constraint. If the slack is zero, then the corresponding constraint is active.
<b><i>success</i></b>	[bool] Returns True if the algorithm succeeded in finding an optimal solution.
<b><i>status</i></b>	[int] An integer representing the exit status of the optimization:
	<pre>0 : Optimization terminated successfully 1 : Iteration limit reached 2 : Problem appears to be infeasible 3 : Problem appears to be unbounded</pre>
<b><i>nit</i></b>	[int] The number of iterations performed.
<b><i>message</i></b>	[str] A string descriptor of the exit status of the optimization.

**See also:**

**show\_options**

Additional options accepted by the solvers

**Notes**

This section describes the available solvers that can be selected by the ‘method’ parameter. The default method is *Simplex*. *Interior point* is also available.

Method *simplex* uses the simplex algorithm (as it relates to linear programming, NOT the Nelder-Mead simplex) [R201], [R202]. This algorithm should be reasonably reliable and fast for small problems.

New in version 0.15.0.

Method *interior-point* uses the primal-dual path following algorithm as outlined in [R204]. This algorithm is intended to provide a faster and more reliable alternative to *simplex*, especially for large, sparse problems. Note, however, that the solution returned may be slightly less accurate than that of the simplex method and may not correspond with a vertex of the polytope defined by the constraints.

**References**

[R201], [R202], [R203], [R204], [R205], [R206], [R207], [R208], [R209],<sup>10</sup>

**Examples**

Consider the following problem:

Minimize:  $f = -1 \cdot x[0] + 4 \cdot x[1]$   
**Subject to:**  $-3 \cdot x[0] + 1 \cdot x[1] \leq 6$

$$1 \cdot x[0] + 2 \cdot x[1] \leq 4$$

$$x[1] \geq -3$$

where:  $-\text{inf} \leq x[0] \leq \text{inf}$

This problem deviates from the standard linear programming problem. In standard form, linear programming problems assume the variables  $x$  are non-negative. Since the variables don’t have standard bounds where  $0 \leq x \leq \text{inf}$ , the bounds of the variables must be explicitly set.

There are two upper-bound constraints, which can be expressed as

$$\text{dot}(A\_ub, x) \leq b\_ub$$

<sup>10</sup> Andersen, Erling D., et al. Implementation of interior point methods for large scale linear programming. HEC/Universite de Geneve, 1996.

The input for this problem is as follows:

```

>>> c = [-1, 4]
>>> A = [[-3, 1], [1, 2]]
>>> b = [6, 4]
>>> x0_bounds = (None, None)
>>> x1_bounds = (-3, None)
>>> from scipy.optimize import linprog
>>> res = linprog(c, A_ub=A, b_ub=b, bounds=(x0_bounds, x1_bounds),
...             options={"disp": True})
Optimization terminated successfully.
    Current function value: -22.000000
    Iterations: 1
>>> print(res)
fun: -22.0
message: 'Optimization terminated successfully.'
nit: 1
slack: array([ 39.,  0.])
status: 0
success: True
x: array([ 10., -3.])
    
```

Note the actual objective value is 11.428571. In this case we minimized the negative of the objective function.

The `linprog` function supports the following methods:

### `linprog(method='simplex')`

`scipy.optimize.linprog(c, A_ub=None, b_ub=None, A_eq=None, b_eq=None, bounds=None, method='simplex', callback=None, options={'disp': False, 'bland': False, 'tol': 1e-12, 'maxiter': 1000})`

Solve the following linear programming problem via a two-phase simplex algorithm.:

```

minimize:    c^T * x

subject to:  A_ub * x <= b_ub
             A_eq * x == b_eq
    
```

**Parameters** `c`: array\_like

Coefficients of the linear objective function to be minimized.

`A_ub`: array\_like

2-D array which, when matrix-multiplied by `x`, gives the values of the upper-bound inequality constraints at `x`.

`b_ub`: array\_like

1-D array of values representing the upper-bound of each inequality constraint (row) in `A_ub`.

`A_eq`: array\_like

2-D array which, when matrix-multiplied by `x`, gives the values of the equality constraints at `x`.

`b_eq`: array\_like

1-D array of values representing the RHS of each equality constraint (row) in `A_eq`.

`bounds`: array\_like

The bounds for each independent variable in the solution, which can take one of three forms:

None : The default bounds, all variables are non-negative. (lb, ub) : If a 2-element sequence is provided, the same lower bound (lb) and upper bound (ub) will be applied to all variables.

`[(lb_0, ub_0), (lb_1, ub_1), ...]`  
 [If an n x 2 sequence is provided,] each variable `x_i` will be bounded by `lb[i]` and `ub[i]`.

Infinite bounds are specified using `-np.inf` (negative) or `np.inf` (positive).

**callback** : callable

If a callback function is provide, it will be called within each iteration of the simplex algorithm. The callback must have the signature `callback(xk, **kwargs)` where `xk` is the current solution vector and `kwargs` is a dictionary containing the following:

```
"tableau" : The current Simplex algorithm tableau
"nit" : The current iteration.
"pivot" : The pivot (row, column) used for the next_
           iteration.
"phase" : Whether the algorithm is in Phase 1 or Phase_
           2.
"bv" : A structured array containing a string_
        representation of each
```

**Returns** A `scipy.optimize.OptimizeResult` consisting of the following fields:

<b>x</b>	[ndarray] The independent variable vector which optimizes the linear programming problem.
<b>fun</b>	[float] Value of the objective function.
<b>slack</b>	[ndarray] The values of the slack variables. Each slack variable corresponds to an inequality constraint. If the slack is zero, then the corresponding constraint is active.
<b>success</b>	[bool] Returns True if the algorithm succeeded in finding an optimal solution.
<b>status</b>	[int] An integer representing the exit status of the optimization:

```
0 : Optimization terminated successfully
1 : Iteration limit reached
2 : Problem appears to be infeasible
3 : Problem appears to be unbounded
```

<b>nit</b>	[int] The number of iterations performed.
<b>message</b>	[str] A string descriptor of the exit status of the optimization.

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.linprog`

**Options**

<b>maxiter</b> : int	The maximum number of iterations to perform.
<b>disp</b> : bool	If True, print exit status message to <code>sys.stdout</code>
<b>tol</b> : float	The tolerance which determines when a solution is “close enough” to zero in Phase 1 to be considered a basic feasible solution or close enough to positive to serve as an optimal solution.
<b>bland</b> : bool	

If True, use Bland's anti-cycling rule [3] to choose pivots to prevent cycling. If False, choose pivots which should lead to a converged solution more quickly. The latter method is subject to cycling (non-convergence) in rare instances.

### References

[R908], [R909], [R910]

### Examples

Consider the following problem:

Minimize:  $f = -1*x[0] + 4*x[1]$   
 Subject to:  $-3*x[0] + 1*x[1] \leq 6$

$$1*x[0] + 2*x[1] \leq 4$$

$$x[1] \geq -3$$

where:  $-\text{inf} \leq x[0] \leq \text{inf}$

This problem deviates from the standard linear programming problem. In standard form, linear programming problems assume the variables  $x$  are non-negative. Since the variables don't have standard bounds where  $0 \leq x \leq \text{inf}$ , the bounds of the variables must be explicitly set.

There are two upper-bound constraints, which can be expressed as

$$\text{dot}(A\_ub, x) \leq b\_ub$$

The input for this problem is as follows:

```
>>> from scipy.optimize import linprog
>>> c = [-1, 4]
>>> A = [[-3, 1], [1, 2]]
>>> b = [6, 4]
>>> x0_bnds = (None, None)
>>> x1_bnds = (-3, None)
>>> res = linprog(c, A, b, bounds=(x0_bnds, x1_bnds))
>>> print(res)
fun: -22.0
message: 'Optimization terminated successfully.'
nit: 1
slack: array([ 39.,  0.])
status: 0
success: True
x: array([ 10., -3.])
```

### linprog(method='interior-point')

`scipy.optimize.linprog(c, A_ub=None, b_ub=None, A_eq=None, b_eq=None, bounds=None, method='interior-point', callback=None, options={'disp': False, 'sym_pos': True, 'alpha0': 0.99995, 'cholesky': None, 'tol': 1e-08, 'rr': True, 'ip': False, 'permc_spec': 'MMD_AT_PLUS_A', 'pc': True, 'beta': 0.1, 'lstsq': False, 'sparse': False, 'maxiter': 1000, 'presolve': True, '_sparse_presolve': False})`

Minimize a linear objective function subject to linear equality constraints, linear inequality constraints, and simple bounds using the interior point method of [R901].

Linear programming is intended to solve problems of the following form:

```

Minimize:    c^T * x

Subject to:  A_ub * x <= b_ub
            A_eq * x == b_eq
            bounds[i][0] < x_i < bounds[i][1]

```

**Parameters** **c** : array\_like

Coefficients of the linear objective function to be minimized.

**A\_ub** : array\_like, optional

2-D array which, when matrix-multiplied by *x*, gives the values of the upper-bound inequality constraints at *x*.

**b\_ub** : array\_like, optional

1-D array of values representing the upper-bound of each inequality constraint (row) in *A\_ub*.

**A\_eq** : array\_like, optional

2-D array which, when matrix-multiplied by *x*, gives the values of the equality constraints at *x*.

**b\_eq** : array\_like, optional

1-D array of values representing the right hand side of each equality constraint (row) in *A\_eq*.

**bounds** : sequence, optional

(*min*, *max*) pairs for each element in *x*, defining the bounds on that parameter. Use *None* for one of *min* or *max* when there is no bound in that direction. By default bounds are (0, *None*) (non-negative). If a sequence containing a single tuple is provided, then *min* and *max* will be applied to all variables in the problem.

**Returns** A `scipy.optimize.OptimizeResult` consisting of the following fields:

**x** [ndarray] The independent variable vector which optimizes the linear programming problem.

**fun** [float] The optimal value of the objective function

**con** [float] The residuals of the equality constraints (nominally zero).

**slack** [ndarray] The values of the slack variables. Each slack variable corresponds to an inequality constraint. If the slack is zero, then the corresponding constraint is active.

**success** [bool] Returns True if the algorithm succeeded in finding an optimal solution.

**status** [int] An integer representing the exit status of the optimization:

```

0 : Optimization terminated successfully
1 : Iteration limit reached
2 : Problem appears to be infeasible
3 : Problem appears to be unbounded
4 : Serious numerical difficulties_
   ↳ encountered

```

**nit**  
**message**

[int] The number of iterations performed.  
[str] A string descriptor of the exit status of the optimization.

**See also:**

For documentation for the rest of the parameters, see `scipy.optimize.linprog`

**Options** **maxiter** : int (default = 1000)

The maximum number of iterations of the algorithm.

**disp** : bool (default = False)

Set to True if indicators of optimization status are to be printed to the console each iteration.

- tol** : float (default = 1e-8)  
Termination tolerance to be used for all termination criteria; see [R901] Section 4.5.
- alpha0** : float (default = 0.99995)  
The maximal step size for Mehrota's predictor-corrector search direction; see  $\beta_3$  of [R901] Table 8.1.
- beta** : float (default = 0.1)  
The desired reduction of the path parameter  $\mu$  (see [R903]) when Mehrota's predictor-corrector is not in use (uncommon).
- sparse** : bool (default = False)  
Set to `True` if the problem is to be treated as sparse after presolve. If either `A_eq` or `A_ub` is a sparse matrix, this option will automatically be set `True`, and the problem will be treated as sparse even during presolve. If your constraint matrices contain mostly zeros and the problem is not very small (less than about 100 constraints or variables), consider setting `True` or providing `A_eq` and `A_ub` as sparse matrices.
- lstsq** : bool (default = False)  
Set to `True` if the problem is expected to be very poorly conditioned. This should always be left `False` unless severe numerical difficulties are encountered. Leave this at the default unless you receive a warning message suggesting otherwise.
- sym\_pos** : bool (default = True)  
Leave `True` if the problem is expected to yield a well conditioned symmetric positive definite normal equation matrix (almost always). Leave this at the default unless you receive a warning message suggesting otherwise.
- cholesky** : bool (default = True)  
Set to `True` if the normal equations are to be solved by explicit Cholesky decomposition followed by explicit forward/backward substitution. This is typically faster for moderate, dense problems that are numerically well-behaved.
- pc** : bool (default = True)  
Leave `True` if the predictor-corrector method of Mehrota is to be used. This is almost always (if not always) beneficial.
- ip** : bool (default = False)  
Set to `True` if the improved initial point suggestion due to [R901] Section 4.3 is desired. Whether this is beneficial or not depends on the problem.
- presolve** : bool (default = True)  
Leave `True` if presolve routine should be run. The presolve routine is almost always useful because it can detect trivial infeasibilities and unbound-ness, eliminate fixed variables, and remove redundancies. One circumstance in which it might be turned off (set `False`) is when it detects that the problem is trivially unbounded; it is possible that that the problem is truly infeasible but this has not been detected.
- rr** : bool (default = True)  
Default `True` attempts to eliminate any redundant rows in `A_eq`. Set `False` if `A_eq` is known to be of full row rank, or if you are looking for a potential speedup (at the expense of reliability).
- permc\_spec** : str (default = 'MMD\_AT\_PLUS\_A')  
(Has effect only with `sparse = True`, `lstsq = False`, `sym_pos = True`.) A matrix is factorized in each iteration of the algorithm. This option specifies how to permute the columns of the matrix for sparsity preservation. Acceptable values are:
- `NATURAL`: natural ordering.

- MMD\_ATA: minimum degree ordering on the structure of  $A^T A$ .
- MMD\_AT\_PLUS\_A: minimum degree ordering on the structure of  $A^T + A$ .
- COLAMD: approximate minimum degree column ordering.

This option can impact the convergence of the interior point algorithm; test different values to determine which performs best for your problem. For more information, refer to `scipy.sparse.linalg.splu`.

### Notes

This method implements the algorithm outlined in [R901] with ideas from [R905] and a structure inspired by the simpler methods of [R903] and [R904].

First, a presolve procedure based on [R905] attempts to identify trivial infeasibilities, trivial unboundedness, and potential problem simplifications. Specifically, it checks for:

- rows of zeros in `A_eq` or `A_ub`, representing trivial constraints;
- columns of zeros in `A_eq` and `A_ub`, representing unconstrained variables;
- column singletons in `A_eq`, representing fixed variables; and
- column singletons in `A_ub`, representing simple bounds.

If presolve reveals that the problem is unbounded (e.g. an unconstrained and unbounded variable has negative cost) or infeasible (e.g. a row of zeros in `A_eq` corresponds with a nonzero in `b_eq`), the solver terminates with the appropriate status code. Note that presolve terminates as soon as any sign of unboundedness is detected; consequently, a problem may be reported as unbounded when in reality the problem is infeasible (but infeasibility has not been detected yet). Therefore, if the output message states that unboundedness is detected in presolve and it is necessary to know whether the problem is actually infeasible, set option `presolve=False`.

If neither infeasibility nor unboundedness are detected in a single pass of the presolve check, bounds are tightened where possible and fixed variables are removed from the problem. Then, linearly dependent rows of the `A_eq` matrix are removed, (unless they represent an infeasibility) to avoid numerical difficulties in the primary solve routine. Note that rows that are nearly linearly dependent (within a prescribed tolerance) may also be removed, which can change the optimal solution in rare cases. If this is a concern, eliminate redundancy from your problem formulation and run with option `rr=False` or `presolve=False`.

Several potential improvements can be made here: additional presolve checks outlined in [R905] should be implemented, the presolve routine should be run multiple times (until no further simplifications can be made), and more of the efficiency improvements from [R902] should be implemented in the redundancy removal routines.

After presolve, the problem is transformed to standard form by converting the (tightened) simple bounds to upper bound constraints, introducing non-negative slack variables for inequality constraints, and expressing unbounded variables as the difference between two non-negative variables.

The primal-dual path following method begins with initial ‘guesses’ of the primal and dual variables of the standard form problem and iteratively attempts to solve the (nonlinear) Karush-Kuhn-Tucker conditions for the problem with a gradually reduced logarithmic barrier term added to the objective. This particular implementation uses a homogeneous self-dual formulation, which provides certificates of infeasibility or unboundedness where applicable.

The default initial point for the primal and dual variables is that defined in [R901] Section 4.4 Equation 8.22. Optionally (by setting initial point option `ip=True`), an alternate (potentially improved) starting point can be calculated according to the additional recommendations of [R901] Section 4.4.

A search direction is calculated using the predictor-corrector method (single correction) proposed by Mehrotra and detailed in [R901] Section 4.1. (A potential improvement would be to implement the method of multiple corrections described in [R901] Section 4.2.) In practice, this is accomplished by solving the normal equations, [R901] Section 5.1 Equations 8.31 and 8.32, derived from the Newton equations [R901] Section 5 Equations 8.25 (compare to [R901] Section 4 Equations 8.6-8.8). The advantage of solving the normal equations rather than 8.25 directly is that the matrices involved are symmetric positive definite, so Cholesky decomposition can be used rather than the more expensive LU factorization.

With the default `cholesky=True`, this is accomplished using `scipy.linalg.cho_factor` followed by forward/backward substitutions via `scipy.linalg.cho_solve`. With `cholesky=False` and `sym_pos=True`, Cholesky decomposition is performed instead by `scipy.linalg.solve`. Based on speed tests, this also appears to retain the Cholesky decomposition of the matrix for later use, which is beneficial as the same system is solved four times with different right hand sides in each iteration of the algorithm.

In problems with redundancy (e.g. if `presolve` is turned off with option `presolve=False`) or if the matrices become ill-conditioned (e.g. as the solution is approached and some decision variables approach zero), Cholesky decomposition can fail. Should this occur, successively more robust solvers (`scipy.linalg.solve` with `sym_pos=False` then `scipy.linalg.lstsq`) are tried, at the cost of computational efficiency. These solvers can be used from the outset by setting the options `sym_pos=False` and `lstsq=True`, respectively.

Note that with the option `sparse=True`, the normal equations are solved using `scipy.sparse.linalg.spsolve`. Unfortunately, this uses the more expensive LU decomposition from the outset, but for large, sparse problems, the use of sparse linear algebra techniques improves the solve speed despite the use of LU rather than Cholesky decomposition. A simple improvement would be to use the sparse Cholesky decomposition of CHOLMOD via `scikit-sparse` when available.

Other potential improvements for combatting issues associated with dense columns in otherwise sparse problems are outlined in [R901] Section 5.3 and [R907] Section 4.1-4.2; the latter also discusses the alleviation of accuracy issues associated with the substitution approach to free variables.

After calculating the search direction, the maximum possible step size that does not activate the non-negativity constraints is calculated, and the smaller of this step size and unity is applied (as in [R901] Section 4.1.) [R901] Section 4.3 suggests improvements for choosing the step size.

The new point is tested according to the termination conditions of [R901] Section 4.5. The same tolerance, which can be set using the `tol` option, is used for all checks. (A potential improvement would be to expose the different tolerances to be set independently.) If optimality, unboundedness, or infeasibility is detected, the solve procedure terminates; otherwise it repeats.

If optimality is achieved, a `postsolve` procedure undoes transformations associated with `presolve` and converting to standard form. It then calculates the residuals (equality constraint violations, which should be very small) and slacks (difference between the left and right hand sides of the upper bound constraints) of the original problem, which are returned with the solution in an `OptimizeResult` object.

### References

[R901], [R902], [R903], [R904], [R905], [R906], [R907]

The simplex method supports callback functions, such as:

<code>linprog_verbose_callback(xk, **kwargs)</code>	A sample callback function demonstrating the linprog callback interface.
---	--

---

`scipy.optimize.linprog_verbose_callback(xk, **kwargs)`

A sample callback function demonstrating the linprog callback interface. This callback produces detailed output to `sys.stdout` before each iteration and after the final iteration of the simplex algorithm.

**Parameters**

- xk** : array\_like  
The current solution vector.
- \*\*kwargs** : dict  
A dictionary containing the following parameters:
  - tableau** [array\_like] The current tableau of the simplex algorithm. Its structure is defined in `._solve_simplex`.
  - phase** [int] The current phase of the simplex algorithm (1 or 2)
  - nit** [int] The current iteration number.
  - pivot** [tuple(int, int)] The index of the tableau selected as the next pivot, or nan if no pivot exists

**basis** [array(int)] A list of the current basic variables. Each element contains the name of a basic variable and its value.

**complete** [bool] True if the simplex algorithm has completed (and this is the final call to callback), otherwise False.

Assignment problems:

---

`linear_sum_assignment(cost_matrix)` Solve the linear sum assignment problem.

---

`scipy.optimize.linear_sum_assignment(cost_matrix)`  
Solve the linear sum assignment problem.

The linear sum assignment problem is also known as minimum weight matching in bipartite graphs. A problem instance is described by a matrix  $C$ , where each  $C[i,j]$  is the cost of matching vertex  $i$  of the first partite set (a “worker”) and vertex  $j$  of the second set (a “job”). The goal is to find a complete assignment of workers to jobs of minimal cost.

Formally, let  $X$  be a boolean matrix where  $X[i,j] = 1$  iff row  $i$  is assigned to column  $j$ . Then the optimal assignment has cost

$$\min \sum_i \sum_j C_{i,j} X_{i,j}$$

s.t. each row is assignment to at most one column, and each column to at most one row.

This function can also solve a generalization of the classic assignment problem where the cost matrix is rectangular. If it has more rows than columns, then not every row needs to be assigned to a column, and vice versa.

The method used is the Hungarian algorithm, also known as the Munkres or Kuhn-Munkres algorithm.

**Parameters** **cost\_matrix**: array  
The cost matrix of the bipartite graph.

**Returns** **row\_ind, col\_ind**: array  
An array of row indices and one of corresponding column indices giving the optimal assignment. The cost of the assignment can be computed as `cost_matrix[row_ind, col_ind].sum()`. The row indices will be sorted; in the case of a square cost matrix they will be equal to `numpy.arange(cost_matrix.shape[0])`.

### Notes

New in version 0.17.0.

### References

- 1.<http://csclab.murraystate.edu/bob.pilgrim/445/munkres.html>
- 2.Harold W. Kuhn. The Hungarian Method for the assignment problem. *Naval Research Logistics Quarterly*, 2:83-97, 1955.
- 3.Harold W. Kuhn. Variants of the Hungarian method for assignment problems. *Naval Research Logistics Quarterly*, 3: 253-258, 1956.
- 4.Munkres, J. Algorithms for the Assignment and Transportation Problems. *J. SIAM*, 5(1):32-38, March, 1957.
- 5.[https://en.wikipedia.org/wiki/Hungarian\\_algorithm](https://en.wikipedia.org/wiki/Hungarian_algorithm)

### Examples

```
>>> cost = np.array([[4, 1, 3], [2, 0, 5], [3, 2, 2]])
>>> from scipy.optimize import linear_sum_assignment
```

```
>>> row_ind, col_ind = linear_sum_assignment(cost)
>>> col_ind
array([1, 0, 2])
>>> cost[row_ind, col_ind].sum()
5
```

### 5.18.5 Utilities

<code>approx_fprime(xk, f, epsilon, *args)</code>	Finite-difference approximation of the gradient of a scalar function.
<code>bracket(func[, xa, xb, args, grow_limit, ...])</code>	Bracket the minimum of the function.
<code>check_grad(func, grad, x0, *args, **kwargs)</code>	Check the correctness of a gradient function by comparing it against a (forward) finite-difference approximation of the gradient.
<code>line_search(f, myfprime, xk, pk[, gfk, ...])</code>	Find alpha that satisfies strong Wolfe conditions.
<code>show_options([solver, method, disp])</code>	Show documentation for additional options of optimization solvers.
<code>LbfgsInvHessProduct(sk, yk)</code>	Linear operator for the L-BFGS approximate inverse Hessian.

`scipy.optimize.approx_fprime(xk, f, epsilon, *args)`

Finite-difference approximation of the gradient of a scalar function.

**Parameters** `xk` : array\_like

The coordinate vector at which to determine the gradient of  $f$ .

`f` : callable

The function of which to determine the gradient (partial derivatives). Should take  $xk$  as first argument, other arguments to  $f$  can be supplied in `*args`. Should return a scalar, the value of the function at  $xk$ .

`epsilon` : array\_like

Increment to  $xk$  to use for determining the function gradient. If a scalar, uses the same finite difference delta for all partial derivatives. If an array, should contain one value per element of  $xk$ .

`*args` : args, optional

Any other arguments that are to be passed to  $f$ .

**Returns**

`grad` : ndarray

The partial derivatives of  $f$  to  $xk$ .

**See also:**

`check_grad` Check correctness of gradient function against `approx_fprime`.

**Notes**

The function gradient is determined by the forward finite difference formula:

$$f'[i] = \frac{f(xk[i] + \epsilon[i]) - f(xk[i])}{\epsilon[i]}$$

The main use of `approx_fprime` is in scalar function optimizers like `fmin_bfgs`, to determine numerically the Jacobian of a function.

**Examples**

```
>>> from scipy import optimize
>>> def func(x, c0, c1):
...     "Coordinate vector `x` should be an array of size two."
...     return c0 * x[0]**2 + c1*x[1]**2
```

```
>>> x = np.ones(2)
>>> c0, c1 = (1, 200)
>>> eps = np.sqrt(np.finfo(float).eps)
>>> optimize.approx_fprime(x, func, [eps, np.sqrt(200) * eps], c0, c1)
array([ 2.          , 400.00004198])
```

`scipy.optimize.bracket` (*func*, *xa=0.0*, *xb=1.0*, *args=()*, *grow\_limit=110.0*, *maxiter=1000*)

Bracket the minimum of the function.

Given a function and distinct initial points, search in the downhill direction (as defined by the initial points) and return new points *xa*, *xb*, *xc* that bracket the minimum of the function  $f(xa) > f(xb) < f(xc)$ . It doesn't always mean that obtained solution will satisfy  $xa \leq x \leq xb$

**Parameters**

- func** : callable  $f(x, *args)$   
Objective function to minimize.
- xa, xb** : float, optional  
Bracketing interval. Defaults *xa* to 0.0, and *xb* to 1.0.
- args** : tuple, optional  
Additional arguments (if present), passed to *func*.
- grow\_limit** : float, optional  
Maximum grow limit. Defaults to 110.0
- maxiter** : int, optional  
Maximum number of iterations to perform. Defaults to 1000.

**Returns**

- xa, xb, xc** : float  
Bracket.
- fa, fb, fc** : float  
Objective function values in bracket.
- funcalls** : int  
Number of function evaluations made.

`scipy.optimize.check_grad` (*func*, *grad*, *x0*, *\*args*, *\*\*kwargs*)

Check the correctness of a gradient function by comparing it against a (forward) finite-difference approximation of the gradient.

**Parameters**

- func** : callable  $func(x0, *args)$   
Function whose derivative is to be checked.
- grad** : callable  $grad(x0, *args)$   
Gradient of *func*.
- x0** : ndarray  
Points to check *grad* against forward difference approximation of *grad* using *func*.
- args** : *\*args*, optional  
Extra arguments passed to *func* and *grad*.
- epsilon** : float, optional  
Step size used for the finite difference approximation. It defaults to  $\sqrt{\text{numpy.finfo(float).eps}}$ , which is approximately 1.49e-08.

**Returns**

- err** : float  
The square root of the sum of squares (i.e. the 2-norm) of the difference between  $grad(x0, *args)$  and the finite difference approximation of *grad* using *func* at the points *x0*.

See also:

`approx_fprime`

**Examples**

```
>>> def func(x):
...     return x[0]**2 - 0.5 * x[1]**3
>>> def grad(x):
...     return [2 * x[0], -1.5 * x[1]**2]
>>> from scipy.optimize import check_grad
>>> check_grad(func, grad, [1.5, -1.5])
2.9802322387695312e-08
```

`scipy.optimize.line_search` (*f*, *myfprime*, *xk*, *pk*, *gfk=None*, *old\_fval=None*, *old\_old\_fval=None*, *args=()*, *c1=0.0001*, *c2=0.9*, *amax=None*, *extra\_condition=None*, *maxiter=10*)

Find alpha that satisfies strong Wolfe conditions.

- Parameters**
- f**: callable *f*(*x*,\**args*)  
Objective function.
  - myfprime**: callable *f'*(*x*,\**args*)  
Objective function gradient.
  - xk**: ndarray  
Starting point.
  - pk**: ndarray  
Search direction.
  - gfk**: ndarray, optional  
Gradient value for *x*=*xk* (*xk* being the current parameter estimate). Will be recomputed if omitted.
  - old\_fval**: float, optional  
Function value for *x*=*xk*. Will be recomputed if omitted.
  - old\_old\_fval**: float, optional  
Function value for the point preceding *x*=*xk*
  - args**: tuple, optional  
Additional arguments passed to objective function.
  - c1**: float, optional  
Parameter for Armijo condition rule.
  - c2**: float, optional  
Parameter for curvature condition rule.
  - amax**: float, optional  
Maximum step size
  - extra\_condition**: callable, optional  
A callable of the form `extra_condition(alpha, x, f, g)` returning a boolean. Arguments are the proposed step *alpha* and the corresponding *x*, *f* and *g* values. The line search accepts the value of *alpha* only if this callable returns `True`. If the callable returns `False` for the step length, the algorithm will continue with new iterates. The callable is only called for iterates satisfying the strong Wolfe conditions.
  - maxiter**: int, optional  
Maximum number of iterations to perform
- Returns**
- alpha**: float or None  
Alpha for which  $x_{new} = x_0 + alpha * pk$ , or None if the line search algorithm did not converge.
  - fc**: int  
Number of function evaluations made.
  - gc**: int

Number of gradient evaluations made.

**new\_fval** : float or None  
New function value  $f(x_{\text{new}}) = f(x_0 + \alpha * pk)$ , or None if the line search algorithm did not converge.

**old\_fval** : float  
Old function value  $f(x_0)$ .

**new\_slope** : float or None  
The local slope along the search direction at the new value  $\langle \text{myfprime}(x_{\text{new}}), pk \rangle$ , or None if the line search algorithm did not converge.

**Notes**

Uses the line search algorithm to enforce strong Wolfe conditions. See Wright and Nocedal, ‘Numerical Optimization’, 1999, pg. 59-60.

For the zoom phase it uses an algorithm by [...].

`scipy.optimize.show_options(solver=None, method=None, disp=True)`

Show documentation for additional options of optimization solvers.

These are method-specific options that can be supplied through the `options` dict.

<b>Parameters</b>	<b>solver</b> : str	Type of optimization solver. One of ‘minimize’, ‘minimize_scalar’, ‘root’, or ‘linprog’.
	<b>method</b> : str, optional	If not given, shows all methods of the specified solver. Otherwise, show only the options for the specified method. Valid values corresponds to methods’ names of respective solver (e.g. ‘BFGS’ for ‘minimize’).
	<b>disp</b> : bool, optional	Whether to print the result rather than returning it.
<b>Returns</b>	text	Either None (for <code>disp=False</code> ) or the text string ( <code>disp=True</code> )

**Notes**

The solver-specific methods are:

`scipy.optimize.minimize`

- Nelder-Mead
- Powell
- CG
- BFGS
- Newton-CG
- L-BFGS-B
- TNC
- COBYLA
- SLSQP
- dogleg
- trust-ncg

`scipy.optimize.root`

- hybr
- lm
- broyden1
- broyden2
- anderson
- linearmixing

- diagbroyden*
- excitingmixing*
- krylov*
- df-sane*
- scipy.optimize.minimize\_scalar*
  - brent*
  - golden*
  - bounded*
- scipy.optimize.linprog*
  - simplex*
  - interior-point*

**class** `scipy.optimize.LbfgsInvHessProduct` (*sk*, *yk*)  
 Linear operator for the L-BFGS approximate inverse Hessian.

This operator computes the product of a vector with the approximate inverse of the Hessian of the objective function, using the L-BFGS limited memory approximation to the inverse Hessian, accumulated during the optimization.

Objects of this class implement the `scipy.sparse.linalg.LinearOperator` interface.

- Parameters**
- sk** : array\_like, shape=(*n\_corr*, *n*)  
 Array of *n\_corr* most recent updates to the solution vector. (See [1]).
  - yk** : array\_like, shape=(*n\_corr*, *n*)  
 Array of *n\_corr* most recent updates to the gradient. (See [1]).

**References**

[R187]

**Attributes**

<i>H</i>	Hermitian adjoint.
<i>T</i>	Transpose this linear operator.

`LbfgsInvHessProduct.H`

Hermitian adjoint.

Returns the Hermitian adjoint of self, aka the Hermitian conjugate or Hermitian transpose. For a complex matrix, the Hermitian adjoint is equal to the conjugate transpose.

Can be abbreviated `self.H` instead of `self.adjoint()`.

- Returns** **A\_H** : LinearOperator  
 Hermitian adjoint of self.

`LbfgsInvHessProduct.T`

Transpose this linear operator.

Returns a LinearOperator that represents the transpose of this one. Can be abbreviated `self.T` instead of `self.transpose()`.

**Methods**

<code>__call__(x)</code>	
<code>adjoint()</code>	Hermitian adjoint.
<code>dot(x)</code>	Matrix-matrix or matrix-vector multiplication.

Continued on next page

Table 5.134 – continued from previous page

<code>matmat(X)</code>	Matrix-matrix multiplication.
<code>matvec(x)</code>	Matrix-vector multiplication.
<code>rmatvec(x)</code>	Adjoint matrix-vector multiplication.
<code>todense()</code>	Return a dense array representation of this operator.
<code>transpose()</code>	Transpose this linear operator.

`LbfgsInvHessProduct.__call__(x)`

`LbfgsInvHessProduct.adjoint()`

Hermitian adjoint.

Returns the Hermitian adjoint of self, aka the Hermitian conjugate or Hermitian transpose. For a complex matrix, the Hermitian adjoint is equal to the conjugate transpose.

Can be abbreviated self.H instead of self.adjoint().

**Returns** **A\_H** : LinearOperator  
Hermitian adjoint of self.

`LbfgsInvHessProduct.dot(x)`

Matrix-matrix or matrix-vector multiplication.

**Parameters** **x** : array\_like

**Returns** **Ax** : array 1-d or 2-d array, representing a vector or matrix.

1-d or 2-d array (depending on the shape of x) that represents the result of applying this linear operator on x.

`LbfgsInvHessProduct.matmat(X)`

Matrix-matrix multiplication.

Performs the operation  $y=A*X$  where A is an MxN linear operator and X dense N\*K matrix or ndarray.

**Parameters** **X** : {matrix, ndarray}

**Returns** **Y** : {matrix, ndarray} An array with shape (N,K).

A matrix or ndarray with shape (M,K) depending on the type of the X argument.

#### Notes

This matmat wraps any user-specified matmat routine or overridden `_matmat` method to ensure that y has the correct type.

`LbfgsInvHessProduct.matvec(x)`

Matrix-vector multiplication.

Performs the operation  $y=A*x$  where A is an MxN linear operator and x is a column vector or 1-d array.

**Parameters** **x** : {matrix, ndarray}

**Returns** **y** : {matrix, ndarray} An array with shape (N,) or (N,1).

A matrix or ndarray with shape (M,) or (M,1) depending on the type and shape of the x argument.

#### Notes

This matvec wraps the user-specified matvec routine or overridden `_matvec` method to ensure that y has the correct shape and type.

`LbfgsInvHessProduct.rmatvec(x)`

Adjoint matrix-vector multiplication.

Performs the operation  $y = A^H * x$  where  $A$  is an  $M \times N$  linear operator and  $x$  is a column vector or 1-d array.

**Parameters** `x` : {matrix, ndarray}

**Returns** `y` : {matrix, ndarray} An array with shape (M,) or (M,1).

A matrix or ndarray with shape (N,) or (N,1) depending on the type and shape of the `x` argument.

**Notes**

This `rmatvec` wraps the user-specified `rmatvec` routine or overridden `_rmatvec` method to ensure that `y` has the correct shape and type.

`LbfgsInvHessProduct.todense()`

Return a dense array representation of this operator.

**Returns** `arr` : ndarray, shape=(n, n)

An array with the same shape and containing the same data represented by this *LinearOperator*.

`LbfgsInvHessProduct.transpose()`

Transpose this linear operator.

Returns a *LinearOperator* that represents the transpose of this one. Can be abbreviated `self.T` instead of `self.transpose()`.

## 5.19 Nonlinear solvers

This is a collection of general-purpose nonlinear multidimensional solvers. These solvers find  $x$  for which  $F(x) = 0$ . Both  $x$  and  $F$  can be multidimensional.

### 5.19.1 Routines

Large-scale nonlinear solvers:

<code>newton_krylov(F, xin[, iter, rdiff, method, ...])</code>	Find a root of a function, using Krylov approximation for inverse Jacobian.
<code>anderson(F, xin[, iter, alpha, w0, M, ...])</code>	Find a root of a function, using (extended) Anderson mixing.

General nonlinear solvers:

<code>broyden1(F, xin[, iter, alpha, ...])</code>	Find a root of a function, using Broyden's first Jacobian approximation.
<code>broyden2(F, xin[, iter, alpha, ...])</code>	Find a root of a function, using Broyden's second Jacobian approximation.

Simple iterations:

<code>excitingmixing(F, xin[, iter, alpha, ...])</code>	Find a root of a function, using a tuned diagonal Jacobian approximation.
<code>linearmixing(F, xin[, iter, alpha, verbose, ...])</code>	Find a root of a function, using a scalar Jacobian approximation.
<code>diagbroyden(F, xin[, iter, alpha, verbose, ...])</code>	Find a root of a function, using diagonal Broyden Jacobian approximation.

## 5.19.2 Examples

### Small problem

```
>>> def F(x):
...     return np.cos(x) + x[::-1] - [1, 2, 3, 4]
>>> import scipy.optimize
>>> x = scipy.optimize.broyden1(F, [1,1,1,1], f_tol=1e-14)
>>> x
array([ 4.04674914,  3.91158389,  2.71791677,  1.61756251])
>>> np.cos(x) + x[::-1]
array([ 1.,  2.,  3.,  4.])
```

### Large problem

Suppose that we needed to solve the following integrodifferential equation on the square  $[0, 1] \times [0, 1]$ :

$$\nabla^2 P = 10 \left( \int_0^1 \int_0^1 \cosh(P) dx dy \right)^2$$

with  $P(x, 1) = 1$  and  $P = 0$  elsewhere on the boundary of the square.

The solution can be found using the `newton_krylov` solver:

```
import numpy as np
from scipy.optimize import newton_krylov
from numpy import cosh, zeros_like, mgrid, zeros

# parameters
nx, ny = 75, 75
hx, hy = 1./(nx-1), 1./(ny-1)

P_left, P_right = 0, 0
P_top, P_bottom = 1, 0

def residual(P):
    d2x = zeros_like(P)
    d2y = zeros_like(P)

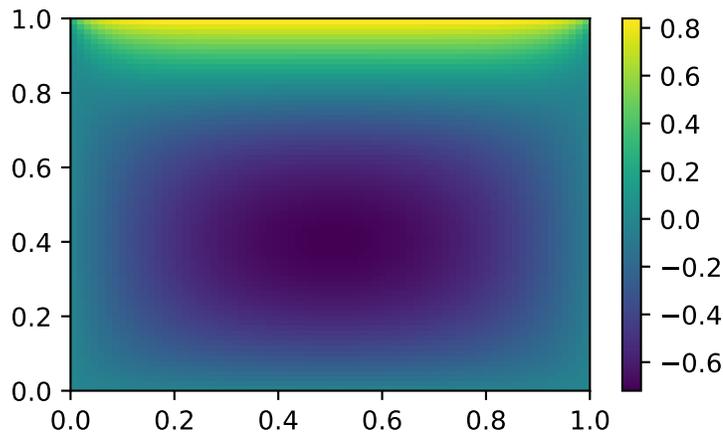
    d2x[1:-1] = (P[2:] - 2*P[1:-1] + P[:-2]) / hx/hx
    d2x[0] = (P[1] - 2*P[0] + P_left) / hx/hx
    d2x[-1] = (P_right - 2*P[-1] + P[-2]) / hx/hx

    d2y[:,1:-1] = (P[:,2:] - 2*P[:,1:-1] + P[:, :-2]) / hy/hy
    d2y[:,0] = (P[:,1] - 2*P[:,0] + P_bottom) / hy/hy
    d2y[:, -1] = (P_top - 2*P[:, -1] + P[:, -2]) / hy/hy

    return d2x + d2y - 10*cosh(P).mean()**2
```

```
# solve
guess = zeros((nx, ny), float)
sol = newton_krylov(residual, guess, method='lgmres', verbose=1)
print('Residual: %g' % abs(residual(sol)).max())

# visualize
import matplotlib.pyplot as plt
x, y = mgrid[0:1:(nx*1j), 0:1:(ny*1j)]
plt.pcolor(x, y, sol)
plt.colorbar()
plt.show()
```



## 5.20 Signal processing (`scipy.signal`)

### 5.20.1 Convolution

<code>convolve(in1, in2[, mode, method])</code>	Convolve two N-dimensional arrays.
<code>correlate(in1, in2[, mode, method])</code>	Cross-correlate two N-dimensional arrays.
<code>fftconvolve(in1, in2[, mode])</code>	Convolve two N-dimensional arrays using FFT.
<code>convolve2d(in1, in2[, mode, boundary, fillvalue])</code>	Convolve two 2-dimensional arrays.
<code>correlate2d(in1, in2[, mode, boundary, ...])</code>	Cross-correlate two 2-dimensional arrays.
<code>sepfir2d((input, hrow, hcol) -&gt; output)</code>	Description:
<code>choose_conv_method(in1, in2[, mode, measure])</code>	Find the fastest convolution/correlation method.

`scipy.signal.convolve` (*in1*, *in2*, *mode*='full', *method*='auto')

Convolve two N-dimensional arrays.

Convolve *in1* and *in2*, with the output size determined by the *mode* argument.

**Parameters** **in1** : array\_like  
First input.

**in2** : array\_like  
Second input. Should have the same number of dimensions as *in1*.

**mode** : str { 'full', 'valid', 'same' }, optional  
 A string indicating the size of the output:

- full** The output is the full discrete linear convolution of the inputs. (Default)
- valid** The output consists only of those elements that do not rely on the zero-padding. In 'valid' mode, either *in1* or *in2* must be at least as large as the other in every dimension.
- same** The output is the same size as *in1*, centered with respect to the 'full' output.

**method** : str { 'auto', 'direct', 'fft' }, optional  
 A string indicating which method to use to calculate the convolution.

- direct** The convolution is determined directly from sums, the definition of convolution.
- fft** The Fourier Transform is used to perform the convolution by calling `fftconvolve`.
- auto** Automatically chooses direct or Fourier method based on an estimate of which is faster (default). See Notes for more detail.

**Returns** **convolve** : array  
 An N-dimensional array containing a subset of the discrete linear convolution of *in1* with *in2*.  
 New in version 0.19.0.

**See also:**`numpy.polymul`

performs polynomial multiplication (same operation, but also accepts poly1d objects)

`choose_conv_method`

chooses the fastest appropriate convolution method

`fftconvolve`**Notes**

By default, `convolve` and `correlate` use `method='auto'`, which calls `choose_conv_method` to choose the fastest method using pre-computed values (`choose_conv_method` can also measure real-world timing with a keyword argument). Because `fftconvolve` relies on floating point numbers, there are certain constraints that may force `method=direct` (more detail in `choose_conv_method` docstring).

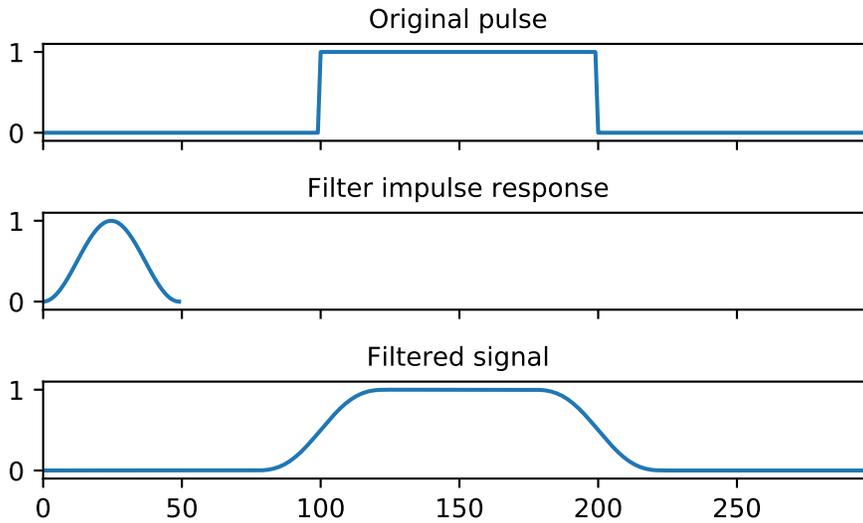
**Examples**

Smooth a square pulse using a Hann window:

```
>>> from scipy import signal
>>> sig = np.repeat([0., 1., 0.], 100)
>>> win = signal.hann(50)
>>> filtered = signal.convolve(sig, win, mode='same') / sum(win)
```

```
>>> import matplotlib.pyplot as plt
>>> fig, (ax_orig, ax_win, ax_filt) = plt.subplots(3, 1, sharex=True)
>>> ax_orig.plot(sig)
>>> ax_orig.set_title('Original pulse')
>>> ax_orig.margins(0, 0.1)
>>> ax_win.plot(win)
>>> ax_win.set_title('Filter impulse response')
>>> ax_win.margins(0, 0.1)
>>> ax_filt.plot(filtered)
>>> ax_filt.set_title('Filtered signal')
>>> ax_filt.margins(0, 0.1)
```

```
>>> fig.tight_layout()
>>> fig.show()
```



`scipy.signal.correlate` (*in1*, *in2*, *mode*='full', *method*='auto')

Cross-correlate two N-dimensional arrays.

Cross-correlate *in1* and *in2*, with the output size determined by the *mode* argument.

**Parameters**

- in1** : array\_like  
First input.
- in2** : array\_like  
Second input. Should have the same number of dimensions as *in1*.
- mode** : str {'full', 'valid', 'same'}, optional  
A string indicating the size of the output:
  - full** : The output is the full discrete linear cross-correlation of the inputs. (Default)
  - valid** : The output consists only of those elements that do not rely on the zero-padding. In 'valid' mode, either *in1* or *in2* must be at least as large as the other in every dimension.
  - same** : The output is the same size as *in1*, centered with respect to the 'full' output.
- method** : str {'auto', 'direct', 'fft'}, optional  
A string indicating which method to use to calculate the correlation.
  - direct** : The correlation is determined directly from sums, the definition of correlation.
  - fft** : The Fast Fourier Transform is used to perform the correlation more quickly (only available for numerical arrays.)
  - auto** : Automatically chooses direct or Fourier method based on an estimate of which is faster (default). See *convolve* Notes for more detail.

**Returns**

- correlate** : array  
An N-dimensional array containing a subset of the discrete linear cross-correlation of *in1* with *in2*.

New in version 0.19.0.

See also:

`choose_conv_method`

contains more documentation on *method*.

**Notes**

The correlation  $z$  of two  $d$ -dimensional arrays  $x$  and  $y$  is defined as:

$$z[\dots, k, \dots] = \text{sum}[\dots, i_1, \dots] x[\dots, i_1, \dots] * \text{conj}(y[\dots, i_1 - k, \dots])$$

This way, if  $x$  and  $y$  are 1-D arrays and  $z = \text{correlate}(x, y, \text{'full'})$  then

$$z[k] = (x * y)(k - N + 1) = \sum_{l=0}^{|x|-1} x_l y_{l-k+N-1}^*$$

for  $k = 0, 1, \dots, |x| + |y| - 2$

where  $|x|$  is the length of  $x$ ,  $N = \max(|x|, |y|)$ , and  $y_m$  is 0 when  $m$  is outside the range of  $y$ .

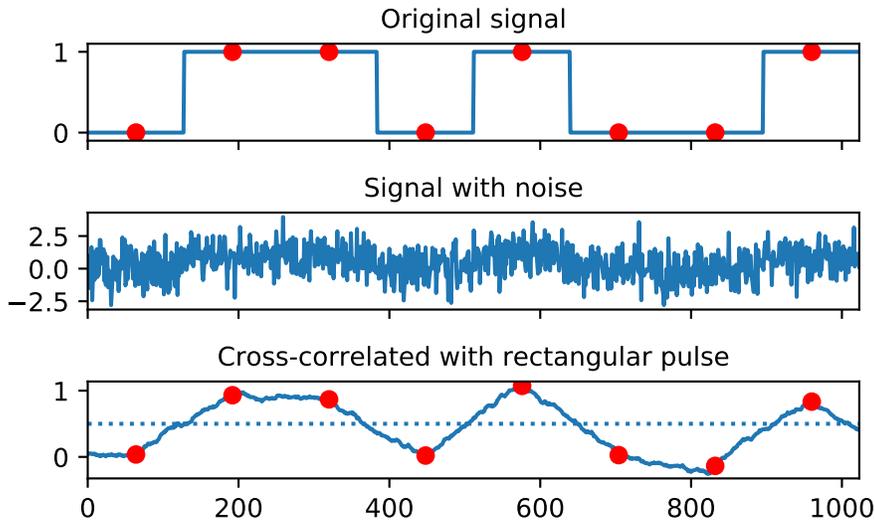
`method='fft'` only works for numerical arrays as it relies on `fftconvolve`. In certain cases (i.e., arrays of objects or when rounding integers can lose precision), `method='direct'` is always used.

**Examples**

Implement a matched filter using cross-correlation, to recover a signal that has passed through a noisy channel.

```
>>> from scipy import signal
>>> sig = np.repeat([0., 1., 1., 0., 1., 0., 0., 1.], 128)
>>> sig_noise = sig + np.random.randn(len(sig))
>>> corr = signal.correlate(sig_noise, np.ones(128), mode='same') / 128
```

```
>>> import matplotlib.pyplot as plt
>>> clock = np.arange(64, len(sig), 128)
>>> fig, (ax_orig, ax_noise, ax_corr) = plt.subplots(3, 1, sharex=True)
>>> ax_orig.plot(sig)
>>> ax_orig.plot(clock, sig[clock], 'ro')
>>> ax_orig.set_title('Original signal')
>>> ax_noise.plot(sig_noise)
>>> ax_noise.set_title('Signal with noise')
>>> ax_corr.plot(corr)
>>> ax_corr.plot(clock, corr[clock], 'ro')
>>> ax_corr.axhline(0.5, ls=':')
>>> ax_corr.set_title('Cross-correlated with rectangular pulse')
>>> ax_orig.margins(0, 0.1)
>>> fig.tight_layout()
>>> fig.show()
```



`scipy.signal.fftconvolve` (*in1*, *in2*, *mode*='full')

Convolve two N-dimensional arrays using FFT.

Convolve *in1* and *in2* using the fast Fourier transform method, with the output size determined by the *mode* argument.

This is generally much faster than `convolve` for large arrays ( $n > \sim 500$ ), but can be slower when only a few output values are needed, and can only output float arrays (int or object array inputs will be cast to float).

As of v0.19, `convolve` automatically chooses this method or the direct method based on an estimation of which is faster.

**Parameters**

**in1** : array\_like  
First input.

**in2** : array\_like  
Second input. Should have the same number of dimensions as *in1*. If operating in 'valid' mode, either *in1* or *in2* must be at least as large as the other in every dimension.

**mode** : str {'full', 'valid', 'same'}, optional  
A string indicating the size of the output:

- full**        The output is the full discrete linear convolution of the inputs. (Default)
- valid**        The output consists only of those elements that do not rely on the zero-padding.
- same**         The output is the same size as *in1*, centered with respect to the 'full' output.

**Returns**

**out** : array  
An N-dimensional array containing a subset of the discrete linear convolution of *in1* with *in2*.

### Examples

Autocorrelation of white noise is an impulse.

```
>>> from scipy import signal
>>> sig = np.random.randn(1000)
>>> autocorr = signal.fftconvolve(sig, sig[::-1], mode='full')
```

```

>>> import matplotlib.pyplot as plt
>>> fig, (ax_orig, ax_mag) = plt.subplots(2, 1)
>>> ax_orig.plot(sig)
>>> ax_orig.set_title('White noise')
>>> ax_mag.plot(np.arange(-len(sig)+1, len(sig)), autocorr)
>>> ax_mag.set_title('Autocorrelation')
>>> fig.tight_layout()
>>> fig.show()

```

Gaussian blur implemented using FFT convolution. Notice the dark borders around the image, due to the zero-padding beyond its boundaries. The `convolve2d` function allows for other types of image boundaries, but is far slower.

```

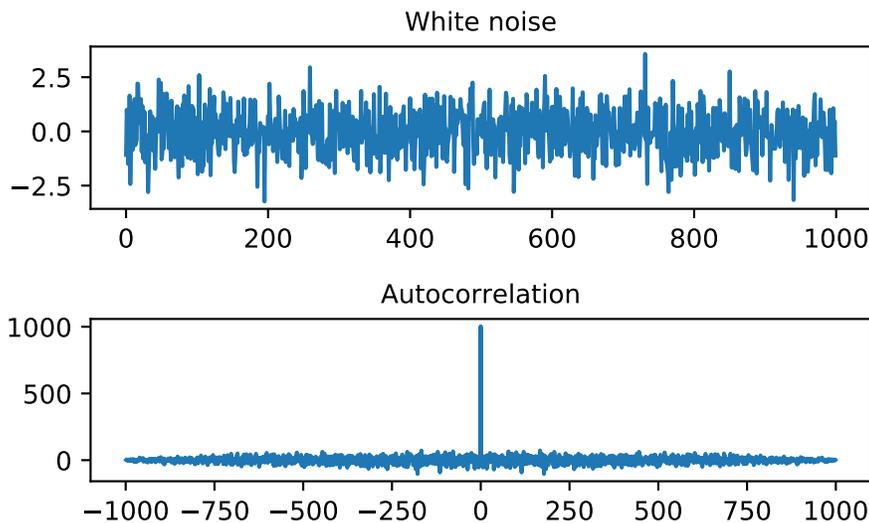
>>> from scipy import misc
>>> face = misc.face(gray=True)
>>> kernel = np.outer(signal.gaussian(70, 8), signal.gaussian(70, 8))
>>> blurred = signal.fftconvolve(face, kernel, mode='same')

```

```

>>> fig, (ax_orig, ax_kernel, ax_blurred) = plt.subplots(3, 1,
...                                                    figsize=(6, 15))
>>> ax_orig.imshow(face, cmap='gray')
>>> ax_orig.set_title('Original')
>>> ax_orig.set_axis_off()
>>> ax_kernel.imshow(kernel, cmap='gray')
>>> ax_kernel.set_title('Gaussian kernel')
>>> ax_kernel.set_axis_off()
>>> ax_blurred.imshow(blurred, cmap='gray')
>>> ax_blurred.set_title('Blurred')
>>> ax_blurred.set_axis_off()
>>> fig.show()

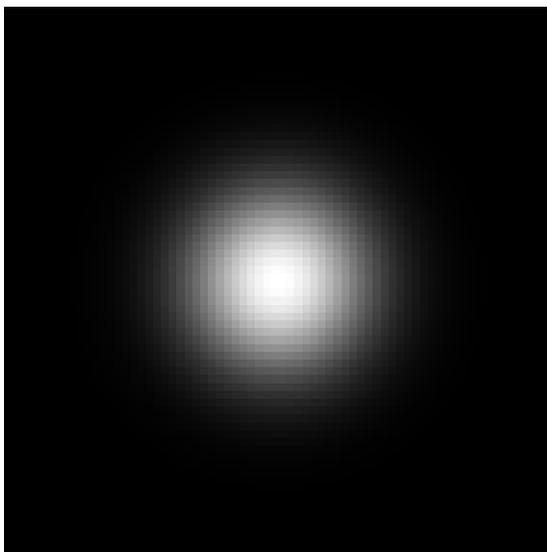
```



Original



Gaussian kernel



Blurred



`scipy.signal.convolve2d`(*in1*, *in2*, *mode*='full', *boundary*='fill', *fillvalue*=0)

Convolve two 2-dimensional arrays.

Convolve *in1* and *in2* with output size determined by *mode*, and boundary conditions determined by *boundary* and *fillvalue*.

**Parameters**

**in1** : array\_like  
First input.

**in2** : array\_like  
Second input. Should have the same number of dimensions as *in1*. If operating in 'valid' mode, either *in1* or *in2* must be at least as large as the other in every dimension.

**mode** : str {'full', 'valid', 'same'}, optional  
A string indicating the size of the output:  
**full**        The output is the full discrete linear convolution of the inputs. (Default)  
**valid**        The output consists only of those elements that do not rely on the zero-padding.  
**same**         The output is the same size as *in1*, centered with respect to the 'full' output.

**boundary** : str {'fill', 'wrap', 'symm'}, optional  
A flag indicating how to handle boundaries:  
**fill**         pad input arrays with *fillvalue*. (default)  
**wrap**         circular boundary conditions.  
**symm**         symmetrical boundary conditions.

**fillvalue** : scalar, optional  
Value to fill pad input arrays with. Default is 0.

**Returns**

**out** : ndarray  
A 2-dimensional array containing a subset of the discrete linear convolution of *in1* with *in2*.

### Examples

Compute the gradient of an image by 2D convolution with a complex Scharr operator. (Horizontal operator is real, vertical is imaginary.) Use symmetric boundary condition to avoid creating edges at the image boundaries.

```
>>> from scipy import signal
>>> from scipy import misc
>>> ascent = misc.ascent()
>>> scharr = np.array([[ -3-3j,  0-10j,  +3 -3j],
...                  [-10+0j,  0+ 0j,  +10 +0j],
...                  [ -3+3j,  0+10j,  +3 +3j]]) # Gx + j*Gy
>>> grad = signal.convolve2d(ascent, scharr, boundary='symm', mode='same')
```

```
>>> import matplotlib.pyplot as plt
>>> fig, (ax_orig, ax_mag, ax_ang) = plt.subplots(3, 1, figsize=(6, 15))
>>> ax_orig.imshow(ascent, cmap='gray')
>>> ax_orig.set_title('Original')
>>> ax_orig.set_axis_off()
>>> ax_mag.imshow(np.absolute(grad), cmap='gray')
>>> ax_mag.set_title('Gradient magnitude')
>>> ax_mag.set_axis_off()
>>> ax_ang.imshow(np.angle(grad), cmap='hsv') # hsv is cyclic, like angles
>>> ax_ang.set_title('Gradient orientation')
>>> ax_ang.set_axis_off()
>>> fig.show()
```

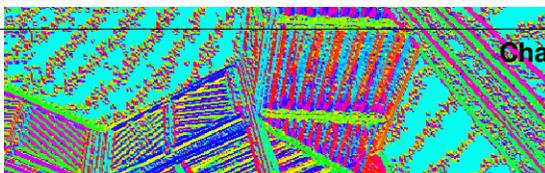
Original



Gradient magnitude



Gradient orientation



`scipy.signal.correlate2d` (*in1*, *in2*, *mode*='full', *boundary*='fill', *fillvalue*=0)

Cross-correlate two 2-dimensional arrays.

Cross correlate *in1* and *in2* with output size determined by *mode*, and boundary conditions determined by *boundary* and *fillvalue*.

**Parameters**

**in1** : array\_like  
First input.

**in2** : array\_like  
Second input. Should have the same number of dimensions as *in1*. If operating in 'valid' mode, either *in1* or *in2* must be at least as large as the other in every dimension.

**mode** : str {'full', 'valid', 'same'}, optional  
A string indicating the size of the output:  
**full**        The output is the full discrete linear cross-correlation of the inputs. (Default)  
**valid**        The output consists only of those elements that do not rely on the zero-padding.  
**same**         The output is the same size as *in1*, centered with respect to the 'full' output.

**boundary** : str {'fill', 'wrap', 'symm'}, optional  
A flag indicating how to handle boundaries:  
**fill**         pad input arrays with *fillvalue*. (default)  
**wrap**         circular boundary conditions.  
**symm**         symmetrical boundary conditions.

**fillvalue** : scalar, optional  
Value to fill pad input arrays with. Default is 0.

**Returns**

**correlate2d** : ndarray  
A 2-dimensional array containing a subset of the discrete linear cross-correlation of *in1* with *in2*.

### Examples

Use 2D cross-correlation to find the location of a template in a noisy image:

```
>>> from scipy import signal
>>> from scipy import misc
>>> face = misc.face(gray=True) - misc.face(gray=True).mean()
>>> template = np.copy(face[300:365, 670:750]) # right eye
>>> template -= template.mean()
>>> face = face + np.random.randn(*face.shape) * 50 # add noise
>>> corr = signal.correlate2d(face, template, boundary='symm', mode='same')
>>> y, x = np.unravel_index(np.argmax(corr), corr.shape) # find the match
```

```
>>> import matplotlib.pyplot as plt
>>> fig, (ax_orig, ax_template, ax_corr) = plt.subplots(3, 1,
...                                                figsize=(6, 15))
>>> ax_orig.imshow(face, cmap='gray')
>>> ax_orig.set_title('Original')
>>> ax_orig.set_axis_off()
>>> ax_template.imshow(template, cmap='gray')
>>> ax_template.set_title('Template')
>>> ax_template.set_axis_off()
>>> ax_corr.imshow(corr, cmap='gray')
>>> ax_corr.set_title('Cross-correlation')
>>> ax_corr.set_axis_off()
>>> ax_orig.plot(x, y, 'ro')
>>> fig.show()
```

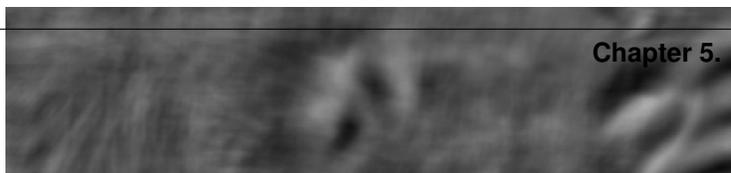
Original



Template



Cross-correlation



`scipy.signal.sepfir2d(input, hrow, hcol) → output`

Description:

Convolve the rank-2 input array with the separable filter defined by the rank-1 arrays `hrow`, and `hcol`. Mirror symmetric boundary conditions are assumed. This function can be used to find an image given its B-spline representation.

`scipy.signal.choose_conv_method(in1, in2, mode='full', measure=False)`

Find the fastest convolution/correlation method.

This primarily exists to be called during the `method='auto'` option in `convolve` and `correlate`, but can also be used when performing many convolutions of the same input shapes and dtypes, determining which method to use for all of them, either to avoid the overhead of the 'auto' option or to use accurate real-world measurements.

**Parameters**

- in1** : array\_like  
The first argument passed into the convolution function.
- in2** : array\_like  
The second argument passed into the convolution function.
- mode** : str { 'full', 'valid', 'same' }, optional  
A string indicating the size of the output:
  - full** : The output is the full discrete linear convolution of the inputs. (Default)
  - valid** : The output consists only of those elements that do not rely on the zero-padding.
  - same** : The output is the same size as `in1`, centered with respect to the 'full' output.
- measure** : bool, optional  
If True, run and time the convolution of `in1` and `in2` with both methods and return the fastest. If False (default), predict the fastest method using precomputed values.

**Returns**

- method** : str  
A string indicating which convolution method is fastest, either 'direct' or 'fft'
- times** : dict, optional  
A dictionary containing the times (in seconds) needed for each method. This value is only returned if `measure=True`.

**See also:**

`convolve`, `correlate`

**Notes**

For large `n`, `measure=False` is accurate and can quickly determine the fastest method to perform the convolution. However, this is not as accurate for small `n` (when any dimension in the input or output is small).

In practice, we found that this function estimates the faster method up to a multiplicative factor of 5 (i.e., the estimated method is *at most* 5 times slower than the fastest method). The estimation values were tuned on an early 2015 MacBook Pro with 8GB RAM but we found that the prediction held *fairly* accurately across different machines.

If `measure=True`, time the convolutions. Because this function uses `fftconvolve`, an error will be thrown if it does not support the inputs. There are cases when `fftconvolve` supports the inputs but this function returns `direct` (e.g., to protect against floating point integer precision).

New in version 0.19.

**Examples**

Estimate the fastest method for a given input:

```
>>> from scipy import signal
>>> a = np.random.randn(1000)
>>> b = np.random.randn(1000000)
>>> method = signal.choose_conv_method(a, b, mode='same')
>>> method
'fft'
```

This can then be applied to other arrays of the same dtype and shape:

```
>>> c = np.random.randn(1000)
>>> d = np.random.randn(1000000)
>>> # `method` works with correlate and convolve
>>> corr1 = signal.correlate(a, b, mode='same', method=method)
>>> corr2 = signal.correlate(c, d, mode='same', method=method)
>>> conv1 = signal.convolve(a, b, mode='same', method=method)
>>> conv2 = signal.convolve(c, d, mode='same', method=method)
```

## 5.20.2 B-splines

<i>bspline</i> (x, n)	B-spline basis function of order n.
<i>cubic</i> (x)	A cubic B-spline.
<i>quadratic</i> (x)	A quadratic B-spline.
<i>gauss_spline</i> (x, n)	Gaussian approximation to B-spline basis function of order n.
<i>cspline1d</i> (signal[, lamb])	Compute cubic spline coefficients for rank-1 array.
<i>qspline1d</i> (signal[, lamb])	Compute quadratic spline coefficients for rank-1 array.
<i>cspline2d</i> ((input {, lambda, precision}) -> ck)	Description:
<i>qspline2d</i> ((input {, lambda, precision}) -> qk)	Description:
<i>cspline1d_eval</i> (cj, newx[, dx, x0])	Evaluate a spline at the new set of points.
<i>qspline1d_eval</i> (cj, newx[, dx, x0])	Evaluate a quadratic spline at the new set of points.
<i>spline_filter</i> (lin[, lmbda])	Smoothing spline (cubic) filtering of a rank-2 array.

`scipy.signal.bspline`(x, n)  
B-spline basis function of order n.

### Notes

Uses `numpy.piecewise` and automatic function-generator.

`scipy.signal.cubic`(x)  
A cubic B-spline.

This is a special case of `bspline`, and equivalent to `bspline(x, 3)`.

`scipy.signal.quadratic`(x)  
A quadratic B-spline.

This is a special case of `bspline`, and equivalent to `bspline(x, 2)`.

`scipy.signal.gauss_spline`(x, n)  
Gaussian approximation to B-spline basis function of order n.

`scipy.signal.cspline1d`(signal, lamb=0.0)  
Compute cubic spline coefficients for rank-1 array.



`scipy.signal.spline_filter` (*lin*, *lmbda*=5.0)  
 Smoothing spline (cubic) filtering of a rank-2 array.

Filter an input data set, *lin*, using a (cubic) smoothing spline of fall-off *lmbda*.

### 5.20.3 Filtering

<code>order_filter(a, domain, rank)</code>	Perform an order filter on an N-dimensional array.
<code>medfilt(volume[, kernel_size])</code>	Perform a median filter on an N-dimensional array.
<code>medfilt2d(input[, kernel_size])</code>	Median filter a 2-dimensional array.
<code>wiener(im[, mysize, noise])</code>	Perform a Wiener filter on an N-dimensional array.
<code>symiirorder1((input, c0, z1 {, ...}))</code>	Implement a smoothing IIR filter with mirror-symmetric boundary conditions using a cascade of first-order sections.
<code>symiirorder2((input, r, omega {, ...}))</code>	Implement a smoothing IIR filter with mirror-symmetric boundary conditions using a cascade of second-order sections.
<code>lfiltfilt(b, a, x[, axis, zi])</code>	Filter data along one-dimension with an IIR or FIR filter.
<code>lfiltic(b, a, y[, x])</code>	Construct initial conditions for <code>lfilt</code> given input and output vectors.
<code>lfiltfilt_zi(b, a)</code>	Construct initial conditions for <code>lfilt</code> for step response steady-state.
<code>filtfilt(b, a, x[, axis, padtype, padlen, ...])</code>	Apply a digital filter forward and backward to a signal.
<code>savgol_filter(x, window_length, polyorder[, ...])</code>	Apply a Savitzky-Golay filter to an array.
<code>deconvolve(signal, divisor)</code>	Deconvolves <code>divisor</code> out of <code>signal</code> using inverse filtering.
<code>sosfilt(sos, x[, axis, zi])</code>	Filter data along one dimension using cascaded second-order sections.
<code>sosfilt_zi(sos)</code>	Construct initial conditions for <code>sosfilt</code> for step response steady-state.
<code>sosfiltfilt(sos, x[, axis, padtype, padlen])</code>	A forward-backward digital filter using cascaded second-order sections.
<code>hilbert(x[, N, axis])</code>	Compute the analytic signal, using the Hilbert transform.
<code>hilbert2(x[, N])</code>	Compute the '2-D' analytic signal of <i>x</i>
<code>decimate(x, q[, n, ftype, axis, zero_phase])</code>	Downsample the signal after applying an anti-aliasing filter.
<code>detrend(data[, axis, type, bp])</code>	Remove linear trend along <i>axis</i> from data.
<code>resample(x, num[, t, axis, window])</code>	Resample <i>x</i> to <i>num</i> samples using Fourier method along the given <i>axis</i> .
<code>resample_poly(x, up, down[, axis, window])</code>	Resample <i>x</i> along the given <i>axis</i> using polyphase filtering.
<code>upfirdn(h, x[, up, down, axis])</code>	Upsample, FIR filter, and downsample

`scipy.signal.order_filter` (*a*, *domain*, *rank*)  
 Perform an order filter on an N-dimensional array.

Perform an order filter on the array *in*. The *domain* argument acts as a mask centered over each pixel. The non-zero elements of *domain* are used to select elements surrounding each input pixel which are placed in a list. The list is sorted, and the output for that pixel is the element corresponding to *rank* in the sorted list.

**Parameters**    **a** : ndarray

The N-dimensional input array.

**domain** : array\_like

A mask array with the same number of dimensions as *a*. Each dimension should have an odd number of elements.

**rank** : int  
A non-negative integer which selects the element from the sorted list (0 corresponds to the smallest element, 1 is the next smallest element, etc.).

**Returns** **out** : ndarray  
The results of the order filter in an array with the same shape as *a*.

**Examples**

```
>>> from scipy import signal
>>> x = np.arange(25).reshape(5, 5)
>>> domain = np.identity(3)
>>> x
array([[ 0,  1,  2,  3,  4],
       [ 5,  6,  7,  8,  9],
       [10, 11, 12, 13, 14],
       [15, 16, 17, 18, 19],
       [20, 21, 22, 23, 24]])
>>> signal.order_filter(x, domain, 0)
array([[ 0.,  0.,  0.,  0.,  0.],
       [ 0.,  0.,  1.,  2.,  0.],
       [ 0.,  5.,  6.,  7.,  0.],
       [ 0., 10., 11., 12.,  0.],
       [ 0.,  0.,  0.,  0.,  0.]])
>>> signal.order_filter(x, domain, 2)
array([[ 6.,  7.,  8.,  9.,  4.],
       [11., 12., 13., 14.,  9.],
       [16., 17., 18., 19., 14.],
       [21., 22., 23., 24., 19.],
       [20., 21., 22., 23., 24.]])
```

`scipy.signal.medfilt` (*volume*, *kernel\_size=None*)

Perform a median filter on an N-dimensional array.

Apply a median filter to the input array using a local window-size given by *kernel\_size*.

**Parameters** **volume** : array\_like  
An N-dimensional input array.

**kernel\_size** : array\_like, optional  
A scalar or an N-length list giving the size of the median filter window in each dimension. Elements of *kernel\_size* should be odd. If *kernel\_size* is a scalar, then this scalar is used as the size in each dimension. Default size is 3 for each dimension.

**Returns** **out** : ndarray  
An array the same size as input containing the median filtered result.

`scipy.signal.medfilt2d` (*input*, *kernel\_size=3*)

Median filter a 2-dimensional array.

Apply a median filter to the *input* array using a local window-size given by *kernel\_size* (must be odd).

**Parameters** **input** : array\_like  
A 2-dimensional input array.

**kernel\_size** : array\_like, optional  
A scalar or a list of length 2, giving the size of the median filter window in each dimension. Elements of *kernel\_size* should be odd. If *kernel\_size* is a scalar, then this scalar is used as the size in each dimension. Default is a kernel of size (3, 3).

**Returns** **out** : ndarray  
An array the same size as input containing the median filtered result.

`scipy.signal.wiener` (*im*, *mysize*=None, *noise*=None)

Perform a Wiener filter on an N-dimensional array.

Apply a Wiener filter to the N-dimensional array *im*.

**Parameters**

- im** : ndarray  
An N-dimensional array.
- mysize** : int or array\_like, optional  
A scalar or an N-length list giving the size of the Wiener filter window in each dimension. Elements of *mysize* should be odd. If *mysize* is a scalar, then this scalar is used as the size in each dimension.
- noise** : float, optional  
The noise-power to use. If None, then noise is estimated as the average of the local variance of the input.

**Returns**

- out** : ndarray  
Wiener filtered result with the same shape as *im*.

`scipy.signal.symiirorder1` (*input*, *c0*, *z1* {, *precision*}) → output

Implement a smoothing IIR filter with mirror-symmetric boundary conditions using a cascade of first-order sections. The second section uses a reversed sequence. This implements a system with the following transfer function and mirror-symmetric boundary conditions:

$$H(z) = \frac{c0}{(1-z1/z)(1-z1z)}$$

The resulting signal will have mirror symmetric boundary conditions as well.

**Parameters**

- input** : ndarray  
The input signal.
- c0, z1** : scalar  
Parameters in the transfer function.
- precision** :  
Specifies the precision for calculating initial conditions of the recursive filter based on mirror-symmetric input.

**Returns**

- output** : ndarray  
The filtered signal.

`scipy.signal.symiirorder2` (*input*, *r*, *omega* {, *precision*}) → output

Implement a smoothing IIR filter with mirror-symmetric boundary conditions using a cascade of second-order sections. The second section uses a reversed sequence. This implements the following transfer function:

$$H(z) = \frac{cs^2}{(1-a2/z-a3/z^2)(1-a2z-a3z^2)}$$

where:

$$\begin{aligned} a2 &= (2 r \cos \omega) \\ a3 &= -r^2 \\ cs &= 1 - 2 r \cos \omega + r^2 \end{aligned}$$

**Parameters**

- input** : ndarray  
The input signal.
- r, omega** : scalar  
Parameters in the transfer function.
- precision** :

**Returns** **output** : ndarray  
 Specifies the precision for calculating initial conditions of the recursive filter based on mirror-symmetric input.  
 The filtered signal.

`scipy.signal.lfilter` (*b, a, x, axis=-1, zi=None*)

Filter data along one-dimension with an IIR or FIR filter.

Filter a data sequence, *x*, using a digital filter. This works for many fundamental data types (including Object type). The filter is a direct form II transposed implementation of the standard difference equation (see Notes).

**Parameters**

- b** : array\_like  
The numerator coefficient vector in a 1-D sequence.
- a** : array\_like  
The denominator coefficient vector in a 1-D sequence. If *a*[0] is not 1, then both *a* and *b* are normalized by *a*[0].
- x** : array\_like  
An N-dimensional input array.
- axis** : int, optional  
The axis of the input data array along which to apply the linear filter. The filter is applied to each subarray along this axis. Default is -1.
- zi** : array\_like, optional  
Initial conditions for the filter delays. It is a vector (or array of vectors for an N-dimensional input) of length  $\max(\text{len}(a), \text{len}(b)) - 1$ . If *zi* is None or is not given then initial rest is assumed. See *lfiltic* for more information.

**Returns**

- y** : array  
The output of the digital filter.
- zf** : array, optional  
If *zi* is None, this is not returned, otherwise, *zf* holds the final filter delay values.

See also:

**lfiltic** Construct initial conditions for *lfilter*.

**lfilter\_zi** Compute initial state (steady state of step response) for *lfilter*.

**filtfilt** A forward-backward filter, to obtain a filter with linear phase.

**savgol\_filter**

A Savitzky-Golay filter.

**sosfilt** Filter data using cascaded second-order sections.

**sosfiltfilt**

A forward-backward filter using second-order sections.

Notes

The filter function is implemented as a direct II transposed structure. This means that the filter implements:

$$a[0]*y[n] = b[0]*x[n] + b[1]*x[n-1] + \dots + b[M]*x[n-M] \\ - a[1]*y[n-1] - \dots - a[N]*y[n-N]$$

where *M* is the degree of the numerator, *N* is the degree of the denominator, and *n* is the sample number. It is implemented using the following difference equations (assuming *M* = *N*):

$$a[0]*y[n] = b[0] * x[n] + d[0][n-1] \\ d[0][n] = b[1] * x[n] - a[1] * y[n] + d[1][n-1] \\ d[1][n] = b[2] * x[n] - a[2] * y[n] + d[2][n-1] \\ \dots$$

$$\begin{aligned}d[N-2][n] &= b[N-1]*x[n] - a[N-1]*y[n] + d[N-1][n-1] \\d[N-1][n] &= b[N] * x[n] - a[N] * y[n]\end{aligned}$$

where  $d$  are the state variables.

The rational transfer function describing this filter in the  $z$ -transform domain is:

$$Y(z) = \frac{b[0] + b[1]z^{-1} + \dots + b[M]z^{-M}}{a[0] + a[1]z^{-1} + \dots + a[N]z^{-N}} X(z)$$

### Examples

Generate a noisy signal to be filtered:

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
>>> t = np.linspace(-1, 1, 201)
>>> x = (np.sin(2*np.pi*0.75*t*(1-t) + 2.1) +
...      0.1*np.sin(2*np.pi*1.25*t + 1) +
...      0.18*np.cos(2*np.pi*3.85*t))
>>> xn = x + np.random.randn(len(t)) * 0.08
```

Create an order 3 lowpass butterworth filter:

```
>>> b, a = signal.butter(3, 0.05)
```

Apply the filter to  $x_n$ . Use `lfilter_zi` to choose the initial condition of the filter:

```
>>> zi = signal.lfilter_zi(b, a)
>>> z, _ = signal.lfilter(b, a, xn, zi=zi*xn[0])
```

Apply the filter again, to have a result filtered at an order the same as `filtfilt`:

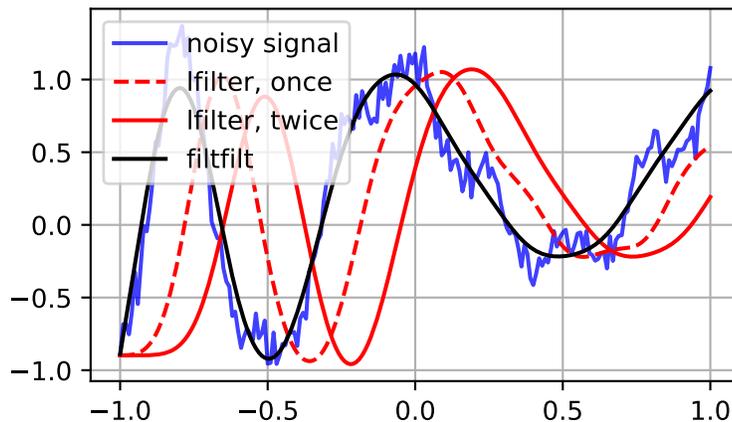
```
>>> z2, _ = signal.lfilter(b, a, z, zi=zi*z[0])
```

Use `filtfilt` to apply the filter:

```
>>> y = signal.filtfilt(b, a, xn)
```

Plot the original signal and the various filtered versions:

```
>>> plt.figure
>>> plt.plot(t, xn, 'b', alpha=0.75)
>>> plt.plot(t, z, 'r--', t, z2, 'r', t, y, 'k')
>>> plt.legend(('noisy signal', 'lfilter, once', 'lfilter, twice',
...          'filtfilt'), loc='best')
>>> plt.grid(True)
>>> plt.show()
```



`scipy.signal.lfiltic` (*b*, *a*, *y*, *x=None*)

Construct initial conditions for `lfilter` given input and output vectors.

Given a linear filter (*b*, *a*) and initial conditions on the output *y* and the input *x*, return the initial conditions on the state vector *zi* which is used by `lfilter` to generate the output given the input.

**Parameters**

- b** : array\_like  
Linear filter term.
- a** : array\_like  
Linear filter term.
- y** : array\_like  
Initial conditions.  
If  $N = \text{len}(a) - 1$ , then  $y = \{y[-1], y[-2], \dots, y[-N]\}$ .  
If *y* is too short, it is padded with zeros.
- x** : array\_like, optional  
Initial conditions.  
If  $M = \text{len}(b) - 1$ , then  $x = \{x[-1], x[-2], \dots, x[-M]\}$ .  
If *x* is not given, its initial conditions are assumed zero.  
If *x* is too short, it is padded with zeros.

**Returns**

- zi** : ndarray  
The state vector  $z_i = \{z_0[-1], z_1[-1], \dots, z_{K-1}[-1]\}$ , where  $K = \max(M, N)$ .

**See also:**

`lfilter`, `lfilter_zi`

`scipy.signal.lfilter_zi` (*b*, *a*)

Construct initial conditions for `lfilter` for step response steady-state.

Compute an initial state *zi* for the `lfilter` function that corresponds to the steady state of the step response.

A typical use of this function is to set the initial state so that the output of the filter starts at the same value as the first element of the signal to be filtered.

**Parameters**

- b, a** : array\_like (1-D)  
The IIR filter coefficients. See `lfilter` for more information.

**Returns**

- zi** : 1-D ndarray  
The initial state for the filter.

**See also:**

*lfilter*, *lfiltic*, *filtfilt*

**Notes**

A linear filter with order  $m$  has a state space representation  $(A, B, C, D)$ , for which the output  $y$  of the filter can be expressed as:

$$\begin{aligned} z(n+1) &= A*z(n) + B*x(n) \\ y(n) &= C*z(n) + D*x(n) \end{aligned}$$

where  $z(n)$  is a vector of length  $m$ ,  $A$  has shape  $(m, m)$ ,  $B$  has shape  $(m, 1)$ ,  $C$  has shape  $(1, m)$  and  $D$  has shape  $(1, 1)$  (assuming  $x(n)$  is a scalar). `lfilter_zi` solves:

$$z_i = A*z_i + B$$

In other words, it finds the initial condition for which the response to an input of all ones is a constant.

Given the filter coefficients  $a$  and  $b$ , the state space matrices for the transposed direct form II implementation of the linear filter, which is the implementation used by `scipy.signal.lfilter`, are:

$$\begin{aligned} A &= \text{scipy.linalg.companion}(a).T \\ B &= b[1:] - a[1:]*b[0] \end{aligned}$$

assuming  $a[0]$  is 1.0; if  $a[0]$  is not 1,  $a$  and  $b$  are first divided by  $a[0]$ .

**Examples**

The following code creates a lowpass Butterworth filter. Then it applies that filter to an array whose values are all 1.0; the output is also all 1.0, as expected for a lowpass filter. If the `zi` argument of `lfilter` had not been given, the output would have shown the transient signal.

```
>>> from numpy import array, ones
>>> from scipy.signal import lfilter, lfilter_zi, butter
>>> b, a = butter(5, 0.25)
>>> zi = lfilter_zi(b, a)
>>> y, zo = lfilter(b, a, ones(10), zi=zi)
>>> y
array([1., 1., 1., 1., 1., 1., 1., 1., 1., 1.])
```

Another example:

```
>>> x = array([0.5, 0.5, 0.5, 0.0, 0.0, 0.0, 0.0])
>>> y, zf = lfilter(b, a, x, zi=zi*x[0])
>>> y
array([ 0.5          ,  0.5          ,  0.5          ,  0.49836039,  0.48610528,
        0.44399389,  0.35505241])
```

Note that the `zi` argument to `lfilter` was computed using `lfilter_zi` and scaled by  $x[0]$ . Then the output  $y$  has no transient until the input drops from 0.5 to 0.0.

`scipy.signal.filtfilt` ( $b, a, x, axis=-1, padtype='odd', padlen=None, method='pad', irlen=None$ )

Apply a digital filter forward and backward to a signal.

This function applies a linear digital filter twice, once forward and once backwards. The combined filter has zero phase and a filter order twice that of the original.

The function provides options for handling the edges of the signal.

**Parameters**  $b$ : (N,) array\_like

The numerator coefficient vector of the filter.

**a** : (N,) array\_like  
The denominator coefficient vector of the filter. If `a[0]` is not 1, then both `a` and `b` are normalized by `a[0]`.

**x** : array\_like  
The array of data to be filtered.

**axis** : int, optional  
The axis of `x` to which the filter is applied. Default is -1.

**padtype** : str or None, optional  
Must be 'odd', 'even', 'constant', or None. This determines the type of extension to use for the padded signal to which the filter is applied. If `padtype` is None, no padding is used. The default is 'odd'.

**padlen** : int or None, optional  
The number of elements by which to extend `x` at both ends of `axis` before applying the filter. This value must be less than `x.shape[axis] - 1`. `padlen=0` implies no padding. The default value is `3 * max(len(a), len(b))`.

**method** : str, optional  
Determines the method for handling the edges of the signal, either "pad" or "gust". When `method` is "pad", the signal is padded; the type of padding is determined by `padtype` and `padlen`, and `irlen` is ignored. When `method` is "gust", Gustafsson's method is used, and `padtype` and `padlen` are ignored.

**irlen** : int or None, optional  
When `method` is "gust", `irlen` specifies the length of the impulse response of the filter. If `irlen` is None, no part of the impulse response is ignored. For a long signal, specifying `irlen` can significantly improve the performance of the filter.

**Returns** **y** : ndarray  
The filtered output with the same shape as `x`.

**See also:**

`sosfiltfilt`, `lfilter_zi`, `lfilter`, `lfiltic`, `savgol_filter`, `sosfilt`

**Notes**

When `method` is "pad", the function pads the data along the given axis in one of three ways: odd, even or constant. The odd and even extensions have the corresponding symmetry about the end point of the data. The constant extension extends the data with the values at the end points. On both the forward and backward passes, the initial condition of the filter is found by using `lfilter_zi` and scaling it by the end point of the extended data.

When `method` is "gust", Gustafsson's method [R252] is used. Initial conditions are chosen for the forward and backward passes so that the forward-backward filter gives the same result as the backward-forward filter.

The option to use Gustafsson's method was added in scipy version 0.16.0.

**References**

[R252]

**Examples**

The examples will use several functions from `scipy.signal`.

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

First we create a one second signal that is the sum of two pure sine waves, with frequencies 5 Hz and 250 Hz, sampled at 2000 Hz.

```
>>> t = np.linspace(0, 1.0, 2001)
>>> xlow = np.sin(2 * np.pi * 5 * t)
>>> xhigh = np.sin(2 * np.pi * 250 * t)
>>> x = xlow + xhigh
```

Now create a lowpass Butterworth filter with a cutoff of 0.125 times the Nyquist rate, or 125 Hz, and apply it to *x* with *filtfilt*. The result should be approximately *xlow*, with no phase shift.

```
>>> b, a = signal.butter(8, 0.125)
>>> y = signal.filtfilt(b, a, x, padlen=150)
>>> np.abs(y - xlow).max()
9.1086182074789912e-06
```

We get a fairly clean result for this artificial example because the odd extension is exact, and with the moderately long padding, the filter's transients have dissipated by the time the actual data is reached. In general, transient effects at the edges are unavoidable.

The following example demonstrates the option `method="gust"`.

First, create a filter.

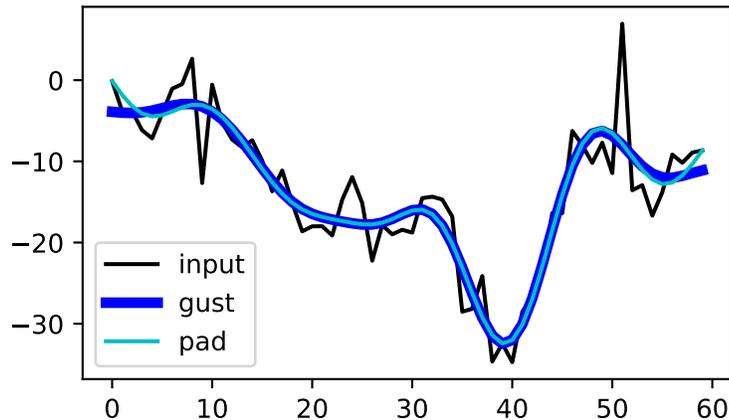
```
>>> b, a = signal.ellip(4, 0.01, 120, 0.125) # Filter to be applied.
>>> np.random.seed(123456)
```

*sig* is a random input signal to be filtered.

```
>>> n = 60
>>> sig = np.random.randn(n)**3 + 3*np.random.randn(n).cumsum()
```

Apply *filtfilt* to *sig*, once using the Gustafsson method, and once using padding, and plot the results for comparison.

```
>>> fgust = signal.filtfilt(b, a, sig, method="gust")
>>> fpad = signal.filtfilt(b, a, sig, padlen=50)
>>> plt.plot(sig, 'k-', label='input')
>>> plt.plot(fgust, 'b-', linewidth=4, label='gust')
>>> plt.plot(fpad, 'c-', linewidth=1.5, label='pad')
>>> plt.legend(loc='best')
>>> plt.show()
```



The *irlen* argument can be used to improve the performance of Gustafsson's method.

Estimate the impulse response length of the filter.

```
>>> z, p, k = signal.tf2zpk(b, a)
>>> eps = 1e-9
>>> r = np.max(np.abs(p))
>>> approx_impulse_len = int(np.ceil(np.log(eps) / np.log(r)))
>>> approx_impulse_len
137
```

Apply the filter to a longer signal, with and without the *irlen* argument. The difference between *y1* and *y2* is small. For long signals, using *irlen* gives a significant performance improvement.

```
>>> x = np.random.randn(5000)
>>> y1 = signal.filtfilt(b, a, x, method='gust')
>>> y2 = signal.filtfilt(b, a, x, method='gust', irlen=approx_impulse_len)
>>> print(np.max(np.abs(y1 - y2)))
1.80056858312e-10
```

`scipy.signal.savgol_filter(x, window_length, polyorder, deriv=0, delta=1.0, axis=-1, mode='interp', cval=0.0)`

Apply a Savitzky-Golay filter to an array.

This is a 1-d filter. If *x* has dimension greater than 1, *axis* determines the axis along which the filter is applied.

**Parameters** *x* : array\_like

The data to be filtered. If *x* is not a single or double precision floating point array, it will be converted to type `numpy.float64` before filtering.

**window\_length** : int

The length of the filter window (i.e. the number of coefficients). *window\_length* must be a positive odd integer. If *mode* is 'interp', *window\_length* must be less than or equal to the size of *x*.

**polyorder** : int

The order of the polynomial used to fit the samples. *polyorder* must be less than *window\_length*.

**deriv** : int, optional

The order of the derivative to compute. This must be a nonnegative integer. The default is 0, which means to filter the data without differentiating.

**delta** : float, optional

The spacing of the samples to which the filter will be applied. This is only used if `deriv > 0`. Default is 1.0.

**axis** : int, optional

The axis of the array  $x$  along which the filter is to be applied. Default is -1.

**mode** : str, optional

Must be 'mirror', 'constant', 'nearest', 'wrap' or 'interp'. This determines the type of extension to use for the padded signal to which the filter is applied. When *mode* is 'constant', the padding value is given by *cval*. See the Notes for more details on 'mirror', 'constant', 'wrap', and 'nearest'. When the 'interp' mode is selected (the default), no extension is used. Instead, a degree *polyorder* polynomial is fit to the last *window\_length* values of the edges, and this polynomial is used to evaluate the last *window\_length // 2* output values.

**cval** : scalar, optional

Value to fill past the edges of the input if *mode* is 'constant'. Default is 0.0.

**Returns** **y** : ndarray, same shape as  $x$

The filtered data.

**See also:**

`savgol_coeffs`

**Notes**

Details on the *mode* options:

**'mirror'**: Repeats the values at the edges in reverse order. The value closest to the edge is not included.  
**'nearest'**: The extension contains the nearest input value.  
**'constant'**: The extension contains the value given by the *cval* argument.  
**'wrap'**: The extension contains the values from the other end of the array.

For example, if the input is [1, 2, 3, 4, 5, 6, 7, 8], and *window\_length* is 7, the following shows the extended data for the various *mode* options (assuming *cval* is 0):

mode	Ext	Input	Ext
'mirror'	4 3 2	1 2 3 4 5 6 7 8	7 6 5
'nearest'	1 1 1	1 2 3 4 5 6 7 8	8 8 8
'constant'	0 0 0	1 2 3 4 5 6 7 8	0 0 0
'wrap'	6 7 8	1 2 3 4 5 6 7 8	1 2 3

New in version 0.14.0.

**Examples**

```
>>> from scipy.signal import savgol_filter
>>> np.set_printoptions(precision=2) # For compact display.
>>> x = np.array([2, 2, 5, 2, 1, 0, 1, 4, 9])
```

Filter with a window length of 5 and a degree 2 polynomial. Use the defaults for all other parameters.

```
>>> savgol_filter(x, 5, 2)
array([ 1.66,  3.17,  3.54,  2.86,  0.66,  0.17,  1. ,  4. ,  9. ])
```

Note that the last five values in  $x$  are samples of a parabola, so when *mode*='interp' (the default) is used with *polyorder*=2, the last three values are unchanged. Compare that to, for example, *mode*='nearest':

```
>>> savgol_filter(x, 5, 2, mode='nearest')
array([ 1.74,  3.03,  3.54,  2.86,  0.66,  0.17,  1. ,  4.6 ,  7.97])
```

`scipy.signal.deconvolve` (*signal*, *divisor*)

Deconvolves divisor out of signal using inverse filtering.

Returns the quotient and remainder such that `signal = convolve(divisor, quotient) + remainder`

**Parameters**

- signal** : array\_like  
Signal data, typically a recorded signal
- divisor** : array\_like  
Divisor data, typically an impulse response or filter that was applied to the original signal

**Returns**

- quotient** : ndarray  
Quotient, typically the recovered original signal
- remainder** : ndarray  
Remainder

See also:

[`numpy.polydiv`](#)

performs polynomial division (same operation, but also accepts `poly1d` objects)

**Examples**

Deconvolve a signal that's been filtered:

```
>>> from scipy import signal
>>> original = [0, 1, 0, 0, 1, 1, 0, 0]
>>> impulse_response = [2, 1]
>>> recorded = signal.convolve(impulse_response, original)
>>> recorded
array([0, 2, 1, 0, 2, 3, 1, 0, 0])
>>> recovered, remainder = signal.deconvolve(recorded, impulse_response)
>>> recovered
array([ 0.,  1.,  0.,  0.,  1.,  1.,  0.,  0.]
```

`scipy.signal.sosfilt` (*sos*, *x*, *axis=-1*, *zi=None*)

Filter data along one dimension using cascaded second-order sections.

Filter a data sequence, *x*, using a digital IIR filter defined by *sos*. This is implemented by performing `lfilter` for each second-order section. See `lfilter` for details.

**Parameters**

- sos** : array\_like  
Array of second-order filter coefficients, must have shape `(n_sections, 6)`. Each row corresponds to a second-order section, with the first three columns providing the numerator coefficients and the last three providing the denominator coefficients.
- x** : array\_like  
An N-dimensional input array.
- axis** : int, optional  
The axis of the input data array along which to apply the linear filter. The filter is applied to each subarray along this axis. Default is -1.
- zi** : array\_like, optional  
Initial conditions for the cascaded filter delays. It is a (at least 2D) vector of shape `(n_sections, ..., 2, ...)`, where `..., 2, ...` denotes the shape of *x*, but with `x.shape[axis]` replaced by 2. If *zi* is None or is not given then initial rest (i.e. all zeros) is assumed. Note that

**Returns**

- y** : ndarray
  - these initial conditions are *not* the same as the initial conditions given by *lfiltic* or *lfilter\_zi*.
  - The output of the digital filter.
- zf** : ndarray, optional
  - If *zi* is None, this is not returned, otherwise, *zf* holds the final filter delay values.

**See also:**

*zpk2sos*, *sos2zpk*, *sosfilt\_zi*, *sosfiltfilt*, *sosfreqz*

**Notes**

The filter function is implemented as a series of second-order filters with direct-form II transposed structure. It is designed to minimize numerical precision errors for high-order filters.

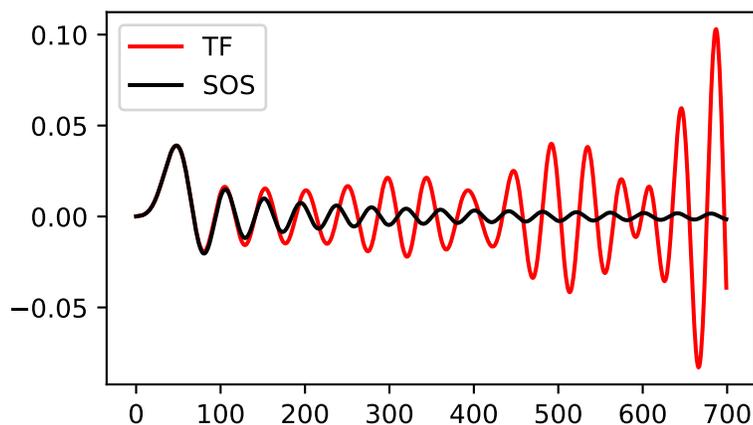
New in version 0.16.0.

**Examples**

Plot a 13th-order filter's impulse response using both *lfilter* and *sosfilt*, showing the instability that results from trying to do a 13th-order filter in a single stage (the numerical error pushes some poles outside of the unit circle):

```

>>> import matplotlib.pyplot as plt
>>> from scipy import signal
>>> b, a = signal.ellip(13, 0.009, 80, 0.05, output='ba')
>>> sos = signal.ellip(13, 0.009, 80, 0.05, output='sos')
>>> x = signal.unit_impulse(700)
>>> y_tf = signal.lfilter(b, a, x)
>>> y_sos = signal.sosfilt(sos, x)
>>> plt.plot(y_tf, 'r', label='TF')
>>> plt.plot(y_sos, 'k', label='SOS')
>>> plt.legend(loc='best')
>>> plt.show()
    
```



`scipy.signal.sosfilt_zi(sos)`

Construct initial conditions for `sosfilt` for step response steady-state.

Compute an initial state  $z_i$  for the `sosfilt` function that corresponds to the steady state of the step response.

A typical use of this function is to set the initial state so that the output of the filter starts at the same value as the first element of the signal to be filtered.

**Parameters** `sos` : array\_like  
 Array of second-order filter coefficients, must have shape  $(n\_sections, 6)$ . See `sosfilt` for the SOS filter format specification.

**Returns** `zi` : ndarray  
 Initial conditions suitable for use with `sosfilt`, shape  $(n\_sections, 2)$ .

**See also:**

`sosfilt`, `zpk2sos`

**Notes**

New in version 0.16.0.

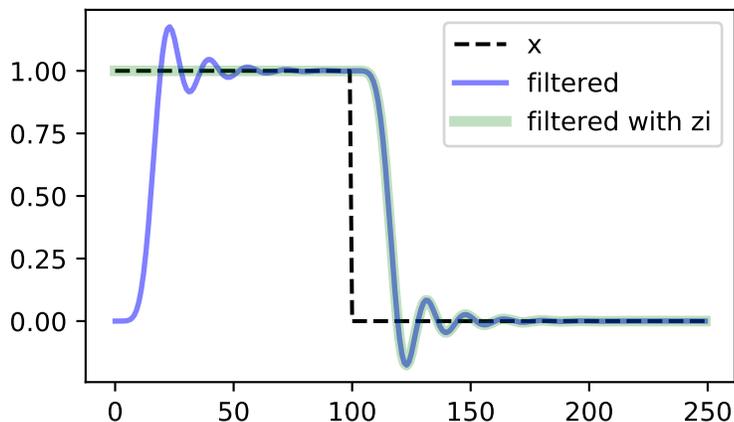
**Examples**

Filter a rectangular pulse that begins at time 0, with and without the use of the `zi` argument of `scipy.signal.sosfilt`.

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

```
>>> sos = signal.butter(9, 0.125, output='sos')
>>> zi = signal.sosfilt_zi(sos)
>>> x = (np.arange(250) < 100).astype(int)
>>> f1 = signal.sosfilt(sos, x)
>>> f2, zo = signal.sosfilt(sos, x, zi=zi)
```

```
>>> plt.plot(x, 'k--', label='x')
>>> plt.plot(f1, 'b', alpha=0.5, linewidth=2, label='filtered')
>>> plt.plot(f2, 'g', alpha=0.25, linewidth=4, label='filtered with zi')
>>> plt.legend(loc='best')
>>> plt.show()
```



`scipy.signal.sosfiltfilt` (*sos*, *x*, *axis=-1*, *padtype='odd'*, *padlen=None*)

A forward-backward digital filter using cascaded second-order sections.

See `filtfilt` for more complete information about this method.

**Parameters**

**sos** : array\_like  
 Array of second-order filter coefficients, must have shape (n\_sections, 6). Each row corresponds to a second-order section, with the first three columns providing the numerator coefficients and the last three providing the denominator coefficients.

**x** : array\_like  
 The array of data to be filtered.

**axis** : int, optional  
 The axis of *x* to which the filter is applied. Default is -1.

**padtype** : str or None, optional  
 Must be 'odd', 'even', 'constant', or None. This determines the type of extension to use for the padded signal to which the filter is applied. If *padtype* is None, no padding is used. The default is 'odd'.

**padlen** : int or None, optional  
 The number of elements by which to extend *x* at both ends of *axis* before applying the filter. This value must be less than `x.shape[axis] - 1`. `padlen=0` implies no padding. The default value is:

```
3 * (2 * len(sos) + 1 - min((sos[:, 2] == 0).sum(),
                             (sos[:, 5] == 0).sum()))
```

The extra subtraction at the end attempts to compensate for poles and zeros at the origin (e.g. for odd-order filters) to yield equivalent estimates of *padlen* to those of `filtfilt` for second-order section filters built with `scipy.signal` functions.

**Returns**

**y** : ndarray  
 The filtered output with the same shape as *x*.

**See also:**

`filtfilt`, `sosfilt`, `sosfilt_zi`, `sosfreqz`

**Notes**

New in version 0.18.0.

**Examples**

```
>>> from scipy.signal import sosfiltfilt, butter
>>> import matplotlib.pyplot as plt
```

Create an interesting signal to filter.

```
>>> n = 201
>>> t = np.linspace(0, 1, n)
>>> np.random.seed(123)
>>> x = 1 + (t < 0.5) - 0.25*t**2 + 0.05*np.random.randn(n)
```

Create a lowpass Butterworth filter, and use it to filter *x*.

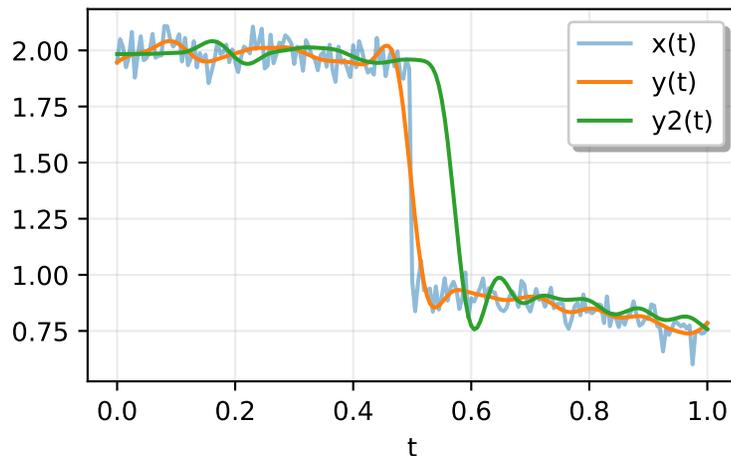
```
>>> sos = butter(4, 0.125, output='sos')
>>> y = sosfiltfilt(sos, x)
```

For comparison, apply an 8th order filter using `sosfilt`. The filter is initialized using the mean of the first four values of `x`.

```
>>> from scipy.signal import sosfilt, sosfilt_zi
>>> sos8 = butter(8, 0.125, output='sos')
>>> zi = x[:4].mean() * sosfilt_zi(sos8)
>>> y2, zo = sosfilt(sos8, x, zi=zi)
```

Plot the results. Note that the phase of `y` matches the input, while `y2` has a significant phase delay.

```
>>> plt.plot(t, x, alpha=0.5, label='x(t)')
>>> plt.plot(t, y, label='y(t)')
>>> plt.plot(t, y2, label='y2(t)')
>>> plt.legend(framealpha=1, shadow=True)
>>> plt.grid(alpha=0.25)
>>> plt.xlabel('t')
>>> plt.show()
```



`scipy.signal.hilbert` ( $x$ ,  $N=None$ ,  $axis=-1$ )

Compute the analytic signal, using the Hilbert transform.

The transformation is done along the last axis by default.

**Parameters**

- x** : array\_like  
Signal data. Must be real.
- N** : int, optional  
Number of Fourier components. Default: `x.shape[axis]`
- axis** : int, optional  
Axis along which to do the transformation. Default: -1.

**Returns**

- xa** : ndarray  
Analytic signal of `x`, of each 1-D array along `axis`

See also:

`scipy.fftpack.hilbert`

Return Hilbert transform of a periodic sequence `x`.

### Notes

The analytic signal  $x_a(t)$  of signal  $x(t)$  is:

$$x_a = F^{-1}(F(x)2U) = x + iy$$

where  $F$  is the Fourier transform,  $U$  the unit step function, and  $y$  the Hilbert transform of  $x$ . [R271]

In other words, the negative half of the frequency spectrum is zeroed out, turning the real-valued signal into a complex signal. The Hilbert transformed signal can be obtained from `np.imag(hilbert(x))`, and the original signal from `np.real(hilbert(x))`.

### References

[R271], [R272], [R273]

### Examples

In this example we use the Hilbert transform to determine the amplitude envelope and instantaneous frequency of an amplitude-modulated signal.

```
>>> import numpy as np
>>> import matplotlib.pyplot as plt
>>> from scipy.signal import hilbert, chirp
```

```
>>> duration = 1.0
>>> fs = 400.0
>>> samples = int(fs*duration)
>>> t = np.arange(samples) / fs
```

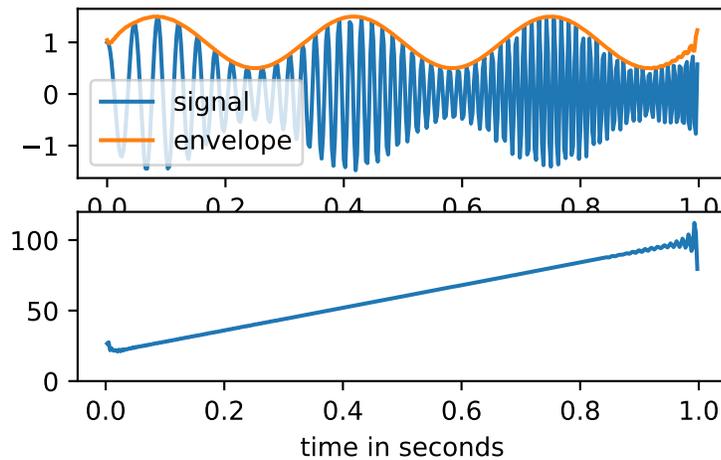
We create a chirp of which the frequency increases from 20 Hz to 100 Hz and apply an amplitude modulation.

```
>>> signal = chirp(t, 20.0, t[-1], 100.0)
>>> signal *= (1.0 + 0.5 * np.sin(2.0*np.pi*3.0*t) )
```

The amplitude envelope is given by magnitude of the analytic signal. The instantaneous frequency can be obtained by differentiating the instantaneous phase in respect to time. The instantaneous phase corresponds to the phase angle of the analytic signal.

```
>>> analytic_signal = hilbert(signal)
>>> amplitude_envelope = np.abs(analytic_signal)
>>> instantaneous_phase = np.unwrap(np.angle(analytic_signal))
>>> instantaneous_frequency = (np.diff(instantaneous_phase) /
...                             (2.0*np.pi) * fs)
```

```
>>> fig = plt.figure()
>>> ax0 = fig.add_subplot(211)
>>> ax0.plot(t, signal, label='signal')
>>> ax0.plot(t, amplitude_envelope, label='envelope')
>>> ax0.set_xlabel("time in seconds")
>>> ax0.legend()
>>> ax1 = fig.add_subplot(212)
>>> ax1.plot(t[1:], instantaneous_frequency)
>>> ax1.set_xlabel("time in seconds")
>>> ax1.set_ylim(0.0, 120.0)
```



`scipy.signal.hilbert2(x, N=None)`

Compute the ‘2-D’ analytic signal of  $x$

**Parameters**

- x** : array\_like  
2-D signal data.
- N** : int or tuple of two ints, optional  
Number of Fourier components. Default is `x.shape`

**Returns**

- xa** : ndarray  
Analytic signal of  $x$  taken along axes (0,1).

### References

[R274]

`scipy.signal.decimate(x, q, n=None, ftype='iir', axis=-1, zero_phase=True)`

Downsample the signal after applying an anti-aliasing filter.

By default, an order 8 Chebyshev type I filter is used. A 30 point FIR filter with Hamming window is used if `ftype` is ‘fir’.

**Parameters**

- x** : array\_like  
The signal to be downsampled, as an N-dimensional array.
- q** : int  
The downsampling factor. When using IIR downsampling, it is recommended to call `decimate` multiple times for downsampling factors higher than 13.
- n** : int, optional  
The order of the filter (1 less than the length for ‘fir’). Defaults to 8 for ‘iir’ and 20 times the downsampling factor for ‘fir’.
- ftype** : str {‘iir’, ‘fir’} or `dlti` instance, optional  
If ‘iir’ or ‘fir’, specifies the type of lowpass filter. If an instance of an `dlti` object, uses that object to filter before downsampling.
- axis** : int, optional  
The axis along which to decimate.
- zero\_phase** : bool, optional  
Prevent phase shift by filtering with `filtfilt` instead of `lfilter` when using an IIR filter, and shifting the outputs back by the filter’s group delay

**Returns** **y** : ndarray  
 when using an FIR filter. The default value of `True` is recommended, since a phase shift is generally not desired.  
 New in version 0.18.0.  
 The down-sampled signal.

**See also:**

**resample** Resample up or down using the FFT method.

**resample\_poly**

Resample using polyphase filtering and an FIR filter.

**Notes**

The `zero_phase` keyword was added in 0.18.0. The possibility to use instances of `dlti` as `ftype` was added in 0.18.0.

`scipy.signal.detrend` (*data*, *axis=-1*, *type='linear'*, *bp=0*)

Remove linear trend along axis from data.

**Parameters** **data** : array\_like

The input data.

**axis** : int, optional

The axis along which to detrend the data. By default this is the last axis (-1).

**type** : {'linear', 'constant'}, optional

The type of detrending. If `type == 'linear'` (default), the result of a linear least-squares fit to *data* is subtracted from *data*. If `type == 'constant'`, only the mean of *data* is subtracted.

**bp** : array\_like of ints, optional

A sequence of break points. If given, an individual linear fit is performed for each part of *data* between two break points. Break points are specified as indices into *data*.

**Returns** **ret** : ndarray

The detrended input data.

**Examples**

```
>>> from scipy import signal
>>> randgen = np.random.RandomState(9)
>>> npoints = 1000
>>> noise = randgen.randn(npoints)
>>> x = 3 + 2*np.linspace(0, 1, npoints) + noise
>>> (signal.detrend(x) - noise).max() < 0.01
True
```

`scipy.signal.resample` (*x*, *num*, *t=None*, *axis=0*, *window=None*)

Resample *x* to *num* samples using Fourier method along the given axis.

The resampled signal starts at the same value as *x* but is sampled with a spacing of `len(x) / num * (spacing of x)`. Because a Fourier method is used, the signal is assumed to be periodic.

**Parameters** **x** : array\_like

The data to be resampled.

**num** : int

The number of samples in the resampled signal.

**t** : array\_like, optional

If *t* is given, it is assumed to be the sample positions associated with the signal data in *x*.

**axis** : int, optional  
The axis of  $x$  that is resampled. Default is 0.

**window** : array\_like, callable, string, float, or tuple, optional  
Specifies the window applied to the signal in the Fourier domain. See below for details.

**Returns** resampled\_x or (resampled\_x, resampled\_t)  
Either the resampled array, or, if  $t$  was given, a tuple containing the resampled array and the corresponding resampled positions.

**See also:**

**decimate** Downsample the signal after applying an FIR or IIR filter.

**resample\_poly**

Resample using polyphase filtering and an FIR filter.

**Notes**

The argument *window* controls a Fourier-domain window that tapers the Fourier spectrum before zero-padding to alleviate ringing in the resampled values for sampled signals you didn't intend to be interpreted as band-limited.

If *window* is a function, then it is called with a vector of inputs indicating the frequency bins (i.e. `fft-freq(x.shape[axis])`).

If *window* is an array of the same length as  $x.shape[axis]$  it is assumed to be the window to be applied directly in the Fourier domain (with dc and low-frequency first).

For any other type of *window*, the function `scipy.signal.get_window` is called to generate the window.

The first sample of the returned vector is the same as the first sample of the input vector. The spacing between samples is changed from  $dx$  to  $dx * \text{len}(x) / \text{num}$ .

If  $t$  is not None, then it represents the old sample positions, and the new sample positions will be returned as well as the new samples.

As noted, *resample* uses FFT transformations, which can be very slow if the number of input or output samples is large and prime; see `scipy.fftpack.fft`.

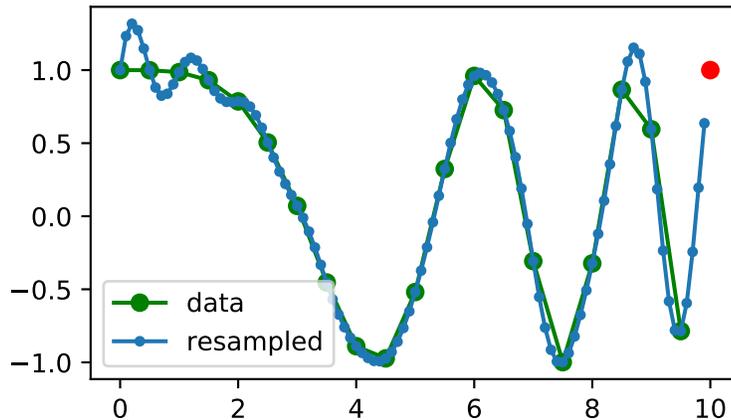
**Examples**

Note that the end of the resampled data rises to meet the first sample of the next cycle:

```
>>> from scipy import signal
```

```
>>> x = np.linspace(0, 10, 20, endpoint=False)
>>> y = np.cos(-x**2/6.0)
>>> f = signal.resample(y, 100)
>>> xnew = np.linspace(0, 10, 100, endpoint=False)
```

```
>>> import matplotlib.pyplot as plt
>>> plt.plot(x, y, 'go-', xnew, f, '.-', 10, y[0], 'ro')
>>> plt.legend(['data', 'resampled'], loc='best')
>>> plt.show()
```



```
scipy.signal.resample_poly(x, up, down, axis=0, window=('kaiser', 5.0))
```

Resample  $x$  along the given axis using polyphase filtering.

The signal  $x$  is upsampled by the factor  $up$ , a zero-phase low-pass FIR filter is applied, and then it is downsampled by the factor  $down$ . The resulting sample rate is  $up / down$  times the original sample rate. Values beyond the boundary of the signal are assumed to be zero during the filtering step.

**Parameters**

- x** : array\_like  
The data to be resampled.
- up** : int  
The upsampling factor.
- down** : int  
The downsampling factor.
- axis** : int, optional  
The axis of  $x$  that is resampled. Default is 0.
- window** : string, tuple, or array\_like, optional  
Desired window to use to design the low-pass filter, or the FIR filter coefficients to employ. See below for details.

**Returns**

- resampled\_x** : array  
The resampled array.

**See also:**

**decimate** Downsample the signal after applying an FIR or IIR filter.  
**resample** Resample up or down using the FFT method.

**Notes**

This polyphase method will likely be faster than the Fourier method in `scipy.signal.resample` when the number of samples is large and prime, or when the number of samples is large and  $up$  and  $down$  share a large greatest common denominator. The length of the FIR filter used will depend on  $\max(up, down) // \gcd(up, down)$ , and the number of operations during polyphase filtering will depend on the filter length and  $down$  (see `scipy.signal.upfirdn` for details).

The argument `window` specifies the FIR low-pass filter design.

If `window` is an array\_like it is assumed to be the FIR filter coefficients. Note that the FIR filter is applied after the upsampling step, so it should be designed to operate on a signal at a sampling frequency higher than the original by a factor of  $up // \gcd(up, down)$ . This function's output will be centered with respect to this array, so it

is best to pass a symmetric filter with an odd number of samples if, as is usually the case, a zero-phase filter is desired.

For any other type of *window*, the functions `scipy.signal.get_window` and `scipy.signal.firwin` are called to generate the appropriate filter coefficients.

The first sample of the returned vector is the same as the first sample of the input vector. The spacing between samples is changed from `dx` to `dx * down / float(up)`.

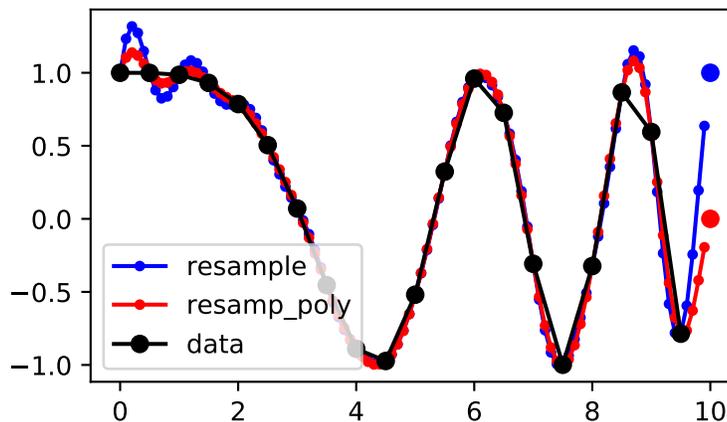
### Examples

Note that the end of the resampled data rises to meet the first sample of the next cycle for the FFT method, and gets closer to zero for the polyphase method:

```
>>> from scipy import signal
```

```
>>> x = np.linspace(0, 10, 20, endpoint=False)
>>> y = np.cos(-x**2/6.0)
>>> f_fft = signal.resample(y, 100)
>>> f_poly = signal.resample_poly(y, 100, 20)
>>> xnew = np.linspace(0, 10, 100, endpoint=False)
```

```
>>> import matplotlib.pyplot as plt
>>> plt.plot(xnew, f_fft, 'b.-', xnew, f_poly, 'r.-')
>>> plt.plot(x, y, 'ko-')
>>> plt.plot(10, y[0], 'bo', 10, 0., 'ro') # boundaries
>>> plt.legend(['resample', 'resamp_poly', 'data'], loc='best')
>>> plt.show()
```



`scipy.signal.upfirdn` (*h*, *x*, *up*=1, *down*=1, *axis*=-1)

Upsample, FIR filter, and downsample

**Parameters**

- h**: array\_like  
1-dimensional FIR (finite-impulse response) filter coefficients.
- x**: array\_like  
Input signal array.
- up**: int, optional  
Upsampling rate. Default is 1.

	<b>down</b> : int, optional	Downsampling rate. Default is 1.
	<b>axis</b> : int, optional	The axis of the input data array along which to apply the linear filter. The filter is applied to each subarray along this axis. Default is -1.
<b>Returns</b>	<b>y</b> : ndarray	The output signal array. Dimensions will be the same as <i>x</i> except for along <i>axis</i> , which will change size according to the <i>h</i> , <i>up</i> , and <i>down</i> parameters.

### Notes

The algorithm is an implementation of the block diagram shown on page 129 of the Vaidyanathan text [R305] (Figure 4.3-8d).

The direct approach of upsampling by factor of *P* with zero insertion, FIR filtering of length *N*, and downsampling by factor of *Q* is  $O(N*Q)$  per output sample. The polyphase implementation used here is  $O(N/P)$ .

New in version 0.18.

### Examples

Simple operations:

```
>>> from scipy.signal import upfirdn
>>> upfirdn([1, 1, 1], [1, 1, 1]) # FIR filter
array([ 1.,  2.,  3.,  2.,  1.])
>>> upfirdn([1], [1, 2, 3], 3) # upsampling with zeros insertion
array([ 1.,  0.,  0.,  2.,  0.,  0.,  3.,  0.,  0.])
>>> upfirdn([1, 1, 1], [1, 2, 3], 3) # upsampling with sample-and-hold
array([ 1.,  1.,  1.,  2.,  2.,  2.,  3.,  3.,  3.])
>>> upfirdn([.5, 1, .5], [1, 1, 1], 2) # linear interpolation
array([ 0.5,  1.,  1.,  1.,  1.,  1.,  0.5,  0. ])
>>> upfirdn([1], np.arange(10), 1, 3) # decimation by 3
array([ 0.,  3.,  6.,  9.])
>>> upfirdn([.5, 1, .5], np.arange(10), 2, 3) # linear interp, rate 2/3
array([ 0.,  1.,  2.5,  4.,  5.5,  7.,  8.5,  0. ])
```

Apply a single filter to multiple signals:

```
>>> x = np.reshape(np.arange(8), (4, 2))
>>> x
array([[0, 1],
       [2, 3],
       [4, 5],
       [6, 7]])
```

Apply along the last dimension of *x*:

```
>>> h = [1, 1]
>>> upfirdn(h, x, 2)
array([[ 0.,  0.,  1.,  1.],
       [ 2.,  2.,  3.,  3.],
       [ 4.,  4.,  5.,  5.],
       [ 6.,  6.,  7.,  7.]])
```

Apply along the 0th dimension of *x*:

```
>>> upfirdn(h, x, 2, axis=0)
array([[ 0.,  1.],
       [ 0.,  1.]])
```

```
[ 2., 3.],
 [ 2., 3.],
 [ 4., 5.],
 [ 4., 5.],
 [ 6., 7.],
 [ 6., 7.]])
```

## 5.20.4 Filter design

<i>bilinear</i> (b, a[, fs])	Return a digital filter from an analog one using a bilinear transform.
<i>findfreqs</i> (num, den, N[, kind])	Find array of frequencies for computing the response of an analog filter.
<i>firls</i> (numtaps, bands, desired[, weight, nyq, fs])	FIR filter design using least-squares error minimization.
<i>firwin</i> (numtaps, cutoff[, width, window, ...])	FIR filter design using the window method.
<i>firwin2</i> (numtaps, freq, gain[, nfreqs, ...])	FIR filter design using the window method.
<i>freqs</i> (b, a[, worN, plot])	Compute frequency response of analog filter.
<i>freqs_zpk</i> (z, p, k[, worN])	Compute frequency response of analog filter.
<i>freqz</i> (b[, a, worN, whole, plot])	Compute the frequency response of a digital filter.
<i>freqz_zpk</i> (z, p, k[, worN, whole])	Compute the frequency response of a digital filter in ZPK form.
<i>sosfreqz</i> (sos[, worN, whole])	Compute the frequency response of a digital filter in SOS format.
<i>group_delay</i> (system[, w, whole])	Compute the group delay of a digital filter.
<i>iirdesign</i> (wp, ws, gpass, gstop[, analog, ...])	Complete IIR digital and analog filter design.
<i>iirfilter</i> (N, Wn[, rp, rs, btype, analog, ...])	IIR digital and analog filter design given order and critical points.
<i>kaiser_atten</i> (numtaps, width)	Compute the attenuation of a Kaiser FIR filter.
<i>kaiser_beta</i> (a)	Compute the Kaiser parameter <i>beta</i> , given the attenuation <i>a</i> .
<i>kaiserord</i> (ripple, width)	Determine the filter window parameters for the Kaiser window method.
<i>minimum_phase</i> (h[, method, n_fft])	Convert a linear-phase FIR filter to minimum phase
<i>savgol_coeffs</i> (window_length, polyorder[, ...])	Compute the coefficients for a 1-d Savitzky-Golay FIR filter.
<i>remez</i> (numtaps, bands, desired[, weight, Hz, ...])	Calculate the minimax optimal filter using the Remez exchange algorithm.
<i>unique_roots</i> (p[, tol, rtype])	Determine unique roots and their multiplicities from a list of roots.
<i>residue</i> (b, a[, tol, rtype])	Compute partial-fraction expansion of $b(s) / a(s)$ .
<i>residuez</i> (b, a[, tol, rtype])	Compute partial-fraction expansion of $b(z) / a(z)$ .
<i>invres</i> (r, p, k[, tol, rtype])	Compute $b(s)$ and $a(s)$ from partial fraction expansion.
<i>invresz</i> (r, p, k[, tol, rtype])	Compute $b(z)$ and $a(z)$ from partial fraction expansion.
<i>BadCoefficients</i>	Warning about badly conditioned filter coefficients

`scipy.signal.bilinear` (*b, a, fs=1.0*)

Return a digital filter from an analog one using a bilinear transform.

The bilinear transform substitutes  $(z-1) / (z+1)$  for  $s$ .

`scipy.signal.findfreqs` (*num, den, N, kind='ba'*)

Find array of frequencies for computing the response of an analog filter.

**Parameters**

- num, den** : array\_like, 1-D  
The polynomial coefficients of the numerator and denominator of the transfer function of the filter or LTI system, where the coefficients are ordered from highest to lowest degree. Or, the roots of the transfer function numerator and denominator (i.e. zeroes and poles).
- N** : int  
The length of the array to be computed.
- kind** : str {'ba', 'zp'}, optional  
Specifies whether the numerator and denominator are specified by their polynomial coefficients ('ba'), or their roots ('zp').

**Returns**

- w** : (N,) ndarray  
A 1-D array of frequencies, logarithmically spaced.

**Examples**

Find a set of nine frequencies that span the “interesting part” of the frequency response for the filter with the transfer function

$$H(s) = s / (s^2 + 8s + 25)$$

```
>>> from scipy import signal
>>> signal.findfreqs([1, 0], [1, 8, 25], N=9)
array([[ 1.00000000e-02,  3.16227766e-02,  1.00000000e-01,
         3.16227766e-01,  1.00000000e+00,  3.16227766e+00,
         1.00000000e+01,  3.16227766e+01,  1.00000000e+02]])
```

`scipy.signal.firls` (*numtaps, bands, desired, weight=None, nyq=None, fs=None*)  
FIR filter design using least-squares error minimization.

Calculate the filter coefficients for the linear-phase finite impulse response (FIR) filter which has the best approximation to the desired frequency response described by *bands* and *desired* in the least squares sense (i.e., the integral of the weighted mean-squared error within the specified bands is minimized).

**Parameters**

- numtaps** : int  
The number of taps in the FIR filter. *numtaps* must be odd.
- bands** : array\_like  
A monotonic nondecreasing sequence containing the band edges in Hz. All elements must be non-negative and less than or equal to the Nyquist frequency given by *nyq*.
- desired** : array\_like  
A sequence the same size as *bands* containing the desired gain at the start and end point of each band.
- weight** : array\_like, optional  
A relative weighting to give to each band region when solving the least squares problem. *weight* has to be half the size of *bands*.
- nyq** : float, optional  
*Deprecated. Use 'fs' instead.* Nyquist frequency. Each frequency in *bands* must be between 0 and *nyq* (inclusive). Default is 1.
- fs** : float, optional  
The sampling frequency of the signal. Each frequency in *bands* must be between 0 and *fs*/2 (inclusive). Default is 2.

**Returns**

- coeffs** : ndarray  
Coefficients of the optimal (in a least squares sense) FIR filter.

See also:

*firwin, firwin2, minimum\_phase, remez*

### Notes

This implementation follows the algorithm given in [R254]. As noted there, least squares design has multiple advantages:

1. Optimal in a least-squares sense.
2. Simple, non-iterative method.
3. The general solution can be obtained by solving a linear system of equations.
4. Allows the use of a frequency dependent weighting function.

This function constructs a Type I linear phase FIR filter, which contains an odd number of *coeffs* satisfying for  $n < numtaps$ :

$$coeffs(n) = coeffs(numtaps - 1 - n)$$

The odd number of coefficients and filter symmetry avoid boundary conditions that could otherwise occur at the Nyquist and 0 frequencies (e.g., for Type II, III, or IV variants).

New in version 0.18.

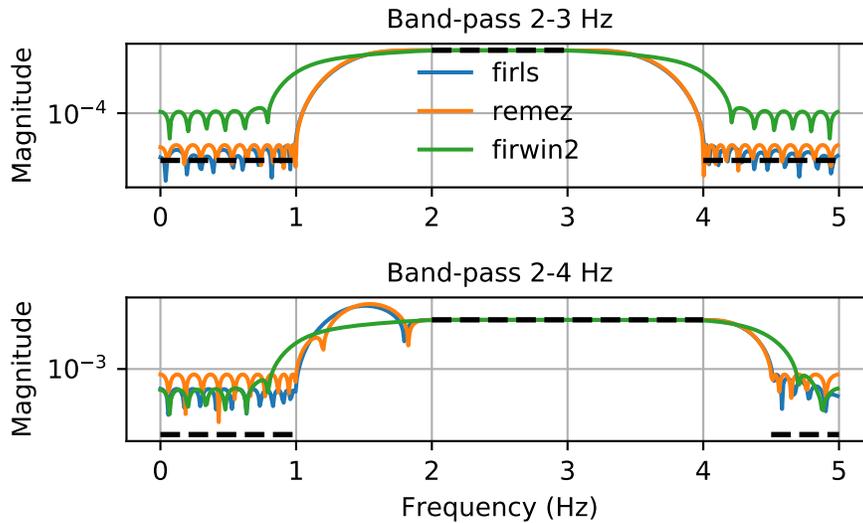
### References

[R254]

### Examples

We want to construct a band-pass filter. Note that the behavior in the frequency ranges between our stop bands and pass bands is unspecified, and thus may overshoot depending on the parameters of our filter:

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
>>> fig, axs = plt.subplots(2)
>>> fs = 10.0 # Hz
>>> desired = (0, 0, 1, 1, 0, 0)
>>> for bi, bands in enumerate(((0, 1, 2, 3, 4, 5), (0, 1, 2, 4, 4.5, 5))):
...     fir_firls = signal.firls(73, bands, desired, fs=fs)
...     fir_remez = signal.remez(73, bands, desired[:,2], fs=fs)
...     fir_firwin2 = signal.firwin2(73, bands, desired, fs=fs)
...     hs = list()
...     ax = axs[bi]
...     for fir in (fir_firls, fir_remez, fir_firwin2):
...         freq, response = signal.freqz(fir)
...         hs.append(ax.semilogy(0.5*fs*freq/np.pi, np.abs(response))[0])
...     for band, gains in zip(zip(bands[:,2], bands[1:,2]),
...                             zip(desired[:,2], desired[1:,2])):
...         ax.semilogy(band, np.maximum(gains, 1e-7), 'k--', linewidth=2)
...     if bi == 0:
...         ax.legend(hs, ('firls', 'remez', 'firwin2'),
...                     loc='lower center', frameon=False)
...     else:
...         ax.set_xlabel('Frequency (Hz)')
...     ax.grid(True)
...     ax.set(title='Band-pass %d-%d Hz' % bands[2:4], ylabel='Magnitude')
...
>>> fig.tight_layout()
>>> plt.show()
```



`scipy.signal.firwin` (*numtaps*, *cutoff*, *width=None*, *window='hamming'*, *pass\_zero=True*, *scale=True*, *nyq=None*, *fs=None*)  
 FIR filter design using the window method.

This function computes the coefficients of a finite impulse response filter. The filter will have linear phase; it will be Type I if *numtaps* is odd and Type II if *numtaps* is even.

Type II filters always have zero response at the Nyquist frequency, so a `ValueError` exception is raised if `firwin` is called with *numtaps* even and having a passband whose right end is at the Nyquist frequency.

**Parameters** **numtaps** : int

Length of the filter (number of coefficients, i.e. the filter order + 1). *numtaps* must be even if a passband includes the Nyquist frequency.

**cutoff** : float or 1D array\_like

Cutoff frequency of filter (expressed in the same units as *nyq*) OR an array of cutoff frequencies (that is, band edges). In the latter case, the frequencies in *cutoff* should be positive and monotonically increasing between 0 and *nyq*. The values 0 and *nyq* must not be included in *cutoff*.

**width** : float or None, optional

If *width* is not None, then assume it is the approximate width of the transition region (expressed in the same units as *nyq*) for use in Kaiser FIR filter design. In this case, the *window* argument is ignored.

**window** : string or tuple of string and parameter values, optional

Desired window to use. See `scipy.signal.get_window` for a list of windows and required parameters.

**pass\_zero** : bool, optional

If True, the gain at the frequency 0 (i.e. the “DC gain”) is 1. Otherwise the DC gain is 0.

**scale** : bool, optional

Set to True to scale the coefficients so that the frequency response is exactly unity at a certain frequency. That frequency is either:

- 0 (DC) if the first passband starts at 0 (i.e. *pass\_zero* is True)
- *nyq* (the Nyquist frequency) if the first passband ends at *nyq* (i.e the filter is a single band highpass filter); center of first passband otherwise

**nyq** : float, optional

*Deprecated. Use 'fs' instead.* This is the Nyquist frequency. Each frequency in *cutoff* must be between 0 and *nyq*. Default is 1.

	<b>fs</b> : float, optional	The sampling frequency of the signal. Each frequency in <i>cutoff</i> must be between 0 and $f_s/2$ . Default is 2.
<b>Returns</b>	<b>h</b> : (numtaps,) ndarray	Coefficients of length <i>numtaps</i> FIR filter.
<b>Raises</b>	<b>ValueError</b>	If any value in <i>cutoff</i> is less than or equal to 0 or greater than or equal to $f_s/2$ , if the values in <i>cutoff</i> are not strictly monotonically increasing, or if <i>numtaps</i> is even but a passband includes the Nyquist frequency.

**See also:**

*firwin2*, *firls*, *minimum\_phase*, *remez*

**Examples**

Low-pass from 0 to f:

```
>>> from scipy import signal
>>> numtaps = 3
>>> f = 0.1
>>> signal.firwin(numtaps, f)
array([ 0.06799017,  0.86401967,  0.06799017])
```

Use a specific window function:

```
>>> signal.firwin(numtaps, f, window='nuttall')
array([ 3.56607041e-04,  9.99286786e-01,  3.56607041e-04])
```

High-pass ('stop' from 0 to f):

```
>>> signal.firwin(numtaps, f, pass_zero=False)
array([-0.00859313,  0.98281375, -0.00859313])
```

Band-pass:

```
>>> f1, f2 = 0.1, 0.2
>>> signal.firwin(numtaps, [f1, f2], pass_zero=False)
array([ 0.06301614,  0.88770441,  0.06301614])
```

Band-stop:

```
>>> signal.firwin(numtaps, [f1, f2])
array([-0.00801395,  1.0160279 , -0.00801395])
```

Multi-band (passbands are [0, f1], [f2, f3] and [f4, 1]):

```
>>> f3, f4 = 0.3, 0.4
>>> signal.firwin(numtaps, [f1, f2, f3, f4])
array([-0.01376344,  1.02752689, -0.01376344])
```

Multi-band (passbands are [f1, f2] and [f3,f4]):

```
>>> signal.firwin(numtaps, [f1, f2, f3, f4], pass_zero=False)
array([ 0.04890915,  0.91284326,  0.04890915])
```

`scipy.signal.firwin2` (*numtaps*, *freq*, *gain*, *nfreqs=None*, *window='hamming'*, *nyq=None*, *antisymmetric=False*, *fs=None*)

FIR filter design using the window method.

From the given frequencies *freq* and corresponding gains *gain*, this function constructs an FIR filter with linear phase and (approximately) the given frequency response.

**Parameters**

**numtaps** : int  
The number of taps in the FIR filter. *numtaps* must be less than *nfreqs*.

**freq** : array\_like, 1D  
The frequency sampling points. Typically 0.0 to 1.0 with 1.0 being Nyquist. The Nyquist frequency is half *fs*. The values in *freq* must be nondecreasing. A value can be repeated once to implement a discontinuity. The first value in *freq* must be 0, and the last value must be  $fs/2$ .

**gain** : array\_like  
The filter gains at the frequency sampling points. Certain constraints to gain values, depending on the filter type, are applied, see Notes for details.

**nfreqs** : int, optional  
The size of the interpolation mesh used to construct the filter. For most efficient behavior, this should be a power of 2 plus 1 (e.g, 129, 257, etc). The default is one more than the smallest power of 2 that is not less than *numtaps*. *nfreqs* must be greater than *numtaps*.

**window** : string or (string, float) or float, or None, optional  
Window function to use. Default is “hamming”. See `scipy.signal.get_window` for the complete list of possible values. If None, no window function is applied.

**nyq** : float, optional  
*Deprecated. Use 'fs' instead.* This is the Nyquist frequency. Each frequency in *freq* must be between 0 and *nyq*. Default is 1.

**antisymmetric** : bool, optional  
Whether resulting impulse response is symmetric/antisymmetric. See Notes for more details.

**fs** : float, optional  
The sampling frequency of the signal. Each frequency in *freq* must be between 0 and  $fs/2$ . Default is 2.

**Returns**

**taps** : ndarray  
The filter coefficients of the FIR filter, as a 1-D array of length *numtaps*.

**See also:**

`firls`, `firwin`, `minimum_phase`, `remez`

### Notes

From the given set of frequencies and gains, the desired response is constructed in the frequency domain. The inverse FFT is applied to the desired response to create the associated convolution kernel, and the first *numtaps* coefficients of this kernel, scaled by *window*, are returned.

The FIR filter will have linear phase. The type of filter is determined by the value of ‘numtaps’ and *antisymmetric* flag. There are four possible combinations:

- odd *numtaps*, *antisymmetric* is False, type I filter is produced
- even *numtaps*, *antisymmetric* is False, type II filter is produced
- odd *numtaps*, *antisymmetric* is True, type III filter is produced
- even *numtaps*, *antisymmetric* is True, type IV filter is produced

Magnitude response of all but type I filters are subjects to following constraints:

- type II – zero at the Nyquist frequency
- type III – zero at zero and Nyquist frequencies
- type IV – zero at zero frequency

New in version 0.9.0.

### References

[R255], [R256]

### Examples

A lowpass FIR filter with a response that is 1 on [0.0, 0.5], and that decreases linearly on [0.5, 1.0] from 1 to 0:

```
>>> from scipy import signal
>>> taps = signal.firwin2(150, [0.0, 0.5, 1.0], [1.0, 1.0, 0.0])
>>> print(taps[72:78])
[-0.02286961 -0.06362756  0.57310236  0.57310236 -0.06362756 -0.02286961]
```

`scipy.signal.freqs` (*b*, *a*, *worN=None*, *plot=None*)

Compute frequency response of analog filter.

Given the M-order numerator *b* and N-order denominator *a* of an analog filter, compute its frequency response:

$$H(w) = \frac{b[0]*(jw)**M + b[1]*(jw)**(M-1) + \dots + b[M]}{a[0]*(jw)**N + a[1]*(jw)**(N-1) + \dots + a[N]}$$

**Parameters** **b** : array\_like

Numerator of a linear filter.

**a** : array\_like

Denominator of a linear filter.

**worN** : {None, int, array\_like}, optional

If None, then compute at 200 frequencies around the interesting parts of the response curve (determined by pole-zero locations). If a single integer, then compute at that many frequencies. Otherwise, compute the response at the angular frequencies (e.g. rad/s) given in *worN*.

**plot** : callable, optional

A callable that takes two arguments. If given, the return parameters *w* and *h* are passed to plot. Useful for plotting the frequency response inside *freqs*.

**Returns** **w** : ndarray

The angular frequencies at which *h* was computed.

**h** : ndarray

The frequency response.

**See also:**

**freqz** Compute the frequency response of a digital filter.

### Notes

Using Matplotlib's "plot" function as the callable for *plot* produces unexpected results, this plots the real part of the complex transfer function, not the magnitude. Try `lambda w, h: plot(w, abs(h))`.

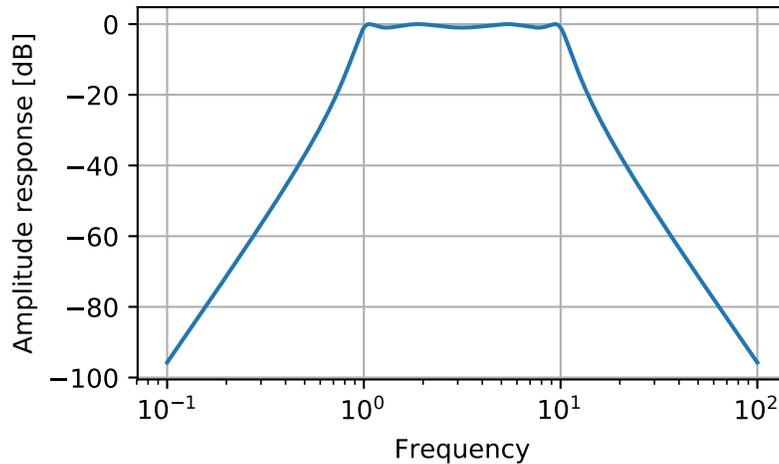
### Examples

```
>>> from scipy.signal import freqs, iirfilter
```

```
>>> b, a = iirfilter(4, [1, 10], 1, 60, analog=True, ftype='cheby1')
```

```
>>> w, h = freqs(b, a, worN=np.logspace(-1, 2, 1000))
```

```
>>> import matplotlib.pyplot as plt
>>> plt.semilogx(w, 20 * np.log10(abs(h)))
>>> plt.xlabel('Frequency')
>>> plt.ylabel('Amplitude response [dB]')
>>> plt.grid()
>>> plt.show()
```



`scipy.signal.freqs_zpk` (*z*, *p*, *k*, *worN=None*)

Compute frequency response of analog filter.

Given the zeros *z*, poles *p*, and gain *k* of a filter, compute its frequency response:

$$H(\omega) = k * \frac{(j\omega - z[0]) * (j\omega - z[1]) * \dots * (j\omega - z[-1])}{(j\omega - p[0]) * (j\omega - p[1]) * \dots * (j\omega - p[-1])}$$

**Parameters**

- z** : array\_like  
Zeroes of a linear filter
- p** : array\_like  
Poles of a linear filter
- k** : scalar  
Gain of a linear filter
- worN** : {None, int, array\_like}, optional  
If None, then compute at 200 frequencies around the interesting parts of the response curve (determined by pole-zero locations). If a single integer, then compute at that many frequencies. Otherwise, compute the response at the angular frequencies (e.g. rad/s) given in *worN*.

**Returns**

- w** : ndarray  
The angular frequencies at which *h* was computed.
- h** : ndarray  
The frequency response.

See also:

- freqs** Compute the frequency response of an analog filter in TF form
- freqz** Compute the frequency response of a digital filter in TF form
- freqz\_zpk** Compute the frequency response of a digital filter in ZPK form

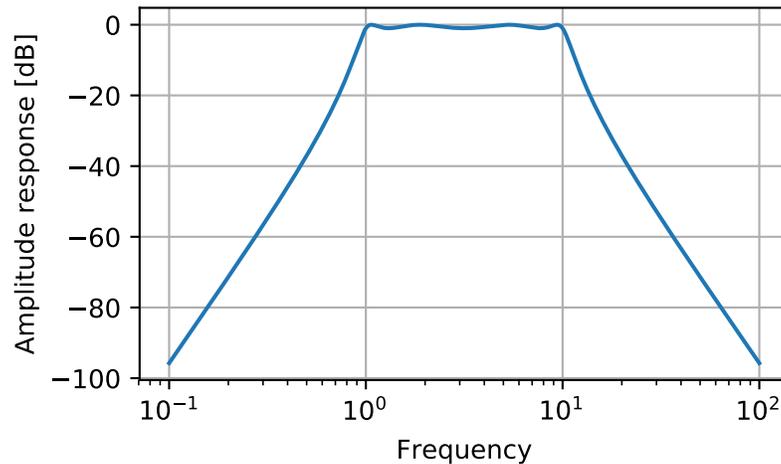
**Notes****Examples**

```
>>> from scipy.signal import freqs_zpk, iirfilter
```

```
>>> z, p, k = iirfilter(4, [1, 10], 1, 60, analog=True, ftype='cheby1',
...                    output='zpk')
```

```
>>> w, h = freqs_zpk(z, p, k, worN=np.logspace(-1, 2, 1000))
```

```
>>> import matplotlib.pyplot as plt
>>> plt.semilogx(w, 20 * np.log10(abs(h)))
>>> plt.xlabel('Frequency')
>>> plt.ylabel('Amplitude response [dB]')
>>> plt.grid()
>>> plt.show()
```



`scipy.signal.freqz` (*b*, *a*=1, *worN*=None, *whole*=False, *plot*=None)

Compute the frequency response of a digital filter.

Given the *M*-order numerator *b* and *N*-order denominator *a* of a digital filter, compute its frequency response:

$$H(e^{j\omega}) = \frac{B(e^{j\omega})}{A(e^{j\omega})} = \frac{b[0] + b[1]e^{-j\omega} + \dots + b[M]e^{-j\omega M}}{a[0] + a[1]e^{-j\omega} + \dots + a[N]e^{-j\omega N}}$$

**Parameters** **b**: array\_like

Numerator of a linear filter. If *b* has dimension greater than 1, it is assumed that the coefficients are stored in the first dimension, and `b.shape[1:]`, `a.shape[1:]`, and the shape of the frequencies array must be compatible for broadcasting.

**a**: array\_like

Denominator of a linear filter. If  $b$  has dimension greater than 1, it is assumed that the coefficients are stored in the first dimension, and  $b.shape[1:]$ ,  $a.shape[1:]$ , and the shape of the frequencies array must be compatible for broadcasting.

**worN** : {None, int, array\_like}, optional

If None (default), then compute at 512 equally spaced frequencies. If a single integer, then compute at that many frequencies. This is a convenient alternative to:

```
np.linspace(0, 2*pi if whole else pi, N,
            ↪endpoint=False)
```

Using a number that is fast for FFT computations can result in faster computations (see Notes). If an array\_like, compute the response at the frequencies given (in radians/sample).

**whole** : bool, optional

Normally, frequencies are computed from 0 to the Nyquist frequency,  $\pi$  radians/sample (upper-half of unit-circle). If *whole* is True, compute frequencies from 0 to  $2\pi$  radians/sample.

**plot** : callable

A callable that takes two arguments. If given, the return parameters  $w$  and  $h$  are passed to plot. Useful for plotting the frequency response inside *freqz*.

#### Returns

**w** : ndarray

The normalized frequencies at which  $h$  was computed, in radians/sample.

**h** : ndarray

The frequency response, as complex numbers.

#### See also:

*freqz\_zpk*, *sosfreqz*

#### Notes

Using Matplotlib's `matplotlib.pyplot.plot` function as the callable for *plot* produces unexpected results, as this plots the real part of the complex transfer function, not the magnitude. Try `lambda w, h: plot(w, np.abs(h))`.

A direct computation via (R)FFT is used to compute the frequency response when the following conditions are met:

1. An integer value is given for *worN*.
2. *worN* is fast to compute via FFT (i.e., `next_fast_len(worN)` equals *worN*).
3. The denominator coefficients are a single value (`a.shape[0] == 1`).
4. *worN* is at least as long as the numerator coefficients (`worN >= b.shape[0]`).
5. If `b.ndim > 1`, then `b.shape[-1] == 1`.

For long FIR filters, the FFT approach can have lower error and be much faster than the equivalent direct polynomial calculation.

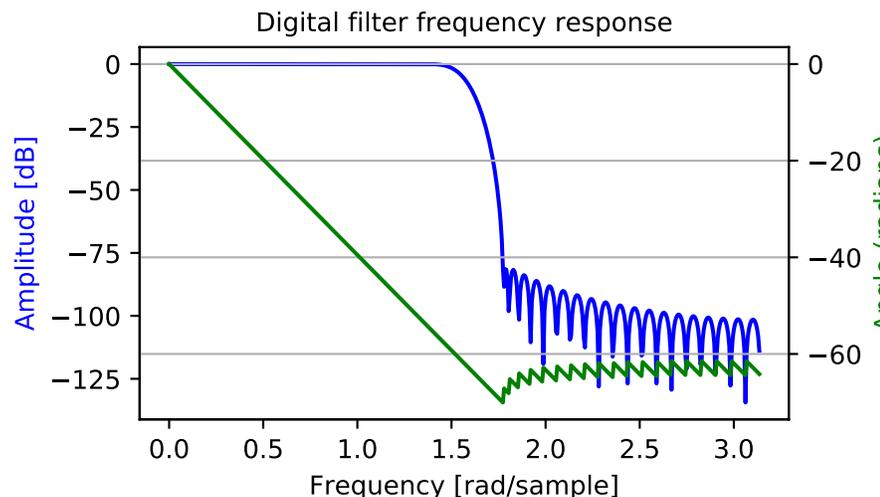
#### Examples

```
>>> from scipy import signal
>>> b = signal.firwin(80, 0.5, window=('kaiser', 8))
>>> w, h = signal.freqz(b)
```

```
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> plt.title('Digital filter frequency response')
>>> ax1 = fig.add_subplot(111)
```

```
>>> plt.plot(w, 20 * np.log10(abs(h)), 'b')
>>> plt.ylabel('Amplitude [dB]', color='b')
>>> plt.xlabel('Frequency [rad/sample]')
```

```
>>> ax2 = ax1.twinx()
>>> angles = np.unwrap(np.angle(h))
>>> plt.plot(w, angles, 'g')
>>> plt.ylabel('Angle (radians)', color='g')
>>> plt.grid()
>>> plt.axis('tight')
>>> plt.show()
```



### Broadcasting Examples

Suppose we have two FIR filters whose coefficients are stored in the rows of an array with shape (2, 25). For this demonstration we'll use random data:

```
>>> np.random.seed(42)
>>> b = np.random.rand(2, 25)
```

To compute the frequency response for these two filters with one call to `freqz`, we must pass in `b.T`, because `freqz` expects the first axis to hold the coefficients. We must then extend the shape with a trivial dimension of length 1 to allow broadcasting with the array of frequencies. That is, we pass in `b.T[..., np.newaxis]`, which has shape (25, 2, 1):

```
>>> w, h = signal.freqz(b.T[..., np.newaxis], worN=1024)
>>> w.shape
(1024,)
>>> h.shape
(2, 1024)
```

Now suppose we have two transfer functions, with the same numerator coefficients `b = [0.5, 0.5]`. The coefficients for the two denominators are stored in the first dimension of the two-dimensional array `a`:

```
a = [ 1 1 ]
     [-0.25, -0.5 ]
```

```
>>> b = np.array([0.5, 0.5])
>>> a = np.array([[1, 1], [-0.25, -0.5]])
```

Only *a* is more than one-dimensional. To make it compatible for broadcasting with the frequencies, we extend it with a trivial dimension in the call to *freqz*:

```
>>> w, h = signal.freqz(b, a[..., np.newaxis], worN=1024)
>>> w.shape
(1024,)
>>> h.shape
(2, 1024)
```

`scipy.signal.freqz_zpk(z, p, k, worN=None, whole=False)`

Compute the frequency response of a digital filter in ZPK form.

Given the Zeros, Poles and Gain of a digital filter, compute its frequency response:

$$H(z) = k \prod_i (z - Z[i]) / \prod_j (z - P[j])$$

where *k* is the gain, *Z* are the zeros and *P* are the poles.

<b>Parameters</b>	<b>z</b> : array_like	Zeroes of a linear filter
	<b>p</b> : array_like	Poles of a linear filter
	<b>k</b> : scalar	Gain of a linear filter
	<b>worN</b> : {None, int, array_like}, optional	If single integer (default 512, same as None), then compute at <i>worN</i> frequencies equally spaced around the unit circle. If an array_like, compute the response at the frequencies given (in radians/sample).
	<b>whole</b> : bool, optional	Normally, frequencies are computed from 0 to the Nyquist frequency, pi radians/sample (upper-half of unit-circle). If <i>whole</i> is True, compute frequencies from 0 to 2*pi radians/sample.
<b>Returns</b>	<b>w</b> : ndarray	The normalized frequencies at which <i>h</i> was computed, in radians/sample.
	<b>h</b> : ndarray	The frequency response.

See also:

**freqs** Compute the frequency response of an analog filter in TF form  
**freqs\_zpk** Compute the frequency response of an analog filter in ZPK form  
**freqz** Compute the frequency response of a digital filter in TF form

Notes

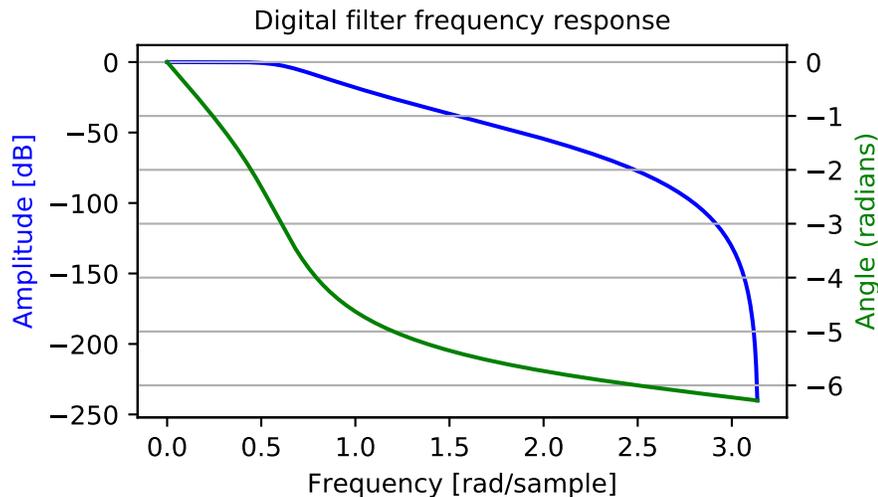
Examples

```
>>> from scipy import signal
>>> z, p, k = signal.butter(4, 0.2, output='zpk')
>>> w, h = signal.freqz_zpk(z, p, k)
```

```
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> plt.title('Digital filter frequency response')
>>> ax1 = fig.add_subplot(111)
```

```
>>> plt.plot(w, 20 * np.log10(abs(h)), 'b')
>>> plt.ylabel('Amplitude [dB]', color='b')
>>> plt.xlabel('Frequency [rad/sample]')
```

```
>>> ax2 = ax1.twinx()
>>> angles = np.unwrap(np.angle(h))
>>> plt.plot(w, angles, 'g')
>>> plt.ylabel('Angle (radians)', color='g')
>>> plt.grid()
>>> plt.axis('tight')
>>> plt.show()
```



`scipy.signal.sosfreqz` (*sos*, *worN=None*, *whole=False*)

Compute the frequency response of a digital filter in SOS format.

Given *sos*, an array with shape (n, 6) of second order sections of a digital filter, compute the frequency response of the system function:

$$H(z) = \frac{B_0(z)}{A_0(z)} * \frac{B_1(z)}{A_1(z)} * \dots * \frac{B_{n-1}(z)}{A_{n-1}(z)}$$

for  $z = \exp(\omega j)$ , where  $B\{k\}(z)$  and  $A\{k\}(z)$  are numerator and denominator of the transfer function of the  $k$ -th second order section.

**Parameters** *sos* : array\_like

Array of second-order filter coefficients, must have shape (n\_sections, 6). Each row corresponds to a second-order section, with the first three columns providing the numerator coefficients and the last three providing the denominator coefficients.

*worN* : {None, int, array\_like}, optional

If None (default), then compute at 512 frequencies equally spaced around the unit circle. If a single integer, then compute at that many frequencies. Using a number that is fast for FFT computations can result in faster computations (see Notes of `freqz`). If an array\_like, compute the response at the frequencies given (in radians/sample; must be 1D).

*whole* : bool, optional

Normally, frequencies are computed from 0 to the Nyquist frequency,  $\pi$  radians/sample (upper-half of unit-circle). If *whole* is True, compute frequencies from 0 to  $2\pi$  radians/sample.

**Returns**

**w** : ndarray  
The normalized frequencies at which *h* was computed, in radians/sample.

**h** : ndarray  
The frequency response, as complex numbers.

**See also:***freqz, sosfilt***Notes**

New in version 0.19.0.

**Examples**

Design a 15th-order bandpass filter in SOS format.

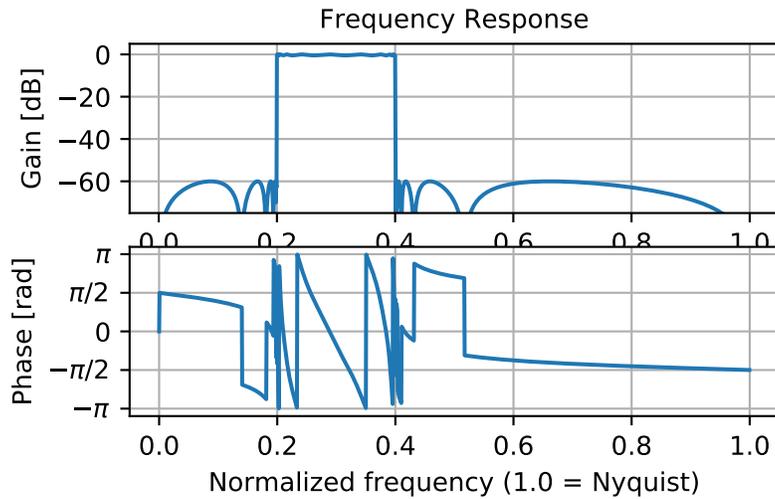
```
>>> from scipy import signal
>>> sos = signal.ellip(15, 0.5, 60, (0.2, 0.4), btype='bandpass',
...                       output='sos')
```

Compute the frequency response at 1500 points from DC to Nyquist.

```
>>> w, h = signal.sosfreqz(sos, worN=1500)
```

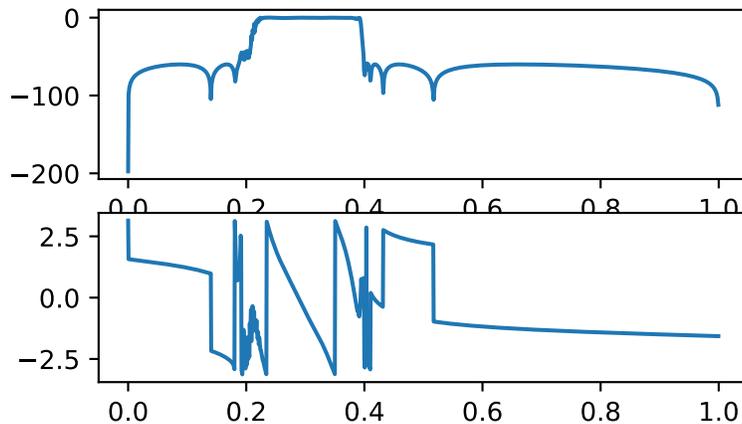
Plot the response.

```
>>> import matplotlib.pyplot as plt
>>> plt.subplot(2, 1, 1)
>>> db = 20*np.log10(np.abs(h))
>>> plt.plot(w/np.pi, db)
>>> plt.ylim(-75, 5)
>>> plt.grid(True)
>>> plt.yticks([0, -20, -40, -60])
>>> plt.ylabel('Gain [dB]')
>>> plt.title('Frequency Response')
>>> plt.subplot(2, 1, 2)
>>> plt.plot(w/np.pi, np.angle(h))
>>> plt.grid(True)
>>> plt.yticks([-np.pi, -0.5*np.pi, 0, 0.5*np.pi, np.pi],
...           [r'$-\pi$', r'$-\pi/2$', '0', r'$\pi/2$', r'$\pi$'])
>>> plt.ylabel('Phase [rad]')
>>> plt.xlabel('Normalized frequency (1.0 = Nyquist)')
>>> plt.show()
```



If the same filter is implemented as a single transfer function, numerical error corrupts the frequency response:

```
>>> b, a = signal.ellip(15, 0.5, 60, (0.2, 0.4), btype='bandpass',
...                   output='ba')
>>> w, h = signal.freqz(b, a, worN=1500)
>>> plt.subplot(2, 1, 1)
>>> db = 20*np.log10(np.abs(h))
>>> plt.plot(w/np.pi, db)
>>> plt.subplot(2, 1, 2)
>>> plt.plot(w/np.pi, np.angle(h))
>>> plt.show()
```



`scipy.signal.group_delay(system, w=None, whole=False)`  
 Compute the group delay of a digital filter.

The group delay measures by how many samples amplitude envelopes of various spectral components of a signal are delayed by a filter. It is formally defined as the derivative of continuous (unwrapped) phase:

$$D(\omega) = - \frac{d}{d\omega} \arg H(e^{j\omega})$$

**Parameters**

- system** : tuple of array\_like (b, a)  
Numerator and denominator coefficients of a filter transfer function.
- w** : {None, int, array-like}, optional  
If None (default), then compute at 512 frequencies equally spaced around the unit circle. If a single integer, then compute at that many frequencies. If array, compute the delay at the frequencies given (in radians/sample).
- whole** : bool, optional  
Normally, frequencies are computed from 0 to the Nyquist frequency, pi radians/sample (upper-half of unit-circle). If *whole* is True, compute frequencies from 0 to  $2\pi$  radians/sample.

**Returns**

- w** : ndarray  
The normalized frequencies at which the group delay was computed, in radians/sample.
- gd** : ndarray  
The group delay.

**See also:**

**freqz**      Frequency response of a digital filter

#### Notes

The similar function in MATLAB is called *grpdelay*.

If the transfer function  $H(z)$  has zeros or poles on the unit circle, the group delay at corresponding frequencies is undefined. When such a case arises the warning is raised and the group delay is set to 0 at those frequencies.

For the details of numerical computation of the group delay refer to [R258].

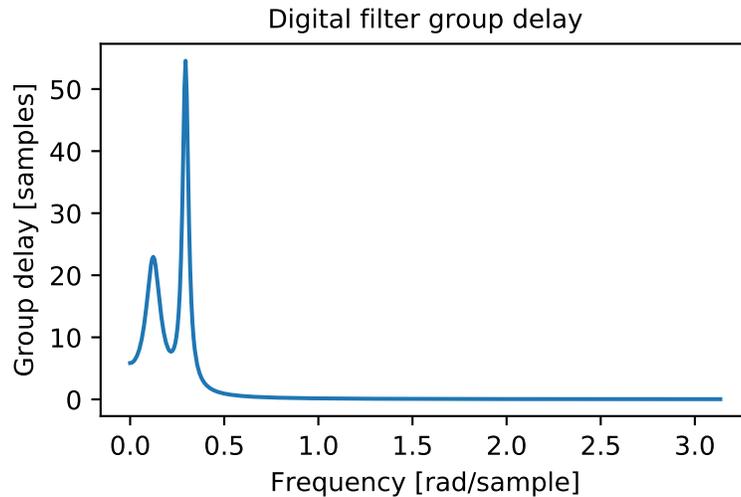
#### References

[R258]

#### Examples

```
>>> from scipy import signal
>>> b, a = signal.iirdesign(0.1, 0.3, 5, 50, ftype='cheby1')
>>> w, gd = signal.group_delay((b, a))
```

```
>>> import matplotlib.pyplot as plt
>>> plt.title('Digital filter group delay')
>>> plt.plot(w, gd)
>>> plt.ylabel('Group delay [samples]')
>>> plt.xlabel('Frequency [rad/sample]')
>>> plt.show()
```



`scipy.signal.iirdesign` (*wp*, *ws*, *gpass*, *gstop*, *analog=False*, *ftype='ellip'*, *output='ba'*)

Complete IIR digital and analog filter design.

Given passband and stopband frequencies and gains, construct an analog or digital IIR filter of minimum order for a given basic type. Return the output in numerator, denominator ('ba'), pole-zero ('zpk') or second order sections ('sos') form.

**Parameters**    **wp, ws** : float

Passband and stopband edge frequencies. For digital filters, these are normalized from 0 to 1, where 1 is the Nyquist frequency, pi radians/sample. (*wp* and *ws* are thus in half-cycles / sample.) For example:

- Lowpass: *wp* = 0.2, *ws* = 0.3
- Highpass: *wp* = 0.3, *ws* = 0.2
- Bandpass: *wp* = [0.2, 0.5], *ws* = [0.4, 0.6]
- Bandstop: *wp* = [0.1, 0.6], *ws* = [0.2, 0.5]

For analog filters, *wp* and *ws* are angular frequencies (e.g. rad/s).

**gpass** : float

The maximum loss in the passband (dB).

**gstop** : float

The minimum attenuation in the stopband (dB).

**analog** : bool, optional

When True, return an analog filter, otherwise a digital filter is returned.

**ftype** : str, optional

The type of IIR filter to design:

- Butterworth: 'butter'
- Chebyshev I: 'cheby1'
- Chebyshev II: 'cheby2'
- Cauchy/elliptic: 'ellip'
- Bessel/Thomson: 'bessel'

**output** : {'ba', 'zpk', 'sos'}, optional

Type of output: numerator/denominator ('ba'), pole-zero ('zpk'), or second-order sections ('sos'). Default is 'ba'.

**Returns**

**b, a** : ndarray, ndarray

Numerator (*b*) and denominator (*a*) polynomials of the IIR filter. Only returned if *output*='ba'.

**z, p, k** : ndarray, ndarray, float

Zeros, poles, and system gain of the IIR filter transfer function. Only returned if *output*='zpk'.

**sos** : ndarray

Second-order sections representation of the IIR filter. Only returned if `output=='sos'`.

**See also:**

**butter** Filter design using order and critical points

*cheby1, cheby2, ellip, bessel*

**buttord** Find order and critical points from passband and stopband spec

*cheb1ord, cheb2ord, ellipord*

**iirfilter** General filter design using order and critical frequencies

**Notes**

The 'sos' output parameter was added in 0.16.0.

`scipy.signal.iirfilter(N, Wn, rp=None, rs=None, btype='band', analog=False, ftype='butter', output='ba')`

IIR digital and analog filter design given order and critical points.

Design an Nth-order digital or analog filter and return the filter coefficients.

**Parameters** **N** : int

The order of the filter.

**Wn** : array\_like

A scalar or length-2 sequence giving the critical frequencies. For digital filters, *Wn* is normalized from 0 to 1, where 1 is the Nyquist frequency, pi radians/sample. (*Wn* is thus in half-cycles / sample.) For analog filters, *Wn* is an angular frequency (e.g. rad/s).

**rp** : float, optional

For Chebyshev and elliptic filters, provides the maximum ripple in the passband. (dB)

**rs** : float, optional

For Chebyshev and elliptic filters, provides the minimum attenuation in the stop band. (dB)

**btype** : { 'bandpass', 'lowpass', 'highpass', 'bandstop' }, optional

The type of filter. Default is 'bandpass'.

**analog** : bool, optional

When True, return an analog filter, otherwise a digital filter is returned.

**ftype** : str, optional

The type of IIR filter to design:

- Butterworth: 'butter'
- Chebyshev I: 'cheby1'
- Chebyshev II: 'cheby2'
- Cauchy/elliptic: 'ellip'
- Bessel/Thomson: 'bessel'

**output** : { 'ba', 'zpk', 'sos' }, optional

Type of output: numerator/denominator ('ba'), pole-zero ('zpk'), or second-order sections ('sos'). Default is 'ba'.

**Returns**

**b, a** : ndarray, ndarray

Numerator (*b*) and denominator (*a*) polynomials of the IIR filter. Only returned if `output='ba'`.

**z, p, k** : ndarray, ndarray, float

Zeros, poles, and system gain of the IIR filter transfer function. Only returned if `output='zpk'`.

**sos** : ndarray

Second-order sections representation of the IIR filter. Only returned if `output=='sos'`.

**See also:**

**butter** Filter design using order and critical points

*cheby1, cheby2, ellip, bessel*

**buttord** Find order and critical points from passband and stopband spec

*cheb1ord, cheb2ord, ellipord*

**iirdesign** General filter design using passband and stopband spec

### Notes

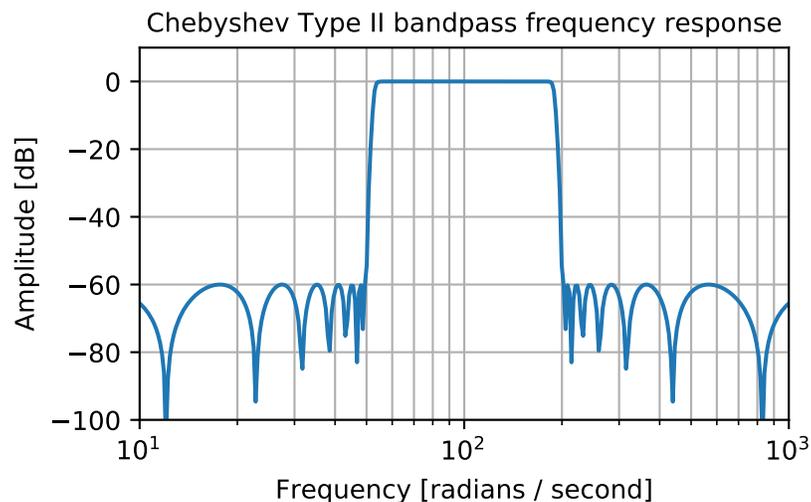
The 'sos' output parameter was added in 0.16.0.

### Examples

Generate a 17th-order Chebyshev II bandpass filter and plot the frequency response:

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

```
>>> b, a = signal.iirfilter(17, [50, 200], rs=60, btype='band',
...                          analog=True, ftype='cheby2')
>>> w, h = signal.freqs(b, a, 1000)
>>> fig = plt.figure()
>>> ax = fig.add_subplot(111)
>>> ax.semilogx(w, 20 * np.log10(abs(h)))
>>> ax.set_title('Chebyshev Type II bandpass frequency response')
>>> ax.set_xlabel('Frequency [radians / second]')
>>> ax.set_ylabel('Amplitude [dB]')
>>> ax.axis((10, 1000, -100, 10))
>>> ax.grid(which='both', axis='both')
>>> plt.show()
```



`scipy.signal.kaiser_atten(numtaps, width)`

Compute the attenuation of a Kaiser FIR filter.

Given the number of taps  $N$  and the transition width  $width$ , compute the attenuation  $a$  in dB, given by Kaiser's formula:

$$a = 2.285 * (N - 1) * \pi * width + 7.95$$

**Parameters**

- numtaps** : int  
The number of taps in the FIR filter.
- width** : float  
The desired width of the transition region between passband and stopband (or, in general, at any discontinuity) for the filter, expressed as a fraction of the Nyquist frequency.

**Returns**

- a** : float  
The attenuation of the ripple, in dB.

**See also:**

*kaiserord*, *kaiser\_beta*

**Examples**

Suppose we want to design a FIR filter using the Kaiser window method that will have 211 taps and a transition width of 9 Hz for a signal that is sampled at 480 Hz. Expressed as a fraction of the Nyquist frequency, the width is  $9/(0.5*480) = 0.0375$ . The approximate attenuation (in dB) is computed as follows:

```

>>> from scipy.signal import kaiser_atten
>>> kaiser_atten(211, 0.0375)
64.48099630593983
    
```

`scipy.signal.kaiser_beta(a)`

Compute the Kaiser parameter *beta*, given the attenuation *a*.

**Parameters**

- a** : float  
The desired attenuation in the stopband and maximum ripple in the passband, in dB. This should be a *positive* number.

**Returns**

- beta** : float  
The *beta* parameter to be used in the formula for a Kaiser window.

**References**

Oppenheim, Schafer, “Discrete-Time Signal Processing”, p.475-476.

**Examples**

Suppose we want to design a lowpass filter, with 65 dB attenuation in the stop band. The Kaiser window parameter to be used in the window method is computed by *kaiser\_beta(65)*:

```

>>> from scipy.signal import kaiser_beta
>>> kaiser_beta(65)
6.20426
    
```

`scipy.signal.kaiserord(ripple, width)`

Determine the filter window parameters for the Kaiser window method.

The parameters returned by this function are generally used to create a finite impulse response filter using the window method, with either *firwin* or *firwin2*.

**Parameters**

- ripple** : float  
Upper bound for the deviation (in dB) of the magnitude of the filter’s frequency response from that of the desired filter (not including frequencies in any transition intervals). That is, if *w* is the frequency expressed as a fraction of the Nyquist frequency, *A(w)* is the actual frequency response of the filter and *D(w)* is the desired frequency response, the design requirement is that:

```
abs(A(w) - D(w)) < 10**(-ripple/20)
```

for  $0 \leq w \leq 1$  and  $w$  not in a transition interval.

**width** : float

Width of transition region, normalized so that 1 corresponds to pi radians / sample. That is, the frequency is expressed as a fraction of the Nyquist frequency.

**Returns**

**numtaps** : int

The length of the Kaiser window.

**beta** : float

The beta parameter for the Kaiser window.

**See also:**

*kaiser\_beta*, *kaiser\_atten*

**Notes**

There are several ways to obtain the Kaiser window:

- `signal.kaiser(numtaps, beta, sym=True)`
- `signal.get_window(beta, numtaps)`
- `signal.get_window('kaiser', beta), numtaps)`

The empirical equations discovered by Kaiser are used.

**References**

Oppenheim, Schafer, “Discrete-Time Signal Processing”, p.475-476.

**Examples**

We will use the Kaiser window method to design a lowpass FIR filter for a signal that is sampled at 1000 Hz.

We want at least 65 dB rejection in the stop band, and in the pass band the gain should vary no more than 0.5%.

We want a cutoff frequency of 175 Hz, with a transition between the pass band and the stop band of 24 Hz. That is, in the band [0, 163], the gain varies no more than 0.5%, and in the band [187, 500], the signal is attenuated by at least 65 dB.

```
>>> from scipy.signal import kaiserord, firwin, freqz
>>> import matplotlib.pyplot as plt
>>> fs = 1000.0
>>> cutoff = 175
>>> width = 24
```

The Kaiser method accepts just a single parameter to control the pass band ripple and the stop band rejection, so we use the more restrictive of the two. In this case, the pass band ripple is 0.005, or 46.02 dB, so we will use 65 dB as the design parameter.

Use *kaiserord* to determine the length of the filter and the parameter for the Kaiser window.

```
>>> numtaps, beta = kaiserord(65, width/(0.5*fs))
>>> numtaps
167
>>> beta
6.20426
```

Use *firwin* to create the FIR filter.

```
>>> taps = firwin(numtaps, cutoff, window='kaiser', beta),
...               scale=False, nyq=0.5*fs)
```

Compute the frequency response of the filter.  $w$  is the array of frequencies, and  $h$  is the corresponding complex array of frequency responses.

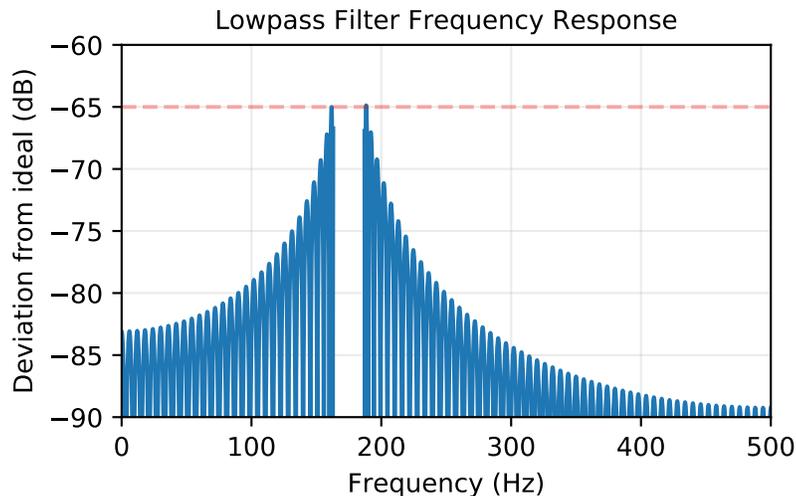
```
>>> w, h = freqz(taps, worN=8000)
>>> w *= 0.5*fs/np.pi # Convert w to Hz.
```

Compute the deviation of the magnitude of the filter's response from that of the ideal lowpass filter. Values in the transition region are set to `nan`, so they won't appear in the plot.

```
>>> ideal = w < cutoff # The "ideal" frequency response.
>>> deviation = np.abs(np.abs(h) - ideal)
>>> deviation[(w > cutoff - 0.5*width) & (w < cutoff + 0.5*width)] = np.nan
```

Plot the deviation. A close look at the left end of the stop band shows that the requirement for 65 dB attenuation is violated in the first lobe by about 0.125 dB. This is not unusual for the Kaiser window method.

```
>>> plt.plot(w, 20*np.log10(np.abs(deviation)))
>>> plt.xlim(0, 0.5*fs)
>>> plt.ylim(-90, -60)
>>> plt.grid(alpha=0.25)
>>> plt.axhline(-65, color='r', ls='--', alpha=0.3)
>>> plt.xlabel('Frequency (Hz)')
>>> plt.ylabel('Deviation from ideal (dB)')
>>> plt.title('Lowpass Filter Frequency Response')
>>> plt.show()
```



`scipy.signal.minimum_phase` ( $h$ , *method*='homomorphic', *n\_fft*=None)

Convert a linear-phase FIR filter to minimum phase

**Parameters** **h** : array

Linear-phase FIR filter coefficients.

**method** : {'hilbert', 'homomorphic'}

The method to use:

**'homomorphic' (default)**

This method [R289] [R290] works best with filters with an odd number of taps, and the resulting minimum phase filter will have a magnitude response that approximates the

square root of the the original filter's magnitude response.

**'hilbert'** This method [R286] is designed to be used with equiripple filters (e.g., from *remez*) with unity or zero gain regions.

**n\_fft** : int  
The number of points to use for the FFT. Should be at least a few times larger than the signal length (see Notes).

**Returns** **h\_minimum** : array  
The minimum-phase version of the filter, with length  $(\text{length}(h) + 1) // 2$ .

**See also:**

*firwin*, *firwin2*, *remez*

**Notes**

Both the Hilbert [R286] or homomorphic [R289] [R290] methods require selection of an FFT length to estimate the complex cepstrum of the filter.

In the case of the Hilbert method, the deviation from the ideal spectrum *epsilon* is related to the number of stopband zeros *n\_stop* and FFT length *n\_fft* as:

```
epsilon = 2. * n_stop / n_fft
```

For example, with 100 stopband zeros and a FFT length of 2048, *epsilon* = 0.0976. If we conservatively assume that the number of stopband zeros is one less than the filter length, we can take the FFT length to be the next power of 2 that satisfies *epsilon*=0.01 as:

```
n_fft = 2 ** int(np.ceil(np.log2(2 * (len(h) - 1) / 0.01)))
```

This gives reasonable results for both the Hilbert and homomorphic methods, and gives the value used when *n\_fft*=None.

Alternative implementations exist for creating minimum-phase filters, including zero inversion [R287] and spectral factorization [R288] [R289]. For more information, see:

<http://dspguru.com/dsp/howtos/how-to-design-minimum-phase-fir-filters>

**References**

[R286], [R287], [R288], [R289], [R290]

**Examples**

Create an optimal linear-phase filter, then convert it to minimum phase:

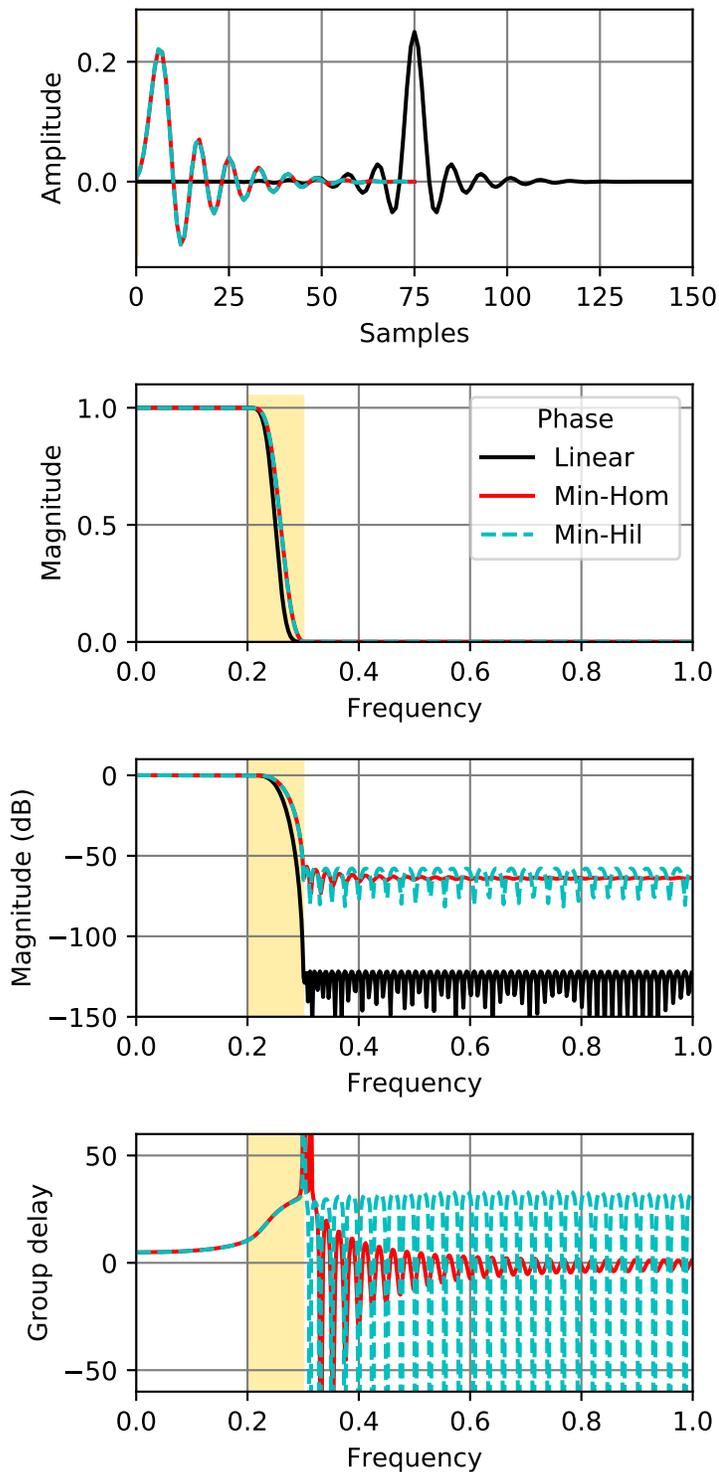
```
>>> from scipy.signal import remez, minimum_phase, freqz, group_delay
>>> import matplotlib.pyplot as plt
>>> freq = [0, 0.2, 0.3, 1.0]
>>> desired = [1, 0]
>>> h_linear = remez(151, freq, desired, Hz=2.)
```

Convert it to minimum phase:

```
>>> h_min_hom = minimum_phase(h_linear, method='homomorphic')
>>> h_min_hil = minimum_phase(h_linear, method='hilbert')
```

Compare the three filters:

```
>>> fig, axs = plt.subplots(4, figsize=(4, 8))
>>> for h, style, color in zip((h_linear, h_min_hom, h_min_hil),
...                           ('-', '-', '--'), ('k', 'r', 'c')):
...     w, H = freqz(h)
...     w, gd = group_delay((h, 1))
...     w /= np.pi
...     axs[0].plot(h, color=color, linestyle=style)
...     axs[1].plot(w, np.abs(H), color=color, linestyle=style)
...     axs[2].plot(w, 20 * np.log10(np.abs(H)), color=color, linestyle=style)
...     axs[3].plot(w, gd, color=color, linestyle=style)
>>> for ax in axs:
...     ax.grid(True, color='0.5')
...     ax.fill_between(freq[1:3], *ax.get_ylim(), color='#ffeeaa', zorder=1)
>>> axs[0].set(xlim=[0, len(h_linear) - 1], ylabel='Amplitude', xlabel='Samples')
>>> axs[1].legend(['Linear', 'Min-Hom', 'Min-Hil'], title='Phase')
>>> for ax, ylim in zip(axs[1:], ([0, 1.1], [-150, 10], [-60, 60])):
...     ax.set(xlim=[0, 1], ylim=ylim, xlabel='Frequency')
>>> axs[1].set(ylabel='Magnitude')
>>> axs[2].set(ylabel='Magnitude (dB)')
>>> axs[3].set(ylabel='Group delay')
>>> plt.tight_layout()
```



```
scipy.signal.savgol_coeffs(window_length, polyorder, deriv=0, delta=1.0, pos=None,
                           use='conv')
```

Compute the coefficients for a 1-d Savitzky-Golay FIR filter.

**Parameters** **window\_length** : int

The length of the filter window (i.e. the number of coefficients). *win-*

*dow\_length* must be an odd positive integer.

**polyorder** : int

The order of the polynomial used to fit the samples. *polyorder* must be less than *window\_length*.

**deriv** : int, optional

The order of the derivative to compute. This must be a nonnegative integer. The default is 0, which means to filter the data without differentiating.

**delta** : float, optional

The spacing of the samples to which the filter will be applied. This is only used if *deriv* > 0.

**pos** : int or None, optional

If *pos* is not None, it specifies evaluation position within the window. The default is the middle of the window.

**use** : str, optional

Either 'conv' or 'dot'. This argument chooses the order of the coefficients. The default is 'conv', which means that the coefficients are ordered to be used in a convolution. With *use*='dot', the order is reversed, so the filter is applied by dotting the coefficients with the data set.

**Returns**

**coeffs** : 1-d ndarray

The filter coefficients.

**See also:**

*savgol\_filter*

**Notes**

New in version 0.14.0.

**References**

A. Savitzky, M. J. E. Golay, Smoothing and Differentiation of Data by Simplified Least Squares Procedures. Analytical Chemistry, 1964, 36 (8), pp 1627-1639.

**Examples**

```
>>> from scipy.signal import savgol_coeffs
>>> savgol_coeffs(5, 2)
array([-0.08571429,  0.34285714,  0.48571429,  0.34285714, -0.08571429])
>>> savgol_coeffs(5, 2, deriv=1)
array([ 2.00000000e-01,  1.00000000e-01,  2.00607895e-16,
        -1.00000000e-01, -2.00000000e-01])
```

Note that *use*='dot' simply reverses the coefficients.

```
>>> savgol_coeffs(5, 2, pos=3)
array([ 0.25714286,  0.37142857,  0.34285714,  0.17142857, -0.14285714])
>>> savgol_coeffs(5, 2, pos=3, use='dot')
array([-0.14285714,  0.17142857,  0.34285714,  0.37142857,  0.25714286])
```

*x* contains data from the parabola  $x = t^2$ , sampled at  $t = -1, 0, 1, 2, 3$ . *c* holds the coefficients that will compute the derivative at the last position. When dotted with *x* the result should be 6.

```
>>> x = np.array([1, 0, 1, 4, 9])
>>> c = savgol_coeffs(5, 2, pos=4, deriv=1, use='dot')
>>> c.dot(x)
6.0000000000000018
```

`scipy.signal.remez` (*numtaps*, *bands*, *desired*, *weight=None*, *Hz=None*, *type='bandpass'*, *maxiter=25*, *grid\_density=16*, *fs=None*)

Calculate the minimax optimal filter using the Remez exchange algorithm.

Calculate the filter-coefficients for the finite impulse response (FIR) filter whose transfer function minimizes the maximum error between the desired gain and the realized gain in the specified frequency bands using the Remez exchange algorithm.

**Parameters**    **numtaps** : int

The desired number of taps in the filter. The number of taps is the number of terms in the filter, or the filter order plus one.

**bands** : array\_like

A monotonic sequence containing the band edges. All elements must be non-negative and less than half the sampling frequency as given by *fs*.

**desired** : array\_like

A sequence half the size of *bands* containing the desired gain in each of the specified bands.

**weight** : array\_like, optional

A relative weighting to give to each band region. The length of *weight* has to be half the length of *bands*.

**Hz** : scalar, optional

*Deprecated. Use 'fs' instead.* The sampling frequency in Hz. Default is 1.

**type** : {'bandpass', 'differentiator', 'hilbert'}, optional

The type of filter:

- **'bandpass'** : flat response in bands. This is the default.
- **'differentiator'** : frequency proportional response in bands.
- **'hilbert'** : [filter with odd symmetry, that is, type III] (for even order) or type IV (for odd order) linear phase filters.

**maxiter** : int, optional

Maximum number of iterations of the algorithm. Default is 25.

**grid\_density** : int, optional

Grid density. The dense grid used in *remez* is of size  $(\text{numtaps} + 1) * \text{grid\_density}$ . Default is 16.

**fs** : float, optional

The sampling frequency of the signal. Default is 1.

**Returns**

**out** : ndarray

A rank-1 array containing the coefficients of the optimal (in a minimax sense) filter.

**See also:**

*firls*, *firwin*, *firwin2*, *minimum\_phase*

**References**

[R296], [R297]

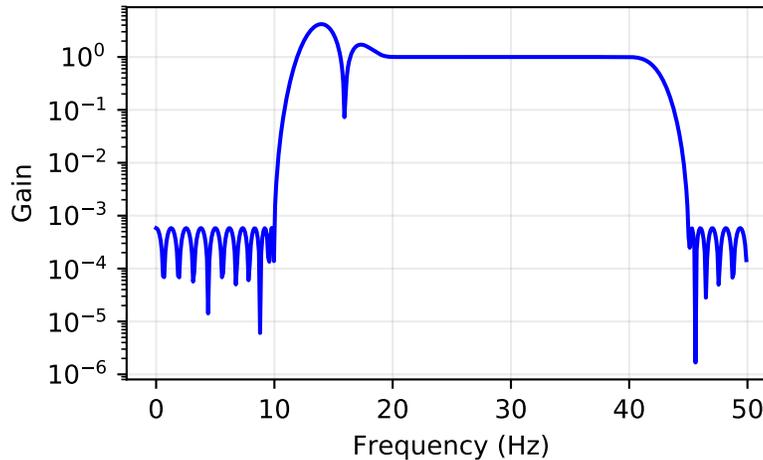
**Examples**

For a signal sampled at 100 Hz, we want to construct a filter with a passband at 20-40 Hz, and stop bands at 0-10 Hz and 45-50 Hz. Note that this means that the behavior in the frequency ranges between those bands is unspecified and may overshoot.

```
>>> from scipy import signal
>>> fs = 100
>>> bpass = signal.remez(72, [0, 10, 20, 40, 45, 50], [0, 1, 0], fs=fs)
>>> freq, response = signal.freqz(bpass)
```

```

>>> import matplotlib.pyplot as plt
>>> plt.semilogy(0.5*fs*freq/np.pi, np.abs(response), 'b-')
>>> plt.grid(alpha=0.25)
>>> plt.xlabel('Frequency (Hz)')
>>> plt.ylabel('Gain')
>>> plt.show()
    
```



`scipy.signal.unique_roots` ( $p$ ,  $tol=0.001$ ,  $rtype='min'$ )

Determine unique roots and their multiplicities from a list of roots.

**Parameters** **p** : array\_like

The list of roots.

**tol** : float, optional

The tolerance for two roots to be considered equal. Default is 1e-3.

**rtype** : {'max', 'min', 'avg'}, optional

How to determine the returned root if multiple roots are within  $tol$  of each other.

- 'max': pick the maximum of those roots.
- 'min': pick the minimum of those roots.
- 'avg': take the average of those roots.

**Returns** **pout** : ndarray

The list of unique roots, sorted from low to high.

**mult** : ndarray

The multiplicity of each root.

### Notes

This utility function is not specific to roots but can be used for any sequence of values for which uniqueness and multiplicity has to be determined. For a more general routine, see `numpy.unique`.

### Examples

```

>>> from scipy import signal
>>> vals = [0, 1.3, 1.31, 2.8, 1.25, 2.2, 10.3]
>>> uniq, mult = signal.unique_roots(vals, tol=2e-2, rtype='avg')
    
```

Check which roots have multiplicity larger than 1:

```
>>> uniq[mult > 1]
array([ 1.305])
```

`scipy.signal.residue` (*b*, *a*, *tol*=0.001, *rtype*='avg')

Compute partial-fraction expansion of  $b(s) / a(s)$ .

If  $M$  is the degree of numerator  $b$  and  $N$  the degree of denominator  $a$ :

$$H(s) = \frac{b(s)}{a(s)} = \frac{b[0] s^{(M)} + b[1] s^{(M-1)} + \dots + b[M]}{a[0] s^{(N)} + a[1] s^{(N-1)} + \dots + a[N]}$$

then the partial-fraction expansion  $H(s)$  is defined as:

$$= \frac{r[0]}{(s-p[0])} + \frac{r[1]}{(s-p[1])} + \dots + \frac{r[-1]}{(s-p[-1])} + k(s)$$

If there are any repeated roots (closer together than *tol*), then  $H(s)$  has terms like:

$$\frac{r[i]}{(s-p[i])} + \frac{r[i+1]}{(s-p[i])**2} + \dots + \frac{r[i+n-1]}{(s-p[i])**n}$$

This function is used for polynomials in positive powers of  $s$  or  $z$ , such as analog filters or digital filters in controls engineering. For negative powers of  $z$  (typical for digital filters in DSP), use `residuez`.

**Parameters**

- b** : array\_like  
Numerator polynomial coefficients.
- a** : array\_like  
Denominator polynomial coefficients.

**Returns**

- r** : ndarray  
Residues.
- p** : ndarray  
Poles.
- k** : ndarray  
Coefficients of the direct polynomial term.

**See also:**

`invres`, `residuez`, `numpy.poly`, `unique_roots`

`scipy.signal.residuez` (*b*, *a*, *tol*=0.001, *rtype*='avg')

Compute partial-fraction expansion of  $b(z) / a(z)$ .

If  $M$  is the degree of numerator  $b$  and  $N$  the degree of denominator  $a$ :

$$H(z) = \frac{b(z)}{a(z)} = \frac{b[0] + b[1] z^{(-1)} + \dots + b[M] z^{(-M)}}{a[0] + a[1] z^{(-1)} + \dots + a[N] z^{(-N)}}$$

then the partial-fraction expansion  $H(z)$  is defined as:

$$= \frac{r[0]}{(1-p[0]z^{(-1)})} + \dots + \frac{r[-1]}{(1-p[-1]z^{(-1)})} + k[0] + k[1]z^{(-1)} \dots$$

If there are any repeated roots (closer than *tol*), then the partial fraction expansion has terms like:

$$\frac{r[i]}{(1-p[i]z^{**(-1)})} + \frac{r[i+1]}{(1-p[i]z^{**(-1)})**2} + \dots + \frac{r[i+n-1]}{(1-p[i]z^{**(-1)})**n}$$

This function is used for polynomials in negative powers of z, such as digital filters in DSP. For positive powers, use *residue*.

**Parameters**

- b** : array\_like  
Numerator polynomial coefficients.
- a** : array\_like  
Denominator polynomial coefficients.

**Returns**

- r** : ndarray  
Residues.
- p** : ndarray  
Poles.
- k** : ndarray  
Coefficients of the direct polynomial term.

**See also:**

*invresz, residue, unique\_roots*

`scipy.signal.invres(r, p, k, tol=0.001, rtype='avg')`  
Compute b(s) and a(s) from partial fraction expansion.

If *M* is the degree of numerator *b* and *N* the degree of denominator *a*:

$$H(s) = \frac{b(s)}{a(s)} = \frac{b[0] s^{** (M)} + b[1] s^{** (M-1)} + \dots + b[M]}{a[0] s^{** (N)} + a[1] s^{** (N-1)} + \dots + a[N]}$$

then the partial-fraction expansion H(s) is defined as:

$$= \frac{r[0]}{(s-p[0])} + \frac{r[1]}{(s-p[1])} + \dots + \frac{r[-1]}{(s-p[-1])} + k(s)$$

If there are any repeated roots (closer together than *tol*), then H(s) has terms like:

$$\frac{r[i]}{(s-p[i])} + \frac{r[i+1]}{(s-p[i])**2} + \dots + \frac{r[i+n-1]}{(s-p[i])**n}$$

This function is used for polynomials in positive powers of s or z, such as analog filters or digital filters in controls engineering. For negative powers of z (typical for digital filters in DSP), use *invresz*.

**Parameters**

- r** : array\_like  
Residues.
- p** : array\_like  
Poles.
- k** : array\_like  
Coefficients of the direct polynomial term.
- tol** : float, optional  
The tolerance for two roots to be considered equal. Default is 1e-3.
- rtype** : { 'max', 'min', 'avg' }, optional  
How to determine the returned root if multiple roots are within *tol* of each other.

- 'max': pick the maximum of those roots.
- 'min': pick the minimum of those roots.

**Returns**

- b** : ndarray  
Numerator polynomial coefficients.
- a** : ndarray  
Denominator polynomial coefficients.

•‘avg’: take the average of those roots.

**See also:**

*residue, invresz, unique\_roots*

`scipy.signal.invresz(r, p, k, tol=0.001, rtype='avg')`  
Compute  $b(z)$  and  $a(z)$  from partial fraction expansion.

If  $M$  is the degree of numerator  $b$  and  $N$  the degree of denominator  $a$ :

$$H(z) = \frac{b(z)}{a(z)} = \frac{b[0] + b[1]z^{-1} + \dots + b[M]z^{-M}}{a[0] + a[1]z^{-1} + \dots + a[N]z^{-N}}$$

then the partial-fraction expansion  $H(z)$  is defined as:

$$= \frac{r[0]}{(1-p[0]z^{-1})} + \dots + \frac{r[-1]}{(1-p[-1]z^{-1})} + k[0] + k[1]z^{-1} \dots$$

If there are any repeated roots (closer than *tol*), then the partial fraction expansion has terms like:

$$\frac{r[i]}{(1-p[i]z^{-1})} + \frac{r[i+1]}{(1-p[i]z^{-1})^2} + \dots + \frac{r[i+n-1]}{(1-p[i]z^{-1})^n}$$

This function is used for polynomials in negative powers of  $z$ , such as digital filters in DSP. For positive powers, use *invres*.

**Parameters**

- r** : array\_like  
Residues.
- p** : array\_like  
Poles.
- k** : array\_like  
Coefficients of the direct polynomial term.
- tol** : float, optional  
The tolerance for two roots to be considered equal. Default is 1e-3.
- rtype** : {‘max’, ‘min’, ‘avg’}, optional  
How to determine the returned root if multiple roots are within *tol* of each other.
  - ‘max’: pick the maximum of those roots.
  - ‘min’: pick the minimum of those roots.
  - ‘avg’: take the average of those roots.

**Returns**

- b** : ndarray  
Numerator polynomial coefficients.
- a** : ndarray  
Denominator polynomial coefficients.

**See also:**

*residuez, unique\_roots, invres*

**exception** `scipy.signal.BadCoefficients`

Warning about badly conditioned filter coefficients

Lower-level filter design functions:

<code>abcd_normalize([A, B, C, D])</code>	Check state-space matrices and ensure they are two-dimensional.
<code>band_stop_obj(wp, ind, passb, stopb, gpass, ...)</code>	Band Stop Objective Function for order minimization.
<code>besselap(N[, norm])</code>	Return (z,p,k) for analog prototype of an Nth-order Bessel filter.
<code>buttap(N)</code>	Return (z,p,k) for analog prototype of Nth-order Butterworth filter.
<code>cheblap(N, rp)</code>	Return (z,p,k) for Nth-order Chebyshev type I analog low-pass filter.
<code>cheb2ap(N, rs)</code>	Return (z,p,k) for Nth-order Chebyshev type I analog low-pass filter.
<code>cmplx_sort(p)</code>	Sort roots based on magnitude.
<code>ellipap(N, rp, rs)</code>	Return (z,p,k) of Nth-order elliptic analog lowpass filter.
<code>lp2bp(b, a[, wo, bw])</code>	Transform a lowpass filter prototype to a bandpass filter.
<code>lp2bs(b, a[, wo, bw])</code>	Transform a lowpass filter prototype to a bandstop filter.
<code>lp2hp(b, a[, wo])</code>	Transform a lowpass filter prototype to a highpass filter.
<code>lp2lp(b, a[, wo])</code>	Transform a lowpass filter prototype to a different frequency.
<code>normalize(b, a)</code>	Normalize numerator/denominator of a continuous-time transfer function.

`scipy.signal.abcd_normalize` (*A=None, B=None, C=None, D=None*)

Check state-space matrices and ensure they are two-dimensional.

If enough information on the system is provided, that is, enough properly-shaped arrays are passed to the function, the missing ones are built from this information, ensuring the correct number of rows and columns. Otherwise a `ValueError` is raised.

**Parameters** **A, B, C, D** : array\_like, optional  
 State-space matrices. All of them are None (missing) by default. See `ss2tf` for format.

**Returns** **A, B, C, D** : array  
 Properly shaped state-space matrices.

**Raises** **ValueError**  
 If not enough information on the system was provided.

`scipy.signal.band_stop_obj` (*wp, ind, passb, stopb, gpass, gstop, type*)

Band Stop Objective Function for order minimization.

Returns the non-integer order for an analog band stop filter.

**Parameters** **wp** : scalar  
 Edge of passband *passb*.

**ind** : int, {0, 1}  
 Index specifying which *passb* edge to vary (0 or 1).

**passb** : ndarray  
 Two element sequence of fixed passband edges.

**stopb** : ndarray  
 Two element sequence of fixed stopband edges.

**gstop** : float  
 Amount of attenuation in stopband in dB.

**gpass** : float  
 Amount of ripple in the passband in dB.

**type** : { 'butter', 'cheby', 'ellip' }

**Returns** **n** : scalar  
 Type of filter.

Filter order (possibly non-integer).

`scipy.signal.besselap` ( $N$ ,  $norm='phase'$ )

Return (z,p,k) for analog prototype of an Nth-order Bessel filter.

**Parameters**  $N$  : int

The order of the filter.

**norm** : { 'phase', 'delay', 'mag' }, optional

Frequency normalization:

**phase** The filter is normalized such that the phase response reaches its midpoint at an angular (e.g. rad/s) cutoff frequency of 1. This happens for both low-pass and high-pass filters, so this is the “phase-matched” case. [R235]

The magnitude response asymptotes are the same as a Butterworth filter of the same order with a cutoff of  $Wn$ .

This is the default, and matches MATLAB’s implementation.

**delay** The filter is normalized such that the group delay in the pass-band is 1 (e.g. 1 second). This is the “natural” type obtained by solving Bessel polynomials.

**mag** The filter is normalized such that the gain magnitude is -3 dB at angular frequency 1. This is called “frequency normalization” by Bond. [R230]

New in version 0.18.0.

**Returns**  $z$  : ndarray

Zeros of the transfer function. Is always an empty array.

$p$  : ndarray

Poles of the transfer function.

$k$  : scalar

Gain of the transfer function. For phase-normalized, this is always 1.

**See also:**

**bessel** Filter design function using this prototype

**Notes**

To find the pole locations, approximate starting points are generated [R231] for the zeros of the ordinary Bessel polynomial [R232], then the Aberth-Ehrlich method [R233] [R234] is used on the  $K_v(x)$  Bessel function to calculate more accurate zeros, and these locations are then inverted about the unit circle.

**References**

[R230], [R231], [R232], [R233], [R234], [R235]

`scipy.signal.buttap` ( $N$ )

Return (z,p,k) for analog prototype of Nth-order Butterworth filter.

The filter will have an angular (e.g. rad/s) cutoff frequency of 1.

**See also:**

**butter** Filter design function using this prototype

`scipy.signal.cheblap` ( $N$ ,  $rp$ )

Return (z,p,k) for Nth-order Chebyshev type I analog lowpass filter.

The returned filter prototype has  $rp$  decibels of ripple in the passband.

The filter’s angular (e.g. rad/s) cutoff frequency is normalized to 1, defined as the point at which the gain first drops below  $-rp$ .

**See also:**

**cheby1** Filter design function using this prototype

`scipy.signal.cheb2ap` ( $N, rs$ )

Return  $(z,p,k)$  for Nth-order Chebyshev type I analog lowpass filter.

The returned filter prototype has  $rs$  decibels of ripple in the stopband.

The filter's angular (e.g. rad/s) cutoff frequency is normalized to 1, defined as the point at which the gain first reaches  $-rs$ .

**See also:**

**cheby2** Filter design function using this prototype

`scipy.signal.cmplx_sort` ( $p$ )

Sort roots based on magnitude.

**Parameters** **p** : array\_like

**Returns** **p\_sorted** : ndarray The roots to sort, as a 1-D array.

Sorted roots.

**indx** : ndarray

Array of indices needed to sort the input  $p$ .

`scipy.signal.ellipap` ( $N, rp, rs$ )

Return  $(z,p,k)$  of Nth-order elliptic analog lowpass filter.

The filter is a normalized prototype that has  $rp$  decibels of ripple in the passband and a stopband  $rs$  decibels down.

The filter's angular (e.g. rad/s) cutoff frequency is normalized to 1, defined as the point at which the gain first drops below  $-rp$ .

**See also:**

**ellip** Filter design function using this prototype

**References**

[R251]

`scipy.signal.lp2bp` ( $b, a, wo=1.0, bw=1.0$ )

Transform a lowpass filter prototype to a bandpass filter.

Return an analog band-pass filter with center frequency  $wo$  and bandwidth  $bw$  from an analog low-pass filter prototype with unity cutoff frequency, in transfer function ('ba') representation.

`scipy.signal.lp2bs` ( $b, a, wo=1.0, bw=1.0$ )

Transform a lowpass filter prototype to a bandstop filter.

Return an analog band-stop filter with center frequency  $wo$  and bandwidth  $bw$  from an analog low-pass filter prototype with unity cutoff frequency, in transfer function ('ba') representation.

`scipy.signal.lp2hp` ( $b, a, wo=1.0$ )

Transform a lowpass filter prototype to a highpass filter.

Return an analog high-pass filter with cutoff frequency  $wo$  from an analog low-pass filter prototype with unity cutoff frequency, in transfer function ('ba') representation.

`scipy.signal.lp2lp` ( $b, a, wo=1.0$ )

Transform a lowpass filter prototype to a different frequency.

Return an analog low-pass filter with cutoff frequency  $wo$  from an analog low-pass filter prototype with unity cutoff frequency, in transfer function ('ba') representation.

`scipy.signal.normalize(b, a)`

Normalize numerator/denominator of a continuous-time transfer function.

If values of  $b$  are too close to 0, they are removed. In that case, a `BadCoefficients` warning is emitted.

<b>Parameters</b>	<b>b: array_like</b>	Numerator of the transfer function. Can be a 2d array to normalize multiple transfer functions.
	<b>a: array_like</b>	Denominator of the transfer function. At most 1d.
<b>Returns</b>	<b>num: array</b>	The numerator of the normalized transfer function. At least a 1d array. A 2d-array if the input <i>num</i> is a 2d array.
	<b>den: 1d-array</b>	The denominator of the normalized transfer function.

#### Notes

Coefficients for both the numerator and denominator should be specified in descending exponent order (e.g.,  $s^2 + 3s + 5$  would be represented as `[1, 3, 5]`).

## 5.20.5 Matlab-style IIR filter design

<code>butter(N, Wn[, btype, analog, output])</code>	Butterworth digital and analog filter design.
<code>buttord(wp, ws, gpass, gstop[, analog])</code>	Butterworth filter order selection.
<code>cheby1(N, rp, Wn[, btype, analog, output])</code>	Chebyshev type I digital and analog filter design.
<code>cheblord(wp, ws, gpass, gstop[, analog])</code>	Chebyshev type I filter order selection.
<code>cheby2(N, rs, Wn[, btype, analog, output])</code>	Chebyshev type II digital and analog filter design.
<code>cheb2ord(wp, ws, gpass, gstop[, analog])</code>	Chebyshev type II filter order selection.
<code>ellip(N, rp, rs, Wn[, btype, analog, output])</code>	Elliptic (Cauer) digital and analog filter design.
<code>ellipord(wp, ws, gpass, gstop[, analog])</code>	Elliptic (Cauer) filter order selection.
<code>bessel(N, Wn[, btype, analog, output, norm])</code>	Bessel/Thomson digital and analog filter design.
<code>iirnotch(w0, Q)</code>	Design second-order IIR notch digital filter.
<code>iirpeak(w0, Q)</code>	Design second-order IIR peak (resonant) digital filter.

`scipy.signal.butter(N, Wn, btype='low', analog=False, output='ba')`

Butterworth digital and analog filter design.

Design an Nth-order digital or analog Butterworth filter and return the filter coefficients.

<b>Parameters</b>	<b>N : int</b>	The order of the filter.
	<b>Wn : array_like</b>	A scalar or length-2 sequence giving the critical frequencies. For a Butterworth filter, this is the point at which the gain drops to $1/\sqrt{2}$ that of the passband (the “-3 dB point”). For digital filters, $Wn$ is normalized from 0 to 1, where 1 is the Nyquist frequency, $\pi$ radians/sample. ( $Wn$ is thus in half-cycles / sample.) For analog filters, $Wn$ is an angular frequency (e.g. rad/s).
	<b>btype : { 'lowpass', 'highpass', 'bandpass', 'bandstop' }, optional</b>	The type of filter. Default is 'lowpass'.
	<b>analog : bool, optional</b>	When True, return an analog filter, otherwise a digital filter is returned.
	<b>output : { 'ba', 'zpk', 'sos' }, optional</b>	

**Returns**

**b, a** : ndarray, ndarray  
 Type of output: numerator/denominator ('ba'), pole-zero ('zpk'), or second-order sections ('sos'). Default is 'ba'.  
 Numerator (*b*) and denominator (*a*) polynomials of the IIR filter. Only returned if `output='ba'`.

**z, p, k** : ndarray, ndarray, float  
 Zeros, poles, and system gain of the IIR filter transfer function. Only returned if `output='zpk'`.

**sos** : ndarray  
 Second-order sections representation of the IIR filter. Only returned if `output=='sos'`.

**See also:***butterd, butterap***Notes**

The Butterworth filter has maximally flat frequency response in the passband.

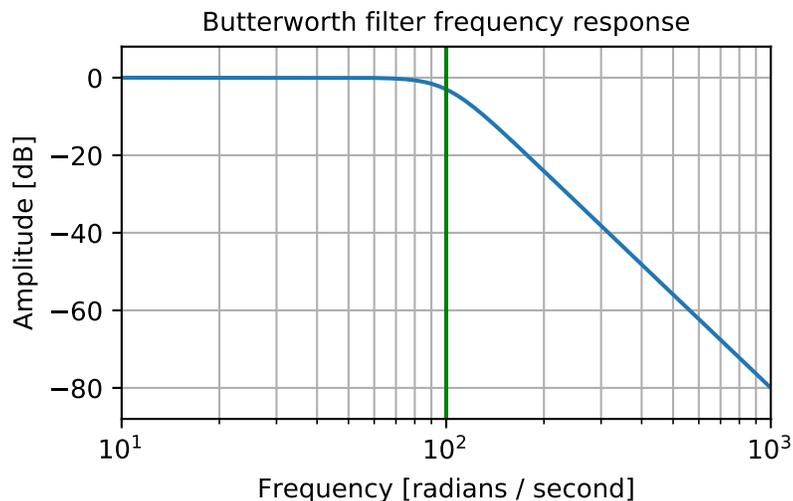
The 'sos' output parameter was added in 0.16.0.

**Examples**

Plot the filter's frequency response, showing the critical points:

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

```
>>> b, a = signal.butter(4, 100, 'low', analog=True)
>>> w, h = signal.freqs(b, a)
>>> plt.semilogx(w, 20 * np.log10(abs(h)))
>>> plt.title('Butterworth filter frequency response')
>>> plt.xlabel('Frequency [radians / second]')
>>> plt.ylabel('Amplitude [dB]')
>>> plt.margins(0, 0.1)
>>> plt.grid(which='both', axis='both')
>>> plt.axvline(100, color='green') # cutoff frequency
>>> plt.show()
```



`scipy.signal.buttord` (*wp*, *ws*, *gpass*, *gstop*, *analog=False*)

Butterworth filter order selection.

Return the order of the lowest order digital or analog Butterworth filter that loses no more than *gpass* dB in the passband and has at least *gstop* dB attenuation in the stopband.

**Parameters**    **wp, ws** : float

Passband and stopband edge frequencies. For digital filters, these are normalized from 0 to 1, where 1 is the Nyquist frequency, pi radians/sample. (*wp* and *ws* are thus in half-cycles / sample.) For example:

- Lowpass: *wp* = 0.2, *ws* = 0.3
- Highpass: *wp* = 0.3, *ws* = 0.2
- Bandpass: *wp* = [0.2, 0.5], *ws* = [0.1, 0.6]
- Bandstop: *wp* = [0.1, 0.6], *ws* = [0.2, 0.5]

For analog filters, *wp* and *ws* are angular frequencies (e.g. rad/s).

**gpass** : float

The maximum loss in the passband (dB).

**gstop** : float

The minimum attenuation in the stopband (dB).

**analog** : bool, optional

When True, return an analog filter, otherwise a digital filter is returned.

**Returns**

**ord** : int

The lowest order for a Butterworth filter which meets specs.

**wn** : ndarray or float

The Butterworth natural frequency (i.e. the “3dB frequency”). Should be used with *butter* to give filter results.

**See also:**

**butter**    Filter design using order and critical points

**cheb1ord**    Find order and critical points from passband and stopband spec

*cheb2ord*, *ellipord*

**iirfilter**    General filter design using order and critical frequencies

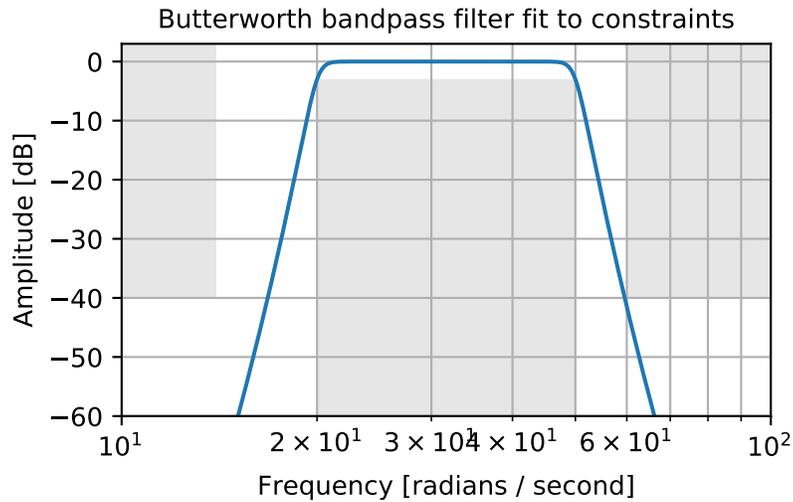
**iirdesign**    General filter design using passband and stopband spec

**Examples**

Design an analog bandpass filter with passband within 3 dB from 20 to 50 rad/s, while rejecting at least -40 dB below 14 and above 60 rad/s. Plot its frequency response, showing the passband and stopband constraints in gray.

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

```
>>> N, Wn = signal.buttord([20, 50], [14, 60], 3, 40, True)
>>> b, a = signal.butter(N, Wn, 'band', True)
>>> w, h = signal.freqs(b, a, np.logspace(1, 2, 500))
>>> plt.semilogx(w, 20 * np.log10(abs(h)))
>>> plt.title('Butterworth bandpass filter fit to constraints')
>>> plt.xlabel('Frequency [radians / second]')
>>> plt.ylabel('Amplitude [dB]')
>>> plt.grid(which='both', axis='both')
>>> plt.fill([1, 14, 14, 1], [-40, -40, 99, 99], '0.9', lw=0) # stop
>>> plt.fill([20, 20, 50, 50], [-99, -3, -3, -99], '0.9', lw=0) # pass
>>> plt.fill([60, 60, 1e9, 1e9], [99, -40, -40, 99], '0.9', lw=0) # stop
>>> plt.axis([10, 100, -60, 3])
>>> plt.show()
```



`scipy.signal.cheby1(N, rp, Wn, btype='low', analog=False, output='ba')`  
Chebyshev type I digital and analog filter design.

Design an Nth-order digital or analog Chebyshev type I filter and return the filter coefficients.

**Parameters**

- N** : int  
The order of the filter.
- rp** : float  
The maximum ripple allowed below unity gain in the passband. Specified in decibels, as a positive number.
- Wn** : array\_like  
A scalar or length-2 sequence giving the critical frequencies. For Type I filters, this is the point in the transition band at which the gain first drops below  $-rp$ . For digital filters,  $Wn$  is normalized from 0 to 1, where 1 is the Nyquist frequency,  $\pi$  radians/sample. ( $Wn$  is thus in half-cycles / sample.) For analog filters,  $Wn$  is an angular frequency (e.g. rad/s).
- btype** : {'lowpass', 'highpass', 'bandpass', 'bandstop'}, optional  
The type of filter. Default is 'lowpass'.
- analog** : bool, optional  
When True, return an analog filter, otherwise a digital filter is returned.
- output** : {'ba', 'zpk', 'sos'}, optional  
Type of output: numerator/denominator ('ba'), pole-zero ('zpk'), or second-order sections ('sos'). Default is 'ba'.

**Returns**

- b, a** : ndarray, ndarray  
Numerator ( $b$ ) and denominator ( $a$ ) polynomials of the IIR filter. Only returned if `output='ba'`.
- z, p, k** : ndarray, ndarray, float  
Zeros, poles, and system gain of the IIR filter transfer function. Only returned if `output='zpk'`.
- sos** : ndarray  
Second-order sections representation of the IIR filter. Only returned if `output=='sos'`.

**See also:**

`cheblord`, `cheblap`

### Notes

The Chebyshev type I filter maximizes the rate of cutoff between the frequency response's passband and stopband, at the expense of ripple in the passband and increased ringing in the step response.

Type I filters roll off faster than Type II (*cheby2*), but Type II filters do not have any ripple in the passband.

The equiripple passband has  $N$  maxima or minima (for example, a 5th-order filter has 3 maxima and 2 minima). Consequently, the DC gain is unity for odd-order filters, or  $-rp$  dB for even-order filters.

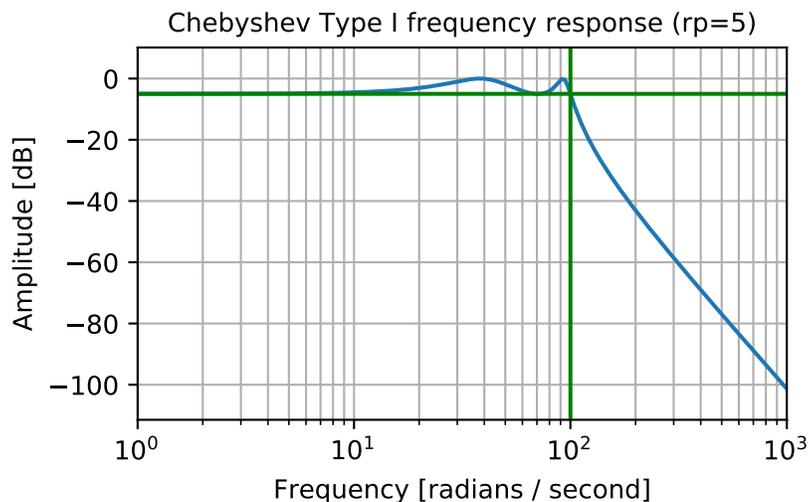
The 'sos' output parameter was added in 0.16.0.

### Examples

Plot the filter's frequency response, showing the critical points:

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt

>>> b, a = signal.cheby1(4, 5, 100, 'low', analog=True)
>>> w, h = signal.freqs(b, a)
>>> plt.semilogx(w, 20 * np.log10(abs(h)))
>>> plt.title('Chebyshev Type I frequency response (rp=5)')
>>> plt.xlabel('Frequency [radians / second]')
>>> plt.ylabel('Amplitude [dB]')
>>> plt.margins(0, 0.1)
>>> plt.grid(which='both', axis='both')
>>> plt.axvline(100, color='green') # cutoff frequency
>>> plt.axhline(-5, color='green') # rp
>>> plt.show()
```



`scipy.signal.cheblord` (*wp, ws, gpass, gstop, analog=False*)  
Chebyshev type I filter order selection.

Return the order of the lowest order digital or analog Chebyshev Type I filter that loses no more than *gpass* dB in the passband and has at least *gstop* dB attenuation in the stopband.

**Parameters** `wp, ws` : float

Passband and stopband edge frequencies. For digital filters, these are normalized from 0 to 1, where 1 is the Nyquist frequency, pi radians/sample. (*wp* and *ws* are thus in half-cycles / sample.) For example:

- Lowpass: *wp* = 0.2, *ws* = 0.3
- Highpass: *wp* = 0.3, *ws* = 0.2
- Bandpass: *wp* = [0.2, 0.5], *ws* = [0.1, 0.6]
- Bandstop: *wp* = [0.1, 0.6], *ws* = [0.2, 0.5]

For analog filters, *wp* and *ws* are angular frequencies (e.g. rad/s).

**gpass** : float

The maximum loss in the passband (dB).

**gstop** : float

The minimum attenuation in the stopband (dB).

**analog** : bool, optional

When True, return an analog filter, otherwise a digital filter is returned.

**Returns**

**ord** : int

The lowest order for a Chebyshev type I filter that meets specs.

**wn** : ndarray or float

The Chebyshev natural frequency (the “3dB frequency”) for use with *cheby1* to give filter results.

**See also:**

**cheby1** Filter design using order and critical points

**buttord** Find order and critical points from passband and stopband spec

*cheb2ord*, *ellipord*

**iirfilter** General filter design using order and critical frequencies

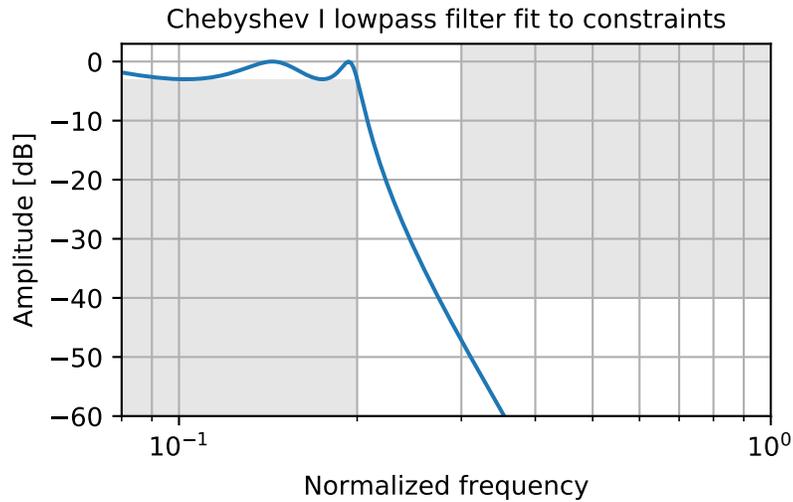
**iirdesign** General filter design using passband and stopband spec

**Examples**

Design a digital lowpass filter such that the passband is within 3 dB up to  $0.2 \cdot (fs/2)$ , while rejecting at least -40 dB above  $0.3 \cdot (fs/2)$ . Plot its frequency response, showing the passband and stopband constraints in gray.

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

```
>>> N, Wn = signal.cheblord(0.2, 0.3, 3, 40)
>>> b, a = signal.cheby1(N, 3, Wn, 'low')
>>> w, h = signal.freqz(b, a)
>>> plt.semilogx(w / np.pi, 20 * np.log10(abs(h)))
>>> plt.title('Chebyshev I lowpass filter fit to constraints')
>>> plt.xlabel('Normalized frequency')
>>> plt.ylabel('Amplitude [dB]')
>>> plt.grid(which='both', axis='both')
>>> plt.fill([0.01, 0.2, 0.2, .01], [-3, -3, -99, -99], '0.9', lw=0) # stop
>>> plt.fill([0.3, 0.3, 2, 2], [9, -40, -40, 9], '0.9', lw=0) # pass
>>> plt.axis([0.08, 1, -60, 3])
>>> plt.show()
```



`scipy.signal.cheby2(N, rs, Wn, btype='low', analog=False, output='ba')`  
 Chebyshev type II digital and analog filter design.

Design an Nth-order digital or analog Chebyshev type II filter and return the filter coefficients.

**Parameters**

- N** : int  
The order of the filter.
- rs** : float  
The minimum attenuation required in the stop band. Specified in decibels, as a positive number.
- Wn** : array\_like  
A scalar or length-2 sequence giving the critical frequencies. For Type II filters, this is the point in the transition band at which the gain first reaches  $-rs$ . For digital filters,  $Wn$  is normalized from 0 to 1, where 1 is the Nyquist frequency, pi radians/sample. ( $Wn$  is thus in half-cycles / sample.) For analog filters,  $Wn$  is an angular frequency (e.g. rad/s).
- btype** : {'lowpass', 'highpass', 'bandpass', 'bandstop'}, optional  
The type of filter. Default is 'lowpass'.
- analog** : bool, optional  
When True, return an analog filter, otherwise a digital filter is returned.
- output** : {'ba', 'zpk', 'sos'}, optional  
Type of output: numerator/denominator ('ba'), pole-zero ('zpk'), or second-order sections ('sos'). Default is 'ba'.

**Returns**

- b, a** : ndarray, ndarray  
Numerator ( $b$ ) and denominator ( $a$ ) polynomials of the IIR filter. Only returned if `output='ba'`.
- z, p, k** : ndarray, ndarray, float  
Zeros, poles, and system gain of the IIR filter transfer function. Only returned if `output='zpk'`.
- sos** : ndarray  
Second-order sections representation of the IIR filter. Only returned if `output=='sos'`.

**See also:**

`cheb2ord`, `cheb2ap`

**Notes**

The Chebyshev type II filter maximizes the rate of cutoff between the frequency response's passband and stopband, at the expense of ripple in the stopband and increased ringing in the step response.

Type II filters do not roll off as fast as Type I (*cheby1*).

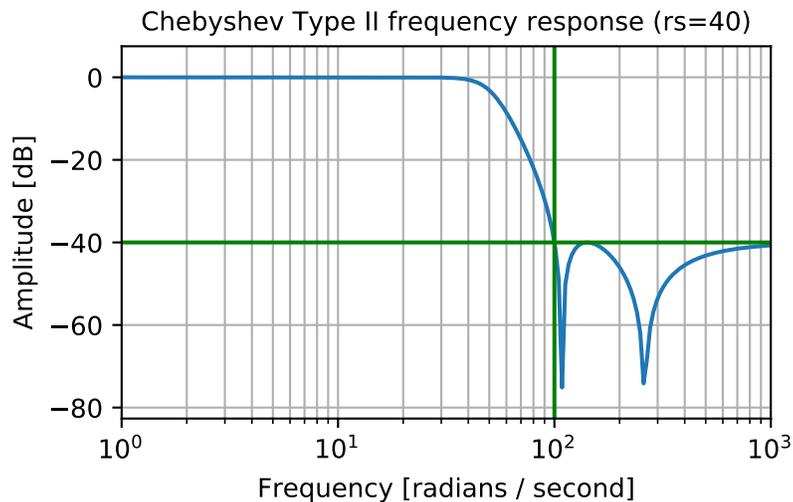
The 'sos' output parameter was added in 0.16.0.

**Examples**

Plot the filter's frequency response, showing the critical points:

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

```
>>> b, a = signal.cheby2(4, 40, 100, 'low', analog=True)
>>> w, h = signal.freqs(b, a)
>>> plt.semilogx(w, 20 * np.log10(abs(h)))
>>> plt.title('Chebyshev Type II frequency response (rs=40)')
>>> plt.xlabel('Frequency [radians / second]')
>>> plt.ylabel('Amplitude [dB]')
>>> plt.margins(0, 0.1)
>>> plt.grid(which='both', axis='both')
>>> plt.axvline(100, color='green') # cutoff frequency
>>> plt.axhline(-40, color='green') # rs
>>> plt.show()
```



`scipy.signal.cheb2ord` (*wp, ws, gpass, gstop, analog=False*)

Chebyshev type II filter order selection.

Return the order of the lowest order digital or analog Chebyshev Type II filter that loses no more than *gpass* dB in the passband and has at least *gstop* dB attenuation in the stopband.

**Parameters** `wp, ws` : float

Passband and stopband edge frequencies. For digital filters, these are normalized from 0 to 1, where 1 is the Nyquist frequency, pi radians/sample. (*wp* and *ws* are thus in half-cycles / sample.) For example:

- Lowpass: `wp = 0.2, ws = 0.3`
- Highpass: `wp = 0.3, ws = 0.2`

- Bandpass:  $w_p = [0.2, 0.5]$ ,  $w_s = [0.1, 0.6]$
- Bandstop:  $w_p = [0.1, 0.6]$ ,  $w_s = [0.2, 0.5]$

For analog filters,  $w_p$  and  $w_s$  are angular frequencies (e.g. rad/s).

**gpass** : float

The maximum loss in the passband (dB).

**gstop** : float

The minimum attenuation in the stopband (dB).

**analog** : bool, optional

When True, return an analog filter, otherwise a digital filter is returned.

**Returns**

**ord** : int

The lowest order for a Chebyshev type II filter that meets specs.

**wn** : ndarray or float

The Chebyshev natural frequency (the “3dB frequency”) for use with *cheby2* to give filter results.

**See also:**

**cheby2** Filter design using order and critical points

**buttord** Find order and critical points from passband and stopband spec

*cheblord*, *ellipord*

**iirfilter** General filter design using order and critical frequencies

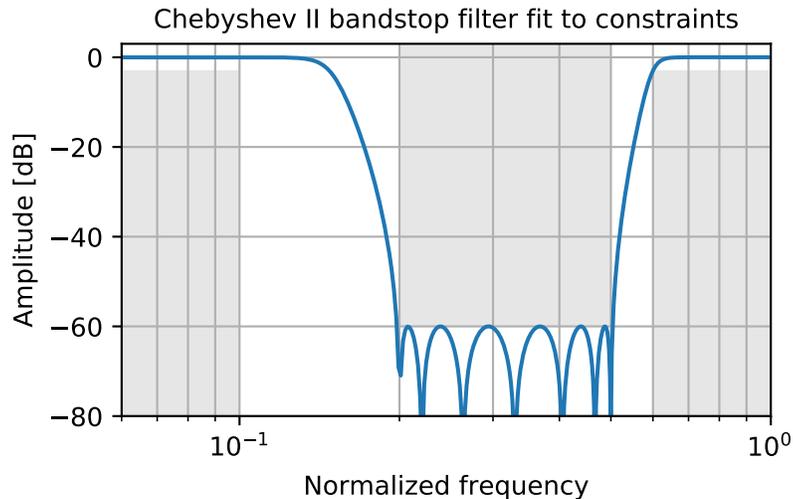
**iirdesign** General filter design using passband and stopband spec

**Examples**

Design a digital bandstop filter which rejects -60 dB from  $0.2*(fs/2)$  to  $0.5*(fs/2)$ , while staying within 3 dB below  $0.1*(fs/2)$  or above  $0.6*(fs/2)$ . Plot its frequency response, showing the passband and stopband constraints in gray.

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

```
>>> N, Wn = signal.cheb2ord([0.1, 0.6], [0.2, 0.5], 3, 60)
>>> b, a = signal.cheby2(N, 60, Wn, 'stop')
>>> w, h = signal.freqz(b, a)
>>> plt.semilogx(w / np.pi, 20 * np.log10(abs(h)))
>>> plt.title('Chebyshev II bandstop filter fit to constraints')
>>> plt.xlabel('Normalized frequency')
>>> plt.ylabel('Amplitude [dB]')
>>> plt.grid(which='both', axis='both')
>>> plt.fill([.01, .1, .1, .01], [-3, -3, -99, -99], '0.9', lw=0) # stop
>>> plt.fill([.2, .2, .5, .5], [ 9, -60, -60,  9], '0.9', lw=0) # pass
>>> plt.fill([.6, .6, 2, 2], [-99, -3, -3, -99], '0.9', lw=0) # stop
>>> plt.axis([0.06, 1, -80, 3])
>>> plt.show()
```



`scipy.signal.ellip` ( $N$ ,  $rp$ ,  $rs$ ,  $Wn$ ,  $btype='low'$ ,  $analog=False$ ,  $output='ba'$ )  
 Elliptic (Cauer) digital and analog filter design.

Design an  $N$ th-order digital or analog elliptic filter and return the filter coefficients.

**Parameters**

- $N$**  : int  
The order of the filter.
- $rp$**  : float  
The maximum ripple allowed below unity gain in the passband. Specified in decibels, as a positive number.
- $rs$**  : float  
The minimum attenuation required in the stop band. Specified in decibels, as a positive number.
- $Wn$**  : array\_like  
A scalar or length-2 sequence giving the critical frequencies. For elliptic filters, this is the point in the transition band at which the gain first drops below  $-rp$ . For digital filters,  $Wn$  is normalized from 0 to 1, where 1 is the Nyquist frequency,  $\pi$  radians/sample. ( $Wn$  is thus in half-cycles / sample.) For analog filters,  $Wn$  is an angular frequency (e.g. rad/s).
- $btype$**  : {'lowpass', 'highpass', 'bandpass', 'bandstop'}, optional  
The type of filter. Default is 'lowpass'.
- $analog$**  : bool, optional  
When True, return an analog filter, otherwise a digital filter is returned.
- $output$**  : {'ba', 'zpk', 'sos'}, optional  
Type of output: numerator/denominator ('ba'), pole-zero ('zpk'), or second-order sections ('sos'). Default is 'ba'.

**Returns**

- $b$ ,  $a$**  : ndarray, ndarray  
Numerator ( $b$ ) and denominator ( $a$ ) polynomials of the IIR filter. Only returned if `output='ba'`.
- $z$ ,  $p$ ,  $k$**  : ndarray, ndarray, float  
Zeros, poles, and system gain of the IIR filter transfer function. Only returned if `output='zpk'`.
- $sos$**  : ndarray  
Second-order sections representation of the IIR filter. Only returned if `output=='sos'`.

See also:

*ellipord, ellipap*

### Notes

Also known as Cauer or Zolotarev filters, the elliptical filter maximizes the rate of transition between the frequency response's passband and stopband, at the expense of ripple in both, and increased ringing in the step response.

As *rp* approaches 0, the elliptical filter becomes a Chebyshev type II filter (*cheby2*). As *rs* approaches 0, it becomes a Chebyshev type I filter (*cheby1*). As both approach 0, it becomes a Butterworth filter (*butter*).

The equiripple passband has *N* maxima or minima (for example, a 5th-order filter has 3 maxima and 2 minima). Consequently, the DC gain is unity for odd-order filters, or -*rp* dB for even-order filters.

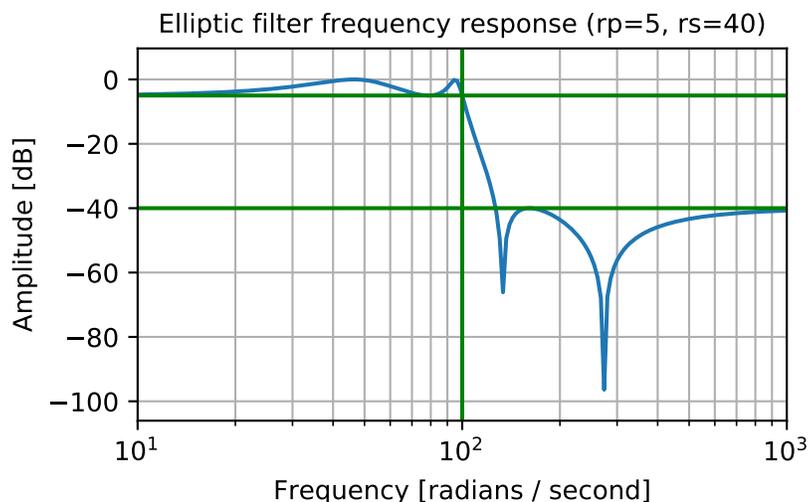
The 'sos' output parameter was added in 0.16.0.

### Examples

Plot the filter's frequency response, showing the critical points:

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

```
>>> b, a = signal.ellip(4, 5, 40, 100, 'low', analog=True)
>>> w, h = signal.freqs(b, a)
>>> plt.semilogx(w, 20 * np.log10(abs(h)))
>>> plt.title('Elliptic filter frequency response (rp=5, rs=40)')
>>> plt.xlabel('Frequency [radians / second]')
>>> plt.ylabel('Amplitude [dB]')
>>> plt.margins(0, 0.1)
>>> plt.grid(which='both', axis='both')
>>> plt.axvline(100, color='green') # cutoff frequency
>>> plt.axhline(-40, color='green') # rs
>>> plt.axhline(-5, color='green') # rp
>>> plt.show()
```



`scipy.signal.ellipord` (*wp, ws, gpass, gstop, analog=False*)  
Elliptic (Cauer) filter order selection.

Return the order of the lowest order digital or analog elliptic filter that loses no more than *gpass* dB in the passband and has at least *gstop* dB attenuation in the stopband.

**Parameters**

**wp, ws** : float  
 Passband and stopband edge frequencies. For digital filters, these are normalized from 0 to 1, where 1 is the Nyquist frequency, pi radians/sample. (*wp* and *ws* are thus in half-cycles / sample.) For example:

- Lowpass: *wp* = 0.2, *ws* = 0.3
- Highpass: *wp* = 0.3, *ws* = 0.2
- Bandpass: *wp* = [0.2, 0.5], *ws* = [0.1, 0.6]
- Bandstop: *wp* = [0.1, 0.6], *ws* = [0.2, 0.5]

For analog filters, *wp* and *ws* are angular frequencies (e.g. rad/s).

**gpass** : float  
 The maximum loss in the passband (dB).

**gstop** : float  
 The minimum attenuation in the stopband (dB).

**analog** : bool, optional  
 When True, return an analog filter, otherwise a digital filter is returned.

**Returns**

**ord** : int  
 The lowest order for an Elliptic (Cauer) filter that meets specs.

**wn** : ndarray or float  
 The Chebyshev natural frequency (the “3dB frequency”) for use with *ellip* to give filter results.

**See also:**

**ellip** Filter design using order and critical points  
**buttord** Find order and critical points from passband and stopband spec

*cheblord*, *cheb2ord*

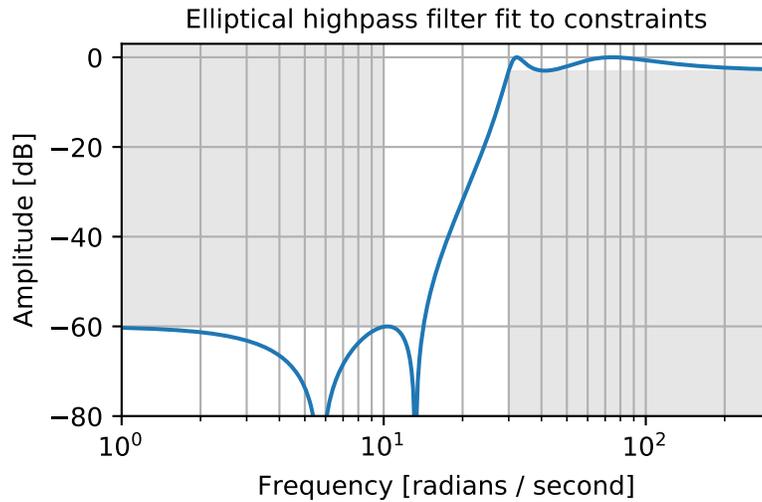
**iirfilter** General filter design using order and critical frequencies  
**iirdesign** General filter design using passband and stopband spec

### Examples

Design an analog highpass filter such that the passband is within 3 dB above 30 rad/s, while rejecting -60 dB at 10 rad/s. Plot its frequency response, showing the passband and stopband constraints in gray.

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt

>>> N, Wn = signal.ellipord(30, 10, 3, 60, True)
>>> b, a = signal.ellip(N, 3, 60, Wn, 'high', True)
>>> w, h = signal.freqs(b, a, np.logspace(0, 3, 500))
>>> plt.semilogx(w, 20 * np.log10(abs(h)))
>>> plt.title('Elliptical highpass filter fit to constraints')
>>> plt.xlabel('Frequency [radians / second]')
>>> plt.ylabel('Amplitude [dB]')
>>> plt.grid(which='both', axis='both')
>>> plt.fill([.1, 10, 10, .1], [1e4, 1e4, -60, -60], '0.9', lw=0) # stop
>>> plt.fill([30, 30, 1e9, 1e9], [-99, -3, -3, -99], '0.9', lw=0) # pass
>>> plt.axis([1, 300, -80, 3])
>>> plt.show()
```



`scipy.signal.bessel` ( $N$ ,  $Wn$ ,  $btype='low'$ ,  $analog=False$ ,  $output='ba'$ ,  $norm='phase'$ )  
Bessel/Thomson digital and analog filter design.

Design an  $N$ th-order digital or analog Bessel filter and return the filter coefficients.

**Parameters**  $N$  : int

The order of the filter.

$Wn$  : array\_like

A scalar or length-2 sequence giving the critical frequencies (defined by the *norm* parameter). For analog filters,  $Wn$  is an angular frequency (e.g. rad/s). For digital filters,  $Wn$  is normalized from 0 to 1, where 1 is the Nyquist frequency,  $\pi$  radians/sample. ( $Wn$  is thus in half-cycles / sample.)

**btype** : {'lowpass', 'highpass', 'bandpass', 'bandstop'}, optional

The type of filter. Default is 'lowpass'.

**analog** : bool, optional

When True, return an analog filter, otherwise a digital filter is returned. (See Notes.)

**output** : {'ba', 'zpk', 'sos'}, optional

Type of output: numerator/denominator ('ba'), pole-zero ('zpk'), or second-order sections ('sos'). Default is 'ba'.

**norm** : {'phase', 'delay', 'mag'}, optional

Critical frequency normalization:

**phase**

The filter is normalized such that the phase response reaches its midpoint at angular (e.g. rad/s) frequency  $Wn$ . This happens for both low-pass and high-pass filters, so this is the "phase-matched" case.

The magnitude response asymptotes are the same as a Butterworth filter of the same order with a cutoff of  $Wn$ .

This is the default, and matches MATLAB's implementation.

**delay**

The filter is normalized such that the group delay in the passband is  $1/Wn$  (e.g. seconds). This is the "natural" type obtained by solving Bessel polynomials.

**mag**

The filter is normalized such that the gain magnitude is -3 dB at angular frequency  $Wn$ .

**Returns**  $b, a$  : ndarray, ndarray New in version 0.18.0.

Numerator ( $b$ ) and denominator ( $a$ ) polynomials of the IIR filter. Only returned if `output='ba'`.

**z, p, k** : ndarray, ndarray, float  
Zeros, poles, and system gain of the IIR filter transfer function. Only returned if `output='zpk'`.

**sos** : ndarray  
Second-order sections representation of the IIR filter. Only returned if `output=='sos'`.

### Notes

Also known as a Thomson filter, the analog Bessel filter has maximally flat group delay and maximally linear phase response, with very little ringing in the step response. [R229]

The Bessel is inherently an analog filter. This function generates digital Bessel filters using the bilinear transform, which does not preserve the phase response of the analog filter. As such, it is only approximately correct at frequencies below about  $fs/4$ . To get maximally-flat group delay at higher frequencies, the analog Bessel filter must be transformed using phase-preserving techniques.

See `besselap` for implementation details and references.

The `'sos'` output parameter was added in 0.16.0.

### References

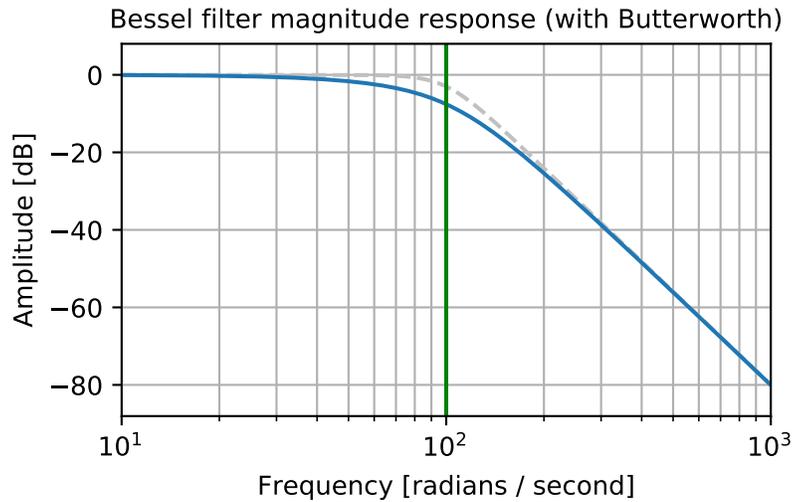
[R229]

### Examples

Plot the phase-normalized frequency response, showing the relationship to the Butterworth's cutoff frequency (green):

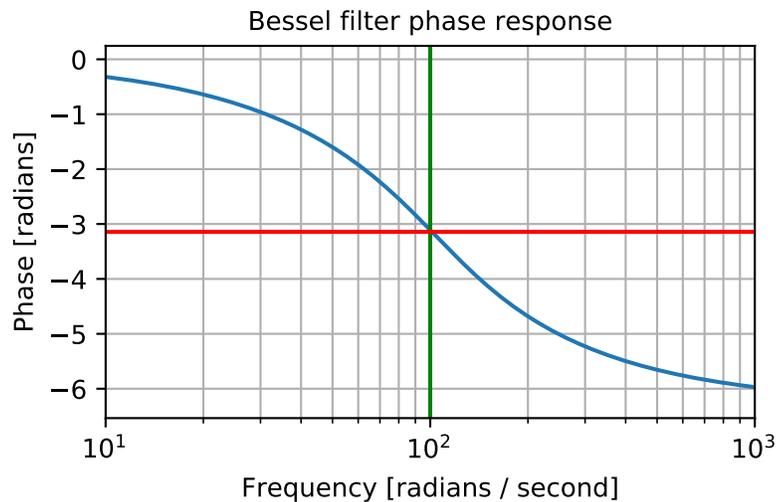
```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt

>>> b, a = signal.butter(4, 100, 'low', analog=True)
>>> w, h = signal.freqs(b, a)
>>> plt.semilogx(w, 20 * np.log10(np.abs(h)), color='silver', ls='dashed')
>>> b, a = signal.bessel(4, 100, 'low', analog=True, norm='phase')
>>> w, h = signal.freqs(b, a)
>>> plt.semilogx(w, 20 * np.log10(np.abs(h)))
>>> plt.title('Bessel filter magnitude response (with Butterworth)')
>>> plt.xlabel('Frequency [radians / second]')
>>> plt.ylabel('Amplitude [dB]')
>>> plt.margins(0, 0.1)
>>> plt.grid(which='both', axis='both')
>>> plt.axvline(100, color='green') # cutoff frequency
>>> plt.show()
```



and the phase midpoint:

```
>>> plt.figure()
>>> plt.semilogx(w, np.unwrap(np.angle(h)))
>>> plt.axvline(100, color='green') # cutoff frequency
>>> plt.axhline(-np.pi, color='red') # phase midpoint
>>> plt.title('Bessel filter phase response')
>>> plt.xlabel('Frequency [radians / second]')
>>> plt.ylabel('Phase [radians]')
>>> plt.margins(0, 0.1)
>>> plt.grid(which='both', axis='both')
>>> plt.show()
```



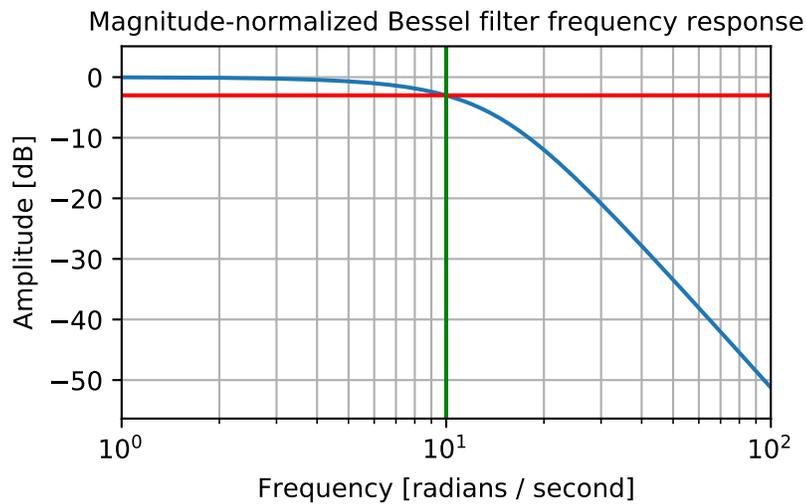
Plot the magnitude-normalized frequency response, showing the -3 dB cutoff:

```
>>> b, a = signal.bessel(3, 10, 'low', analog=True, norm='mag')
>>> w, h = signal.freqs(b, a)
>>> plt.semilogx(w, 20 * np.log10(np.abs(h)))
```

```

>>> plt.axhline(-3, color='red') # -3 dB magnitude
>>> plt.axvline(10, color='green') # cutoff frequency
>>> plt.title('Magnitude-normalized Bessel filter frequency response')
>>> plt.xlabel('Frequency [radians / second]')
>>> plt.ylabel('Amplitude [dB]')
>>> plt.margins(0, 0.1)
>>> plt.grid(which='both', axis='both')
>>> plt.show()

```

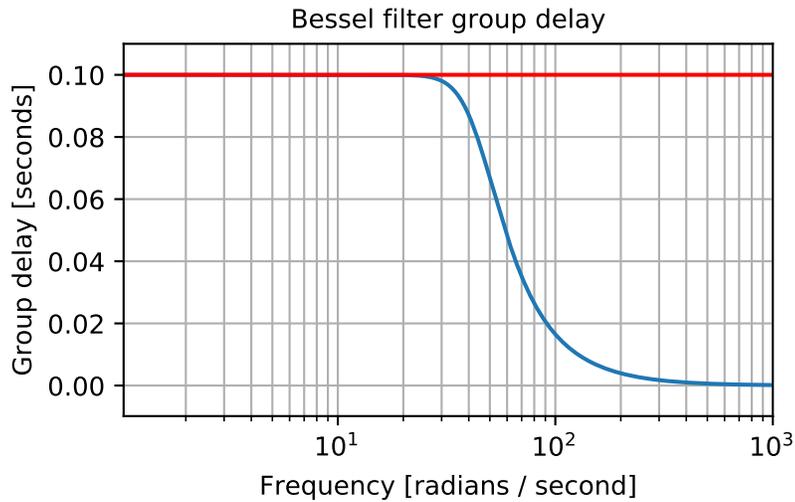


Plot the delay-normalized filter, showing the maximally-flat group delay at 0.1 seconds:

```

>>> b, a = signal.bessel(5, 1/0.1, 'low', analog=True, norm='delay')
>>> w, h = signal.freqs(b, a)
>>> plt.figure()
>>> plt.semilogx(w[1:], -np.diff(np.unwrap(np.angle(h)))/np.diff(w))
>>> plt.axhline(0.1, color='red') # 0.1 seconds group delay
>>> plt.title('Bessel filter group delay')
>>> plt.xlabel('Frequency [radians / second]')
>>> plt.ylabel('Group delay [seconds]')
>>> plt.margins(0, 0.1)
>>> plt.grid(which='both', axis='both')
>>> plt.show()

```



`scipy.signal.iirnotch(w0, Q)`

Design second-order IIR notch digital filter.

A notch filter is a band-stop filter with a narrow bandwidth (high quality factor). It rejects a narrow frequency band and leaves the rest of the spectrum little changed.

**Parameters** **w0** : float

Normalized frequency to remove from a signal. It is a scalar that must satisfy  $0 < w0 < 1$ , with  $w0 = 1$  corresponding to half of the sampling frequency.

**Q** : float

Quality factor. Dimensionless parameter that characterizes notch filter -3 dB bandwidth  $bw$  relative to its center frequency,  $Q = w0/bw$ .

**Returns**

**b, a** : ndarray, ndarray  
 Numerator (b) and denominator (a) polynomials of the IIR filter.

**See also:**

`iirpeak`

**Notes**

**References**

[R275]

**Examples**

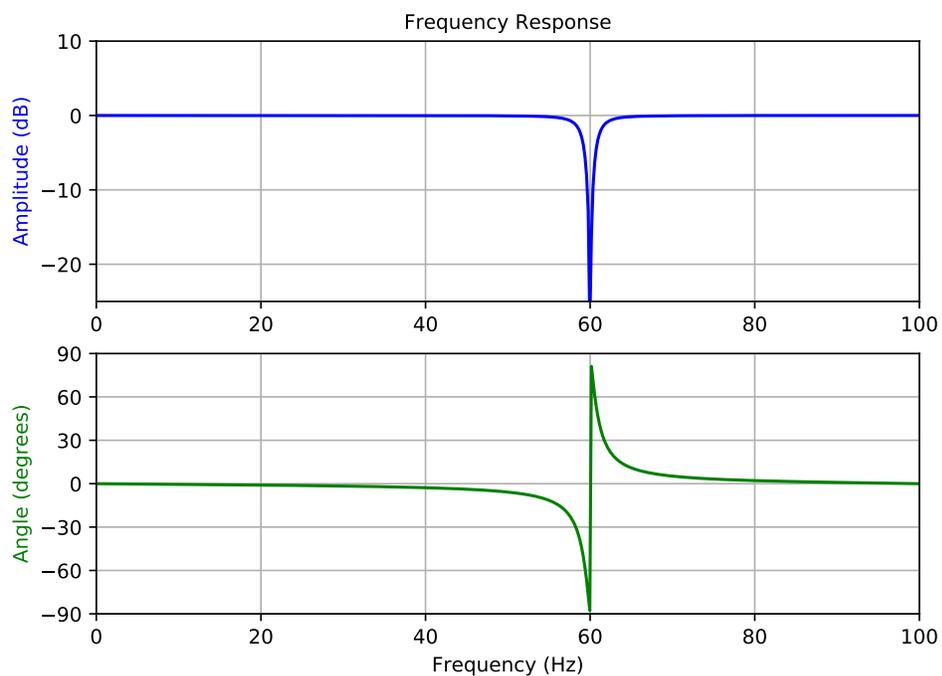
Design and plot filter to remove the 60Hz component from a signal sampled at 200Hz, using a quality factor  $Q = 30$

```
>>> from scipy import signal
>>> import numpy as np
>>> import matplotlib.pyplot as plt
```

```
>>> fs = 200.0 # Sample frequency (Hz)
>>> f0 = 60.0 # Frequency to be removed from signal (Hz)
>>> Q = 30.0 # Quality factor
>>> w0 = f0/(fs/2) # Normalized Frequency
```

```
>>> # Design notch filter
>>> b, a = signal.iirnotch(w0, Q)
```

```
>>> # Frequency response
>>> w, h = signal.freqz(b, a)
>>> # Generate frequency axis
>>> freq = w*fs/(2*np.pi)
>>> # Plot
>>> fig, ax = plt.subplots(2, 1, figsize=(8, 6))
>>> ax[0].plot(freq, 20*np.log10(abs(h)), color='blue')
>>> ax[0].set_title("Frequency Response")
>>> ax[0].set_ylabel("Amplitude (dB)", color='blue')
>>> ax[0].set_xlim([0, 100])
>>> ax[0].set_ylim([-25, 10])
>>> ax[0].grid()
>>> ax[1].plot(freq, np.unwrap(np.angle(h))*180/np.pi, color='green')
>>> ax[1].set_ylabel("Angle (degrees)", color='green')
>>> ax[1].set_xlabel("Frequency (Hz)")
>>> ax[1].set_xlim([0, 100])
>>> ax[1].set_yticks([-90, -60, -30, 0, 30, 60, 90])
>>> ax[1].set_ylim([-90, 90])
>>> ax[1].grid()
>>> plt.show()
```



`scipy.signal.iirpeak(w0, Q)`  
Design second-order IIR peak (resonant) digital filter.

A peak filter is a band-pass filter with a narrow bandwidth (high quality factor). It rejects components outside a narrow frequency band.

<b>Parameters</b>	<b>w0</b> : float	Normalized frequency to be retained in a signal. It is a scalar that must satisfy $0 < w0 < 1$ , with $w0 = 1$ corresponding to half of the sampling frequency.
	<b>Q</b> : float	Quality factor. Dimensionless parameter that characterizes peak filter -3 dB bandwidth $bw$ relative to its center frequency, $Q = w0/bw$ .
<b>Returns</b>	<b>b, a</b> : ndarray, ndarray	Numerator (b) and denominator (a) polynomials of the IIR filter.

**See also:**

`iirnotch`

**Notes**

**References**

[R276]

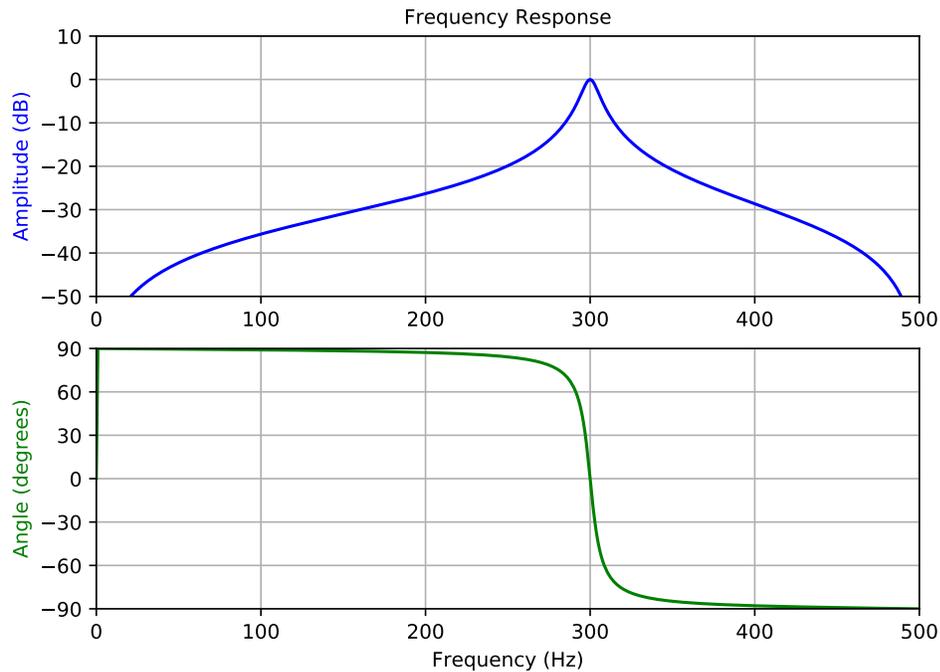
**Examples**

Design and plot filter to remove the frequencies other than the 300Hz component from a signal sampled at 1000Hz, using a quality factor  $Q = 30$

```
>>> from scipy import signal
>>> import numpy as np
>>> import matplotlib.pyplot as plt
```

```
>>> fs = 1000.0 # Sample frequency (Hz)
>>> f0 = 300.0 # Frequency to be retained (Hz)
>>> Q = 30.0 # Quality factor
>>> w0 = f0/(fs/2) # Normalized Frequency
>>> # Design peak filter
>>> b, a = signal.iirpeak(w0, Q)
```

```
>>> # Frequency response
>>> w, h = signal.freqz(b, a)
>>> # Generate frequency axis
>>> freq = w*fs/(2*np.pi)
>>> # Plot
>>> fig, ax = plt.subplots(2, 1, figsize=(8, 6))
>>> ax[0].plot(freq, 20*np.log10(abs(h)), color='blue')
>>> ax[0].set_title("Frequency Response")
>>> ax[0].set_ylabel("Amplitude (dB)", color='blue')
>>> ax[0].set_xlim([0, 500])
>>> ax[0].set_ylim([-50, 10])
>>> ax[0].grid()
>>> ax[1].plot(freq, np.unwrap(np.angle(h))*180/np.pi, color='green')
>>> ax[1].set_ylabel("Angle (degrees)", color='green')
>>> ax[1].set_xlabel("Frequency (Hz)")
>>> ax[1].set_xlim([0, 500])
>>> ax[1].set_yticks([-90, -60, -30, 0, 30, 60, 90])
>>> ax[1].set_ylim([-90, 90])
>>> ax[1].grid()
>>> plt.show()
```



## 5.20.6 Continuous-Time Linear Systems

<code>lti(*system)</code>	Continuous-time linear time invariant system base class.
<code>StateSpace(*system, **kwargs)</code>	Linear Time Invariant system in state-space form.
<code>TransferFunction(*system, **kwargs)</code>	Linear Time Invariant system class in transfer function form.
<code>ZerosPolesGain(*system, **kwargs)</code>	Linear Time Invariant system class in zeros, poles, gain form.
<code>lsim(system, U, T[, X0, interp])</code>	Simulate output of a continuous-time linear system.
<code>lsim2(system[, U, T, X0])</code>	Simulate output of a continuous-time linear system, by using the ODE solver <code>scipy.integrate.odeint</code> .
<code>impulse(system[, X0, T, N])</code>	Impulse response of continuous-time system.
<code>impulse2(system[, X0, T, N])</code>	Impulse response of a single-input, continuous-time linear system.
<code>step(system[, X0, T, N])</code>	Step response of continuous-time system.
<code>step2(system[, X0, T, N])</code>	Step response of continuous-time system.
<code>freqresp(system[, w, n])</code>	Calculate the frequency response of a continuous-time system.
<code>bode(system[, w, n])</code>	Calculate Bode magnitude and phase data of a continuous-time system.

**class** `scipy.signal.lti` (\*system)  
 Continuous-time linear time invariant system base class.

**Parameters** \*system : arguments

The `lti` class can be instantiated with either 2, 3 or 4 arguments. The following gives the number of arguments and the corresponding continuous-time subclass that is created:

- 2: `TransferFunction`: (numerator, denominator)
- 3: `ZerosPolesGain`: (zeros, poles, gain)
- 4: `StateSpace`: (A, B, C, D)

Each argument can be an array or a sequence.

**See also:**

`ZerosPolesGain`, `StateSpace`, `TransferFunction`, `dlti`

**Notes**

`lti` instances do not exist directly. Instead, `lti` creates an instance of one of its subclasses: `StateSpace`, `TransferFunction` or `ZerosPolesGain`.

If (numerator, denominator) is passed in for \*system, coefficients for both the numerator and denominator should be specified in descending exponent order (e.g.,  $s^2 + 3s + 5$  would be represented as [1, 3, 5]).

Changing the value of properties that are not directly part of the current system representation (such as the zeros of a `StateSpace` system) is very inefficient and may lead to numerical inaccuracies. It is better to convert to the specific system representation first. For example, call `sys = sys.to_zpk()` before accessing/changing the zeros, poles or gain.

**Examples**

```
>>> from scipy import signal
```

```
>>> signal.lti(1, 2, 3, 4)
StateSpaceContinuous(
array([[1]]),
array([[2]]),
array([[3]]),
array([[4]]),
dt: None
)
```

```
>>> signal.lti([1, 2], [3, 4], 5)
ZerosPolesGainContinuous(
array([1, 2]),
array([3, 4]),
5,
dt: None
)
```

```
>>> signal.lti([3, 4], [1, 2])
TransferFunctionContinuous(
array([ 3.,  4.]),
array([ 1.,  2.]),
dt: None
)
```

*Attributes*

<i>dt</i>	Return the sampling time of the system, <i>None</i> for <i>lti</i> systems.
<i>poles</i>	Poles of the system.
<i>zeros</i>	Zeros of the system.

`lti.dt`  
Return the sampling time of the system, *None* for *lti* systems.

`lti.poles`  
Poles of the system.

`lti.zeros`  
Zeros of the system.

### Methods

<code>bode([w, n])</code>	Calculate Bode magnitude and phase data of a continuous-time system.
<code>freqresp([w, n])</code>	Calculate the frequency response of a continuous-time system.
<code>impulse([X0, T, N])</code>	Return the impulse response of a continuous-time system.
<code>output(U, T[, X0])</code>	Return the response of a continuous-time system to input <i>U</i> .
<code>step([X0, T, N])</code>	Return the step response of a continuous-time system.
<code>to_discrete(dt[, method, alpha])</code>	Return a discretized version of the current system.

`lti.bode (w=None, n=100)`  
Calculate Bode magnitude and phase data of a continuous-time system.

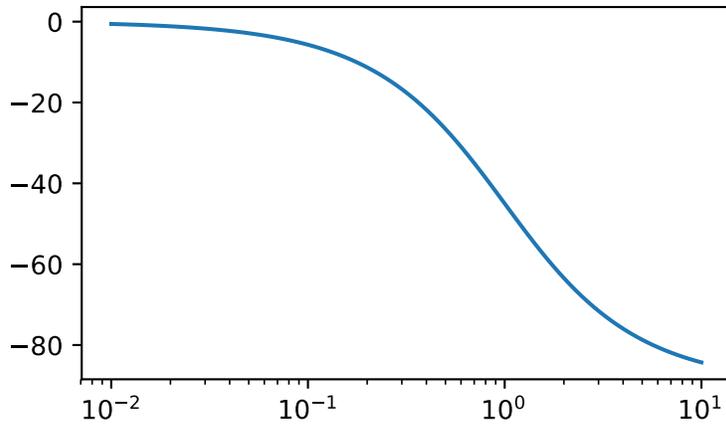
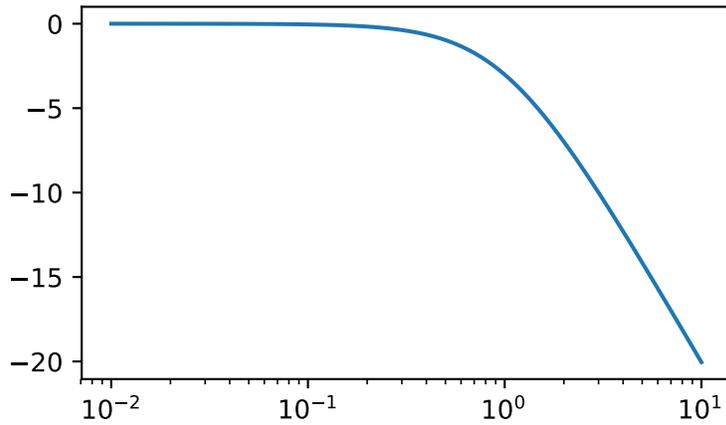
Returns a 3-tuple containing arrays of frequencies [rad/s], magnitude [dB] and phase [deg]. See *bode* for details.

### Examples

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

```
>>> sys = signal.TransferFunction([1], [1, 1])
>>> w, mag, phase = sys.bode()
```

```
>>> plt.figure()
>>> plt.semilogx(w, mag)    # Bode magnitude plot
>>> plt.figure()
>>> plt.semilogx(w, phase) # Bode phase plot
>>> plt.show()
```



`lti.freqresp` (*w=None, n=10000*)

Calculate the frequency response of a continuous-time system.

Returns a 2-tuple containing arrays of frequencies [rad/s] and complex magnitude. See *freqresp* for details.

`lti.impulse` (*X0=None, T=None, N=None*)

Return the impulse response of a continuous-time system. See *impulse* for details.

`lti.output` (*U, T, X0=None*)

Return the response of a continuous-time system to input *U*. See *lsim* for details.

`lti.step` (*X0=None, T=None, N=None*)

Return the step response of a continuous-time system. See *step* for details.

`lti.to_discrete` (*dt, method='zoh', alpha=None*)

Return a discretized version of the current system.

Parameters: See *cont2discrete* for details.

**Returns** sys: instance of *dlti*

**class** `scipy.signal.StateSpace` (\*system, \*\*kwargs)  
Linear Time Invariant system in state-space form.

Represents the system as the continuous-time, first order differential equation  $\dot{x} = Ax + Bu$  or the discrete-time difference equation  $x[k+1] = Ax[k] + Bu[k]$ . *StateSpace* systems inherit additional functionality from the *lti*, respectively the *dlti* classes, depending on which system representation is used.

**Parameters** \*system: arguments

The *StateSpace* class can be instantiated with 1 or 3 arguments. The following gives the number of input arguments and their interpretation:

- 1: *lti* or *dlti* system: (*StateSpace*,
- TransferFunction* or *ZerosPolesGain*)
- 4: array\_like: (A, B, C, D)

**dt: float, optional**

Sampling time [s] of the discrete-time systems. Defaults to *None* (continuous-time). Must be specified as a keyword argument, for example, `dt=0.1`.

**See also:**

*TransferFunction*, *ZerosPolesGain*, *lti*, *dlti*, *ss2zpk*, *ss2tf*, *zpk2sos*

**Notes**

Changing the value of properties that are not part of the *StateSpace* system representation (such as *zeros* or *poles*) is very inefficient and may lead to numerical inaccuracies. It is better to convert to the specific system representation first. For example, call `sys = sys.to_zpk()` before accessing/changing the zeros, poles or gain.

**Examples**

```
>>> from scipy import signal
```

```
>>> a = np.array([[0, 1], [0, 0]])
>>> b = np.array([[0], [1]])
>>> c = np.array([[1, 0]])
>>> d = np.array([[0]])
```

```
>>> sys = signal.StateSpace(a, b, c, d)
>>> print(sys)
StateSpaceContinuous(
array([[0, 1],
       [0, 0]]),
array([[0],
       [1]]),
array([[1, 0]]),
array([[0]]),
dt: None
)
```

```
>>> sys.to_discrete(0.1)
StateSpaceDiscrete(
array([[ 1. ,  0.1],
       [ 0. ,  1. ]]),
array([[ 0.005],
       [ 0.1  ]]),
array([[1, 0]]),
```

```
array([[0]]),
dt: 0.1
)
```

```
>>> a = np.array([[1, 0.1], [0, 1]])
>>> b = np.array([[0.005], [0.1]])
```

```
>>> signal.StateSpace(a, b, c, d, dt=0.1)
StateSpaceDiscrete(
array([[ 1. ,  0.1],
       [ 0. ,  1. ]]),
array([[ 0.005],
       [ 0.1 ]]),
array([[1, 0]]),
array([[0]]),
dt: 0.1
)
```

**Attributes**

<i>A</i>	State matrix of the <i>StateSpace</i> system.
<i>B</i>	Input matrix of the <i>StateSpace</i> system.
<i>C</i>	Output matrix of the <i>StateSpace</i> system.
<i>D</i>	Feedthrough matrix of the <i>StateSpace</i> system.
<i>dt</i>	Return the sampling time of the system, <i>None</i> for <i>lti</i> systems.
<i>poles</i>	Poles of the system.
<i>zeros</i>	Zeros of the system.

**StateSpace.A**  
State matrix of the *StateSpace* system.

**StateSpace.B**  
Input matrix of the *StateSpace* system.

**StateSpace.C**  
Output matrix of the *StateSpace* system.

**StateSpace.D**  
Feedthrough matrix of the *StateSpace* system.

**StateSpace.dt**  
Return the sampling time of the system, *None* for *lti* systems.

**StateSpace.poles**  
Poles of the system.

**StateSpace.zeros**  
Zeros of the system.

**Methods**

<i>to_ss()</i>	Return a copy of the current <i>StateSpace</i> system.
<i>to_tf(**kwargs)</i>	Convert system representation to <i>TransferFunction</i> .

Continued on next page

Table 5.148 – continued from previous page

<code>to_zpk(**kwargs)</code>	Convert system representation to <i>ZerosPolesGain</i> .
<code>StateSpace.to_ss()</code>	Return a copy of the current <i>StateSpace</i> system.
<b>Returns</b>	<b>sys</b> : instance of <i>StateSpace</i> The current system (copy)
<code>StateSpace.to_tf(**kwargs)</code>	Convert system representation to <i>TransferFunction</i> .
<b>Parameters</b>	<b>kwargs</b> : dict, optional Additional keywords passed to <i>ss2zpk</i>
<b>Returns</b>	<b>sys</b> : instance of <i>TransferFunction</i> Transfer function of the current system
<code>StateSpace.to_zpk(**kwargs)</code>	Convert system representation to <i>ZerosPolesGain</i> .
<b>Parameters</b>	<b>kwargs</b> : dict, optional Additional keywords passed to <i>ss2zpk</i>
<b>Returns</b>	<b>sys</b> : instance of <i>ZerosPolesGain</i> Zeros, poles, gain representation of the current system
<b>class</b> <code>scipy.signal.TransferFunction(*system, **kwargs)</code>	Linear Time Invariant system class in transfer function form.
	Represents the system as the continuous-time transfer function $H(s) = \sum_{i=0}^N b[N-i]s^i / \sum_{j=0}^M a[M-j]s^j$ or the discrete-time transfer function $H(z) = \sum_{i=0}^N b[N-i]z^i / \sum_{j=0}^M a[M-j]z^j$ , where <i>b</i> are elements of the numerator <i>num</i> , <i>a</i> are elements of the denominator <i>den</i> , and $N == \text{len}(b) - 1, M == \text{len}(a) - 1$ . <i>TransferFunction</i> systems inherit additional functionality from the <i>lti</i> , respectively the <i>dlti</i> classes, depending on which system representation is used.
<b>Parameters</b>	<b>*system: arguments</b> The <i>TransferFunction</i> class can be instantiated with 1 or 2 arguments. The following gives the number of input arguments and their interpretation: •1: <i>lti</i> or <i>dlti</i> system: ( <i>StateSpace</i> , <i>TransferFunction</i> or <i>ZerosPolesGain</i> ) •2: array_like: (numerator, denominator)
	<b>dt: float, optional</b> Sampling time [s] of the discrete-time systems. Defaults to <i>None</i> (continuous-time). Must be specified as a keyword argument, for example, <code>dt=0.1</code> .
<b>See also:</b>	<i>ZerosPolesGain</i> , <i>StateSpace</i> , <i>lti</i> , <i>dlti</i> , <i>tf2ss</i> , <i>tf2zpk</i> , <i>tf2sos</i>
<b>Notes</b>	Changing the value of properties that are not part of the <i>TransferFunction</i> system representation (such as the <i>A</i> , <i>B</i> , <i>C</i> , <i>D</i> state-space matrices) is very inefficient and may lead to numerical inaccuracies. It is better to convert to the specific system representation first. For example, call <code>sys = sys.to_ss()</code> before accessing/changing the <i>A</i> , <i>B</i> , <i>C</i> , <i>D</i> system matrices.  If (numerator, denominator) is passed in for <i>*system</i> , coefficients for both the numerator and denominator should be specified in descending exponent order (e.g. $s^2 + 3s + 5$ or $z^2 + 3z + 5$ would be represented as <code>[1, 3, 5]</code> )

**Examples**

Construct the transfer function:

$$H(s) = \frac{s^2 + 3s + 3}{s^2 + 2s + 1}$$

```
>>> from scipy import signal
```

```
>>> num = [1, 3, 3]
>>> den = [1, 2, 1]
```

```
>>> signal.TransferFunction(num, den)
TransferFunctionContinuous(
array([ 1.,  3.,  3.]),
array([ 1.,  2.,  1.]),
dt: None
)
```

Construct the transfer function with a sampling time of 0.1 seconds:

$$H(z) = \frac{z^2 + 3z + 3}{z^2 + 2z + 1}$$

```
>>> signal.TransferFunction(num, den, dt=0.1)
TransferFunctionDiscrete(
array([ 1.,  3.,  3.]),
array([ 1.,  2.,  1.]),
dt: 0.1
)
```

**Attributes**

<i>den</i>	Denominator of the <i>TransferFunction</i> system.
<i>dt</i>	Return the sampling time of the system, <i>None</i> for <i>lti</i> systems.
<i>num</i>	Numerator of the <i>TransferFunction</i> system.
<i>poles</i>	Poles of the system.
<i>zeros</i>	Zeros of the system.

`TransferFunction.den`  
Denominator of the *TransferFunction* system.

`TransferFunction.dt`  
Return the sampling time of the system, *None* for *lti* systems.

`TransferFunction.num`  
Numerator of the *TransferFunction* system.

`TransferFunction.poles`  
Poles of the system.

`TransferFunction.zeros`  
Zeros of the system.

*Methods*

<code>to_ss()</code>	Convert system representation to <i>StateSpace</i> .
<code>to_tf()</code>	Return a copy of the current <i>TransferFunction</i> system.
<code>to_zpk()</code>	Convert system representation to <i>ZerosPolesGain</i> .

`TransferFunction.to_ss()`

Convert system representation to *StateSpace*.

**Returns** `sys` : instance of *StateSpace*  
State space model of the current system

`TransferFunction.to_tf()`

Return a copy of the current *TransferFunction* system.

**Returns** `sys` : instance of *TransferFunction*  
The current system (copy)

`TransferFunction.to_zpk()`

Convert system representation to *ZerosPolesGain*.

**Returns** `sys` : instance of *ZerosPolesGain*  
Zeros, poles, gain representation of the current system

**class** `scipy.signal.ZerosPolesGain(*system, **kwargs)`

Linear Time Invariant system class in zeros, poles, gain form.

Represents the system as the continuous- or discrete-time transfer function  $H(s) = k \prod_i (s - z[i]) / \prod_j (s - p[j])$ , where  $k$  is the *gain*,  $z$  are the *zeros* and  $p$  are the *poles*. *ZerosPolesGain* systems inherit additional functionality from the *lti*, respectively the *dlti* classes, depending on which system representation is used.

**Parameters** `*system` : arguments

The *ZerosPolesGain* class can be instantiated with 1 or 3 arguments.

The following gives the number of input arguments and their interpretation:

- 1: *lti* or *dlti* system: (*StateSpace*, *TransferFunction* or *ZerosPolesGain*)
- 3: *array\_like*: (zeros, poles, gain)

**dt**: float, optional

Sampling time [s] of the discrete-time systems. Defaults to *None* (continuous-time). Must be specified as a keyword argument, for example, `dt=0.1`.

**See also:**

*TransferFunction*, *StateSpace*, *lti*, *dlti*, *zpk2ss*, *zpk2tf*, *zpk2sos*

**Notes**

Changing the value of properties that are not part of the *ZerosPolesGain* system representation (such as the *A*, *B*, *C*, *D* state-space matrices) is very inefficient and may lead to numerical inaccuracies. It is better to convert to the specific system representation first. For example, call `sys = sys.to_ss()` before accessing/changing the *A*, *B*, *C*, *D* system matrices.

**Examples**

```
>>> from scipy import signal
```

Transfer function:  $H(s) = 5(s - 1)(s - 2) / (s - 3)(s - 4)$

```
>>> signal.ZerosPolesGain([1, 2], [3, 4], 5)
ZerosPolesGainContinuous(
array([1, 2]),
array([3, 4]),
5,
dt: None
)
```

Transfer function:  $H(z) = 5(z - 1)(z - 2) / (z - 3)(z - 4)$

```
>>> signal.ZerosPolesGain([1, 2], [3, 4], 5, dt=0.1)
ZerosPolesGainDiscrete(
array([1, 2]),
array([3, 4]),
5,
dt: 0.1
)
```

### Attributes

<code>dt</code>	Return the sampling time of the system, <i>None</i> for <i>lti</i> systems.
<code>gain</code>	Gain of the <i>ZerosPolesGain</i> system.
<code>poles</code>	Poles of the <i>ZerosPolesGain</i> system.
<code>zeros</code>	Zeros of the <i>ZerosPolesGain</i> system.

#### `ZerosPolesGain.dt`

Return the sampling time of the system, *None* for *lti* systems.

#### `ZerosPolesGain.gain`

Gain of the *ZerosPolesGain* system.

#### `ZerosPolesGain.poles`

Poles of the *ZerosPolesGain* system.

#### `ZerosPolesGain.zeros`

Zeros of the *ZerosPolesGain* system.

### Methods

<code>to_ss()</code>	Convert system representation to <i>StateSpace</i> .
<code>to_tf()</code>	Convert system representation to <i>TransferFunction</i> .
<code>to_zpk()</code>	Return a copy of the current 'ZerosPolesGain' system.

#### `ZerosPolesGain.to_ss()`

Convert system representation to *StateSpace*.

**Returns** `sys`: instance of *StateSpace*  
State space model of the current system

#### `ZerosPolesGain.to_tf()`

Convert system representation to *TransferFunction*.

**Returns** `sys`: instance of *TransferFunction*  
Transfer function of the current system

`ZerosPolesGain.to_zpk()`

Return a copy of the current ‘ZerosPolesGain’ system.

**Returns** `sys` : instance of `ZerosPolesGain`  
The current system (copy)

`scipy.signal.lsim(system, U, T, X0=None, interp=True)`

Simulate output of a continuous-time linear system.

**Parameters** `system` : an instance of the LTI class or a tuple describing the system.  
The following gives the number of elements in the tuple and the interpretation:

- 1: (instance of `lti`)
- 2: (num, den)
- 3: (zeros, poles, gain)
- 4: (A, B, C, D)

`U` : array\_like

An input array describing the input at each time  $T$  (interpolation is assumed between given times). If there are multiple inputs, then each column of the rank-2 array represents an input. If  $U = 0$  or `None`, a zero input is used.

`T` : array\_like

The time steps at which the input is defined and at which the output is desired. Must be nonnegative, increasing, and equally spaced.

`X0` : array\_like, optional

The initial conditions on the state vector (zero by default).

`interp` : bool, optional

Whether to use linear (`True`, the default) or zero-order-hold (`False`) interpolation for the input array.

**Returns** `T` : 1D ndarray

Time values for the output.

`yout` : 1D ndarray

System response.

`xout` : ndarray

Time evolution of the state vector.

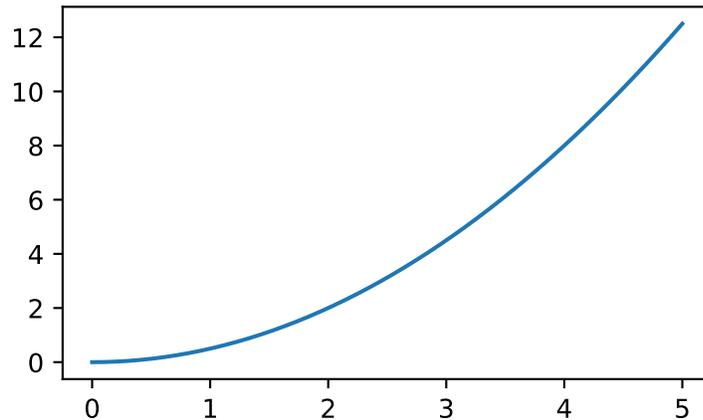
### Notes

If (num, den) is passed in for `system`, coefficients for both the numerator and denominator should be specified in descending exponent order (e.g.  $s^2 + 3s + 5$  would be represented as `[1, 3, 5]`).

### Examples

Simulate a double integrator  $y'' = u$ , with a constant input  $u = 1$

```
>>> from scipy import signal
>>> system = signal.lti([[0., 1.], [0., 0.]], [[0.], [1.]], [[1., 0.]], 0.)
>>> t = np.linspace(0, 5)
>>> u = np.ones_like(t)
>>> tout, y, x = signal.lsim(system, u, t)
>>> import matplotlib.pyplot as plt
>>> plt.plot(t, y)
```



`scipy.signal.lsim2(system, U=None, T=None, X0=None, **kwargs)`

Simulate output of a continuous-time linear system, by using the ODE solver `scipy.integrate.odeint`.

**Parameters** **system** : an instance of the `lti` class or a tuple describing the system.  
The following gives the number of elements in the tuple and the interpretation:

- 1: (instance of `lti`)
- 2: (num, den)
- 3: (zeros, poles, gain)
- 4: (A, B, C, D)

**U** : array\_like (1D or 2D), optional

An input array describing the input at each time `T`. Linear interpolation is used between given times. If there are multiple inputs, then each column of the rank-2 array represents an input. If `U` is not given, the input is assumed to be zero.

**T** : array\_like (1D or 2D), optional

The time steps at which the input is defined and at which the output is desired. The default is 101 evenly spaced points on the interval `[0,10.0]`.

**X0** : array\_like (1D), optional

The initial condition of the state vector. If `X0` is not given, the initial conditions are assumed to be 0.

**kwargs** : dict

Additional keyword arguments are passed on to the function `odeint`. See the notes below for more details.

**Returns** **T** : 1D ndarray

The time values for the output.

**yout** : ndarray

The response of the system.

**xout** : ndarray

The time-evolution of the state-vector.

### Notes

This function uses `scipy.integrate.odeint` to solve the system's differential equations. Additional keyword arguments given to `lsim2` are passed on to `odeint`. See the documentation for `scipy.integrate.odeint` for the full list of arguments.

If (num, den) is passed in for `system`, coefficients for both the numerator and denominator should be specified in descending exponent order (e.g.  $s^2 + 3s + 5$  would be represented as `[1, 3, 5]`).

`scipy.signal.impulse` (*system*, *X0=None*, *T=None*, *N=None*)

Impulse response of continuous-time system.

**Parameters**

- system** : an instance of the LTI class or a tuple of array\_like describing the system. The following gives the number of elements in the tuple and the interpretation:
  - 1 (instance of *lti*)
  - 2 (num, den)
  - 3 (zeros, poles, gain)
  - 4 (A, B, C, D)
- X0** : array\_like, optional  
Initial state-vector. Defaults to zero.
- T** : array\_like, optional  
Time points. Computed if not given.
- N** : int, optional  
The number of time points to compute (if *T* is not given).

**Returns**

- T** : ndarray  
A 1-D array of time points.
- yout** : ndarray  
A 1-D array containing the impulse response of the system (except for singularities at zero).

**Notes**

If (num, den) is passed in for *system*, coefficients for both the numerator and denominator should be specified in descending exponent order (e.g.  $s^2 + 3s + 5$  would be represented as [1, 3, 5]).

`scipy.signal.impulse2` (*system*, *X0=None*, *T=None*, *N=None*, **\*\*kwargs**)

Impulse response of a single-input, continuous-time linear system.

**Parameters**

- system** : an instance of the LTI class or a tuple of array\_like describing the system. The following gives the number of elements in the tuple and the interpretation:
  - 1 (instance of *lti*)
  - 2 (num, den)
  - 3 (zeros, poles, gain)
  - 4 (A, B, C, D)
- X0** : 1-D array\_like, optional  
The initial condition of the state vector. Default: 0 (the zero vector).
- T** : 1-D array\_like, optional  
The time steps at which the input is defined and at which the output is desired. If *T* is not given, the function will generate a set of time samples automatically.
- N** : int, optional  
Number of time points to compute. Default: 100.
- kwargs** : various types  
Additional keyword arguments are passed on to the function `scipy.signal.lsim2`, which in turn passes them on to `scipy.integrate.odeint`; see the latter's documentation for information about these arguments.

**Returns**

- T** : ndarray  
The time values for the output.
- yout** : ndarray  
The output response of the system.

**See also:**

`impulse`, `lsim2`, `integrate.odeint`

**Notes**

The solution is generated by calling `scipy.signal.lsim2`, which uses the differential equation solver `scipy.integrate.odeint`.

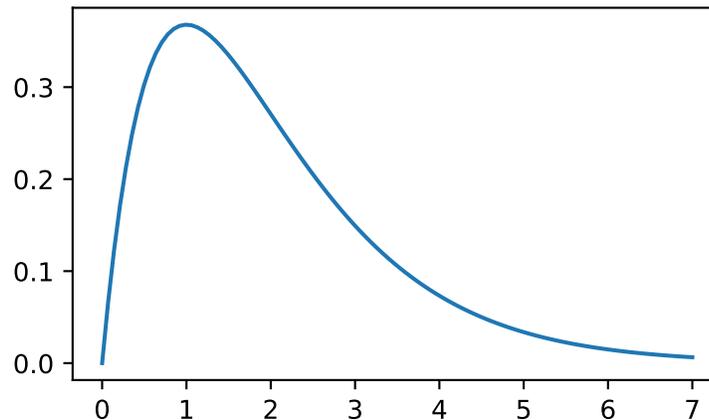
If `(num, den)` is passed in for `system`, coefficients for both the numerator and denominator should be specified in descending exponent order (e.g.  $s^2 + 3s + 5$  would be represented as `[1, 3, 5]`).

New in version 0.8.0.

**Examples**

Second order system with a repeated root:  $x''(t) + 2x'(t) + x(t) = u(t)$

```
>>> from scipy import signal
>>> system = ([1.0], [1.0, 2.0, 1.0])
>>> t, y = signal.impulse2(system)
>>> import matplotlib.pyplot as plt
>>> plt.plot(t, y)
```



`scipy.signal.step` (`system`, `X0=None`, `T=None`, `N=None`)

Step response of continuous-time system.

**Parameters** `system` : an instance of the LTI class or a tuple of array\_like describing the system. The following gives the number of elements in the tuple and the interpretation:

- 1 (instance of `lti`)
- 2 (num, den)
- 3 (zeros, poles, gain)
- 4 (A, B, C, D)

`X0` : array\_like, optional  
Initial state-vector (default is zero).

`T` : array\_like, optional  
Time points (computed if not given).

`N` : int, optional  
Number of time points to compute if `T` is not given.

**Returns** `T` : 1D ndarray  
Output time points.

`yout` : 1D ndarray  
Step response of system.

**See also:**

`scipy.signal.step2`

**Notes**

If (num, den) is passed in for `system`, coefficients for both the numerator and denominator should be specified in descending exponent order (e.g.  $s^2 + 3s + 5$  would be represented as `[1, 3, 5]`).

`scipy.signal.step2` (*system*, *X0=None*, *T=None*, *N=None*, *\*\*kwargs*)  
 Step response of continuous-time system.

This function is functionally the same as `scipy.signal.step`, but it uses the function `scipy.signal.lsim2` to compute the step response.

**Parameters**

- system** : an instance of the LTI class or a tuple of array\_like describing the system. The following gives the number of elements in the tuple and the interpretation:
  - 1 (instance of *lti*)
  - 2 (num, den)
  - 3 (zeros, poles, gain)
  - 4 (A, B, C, D)
- X0** : array\_like, optional  
 Initial state-vector (default is zero).
- T** : array\_like, optional  
 Time points (computed if not given).
- N** : int, optional  
 Number of time points to compute if *T* is not given.
- kwargs** : various types  
 Additional keyword arguments are passed on the function `scipy.signal.lsim2`, which in turn passes them on to `scipy.integrate.odeint`. See the documentation for `scipy.integrate.odeint` for information about these arguments.

**Returns**

- T** : 1D ndarray  
 Output time points.
- yout** : 1D ndarray  
 Step response of system.

**See also:**

`scipy.signal.step`

**Notes**

If (num, den) is passed in for `system`, coefficients for both the numerator and denominator should be specified in descending exponent order (e.g.  $s^2 + 3s + 5$  would be represented as `[1, 3, 5]`).

New in version 0.8.0.

`scipy.signal.freqresp` (*system*, *w=None*, *n=10000*)  
 Calculate the frequency response of a continuous-time system.

**Parameters**

- system** : an instance of the *lti* class or a tuple describing the system. The following gives the number of elements in the tuple and the interpretation:
  - 1 (instance of *lti*)
  - 2 (num, den)
  - 3 (zeros, poles, gain)
  - 4 (A, B, C, D)
- w** : array\_like, optional  
 Array of frequencies (in rad/s). Magnitude and phase data is calculated for every value in this array. If not given, a reasonable set will be calculated.
- n** : int, optional

**Returns**

- w** : 1D ndarray  
Number of frequency points to compute if  $w$  is not given. The  $n$  frequencies are logarithmically spaced in an interval chosen to include the influence of the poles and zeros of the system.
- H** : 1D ndarray  
Frequency array [rad/s]  
Array of complex magnitude values

**Notes**

If (num, den) is passed in for `system`, coefficients for both the numerator and denominator should be specified in descending exponent order (e.g.  $s^2 + 3s + 5$  would be represented as [1, 3, 5]).

**Examples**

Generating the Nyquist plot of a transfer function

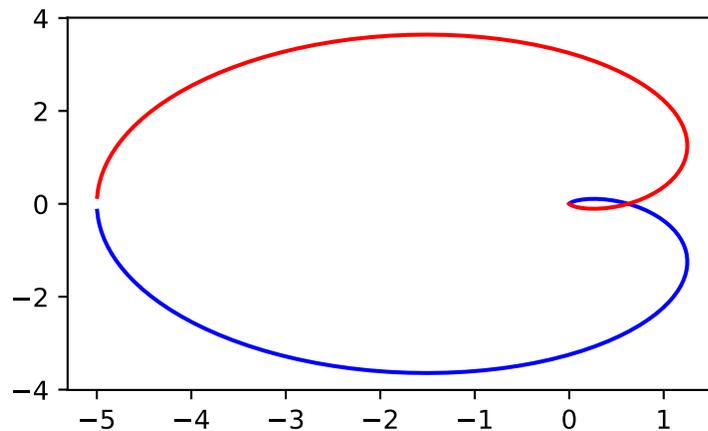
```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

Transfer function:  $H(s) = 5 / (s-1)^3$

```
>>> s1 = signal.ZerosPolesGain([], [1, 1, 1], [5])
```

```
>>> w, H = signal.freqresp(s1)
```

```
>>> plt.figure()
>>> plt.plot(H.real, H.imag, "b")
>>> plt.plot(H.real, -H.imag, "r")
>>> plt.show()
```



`scipy.signal.bode` (*system*, *w=None*, *n=100*)

Calculate Bode magnitude and phase data of a continuous-time system.

**Parameters** **system** : an instance of the LTI class or a tuple describing the system.

The following gives the number of elements in the tuple and the interpretation:

- 1 (instance of *Lti*)

- 2 (num, den)
- 3 (zeros, poles, gain)
- 4 (A, B, C, D)

**w** : array\_like, optional  
 Array of frequencies (in rad/s). Magnitude and phase data is calculated for every value in this array. If not given a reasonable set will be calculated.

**n** : int, optional  
 Number of frequency points to compute if *w* is not given. The *n* frequencies are logarithmically spaced in an interval chosen to include the influence of the poles and zeros of the system.

**Returns**

**w** : 1D ndarray  
 Frequency array [rad/s]  
**mag** : 1D ndarray  
 Magnitude array [dB]  
**phase** : 1D ndarray  
 Phase array [deg]

**Notes**

If (num, den) is passed in for *system*, coefficients for both the numerator and denominator should be specified in descending exponent order (e.g.  $s^2 + 3s + 5$  would be represented as [1, 3, 5]).

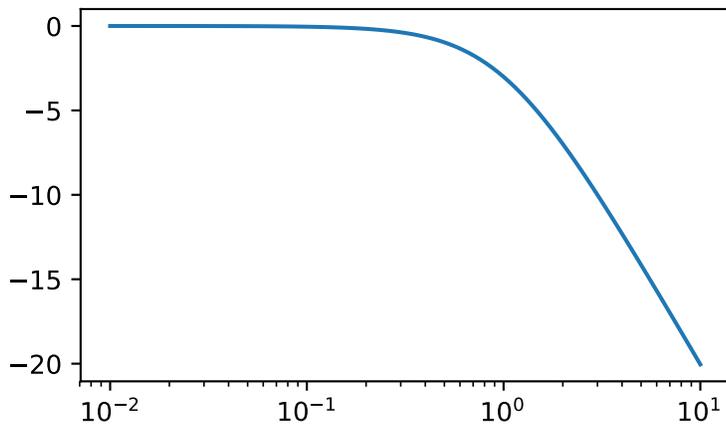
New in version 0.11.0.

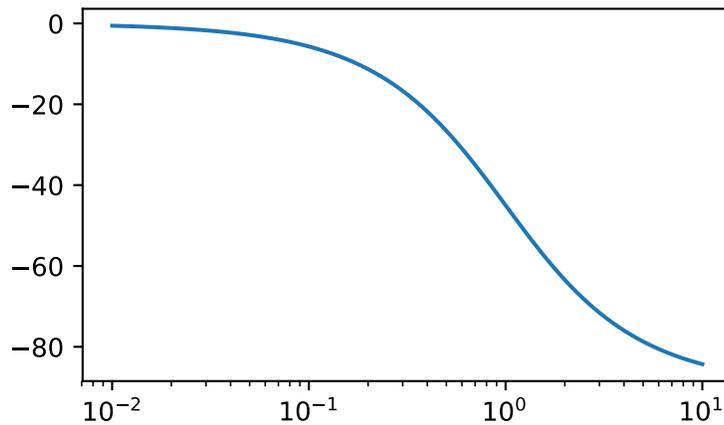
**Examples**

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

```
>>> sys = signal.TransferFunction([1], [1, 1])
>>> w, mag, phase = signal.bode(sys)
```

```
>>> plt.figure()
>>> plt.semilogx(w, mag) # Bode magnitude plot
>>> plt.figure()
>>> plt.semilogx(w, phase) # Bode phase plot
>>> plt.show()
```





### 5.20.7 Discrete-Time Linear Systems

<code>dlti(*system, **kwargs)</code>	Discrete-time linear time invariant system base class.
<code>StateSpace(*system, **kwargs)</code>	Linear Time Invariant system in state-space form.
<code>TransferFunction(*system, **kwargs)</code>	Linear Time Invariant system class in transfer function form.
<code>ZerosPolesGain(*system, **kwargs)</code>	Linear Time Invariant system class in zeros, poles, gain form.
<code>dlsim(system, u[, t, x0])</code>	Simulate output of a discrete-time linear system.
<code>dimpulse(system[, x0, t, n])</code>	Impulse response of discrete-time system.
<code>dstep(system[, x0, t, n])</code>	Step response of discrete-time system.
<code>dfreqresp(system[, w, n, whole])</code>	Calculate the frequency response of a discrete-time system.
<code>dbode(system[, w, n])</code>	Calculate Bode magnitude and phase data of a discrete-time system.

**class** `scipy.signal.dlti` (\*system, \*\*kwargs)  
Discrete-time linear time invariant system base class.

**Parameters** \*system: arguments

The `dlti` class can be instantiated with either 2, 3 or 4 arguments. The following gives the number of arguments and the corresponding discrete-time subclass that is created:

- 2: `TransferFunction`: (numerator, denominator)
- 3: `ZerosPolesGain`: (zeros, poles, gain)
- 4: `StateSpace`: (A, B, C, D)

Each argument can be an array or a sequence.

**dt**: float, optional

Sampling time [s] of the discrete-time systems. Defaults to `True` (unspecified sampling time). Must be specified as a keyword argument, for example, `dt=0.1`.

**See also:**

`ZerosPolesGain`, `StateSpace`, `TransferFunction`, `lti`

**Notes**

*dlti* instances do not exist directly. Instead, *dlti* creates an instance of one of its subclasses: *StateSpace*, *TransferFunction* or *ZerosPolesGain*.

Changing the value of properties that are not directly part of the current system representation (such as the *zeros* of a *StateSpace* system) is very inefficient and may lead to numerical inaccuracies. It is better to convert to the specific system representation first. For example, call `sys = sys.to_zpk()` before accessing/changing the zeros, poles or gain.

If (numerator, denominator) is passed in for *\*system*, coefficients for both the numerator and denominator should be specified in descending exponent order (e.g.,  $z^2 + 3z + 5$  would be represented as `[1, 3, 5]`).

New in version 0.18.0.

**Examples**

```
>>> from scipy import signal
```

```
>>> signal.dlti(1, 2, 3, 4)
StateSpaceDiscrete(
array([[1]]),
array([[2]]),
array([[3]]),
array([[4]]),
dt: True
)
```

```
>>> signal.dlti(1, 2, 3, 4, dt=0.1)
StateSpaceDiscrete(
array([[1]]),
array([[2]]),
array([[3]]),
array([[4]]),
dt: 0.1
)
```

```
>>> signal.dlti([1, 2], [3, 4], 5, dt=0.1)
ZerosPolesGainDiscrete(
array([1, 2]),
array([3, 4]),
5,
dt: 0.1
)
```

```
>>> signal.dlti([3, 4], [1, 2], dt=0.1)
TransferFunctionDiscrete(
array([ 3.,  4.]),
array([ 1.,  2.]),
dt: 0.1
)
```

**Attributes**

*dt*

Return the sampling time of the system.

Continued on next page

Table 5.154 – continued from previous page

<i>poles</i>	Poles of the system.
<i>zeros</i>	Zeros of the system.

`dlti.dt`  
Return the sampling time of the system.

`dlti.poles`  
Poles of the system.

`dlti.zeros`  
Zeros of the system.

### Methods

<code>bode([w, n])</code>	Calculate Bode magnitude and phase data of a discrete-time system.
<code>freqresp([w, n, whole])</code>	Calculate the frequency response of a discrete-time system.
<code>impulse([x0, t, n])</code>	Return the impulse response of the discrete-time <i>dlti</i> system.
<code>output(u, t[, x0])</code>	Return the response of the discrete-time system to input <i>u</i> .
<code>step([x0, t, n])</code>	Return the step response of the discrete-time <i>dlti</i> system.

`dlti.bode (w=None, n=100)`  
Calculate Bode magnitude and phase data of a discrete-time system.

Returns a 3-tuple containing arrays of frequencies [rad/s], magnitude [dB] and phase [deg]. See *dbode* for details.

### Examples

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

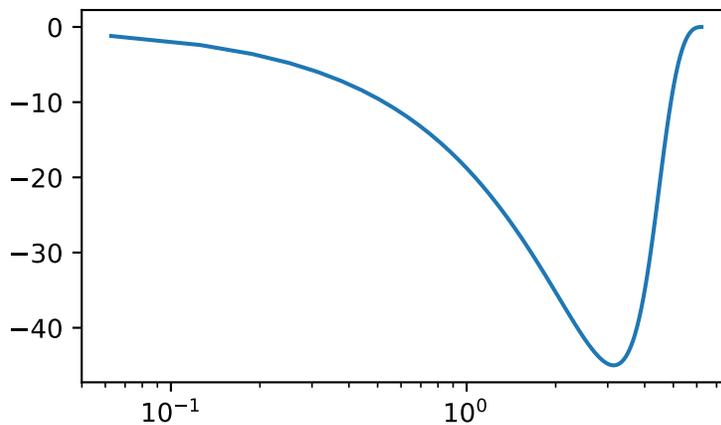
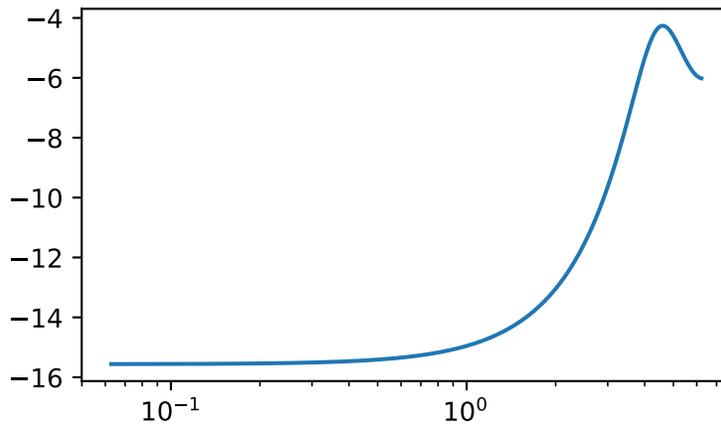
Transfer function:  $H(z) = 1 / (z^2 + 2z + 3)$  with sampling time 0.5s

```
>>> sys = signal.TransferFunction([1], [1, 2, 3], dt=0.5)
```

Equivalent: `signal.dbode(sys)`

```
>>> w, mag, phase = sys.bode()
```

```
>>> plt.figure()
>>> plt.semilogx(w, mag)      # Bode magnitude plot
>>> plt.figure()
>>> plt.semilogx(w, phase)   # Bode phase plot
>>> plt.show()
```



`dlti.freqresp` (*w=None, n=10000, whole=False*)

Calculate the frequency response of a discrete-time system.

Returns a 2-tuple containing arrays of frequencies [rad/s] and complex magnitude. See `dfreqresp` for details.

`dlti.impulse` (*x0=None, t=None, n=None*)

Return the impulse response of the discrete-time `dlti` system. See `dimpulse` for details.

`dlti.output` (*u, t, x0=None*)

Return the response of the discrete-time system to input *u*. See `dlsim` for details.

`dlti.step` (*x0=None, t=None, n=None*)

Return the step response of the discrete-time `dlti` system. See `dstep` for details.

`scipy.signal.dlsim` (*system, u, t=None, x0=None*)

Simulate output of a discrete-time linear system.

**Parameters** `system` : tuple of array\_like or instance of `dlti`

A tuple describing the system. The following gives the number of elements in the tuple and the interpretation:

- 1: (instance of *dlti*)
- 3: (num, den, dt)
- 4: (zeros, poles, gain, dt)
- 5: (A, B, C, D, dt)

**u** : array\_like

An input array describing the input at each time  $t$  (interpolation is assumed between given times). If there are multiple inputs, then each column of the rank-2 array represents an input.

**t** : array\_like, optional

The time steps at which the input is defined. If  $t$  is given, it must be the same length as  $u$ , and the final value in  $t$  determines the number of steps returned in the output.

**x0** : array\_like, optional

The initial conditions on the state vector (zero by default).

**Returns**

**tout** : ndarray

Time values for the output, as a 1-D array.

**yout** : ndarray

System response, as a 1-D array.

**xout** : ndarray, optional

Time-evolution of the state-vector. Only generated if the input is a *StateSpace* system.

**See also:**

*lsim*, *dstep*, *dimpulse*, *cont2discrete*

**Examples**

A simple integrator transfer function with a discrete time step of 1.0 could be implemented as:

```
>>> from scipy import signal
>>> tf = ([1.0,], [1.0, -1.0], 1.0)
>>> t_in = [0.0, 1.0, 2.0, 3.0]
>>> u = np.asarray([0.0, 0.0, 1.0, 1.0])
>>> t_out, y = signal.dlsim(tf, u, t=t_in)
>>> y.T
array([[ 0.,  0.,  0.,  1.]])
```

`scipy.signal.dimpulse` (*system*, *x0=None*, *t=None*, *n=None*)

Impulse response of discrete-time system.

**Parameters** **system** : tuple of array\_like or instance of *dlti*

A tuple describing the system. The following gives the number of elements in the tuple and the interpretation:

- 1: (instance of *dlti*)
- 3: (num, den, dt)
- 4: (zeros, poles, gain, dt)
- 5: (A, B, C, D, dt)

**x0** : array\_like, optional

Initial state-vector. Defaults to zero.

**t** : array\_like, optional

Time points. Computed if not given.

**n** : int, optional

The number of time points to compute (if  $t$  is not given).

**Returns**

**tout** : ndarray

Time values for the output, as a 1-D array.

**yout** : ndarray

Impulse response of system. Each element of the tuple represents the output of the system based on an impulse in each input.

**See also:**

*impulse, dstep, dlsim, cont2discrete*

`scipy.signal.dstep` (*system, x0=None, t=None, n=None*)

Step response of discrete-time system.

**Parameters** **system** : tuple of array\_like

A tuple describing the system. The following gives the number of elements in the tuple and the interpretation:

- 1: (instance of *dlti*)
- 2: (num, den, dt)
- 3: (zeros, poles, gain, dt)
- 4: (A, B, C, D, dt)

**x0** : array\_like, optional

Initial state-vector. Defaults to zero.

**t** : array\_like, optional

Time points. Computed if not given.

**n** : int, optional

The number of time points to compute (if *t* is not given).

**Returns**

**tout** : ndarray

Output time points, as a 1-D array.

**yout** : ndarray

Step response of system. Each element of the tuple represents the output of the system based on a step response to each input.

**See also:**

*step, dimpulse, dlsim, cont2discrete*

`scipy.signal.dfreqresp` (*system, w=None, n=10000, whole=False*)

Calculate the frequency response of a discrete-time system.

**Parameters** **system** : an instance of the *dlti* class or a tuple describing the system.

The following gives the number of elements in the tuple and the interpretation:

- 1 (instance of *dlti*)
- 2 (numerator, denominator, dt)
- 3 (zeros, poles, gain, dt)
- 4 (A, B, C, D, dt)

**w** : array\_like, optional

Array of frequencies (in radians/sample). Magnitude and phase data is calculated for every value in this array. If not given a reasonable set will be calculated.

**n** : int, optional

Number of frequency points to compute if *w* is not given. The *n* frequencies are logarithmically spaced in an interval chosen to include the influence of the poles and zeros of the system.

**whole** : bool, optional

Normally, if 'w' is not given, frequencies are computed from 0 to the Nyquist frequency, pi radians/sample (upper-half of unit-circle). If *whole* is True, compute frequencies from 0 to 2\*pi radians/sample.

**Returns**

**w** : 1D ndarray

Frequency array [radians/sample]

**H** : 1D ndarray

Array of complex magnitude values

**Notes**

If (num, den) is passed in for *system*, coefficients for both the numerator and denominator should be specified in descending exponent order (e.g.  $z^2 + 3z + 5$  would be represented as `[1, 3, 5]`).

New in version 0.18.0.

### Examples

Generating the Nyquist plot of a transfer function

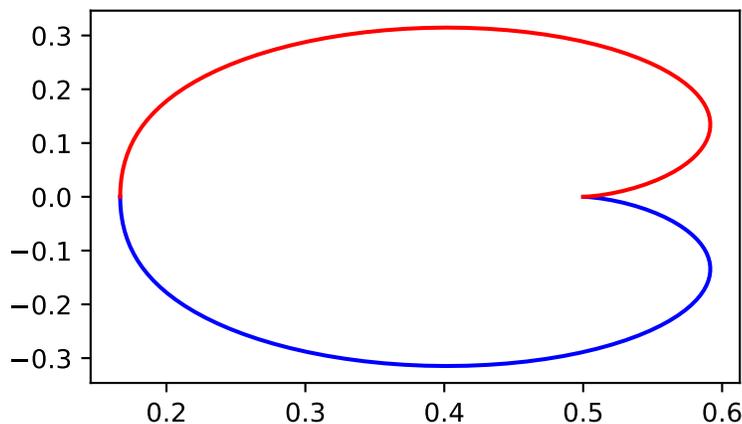
```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

Transfer function:  $H(z) = 1 / (z^2 + 2z + 3)$

```
>>> sys = signal.TransferFunction([1], [1, 2, 3], dt=0.05)
```

```
>>> w, H = signal.dfreqresp(sys)
```

```
>>> plt.figure()
>>> plt.plot(H.real, H.imag, "b")
>>> plt.plot(H.real, -H.imag, "r")
>>> plt.show()
```



`scipy.signal.dbode` (*system*, *w=None*, *n=100*)

Calculate Bode magnitude and phase data of a discrete-time system.

**Parameters** **system** : an instance of the LTI class or a tuple describing the system.

The following gives the number of elements in the tuple and the interpretation:

- 1 (instance of *dlti*)
- 2 (num, den, dt)
- 3 (zeros, poles, gain, dt)
- 4 (A, B, C, D, dt)

**w** : array\_like, optional

Array of frequencies (in radians/sample). Magnitude and phase data is calculated for every value in this array. If not given a reasonable set will be calculated.

**n** : int, optional

Number of frequency points to compute if *w* is not given. The *n* frequencies are logarithmically spaced in an interval chosen to include the influence of the poles and zeros of the system.

**Returns** **w** : 1D ndarray

Frequency array [rad/time\_unit]  
**mag** : 1D ndarray  
 Magnitude array [dB]  
**phase** : 1D ndarray  
 Phase array [deg]

### Notes

If (num, den) is passed in for `system`, coefficients for both the numerator and denominator should be specified in descending exponent order (e.g.  $z^2 + 3z + 5$  would be represented as `[1, 3, 5]`).

New in version 0.18.0.

### Examples

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

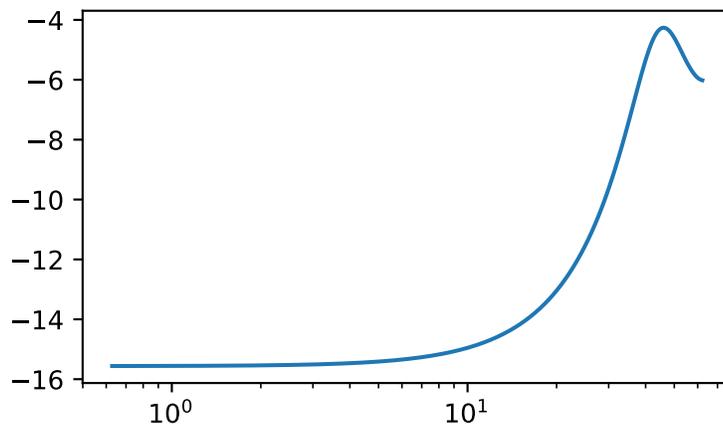
Transfer function:  $H(z) = 1 / (z^2 + 2z + 3)$

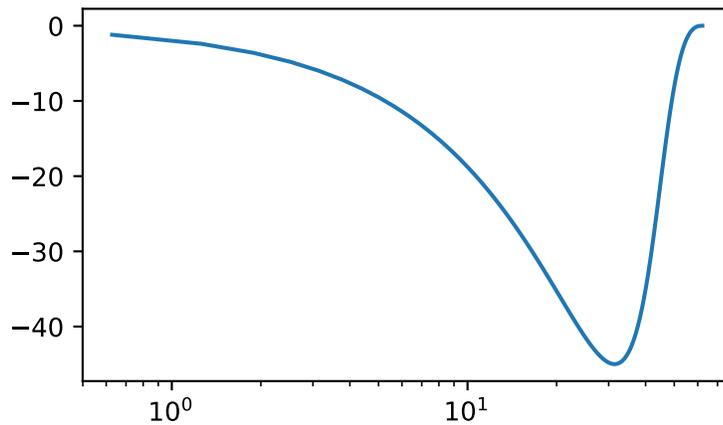
```
>>> sys = signal.TransferFunction([1], [1, 2, 3], dt=0.05)
```

Equivalent: `sys.bode()`

```
>>> w, mag, phase = signal.dbode(sys)
```

```
>>> plt.figure()
>>> plt.semilogx(w, mag) # Bode magnitude plot
>>> plt.figure()
>>> plt.semilogx(w, phase) # Bode phase plot
>>> plt.show()
```





## 5.20.8 LTI Representations

<code>tf2zpk(b, a)</code>	Return zero, pole, gain (z, p, k) representation from a numerator, denominator representation of a linear filter.
<code>tf2sos(b, a[, pairing])</code>	Return second-order sections from transfer function representation
<code>tf2ss(num, den)</code>	Transfer function to state-space representation.
<code>zpk2tf(z, p, k)</code>	Return polynomial transfer function representation from zeros and poles
<code>zpk2sos(z, p, k[, pairing])</code>	Return second-order sections from zeros, poles, and gain of a system
<code>zpk2ss(z, p, k)</code>	Zero-pole-gain representation to state-space representation
<code>ss2tf(A, B, C, D[, input])</code>	State-space to transfer function.
<code>ss2zpk(A, B, C, D[, input])</code>	State-space representation to zero-pole-gain representation.
<code>sos2zpk(sos)</code>	Return zeros, poles, and gain of a series of second-order sections
<code>sos2tf(sos)</code>	Return a single transfer function from a series of second-order sections
<code>cont2discrete(system, dt[, method, alpha])</code>	Transform a continuous to a discrete state-space system.
<code>place_poles(A, B, poles[, method, rtol, maxiter])</code>	Compute K such that eigenvalues (A - dot(B, K))=poles.

`scipy.signal.tf2zpk(b, a)`

Return zero, pole, gain (z, p, k) representation from a numerator, denominator representation of a linear filter.

**Parameters**

- b** : array\_like  
Numerator polynomial coefficients.
- a** : array\_like  
Denominator polynomial coefficients.

**Returns**

- z** : ndarray  
Zeros of the transfer function.
- p** : ndarray  
Poles of the transfer function.

**k** : float  
System gain.

**Notes**

If some values of  $b$  are too close to 0, they are removed. In that case, a `BadCoefficients` warning is emitted.

The  $b$  and  $a$  arrays are interpreted as coefficients for positive, descending powers of the transfer function variable. So the inputs  $b = [b_0, b_1, \dots, b_M]$  and  $a = [a_0, a_1, \dots, a_N]$  can represent an analog filter of the form:

$$H(s) = \frac{b_0 s^M + b_1 s^{(M-1)} + \dots + b_M}{a_0 s^N + a_1 s^{(N-1)} + \dots + a_N}$$

or a discrete-time filter of the form:

$$H(z) = \frac{b_0 z^M + b_1 z^{(M-1)} + \dots + b_M}{a_0 z^N + a_1 z^{(N-1)} + \dots + a_N}$$

This “positive powers” form is found more commonly in controls engineering. If  $M$  and  $N$  are equal (which is true for all filters generated by the bilinear transform), then this happens to be equivalent to the “negative powers” discrete-time form preferred in DSP:

$$H(z) = \frac{b_0 + b_1 z^{-1} + \dots + b_M z^{-M}}{a_0 + a_1 z^{-1} + \dots + a_N z^{-N}}$$

Although this is true for common filters, remember that this is not true in the general case. If  $M$  and  $N$  are not equal, the discrete-time transfer function coefficients must first be converted to the “positive powers” form before finding the poles and zeros.

`scipy.signal.tf2sos(b, a, pairing='nearest')`

Return second-order sections from transfer function representation

**Parameters**

- b** : array\_like  
Numerator polynomial coefficients.
- a** : array\_like  
Denominator polynomial coefficients.
- pairing** : {'nearest', 'keep\_odd'}, optional  
The method to use to combine pairs of poles and zeros into sections. See `zpk2sos`.

**Returns**

- sos** : ndarray  
Array of second-order filter coefficients, with shape `(n_sections, 6)`. See `sosfilt` for the SOS filter format specification.

**See also:**

`zpk2sos`, `sosfilt`

**Notes**

It is generally discouraged to convert from TF to SOS format, since doing so usually will not improve numerical precision errors. Instead, consider designing filters in ZPK format and converting directly to SOS. TF is converted to SOS by first converting to ZPK format, then converting ZPK to SOS.

New in version 0.16.0.

`scipy.signal.tf2ss(num, den)`

Transfer function to state-space representation.

**Parameters**

- num, den** : array\_like  
Sequences representing the coefficients of the numerator and denominator polynomials, in order of descending degree. The denominator needs to be at least as long as the numerator.

**Returns**

- A, B, C, D** : ndarray  
State space representation of the system, in controller canonical form.

**Examples**

Convert the transfer function:

$$H(s) = \frac{s^2 + 3s + 3}{s^2 + 2s + 1}$$

```
>>> num = [1, 3, 3]
>>> den = [1, 2, 1]
```

to the state-space representation:

$$\dot{\mathbf{x}}(t) = \begin{bmatrix} -2 & -1 \\ 1 & 0 \end{bmatrix} \mathbf{x}(t) + \begin{bmatrix} 1 \\ 0 \end{bmatrix} \mathbf{u}(t)$$

$$\mathbf{y}(t) = [1 \ 2] \mathbf{x}(t) + [1] \mathbf{u}(t)$$

```
>>> from scipy.signal import tf2ss
>>> A, B, C, D = tf2ss(num, den)
>>> A
array([[ -2.,  -1.],
       [  1.,   0.]])
>>> B
array([[ 1.],
       [ 0.]])
>>> C
array([[ 1.,  2.]])
>>> D
array([[ 1.]])
```

`scipy.signal.zpk2tf` (*z*, *p*, *k*)

Return polynomial transfer function representation from zeros and poles

**Parameters**

- z** : array\_like  
Zeros of the transfer function.
- p** : array\_like  
Poles of the transfer function.
- k** : float  
System gain.

**Returns**

- b** : ndarray  
Numerator polynomial coefficients.
- a** : ndarray  
Denominator polynomial coefficients.

`scipy.signal.zpk2sos` (*z*, *p*, *k*, *pairing*=*'nearest'*)

Return second-order sections from zeros, poles, and gain of a system

**Parameters**

- z** : array\_like  
Zeros of the transfer function.
- p** : array\_like  
Poles of the transfer function.
- k** : float  
System gain.
- pairing** : {'nearest', 'keep\_odd'}, optional  
The method to use to combine pairs of poles and zeros into sections. See Notes below.

**Returns**

- sos** : ndarray

Array of second-order filter coefficients, with shape `(n_sections, 6)`. See `sosfilt` for the SOS filter format specification.

**See also:**

`sosfilt`

**Notes**

The algorithm used to convert ZPK to SOS format is designed to minimize errors due to numerical precision issues. The pairing algorithm attempts to minimize the peak gain of each biquadratic section. This is done by pairing poles with the nearest zeros, starting with the poles closest to the unit circle.

**Algorithms**

The current algorithms are designed specifically for use with digital filters. (The output coefficients are not correct for analog filters.)

The steps in the `pairing='nearest'` and `pairing='keep_odd'` algorithms are mostly shared. The `nearest` algorithm attempts to minimize the peak gain, while `'keep_odd'` minimizes peak gain under the constraint that odd-order systems should retain one section as first order. The algorithm steps and are as follows:

As a pre-processing step, add poles or zeros to the origin as necessary to obtain the same number of poles and zeros for pairing. If `pairing == 'nearest'` and there are an odd number of poles, add an additional pole and a zero at the origin.

The following steps are then iterated over until no more poles or zeros remain:

1. Take the (next remaining) pole (complex or real) closest to the unit circle to begin a new filter section.
2. If the pole is real and there are no other remaining real poles<sup>1</sup>, add the closest real zero to the section and leave it as a first order section. Note that after this step we are guaranteed to be left with an even number of real poles, complex poles, real zeros, and complex zeros for subsequent pairing iterations.
3. Else:
  - (a) If the pole is complex and the zero is the only remaining real zero\*, then pair the pole with the *next* closest zero (guaranteed to be complex). This is necessary to ensure that there will be a real zero remaining to eventually create a first-order section (thus keeping the odd order).
  - (b) Else pair the pole with the closest remaining zero (complex or real).
  - (c) Proceed to complete the second-order section by adding another pole and zero to the current pole and zero in the section:
    - i. If the current pole and zero are both complex, add their conjugates.
    - ii. Else if the pole is complex and the zero is real, add the conjugate pole and the next closest real zero.
    - iii. Else if the pole is real and the zero is complex, add the conjugate zero and the real pole closest to those zeros.
    - iv. Else (we must have a real pole and real zero) add the next real pole closest to the unit circle, and then add the real zero closest to that pole.

New in version 0.16.0.

**Examples**

Design a 6th order low-pass elliptic digital filter for a system with a sampling rate of 8000 Hz that has a pass-band corner frequency of 1000 Hz. The ripple in the pass-band should not exceed 0.087 dB, and the attenuation in the stop-band should be at least 90 dB.

In the following call to `signal.ellip`, we could use `output='sos'`, but for this example, we'll use `output='zpk'`, and then convert to SOS format with `zpk2sos`:

```
>>> from scipy import signal
>>> z, p, k = signal.ellip(6, 0.087, 90, 1000/(0.5*8000), output='zpk')
```

<sup>1</sup> This conditional can only be met for specific odd-order inputs with the `pairing == 'keep_odd'` method.

Now convert to SOS format.

```
>>> sos = signal.zpk2sos(z, p, k)
```

The coefficients of the numerators of the sections:

```
>>> sos[:, :3]
array([[ 0.0014154 ,  0.00248707,  0.0014154 ],
       [ 1.          ,  0.72965193,  1.          ],
       [ 1.          ,  0.17594966,  1.          ]])
```

The symmetry in the coefficients occurs because all the zeros are on the unit circle.

The coefficients of the denominators of the sections:

```
>>> sos[:, 3:]
array([[ 1.          , -1.32543251,  0.46989499],
       [ 1.          , -1.26117915,  0.6262586 ],
       [ 1.          , -1.25707217,  0.86199667]])
```

The next example shows the effect of the *pairing* option. We have a system with three poles and three zeros, so the SOS array will have shape (2, 6). This means there is, in effect, an extra pole and an extra zero at the origin in the SOS representation.

```
>>> z1 = np.array([-1, -0.5-0.5j, -0.5+0.5j])
>>> p1 = np.array([0.75, 0.8+0.1j, 0.8-0.1j])
```

With `pairing='nearest'` (the default), we obtain

```
>>> signal.zpk2sos(z1, p1, 1)
array([[ 1. ,  1. ,  0.5 ,  1. , -0.75,  0. ],
       [ 1. ,  1. ,  0. ,  1. , -1.6 ,  0.65]])
```

The first section has the zeros  $\{-0.5-0.05j, -0.5+0.5j\}$  and the poles  $\{0, 0.75\}$ , and the second section has the zeros  $\{-1, 0\}$  and poles  $\{0.8+0.1j, 0.8-0.1j\}$ . Note that the extra pole and zero at the origin have been assigned to different sections.

With `pairing='keep_odd'`, we obtain:

```
>>> signal.zpk2sos(z1, p1, 1, pairing='keep_odd')
array([[ 1. ,  1. ,  0. ,  1. , -0.75,  0. ],
       [ 1. ,  1. ,  0.5 ,  1. , -1.6 ,  0.65]])
```

The extra pole and zero at the origin are in the same section. The first section is, in effect, a first-order section.

`scipy.signal.zpk2ss(z, p, k)`

Zero-pole-gain representation to state-space representation

**Parameters** **z, p**: sequence  
Zeros and poles.

**k**: float

**Returns** **A, B, C, D**: ndarray  
System gain.  
State space representation of the system, in controller canonical form.

`scipy.signal.ss2tf(A, B, C, D, input=0)`

State-space to transfer function.

A, B, C, D defines a linear state-space system with  $p$  inputs,  $q$  outputs, and  $n$  state variables.

**Parameters** **A**: array\_like

State (or system) matrix of shape  $(n, n)$

**B** : array\_like  
Input matrix of shape  $(n, p)$

**C** : array\_like  
Output matrix of shape  $(q, n)$

**D** : array\_like  
Feedthrough (or feedforward) matrix of shape  $(q, p)$

**input** : int, optional  
For multiple-input systems, the index of the input to use.

**Returns**

**num** : 2-D ndarray  
Numerator(s) of the resulting transfer function(s). *num* has one row for each of the system's outputs. Each row is a sequence representation of the numerator polynomial.

**den** : 1-D ndarray  
Denominator of the resulting transfer function(s). *den* is a sequence representation of the denominator polynomial.

### Examples

Convert the state-space representation:

$$\dot{\mathbf{x}}(t) = \begin{bmatrix} -2 & -1 \\ 1 & 0 \end{bmatrix} \mathbf{x}(t) + \begin{bmatrix} 1 \\ 0 \end{bmatrix} \mathbf{u}(t)$$

$$\mathbf{y}(t) = [1 \ 2] \mathbf{x}(t) + [1] \mathbf{u}(t)$$

```
>>> A = [[-2, -1], [1, 0]]
>>> B = [[1], [0]] # 2-dimensional column vector
>>> C = [[1, 2]] # 2-dimensional row vector
>>> D = 1
```

to the transfer function:

$$H(s) = \frac{s^2 + 3s + 3}{s^2 + 2s + 1}$$

```
>>> from scipy.signal import ss2tf
>>> ss2tf(A, B, C, D)
(array([[1, 3, 3]]), array([ 1., 2., 1.]))
```

`scipy.signal.ss2zpk(A, B, C, D, input=0)`

State-space representation to zero-pole-gain representation.

A, B, C, D defines a linear state-space system with  $p$  inputs,  $q$  outputs, and  $n$  state variables.

**Parameters**

**A** : array\_like  
State (or system) matrix of shape  $(n, n)$

**B** : array\_like  
Input matrix of shape  $(n, p)$

**C** : array\_like  
Output matrix of shape  $(q, n)$

**D** : array\_like  
Feedthrough (or feedforward) matrix of shape  $(q, p)$

**input** : int, optional  
For multiple-input systems, the index of the input to use.

**Returns**

**z, p** : sequence

**k** : float  
Zeros and poles.  
System gain.

`scipy.signal.sos2zpk` (*sos*)

Return zeros, poles, and gain of a series of second-order sections

**Parameters** **sos** : array\_like  
Array of second-order filter coefficients, must have shape  $(n\_sections, 6)$ . See `sosfilt` for the SOS filter format specification.

**Returns** **z** : ndarray  
Zeros of the transfer function.

**p** : ndarray  
Poles of the transfer function.

**k** : float  
System gain.

#### Notes

New in version 0.16.0.

`scipy.signal.sos2tf` (*sos*)

Return a single transfer function from a series of second-order sections

**Parameters** **sos** : array\_like  
Array of second-order filter coefficients, must have shape  $(n\_sections, 6)$ . See `sosfilt` for the SOS filter format specification.

**Returns** **b** : ndarray  
Numerator polynomial coefficients.

**a** : ndarray  
Denominator polynomial coefficients.

#### Notes

New in version 0.16.0.

`scipy.signal.cont2discrete` (*system, dt, method='zoh', alpha=None*)

Transform a continuous to a discrete state-space system.

**Parameters** **system** : a tuple describing the system or an instance of `lti`  
The following gives the number of elements in the tuple and the interpretation:

- 1: (instance of `lti`)
- 2: (num, den)
- 3: (zeros, poles, gain)
- 4: (A, B, C, D)

**dt** : float  
The discretization time step.

**method** : {"gbt", "bilinear", "euler", "backward\_diff", "zoh"}, optional  
Which method to use:

- gbt: generalized bilinear transformation
- bilinear: Tustin's approximation ("gbt" with `alpha=0.5`)
- euler: Euler (or forward differencing) method ("gbt" with `alpha=0`)
- backward\_diff: Backwards differencing ("gbt" with `alpha=1.0`)
- zoh: zero-order hold (default)

**alpha** : float within [0, 1], optional  
The generalized bilinear transformation weighting parameter, which should only be specified with `method="gbt"`, and is ignored otherwise

**Returns** **sysd** : tuple containing the discrete system  
Based on the input type, the output will be of the form

- (num, den, dt) for transfer function input.
- (zeros, poles, gain, dt) for zeros-poles-gain input

•(A, B, C, D, dt) for state-space system input

**Notes**

By default, the routine uses a Zero-Order Hold (zoh) method to perform the transformation. Alternatively, a generalized bilinear transformation may be used, which includes the common Tustin's bilinear approximation, an Euler's method technique, or a backwards differencing technique.

The Zero-Order Hold (zoh) method is based on [R246], the generalized bilinear approximation is based on [R247] and [R248].

**References**

[R246], [R247], [R248]

`scipy.signal.place_poles(A, B, poles, method='YT', rtol=0.001, maxiter=30)`

Compute K such that eigenvalues  $(A - B \cdot K) = \text{poles}$ .

K is the gain matrix such as the plant described by the linear system  $AX + BU$  will have its closed-loop poles, i.e the eigenvalues  $A - B \cdot K$ , as close as possible to those asked for in poles.

SISO, MISO and MIMO systems are supported.

**Parameters** **A, B** : ndarray

State-space representation of linear system  $AX + BU$ .

**poles** : array\_like

Desired real poles and/or complex conjugates poles. Complex poles are only supported with `method="YT"` (default).

**method**: {'YT', 'KNV0'}, optional

Which method to choose to find the gain matrix K. One of:

- 'YT': Yang Tits
- 'KNV0': Kautsky, Nichols, Van Dooren update method 0

See References and Notes for details on the algorithms.

**rtol**: float, optional

After each iteration the determinant of the eigenvectors of  $A - B \cdot K$  is compared to its previous value, when the relative error between these two values becomes lower than `rtol` the algorithm stops. Default is  $1e-3$ .

**maxiter**: int, optional

Maximum number of iterations to compute the gain matrix. Default is 30.

**Returns**

**full\_state\_feedback** : Bunch object

*full\_state\_feedback is composed of:*

**gain\_matrix** [1-D ndarray] The closed loop matrix K such as the eigenvalues of  $A - BK$  are as close as possible to the requested poles.

**computed\_poles**

[1-D ndarray] The poles corresponding to  $A - BK$  sorted as first the real poles in increasing order, then the complex conjugates in lexicographic order.

**requested\_poles**

[1-D ndarray] The poles the algorithm was asked to place sorted as above, they may differ from what was achieved.

**X**

[2-D ndarray] The transfer matrix such as  $X * \text{diag}(\text{poles}) = (A - B \cdot K) * X$  (see Notes)

<b><i>rtol</i></b>	[float] The relative tolerance achieved on $\det(X)$ (see Notes). <i>rtol</i> will be NaN if it is possible to solve the system $\text{diag}(\text{poles}) = (A - B*K)$ , or 0 when the optimization algorithms can't do anything i.e when $B.\text{shape}[1] == 1$ .
<b><i>nb_iter</i></b>	[int] The number of iterations performed before converging. <i>nb_iter</i> will be NaN if it is possible to solve the system $\text{diag}(\text{poles}) = (A - B*K)$ , or 0 when the optimization algorithms can't do anything i.e when $B.\text{shape}[1] == 1$ .

### Notes

The Tits and Yang (YT), [R295] paper is an update of the original Kautsky et al. (KNV) paper [R294]. KNV relies on rank-1 updates to find the transfer matrix  $X$  such that  $X * \text{diag}(\text{poles}) = (A - B*K)*X$ , whereas YT uses rank-2 updates. This yields on average more robust solutions (see [R295] pp 21-22), furthermore the YT algorithm supports complex poles whereas KNV does not in its original version. Only update method 0 proposed by KNV has been implemented here, hence the name 'KNV0'.

KNV extended to complex poles is used in Matlab's `place` function, YT is distributed under a non-free licence by Slicot under the name `robpole`. It is unclear and undocumented how KNV0 has been extended to complex poles (Tits and Yang claim on page 14 of their paper that their method can not be used to extend KNV to complex poles), therefore only YT supports them in this implementation.

As the solution to the problem of pole placement is not unique for MIMO systems, both methods start with a tentative transfer matrix which is altered in various way to increase its determinant. Both methods have been proven to converge to a stable solution, however depending on the way the initial transfer matrix is chosen they will converge to different solutions and therefore there is absolutely no guarantee that using 'KNV0' will yield results similar to Matlab's or any other implementation of these algorithms.

Using the default method 'YT' should be fine in most cases; 'KNV0' is only provided because it is needed by 'YT' in some specific cases. Furthermore 'YT' gives on average more robust results than 'KNV0' when  $\text{abs}(\det(X))$  is used as a robustness indicator.

[R295] is available as a technical report on the following URL: <http://drum.lib.umd.edu/handle/1903/5598>

### References

[R294], [R295]

### Examples

A simple example demonstrating real pole placement using both KNV and YT algorithms. This is example number 1 from section 4 of the reference KNV publication ([R294]):

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt

>>> A = np.array([[ 1.380,  -0.2077,  6.715,  -5.676  ],
...              [-0.5814, -4.290,   0,      0.6750  ],
...              [ 1.067,   4.273,  -6.654,  5.893  ],
...              [ 0.0480,  4.273,   1.343, -2.104  ]])
>>> B = np.array([[ 0,   5.679  ],
...              [ 1.136,  1.136  ],
...              [ 0,   0,   ]])
```

```
...          [-3.146,  0      ]])
>>> P = np.array([-0.2, -0.5, -5.0566, -8.6659])
```

Now compute  $K$  with KNV method 0, with the default YT method and with the YT method while forcing 100 iterations of the algorithm and print some results after each call.

```
>>> fsf1 = signal.place_poles(A, B, P, method='KNV0')
>>> fsf1.gain_matrix
array([[ 0.20071427, -0.96665799,  0.24066128, -0.10279785],
       [ 0.50587268,  0.57779091,  0.51795763, -0.41991442]])
```

```
>>> fsf2 = signal.place_poles(A, B, P) # uses YT method
>>> fsf2.computed_poles
array([-8.6659, -5.0566, -0.5      , -0.2     ])
```

```
>>> fsf3 = signal.place_poles(A, B, P, rtol=-1, maxiter=100)
>>> fsf3.X
array([[ 0.52072442+0.j, -0.08409372+0.j, -0.56847937+0.j,  0.74823657+0.j],
       [-0.04977751+0.j, -0.80872954+0.j,  0.13566234+0.j, -0.29322906+0.j],
       [-0.82266932+0.j, -0.19168026+0.j, -0.56348322+0.j, -0.43815060+0.j],
       [ 0.22267347+0.j,  0.54967577+0.j, -0.58387806+0.j, -0.40271926+0.j]])
```

The absolute value of the determinant of  $X$  is a good indicator to check the robustness of the results, both 'KNV0' and 'YT' aim at maximizing it. Below a comparison of the robustness of the results above:

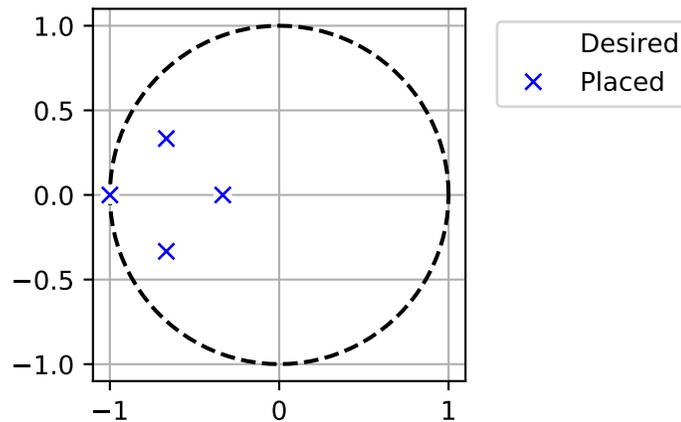
```
>>> abs(np.linalg.det(fsf1.X)) < abs(np.linalg.det(fsf2.X))
True
>>> abs(np.linalg.det(fsf2.X)) < abs(np.linalg.det(fsf3.X))
True
```

Now a simple example for complex poles:

```
>>> A = np.array([[ 0,  7/3.,  0,  0 ],
...             [ 0,  0,  0,  7/9. ],
...             [ 0,  0,  0,  0 ],
...             [ 0,  0,  0,  0 ]])
>>> B = np.array([[ 0,  0 ],
...             [ 0,  0 ],
...             [ 1,  0 ],
...             [ 0,  1 ]])
>>> P = np.array([-3, -1, -2-1j, -2+1j]) / 3.
>>> fsf = signal.place_poles(A, B, P, method='YT')
```

We can plot the desired and computed poles in the complex plane:

```
>>> t = np.linspace(0, 2*np.pi, 401)
>>> plt.plot(np.cos(t), np.sin(t), 'k--') # unit circle
>>> plt.plot(fsf.requested_poles.real, fsf.requested_poles.imag,
...         'wo', label='Desired')
>>> plt.plot(fsf.computed_poles.real, fsf.computed_poles.imag, 'bx',
...         label='Placed')
>>> plt.grid()
>>> plt.axis('image')
>>> plt.axis([-1.1, 1.1, -1.1, 1.1])
>>> plt.legend(bbox_to_anchor=(1.05, 1), loc=2, numpoints=1)
```



### 5.20.9 Waveforms

<code>chirp(t, f0, t1, f1[, method, phi, vertex_zero])</code>	Frequency-swept cosine generator.
<code>gausspulse(t[, fc, bw, bwr, tpr, retquad, ...])</code>	Return a Gaussian modulated sinusoid:
<code>max_len_seq(nbites[, state, length, taps])</code>	Maximum length sequence (MLS) generator.
<code>sawtooth(t[, width])</code>	Return a periodic sawtooth or triangle waveform.
<code>square(t[, duty])</code>	Return a periodic square-wave waveform.
<code>sweep_poly(t, poly[, phi])</code>	Frequency-swept cosine generator, with a time-dependent frequency.
<code>unit_impulse(shape[, idx, dtype])</code>	Unit impulse signal (discrete delta function) or unit basis vector.

`scipy.signal.chirp(t, f0, t1, f1, method='linear', phi=0, vertex_zero=True)`

Frequency-swept cosine generator.

In the following, ‘Hz’ should be interpreted as ‘cycles per unit’; there is no requirement here that the unit is one second. The important distinction is that the units of rotation are cycles, not radians. Likewise,  $t$  could be a measurement of space instead of time.

<b>Parameters</b>	<b>t</b> : array_like	Times at which to evaluate the waveform.
	<b>f0</b> : float	Frequency (e.g. Hz) at time $t=0$ .
	<b>t1</b> : float	Time at which $f1$ is specified.
	<b>f1</b> : float	Frequency (e.g. Hz) of the waveform at time $t1$ .
	<b>method</b> : {‘linear’, ‘quadratic’, ‘logarithmic’, ‘hyperbolic’}, optional	Kind of frequency sweep. If not given, <i>linear</i> is assumed. See Notes below for more details.
	<b>phi</b> : float, optional	Phase offset, in degrees. Default is 0.
	<b>vertex_zero</b> : bool, optional	

**Returns** `y` : ndarray

This parameter is only used when *method* is 'quadratic'. It determines whether the vertex of the parabola that is the graph of the frequency is at  $t=0$  or  $t=t1$ .

A numpy array containing the signal evaluated at  $t$  with the requested time-varying frequency. More precisely, the function returns  $\cos(\text{phase} + (\pi/180) * \text{phi})$  where *phase* is the integral (from 0 to  $t$ ) of  $2 * \pi * f(t)$ .  $f(t)$  is defined below.

**See also:**

`sweep_poly`

**Notes**

There are four options for the *method*. The following formulas give the instantaneous frequency (in Hz) of the signal generated by `chirp()`. For convenience, the shorter names shown below may also be used.

linear, lin, li:

$$f(t) = f0 + (f1 - f0) * t / t1$$

quadratic, quad, q:

The graph of the frequency  $f(t)$  is a parabola through  $(0, f0)$  and  $(t1, f1)$ . By default, the vertex of the parabola is at  $(0, f0)$ . If *vertex\_zero* is False, then the vertex is at  $(t1, f1)$ . The formula is:

if *vertex\_zero* is True:

$$f(t) = f0 + (f1 - f0) * t**2 / t1**2$$

else:

$$f(t) = f1 - (f1 - f0) * (t1 - t)**2 / t1**2$$

To use a more general quadratic function, or an arbitrary polynomial, use the function `scipy.signal.waveforms.sweep_poly`.

logarithmic, log, lo:

$$f(t) = f0 * (f1/f0)**(t/t1)$$

$f0$  and  $f1$  must be nonzero and have the same sign.

This signal is also known as a geometric or exponential chirp.

hyperbolic, hyp:

$$f(t) = f0 * f1 * t1 / ((f0 - f1) * t + f1 * t1)$$

$f0$  and  $f1$  must be nonzero.

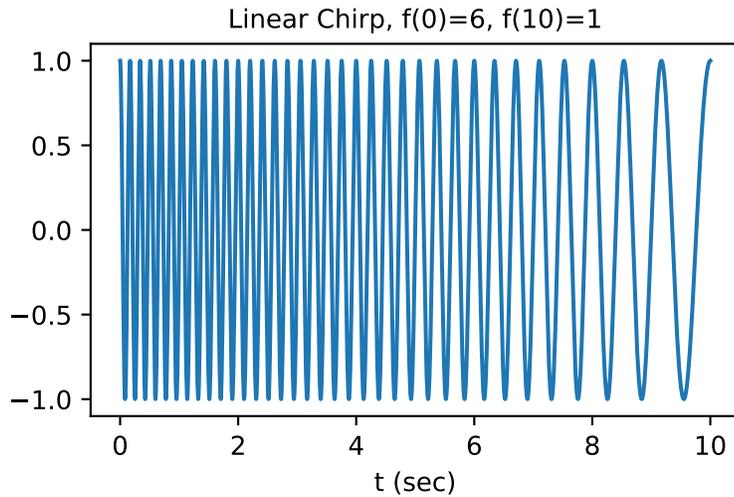
**Examples**

The following will be used in the examples:

```
>>> from scipy.signal import chirp, spectrogram
>>> import matplotlib.pyplot as plt
```

For the first example, we'll plot the waveform for a linear chirp from 6 Hz to 1 Hz over 10 seconds:

```
>>> t = np.linspace(0, 10, 5001)
>>> w = chirp(t, f0=6, f1=1, t1=10, method='linear')
>>> plt.plot(t, w)
>>> plt.title("Linear Chirp, f(0)=6, f(10)=1")
>>> plt.xlabel('t (sec)')
>>> plt.show()
```

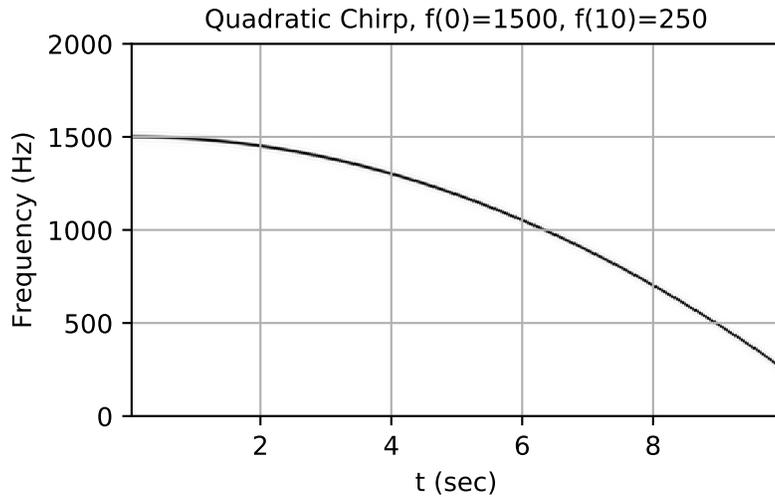


For the remaining examples, we'll use higher frequency ranges, and demonstrate the result using `scipy.signal.spectrogram`. We'll use a 10 second interval sampled at 8000 Hz.

```
>>> fs = 8000
>>> T = 10
>>> t = np.linspace(0, T, T*fs, endpoint=False)
```

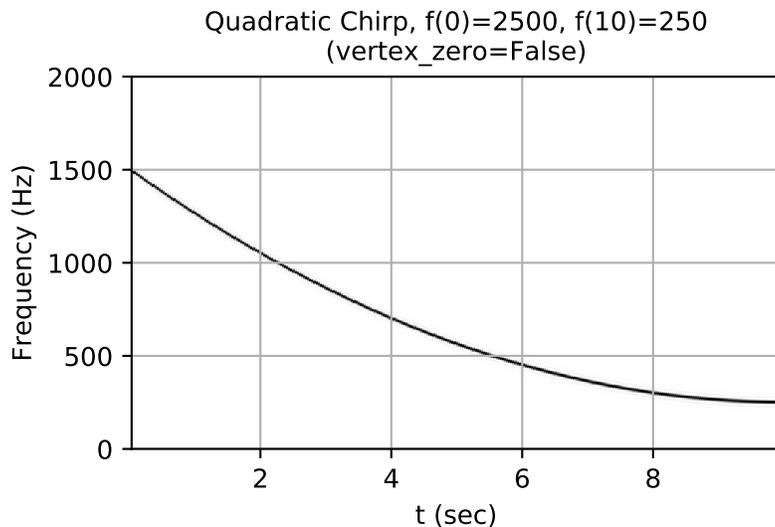
Quadratic chirp from 1500 Hz to 250 Hz over 10 seconds (vertex of the parabolic curve of the frequency is at  $t=0$ ):

```
>>> w = chirp(t, f0=1500, f1=250, t1=10, method='quadratic')
>>> ff, tt, Sxx = spectrogram(w, fs=fs, noverlap=256, nperseg=512,
...                           nfft=2048)
>>> plt.pcolormesh(tt, ff[:513], Sxx[:513], cmap='gray_r')
>>> plt.title('Quadratic Chirp, f(0)=1500, f(10)=250')
>>> plt.xlabel('t (sec)')
>>> plt.ylabel('Frequency (Hz)')
>>> plt.grid()
>>> plt.show()
```



Quadratic chirp from 1500 Hz to 250 Hz over 10 seconds (vertex of the parabolic curve of the frequency is at  $t=10$ ):

```
>>> w = chirp(t, f0=1500, f1=250, t1=10, method='quadratic',
...          vertex_zero=False)
>>> ff, tt, Sxx = spectrogram(w, fs=fs, noverlap=256, nperseg=512,
...                            nfft=2048)
>>> plt.pcolormesh(tt, ff[:513], Sxx[:513], cmap='gray_r')
>>> plt.title('Quadratic Chirp, f(0)=2500, f(10)=250\n' +
...          '(vertex_zero=False)')
>>> plt.xlabel('t (sec)')
>>> plt.ylabel('Frequency (Hz)')
>>> plt.grid()
>>> plt.show()
```

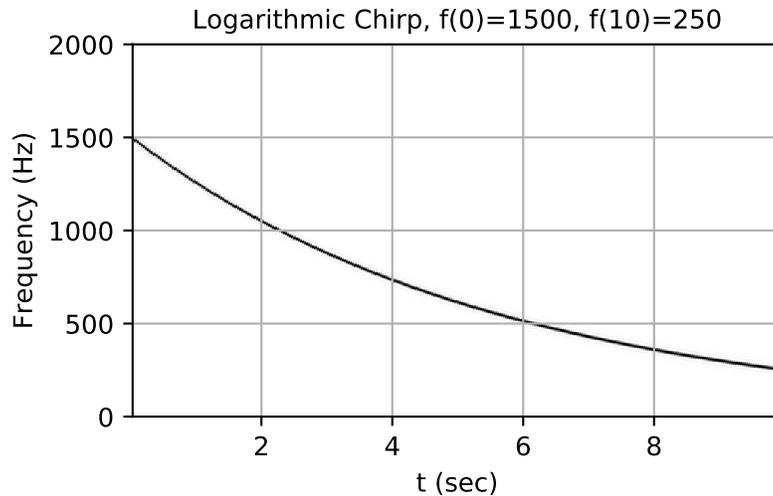


Logarithmic chirp from 1500 Hz to 250 Hz over 10 seconds:

```

>>> w = chirp(t, f0=1500, f1=250, t1=10, method='logarithmic')
>>> ff, tt, Sxx = spectrogram(w, fs=fs, noverlap=256, nperseg=512,
...                             nfft=2048)
>>> plt.pcolormesh(tt, ff[:513], Sxx[:513], cmap='gray_r')
>>> plt.title('Logarithmic Chirp, f(0)=1500, f(10)=250')
>>> plt.xlabel('t (sec)')
>>> plt.ylabel('Frequency (Hz)')
>>> plt.grid()
>>> plt.show()

```

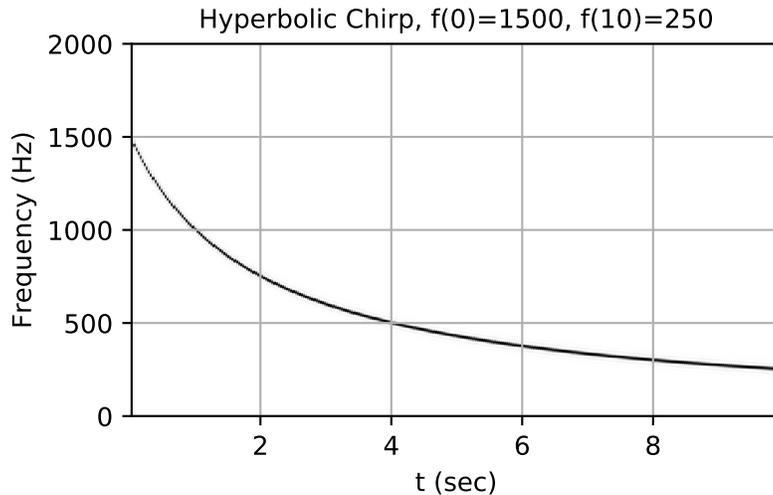


Hyperbolic chirp from 1500 Hz to 250 Hz over 10 seconds:

```

>>> w = chirp(t, f0=1500, f1=250, t1=10, method='hyperbolic')
>>> ff, tt, Sxx = spectrogram(w, fs=fs, noverlap=256, nperseg=512,
...                             nfft=2048)
>>> plt.pcolormesh(tt, ff[:513], Sxx[:513], cmap='gray_r')
>>> plt.title('Hyperbolic Chirp, f(0)=1500, f(10)=250')
>>> plt.xlabel('t (sec)')
>>> plt.ylabel('Frequency (Hz)')
>>> plt.grid()
>>> plt.show()

```



`scipy.signal.gausspulse` (*t*, *fc*=1000, *bw*=0.5, *bwr*=-6, *tpr*=-60, *retquad*=False, *retenv*=False)

Return a Gaussian modulated sinusoid:

$$\exp(-a t^2) \exp(1j \cdot 2 \cdot \pi \cdot f_c \cdot t).$$

If *retquad* is True, then return the real and imaginary parts (in-phase and quadrature). If *retenv* is True, then return the envelope (unmodulated signal). Otherwise, return the real part of the modulated sinusoid.

**Parameters**

- t** : ndarray or the string 'cutoff'  
Input array.
- fc** : int, optional  
Center frequency (e.g. Hz). Default is 1000.
- bw** : float, optional  
Fractional bandwidth in frequency domain of pulse (e.g. Hz). Default is 0.5.
- bwr** : float, optional  
Reference level at which fractional bandwidth is calculated (dB). Default is -6.
- tpr** : float, optional  
If *t* is 'cutoff', then the function returns the cutoff time for when the pulse amplitude falls below *tpr* (in dB). Default is -60.
- retquad** : bool, optional  
If True, return the quadrature (imaginary) as well as the real part of the signal. Default is False.
- retenv** : bool, optional  
If True, return the envelope of the signal. Default is False.

**Returns**

- yI** : ndarray  
Real part of signal. Always returned.
- yQ** : ndarray  
Imaginary part of signal. Only returned if *retquad* is True.
- yenv** : ndarray  
Envelope of signal. Only returned if *retenv* is True.

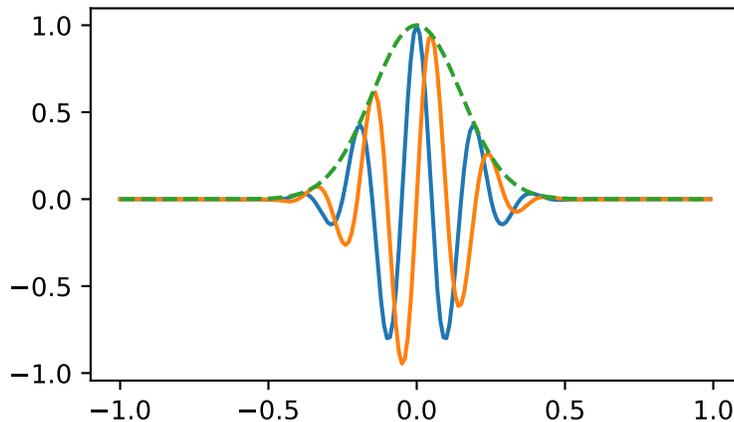
**See also:**

`scipy.signal.morlet`

**Examples**

Plot real component, imaginary component, and envelope for a 5 Hz pulse, sampled at 100 Hz for 2 seconds:

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
>>> t = np.linspace(-1, 1, 2 * 100, endpoint=False)
>>> i, q, e = signal.gausspulse(t, fc=5, retquad=True, retenv=True)
>>> plt.plot(t, i, t, q, t, e, '--')
```



`scipy.signal.max_len_seq` (*nbits*, *state=None*, *length=None*, *taps=None*)

Maximum length sequence (MLS) generator.

**Parameters** **nbits** : int

Number of bits to use. Length of the resulting sequence will be  $(2^{**nbits}) - 1$ . Note that generating long sequences (e.g., greater than `nbits == 16`) can take a long time.

**state** : array\_like, optional

If array, must be of length `nbits`, and will be cast to binary (bool) representation. If `None`, a seed of ones will be used, producing a repeatable representation. If `state` is all zeros, an error is raised as this is invalid. Default: `None`.

**length** : int, optional

Number of samples to compute. If `None`, the entire length  $(2^{**nbits}) - 1$  is computed.

**taps** : array\_like, optional

Polynomial taps to use (e.g., `[7, 6, 1]` for an 8-bit sequence). If `None`, taps will be automatically selected (for up to `nbits == 32`).

**Returns**

**seq** : array

Resulting MLS sequence of 0's and 1's.

**state** : array

The final state of the shift register.

**Notes**

The algorithm for MLS generation is generically described in:

[https://en.wikipedia.org/wiki/Maximum\\_length\\_sequence](https://en.wikipedia.org/wiki/Maximum_length_sequence)

The default values for taps are specifically taken from the first option listed for each value of `nbits` in:

[http://www.newwaveinstruments.com/resources/articles/m\\_sequence\\_linear\\_feedback\\_shift\\_register\\_lfsr.htm](http://www.newwaveinstruments.com/resources/articles/m_sequence_linear_feedback_shift_register_lfsr.htm)

New in version 0.15.0.

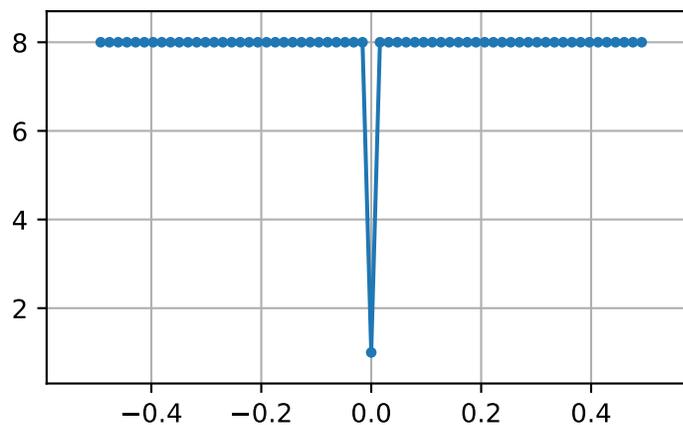
### Examples

MLS uses binary convention:

```
>>> from scipy.signal import max_len_seq
>>> max_len_seq(4)[0]
array([1, 1, 1, 1, 0, 1, 0, 1, 1, 0, 0, 1, 0, 0, 0], dtype=int8)
```

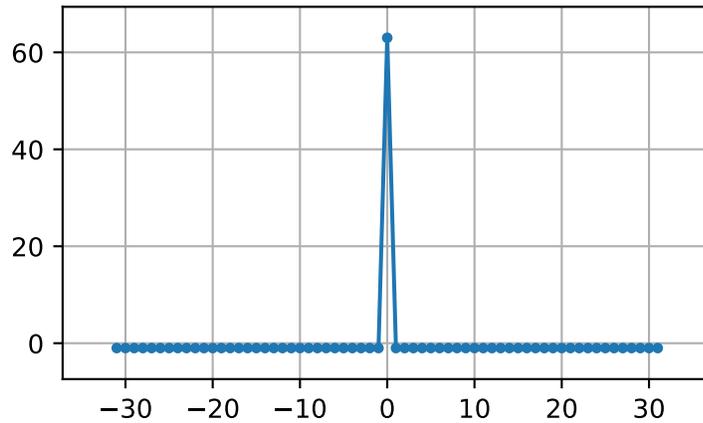
MLS has a white spectrum (except for DC):

```
>>> import matplotlib.pyplot as plt
>>> from numpy.fft import fft, ifft, fftshift, fftfreq
>>> seq = max_len_seq(6)[0]*2-1 # +1 and -1
>>> spec = fft(seq)
>>> N = len(seq)
>>> plt.plot(fftshift(fftfreq(N)), fftshift(np.abs(spec)), '-.')
>>> plt.margins(0.1, 0.1)
>>> plt.grid(True)
>>> plt.show()
```



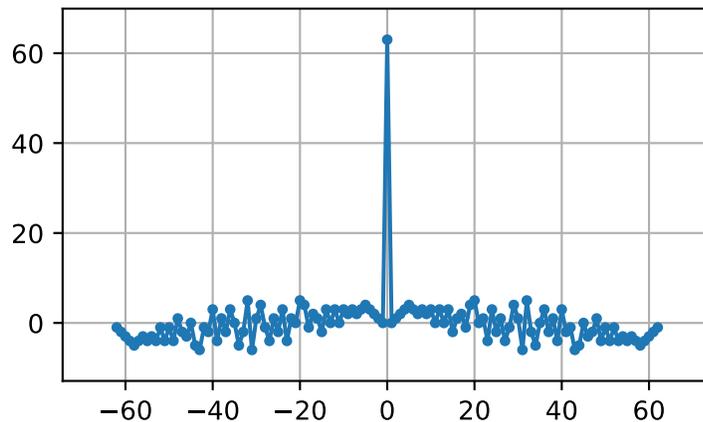
Circular autocorrelation of MLS is an impulse:

```
>>> acorrirc = ifft(spec * np.conj(spec)).real
>>> plt.figure()
>>> plt.plot(np.arange(-N/2+1, N/2+1), fftshift(acorrirc), '-.')
>>> plt.margins(0.1, 0.1)
>>> plt.grid(True)
>>> plt.show()
```



Linear autocorrelation of MLS is approximately an impulse:

```
>>> acorr = np.correlate(seq, seq, 'full')
>>> plt.figure()
>>> plt.plot(np.arange(-N+1, N), acorr, '-.')
>>> plt.margins(0.1, 0.1)
>>> plt.grid(True)
>>> plt.show()
```



`scipy.signal.sawtooth`(*t*, *width*=1)

Return a periodic sawtooth or triangle waveform.

The sawtooth waveform has a period  $2\pi$ , rises from -1 to 1 on the interval 0 to  $\text{width}\cdot 2\pi$ , then drops from 1 to -1 on the interval  $\text{width}\cdot 2\pi$  to  $2\pi$ . *width* must be in the interval [0, 1].

Note that this is not band-limited. It produces an infinite number of harmonics, which are aliased back and forth across the frequency spectrum.

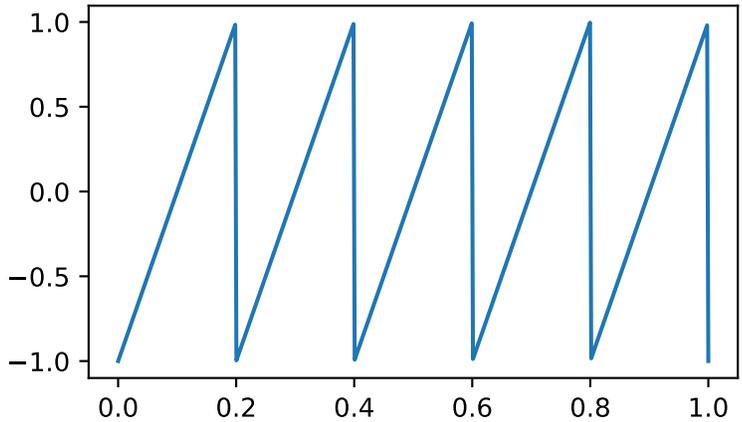
*Parameters*    *t*: array\_like

Time.  
**width** : array\_like, optional  
 Width of the rising ramp as a proportion of the total cycle. Default is 1, producing a rising ramp, while 0 produces a falling ramp. *width* = 0.5 produces a triangle wave. If an array, causes wave shape to change over time, and must be the same length as *t*.  
**Returns** *y* : ndarray  
 Output array containing the sawtooth waveform.

**Examples**

A 5 Hz waveform sampled at 500 Hz for 1 second:

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
>>> t = np.linspace(0, 1, 500)
>>> plt.plot(t, signal.sawtooth(2 * np.pi * 5 * t))
```



`scipy.signal.square(t, duty=0.5)`  
 Return a periodic square-wave waveform.

The square wave has a period  $2\pi$ , has value +1 from 0 to  $2\pi \cdot \text{duty}$  and -1 from  $2\pi \cdot \text{duty}$  to  $2\pi$ . *duty* must be in the interval [0,1].

Note that this is not band-limited. It produces an infinite number of harmonics, which are aliased back and forth across the frequency spectrum.

**Parameters** *t* : array\_like  
 The input time array.  
*duty* : array\_like, optional  
 Duty cycle. Default is 0.5 (50% duty cycle). If an array, causes wave shape to change over time, and must be the same length as *t*.  
**Returns** *y* : ndarray  
 Output array containing the square waveform.

**Examples**

A 5 Hz waveform sampled at 500 Hz for 1 second:

```

>>> from scipy import signal
>>> import matplotlib.pyplot as plt
>>> t = np.linspace(0, 1, 500, endpoint=False)
>>> plt.plot(t, signal.square(2 * np.pi * 5 * t))
>>> plt.ylim(-2, 2)

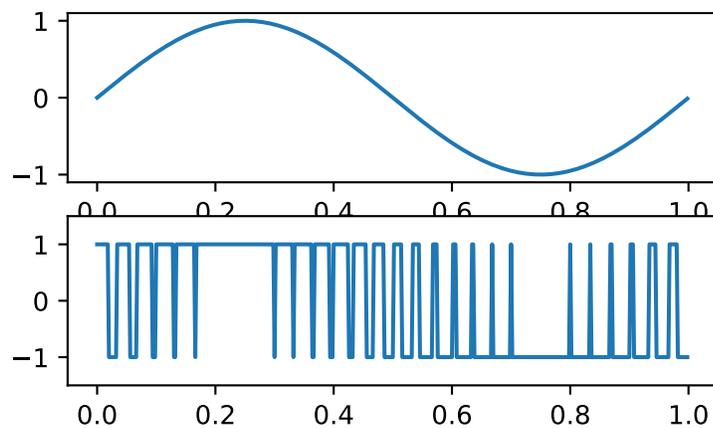
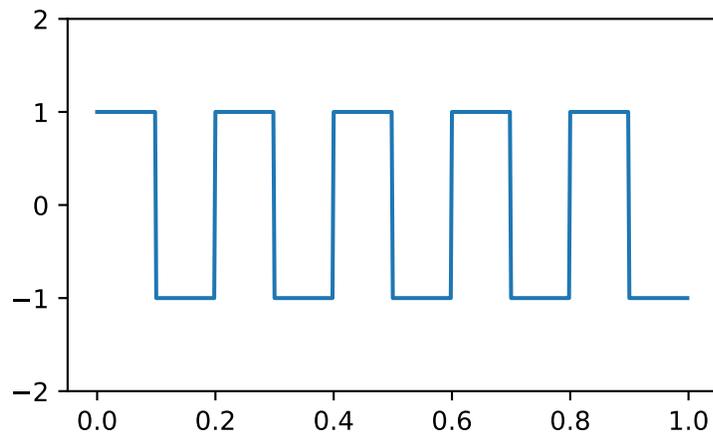
```

A pulse-width modulated sine wave:

```

>>> plt.figure()
>>> sig = np.sin(2 * np.pi * t)
>>> pwm = signal.square(2 * np.pi * 30 * t, duty=(sig + 1)/2)
>>> plt.subplot(2, 1, 1)
>>> plt.plot(t, sig)
>>> plt.subplot(2, 1, 2)
>>> plt.plot(t, pwm)
>>> plt.ylim(-1.5, 1.5)

```



`scipy.signal.sweep_poly(t, poly, phi=0)`

Frequency-swept cosine generator, with a time-dependent frequency.

This function generates a sinusoidal function whose instantaneous frequency varies with time. The frequency at time  $t$  is given by the polynomial  $poly$ .

**Parameters** `t` : ndarray

Times at which to evaluate the waveform.

**poly** : 1-D array\_like or instance of `numpy.poly1d`

The desired frequency expressed as a polynomial. If  $poly$  is a list or ndarray of length  $n$ , then the elements of  $poly$  are the coefficients of the polynomial, and the instantaneous frequency is

$$f(t) = poly[0]*t^{n-1} + poly[1]*t^{n-2} + \dots + poly[n-1]$$

If  $poly$  is an instance of `numpy.poly1d`, then the instantaneous frequency is

$$f(t) = poly(t)$$

**phi** : float, optional

Phase offset, in degrees, Default: 0.

**Returns**

**sweep\_poly** : ndarray

A numpy array containing the signal evaluated at  $t$  with the requested time-varying frequency. More precisely, the function returns  $\cos(\text{phase} + (\pi/180)*\text{phi})$ , where  $phase$  is the integral (from 0 to  $t$ ) of  $2 * \pi * f(t)$ ;  $f(t)$  is defined above.

**See also:**

`chirp`

**Notes**

New in version 0.8.0.

If  $poly$  is a list or ndarray of length  $n$ , then the elements of  $poly$  are the coefficients of the polynomial, and the instantaneous frequency is:

$$f(t) = poly[0]*t^{n-1} + poly[1]*t^{n-2} + \dots + poly[n-1]$$

If  $poly$  is an instance of `numpy.poly1d`, then the instantaneous frequency is:

$$f(t) = poly(t)$$

Finally, the output  $s$  is:

$$\cos(\text{phase} + (\pi/180)*\text{phi})$$

where  $phase$  is the integral from 0 to  $t$  of  $2 * \pi * f(t)$ ,  $f(t)$  as defined above.

**Examples**

Compute the waveform with instantaneous frequency:

```
f(t) = 0.025*t**3 - 0.36*t**2 + 1.25*t + 2
```

over the interval  $0 \leq t \leq 10$ .

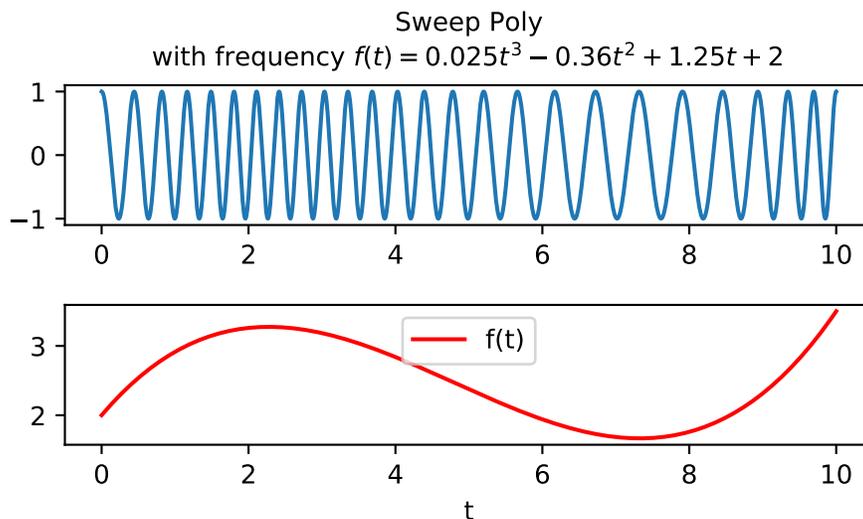
```
>>> from scipy.signal import sweep_poly
>>> p = np.poly1d([0.025, -0.36, 1.25, 2.0])
>>> t = np.linspace(0, 10, 5001)
>>> w = sweep_poly(t, p)
```

Plot it:

```

>>> import matplotlib.pyplot as plt
>>> plt.subplot(2, 1, 1)
>>> plt.plot(t, w)
>>> plt.title("Sweep Poly\nwith frequency " +
...          "$f(t) = 0.025t^3 - 0.36t^2 + 1.25t + 2$")
>>> plt.subplot(2, 1, 2)
>>> plt.plot(t, p(t), 'r', label='f(t)')
>>> plt.legend()
>>> plt.xlabel('t')
>>> plt.tight_layout()
>>> plt.show()

```



`scipy.signal.unit_impulse` (*shape*, *idx=None*, *dtype=<type 'float'>*)

Unit impulse signal (discrete delta function) or unit basis vector.

**Parameters**    **shape** : int or tuple of int

Number of samples in the output (1-D), or a tuple that represents the shape of the output (N-D).

**idx** : None or int or tuple of int or 'mid', optional

Index at which the value is 1. If None, defaults to the 0th element. If `idx='mid'`, the impulse will be centered at `shape // 2` in all dimensions. If an int, the impulse will be at `idx` in all dimensions.

**dtype** : data-type, optional

The desired data-type for the array, e.g., `numpy.int8`. Default is `numpy.float64`.

**Returns**        **y** : ndarray

Output array containing an impulse signal.

### Notes

The 1D case is also known as the Kronecker delta.

New in version 0.19.0.

### Examples

An impulse at the 0th element ( $\delta[n]$ ):

```
>>> from scipy import signal
>>> signal.unit_impulse(8)
array([ 1.,  0.,  0.,  0.,  0.,  0.,  0.,  0.])
```

Impulse offset by 2 samples ( $\delta[n - 2]$ ):

```
>>> signal.unit_impulse(7, 2)
array([ 0.,  0.,  1.,  0.,  0.,  0.,  0.])
```

2-dimensional impulse, centered:

```
>>> signal.unit_impulse((3, 3), 'mid')
array([[ 0.,  0.,  0.],
       [ 0.,  1.,  0.],
       [ 0.,  0.,  0.]])
```

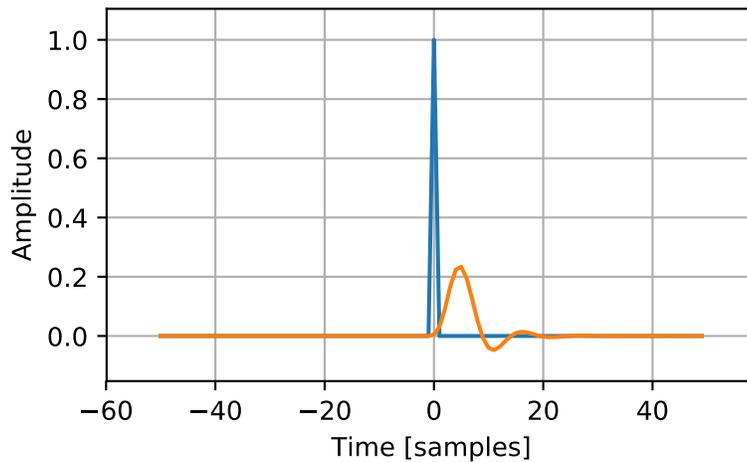
Impulse at (2, 2), using broadcasting:

```
>>> signal.unit_impulse((4, 4), 2)
array([[ 0.,  0.,  0.,  0.],
       [ 0.,  0.,  0.,  0.],
       [ 0.,  0.,  1.,  0.],
       [ 0.,  0.,  0.,  0.]])
```

Plot the impulse response of a 4th-order Butterworth lowpass filter:

```
>>> imp = signal.unit_impulse(100, 'mid')
>>> b, a = signal.butter(4, 0.2)
>>> response = signal.lfilter(b, a, imp)
```

```
>>> import matplotlib.pyplot as plt
>>> plt.plot(np.arange(-50, 50), imp)
>>> plt.plot(np.arange(-50, 50), response)
>>> plt.margins(0.1, 0.1)
>>> plt.xlabel('Time [samples]')
>>> plt.ylabel('Amplitude')
>>> plt.grid(True)
>>> plt.show()
```



### 5.20.10 Window functions

<code>get_window(window, Nx[, fftbins])</code>	Return a window.
<code>barthann(M[, sym])</code>	Return a modified Bartlett-Hann window.
<code>bartlett(M[, sym])</code>	Return a Bartlett window.
<code>blackman(M[, sym])</code>	Return a Blackman window.
<code>blackmanharris(M[, sym])</code>	Return a minimum 4-term Blackman-Harris window.
<code>bohman(M[, sym])</code>	Return a Bohman window.
<code>boxcar(M[, sym])</code>	Return a boxcar or rectangular window.
<code>chebwin(M, at[, sym])</code>	Return a Dolph-Chebyshev window.
<code>cosine(M[, sym])</code>	Return a window with a simple cosine shape.
<code>exponential(M[, center, tau, sym])</code>	Return an exponential (or Poisson) window.
<code>flattop(M[, sym])</code>	Return a flat top window.
<code>gaussian(M, std[, sym])</code>	Return a Gaussian window.
<code>general_gaussian(M, p, sig[, sym])</code>	Return a window with a generalized Gaussian shape.
<code>hamming(M[, sym])</code>	Return a Hamming window.
<code>hann(M[, sym])</code>	Return a Hann window.
<code>hanning(M[, sym])</code>	Return a Hann window.
<code>kaiser(M, beta[, sym])</code>	Return a Kaiser window.
<code>nutall(M[, sym])</code>	Return a minimum 4-term Blackman-Harris window according to Nuttall.
<code>parzen(M[, sym])</code>	Return a Parzen window.
<code>slepian(M, width[, sym])</code>	Return a digital Slepian (DPSS) window.
<code>triang(M[, sym])</code>	Return a triangular window.
<code>tukey(M[, alpha, sym])</code>	Return a Tukey window, also known as a tapered cosine window.

`scipy.signal.get_window(window, Nx, fftbins=True)`

Return a window.

**Parameters** `window` : string, float, or tuple

The type of window to create. See below for more details.

**Nx** : int  
 The number of samples in the window.

**fftbins** : bool, optional  
 If True (default), create a “periodic” window, ready to use with *fftshift* and be multiplied by the result of an FFT (see also *fftpack.fftfreq*). If False, create a “symmetric” window, for use in filter design.

**Returns**     **get\_window** : ndarray  
 Returns a window of length *Nx* and type *window*

### Notes

Window types:

*boxcar*, *triang*, *blackman*, *hamming*, *hann*, *bartlett*, *flattop*, *parzen*, *bohman*, *blackmanharris*, *nutall*, *barthann*, *kaiser* (needs beta), *gaussian* (needs standard deviation), *general\_gaussian* (needs power, width), *slepian* (needs width), *chebwin* (needs attenuation), *exponential* (needs decay scale), *tukey* (needs taper fraction)

If the window requires no parameters, then *window* can be a string.

If the window requires parameters, then *window* must be a tuple with the first argument the string name of the window, and the next arguments the needed parameters.

If *window* is a floating point number, it is interpreted as the beta parameter of the *kaiser* window.

Each of the window types listed above is also the name of a function that can be called directly to create a window of that type.

### Examples

```

>>> from scipy import signal
>>> signal.get_window('triang', 7)
array([ 0.125,  0.375,  0.625,  0.875,  0.875,  0.625,  0.375])
>>> signal.get_window(('kaiser', 4.0), 9)
array([ 0.08848053,  0.29425961,  0.56437221,  0.82160913,  0.97885093,
        0.97885093,  0.82160913,  0.56437221,  0.29425961])
>>> signal.get_window(4.0, 9)
array([ 0.08848053,  0.29425961,  0.56437221,  0.82160913,  0.97885093,
        0.97885093,  0.82160913,  0.56437221,  0.29425961])
    
```

`scipy.signal.barthann` (*M*, *sym=True*)

Return a modified Bartlett-Hann window.

**Parameters**     **M** : int  
 Number of points in the output window. If zero or less, an empty array is returned.

**sym** : bool, optional  
 When True (default), generates a symmetric window, for use in filter design. When False, generates a periodic window, for use in spectral analysis.

**Returns**     **w** : ndarray  
 The window, with the maximum value normalized to 1 (though the value 1 does not appear if *M* is even and *sym* is True).

### Examples

Plot the window and its frequency response:

```

>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
    
```

```

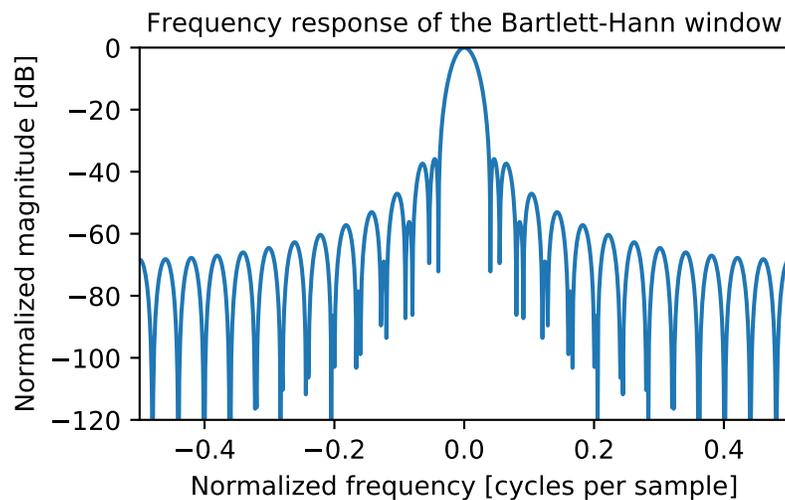
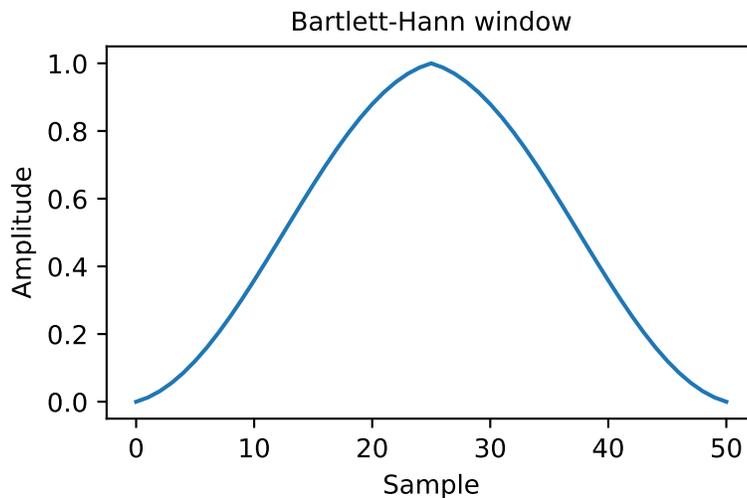
>>> window = signal.bartlett(51)
>>> plt.plot(window)
>>> plt.title("Bartlett-Hann window")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")

```

```

>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title("Frequency response of the Bartlett-Hann window")
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")

```



`scipy.signal.bartlett` ( $M$ ,  $sym=True$ )

Return a Bartlett window.

The Bartlett window is very similar to a triangular window, except that the end points are at zero. It is often used in signal processing for tapering a signal, without generating too much ripple in the frequency domain.

**Parameters**

**M** : int  
Number of points in the output window. If zero or less, an empty array is returned.

**sym** : bool, optional  
When True (default), generates a symmetric window, for use in filter design.  
When False, generates a periodic window, for use in spectral analysis.

**Returns**

**w** : ndarray  
The triangular window, with the first and last samples equal to zero and the maximum value normalized to 1 (though the value 1 does not appear if *M* is even and *sym* is True).

**See also:**

**triang** A triangular window that does not touch zero at the ends

**Notes**

The Bartlett window is defined as

$$w(n) = \frac{2}{M-1} \left( \frac{M-1}{2} - \left| n - \frac{M-1}{2} \right| \right)$$

Most references to the Bartlett window come from the signal processing literature, where it is used as one of many windowing functions for smoothing values. Note that convolution with this window produces linear interpolation. It is also known as an apodization (which means "removing the foot", i.e. smoothing discontinuities at the beginning and end of the sampled signal) or tapering function. The Fourier transform of the Bartlett is the product of two sinc functions. Note the excellent discussion in Kanasewich. [R225]

**References**

[R224], [R225], [R226], [R227], [R228]

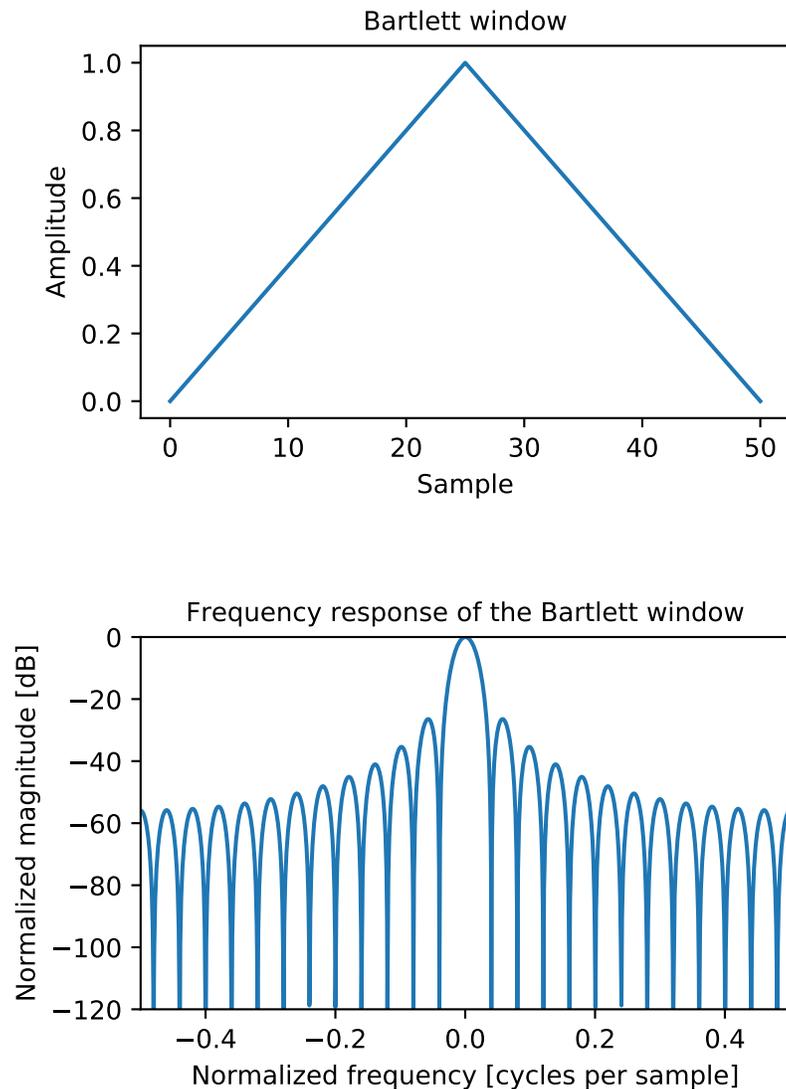
**Examples**

Plot the window and its frequency response:

```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

```
>>> window = signal.bartlett(51)
>>> plt.plot(window)
>>> plt.title("Bartlett window")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```

```
>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title("Frequency response of the Bartlett window")
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
```



`scipy.signal.blackman` ( $M$ ,  $sym=True$ )

Return a Blackman window.

The Blackman window is a taper formed by using the first three terms of a summation of cosines. It was designed to have close to the minimal leakage possible. It is close to optimal, only slightly worse than a Kaiser window.

**Parameters**  $M$  : int

Number of points in the output window. If zero or less, an empty array is returned.

$sym$  : bool, optional

When True (default), generates a symmetric window, for use in filter design. When False, generates a periodic window, for use in spectral analysis.

**Returns**  $w$  : ndarray

The window, with the maximum value normalized to 1 (though the value 1 does not appear if  $M$  is even and  $sym$  is True).

### Notes

The Blackman window is defined as

$$w(n) = 0.42 - 0.5 \cos(2\pi n/M) + 0.08 \cos(4\pi n/M)$$

The “exact Blackman” window was designed to null out the third and fourth sidelobes, but has discontinuities at the boundaries, resulting in a 6 dB/oct fall-off. This window is an approximation of the “exact” window, which does not null the sidelobes as well, but is smooth at the edges, improving the fall-off rate to 18 dB/oct. [R238]

Most references to the Blackman window come from the signal processing literature, where it is used as one of many windowing functions for smoothing values. It is also known as an apodization (which means “removing the foot”, i.e. smoothing discontinuities at the beginning and end of the sampled signal) or tapering function. It is known as a “near optimal” tapering function, almost as good (by some measures) as the Kaiser window.

### References

[R236], [R237], [R238]

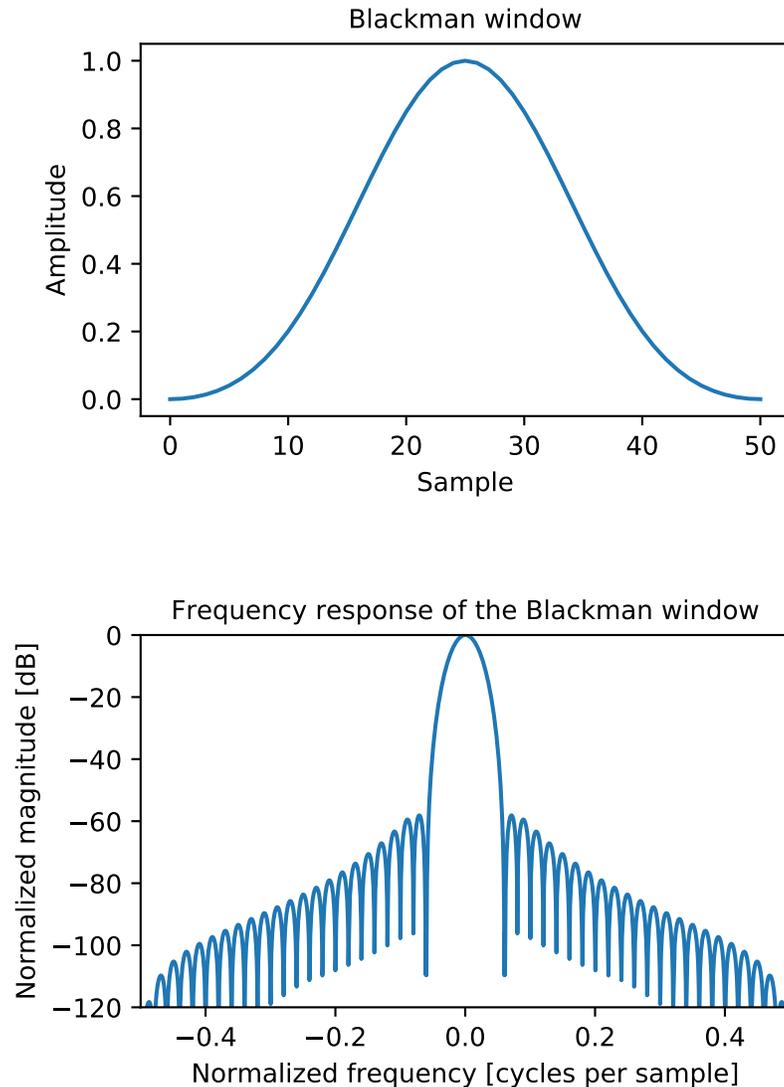
### Examples

Plot the window and its frequency response:

```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

```
>>> window = signal.blackman(51)
>>> plt.plot(window)
>>> plt.title("Blackman window")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```

```
>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title("Frequency response of the Blackman window")
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
```



`scipy.signal.blackmanharris` ( $M$ ,  $sym=True$ )  
 Return a minimum 4-term Blackman-Harris window.

**Parameters**     $M$  : int

Number of points in the output window. If zero or less, an empty array is returned.

$sym$  : bool, optional

When True (default), generates a symmetric window, for use in filter design. When False, generates a periodic window, for use in spectral analysis.

**Returns**         $w$  : ndarray

The window, with the maximum value normalized to 1 (though the value 1 does not appear if  $M$  is even and  $sym$  is True).

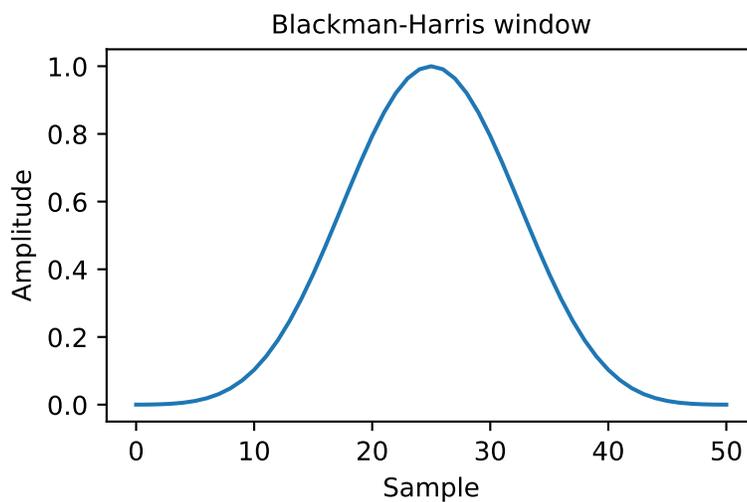
### Examples

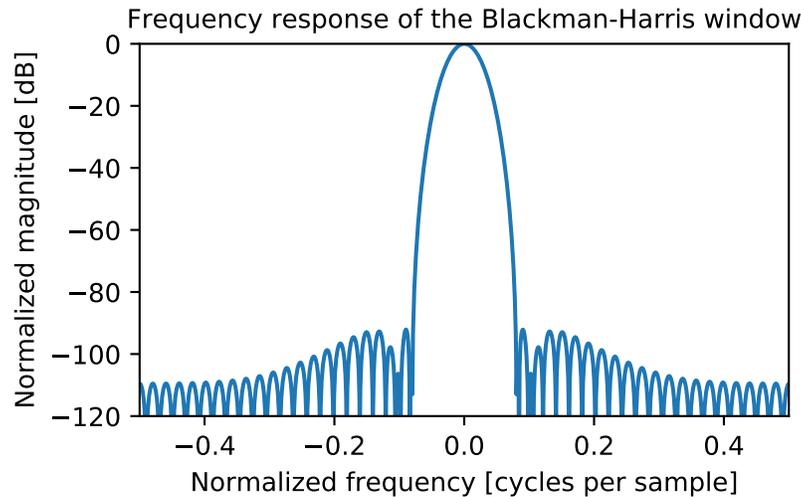
Plot the window and its frequency response:

```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

```
>>> window = signal.blackmanharris(51)
>>> plt.plot(window)
>>> plt.title("Blackman-Harris window")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```

```
>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title("Frequency response of the Blackman-Harris window")
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
```





`scipy.signal.bohman` ( $M$ ,  $sym=True$ )

Return a Bohman window.

**Parameters**  $M$  : int

Number of points in the output window. If zero or less, an empty array is returned.

$sym$  : bool, optional

When True (default), generates a symmetric window, for use in filter design. When False, generates a periodic window, for use in spectral analysis.

**Returns**  $w$  : ndarray

The window, with the maximum value normalized to 1 (though the value 1 does not appear if  $M$  is even and  $sym$  is True).

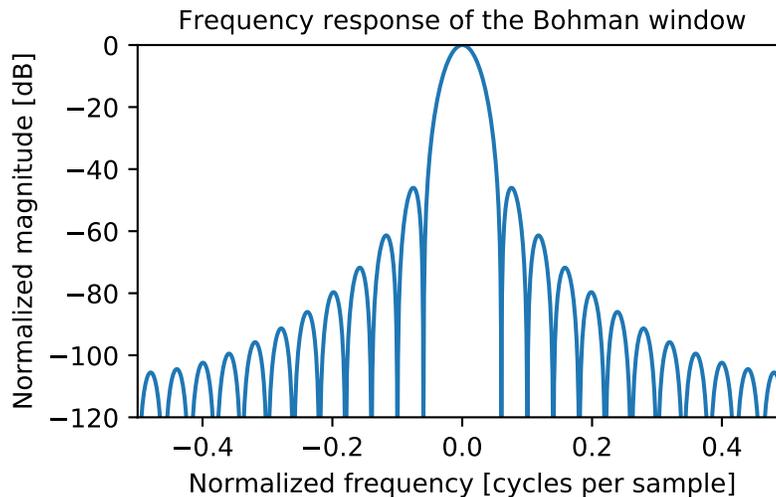
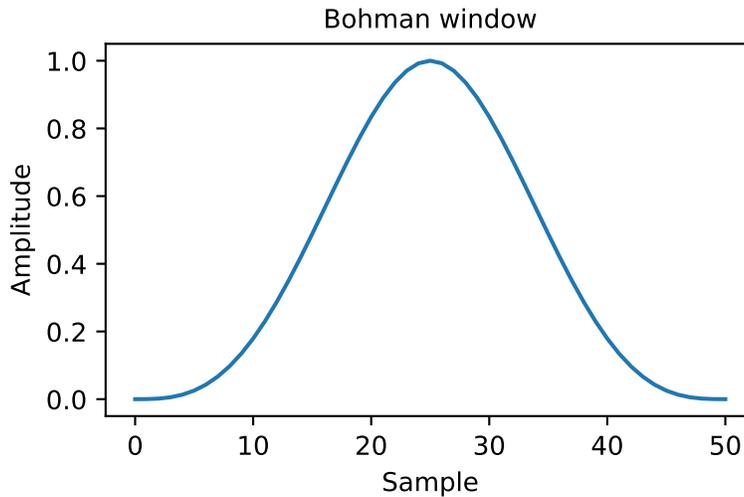
### Examples

Plot the window and its frequency response:

```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

```
>>> window = signal.bohman(51)
>>> plt.plot(window)
>>> plt.title("Bohman window")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```

```
>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title("Frequency response of the Bohman window")
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
```



`scipy.signal.boxcar` ( $M$ ,  $sym=True$ )

Return a boxcar or rectangular window.

Also known as a rectangular window or Dirichlet window, this is equivalent to no window at all.

**Parameters**  $M$  : int

Number of points in the output window. If zero or less, an empty array is returned.

$sym$  : bool, optional

Whether the window is symmetric. (Has no effect for boxcar.)

**Returns**  $w$  : ndarray

The window, with the maximum value normalized to 1.

### Examples

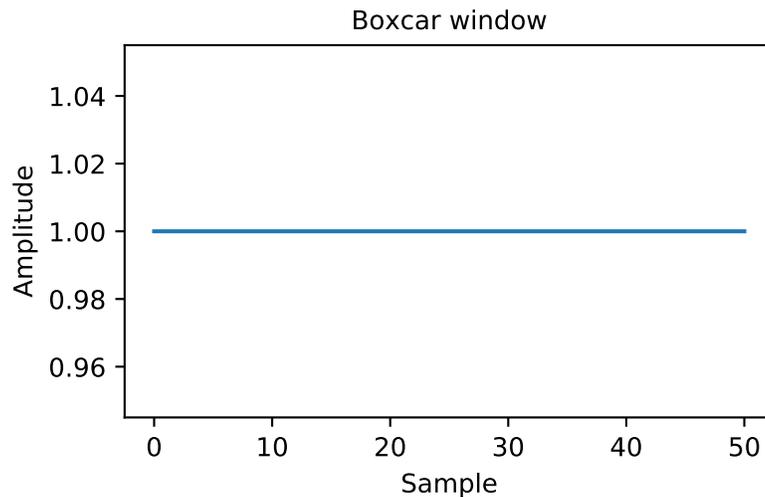
Plot the window and its frequency response:

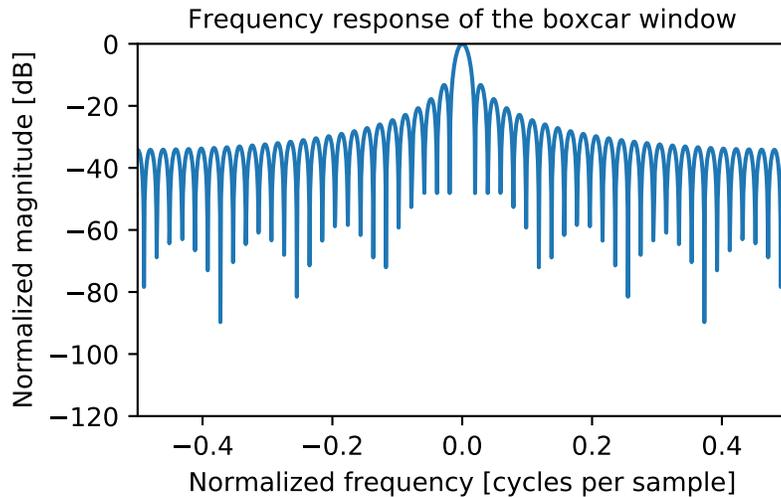
```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
```

```
>>> import matplotlib.pyplot as plt
```

```
>>> window = signal.boxcar(51)
>>> plt.plot(window)
>>> plt.title("Boxcar window")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```

```
>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title("Frequency response of the boxcar window")
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
```





`scipy.signal.chebwin` ( $M$ ,  $at$ ,  $sym=True$ )

Return a Dolph-Chebyshev window.

**Parameters**  $M$  : int

Number of points in the output window. If zero or less, an empty array is returned.

$at$  : float

Attenuation (in dB).

$sym$  : bool, optional

When True (default), generates a symmetric window, for use in filter design. When False, generates a periodic window, for use in spectral analysis.

**Returns**  $w$  : ndarray

The window, with the maximum value always normalized to 1

### Notes

This window optimizes for the narrowest main lobe width for a given order  $M$  and sidelobe equiripple attenuation  $at$ , using Chebyshev polynomials. It was originally developed by Dolph to optimize the directionality of radio antenna arrays.

Unlike most windows, the Dolph-Chebyshev is defined in terms of its frequency response:

$$W(k) = \frac{\cos\{M \cos^{-1}[\beta \cos(\frac{\pi k}{M})]\}}{\cosh[M \cosh^{-1}(\beta)]}$$

where

$$\beta = \cosh \left[ \frac{1}{M} \cosh^{-1}(10^{\frac{A}{20}}) \right]$$

and  $0 \leq \text{abs}(k) \leq M-1$ .  $A$  is the attenuation in decibels ( $at$ ).

The time domain window is then generated using the IFFT, so power-of-two  $M$  are the fastest to generate, and prime number  $M$  are the slowest.

The equiripple condition in the frequency domain creates impulses in the time domain, which appear at the ends of the window.

### References

[R239], [R240], [R241]

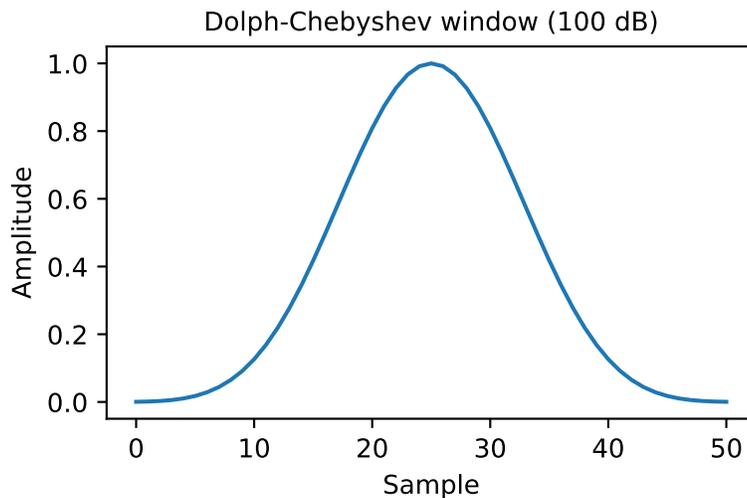
### Examples

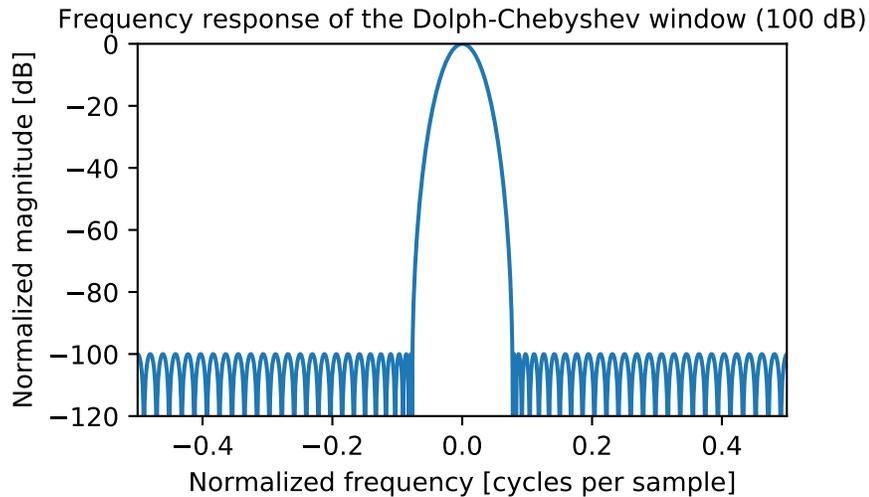
Plot the window and its frequency response:

```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

```
>>> window = signal.chebwin(51, at=100)
>>> plt.plot(window)
>>> plt.title("Dolph-Chebyshev window (100 dB)")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```

```
>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title("Frequency response of the Dolph-Chebyshev window (100 dB)")
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
```





`scipy.signal.cosine` ( $M$ ,  $sym=True$ )

Return a window with a simple cosine shape.

**Parameters**  $M$  : int

Number of points in the output window. If zero or less, an empty array is returned.

$sym$  : bool, optional

When True (default), generates a symmetric window, for use in filter design. When False, generates a periodic window, for use in spectral analysis.

**Returns**  $w$  : ndarray

The window, with the maximum value normalized to 1 (though the value 1 does not appear if  $M$  is even and  $sym$  is True).

### Notes

New in version 0.13.0.

### Examples

Plot the window and its frequency response:

```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

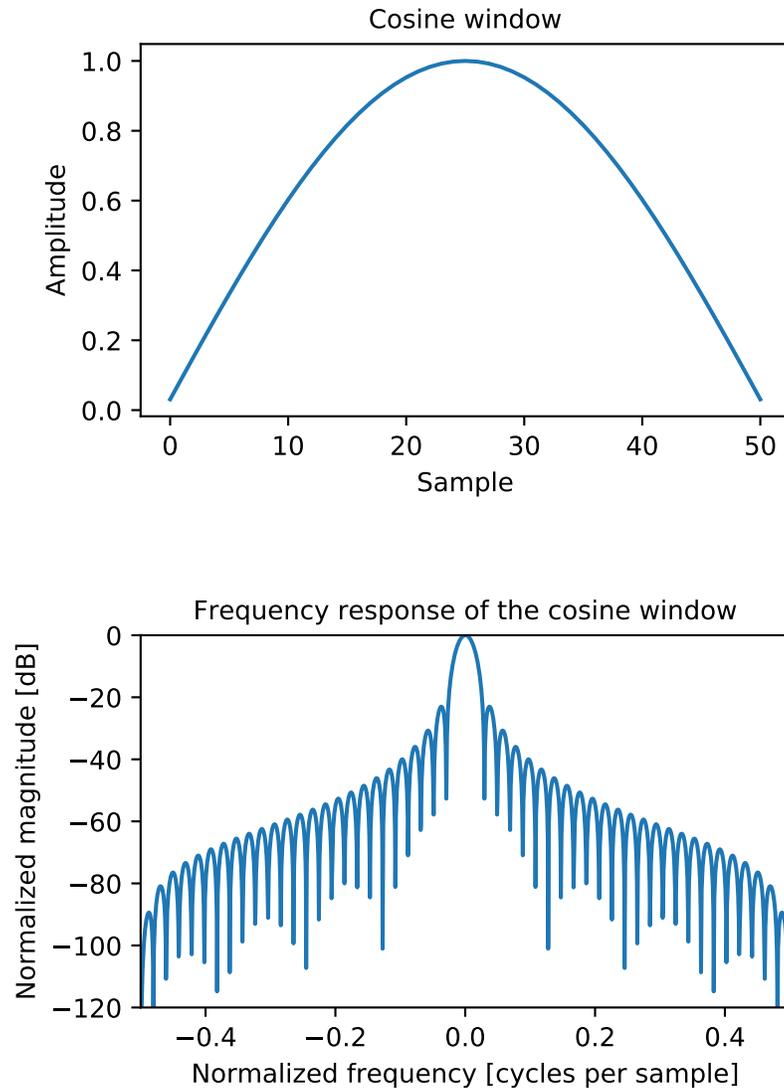
```
>>> window = signal.cosine(51)
>>> plt.plot(window)
>>> plt.title("Cosine window")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```

```
>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title("Frequency response of the cosine window")
```

```

>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
>>> plt.show()

```



`scipy.signal.exponential` ( $M$ , *center=None*, *tau=1.0*, *sym=True*)

Return an exponential (or Poisson) window.

**Parameters**  $M$ : int

Number of points in the output window. If zero or less, an empty array is returned.

**center**: float, optional

Parameter defining the center location of the window function. The default value if not given is  $center = (M-1) / 2$ . This parameter must take its default value for symmetric windows.

**tau**: float, optional

Parameter defining the decay. For  $center = 0$  use  $tau = -(M-1) / \ln(x)$  if  $x$  is the fraction of the window remaining at the end.

**sym** : bool, optional  
 When True (default), generates a symmetric window, for use in filter design.  
 When False, generates a periodic window, for use in spectral analysis.

**Returns** **w** : ndarray  
 The window, with the maximum value normalized to 1 (though the value 1 does not appear if  $M$  is even and *sym* is True).

**Notes**

The Exponential window is defined as

$$w(n) = e^{-|n-center|/\tau}$$

**References**

S. Gade and H. Herlufsen, “Windows to FFT analysis (Part I)”, Technical Review 3, Bruel & Kjaer, 1987.

**Examples**

Plot the symmetric window and its frequency response:

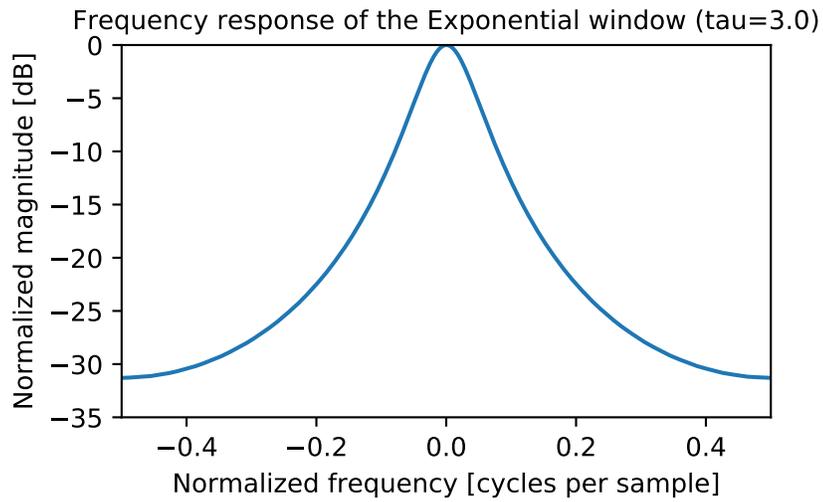
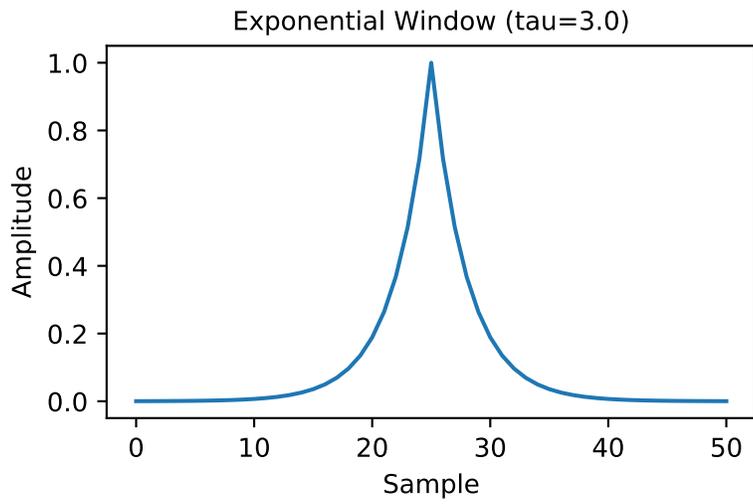
```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

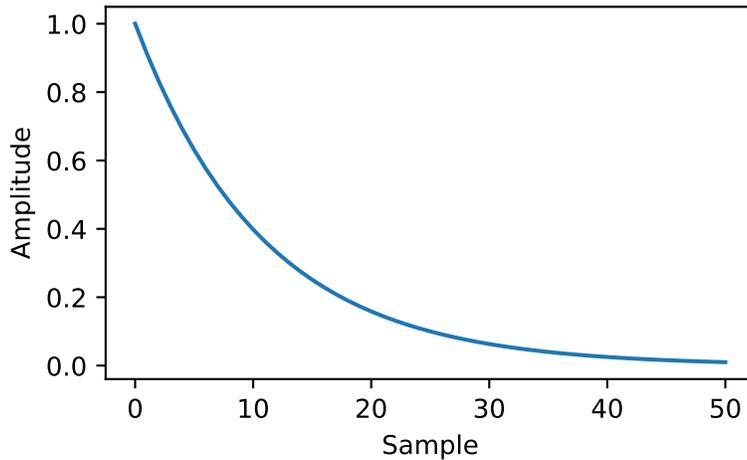
```
>>> M = 51
>>> tau = 3.0
>>> window = signal.exponential(M, tau=tau)
>>> plt.plot(window)
>>> plt.title("Exponential Window (tau=3.0)")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```

```
>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -35, 0])
>>> plt.title("Frequency response of the Exponential window (tau=3.0)")
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
```

This function can also generate non-symmetric windows:

```
>>> tau2 = -(M-1) / np.log(0.01)
>>> window2 = signal.exponential(M, 0, tau2, False)
>>> plt.figure()
>>> plt.plot(window2)
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```





`scipy.signal.flattop` ( $M$ ,  $sym=True$ )

Return a flat top window.

**Parameters**  $M$  : int

Number of points in the output window. If zero or less, an empty array is returned.

$sym$  : bool, optional

When True (default), generates a symmetric window, for use in filter design. When False, generates a periodic window, for use in spectral analysis.

**Returns**  $w$  : ndarray

The window, with the maximum value normalized to 1 (though the value 1 does not appear if  $M$  is even and  $sym$  is True).

### Notes

Flat top windows are used for taking accurate measurements of signal amplitude in the frequency domain, with minimal scalloping error from the center of a frequency bin to its edges, compared to others. This is a 5th-order cosine window, with the 5 terms optimized to make the main lobe maximally flat. [R257]

### References

[R257]

### Examples

Plot the window and its frequency response:

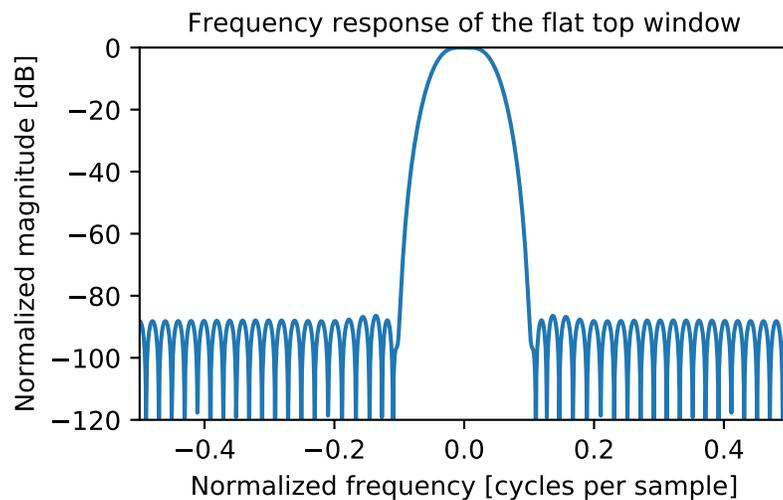
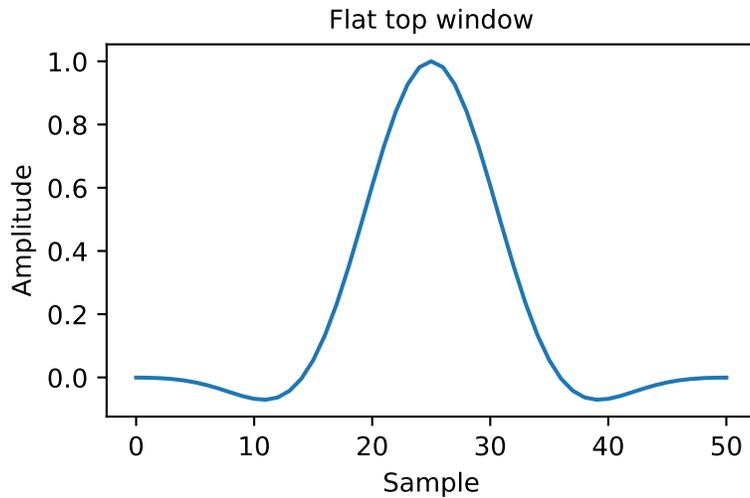
```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

```
>>> window = signal.flattop(51)
>>> plt.plot(window)
>>> plt.title("Flat top window")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```

```

>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title("Frequency response of the flat top window")
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")

```



`scipy.signal.gaussian` ( $M$ ,  $std$ ,  $sym=True$ )

Return a Gaussian window.

**Parameters**  $M$ : int

Number of points in the output window. If zero or less, an empty array is returned.

$std$ : float

The standard deviation, sigma.

**sym** : bool, optional  
 When True (default), generates a symmetric window, for use in filter design.  
 When False, generates a periodic window, for use in spectral analysis.

**Returns** **w** : ndarray  
 The window, with the maximum value normalized to 1 (though the value 1 does not appear if  $M$  is even and *sym* is True).

**Notes**

The Gaussian window is defined as

$$w(n) = e^{-\frac{1}{2}\left(\frac{n}{\sigma}\right)^2}$$

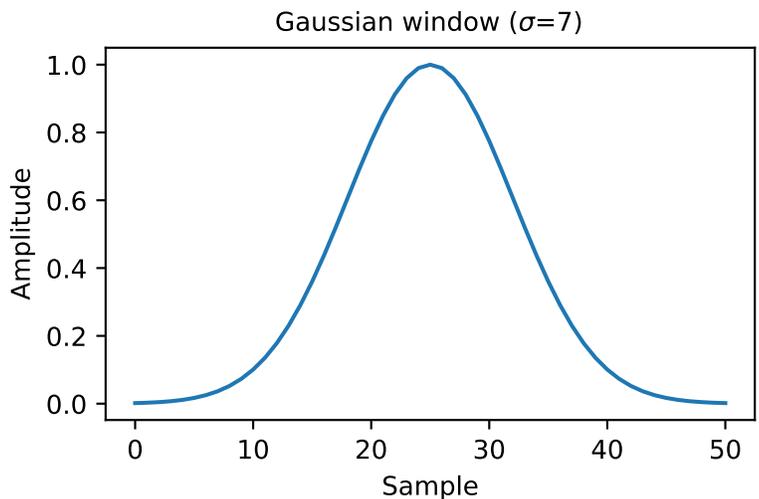
**Examples**

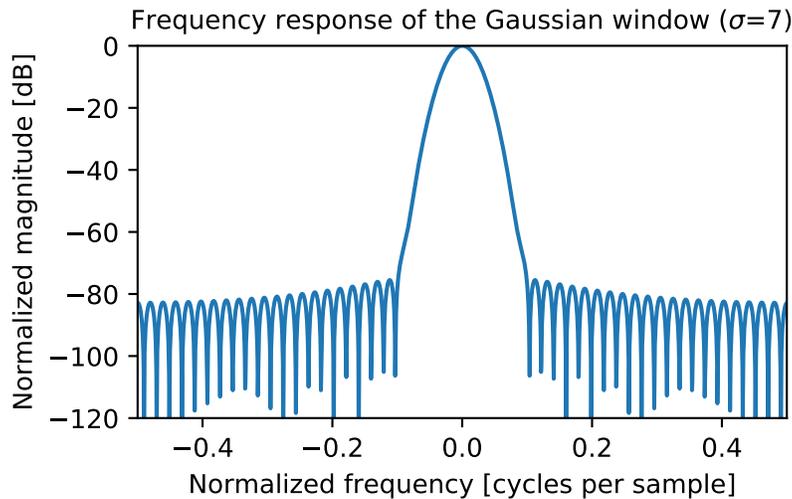
Plot the window and its frequency response:

```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

```
>>> window = signal.gaussian(51, std=7)
>>> plt.plot(window)
>>> plt.title(r"Gaussian window ( $\sigma=7$ )")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```

```
>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title(r"Frequency response of the Gaussian window ( $\sigma=7$ )")
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
```





`scipy.signal.general_gaussian` ( $M, p, sig, sym=True$ )

Return a window with a generalized Gaussian shape.

**Parameters**  $M$  : int

Number of points in the output window. If zero or less, an empty array is returned.

$p$  : float

Shape parameter.  $p = 1$  is identical to *gaussian*,  $p = 0.5$  is the same shape as the Laplace distribution.

$sig$  : float

The standard deviation, sigma.

$sym$  : bool, optional

When True (default), generates a symmetric window, for use in filter design. When False, generates a periodic window, for use in spectral analysis.

**Returns**  $w$  : ndarray

The window, with the maximum value normalized to 1 (though the value 1 does not appear if  $M$  is even and  $sym$  is True).

### Notes

The generalized Gaussian window is defined as

$$w(n) = e^{-\frac{1}{2} \left| \frac{n}{\sigma} \right|^{2p}}$$

the half-power point is at

$$(2 \log(2))^{1/(2p)} \sigma$$

### Examples

Plot the window and its frequency response:

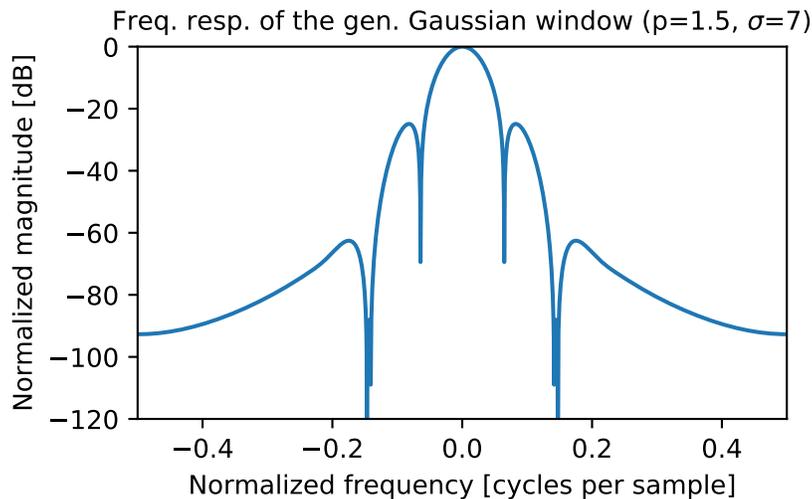
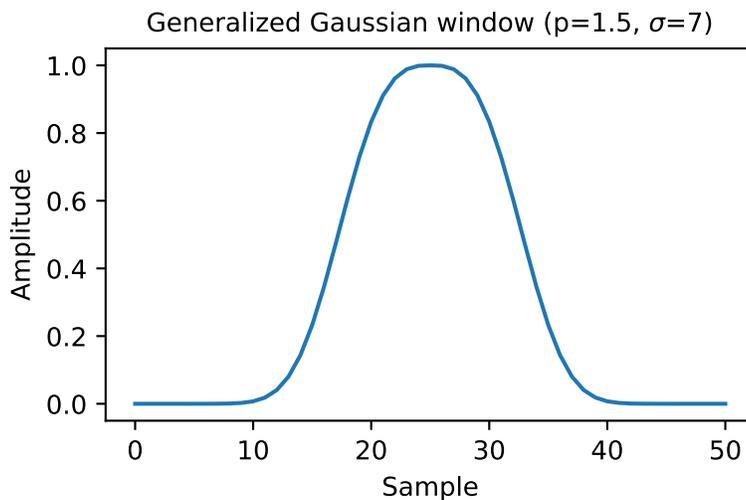
```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

```

>>> window = signal.general_gaussian(51, p=1.5, sig=7)
>>> plt.plot(window)
>>> plt.title(r"Generalized Gaussian window (p=1.5, $\sigma$=7)")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
    
```

```

>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max()))))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title(r"Freq. resp. of the gen. Gaussian "
...         r"window (p=1.5, $\sigma$=7)")
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
    
```



`scipy.signal.hamming` ( $M$ ,  $sym=True$ )

Return a Hamming window.

The Hamming window is a taper formed by using a raised cosine with non-zero endpoints, optimized to minimize the nearest side lobe.

**Parameters**

- M** : int  
Number of points in the output window. If zero or less, an empty array is returned.
- sym** : bool, optional  
When True (default), generates a symmetric window, for use in filter design.  
When False, generates a periodic window, for use in spectral analysis.

**Returns**

- w** : ndarray  
The window, with the maximum value normalized to 1 (though the value 1 does not appear if  $M$  is even and  $sym$  is True).

### Notes

The Hamming window is defined as

$$w(n) = 0.54 - 0.46 \cos\left(\frac{2\pi n}{M-1}\right) \quad 0 \leq n \leq M-1$$

The Hamming was named for R. W. Hamming, an associate of J. W. Tukey and is described in Blackman and Tukey. It was recommended for smoothing the truncated autocovariance function in the time domain. Most references to the Hamming window come from the signal processing literature, where it is used as one of many windowing functions for smoothing values. It is also known as an apodization (which means “removing the foot”, i.e. smoothing discontinuities at the beginning and end of the sampled signal) or tapering function.

### References

[R259], [R260], [R261], [R262]

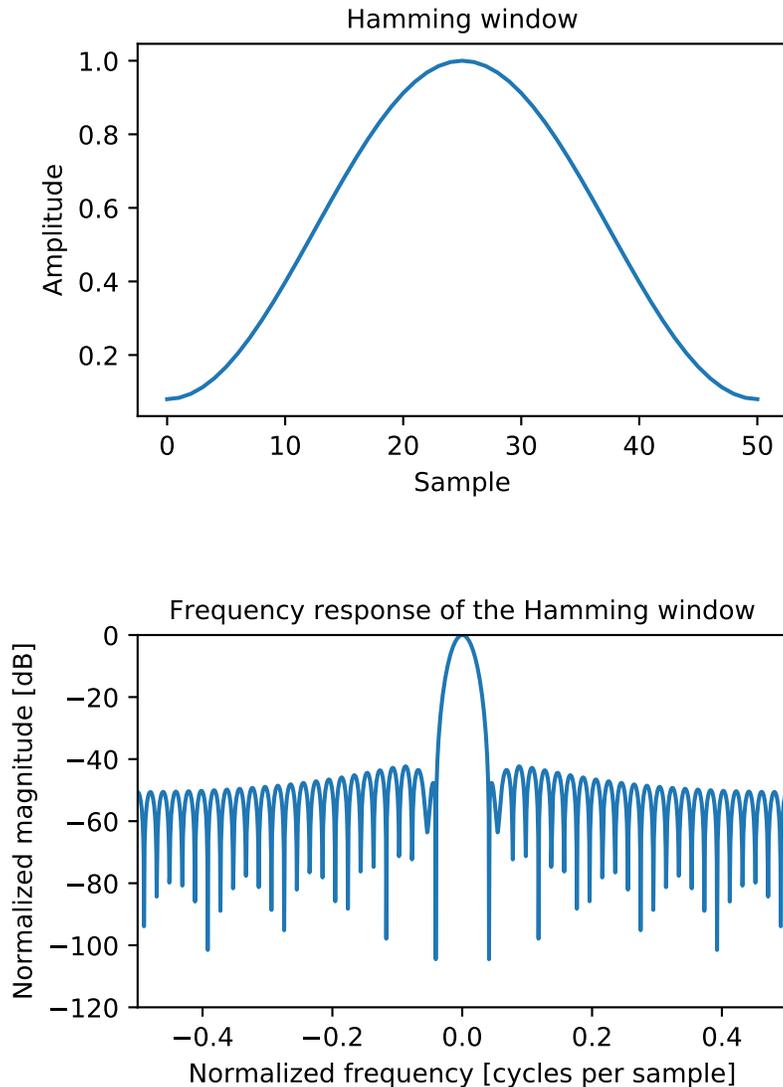
### Examples

Plot the window and its frequency response:

```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

```
>>> window = signal.hamming(51)
>>> plt.plot(window)
>>> plt.title("Hamming window")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```

```
>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title("Frequency response of the Hamming window")
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
```



`scipy.signal.hann` ( $M$ ,  $sym=True$ )

Return a Hann window.

The Hann window is a taper formed by using a raised cosine or sine-squared with ends that touch zero.

**Parameters**  $M$  : int

Number of points in the output window. If zero or less, an empty array is returned.

$sym$  : bool, optional

When True (default), generates a symmetric window, for use in filter design. When False, generates a periodic window, for use in spectral analysis.

**Returns**  $w$  : ndarray

The window, with the maximum value normalized to 1 (though the value 1 does not appear if  $M$  is even and  $sym$  is True).

**Notes**

The Hann window is defined as

$$w(n) = 0.5 - 0.5 \cos\left(\frac{2\pi n}{M-1}\right) \quad 0 \leq n \leq M-1$$

The window was named for Julius von Hann, an Austrian meteorologist. It is also known as the Cosine Bell. It is sometimes erroneously referred to as the “Hanning” window, from the use of “hann” as a verb in the original paper and confusion with the very similar Hamming window.

Most references to the Hann window come from the signal processing literature, where it is used as one of many windowing functions for smoothing values. It is also known as an apodization (which means “removing the foot”, i.e. smoothing discontinuities at the beginning and end of the sampled signal) or tapering function.

**References**

[R263], [R264], [R265], [R266]

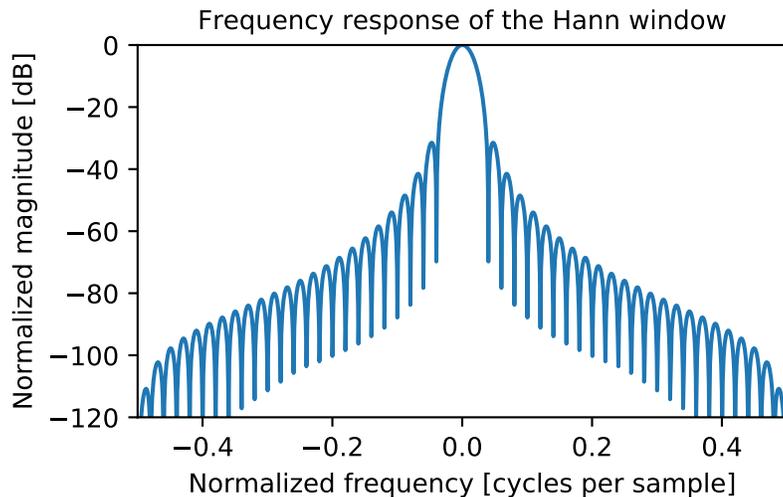
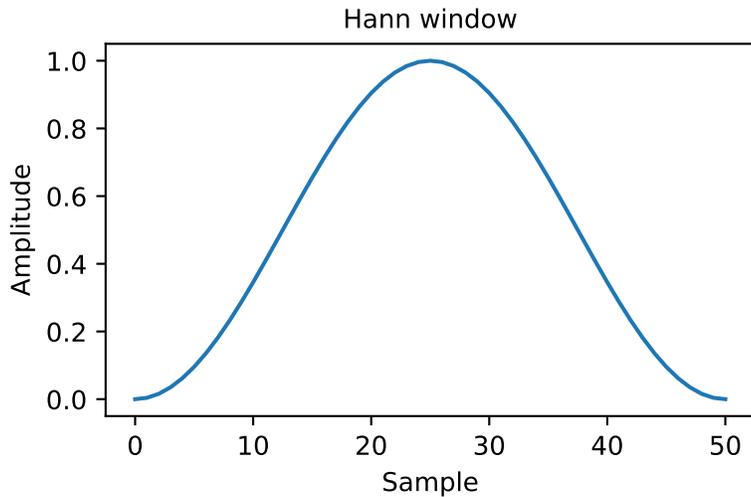
**Examples**

Plot the window and its frequency response:

```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

```
>>> window = signal.hann(51)
>>> plt.plot(window)
>>> plt.title("Hann window")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```

```
>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title("Frequency response of the Hann window")
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
```



`scipy.signal.hanning` ( $M$ ,  $sym=True$ )

Return a Hann window.

The Hann window is a taper formed by using a raised cosine or sine-squared with ends that touch zero.

**Parameters**  $M$  : int

Number of points in the output window. If zero or less, an empty array is returned.

$sym$  : bool, optional

When True (default), generates a symmetric window, for use in filter design. When False, generates a periodic window, for use in spectral analysis.

**Returns**  $w$  : ndarray

The window, with the maximum value normalized to 1 (though the value 1 does not appear if  $M$  is even and  $sym$  is True).

**Notes**

The Hann window is defined as

$$w(n) = 0.5 - 0.5 \cos\left(\frac{2\pi n}{M-1}\right) \quad 0 \leq n \leq M-1$$

The window was named for Julius von Hann, an Austrian meteorologist. It is also known as the Cosine Bell. It is sometimes erroneously referred to as the “Hanning” window, from the use of “hann” as a verb in the original paper and confusion with the very similar Hamming window.

Most references to the Hann window come from the signal processing literature, where it is used as one of many windowing functions for smoothing values. It is also known as an apodization (which means “removing the foot”, i.e. smoothing discontinuities at the beginning and end of the sampled signal) or tapering function.

**References**

[R267], [R268], [R269], [R270]

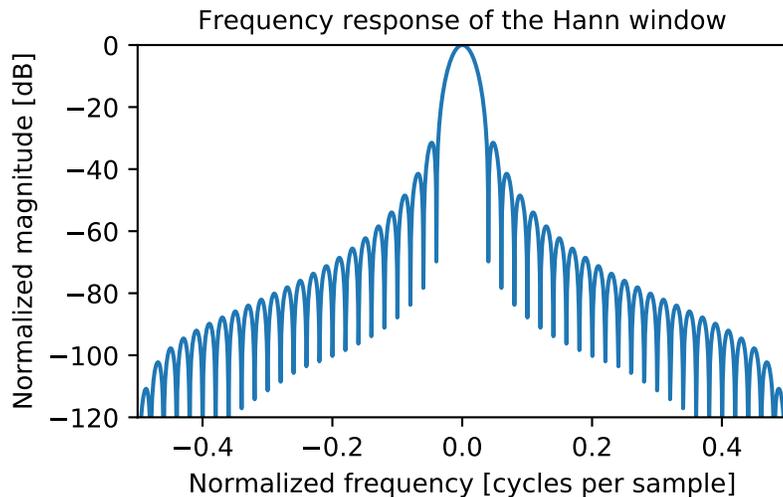
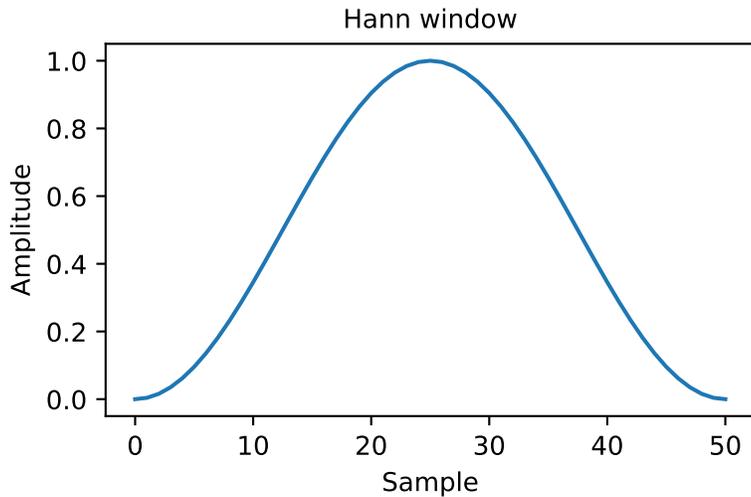
**Examples**

Plot the window and its frequency response:

```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

```
>>> window = signal.hann(51)
>>> plt.plot(window)
>>> plt.title("Hann window")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```

```
>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title("Frequency response of the Hann window")
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
```



`scipy.signal.kaiser` ( $M$ ,  $\beta$ ,  $\text{sym}=\text{True}$ )

Return a Kaiser window.

The Kaiser window is a taper formed by using a Bessel function.

**Parameters**  $M$  : int

Number of points in the output window. If zero or less, an empty array is returned.

$\beta$  : float

Shape parameter, determines trade-off between main-lobe width and side lobe level. As  $\beta$  gets large, the window narrows.

$\text{sym}$  : bool, optional

When True (default), generates a symmetric window, for use in filter design. When False, generates a periodic window, for use in spectral analysis.

**Returns**  $w$  : ndarray

The window, with the maximum value normalized to 1 (though the value 1 does not appear if  $M$  is even and  $\text{sym}$  is True).

**Notes**

The Kaiser window is defined as

$$w(n) = I_0 \left( \beta \sqrt{1 - \frac{4n^2}{(M-1)^2}} \right) / I_0(\beta)$$

with

$$-\frac{M-1}{2} \leq n \leq \frac{M-1}{2},$$

where  $I_0$  is the modified zeroth-order Bessel function.

The Kaiser was named for Jim Kaiser, who discovered a simple approximation to the DPSS window based on Bessel functions. The Kaiser window is a very good approximation to the Digital Prolate Spheroidal Sequence, or Slepian window, which is the transform which maximizes the energy in the main lobe of the window relative to total energy.

The Kaiser can approximate other windows by varying the beta parameter. (Some literature uses alpha = beta/pi.) [R282]

beta	Window shape
0	Rectangular
5	Similar to a Hamming
6	Similar to a Hann
8.6	Similar to a Blackman

A beta value of 14 is probably a good starting point. Note that as beta gets large, the window narrows, and so the number of samples needs to be large enough to sample the increasingly narrow spike, otherwise NaNs will be returned.

Most references to the Kaiser window come from the signal processing literature, where it is used as one of many windowing functions for smoothing values. It is also known as an apodization (which means “removing the foot”, i.e. smoothing discontinuities at the beginning and end of the sampled signal) or tapering function.

**References**

[R279], [R280], [R281], [R282]

**Examples**

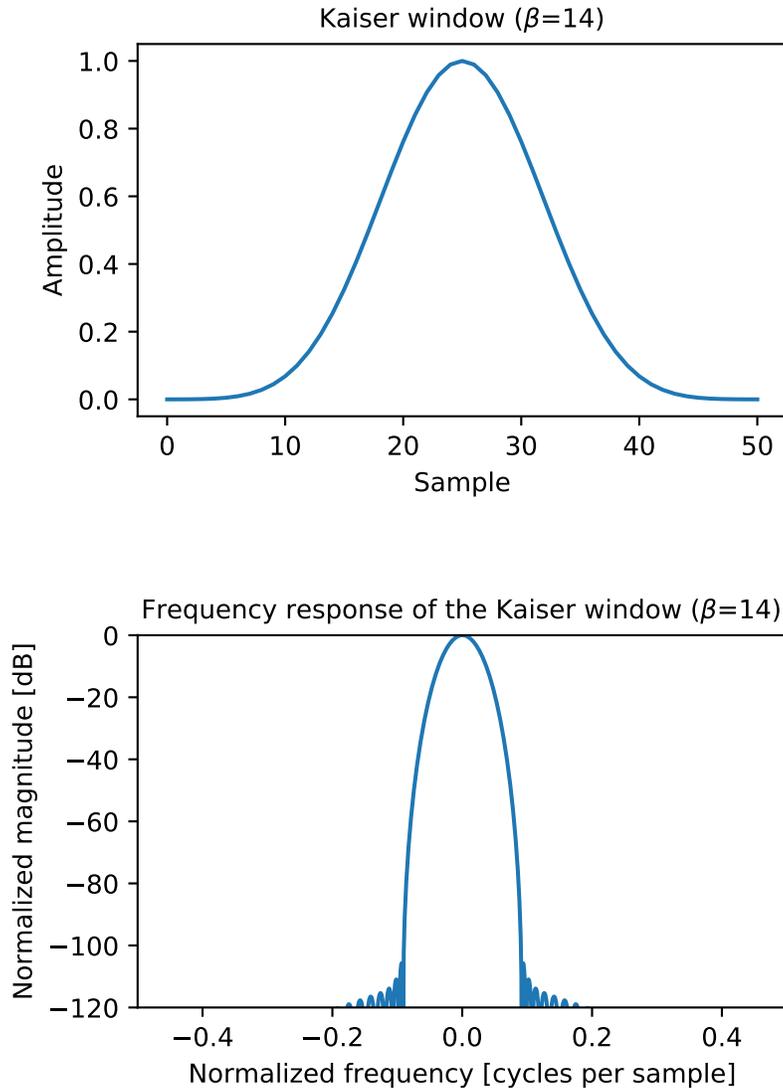
Plot the window and its frequency response:

```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

```
>>> window = signal.kaiser(51, beta=14)
>>> plt.plot(window)
>>> plt.title(r"Kaiser window (\beta=14)")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```

```
>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
```

```
>>> plt.title(r"Frequency response of the Kaiser window ( $\beta=14$ )")
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
```



`scipy.signal.nuttall` ( $M$ ,  $sym=True$ )

Return a minimum 4-term Blackman-Harris window according to Nuttall.

This variation is called “Nuttall4c” by Heinzel. [R292]

**Parameters**  $M$  : int

Number of points in the output window. If zero or less, an empty array is returned.

$sym$  : bool, optional

When True (default), generates a symmetric window, for use in filter design.

When False, generates a periodic window, for use in spectral analysis.

**Returns**  $w$  : ndarray

The window, with the maximum value normalized to 1 (though the value 1 does not appear if  $M$  is even and  $sym$  is True).

## References

[R291], [R292]

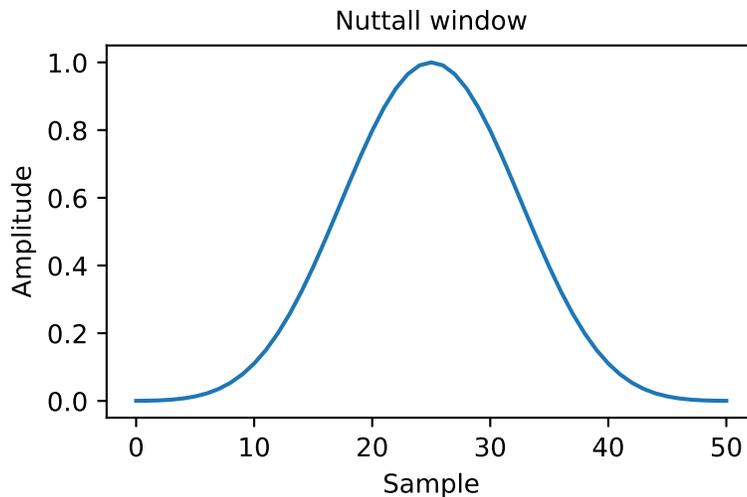
## Examples

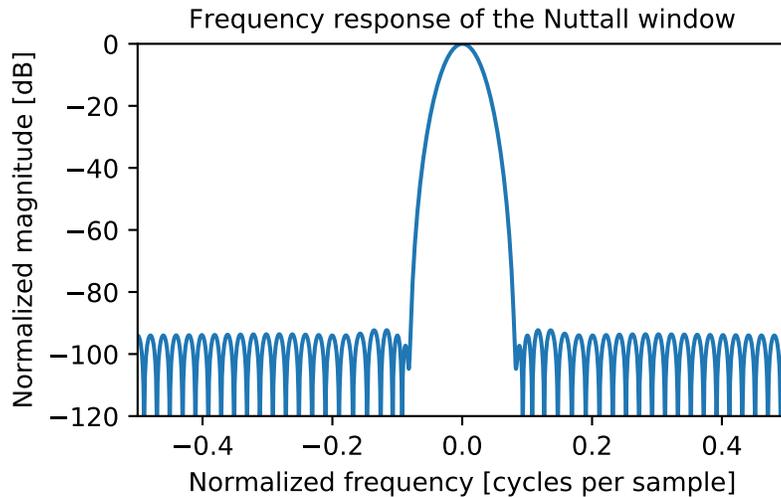
Plot the window and its frequency response:

```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

```
>>> window = signal.nuttall(51)
>>> plt.plot(window)
>>> plt.title("Nuttall window")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```

```
>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title("Frequency response of the Nuttall window")
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
```





`scipy.signal.parzen` ( $M$ ,  $sym=True$ )

Return a Parzen window.

**Parameters**  $M$  : int

Number of points in the output window. If zero or less, an empty array is returned.

$sym$  : bool, optional

When True (default), generates a symmetric window, for use in filter design. When False, generates a periodic window, for use in spectral analysis.

**Returns**  $w$  : ndarray

The window, with the maximum value normalized to 1 (though the value 1 does not appear if  $M$  is even and  $sym$  is True).

### References

[R293]

### Examples

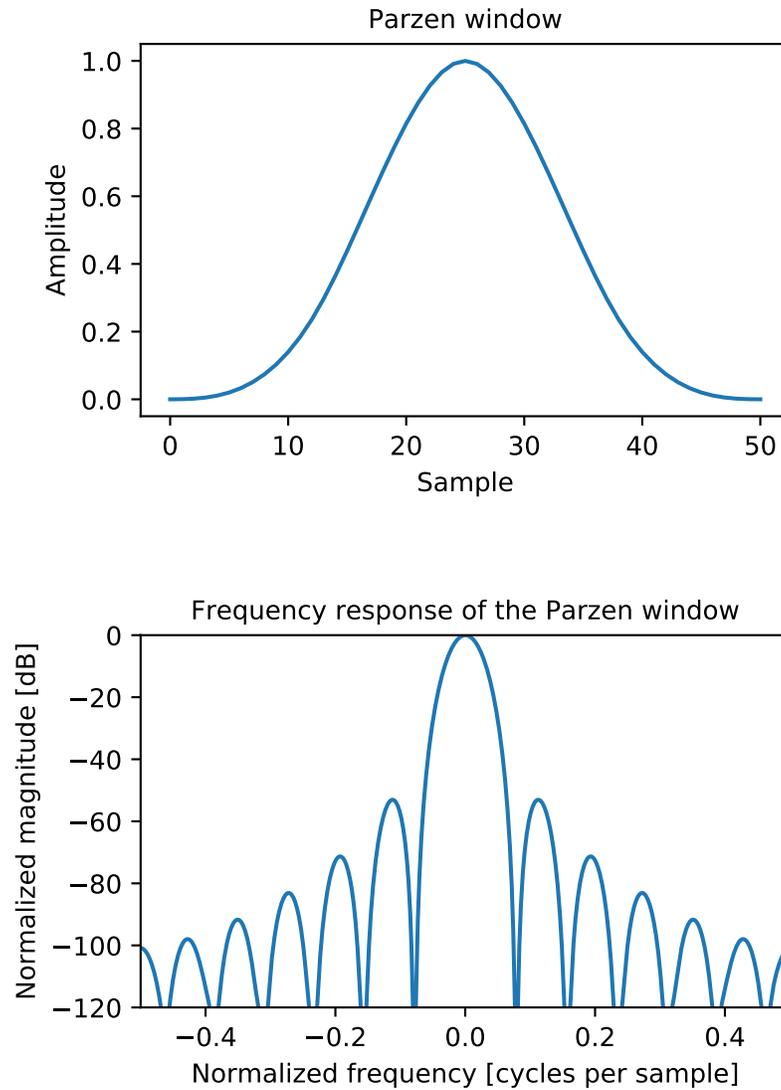
Plot the window and its frequency response:

```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

```
>>> window = signal.parzen(51)
>>> plt.plot(window)
>>> plt.title("Parzen window")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```

```
>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title("Frequency response of the Parzen window")
```

```
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
```



`scipy.signal.slepian` ( $M$ ,  $width$ ,  $sym=True$ )

Return a digital Slepian (DPSS) window.

Used to maximize the energy concentration in the main lobe. Also called the digital prolate spheroidal sequence (DPSS).

**Parameters**    **M** : int

Number of points in the output window. If zero or less, an empty array is returned.

**width** : float

Bandwidth

**sym** : bool, optional

When True (default), generates a symmetric window, for use in filter design.

When False, generates a periodic window, for use in spectral analysis.

**Returns**        **w** : ndarray

The window, with the maximum value always normalized to 1

### References

[R298], [R299]

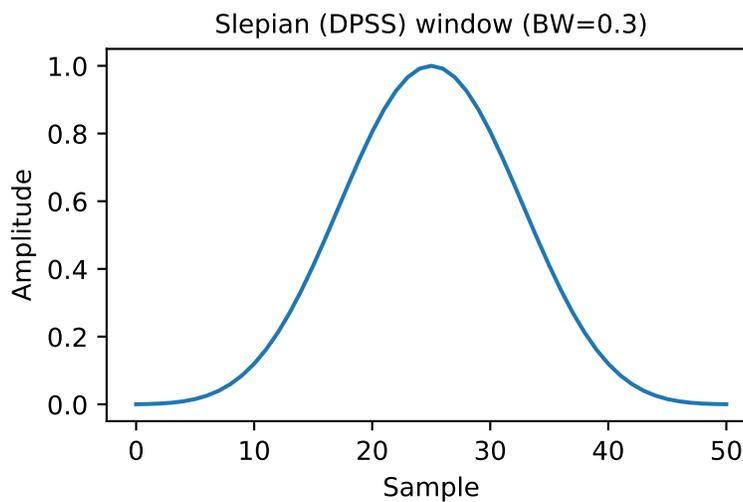
### Examples

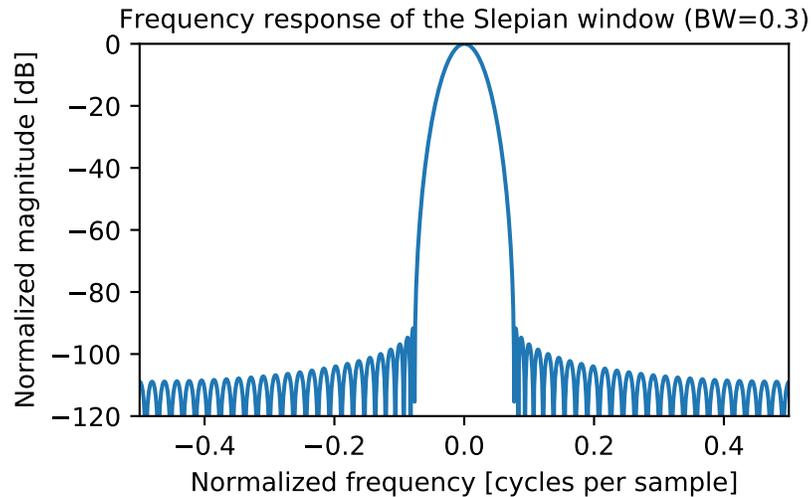
Plot the window and its frequency response:

```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

```
>>> window = signal.slepian(51, width=0.3)
>>> plt.plot(window)
>>> plt.title("Slepian (DPSS) window (BW=0.3)")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```

```
>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title("Frequency response of the Slepian window (BW=0.3)")
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
```





`scipy.signal.triang` ( $M$ ,  $sym=True$ )

Return a triangular window.

**Parameters**  $M$  : int

Number of points in the output window. If zero or less, an empty array is returned.

$sym$  : bool, optional

When True (default), generates a symmetric window, for use in filter design. When False, generates a periodic window, for use in spectral analysis.

**Returns**  $w$  : ndarray

The window, with the maximum value normalized to 1 (though the value 1 does not appear if  $M$  is even and  $sym$  is True).

**See also:**

**bartlett** A triangular window that touches zero

**Examples**

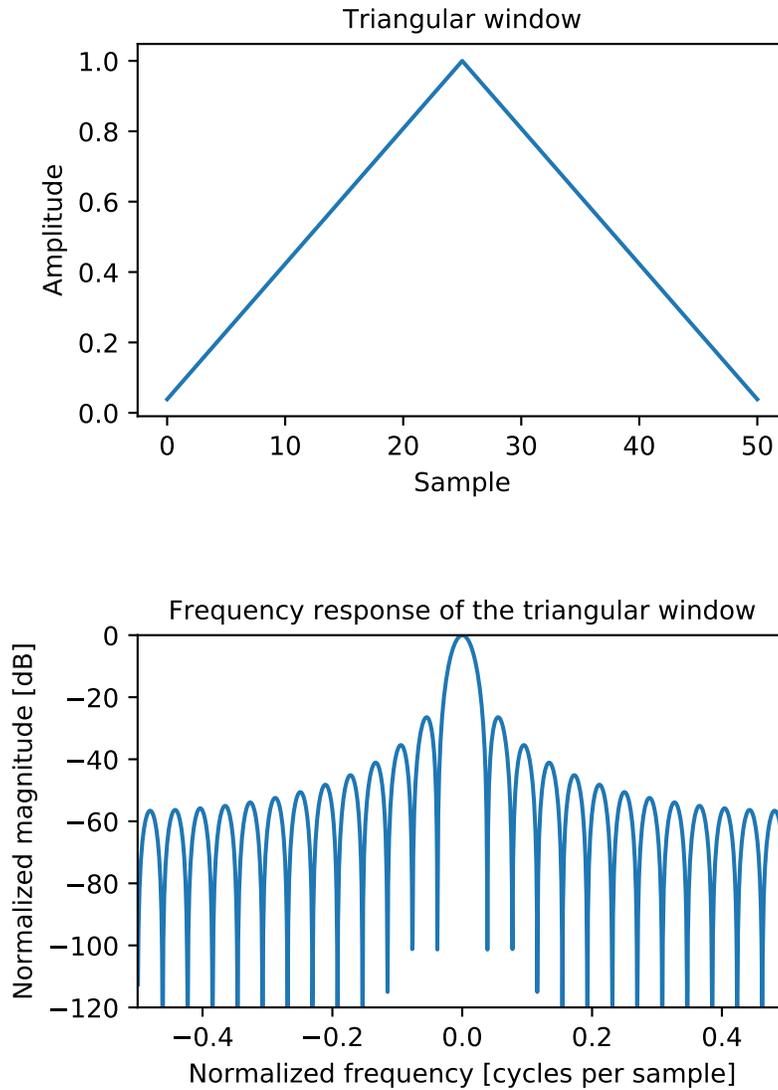
Plot the window and its frequency response:

```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

```
>>> window = signal.triang(51)
>>> plt.plot(window)
>>> plt.title("Triangular window")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
```

```
>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title("Frequency response of the triangular window")
```

```
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
```



`scipy.signal.tukey` ( $M$ ,  $\alpha=0.5$ ,  $\text{sym}=\text{True}$ )

Return a Tukey window, also known as a tapered cosine window.

**Parameters**  $M$  : int

Number of points in the output window. If zero or less, an empty array is returned.

**alpha** : float, optional

Shape parameter of the Tukey window, representing the fraction of the window inside the cosine tapered region. If zero, the Tukey window is equivalent to a rectangular window. If one, the Tukey window is equivalent to a Hann window.

**sym** : bool, optional

When True (default), generates a symmetric window, for use in filter design. When False, generates a periodic window, for use in spectral analysis.

**Returns** `w` : ndarray

The window, with the maximum value normalized to 1 (though the value 1 does not appear if  $M$  is even and `sym` is True).

### References

[R303], [R304]

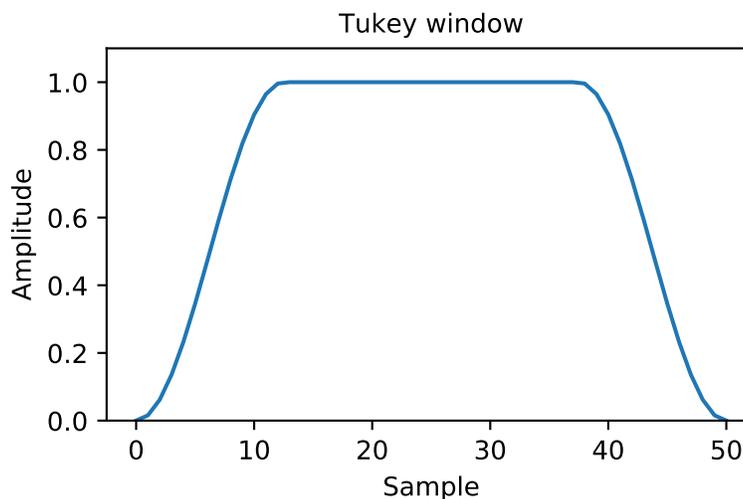
### Examples

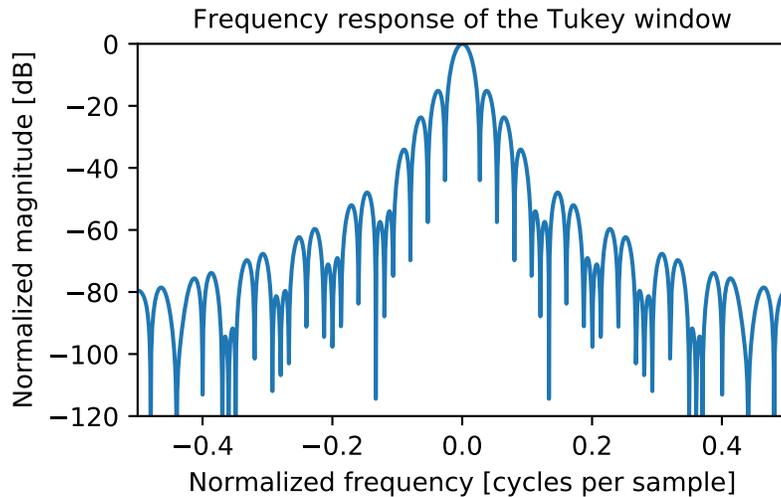
Plot the window and its frequency response:

```
>>> from scipy import signal
>>> from scipy.fftpack import fft, fftshift
>>> import matplotlib.pyplot as plt
```

```
>>> window = signal.tukey(51)
>>> plt.plot(window)
>>> plt.title("Tukey window")
>>> plt.ylabel("Amplitude")
>>> plt.xlabel("Sample")
>>> plt.ylim([0, 1.1])
```

```
>>> plt.figure()
>>> A = fft(window, 2048) / (len(window)/2.0)
>>> freq = np.linspace(-0.5, 0.5, len(A))
>>> response = 20 * np.log10(np.abs(fftshift(A / abs(A).max())))
>>> plt.plot(freq, response)
>>> plt.axis([-0.5, 0.5, -120, 0])
>>> plt.title("Frequency response of the Tukey window")
>>> plt.ylabel("Normalized magnitude [dB]")
>>> plt.xlabel("Normalized frequency [cycles per sample]")
```





## 5.20.11 Wavelets

<code>cascade(hk[, J])</code>	Return (x, phi, psi) at dyadic points $K/2^{**J}$ from filter coefficients.
<code>daub(p)</code>	The coefficients for the FIR low-pass filter producing Daubechies wavelets.
<code>morlet(M[, w, s, complete])</code>	Complex Morlet wavelet.
<code>qmf(hk)</code>	Return high-pass qmf filter from low-pass
<code>ricker(points, a)</code>	Return a Ricker wavelet, also known as the “Mexican hat wavelet”.
<code>cwt(data, wavelet, widths)</code>	Continuous wavelet transform.

`scipy.signal.cascade(hk, J=7)`

Return (x, phi, psi) at dyadic points  $K/2^{**J}$  from filter coefficients.

**Parameters** **hk** : array\_like

Coefficients of low-pass filter.

**J** : int, optional

Values will be computed at grid points  $K/2^{**J}$ . Default is 7.

**Returns**

**x** : ndarray

The dyadic points  $K/2^{**J}$  for  $K=0 \dots N * (2^{**J}) - 1$  where  $\text{len}(hk) = \text{len}(gk) = N+1$ .

**phi** : ndarray

The scaling function  $\text{phi}(x)$  at  $x$ :  $\text{phi}(x) = \text{sum}(hk * \text{phi}(2x-k))$ , where  $k$  is from 0 to  $N$ .

**psi** : ndarray, optional

The wavelet function  $\text{psi}(x)$  at  $x$ :  $\text{psi}(x) = \text{sum}(gk * \text{phi}(2x-k))$ , where  $k$  is from 0 to  $N$ . *psi* is only returned if *gk* is not None.

### Notes

The algorithm uses the vector cascade algorithm described by Strang and Nguyen in “Wavelets and Filter Banks”. It builds a dictionary of values and slices for quick reuse. Then inserts vectors into final vector at



where  $A = 2/\sqrt{3a}\pi^{1/4}$ .

**Parameters** **points** : int  
Number of points in *vector*. Will be centered around 0.

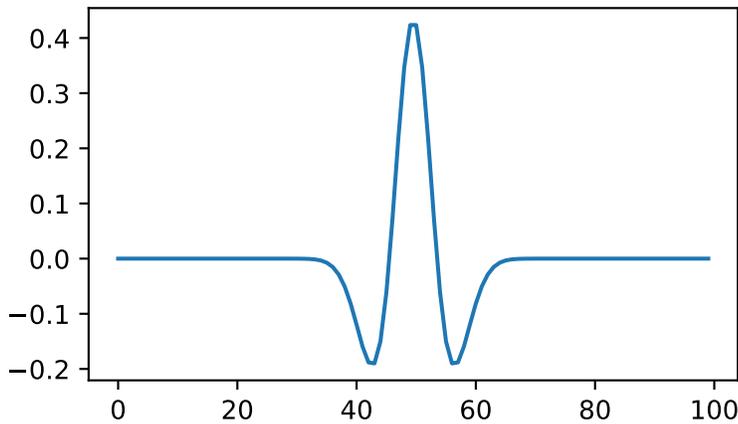
**a** : scalar  
Width parameter of the wavelet.

**Returns** **vector** : (N,) ndarray  
Array of length *points* in shape of ricker curve.

**Examples**

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

```
>>> points = 100
>>> a = 4.0
>>> vec2 = signal.ricker(points, a)
>>> print(len(vec2))
100
>>> plt.plot(vec2)
>>> plt.show()
```



`scipy.signal.cwt` (*data*, *wavelet*, *widths*)

Continuous wavelet transform.

Performs a continuous wavelet transform on *data*, using the *wavelet* function. A CWT performs a convolution with *data* using the *wavelet* function, which is characterized by a width parameter and length parameter.

**Parameters** **data** : (N,) ndarray  
data on which to perform the transform.

**wavelet** : function  
Wavelet function, which should take 2 arguments. The first argument is the number of points that the returned vector will have (`len(wavelet(length,width)) == length`). The second is a width parameter, defining the size of the wavelet (e.g. standard deviation of a gaussian). See *ricker*, which satisfies these requirements.

**widths** : (M,) sequence  
Widths to use for transform.

**Returns** **cwt**: (M, N) ndarray

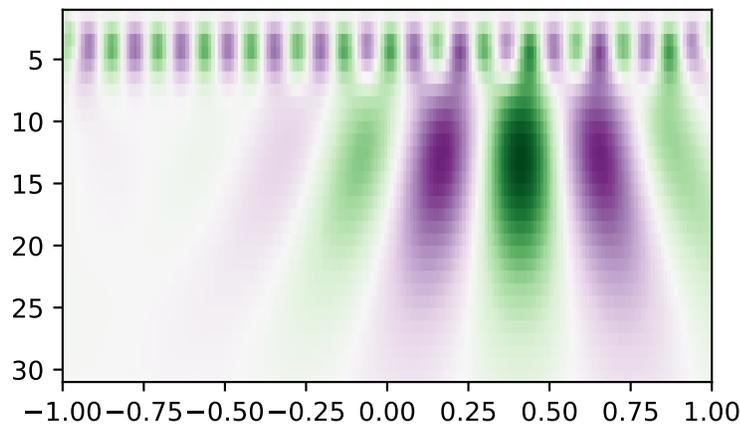
Will have shape of `(len(widths), len(data))`.

### Notes

```
length = min(10 * width[ii], len(data))
cwt[ii, :] = signal.convolve(data, wavelet(length,
                                         width[ii]), mode='same')
```

### Examples

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
>>> t = np.linspace(-1, 1, 200, endpoint=False)
>>> sig = np.cos(2 * np.pi * 7 * t) + signal.gausspulse(t - 0.4, fc=2)
>>> widths = np.arange(1, 31)
>>> cwtmatr = signal.cwt(sig, signal.ricker, widths)
>>> plt.imshow(cwtmatr, extent=[-1, 1, 31, 1], cmap='PRGn', aspect='auto',
...           vmax=abs(cwtmatr).max(), vmin=-abs(cwtmatr).max())
>>> plt.show()
```



## 5.20.12 Peak finding

<code>find_peaks_cwt(vector, widths[, wavelet, ...])</code>	Attempt to find the peaks in a 1-D array.
<code>argrelnmin(data[, axis, order, mode])</code>	Calculate the relative minima of <i>data</i> .
<code>argrelnmax(data[, axis, order, mode])</code>	Calculate the relative maxima of <i>data</i> .
<code>argrelnrema(data, comparator[, axis, ...])</code>	Calculate the relative extrema of <i>data</i> .

`scipy.signal.find_peaks_cwt` (*vector*, *widths*, *wavelet=None*, *max\_distances=None*, *gap\_thresh=None*, *min\_length=None*, *min\_snr=1*, *noise\_perc=10*)  
 Attempt to find the peaks in a 1-D array.

The general approach is to smooth *vector* by convolving it with *wavelet(width)* for each width in *widths*. Relative maxima which appear at enough length scales, and with sufficiently high SNR, are accepted.

**Parameters** *vector* : ndarray

1-D array in which to find the peaks.

**widths** : sequence

1-D array of widths to use for calculating the CWT matrix. In general, this range should cover the expected width of peaks of interest.

**wavelet** : callable, optional

Should take two parameters and return a 1-D array to convolve with *vector*. The first parameter determines the number of points of the returned wavelet array, the second parameter is the scale (*width*) of the wavelet. Should be normalized and symmetric. Default is the ricker wavelet.

**max\_distances** : ndarray, optional

At each row, a ridge line is only connected if the relative max at row[n] is within `max_distances[n]` from the relative max at row[n+1]. Default value is `widths/4`.

**gap\_thresh** : float, optional

If a relative maximum is not found within *max\_distances*, there will be a gap. A ridge line is discontinued if there are more than *gap\_thresh* points without connecting a new relative maximum. Default is the first value of the widths array i.e. `widths[0]`.

**min\_length** : int, optional

Minimum length a ridge line needs to be acceptable. Default is `cwt.shape[0] / 4`, ie 1/4-th the number of widths.

**min\_snr** : float, optional

Minimum SNR ratio. Default 1. The signal is the value of the cwt matrix at the shortest length scale (`cwt[0, loc]`), the noise is the *noise\_perc*'th percentile of datapoints contained within a window of *window\_size* around `cwt[0, loc]`.

**noise\_perc** : float, optional

When calculating the noise floor, percentile of data points examined below which to consider noise. Calculated using *stats.scoreatpercentile*. Default is 10.

**Returns**

**peaks\_indices** : ndarray

Indices of the locations in the *vector* where peaks were found. The list is sorted.

**See also:**

*cwt*

**Notes**

This approach was designed for finding sharp peaks among noisy data, however with proper parameter selection it should function well for different peak shapes.

*The algorithm is as follows:*

1. Perform a continuous wavelet transform on *vector*, for the supplied *widths*. This is a convolution of *vector* with *wavelet(width)* for each width in *widths*. See *cwt*
2. Identify "ridge lines" in the cwt matrix. These are relative maxima at each row, connected across adjacent rows. See *identify\_ridge\_lines*
3. Filter the *ridge\_lines* using *filter\_ridge\_lines*.

New in version 0.11.0.

**References**

[R253]

**Examples**

```
>>> from scipy import signal
>>> xs = np.arange(0, np.pi, 0.05)
>>> data = np.sin(xs)
>>> peakind = signal.find_peaks_cwt(data, np.arange(1,10))
>>> peakind, xs[peakind], data[peakind]
([32], array([ 1.6]), array([ 0.9995736]))
```

`scipy.signal.argrelmin` (*data*, *axis=0*, *order=1*, *mode='clip'*)

Calculate the relative minima of *data*.

**Parameters**

- data** : ndarray  
Array in which to find the relative minima.
- axis** : int, optional  
Axis over which to select from *data*. Default is 0.
- order** : int, optional  
How many points on each side to use for the comparison to consider `comparator(n, n+x)` to be True.
- mode** : str, optional  
How the edges of the vector are treated. Available options are 'wrap' (wrap around) or 'clip' (treat overflow as the same as the last (or first) element). Default 'clip'. See `numpy.take`.

**Returns**

- extrema** : tuple of ndarrays  
Indices of the minima in arrays of integers. `extrema[k]` is the array of indices of axis *k* of *data*. Note that the return value is a tuple even when *data* is one-dimensional.

**See also:**

`argrelextrema`, `argrelmax`

**Notes**

This function uses `argrelextrema` with `np.less` as comparator.

New in version 0.11.0.

**Examples**

```
>>> from scipy.signal import argrelmin
>>> x = np.array([2, 1, 2, 3, 2, 0, 1, 0])
>>> argrelmin(x)
(array([1, 5]),)
>>> y = np.array([[1, 2, 1, 2],
...              [2, 2, 0, 0],
...              [5, 3, 4, 4]])
...
>>> argrelmin(y, axis=1)
(array([0, 2]), array([2, 1]))
```

`scipy.signal.argrelmax` (*data*, *axis=0*, *order=1*, *mode='clip'*)

Calculate the relative maxima of *data*.

**Parameters**

- data** : ndarray  
Array in which to find the relative maxima.
- axis** : int, optional  
Axis over which to select from *data*. Default is 0.
- order** : int, optional

How many points on each side to use for the comparison to consider `comparator(n, n+x)` to be True.

**mode** : str, optional  
 How the edges of the vector are treated. Available options are ‘wrap’ (wrap around) or ‘clip’ (treat overflow as the same as the last (or first) element). Default ‘clip’. See `numpy.take`.

**Returns** **extrema** : tuple of ndarrays  
 Indices of the maxima in arrays of integers. `extrema[k]` is the array of indices of axis *k* of *data*. Note that the return value is a tuple even when *data* is one-dimensional.

**See also:**

`argrelextrema`, `argrelmin`

**Notes**

This function uses `argrelextrema` with `np.greater` as comparator.

New in version 0.11.0.

**Examples**

```
>>> from scipy.signal import argrelmax
>>> x = np.array([2, 1, 2, 3, 2, 0, 1, 0])
>>> argrelmax(x)
(array([3, 6]),)
>>> y = np.array([[1, 2, 1, 2],
...               [2, 2, 0, 0],
...               [5, 3, 4, 4]])
...
>>> argrelmax(y, axis=1)
(array([0]), array([1]))
```

`scipy.signal.argrelextrema` (*data*, *comparator*, *axis=0*, *order=1*, *mode='clip'*)

Calculate the relative extrema of *data*.

**Parameters** **data** : ndarray  
 Array in which to find the relative extrema.

**comparator** : callable  
 Function to use to compare two data points. Should take two arrays as arguments.

**axis** : int, optional  
 Axis over which to select from *data*. Default is 0.

**order** : int, optional  
 How many points on each side to use for the comparison to consider `comparator(n, n+x)` to be True.

**mode** : str, optional  
 How the edges of the vector are treated. ‘wrap’ (wrap around) or ‘clip’ (treat overflow as the same as the last (or first) element). Default is ‘clip’.

**Returns** **extrema** : tuple of ndarrays  
 See `numpy.take`.  
 Indices of the maxima in arrays of integers. `extrema[k]` is the array of indices of axis *k* of *data*. Note that the return value is a tuple even when *data* is one-dimensional.

**See also:**

`argrelmin`, `argrelmax`

### Notes

New in version 0.11.0.

### Examples

```

>>> from scipy.signal import argrextrema
>>> x = np.array([2, 1, 2, 3, 2, 0, 1, 0])
>>> argrextrema(x, np.greater)
(array([3, 6]),)
>>> y = np.array([[1, 2, 1, 2],
...               [2, 2, 0, 0],
...               [5, 3, 4, 4]])
...
>>> argrextrema(y, np.less, axis=1)
(array([0, 2]), array([2, 1]))

```

## 5.20.13 Spectral Analysis

<code>periodogram(x[, fs, window, nfft, detrend, ...])</code>	Estimate power spectral density using a periodogram.
<code>welch(x[, fs, window, nperseg, noverlap, ...])</code>	Estimate power spectral density using Welch's method.
<code>csd(x, y[, fs, window, nperseg, noverlap, ...])</code>	Estimate the cross power spectral density, $P_{xy}$ , using Welch's method.
<code>coherence(x, y[, fs, window, nperseg, ...])</code>	Estimate the magnitude squared coherence estimate, $C_{xy}$ , of discrete-time signals $X$ and $Y$ using Welch's method.
<code>spectrogram(x[, fs, window, nperseg, ...])</code>	Compute a spectrogram with consecutive Fourier transforms.
<code>lombscargle(x, y, freqs)</code>	Computes the Lomb-Scargle periodogram.
<code>vectorstrength(events, period)</code>	Determine the vector strength of the events corresponding to the given period.
<code>stft(x[, fs, window, nperseg, noverlap, ...])</code>	Compute the Short Time Fourier Transform (STFT).
<code>istft(Zxx[, fs, window, nperseg, noverlap, ...])</code>	Perform the inverse Short Time Fourier transform (iSTFT).
<code>check_COLA(window, nperseg, noverlap[, tol])</code>	Check whether the Constant OverLap Add (COLA) constraint is met

`scipy.signal.periodogram(x, fs=1.0, window='boxcar', nfft=None, detrend='constant', return_onesided=True, scaling='density', axis=-1)`  
 Estimate power spectral density using a periodogram.

**Parameters** `x` : array\_like

Time series of measurement values

`fs` : float, optional

Sampling frequency of the  $x$  time series. Defaults to 1.0.

`window` : str or tuple or array\_like, optional

Desired window to use. If `window` is a string or tuple, it is passed to `get_window` to generate the window values, which are DFT-even by default. See `get_window` for a list of windows and required parameters. If `window` is array\_like it will be used directly as the window and its length must be `nperseg`. Defaults to 'boxcar'.

`nfft` : int, optional

Length of the FFT used. If `None` the length of  $x$  will be used.

`detrend` : str or function or `False`, optional

Specifies how to detrend each segment. If *detrend* is a string, it is passed as the *type* argument to the *detrend* function. If it is a function, it takes a segment and returns a detrended segment. If *detrend* is *False*, no detrending is done. Defaults to 'constant'.

**return\_onesided** : bool, optional

If *True*, return a one-sided spectrum for real data. If *False* return a two-sided spectrum. Note that for complex data, a two-sided spectrum is always returned.

**scaling** : { 'density', 'spectrum' }, optional

Selects between computing the power spectral density ('density') where *Pxx* has units of  $V^{**2}/Hz$  and computing the power spectrum ('spectrum') where *Pxx* has units of  $V^{**2}$ , if *x* is measured in V and *fs* is measured in Hz. Defaults to 'density'

**axis** : int, optional

Axis along which the periodogram is computed; the default is over the last axis (i.e. *axis=-1*).

**Returns**

**f** : ndarray

Array of sample frequencies.

**Pxx** : ndarray

Power spectral density or power spectrum of *x*.

**See also:**

**welch** Estimate power spectral density using Welch's method

**lombscargle** Lomb-Scargle periodogram for unevenly sampled data

**Notes**

New in version 0.12.0.

**Examples**

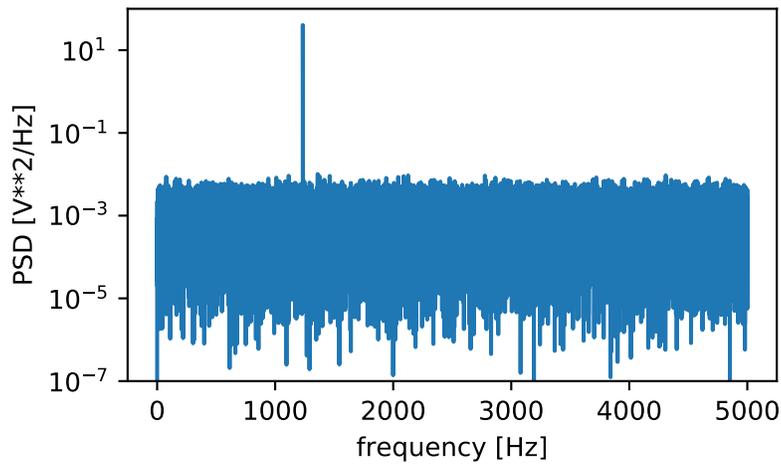
```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
>>> np.random.seed(1234)
```

Generate a test signal, a 2 Vrms sine wave at 1234 Hz, corrupted by 0.001  $V^{**2}/Hz$  of white noise sampled at 10 kHz.

```
>>> fs = 10e3
>>> N = 1e5
>>> amp = 2*np.sqrt(2)
>>> freq = 1234.0
>>> noise_power = 0.001 * fs / 2
>>> time = np.arange(N) / fs
>>> x = amp*np.sin(2*np.pi*freq*time)
>>> x += np.random.normal(scale=np.sqrt(noise_power), size=time.shape)
```

Compute and plot the power spectral density.

```
>>> f, Pxx_den = signal.periodogram(x, fs)
>>> plt.semilogy(f, Pxx_den)
>>> plt.ylim([1e-7, 1e2])
>>> plt.xlabel('frequency [Hz]')
>>> plt.ylabel('PSD [V**2/Hz]')
>>> plt.show()
```

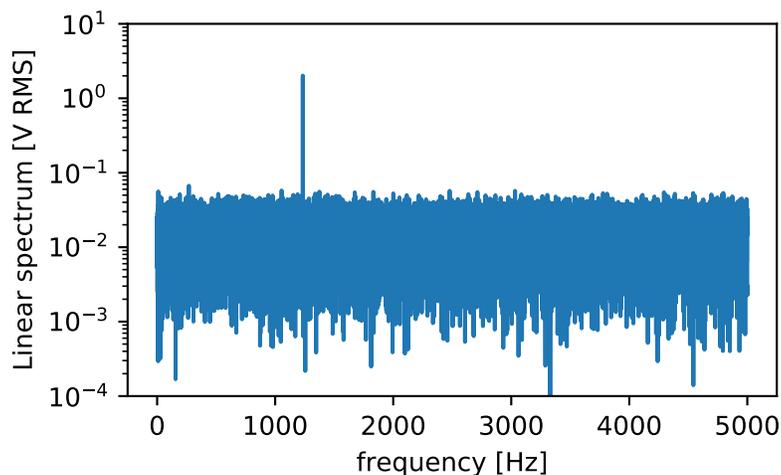


If we average the last half of the spectral density, to exclude the peak, we can recover the noise power on the signal.

```
>>> np.mean(Pxx_den[25000:])
0.00099728892368242854
```

Now compute and plot the power spectrum.

```
>>> f, Pxx_spec = signal.periodogram(x, fs, 'flattop', scaling='spectrum')
>>> plt.figure()
>>> plt.semilogy(f, np.sqrt(Pxx_spec))
>>> plt.ylim([1e-4, 1e1])
>>> plt.xlabel('frequency [Hz]')
>>> plt.ylabel('Linear spectrum [V RMS]')
>>> plt.show()
```



The peak height in the power spectrum is an estimate of the RMS amplitude.

```
>>> np.sqrt(Pxx_spec.max())
2.0077340678640727
```

`scipy.signal.welch(x, fs=1.0, window='hann', nperseg=None, noverlap=None, nfft=None, detrend='constant', return_onesided=True, scaling='density', axis=-1)`  
 Estimate power spectral density using Welch's method.

Welch's method [R306] computes an estimate of the power spectral density by dividing the data into overlapping segments, computing a modified periodogram for each segment and averaging the periodograms.

**Parameters**

- x** : array\_like  
Time series of measurement values
- fs** : float, optional  
Sampling frequency of the *x* time series. Defaults to 1.0.
- window** : str or tuple or array\_like, optional  
Desired window to use. If *window* is a string or tuple, it is passed to *get\_window* to generate the window values, which are DFT-even by default. See *get\_window* for a list of windows and required parameters. If *window* is array\_like it will be used directly as the window and its length must be *nperseg*. Defaults to a Hann window.
- nperseg** : int, optional  
Length of each segment. Defaults to None, but if window is str or tuple, is set to 256, and if window is array\_like, is set to the length of the window.
- nooverlap** : int, optional  
Number of points to overlap between segments. If None, *nooverlap* = *nperseg* // 2. Defaults to None.
- nfft** : int, optional  
Length of the FFT used, if a zero padded FFT is desired. If None, the FFT length is *nperseg*. Defaults to None.
- detrend** : str or function or False, optional  
Specifies how to detrend each segment. If *detrend* is a string, it is passed as the *type* argument to the *detrend* function. If it is a function, it takes a segment and returns a detrended segment. If *detrend* is False, no detrending is done. Defaults to 'constant'.
- return\_onesided** : bool, optional  
If True, return a one-sided spectrum for real data. If False return a two-sided spectrum. Note that for complex data, a two-sided spectrum is always returned.
- scaling** : { 'density', 'spectrum' }, optional  
Selects between computing the power spectral density ('density') where *Pxx* has units of V\*\*2/Hz and computing the power spectrum ('spectrum') where *Pxx* has units of V\*\*2, if *x* is measured in V and *fs* is measured in Hz. Defaults to 'density'
- axis** : int, optional  
Axis along which the periodogram is computed; the default is over the last axis (i.e. *axis*=-1).

**Returns**

- f** : ndarray  
Array of sample frequencies.
- Pxx** : ndarray  
Power spectral density or power spectrum of *x*.

See also:

**periodogram**  
 Simple, optionally modified periodogram

**lombscargle**

Lomb-Scargle periodogram for unevenly sampled data

**Notes**

An appropriate amount of overlap will depend on the choice of window and on your requirements. For the default Hann window an overlap of 50% is a reasonable trade off between accurately estimating the signal power, while not over counting any of the data. Narrower windows may require a larger overlap.

If *noverlap* is 0, this method is equivalent to Bartlett's method [R307].

New in version 0.12.0.

**References**

[R306], [R307]

**Examples**

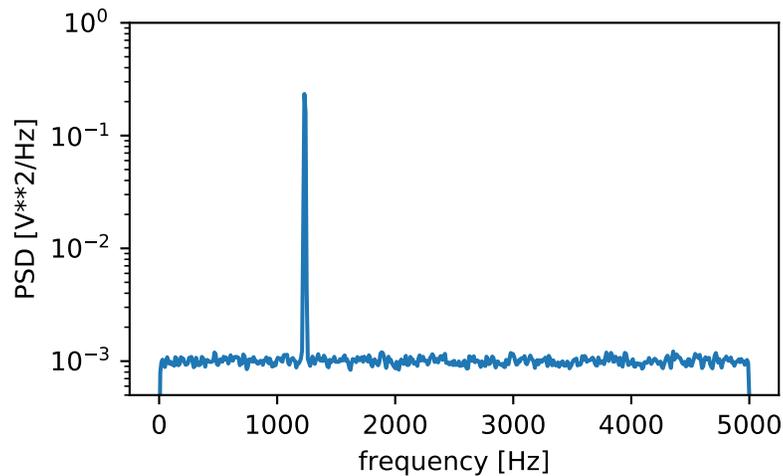
```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
>>> np.random.seed(1234)
```

Generate a test signal, a 2 Vrms sine wave at 1234 Hz, corrupted by 0.001 V\*\*2/Hz of white noise sampled at 10 kHz.

```
>>> fs = 10e3
>>> N = 1e5
>>> amp = 2*np.sqrt(2)
>>> freq = 1234.0
>>> noise_power = 0.001 * fs / 2
>>> time = np.arange(N) / fs
>>> x = amp*np.sin(2*np.pi*freq*time)
>>> x += np.random.normal(scale=np.sqrt(noise_power), size=time.shape)
```

Compute and plot the power spectral density.

```
>>> f, Pxx_den = signal.welch(x, fs, nperseg=1024)
>>> plt.semilogy(f, Pxx_den)
>>> plt.ylim([0.5e-3, 1])
>>> plt.xlabel('frequency [Hz]')
>>> plt.ylabel('PSD [V**2/Hz]')
>>> plt.show()
```

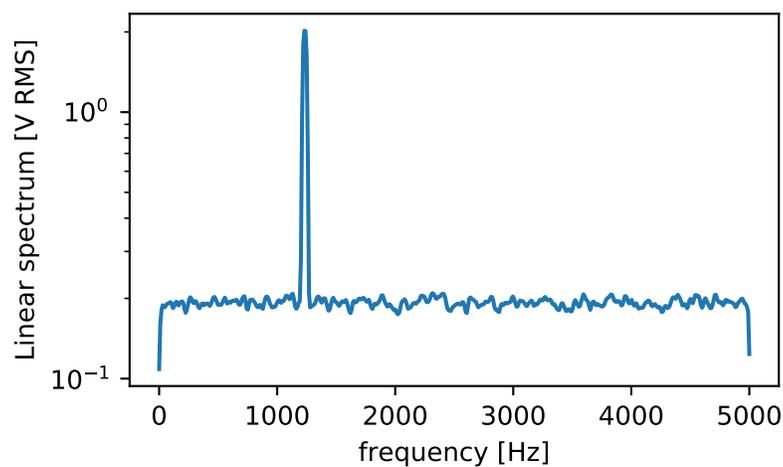


If we average the last half of the spectral density, to exclude the peak, we can recover the noise power on the signal.

```
>>> np.mean(Pxx_den[256:])
0.0009924865443739191
```

Now compute and plot the power spectrum.

```
>>> f, Pxx_spec = signal.welch(x, fs, 'flattop', 1024, scaling='spectrum')
>>> plt.figure()
>>> plt.semilogy(f, np.sqrt(Pxx_spec))
>>> plt.xlabel('frequency [Hz]')
>>> plt.ylabel('Linear spectrum [V RMS]')
>>> plt.show()
```



The peak height in the power spectrum is an estimate of the RMS amplitude.

```
>>> np.sqrt(Pxx_spec.max())
2.0077340678640727
```

`scipy.signal.csd(x, y, fs=1.0, window='hann', nperseg=None, noverlap=None, nfft=None, detrend='constant', return_onesided=True, scaling='density', axis=-1)`

Estimate the cross power spectral density,  $P_{xy}$ , using Welch's method.

**Parameters**

- x** : array\_like  
Time series of measurement values
- y** : array\_like  
Time series of measurement values
- fs** : float, optional  
Sampling frequency of the  $x$  and  $y$  time series. Defaults to 1.0.
- window** : str or tuple or array\_like, optional  
Desired window to use. If *window* is a string or tuple, it is passed to `get_window` to generate the window values, which are DFT-even by default. See `get_window` for a list of windows and required parameters. If *window* is array\_like it will be used directly as the window and its length must be `nperseg`. Defaults to a Hann window.
- nperseg** : int, optional  
Length of each segment. Defaults to `None`, but if *window* is str or tuple, is set to 256, and if *window* is array\_like, is set to the length of the window.
- noverlap** : int, optional  
Number of points to overlap between segments. If `None`, `noverlap = nperseg // 2`. Defaults to `None`.
- nfft** : int, optional  
Length of the FFT used, if a zero padded FFT is desired. If `None`, the FFT length is `nperseg`. Defaults to `None`.
- detrend** : str or function or `False`, optional  
Specifies how to detrend each segment. If *detrend* is a string, it is passed as the *type* argument to the *detrend* function. If it is a function, it takes a segment and returns a detrended segment. If *detrend* is `False`, no detrending is done. Defaults to 'constant'.
- return\_onesided** : bool, optional  
If `True`, return a one-sided spectrum for real data. If `False` return a two-sided spectrum. Note that for complex data, a two-sided spectrum is always returned.
- scaling** : { 'density', 'spectrum' }, optional  
Selects between computing the cross spectral density ('density') where  $P_{xy}$  has units of  $V^{**2}/Hz$  and computing the cross spectrum ('spectrum') where  $P_{xy}$  has units of  $V^{**2}$ , if  $x$  and  $y$  are measured in  $V$  and  $fs$  is measured in  $Hz$ . Defaults to 'density'
- axis** : int, optional  
Axis along which the CSD is computed for both inputs; the default is over the last axis (i.e. `axis=-1`).

**Returns**

- f** : ndarray  
Array of sample frequencies.
- Pxy** : ndarray  
Cross spectral density or cross power spectrum of  $x,y$ .

See also:

**periodogram**

Simple, optionally modified periodogram

**lombscargle**

Lomb-Scargle periodogram for unevenly sampled data

**welch** Power spectral density by Welch's method. [Equivalent to `csd(x,x)`]  
**coherence** Magnitude squared coherence by Welch's method.

### Notes

By convention, `Pxy` is computed with the conjugate FFT of `X` multiplied by the FFT of `Y`.

If the input series differ in length, the shorter series will be zero-padded to match.

An appropriate amount of overlap will depend on the choice of window and on your requirements. For the default Hann window an overlap of 50% is a reasonable trade off between accurately estimating the signal power, while not over counting any of the data. Narrower windows may require a larger overlap.

New in version 0.16.0.

### References

[R249], [R250]

### Examples

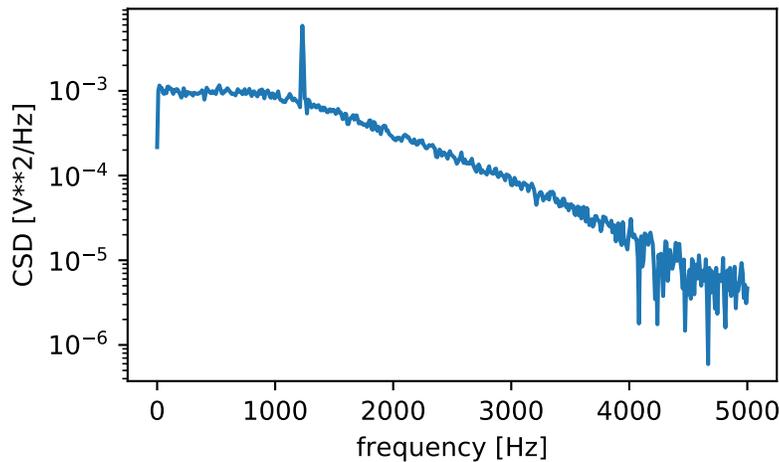
```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

Generate two test signals with some common features.

```
>>> fs = 10e3
>>> N = 1e5
>>> amp = 20
>>> freq = 1234.0
>>> noise_power = 0.001 * fs / 2
>>> time = np.arange(N) / fs
>>> b, a = signal.butter(2, 0.25, 'low')
>>> x = np.random.normal(scale=np.sqrt(noise_power), size=time.shape)
>>> y = signal.lfilter(b, a, x)
>>> x += amp*np.sin(2*np.pi*freq*time)
>>> y += np.random.normal(scale=0.1*np.sqrt(noise_power), size=time.shape)
```

Compute and plot the magnitude of the cross spectral density.

```
>>> f, Pxy = signal.csd(x, y, fs, nperseg=1024)
>>> plt.semilogy(f, np.abs(Pxy))
>>> plt.xlabel('frequency [Hz]')
>>> plt.ylabel('CSD [V**2/Hz]')
>>> plt.show()
```



`scipy.signal.coherence` (*x*, *y*, *fs*=1.0, *window*='hann', *nperseg*=None, *noverlap*=None, *nfft*=None, *detrend*='constant', *axis*=-1)

Estimate the magnitude squared coherence estimate,  $C_{xy}$ , of discrete-time signals *X* and *Y* using Welch's method.

$C_{xy} = \text{abs}(P_{xy}) ** 2 / (P_{xx} * P_{yy})$ , where  $P_{xx}$  and  $P_{yy}$  are power spectral density estimates of *X* and *Y*, and  $P_{xy}$  is the cross spectral density estimate of *X* and *Y*.

**Parameters**

- x** : array\_like  
Time series of measurement values
- y** : array\_like  
Time series of measurement values
- fs** : float, optional  
Sampling frequency of the *x* and *y* time series. Defaults to 1.0.
- window** : str or tuple or array\_like, optional  
Desired window to use. If *window* is a string or tuple, it is passed to `get_window` to generate the window values, which are DFT-even by default. See `get_window` for a list of windows and required parameters. If *window* is array\_like it will be used directly as the window and its length must be *nperseg*. Defaults to a Hann window.
- nperseg** : int, optional  
Length of each segment. Defaults to None, but if *window* is str or tuple, is set to 256, and if *window* is array\_like, is set to the length of the window.
- noverlap**: int, optional  
Number of points to overlap between segments. If None, *noverlap* = *nperseg* // 2. Defaults to None.
- nfft** : int, optional  
Length of the FFT used, if a zero padded FFT is desired. If None, the FFT length is *nperseg*. Defaults to None.
- detrend** : str or function or False, optional  
Specifies how to detrend each segment. If *detrend* is a string, it is passed as the *type* argument to the *detrend* function. If it is a function, it takes a segment and returns a detrended segment. If *detrend* is False, no detrending is done. Defaults to 'constant'.
- axis** : int, optional

**Returns**

<b>f</b> : ndarray	Axis along which the coherence is computed for both inputs; the default is over the last axis (i.e. <code>axis=-1</code> ).
<b>Cxy</b> : ndarray	Array of sample frequencies. Magnitude squared coherence of x and y.

See also:

**periodogram**

Simple, optionally modified periodogram

**lombscargle**

Lomb-Scargle periodogram for unevenly sampled data

**welch**

Power spectral density by Welch's method.

**csd**

Cross spectral density by Welch's method.

**Notes**

An appropriate amount of overlap will depend on the choice of window and on your requirements. For the default Hann window an overlap of 50% is a reasonable trade off between accurately estimating the signal power, while not over counting any of the data. Narrower windows may require a larger overlap.

New in version 0.16.0.

**References**

[R244], [R245]

**Examples**

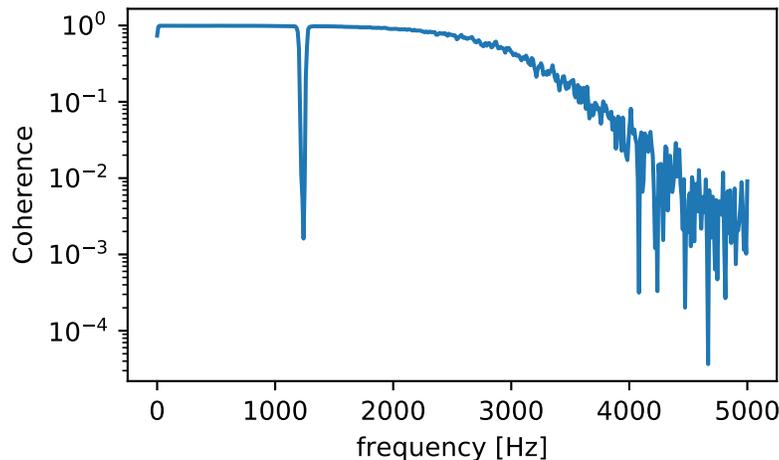
```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

Generate two test signals with some common features.

```
>>> fs = 10e3
>>> N = 1e5
>>> amp = 20
>>> freq = 1234.0
>>> noise_power = 0.001 * fs / 2
>>> time = np.arange(N) / fs
>>> b, a = signal.butter(2, 0.25, 'low')
>>> x = np.random.normal(scale=np.sqrt(noise_power), size=time.shape)
>>> y = signal.lfilter(b, a, x)
>>> x += amp*np.sin(2*np.pi*freq*time)
>>> y += np.random.normal(scale=0.1*np.sqrt(noise_power), size=time.shape)
```

Compute and plot the coherence.

```
>>> f, Cxy = signal.coherence(x, y, fs, nperseg=1024)
>>> plt.semilogy(f, Cxy)
>>> plt.xlabel('frequency [Hz]')
>>> plt.ylabel('Coherence')
>>> plt.show()
```



```
scipy.signal.spectrogram(x, fs=1.0, window=('tukey', 0.25), nperseg=None, noverlap=None,
                        nfft=None, detrend='constant', return_onesided=True, scaling='density', axis=-1, mode='psd')
```

Compute a spectrogram with consecutive Fourier transforms.

Spectrograms can be used as a way of visualizing the change of a nonstationary signal's frequency content over time.

**Parameters**

- x** : array\_like  
Time series of measurement values
- fs** : float, optional  
Sampling frequency of the *x* time series. Defaults to 1.0.
- window** : str or tuple or array\_like, optional  
Desired window to use. If *window* is a string or tuple, it is passed to *get\_window* to generate the window values, which are DFT-even by default. See *get\_window* for a list of windows and required parameters. If *window* is array\_like it will be used directly as the window and its length must be *nperseg*. Defaults to a Tukey window with shape parameter of 0.25.
- nperseg** : int, optional  
Length of each segment. Defaults to None, but if *window* is str or tuple, is set to 256, and if *window* is array\_like, is set to the length of the window.
- noverlap** : int, optional  
Number of points to overlap between segments. If None, *noverlap* = *nperseg* // 8. Defaults to None.
- nfft** : int, optional  
Length of the FFT used, if a zero padded FFT is desired. If None, the FFT length is *nperseg*. Defaults to None.
- detrend** : str or function or False, optional  
Specifies how to detrend each segment. If *detrend* is a string, it is passed as the *type* argument to the *detrend* function. If it is a function, it takes a segment and returns a detrended segment. If *detrend* is False, no detrending is done. Defaults to 'constant'.
- return\_onesided** : bool, optional  
If True, return a one-sided spectrum for real data. If False return a two-sided spectrum. Note that for complex data, a two-sided spectrum is always returned.

**scaling** : { 'density', 'spectrum' }, optional  
 Selects between computing the power spectral density ('density') where  $S_{xx}$  has units of  $V^{**2}/\text{Hz}$  and computing the power spectrum ('spectrum') where  $S_{xx}$  has units of  $V^{**2}$ , if  $x$  is measured in  $V$  and  $fs$  is measured in  $\text{Hz}$ . Defaults to 'density'.

**axis** : int, optional  
 Axis along which the spectrogram is computed; the default is over the last axis (i.e. `axis=-1`).

**mode** : str, optional  
 Defines what kind of return values are expected. Options are ['psd', 'complex', 'magnitude', 'angle', 'phase']. 'complex' is equivalent to the output of `stft` with no padding or boundary extension. 'magnitude' returns the absolute magnitude of the STFT. 'angle' and 'phase' return the complex angle of the STFT, with and without unwrapping, respectively.

**Returns**

**f** : ndarray  
 Array of sample frequencies.

**t** : ndarray  
 Array of segment times.

**Sxx** : ndarray  
 Spectrogram of  $x$ . By default, the last axis of  $S_{xx}$  corresponds to the segment times.

**See also:**

**periodogram**

Simple, optionally modified periodogram

**lombscargle**

Lomb-Scargle periodogram for unevenly sampled data

**welch**

Power spectral density by Welch's method.

**csd**

Cross spectral density by Welch's method.

**Notes**

An appropriate amount of overlap will depend on the choice of window and on your requirements. In contrast to `welch`'s method, where the entire data stream is averaged over, one may wish to use a smaller overlap (or perhaps none at all) when computing a spectrogram, to maintain some statistical independence between individual segments. It is for this reason that the default window is a Tukey window with 1/8th of a window's length overlap at each end.

New in version 0.16.0.

**References**

[R300]

**Examples**

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

Generate a test signal, a 2 Vrms sine wave whose frequency is slowly modulated around 3kHz, corrupted by white noise of exponentially decreasing magnitude sampled at 10 kHz.

```
>>> fs = 10e3
>>> N = 1e5
>>> amp = 2 * np.sqrt(2)
>>> noise_power = 0.01 * fs / 2
>>> time = np.arange(N) / float(fs)
```

```

>>> mod = 500*np.cos(2*np.pi*0.25*time)
>>> carrier = amp * np.sin(2*np.pi*3e3*time + mod)
>>> noise = np.random.normal(scale=np.sqrt(noise_power), size=time.shape)
>>> noise *= np.exp(-time/5)
>>> x = carrier + noise

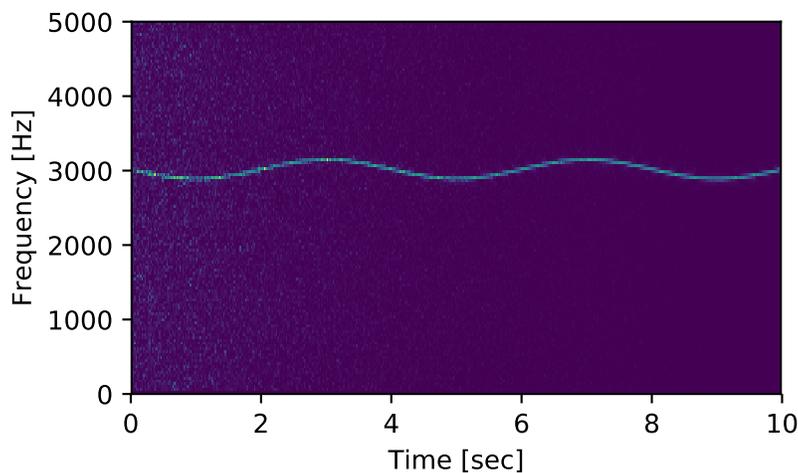
```

Compute and plot the spectrogram.

```

>>> f, t, Sxx = signal.spectrogram(x, fs)
>>> plt.pcolormesh(t, f, Sxx)
>>> plt.ylabel('Frequency [Hz]')
>>> plt.xlabel('Time [sec]')
>>> plt.show()

```



`scipy.signal.lombscargle(x, y, freqs)`

Computes the Lomb-Scargle periodogram.

The Lomb-Scargle periodogram was developed by Lomb [R283] and further extended by Scargle [R284] to find, and test the significance of weak periodic signals with uneven temporal sampling.

When *normalize* is False (default) the computed periodogram is unnormalized, it takes the value  $(A^{**2}) * N/4$  for a harmonic signal with amplitude A for sufficiently large N.

When *normalize* is True the computed periodogram is normalized by the residuals of the data around a constant reference model (at zero).

Input arrays should be one-dimensional and will be cast to float64.

**Parameters**

- x** : array\_like  
Sample times.
- y** : array\_like  
Measurement values.
- freqs** : array\_like  
Angular frequencies for output periodogram.
- precenter** : bool, optional  
Pre-center amplitudes by subtracting the mean.
- normalize** : bool, optional  
Compute normalized periodogram.

**Returns**

- pgram** : array\_like

**Raises** **ValueError** Lomb-Scargle periodogram.  
If the input arrays  $x$  and  $y$  do not have the same shape.

**Notes**

This subroutine calculates the periodogram using a slightly modified algorithm due to Townsend [R285] which allows the periodogram to be calculated using only a single pass through the input arrays for each frequency.

The algorithm running time scales roughly as  $O(x * \text{freqs})$  or  $O(N^2)$  for a large number of samples and frequencies.

**References**

[R283], [R284], [R285]

**Examples**

```
>>> import scipy.signal
>>> import matplotlib.pyplot as plt
```

First define some input parameters for the signal:

```
>>> A = 2.
>>> w = 1.
>>> phi = 0.5 * np.pi
>>> nin = 1000
>>> nout = 100000
>>> frac_points = 0.9 # Fraction of points to select
```

Randomly select a fraction of an array with timesteps:

```
>>> r = np.random.rand(nin)
>>> x = np.linspace(0.01, 10*np.pi, nin)
>>> x = x[r >= frac_points]
```

Plot a sine wave for the selected times:

```
>>> y = A * np.sin(w*x+phi)
```

Define the array of frequencies for which to compute the periodogram:

```
>>> f = np.linspace(0.01, 10, nout)
```

Calculate Lomb-Scargle periodogram:

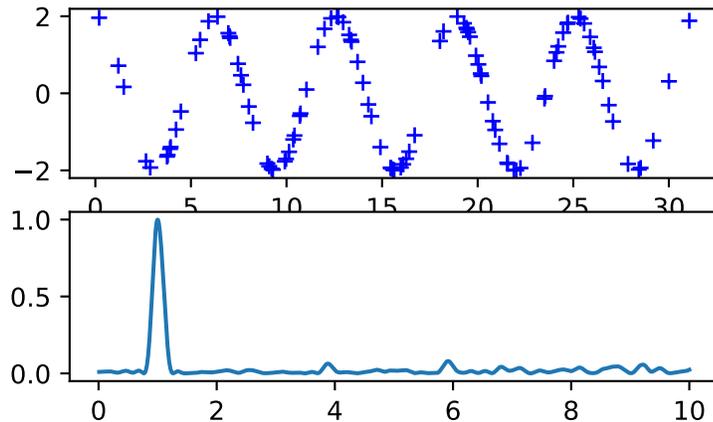
```
>>> import scipy.signal as signal
>>> pgram = signal.lombscargle(x, y, f, normalize=True)
```

Now make a plot of the input data:

```
>>> plt.subplot(2, 1, 1)
>>> plt.plot(x, y, 'b+')
```

Then plot the normalized periodogram:

```
>>> plt.subplot(2, 1, 2)
>>> plt.plot(f, pgram)
>>> plt.show()
```



`scipy.signal.vectorstrength(events, period)`

Determine the vector strength of the events corresponding to the given period.

The vector strength is a measure of phase synchrony, how well the timing of the events is synchronized to a single period of a periodic signal.

If multiple periods are used, calculate the vector strength of each. This is called the “resonating vector strength”.

**Parameters** **events** : 1D array\_like

An array of time points containing the timing of the events.

**period** : float or array\_like

The period of the signal that the events should synchronize to. The period is in the same units as *events*. It can also be an array of periods, in which case the outputs are arrays of the same length.

**Returns** **strength** : float or 1D array

The strength of the synchronization. 1.0 is perfect synchronization and 0.0 is no synchronization. If *period* is an array, this is also an array with each element containing the vector strength at the corresponding period.

**phase** : float or array

The phase that the events are most strongly synchronized to in radians. If *period* is an array, this is also an array with each element containing the phase for the corresponding period.

### References

*van Hemmen, JL, Longtin, A, and Vollmayr, AN. Testing resonating vector*

*strength: Auditory system, electric fish, and noise.* Chaos 21, 047508 (2011); DOI:10.1063/1.3670512.

*van Hemmen, JL. Vector strength after Goldberg, Brown, and von Mises:*

*biological and mathematical perspectives.* Biol Cybern. 2013 Aug;107(4):385-96. DOI:10.1007/s00422-013-0561-7.

*van Hemmen, JL and Vollmayr, AN. Resonating vector strength: what happens*

*when we vary the “probing” frequency while keeping the spike times fixed.* Biol Cybern. 2013 Aug;107(4):491-94. DOI:10.1007/s00422-013-0560-8.

`scipy.signal.stft(x, fs=1.0, window='hann', nperseg=256, noverlap=None, nfft=None, detrend=False, return_onesided=True, boundary='zeros', padded=True, axis=-1)`  
Compute the Short Time Fourier Transform (STFT).

STFTs can be used as a way of quantifying the change of a nonstationary signal's frequency and phase content over time.

**Parameters**

- x** : array\_like  
Time series of measurement values
- fs** : float, optional  
Sampling frequency of the *x* time series. Defaults to 1.0.
- window** : str or tuple or array\_like, optional  
Desired window to use. If *window* is a string or tuple, it is passed to *get\_window* to generate the window values, which are DFT-even by default. See *get\_window* for a list of windows and required parameters. If *window* is array\_like it will be used directly as the window and its length must be *nperseg*. Defaults to a Hann window.
- nperseg** : int, optional  
Length of each segment. Defaults to 256.
- noverlap** : int, optional  
Number of points to overlap between segments. If *None*, *noverlap* = *nperseg* // 2. Defaults to *None*. When specified, the COLA constraint must be met (see Notes below).
- nfft** : int, optional  
Length of the FFT used, if a zero padded FFT is desired. If *None*, the FFT length is *nperseg*. Defaults to *None*.
- detrend** : str or function or *False*, optional  
Specifies how to detrend each segment. If *detrend* is a string, it is passed as the *type* argument to the *detrend* function. If it is a function, it takes a segment and returns a detrended segment. If *detrend* is *False*, no detrending is done. Defaults to *False*.
- return\_onesided** : bool, optional  
If *True*, return a one-sided spectrum for real data. If *False* return a two-sided spectrum. Note that for complex data, a two-sided spectrum is always returned. Defaults to *True*.
- boundary** : str or *None*, optional  
Specifies whether the input signal is extended at both ends, and how to generate the new values, in order to center the first windowed segment on the first input point. This has the benefit of enabling reconstruction of the first input point when the employed window function starts at zero. Valid options are ['even', 'odd', 'constant', 'zeros', *None*]. Defaults to 'zeros', for zero padding extension. I.e. [1, 2, 3, 4] is extended to [0, 1, 2, 3, 4, 0] for *nperseg*=3.
- padded** : bool, optional  
Specifies whether the input signal is zero-padded at the end to make the signal fit exactly into an integer number of window segments, so that all of the signal is included in the output. Defaults to *True*. Padding occurs after boundary extension, if *boundary* is not *None*, and *padded* is *True*, as is the default.
- axis** : int, optional  
Axis along which the STFT is computed; the default is over the last axis (i.e. *axis*=-1).

**Returns**

- f** : ndarray  
Array of sample frequencies.
- t** : ndarray  
Array of segment times.
- Zxx** : ndarray

STFT of  $x$ . By default, the last axis of  $Z_{xx}$  corresponds to the segment times.

**See also:**

**istft** Inverse Short Time Fourier Transform  
**check\_COLA** Check whether the Constant OverLap Add (COLA) constraint is met  
**welch** Power spectral density by Welch's method.  
**spectrogram**  
 Spectrogram by Welch's method.  
**csd** Cross spectral density by Welch's method.  
**lombscargle**  
 Lomb-Scargle periodogram for unevenly sampled data

**Notes**

In order to enable inversion of an STFT via the inverse STFT in *istft*, the signal windowing must obey the constraint of “Constant OverLap Add” (COLA), and the input signal must have complete windowing coverage (i.e.  $(x.shape[axis] - nperseg) \% (nperseg - noverlap) == 0$ ). The *padded* argument may be used to accomplish this.

The COLA constraint ensures that every point in the input data is equally weighted, thereby avoiding aliasing and allowing full reconstruction. Whether a choice of *window*, *nperseg*, and *noverlap* satisfy this constraint can be tested with *check\_COLA*.

New in version 0.19.0.

**References**

[R301], [R302]

**Examples**

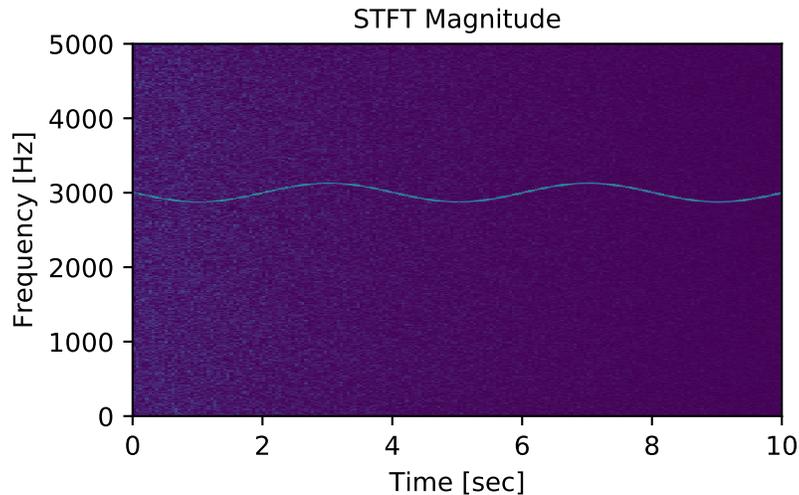
```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

Generate a test signal, a 2 Vrms sine wave whose frequency is slowly modulated around 3kHz, corrupted by white noise of exponentially decreasing magnitude sampled at 10 kHz.

```
>>> fs = 10e3
>>> N = 1e5
>>> amp = 2 * np.sqrt(2)
>>> noise_power = 0.01 * fs / 2
>>> time = np.arange(N) / float(fs)
>>> mod = 500 * np.cos(2 * np.pi * 0.25 * time)
>>> carrier = amp * np.sin(2 * np.pi * 3e3 * time + mod)
>>> noise = np.random.normal(scale=np.sqrt(noise_power),
...                          size=time.shape)
>>> noise *= np.exp(-time/5)
>>> x = carrier + noise
```

Compute and plot the STFT's magnitude.

```
>>> f, t, Zxx = signal.stft(x, fs, nperseg=1000)
>>> plt.pcolormesh(t, f, np.abs(Zxx), vmin=0, vmax=amp)
>>> plt.title('STFT Magnitude')
>>> plt.ylabel('Frequency [Hz]')
>>> plt.xlabel('Time [sec]')
>>> plt.show()
```



`scipy.signal.istft` (*Zxx*, *fs=1.0*, *window='hann'*, *nperseg=None*, *noverlap=None*, *nfft=None*, *input\_onesided=True*, *boundary=True*, *time\_axis=-1*, *freq\_axis=-2*)  
 Perform the inverse Short Time Fourier transform (iSTFT).

**Parameters** *Zxx* : array\_like

STFT of the signal to be reconstructed. If a purely real array is passed, it will be cast to a complex data type.

*fs* : float, optional

Sampling frequency of the time series. Defaults to 1.0.

**window** : str or tuple or array\_like, optional

Desired window to use. If *window* is a string or tuple, it is passed to `get_window` to generate the window values, which are DFT-even by default. See `get_window` for a list of windows and required parameters. If *window* is array\_like it will be used directly as the window and its length must be *nperseg*. Defaults to a Hann window. Must match the window used to generate the STFT for faithful inversion.

**nperseg** : int, optional

Number of data points corresponding to each STFT segment. This parameter must be specified if the number of data points per segment is odd, or if the STFT was padded via *nfft* > *nperseg*. If *None*, the value depends on the shape of *Zxx* and *input\_onesided*. If *input\_onesided* is *True*, *nperseg*=2\*(*Zxx*.shape[*freq\_axis*] - 1). Otherwise, *nperseg*=*Zxx*.shape[*freq\_axis*]. Defaults to *None*.

**noverlap** : int, optional

Number of points to overlap between segments. If *None*, half of the segment length. Defaults to *None*. When specified, the COLA constraint must be met (see Notes below), and should match the parameter used to generate the STFT. Defaults to *None*.

**nfft** : int, optional

Number of FFT points corresponding to each STFT segment. This parameter must be specified if the STFT was padded via *nfft* > *nperseg*. If *None*, the default values are the same as for *nperseg*, detailed above, with one exception: if *input\_onesided* is *True* and *nperseg*==2\**Zxx*.shape[*freq\_axis*] - 1, *nfft* also takes on that value. This case allows the proper inversion of an odd-length unpadded STFT using *nfft*=*None*. Defaults to *None*.

**input\_onesided** : bool, optional  
 If *True*, interpret the input array as one-sided FFTs, such as is returned by *stft* with `return_onesided=True` and `numpy.fft.rfft`. If *False*, interpret the input as a two-sided FFT. Defaults to *True*.

**boundary** : bool, optional  
 Specifies whether the input signal was extended at its boundaries by supplying a non-*None* boundary argument to *stft*. Defaults to *True*.

**time\_axis** : int, optional  
 Where the time segments of the STFT is located; the default is the last axis (i.e. `axis=-1`).

**freq\_axis** : int, optional  
 Where the frequency axis of the STFT is located; the default is the penultimate axis (i.e. `axis=-2`).

**Returns**

**t** : ndarray  
 Array of output data times.

**x** : ndarray  
 iSTFT of  $Z_{xx}$ .

**See also:**

**stft** Short Time Fourier Transform  
**check\_COLA** Check whether the Constant OverLap Add (COLA) constraint is met

**Notes**

In order to enable inversion of an STFT via the inverse STFT with *istft*, the signal windowing must obey the constraint of “Constant OverLap Add” (COLA). This ensures that every point in the input data is equally weighted, thereby avoiding aliasing and allowing full reconstruction. Whether a choice of *window*, *nperseg*, and *noverlap* satisfy this constraint can be tested with *check\_COLA*, by using `nperseg = Zxx.shape[freq_axis]`.

An STFT which has been modified (via masking or otherwise) is not guaranteed to correspond to a exactly realizable signal. This function implements the iSTFT via the least-squares estimation algorithm detailed in [R278], which produces a signal that minimizes the mean squared error between the STFT of the returned signal and the modified STFT.

New in version 0.19.0.

**References**

[R277], [R278]

**Examples**

```
>>> from scipy import signal
>>> import matplotlib.pyplot as plt
```

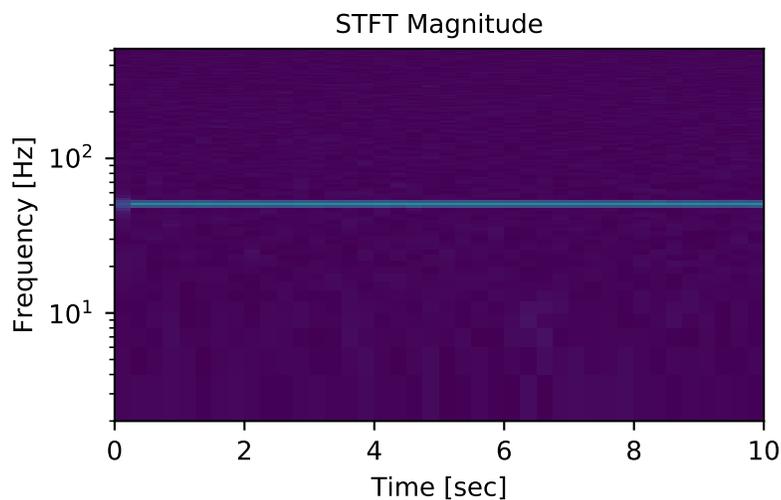
Generate a test signal, a 2 Vrms sine wave at 50Hz corrupted by 0.001 V\*\*2/Hz of white noise sampled at 1024 Hz.

```
>>> fs = 1024
>>> N = 10*fs
>>> nperseg = 512
>>> amp = 2 * np.sqrt(2)
>>> noise_power = 0.001 * fs / 2
>>> time = np.arange(N) / float(fs)
>>> carrier = amp * np.sin(2*np.pi*50*time)
>>> noise = np.random.normal(scale=np.sqrt(noise_power),
```

```
... size=time.shape)
>>> x = carrier + noise
```

Compute the STFT, and plot its magnitude

```
>>> f, t, Zxx = signal.stft(x, fs=fs, nperseg=nperseg)
>>> plt.figure()
>>> plt.pcolormesh(t, f, np.abs(Zxx), vmin=0, vmax=amp)
>>> plt.ylim([f[1], f[-1]])
>>> plt.title('STFT Magnitude')
>>> plt.ylabel('Frequency [Hz]')
>>> plt.xlabel('Time [sec]')
>>> plt.yscale('log')
>>> plt.show()
```

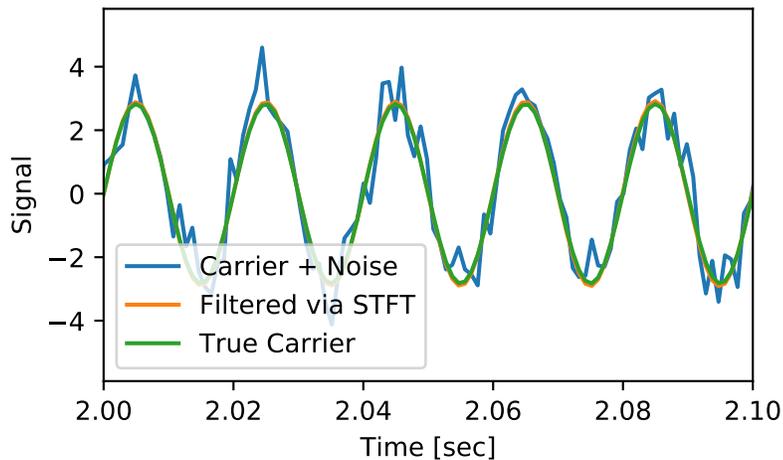


Zero the components that are 10% or less of the carrier magnitude, then convert back to a time series via inverse STFT

```
>>> Zxx = np.where(np.abs(Zxx) >= amp/10, Zxx, 0)
>>> _, xrec = signal.istft(Zxx, fs)
```

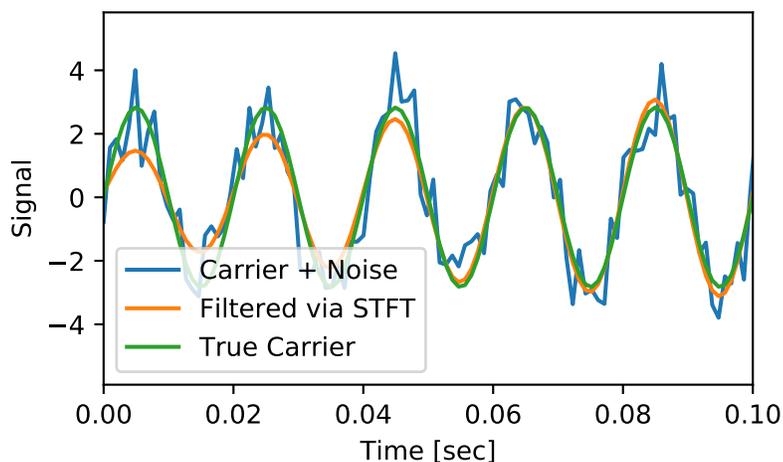
Compare the cleaned signal with the original and true carrier signals.

```
>>> plt.figure()
>>> plt.plot(time, x, time, xrec, time, carrier)
>>> plt.xlim([2, 2.1])
>>> plt.xlabel('Time [sec]')
>>> plt.ylabel('Signal')
>>> plt.legend(['Carrier + Noise', 'Filtered via STFT', 'True Carrier'])
>>> plt.show()
```



Note that the cleaned signal does not start as abruptly as the original, since some of the coefficients of the transient were also removed:

```
>>> plt.figure()
>>> plt.plot(time, x, time, xrec, time, carrier)
>>> plt.xlim([0, 0.1])
>>> plt.xlabel('Time [sec]')
>>> plt.ylabel('Signal')
>>> plt.legend(['Carrier + Noise', 'Filtered via STFT', 'True Carrier'])
>>> plt.show()
```



`scipy.signal.check_COLA(window, nperseg, noverlap, tol=1e-10)`

Check whether the Constant OverLap Add (COLA) constraint is met

**Parameters** **window** : str or tuple or array\_like

Desired window to use. If *window* is a string or tuple, it is passed to *get\_window* to generate the window values, which are DFT-even by default. See *get\_window* for a list of windows and required parameters. If

*window* is array\_like it will be used directly as the window and its length must be *nperseg*.

**nperseg** : int  
Length of each segment.

**noverlap** : int  
Number of points to overlap between segments.

**tol** : float, optional  
The allowed variance of a bin's weighted sum from the median bin sum.

**Returns** **verdict** : bool  
*True* if chosen combination satisfies COLA within *tol*, *False* otherwise

**See also:**

**stft** Short Time Fourier Transform  
**istft** Inverse Short Time Fourier Transform

**Notes**

In order to enable inversion of an STFT via the inverse STFT in *istft*, the signal windowing must obey the constraint of “Constant OverLap Add” (COLA). This ensures that every point in the input data is equally weighted, thereby avoiding aliasing and allowing full reconstruction.

**Some examples of windows that satisfy COLA:**

- Rectangular window at overlap of 0, 1/2, 2/3, 3/4, ...
- Bartlett window at overlap of 1/2, 3/4, 5/6, ...
- Hann window at 1/2, 2/3, 3/4, ...
- Any Blackman family window at 2/3 overlap
- Any window with `noverlap = nperseg-1`

A very comprehensive list of other windows may be found in [R243], wherein the COLA condition is satisfied when the “Amplitude Flatness” is unity.

New in version 0.19.0.

**References**

[R242], [R243]

**Examples**

```
>>> from scipy import signal
```

Confirm COLA condition for rectangular window of 75% (3/4) overlap:

```
>>> signal.check_COLA(signal.boxcar(100), 100, 75)
True
```

COLA is not true for 25% (1/4) overlap, though:

```
>>> signal.check_COLA(signal.boxcar(100), 100, 25)
False
```

“Symmetrical” Hann window (for filter design) is not COLA:

```
>>> signal.check_COLA(signal.hann(120, sym=True), 120, 60)
False
```

“Periodic” or “DFT-even” Hann window (for FFT analysis) is COLA for overlap of 1/2, 2/3, 3/4, etc.:

```
>>> signal.check_COLA(signal.hann(120, sym=False), 120, 60)
True
```

```
>>> signal.check_COLA(signal.hann(120, sym=False), 120, 80)
True
```

```
>>> signal.check_COLA(signal.hann(120, sym=False), 120, 90)
True
```

## 5.21 Sparse matrices (scipy.sparse)

SciPy 2-D sparse matrix package for numeric data.

### 5.21.1 Contents

#### Sparse matrix classes

<code>bsr_matrix</code> (arg1[, shape, dtype, copy, blocksize])	Block Sparse Row matrix
<code>coo_matrix</code> (arg1[, shape, dtype, copy])	A sparse matrix in COOrdinate format.
<code>csc_matrix</code> (arg1[, shape, dtype, copy])	Compressed Sparse Column matrix
<code>csr_matrix</code> (arg1[, shape, dtype, copy])	Compressed Sparse Row matrix
<code>dia_matrix</code> (arg1[, shape, dtype, copy])	Sparse matrix with DIAGonal storage
<code>dok_matrix</code> (arg1[, shape, dtype, copy])	Dictionary Of Keys based sparse matrix.
<code>lil_matrix</code> (arg1[, shape, dtype, copy])	Row-based linked list sparse matrix
<code>spmatrix</code> ([maxprint])	This class provides a base class for all sparse matrices.

**class** `scipy.sparse.bsr_matrix` (*arg1*, *shape=None*, *dtype=None*, *copy=False*, *blocksize=None*)

Block Sparse Row matrix

*This can be instantiated in several ways:*

`bsr_matrix(D, [blocksize=(R,C)])`

where D is a dense matrix or 2-D ndarray.

`bsr_matrix(S, [blocksize=(R,C)])`

with another sparse matrix S (equivalent to S.tobsr())

`bsr_matrix((M, N), [blocksize=(R,C), dtype])`

to construct an empty matrix with shape (M, N) dtype is optional, defaulting to dtype='d'.

`bsr_matrix((data, ij), [blocksize=(R,C), shape=(M, N)])`

where data and ij satisfy `a[ij[0, k], ij[1, k]] = data[k]`

`bsr_matrix((data, indices, indptr), [shape=(M, N)])`

is the standard BSR representation where the block column indices for row i are stored in `indices[indptr[i]:indptr[i+1]]` and their corresponding block values are stored in `data[indptr[i]: indptr[i+1]]`. If the shape parameter is not supplied, the matrix dimensions are inferred from the index arrays.

*Notes*

Sparse matrices can be used in arithmetic operations: they support addition, subtraction, multiplication, division, and matrix power.

**Summary of BSR format**

The Block Compressed Row (BSR) format is very similar to the Compressed Sparse Row (CSR) format. BSR is appropriate for sparse matrices with dense sub matrices like the last example below. Block matrices often arise in vector-valued finite element discretizations. In such cases, BSR is considerably more efficient than CSR and CSC for many sparse arithmetic operations.

**Blocksize**

The blocksize (R,C) must evenly divide the shape of the matrix (M,N). That is, R and C must satisfy the relationship  $M \% R = 0$  and  $N \% C = 0$ .

If no blocksize is specified, a simple heuristic is applied to determine an appropriate blocksize.

*Examples*

```
>>> from scipy.sparse import bsr_matrix
>>> bsr_matrix((3, 4), dtype=np.int8).toarray()
array([[0, 0, 0, 0],
       [0, 0, 0, 0],
       [0, 0, 0, 0]], dtype=int8)
```

```
>>> row = np.array([0, 0, 1, 2, 2, 2])
>>> col = np.array([0, 2, 2, 0, 1, 2])
>>> data = np.array([1, 2, 3, 4, 5, 6])
>>> bsr_matrix((data, (row, col)), shape=(3, 3)).toarray()
array([[1, 0, 2],
       [0, 0, 3],
       [4, 5, 6]])
```

```
>>> indptr = np.array([0, 2, 3, 6])
>>> indices = np.array([0, 2, 2, 0, 1, 2])
>>> data = np.array([1, 2, 3, 4, 5, 6]).repeat(4).reshape(6, 2, 2)
>>> bsr_matrix((data, indices, indptr), shape=(6, 6)).toarray()
array([[1, 1, 0, 0, 2, 2],
       [1, 1, 0, 0, 2, 2],
       [0, 0, 0, 0, 3, 3],
       [0, 0, 0, 0, 3, 3],
       [4, 4, 5, 5, 6, 6],
       [4, 4, 5, 5, 6, 6]])
```

*Attributes*

<i>shape</i>	Get shape of a matrix.
<i>nnz</i>	Number of stored values, including explicit zeros.
<i>has_sorted_indices</i>	Determine whether the matrix has sorted indices

`bsr_matrix.shape`  
Get shape of a matrix.

`bsr_matrix.nnz`  
Number of stored values, including explicit zeros.

**See also:****count\_nonzero**

Number of non-zero entries

**bsr\_matrix.has\_sorted\_indices**

Determine whether the matrix has sorted indices

**Returns**

- True: if the indices of the matrix are in sorted order
- False: otherwise

<b>dtype</b>	(dtype) Data type of the matrix
<b>ndim</b>	(int) Number of dimensions (this is always 2)
<b>data</b>	Data array of the matrix
<b>indices</b>	BSR format index array
<b>indptr</b>	BSR format index pointer array
<b>blocksize</b>	Block size of the matrix

**Methods**

<i>arcsin()</i>	Element-wise arcsin.
<i>arcsinh()</i>	Element-wise arcsinh.
<i>arctan()</i>	Element-wise arctan.
<i>arctanh()</i>	Element-wise arctanh.
<i>argmax([axis, out])</i>	Return indices of maximum elements along an axis.
<i>argmin([axis, out])</i>	Return indices of minimum elements along an axis.
<i>asformat(format)</i>	Return this matrix in a given sparse format
<i>asfptype()</i>	Upcast matrix to a floating point format (if necessary)
<i>astype(dtype[, casting, copy])</i>	Cast the matrix elements to a specified type.
<i>ceil()</i>	Element-wise ceil.
<i>check_format([full_check])</i>	check whether the matrix format is valid
<i>conj()</i>	Element-wise complex conjugation.
<i>conjugate()</i>	Element-wise complex conjugation.
<i>copy()</i>	Returns a copy of this matrix.
<i>count_nonzero()</i>	Number of non-zero entries, equivalent to
<i>deg2rad()</i>	Element-wise deg2rad.
<i>diagonal([k])</i>	Returns the k-th diagonal of the matrix.
<i>dot(other)</i>	Ordinary dot product
<i>eliminate_zeros()</i>	Remove zero elements in-place.
<i>expm1()</i>	Element-wise expm1.
<i>floor()</i>	Element-wise floor.
<i>getH()</i>	Return the Hermitian transpose of this matrix.
<i>get_shape()</i>	Get shape of a matrix.
<i>getcol(j)</i>	Returns a copy of column j of the matrix, as an (m x 1) sparse matrix (column vector).
<i>getformat()</i>	Format of a matrix representation as a string.
<i>getmaxprint()</i>	Maximum number of elements to display when printed.
<i>getnnz([axis])</i>	Number of stored values, including explicit zeros.
<i>getrow(i)</i>	Returns a copy of row i of the matrix, as a (1 x n) sparse matrix (row vector).
<i>log1p()</i>	Element-wise log1p.
<i>matmat(*args, **kwargs)</i>	<i>matmat</i> is deprecated!
<i>matvec(*args, **kwargs)</i>	<i>matvec</i> is deprecated!

Continued on next page

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<code>max([axis, out])</code>	Return the maximum of the matrix or maximum along an axis.
<code>maximum(other)</code>	Element-wise maximum between this and another matrix.
<code>mean([axis, dtype, out])</code>	Compute the arithmetic mean along the specified axis.
<code>min([axis, out])</code>	Return the minimum of the matrix or maximum along an axis.
<code>minimum(other)</code>	Element-wise minimum between this and another matrix.
<code>multiply(other)</code>	Point-wise multiplication by another matrix, vector, or scalar.
<code>nonzero()</code>	nonzero indices
<code>power(n[, dtype])</code>	This function performs element-wise power.
<code>prune()</code>	Remove empty space after all non-zero elements.
<code>rad2deg()</code>	Element-wise rad2deg.
<code>reshape(shape[, order])</code>	Gives a new shape to a sparse matrix without changing its data.
<code>rint()</code>	Element-wise rint.
<code>set_shape(shape)</code>	See <code>reshape</code> .
<code>setdiag(values[, k])</code>	Set diagonal or off-diagonal elements of the array.
<code>sign()</code>	Element-wise sign.
<code>sin()</code>	Element-wise sin.
<code>sinh()</code>	Element-wise sinh.
<code>sort_indices()</code>	Sort the indices of this matrix <i>in place</i>
<code>sorted_indices()</code>	Return a copy of this matrix with sorted indices
<code>sqrt()</code>	Element-wise sqrt.
<code>sum([axis, dtype, out])</code>	Sum the matrix elements over a given axis.
<code>sum_duplicates()</code>	Eliminate duplicate matrix entries by adding them together
<code>tan()</code>	Element-wise tan.
<code>tanh()</code>	Element-wise tanh.
<code>toarray([order, out])</code>	Return a dense ndarray representation of this matrix.
<code>tobsr([blocksize, copy])</code>	Convert this matrix into Block Sparse Row Format.
<code>tocoo([copy])</code>	Convert this matrix to COOrdinate format.
<code>tocsc([copy])</code>	Convert this matrix to Compressed Sparse Column format.
<code>tocsr([copy])</code>	Convert this matrix to Compressed Sparse Row format.
<code>todense([order, out])</code>	Return a dense matrix representation of this matrix.
<code>todia([copy])</code>	Convert this matrix to sparse DIAgonal format.
<code>todok([copy])</code>	Convert this matrix to Dictionary Of Keys format.
<code>tolil([copy])</code>	Convert this matrix to LInked List format.
<code>transpose([axes, copy])</code>	Reverses the dimensions of the sparse matrix.
<code>trunc()</code>	Element-wise trunc.

`bsr_matrix.arcsin()`

Element-wise arcsin.

See `numpy.arcsin` for more information.

`bsr_matrix.arcsinh()`

Element-wise arcsinh.

See `numpy.arcsinh` for more information.

`bsr_matrix.arctan()`  
Element-wise arctan.

See `numpy.arctan` for more information.

`bsr_matrix.arctanh()`  
Element-wise arctanh.

See `numpy.arctanh` for more information.

`bsr_matrix.argmax` (*axis=None, out=None*)  
Return indices of maximum elements along an axis.

Implicit zero elements are also taken into account. If there are several maximum values, the index of the first occurrence is returned.

**Parameters**    **axis** : {-2, -1, 0, 1, None}, optional  
Axis along which the argmax is computed. If None (default), index of the maximum element in the flatten data is returned.

**out** : None, optional  
This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns**        **ind** : np.matrix or int  
Indices of maximum elements. If matrix, its size along *axis* is 1.

`bsr_matrix.argmin` (*axis=None, out=None*)  
Return indices of minimum elements along an axis.

Implicit zero elements are also taken into account. If there are several minimum values, the index of the first occurrence is returned.

**Parameters**    **axis** : {-2, -1, 0, 1, None}, optional  
Axis along which the argmin is computed. If None (default), index of the minimum element in the flatten data is returned.

**out** : None, optional  
This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns**        **ind** : np.matrix or int  
Indices of minimum elements. If matrix, its size along *axis* is 1.

`bsr_matrix.asformat` (*format*)  
Return this matrix in a given sparse format

**Parameters**    **format** : {string, None}  
*desired sparse matrix format*

- None for no format conversion
- “csr” for `csr_matrix` format
- “csc” for `csc_matrix` format
- “lil” for `lil_matrix` format
- “dok” for `dok_matrix` format and so on

`bsr_matrix.asfptype()`  
Upcast matrix to a floating point format (if necessary)

`bsr_matrix.astype` (*dtype, casting='unsafe', copy=True*)  
Cast the matrix elements to a specified type.

**Parameters**    **dtype** : string or numpy dtype  
Typecode or data-type to which to cast the data.

**casting** : { 'no', 'equiv', 'safe', 'same\_kind', 'unsafe' }, optional

Controls what kind of data casting may occur. Defaults to 'unsafe' for backwards compatibility. 'no' means the data types should not be cast at all. 'equiv' means only byte-order changes are allowed. 'safe' means only casts which can preserve values are allowed. 'same\_kind' means only safe casts or casts within a kind, like float64 to float32, are allowed. 'unsafe' means any data conversions may be done.

**copy** : bool, optional

If *copy* is *False*, the result might share some memory with this matrix. If *copy* is *True*, it is guaranteed that the result and this matrix do not share any memory.

`bsr_matrix.ceil()`

Element-wise ceil.

See `numpy.ceil` for more information.

`bsr_matrix.check_format` (*full\_check=True*)

check whether the matrix format is valid

**Parameters:**

***full\_check***: True - rigorous check, O(N) operations : default False - basic check, O(1) operations

`bsr_matrix.conj()`

Element-wise complex conjugation.

If the matrix is of non-complex data type, then this method does nothing and the data is not copied.

`bsr_matrix.conjugate()`

Element-wise complex conjugation.

If the matrix is of non-complex data type, then this method does nothing and the data is not copied.

`bsr_matrix.copy()`

Returns a copy of this matrix.

No data/indices will be shared between the returned value and current matrix.

`bsr_matrix.count_nonzero()`

Number of non-zero entries, equivalent to

`np.count_nonzero(a.toarray())`

Unlike `getnnz()` and the `nnz` property, which return the number of stored entries (the length of the data attribute), this method counts the actual number of non-zero entries in data.

`bsr_matrix.deg2rad()`

Element-wise deg2rad.

See `numpy.deg2rad` for more information.

`bsr_matrix.diagonal` (*k=0*)

Returns the k-th diagonal of the matrix.

**Parameters** **k** : int, optional

Which diagonal to set, corresponding to elements `a[i, i+k]`. Default: 0 (the main diagonal).

**See also:**

[\*numpy.diagonal\*](#)

Equivalent numpy function.

**Examples**

```
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> A.diagonal()
array([1, 0, 5])
>>> A.diagonal(k=1)
array([2, 3])
```

`bsr_matrix.dot(other)`  
Ordinary dot product

**Examples**

```
>>> import numpy as np
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> v = np.array([1, 0, -1])
>>> A.dot(v)
array([ 1, -3, -1], dtype=int64)
```

`bsr_matrix.eliminate_zeros()`  
Remove zero elements in-place.

`bsr_matrix.expm1()`  
Element-wise `expm1`.

See `numpy.expm1` for more information.

`bsr_matrix.floor()`  
Element-wise floor.

See `numpy.floor` for more information.

`bsr_matrix.getH()`  
Return the Hermitian transpose of this matrix.

**See also:**

**`np.matrix.getH`**  
NumPy's implementation of `getH` for matrices

`bsr_matrix.get_shape()`  
Get shape of a matrix.

`bsr_matrix.getcol(j)`  
Returns a copy of column *j* of the matrix, as an (*m* x 1) sparse matrix (column vector).

`bsr_matrix.getformat()`  
Format of a matrix representation as a string.

`bsr_matrix.getmaxprint()`  
Maximum number of elements to display when printed.

`bsr_matrix.getnnz(axis=None)`  
Number of stored values, including explicit zeros.

**Parameters** `axis`: None, 0, or 1

Select between the number of values across the whole matrix, in each column, or in each row.

**See also:**

**count\_nonzero**

Number of non-zero entries

`bsr_matrix.getrow(i)`

Returns a copy of row *i* of the matrix, as a (1 x n) sparse matrix (row vector).

`bsr_matrix.log1p()`

Element-wise log1p.

See `numpy.log1p` for more information.

`bsr_matrix.matmat(*args, **kws)`

*matmat* is deprecated! BSR *matmat* is deprecated in scipy 0.19.0. Use `*` operator instead.

Multiply this sparse matrix by other matrix.

`bsr_matrix.matvec(*args, **kws)`

*matvec* is deprecated! BSR *matvec* is deprecated in scipy 0.19.0. Use `*` operator instead.

Multiply matrix by vector.

`bsr_matrix.max(axis=None, out=None)`

Return the maximum of the matrix or maximum along an axis. This takes all elements into account, not just the non-zero ones.

**Parameters** **axis** : {-2, -1, 0, 1, None} optional

Axis along which the sum is computed. The default is to compute the maximum over all the matrix elements, returning a scalar (i.e. *axis* = *None*).

**out** : None, optional

This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns** **amax** : `coo_matrix` or scalar

Maximum of *a*. If *axis* is *None*, the result is a scalar value. If *axis* is given, the result is a `sparse.coo_matrix` of dimension `a.ndim - 1`.

**See also:**

**min** The minimum value of a sparse matrix along a given axis.

**`np.matrix.max`**

NumPy's implementation of 'max' for matrices

`bsr_matrix.maximum(other)`

Element-wise maximum between this and another matrix.

`bsr_matrix.mean(axis=None, dtype=None, out=None)`

Compute the arithmetic mean along the specified axis.

Returns the average of the matrix elements. The average is taken over all elements in the matrix by default, otherwise over the specified axis. *float64* intermediate and return values are used for integer inputs.

**Parameters** **axis** : {-2, -1, 0, 1, None} optional

Axis along which the mean is computed. The default is to compute the mean of all elements in the matrix (i.e. *axis* = *None*).

**dtype** : data-type, optional

Type to use in computing the mean. For integer inputs, the default is *float64*; for floating point inputs, it is the same as the input dtype.

**out** : `np.matrix`, optional

Alternative output matrix in which to place the result. It must have the same shape as the expected output, but the type of the output values will be cast if necessary.

**Returns** **m** : np.matrix

**See also:**

**np.matrix.mean**

NumPy's implementation of 'mean' for matrices

**bsr\_matrix.min** (*axis=None, out=None*)

Return the minimum of the matrix or maximum along an axis. This takes all elements into account, not just the non-zero ones.

**Parameters** **axis** : {-2, -1, 0, 1, None} optional

Axis along which the sum is computed. The default is to compute the minimum over all the matrix elements, returning a scalar (i.e. *axis = None*).

**out** : None, optional

This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns** **amin** : coo\_matrix or scalar

Minimum of *a*. If *axis* is None, the result is a scalar value. If *axis* is given, the result is a sparse.coo\_matrix of dimension `a.ndim - 1`.

**See also:**

**max** The maximum value of a sparse matrix along a given axis.

**np.matrix.min**

NumPy's implementation of 'min' for matrices

**bsr\_matrix.minimum** (*other*)

Element-wise minimum between this and another matrix.

**bsr\_matrix.multiply** (*other*)

Point-wise multiplication by another matrix, vector, or scalar.

**bsr\_matrix.nonzero** ()

nonzero indices

Returns a tuple of arrays (row,col) containing the indices of the non-zero elements of the matrix.

**Examples**

```
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> A.nonzero()
(array([0, 0, 1, 2, 2]), array([0, 1, 2, 0, 2]))
```

**bsr\_matrix.power** (*n, dtype=None*)

This function performs element-wise power.

**Parameters** **n** : n is a scalar

**dtype** : If dtype is not specified, the current dtype will be preserved.

**bsr\_matrix.prune** ()

Remove empty space after all non-zero elements.

**bsr\_matrix.rad2deg** ()

Element-wise rad2deg.

See `numpy.rad2deg` for more information.

**bsr\_matrix.reshape** (*shape, order='C'*)

Gives a new shape to a sparse matrix without changing its data.

**Parameters** **shape** : length-2 tuple of ints  
 The new shape should be compatible with the original shape.  
**order** : 'C', optional  
 This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.  
**Returns** **reshaped\_matrix** : *self* with the new dimensions of *shape*

**See also:**

**`np.matrix.reshape`**  
 NumPy's implementation of 'reshape' for matrices

`bsr_matrix.rint()`  
 Element-wise rint.

See `numpy rint` for more information.

`bsr_matrix.set_shape(shape)`  
 See *reshape*.

`bsr_matrix.setdiag(values, k=0)`  
 Set diagonal or off-diagonal elements of the array.

**Parameters** **values** : array\_like  
 New values of the diagonal elements.  
 Values may have any length. If the diagonal is longer than values, then the remaining diagonal entries will not be set. If values if longer than the diagonal, then the remaining values are ignored.  
 If a scalar value is given, all of the diagonal is set to it.  
**k** : int, optional  
 Which off-diagonal to set, corresponding to elements `a[i,i+k]`. Default: 0 (the main diagonal).

`bsr_matrix.sign()`  
 Element-wise sign.

See `numpy.sign` for more information.

`bsr_matrix.sin()`  
 Element-wise sin.

See `numpy.sin` for more information.

`bsr_matrix.sinh()`  
 Element-wise sinh.

See `numpy.sinh` for more information.

`bsr_matrix.sort_indices()`  
 Sort the indices of this matrix *in place*

`bsr_matrix.sorted_indices()`  
 Return a copy of this matrix with sorted indices

`bsr_matrix.sqrt()`  
 Element-wise sqrt.

See `numpy.sqrt` for more information.

`bsr_matrix.sum(axis=None, dtype=None, out=None)`  
 Sum the matrix elements over a given axis.

**Parameters** **axis** : {-2, -1, 0, 1, None} optional

Axis along which the sum is computed. The default is to compute the sum of all the matrix elements, returning a scalar (i.e. *axis = None*).

**dtype** : dtype, optional

The type of the returned matrix and of the accumulator in which the elements are summed. The dtype of *a* is used by default unless *a* has an integer dtype of less precision than the default platform integer. In that case, if *a* is signed then the platform integer is used while if *a* is unsigned then an unsigned integer of the same precision as the platform integer is used.

**out** : np.matrix, optional

Alternative output matrix in which to place the result. It must have the same shape as the expected output, but the type of the output values will be cast if necessary.

**Returns**

**sum\_along\_axis** : np.matrix

A matrix with the same shape as *self*, with the specified axis removed.

**See also:**

***np.matrix.sum***

NumPy's implementation of 'sum' for matrices

***bsr\_matrix.sum\_duplicates()***

Eliminate duplicate matrix entries by adding them together

The is an *in place* operation

***bsr\_matrix.tan()***

Element-wise tan.

See `numpy.tan` for more information.

***bsr\_matrix.tanh()***

Element-wise tanh.

See `numpy.tanh` for more information.

***bsr\_matrix.toarray (order=None, out=None)***

Return a dense ndarray representation of this matrix.

**Parameters** **order** : {'C', 'F'}, optional

Whether to store multi-dimensional data in C (row-major) or Fortran (column-major) order in memory. The default is 'None', indicating the NumPy default of C-ordered. Cannot be specified in conjunction with the *out* argument.

**out** : ndarray, 2-dimensional, optional

If specified, uses this array as the output buffer instead of allocating a new array to return. The provided array must have the same shape and dtype as the sparse matrix on which you are calling the method. For most sparse types, *out* is required to be memory contiguous (either C or Fortran ordered).

**Returns**

**arr** : ndarray, 2-dimensional

An array with the same shape and containing the same data represented by the sparse matrix, with the requested memory order. If *out* was passed, the same object is returned after being modified in-place to contain the appropriate values.

***bsr\_matrix.tobsr (blocksize=None, copy=False)***

Convert this matrix into Block Sparse Row Format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `bsr_matrix`.

If `blocksize=(R, C)` is provided, it will be used for determining block size of the `bsr_matrix`.

`bsr_matrix.tocoo (copy=True)`

Convert this matrix to COOrdinate format.

When `copy=False` the data array will be shared between this matrix and the resultant `coo_matrix`.

`bsr_matrix.tocsc (copy=False)`

Convert this matrix to Compressed Sparse Column format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `csc_matrix`.

`bsr_matrix.tocsr (copy=False)`

Convert this matrix to Compressed Sparse Row format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `csr_matrix`.

`bsr_matrix.todense (order=None, out=None)`

Return a dense matrix representation of this matrix.

**Parameters** `order` : {'C', 'F'}, optional

Whether to store multi-dimensional data in C (row-major) or Fortran (column-major) order in memory. The default is 'None', indicating the NumPy default of C-ordered. Cannot be specified in conjunction with the `out` argument.

`out` : ndarray, 2-dimensional, optional

If specified, uses this array (or `numpy.matrix`) as the output buffer instead of allocating a new array to return. The provided array must have the same shape and dtype as the sparse matrix on which you are calling the method.

**Returns** `arr` : numpy.matrix, 2-dimensional

A NumPy matrix object with the same shape and containing the same data represented by the sparse matrix, with the requested memory order. If `out` was passed and was an array (rather than a `numpy.matrix`), it will be filled with the appropriate values and returned wrapped in a `numpy.matrix` object that shares the same memory.

`bsr_matrix.todia (copy=False)`

Convert this matrix to sparse DIAgonal format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `dia_matrix`.

`bsr_matrix.todok (copy=False)`

Convert this matrix to Dictionary Of Keys format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `dok_matrix`.

`bsr_matrix.tolil (copy=False)`

Convert this matrix to LInked List format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `lil_matrix`.

`bsr_matrix.ttranspose (axes=None, copy=False)`

Reverses the dimensions of the sparse matrix.

**Parameters** `axes` : None, optional

This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value.

`copy` : bool, optional

Indicates whether or not attributes of *self* should be copied whenever possible. The degree to which attributes are copied varies depending

**Returns** `p` : *self* with the dimensions reversed.

See also:

**`np.matrix.transpose`**

NumPy's implementation of 'transpose' for matrices

`bsr_matrix.trunc()`

Element-wise trunc.

See `numpy.trunc` for more information.

**class** `scipy.sparse.coo_matrix` (*arg1*, *shape=None*, *dtype=None*, *copy=False*)  
A sparse matrix in COOrdinate format.

Also known as the 'ijv' or 'triplet' format.

*This can be instantiated in several ways:*

**`coo_matrix(D)`**

with a dense matrix D

**`coo_matrix(S)`** with another sparse matrix S (equivalent to `S.tocoo()`)

**`coo_matrix((M, N), [dtype])`**

to construct an empty matrix with shape (M, N) dtype is optional, defaulting to dtype='d'.

**`coo_matrix((data, (i, j)), [shape=(M, N)])`**

*to construct from three arrays:*

1.`data[:]` the entries of the matrix, in any order

2.`i[:]` the row indices of the matrix entries

3.`j[:]` the column indices of the matrix entries

Where  $A[i[k], j[k]] = data[k]$ . When shape is not specified, it is inferred from the index arrays

### Notes

Sparse matrices can be used in arithmetic operations: they support addition, subtraction, multiplication, division, and matrix power.

### Advantages of the COO format

- facilitates fast conversion among sparse formats
- permits duplicate entries (see example)
- very fast conversion to and from CSR/CSC formats

### Disadvantages of the COO format

• *does not directly support:*

–arithmetic operations

–slicing

### Intended Usage

- COO is a fast format for constructing sparse matrices
- Once a matrix has been constructed, convert to CSR or CSC format for fast arithmetic and matrix vector operations
- By default when converting to CSR or CSC format, duplicate (i,j) entries will be summed together. This facilitates efficient construction of finite element matrices and the like. (see example)

**Examples**

```
>>> # Constructing an empty matrix
>>> from scipy.sparse import coo_matrix
>>> coo_matrix((3, 4), dtype=np.int8).toarray()
array([[0, 0, 0, 0],
       [0, 0, 0, 0],
       [0, 0, 0, 0]], dtype=int8)
```

```
>>> # Constructing a matrix using ijv format
>>> row = np.array([0, 3, 1, 0])
>>> col = np.array([0, 3, 1, 2])
>>> data = np.array([4, 5, 7, 9])
>>> coo_matrix((data, (row, col)), shape=(4, 4)).toarray()
array([[4, 0, 9, 0],
       [0, 7, 0, 0],
       [0, 0, 0, 0],
       [0, 0, 0, 5]])
```

```
>>> # Constructing a matrix with duplicate indices
>>> row = np.array([0, 0, 1, 3, 1, 0, 0])
>>> col = np.array([0, 2, 1, 3, 1, 0, 0])
>>> data = np.array([1, 1, 1, 1, 1, 1, 1])
>>> coo = coo_matrix((data, (row, col)), shape=(4, 4))
>>> # Duplicate indices are maintained until implicitly or explicitly summed
>>> np.max(coo.data)
1
>>> coo.toarray()
array([[3, 0, 1, 0],
       [0, 2, 0, 0],
       [0, 0, 0, 0],
       [0, 0, 0, 1]])
```

**Attributes**

<i>shape</i>	Get shape of a matrix.
<i>nnz</i>	Number of stored values, including explicit zeros.

`coo_matrix.shape`  
Get shape of a matrix.

`coo_matrix.nnz`  
Number of stored values, including explicit zeros.

**See also:**

`count_nonzero`  
Number of non-zero entries

<code>dtype</code>	(dtype) Data type of the matrix
<code>ndim</code>	(int) Number of dimensions (this is always 2)
<code>data</code>	COO format data array of the matrix
<code>row</code>	COO format row index array of the matrix
<code>col</code>	COO format column index array of the matrix

**Methods**

<i>arcsin()</i>	Element-wise arcsin.
<i>arcsinh()</i>	Element-wise arcsinh.
<i>arctan()</i>	Element-wise arctan.
<i>arctanh()</i>	Element-wise arctanh.
<i>argmax</i> ([axis, out])	Return indices of maximum elements along an axis.
<i>argmin</i> ([axis, out])	Return indices of minimum elements along an axis.
<i>asformat</i> (format)	Return this matrix in a given sparse format
<i>asfptype</i> ()	Upcast matrix to a floating point format (if necessary)
<i>astype</i> (dtype[, casting, copy])	Cast the matrix elements to a specified type.
<i>ceil</i> ()	Element-wise ceil.
<i>conj</i> ()	Element-wise complex conjugation.
<i>conjugate</i> ()	Element-wise complex conjugation.
<i>copy</i> ()	Returns a copy of this matrix.
<i>count_nonzero</i> ()	Number of non-zero entries, equivalent to
<i>deg2rad</i> ()	Element-wise deg2rad.
<i>diagonal</i> ([k])	Returns the k-th diagonal of the matrix.
<i>dot</i> (other)	Ordinary dot product
<i>eliminate_zeros</i> ()	Remove zero entries from the matrix
<i>expm1</i> ()	Element-wise expm1.
<i>floor</i> ()	Element-wise floor.
<i>getH</i> ()	Return the Hermitian transpose of this matrix.
<i>get_shape</i> ()	Get shape of a matrix.
<i>getcol</i> (j)	Returns a copy of column j of the matrix, as an (m x 1) sparse matrix (column vector).
<i>getformat</i> ()	Format of a matrix representation as a string.
<i>getmaxprint</i> ()	Maximum number of elements to display when printed.
<i>getnnz</i> ([axis])	Number of stored values, including explicit zeros.
<i>getrow</i> (i)	Returns a copy of row i of the matrix, as a (1 x n) sparse matrix (row vector).
<i>log1p</i> ()	Element-wise log1p.
<i>max</i> ([axis, out])	Return the maximum of the matrix or maximum along an axis.
<i>maximum</i> (other)	Element-wise maximum between this and another matrix.
<i>mean</i> ([axis, dtype, out])	Compute the arithmetic mean along the specified axis.
<i>min</i> ([axis, out])	Return the minimum of the matrix or maximum along an axis.
<i>minimum</i> (other)	Element-wise minimum between this and another matrix.
<i>multiply</i> (other)	Point-wise multiplication by another matrix
<i>nonzero</i> ()	nonzero indices
<i>power</i> (n[, dtype])	This function performs element-wise power.
<i>rad2deg</i> ()	Element-wise rad2deg.
<i>reshape</i> (shape[, order])	Gives a new shape to a sparse matrix without changing its data.
<i>rint</i> ()	Element-wise rint.
<i>set_shape</i> (shape)	See <i>reshape</i> .
<i>setdiag</i> (values[, k])	Set diagonal or off-diagonal elements of the array.
<i>sign</i> ()	Element-wise sign.
<i>sin</i> ()	Element-wise sin.

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<code>sinh()</code>	Element-wise sinh.
<code>sqrt()</code>	Element-wise sqrt.
<code>sum([axis, dtype, out])</code>	Sum the matrix elements over a given axis.
<code>sum_duplicates()</code>	Eliminate duplicate matrix entries by adding them together
<code>tan()</code>	Element-wise tan.
<code>tanh()</code>	Element-wise tanh.
<code>toarray([order, out])</code>	See the docstring for <code>spmatrix.toarray</code> .
<code>tobsr([blocksize, copy])</code>	Convert this matrix to Block Sparse Row format.
<code>tocoo([copy])</code>	Convert this matrix to COOrdinate format.
<code>tocsc([copy])</code>	Convert this matrix to Compressed Sparse Column format
<code>tocsr([copy])</code>	Convert this matrix to Compressed Sparse Row format
<code>todense([order, out])</code>	Return a dense matrix representation of this matrix.
<code>todia([copy])</code>	Convert this matrix to sparse DIAGONAL format.
<code>todok([copy])</code>	Convert this matrix to Dictionary Of Keys format.
<code>tolil([copy])</code>	Convert this matrix to LIInked List format.
<code>transpose([axes, copy])</code>	Reverses the dimensions of the sparse matrix.
<code>trunc()</code>	Element-wise trunc.

`coo_matrix.arcsin()`  
Element-wise arcsin.

See `numpy.arcsin` for more information.

`coo_matrix.arcsinh()`  
Element-wise arcsinh.

See `numpy.arcsinh` for more information.

`coo_matrix.arctan()`  
Element-wise arctan.

See `numpy.arctan` for more information.

`coo_matrix.arctanh()`  
Element-wise arctanh.

See `numpy.arctanh` for more information.

`coo_matrix.argmax(axis=None, out=None)`  
Return indices of maximum elements along an axis.

Implicit zero elements are also taken into account. If there are several maximum values, the index of the first occurrence is returned.

**Parameters** **axis** : {-2, -1, 0, 1, None}, optional  
Axis along which the argmax is computed. If None (default), index of the maximum element in the flattened data is returned.

**out** : None, optional  
This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns** **ind** : np.matrix of int  
Indices of maximum elements. If matrix, its size along *axis* is 1.

`coo_matrix.argmin(axis=None, out=None)`  
Return indices of minimum elements along an axis.

Implicit zero elements are also taken into account. If there are several minimum values, the index of the first occurrence is returned.

**Parameters** **axis** : {-2, -1, 0, 1, None}, optional  
 Axis along which the argmin is computed. If None (default), index of the minimum element in the flatten data is returned.

**out** : None, optional  
 This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns** **ind** : np.matrix or int  
 Indices of minimum elements. If matrix, its size along *axis* is 1.

`coo_matrix.asformat` (*format*)

Return this matrix in a given sparse format

**Parameters** **format** : {string, None}  
*desired sparse matrix format*

- None for no format conversion
- “csr” for csr\_matrix format
- “csc” for csc\_matrix format
- “lil” for lil\_matrix format
- “dok” for dok\_matrix format and so on

`coo_matrix.asfptype` ()

Upcast matrix to a floating point format (if necessary)

`coo_matrix.astype` (*dtype*, *casting*='unsafe', *copy*=True)

Cast the matrix elements to a specified type.

**Parameters** **dtype** : string or numpy dtype  
 Typecode or data-type to which to cast the data.

**casting** : {'no', 'equiv', 'safe', 'same\_kind', 'unsafe'}, optional  
 Controls what kind of data casting may occur. Defaults to 'unsafe' for backwards compatibility. 'no' means the data types should not be cast at all. 'equiv' means only byte-order changes are allowed. 'safe' means only casts which can preserve values are allowed. 'same\_kind' means only safe casts or casts within a kind, like float64 to float32, are allowed. 'unsafe' means any data conversions may be done.

**copy** : bool, optional  
 If *copy* is *False*, the result might share some memory with this matrix. If *copy* is *True*, it is guaranteed that the result and this matrix do not share any memory.

`coo_matrix.ceil` ()

Element-wise ceil.

See `numpy.ceil` for more information.

`coo_matrix.conj` ()

Element-wise complex conjugation.

If the matrix is of non-complex data type, then this method does nothing and the data is not copied.

`coo_matrix.conjugate` ()

Element-wise complex conjugation.

If the matrix is of non-complex data type, then this method does nothing and the data is not copied.

`coo_matrix.copy()`

Returns a copy of this matrix.

No data/indices will be shared between the returned value and current matrix.

`coo_matrix.count_nonzero()`

Number of non-zero entries, equivalent to

`np.count_nonzero(a.toarray())`

Unlike `getnnz()` and the `nnz` property, which return the number of stored entries (the length of the data attribute), this method counts the actual number of non-zero entries in data.

`coo_matrix.deg2rad()`

Element-wise `deg2rad`.

See `numpy.deg2rad` for more information.

`coo_matrix.diagonal(k=0)`

Returns the k-th diagonal of the matrix.

**Parameters** `k` : int, optional

Which diagonal to set, corresponding to elements `a[i, i+k]`. Default: 0 (the main diagonal).

**See also:**

[\*numpy.diagonal\*](#)

Equivalent numpy function.

#### Examples

```
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> A.diagonal()
array([1, 0, 5])
>>> A.diagonal(k=1)
array([2, 3])
```

`coo_matrix.dot(other)`

Ordinary dot product

#### Examples

```
>>> import numpy as np
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> v = np.array([1, 0, -1])
>>> A.dot(v)
array([ 1, -3, -1], dtype=int64)
```

`coo_matrix.eliminate_zeros()`

Remove zero entries from the matrix

This is an *in place* operation

`coo_matrix.expm1()`

Element-wise `expm1`.

See `numpy.expm1` for more information.

`coo_matrix.floor()`

Element-wise floor.

See `numpy.floor` for more information.

`coo_matrix.getH()`

Return the Hermitian transpose of this matrix.

**See also:**

**`np.matrix.getH`**

NumPy's implementation of `getH` for matrices

`coo_matrix.get_shape()`

Get shape of a matrix.

`coo_matrix.getcol(j)`

Returns a copy of column `j` of the matrix, as an  $(m \times 1)$  sparse matrix (column vector).

`coo_matrix.getformat()`

Format of a matrix representation as a string.

`coo_matrix.getmaxprint()`

Maximum number of elements to display when printed.

`coo_matrix.getnnz(axis=None)`

Number of stored values, including explicit zeros.

**Parameters** **axis** : None, 0, or 1

Select between the number of values across the whole matrix, in each column, or in each row.

**See also:**

**`count_nonzero`**

Number of non-zero entries

`coo_matrix.getrow(i)`

Returns a copy of row `i` of the matrix, as a  $(1 \times n)$  sparse matrix (row vector).

`coo_matrix.log1p()`

Element-wise `log1p`.

See `numpy.log1p` for more information.

`coo_matrix.max(axis=None, out=None)`

Return the maximum of the matrix or maximum along an axis. This takes all elements into account, not just the non-zero ones.

**Parameters** **axis** : {-2, -1, 0, 1, None} optional

Axis along which the sum is computed. The default is to compute the maximum over all the matrix elements, returning a scalar (i.e. `axis = None`).

**out** : None, optional

This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns** **amax** : `coo_matrix` or scalar

Maximum of `a`. If `axis` is None, the result is a scalar value. If `axis` is given, the result is a `sparse.coo_matrix` of dimension `a.ndim - 1`.

**See also:**

**`min`** The minimum value of a sparse matrix along a given axis.

**`np.matrix.max`**

NumPy's implementation of 'max' for matrices

`coo_matrix.maximum` (*other*)

Element-wise maximum between this and another matrix.

`coo_matrix.mean` (*axis=None, dtype=None, out=None*)

Compute the arithmetic mean along the specified axis.

Returns the average of the matrix elements. The average is taken over all elements in the matrix by default, otherwise over the specified axis. *float64* intermediate and return values are used for integer inputs.

**Parameters**

- axis** : {-2, -1, 0, 1, None} optional  
Axis along which the mean is computed. The default is to compute the mean of all elements in the matrix (i.e. *axis = None*).
- dtype** : data-type, optional  
Type to use in computing the mean. For integer inputs, the default is *float64*; for floating point inputs, it is the same as the input dtype.
- out** : np.matrix, optional  
Alternative output matrix in which to place the result. It must have the same shape as the expected output, but the type of the output values will be cast if necessary.

**Returns** **m** : np.matrix

**See also:**

**`np.matrix.mean`**

NumPy's implementation of 'mean' for matrices

`coo_matrix.min` (*axis=None, out=None*)

Return the minimum of the matrix or maximum along an axis. This takes all elements into account, not just the non-zero ones.

**Parameters**

- axis** : {-2, -1, 0, 1, None} optional  
Axis along which the sum is computed. The default is to compute the minimum over all the matrix elements, returning a scalar (i.e. *axis = None*).
- out** : None, optional  
This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns** **amin** : `coo_matrix` or scalar  
Minimum of *a*. If *axis* is None, the result is a scalar value. If *axis* is given, the result is a `sparse.coo_matrix` of dimension `a.ndim - 1`.

**See also:**

**max** The maximum value of a sparse matrix along a given axis.

**`np.matrix.min`**

NumPy's implementation of 'min' for matrices

`coo_matrix.minimum` (*other*)

Element-wise minimum between this and another matrix.

`coo_matrix.multiply` (*other*)

Point-wise multiplication by another matrix

`coo_matrix.nonzero` ()

nonzero indices

Returns a tuple of arrays (row,col) containing the indices of the non-zero elements of the matrix.

**Examples**

```
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> A.nonzero()
(array([0, 0, 1, 2, 2]), array([0, 1, 2, 0, 2]))
```

`coo_matrix.power` (*n*, *dtype=None*)

This function performs element-wise power.

**Parameters** **n** : *n* is a scalar  
**dtype** : If *dtype* is not specified, the current *dtype* will be preserved.

`coo_matrix.rad2deg` ()

Element-wise `rad2deg`.

See `numpy.rad2deg` for more information.

`coo_matrix.reshape` (*shape*, *order='C'*)

Gives a new shape to a sparse matrix without changing its data.

**Parameters** **shape** : length-2 tuple of ints  
 The new shape should be compatible with the original shape.  
**order** : 'C', optional  
 This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns** **reshaped\_matrix** : *self* with the new dimensions of *shape*

**See also:**

**`np.matrix.reshape`**

NumPy's implementation of 'reshape' for matrices

`coo_matrix.rint` ()

Element-wise `rint`.

See `numpy.rint` for more information.

`coo_matrix.set_shape` (*shape*)

See `reshape`.

`coo_matrix.setdiag` (*values*, *k=0*)

Set diagonal or off-diagonal elements of the array.

**Parameters** **values** : *array\_like*  
 New values of the diagonal elements.  
 Values may have any length. If the diagonal is longer than *values*, then the remaining diagonal entries will not be set. If *values* is longer than the diagonal, then the remaining values are ignored.  
 If a scalar value is given, all of the diagonal is set to it.

**k** : int, optional

Which off-diagonal to set, corresponding to elements `a[i,i+k]`. Default: 0 (the main diagonal).

`coo_matrix.sign` ()

Element-wise `sign`.

See `numpy.sign` for more information.

`coo_matrix.sin` ()

Element-wise `sin`.

See `numpy.sin` for more information.

`coo_matrix.sinh()`  
Element-wise `sinh`.

See `numpy.sinh` for more information.

`coo_matrix.sqrt()`  
Element-wise `sqrt`.

See `numpy.sqrt` for more information.

`coo_matrix.sum(axis=None, dtype=None, out=None)`  
Sum the matrix elements over a given axis.

**Parameters**

- axis** : {-2, -1, 0, 1, None} optional  
Axis along which the sum is computed. The default is to compute the sum of all the matrix elements, returning a scalar (i.e. *axis = None*).
- dtype** : dtype, optional  
The type of the returned matrix and of the accumulator in which the elements are summed. The dtype of *a* is used by default unless *a* has an integer dtype of less precision than the default platform integer. In that case, if *a* is signed then the platform integer is used while if *a* is unsigned then an unsigned integer of the same precision as the platform integer is used.
- out** : np.matrix, optional  
Alternative output matrix in which to place the result. It must have the same shape as the expected output, but the type of the output values will be cast if necessary.

**Returns**

**sum\_along\_axis** : np.matrix  
A matrix with the same shape as *self*, with the specified axis removed.

**See also:**

**`np.matrix.sum`**  
NumPy's implementation of 'sum' for matrices

`coo_matrix.sum_duplicates()`  
Eliminate duplicate matrix entries by adding them together

This is an *in place* operation

`coo_matrix.tan()`  
Element-wise `tan`.

See `numpy.tan` for more information.

`coo_matrix.tanh()`  
Element-wise `tanh`.

See `numpy.tanh` for more information.

`coo_matrix.toarray(order=None, out=None)`  
See the docstring for `spmatrix.toarray`.

`coo_matrix.tobsr(blocksize=None, copy=False)`  
Convert this matrix to Block Sparse Row format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `bsr_matrix`.

When `blocksize=(R, C)` is provided, it will be used for construction of the `bsr_matrix`.

`coo_matrix.tocoo` (*copy=False*)  
Convert this matrix to COOrdinate format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `coo_matrix`.

`coo_matrix.tocsc` (*copy=False*)  
Convert this matrix to Compressed Sparse Column format

Duplicate entries will be summed together.

### Examples

```
>>> from numpy import array
>>> from scipy.sparse import coo_matrix
>>> row = array([0, 0, 1, 3, 1, 0, 0])
>>> col = array([0, 2, 1, 3, 1, 0, 0])
>>> data = array([1, 1, 1, 1, 1, 1, 1])
>>> A = coo_matrix((data, (row, col)), shape=(4, 4)).tocsc()
>>> A.toarray()
array([[3, 0, 1, 0],
       [0, 2, 0, 0],
       [0, 0, 0, 0],
       [0, 0, 0, 1]])
```

`coo_matrix.tocsr` (*copy=False*)  
Convert this matrix to Compressed Sparse Row format

Duplicate entries will be summed together.

### Examples

```
>>> from numpy import array
>>> from scipy.sparse import coo_matrix
>>> row = array([0, 0, 1, 3, 1, 0, 0])
>>> col = array([0, 2, 1, 3, 1, 0, 0])
>>> data = array([1, 1, 1, 1, 1, 1, 1])
>>> A = coo_matrix((data, (row, col)), shape=(4, 4)).tocsr()
>>> A.toarray()
array([[3, 0, 1, 0],
       [0, 2, 0, 0],
       [0, 0, 0, 0],
       [0, 0, 0, 1]])
```

`coo_matrix.todense` (*order=None, out=None*)  
Return a dense matrix representation of this matrix.

**Parameters**    **order** : {'C', 'F'}, optional

Whether to store multi-dimensional data in C (row-major) or Fortran (column-major) order in memory. The default is 'None', indicating the NumPy default of C-ordered. Cannot be specified in conjunction with the *out* argument.

**out** : ndarray, 2-dimensional, optional

If specified, uses this array (or `numpy.matrix`) as the output buffer instead of allocating a new array to return. The provided array must have the same shape and dtype as the sparse matrix on which you are calling the method.

**Returns**        **arr** : `numpy.matrix`, 2-dimensional

A NumPy matrix object with the same shape and containing the same data represented by the sparse matrix, with the requested memory

order. If *out* was passed and was an array (rather than a `numpy.matrix`), it will be filled with the appropriate values and returned wrapped in a `numpy.matrix` object that shares the same memory.

`coo_matrix.todia (copy=False)`

Convert this matrix to sparse DIAgonal format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `dia_matrix`.

`coo_matrix.todok (copy=False)`

Convert this matrix to Dictionary Of Keys format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `dok_matrix`.

`coo_matrix.tolil (copy=False)`

Convert this matrix to LInked List format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `lil_matrix`.

`coo_matrix.transpose (axes=None, copy=False)`

Reverses the dimensions of the sparse matrix.

**Parameters** `axes` : None, optional

This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value.

`copy` : bool, optional

Indicates whether or not attributes of *self* should be copied whenever possible. The degree to which attributes are copied varies depending on the type of sparse matrix being used.

**Returns** `p` : *self* with the dimensions reversed.

**See also:**

**`np.matrix.transpose`**

NumPy's implementation of 'transpose' for matrices

`coo_matrix.trunc ()`

Element-wise trunc.

See `numpy.trunc` for more information.

**class** `scipy.sparse.csc_matrix (arg1, shape=None, dtype=None, copy=False)`

Compressed Sparse Column matrix

This can be instantiated in several ways:

`csc_matrix(D)` with a dense matrix or rank-2 ndarray *D*  
`csc_matrix(S)` with another sparse matrix *S* (equivalent to `S.tocsc()`)  
`csc_matrix((M, N), [dtype])`

to construct an empty matrix with shape (M, N) dtype is optional, defaulting to dtype='d'.  
`csc_matrix((data, (row_ind, col_ind)), [shape=(M, N)])`

where `data`, `row_ind` and `col_ind` satisfy the relationship `a[row_ind[k],`

`col_ind[k]] = data[k]`.  
`csc_matrix((data, indices, indptr), [shape=(M, N)])`

is the standard CSC representation where the row indices for column *i* are stored in `indices[indptr[i]:indptr[i+1]]` and their corresponding values are stored in `data[indptr[i]:indptr[i+1]]`. If the shape parameter is not supplied, the matrix dimensions are inferred from the index arrays.

**Notes**

Sparse matrices can be used in arithmetic operations: they support addition, subtraction, multiplication, division, and matrix power.

### Advantages of the CSC format

- efficient arithmetic operations  $CSC + CSC$ ,  $CSC * CSC$ , etc.
- efficient column slicing
- fast matrix vector products (CSR, BSR may be faster)

### Disadvantages of the CSC format

- slow row slicing operations (consider CSR)
- changes to the sparsity structure are expensive (consider LIL or DOK)

### Examples

```
>>> import numpy as np
>>> from scipy.sparse import csc_matrix
>>> csc_matrix((3, 4), dtype=np.int8).toarray()
array([[0, 0, 0, 0],
       [0, 0, 0, 0],
       [0, 0, 0, 0]], dtype=int8)
```

```
>>> row = np.array([0, 2, 2, 0, 1, 2])
>>> col = np.array([0, 0, 1, 2, 2, 2])
>>> data = np.array([1, 2, 3, 4, 5, 6])
>>> csc_matrix((data, (row, col)), shape=(3, 3)).toarray()
array([[1, 0, 4],
       [0, 0, 5],
       [2, 3, 6]])
```

```
>>> indptr = np.array([0, 2, 3, 6])
>>> indices = np.array([0, 2, 2, 0, 1, 2])
>>> data = np.array([1, 2, 3, 4, 5, 6])
>>> csc_matrix((data, indices, indptr), shape=(3, 3)).toarray()
array([[1, 0, 4],
       [0, 0, 5],
       [2, 3, 6]])
```

### Attributes

<code>shape</code>	Get shape of a matrix.
<code>nnz</code>	Number of stored values, including explicit zeros.
<code>has_sorted_indices</code>	Determine whether the matrix has sorted indices

`csc_matrix.shape`  
Get shape of a matrix.

`csc_matrix.nnz`  
Number of stored values, including explicit zeros.

#### See also:

`count_nonzero`  
Number of non-zero entries

`csc_matrix.has_sorted_indices`  
Determine whether the matrix has sorted indices

#### Returns

- True: if the indices of the matrix are in sorted order

•False: otherwise

<code>dtype</code>	(dtype) Data type of the matrix
<code>ndim</code>	(int) Number of dimensions (this is always 2)
<code>data</code>	Data array of the matrix
<code>indices</code>	CSC format index array
<code>indptr</code>	CSC format index pointer array

**Methods**

<code>arcsin()</code>	Element-wise arcsin.
<code>arcsinh()</code>	Element-wise arcsinh.
<code>arctan()</code>	Element-wise arctan.
<code>arctanh()</code>	Element-wise arctanh.
<code>argmax([axis, out])</code>	Return indices of maximum elements along an axis.
<code>argmin([axis, out])</code>	Return indices of minimum elements along an axis.
<code>asformat(format)</code>	Return this matrix in a given sparse format
<code>asfptype()</code>	Upcast matrix to a floating point format (if necessary)
<code>astype(dtype[, casting, copy])</code>	Cast the matrix elements to a specified type.
<code>ceil()</code>	Element-wise ceil.
<code>check_format([full_check])</code>	check whether the matrix format is valid
<code>conj()</code>	Element-wise complex conjugation.
<code>conjugate()</code>	Element-wise complex conjugation.
<code>copy()</code>	Returns a copy of this matrix.
<code>count_nonzero()</code>	Number of non-zero entries, equivalent to
<code>deg2rad()</code>	Element-wise deg2rad.
<code>diagonal([k])</code>	Returns the k-th diagonal of the matrix.
<code>dot(other)</code>	Ordinary dot product
<code>eliminate_zeros()</code>	Remove zero entries from the matrix
<code>expm1()</code>	Element-wise expm1.
<code>floor()</code>	Element-wise floor.
<code>getH()</code>	Return the Hermitian transpose of this matrix.
<code>get_shape()</code>	Get shape of a matrix.
<code>getcol(i)</code>	Returns a copy of column i of the matrix, as a (m x 1) CSC matrix (column vector).
<code>getformat()</code>	Format of a matrix representation as a string.
<code>getmaxprint()</code>	Maximum number of elements to display when printed.
<code>getnnz([axis])</code>	Number of stored values, including explicit zeros.
<code>getrow(i)</code>	Returns a copy of row i of the matrix, as a (1 x n) CSR matrix (row vector).
<code>log1p()</code>	Element-wise log1p.
<code>max([axis, out])</code>	Return the maximum of the matrix or maximum along an axis.
<code>maximum(other)</code>	Element-wise maximum between this and another matrix.
<code>mean([axis, dtype, out])</code>	Compute the arithmetic mean along the specified axis.
<code>min([axis, out])</code>	Return the minimum of the matrix or maximum along an axis.
<code>minimum(other)</code>	Element-wise minimum between this and another matrix.
<code>multiply(other)</code>	Point-wise multiplication by another matrix, vector, or scalar.

Continued on next page

Table 5.168 – continued from previous page

<code>nonzero()</code>	nonzero indices
<code>power(n[, dtype])</code>	This function performs element-wise power.
<code>prune()</code>	Remove empty space after all non-zero elements.
<code>rad2deg()</code>	Element-wise rad2deg.
<code>reshape(shape[, order])</code>	Gives a new shape to a sparse matrix without changing its data.
<code>rint()</code>	Element-wise rint.
<code>set_shape(shape)</code>	See <code>reshape</code> .
<code>setdiag(values[, k])</code>	Set diagonal or off-diagonal elements of the array.
<code>sign()</code>	Element-wise sign.
<code>sin()</code>	Element-wise sin.
<code>sinh()</code>	Element-wise sinh.
<code>sort_indices()</code>	Sort the indices of this matrix <i>in place</i>
<code>sorted_indices()</code>	Return a copy of this matrix with sorted indices
<code>sqrt()</code>	Element-wise sqrt.
<code>sum([axis, dtype, out])</code>	Sum the matrix elements over a given axis.
<code>sum_duplicates()</code>	Eliminate duplicate matrix entries by adding them together
<code>tan()</code>	Element-wise tan.
<code>tanh()</code>	Element-wise tanh.
<code>toarray([order, out])</code>	Return a dense ndarray representation of this matrix.
<code>tobsr([blocksize, copy])</code>	Convert this matrix to Block Sparse Row format.
<code>tocoo([copy])</code>	Convert this matrix to COOrdinate format.
<code>tocsc([copy])</code>	Convert this matrix to Compressed Sparse Column format.
<code>tocsr([copy])</code>	Convert this matrix to Compressed Sparse Row format.
<code>todense([order, out])</code>	Return a dense matrix representation of this matrix.
<code>todia([copy])</code>	Convert this matrix to sparse DIAgonal format.
<code>todok([copy])</code>	Convert this matrix to Dictionary Of Keys format.
<code>tolil([copy])</code>	Convert this matrix to LInked List format.
<code>transpose([axes, copy])</code>	Reverses the dimensions of the sparse matrix.
<code>trunc()</code>	Element-wise trunc.

`csc_matrix.arcsin()`

Element-wise arcsin.

See `numpy.arcsin` for more information.

`csc_matrix.arcsinh()`

Element-wise arcsinh.

See `numpy.arcsinh` for more information.

`csc_matrix.arctan()`

Element-wise arctan.

See `numpy.arctan` for more information.

`csc_matrix.arctanh()`

Element-wise arctanh.

See `numpy.arctanh` for more information.

`csc_matrix.argmax(axis=None, out=None)`

Return indices of maximum elements along an axis.

Implicit zero elements are also taken into account. If there are several maximum values, the index of the first occurrence is returned.

**Parameters** **axis** : {-2, -1, 0, 1, None}, optional  
 Axis along which the argmax is computed. If None (default), index of the maximum element in the flatten data is returned.

**out** : None, optional  
 This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns** **ind** : np.matrix or int  
 Indices of maximum elements. If matrix, its size along *axis* is 1.

`csc_matrix.argmax` (*axis=None, out=None*)

Return indices of minimum elements along an axis.

Implicit zero elements are also taken into account. If there are several minimum values, the index of the first occurrence is returned.

**Parameters** **axis** : {-2, -1, 0, 1, None}, optional  
 Axis along which the argmin is computed. If None (default), index of the minimum element in the flatten data is returned.

**out** : None, optional  
 This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns** **ind** : np.matrix or int  
 Indices of minimum elements. If matrix, its size along *axis* is 1.

`csc_matrix.asformat` (*format*)

Return this matrix in a given sparse format

**Parameters** **format** : {string, None}  
*desired sparse matrix format*

- None for no format conversion
- “csr” for csr\_matrix format
- “csc” for csc\_matrix format
- “lil” for lil\_matrix format
- “dok” for dok\_matrix format and so on

`csc_matrix.asfptype` ()

Upcast matrix to a floating point format (if necessary)

`csc_matrix.astype` (*dtype, casting='unsafe', copy=True*)

Cast the matrix elements to a specified type.

**Parameters** **dtype** : string or numpy dtype  
 Typecode or data-type to which to cast the data.

**casting** : {'no', 'equiv', 'safe', 'same\_kind', 'unsafe'}, optional  
 Controls what kind of data casting may occur. Defaults to 'unsafe' for backwards compatibility. 'no' means the data types should not be cast at all. 'equiv' means only byte-order changes are allowed. 'safe' means only casts which can preserve values are allowed. 'same\_kind' means only safe casts or casts within a kind, like float64 to float32, are allowed. 'unsafe' means any data conversions may be done.

**copy** : bool, optional

If *copy* is *False*, the result might share some memory with this matrix. If *copy* is *True*, it is guaranteed that the result and this matrix do not share any memory.

`csc_matrix.ceil()`  
Element-wise ceil.

See `numpy.ceil` for more information.

`csc_matrix.check_format` (*full\_check=True*)  
check whether the matrix format is valid

**Parameters** **full\_check** : bool, optional  
If *True*, rigorous check, O(N) operations. Otherwise basic check, O(1) operations (default *True*).

`csc_matrix.conj()`  
Element-wise complex conjugation.

If the matrix is of non-complex data type, then this method does nothing and the data is not copied.

`csc_matrix.conjugate()`  
Element-wise complex conjugation.

If the matrix is of non-complex data type, then this method does nothing and the data is not copied.

`csc_matrix.copy()`  
Returns a copy of this matrix.

No data/indices will be shared between the returned value and current matrix.

`csc_matrix.count_nonzero()`  
Number of non-zero entries, equivalent to  
`np.count_nonzero(a.toarray())`

Unlike `getnnz()` and the `nnz` property, which return the number of stored entries (the length of the data attribute), this method counts the actual number of non-zero entries in data.

`csc_matrix.deg2rad()`  
Element-wise `deg2rad`.

See `numpy.deg2rad` for more information.

`csc_matrix.diagonal` (*k=0*)  
Returns the *k*-th diagonal of the matrix.

**Parameters** **k** : int, optional  
Which diagonal to set, corresponding to elements `a[i, i+k]`. Default: 0 (the main diagonal).

**See also:**

[\*numpy.diagonal\*](#)  
Equivalent `numpy` function.

**Examples**

```
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> A.diagonal()
array([1, 0, 5])
>>> A.diagonal(k=1)
array([2, 3])
```

`csc_matrix.dot` (*other*)  
 Ordinary dot product

**Examples**

```
>>> import numpy as np
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> v = np.array([1, 0, -1])
>>> A.dot(v)
array([ 1, -3, -1], dtype=int64)
```

`csc_matrix.eliminate_zeros` ()  
 Remove zero entries from the matrix

This is an *in place* operation

`csc_matrix.expm1` ()  
 Element-wise expm1.

See `numpy.expm1` for more information.

`csc_matrix.floor` ()  
 Element-wise floor.

See `numpy.floor` for more information.

`csc_matrix.getH` ()  
 Return the Hermitian transpose of this matrix.

**See also:**

`np.matrix.getH`  
 NumPy's implementation of *getH* for matrices

`csc_matrix.get_shape` ()  
 Get shape of a matrix.

`csc_matrix.getcol` (*i*)  
 Returns a copy of column *i* of the matrix, as a (m x 1) CSC matrix (column vector).

`csc_matrix.getformat` ()  
 Format of a matrix representation as a string.

`csc_matrix.getmaxprint` ()  
 Maximum number of elements to display when printed.

`csc_matrix.getnnz` (*axis=None*)  
 Number of stored values, including explicit zeros.

**Parameters** `axis` : None, 0, or 1

Select between the number of values across the whole matrix, in each column, or in each row.

**See also:**

`count_nonzero`  
 Number of non-zero entries

`csc_matrix.getrow` (*i*)  
 Returns a copy of row *i* of the matrix, as a (1 x n) CSR matrix (row vector).

`csc_matrix.log1p()`  
Element-wise log1p.

See `numpy.log1p` for more information.

`csc_matrix.max` (*axis=None, out=None*)

Return the maximum of the matrix or maximum along an axis. This takes all elements into account, not just the non-zero ones.

**Parameters** **axis** : {-2, -1, 0, 1, None} optional  
Axis along which the sum is computed. The default is to compute the maximum over all the matrix elements, returning a scalar (i.e. *axis = None*).

**out** : None, optional  
This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns** **amax** : `coo_matrix` or scalar  
Maximum of *a*. If *axis* is None, the result is a scalar value. If *axis* is given, the result is a `sparse.coo_matrix` of dimension `a.ndim - 1`.

**See also:**

**min** The minimum value of a sparse matrix along a given axis.

**`np.matrix.max`**

NumPy's implementation of 'max' for matrices

`csc_matrix.maximum` (*other*)

Element-wise maximum between this and another matrix.

`csc_matrix.mean` (*axis=None, dtype=None, out=None*)

Compute the arithmetic mean along the specified axis.

Returns the average of the matrix elements. The average is taken over all elements in the matrix by default, otherwise over the specified axis. `float64` intermediate and return values are used for integer inputs.

**Parameters** **axis** : {-2, -1, 0, 1, None} optional  
Axis along which the mean is computed. The default is to compute the mean of all elements in the matrix (i.e. *axis = None*).

**dtype** : data-type, optional  
Type to use in computing the mean. For integer inputs, the default is `float64`; for floating point inputs, it is the same as the input dtype.

**out** : `np.matrix`, optional  
Alternative output matrix in which to place the result. It must have the same shape as the expected output, but the type of the output values will be cast if necessary.

**Returns** **m** : `np.matrix`

**See also:**

**`np.matrix.mean`**

NumPy's implementation of 'mean' for matrices

`csc_matrix.min` (*axis=None, out=None*)

Return the minimum of the matrix or maximum along an axis. This takes all elements into account, not just the non-zero ones.

**Parameters** **axis** : {-2, -1, 0, 1, None} optional  
Axis along which the sum is computed. The default is to compute the minimum over all the matrix elements, returning a scalar (i.e. *axis = None*).

**out** : None, optional

This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns**

**amin** : `coo_matrix` or scalar

Minimum of *a*. If *axis* is None, the result is a scalar value. If *axis* is given, the result is a `sparse.coo_matrix` of dimension `a.ndim - 1`.

**See also:**

**max** The maximum value of a sparse matrix along a given axis.

**`np.matrix.min`**

NumPy's implementation of 'min' for matrices

`csc_matrix.minimum` (*other*)

Element-wise minimum between this and another matrix.

`csc_matrix.multiply` (*other*)

Point-wise multiplication by another matrix, vector, or scalar.

`csc_matrix.nonzero` ()

nonzero indices

Returns a tuple of arrays (row,col) containing the indices of the non-zero elements of the matrix.

**Examples**

```
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> A.nonzero()
(array([0, 0, 1, 2, 2]), array([0, 1, 2, 0, 2]))
```

`csc_matrix.power` (*n*, *dtype=None*)

This function performs element-wise power.

**Parameters** **n** : *n* is a scalar

**dtype** : If *dtype* is not specified, the current *dtype* will be preserved.

`csc_matrix.prune` ()

Remove empty space after all non-zero elements.

`csc_matrix.rad2deg` ()

Element-wise rad2deg.

See `numpy.rad2deg` for more information.

`csc_matrix.reshape` (*shape*, *order='C'*)

Gives a new shape to a sparse matrix without changing its data.

**Parameters** **shape** : length-2 tuple of ints

The new shape should be compatible with the original shape.

**order** : 'C', optional

This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns** **reshaped\_matrix** : *self* with the new dimensions of *shape*

**See also:**

**`np.matrix.reshape`**

NumPy's implementation of 'reshape' for matrices

`csc_matrix.rint()`

Element-wise rint.

See `numpy rint` for more information.

`csc_matrix.set_shape(shape)`

See `reshape`.

`csc_matrix.setdiag(values, k=0)`

Set diagonal or off-diagonal elements of the array.

**Parameters** **values** : array\_like

New values of the diagonal elements.

Values may have any length. If the diagonal is longer than values, then the remaining diagonal entries will not be set. If values is longer than the diagonal, then the remaining values are ignored.

If a scalar value is given, all of the diagonal is set to it.

**k** : int, optional

Which off-diagonal to set, corresponding to elements `a[i,i+k]`. Default: 0 (the main diagonal).

`csc_matrix.sign()`

Element-wise sign.

See `numpy.sign` for more information.

`csc_matrix.sin()`

Element-wise sin.

See `numpy.sin` for more information.

`csc_matrix.sinh()`

Element-wise sinh.

See `numpy.sinh` for more information.

`csc_matrix.sort_indices()`

Sort the indices of this matrix *in place*

`csc_matrix.sorted_indices()`

Return a copy of this matrix with sorted indices

`csc_matrix.sqrt()`

Element-wise sqrt.

See `numpy.sqrt` for more information.

`csc_matrix.sum(axis=None, dtype=None, out=None)`

Sum the matrix elements over a given axis.

**Parameters** **axis** : {-2, -1, 0, 1, None} optional

Axis along which the sum is computed. The default is to compute the sum of all the matrix elements, returning a scalar (i.e. `axis = None`).

**dtype** : dtype, optional

The type of the returned matrix and of the accumulator in which the elements are summed. The dtype of `a` is used by default unless `a` has an integer dtype of less precision than the default platform integer. In that case, if `a` is signed then the platform integer is used while if `a` is unsigned then an unsigned integer of the same precision as the platform integer is used.

**out** : np.matrix, optional

**Returns** `sum_along_axis`: `np.matrix`  
 Alternative output matrix in which to place the result. It must have the same shape as the expected output, but the type of the output values will be cast if necessary.  
 A matrix with the same shape as *self*, with the specified axis removed.

**See also:**

`np.matrix.sum`

NumPy's implementation of 'sum' for matrices

`csc_matrix.sum_duplicates()`

Eliminate duplicate matrix entries by adding them together

The is an *in place* operation

`csc_matrix.tan()`

Element-wise tan.

See `numpy.tan` for more information.

`csc_matrix.tanh()`

Element-wise tanh.

See `numpy.tanh` for more information.

`csc_matrix.toarray (order=None, out=None)`

Return a dense ndarray representation of this matrix.

**Parameters** `order` : {'C', 'F'}, optional

Whether to store multi-dimensional data in C (row-major) or Fortran (column-major) order in memory. The default is 'None', indicating the NumPy default of C-ordered. Cannot be specified in conjunction with the *out* argument.

`out` : ndarray, 2-dimensional, optional

If specified, uses this array as the output buffer instead of allocating a new array to return. The provided array must have the same shape and dtype as the sparse matrix on which you are calling the method. For most sparse types, *out* is required to be memory contiguous (either C or Fortran ordered).

**Returns** `arr` : ndarray, 2-dimensional

An array with the same shape and containing the same data represented by the sparse matrix, with the requested memory order. If *out* was passed, the same object is returned after being modified in-place to contain the appropriate values.

`csc_matrix.tobsr (blocksize=None, copy=False)`

Convert this matrix to Block Sparse Row format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `bsr_matrix`.

When `blocksize=(R, C)` is provided, it will be used for construction of the `bsr_matrix`.

`csc_matrix.tocoo (copy=True)`

Convert this matrix to COOrdinate format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `coo_matrix`.

`csc_matrix.tocsc (copy=False)`

Convert this matrix to Compressed Sparse Column format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `csc_matrix`.

`csc_matrix.tocsr` (*copy=False*)

Convert this matrix to Compressed Sparse Row format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `csr_matrix`.

`csc_matrix.todense` (*order=None, out=None*)

Return a dense matrix representation of this matrix.

**Parameters**    **order** : {'C', 'F'}, optional

Whether to store multi-dimensional data in C (row-major) or Fortran (column-major) order in memory. The default is 'None', indicating the NumPy default of C-ordered. Cannot be specified in conjunction with the *out* argument.

**out** : ndarray, 2-dimensional, optional

If specified, uses this array (or `numpy.matrix`) as the output buffer instead of allocating a new array to return. The provided array must have the same shape and dtype as the sparse matrix on which you are

**Returns**        **arr** : `numpy.matrix`, 2-dimensional

A NumPy matrix object with the same shape and containing the same data represented by the sparse matrix, with the requested memory order. If *out* was passed and was an array (rather than a `numpy.matrix`), it will be filled with the appropriate values and returned wrapped in a `numpy.matrix` object that shares the same memory.

`csc_matrix.todia` (*copy=False*)

Convert this matrix to sparse DIAgonal format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `dia_matrix`.

`csc_matrix.todok` (*copy=False*)

Convert this matrix to Dictionary Of Keys format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `dok_matrix`.

`csc_matrix.tolil` (*copy=False*)

Convert this matrix to LInked List format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `lil_matrix`.

`csc_matrix.transpose` (*axes=None, copy=False*)

Reverses the dimensions of the sparse matrix.

**Parameters**    **axes** : None, optional

This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value.

**copy** : bool, optional

Indicates whether or not attributes of *self* should be copied whenever possible. The degree to which attributes are copied varies depending on the type of sparse matrix being used.

**Returns**        **p** : *self* with the dimensions reversed.

**See also:**

**`np.matrix.transpose`**

NumPy's implementation of 'transpose' for matrices

`csc_matrix.trunc` ()

Element-wise trunc.

See `numpy.trunc` for more information.

**class** `scipy.sparse.csr_matrix` (*arg1*, *shape=None*, *dtype=None*, *copy=False*)  
Compressed Sparse Row matrix

*This can be instantiated in several ways:*

`csr_matrix(D)` with a dense matrix or rank-2 ndarray *D*

`csr_matrix(S)` with another sparse matrix *S* (equivalent to `S.tocsr()`)

`csr_matrix((M, N), [dtype])`

to construct an empty matrix with shape *(M, N)* *dtype* is optional, defaulting to `dtype='d'`.

`csr_matrix((data, (row_ind, col_ind)), [shape=(M, N)])`

where *data*, *row\_ind* and *col\_ind* satisfy the relationship `a[row_ind[k], col_ind[k]] = data[k]`.

`csr_matrix((data, indices, indptr), [shape=(M, N)])`

is the standard CSR representation where the column indices for row *i* are stored in `indices[indptr[i]:indptr[i+1]]` and their corresponding values are stored in `data[indptr[i]:indptr[i+1]]`. If the *shape* parameter is not supplied, the matrix dimensions are inferred from the index arrays.

### Notes

Sparse matrices can be used in arithmetic operations: they support addition, subtraction, multiplication, division, and matrix power.

#### Advantages of the CSR format

- efficient arithmetic operations CSR + CSR, CSR \* CSR, etc.
- efficient row slicing
- fast matrix vector products

#### Disadvantages of the CSR format

- slow column slicing operations (consider CSC)
- changes to the sparsity structure are expensive (consider LIL or DOK)

### Examples

```
>>> import numpy as np
>>> from scipy.sparse import csr_matrix
>>> csr_matrix((3, 4), dtype=np.int8).toarray()
array([[0, 0, 0, 0],
       [0, 0, 0, 0],
       [0, 0, 0, 0]], dtype=int8)
```

```
>>> row = np.array([0, 0, 1, 2, 2, 2])
>>> col = np.array([0, 2, 2, 0, 1, 2])
>>> data = np.array([1, 2, 3, 4, 5, 6])
>>> csr_matrix((data, (row, col)), shape=(3, 3)).toarray()
array([[1, 0, 2],
       [0, 0, 3],
       [4, 5, 6]])
```

```
>>> indptr = np.array([0, 2, 3, 6])
>>> indices = np.array([0, 2, 2, 0, 1, 2])
>>> data = np.array([1, 2, 3, 4, 5, 6])
>>> csr_matrix((data, indices, indptr), shape=(3, 3)).toarray()
array([[1, 0, 2],
       [0, 0, 3],
       [4, 5, 6]])
```

As an example of how to construct a CSR matrix incrementally, the following snippet builds a term-document matrix from texts:

```
>>> docs = [["hello", "world", "hello"], ["goodbye", "cruel", "world"]]
>>> indptr = [0]
>>> indices = []
>>> data = []
>>> vocabulary = {}
>>> for d in docs:
...     for term in d:
...         index = vocabulary.setdefault(term, len(vocabulary))
...         indices.append(index)
...         data.append(1)
...         indptr.append(len(indices))
...
>>> csr_matrix((data, indices, indptr), dtype=int).toarray()
array([[2, 1, 0, 0],
       [0, 1, 1, 1]])
```

### Attributes

<i>shape</i>	Get shape of a matrix.
<i>nnz</i>	Number of stored values, including explicit zeros.
<i>has_sorted_indices</i>	Determine whether the matrix has sorted indices

`csr_matrix.shape`  
Get shape of a matrix.

`csr_matrix.nnz`  
Number of stored values, including explicit zeros.

#### See also:

**count\_nonzero**  
Number of non-zero entries

`csr_matrix.has_sorted_indices`  
Determine whether the matrix has sorted indices

#### Returns

- True: if the indices of the matrix are in sorted order
- False: otherwise

<code>dtype</code>	(dtype) Data type of the matrix
<code>ndim</code>	(int) Number of dimensions (this is always 2)
<code>data</code>	CSR format data array of the matrix
<code>indices</code>	CSR format index array of the matrix
<code>indptr</code>	CSR format index pointer array of the matrix

### Methods

<code>arcsin()</code>	Element-wise arcsin.
<code>arcsinh()</code>	Element-wise arcsinh.
<code>arctan()</code>	Element-wise arctan.
<code>arctanh()</code>	Element-wise arctanh.
<code>argmax([axis, out])</code>	Return indices of maximum elements along an axis.

Continued on next page

Table 5.170 – continued from previous page

<code>argmin([axis, out])</code>	Return indices of minimum elements along an axis.
<code>asformat(format)</code>	Return this matrix in a given sparse format
<code>asfptype()</code>	Upcast matrix to a floating point format (if necessary)
<code>astype(dtype[, casting, copy])</code>	Cast the matrix elements to a specified type.
<code>ceil()</code>	Element-wise ceil.
<code>check_format([full_check])</code>	check whether the matrix format is valid
<code>conj()</code>	Element-wise complex conjugation.
<code>conjugate()</code>	Element-wise complex conjugation.
<code>copy()</code>	Returns a copy of this matrix.
<code>count_nonzero()</code>	Number of non-zero entries, equivalent to
<code>deg2rad()</code>	Element-wise deg2rad.
<code>diagonal([k])</code>	Returns the k-th diagonal of the matrix.
<code>dot(other)</code>	Ordinary dot product
<code>eliminate_zeros()</code>	Remove zero entries from the matrix
<code>expm1()</code>	Element-wise expm1.
<code>floor()</code>	Element-wise floor.
<code>getH()</code>	Return the Hermitian transpose of this matrix.
<code>get_shape()</code>	Get shape of a matrix.
<code>getcol(i)</code>	Returns a copy of column i of the matrix, as a (m x 1) CSR matrix (column vector).
<code>getformat()</code>	Format of a matrix representation as a string.
<code>getmaxprint()</code>	Maximum number of elements to display when printed.
<code>getnnz([axis])</code>	Number of stored values, including explicit zeros.
<code>getrow(i)</code>	Returns a copy of row i of the matrix, as a (1 x n) CSR matrix (row vector).
<code>log1p()</code>	Element-wise log1p.
<code>max([axis, out])</code>	Return the maximum of the matrix or maximum along an axis.
<code>maximum(other)</code>	Element-wise maximum between this and another matrix.
<code>mean([axis, dtype, out])</code>	Compute the arithmetic mean along the specified axis.
<code>min([axis, out])</code>	Return the minimum of the matrix or maximum along an axis.
<code>minimum(other)</code>	Element-wise minimum between this and another matrix.
<code>multiply(other)</code>	Point-wise multiplication by another matrix, vector, or scalar.
<code>nonzero()</code>	nonzero indices
<code>power(n[, dtype])</code>	This function performs element-wise power.
<code>prune()</code>	Remove empty space after all non-zero elements.
<code>rad2deg()</code>	Element-wise rad2deg.
<code>reshape(shape[, order])</code>	Gives a new shape to a sparse matrix without changing its data.
<code>rint()</code>	Element-wise rint.
<code>set_shape(shape)</code>	See <i>reshape</i> .
<code>setdiag(values[, k])</code>	Set diagonal or off-diagonal elements of the array.
<code>sign()</code>	Element-wise sign.
<code>sin()</code>	Element-wise sin.
<code>sinh()</code>	Element-wise sinh.
<code>sort_indices()</code>	Sort the indices of this matrix <i>in place</i>

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Table 5.170 – continued from previous page

<code>sorted_indices()</code>	Return a copy of this matrix with sorted indices
<code>sqrt()</code>	Element-wise sqrt.
<code>sum([axis, dtype, out])</code>	Sum the matrix elements over a given axis.
<code>sum_duplicates()</code>	Eliminate duplicate matrix entries by adding them together
<code>tan()</code>	Element-wise tan.
<code>tanh()</code>	Element-wise tanh.
<code>toarray([order, out])</code>	Return a dense ndarray representation of this matrix.
<code>tobsr([blocksize, copy])</code>	Convert this matrix to Block Sparse Row format.
<code>tocoo([copy])</code>	Convert this matrix to COOrdinate format.
<code>tocsc([copy])</code>	Convert this matrix to Compressed Sparse Column format.
<code>tocsr([copy])</code>	Convert this matrix to Compressed Sparse Row format.
<code>todense([order, out])</code>	Return a dense matrix representation of this matrix.
<code>todia([copy])</code>	Convert this matrix to sparse DIagonal format.
<code>todok([copy])</code>	Convert this matrix to Dictionary Of Keys format.
<code>tolil([copy])</code>	Convert this matrix to LInked List format.
<code>transpose([axes, copy])</code>	Reverses the dimensions of the sparse matrix.
<code>trunc()</code>	Element-wise trunc.

`csr_matrix.arcsin()`  
Element-wise arcsin.

See `numpy.arcsin` for more information.

`csr_matrix.arcsinh()`  
Element-wise arcsinh.

See `numpy.arcsinh` for more information.

`csr_matrix.arctan()`  
Element-wise arctan.

See `numpy.arctan` for more information.

`csr_matrix.arctanh()`  
Element-wise arctanh.

See `numpy.arctanh` for more information.

`csr_matrix.argmax(axis=None, out=None)`  
Return indices of maximum elements along an axis.

Implicit zero elements are also taken into account. If there are several maximum values, the index of the first occurrence is returned.

**Parameters** `axis` : {-2, -1, 0, 1, None}, optional  
Axis along which the argmax is computed. If None (default), index of the maximum element in the flatten data is returned.

`out` : None, optional  
This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns** `ind` : np.matrix or int  
Indices of maximum elements. If matrix, its size along `axis` is 1.

`csr_matrix.argmin(axis=None, out=None)`  
Return indices of minimum elements along an axis.

Implicit zero elements are also taken into account. If there are several minimum values, the index of the first occurrence is returned.

**Parameters** **axis** : {-2, -1, 0, 1, None}, optional  
 Axis along which the argmin is computed. If None (default), index of the minimum element in the flatten data is returned.

**out** : None, optional  
 This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns** **ind** : np.matrix or int  
 Indices of minimum elements. If matrix, its size along *axis* is 1.

`csr_matrix.asformat` (*format*)

Return this matrix in a given sparse format

**Parameters** **format** : {string, None}  
*desired sparse matrix format*

- None for no format conversion
- “csr” for csr\_matrix format
- “csc” for csc\_matrix format
- “lil” for lil\_matrix format
- “dok” for dok\_matrix format and so on

`csr_matrix.asfptype` ()

Upcast matrix to a floating point format (if necessary)

`csr_matrix.astype` (*dtype*, *casting='unsafe'*, *copy=True*)

Cast the matrix elements to a specified type.

**Parameters** **dtype** : string or numpy dtype  
 Typecode or data-type to which to cast the data.

**casting** : {'no', 'equiv', 'safe', 'same\_kind', 'unsafe'}, optional  
 Controls what kind of data casting may occur. Defaults to 'unsafe' for backwards compatibility. 'no' means the data types should not be cast at all. 'equiv' means only byte-order changes are allowed. 'safe' means only casts which can preserve values are allowed. 'same\_kind' means only safe casts or casts within a kind, like float64 to float32, are allowed. 'unsafe' means any data conversions may be done.

**copy** : bool, optional  
 If *copy* is *False*, the result might share some memory with this matrix. If *copy* is *True*, it is guaranteed that the result and this matrix do not share any memory.

`csr_matrix.ceil` ()

Element-wise ceil.

See `numpy.ceil` for more information.

`csr_matrix.check_format` (*full\_check=True*)

check whether the matrix format is valid

**Parameters** **full\_check** : bool, optional  
 If *True*, rigorous check, O(N) operations. Otherwise basic check, O(1) operations (default *True*).

`csr_matrix.conj` ()

Element-wise complex conjugation.

If the matrix is of non-complex data type, then this method does nothing and the data is not copied.

`csr_matrix.conjugate()`  
Element-wise complex conjugation.

If the matrix is of non-complex data type, then this method does nothing and the data is not copied.

`csr_matrix.copy()`  
Returns a copy of this matrix.  
No data/indices will be shared between the returned value and current matrix.

`csr_matrix.count_nonzero()`  
Number of non-zero entries, equivalent to  
`np.count_nonzero(a.toarray())`

Unlike `getnnz()` and the `nnz` property, which return the number of stored entries (the length of the data attribute), this method counts the actual number of non-zero entries in data.

`csr_matrix.deg2rad()`  
Element-wise `deg2rad`.  
See `numpy.deg2rad` for more information.

`csr_matrix.diagonal(k=0)`  
Returns the k-th diagonal of the matrix.

**Parameters** `k` : int, optional  
Which diagonal to set, corresponding to elements `a[i, i+k]`. Default: 0 (the main diagonal).

**See also:**

`numpy.diagonal`  
Equivalent numpy function.

**Examples**

```
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> A.diagonal()
array([1, 0, 5])
>>> A.diagonal(k=1)
array([2, 3])
```

`csr_matrix.dot(other)`  
Ordinary dot product

**Examples**

```
>>> import numpy as np
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> v = np.array([1, 0, -1])
>>> A.dot(v)
array([ 1, -3, -1], dtype=int64)
```

`csr_matrix.eliminate_zeros()`  
Remove zero entries from the matrix  
This is an *in place* operation

`csr_matrix.expml()`  
Element-wise `expml`.

See `numpy.expml` for more information.

`csr_matrix.floor()`  
Element-wise `floor`.

See `numpy.floor` for more information.

`csr_matrix.getH()`  
Return the Hermitian transpose of this matrix.

**See also:**

**`np.matrix.getH`**  
NumPy's implementation of `getH` for matrices

`csr_matrix.get_shape()`  
Get shape of a matrix.

`csr_matrix.getcol(i)`  
Returns a copy of column `i` of the matrix, as a (`m` x 1) CSR matrix (column vector).

`csr_matrix.getformat()`  
Format of a matrix representation as a string.

`csr_matrix.getmaxprint()`  
Maximum number of elements to display when printed.

`csr_matrix.getnnz(axis=None)`  
Number of stored values, including explicit zeros.

**Parameters** **axis** : None, 0, or 1  
Select between the number of values across the whole matrix, in each column, or in each row.

**See also:**

**`count_nonzero`**  
Number of non-zero entries

`csr_matrix.getrow(i)`  
Returns a copy of row `i` of the matrix, as a (1 x `n`) CSR matrix (row vector).

`csr_matrix.log1p()`  
Element-wise `log1p`.

See `numpy.log1p` for more information.

`csr_matrix.max(axis=None, out=None)`  
Return the maximum of the matrix or maximum along an axis. This takes all elements into account, not just the non-zero ones.

**Parameters** **axis** : {-2, -1, 0, 1, None} optional  
Axis along which the sum is computed. The default is to compute the maximum over all the matrix elements, returning a scalar (i.e. `axis = None`).

**out** : None, optional  
This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns** **amax** : `coo_matrix` or scalar

Maximum of  $a$ . If  $axis$  is `None`, the result is a scalar value. If  $axis$  is given, the result is a `sparse.coo_matrix` of dimension `a.ndim - 1`.

**See also:**

**min** The minimum value of a sparse matrix along a given axis.

**`np.matrix.max`**

NumPy's implementation of 'max' for matrices

`csr_matrix.maximum` (*other*)

Element-wise maximum between this and another matrix.

`csr_matrix.mean` ( $axis=None$ ,  $dtype=None$ ,  $out=None$ )

Compute the arithmetic mean along the specified axis.

Returns the average of the matrix elements. The average is taken over all elements in the matrix by default, otherwise over the specified axis. `float64` intermediate and return values are used for integer inputs.

**Parameters** **axis** : {-2, -1, 0, 1, None} optional

Axis along which the mean is computed. The default is to compute the mean of all elements in the matrix (i.e.  $axis = None$ ).

**dtype** : data-type, optional

Type to use in computing the mean. For integer inputs, the default is `float64`; for floating point inputs, it is the same as the input dtype.

**out** : `np.matrix`, optional

Alternative output matrix in which to place the result. It must have the same shape as the expected output, but the type of the output values will be cast if necessary.

**Returns** **m** : `np.matrix`

**See also:**

**`np.matrix.mean`**

NumPy's implementation of 'mean' for matrices

`csr_matrix.min` ( $axis=None$ ,  $out=None$ )

Return the minimum of the matrix or maximum along an axis. This takes all elements into account, not just the non-zero ones.

**Parameters** **axis** : {-2, -1, 0, 1, None} optional

Axis along which the sum is computed. The default is to compute the minimum over all the matrix elements, returning a scalar (i.e.  $axis = None$ ).

**out** : None, optional

This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns** **amin** : `coo_matrix` or scalar

Minimum of  $a$ . If  $axis$  is `None`, the result is a scalar value. If  $axis$  is given, the result is a `sparse.coo_matrix` of dimension `a.ndim - 1`.

**See also:**

**max** The maximum value of a sparse matrix along a given axis.

**`np.matrix.min`**

NumPy's implementation of 'min' for matrices

`csr_matrix.minimum` (*other*)

Element-wise minimum between this and another matrix.

`csr_matrix.multiply` (*other*)

Point-wise multiplication by another matrix, vector, or scalar.

`csr_matrix.nonzero()`  
 nonzero indices

Returns a tuple of arrays (row,col) containing the indices of the non-zero elements of the matrix.

**Examples**

```
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1,2,0],[0,0,3],[4,0,5]])
>>> A.nonzero()
(array([0, 0, 1, 2, 2]), array([0, 1, 2, 0, 2]))
```

`csr_matrix.power(n, dtype=None)`  
 This function performs element-wise power.

**Parameters** **n** : n is a scalar  
**dtype** : If dtype is not specified, the current dtype will be preserved.

`csr_matrix.prune()`  
 Remove empty space after all non-zero elements.

`csr_matrix.rad2deg()`  
 Element-wise rad2deg.  
 See `numpy.rad2deg` for more information.

`csr_matrix.reshape(shape, order='C')`  
 Gives a new shape to a sparse matrix without changing its data.

**Parameters** **shape** : length-2 tuple of ints  
 The new shape should be compatible with the original shape.  
**order** : 'C', optional  
 This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns** **reshaped\_matrix** : *self* with the new dimensions of *shape*

**See also:**

**`np.matrix.reshape`**  
 NumPy's implementation of 'reshape' for matrices

`csr_matrix.rint()`  
 Element-wise rint.  
 See `numpy.rint` for more information.

`csr_matrix.set_shape(shape)`  
 See `reshape`.

`csr_matrix.setdiag(values, k=0)`  
 Set diagonal or off-diagonal elements of the array.

**Parameters** **values** : array\_like  
 New values of the diagonal elements.  
 Values may have any length. If the diagonal is longer than values, then the remaining diagonal entries will not be set. If values if longer than the diagonal, then the remaining values are ignored.  
 If a scalar value is given, all of the diagonal is set to it.

**k** : int, optional  
 Which off-diagonal to set, corresponding to elements `a[i,i+k]`. Default: 0 (the main diagonal).

`csr_matrix.sign()`  
Element-wise sign.

See `numpy.sign` for more information.

`csr_matrix.sin()`  
Element-wise sin.

See `numpy.sin` for more information.

`csr_matrix.sinh()`  
Element-wise sinh.

See `numpy.sinh` for more information.

`csr_matrix.sort_indices()`  
Sort the indices of this matrix *in place*

`csr_matrix.sorted_indices()`  
Return a copy of this matrix with sorted indices

`csr_matrix.sqrt()`  
Element-wise sqrt.

See `numpy.sqrt` for more information.

`csr_matrix.sum(axis=None, dtype=None, out=None)`  
Sum the matrix elements over a given axis.

**Parameters** **axis** : {-2, -1, 0, 1, None} optional

Axis along which the sum is computed. The default is to compute the sum of all the matrix elements, returning a scalar (i.e. *axis = None*).

**dtype** : dtype, optional

The type of the returned matrix and of the accumulator in which the elements are summed. The dtype of *a* is used by default unless *a* has an integer dtype of less precision than the default platform integer. In that case, if *a* is signed then the platform integer is used while if *a* is unsigned then an unsigned integer of the same precision as the platform integer is used.

**out** : np.matrix, optional

Alternative output matrix in which to place the result. It must have the same shape as the expected output, but the type of the output values will be cast if necessary.

**Returns** **sum\_along\_axis** : np.matrix

A matrix with the same shape as *self*, with the specified axis removed.

**See also:**

**`np.matrix.sum`**

NumPy's implementation of 'sum' for matrices

`csr_matrix.sum_duplicates()`  
Eliminate duplicate matrix entries by adding them together

This is an *in place* operation

`csr_matrix.tan()`  
Element-wise tan.

See `numpy.tan` for more information.

`csr_matrix.tanh()`  
Element-wise tanh.

See `numpy.tanh` for more information.

`csr_matrix.toarray` (*order=None, out=None*)

Return a dense ndarray representation of this matrix.

**Parameters** **order** : {'C', 'F'}, optional

Whether to store multi-dimensional data in C (row-major) or Fortran (column-major) order in memory. The default is 'None', indicating the NumPy default of C-ordered. Cannot be specified in conjunction with the *out* argument.

**out** : ndarray, 2-dimensional, optional

If specified, uses this array as the output buffer instead of allocating a new array to return. The provided array must have the same shape and dtype as the sparse matrix on which you are calling the method. For most sparse types, *out* is required to be memory contiguous (either C or Fortran ordered).

**Returns** **arr** : ndarray, 2-dimensional

An array with the same shape and containing the same data represented by the sparse matrix, with the requested memory order. If *out* was passed, the same object is returned after being modified in-place to contain the appropriate values.

`csr_matrix.tobsr` (*blocksize=None, copy=True*)

Convert this matrix to Block Sparse Row format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `bsr_matrix`.

When *blocksize=(R, C)* is provided, it will be used for construction of the `bsr_matrix`.

`csr_matrix.tocoo` (*copy=True*)

Convert this matrix to COOrdinate format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `coo_matrix`.

`csr_matrix.tocsc` (*copy=False*)

Convert this matrix to Compressed Sparse Column format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `csc_matrix`.

`csr_matrix.tocsr` (*copy=False*)

Convert this matrix to Compressed Sparse Row format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `csr_matrix`.

`csr_matrix.todense` (*order=None, out=None*)

Return a dense matrix representation of this matrix.

**Parameters** **order** : {'C', 'F'}, optional

Whether to store multi-dimensional data in C (row-major) or Fortran (column-major) order in memory. The default is 'None', indicating the NumPy default of C-ordered. Cannot be specified in conjunction with the *out* argument.

**out** : ndarray, 2-dimensional, optional

If specified, uses this array (or `numpy.matrix`) as the output buffer instead of allocating a new array to return. The provided array must have the same shape and dtype as the sparse matrix on which you are calling the method.

**Returns** **arr** : `numpy.matrix`, 2-dimensional

A NumPy matrix object with the same shape and containing the same data represented by the sparse matrix, with the requested memory

order. If *out* was passed and was an array (rather than a `numpy.matrix`), it will be filled with the appropriate values and returned wrapped in a `numpy.matrix` object that shares the same memory.

`csr_matrix.todia` (*copy=False*)

Convert this matrix to sparse DIAgonal format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `dia_matrix`.

`csr_matrix.todok` (*copy=False*)

Convert this matrix to Dictionary Of Keys format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `dok_matrix`.

`csr_matrix.tolil` (*copy=False*)

Convert this matrix to LInked List format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `lil_matrix`.

`csr_matrix.transpose` (*axes=None, copy=False*)

Reverses the dimensions of the sparse matrix.

**Parameters** *axes* : None, optional

This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value.

*copy* : bool, optional

Indicates whether or not attributes of *self* should be copied whenever possible. The degree to which attributes are copied varies depending on the type of sparse matrix being used.

**Returns** *p* : *self* with the dimensions reversed.

**See also:**

`np.matrix.transpose`

NumPy's implementation of 'transpose' for matrices

`csr_matrix.trunc` ()

Element-wise trunc.

See `numpy.trunc` for more information.

**class** `scipy.sparse.dia_matrix` (*arg1, shape=None, dtype=None, copy=False*)

Sparse matrix with DIAgonal storage

*This can be instantiated in several ways:*

`dia_matrix(D)` with a dense matrix

`dia_matrix(S)` with another sparse matrix *S* (equivalent to `S.todia()`)

`dia_matrix((M, N), [dtype])`

to construct an empty matrix with shape (M, N), *dtype* is optional, defaulting to `dtype='d'`.

`dia_matrix((data, offsets), shape=(M, N))`

where the `data[k, :]` stores the diagonal entries for diagonal `offsets[k]` (See example below)

**Notes**

Sparse matrices can be used in arithmetic operations: they support addition, subtraction, multiplication, division, and matrix power.

**Examples**

```
>>> import numpy as np
>>> from scipy.sparse import dia_matrix
>>> dia_matrix((3, 4), dtype=np.int8).toarray()
array([[0, 0, 0, 0],
       [0, 0, 0, 0],
       [0, 0, 0, 0]], dtype=int8)
```

```
>>> data = np.array([[1, 2, 3, 4]]).repeat(3, axis=0)
>>> offsets = np.array([0, -1, 2])
>>> dia_matrix((data, offsets), shape=(4, 4)).toarray()
array([[1, 0, 3, 0],
       [1, 2, 0, 4],
       [0, 2, 3, 0],
       [0, 0, 3, 4]])
```

**Attributes**

<i>shape</i>	Get shape of a matrix.
<i>nnz</i>	Number of stored values, including explicit zeros.

`dia_matrix.shape`  
Get shape of a matrix.

`dia_matrix.nnz`  
Number of stored values, including explicit zeros.

**See also:**

**count\_nonzero**  
Number of non-zero entries

<code>dtype</code>	(dtype) Data type of the matrix
<code>ndim</code>	(int) Number of dimensions (this is always 2)
<code>data</code>	DIA format data array of the matrix
<code>offsets</code>	DIA format offset array of the matrix

**Methods**

<i>arcsin()</i>	Element-wise arcsin.
<i>arcsinh()</i>	Element-wise arcsinh.
<i>arctan()</i>	Element-wise arctan.
<i>arctanh()</i>	Element-wise arctanh.
<i>asformat(format)</i>	Return this matrix in a given sparse format
<i>asfptype()</i>	Upcast matrix to a floating point format (if necessary)
<i>astype(dtype[, casting, copy])</i>	Cast the matrix elements to a specified type.
<i>ceil()</i>	Element-wise ceil.
<i>conj()</i>	Element-wise complex conjugation.
<i>conjugate()</i>	Element-wise complex conjugation.
<i>copy()</i>	Returns a copy of this matrix.
<i>count_nonzero()</i>	Number of non-zero entries, equivalent to
<i>deg2rad()</i>	Element-wise deg2rad.
<i>diagonal([k])</i>	Returns the k-th diagonal of the matrix.

Continued on next page

Table 5.172 – continued from previous page

<code>dot(other)</code>	Ordinary dot product
<code>expm1()</code>	Element-wise <code>expm1</code> .
<code>floor()</code>	Element-wise floor.
<code>getH()</code>	Return the Hermitian transpose of this matrix.
<code>get_shape()</code>	Get shape of a matrix.
<code>getcol(j)</code>	Returns a copy of column <code>j</code> of the matrix, as an $(m \times 1)$ sparse matrix (column vector).
<code>getformat()</code>	Format of a matrix representation as a string.
<code>getmaxprint()</code>	Maximum number of elements to display when printed.
<code>getnnz([axis])</code>	Number of stored values, including explicit zeros.
<code>getrow(i)</code>	Returns a copy of row <code>i</code> of the matrix, as a $(1 \times n)$ sparse matrix (row vector).
<code>log1p()</code>	Element-wise <code>log1p</code> .
<code>maximum(other)</code>	Element-wise maximum between this and another matrix.
<code>mean([axis, dtype, out])</code>	Compute the arithmetic mean along the specified axis.
<code>minimum(other)</code>	Element-wise minimum between this and another matrix.
<code>multiply(other)</code>	Point-wise multiplication by another matrix
<code>nonzero()</code>	nonzero indices
<code>power(n[, dtype])</code>	This function performs element-wise power.
<code>rad2deg()</code>	Element-wise <code>rad2deg</code> .
<code>reshape(shape[, order])</code>	Gives a new shape to a sparse matrix without changing its data.
<code>rint()</code>	Element-wise <code>rint</code> .
<code>set_shape(shape)</code>	See <code>reshape</code> .
<code>setdiag(values[, k])</code>	Set diagonal or off-diagonal elements of the array.
<code>sign()</code>	Element-wise <code>sign</code> .
<code>sin()</code>	Element-wise <code>sin</code> .
<code>sinh()</code>	Element-wise <code>sinh</code> .
<code>sqrt()</code>	Element-wise <code>sqrt</code> .
<code>sum([axis, dtype, out])</code>	Sum the matrix elements over a given axis.
<code>tan()</code>	Element-wise <code>tan</code> .
<code>tanh()</code>	Element-wise <code>tanh</code> .
<code>toarray([order, out])</code>	Return a dense ndarray representation of this matrix.
<code>tobsr([blocksize, copy])</code>	Convert this matrix to Block Sparse Row format.
<code>tocoo([copy])</code>	Convert this matrix to COOrdinate format.
<code>tocsc([copy])</code>	Convert this matrix to Compressed Sparse Column format.
<code>tocsr([copy])</code>	Convert this matrix to Compressed Sparse Row format.
<code>todense([order, out])</code>	Return a dense matrix representation of this matrix.
<code>todia([copy])</code>	Convert this matrix to sparse DIAgonal format.
<code>todok([copy])</code>	Convert this matrix to Dictionary Of Keys format.
<code>tolil([copy])</code>	Convert this matrix to LInked List format.
<code>transpose([axes, copy])</code>	Reverses the dimensions of the sparse matrix.
<code>trunc()</code>	Element-wise <code>trunc</code> .

`dia_matrix.arcsin()`  
Element-wise `arcsin`.

See `numpy.arcsin` for more information.

`dia_matrix.arcsinh()`  
Element-wise arcsinh.

See `numpy.arcsinh` for more information.

`dia_matrix.arctan()`  
Element-wise arctan.

See `numpy.arctan` for more information.

`dia_matrix.arctanh()`  
Element-wise arctanh.

See `numpy.arctanh` for more information.

`dia_matrix.asformat(format)`  
Return this matrix in a given sparse format

**Parameters** **format** : {string, None}  
*desired sparse matrix format*

- None for no format conversion
- “csr” for `csr_matrix` format
- “csc” for `csc_matrix` format
- “lil” for `lil_matrix` format
- “dok” for `dok_matrix` format and so on

`dia_matrix.asfptype()`  
Upcast matrix to a floating point format (if necessary)

`dia_matrix.astype(dtype, casting='unsafe', copy=True)`  
Cast the matrix elements to a specified type.

**Parameters** **dtype** : string or numpy dtype  
Typecode or data-type to which to cast the data.

**casting** : {'no', 'equiv', 'safe', 'same\_kind', 'unsafe'}, optional  
Controls what kind of data casting may occur. Defaults to 'unsafe' for backwards compatibility. 'no' means the data types should not be cast at all. 'equiv' means only byte-order changes are allowed. 'safe' means only casts which can preserve values are allowed. 'same\_kind' means only safe casts or casts within a kind, like float64 to float32, are allowed. 'unsafe' means any data conversions may be done.

**copy** : bool, optional  
If `copy` is `False`, the result might share some memory with this matrix. If `copy` is `True`, it is guaranteed that the result and this matrix do not share any memory.

`dia_matrix.ceil()`  
Element-wise ceil.

See `numpy.ceil` for more information.

`dia_matrix.conj()`  
Element-wise complex conjugation.

If the matrix is of non-complex data type, then this method does nothing and the data is not copied.

`dia_matrix.conjugate()`  
Element-wise complex conjugation.

If the matrix is of non-complex data type, then this method does nothing and the data is not copied.

`dia_matrix.copy()`

Returns a copy of this matrix.

No data/indices will be shared between the returned value and current matrix.

`dia_matrix.count_nonzero()`

Number of non-zero entries, equivalent to

`np.count_nonzero(a.toarray())`

Unlike `getnnz()` and the `nnz` property, which return the number of stored entries (the length of the data attribute), this method counts the actual number of non-zero entries in data.

`dia_matrix.deg2rad()`

Element-wise `deg2rad`.

See `numpy.deg2rad` for more information.

`dia_matrix.diagonal(k=0)`

Returns the *k*-th diagonal of the matrix.

**Parameters** *k* : int, optional

Which diagonal to set, corresponding to elements `a[i, i+k]`. Default: 0 (the main diagonal).

**See also:**

[\*numpy.diagonal\*](#)

Equivalent numpy function.

**Examples**

```
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> A.diagonal()
array([1, 0, 5])
>>> A.diagonal(k=1)
array([2, 3])
```

`dia_matrix.dot(other)`

Ordinary dot product

**Examples**

```
>>> import numpy as np
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> v = np.array([1, 0, -1])
>>> A.dot(v)
array([ 1, -3, -1], dtype=int64)
```

`dia_matrix.expm1()`

Element-wise `expm1`.

See `numpy.expm1` for more information.

`dia_matrix.floor()`

Element-wise `floor`.

See `numpy.floor` for more information.

`dia_matrix.getH()`

Return the Hermitian transpose of this matrix.

**See also:**

**`np.matrix.getH`**

NumPy's implementation of `getH` for matrices

`dia_matrix.get_shape()`

Get shape of a matrix.

`dia_matrix.getcol(j)`

Returns a copy of column `j` of the matrix, as an  $(m \times 1)$  sparse matrix (column vector).

`dia_matrix.getformat()`

Format of a matrix representation as a string.

`dia_matrix.getmaxprint()`

Maximum number of elements to display when printed.

`dia_matrix.getnnz(axis=None)`

Number of stored values, including explicit zeros.

**Parameters** **axis** : None, 0, or 1

Select between the number of values across the whole matrix, in each column, or in each row.

**See also:**

**`count_nonzero`**

Number of non-zero entries

`dia_matrix.getrow(i)`

Returns a copy of row `i` of the matrix, as a  $(1 \times n)$  sparse matrix (row vector).

`dia_matrix.log1p()`

Element-wise `log1p`.

See `numpy.log1p` for more information.

`dia_matrix.maximum(other)`

Element-wise maximum between this and another matrix.

`dia_matrix.mean(axis=None, dtype=None, out=None)`

Compute the arithmetic mean along the specified axis.

Returns the average of the matrix elements. The average is taken over all elements in the matrix by default, otherwise over the specified axis. `float64` intermediate and return values are used for integer inputs.

**Parameters** **axis** :  $\{-2, -1, 0, 1, \text{None}\}$  optional

Axis along which the mean is computed. The default is to compute the mean of all elements in the matrix (i.e. `axis = None`).

**dtype** : data-type, optional

Type to use in computing the mean. For integer inputs, the default is `float64`; for floating point inputs, it is the same as the input dtype.

**out** : `np.matrix`, optional

Alternative output matrix in which to place the result. It must have the same shape as the expected output, but the type of the output values will be cast if necessary.

**Returns** **m** : `np.matrix`

**See also:**

**np.matrix.mean**

NumPy's implementation of 'mean' for matrices

`dia_matrix.minimum (other)`

Element-wise minimum between this and another matrix.

`dia_matrix.multiply (other)`

Point-wise multiplication by another matrix

`dia_matrix.nonzero ()`

nonzero indices

Returns a tuple of arrays (row,col) containing the indices of the non-zero elements of the matrix.

**Examples**

```
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1,2,0],[0,0,3],[4,0,5]])
>>> A.nonzero()
(array([0, 0, 1, 2, 2]), array([0, 1, 2, 0, 2]))
```

`dia_matrix.power (n, dtype=None)`

This function performs element-wise power.

**Parameters****n** : n is a scalar**dtype** : If dtype is not specified, the current dtype will be preserved.`dia_matrix.rad2deg ()`

Element-wise rad2deg.

See `numpy.rad2deg` for more information.`dia_matrix.reshape (shape, order='C')`

Gives a new shape to a sparse matrix without changing its data.

**Parameters****shape** : length-2 tuple of ints

The new shape should be compatible with the original shape.

**order** : 'C', optionalThis argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.**Returns****reshaped\_matrix** : *self* with the new dimensions of *shape***See also:****np.matrix.reshape**

NumPy's implementation of 'reshape' for matrices

`dia_matrix.rint ()`

Element-wise rint.

See `numpy.rint` for more information.`dia_matrix.set_shape (shape)`See `reshape`.`dia_matrix.setdiag (values, k=0)`

Set diagonal or off-diagonal elements of the array.

**Parameters****values** : array\_like

New values of the diagonal elements.

Values may have any length. If the diagonal is longer than values, then the remaining diagonal entries will not be set. If values are longer than the diagonal, then the remaining values are ignored. If a scalar value is given, all of the diagonal is set to it.

**k** : int, optional

Which off-diagonal to set, corresponding to elements  $a[i,i+k]$ . Default: 0 (the main diagonal).

`dia_matrix.sign()`

Element-wise sign.

See `numpy.sign` for more information.

`dia_matrix.sin()`

Element-wise sin.

See `numpy.sin` for more information.

`dia_matrix.sinh()`

Element-wise sinh.

See `numpy.sinh` for more information.

`dia_matrix.sqrt()`

Element-wise sqrt.

See `numpy.sqrt` for more information.

`dia_matrix.sum(axis=None, dtype=None, out=None)`

Sum the matrix elements over a given axis.

**Parameters** **axis** : {-2, -1, 0, 1, None} optional

Axis along which the sum is computed. The default is to compute the sum of all the matrix elements, returning a scalar (i.e. *axis = None*).

**dtype** : dtype, optional

The type of the returned matrix and of the accumulator in which the elements are summed. The dtype of *a* is used by default unless *a* has an integer dtype of less precision than the default platform integer. In that case, if *a* is signed then the platform integer is used while if *a* is unsigned then an unsigned integer of the same precision as the platform integer is used.

**out** : np.matrix, optional

Alternative output matrix in which to place the result. It must have the same shape as the expected output, but the type of the output values will be cast if necessary.

**Returns** **sum\_along\_axis** : np.matrix

A matrix with the same shape as *self*, with the specified axis removed.

**See also:**

**`np.matrix.sum`**

NumPy's implementation of 'sum' for matrices

`dia_matrix.tan()`

Element-wise tan.

See `numpy.tan` for more information.

`dia_matrix.tanh()`

Element-wise tanh.

See `numpy.tanh` for more information.

`dia_matrix.toarray` (*order=None, out=None*)

Return a dense ndarray representation of this matrix.

**Parameters** **order** : {'C', 'F'}, optional

Whether to store multi-dimensional data in C (row-major) or Fortran (column-major) order in memory. The default is 'None', indicating the NumPy default of C-ordered. Cannot be specified in conjunction with the *out* argument.

**out** : ndarray, 2-dimensional, optional

If specified, uses this array as the output buffer instead of allocating a new array to return. The provided array must have the same shape and dtype as the sparse matrix on which you are calling the method. For most sparse types, *out* is required to be memory contiguous (either C or Fortran ordered).

**Returns** **arr** : ndarray, 2-dimensional

An array with the same shape and containing the same data represented by the sparse matrix, with the requested memory order. If *out* was passed, the same object is returned after being modified in-place to contain the appropriate values.

`dia_matrix.tobsr` (*blocksize=None, copy=False*)

Convert this matrix to Block Sparse Row format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `bsr_matrix`.

When *blocksize=(R, C)* is provided, it will be used for construction of the `bsr_matrix`.

`dia_matrix.tocoo` (*copy=False*)

Convert this matrix to COOrdinate format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `coo_matrix`.

`dia_matrix.tocsc` (*copy=False*)

Convert this matrix to Compressed Sparse Column format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `csc_matrix`.

`dia_matrix.tocsr` (*copy=False*)

Convert this matrix to Compressed Sparse Row format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `csr_matrix`.

`dia_matrix.todense` (*order=None, out=None*)

Return a dense matrix representation of this matrix.

**Parameters** **order** : {'C', 'F'}, optional

Whether to store multi-dimensional data in C (row-major) or Fortran (column-major) order in memory. The default is 'None', indicating the NumPy default of C-ordered. Cannot be specified in conjunction with the *out* argument.

**out** : ndarray, 2-dimensional, optional

If specified, uses this array (or `numpy.matrix`) as the output buffer instead of allocating a new array to return. The provided array must have the same shape and dtype as the sparse matrix on which you are calling the method.

**Returns** **arr** : `numpy.matrix`, 2-dimensional

A NumPy matrix object with the same shape and containing the same data represented by the sparse matrix, with the requested memory order. If *out* was passed and was an array (rather than a `numpy.matrix`), it will be filled with the appropriate values and returned wrapped in a `numpy.matrix` object that shares the same memory.

`dia_matrix.todia (copy=False)`

Convert this matrix to sparse DIAgonal format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `dia_matrix`.

`dia_matrix.todok (copy=False)`

Convert this matrix to Dictionary Of Keys format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `dok_matrix`.

`dia_matrix.tolil (copy=False)`

Convert this matrix to LInked List format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `lil_matrix`.

`dia_matrix.transpose (axes=None, copy=False)`

Reverses the dimensions of the sparse matrix.

**Parameters** `axes` : None, optional

This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value.

`copy` : bool, optional

Indicates whether or not attributes of *self* should be copied whenever possible. The degree to which attributes are copied varies depending on the type of sparse matrix being used.

**Returns** `p` : *self* with the dimensions reversed.

**See also:**

`np.matrix.transpose`

NumPy's implementation of 'transpose' for matrices

`dia_matrix.trunc ()`

Element-wise trunc.

See `numpy.trunc` for more information.

**class** `scipy.sparse.dok_matrix (arg1, shape=None, dtype=None, copy=False)`

Dictionary Of Keys based sparse matrix.

This is an efficient structure for constructing sparse matrices incrementally.

*This can be instantiated in several ways:*

`dok_matrix(D)`

with a dense matrix, D

`dok_matrix(S)` with a sparse matrix, S

`dok_matrix((M,N), [dtype])`

create the matrix with initial shape (M,N) dtype is optional, defaulting to dtype='d'

**Notes**

Sparse matrices can be used in arithmetic operations: they support addition, subtraction, multiplication, division, and matrix power.

Allows for efficient O(1) access of individual elements. Duplicates are not allowed. Can be efficiently converted to a `coo_matrix` once constructed.

**Examples**

```
>>> import numpy as np
>>> from scipy.sparse import dok_matrix
```

```
>>> S = dok_matrix((5, 5), dtype=np.float32)
>>> for i in range(5):
...     for j in range(5):
...         S[i, j] = i + j      # Update element
```

**Attributes**

<i>shape</i>	Get shape of a matrix.
<i>nnz</i>	Number of stored values, including explicit zeros.

`dok_matrix.shape`  
Get shape of a matrix.

`dok_matrix.nnz`  
Number of stored values, including explicit zeros.

**See also:**

**count\_nonzero**  
Number of non-zero entries

<code>dtype</code>	(dtype) Data type of the matrix
<code>ndim</code>	(int) Number of dimensions (this is always 2)

**Methods**

<i>asformat(format)</i>	Return this matrix in a given sparse format
<i>asfptype()</i>	Upcast matrix to a floating point format (if necessary)
<i>astype(dtype[, casting, copy])</i>	Cast the matrix elements to a specified type.
<i>clear()</i> -> None. Remove all items from D.)	
<i>conj()</i>	Element-wise complex conjugation.
<i>conjtransp()</i>	Return the conjugate transpose.
<i>conjugate()</i>	Element-wise complex conjugation.
<i>copy()</i>	Returns a copy of this matrix.
<i>count_nonzero()</i>	Number of non-zero entries, equivalent to
<i>diagonal([k])</i>	Returns the k-th diagonal of the matrix.
<i>dot(other)</i>	Ordinary dot product
<i>fromkeys(...)</i>	v defaults to None.
<i>get(key[, default])</i>	This overrides the dict.get method, providing type checking but otherwise equivalent functionality.
<i>getH()</i>	Return the Hermitian transpose of this matrix.
<i>get_shape()</i>	Get shape of a matrix.
<i>getcol(j)</i>	Returns the j-th column as a (m x 1) DOK matrix.
<i>getformat()</i>	Format of a matrix representation as a string.
<i>getmaxprint()</i>	Maximum number of elements to display when printed.
<i>getnnz([axis])</i>	Number of stored values, including explicit zeros.
<i>getrow(i)</i>	Returns the i-th row as a (1 x n) DOK matrix.
<i>has_key(k)</i> -> True if D has a key k, else False)	
<i>items()</i> -> list of D's (key, value) pairs, ...)	
<i>iteritems()</i> -> an iterator over the (key, ...)	
<i>iterkeys()</i> -> an iterator over the keys of D)	
<i>itervalues(...)</i>	
<i>keys()</i> -> list of D's keys)	

Continued on next page

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<code>maximum(other)</code>	Element-wise maximum between this and another matrix.
<code>mean([axis, dtype, out])</code>	Compute the arithmetic mean along the specified axis.
<code>minimum(other)</code>	Element-wise minimum between this and another matrix.
<code>multiply(other)</code>	Point-wise multiplication by another matrix
<code>nonzero()</code>	nonzero indices
<code>pop((k[,d]) -&gt; v, ...)</code>	If key is not found, d is returned if given, otherwise KeyError is raised
<code>popitem() -&gt; (k, v), ...)</code>	2-tuple; but raise KeyError if D is empty.
<code>power(n[, dtype])</code>	Element-wise power.
<code>reshape(shape[, order])</code>	Gives a new shape to a sparse matrix without changing its data.
<code>resize(shape)</code>	Resize the matrix in-place to dimensions given by <i>shape</i> .
<code>set_shape(shape)</code>	See <i>reshape</i> .
<code>setdefault((k[,d]) -&gt; D.get(k,d), ...)</code>	
<code>setdiag(values[, k])</code>	Set diagonal or off-diagonal elements of the array.
<code>sum([axis, dtype, out])</code>	Sum the matrix elements over a given axis.
<code>toarray([order, out])</code>	Return a dense ndarray representation of this matrix.
<code>tobsr([blocksize, copy])</code>	Convert this matrix to Block Sparse Row format.
<code>tocoo([copy])</code>	Convert this matrix to COOrdinate format.
<code>tocsc([copy])</code>	Convert this matrix to Compressed Sparse Column format.
<code>tocsr([copy])</code>	Convert this matrix to Compressed Sparse Row format.
<code>todense([order, out])</code>	Return a dense matrix representation of this matrix.
<code>todia([copy])</code>	Convert this matrix to sparse DIAgonal format.
<code>todok([copy])</code>	Convert this matrix to Dictionary Of Keys format.
<code>tolil([copy])</code>	Convert this matrix to LIInked List format.
<code>transpose([axes, copy])</code>	Reverses the dimensions of the sparse matrix.
<code>update(val)</code>	
<code>values() -&gt; list of D's values)</code>	
<code>viewitems(...)</code>	
<code>viewkeys(...)</code>	
<code>viewvalues(...)</code>	

`dok_matrix.asformat` (*format*)

Return this matrix in a given sparse format

**Parameters** **format** : {string, None}  
*desired sparse matrix format*

- None for no format conversion
- “csr” for csr\_matrix format
- “csc” for csc\_matrix format
- “lil” for lil\_matrix format
- “dok” for dok\_matrix format and so on

`dok_matrix.asfptype` ()

Upcast matrix to a floating point format (if necessary)

`dok_matrix.astype` (*dtype, casting='unsafe', copy=True*)

Cast the matrix elements to a specified type.

**Parameters**

- dtype** : string or numpy dtype  
Typecode or data-type to which to cast the data.
- casting** : {'no', 'equiv', 'safe', 'same\_kind', 'unsafe'}, optional  
Controls what kind of data casting may occur. Defaults to 'unsafe' for backwards compatibility. 'no' means the data types should not be cast at all. 'equiv' means only byte-order changes are allowed. 'safe' means only casts which can preserve values are allowed. 'same\_kind' means only safe casts or casts within a kind, like float64 to float32, are allowed. 'unsafe' means any data conversions may be done.
- copy** : bool, optional  
If *copy* is *False*, the result might share some memory with this matrix. If *copy* is *True*, it is guaranteed that the result and this matrix do not share any memory.

`dok_matrix.clear()` → None. Remove all items from D.

`dok_matrix.conj()`  
Element-wise complex conjugation.

If the matrix is of non-complex data type, then this method does nothing and the data is not copied.

`dok_matrix.conjtransp()`  
Return the conjugate transpose.

`dok_matrix.conjugate()`  
Element-wise complex conjugation.

If the matrix is of non-complex data type, then this method does nothing and the data is not copied.

`dok_matrix.copy()`  
Returns a copy of this matrix.

No data/indices will be shared between the returned value and current matrix.

`dok_matrix.count_nonzero()`  
Number of non-zero entries, equivalent to

`np.count_nonzero(a.toarray())`

Unlike `getnnz()` and the `nnz` property, which return the number of stored entries (the length of the data attribute), this method counts the actual number of non-zero entries in data.

`dok_matrix.diagonal(k=0)`  
Returns the k-th diagonal of the matrix.

**Parameters**

- k** : int, optional  
Which diagonal to set, corresponding to elements `a[i, i+k]`. Default: 0 (the main diagonal).

**See also:**

[\*numpy.diagonal\*](#)  
Equivalent numpy function.

**Examples**

```
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> A.diagonal()
array([1, 0, 5])
```

```
>>> A.diagonal(k=1)
array([2, 3])
```

`dok_matrix.dot` (*other*)  
 Ordinary dot product

**Examples**

```
>>> import numpy as np
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> v = np.array([1, 0, -1])
>>> A.dot(v)
array([ 1, -3, -1], dtype=int64)
```

`dok_matrix.fromkeys` (*S*[, *v*]) → New dict with keys from *S* and values equal to *v*.  
*v* defaults to None.

`dok_matrix.get` (*key*, *default=0.0*)  
 This overrides the dict.get method, providing type checking but otherwise equivalent functionality.

`dok_matrix.getH` ()  
 Return the Hermitian transpose of this matrix.

**See also:**

**`np.matrix.getH`**  
 NumPy's implementation of *getH* for matrices

`dok_matrix.get_shape` ()  
 Get shape of a matrix.

`dok_matrix.getcol` (*j*)  
 Returns the *j*-th column as a (m x 1) DOK matrix.

`dok_matrix.getformat` ()  
 Format of a matrix representation as a string.

`dok_matrix.getmaxprint` ()  
 Maximum number of elements to display when printed.

`dok_matrix.getnnz` (*axis=None*)  
 Number of stored values, including explicit zeros.

**Parameters** **axis** : None, 0, or 1  
 Select between the number of values across the whole matrix, in each column, or in each row.

**See also:**

**`count_nonzero`**  
 Number of non-zero entries

`dok_matrix.getrow` (*i*)  
 Returns the *i*-th row as a (1 x n) DOK matrix.

`dok_matrix.has_key` (*k*) → True if *D* has a key *k*, else False

`dok_matrix.items` () → list of *D*'s (key, value) pairs, as 2-tuples

`dok_matrix.iteritems()` → an iterator over the (key, value) items of D

`dok_matrix.iterkeys()` → an iterator over the keys of D

`dok_matrix.itervalues()` → an iterator over the values of D

`dok_matrix.keys()` → list of D's keys

`dok_matrix.maximum(other)`

Element-wise maximum between this and another matrix.

`dok_matrix.mean(axis=None, dtype=None, out=None)`

Compute the arithmetic mean along the specified axis.

Returns the average of the matrix elements. The average is taken over all elements in the matrix by default, otherwise over the specified axis. *float64* intermediate and return values are used for integer inputs.

**Parameters** **axis** : {-2, -1, 0, 1, None} optional

Axis along which the mean is computed. The default is to compute the mean of all elements in the matrix (i.e. *axis = None*).

**dtype** : data-type, optional

Type to use in computing the mean. For integer inputs, the default is *float64*; for floating point inputs, it is the same as the input dtype.

**out** : np.matrix, optional

Alternative output matrix in which to place the result. It must have the same shape as the expected output, but the type of the output values will be cast if necessary.

**Returns** **m** : np.matrix

**See also:**

**`np.matrix.mean`**

NumPy's implementation of 'mean' for matrices

`dok_matrix.minimum(other)`

Element-wise minimum between this and another matrix.

`dok_matrix.multiply(other)`

Point-wise multiplication by another matrix

`dok_matrix.nonzero()`

nonzero indices

Returns a tuple of arrays (row,col) containing the indices of the non-zero elements of the matrix.

**Examples**

```
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> A.nonzero()
(array([0, 0, 1, 2, 2]), array([0, 1, 2, 0, 2]))
```

`dok_matrix.pop(k[, d])` → v, remove specified key and return the corresponding value.

If key is not found, d is returned if given, otherwise `KeyError` is raised

`dok_matrix.popitem()` → (k, v), remove and return some (key, value) pair as a

2-tuple; but raise `KeyError` if D is empty.

`dok_matrix.power` (*n*, *dtype=None*)

Element-wise power.

`dok_matrix.reshape` (*shape*, *order='C'*)

Gives a new shape to a sparse matrix without changing its data.

**Parameters** **shape** : length-2 tuple of ints

The new shape should be compatible with the original shape.

**order** : 'C', optional

This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this

**Returns** **reshaped\_matrix** : *self* with the new dimensions of *shape*

**See also:**

**`np.matrix.reshape`**

NumPy's implementation of 'reshape' for matrices

`dok_matrix.resize` (*shape*)

Resize the matrix in-place to dimensions given by *shape*.

Any non-zero elements that lie outside the new shape are removed.

`dok_matrix.set_shape` (*shape*)

See *reshape*.

`dok_matrix.setdefault` (*k*[, *d*]) → *D.get(k,d)*, also set *D[k]=d* if *k* not in *D*

`dok_matrix.setdiag` (*values*, *k=0*)

Set diagonal or off-diagonal elements of the array.

**Parameters** **values** : array\_like

New values of the diagonal elements.

Values may have any length. If the diagonal is longer than *values*, then the remaining diagonal entries will not be set. If *values* is longer than the diagonal, then the remaining *values* are ignored.

If a scalar value is given, all of the diagonal is set to it.

**k** : int, optional

Which off-diagonal to set, corresponding to elements *a[i,i+k]*. Default: 0 (the main diagonal).

`dok_matrix.sum` (*axis=None*, *dtype=None*, *out=None*)

Sum the matrix elements over a given axis.

**Parameters** **axis** : {-2, -1, 0, 1, None} optional

Axis along which the sum is computed. The default is to compute the sum of all the matrix elements, returning a scalar (i.e. *axis = None*).

**dtype** : dtype, optional

The type of the returned matrix and of the accumulator in which the elements are summed. The dtype of *a* is used by default unless *a* has an integer dtype of less precision than the default platform integer. In that case, if *a* is signed then the platform integer is used while if *a* is unsigned then an unsigned integer of the same precision as the platform integer is used.

**out** : np.matrix, optional

Alternative output matrix in which to place the result. It must have the same shape as the expected output, but the type of the output

**Returns** **sum\_along\_axis** : np.matrix

A matrix with the same shape as *self*, with the specified axis removed.

**See also:**

**`np.matrix.sum`**

NumPy's implementation of 'sum' for matrices

`dok_matrix.toarray` (*order=None, out=None*)

Return a dense ndarray representation of this matrix.

**Parameters** **order** : {'C', 'F'}, optional

Whether to store multi-dimensional data in C (row-major) or Fortran (column-major) order in memory. The default is 'None', indicating the NumPy default of C-ordered. Cannot be specified in conjunction with the *out* argument.

**out** : ndarray, 2-dimensional, optional

If specified, uses this array as the output buffer instead of allocating a new array to return. The provided array must have the same shape and dtype as the sparse matrix on which you are calling the method. For most sparse types, *out* is required to be memory contiguous (either C or Fortran ordered).

**Returns** **arr** : ndarray, 2-dimensional

An array with the same shape and containing the same data represented by the sparse matrix, with the requested memory order. If *out* was passed, the same object is returned after being modified in-place to contain the appropriate values.

`dok_matrix.tobsr` (*blocksize=None, copy=False*)

Convert this matrix to Block Sparse Row format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `bsr_matrix`.

When *blocksize=(R, C)* is provided, it will be used for construction of the `bsr_matrix`.

`dok_matrix.tocoo` (*copy=False*)

Convert this matrix to COOrdinate format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `coo_matrix`.

`dok_matrix.tocsc` (*copy=False*)

Convert this matrix to Compressed Sparse Column format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `csc_matrix`.

`dok_matrix.tocsr` (*copy=False*)

Convert this matrix to Compressed Sparse Row format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `csr_matrix`.

`dok_matrix.todense` (*order=None, out=None*)

Return a dense matrix representation of this matrix.

**Parameters** **order** : {'C', 'F'}, optional

Whether to store multi-dimensional data in C (row-major) or Fortran (column-major) order in memory. The default is 'None', indicating the NumPy default of C-ordered. Cannot be specified in conjunction with the *out* argument.

**out** : ndarray, 2-dimensional, optional

If specified, uses this array (or `numpy.matrix`) as the output buffer instead of allocating a new array to return. The provided array must have the same shape and dtype as the sparse matrix on which you are calling the method.

**Returns**     **arr** : numpy.matrix, 2-dimensional  
 A NumPy matrix object with the same shape and containing the same data represented by the sparse matrix, with the requested memory order. If *out* was passed and was an array (rather than a `numpy.matrix`), it will be filled with the appropriate values and returned wrapped in a `numpy.matrix` object that shares the same memory.

`dok_matrix.todia (copy=False)`  
 Convert this matrix to sparse DIAgonal format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `dia_matrix`.

`dok_matrix.todok (copy=False)`  
 Convert this matrix to Dictionary Of Keys format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `dok_matrix`.

`dok_matrix.tolil (copy=False)`  
 Convert this matrix to LInked List format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `lil_matrix`.

`dok_matrix.transpose (axes=None, copy=False)`  
 Reverses the dimensions of the sparse matrix.

**Parameters**   **axes** : None, optional  
 This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value.

**copy** : bool, optional  
 Indicates whether or not attributes of *self* should be copied whenever possible. The degree to which attributes are copied varies depending on the type of sparse matrix being used.

**Returns**     **p** : *self* with the dimensions reversed.

**See also:**

**`np.matrix.transpose`**  
 NumPy's implementation of 'transpose' for matrices

`dok_matrix.update (val)`

`dok_matrix.values ()` → list of D's values

`dok_matrix.viewitems ()` → a set-like object providing a view on D's items

`dok_matrix.viewkeys ()` → a set-like object providing a view on D's keys

`dok_matrix.viewvalues ()` → an object providing a view on D's values

**class** `scipy.sparse.lil_matrix (arg1, shape=None, dtype=None, copy=False)`  
 Row-based linked list sparse matrix

This is a structure for constructing sparse matrices incrementally. Note that inserting a single item can take linear time in the worst case; to construct a matrix efficiently, make sure the items are pre-sorted by index, per row.

*This can be instantiated in several ways:*

`lil_matrix(D)` with a dense matrix or rank-2 ndarray D

`lil_matrix(S)` with another sparse matrix S (equivalent to `S.tolil()`)  
`lil_matrix((M, N), [dtype])`  
to construct an empty matrix with shape (M, N) dtype is optional, defaulting to `dtype='d'`.

**Notes**

Sparse matrices can be used in arithmetic operations: they support addition, subtraction, multiplication, division, and matrix power.

**Advantages of the LIL format**

- supports flexible slicing
- changes to the matrix sparsity structure are efficient

**Disadvantages of the LIL format**

- arithmetic operations LIL + LIL are slow (consider CSR or CSC)
- slow column slicing (consider CSC)
- slow matrix vector products (consider CSR or CSC)

**Intended Usage**

- LIL is a convenient format for constructing sparse matrices
- once a matrix has been constructed, convert to CSR or CSC format for fast arithmetic and matrix vector operations
- consider using the COO format when constructing large matrices

**Data Structure**

- An array (`self.rows`) of rows, each of which is a sorted list of column indices of non-zero elements.
- The corresponding nonzero values are stored in similar fashion in `self.data`.

**Attributes**

<code>shape</code>	Get shape of a matrix.
<code>nnz</code>	Number of stored values, including explicit zeros.

`lil_matrix.shape`  
Get shape of a matrix.

`lil_matrix.nnz`  
Number of stored values, including explicit zeros.

**See also:**

`count_nonzero`  
Number of non-zero entries

<code>dtype</code>	(dtype) Data type of the matrix
<code>ndim</code>	(int) Number of dimensions (this is always 2)
<code>data</code>	LIL format data array of the matrix
<code>rows</code>	LIL format row index array of the matrix

**Methods**

<code>asformat(format)</code>	Return this matrix in a given sparse format
<code>asfptype()</code>	Upcast matrix to a floating point format (if necessary)

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<code>astype(dtype[, casting, copy])</code>	Cast the matrix elements to a specified type.
<code>conj()</code>	Element-wise complex conjugation.
<code>conjugate()</code>	Element-wise complex conjugation.
<code>copy()</code>	Returns a copy of this matrix.
<code>count_nonzero()</code>	Number of non-zero entries, equivalent to
<code>diagonal([k])</code>	Returns the k-th diagonal of the matrix.
<code>dot(other)</code>	Ordinary dot product
<code>getH()</code>	Return the Hermitian transpose of this matrix.
<code>get_shape()</code>	Get shape of a matrix.
<code>getcol(j)</code>	Returns a copy of column j of the matrix, as an (m x 1) sparse matrix (column vector).
<code>getformat()</code>	Format of a matrix representation as a string.
<code>getmaxprint()</code>	Maximum number of elements to display when printed.
<code>getnnz([axis])</code>	Number of stored values, including explicit zeros.
<code>getrow(i)</code>	Returns a copy of the ‘i’th row.
<code>getrowview(i)</code>	Returns a view of the ‘i’th row (without copying).
<code>maximum(other)</code>	Element-wise maximum between this and another matrix.
<code>mean([axis, dtype, out])</code>	Compute the arithmetic mean along the specified axis.
<code>minimum(other)</code>	Element-wise minimum between this and another matrix.
<code>multiply(other)</code>	Point-wise multiplication by another matrix
<code>nonzero()</code>	nonzero indices
<code>power(n[, dtype])</code>	Element-wise power.
<code>reshape(shape[, order])</code>	Gives a new shape to a sparse matrix without changing its data.
<code>set_shape(shape)</code>	See <i>reshape</i> .
<code>setdiag(values[, k])</code>	Set diagonal or off-diagonal elements of the array.
<code>sum([axis, dtype, out])</code>	Sum the matrix elements over a given axis.
<code>toarray([order, out])</code>	Return a dense ndarray representation of this matrix.
<code>tobsr([blocksize, copy])</code>	Convert this matrix to Block Sparse Row format.
<code>tocoo([copy])</code>	Convert this matrix to COOrdinate format.
<code>tocsc([copy])</code>	Convert this matrix to Compressed Sparse Column format.
<code>tocsr([copy])</code>	Convert this matrix to Compressed Sparse Row format.
<code>todense([order, out])</code>	Return a dense matrix representation of this matrix.
<code>todia([copy])</code>	Convert this matrix to sparse DIAgonal format.
<code>todok([copy])</code>	Convert this matrix to Dictionary Of Keys format.
<code>tolil([copy])</code>	Convert this matrix to LInked List format.
<code>transpose([axes, copy])</code>	Reverses the dimensions of the sparse matrix.

`lil_matrix.asformat(format)`

Return this matrix in a given sparse format

**Parameters** `format` : {string, None}

*desired sparse matrix format*

- None for no format conversion
- “csr” for `csr_matrix` format
- “csc” for `csc_matrix` format
- “lil” for `lil_matrix` format
- “dok” for `dok_matrix` format and so on

`lil_matrix.astype()`

Upcast matrix to a floating point format (if necessary)

`lil_matrix.astype(dtype, casting='unsafe', copy=True)`

Cast the matrix elements to a specified type.

**Parameters** `dtype` : string or numpy dtype

Typecode or data-type to which to cast the data.

`casting` : {'no', 'equiv', 'safe', 'same\_kind', 'unsafe'}, optional

Controls what kind of data casting may occur. Defaults to 'unsafe' for backwards compatibility. 'no' means the data types should not be cast at all. 'equiv' means only byte-order changes are allowed. 'safe' means only casts which can preserve values are allowed. 'same\_kind' means only safe casts or casts within a kind, like float64 to float32, are allowed. 'unsafe' means any data conversions may be done.

`copy` : bool, optional

If `copy` is *False*, the result might share some memory with this matrix. If `copy` is *True*, it is guaranteed that the result and this matrix do not share any memory.

`lil_matrix.conj()`

Element-wise complex conjugation.

If the matrix is of non-complex data type, then this method does nothing and the data is not copied.

`lil_matrix.conjugate()`

Element-wise complex conjugation.

If the matrix is of non-complex data type, then this method does nothing and the data is not copied.

`lil_matrix.copy()`

Returns a copy of this matrix.

No data/indices will be shared between the returned value and current matrix.

`lil_matrix.count_nonzero()`

Number of non-zero entries, equivalent to

`np.count_nonzero(a.toarray())`

Unlike `getnnz()` and the `nnz` property, which return the number of stored entries (the length of the data attribute), this method counts the actual number of non-zero entries in data.

`lil_matrix.diagonal(k=0)`

Returns the k-th diagonal of the matrix.

**Parameters** `k` : int, optional

Which diagonal to set, corresponding to elements `a[i, i+k]`. Default: 0 (the main diagonal).

**See also:**

[\*numpy.diagonal\*](#)

Equivalent numpy function.

**Examples**

```
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> A.diagonal()
array([1, 0, 5])
```

```
>>> A.diagonal(k=1)
array([2, 3])
```

`lil_matrix.dot` (*other*)  
 Ordinary dot product

**Examples**

```
>>> import numpy as np
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> v = np.array([1, 0, -1])
>>> A.dot(v)
array([ 1, -3, -1], dtype=int64)
```

`lil_matrix.getH` ()  
 Return the Hermitian transpose of this matrix.

**See also:**

`np.matrix.getH`  
 NumPy's implementation of *getH* for matrices

`lil_matrix.get_shape` ()  
 Get shape of a matrix.

`lil_matrix.getcol` (*j*)  
 Returns a copy of column *j* of the matrix, as an (*m* x 1) sparse matrix (column vector).

`lil_matrix.getformat` ()  
 Format of a matrix representation as a string.

`lil_matrix.getmaxprint` ()  
 Maximum number of elements to display when printed.

`lil_matrix.getnnz` (*axis=None*)  
 Number of stored values, including explicit zeros.

**Parameters** `axis` : None, 0, or 1

Select between the number of values across the whole matrix, in each column, or in each row.

**See also:**

`count_nonzero`  
 Number of non-zero entries

`lil_matrix.getrow` (*i*)  
 Returns a copy of the '*i*'th row.

`lil_matrix.getrowview` (*i*)  
 Returns a view of the '*i*'th row (without copying).

`lil_matrix.maximum` (*other*)  
 Element-wise maximum between this and another matrix.

`lil_matrix.mean` (*axis=None, dtype=None, out=None*)  
 Compute the arithmetic mean along the specified axis.

Returns the average of the matrix elements. The average is taken over all elements in the matrix by default, otherwise over the specified axis. *float64* intermediate and return values are used for integer inputs.

**Parameters**

- axis** : {-2, -1, 0, 1, None} optional  
Axis along which the mean is computed. The default is to compute the mean of all elements in the matrix (i.e. *axis = None*).
- dtype** : data-type, optional  
Type to use in computing the mean. For integer inputs, the default is *float64*; for floating point inputs, it is the same as the input dtype.
- out** : np.matrix, optional  
Alternative output matrix in which to place the result. It must have the same shape as the expected output, but the type of the output values will be cast if necessary.

**Returns** **m** : np.matrix

**See also:**

**`np.matrix.mean`**

NumPy's implementation of 'mean' for matrices

`lil_matrix.minimum` (*other*)

Element-wise minimum between this and another matrix.

`lil_matrix.multiply` (*other*)

Point-wise multiplication by another matrix

`lil_matrix.nonzero` ()

nonzero indices

Returns a tuple of arrays (row,col) containing the indices of the non-zero elements of the matrix.

**Examples**

```
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> A.nonzero()
(array([0, 0, 1, 2, 2]), array([0, 1, 2, 0, 2]))
```

`lil_matrix.power` (*n*, *dtype=None*)

Element-wise power.

`lil_matrix.reshape` (*shape*, *order='C'*)

Gives a new shape to a sparse matrix without changing its data.

**Parameters** **shape** : length-2 tuple of ints

The new shape should be compatible with the original shape.

**order** : 'C', optional

This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value, as this argument is not used.

**Returns** **reshaped\_matrix** : *self* with the new dimensions of *shape*

**See also:**

**`np.matrix.reshape`**

NumPy's implementation of 'reshape' for matrices

`lil_matrix.set_shape` (*shape*)

See *reshape*.

`lil_matrix.setdiag` (*values*, *k=0*)

Set diagonal or off-diagonal elements of the array.

**Parameters** **values** : array\_like

New values of the diagonal elements.

Values may have any length. If the diagonal is longer than values, then the remaining diagonal entries will not be set. If values are longer than the diagonal, then the remaining values are ignored.

If a scalar value is given, all of the diagonal is set to it.

**k** : int, optional

Which off-diagonal to set, corresponding to elements  $a[i,i+k]$ . Default: 0 (the main diagonal).

`lil_matrix.sum` (*axis=None, dtype=None, out=None*)

Sum the matrix elements over a given axis.

**Parameters** **axis** : {-2, -1, 0, 1, None} optional

Axis along which the sum is computed. The default is to compute the sum of all the matrix elements, returning a scalar (i.e. *axis = None*).

**dtype** : dtype, optional

The type of the returned matrix and of the accumulator in which the elements are summed. The dtype of *a* is used by default unless *a* has an integer dtype of less precision than the default platform integer. In that case, if *a* is signed then the platform integer is used while if *a* is unsigned then an unsigned integer of the same precision as the platform integer is used.

**out** : np.matrix, optional

Alternative output matrix in which to place the result. It must have the same shape as the expected output, but the type of the output values will be cast if necessary.

**Returns** **sum\_along\_axis** : np.matrix

A matrix with the same shape as *self*, with the specified axis removed.

See also:

`np.matrix.sum`

NumPy's implementation of 'sum' for matrices

`lil_matrix.toarray` (*order=None, out=None*)

Return a dense ndarray representation of this matrix.

**Parameters** **order** : {'C', 'F'}, optional

Whether to store multi-dimensional data in C (row-major) or Fortran (column-major) order in memory. The default is 'None', indicating the NumPy default of C-ordered. Cannot be specified in conjunction with the *out* argument.

**out** : ndarray, 2-dimensional, optional

If specified, uses this array as the output buffer instead of allocating a new array to return. The provided array must have the same shape and dtype as the sparse matrix on which you are calling the method. For most sparse types, *out* is required to be memory contiguous (either C or Fortran ordered).

**Returns** **arr** : ndarray, 2-dimensional

An array with the same shape and containing the same data represented by the sparse matrix, with the requested memory order. If *out* was passed, the same object is returned after being modified in-place to contain the appropriate values.

`lil_matrix.tobsr` (*blocksize=None, copy=False*)

Convert this matrix to Block Sparse Row format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `bsr_matrix`.

When `blocksize=(R, C)` is provided, it will be used for construction of the `bsr_matrix`.

`lil_matrix.tocoo` (*copy=False*)

Convert this matrix to COOrdinate format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `coo_matrix`.

`lil_matrix.tocsf` (*copy=False*)

Convert this matrix to Compressed Sparse Column format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `csc_matrix`.

`lil_matrix.tocsr` (*copy=False*)

Convert this matrix to Compressed Sparse Row format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `csr_matrix`.

`lil_matrix.todense` (*order=None, out=None*)

Return a dense matrix representation of this matrix.

**Parameters**    **order** : {'C', 'F'}, optional

Whether to store multi-dimensional data in C (row-major) or Fortran (column-major) order in memory. The default is 'None', indicating the NumPy default of C-ordered. Cannot be specified in conjunction with the `out` argument.

**out** : ndarray, 2-dimensional, optional

If specified, uses this array (or `numpy.matrix`) as the output buffer instead of allocating a new array to return. The provided array must have the same shape and dtype as the sparse matrix on which you are calling the method.

**Returns**        **arr** : numpy.matrix, 2-dimensional

A NumPy matrix object with the same shape and containing the same data represented by the sparse matrix, with the requested memory order. If `out` was passed and was an array (rather than a `numpy.matrix`), it will be filled with the appropriate values and returned wrapped in a `numpy.matrix` object that shares the same memory.

`lil_matrix.todia` (*copy=False*)

Convert this matrix to sparse DIAgonal format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `dia_matrix`.

`lil_matrix.todok` (*copy=False*)

Convert this matrix to Dictionary Of Keys format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `dok_matrix`.

`lil_matrix.tolil` (*copy=False*)

Convert this matrix to LInked List format.

With `copy=False`, the data/indices may be shared between this matrix and the resultant `lil_matrix`.

`lil_matrix.transpose` (*axes=None, copy=False*)

Reverses the dimensions of the sparse matrix.

**Parameters**    **axes** : None, optional

This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value.

**copy** : bool, optional

Indicates whether or not attributes of *self* should be copied whenever possible. The degree to which attributes are copied varies depending

**Returns**        **p** : *self* with the dimensions reversed.

See also:

**`np.matrix.transpose`**

NumPy's implementation of 'transpose' for matrices

**class** `scipy.sparse.spmatrix` (*maxprint=50*)

This class provides a base class for all sparse matrices. It cannot be instantiated. Most of the work is provided by subclasses.

**Attributes**

<code>nnz</code>	Number of stored values, including explicit zeros.
<code>shape</code>	Get shape of a matrix.

`spmatrix.nnz`

Number of stored values, including explicit zeros.

See also:

**`count_nonzero`**

Number of non-zero entries

`spmatrix.shape`

Get shape of a matrix.

**Methods**

<code>asformat(format)</code>	Return this matrix in a given sparse format
<code>asfptype()</code>	Upcast matrix to a floating point format (if necessary)
<code>astype(dtype[, casting, copy])</code>	Cast the matrix elements to a specified type.
<code>conj()</code>	Element-wise complex conjugation.
<code>conjugate()</code>	Element-wise complex conjugation.
<code>copy()</code>	Returns a copy of this matrix.
<code>count_nonzero()</code>	Number of non-zero entries, equivalent to
<code>diagonal([k])</code>	Returns the k-th diagonal of the matrix.
<code>dot(other)</code>	Ordinary dot product
<code>getH()</code>	Return the Hermitian transpose of this matrix.
<code>get_shape()</code>	Get shape of a matrix.
<code>getcol(j)</code>	Returns a copy of column j of the matrix, as an (m x 1) sparse matrix (column vector).
<code>getformat()</code>	Format of a matrix representation as a string.
<code>getmaxprint()</code>	Maximum number of elements to display when printed.
<code>getnnz([axis])</code>	Number of stored values, including explicit zeros.
<code>getrow(i)</code>	Returns a copy of row i of the matrix, as a (1 x n) sparse matrix (row vector).
<code>maximum(other)</code>	Element-wise maximum between this and another matrix.
<code>mean([axis, dtype, out])</code>	Compute the arithmetic mean along the specified axis.
<code>minimum(other)</code>	Element-wise minimum between this and another matrix.
<code>multiply(other)</code>	Point-wise multiplication by another matrix
<code>nonzero()</code>	nonzero indices
<code>power(n[, dtype])</code>	Element-wise power.

Continued on next page

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<code>reshape(shape[, order])</code>	Gives a new shape to a sparse matrix without changing its data.
<code>set_shape(shape)</code>	See <code>reshape</code> .
<code>setdiag(values[, k])</code>	Set diagonal or off-diagonal elements of the array.
<code>sum([axis, dtype, out])</code>	Sum the matrix elements over a given axis.
<code>toarray([order, out])</code>	Return a dense ndarray representation of this matrix.
<code>tobsr([blocksize, copy])</code>	Convert this matrix to Block Sparse Row format.
<code>tocoo([copy])</code>	Convert this matrix to COOrdinate format.
<code>tocsc([copy])</code>	Convert this matrix to Compressed Sparse Column format.
<code>tocsr([copy])</code>	Convert this matrix to Compressed Sparse Row format.
<code>todense([order, out])</code>	Return a dense matrix representation of this matrix.
<code>todia([copy])</code>	Convert this matrix to sparse DIAgonal format.
<code>todok([copy])</code>	Convert this matrix to Dictionary Of Keys format.
<code>tolil([copy])</code>	Convert this matrix to LInked List format.
<code>transpose([axes, copy])</code>	Reverses the dimensions of the sparse matrix.

`spmatrix.asformat` (*format*)

Return this matrix in a given sparse format

**Parameters** `format` : {string, None}

*desired sparse matrix format*

- None for no format conversion
- “csr” for `csr_matrix` format
- “csc” for `csc_matrix` format
- “lil” for `lil_matrix` format
- “dok” for `dok_matrix` format and so on

`spmatrix.asfptype` ()

Upcast matrix to a floating point format (if necessary)

`spmatrix.astype` (*dtype*, *casting*='unsafe', *copy*=True)

Cast the matrix elements to a specified type.

**Parameters** `dtype` : string or numpy dtype

Typecode or data-type to which to cast the data.

**casting** : {'no', 'equiv', 'safe', 'same\_kind', 'unsafe'}, optional

Controls what kind of data casting may occur. Defaults to 'unsafe' for backwards compatibility. 'no' means the data types should not be cast at all. 'equiv' means only byte-order changes are allowed. 'safe' means only casts which can preserve values are allowed. 'same\_kind' means only safe casts or casts within a kind, like float64 to float32, are allowed. 'unsafe' means any data conversions may be done.

**copy** : bool, optional

If `copy` is *False*, the result might share some memory with this matrix. If `copy` is *True*, it is guaranteed that the result and this matrix do not share any memory.

`spmatrix.conj` ()

Element-wise complex conjugation.

If the matrix is of non-complex data type, then this method does nothing and the data is not copied.

`spmatrix.conjugate()`

Element-wise complex conjugation.

If the matrix is of non-complex data type, then this method does nothing and the data is not copied.

`spmatrix.copy()`

Returns a copy of this matrix.

No data/indices will be shared between the returned value and current matrix.

`spmatrix.count_nonzero()`

Number of non-zero entries, equivalent to

`np.count_nonzero(a.toarray())`

Unlike `getnnz()` and the `nnz` property, which return the number of stored entries (the length of the data attribute), this method counts the actual number of non-zero entries in data.

`spmatrix.diagonal(k=0)`

Returns the k-th diagonal of the matrix.

**Parameters** `k` : int, optional

Which diagonal to set, corresponding to elements `a[i, i+k]`. Default: 0 (the main diagonal).

**See also:**

[\*numpy.diagonal\*](#)

Equivalent numpy function.

**Examples**

```
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> A.diagonal()
array([1, 0, 5])
>>> A.diagonal(k=1)
array([2, 3])
```

`spmatrix.dot(other)`

Ordinary dot product

**Examples**

```
>>> import numpy as np
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> v = np.array([1, 0, -1])
>>> A.dot(v)
array([ 1, -3, -1], dtype=int64)
```

`spmatrix.getH()`

Return the Hermitian transpose of this matrix.

**See also:**

[\*np.matrix.getH\*](#)

NumPy's implementation of `getH` for matrices

`spmatrix.get_shape()`

Get shape of a matrix.

`spmatrix.getcol(j)`

Returns a copy of column *j* of the matrix, as an (*m* x 1) sparse matrix (column vector).

`spmatrix.getformat()`

Format of a matrix representation as a string.

`spmatrix.getmaxprint()`

Maximum number of elements to display when printed.

`spmatrix.getnnz(axis=None)`

Number of stored values, including explicit zeros.

**Parameters** **axis** : None, 0, or 1

Select between the number of values across the whole matrix, in each column, or in each row.

**See also:**

**count\_nonzero**

Number of non-zero entries

`spmatrix.getrow(i)`

Returns a copy of row *i* of the matrix, as a (1 x *n*) sparse matrix (row vector).

`spmatrix.maximum(other)`

Element-wise maximum between this and another matrix.

`spmatrix.mean(axis=None, dtype=None, out=None)`

Compute the arithmetic mean along the specified axis.

Returns the average of the matrix elements. The average is taken over all elements in the matrix by default, otherwise over the specified axis. *float64* intermediate and return values are used for integer inputs.

**Parameters** **axis** : {-2, -1, 0, 1, None} optional

Axis along which the mean is computed. The default is to compute the mean of all elements in the matrix (i.e. *axis = None*).

**dtype** : data-type, optional

Type to use in computing the mean. For integer inputs, the default is *float64*; for floating point inputs, it is the same as the input dtype.

**out** : np.matrix, optional

Alternative output matrix in which to place the result. It must have the same shape as the expected output, but the type of the output values will be cast if necessary.

**Returns** **m** : np.matrix

**See also:**

**np.matrix.mean**

NumPy's implementation of 'mean' for matrices

`spmatrix.minimum(other)`

Element-wise minimum between this and another matrix.

`spmatrix.multiply(other)`

Point-wise multiplication by another matrix

`spmatrix.nonzero()`

nonzero indices

Returns a tuple of arrays (row,col) containing the indices of the non-zero elements of the matrix.



A matrix with the same shape as *self*, with the specified axis removed.

**See also:**

**`np.matrix.sum`**

NumPy's implementation of 'sum' for matrices

`spmatrix.toarray` (*order=None, out=None*)

Return a dense ndarray representation of this matrix.

**Parameters** **order** : {'C', 'F'}, optional

Whether to store multi-dimensional data in C (row-major) or Fortran (column-major) order in memory. The default is 'None', indicating the NumPy default of C-ordered. Cannot be specified in conjunction with the *out* argument.

**out** : ndarray, 2-dimensional, optional

If specified, uses this array as the output buffer instead of allocating a new array to return. The provided array must have the same shape and dtype as the sparse matrix on which you are calling the method. For most sparse types, *out* is required to be memory contiguous (either C or Fortran ordered).

**Returns** **arr** : ndarray, 2-dimensional

An array with the same shape and containing the same data represented by the sparse matrix, with the requested memory order. If *out* was passed, the same object is returned after being modified in-place to contain the appropriate values.

`spmatrix.tobsr` (*blocksize=None, copy=False*)

Convert this matrix to Block Sparse Row format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `bsr_matrix`.

When *blocksize=(R, C)* is provided, it will be used for construction of the `bsr_matrix`.

`spmatrix.tocoo` (*copy=False*)

Convert this matrix to COOrdinate format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `coo_matrix`.

`spmatrix.tocsc` (*copy=False*)

Convert this matrix to Compressed Sparse Column format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `csc_matrix`.

`spmatrix.tocsr` (*copy=False*)

Convert this matrix to Compressed Sparse Row format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `csr_matrix`.

`spmatrix.todense` (*order=None, out=None*)

Return a dense matrix representation of this matrix.

**Parameters** **order** : {'C', 'F'}, optional

Whether to store multi-dimensional data in C (row-major) or Fortran (column-major) order in memory. The default is 'None', indicating the NumPy default of C-ordered. Cannot be specified in conjunction with the *out* argument.

**out** : ndarray, 2-dimensional, optional

If specified, uses this array (or `numpy.matrix`) as the output buffer instead of allocating a new array to return. The provided array must have the same shape and dtype as the sparse matrix on which you are calling the method.

**Returns**     **arr** : `numpy.matrix`, 2-dimensional  
 A NumPy matrix object with the same shape and containing the same data represented by the sparse matrix, with the requested memory order. If *out* was passed and was an array (rather than a `numpy.matrix`), it will be filled with the appropriate values and returned wrapped in a `numpy.matrix` object that shares the same memory.

`spmatrix.todia` (*copy=False*)  
 Convert this matrix to sparse DIAgonal format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `dia_matrix`.

`spmatrix.todok` (*copy=False*)  
 Convert this matrix to Dictionary Of Keys format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `dok_matrix`.

`spmatrix.tolil` (*copy=False*)  
 Convert this matrix to LInked List format.

With *copy=False*, the data/indices may be shared between this matrix and the resultant `lil_matrix`.

`spmatrix.transpose` (*axes=None, copy=False*)  
 Reverses the dimensions of the sparse matrix.

**Parameters**   **axes** : None, optional  
 This argument is in the signature *solely* for NumPy compatibility reasons. Do not pass in anything except for the default value.

**copy** : bool, optional  
 Indicates whether or not attributes of *self* should be copied whenever possible. The degree to which attributes are copied varies depending on the type of sparse matrix being used.

**Returns**     **p** : *self* with the dimensions reversed.

**See also:**

**`np.matrix.transpose`**  
 NumPy's implementation of 'transpose' for matrices

## Functions

Building sparse matrices:

<code>eye(m[, n, k, dtype, format])</code>	Sparse matrix with ones on diagonal
<code>identity(n[, dtype, format])</code>	Identity matrix in sparse format
<code>kron(A, B[, format])</code>	kronecker product of sparse matrices A and B
<code>kronsum(A, B[, format])</code>	kronecker sum of sparse matrices A and B
<code>diags(diagonals[, offsets, shape, format, dtype])</code>	Construct a sparse matrix from diagonals.
<code>spdiags(data, diags, m, n[, format])</code>	Return a sparse matrix from diagonals.
<code>block_diag(mats[, format, dtype])</code>	Build a block diagonal sparse matrix from provided matrices.
<code>tril(A[, k, format])</code>	Return the lower triangular portion of a matrix in sparse format
<code>triu(A[, k, format])</code>	Return the upper triangular portion of a matrix in sparse format
<code>bmat(blocks[, format, dtype])</code>	Build a sparse matrix from sparse sub-blocks
<code>hstack(blocks[, format, dtype])</code>	Stack sparse matrices horizontally (column wise)

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Table 5.179 – continued from previous page

<code>vstack(blocks[, format, dtype])</code>	Stack sparse matrices vertically (row wise)
<code>rand(m, n[, density, format, dtype, ...])</code>	Generate a sparse matrix of the given shape and density with uniformly distributed values.
<code>random(m, n[, density, format, dtype, ...])</code>	Generate a sparse matrix of the given shape and density with randomly distributed values.

`scipy.sparse.eye(m, n=None, k=0, dtype=<type 'float'>, format=None)`

Sparse matrix with ones on diagonal

Returns a sparse (m x n) matrix where the k-th diagonal is all ones and everything else is zeros.

**Parameters**

- m** : int  
Number of rows in the matrix.
- n** : int, optional  
Number of columns. Default: *m*.
- k** : int, optional  
Diagonal to place ones on. Default: 0 (main diagonal).
- dtype** : dtype, optional  
Data type of the matrix.
- format** : str, optional  
Sparse format of the result, e.g. format="csr", etc.

### Examples

```
>>> from scipy import sparse
>>> sparse.eye(3).toarray()
array([[ 1.,  0.,  0.],
       [ 0.,  1.,  0.],
       [ 0.,  0.,  1.]])
>>> sparse.eye(3, dtype=np.int8)
<3x3 sparse matrix of type '<class 'numpy.int8'>'
with 3 stored elements (1 diagonals) in DIAgonal format>
```

`scipy.sparse.identity(n, dtype='d', format=None)`

Identity matrix in sparse format

Returns an identity matrix with shape (n,n) using a given sparse format and dtype.

**Parameters**

- n** : int  
Shape of the identity matrix.
- dtype** : dtype, optional  
Data type of the matrix
- format** : str, optional  
Sparse format of the result, e.g. format="csr", etc.

### Examples

```
>>> from scipy.sparse import identity
>>> identity(3).toarray()
array([[ 1.,  0.,  0.],
       [ 0.,  1.,  0.],
       [ 0.,  0.,  1.]])
>>> identity(3, dtype='int8', format='dia')
<3x3 sparse matrix of type '<class 'numpy.int8'>'
with 3 stored elements (1 diagonals) in DIAgonal format>
```

`scipy.sparse.kron(A, B, format=None)`  
 kronecker product of sparse matrices A and B

**Parameters**

- A** : sparse or dense matrix  
first matrix of the product
- B** : sparse or dense matrix  
second matrix of the product
- format** : str, optional  
format of the result (e.g. "csr")

**Returns** kronecker product in a sparse matrix format

**Examples**

```
>>> from scipy import sparse
>>> A = sparse.csr_matrix(np.array([[0, 2], [5, 0]]))
>>> B = sparse.csr_matrix(np.array([[1, 2], [3, 4]]))
>>> sparse.kron(A, B).toarray()
array([[ 0,  0,  2,  4],
       [ 0,  0,  6,  8],
       [ 5, 10,  0,  0],
       [15, 20,  0,  0]])
```

```
>>> sparse.kron(A, [[1, 2], [3, 4]].toarray())
array([[ 0,  0,  2,  4],
       [ 0,  0,  6,  8],
       [ 5, 10,  0,  0],
       [15, 20,  0,  0]])
```

`scipy.sparse.kronsum(A, B, format=None)`  
 kronecker sum of sparse matrices A and B

Kronecker sum of two sparse matrices is a sum of two Kronecker products  $\text{kron}(I_n, A) + \text{kron}(B, I_m)$  where A has shape (m,m) and B has shape (n,n) and  $I_m$  and  $I_n$  are identity matrices of shape (m,m) and (n,n) respectively.

**Parameters**

- A** : square matrix
- B** : square matrix
- format** : str  
format of the result (e.g. "csr")

**Returns** kronecker sum in a sparse matrix format

`scipy.sparse.diags(diagonals, offsets=0, shape=None, format=None, dtype=None)`  
 Construct a sparse matrix from diagonals.

**Parameters**

- diagonals** : sequence of array\_like  
Sequence of arrays containing the matrix diagonals, corresponding to *offsets*.
- offsets** : sequence of int or an int, optional  
**Diagonals to set:**
  - k = 0 the main diagonal (default)
  - k > 0 the k-th upper diagonal
  - k < 0 the k-th lower diagonal
- shape** : tuple of int, optional  
Shape of the result. If omitted, a square matrix large enough to contain the diagonals is returned.

**format** : {"dia", "csr", "csc", "lil", ...}, optional  
 Matrix format of the result. By default (format=None) an appropriate sparse matrix format is returned. This choice is subject to change.

**dtype** : dtype, optional  
 Data type of the matrix.

**See also:**

**spdiags** construct matrix from diagonals

**Notes**

This function differs from *spdiags* in the way it handles off-diagonals.

The result from *diags* is the sparse equivalent of:

```
np.diag(diagonals[0], offsets[0])
+ ...
+ np.diag(diagonals[k], offsets[k])
```

Repeated diagonal offsets are disallowed.

New in version 0.11.

**Examples**

```
>>> from scipy.sparse import diags
>>> diagonals = [[1, 2, 3, 4], [1, 2, 3], [1, 2]]
>>> diags(diagonals, [0, -1, 2]).toarray()
array([[1, 0, 1, 0],
       [1, 2, 0, 2],
       [0, 2, 3, 0],
       [0, 0, 3, 4]])
```

Broadcasting of scalars is supported (but shape needs to be specified):

```
>>> diags([1, -2, 1], [-1, 0, 1], shape=(4, 4)).toarray()
array([[ -2.,  1.,  0.,  0.],
       [  1., -2.,  1.,  0.],
       [  0.,  1., -2.,  1.],
       [  0.,  0.,  1., -2.]])
```

If only one diagonal is wanted (as in `numpy.diag`), the following works as well:

```
>>> diags([1, 2, 3], 1).toarray()
array([[ 0.,  1.,  0.,  0.],
       [ 0.,  0.,  2.,  0.],
       [ 0.,  0.,  0.,  3.],
       [ 0.,  0.,  0.,  0.]])
```

`scipy.sparse.spdiags` (*data*, *diags*, *m*, *n*, *format=None*)

Return a sparse matrix from diagonals.

**Parameters**

- data** : array\_like  
matrix diagonals stored row-wise
- diags** : diagonals to set
  - $k = 0$  the main diagonal
  - $k > 0$  the  $k$ -th upper diagonal
  - $k < 0$  the  $k$ -th lower diagonal
- m, n** : int  
shape of the result

**format** : str, optional

Format of the result. By default (format=None) an appropriate sparse matrix format is returned. This choice is subject to change.

**See also:**

**diags** more convenient form of this function

**dia\_matrix** the sparse DIAgonal format.

**Examples**

```
>>> from scipy.sparse import spdiags
>>> data = np.array([[1, 2, 3, 4], [1, 2, 3, 4], [1, 2, 3, 4]])
>>> diags = np.array([0, -1, 2])
>>> spdiags(data, diags, 4, 4).toarray()
array([[1, 0, 3, 0],
       [1, 2, 0, 4],
       [0, 2, 3, 0],
       [0, 0, 3, 4]])
```

`scipy.sparse.block_diag(mats, format=None, dtype=None)`

Build a block diagonal sparse matrix from provided matrices.

**Parameters** **mats** : sequence of matrices

Input matrices.

**format** : str, optional

The sparse format of the result (e.g. “csr”). If not given, the matrix is returned in “coo” format.

**dtype** : dtype specifier, optional

The data-type of the output matrix. If not given, the dtype is determined from that of *blocks*.

**Returns** **res** : sparse matrix

**See also:**

*bmat, diags*

**Notes**

New in version 0.11.0.

**Examples**

```
>>> from scipy.sparse import coo_matrix, block_diag
>>> A = coo_matrix([[1, 2], [3, 4]])
>>> B = coo_matrix([[5], [6]])
>>> C = coo_matrix([[7]])
>>> block_diag((A, B, C)).toarray()
array([[1, 2, 0, 0],
       [3, 4, 0, 0],
       [0, 0, 5, 0],
       [0, 0, 6, 0],
       [0, 0, 0, 7]])
```

`scipy.sparse.tril(A, k=0, format=None)`

Return the lower triangular portion of a matrix in sparse format

**Returns the elements on or below the *k*-th diagonal of the matrix *A*.**

- *k* = 0 corresponds to the main diagonal
- *k* > 0 is above the main diagonal

- $k < 0$  is below the main diagonal

**Parameters** **A** : dense or sparse matrix  
Matrix whose lower triangular portion is desired.

**k** : integer  
The top-most diagonal of the lower triangle.

**format** : string  
Sparse format of the result, e.g. format="csr", etc.

**Returns** **L** : sparse matrix  
Lower triangular portion of A in sparse format.

**See also:**

**triu** upper triangle in sparse format

**Examples**

```
>>> from scipy.sparse import csr_matrix, tril
>>> A = csr_matrix([[1, 2, 0, 0, 3], [4, 5, 0, 6, 7], [0, 0, 8, 9, 0]],
...               dtype='int32')
>>> A.toarray()
array([[1, 2, 0, 0, 3],
       [4, 5, 0, 6, 7],
       [0, 0, 8, 9, 0]])
>>> tril(A).toarray()
array([[1, 0, 0, 0, 0],
       [4, 5, 0, 0, 0],
       [0, 0, 8, 0, 0]])
>>> tril(A).nnz
4
>>> tril(A, k=1).toarray()
array([[1, 2, 0, 0, 0],
       [4, 5, 0, 0, 0],
       [0, 0, 8, 9, 0]])
>>> tril(A, k=-1).toarray()
array([[0, 0, 0, 0, 0],
       [4, 0, 0, 0, 0],
       [0, 0, 0, 0, 0]])
>>> tril(A, format='csc')
<3x5 sparse matrix of type '<class 'numpy.int32'>'
with 4 stored elements in Compressed Sparse Column format>
```

`scipy.sparse.triu(A, k=0, format=None)`

Return the upper triangular portion of a matrix in sparse format

**Returns the elements on or above the  $k$ -th diagonal of the matrix A.**

- $k = 0$  corresponds to the main diagonal
- $k > 0$  is above the main diagonal
- $k < 0$  is below the main diagonal

**Parameters** **A** : dense or sparse matrix  
Matrix whose upper triangular portion is desired.

**k** : integer  
The bottom-most diagonal of the upper triangle.

**format** : string  
Sparse format of the result, e.g. format="csr", etc.

**Returns** **L** : sparse matrix  
Upper triangular portion of A in sparse format.

**See also:****tril** lower triangle in sparse format**Examples**

```

>>> from scipy.sparse import csr_matrix, triu
>>> A = csr_matrix([[1, 2, 0, 0, 3], [4, 5, 0, 6, 7], [0, 0, 8, 9, 0]],
...               dtype='int32')
>>> A.toarray()
array([[1, 2, 0, 0, 3],
       [4, 5, 0, 6, 7],
       [0, 0, 8, 9, 0]])
>>> triu(A).toarray()
array([[1, 2, 0, 0, 3],
       [0, 5, 0, 6, 7],
       [0, 0, 8, 9, 0]])
>>> triu(A).nnz
8
>>> triu(A, k=1).toarray()
array([[0, 2, 0, 0, 3],
       [0, 0, 0, 6, 7],
       [0, 0, 0, 9, 0]])
>>> triu(A, k=-1).toarray()
array([[1, 2, 0, 0, 3],
       [4, 5, 0, 6, 7],
       [0, 0, 8, 9, 0]])
>>> triu(A, format='csc')
<3x5 sparse matrix of type '<class 'numpy.int32'>'
  with 8 stored elements in Compressed Sparse Column format>

```

`scipy.sparse.bmat` (*blocks, format=None, dtype=None*)

Build a sparse matrix from sparse sub-blocks

**Parameters** **blocks** : array\_like

Grid of sparse matrices with compatible shapes. An entry of None implies an all-zero matrix.

**format** : {'bsr', 'coo', 'csc', 'csr', 'dia', 'dok', 'lil'}, optional

The sparse format of the result (e.g. "csr"). By default an appropriate sparse matrix format is returned. This choice is subject to change.

**dtype** : dtype, optional

The data-type of the output matrix. If not given, the dtype is determined from that of *blocks*.

**Returns** **bmat** : sparse matrix

**See also:***block\_diag, diags***Examples**

```

>>> from scipy.sparse import coo_matrix, bmat
>>> A = coo_matrix([[1, 2], [3, 4]])
>>> B = coo_matrix([[5], [6]])
>>> C = coo_matrix([[7]])
>>> bmat([[A, B], [None, C]]).toarray()
array([[1, 2, 5],
       [3, 4, 6],
       [0, 0, 7]])

```

```
>>> bmat([[A, None], [None, C]].toarray()
array([[1, 2, 0],
       [3, 4, 0],
       [0, 0, 7]])
```

`scipy.sparse.hstack` (*blocks, format=None, dtype=None*)

Stack sparse matrices horizontally (column wise)

**Parameters** **blocks**

sequence of sparse matrices with compatible shapes

**format** : str

sparse format of the result (e.g. “csr”) by default an appropriate sparse matrix format is returned. This choice is subject to change.

**dtype** : dtype, optional

The data-type of the output matrix. If not given, the dtype is determined from that of *blocks*.

**See also:**

**vstack** stack sparse matrices vertically (row wise)

**Examples**

```
>>> from scipy.sparse import coo_matrix,.hstack
>>> A = coo_matrix([[1, 2], [3, 4]])
>>> B = coo_matrix([[5], [6]])
>>>.hstack([A,B]).toarray()
array([[1, 2, 5],
       [3, 4, 6]])
```

`scipy.sparse.vstack` (*blocks, format=None, dtype=None*)

Stack sparse matrices vertically (row wise)

**Parameters** **blocks**

sequence of sparse matrices with compatible shapes

**format** : str, optional

sparse format of the result (e.g. “csr”) by default an appropriate sparse matrix format is returned. This choice is subject to change.

**dtype** : dtype, optional

The data-type of the output matrix. If not given, the dtype is determined from that of *blocks*.

**See also:**

**hstack** stack sparse matrices horizontally (column wise)

**Examples**

```
>>> from scipy.sparse import coo_matrix, vstack
>>> A = coo_matrix([[1, 2], [3, 4]])
>>> B = coo_matrix([[5, 6]])
>>> vstack([A, B]).toarray()
array([[1, 2],
       [3, 4],
       [5, 6]])
```

`scipy.sparse.rand` (*m, n, density=0.01, format='coo', dtype=None, random\_state=None*)

Generate a sparse matrix of the given shape and density with uniformly distributed values.

**Parameters**

- m, n** : int  
shape of the matrix
- density** : real, optional  
density of the generated matrix: density equal to one means a full matrix, density of 0 means a matrix with no non-zero items.
- format** : str, optional  
sparse matrix format.
- dtype** : dtype, optional  
type of the returned matrix values.
- random\_state** : {numpy.random.RandomState, int}, optional  
Random number generator or random seed. If not given, the singleton numpy.random will be used.

**Returns**

- res** : sparse matrix

See also:

**scipy.sparse.random**

Similar function that allows a user-specified random data source.

**Notes**

Only float types are supported for now.

**Examples**

```
>>> from scipy.sparse import rand
>>> matrix = rand(3, 4, density=0.25, format="csr", random_state=42)
>>> matrix
<3x4 sparse matrix of type '<class 'numpy.float64'>'
  with 3 stored elements in Compressed Sparse Row format>
>>> matrix.todense()
matrix([[ 0.          ,  0.59685016,  0.779691   ,  0.          ],
        [ 0.          ,  0.          ,  0.          ,  0.44583275],
        [ 0.          ,  0.          ,  0.          ,  0.          ]])
```

`scipy.sparse.random(m, n, density=0.01, format='coo', dtype=None, random_state=None, data_rvs=None)`

Generate a sparse matrix of the given shape and density with randomly distributed values.

**Parameters**

- m, n** : int  
shape of the matrix
- density** : real, optional  
density of the generated matrix: density equal to one means a full matrix, density of 0 means a matrix with no non-zero items.
- format** : str, optional  
sparse matrix format.
- dtype** : dtype, optional  
type of the returned matrix values.
- random\_state** : {numpy.random.RandomState, int}, optional  
Random number generator or random seed. If not given, the singleton numpy.random will be used. This random state will be used for sampling the sparsity structure, but not necessarily for sampling the values of the structurally nonzero entries of the matrix.
- data\_rvs** : callable, optional  
Samples a requested number of random values. This function should take a single argument specifying the length of the ndarray that it will return. The structurally nonzero entries of the sparse random matrix will be taken from the array sampled by this function. By default, uniform [0, 1) random

values will be sampled using the same random state as is used for sampling the sparsity structure.

**Returns** `res` : sparse matrix

**Notes**

Only float types are supported for now.

**Examples**

```
>>> from scipy.sparse import random
>>> from scipy import stats
>>> class CustomRandomState(object):
...     def randint(self, k):
...         i = np.random.randint(k)
...         return i - i % 2
>>> rs = CustomRandomState()
>>> rvs = stats.poisson(25, loc=10).rvs
>>> S = random(3, 4, density=0.25, random_state=rs, data_rvs=rvs)
>>> S.A
array([[ 36.,   0.,  33.,   0.], # random
       [  0.,   0.,   0.,   0.],
       [  0.,   0.,  36.,   0.]])
```

Save and load sparse matrices:

`save_npz(file, matrix[, compressed])`

Save a sparse matrix to a file using `.npz` format.

`load_npz(file)`

Load a sparse matrix from a file using `.npz` format.

`scipy.sparse.save_npz(file, matrix, compressed=True)`

Save a sparse matrix to a file using `.npz` format.

**Parameters** `file` : str or file-like object

Either the file name (string) or an open file (file-like object) where the data will be saved. If file is a string, the `.npz` extension will be appended to the file name if it is not already there.

**matrix**: `spmatrix` (format: `"csc"`, `"csr"`, `"bsr"`, `"dia"` or `coo`)

The sparse matrix to save.

**compressed** : bool, optional

Allow compressing the file. Default: True

See also:

`scipy.sparse.load_npz`

Load a sparse matrix from a file using `.npz` format.

`numpy.savez`

Save several arrays into a `.npz` archive.

`numpy.savez_compressed`

Save several arrays into a compressed `.npz` archive.

**Examples**

Store sparse matrix to disk, and load it again:

```
>>> import scipy.sparse
>>> sparse_matrix = scipy.sparse.csc_matrix(np.array([[0, 0, 3], [4, 0, 0]]))
>>> sparse_matrix
<2x3 sparse matrix of type '<class 'numpy.int64''>'
```

```
with 2 stored elements in Compressed Sparse Column format>
>>> sparse_matrix.todense()
matrix([[0, 0, 3],
        [4, 0, 0]], dtype=int64)
```

```
>>> scipy.sparse.save_npz('/tmp/sparse_matrix.npz', sparse_matrix)
>>> sparse_matrix = scipy.sparse.load_npz('/tmp/sparse_matrix.npz')
```

```
>>> sparse_matrix
<2x3 sparse matrix of type '<class 'numpy.int64'>'
with 2 stored elements in Compressed Sparse Column format>
>>> sparse_matrix.todense()
matrix([[0, 0, 3],
        [4, 0, 0]], dtype=int64)
```

`scipy.sparse.load_npz` (*file*)

Load a sparse matrix from a file using `.npz` format.

<b>Parameters</b>	<b>file</b> : str or file-like object	Either the file name (string) or an open file (file-like object) where the data will be loaded.
<b>Returns</b>	<b>result</b> : csc_matrix, csr_matrix, bsr_matrix, dia_matrix or coo_matrix	A sparse matrix containing the loaded data.
<b>Raises</b>	<b>IOError</b>	If the input file does not exist or cannot be read.

See also:

**`scipy.sparse.save_npz`**

Save a sparse matrix to a file using `.npz` format.

**`numpy.load`** Load several arrays from a `.npz` archive.

**Examples**

Store sparse matrix to disk, and load it again:

```
>>> import scipy.sparse
>>> sparse_matrix = scipy.sparse.csc_matrix(np.array([[0, 0, 3], [4, 0, 0]]))
>>> sparse_matrix
<2x3 sparse matrix of type '<class 'numpy.int64'>'
with 2 stored elements in Compressed Sparse Column format>
>>> sparse_matrix.todense()
matrix([[0, 0, 3],
        [4, 0, 0]], dtype=int64)
```

```
>>> scipy.sparse.save_npz('/tmp/sparse_matrix.npz', sparse_matrix)
>>> sparse_matrix = scipy.sparse.load_npz('/tmp/sparse_matrix.npz')
```

```
>>> sparse_matrix
<2x3 sparse matrix of type '<class 'numpy.int64'>'
with 2 stored elements in Compressed Sparse Column format>
>>> sparse_matrix.todense()
matrix([[0, 0, 3],
        [4, 0, 0]], dtype=int64)
```

Sparse matrix tools:

---

<code>find(A)</code>	Return the indices and values of the nonzero elements of a matrix
----------------------	---

---

`scipy.sparse.find(A)`

Return the indices and values of the nonzero elements of a matrix

**Parameters** `A` : dense or sparse matrix

**Returns** `(I,J,V)` : tuple of arrays  
Matrix whose nonzero elements are desired.

I, J, and V contain the row indices, column indices, and values of the nonzero matrix entries.

### Examples

```
>>> from scipy.sparse import csr_matrix, find
>>> A = csr_matrix([[7.0, 8.0, 0],[0, 0, 9.0]])
>>> find(A)
(array([0, 0, 1], dtype=int32), array([0, 1, 2], dtype=int32), array([ 7.,  8.,  9.]))
```

Identifying sparse matrices:

<code>issparse(x)</code>	Is x of a sparse matrix type?
<code>isspmatrix(x)</code>	Is x of a sparse matrix type?
<code>isspmatrix_csc(x)</code>	Is x of csc_matrix type?
<code>isspmatrix_csr(x)</code>	Is x of csr_matrix type?
<code>isspmatrix_bsr(x)</code>	Is x of a bsr_matrix type?
<code>isspmatrix_lil(x)</code>	Is x of lil_matrix type?
<code>isspmatrix_dok(x)</code>	Is x of dok_matrix type?
<code>isspmatrix_coo(x)</code>	Is x of coo_matrix type?
<code>isspmatrix_dia(x)</code>	Is x of dia_matrix type?

`scipy.sparse.issparse(x)`

Is x of a sparse matrix type?

**Parameters** `x`

**Returns** `bool` object to check for being a sparse matrix

True if x is a sparse matrix, False otherwise

### Notes

`issparse` and `isspmatrix` are aliases for the same function.

### Examples

```
>>> from scipy.sparse import csr_matrix, isspmatrix
>>> isspmatrix(csr_matrix([[5]]))
True
```

```
>>> from scipy.sparse import isspmatrix
>>> isspmatrix(5)
False
```

`scipy.sparse.isspmatrix(x)`

Is x of a sparse matrix type?

<b>Parameters</b>	<b>x</b>	object to check for being a sparse matrix
<b>Returns</b>	bool	True if x is a sparse matrix, False otherwise

**Notes**

issparse and isspmatrix are aliases for the same function.

**Examples**

```
>>> from scipy.sparse import csr_matrix, isspmatrix
>>> isspmatrix(csr_matrix([[5]]))
True
```

```
>>> from scipy.sparse import isspmatrix
>>> isspmatrix(5)
False
```

`scipy.sparse.isspmatrix_csc(x)`

Is x of csc\_matrix type?

<b>Parameters</b>	<b>x</b>	object to check for being a csc matrix
<b>Returns</b>	bool	True if x is a csc matrix, False otherwise

**Examples**

```
>>> from scipy.sparse import csc_matrix, isspmatrix_csc
>>> isspmatrix_csc(csc_matrix([[5]]))
True
```

```
>>> from scipy.sparse import csc_matrix, csr_matrix, isspmatrix_csc
>>> isspmatrix_csc(csr_matrix([[5]]))
False
```

`scipy.sparse.isspmatrix_csr(x)`

Is x of csr\_matrix type?

<b>Parameters</b>	<b>x</b>	object to check for being a csr matrix
<b>Returns</b>	bool	True if x is a csr matrix, False otherwise

**Examples**

```
>>> from scipy.sparse import csr_matrix, isspmatrix_csr
>>> isspmatrix_csr(csr_matrix([[5]]))
True
```

```
>>> from scipy.sparse import csc_matrix, csr_matrix, isspmatrix_csc
>>> isspmatrix_csr(csc_matrix([[5]]))
False
```

`scipy.sparse.isspmatrix_bsr(x)`

Is x of a bsr\_matrix type?

<b>Parameters</b>	<b>x</b>	object to check for being a bsr matrix
<b>Returns</b>	bool	True if x is a bsr matrix, False otherwise

#### Examples

```
>>> from scipy.sparse import bsr_matrix, isspmatrix_bsr
>>> isspmatrix_bsr(bsr_matrix([[5]]))
True
```

```
>>> from scipy.sparse import bsr_matrix, csr_matrix, isspmatrix_bsr
>>> isspmatrix_bsr(csr_matrix([[5]]))
False
```

`scipy.sparse.isspmatrix_lil(x)`

Is x of lil\_matrix type?

<b>Parameters</b>	<b>x</b>	object to check for being a lil matrix
<b>Returns</b>	bool	True if x is a lil matrix, False otherwise

#### Examples

```
>>> from scipy.sparse import lil_matrix, isspmatrix_lil
>>> isspmatrix_lil(lil_matrix([[5]]))
True
```

```
>>> from scipy.sparse import lil_matrix, csr_matrix, isspmatrix_lil
>>> isspmatrix_lil(csr_matrix([[5]]))
False
```

`scipy.sparse.isspmatrix_dok(x)`

Is x of dok\_matrix type?

<b>Parameters</b>	<b>x</b>	object to check for being a dok matrix
<b>Returns</b>	bool	True if x is a dok matrix, False otherwise

#### Examples

```
>>> from scipy.sparse import dok_matrix, isspmatrix_dok
>>> isspmatrix_dok(dok_matrix([[5]]))
True
```

```
>>> from scipy.sparse import dok_matrix, csr_matrix, isspmatrix_dok
>>> isspmatrix_dok(csr_matrix([[5]]))
False
```

`scipy.sparse.isspmatrix_coo(x)`

Is x of coo\_matrix type?

<b>Parameters</b>	<b>x</b>	object to check for being a coo matrix
-------------------	----------	--

**Returns** bool  
True if x is a coo matrix, False otherwise

**Examples**

```
>>> from scipy.sparse import coo_matrix, isspmatrix_coo
>>> isspmatrix_coo(coo_matrix([[5]]))
True
```

```
>>> from scipy.sparse import coo_matrix, csr_matrix, isspmatrix_coo
>>> isspmatrix_coo(csr_matrix([[5]]))
False
```

`scipy.sparse.isspmatrix_dia(x)`  
Is x of `dia_matrix` type?

**Parameters** x object to check for being a dia matrix  
**Returns** bool True if x is a dia matrix, False otherwise

**Examples**

```
>>> from scipy.sparse import dia_matrix, isspmatrix_dia
>>> isspmatrix_dia(dia_matrix([[5]]))
True
```

```
>>> from scipy.sparse import dia_matrix, csr_matrix, isspmatrix_dia
>>> isspmatrix_dia(csr_matrix([[5]]))
False
```

**Submodules**

*csgraph*  
*linalg*

---

**Compressed Sparse Graph Routines (`scipy.sparse.csgraph`)**

Fast graph algorithms based on sparse matrix representations.

**Contents**

<i>connected_components</i> (csgraph[, directed, ...])	Analyze the connected components of a sparse graph
<i>laplacian</i> (csgraph[, normed, return_diag, ...])	Return the Laplacian matrix of a directed graph.
<i>shortest_path</i> (csgraph[, method, directed, ...])	Perform a shortest-path graph search on a positive directed or undirected graph.
<i>dijkstra</i> (csgraph[, directed, indices, ...])	Dijkstra algorithm using Fibonacci Heaps
<i>floyd_warshall</i> (csgraph[, directed, ...])	Compute the shortest path lengths using the Floyd-Warshall algorithm

Continued on next page

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<code>bellman_ford(csgraph[, directed, indices, ...])</code>	Compute the shortest path lengths using the Bellman-Ford algorithm.
<code>johnson(csgraph[, directed, indices, ...])</code>	Compute the shortest path lengths using Johnson's algorithm.
<code>breadth_first_order(csgraph, i_start[, ...])</code>	Return a breadth-first ordering starting with specified node.
<code>depth_first_order(csgraph, i_start[, ...])</code>	Return a depth-first ordering starting with specified node.
<code>breadth_first_tree(csgraph, i_start[, directed])</code>	Return the tree generated by a breadth-first search
<code>depth_first_tree(csgraph, i_start[, directed])</code>	Return a tree generated by a depth-first search.
<code>minimum_spanning_tree(csgraph[, overwrite])</code>	Return a minimum spanning tree of an undirected graph
<code>reverse_cuthill_mckee(graph[, symmetric_mode])</code>	Returns the permutation array that orders a sparse CSR or CSC matrix in Reverse-Cuthill McKee ordering.
<code>maximum_bipartite_matching(graph[, perm_type])</code>	Returns an array of row or column permutations that makes the diagonal of a nonsingular square CSC sparse matrix zero free.
<code>structural_rank(graph)</code>	Compute the structural rank of a graph (matrix) with a given sparsity pattern.
<i>NegativeCycleError</i>	

`scipy.sparse.csgraph.connected_components` (*csgraph*, *directed=True*, *connection='weak'*, *return\_labels=True*)

Analyze the connected components of a sparse graph

New in version 0.11.0.

**Parameters** `csgraph` : array\_like or sparse matrix

The N x N matrix representing the compressed sparse graph. The input `csgraph` will be converted to `csr` format for the calculation.

**directed** : bool, optional

If `True` (default), then operate on a directed graph: only move from point `i` to point `j` along paths `csgraph[i, j]`. If `False`, then find the shortest path on an undirected graph: the algorithm can progress from point `i` to `j` along `csgraph[i, j]` or `csgraph[j, i]`.

**connection** : str, optional

['weak'|'strong']. For directed graphs, the type of connection to use. Nodes `i` and `j` are strongly connected if a path exists both from `i` to `j` and from `j` to `i`. Nodes `i` and `j` are weakly connected if only one of these paths exists. If `directed == False`, this keyword is not referenced.

**return\_labels** : bool, optional

If `True` (default), then return the labels for each of the connected components.

**Returns**

`n_components`: int

The number of connected components.

`labels`: ndarray

The length-N array of labels of the connected components.

### References

[R15]

`scipy.sparse.csgraph.laplacian` (*csgraph*, *normed=False*, *return\_diag=False*, *use\_out\_degree=False*)

Return the Laplacian matrix of a directed graph.

**Parameters** `csgraph` : array\_like or sparse matrix, 2 dimensions

compressed-sparse graph, with shape (N, N).

**normed** : bool, optional  
 If True, then compute normalized Laplacian.

**return\_diag** : bool, optional  
 If True, then also return an array related to vertex degrees.

**use\_out\_degree** : bool, optional  
 If True, then use out-degree instead of in-degree. This distinction matters only if the graph is asymmetric. Default: False.

**Returns** **lap** : ndarray or sparse matrix  
 The N x N laplacian matrix of csgraph. It will be a numpy array (dense) if the input was dense, or a sparse matrix otherwise.

**diag** : ndarray, optional  
 The length-N diagonal of the Laplacian matrix. For the normalized Laplacian, this is the array of square roots of vertex degrees or 1 if the degree is zero.

**Notes**

The Laplacian matrix of a graph is sometimes referred to as the “Kirchoff matrix” or the “admittance matrix”, and is useful in many parts of spectral graph theory. In particular, the eigen-decomposition of the laplacian matrix can give insight into many properties of the graph.

**Examples**

```
>>> from scipy.sparse import csgraph
>>> G = np.arange(5) * np.arange(5)[:, np.newaxis]
>>> G
array([[ 0,  0,  0,  0,  0],
       [ 0,  1,  2,  3,  4],
       [ 0,  2,  4,  6,  8],
       [ 0,  3,  6,  9, 12],
       [ 0,  4,  8, 12, 16]])
>>> csgraph.laplacian(G, normed=False)
array([[ 0,  0,  0,  0,  0],
       [ 0,  9, -2, -3, -4],
       [ 0, -2, 16, -6, -8],
       [ 0, -3, -6, 21, -12],
       [ 0, -4, -8, -12, 24]])
```

`scipy.sparse.csgraph.shortest_path`(*csgraph*, *method*='auto', *directed*=True, *return\_predecessors*=False, *unweighted*=False, *overwrite*=False, *indices*=None)

Perform a shortest-path graph search on a positive directed or undirected graph.

New in version 0.11.0.

**Parameters** **csgraph** : array, matrix, or sparse matrix, 2 dimensions  
 The N x N array of distances representing the input graph.

**method** : string ['auto'|'FW'|'D'], optional  
 Algorithm to use for shortest paths. Options are:  
*'auto'* – (default) select the best among *'FW'*, *'D'*, *'BF'*, or *'J'*  
 based on the input data.  
*'FW'* – *Floyd-Warshall algorithm*. Computational cost is approximately  $O[N^3]$ . The input csgraph will be converted to a dense representation.  
*'D'* – *Dijkstra's algorithm with Fibonacci heaps*. Computational cost is approximately  $O[N(N*k +$

$N \cdot \log(N)$ ], where  $k$  is the average number of connected edges per node. The input `csgraph` will be converted to a csr representation.

**‘BF’ – Bellman-Ford algorithm.** *This algorithm can be used when*

weights are negative. If a negative cycle is encountered, an error will be raised. Computational cost is approximately  $O[N(N^2 k)]$ , where  $k$  is the average number of connected edges per node. The input `csgraph` will be converted to a csr representation.

**‘J’ – Johnson’s algorithm.** *Like the Bellman-Ford algorithm,*

Johnson’s algorithm is designed for use when the weights are negative. It combines the Bellman-Ford algorithm with Dijkstra’s algorithm for faster computation.

**directed** : bool, optional

If True (default), then find the shortest path on a directed graph: only move from point  $i$  to point  $j$  along paths `csgraph[i, j]`. If False, then find the shortest path on an undirected graph: the algorithm can progress from point  $i$  to  $j$  along `csgraph[i, j]` or `csgraph[j, i]`

**return\_predecessors** : bool, optional

If True, return the size  $(N, N)$  predecessor matrix

**unweighted** : bool, optional

If True, then find unweighted distances. That is, rather than finding the path between each point such that the sum of weights is minimized, find the path such that the number of edges is minimized.

**overwrite** : bool, optional

If True, overwrite `csgraph` with the result. This applies only if `method == ‘FW’` and `csgraph` is a dense,  $c$ -ordered array with `dtype=float64`.

**indices** : array\_like or int, optional

If specified, only compute the paths for the points at the given indices. Incompatible with `method == ‘FW’`.

**Returns**

**dist\_matrix** : ndarray

The  $N \times N$  matrix of distances between graph nodes. `dist_matrix[i,j]` gives the shortest distance from point  $i$  to point  $j$  along the graph.

**predecessors** : ndarray

Returned only if `return_predecessors == True`. The  $N \times N$  matrix of predecessors, which can be used to reconstruct the shortest paths. Row  $i$  of the predecessor matrix contains information on the shortest paths from point  $i$ : each entry `predecessors[i, j]` gives the index of the previous node in the path from point  $i$  to point  $j$ . If no path exists between point  $i$  and  $j$ , then `predecessors[i, j] = -9999`

**Raises**

**NegativeCycleError:**

if there are negative cycles in the graph

### Notes

As currently implemented, Dijkstra’s algorithm and Johnson’s algorithm do not work for graphs with direction-dependent distances when `directed == False`. i.e., if `csgraph[i,j]` and `csgraph[j,i]` are non-equal edges, `method=‘D’` may yield an incorrect result.

```
scipy.sparse.csgraph.dijkstra(csgraph, directed=True, indices=None, return_predecessors=False, unweighted=False, limit=np.inf)
```

Dijkstra algorithm using Fibonacci Heaps

New in version 0.11.0.

**Parameters**

- csgraph** : array, matrix, or sparse matrix, 2 dimensions  
The N x N array of non-negative distances representing the input graph.
- directed** : bool, optional  
If True (default), then find the shortest path on a directed graph: only move from point i to point j along paths csgraph[i, j]. If False, then find the shortest path on an undirected graph: the algorithm can progress from point i to j along csgraph[i, j] or csgraph[j, i]
- indices** : array\_like or int, optional  
if specified, only compute the paths for the points at the given indices.
- return\_predecessors** : bool, optional  
If True, return the size (N, N) predecessor matrix
- unweighted** : bool, optional  
If True, then find unweighted distances. That is, rather than finding the path between each point such that the sum of weights is minimized, find the path such that the number of edges is minimized.
- limit** : float, optional  
The maximum distance to calculate, must be  $\geq 0$ . Using a smaller limit will decrease computation time by aborting calculations between pairs that are separated by a distance  $>$  limit. For such pairs, the distance will be equal to `np.inf` (i.e., not connected).

**Returns**

- dist\_matrix** : ndarray  
New in version 0.14.0.  
The matrix of distances between graph nodes. `dist_matrix[i,j]` gives the shortest distance from point i to point j along the graph.
- predecessors** : ndarray  
Returned only if `return_predecessors == True`. The matrix of predecessors, which can be used to reconstruct the shortest paths. Row i of the predecessor matrix contains information on the shortest paths from point i: each entry `predecessors[i, j]` gives the index of the previous node in the path from point i to point j. If no path exists between point i and j, then `predecessors[i, j] = -9999`

**Notes**

As currently implemented, Dijkstra's algorithm does not work for graphs with direction-dependent distances when `directed == False`. i.e., if `csgraph[i,j]` and `csgraph[j,i]` are not equal and both are nonzero, setting `directed=False` will not yield the correct result.

Also, this routine does not work for graphs with negative distances. Negative distances can lead to infinite cycles that must be handled by specialized algorithms such as Bellman-Ford's algorithm or Johnson's algorithm.

`scipy.sparse.csgraph.floyd_warshall` (*csgraph*, *directed=True*, *return\_predecessors=False*, *unweighted=False*, *overwrite=False*)

Compute the shortest path lengths using the Floyd-Warshall algorithm

New in version 0.11.0.

**Parameters**

- csgraph** : array, matrix, or sparse matrix, 2 dimensions  
The N x N array of distances representing the input graph.
- directed** : bool, optional  
If True (default), then find the shortest path on a directed graph: only move from point i to point j along paths csgraph[i, j]. If False, then find the shortest path on an undirected graph: the algorithm can progress from point i to j along csgraph[i, j] or csgraph[j, i]

**return\_predecessors** : bool, optional  
 If True, return the size (N, N) predecessor matrix

**unweighted** : bool, optional  
 If True, then find unweighted distances. That is, rather than finding the path between each point such that the sum of weights is minimized, find the path such that the number of edges is minimized.

**overwrite** : bool, optional  
 If True, overwrite csgraph with the result. This applies only if csgraph is a dense, c-ordered array with dtype=float64.

**Returns** **dist\_matrix** : ndarray  
 The N x N matrix of distances between graph nodes. `dist_matrix[i,j]` gives the shortest distance from point i to point j along the graph.

**predecessors** : ndarray  
 Returned only if `return_predecessors == True`. The N x N matrix of predecessors, which can be used to reconstruct the shortest paths. Row i of the predecessor matrix contains information on the shortest paths from point i: each entry `predecessors[i, j]` gives the index of the previous node in the path from point i to point j. If no path exists between point i and j, then `predecessors[i, j] = -9999`

**Raises** **NegativeCycleError**:  
 if there are negative cycles in the graph

```
scipy.sparse.csgraph.bellman_ford(csgraph, directed=True, indices=None, return_predecessors=False, unweighted=False)
```

Compute the shortest path lengths using the Bellman-Ford algorithm.

The Bellman-ford algorithm can robustly deal with graphs with negative weights. If a negative cycle is detected, an error is raised. For graphs without negative edge weights, dijkstra's algorithm may be faster.

New in version 0.11.0.

**Parameters** **csgraph** : array, matrix, or sparse matrix, 2 dimensions  
 The N x N array of distances representing the input graph.

**directed** : bool, optional  
 If True (default), then find the shortest path on a directed graph: only move from point i to point j along paths `csgraph[i, j]`. If False, then find the shortest path on an undirected graph: the algorithm can progress from point i to j along `csgraph[i, j]` or `csgraph[j, i]`

**indices** : array\_like or int, optional  
 if specified, only compute the paths for the points at the given indices.

**return\_predecessors** : bool, optional  
 If True, return the size (N, N) predecessor matrix

**unweighted** : bool, optional  
 If True, then find unweighted distances. That is, rather than finding the path between each point such that the sum of weights is minimized, find the path such that the number of edges is minimized.

**Returns** **dist\_matrix** : ndarray  
 The N x N matrix of distances between graph nodes. `dist_matrix[i,j]` gives the shortest distance from point i to point j along the graph.

**predecessors** : ndarray  
 Returned only if `return_predecessors == True`. The N x N matrix of predecessors, which can be used to reconstruct the shortest paths. Row i of the predecessor matrix contains information on the shortest paths from point i: each entry `predecessors[i, j]` gives the index of the previous node in the path from point i to point j. If no path exists between point i and j, then `predecessors[i, j] = -9999`

**Raises** **NegativeCycleError**:  
 if there are negative cycles in the graph

*Notes*

This routine is specially designed for graphs with negative edge weights. If all edge weights are positive, then Dijkstra's algorithm is a better choice.

`scipy.sparse.csgraph.johnson` (*csgraph*, *directed=True*, *indices=None*, *return\_predecessors=False*, *unweighted=False*)

Compute the shortest path lengths using Johnson's algorithm.

Johnson's algorithm combines the Bellman-Ford algorithm and Dijkstra's algorithm to quickly find shortest paths in a way that is robust to the presence of negative cycles. If a negative cycle is detected, an error is raised. For graphs without negative edge weights, `dijkstra()` may be faster.

New in version 0.11.0.

**Parameters**

- csgraph** : array, matrix, or sparse matrix, 2 dimensions  
The N x N array of distances representing the input graph.
- directed** : bool, optional  
If True (default), then find the shortest path on a directed graph: only move from point i to point j along paths `csgraph[i, j]`. If False, then find the shortest path on an undirected graph: the algorithm can progress from point i to j along `csgraph[i, j]` or `csgraph[j, i]`
- indices** : array\_like or int, optional  
if specified, only compute the paths for the points at the given indices.
- return\_predecessors** : bool, optional  
If True, return the size (N, N) predecessor matrix
- unweighted** : bool, optional  
If True, then find unweighted distances. That is, rather than finding the path between each point such that the sum of weights is minimized, find the path such that the number of edges is minimized.

**Returns**

- dist\_matrix** : ndarray  
The N x N matrix of distances between graph nodes. `dist_matrix[i,j]` gives the shortest distance from point i to point j along the graph.
- predecessors** : ndarray  
Returned only if `return_predecessors == True`. The N x N matrix of predecessors, which can be used to reconstruct the shortest paths. Row i of the predecessor matrix contains information on the shortest paths from point i: each entry `predecessors[i, j]` gives the index of the previous node in the path from point i to point j. If no path exists between point i and j, then `predecessors[i, j] = -9999`

**Raises**

- NegativeCycleError**:  
if there are negative cycles in the graph

*Notes*

This routine is specially designed for graphs with negative edge weights. If all edge weights are positive, then Dijkstra's algorithm is a better choice.

`scipy.sparse.csgraph.breadth_first_order` (*csgraph*, *i\_start*, *directed=True*, *return\_predecessors=True*)

Return a breadth-first ordering starting with specified node.

Note that a breadth-first order is not unique, but the tree which it generates is unique.

New in version 0.11.0.

**Parameters**

- csgraph** : array\_like or sparse matrix  
The N x N compressed sparse graph. The input `csgraph` will be converted to csr format for the calculation.
- i\_start** : int

The index of starting node.

**directed** : bool, optional  
If True (default), then operate on a directed graph: only move from point *i* to point *j* along paths `csgraph[i, j]`. If False, then find the shortest path on an undirected graph: the algorithm can progress from point *i* to *j* along `csgraph[i, j]` or `csgraph[j, i]`.

**return\_predecessors** : bool, optional  
If True (default), then return the predecessor array (see below).

**Returns** **node\_array** : ndarray, one dimension  
The breadth-first list of nodes, starting with specified node. The length of `node_array` is the number of nodes reachable from the specified node.

**predecessors** : ndarray, one dimension  
Returned only if `return_predecessors` is True. The length-*N* list of predecessors of each node in a breadth-first tree. If node *i* is in the tree, then its parent is given by `predecessors[i]`. If node *i* is not in the tree (and for the parent node) then `predecessors[i] = -9999`.

```
scipy.sparse.csgraph.depth_first_order(csgraph, i_start, directed=True,
                                     return_predecessors=True)
```

Return a depth-first ordering starting with specified node.

Note that a depth-first order is not unique. Furthermore, for graphs with cycles, the tree generated by a depth-first search is not unique either.

New in version 0.11.0.

**Parameters** **csgraph** : array\_like or sparse matrix  
The *N* x *N* compressed sparse graph. The input `csgraph` will be converted to csr format for the calculation.

**i\_start** : int  
The index of starting node.

**directed** : bool, optional  
If True (default), then operate on a directed graph: only move from point *i* to point *j* along paths `csgraph[i, j]`. If False, then find the shortest path on an undirected graph: the algorithm can progress from point *i* to *j* along `csgraph[i, j]` or `csgraph[j, i]`.

**return\_predecessors** : bool, optional  
If True (default), then return the predecessor array (see below).

**Returns** **node\_array** : ndarray, one dimension  
The depth-first list of nodes, starting with specified node. The length of `node_array` is the number of nodes reachable from the specified node.

**predecessors** : ndarray, one dimension  
Returned only if `return_predecessors` is True. The length-*N* list of predecessors of each node in a depth-first tree. If node *i* is in the tree, then its parent is given by `predecessors[i]`. If node *i* is not in the tree (and for the parent node) then `predecessors[i] = -9999`.

```
scipy.sparse.csgraph.breadth_first_tree(csgraph, i_start, directed=True)
```

Return the tree generated by a breadth-first search

Note that a breadth-first tree from a specified node is unique.

New in version 0.11.0.

**Parameters** **csgraph** : array\_like or sparse matrix  
The *N* x *N* matrix representing the compressed sparse graph. The input `csgraph` will be converted to csr format for the calculation.

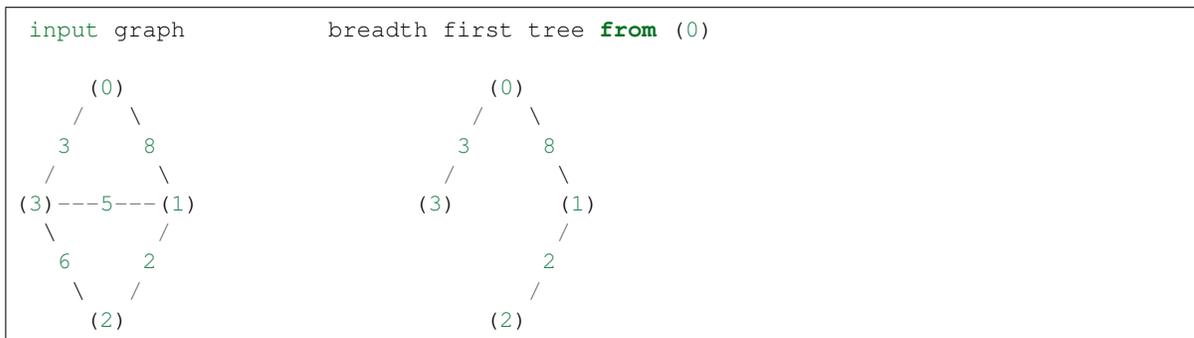
**i\_start** : int  
The index of starting node.

**directed** : bool, optional  
 If True (default), then operate on a directed graph: only move from point *i* to point *j* along paths `csgraph[i, j]`. If False, then find the shortest path on an undirected graph: the algorithm can progress from point *i* to *j* along `csgraph[i, j]` or `csgraph[j, i]`.

**Returns** **cstree** : csr matrix  
 The *N* x *N* directed compressed-sparse representation of the breadth-first tree drawn from `csgraph`, starting at the specified node.

### Examples

The following example shows the computation of a depth-first tree over a simple four-component graph, starting at node 0:



In compressed sparse representation, the solution looks like this:

```
>>> from scipy.sparse import csr_matrix
>>> from scipy.sparse.csgraph import breadth_first_tree
>>> X = csr_matrix([[0, 8, 0, 3],
...                [0, 0, 2, 5],
...                [0, 0, 0, 6],
...                [0, 0, 0, 0]])
>>> Tcsr = breadth_first_tree(X, 0, directed=False)
>>> Tcsr.toarray().astype(int)
array([[0, 8, 0, 3],
       [0, 0, 2, 0],
       [0, 0, 0, 0],
       [0, 0, 0, 0]])
```

Note that the resulting graph is a Directed Acyclic Graph which spans the graph. A breadth-first tree from a given node is unique.

`scipy.sparse.csgraph.depth_first_tree(csgraph, i_start, directed=True)`

Return a tree generated by a depth-first search.

Note that a tree generated by a depth-first search is not unique: it depends on the order that the children of each node are searched.

New in version 0.11.0.

**Parameters** **csgraph** : array\_like or sparse matrix  
 The *N* x *N* matrix representing the compressed sparse graph. The input `csgraph` will be converted to csr format for the calculation.

**i\_start** : int  
 The index of starting node.

**directed** : bool, optional

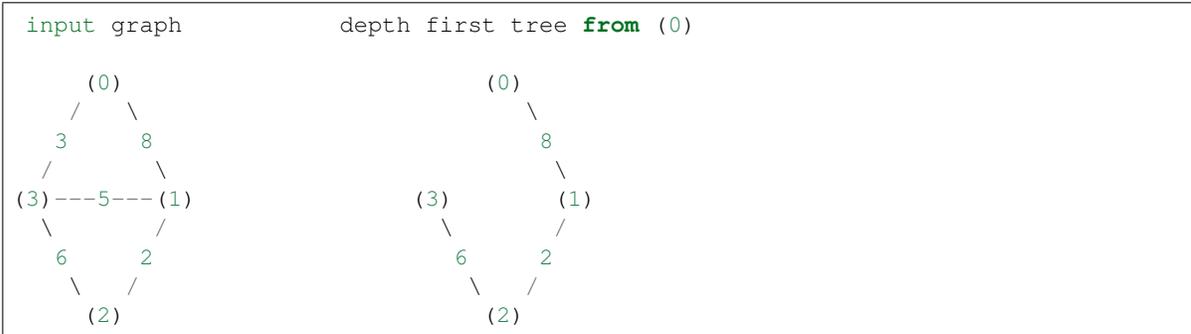
**Returns** **cstree** : csr matrix

If True (default), then operate on a directed graph: only move from point  $i$  to point  $j$  along paths  $\text{csgraph}[i, j]$ . If False, then find the shortest path on an undirected graph: the algorithm can progress from point  $i$  to  $j$  along  $\text{csgraph}[i, j]$  or  $\text{csgraph}[j, i]$ .

The  $N \times N$  directed compressed-sparse representation of the depth- first tree drawn from  $\text{csgraph}$ , starting at the specified node.

### Examples

The following example shows the computation of a depth-first tree over a simple four-component graph, starting at node 0:



In compressed sparse representation, the solution looks like this:

```

>>> from scipy.sparse import csr_matrix
>>> from scipy.sparse.csgraph import depth_first_tree
>>> X = csr_matrix([[0, 8, 0, 3],
...                [0, 0, 2, 5],
...                [0, 0, 0, 6],
...                [0, 0, 0, 0]])
>>> Tcsr = depth_first_tree(X, 0, directed=False)
>>> Tcsr.toarray().astype(int)
array([[0, 8, 0, 0],
       [0, 0, 2, 0],
       [0, 0, 0, 6],
       [0, 0, 0, 0]])
    
```

Note that the resulting graph is a Directed Acyclic Graph which spans the graph. Unlike a breadth-first tree, a depth-first tree of a given graph is not unique if the graph contains cycles. If the above solution had begun with the edge connecting nodes 0 and 3, the result would have been different.

`scipy.sparse.csgraph.minimum_spanning_tree` (*csgraph*, *overwrite=False*)

Return a minimum spanning tree of an undirected graph

A minimum spanning tree is a graph consisting of the subset of edges which together connect all connected nodes, while minimizing the total sum of weights on the edges. This is computed using the Kruskal algorithm.

New in version 0.11.0.

**Parameters** **csgraph** : array\_like or sparse matrix, 2 dimensions  
 The  $N \times N$  matrix representing an undirected graph over  $N$  nodes (see notes below).

**overwrite** : bool, optional  
 if true, then parts of the input graph will be overwritten for efficiency.

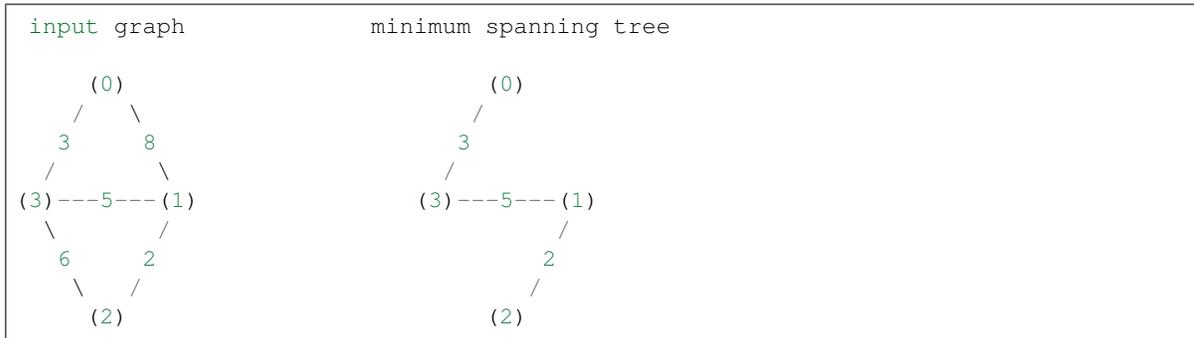
**Returns** **span\_tree** : csr matrix  
 The  $N \times N$  compressed-sparse representation of the undirected minimum spanning tree over the input (see notes below).

**Notes**

This routine uses undirected graphs as input and output. That is, if `graph[i, j]` and `graph[j, i]` are both zero, then nodes `i` and `j` do not have an edge connecting them. If either is nonzero, then the two are connected by the minimum nonzero value of the two.

**Examples**

The following example shows the computation of a minimum spanning tree over a simple four-component graph:



It is easy to see from inspection that the minimum spanning tree involves removing the edges with weights 8 and 6. In compressed sparse representation, the solution looks like this:

```
>>> from scipy.sparse import csr_matrix
>>> from scipy.sparse.csgraph import minimum_spanning_tree
>>> X = csr_matrix([[0, 8, 0, 3],
...                [0, 0, 2, 5],
...                [0, 0, 0, 6],
...                [0, 0, 0, 0]])
>>> Tcsr = minimum_spanning_tree(X)
>>> Tcsr.toarray().astype(int)
array([[0, 0, 0, 3],
       [0, 0, 2, 5],
       [0, 0, 0, 0],
       [0, 0, 0, 0]])
```

`scipy.sparse.csgraph.reverse_cuthill_mckee` (*graph*, *symmetric\_mode=False*)

Returns the permutation array that orders a sparse CSR or CSC matrix in Reverse-Cuthill McKee ordering.

It is assumed by default, `symmetric_mode=False`, that the input matrix is not symmetric and works on the matrix `A+A.T`. If you are guaranteed that the matrix is symmetric in structure (values of matrix elements do not matter) then set `symmetric_mode=True`.

- Parameters**

  - graph** : sparse matrix  
Input sparse in CSC or CSR sparse matrix format.
  - symmetric\_mode** : bool, optional  
Is input matrix guaranteed to be symmetric.

- Returns**

  - perm** : ndarray  
Array of permuted row and column indices.

**Notes**

New in version 0.15.0.



Table 5.185 – continued from previous page

---

<code>reconstruct_path(csgraph, predecessors[, ...])</code>	Construct a tree from a graph and a predecessor list.
---	---

---

`scipy.sparse.csgraph.construct_dist_matrix` (*graph*, *predecessors*, *directed=True*, *null\_value=np.inf*)

Construct distance matrix from a predecessor matrix

New in version 0.11.0.

**Parameters**

- graph** : array\_like or sparse  
The N x N matrix representation of a directed or undirected graph. If dense, then non-edges are indicated by zeros or infinities.
- predecessors** : array\_like  
The N x N matrix of predecessors of each node (see Notes below).
- directed** : bool, optional  
If True (default), then operate on a directed graph: only move from point i to point j along paths `csgraph[i, j]`. If False, then operate on an undirected graph: the algorithm can progress from point i to j along `csgraph[i, j]` or `csgraph[j, i]`.
- null\_value** : bool, optional  
value to use for distances between unconnected nodes. Default is `np.inf`

**Returns**

- dist\_matrix** : ndarray  
The N x N matrix of distances between nodes along the path specified by the predecessor matrix. If no path exists, the distance is zero.

**Notes**

The predecessor matrix is of the form returned by `graph_shortest_path`. Row i of the predecessor matrix contains information on the shortest paths from point i: each entry `predecessors[i, j]` gives the index of the previous node in the path from point i to point j. If no path exists between point i and j, then `predecessors[i, j] = -9999`

`scipy.sparse.csgraph.csgraph_from_dense` (*graph*, *null\_value=0*, *nan\_null=True*, *infinity\_null=True*)

Construct a CSR-format sparse graph from a dense matrix.

New in version 0.11.0.

**Parameters**

- graph** : array\_like  
Input graph. Shape should be (n\_nodes, n\_nodes).
- null\_value** : float or None (optional)  
Value that denotes non-edges in the graph. Default is zero.
- infinity\_null** : bool  
If True (default), then infinite entries (both positive and negative) are treated as null edges.
- nan\_null** : bool  
If True (default), then NaN entries are treated as non-edges

**Returns**

- csgraph** : csr\_matrix  
Compressed sparse representation of graph,

`scipy.sparse.csgraph.csgraph_from_masked` (*graph*)

Construct a CSR-format graph from a masked array.

New in version 0.11.0.

**Parameters**

- graph** : MaskedArray  
Input graph. Shape should be (n\_nodes, n\_nodes).

**Returns**

- csgraph** : csr\_matrix  
Compressed sparse representation of graph,

`scipy.sparse.csgraph.csgraph_masked_from_dense` (*graph*, *null\_value=0*, *nan\_null=True*,  
*infinity\_null=True*, *copy=True*)

Construct a masked array graph representation from a dense matrix.

New in version 0.11.0.

**Parameters**

- graph** : array\_like  
Input graph. Shape should be (n\_nodes, n\_nodes).
- null\_value** : float or None (optional)  
Value that denotes non-edges in the graph. Default is zero.
- infinity\_null** : bool  
If True (default), then infinite entries (both positive and negative) are treated as null edges.
- nan\_null** : bool  
If True (default), then NaN entries are treated as non-edges

**Returns**

- csgraph** : MaskedArray  
masked array representation of graph

`scipy.sparse.csgraph.csgraph_to_dense` (*csgraph*, *null\_value=0*)

Convert a sparse graph representation to a dense representation

New in version 0.11.0.

**Parameters**

- csgraph** : csr\_matrix, csc\_matrix, or lil\_matrix  
Sparse representation of a graph.
- null\_value** : float, optional  
The value used to indicate null edges in the dense representation. Default is 0.

**Returns**

- graph** : ndarray  
The dense representation of the sparse graph.

### Notes

For normal sparse graph representations, calling `csgraph_to_dense` with `null_value=0` produces an equivalent result to using dense format conversions in the main sparse package. When the sparse representations have repeated values, however, the results will differ. The tools in `scipy.sparse` will add repeating values to obtain a final value. This function will select the minimum among repeating values to obtain a final value. For example, here we'll create a two-node directed sparse graph with multiple edges from node 0 to node 1, of weights 2 and 3. This illustrates the difference in behavior:

```
>>> from scipy.sparse import csr_matrix, csgraph
>>> data = np.array([2, 3])
>>> indices = np.array([1, 1])
>>> indptr = np.array([0, 2, 2])
>>> M = csr_matrix((data, indices, indptr), shape=(2, 2))
>>> M.toarray()
array([[0, 5],
       [0, 0]])
>>> csgraph.csgraph_to_dense(M)
array([[0., 2.],
       [0., 0.]])
```

The reason for this difference is to allow a compressed sparse graph to represent multiple edges between any two nodes. As most sparse graph algorithms are concerned with the single lowest-cost edge between any two nodes, the default `scipy.sparse` behavior of summing multiple weights does not make sense in this context.

The other reason for using this routine is to allow for graphs with zero-weight edges. Let's look at the example of a two-node directed graph, connected by an edge of weight zero:

```

>>> from scipy.sparse import csr_matrix, csgraph
>>> data = np.array([0.0])
>>> indices = np.array([1])
>>> indptr = np.array([0, 1, 1])
>>> M = csr_matrix((data, indices, indptr), shape=(2, 2))
>>> M.toarray()
array([[0, 0],
       [0, 0]])
>>> csgraph.csgraph_to_dense(M, np.inf)
array([[ inf,  0.],
       [ inf,  inf]])
    
```

In the first case, the zero-weight edge gets lost in the dense representation. In the second case, we can choose a different null value and see the true form of the graph.

`scipy.sparse.csgraph.csgraph_to_masked(csgraph)`

Convert a sparse graph representation to a masked array representation

New in version 0.11.0.

**Parameters** **csgraph** : `csr_matrix`, `csc_matrix`, or `lil_matrix`

**Returns** **graph** : `MaskedArray` Sparse representation of a graph.

The masked dense representation of the sparse graph.

`scipy.sparse.csgraph.reconstruct_path(csgraph, predecessors, directed=True)`

Construct a tree from a graph and a predecessor list.

New in version 0.11.0.

**Parameters** **csgraph** : `array_like` or sparse matrix

The  $N \times N$  matrix representing the directed or undirected graph from which the predecessors are drawn.

**predecessors** : `array_like`, one dimension

The length- $N$  array of indices of predecessors for the tree. The index of the parent of node  $i$  is given by `predecessors[i]`.

**directed** : `bool`, optional

If `True` (default), then operate on a directed graph: only move from point  $i$  to point  $j$  along paths `csgraph[i, j]`. If `False`, then operate on an undirected graph: the algorithm can progress from point  $i$  to  $j$  along `csgraph[i, j]` or `csgraph[j, i]`.

**Returns** **cstree** : `csr matrix`

The  $N \times N$  directed compressed-sparse representation of the tree drawn from `csgraph` which is encoded by the predecessor list.

## Graph Representations

This module uses graphs which are stored in a matrix format. A graph with  $N$  nodes can be represented by an  $(N \times N)$  adjacency matrix  $G$ . If there is a connection from node  $i$  to node  $j$ , then  $G[i, j] = w$ , where  $w$  is the weight of the connection. For nodes  $i$  and  $j$  which are not connected, the value depends on the representation:

- for dense array representations, non-edges are represented by  $G[i, j] = 0$ , infinity, or `NaN`.
- for dense masked representations (of type `np.ma.MaskedArray`), non-edges are represented by masked values. This can be useful when graphs with zero-weight edges are desired.
- for sparse array representations, non-edges are represented by non-entries in the matrix. This sort of sparse representation also allows for edges with zero weights.

As a concrete example, imagine that you would like to represent the following undirected graph:



This graph has three nodes, where node 0 and 1 are connected by an edge of weight 2, and nodes 0 and 2 are connected by an edge of weight 1. We can construct the dense, masked, and sparse representations as follows, keeping in mind that an undirected graph is represented by a symmetric matrix:

```

>>> G_dense = np.array([[0, 2, 1],
...                    [2, 0, 0],
...                    [1, 0, 0]])
>>> G_masked = np.ma.masked_values(G_dense, 0)
>>> from scipy.sparse import csr_matrix
>>> G_sparse = csr_matrix(G_dense)
  
```

This becomes more difficult when zero edges are significant. For example, consider the situation when we slightly modify the above graph:



This is identical to the previous graph, except nodes 0 and 2 are connected by an edge of zero weight. In this case, the dense representation above leads to ambiguities: how can non-edges be represented if zero is a meaningful value? In this case, either a masked or sparse representation must be used to eliminate the ambiguity:

```

>>> G2_data = np.array([[np.inf, 2, 0 ],
...                    [2, np.inf, np.inf],
...                    [0, np.inf, np.inf]])
>>> G2_masked = np.ma.masked_invalid(G2_data)
>>> from scipy.sparse.csgraph import csgraph_from_dense
>>> # G2_sparse = csr_matrix(G2_data) would give the wrong result
>>> G2_sparse = csgraph_from_dense(G2_data, null_value=np.inf)
>>> G2_sparse.data
array([ 2.,  0.,  2.,  0.])
  
```

Here we have used a utility routine from the `csgraph` submodule in order to convert the dense representation to a sparse representation which can be understood by the algorithms in submodule. By viewing the data array, we can see that the zero values are explicitly encoded in the graph.

## Directed vs. Undirected

Matrices may represent either directed or undirected graphs. This is specified throughout the `csgraph` module by a boolean keyword. Graphs are assumed to be directed by default. In a directed graph, traversal from node  $i$  to node  $j$  can be accomplished over the edge  $G[i, j]$ , but not the edge  $G[j, i]$ . In a non-directed graph, traversal from node  $i$  to node  $j$  can be accomplished over either  $G[i, j]$  or  $G[j, i]$ . If both edges are not null, and the two have unequal weights,

then the smaller of the two is used. Note that a symmetric matrix will represent an undirected graph, regardless of whether the ‘directed’ keyword is set to True or False. In this case, using `directed=True` generally leads to more efficient computation.

The routines in this module accept as input either `scipy.sparse` representations (`csr`, `csc`, or `lil` format), masked representations, or dense representations with non-edges indicated by zeros, infinities, and NaN entries.

### Functions

<code>bellman_ford(csgraph[, directed, indices, ...])</code>	Compute the shortest path lengths using the Bellman-Ford algorithm.
<code>breadth_first_order(csgraph, i_start[, ...])</code>	Return a breadth-first ordering starting with specified node.
<code>breadth_first_tree(csgraph, i_start[, directed])</code>	Return the tree generated by a breadth-first search
<code>connected_components(csgraph[, directed, ...])</code>	Analyze the connected components of a sparse graph
<code>construct_dist_matrix(graph, predecessors[, ...])</code>	Construct distance matrix from a predecessor matrix
<code>csgraph_from_dense(graph[, null_value, ...])</code>	Construct a CSR-format sparse graph from a dense matrix.
<code>csgraph_from_masked(graph)</code>	Construct a CSR-format graph from a masked array.
<code>csgraph_masked_from_dense(graph[, ...])</code>	Construct a masked array graph representation from a dense matrix.
<code>csgraph_to_dense(csgraph[, null_value])</code>	Convert a sparse graph representation to a dense representation
<code>csgraph_to_masked(csgraph)</code>	Convert a sparse graph representation to a masked array representation
<code>depth_first_order(csgraph, i_start[, ...])</code>	Return a depth-first ordering starting with specified node.
<code>depth_first_tree(csgraph, i_start[, directed])</code>	Return a tree generated by a depth-first search.
<code>dijkstra(csgraph[, directed, indices, ...])</code>	Dijkstra algorithm using Fibonacci Heaps
<code>floyd_warshall(csgraph[, directed, ...])</code>	Compute the shortest path lengths using the Floyd-Warshall algorithm
<code>johnson(csgraph[, directed, indices, ...])</code>	Compute the shortest path lengths using Johnson’s algorithm.
<code>laplacian(csgraph[, normed, return_diag, ...])</code>	Return the Laplacian matrix of a directed graph.
<code>maximum_bipartite_matching(graph[, perm_type])</code>	Returns an array of row or column permutations that makes the diagonal of a nonsingular square CSC sparse matrix zero free.
<code>minimum_spanning_tree(csgraph[, overwrite])</code>	Return a minimum spanning tree of an undirected graph
<code>reconstruct_path(csgraph, predecessors[, ...])</code>	Construct a tree from a graph and a predecessor list.
<code>reverse_cuthill_mckee(graph[, symmetric_mode])</code>	Returns the permutation array that orders a sparse CSR or CSC matrix in Reverse-Cuthill McKee ordering.
<code>shortest_path(csgraph[, method, directed, ...])</code>	Perform a shortest-path graph search on a positive directed or undirected graph.
<code>structural_rank(graph)</code>	Compute the structural rank of a graph (matrix) with a given sparsity pattern.

### Exceptions

`NegativeCycleError`

---

## Sparse linear algebra (`scipy.sparse.linalg`)

### Abstract linear operators

---

<code>LinearOperator(dtype, shape)</code>	Common interface for performing matrix vector products
<code>aslinearoperator(A)</code>	Return A as a LinearOperator.

---

**class** `scipy.sparse.linalg.LinearOperator` (*dtype, shape*)

Common interface for performing matrix vector products

Many iterative methods (e.g. `cg`, `gmres`) do not need to know the individual entries of a matrix to solve a linear system  $A*x=b$ . Such solvers only require the computation of matrix vector products,  $A*v$  where  $v$  is a dense vector. This class serves as an abstract interface between iterative solvers and matrix-like objects.

To construct a concrete `LinearOperator`, either pass appropriate callables to the constructor of this class, or subclass it.

A subclass must implement either one of the methods `_matvec` and `_matmat`, and the attributes/properties `shape` (pair of integers) and `dtype` (may be `None`). It may call the `__init__` on this class to have these attributes validated. Implementing `_matvec` automatically implements `_matmat` (using a naive algorithm) and vice-versa.

Optionally, a subclass may implement `_rmatvec` or `_adjoint` to implement the Hermitian adjoint (conjugate transpose). As with `_matvec` and `_matmat`, implementing either `_rmatvec` or `_adjoint` implements the other automatically. Implementing `_adjoint` is preferable; `_rmatvec` is mostly there for backwards compatibility.

**Parameters**

- shape** : tuple  
Matrix dimensions (M,N).
- matvec** : callable `f(v)`  
Returns returns  $A * v$ .
- rmatvec** : callable `f(v)`  
Returns  $A^H * v$ , where  $A^H$  is the conjugate transpose of  $A$ .
- matmat** : callable `f(V)`  
Returns  $A * V$ , where  $V$  is a dense matrix with dimensions (N,K).
- dtype** : dtype  
Data type of the matrix.

See also:

**aslinearoperator**

Construct `LinearOperator`s

**Notes**

The user-defined `matvec()` function must properly handle the case where  $v$  has shape  $(N,)$  as well as the  $(N,1)$  case. The shape of the return type is handled internally by `LinearOperator`.

`LinearOperator` instances can also be multiplied, added with each other and exponentiated, all lazily: the result of these operations is always a new, composite `LinearOperator`, that defers linear operations to the original operators and combines the results.

**Examples**

```
>>> import numpy as np
>>> from scipy.sparse.linalg import LinearOperator
>>> def mv(v):
...     return np.array([2*v[0], 3*v[1]])
...
>>> A = LinearOperator((2,2), matvec=mv)
>>> A
<2x2 _CustomLinearOperator with dtype=float64>
```

```
>>> A.matvec(np.ones(2))
array([ 2.,  3.])
>>> A * np.ones(2)
array([ 2.,  3.])
```

**Attributes**

args	(tuple) For linear operators describing products etc. of other linear operators, the operands of the binary operation.
------	--

**Methods**

<code>__call__(x)</code>	
<code>adjoint()</code>	Hermitian adjoint.
<code>dot(x)</code>	Matrix-matrix or matrix-vector multiplication.
<code>matmat(X)</code>	Matrix-matrix multiplication.
<code>matvec(x)</code>	Matrix-vector multiplication.
<code>rmatvec(x)</code>	Adjoint matrix-vector multiplication.
<code>transpose()</code>	Transpose this linear operator.

`LinearOperator.__call__(x)`

`LinearOperator.adjoint()`

Hermitian adjoint.

Returns the Hermitian adjoint of self, aka the Hermitian conjugate or Hermitian transpose. For a complex matrix, the Hermitian adjoint is equal to the conjugate transpose.

Can be abbreviated self.H instead of self.adjoint().

**Returns** **A\_H** : LinearOperator  
Hermitian adjoint of self.

`LinearOperator.dot(x)`

Matrix-matrix or matrix-vector multiplication.

**Parameters** **x** : array\_like

**Returns** **Ax** : array 1-d or 2-d array, representing a vector or matrix.

1-d or 2-d array (depending on the shape of x) that represents the result of applying this linear operator on x.

`LinearOperator.matmat(X)`

Matrix-matrix multiplication.

Performs the operation  $y=A*X$  where A is an MxN linear operator and X dense N\*K matrix or ndarray.

**Parameters** **X** : {matrix, ndarray}

**Returns** **Y** : {matrix, ndarray} An array with shape (N,K).

A matrix or ndarray with shape (M,K) depending on the type of the X argument.

**Notes**

This matmat wraps any user-specified matmat routine or overridden `_matmat` method to ensure that y has the correct type.

`LinearOperator.matvec(x)`

Matrix-vector multiplication.

Performs the operation  $y=A*x$  where  $A$  is an  $M \times N$  linear operator and  $x$  is a column vector or 1-d array.

**Parameters**  $x$  : {matrix, ndarray}

**Returns**  $y$  : {matrix, ndarray} An array with shape (N,) or (N,1).

A matrix or ndarray with shape (M,) or (M,1) depending on the type and shape of the  $x$  argument.

#### Notes

This `matvec` wraps the user-specified `matvec` routine or overridden `_matvec` method to ensure that  $y$  has the correct shape and type.

`LinearOperator.rmatvec(x)`

Adjoint matrix-vector multiplication.

Performs the operation  $y = A^H * x$  where  $A$  is an  $M \times N$  linear operator and  $x$  is a column vector or 1-d array.

**Parameters**  $x$  : {matrix, ndarray}

**Returns**  $y$  : {matrix, ndarray} An array with shape (M,) or (M,1).

A matrix or ndarray with shape (N,) or (N,1) depending on the type and shape of the  $x$  argument.

#### Notes

This `rmatvec` wraps the user-specified `rmatvec` routine or overridden `_rmatvec` method to ensure that  $y$  has the correct shape and type.

`LinearOperator.transpose()`

Transpose this linear operator.

Returns a `LinearOperator` that represents the transpose of this one. Can be abbreviated `self.T` instead of `self.transpose()`.

`scipy.sparse.linalg.aslinearoperator(A)`

Return  $A$  as a `LinearOperator`.

*'A' may be any of the following types:*

- ndarray
- matrix
- sparse matrix (e.g. `csr_matrix`, `lil_matrix`, etc.)
- `LinearOperator`
- An object with `.shape` and `.matvec` attributes

See the `LinearOperator` documentation for additional information.

#### Examples

```
>>> from scipy.sparse.linalg import aslinearoperator
>>> M = np.array([[1, 2, 3], [4, 5, 6]], dtype=np.int32)
>>> aslinearoperator(M)
<2x3 MatrixLinearOperator with dtype=int32>
```

## Matrix Operations

<code>inv(A)</code>	Compute the inverse of a sparse matrix
<code>expm(A)</code>	Compute the matrix exponential using Pade approximation.
<code>expm_multiply(A, B[, start, stop, num, endpoint])</code>	Compute the action of the matrix exponential of A on B.

`scipy.sparse.linalg.inv(A)`

Compute the inverse of a sparse matrix

**Parameters** **A** : (M,M) ndarray or sparse matrix  
**Returns** **Ainv** : (M,M) ndarray or sparse matrix  
 square matrix to be inverted  
 inverse of A

**Notes**

This computes the sparse inverse of A. If the inverse of A is expected to be non-sparse, it will likely be faster to convert A to dense and use `scipy.linalg.inv`.

**Examples**

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import inv
>>> A = csc_matrix([[1., 0.], [1., 2.]])
>>> Ainv = inv(A)
>>> Ainv
<2x2 sparse matrix of type '<class 'numpy.float64''>'
  with 3 stored elements in Compressed Sparse Column format>
>>> A.dot(Ainv)
<2x2 sparse matrix of type '<class 'numpy.float64''>'
  with 2 stored elements in Compressed Sparse Column format>
>>> A.dot(Ainv).todense()
matrix([[ 1.,  0.],
        [ 0.,  1.]])
```

New in version 0.12.0.

`scipy.sparse.linalg.expm(A)`

Compute the matrix exponential using Pade approximation.

**Parameters** **A** : (M,M) array\_like or sparse matrix  
**Returns** **expA** : (M,M) ndarray  
 2D Array or Matrix (sparse or dense) to be exponentiated  
 Matrix exponential of A

**Notes**

This is algorithm (6.1) which is a simplification of algorithm (5.1).

New in version 0.12.0.

**References**

[R22]

**Examples**

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import expm
>>> A = csc_matrix([[1, 0, 0], [0, 2, 0], [0, 0, 3]])
>>> A.todense()
```

```

matrix([[1, 0, 0],
        [0, 2, 0],
        [0, 0, 3]], dtype=int64)
>>> Aexp = expm(A)
>>> Aexp
<3x3 sparse matrix of type '<class 'numpy.float64''>'
  with 3 stored elements in Compressed Sparse Column format>
>>> Aexp.todense()
matrix([[ 2.71828183,  0.          ,  0.          ],
        [ 0.          ,  7.3890561 ,  0.          ],
        [ 0.          ,  0.          , 20.08553692]])

```

`scipy.sparse.linalg.expm_multiply` (*A*, *B*, *start=None*, *stop=None*, *num=None*, *endpoint=None*)

Compute the action of the matrix exponential of *A* on *B*.

**Parameters**

- A** : transposable linear operator  
The operator whose exponential is of interest.
- B** : ndarray  
The matrix or vector to be multiplied by the matrix exponential of *A*.
- start** : scalar, optional  
The starting time point of the sequence.
- stop** : scalar, optional  
The end time point of the sequence, unless *endpoint* is set to False. In that case, the sequence consists of all but the last of *num* + 1 evenly spaced time points, so that *stop* is excluded. Note that the step size changes when *endpoint* is False.
- num** : int, optional  
Number of time points to use.
- endpoint** : bool, optional  
If True, *stop* is the last time point. Otherwise, it is not included.

**Returns**

- expm\_A\_B** : ndarray  
The result of the action  $e^{t_k A} B$ .

### Notes

The optional arguments defining the sequence of evenly spaced time points are compatible with the arguments of `numpy.linspace`.

The output ndarray shape is somewhat complicated so I explain it here. The ndim of the output could be either 1, 2, or 3. It would be 1 if you are computing the expm action on a single vector at a single time point. It would be 2 if you are computing the expm action on a vector at multiple time points, or if you are computing the expm action on a matrix at a single time point. It would be 3 if you want the action on a matrix with multiple columns at multiple time points. If multiple time points are requested, `expm_A_B[0]` will always be the action of the expm at the first time point, regardless of whether the action is on a vector or a matrix.

### References

[R23], [R24]

### Examples

```

>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import expm, expm_multiply
>>> A = csc_matrix([[1, 0], [0, 1]])
>>> A.todense()
matrix([[1, 0],
        [0, 1]], dtype=int64)
>>> B = np.array([np.exp(-1.), np.exp(-2.)])

```

```

>>> B
array([ 0.36787944,  0.13533528])
>>> expm_multiply(A, B, start=1, stop=2, num=3, endpoint=True)
array([[ 1.          ,  0.36787944],
       [ 1.64872127,  0.60653066],
       [ 2.71828183,  1.          ]])
>>> expm(A).dot(B) # Verify 1st timestep
array([ 1.          ,  0.36787944])
>>> expm(1.5*A).dot(B) # Verify 2nd timestep
array([ 1.64872127,  0.60653066])
>>> expm(2*A).dot(B) # Verify 3rd timestep
array([ 2.71828183,  1.          ])

```

## Matrix norms

<code>norm(x[, ord, axis])</code>	Norm of a sparse matrix
<code>onenormest(A[, t, itmax, compute_v, compute_w])</code>	Compute a lower bound of the 1-norm of a sparse matrix.

`scipy.sparse.linalg.norm(x, ord=None, axis=None)`

Norm of a sparse matrix

This function is able to return one of seven different matrix norms, depending on the value of the `ord` parameter.

**Parameters**

- x** : a sparse matrix  
Input sparse matrix.
- ord** : {non-zero int, inf, -inf, 'fro'}, optional  
Order of the norm (see table under `Notes`). `inf` means numpy's `inf` object.
- axis** : {int, 2-tuple of ints, None}, optional  
If `axis` is an integer, it specifies the axis of `x` along which to compute the vector norms. If `axis` is a 2-tuple, it specifies the axes that hold 2-D matrices, and the matrix norms of these matrices are computed. If `axis` is `None` then either a vector norm (when `x` is 1-D) or a matrix norm (when `x` is 2-D) is returned.

**Returns**

- n** : float or ndarray

### Notes

Some of the `ord` are not implemented because some associated functions like, `_multi_svd_norm`, are not yet available for sparse matrix.

This docstring is modified based on `numpy.linalg.norm`. <https://github.com/numpy/numpy/blob/master/numpy/linalg/linalg.py>

The following norms can be calculated:

ord	norm for sparse matrices
None	Frobenius norm
'fro'	Frobenius norm
inf	max(sum(abs(x), axis=1))
-inf	min(sum(abs(x), axis=1))
0	abs(x).sum(axis=axis)
1	max(sum(abs(x), axis=0))
-1	min(sum(abs(x), axis=0))
2	Not implemented
-2	Not implemented
other	Not implemented

The Frobenius norm is given by [R38]:

$$\|A\|_F = [\sum_{i,j} \text{abs}(a_{i,j})^2]^{1/2}$$

### References

[R38]

### Examples

```
>>> from scipy.sparse import *
>>> import numpy as np
>>> from scipy.sparse.linalg import norm
>>> a = np.arange(9) - 4
>>> a
array([-4, -3, -2, -1, 0, 1, 2, 3, 4])
>>> b = a.reshape((3, 3))
>>> b
array([[ -4,  -3,  -2],
       [ -1,  0,  1],
       [  2,  3,  4]])
```

```
>>> b = csr_matrix(b)
>>> norm(b)
7.745966692414834
>>> norm(b, 'fro')
7.745966692414834
>>> norm(b, np.inf)
9
>>> norm(b, -np.inf)
2
>>> norm(b, 1)
7
>>> norm(b, -1)
6
```

`scipy.sparse.linalg.onenormest` ( $A$ ,  $t=2$ ,  $itmax=5$ ,  $compute_v=False$ ,  $compute_w=False$ )

Compute a lower bound of the 1-norm of a sparse matrix.

**Parameters**  $A$  : ndarray or other linear operator

A linear operator that can be transposed and that can produce matrix products.

$t$  : int, optional

A positive parameter controlling the tradeoff between accuracy versus time and memory usage. Larger values take longer and use more memory but give more accurate output.

**itmax** : int, optional  
 Use at most this many iterations.

**compute\_v** : bool, optional  
 Request a norm-maximizing linear operator input vector if True.

**compute\_w** : bool, optional  
 Request a norm-maximizing linear operator output vector if True.

**Returns** **est** : float  
 An underestimate of the 1-norm of the sparse matrix.

**v** : ndarray, optional  
 The vector such that  $\|Av\|_1 == est * \|v\|_1$ . It can be thought of as an input to the linear operator that gives an output with particularly large norm.

**w** : ndarray, optional  
 The vector  $Av$  which has relatively large 1-norm. It can be thought of as an output of the linear operator that is relatively large in norm compared to the input.

**Notes**

This is algorithm 2.4 of [1].

In [2] it is described as follows. “This algorithm typically requires the evaluation of about  $4t$  matrix-vector products and almost invariably produces a norm estimate (which is, in fact, a lower bound on the norm) correct to within a factor 3.”

New in version 0.13.0.

**References**

[R39], [R40]

**Examples**

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import onenormest
>>> A = csc_matrix([[1., 0., 0.], [5., 8., 2.], [0., -1., 0.]], dtype=float)
>>> A.todense()
matrix([[ 1.,  0.,  0.],
        [ 5.,  8.,  2.],
        [ 0., -1.,  0.]])
>>> onenormest(A)
9.0
>>> np.linalg.norm(A.todense(), ord=1)
9.0
```

**Solving linear problems**

Direct methods for linear equation systems:

<code>spsolve(A, b[, permc_spec, use_umfpack])</code>	Solve the sparse linear system $Ax=b$ , where $b$ may be a vector or a matrix.
<code>spsolve_triangular(A, b[, lower, ...])</code>	Solve the equation $Ax = b$ for $x$ , assuming $A$ is a triangular matrix.
<code>factorized(A)</code>	Return a function for solving a sparse linear system, with $A$ pre-factorized.
<code>MatrixRankWarning</code>	

Continued on next page

Table 5.192 – continued from previous page

<code>use_solver(**kwargs)</code>	Select default sparse direct solver to be used.
-----------------------------------	---

`scipy.sparse.linalg.spsolve` (*A*, *b*, *perm\_spec=None*, *use\_umfpack=True*)

Solve the sparse linear system  $Ax=b$ , where *b* may be a vector or a matrix.

**Parameters**

- A** : ndarray or sparse matrix  
The square matrix *A* will be converted into CSC or CSR form
- b** : ndarray or sparse matrix  
The matrix or vector representing the right hand side of the equation. If a vector, *b.shape* must be (n,) or (n, 1).
- perm\_spec** : str, optional  
How to permute the columns of the matrix for sparsity preservation. (default: 'COLAMD')
  - NATURAL: natural ordering.
  - MMD\_ATA: minimum degree ordering on the structure of  $A^T A$ .
  - MMD\_AT\_PLUS\_A: minimum degree ordering on the structure of  $A^T+A$ .
  - COLAMD: approximate minimum degree column ordering
- use\_umfpack** : bool, optional  
if True (default) then use umfpack for the solution. This is only referenced if *b* is a vector and `scikit-umfpack` is installed.

**Returns**

- x** : ndarray or sparse matrix  
the solution of the sparse linear equation. If *b* is a vector, then *x* is a vector of size *A.shape*[1] If *b* is a matrix, then *x* is a matrix of size (*A.shape*[1], *b.shape*[1])

### Notes

For solving the matrix expression  $AX = B$ , this solver assumes the resulting matrix *X* is sparse, as is often the case for very sparse inputs. If the resulting *X* is dense, the construction of this sparse result will be relatively expensive. In that case, consider converting *A* to a dense matrix and using `scipy.linalg.solve` or its variants.

### Examples

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import spsolve
>>> A = csc_matrix([[3, 2, 0], [1, -1, 0], [0, 5, 1]], dtype=float)
>>> B = csc_matrix([[2, 0], [-1, 0], [2, 0]], dtype=float)
>>> x = spsolve(A, B)
>>> np.allclose(A.dot(x).todense(), B.todense())
True
```

`scipy.sparse.linalg.spsolve_triangular` (*A*, *b*, *lower=True*, *overwrite\_A=False*, *overwrite\_b=False*)

Solve the equation  $Ax = b$  for *x*, assuming *A* is a triangular matrix.

**Parameters**

- A** : (M, M) sparse matrix  
A sparse square triangular matrix. Should be in CSR format.
- b** : (M,) or (M, N) array\_like  
Right-hand side matrix in  $Ax = b$
- lower** : bool, optional  
Whether *A* is a lower or upper triangular matrix. Default is lower triangular matrix.
- overwrite\_A** : bool, optional

Allow changing  $A$ . The indices of  $A$  are going to be sorted and zero entries are going to be removed. Enabling gives a performance gain. Default is False.

**overwrite\_b** : bool, optional

Allow overwriting data in  $b$ . Enabling gives a performance gain. Default is False. If *overwrite\_b* is True, it should be ensured that  $b$  has an appropriate dtype to be able to store the result.

**Returns**

**x** : (M,) or (M, N) ndarray

**Raises**

**LinAlgError**

Solution to the system  $Ax = b$ . Shape of return matches shape of  $b$ .

If  $A$  is singular or not triangular.

**ValueError**

If shape of  $A$  or shape of  $b$  do not match the requirements.

**Notes**

New in version 0.19.0.

**Examples**

```
>>> from scipy.sparse import csr_matrix
>>> from scipy.sparse.linalg import spsolve_triangular
>>> A = csr_matrix([[3, 0, 0], [1, -1, 0], [2, 0, 1]], dtype=float)
>>> B = np.array([[2, 0], [-1, 0], [2, 0]], dtype=float)
>>> x = spsolve_triangular(A, B)
>>> np.allclose(A.dot(x), B)
True
```

`scipy.sparse.linalg.factorized(A)`

Return a function for solving a sparse linear system, with  $A$  pre-factorized.

**Parameters** **A** : (N, N) array\_like

Input.

**Returns** **solve** : callable

To solve the linear system of equations given in  $A$ , the *solve* callable should be passed an ndarray of shape (N,).

**Examples**

```
>>> from scipy.sparse.linalg import factorized
>>> A = np.array([[ 3. ,  2. , -1. ],
...             [ 2. , -2. ,  4. ],
...             [-1. ,  0.5, -1. ]])
>>> solve = factorized(A) # Makes LU decomposition.
>>> rhs1 = np.array([1, -2, 0])
>>> solve(rhs1) # Uses the LU factors.
array([ 1., -2., -2.])
```

**exception** `scipy.sparse.linalg.MatrixRankWarning`

`scipy.sparse.linalg.use_solver(**kwargs)`

Select default sparse direct solver to be used.

**Parameters** **useUmfpack** : bool, optional

Use UMFPACK over SuperLU. Has effect only if scikits.umfpack is installed. Default: True

**assumeSortedIndices** : bool, optional

Allow UMFPACK to skip the step of sorting indices for a CSR/CSC matrix. Has effect only if useUmfpack is True and scikits.umfpack is installed. Default: False

**Notes**

The default sparse solver is umfpack when available (scikits.umfpack is installed). This can be changed by passing useUmfpack = False, which then causes the always present SuperLU based solver to be used.

Umfpack requires a CSR/CSC matrix to have sorted column/row indices. If sure that the matrix fulfills this, pass assumeSortedIndices=True to gain some speed.

Iterative methods for linear equation systems:

<code>bicg(A, b[, x0, tol, maxiter, M, callback])</code>	Use BIConjugate Gradient iteration to solve $Ax = b$ .
<code>bicgstab(A, b[, x0, tol, maxiter, M, callback])</code>	Use BIConjugate Gradient STABILized iteration to solve $Ax = b$ .
<code>cg(A, b[, x0, tol, maxiter, M, callback])</code>	Use Conjugate Gradient iteration to solve $Ax = b$ .
<code>cgs(A, b[, x0, tol, maxiter, M, callback])</code>	Use Conjugate Gradient Squared iteration to solve $Ax = b$ .
<code>gmres(A, b[, x0, tol, restart, maxiter, M, ...])</code>	Use Generalized Minimal RESidual iteration to solve $Ax = b$ .
<code>lgmres(A, b[, x0, tol, maxiter, M, ...])</code>	Solve a matrix equation using the LGMRES algorithm.
<code>minres(A, b[, x0, shift, tol, maxiter, M, ...])</code>	Use MINimum RESidual iteration to solve $Ax=b$
<code>qmr(A, b[, x0, tol, maxiter, M1, M2, callback])</code>	Use Quasi-Minimal Residual iteration to solve $Ax = b$ .
<code>gcrotmk(A, b[, x0, tol, maxiter, M, ...])</code>	Solve a matrix equation using flexible GCROT(m,k) algorithm.

`scipy.sparse.linalg.bicg(A, b, x0=None, tol=1e-05, maxiter=None, M=None, callback=None)`  
 Use BIConjugate Gradient iteration to solve  $Ax = b$ .

**Parameters** **A** : {sparse matrix, dense matrix, LinearOperator}  
 The real or complex N-by-N matrix of the linear system. It is required that the linear operator can produce  $Ax$  and  $A^T x$ .

**b** : {array, matrix}  
 Right hand side of the linear system. Has shape (N,) or (N,1).

**Returns** **x** : {array, matrix}  
 The converged solution.

**info** : integer

**Provides convergence information:**

0 : successful exit >0 : convergence to tolerance not achieved, number of iterations <0 : illegal input or breakdown

**Other Parameters**

**x0** : {array, matrix}  
 Starting guess for the solution.

**tol** : float  
 Tolerance to achieve. The algorithm terminates when either the relative or the absolute residual is below *tol*.

**maxiter** : integer  
 Maximum number of iterations. Iteration will stop after maxiter steps even if the specified tolerance has not been achieved.

**M** : {sparse matrix, dense matrix, LinearOperator}  
 Preconditioner for A. The preconditioner should approximate the inverse of A. Effective preconditioning dramatically improves the rate of conver-

gence, which implies that fewer iterations are needed to reach a given error tolerance.

**callback** : function

User-supplied function to call after each iteration. It is called as `callback(xk)`, where `xk` is the current solution vector.

`scipy.sparse.linalg.bicgstab` (*A*, *b*, *x0=None*, *tol=1e-05*, *maxiter=None*, *M=None*, *callback=None*)

Use BIConjugate Gradient STABILized iteration to solve  $Ax = b$ .

**Parameters** **A** : {sparse matrix, dense matrix, LinearOperator}

The real or complex N-by-N matrix of the linear system.

**b** : {array, matrix}

**Returns** **x** : {array, matrix} Right hand side of the linear system. Has shape (N,) or (N,1).

The converged solution.

**info** : integer

**Provides convergence information:**

0 : successful exit >0 : convergence to tolerance not achieved, number of iterations <0 : illegal input or breakdown

**Other Parameters**

**x0** : {array, matrix}

Starting guess for the solution.

**tol** : float

Tolerance to achieve. The algorithm terminates when either the relative or the absolute residual is below *tol*.

**maxiter** : integer

Maximum number of iterations. Iteration will stop after *maxiter* steps even if the specified tolerance has not been achieved.

**M** : {sparse matrix, dense matrix, LinearOperator}

Preconditioner for *A*. The preconditioner should approximate the inverse of *A*. Effective preconditioning dramatically improves the rate of convergence, which implies that fewer iterations are needed to reach a given error tolerance.

**callback** : function

User-supplied function to call after each iteration. It is called as `callback(xk)`, where `xk` is the current solution vector.

`scipy.sparse.linalg.cg` (*A*, *b*, *x0=None*, *tol=1e-05*, *maxiter=None*, *M=None*, *callback=None*)

Use Conjugate Gradient iteration to solve  $Ax = b$ .

**Parameters** **A** : {sparse matrix, dense matrix, LinearOperator}

The real or complex N-by-N matrix of the linear system. *A* must represent a hermitian, positive definite matrix.

**b** : {array, matrix}

**Returns** **x** : {array, matrix} Right hand side of the linear system. Has shape (N,) or (N,1).

The converged solution.

**info** : integer

**Provides convergence information:**

0 : successful exit >0 : convergence to tolerance not achieved, number of iterations <0 : illegal input or breakdown

**Other Parameters**

**x0** : {array, matrix}

Starting guess for the solution.

**tol** : float

Tolerance to achieve. The algorithm terminates when either the relative or the absolute residual is below *tol*.

**maxiter** : integer

Maximum number of iterations. Iteration will stop after maxiter steps even if the specified tolerance has not been achieved.

**M** : {sparse matrix, dense matrix, LinearOperator}

Preconditioner for A. The preconditioner should approximate the inverse of A. Effective preconditioning dramatically improves the rate of convergence, which implies that fewer iterations are needed to reach a given error tolerance.

**callback** : function

User-supplied function to call after each iteration. It is called as callback(xk), where xk is the current solution vector.

`scipy.sparse.linalg.cg`s (*A*, *b*, *x0=None*, *tol=1e-05*, *maxiter=None*, *M=None*, *callback=None*)

Use Conjugate Gradient Squared iteration to solve  $Ax = b$ .

**Parameters** **A** : {sparse matrix, dense matrix, LinearOperator}

The real-valued N-by-N matrix of the linear system.

**b** : {array, matrix}

Right hand side of the linear system. Has shape (N,) or (N,1).

**Returns** **x** : {array, matrix}

The converged solution.

**info** : integer

**Provides convergence information:**

0 : successful exit >0 : convergence to tolerance not achieved, number of iterations <0 : illegal input or breakdown

**Other Parameters**

**x0** : {array, matrix}

Starting guess for the solution.

**tol** : float

Tolerance to achieve. The algorithm terminates when either the relative or the absolute residual is below *tol*.

**maxiter** : integer

Maximum number of iterations. Iteration will stop after maxiter steps even if the specified tolerance has not been achieved.

**M** : {sparse matrix, dense matrix, LinearOperator}

Preconditioner for A. The preconditioner should approximate the inverse of A. Effective preconditioning dramatically improves the rate of convergence, which implies that fewer iterations are needed to reach a given error tolerance.

**callback** : function

User-supplied function to call after each iteration. It is called as callback(xk), where xk is the current solution vector.

`scipy.sparse.linalg.gmres` (*A*, *b*, *x0=None*, *tol=1e-05*, *restart=None*, *maxiter=None*, *M=None*, *callback=None*, *restrt=None*)

Use Generalized Minimal RESidual iteration to solve  $Ax = b$ .

**Parameters** **A** : {sparse matrix, dense matrix, LinearOperator}

The real or complex N-by-N matrix of the linear system.

**b** : {array, matrix}

Right hand side of the linear system. Has shape (N,) or (N,1).

**Returns** **x** : {array, matrix}

The converged solution.

**info** : int

*Provides convergence information:*

- 0 : successful exit
- >0 : convergence to tolerance not achieved, number of iterations
- <0 : illegal input or breakdown

*Other Parameters*

- x0** : {array, matrix}  
Starting guess for the solution (a vector of zeros by default).
- tol** : float  
Tolerance to achieve. The algorithm terminates when either the relative or the absolute residual is below *tol*.
- restart** : int, optional  
Number of iterations between restarts. Larger values increase iteration cost, but may be necessary for convergence. Default is 20.
- maxiter** : int, optional  
Maximum number of iterations (restart cycles). Iteration will stop after maxiter steps even if the specified tolerance has not been achieved.
- M** : {sparse matrix, dense matrix, LinearOperator}  
Inverse of the preconditioner of A. M should approximate the inverse of A and be easy to solve for (see Notes). Effective preconditioning dramatically improves the rate of convergence, which implies that fewer iterations are needed to reach a given error tolerance. By default, no preconditioner is used.
- callback** : function  
User-supplied function to call after each iteration. It is called as callback(rk), where rk is the current residual vector.
- restrt** : int, optional  
DEPRECATED - use *restart* instead.

**See also:***LinearOperator**Notes*

A preconditioner, P, is chosen such that P is close to A but easy to solve for. The preconditioner parameter required by this routine is  $M = P^{-1}$ . The inverse should preferably not be calculated explicitly. Rather, use the following template to produce M:

```
# Construct a linear operator that computes P^-1 * x.
import scipy.sparse.linalg as spla
M_x = lambda x: spla.spsolve(P, x)
M = spla.LinearOperator((n, n), M_x)
```

*Examples*

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import gmres
>>> A = csc_matrix([[3, 2, 0], [1, -1, 0], [0, 5, 1]], dtype=float)
>>> b = np.array([2, 4, -1], dtype=float)
>>> x, exitCode = gmres(A, b)
>>> print(exitCode)           # 0 indicates successful convergence
0
>>> np.allclose(A.dot(x), b)
True
```

```
scipy.sparse.linalg.lgmres(A, b, x0=None, tol=1e-05, maxiter=1000, M=None, callback=None,
                           inner_m=30, outer_k=3, outer_v=None, store_outer_Av=True,
                           prepend_outer_v=False)
```

Solve a matrix equation using the LGMRES algorithm.

The LGMRES algorithm [R28] [R29] is designed to avoid some problems in the convergence in restarted GMRES, and often converges in fewer iterations.

**Parameters**

**A** : {sparse matrix, dense matrix, LinearOperator}  
The real or complex N-by-N matrix of the linear system.

**b** : {array, matrix}  
Right hand side of the linear system. Has shape (N,) or (N,1).

**x0** : {array, matrix}  
Starting guess for the solution.

**tol** : float, optional  
Tolerance to achieve. The algorithm terminates when either the relative or the absolute residual is below *tol*.

**maxiter** : int, optional  
Maximum number of iterations. Iteration will stop after maxiter steps even if the specified tolerance has not been achieved.

**M** : {sparse matrix, dense matrix, LinearOperator}, optional  
Preconditioner for A. The preconditioner should approximate the inverse of A. Effective preconditioning dramatically improves the rate of convergence, which implies that fewer iterations are needed to reach a given error tolerance.

**callback** : function, optional  
User-supplied function to call after each iteration. It is called as `callback(xk)`, where `xk` is the current solution vector.

**inner\_m** : int, optional  
Number of inner GMRES iterations per each outer iteration.

**outer\_k** : int, optional  
Number of vectors to carry between inner GMRES iterations. According to [R28], good values are in the range of 1...3. However, note that if you want to use the additional vectors to accelerate solving multiple similar problems, larger values may be beneficial.

**outer\_v** : list of tuples, optional  
List containing tuples  $(v, Av)$  of vectors and corresponding matrix-vector products, used to augment the Krylov subspace, and carried between inner GMRES iterations. The element `Av` can be *None* if the matrix-vector product should be re-evaluated. This parameter is modified in-place by *lgmres*, and can be used to pass “guess” vectors in and out of the algorithm when solving similar problems.

**store\_outer\_Av** : bool, optional  
Whether LGMRES should store also  $A*v$  in addition to vectors  $v$  in the *outer\_v* list. Default is True.

**prepend\_outer\_v** : bool, optional  
Whether to put *outer\_v* augmentation vectors before Krylov iterates. In standard LGMRES, `prepend_outer_v=False`.

**Returns**

**x** : array or matrix  
The converged solution.

**info** : int  
Provides convergence information:

- 0 : successful exit
- >0 : convergence to tolerance not achieved, number of iterations
- <0 : illegal input or breakdown

**Notes**

The LGMRES algorithm [R28] [R29] is designed to avoid the slowing of convergence in restarted GMRES, due to alternating residual vectors. Typically, it often outperforms GMRES(m) of comparable memory requirements by some measure, or at least is not much worse.

Another advantage in this algorithm is that you can supply it with ‘guess’ vectors in the *outer\_v* argument that augment the Krylov subspace. If the solution lies close to the span of these vectors, the algorithm converges faster. This can be useful if several very similar matrices need to be inverted one after another, such as in Newton-Krylov iteration where the Jacobian matrix often changes little in the nonlinear steps.

**References**

[R28], [R29]

**Examples**

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import lgmres
>>> A = csc_matrix([[3, 2, 0], [1, -1, 0], [0, 5, 1]], dtype=float)
>>> b = np.array([2, 4, -1], dtype=float)
>>> x, exitCode = lgmres(A, b)
>>> print(exitCode)           # 0 indicates successful convergence
0
>>> np.allclose(A.dot(x), b)
True
```

`scipy.sparse.linalg.minres(A, b, x0=None, shift=0.0, tol=1e-05, maxiter=None, M=None, callback=None, show=False, check=False)`

Use MINimum RESidual iteration to solve  $Ax=b$

MINRES minimizes  $\text{norm}(A*x - b)$  for a real symmetric matrix  $A$ . Unlike the Conjugate Gradient method,  $A$  can be indefinite or singular.

If  $\text{shift} \neq 0$  then the method solves  $(A - \text{shift}*I)x = b$

- Parameters**
  - A** : {sparse matrix, dense matrix, LinearOperator}
    - The real symmetric N-by-N matrix of the linear system
  - b** : {array, matrix}
    - Right hand side of the linear system. Has shape (N,) or (N,1).
- Returns**
  - x** : {array, matrix}
    - The converged solution.
  - info** : integer

**Provides convergence information:**

0 : successful exit >0 : convergence to tolerance not achieved, number of iterations <0 : illegal input or breakdown

**Other Parameters**

- x0** : {array, matrix}
  - Starting guess for the solution.
- tol** : float
  - Tolerance to achieve. The algorithm terminates when either the relative or the absolute residual is below *tol*.
- maxiter** : integer
  - Maximum number of iterations. Iteration will stop after maxiter steps even if the specified tolerance has not been achieved.
- M** : {sparse matrix, dense matrix, LinearOperator}

Preconditioner for A. The preconditioner should approximate the inverse of A. Effective preconditioning dramatically improves the rate of convergence, which implies that fewer iterations are needed to reach a given error tolerance.

**callback** : function

User-supplied function to call after each iteration. It is called as `callback(xk)`, where `xk` is the current solution vector.

### Notes

THIS FUNCTION IS EXPERIMENTAL AND SUBJECT TO CHANGE!

### References

*Solution of sparse indefinite systems of linear equations,*

C. C. Paige and M. A. Saunders (1975), SIAM J. Numer. Anal. 12(4), pp. 617-629. <https://web.stanford.edu/group/SOL/software/minres/>

*This file is a translation of the following MATLAB implementation:*

<https://web.stanford.edu/group/SOL/software/minres/minres-matlab.zip>

`scipy.sparse.linalg.qmr(A, b, x0=None, tol=1e-05, maxiter=None, M1=None, M2=None, callback=None)`

Use Quasi-Minimal Residual iteration to solve  $Ax = b$ .

**Parameters** **A** : {sparse matrix, dense matrix, LinearOperator}

The real-valued N-by-N matrix of the linear system. It is required that the linear operator can produce  $Ax$  and  $A^T x$ .

**b** : {array, matrix}

**Returns** **x** : {array, matrix} Right hand side of the linear system. Has shape (N,) or (N,1).  
The converged solution.

**info** : integer

**Provides convergence information:**

0 : successful exit >0 : convergence to tolerance not achieved, number of iterations <0 : illegal input or breakdown

### Other Parameters

**x0** : {array, matrix}

Starting guess for the solution.

**tol** : float

Tolerance to achieve. The algorithm terminates when either the relative or the absolute residual is below *tol*.

**maxiter** : integer

Maximum number of iterations. Iteration will stop after maxiter steps even if the specified tolerance has not been achieved.

**M1** : {sparse matrix, dense matrix, LinearOperator}

Left preconditioner for A.

**M2** : {sparse matrix, dense matrix, LinearOperator}

Right preconditioner for A. Used together with the left preconditioner M1. The matrix  $M1 * A * M2$  should have better conditioned than A alone.

**callback** : function

User-supplied function to call after each iteration. It is called as `callback(xk)`, where `xk` is the current solution vector.

See also:

*LinearOperator*

*Examples*

```

>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import qmr
>>> A = csc_matrix([[3, 2, 0], [1, -1, 0], [0, 5, 1]], dtype=float)
>>> b = np.array([2, 4, -1], dtype=float)
>>> x, exitCode = qmr(A, b)
>>> print(exitCode)           # 0 indicates successful convergence
0
>>> np.allclose(A.dot(x), b)
True

```

`scipy.sparse.linalg.gcrotnk` (*A*, *b*, *x0=None*, *tol=1e-05*, *maxiter=1000*, *M=None*, *callback=None*, *m=20*, *k=None*, *CU=None*, *discard\_C=False*, *truncate='oldest'*)

Solve a matrix equation using flexible GCROT(m,k) algorithm.

**Parameters**

- A** : {sparse matrix, dense matrix, LinearOperator}
  - The real or complex N-by-N matrix of the linear system.
- b** : {array, matrix}
  - Right hand side of the linear system. Has shape (N,) or (N,1).
- x0** : {array, matrix}
  - Starting guess for the solution.
- tol** : float, optional
  - Tolerance to achieve. The algorithm terminates when either the relative or the absolute residual is below *tol*.
- maxiter** : int, optional
  - Maximum number of iterations. Iteration will stop after maxiter steps even if the specified tolerance has not been achieved.
- M** : {sparse matrix, dense matrix, LinearOperator}, optional
  - Preconditioner for A. The preconditioner should approximate the inverse of A. gcrotnk is a ‘flexible’ algorithm and the preconditioner can vary from iteration to iteration. Effective preconditioning dramatically improves the rate of convergence, which implies that fewer iterations are needed to reach a given error tolerance.
- callback** : function, optional
  - User-supplied function to call after each iteration. It is called as `callback(xk)`, where *xk* is the current solution vector.
- m** : int, optional
  - Number of inner FGMRES iterations per each outer iteration. Default: 20
- k** : int, optional
  - Number of vectors to carry between inner FGMRES iterations. According to [R26], good values are around *m*. Default: *m*
- CU** : list of tuples, optional
  - List of tuples (*c*, *u*) which contain the columns of the matrices C and U in the GCROT(m,k) algorithm. For details, see [R26]. The list given and vectors contained in it are modified in-place. If not given, start from empty matrices. The *c* elements in the tuples can be None, in which case the vectors are recomputed via  $c = A u$  on start and orthogonalized as described in [R27].
- discard\_C** : bool, optional
  - Discard the C-vectors at the end. Useful if recycling Krylov subspaces for different linear systems.
- truncate** : {‘oldest’, ‘smallest’}, optional
  - Truncation scheme to use. Drop: oldest vectors, or vectors with smallest singular values using the scheme discussed in [1,2]. See [R26] for detailed comparison. Default: ‘oldest’

**Returns**

**x** : array or matrix  
The solution found.

**info** : int  
Provides convergence information:

- 0 : successful exit
- >0 : convergence to tolerance not achieved, number of iterations

### References

[R25], [R26], [R27]

Iterative methods for least-squares problems:

<code>lsqr(A, b[, damp, atol, btol, conlim, ...])</code>	Find the least-squares solution to a large, sparse, linear system of equations.
<code>lsmr(A, b[, damp, atol, btol, conlim, ...])</code>	Iterative solver for least-squares problems.

`scipy.sparse.linalg.lsqr(A, b, damp=0.0, atol=1e-08, btol=1e-08, conlim=100000000.0, iter_lim=None, show=False, calc_var=False, x0=None)`

Find the least-squares solution to a large, sparse, linear system of equations.

The function solves  $Ax = b$  or  $\min ||b - Ax||^2$  or  $\min ||Ax - b||^2 + d^2 ||x||^2$ .

The matrix  $A$  may be square or rectangular (over-determined or under-determined), and may have any rank.

```

1. Unsymmetric equations -- solve A*x = b
2. Linear least squares -- solve A*x = b
                           in the least-squares sense
3. Damped least squares -- solve ( A ) * x = ( b )
                           ( damp*I ) ( 0 )
                           in the least-squares sense

```

**Parameters**

**A** : {sparse matrix, ndarray, LinearOperator}  
Representation of an m-by-n matrix. It is required that the linear operator can produce  $Ax$  and  $A^T x$ .

**b** : array\_like, shape (m,)   
Right-hand side vector  $b$ .

**damp** : float   
Damping coefficient.

**atol, btol** : float, optional   
Stopping tolerances. If both are  $1.0e-9$  (say), the final residual norm should be accurate to about 9 digits. (The final  $x$  will usually have fewer correct digits, depending on  $\text{cond}(A)$  and the size of  $\text{damp}$ .)

**conlim** : float, optional   
Another stopping tolerance. `lsqr` terminates if an estimate of  $\text{cond}(A)$  exceeds `conlim`. For compatible systems  $Ax = b$ , `conlim` could be as large as  $1.0e+12$  (say). For least-squares problems, `conlim` should be less than  $1.0e+8$ . Maximum precision can be obtained by setting `atol = btol = conlim = zero`, but the number of iterations may then be excessive.

**iter\_lim** : int, optional   
Explicit limitation on number of iterations (for safety).

**show** : bool, optional   
Display an iteration log.

**calc\_var** : bool, optional  
Whether to estimate diagonals of  $(A'A + \text{damp}^2 * I)^{-1}$ .

**x0** : array\_like, shape (n,), optional  
Initial guess of x, if None zeros are used.  
New in version 1.0.0.

**Returns** **x** : ndarray of float  
The final solution.

**istop** : int  
Gives the reason for termination. 1 means x is an approximate solution to  $Ax = b$ . 2 means x approximately solves the least-squares problem.

**itn** : int  
Iteration number upon termination.

**r1norm** : float  
 $\text{norm}(r)$ , where  $r = b - Ax$ .

**r2norm** : float  
 $\sqrt{\text{norm}(r)^2 + \text{damp}^2 * \text{norm}(x)^2}$ . Equal to *r1norm* if  $\text{damp} == 0$ .

**anorm** : float  
Estimate of Frobenius norm of  $Abar = \begin{bmatrix} A \\ \text{damp} * I \end{bmatrix}$ .

**acond** : float  
Estimate of  $\text{cond}(Abar)$ .

**arnorm** : float  
Estimate of  $\text{norm}(A' * r - \text{damp}^2 * x)$ .

**xnorm** : float  
 $\text{norm}(x)$

**var** : ndarray of float  
If **calc\_var** is True, estimates all diagonals of  $(A'A)^{-1}$  (if  $\text{damp} == 0$ ) or more generally  $(A'A + \text{damp}^2 * I)^{-1}$ . This is well defined if A has full column rank or  $\text{damp} > 0$ . (Not sure what var means if  $\text{rank}(A) < n$  and  $\text{damp} = 0$ .)

### Notes

LSQR uses an iterative method to approximate the solution. The number of iterations required to reach a certain accuracy depends strongly on the scaling of the problem. Poor scaling of the rows or columns of A should therefore be avoided where possible.

For example, in problem 1 the solution is unaltered by row-scaling. If a row of A is very small or large compared to the other rows of A, the corresponding row of  $(A \ b)$  should be scaled up or down.

In problems 1 and 2, the solution x is easily recovered following column-scaling. Unless better information is known, the nonzero columns of A should be scaled so that they all have the same Euclidean norm (e.g., 1.0).

In problem 3, there is no freedom to re-scale if damp is nonzero. However, the value of damp should be assigned only after attention has been paid to the scaling of A.

The parameter damp is intended to help regularize ill-conditioned systems, by preventing the true solution from being very large. Another aid to regularization is provided by the parameter acond, which may be used to terminate iterations before the computed solution becomes very large.

If some initial estimate x0 is known and if  $\text{damp} == 0$ , one could proceed as follows:

1. Compute a residual vector  $r0 = b - A * x0$ .
2. Use LSQR to solve the system  $A * dx = r0$ .
3. Add the correction dx to obtain a final solution  $x = x0 + dx$ .

This requires that x0 be available before and after the call to LSQR. To judge the benefits, suppose LSQR takes k1 iterations to solve  $A * x = b$  and k2 iterations to solve  $A * dx = r0$ . If x0 is "good",  $\text{norm}(r0)$  will be smaller than  $\text{norm}(b)$ . If the same stopping tolerances atol and btol are used for each system, k1 and k2 will be

similar, but the final solution  $x_0 + dx$  should be more accurate. The only way to reduce the total work is to use a larger stopping tolerance for the second system. If some value  $btol$  is suitable for  $A*x = b$ , the larger value  $btol*norm(b)/norm(r_0)$  should be suitable for  $A*dx = r_0$ .

Preconditioning is another way to reduce the number of iterations. If it is possible to solve a related system  $M*x = b$  efficiently, where  $M$  approximates  $A$  in some helpful way (e.g.  $M - A$  has low rank or its elements are small relative to those of  $A$ ), LSQR may converge more rapidly on the system  $A*(inverse)*z = b$ , after which  $x$  can be recovered by solving  $M*x = z$ .

If  $A$  is symmetric, LSQR should not be used!

Alternatives are the symmetric conjugate-gradient method (`cg`) and/or `SYMMLQ`. `SYMMLQ` is an implementation of symmetric `cg` that applies to any symmetric  $A$  and will converge more rapidly than LSQR. If  $A$  is positive definite, there are other implementations of symmetric `cg` that require slightly less work per iteration than `SYMMLQ` (but will take the same number of iterations).

### References

[R35], [R36], [R37]

### Examples

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import lsqr
>>> A = csc_matrix([[1., 0.], [1., 1.], [0., 1.]], dtype=float)
```

The first example has the trivial solution  $[0, 0]$

```
>>> b = np.array([0., 0., 0.], dtype=float)
>>> x, istop, itn, normr = lsqr(A, b)[:4]
The exact solution is x = 0
>>> istop
0
>>> x
array([ 0.,  0.]
```

The stopping code `istop=0` returned indicates that a vector of zeros was found as a solution. The returned solution  $x$  indeed contains  $[0, 0]$ . The next example has a non-trivial solution:

```
>>> b = np.array([1., 0., -1.], dtype=float)
>>> x, istop, itn, rlnorm = lsqr(A, b)[:4]
>>> istop
1
>>> x
array([ 1., -1.])
>>> itn
1
>>> rlnorm
4.440892098500627e-16
```

As indicated by `istop=1`, `lsqr` found a solution obeying the tolerance limits. The given solution  $[1., -1.]$  obviously solves the equation. The remaining return values include information about the number of iterations (`itn=1`) and the remaining difference of left and right side of the solved equation. The final example demonstrates the behavior in the case where there is no solution for the equation:

```
>>> b = np.array([1., 0.01, -1.], dtype=float)
>>> x, istop, itn, rlnorm = lsqr(A, b)[:4]
>>> istop
2
```

```

>>> x
array([ 1.00333333, -0.99666667])
>>> A.dot(x)-b
array([ 0.00333333, -0.00333333,  0.00333333])
>>> rlnorm
0.005773502691896255
    
```

*istop* indicates that the system is inconsistent and thus *x* is rather an approximate solution to the corresponding least-squares problem. *rlnorm* contains the norm of the minimal residual that was found.

`scipy.sparse.linalg.lsmr(A, b, damp=0.0, atol=1e-06, btol=1e-06, conlim=100000000.0, maxiter=None, show=False, x0=None)`  
 Iterative solver for least-squares problems.

`lsmr` solves the system of linear equations  $Ax = b$ . If the system is inconsistent, it solves the least-squares problem  $\min \|b - Ax\|_2$ . *A* is a rectangular matrix of dimension *m*-by-*n*, where all cases are allowed:  $m = n$ ,  $m > n$ , or  $m < n$ . *B* is a vector of length *m*. The matrix *A* may be dense or sparse (usually sparse).

**Parameters** *A* : {matrix, sparse matrix, ndarray, LinearOperator}

Matrix *A* in the linear system.

**b** : array\_like, shape (*m*,)

Vector *b* in the linear system.

**damp** : float

Damping factor for regularized least-squares. `lsmr` solves the regularized least-squares problem:

$$\min \left\| \begin{pmatrix} b - Ax \\ 0 \end{pmatrix} \right\|_2$$

where *damp* is a scalar. If *damp* is `None` or 0, the system is solved without regularization.

**atol, btol** : float, optional

Stopping tolerances. `lsmr` continues iterations until a certain backward error estimate is smaller than some quantity depending on *atol* and *btol*. Let  $r = b - Ax$  be the residual vector for the current approximate solution *x*. If  $Ax = b$  seems to be consistent, `lsmr` terminates when  $\text{norm}(r) \leq \text{atol} * \text{norm}(A) * \text{norm}(x) + \text{btol} * \text{norm}(b)$ . Otherwise, `lsmr` terminates when  $\text{norm}(A^T r) \leq \text{atol} * \text{norm}(A) * \text{norm}(r)$ . If both tolerances are 1.0e-6 (say), the final  $\text{norm}(r)$  should be accurate to about 6 digits. (The final *x* will usually have fewer correct digits, depending on  $\text{cond}(A)$  and the size of `LAMBDA`.) If *atol* or *btol* is `None`, a default value of 1.0e-6 will be used. Ideally, they should be estimates of the relative error in the entries of *A* and *B* respectively. For example, if the entries of *A* have 7 correct digits, set *atol* = 1e-7. This prevents the algorithm from doing unnecessary work beyond the uncertainty of the input data.

**conlim** : float, optional

`lsmr` terminates if an estimate of  $\text{cond}(A)$  exceeds *conlim*. For compatible systems  $Ax = b$ , *conlim* could be as large as 1.0e+12 (say). For least-squares problems, *conlim* should be less than 1.0e+8. If *conlim* is `None`, the default value is 1e+8. Maximum precision can be obtained by setting *atol* = *btol* = *conlim* = 0, but the number of iterations may then be excessive.

**maxiter** : int, optional

`lsmr` terminates if the number of iterations reaches *maxiter*. The default is *maxiter* =  $\min(m, n)$ . For ill-conditioned systems, a larger value of

*maxiter* may be needed.

**show** : bool, optional

Print iterations logs if show=True.

**x0** : array\_like, shape (n,), optional

Initial guess of x, if None zeros are used.

New in version 1.0.0.

### Returns

**x** : ndarray of float

Least-square solution returned.

**istop** : int

istop gives the reason for stopping:

```

istop   = 0 means x=0 is a solution.  If x0 was given,
↳then x=x0 is a
        solution.
        = 1 means x is an approximate solution to A*x
↳= B,
        according to atol and btol.
        = 2 means x approximately solves the least-
↳squares problem
        according to atol.
        = 3 means COND(A) seems to be greater than
↳CONLIM.
        = 4 is the same as 1 with atol = btol = eps
↳(machine
        precision)
        = 5 is the same as 2 with atol = eps.
        = 6 is the same as 3 with CONLIM = 1/eps.
        = 7 means ITN reached maxiter before the other
↳stopping
        conditions were satisfied.

```

**itn** : int

Number of iterations used.

**normr** : float

$\text{norm}(b - Ax)$

**normar** : float

$\text{norm}(A^T (b - Ax))$

**norma** : float

$\text{norm}(A)$

**conda** : float

Condition number of A.

**normx** : float

$\text{norm}(x)$

### Notes

New in version 0.11.0.

### References

[R33], [R34]

### Examples

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import lsqr
>>> A = csc_matrix([[1., 0.], [1., 1.], [0., 1.]], dtype=float)
```

The first example has the trivial solution  $[0, 0]$

```
>>> b = np.array([0., 0., 0.], dtype=float)
>>> x, istop, itn, normr = lsqr(A, b)[:4]
>>> istop
0
>>> x
array([ 0.,  0.]
```

The stopping code  $istop=0$  returned indicates that a vector of zeros was found as a solution. The returned solution  $x$  indeed contains  $[0, 0]$ . The next example has a non-trivial solution:

```
>>> b = np.array([1., 0., -1.], dtype=float)
>>> x, istop, itn, normr = lsqr(A, b)[:4]
>>> istop
1
>>> x
array([ 1., -1.])
>>> itn
1
>>> normr
4.440892098500627e-16
```

As indicated by  $istop=1$ ,  $lsqr$  found a solution obeying the tolerance limits. The given solution  $[1, -1]$  obviously solves the equation. The remaining return values include information about the number of iterations ( $itn=1$ ) and the remaining difference of left and right side of the solved equation. The final example demonstrates the behavior in the case where there is no solution for the equation:

```
>>> b = np.array([1., 0.01, -1.], dtype=float)
>>> x, istop, itn, normr = lsqr(A, b)[:4]
>>> istop
2
>>> x
array([ 1.00333333, -0.99666667])
>>> A.dot(x)-b
array([ 0.00333333, -0.00333333,  0.00333333])
>>> normr
0.005773502691896255
```

$istop$  indicates that the system is inconsistent and thus  $x$  is rather an approximate solution to the corresponding least-squares problem.  $normr$  contains the minimal distance that was found.

## Matrix factorizations

Eigenvalue problems:

`eigs(A[, k, M, sigma, which, v0, nc, ...])`

Find  $k$  eigenvalues and eigenvectors of the square matrix  $A$ .

`eigsh(A[, k, M, sigma, which, v0, nc, ...])`

Find  $k$  eigenvalues and eigenvectors of the real symmetric square matrix or complex hermitian matrix  $A$ .

Continued on next page

Table 5.195 – continued from previous page

<code>lobpcg(A, X[, B, M, Y, tol, maxiter, ...])</code>	Locally Optimal Block Preconditioned Conjugate Gradient Method (LOBPCG)
---	---

`scipy.sparse.linalg.eigs` (*A*, *k*=6, *M*=None, *sigma*=None, *which*='LM', *v0*=None, *ncv*=None, *maxiter*=None, *tol*=0, *return\_eigenvectors*=True, *Minv*=None, *OPinv*=None, *OPpart*=None)

Find *k* eigenvalues and eigenvectors of the square matrix *A*.

Solves  $A * x[i] = w[i] * x[i]$ , the standard eigenvalue problem for *w*[*i*] eigenvalues with corresponding eigenvectors *x*[*i*].

If *M* is specified, solves  $A * x[i] = w[i] * M * x[i]$ , the generalized eigenvalue problem for *w*[*i*] eigenvalues with corresponding eigenvectors *x*[*i*]

**Parameters** *A* : ndarray, sparse matrix or LinearOperator

An array, sparse matrix, or LinearOperator representing the operation  $A * x$ , where *A* is a real or complex square matrix.

*k* : int, optional

The number of eigenvalues and eigenvectors desired. *k* must be smaller than *N*-1. It is not possible to compute all eigenvectors of a matrix.

*M* : ndarray, sparse matrix or LinearOperator, optional

An array, sparse matrix, or LinearOperator representing the operation  $M * x$  for the generalized eigenvalue problem

$$A * x = w * M * x.$$

*M* must represent a real, symmetric matrix if *A* is real, and must represent a complex, hermitian matrix if *A* is complex. For best results, the data type of *M* should be the same as that of *A*. Additionally:

If *sigma* is None, *M* is positive definite

If *sigma* is specified, *M* is positive semi-definite

If *sigma* is None, `eigs` requires an operator to compute the solution of the linear equation  $M * x = b$ . This is done internally via a (sparse) LU decomposition for an explicit matrix *M*, or via an iterative solver for a general linear operator. Alternatively, the user can supply the matrix or operator *Minv*, which gives  $x = Minv * b = M^{-1} * b$ .

*sigma* : real or complex, optional

Find eigenvalues near *sigma* using shift-invert mode. This requires an operator to compute the solution of the linear system  $[A - sigma * M] * x = b$ , where *M* is the identity matrix if unspecified. This is computed internally via a (sparse) LU decomposition for explicit matrices *A* & *M*, or via an iterative solver if either *A* or *M* is a general linear operator. Alternatively, the user can supply the matrix or operator *OPinv*, which gives  $x = OPinv * b = [A - sigma * M]^{-1} * b$ . For a real matrix *A*, shift-invert can either be done in imaginary mode or real mode, specified by the parameter *OPpart* ('r' or 'i'). Note that when *sigma* is specified, the keyword 'which' (below) refers to the shifted eigenvalues *w*' [*i*] where:

**If *A* is real and *OPpart* == 'r' (default),**

$$w'[i] = 1/2 * [1/(w[i]-sigma) + 1/(w[i]-conj(sigma))].$$

**If *A* is real and *OPpart* == 'i',**

$$w'[i] = 1/2i * [1/(w[i]-sigma) - 1/(w[i]-conj(sigma))].$$

If *A* is complex,  $w'[i] = 1/(w[i]-sigma)$ .

*v0* : ndarray, optional

Starting vector for iteration. Default: random

**ncv** : int, optional  
 The number of Lanczos vectors generated *ncv* must be greater than *k*; it is recommended that  $ncv > 2*k$ . Default:  $\min(n, \max(2*k + 1, 20))$

**which** : str, ['LM' | 'SM' | 'LR' | 'SR' | 'LI' | 'SI'], optional  
 Which *k* eigenvectors and eigenvalues to find:  
     'LM' : largest magnitude  
     'SM' : smallest magnitude  
     'LR' : largest real part  
     'SR' : smallest real part  
     'LI' : largest imaginary part  
     'SI' : smallest imaginary part

When *sigma* != None, 'which' refers to the shifted eigenvalues *w*'[i] (see discussion in 'sigma', above). ARPACK is generally better at finding large values than small values. If small eigenvalues are desired, consider using shift-invert mode for better performance.

**maxiter** : int, optional  
 Maximum number of Arnoldi update iterations allowed Default:  $n*10$

**tol** : float, optional  
 Relative accuracy for eigenvalues (stopping criterion) The default value of 0 implies machine precision.

**return\_eigenvectors** : bool, optional  
 Return eigenvectors (True) in addition to eigenvalues

**Minv** : ndarray, sparse matrix or LinearOperator, optional  
 See notes in *M*, above.

**OPinv** : ndarray, sparse matrix or LinearOperator, optional  
 See notes in *sigma*, above.

**OPpart** : {'r' or 'i'}, optional  
 See notes in *sigma*, above

**Returns**

**w** : ndarray  
 Array of *k* eigenvalues.

**v** : ndarray  
 An array of *k* eigenvectors.  $v[:, i]$  is the eigenvector corresponding to the eigenvalue  $w[i]$ .

**Raises**

**ArpackNoConvergence**  
 When the requested convergence is not obtained. The currently converged eigenvalues and eigenvectors can be found as *eigenvalues* and *eigenvectors* attributes of the exception object.

**See also:**

**eigsh** eigenvalues and eigenvectors for symmetric matrix *A*  
**svds** singular value decomposition for a matrix *A*

**Notes**

This function is a wrapper to the ARPACK [R18] SNEUPD, DNEUPD, CNEUPD, ZNEUPD, functions which use the Implicitly Restarted Arnoldi Method to find the eigenvalues and eigenvectors [R19].

**References**

[R18], [R19]

**Examples**

Find 6 eigenvectors of the identity matrix:

```

>>> import scipy.sparse as sparse
>>> id = np.eye(13)
>>> vals, vecs = sparse.linalg.eigs(id, k=6)
>>> vals
array([ 1.+0.j,  1.+0.j,  1.+0.j,  1.+0.j,  1.+0.j,  1.+0.j])
>>> vecs.shape
(13, 6)

```

`scipy.sparse.linalg.eigsh`(*A*, *k*=6, *M*=None, *sigma*=None, *which*='LM', *v0*=None, *ncv*=None, *maxiter*=None, *tol*=0, *return\_eigenvectors*=True, *Minv*=None, *OPinv*=None, *mode*='normal')

Find *k* eigenvalues and eigenvectors of the real symmetric square matrix or complex hermitian matrix *A*.

Solves  $A * x[i] = w[i] * x[i]$ , the standard eigenvalue problem for *w*[*i*] eigenvalues with corresponding eigenvectors *x*[*i*].

If *M* is specified, solves  $A * x[i] = w[i] * M * x[i]$ , the generalized eigenvalue problem for *w*[*i*] eigenvalues with corresponding eigenvectors *x*[*i*]

**Parameters** *A* : An *N* x *N* matrix, array, sparse matrix, or LinearOperator representing the operation  $A * x$ , where *A* is a real symmetric matrix For buckling mode (see below) *A* must additionally be positive-definite

*k* : int, optional  
The number of eigenvalues and eigenvectors desired. *k* must be smaller than *N*. It is not possible to compute all eigenvectors of a matrix.

**Returns** *w* : array  
Array of *k* eigenvalues

*v* : array  
An array representing the *k* eigenvectors. The column *v*[:, *i*] is the eigenvector corresponding to the eigenvalue *w*[*i*].

**Other Parameters**

*M* : An *N* x *N* matrix, array, sparse matrix, or linear operator representing the operation  $M * x$  for the generalized eigenvalue problem  
 $A * x = w * M * x$ .

*M* must represent a real, symmetric matrix if *A* is real, and must represent a complex, hermitian matrix if *A* is complex. For best results, the data type of *M* should be the same as that of *A*. Additionally:

If *sigma* is None, *M* is symmetric positive definite  
If *sigma* is specified, *M* is symmetric positive semi-definite  
In buckling mode, *M* is symmetric indefinite.

If *sigma* is None, `eigsh` requires an operator to compute the solution of the linear equation  $M * x = b$ . This is done internally via a (sparse) LU decomposition for an explicit matrix *M*, or via an iterative solver for a general linear operator. Alternatively, the user can supply the matrix or operator *Minv*, which gives  $x = Minv * b = M^{-1} * b$ .

*sigma* : real

Find eigenvalues near *sigma* using shift-invert mode. This requires an operator to compute the solution of the linear system  $[A - sigma * M] x = b$ , where *M* is the identity matrix if unspecified. This is computed internally via a (sparse) LU decomposition for explicit matrices *A* & *M*, or via an iterative solver if either *A* or *M* is a general linear operator. Alternatively, the user can supply the matrix or operator *OPinv*, which gives  $x = OPinv * b = [A - sigma * M]^{-1} * b$ . Note that when *sigma* is specified, the keyword 'which' refers to the shifted eigenvalues *w*' [*i*] where:

if *mode* == 'normal',  $w'[i] = 1 / (w[i] - sigma)$ .

```

if mode == 'cayley', w'[i] = (w[i] + sigma) /
(w[i] - sigma).
if mode == 'buckling', w'[i] = w[i] / (w[i] -
sigma).

```

(see further discussion in 'mode' below)

**v0** : ndarray, optional

Starting vector for iteration. Default: random

**ncv** : int, optional

The number of Lanczos vectors generated ncv must be greater than k and smaller than n; it is recommended that  $ncv > 2*k$ . Default:  $\min(n, \max(2*k + 1, 20))$

**which** : str ['LM' | 'SM' | 'LA' | 'SA' | 'BE']

If A is a complex hermitian matrix, 'BE' is invalid. Which k eigenvectors and eigenvalues to find:

```

'LM' : Largest (in magnitude) eigenvalues
'SM' : Smallest (in magnitude) eigenvalues
'LA' : Largest (algebraic) eigenvalues
'SA' : Smallest (algebraic) eigenvalues
'BE' : Half (k/2) from each end of the spectrum

```

When k is odd, return one more (k/2+1) from the high end. When sigma != None, 'which' refers to the shifted eigenvalues w'[i] (see discussion in 'sigma', above). ARPACK is generally better at finding large values than small values. If small eigenvalues are desired, consider using shift-invert mode for better performance.

**maxiter** : int, optional

Maximum number of Arnoldi update iterations allowed Default: n\*10

**tol** : float

Relative accuracy for eigenvalues (stopping criterion). The default value of 0 implies machine precision.

**Minv** : N x N matrix, array, sparse matrix, or LinearOperator

See notes in M, above

**OPinv** : N x N matrix, array, sparse matrix, or LinearOperator

See notes in sigma, above.

**return\_eigenvectors** : bool

Return eigenvectors (True) in addition to eigenvalues

**mode** : string ['normal' | 'buckling' | 'cayley']

Specify strategy to use for shift-invert mode. This argument applies only for real-valued A and sigma != None. For shift-invert mode, ARPACK internally solves the eigenvalue problem  $OP * x'[i] = w'[i] * B * x'[i]$  and transforms the resulting Ritz vectors x'[i] and Ritz values w'[i] into the desired eigenvectors and eigenvalues of the problem  $A * x[i] = w[i] * M * x[i]$ . The modes are as follows:

```

'normal' :   OP = [A - sigma * M]^(-1) * M, B = M, w'[i]
             = 1 / (w[i] - sigma)
'buckling' : OP = [A - sigma * M]^(-1) * A, B = A, w'[i] =
             w[i] / (w[i] - sigma)
'cayley' :   OP = [A - sigma * M]^(-1) * [A + sigma * M],
             B = M, w'[i] = (w[i] + sigma) / (w[i] - sigma)

```

The choice of mode will affect which eigenvalues are selected by the keyword 'which', and can also impact the stability of convergence (see [2] for a discussion)

**Raises**

**ArpackNoConvergence**

When the requested convergence is not obtained.

The currently converged eigenvalues and eigenvectors can be found as `eigenvalues` and `eigenvectors` attributes of the exception object.

**See also:**

**eigs** eigenvalues and eigenvectors for a general (nonsymmetric) matrix A  
**svds** singular value decomposition for a matrix A

**Notes**

This function is a wrapper to the ARPACK [R20] SSEUPD and DSEUPD functions which use the Implicitly Restarted Lanczos Method to find the eigenvalues and eigenvectors [R21].

**References**

[R20], [R21]

**Examples**

```
>>> import scipy.sparse as sparse
>>> id = np.eye(13)
>>> vals, vecs = sparse.linalg.eigsh(id, k=6)
>>> vals
array([ 1.+0.j,  1.+0.j,  1.+0.j,  1.+0.j,  1.+0.j,  1.+0.j])
>>> vecs.shape
(13, 6)
```

`scipy.sparse.linalg.lobpcg(A, X, B=None, M=None, Y=None, tol=None, maxiter=20, largest=True, verbosityLevel=0, retLambdaHistory=False, retResidualNormsHistory=False)`

Locally Optimal Block Preconditioned Conjugate Gradient Method (LOBPCG)

LOBPCG is a preconditioned eigensolver for large symmetric positive definite (SPD) generalized eigenproblems.

**Parameters**

- A** : {sparse matrix, dense matrix, LinearOperator}  
The symmetric linear operator of the problem, usually a sparse matrix. Often called the “stiffness matrix”.
- X** : array\_like  
Initial approximation to the k eigenvectors. If A has shape=(n,n) then X should have shape shape=(n,k).
- B** : {dense matrix, sparse matrix, LinearOperator}, optional  
the right hand side operator in a generalized eigenproblem. by default, B = Identity often called the “mass matrix”
- M** : {dense matrix, sparse matrix, LinearOperator}, optional  
preconditioner to A; by default M = Identity M should approximate the inverse of A
- Y** : array\_like, optional  
n-by-sizeY matrix of constraints, sizeY < n The iterations will be performed in the B-orthogonal complement of the column-space of Y. Y must be full rank.

**Returns**

- w** : array  
Array of k eigenvalues
- v** : array  
An array of k eigenvectors. V has the same shape as X.

**Other Parameters**

- tol** : scalar, optional  
Solver tolerance (stopping criterion) by default: `tol=n*sqrt(eps)`
- maxiter** : integer, optional

maximum number of iterations by default: `maxiter=min(n,20)`  
**largest** : bool, optional  
 when True, solve for the largest eigenvalues, otherwise the smallest  
**verbosityLevel** : integer, optional  
 controls solver output. default: `verbosityLevel = 0`.  
**retLambdaHistory** : boolean, optional  
 whether to return eigenvalue history  
**retResidualNormsHistory** : boolean, optional  
 whether to return history of residual norms

*Notes*

If both `retLambdaHistory` and `retResidualNormsHistory` are True, the return tuple has the following format (lambda, V, lambda history, residual norms history).

In the following `n` denotes the matrix size and `m` the number of required eigenvalues (smallest or largest).

The LOBPCG code internally solves eigenproblems of the size  $3 \times m$  on every iteration by calling the “standard” dense eigensolver, so if `m` is not small enough compared to `n`, it does not make sense to call the LOBPCG code, but rather one should use the “standard” eigensolver, e.g. `numpy` or `scipy` function in this case. If one calls the LOBPCG algorithm for  $5 \times m > n$ , it will most likely break internally, so the code tries to call the standard function instead.

It is not that `n` should be large for the LOBPCG to work, but rather the ratio `n/m` should be large. If you call the LOBPCG code with `m=1` and `n=10`, it should work, though `n` is small. The method is intended for extremely large `n/m`, see e.g., reference [28] in <http://arxiv.org/abs/0705.2626>

The convergence speed depends basically on two factors:

1. How well relatively separated the seeking eigenvalues are from the rest of the eigenvalues. One can try to vary `m` to make this better.
2. How well conditioned the problem is. This can be changed by using proper preconditioning. For example, a rod vibration test problem (under tests directory) is ill-conditioned for large `n`, so convergence will be slow, unless efficient preconditioning is used. For this specific problem, a good simple preconditioner function would be a linear solve for `A`, which is easy to code since `A` is tridiagonal.

*Acknowledgements*

`lobpcg.py` code was written by Robert Cimrman. Many thanks belong to Andrew Knyazev, the author of the algorithm, for lots of advice and support.

*References*

[R30], [R31], [R32]

*Examples*

Solve  $Ax = \lambda Bx$  with constraints and preconditioning.

```
>>> from scipy.sparse import spdiags, issparse
>>> from scipy.sparse.linalg import lobpcg, LinearOperator
>>> n = 100
>>> vals = [np.arange(n, dtype=np.float64) + 1]
>>> A = spdiags(vals, 0, n, n)
>>> A.toarray()
array([[ 1.,  0.,  0., ...,  0.,  0.,  0.],
       [ 0.,  2.,  0., ...,  0.,  0.,  0.],
       [ 0.,  0.,  3., ...,  0.,  0.,  0.],
       ...,
       [ 0.,  0.,  0., ..., 98.,  0.,  0.]])
```

```
[ 0., 0., 0., ..., 0., 99., 0.],
 [ 0., 0., 0., ..., 0., 0., 100.]])
```

Constraints.

```
>>> Y = np.eye(n, 3)
```

Initial guess for eigenvectors, should have linearly independent columns. Column dimension = number of requested eigenvalues.

```
>>> X = np.random.rand(n, 3)
```

Preconditioner – inverse of A (as an abstract linear operator).

```
>>> invA = spdiags([1./vals[0]], 0, n, n)
>>> def precondition(x):
...     return invA * x
>>> M = LinearOperator(matvec=precond, shape=(n, n), dtype=float)
```

Here, `invA` could of course have been used directly as a preconditioner. Let us then solve the problem:

```
>>> eigs, vecs = lobpcg(A, X, Y=Y, M=M, tol=1e-4, maxiter=40, largest=False)
>>> eigs
array([ 4., 5., 6.])
```

Note that the vectors passed in `Y` are the eigenvectors of the 3 smallest eigenvalues. The results returned are orthogonal to those.

Singular values problems:

`svds(A[, k, ncv, tol, which, v0, maxiter, ...])`

Compute the largest  $k$  singular values/vectors for a sparse matrix.

`scipy.sparse.linalg.svds(A, k=6, ncv=None, tol=0, which='LM', v0=None, maxiter=None, return_singular_vectors=True)`

Compute the largest  $k$  singular values/vectors for a sparse matrix.

**Parameters** **A** : {sparse matrix, LinearOperator}

Array to compute the SVD on, of shape (M, N)

**k** : int, optional

Number of singular values and vectors to compute. Must be  $1 \leq k < \min(A.shape)$ .

**ncv** : int, optional

The number of Lanczos vectors generated `ncv` must be greater than  $k+1$  and smaller than  $n$ ; it is recommended that `ncv`  $> 2*k$  Default:  $\min(n, \max(2*k + 1, 20))$

**tol** : float, optional

Tolerance for singular values. Zero (default) means machine precision.

**which** : str, ['LM' | 'SM'], optional

Which  $k$  singular values to find:

- 'LM' : largest singular values
- 'SM' : smallest singular values

New in version 0.12.0.

**v0** : ndarray, optional

Starting vector for iteration, of length  $\min(A.shape)$ . Should be an (approximate) left singular vector if  $N > M$  and a right singular vector otherwise.

Default: random  
 New in version 0.12.0.

**maxiter** : int, optional  
 Maximum number of iterations.  
 New in version 0.12.0.

**return\_singular\_vectors** : bool or str, optional

- True: return singular vectors (True) in addition to singular values.

New in version 0.12.0.

- "u": only return the u matrix, without computing vh (if  $N > M$ ).
- "vh": only return the vh matrix, without computing u (if  $N \leq M$ ).

**Returns**

**u** : ndarray, shape=(M, k)  
 New in version 0.16.0.  
 Unitary matrix having left singular vectors as columns. If *return\_singular\_vectors* is "vh", this variable is not computed, and None is returned instead.

**s** : ndarray, shape=(k,)  
 The singular values.

**vt** : ndarray, shape=(k, N)  
 Unitary matrix having right singular vectors as rows. If *return\_singular\_vectors* is "u", this variable is not computed, and None is returned instead.

**Notes**

This is a naive implementation using ARPACK as an eigensolver on  $A.H * A$  or  $A * A.H$ , depending on which one is more efficient.

**Examples**

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import svds, eigs
>>> A = csc_matrix([[1, 0, 0], [5, 0, 2], [0, -1, 0], [0, 0, 3]], dtype=float)
>>> u, s, vt = svds(A, k=2)
>>> s
array([ 2.75193379,  5.6059665 ])
>>> np.sqrt(eigs(A.dot(A.T), k=2)[0]).real
array([ 5.6059665 ,  2.75193379])
```

Complete or incomplete LU factorizations

<code>splu(A[, permc_spec, diag_pivot_thresh, ...])</code>	Compute the LU decomposition of a sparse, square matrix.
<code>spilu(A[, drop_tol, fill_factor, drop_rule, ...])</code>	Compute an incomplete LU decomposition for a sparse, square matrix.
<i>SuperLU</i>	LU factorization of a sparse matrix.

`scipy.sparse.linalg.splu(A, permc_spec=None, diag_pivot_thresh=None, relax=None, panel_size=None, options={})`  
 Compute the LU decomposition of a sparse, square matrix.

**Parameters**

**A** : sparse matrix  
 Sparse matrix to factorize. Should be in CSR or CSC format.

**permc\_spec** : str, optional  
 How to permute the columns of the matrix for sparsity preservation. (default: 'COLAMD')

- **NATURAL**: natural ordering.
- **MMD\_ATA**: minimum degree ordering on the structure of  $A^T A$ .
- **MMD\_AT\_PLUS\_A**: minimum degree ordering on the structure of  $A^T A + A$ .
- **COLAMD**: approximate minimum degree column ordering

**diag\_pivot\_thresh** : float, optional

Threshold used for a diagonal entry to be an acceptable pivot. See SuperLU user's guide for details [R43]

**relax** : int, optional

Expert option for customizing the degree of relaxing supernodes. See SuperLU user's guide for details [R43]

**panel\_size** : int, optional

Expert option for customizing the panel size. See SuperLU user's guide for details [R43]

**options** : dict, optional

Dictionary containing additional expert options to SuperLU. See SuperLU user guide [R43] (section 2.4 on the 'Options' argument) for more details. For example, you can specify `options=dict(Equil=False, IterRefine='SINGLE')` to turn equilibration off and perform a single iterative refinement.

**Returns** **invA** : `scipy.sparse.linalg.SuperLU` Object, which has a `solve` method.

**See also:**

**spilu** incomplete LU decomposition

**Notes**

This function uses the SuperLU library.

**References**

[R43]

**Examples**

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import splu
>>> A = csc_matrix([[1., 0., 0.], [5., 0., 2.], [0., -1., 0.]], dtype=float)
>>> B = splu(A)
>>> x = np.array([1., 2., 3.], dtype=float)
>>> B.solve(x)
array([ 1. , -3. , -1.5])
>>> A.dot(B.solve(x))
array([ 1.,  2.,  3.])
>>> B.solve(A.dot(x))
array([ 1.,  2.,  3.])
```

`scipy.sparse.linalg.spilu`(*A*, *drop\_tol*=None, *fill\_factor*=None, *drop\_rule*=None, *permc\_spec*=None, *diag\_pivot\_thresh*=None, *relax*=None, *panel\_size*=None, *options*=None)

Compute an incomplete LU decomposition for a sparse, square matrix.

The resulting object is an approximation to the inverse of *A*.

**Parameters** **A** : (N, N) array\_like  
Sparse matrix to factorize  
**drop\_tol** : float, optional

Drop tolerance ( $0 \leq \text{tol} \leq 1$ ) for an incomplete LU decomposition. (default:  $1e-4$ )

**fill\_factor** : float, optional

Specifies the fill ratio upper bound ( $\geq 1.0$ ) for ILU. (default: 10)

**drop\_rule** : str, optional

Comma-separated string of drop rules to use. Available rules: `basic`, `prows`, `column`, `area`, `secondary`, `dynamic`, `interp`. (Default: `basic, area`)

See SuperLU documentation for details.

**Remaining other options**

**Returns** **invA\_approx** : Same as for `splu`, `scipy.sparse.linalg.SuperLU` Object, which has a `solve` method.

**See also:**

**splu** complete LU decomposition

**Notes**

To improve the better approximation to the inverse, you may need to increase `fill_factor` AND decrease `drop_tol`.

This function uses the SuperLU library.

**Examples**

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import splu
>>> A = csc_matrix([[1., 0., 0.], [5., 0., 2.], [0., -1., 0.]], dtype=float)
>>> B = splu(A)
>>> x = np.array([1., 2., 3.], dtype=float)
>>> B.solve(x)
array([ 1. , -3. , -1.5])
>>> A.dot(B.solve(x))
array([ 1.,  2.,  3.])
>>> B.solve(A.dot(x))
array([ 1.,  2.,  3.])
```

**class** `scipy.sparse.linalg.SuperLU`

LU factorization of a sparse matrix.

Factorization is represented as:

$$P_r * A * P_c = L * U$$

To construct these *SuperLU* objects, call the `splu` and `spilu` functions.

**Notes**

New in version 0.14.0.

**Examples**

The LU decomposition can be used to solve matrix equations. Consider:

```
>>> import numpy as np
>>> from scipy.sparse import csc_matrix, linalg as sla
>>> A = csc_matrix([[1,2,0,4],[1,0,0,1],[1,0,2,1],[2,2,1,0]])
```

This can be solved for a given right-hand side:

```

>>> lu = sla.splu(A)
>>> b = np.array([1, 2, 3, 4])
>>> x = lu.solve(b)
>>> A.dot(x)
array([ 1.,  2.,  3.,  4.])

```

The `lu` object also contains an explicit representation of the decomposition. The permutations are represented as mappings of indices:

```

>>> lu.perm_r
array([0, 2, 1, 3], dtype=int32)
>>> lu.perm_c
array([2, 0, 1, 3], dtype=int32)

```

The `L` and `U` factors are sparse matrices in `CSC` format:

```

>>> lu.L.A
array([[ 1.,  0.,  0.,  0.],
       [ 0.,  1.,  0.,  0.],
       [ 0.,  0.,  1.,  0.],
       [ 1.,  0.5,  0.5,  1.]])
>>> lu.U.A
array([[ 2.,  0.,  1.,  4.],
       [ 0.,  2.,  1.,  1.],
       [ 0.,  0.,  1.,  1.],
       [ 0.,  0.,  0., -5.]])

```

The permutation matrices can be constructed:

```

>>> Pr = csc_matrix((4, 4))
>>> Pr[lu.perm_r, np.arange(4)] = 1
>>> Pc = csc_matrix((4, 4))
>>> Pc[np.arange(4), lu.perm_c] = 1

```

We can reassemble the original matrix:

```

>>> (Pr.T * (lu.L * lu.U) * Pc.T).A
array([[ 1.,  2.,  0.,  4.],
       [ 1.,  0.,  0.,  1.],
       [ 1.,  0.,  2.,  1.],
       [ 2.,  2.,  1.,  0.]])

```

### Attributes

<code>shape</code>	Shape of the original matrix as a tuple of ints.
<code>nnz</code>	Number of nonzero elements in the matrix.
<code>perm_c</code>	Permutation <code>Pc</code> represented as an array of indices.
<code>perm_r</code>	Permutation <code>Pr</code> represented as an array of indices.
<code>L</code>	Lower triangular factor with unit diagonal as a <code>scipy.sparse.csc_matrix</code> .
<code>U</code>	Upper triangular factor as a <code>scipy.sparse.csc_matrix</code> .

### SuperLU.`shape`

Shape of the original matrix as a tuple of ints.



*Attributes*

eigenvalues	(ndarray) Partial result. Converged eigenvalues.
eigenvectors	(ndarray) Partial result. Converged eigenvectors.

**exception** `scipy.sparse.linalg.ArpackError` (*info*, *infodict*={*c*: {0: 'Normal exit.', 1: 'Maximum number of iterations taken. All possible eigenvalues of OP has been found. IPARAM(5) returns the number of wanted converged Ritz values.', 2: 'No longer an informational error. Deprecated starting with release 2 of ARPACK.', 3: 'No shifts could be applied during a cycle of the Implicitly restarted Arnoldi iteration. One possibility is to increase the size of NCV relative to NEV. ', -9999: 'Could not build an Arnoldi factorization. IPARAM(5) returns the size of the current Arnoldi factorization. The user is advised to check that enough workspace and array storage has been allocated.', -13: "NEV and WHICH = 'BE' are incompatible.", -12: 'IPARAM(1) must be equal to 0 or 1.', -1: 'N must be positive.', -10: 'IPARAM(7) must be 1, 2, 3.', -9: 'Starting vector is zero.', -8: 'Error return from LAPACK eigenvalue calculation;', -7: 'Length of private work array WORKL is not sufficient.', -6: "BMAT must be one of 'I' or 'G'."}, -5: " WHICH must be one of 'LM', 'SM', 'LR', 'SR', 'LI', 'SI'", -4: 'The maximum number of Arnoldi update iterations allowed must be greater than zero.', -3: 'NCV-NEV >= 2 and less than or equal to N.', -2: 'NEV must be positive.', -11: "IPARAM(7) = 1 and BMAT = 'G' are incompatible."}, *s*: {0: 'Normal exit.', 1: 'Maximum number of iterations taken. All possible eigenvalues of OP has been found. IPARAM(5) returns the number of wanted converged Ritz values.', 2: 'No longer an informational error. Deprecated starting with release 2 of ARPACK.', 3: 'No shifts could be applied during a cycle of the Implicitly restarted Arnoldi iteration. One possibility is to increase the size of NCV relative to NEV. ', -9999: 'Could not build an Arnoldi factorization. IPARAM(5) returns the size of the current Arnoldi factorization. The user is advised to check that enough workspace and array storage has been allocated.', -13: "NEV and WHICH = 'BE' are incompatible.", -12: 'IPARAM(1) must be equal to 0 or 1.', -2: 'NEV must be positive.', -10: 'IPARAM(7) must be 1, 2, 3, 4.', -9: 'Starting vector is zero.', -8: 'Error return from LAPACK eigenvalue calculation;', -7: 'Length of private work array WORKL is not sufficient.', -6: "BMAT must be one of 'I' or 'G'."}, -5: " WHICH must be one of 'LM', 'SM', 'LR', 'SR', 'LI', 'SI'", -4: 'The maximum number of Arnoldi update iterations allowed must be greater than zero.', -3: 'NCV-NEV >= 2 and less than or equal to N.', -1: 'N must be positive.', -11: "IPARAM(7) = 1 and BMAT = 'G' are incompatible."}, *z*: {0: 'Normal exit.', 1: 'Maximum number of iterations taken. All possible eigenvalues of OP has been found. IPARAM(5) returns the number of wanted converged Ritz values.', 2: 'No longer an informational error. Deprecated starting with release 2 of ARPACK.', 3: 'No shifts could be applied during a cycle of the Implicitly restarted Arnoldi iteration. One possibility is to increase the size of NCV relative to NEV. ', -9999: 'Could not build an Arnoldi factorization. IPARAM(5) returns the size

ARPACK error

**Functions**

<i>aslinearoperator</i> (A)	Return A as a LinearOperator.
<i>bicg</i> (A, b[, x0, tol, maxiter, M, callback])	Use BIConjugate Gradient iteration to solve $Ax = b$ .
<i>bicgstab</i> (A, b[, x0, tol, maxiter, M, callback])	Use BIConjugate Gradient STABILized iteration to solve $Ax = b$ .
<i>cg</i> (A, b[, x0, tol, maxiter, M, callback])	Use Conjugate Gradient iteration to solve $Ax = b$ .
<i>cgs</i> (A, b[, x0, tol, maxiter, M, callback])	Use Conjugate Gradient Squared iteration to solve $Ax = b$ .
<i>eigs</i> (A[, k, M, sigma, which, v0, ncv, ...])	Find k eigenvalues and eigenvectors of the square matrix A.
<i>eigsh</i> (A[, k, M, sigma, which, v0, ncv, ...])	Find k eigenvalues and eigenvectors of the real symmetric square matrix or complex hermitian matrix A.
<i>expm</i> (A)	Compute the matrix exponential using Pade approximation.
<i>expm_multiply</i> (A, B[, start, stop, num, endpoint])	Compute the action of the matrix exponential of A on B.
<i>factorized</i> (A)	Return a function for solving a sparse linear system, with A pre-factorized.
<i>gcrotmk</i> (A, b[, x0, tol, maxiter, M, ...])	Solve a matrix equation using flexible GCROT(m,k) algorithm.
<i>gmres</i> (A, b[, x0, tol, restart, maxiter, M, ...])	Use Generalized Minimal RESidual iteration to solve $Ax = b$ .
<i>inv</i> (A)	Compute the inverse of a sparse matrix
<i>lgmres</i> (A, b[, x0, tol, maxiter, M, ...])	Solve a matrix equation using the LGMRES algorithm.
<i>lobpcg</i> (A, X[, B, M, Y, tol, maxiter, ...])	Locally Optimal Block Preconditioned Conjugate Gradient Method (LOBPCG)
<i>lsmr</i> (A, b[, damp, atol, btol, conlim, ...])	Iterative solver for least-squares problems.
<i>lsqr</i> (A, b[, damp, atol, btol, conlim, ...])	Find the least-squares solution to a large, sparse, linear system of equations.
<i>minres</i> (A, b[, x0, shift, tol, maxiter, M, ...])	Use MINimum RESidual iteration to solve $Ax=b$
<i>norm</i> (x[, ord, axis])	Norm of a sparse matrix
<i>onenormest</i> (A[, t, itmax, compute_v, compute_w])	Compute a lower bound of the 1-norm of a sparse matrix.
<i>qmr</i> (A, b[, x0, tol, maxiter, M1, M2, callback])	Use Quasi-Minimal Residual iteration to solve $Ax = b$ .
<i>spilu</i> (A[, drop_tol, fill_factor, drop_rule, ...])	Compute an incomplete LU decomposition for a sparse, square matrix.
<i>splu</i> (A[, permc_spec, diag_pivot_thresh, ...])	Compute the LU decomposition of a sparse, square matrix.
<i>spsolve</i> (A, b[, permc_spec, use_umfpack])	Solve the sparse linear system $Ax=b$ , where b may be a vector or a matrix.
<i>spsolve_triangular</i> (A, b[, lower, ...])	Solve the equation $Ax = b$ for x, assuming A is a triangular matrix.
<i>svds</i> (A[, k, ncv, tol, which, v0, maxiter, ...])	Compute the largest k singular values/vectors for a sparse matrix.
<i>use_solver</i> (**kwargs)	Select default sparse direct solver to be used.

**Classes**

<i>LinearOperator</i> (dtype, shape)	Common interface for performing matrix vector products
<i>SuperLU</i>	LU factorization of a sparse matrix.

**Exceptions**

<code>ArpackError(info[, infodict])</code>	ARPACK error
<code>ArpackNoConvergence(msg, eigenvalues, ...)</code>	ARPACK iteration did not converge
<code>MatrixRankWarning</code>	

## Exceptions

<code>SparseEfficiencyWarning</code>
<code>SparseWarning</code>

**exception** `scipy.sparse.SparseEfficiencyWarning`

**exception** `scipy.sparse.SparseWarning`

## 5.21.2 Usage information

There are seven available sparse matrix types:

1. `csc_matrix`: Compressed Sparse Column format
2. `csr_matrix`: Compressed Sparse Row format
3. `bsr_matrix`: Block Sparse Row format
4. `lil_matrix`: List of Lists format
5. `dok_matrix`: Dictionary of Keys format
6. `coo_matrix`: COOrdinate format (aka IJV, triplet format)
7. `dia_matrix`: DIAgonal format

To construct a matrix efficiently, use either `dok_matrix` or `lil_matrix`. The `lil_matrix` class supports basic slicing and fancy indexing with a similar syntax to NumPy arrays. As illustrated below, the COO format may also be used to efficiently construct matrices. Despite their similarity to NumPy arrays, it is **strongly discouraged** to use NumPy functions directly on these matrices because NumPy may not properly convert them for computations, leading to unexpected (and incorrect) results. If you do want to apply a NumPy function to these matrices, first check if SciPy has its own implementation for the given sparse matrix class, or **convert the sparse matrix to a NumPy array** (e.g. using the `toarray()` method of the class) first before applying the method.

To perform manipulations such as multiplication or inversion, first convert the matrix to either CSC or CSR format. The `lil_matrix` format is row-based, so conversion to CSR is efficient, whereas conversion to CSC is less so.

All conversions among the CSR, CSC, and COO formats are efficient, linear-time operations.

### Matrix vector product

To do a vector product between a sparse matrix and a vector simply use the matrix `dot` method, as described in its docstring:

```
>>> import numpy as np
>>> from scipy.sparse import csr_matrix
>>> A = csr_matrix([[1, 2, 0], [0, 0, 3], [4, 0, 5]])
>>> v = np.array([1, 0, -1])
```

```
>>> A.dot(v)
array([ 1, -3, -1], dtype=int64)
```

**Warning:** As of NumPy 1.7, *np.dot* is not aware of sparse matrices, therefore using it will result on unexpected results or errors. The corresponding dense array should be obtained first instead:

```
>>> np.dot(A.toarray(), v)
array([ 1, -3, -1], dtype=int64)
```

but then all the performance advantages would be lost.

The CSR format is specially suitable for fast matrix vector products.

### Example 1

Construct a 1000x1000 `lil_matrix` and add some values to it:

```
>>> from scipy.sparse import lil_matrix
>>> from scipy.sparse.linalg import spsolve
>>> from numpy.linalg import solve, norm
>>> from numpy.random import rand
```

```
>>> A = lil_matrix((1000, 1000))
>>> A[0, :100] = rand(100)
>>> A[1, 100:200] = A[0, :100]
>>> A.setdiag(rand(1000))
```

Now convert it to CSR format and solve  $Ax = b$  for  $x$ :

```
>>> A = A.tocsr()
>>> b = rand(1000)
>>> x = spsolve(A, b)
```

Convert it to a dense matrix and solve, and check that the result is the same:

```
>>> x_ = solve(A.toarray(), b)
```

Now we can compute norm of the error with:

```
>>> err = norm(x-x_)
>>> err < 1e-10
True
```

It should be small :)

### Example 2

Construct a matrix in COO format:

```
>>> from scipy import sparse
>>> from numpy import array
>>> I = array([0,3,1,0])
>>> J = array([0,3,1,2])
```

```
>>> V = array([4, 5, 7, 9])
>>> A = sparse.coo_matrix((V, (I, J)), shape=(4, 4))
```

Notice that the indices do not need to be sorted.

Duplicate (i,j) entries are summed when converting to CSR or CSC.

```
>>> I = array([0, 0, 1, 3, 1, 0, 0])
>>> J = array([0, 2, 1, 3, 1, 0, 0])
>>> V = array([1, 1, 1, 1, 1, 1, 1])
>>> B = sparse.coo_matrix((V, (I, J)), shape=(4, 4)).tocsr()
```

This is useful for constructing finite-element stiffness and mass matrices.

### Further Details

CSR column indices are not necessarily sorted. Likewise for CSC row indices. Use the `.sorted_indices()` and `.sort_indices()` methods when sorted indices are required (e.g. when passing data to other libraries).

## 5.22 Sparse linear algebra (`scipy.sparse.linalg`)

### 5.22.1 Abstract linear operators

<code>LinearOperator(dtype, shape)</code>	Common interface for performing matrix vector products
<code>aslinearoperator(A)</code>	Return A as a LinearOperator.

**class** `scipy.sparse.linalg.LinearOperator` (*dtype, shape*)  
 Common interface for performing matrix vector products

Many iterative methods (e.g. `cg`, `gmres`) do not need to know the individual entries of a matrix to solve a linear system  $Ax=b$ . Such solvers only require the computation of matrix vector products,  $A*v$  where  $v$  is a dense vector. This class serves as an abstract interface between iterative solvers and matrix-like objects.

To construct a concrete `LinearOperator`, either pass appropriate callables to the constructor of this class, or subclass it.

A subclass must implement either one of the methods `_matvec` and `_matmat`, and the attributes/properties `shape` (pair of integers) and `dtype` (may be `None`). It may call the `__init__` on this class to have these attributes validated. Implementing `_matvec` automatically implements `_matmat` (using a naive algorithm) and vice-versa.

Optionally, a subclass may implement `_rmatvec` or `_adjoint` to implement the Hermitian adjoint (conjugate transpose). As with `_matvec` and `_matmat`, implementing either `_rmatvec` or `_adjoint` implements the other automatically. Implementing `_adjoint` is preferable; `_rmatvec` is mostly there for backwards compatibility.

- Parameters**
- shape** : tuple  
Matrix dimensions (M,N).
  - matvec** : callable `f(v)`  
Returns returns  $A * v$ .
  - rmatvec** : callable `f(v)`  
Returns  $A^H * v$ , where  $A^H$  is the conjugate transpose of  $A$ .
  - matmat** : callable `f(V)`

Returns  $A * V$ , where  $V$  is a dense matrix with dimensions  $(N,K)$ .

**dtype** : dtype

Data type of the matrix.

**See also:**

**aslinearoperator**

Construct LinearOperators

**Notes**

The user-defined `matvec()` function must properly handle the case where  $v$  has shape  $(N,)$  as well as the  $(N,1)$  case. The shape of the return type is handled internally by `LinearOperator`.

`LinearOperator` instances can also be multiplied, added with each other and exponentiated, all lazily: the result of these operations is always a new, composite `LinearOperator`, that defers linear operations to the original operators and combines the results.

**Examples**

```
>>> import numpy as np
>>> from scipy.sparse.linalg import LinearOperator
>>> def mv(v):
...     return np.array([2*v[0], 3*v[1]])
...
>>> A = LinearOperator((2,2), matvec=mv)
>>> A
<2x2 _CustomLinearOperator with dtype=float64>
>>> A.matvec(np.ones(2))
array([ 2.,  3.])
>>> A * np.ones(2)
array([ 2.,  3.])
```

**Attributes**

args	(tuple) For linear operators describing products etc. of other linear operators, the operands of the binary operation.
------	--

**Methods**

<code>__call__(x)</code>	
<code>adjoint()</code>	Hermitian adjoint.
<code>dot(x)</code>	Matrix-matrix or matrix-vector multiplication.
<code>matmat(X)</code>	Matrix-matrix multiplication.
<code>matvec(x)</code>	Matrix-vector multiplication.
<code>rmatvec(x)</code>	Adjoint matrix-vector multiplication.
<code>transpose()</code>	Transpose this linear operator.

`LinearOperator.__call__(x)`

`LinearOperator.adjoint()`

Hermitian adjoint.

Returns the Hermitian adjoint of self, aka the Hermitian conjugate or Hermitian transpose. For a complex matrix, the Hermitian adjoint is equal to the conjugate transpose.

Can be abbreviated `self.H` instead of `self.adjoint()`.

**Returns** **A\_H**: LinearOperator  
Hermitian adjoint of self.

LinearOperator.**dot**(x)

Matrix-matrix or matrix-vector multiplication.

**Parameters** **x**: array\_like

**Returns** **Ax**: array 1-d or 2-d array, representing a vector or matrix.

1-d or 2-d array (depending on the shape of x) that represents the result of applying this linear operator on x.

LinearOperator.**matmat**(X)

Matrix-matrix multiplication.

Performs the operation  $y=A*X$  where A is an  $M \times N$  linear operator and X dense  $N \times K$  matrix or ndarray.

**Parameters** **X**: {matrix, ndarray}

**Returns** **Y**: {matrix, ndarray} An array with shape (N,K).

A matrix or ndarray with shape (M,K) depending on the type of the X argument.

**Notes**

This matmat wraps any user-specified matmat routine or overridden `_matmat` method to ensure that y has the correct type.

LinearOperator.**matvec**(x)

Matrix-vector multiplication.

Performs the operation  $y=A*x$  where A is an  $M \times N$  linear operator and x is a column vector or 1-d array.

**Parameters** **x**: {matrix, ndarray}

**Returns** **y**: {matrix, ndarray} An array with shape (N,) or (N,1).

A matrix or ndarray with shape (M,) or (M,1) depending on the type and shape of the x argument.

**Notes**

This matvec wraps the user-specified matvec routine or overridden `_matvec` method to ensure that y has the correct shape and type.

LinearOperator.**rmatvec**(x)

Adjoint matrix-vector multiplication.

Performs the operation  $y = A^H * x$  where A is an  $M \times N$  linear operator and x is a column vector or 1-d array.

**Parameters** **x**: {matrix, ndarray}

**Returns** **y**: {matrix, ndarray} An array with shape (M,) or (M,1).

A matrix or ndarray with shape (N,) or (N,1) depending on the type and shape of the x argument.

**Notes**

This rmatvec wraps the user-specified rmatvec routine or overridden `_rmatvec` method to ensure that y has the correct shape and type.

LinearOperator.**transpose**()

Transpose this linear operator.

Returns a LinearOperator that represents the transpose of this one. Can be abbreviated self.T instead of self.transpose().

`scipy.sparse.linalg.aslinearoperator(A)`

Return A as a LinearOperator.

'A' may be any of the following types:

- ndarray
- matrix
- sparse matrix (e.g. csr\_matrix, lil\_matrix, etc.)
- LinearOperator
- An object with .shape and .matvec attributes

See the LinearOperator documentation for additional information.

### Examples

```
>>> from scipy.sparse.linalg import aslinearoperator
>>> M = np.array([[1,2,3],[4,5,6]], dtype=np.int32)
>>> aslinearoperator(M)
<2x3 MatrixLinearOperator with dtype=int32>
```

## 5.2.2.2 Matrix Operations

<code>inv(A)</code>	Compute the inverse of a sparse matrix
<code>expm(A)</code>	Compute the matrix exponential using Pade approximation.
<code>expm_multiply(A, B[, start, stop, num, endpoint])</code>	Compute the action of the matrix exponential of A on B.

`scipy.sparse.linalg.inv(A)`

Compute the inverse of a sparse matrix

**Parameters** A : (M,M) ndarray or sparse matrix

**Returns** Ainv : (M,M) ndarray or sparse matrix  
square matrix to be inverted  
inverse of A

### Notes

This computes the sparse inverse of A. If the inverse of A is expected to be non-sparse, it will likely be faster to convert A to dense and use `scipy.linalg.inv`.

### Examples

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import inv
>>> A = csc_matrix([[1., 0.], [1., 2.]])
>>> Ainv = inv(A)
>>> Ainv
<2x2 sparse matrix of type '<class 'numpy.float64''>'
  with 3 stored elements in Compressed Sparse Column format>
>>> A.dot(Ainv)
<2x2 sparse matrix of type '<class 'numpy.float64''>'
  with 2 stored elements in Compressed Sparse Column format>
>>> A.dot(Ainv).todense()
matrix([[ 1.,  0.],
        [ 0.,  1.]])
```

New in version 0.12.0.

`scipy.sparse.linalg.expm(A)`

Compute the matrix exponential using Pade approximation.

**Parameters** **A** : (M,M) array\_like or sparse matrix  
**Returns** **expA** : (M,M) ndarray  
 2D Array or Matrix (sparse or dense) to be exponentiated  
 Matrix exponential of A

**Notes**

This is algorithm (6.1) which is a simplification of algorithm (5.1).

New in version 0.12.0.

**References**

[R373]

**Examples**

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import expm
>>> A = csc_matrix([[1, 0, 0], [0, 2, 0], [0, 0, 3]])
>>> A.todense()
matrix([[1, 0, 0],
        [0, 2, 0],
        [0, 0, 3]], dtype=int64)
>>> Aexp = expm(A)
>>> Aexp
<3x3 sparse matrix of type '<class 'numpy.float64''>'
with 3 stored elements in Compressed Sparse Column format>
>>> Aexp.todense()
matrix([[ 2.71828183,  0.,  0.],
        [ 0.,  7.3890561,  0.],
        [ 0.,  0., 20.08553692]])
```

`scipy.sparse.linalg.expm_multiply(A, B, start=None, stop=None, num=None, endpoint=None)`

Compute the action of the matrix exponential of A on B.

**Parameters** **A** : transposable linear operator  
 The operator whose exponential is of interest.  
**B** : ndarray  
 The matrix or vector to be multiplied by the matrix exponential of A.  
**start** : scalar, optional  
 The starting time point of the sequence.  
**stop** : scalar, optional  
 The end time point of the sequence, unless *endpoint* is set to False. In that case, the sequence consists of all but the last of *num* + 1 evenly spaced time points, so that *stop* is excluded. Note that the step size changes when *endpoint* is False.  
**num** : int, optional  
 Number of time points to use.  
**endpoint** : bool, optional  
 If True, *stop* is the last time point. Otherwise, it is not included.  
**Returns** **expm\_A\_B** : ndarray  
 The result of the action  $e^{t_k A} B$ .

### Notes

The optional arguments defining the sequence of evenly spaced time points are compatible with the arguments of `numpy.linspace`.

The output ndarray shape is somewhat complicated so I explain it here. The ndim of the output could be either 1, 2, or 3. It would be 1 if you are computing the expm action on a single vector at a single time point. It would be 2 if you are computing the expm action on a vector at multiple time points, or if you are computing the expm action on a matrix at a single time point. It would be 3 if you want the action on a matrix with multiple columns at multiple time points. If multiple time points are requested, `expm_A_B[0]` will always be the action of the expm at the first time point, regardless of whether the action is on a vector or a matrix.

### References

[R374], [R375]

### Examples

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import expm, expm_multiply
>>> A = csc_matrix([[1, 0], [0, 1]])
>>> A.todense()
matrix([[1, 0],
        [0, 1]], dtype=int64)
>>> B = np.array([np.exp(-1.), np.exp(-2.)])
>>> B
array([ 0.36787944,  0.13533528])
>>> expm_multiply(A, B, start=1, stop=2, num=3, endpoint=True)
array([[ 1.          ,  0.36787944],
       [ 1.64872127,  0.60653066],
       [ 2.71828183,  1.          ]])
>>> expm(A).dot(B) # Verify 1st timestep
array([ 1.          ,  0.36787944])
>>> expm(1.5*A).dot(B) # Verify 2nd timestep
array([ 1.64872127,  0.60653066])
>>> expm(2*A).dot(B) # Verify 3rd timestep
array([ 2.71828183,  1.          ])
```

## 5.22.3 Matrix norms

<code>norm(x[, ord, axis])</code>	Norm of a sparse matrix
<code>onenormest(A[, t, itmax, compute_v, compute_w])</code>	Compute a lower bound of the 1-norm of a sparse matrix.

`scipy.sparse.linalg.norm(x, ord=None, axis=None)`

Norm of a sparse matrix

This function is able to return one of seven different matrix norms, depending on the value of the `ord` parameter.

**Parameters**

- x** : a sparse matrix  
Input sparse matrix.
- ord** : {non-zero int, inf, -inf, 'fro'}, optional  
Order of the norm (see table under `Notes`). `inf` means numpy's `inf` object.
- axis** : {int, 2-tuple of ints, None}, optional  
If `axis` is an integer, it specifies the axis of `x` along which to compute the vector norms. If `axis` is a 2-tuple, it specifies the axes that hold 2-D matrices, and the matrix norms of these matrices are computed. If `axis` is `None` then

either a vector norm (when  $x$  is 1-D) or a matrix norm (when  $x$  is 2-D) is returned.

**Returns**  $n$  : float or ndarray

**Notes**

Some of the ord are not implemented because some associated functions like, `_multi_svd_norm`, are not yet available for sparse matrix.

This docstring is modified based on `numpy.linalg.norm`. <https://github.com/numpy/numpy/blob/master/numpy/linalg/linalg.py>

The following norms can be calculated:

ord	norm for sparse matrices
None	Frobenius norm
'fro'	Frobenius norm
inf	<code>max(sum(abs(x), axis=1))</code>
-inf	<code>min(sum(abs(x), axis=1))</code>
0	<code>abs(x).sum(axis=axis)</code>
1	<code>max(sum(abs(x), axis=0))</code>
-1	<code>min(sum(abs(x), axis=0))</code>
2	Not implemented
-2	Not implemented
other	Not implemented

The Frobenius norm is given by [R389]:

$$\|A\|_F = [\sum_{i,j} abs(a_{i,j})^2]^{1/2}$$

**References**

[R389]

**Examples**

```
>>> from scipy.sparse import *
>>> import numpy as np
>>> from scipy.sparse.linalg import norm
>>> a = np.arange(9) - 4
>>> a
array([-4, -3, -2, -1, 0, 1, 2, 3, 4])
>>> b = a.reshape((3, 3))
>>> b
array([[ -4,  -3,  -2],
       [ -1,   0,   1],
       [  2,   3,   4]])
```

```
>>> b = csr_matrix(b)
>>> norm(b)
7.745966692414834
>>> norm(b, 'fro')
7.745966692414834
>>> norm(b, np.inf)
9
>>> norm(b, -np.inf)
2
>>> norm(b, 1)
7
```

```
>>> norm(b, -1)
6
```

`scipy.sparse.linalg.onenormest` (*A*, *t*=2, *itmax*=5, *compute\_v*=False, *compute\_w*=False)  
 Compute a lower bound of the 1-norm of a sparse matrix.

**Parameters**

- A** : ndarray or other linear operator  
 A linear operator that can be transposed and that can produce matrix products.
- t** : int, optional  
 A positive parameter controlling the tradeoff between accuracy versus time and memory usage. Larger values take longer and use more memory but give more accurate output.
- itmax** : int, optional  
 Use at most this many iterations.
- compute\_v** : bool, optional  
 Request a norm-maximizing linear operator input vector if True.
- compute\_w** : bool, optional  
 Request a norm-maximizing linear operator output vector if True.

**Returns**

- est** : float  
 An underestimate of the 1-norm of the sparse matrix.
- v** : ndarray, optional  
 The vector such that  $\|Av\|_1 == est * \|v\|_1$ . It can be thought of as an input to the linear operator that gives an output with particularly large norm.
- w** : ndarray, optional  
 The vector  $Av$  which has relatively large 1-norm. It can be thought of as an output of the linear operator that is relatively large in norm compared to the input.

### Notes

This is algorithm 2.4 of [1].

In [2] it is described as follows. “This algorithm typically requires the evaluation of about  $4t$  matrix-vector products and almost invariably produces a norm estimate (which is, in fact, a lower bound on the norm) correct to within a factor 3.”

New in version 0.13.0.

### References

[R390], [R391]

### Examples

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import onenormest
>>> A = csc_matrix([[1., 0., 0.], [5., 8., 2.], [0., -1., 0.]], dtype=float)
>>> A.todense()
matrix([[ 1.,  0.,  0.],
        [ 5.,  8.,  2.],
        [ 0., -1.,  0.]])
>>> onenormest(A)
9.0
>>> np.linalg.norm(A.todense(), ord=1)
9.0
```

## 5.22.4 Solving linear problems

Direct methods for linear equation systems:

<code>spsolve(A, b[, permc_spec, use_umfpack])</code>	Solve the sparse linear system $Ax=b$ , where $b$ may be a vector or a matrix.
<code>spsolve_triangular(A, b[, lower, ...])</code>	Solve the equation $Ax = b$ for $x$ , assuming $A$ is a triangular matrix.
<code>factorized(A)</code>	Return a function for solving a sparse linear system, with $A$ pre-factorized.
<code>MatrixRankWarning</code>	
<code>use_solver(**kwargs)</code>	Select default sparse direct solver to be used.

`scipy.sparse.linalg.spsolve(A, b, permc_spec=None, use_umfpack=True)`

Solve the sparse linear system  $Ax=b$ , where  $b$  may be a vector or a matrix.

**Parameters**

- A** : ndarray or sparse matrix  
The square matrix  $A$  will be converted into CSC or CSR form
- b** : ndarray or sparse matrix  
The matrix or vector representing the right hand side of the equation. If a vector,  $b.shape$  must be  $(n,)$  or  $(n, 1)$ .
- permc\_spec** : str, optional  
How to permute the columns of the matrix for sparsity preservation. (default: 'COLAMD')
  - NATURAL: natural ordering.
  - MMD\_ATA: minimum degree ordering on the structure of  $A^T A$ .
  - MMD\_AT\_PLUS\_A: minimum degree ordering on the structure of  $A^T + A$ .
  - COLAMD: approximate minimum degree column ordering
- use\_umfpack** : bool, optional  
if True (default) then use umfpack for the solution. This is only referenced if  $b$  is a vector and `scikit-umfpack` is installed.

**Returns**

- x** : ndarray or sparse matrix  
the solution of the sparse linear equation. If  $b$  is a vector, then  $x$  is a vector of size  $A.shape[1]$  If  $b$  is a matrix, then  $x$  is a matrix of size  $(A.shape[1], b.shape[1])$

### Notes

For solving the matrix expression  $AX = B$ , this solver assumes the resulting matrix  $X$  is sparse, as is often the case for very sparse inputs. If the resulting  $X$  is dense, the construction of this sparse result will be relatively expensive. In that case, consider converting  $A$  to a dense matrix and using `scipy.linalg.solve` or its variants.

### Examples

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import spsolve
>>> A = csc_matrix([[3, 2, 0], [1, -1, 0], [0, 5, 1]], dtype=float)
>>> B = csc_matrix([[2, 0], [-1, 0], [2, 0]], dtype=float)
>>> x = spsolve(A, B)
>>> np.allclose(A.dot(x).todense(), B.todense())
True
```

`scipy.sparse.linalg.spsolve_triangular(A, b, lower=True, overwrite_A=False, overwrite_b=False)`

Solve the equation  $Ax = b$  for  $x$ , assuming  $A$  is a triangular matrix.

**Parameters**

- A** : (M, M) sparse matrix  
A sparse square triangular matrix. Should be in CSR format.
- b** : (M,) or (M, N) array\_like  
Right-hand side matrix in  $A x = b$
- lower** : bool, optional  
Whether *A* is a lower or upper triangular matrix. Default is lower triangular matrix.
- overwrite\_A** : bool, optional  
Allow changing *A*. The indices of *A* are going to be sorted and zero entries are going to be removed. Enabling gives a performance gain. Default is False.
- overwrite\_b** : bool, optional  
Allow overwriting data in *b*. Enabling gives a performance gain. Default is False. If *overwrite\_b* is True, it should be ensured that *b* has an appropriate dtype to be able to store the result.

**Returns** **x** : (M,) or (M, N) ndarray  
Solution to the system  $A x = b$ . Shape of return matches shape of *b*.

**Raises**

- LinAlgError**  
If *A* is singular or not triangular.
- ValueError**  
If shape of *A* or shape of *b* do not match the requirements.

**Notes**

New in version 0.19.0.

**Examples**

```
>>> from scipy.sparse import csr_matrix
>>> from scipy.sparse.linalg import spsolve_triangular
>>> A = csr_matrix([[3, 0, 0], [1, -1, 0], [2, 0, 1]], dtype=float)
>>> B = np.array([[2, 0], [-1, 0], [2, 0]], dtype=float)
>>> x = spsolve_triangular(A, B)
>>> np.allclose(A.dot(x), B)
True
```

`scipy.sparse.linalg.factorized(A)`

Return a function for solving a sparse linear system, with *A* pre-factorized.

**Parameters** **A** : (N, N) array\_like  
Input.

**Returns** **solve** : callable  
To solve the linear system of equations given in *A*, the *solve* callable should be passed an ndarray of shape (N,).

**Examples**

```
>>> from scipy.sparse.linalg import factorized
>>> A = np.array([[ 3. ,  2. , -1. ],
...              [ 2. , -2. ,  4. ],
...              [-1. ,  0.5, -1. ]])
>>> solve = factorized(A) # Makes LU decomposition.
>>> rhs1 = np.array([1, -2, 0])
>>> solve(rhs1) # Uses the LU factors.
array([ 1., -2., -2.])
```

exception `scipy.sparse.linalg.MatrixRankWarning`

`scipy.sparse.linalg.use_solver(**kwargs)`

Select default sparse direct solver to be used.

**Parameters**

- useUmfpack** : bool, optional  
Use UMFPACK over SuperLU. Has effect only if scikits.umfpack is installed. Default: True
- assumeSortedIndices** : bool, optional  
Allow UMFPACK to skip the step of sorting indices for a CSR/CSC matrix. Has effect only if useUmfpack is True and scikits.umfpack is installed. Default: False

**Notes**

The default sparse solver is umfpack when available (scikits.umfpack is installed). This can be changed by passing `useUmfpack = False`, which then causes the always present SuperLU based solver to be used.

Umfpack requires a CSR/CSC matrix to have sorted column/row indices. If sure that the matrix fulfills this, pass `assumeSortedIndices=True` to gain some speed.

Iterative methods for linear equation systems:

<code>bicg(A, b[, x0, tol, maxiter, M, callback])</code>	Use BIConjugate Gradient iteration to solve $Ax = b$ .
<code>bicgstab(A, b[, x0, tol, maxiter, M, callback])</code>	Use BIConjugate Gradient STABILized iteration to solve $Ax = b$ .
<code>cg(A, b[, x0, tol, maxiter, M, callback])</code>	Use Conjugate Gradient iteration to solve $Ax = b$ .
<code>cgs(A, b[, x0, tol, maxiter, M, callback])</code>	Use Conjugate Gradient Squared iteration to solve $Ax = b$ .
<code>gmres(A, b[, x0, tol, restart, maxiter, M, ...])</code>	Use Generalized Minimal RESidual iteration to solve $Ax = b$ .
<code>lgmres(A, b[, x0, tol, maxiter, M, ...])</code>	Solve a matrix equation using the LGMRES algorithm.
<code>minres(A, b[, x0, shift, tol, maxiter, M, ...])</code>	Use MINimum RESidual iteration to solve $Ax=b$
<code>qmr(A, b[, x0, tol, maxiter, M1, M2, callback])</code>	Use Quasi-Minimal Residual iteration to solve $Ax = b$ .
<code>gcrotmk(A, b[, x0, tol, maxiter, M, ...])</code>	Solve a matrix equation using flexible GCROT(m,k) algorithm.

`scipy.sparse.linalg.bicg(A, b, x0=None, tol=1e-05, maxiter=None, M=None, callback=None)`

Use BIConjugate Gradient iteration to solve  $Ax = b$ .

**Parameters**

- A** : {sparse matrix, dense matrix, LinearOperator}  
The real or complex N-by-N matrix of the linear system. It is required that the linear operator can produce  $Ax$  and  $A^T x$ .
- b** : {array, matrix}  
Right hand side of the linear system. Has shape (N,) or (N,1).

**Returns**

- x** : {array, matrix}  
The converged solution.
- info** : integer

**Provides convergence information:**

0 : successful exit >0 : convergence to tolerance not achieved, number of iterations <0 : illegal input or breakdown

**Other Parameters**

- x0** : {array, matrix}  
Starting guess for the solution.
- tol** : float  
Tolerance to achieve. The algorithm terminates when either the relative or the absolute residual is below `tol`.
- maxiter** : integer

Maximum number of iterations. Iteration will stop after `maxiter` steps even if the specified tolerance has not been achieved.

**M** : {sparse matrix, dense matrix, LinearOperator}

Preconditioner for A. The preconditioner should approximate the inverse of A. Effective preconditioning dramatically improves the rate of convergence, which implies that fewer iterations are needed to reach a given error tolerance.

**callback** : function

User-supplied function to call after each iteration. It is called as `callback(xk)`, where `xk` is the current solution vector.

`scipy.sparse.linalg.bicgstab(A, b, x0=None, tol=1e-05, maxiter=None, M=None, callback=None)`

Use BIConjugate Gradient STABILized iteration to solve  $Ax = b$ .

**Parameters** **A** : {sparse matrix, dense matrix, LinearOperator}

The real or complex N-by-N matrix of the linear system.

**b** : {array, matrix}

**Returns** **x** : {array, matrix} Right hand side of the linear system. Has shape (N,) or (N,1).

The converged solution.

**info** : integer

**Provides convergence information:**

0 : successful exit >0 : convergence to tolerance not achieved, number of iterations <0 : illegal input or breakdown

**Other Parameters**

**x0** : {array, matrix}

Starting guess for the solution.

**tol** : float

Tolerance to achieve. The algorithm terminates when either the relative or the absolute residual is below `tol`.

**maxiter** : integer

Maximum number of iterations. Iteration will stop after `maxiter` steps even if the specified tolerance has not been achieved.

**M** : {sparse matrix, dense matrix, LinearOperator}

Preconditioner for A. The preconditioner should approximate the inverse of A. Effective preconditioning dramatically improves the rate of convergence, which implies that fewer iterations are needed to reach a given error tolerance.

**callback** : function

User-supplied function to call after each iteration. It is called as `callback(xk)`, where `xk` is the current solution vector.

`scipy.sparse.linalg.cg(A, b, x0=None, tol=1e-05, maxiter=None, M=None, callback=None)`

Use Conjugate Gradient iteration to solve  $Ax = b$ .

**Parameters** **A** : {sparse matrix, dense matrix, LinearOperator}

The real or complex N-by-N matrix of the linear system. A must represent a hermitian, positive definite matrix.

**b** : {array, matrix}

**Returns** **x** : {array, matrix} Right hand side of the linear system. Has shape (N,) or (N,1).

The converged solution.

**info** : integer

**Provides convergence information:**

0 : successful exit >0 : convergence to tolerance not

achieved, number of iterations <0 : illegal input or break-down

**Other Parameters**

- x0** : {array, matrix}  
Starting guess for the solution.
- tol** : float  
Tolerance to achieve. The algorithm terminates when either the relative or the absolute residual is below *tol*.
- maxiter** : integer  
Maximum number of iterations. Iteration will stop after maxiter steps even if the specified tolerance has not been achieved.
- M** : {sparse matrix, dense matrix, LinearOperator}  
Preconditioner for A. The preconditioner should approximate the inverse of A. Effective preconditioning dramatically improves the rate of convergence, which implies that fewer iterations are needed to reach a given error tolerance.
- callback** : function  
User-supplied function to call after each iteration. It is called as callback(xk), where xk is the current solution vector.

`scipy.sparse.linalg.cgs` (*A*, *b*, *x0=None*, *tol=1e-05*, *maxiter=None*, *M=None*, *callback=None*)

Use Conjugate Gradient Squared iteration to solve  $Ax = b$ .

**Parameters** **A** : {sparse matrix, dense matrix, LinearOperator}  
The real-valued N-by-N matrix of the linear system.

**b** : {array, matrix}

**Returns** **x** : {array, matrix} Right hand side of the linear system. Has shape (N,) or (N,1).

The converged solution.

**info** : integer

**Provides convergence information:**

0 : successful exit >0 : convergence to tolerance not achieved, number of iterations <0 : illegal input or break-down

**Other Parameters**

- x0** : {array, matrix}  
Starting guess for the solution.
- tol** : float  
Tolerance to achieve. The algorithm terminates when either the relative or the absolute residual is below *tol*.
- maxiter** : integer  
Maximum number of iterations. Iteration will stop after maxiter steps even if the specified tolerance has not been achieved.
- M** : {sparse matrix, dense matrix, LinearOperator}  
Preconditioner for A. The preconditioner should approximate the inverse of A. Effective preconditioning dramatically improves the rate of convergence, which implies that fewer iterations are needed to reach a given error tolerance.
- callback** : function  
User-supplied function to call after each iteration. It is called as callback(xk), where xk is the current solution vector.

`scipy.sparse.linalg.gmres` (*A*, *b*, *x0=None*, *tol=1e-05*, *restart=None*, *maxiter=None*, *M=None*, *callback=None*, *restrt=None*)

Use Generalized Minimal RESidual iteration to solve  $Ax = b$ .

**Parameters** **A** : {sparse matrix, dense matrix, LinearOperator}  
The real or complex N-by-N matrix of the linear system.

**Returns**

**b** : {array, matrix}  
Right hand side of the linear system. Has shape (N,) or (N,1).

**x** : {array, matrix}  
The converged solution.

**info** : int  
*Provides convergence information:*

- 0 : successful exit
- >0 : convergence to tolerance not achieved, number of iterations
- <0 : illegal input or breakdown

**Other Parameters**

**x0** : {array, matrix}  
Starting guess for the solution (a vector of zeros by default).

**tol** : float  
Tolerance to achieve. The algorithm terminates when either the relative or the absolute residual is below *tol*.

**restart** : int, optional  
Number of iterations between restarts. Larger values increase iteration cost, but may be necessary for convergence. Default is 20.

**maxiter** : int, optional  
Maximum number of iterations (restart cycles). Iteration will stop after *maxiter* steps even if the specified tolerance has not been achieved.

**M** : {sparse matrix, dense matrix, LinearOperator}  
Inverse of the preconditioner of A. M should approximate the inverse of A and be easy to solve for (see Notes). Effective preconditioning dramatically improves the rate of convergence, which implies that fewer iterations are needed to reach a given error tolerance. By default, no preconditioner is used.

**callback** : function  
User-supplied function to call after each iteration. It is called as `callback(rk)`, where *rk* is the current residual vector.

**restrt** : int, optional  
DEPRECATED - use *restart* instead.

**See also:***LinearOperator***Notes**

A preconditioner, *P*, is chosen such that *P* is close to *A* but easy to solve for. The preconditioner parameter required by this routine is  $M = P^{-1}$ . The inverse should preferably not be calculated explicitly. Rather, use the following template to produce *M*:

```
# Construct a linear operator that computes  $P^{-1} * x$ .
import scipy.sparse.linalg as spla
M_x = lambda x: spla.spsolve(P, x)
M = spla.LinearOperator((n, n), M_x)
```

**Examples**

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import gmres
>>> A = csc_matrix([[3, 2, 0], [1, -1, 0], [0, 5, 1]], dtype=float)
>>> b = np.array([2, 4, -1], dtype=float)
>>> x, exitCode = gmres(A, b)
```

```
>>> print(exitCode)           # 0 indicates successful convergence
0
>>> np.allclose(A.dot(x), b)
True
```

`scipy.sparse.linalg.lgmres` (*A*, *b*, *x0=None*, *tol=1e-05*, *maxiter=1000*, *M=None*, *callback=None*, *inner\_m=30*, *outer\_k=3*, *outer\_v=None*, *store\_outer\_Av=True*, *prepend\_outer\_v=False*)

Solve a matrix equation using the LGMRES algorithm.

The LGMRES algorithm [R379] [R380] is designed to avoid some problems in the convergence in restarted GMRES, and often converges in fewer iterations.

**Parameters**

- A** : {sparse matrix, dense matrix, LinearOperator}
 

The real or complex N-by-N matrix of the linear system.
- b** : {array, matrix}
 

Right hand side of the linear system. Has shape (N,) or (N,1).
- x0** : {array, matrix}
 

Starting guess for the solution.
- tol** : float, optional
 

Tolerance to achieve. The algorithm terminates when either the relative or the absolute residual is below *tol*.
- maxiter** : int, optional
 

Maximum number of iterations. Iteration will stop after *maxiter* steps even if the specified tolerance has not been achieved.
- M** : {sparse matrix, dense matrix, LinearOperator}, optional
 

Preconditioner for A. The preconditioner should approximate the inverse of A. Effective preconditioning dramatically improves the rate of convergence, which implies that fewer iterations are needed to reach a given error tolerance.
- callback** : function, optional
 

User-supplied function to call after each iteration. It is called as `callback(xk)`, where *xk* is the current solution vector.
- inner\_m** : int, optional
 

Number of inner GMRES iterations per each outer iteration.
- outer\_k** : int, optional
 

Number of vectors to carry between inner GMRES iterations. According to [R379], good values are in the range of 1...3. However, note that if you want to use the additional vectors to accelerate solving multiple similar problems, larger values may be beneficial.
- outer\_v** : list of tuples, optional
 

List containing tuples (*v*, *Av*) of vectors and corresponding matrix-vector products, used to augment the Krylov subspace, and carried between inner GMRES iterations. The element *Av* can be *None* if the matrix-vector product should be re-evaluated. This parameter is modified in-place by *lgmres*, and can be used to pass “guess” vectors in and out of the algorithm when solving similar problems.
- store\_outer\_Av** : bool, optional
 

Whether LGMRES should store also  $A*v$  in addition to vectors *v* in the *outer\_v* list. Default is True.
- prepend\_outer\_v** : bool, optional
 

Whether to put *outer\_v* augmentation vectors before Krylov iterates. In standard LGMRES, `prepend_outer_v=False`.

**Returns**

- x** : array or matrix
 

The converged solution.

**info** : int

Provides convergence information:

- 0 : successful exit
- >0 : convergence to tolerance not achieved, number of iterations
- <0 : illegal input or breakdown

**Notes**

The LGMRES algorithm [R379] [R380] is designed to avoid the slowing of convergence in restarted GMRES, due to alternating residual vectors. Typically, it often outperforms GMRES(m) of comparable memory requirements by some measure, or at least is not much worse.

Another advantage in this algorithm is that you can supply it with ‘guess’ vectors in the *outer\_v* argument that augment the Krylov subspace. If the solution lies close to the span of these vectors, the algorithm converges faster. This can be useful if several very similar matrices need to be inverted one after another, such as in Newton-Krylov iteration where the Jacobian matrix often changes little in the nonlinear steps.

**References**

[R379], [R380]

**Examples**

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import lgmres
>>> A = csc_matrix([[3, 2, 0], [1, -1, 0], [0, 5, 1]], dtype=float)
>>> b = np.array([2, 4, -1], dtype=float)
>>> x, exitCode = lgmres(A, b)
>>> print(exitCode)           # 0 indicates successful convergence
0
>>> np.allclose(A.dot(x), b)
True
```

`scipy.sparse.linalg.minres` (*A*, *b*, *x0=None*, *shift=0.0*, *tol=1e-05*, *maxiter=None*, *M=None*, *callback=None*, *show=False*, *check=False*)

Use MINimum RESidual iteration to solve  $Ax=b$ 

MINRES minimizes  $\text{norm}(A*x - b)$  for a real symmetric matrix *A*. Unlike the Conjugate Gradient method, *A* can be indefinite or singular.

If *shift* != 0 then the method solves  $(A - \text{shift}*I)x = b$ **Parameters** *A* : {sparse matrix, dense matrix, LinearOperator}

The real symmetric N-by-N matrix of the linear system

*b* : {array, matrix}

Right hand side of the linear system. Has shape (N,) or (N,1).

**Returns** *x* : {array, matrix}

The converged solution.

**info** : integer**Provides convergence information:**

- 0 : successful exit
- >0 : convergence to tolerance not achieved, number of iterations
- <0 : illegal input or breakdown

**Other Parameters***x0* : {array, matrix}

Starting guess for the solution.

*tol* : floatTolerance to achieve. The algorithm terminates when either the relative or the absolute residual is below *tol*.

**maxiter** : integer

Maximum number of iterations. Iteration will stop after maxiter steps even if the specified tolerance has not been achieved.

**M** : {sparse matrix, dense matrix, LinearOperator}

Preconditioner for A. The preconditioner should approximate the inverse of A. Effective preconditioning dramatically improves the rate of convergence, which implies that fewer iterations are needed to reach a given error tolerance.

**callback** : function

User-supplied function to call after each iteration. It is called as `callback(xk)`, where `xk` is the current solution vector.

*Notes*

THIS FUNCTION IS EXPERIMENTAL AND SUBJECT TO CHANGE!

*References*

*Solution of sparse indefinite systems of linear equations,*

C. C. Paige and M. A. Saunders (1975), SIAM J. Numer. Anal. 12(4), pp. 617-629. <https://web.stanford.edu/group/SOL/software/minres/>

*This file is a translation of the following MATLAB implementation:*

<https://web.stanford.edu/group/SOL/software/minres/minres-matlab.zip>

`scipy.sparse.linalg.qmr(A, b, x0=None, tol=1e-05, maxiter=None, M1=None, M2=None, callback=None)`

Use Quasi-Minimal Residual iteration to solve  $Ax = b$ .

**Parameters** **A** : {sparse matrix, dense matrix, LinearOperator}

The real-valued N-by-N matrix of the linear system. It is required that the linear operator can produce  $Ax$  and  $A^T x$ .

**b** : {array, matrix}

Right hand side of the linear system. Has shape (N,) or (N,1).

**Returns** **x** : {array, matrix}

The converged solution.

**info** : integer

*Provides convergence information:*

0 : successful exit >0 : convergence to tolerance not achieved, number of iterations <0 : illegal input or breakdown

*Other Parameters*

**x0** : {array, matrix}

Starting guess for the solution.

**tol** : float

Tolerance to achieve. The algorithm terminates when either the relative or the absolute residual is below *tol*.

**maxiter** : integer

Maximum number of iterations. Iteration will stop after maxiter steps even if the specified tolerance has not been achieved.

**M1** : {sparse matrix, dense matrix, LinearOperator}

Left preconditioner for A.

**M2** : {sparse matrix, dense matrix, LinearOperator}

Right preconditioner for A. Used together with the left preconditioner M1. The matrix  $M1 * A * M2$  should have better conditioned than A alone.

**callback** : function

User-supplied function to call after each iteration. It is called as `callback(xk)`, where `xk` is the current solution vector.

See also:

*LinearOperator*

**Examples**

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import qmr
>>> A = csc_matrix([[3, 2, 0], [1, -1, 0], [0, 5, 1]], dtype=float)
>>> b = np.array([2, 4, -1], dtype=float)
>>> x, exitCode = qmr(A, b)
>>> print(exitCode)           # 0 indicates successful convergence
0
>>> np.allclose(A.dot(x), b)
True
```

`scipy.sparse.linalg.gcrotmk` (*A*, *b*, *x0=None*, *tol=1e-05*, *maxiter=1000*, *M=None*, *callback=None*, *m=20*, *k=None*, *CU=None*, *discard\_C=False*, *truncate='oldest'*)  
Solve a matrix equation using flexible GCROT(m,k) algorithm.

**Parameters**

- A** : {sparse matrix, dense matrix, LinearOperator}  
The real or complex N-by-N matrix of the linear system.
- b** : {array, matrix}  
Right hand side of the linear system. Has shape (N,) or (N,1).
- x0** : {array, matrix}  
Starting guess for the solution.
- tol** : float, optional  
Tolerance to achieve. The algorithm terminates when either the relative or the absolute residual is below *tol*.
- maxiter** : int, optional  
Maximum number of iterations. Iteration will stop after *maxiter* steps even if the specified tolerance has not been achieved.
- M** : {sparse matrix, dense matrix, LinearOperator}, optional  
Preconditioner for A. The preconditioner should approximate the inverse of A. `gcrotmk` is a ‘flexible’ algorithm and the preconditioner can vary from iteration to iteration. Effective preconditioning dramatically improves the rate of convergence, which implies that fewer iterations are needed to reach a given error tolerance.
- callback** : function, optional  
User-supplied function to call after each iteration. It is called as `callback(xk)`, where *xk* is the current solution vector.
- m** : int, optional  
Number of inner FGMRES iterations per each outer iteration. Default: 20
- k** : int, optional  
Number of vectors to carry between inner FGMRES iterations. According to [R377], good values are around *m*. Default: *m*
- CU** : list of tuples, optional  
List of tuples (*c*, *u*) which contain the columns of the matrices C and U in the GCROT(m,k) algorithm. For details, see [R377]. The list given and vectors contained in it are modified in-place. If not given, start from empty matrices. The *c* elements in the tuples can be `None`, in which case the vectors are recomputed via  $c = A u$  on start and orthogonalized as described in [R378].
- discard\_C** : bool, optional  
Discard the C-vectors at the end. Useful if recycling Krylov subspaces for different linear systems.

**truncate** : { 'oldest', 'smallest' }, optional  
 Truncation scheme to use. Drop: oldest vectors, or vectors with smallest singular values using the scheme discussed in [1,2]. See [R377] for detailed comparison. Default: 'oldest'

**Returns** **x** : array or matrix  
 The solution found.

**info** : int  
 Provides convergence information:  
 •0 : successful exit  
 •>0 : convergence to tolerance not achieved, number of iterations

**References**

[R376], [R377], [R378]

Iterative methods for least-squares problems:

<code>lsqr(A, b[, damp, atol, btol, conlim, ...])</code>	Find the least-squares solution to a large, sparse, linear system of equations.
<code>lsmr(A, b[, damp, atol, btol, conlim, ...])</code>	Iterative solver for least-squares problems.

`scipy.sparse.linalg.lsqr(A, b, damp=0.0, atol=1e-08, btol=1e-08, conlim=100000000.0, iter_lim=None, show=False, calc_var=False, x0=None)`

Find the least-squares solution to a large, sparse, linear system of equations.

The function solves  $Ax = b$  or  $\min ||b - Ax||^2$  or  $\min ||Ax - b||^2 + d^2 ||x||^2$ .

The matrix A may be square or rectangular (over-determined or under-determined), and may have any rank.

```

1. Unsymmetric equations -- solve A*x = b
2. Linear least squares -- solve A*x = b
                           in the least-squares sense
3. Damped least squares -- solve ( A ) * x = ( b )
                           ( damp*I ) ( 0 )
                           in the least-squares sense
    
```

**Parameters** **A** : {sparse matrix, ndarray, LinearOperator}  
 Representation of an m-by-n matrix. It is required that the linear operator can produce Ax and A^T x.

**b** : array\_like, shape (m,)  
 Right-hand side vector b.

**damp** : float  
 Damping coefficient.

**atol, btol** : float, optional  
 Stopping tolerances. If both are 1.0e-9 (say), the final residual norm should be accurate to about 9 digits. (The final x will usually have fewer correct digits, depending on cond(A) and the size of damp.)

**conlim** : float, optional  
 Another stopping tolerance. lsqr terminates if an estimate of cond(A) exceeds conlim. For compatible systems Ax = b, conlim could be as large as 1.0e+12 (say). For least-squares problems, conlim should be less than 1.0e+8. Maximum precision can be obtained by setting atol = btol = conlim = zero, but the number of iterations may then be excessive.

**iter\_lim** : int, optional

Explicit limitation on number of iterations (for safety).

**show** : bool, optional  
Display an iteration log.

**calc\_var** : bool, optional  
Whether to estimate diagonals of  $(A'A + \text{damp}^2 * I)^{-1}$ .

**x0** : array\_like, shape (n,), optional  
Initial guess of x, if None zeros are used.

**Returns** **x** : ndarray of float  
New in version 1.0.0.  
The final solution.

**istop** : int  
Gives the reason for termination. 1 means x is an approximate solution to  $Ax = b$ . 2 means x approximately solves the least-squares problem.

**itn** : int  
Iteration number upon termination.

**r1norm** : float  
 $\text{norm}(r)$ , where  $r = b - Ax$ .

**r2norm** : float  
 $\sqrt{\text{norm}(r)^2 + \text{damp}^2 * \text{norm}(x)^2}$ . Equal to *r1norm* if  $\text{damp} == 0$ .

**anorm** : float  
Estimate of Frobenius norm of  $A_{\text{bar}} = \begin{bmatrix} A \\ \text{damp} * I \end{bmatrix}$ .

**acond** : float  
Estimate of  $\text{cond}(A_{\text{bar}})$ .

**arnorm** : float  
Estimate of  $\text{norm}(A' * r - \text{damp}^2 * x)$ .

**xnorm** : float  
 $\text{norm}(x)$

**var** : ndarray of float  
If **calc\_var** is True, estimates all diagonals of  $(A'A)^{-1}$  (if  $\text{damp} == 0$ ) or more generally  $(A'A + \text{damp}^2 * I)^{-1}$ . This is well defined if A has full column rank or  $\text{damp} > 0$ . (Not sure what var means if  $\text{rank}(A) < n$  and  $\text{damp} = 0$ .)

### Notes

LSQR uses an iterative method to approximate the solution. The number of iterations required to reach a certain accuracy depends strongly on the scaling of the problem. Poor scaling of the rows or columns of A should therefore be avoided where possible.

For example, in problem 1 the solution is unaltered by row-scaling. If a row of A is very small or large compared to the other rows of A, the corresponding row of  $(A \ b)$  should be scaled up or down.

In problems 1 and 2, the solution x is easily recovered following column-scaling. Unless better information is known, the nonzero columns of A should be scaled so that they all have the same Euclidean norm (e.g., 1.0).

In problem 3, there is no freedom to re-scale if damp is nonzero. However, the value of damp should be assigned only after attention has been paid to the scaling of A.

The parameter damp is intended to help regularize ill-conditioned systems, by preventing the true solution from being very large. Another aid to regularization is provided by the parameter acond, which may be used to terminate iterations before the computed solution becomes very large.

If some initial estimate x0 is known and if  $\text{damp} == 0$ , one could proceed as follows:

1. Compute a residual vector  $r0 = b - A * x0$ .
2. Use LSQR to solve the system  $A * dx = r0$ .
3. Add the correction dx to obtain a final solution  $x = x0 + dx$ .

This requires that  $x_0$  be available before and after the call to LSQR. To judge the benefits, suppose LSQR takes  $k_1$  iterations to solve  $A*x = b$  and  $k_2$  iterations to solve  $A*dx = r_0$ . If  $x_0$  is “good”,  $\text{norm}(r_0)$  will be smaller than  $\text{norm}(b)$ . If the same stopping tolerances  $\text{atol}$  and  $\text{btol}$  are used for each system,  $k_1$  and  $k_2$  will be similar, but the final solution  $x_0 + dx$  should be more accurate. The only way to reduce the total work is to use a larger stopping tolerance for the second system. If some value  $\text{btol}$  is suitable for  $A*x = b$ , the larger value  $\text{btol}*\text{norm}(b)/\text{norm}(r_0)$  should be suitable for  $A*dx = r_0$ .

Preconditioning is another way to reduce the number of iterations. If it is possible to solve a related system  $M*x = b$  efficiently, where  $M$  approximates  $A$  in some helpful way (e.g.  $M - A$  has low rank or its elements are small relative to those of  $A$ ), LSQR may converge more rapidly on the system  $A*M(\text{inverse})*z = b$ , after which  $x$  can be recovered by solving  $M*x = z$ .

If  $A$  is symmetric, LSQR should not be used!

Alternatives are the symmetric conjugate-gradient method (`cg`) and/or `SYMMLQ`. `SYMMLQ` is an implementation of symmetric `cg` that applies to any symmetric  $A$  and will converge more rapidly than LSQR. If  $A$  is positive definite, there are other implementations of symmetric `cg` that require slightly less work per iteration than `SYMMLQ` (but will take the same number of iterations).

### References

[R386], [R387], [R388]

### Examples

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import lsqr
>>> A = csc_matrix([[1., 0.], [1., 1.], [0., 1.]], dtype=float)
```

The first example has the trivial solution  $[0, 0]$

```
>>> b = np.array([0., 0., 0.], dtype=float)
>>> x, istop, itn, normr = lsqr(A, b)[:4]
The exact solution is x = 0
>>> istop
0
>>> x
array([ 0.,  0.]
```

The stopping code `istop=0` returned indicates that a vector of zeros was found as a solution. The returned solution  $x$  indeed contains  $[0, 0]$ . The next example has a non-trivial solution:

```
>>> b = np.array([1., 0., -1.], dtype=float)
>>> x, istop, itn, rlnorm = lsqr(A, b)[:4]
>>> istop
1
>>> x
array([ 1., -1.])
>>> itn
1
>>> rlnorm
4.440892098500627e-16
```

As indicated by `istop=1`, `lsqr` found a solution obeying the tolerance limits. The given solution  $[1., -1.]$  obviously solves the equation. The remaining return values include information about the number of iterations (`itn=1`) and the remaining difference of left and right side of the solved equation. The final example demonstrates the behavior in the case where there is no solution for the equation:

```

>>> b = np.array([1., 0.01, -1.], dtype=float)
>>> x, istop, itn, rlnorm = lsqr(A, b)[:4]
>>> istop
2
>>> x
array([ 1.00333333, -0.99666667])
>>> A.dot(x)-b
array([ 0.00333333, -0.00333333,  0.00333333])
>>> rlnorm
0.005773502691896255

```

*istop* indicates that the system is inconsistent and thus *x* is rather an approximate solution to the corresponding least-squares problem. *rlnorm* contains the norm of the minimal residual that was found.

`scipy.sparse.linalg.lsmr(A, b, damp=0.0, atol=1e-06, btol=1e-06, conlim=100000000.0, maxiter=None, show=False, x0=None)`  
Iterative solver for least-squares problems.

*lsmr* solves the system of linear equations  $Ax = b$ . If the system is inconsistent, it solves the least-squares problem  $\min ||b - Ax||_2$ . *A* is a rectangular matrix of dimension *m*-by-*n*, where all cases are allowed:  $m = n$ ,  $m > n$ , or  $m < n$ . *B* is a vector of length *m*. The matrix *A* may be dense or sparse (usually sparse).

**Parameters** *A* : {matrix, sparse matrix, ndarray, LinearOperator}  
Matrix *A* in the linear system.

*b* : array\_like, shape (*m*,)  
Vector *b* in the linear system.

**damp** : float  
Damping factor for regularized least-squares. *lsmr* solves the regularized least-squares problem:

$$\min \begin{pmatrix} ||(b) - (A)x|| \\ ||(0) \quad (damp * I)||_2 \end{pmatrix}$$

where *damp* is a scalar. If *damp* is *None* or 0, the system is solved without regularization.

**atol, btol** : float, optional

Stopping tolerances. *lsmr* continues iterations until a certain backward error estimate is smaller than some quantity depending on *atol* and *btol*. Let  $r = b - Ax$  be the residual vector for the current approximate solution *x*. If  $Ax = b$  seems to be consistent, *lsmr* terminates when  $\text{norm}(r) \leq \text{atol} * \text{norm}(A) * \text{norm}(x) + \text{btol} * \text{norm}(b)$ . Otherwise, *lsmr* terminates when  $\text{norm}(A^T r) \leq \text{atol} * \text{norm}(A) * \text{norm}(r)$ . If both tolerances are 1.0e-6 (say), the final  $\text{norm}(r)$  should be accurate to about 6 digits. (The final *x* will usually have fewer correct digits, depending on  $\text{cond}(A)$  and the size of *LAMBDA*.) If *atol* or *btol* is *None*, a default value of 1.0e-6 will be used. Ideally, they should be estimates of the relative error in the entries of *A* and *B* respectively. For example, if the entries of *A* have 7 correct digits, set *atol* = 1e-7. This prevents the algorithm from doing unnecessary work beyond the uncertainty of the input data.

**conlim** : float, optional

*lsmr* terminates if an estimate of  $\text{cond}(A)$  exceeds *conlim*. For compatible systems  $Ax = b$ , *conlim* could be as large as 1.0e+12 (say). For least-squares problems, *conlim* should be less than 1.0e+8. If *conlim* is *None*, the default value is 1e+8. Maximum precision can be obtained by setting *atol* = *btol* = *conlim* = 0, but the number of iterations may then be excessive.

**maxiter** : int, optional

*lsqr* terminates if the number of iterations reaches *maxiter*. The default is  $\text{maxiter} = \min(m, n)$ . For ill-conditioned systems, a larger value of *maxiter* may be needed.

**show** : bool, optional

Print iterations logs if `show=True`.

**x0** : array\_like, shape (n,), optional

Initial guess of x, if None zeros are used.

New in version 1.0.0.

### Returns

**x** : ndarray of float

Least-square solution returned.

**istop** : int

istop gives the reason for stopping:

```

istop   = 0 means x=0 is a solution.  If x0 was given,
→then x=x0 is a
        solution.
        = 1 means x is an approximate solution to A*x
→= B,
        according to atol and btol.
        = 2 means x approximately solves the least-
→squares problem
        according to atol.
        = 3 means COND(A) seems to be greater than
→CONLIM.
        = 4 is the same as 1 with atol = btol = eps
→(machine
        precision)
        = 5 is the same as 2 with atol = eps.
        = 6 is the same as 3 with CONLIM = 1/eps.
        = 7 means ITN reached maxiter before the other
→stopping
        conditions were satisfied.
    
```

**itn** : int

Number of iterations used.

**normr** : float

$\text{norm}(b - Ax)$

**normar** : float

$\text{norm}(A^T (b - Ax))$

**norma** : float

$\text{norm}(A)$

**conda** : float

Condition number of A.

**normx** : float

$\text{norm}(x)$

### Notes

New in version 0.11.0.

### References

[R384], [R385]

**Examples**

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import lsqr
>>> A = csc_matrix([[1., 0.], [1., 1.], [0., 1.]], dtype=float)
```

The first example has the trivial solution  $[0, 0]$

```
>>> b = np.array([0., 0., 0.], dtype=float)
>>> x, istop, itn, normr = lsqr(A, b)[:4]
>>> istop
0
>>> x
array([ 0.,  0.]
```

The stopping code `istop=0` returned indicates that a vector of zeros was found as a solution. The returned solution `x` indeed contains  $[0, 0]$ . The next example has a non-trivial solution:

```
>>> b = np.array([1., 0., -1.], dtype=float)
>>> x, istop, itn, normr = lsqr(A, b)[:4]
>>> istop
1
>>> x
array([ 1., -1.])
>>> itn
1
>>> normr
4.440892098500627e-16
```

As indicated by `istop=1`, `lsqr` found a solution obeying the tolerance limits. The given solution  $[1, -1]$  obviously solves the equation. The remaining return values include information about the number of iterations (`itn=1`) and the remaining difference of left and right side of the solved equation. The final example demonstrates the behavior in the case where there is no solution for the equation:

```
>>> b = np.array([1., 0.01, -1.], dtype=float)
>>> x, istop, itn, normr = lsqr(A, b)[:4]
>>> istop
2
>>> x
array([ 1.00333333, -0.99666667])
>>> A.dot(x)-b
array([ 0.00333333, -0.00333333,  0.00333333])
>>> normr
0.005773502691896255
```

`istop` indicates that the system is inconsistent and thus `x` is rather an approximate solution to the corresponding least-squares problem. `normr` contains the minimal distance that was found.

**5.22.5 Matrix factorizations**

Eigenvalue problems:

`eigs(A[, k, M, sigma, which, v0, ncv, ...])`

Find `k` eigenvalues and eigenvectors of the square matrix `A`.

Continued on next page

Table 5.212 – continued from previous page

<code>eigsh(A[, k, M, sigma, which, v0, ncv, ...])</code>	Find $k$ eigenvalues and eigenvectors of the real symmetric square matrix or complex hermitian matrix $A$ .
<code>lobpcg(A, X[, B, M, Y, tol, maxiter, ...])</code>	Locally Optimal Block Preconditioned Conjugate Gradient Method (LOBPCG)

`scipy.sparse.linalg.eigs` ( $A, k=6, M=None, sigma=None, which='LM', v0=None, ncv=None, maxiter=None, tol=0, return_eigenvectors=True, Minv=None, OPinv=None, OPpart=None$ )

Find  $k$  eigenvalues and eigenvectors of the square matrix  $A$ .

Solves  $A * x[i] = w[i] * x[i]$ , the standard eigenvalue problem for  $w[i]$  eigenvalues with corresponding eigenvectors  $x[i]$ .

If  $M$  is specified, solves  $A * x[i] = w[i] * M * x[i]$ , the generalized eigenvalue problem for  $w[i]$  eigenvalues with corresponding eigenvectors  $x[i]$

**Parameters**  $A$  : ndarray, sparse matrix or LinearOperator

An array, sparse matrix, or LinearOperator representing the operation  $A * x$ , where  $A$  is a real or complex square matrix.

$k$  : int, optional

The number of eigenvalues and eigenvectors desired.  $k$  must be smaller than  $N-1$ . It is not possible to compute all eigenvectors of a matrix.

$M$  : ndarray, sparse matrix or LinearOperator, optional

An array, sparse matrix, or LinearOperator representing the operation  $M*x$  for the generalized eigenvalue problem

$$A * x = w * M * x.$$

$M$  must represent a real, symmetric matrix if  $A$  is real, and must represent a complex, hermitian matrix if  $A$  is complex. For best results, the data type of  $M$  should be the same as that of  $A$ . Additionally:

If  $sigma$  is None,  $M$  is positive definite

If  $sigma$  is specified,  $M$  is positive semi-definite

If  $sigma$  is None, `eigs` requires an operator to compute the solution of the linear equation  $M * x = b$ . This is done internally via a (sparse) LU decomposition for an explicit matrix  $M$ , or via an iterative solver for a general linear operator. Alternatively, the user can supply the matrix or operator `Minv`, which gives  $x = Minv * b = M^{-1} * b$ .

$sigma$  : real or complex, optional

Find eigenvalues near  $sigma$  using shift-invert mode. This requires an operator to compute the solution of the linear system  $[A - sigma * M] * x = b$ , where  $M$  is the identity matrix if unspecified. This is computed internally via a (sparse) LU decomposition for explicit matrices  $A$  &  $M$ , or via an iterative solver if either  $A$  or  $M$  is a general linear operator. Alternatively, the user can supply the matrix or operator `OPinv`, which gives  $x = OPinv * b = [A - sigma * M]^{-1} * b$ . For a real matrix  $A$ , shift-invert can either be done in imaginary mode or real mode, specified by the parameter `OPpart` ('r' or 'i'). Note that when  $sigma$  is specified, the keyword 'which' (below) refers to the shifted eigenvalues  $w'[i]$  where:

**If  $A$  is real and `OPpart == 'r'` (default),**

$$w'[i] = 1/2 * [1/(w[i]-sigma) + 1/(w[i]-conj(sigma))].$$

**If  $A$  is real and `OPpart == 'i'`,**

$$w'[i] = 1/2i * [1/(w[i]-sigma) - 1/(w[i]-conj(sigma))].$$

If  $A$  is complex,  $w'[i] = 1/(w[i]-\sigma)$ .

**v0** : ndarray, optional

Starting vector for iteration. Default: random

**ncv** : int, optional

The number of Lanczos vectors generated  $ncv$  must be greater than  $k$ ; it is recommended that  $ncv > 2*k$ . Default:  $\min(n, \max(2*k + 1, 20))$

**which** : str, ['LM' | 'SM' | 'LR' | 'SR' | 'LI' | 'SI'], optional

Which  $k$  eigenvectors and eigenvalues to find:

'LM' : largest magnitude

'SM' : smallest magnitude

'LR' : largest real part

'SR' : smallest real part

'LI' : largest imaginary part

'SI' : smallest imaginary part

When  $\sigma \neq \text{None}$ , 'which' refers to the shifted eigenvalues  $w'[i]$  (see discussion in 'sigma', above). ARPACK is generally better at finding large values than small values. If small eigenvalues are desired, consider using shift-invert mode for better performance.

**maxiter** : int, optional

Maximum number of Arnoldi update iterations allowed Default:  $n*10$

**tol** : float, optional

Relative accuracy for eigenvalues (stopping criterion) The default value of 0 implies machine precision.

**return\_eigenvectors** : bool, optional

Return eigenvectors (True) in addition to eigenvalues

**Minv** : ndarray, sparse matrix or LinearOperator, optional

See notes in  $M$ , above.

**OPinv** : ndarray, sparse matrix or LinearOperator, optional

See notes in  $\sigma$ , above.

**OPpart** : {'r' or 'i'}, optional

See notes in  $\sigma$ , above

#### Returns

**w** : ndarray

Array of  $k$  eigenvalues.

**v** : ndarray

An array of  $k$  eigenvectors.  $v[:, i]$  is the eigenvector corresponding to the eigenvalue  $w[i]$ .

#### Raises

**ArpackNoConvergence**

When the requested convergence is not obtained. The currently converged eigenvalues and eigenvectors can be found as `eigenvalues` and `eigenvectors` attributes of the exception object.

#### See also:

**eigsh** eigenvalues and eigenvectors for symmetric matrix  $A$   
**svds** singular value decomposition for a matrix  $A$

#### Notes

This function is a wrapper to the ARPACK [R369] SNEUPD, DNEUPD, CNEUPD, ZNEUPD, functions which use the Implicitly Restarted Arnoldi Method to find the eigenvalues and eigenvectors [R370].

#### References

[R369], [R370]

### Examples

Find 6 eigenvectors of the identity matrix:

```
>>> import scipy.sparse as sparse
>>> id = np.eye(13)
>>> vals, vecs = sparse.linalg.eigs(id, k=6)
>>> vals
array([ 1.+0.j,  1.+0.j,  1.+0.j,  1.+0.j,  1.+0.j,  1.+0.j])
>>> vecs.shape
(13, 6)
```

`scipy.sparse.linalg.eigsh`(*A*, *k*=6, *M*=None, *sigma*=None, *which*='LM', *v0*=None, *ncv*=None, *maxiter*=None, *tol*=0, *return\_eigenvectors*=True, *Minv*=None, *OPinv*=None, *mode*='normal')

Find *k* eigenvalues and eigenvectors of the real symmetric square matrix or complex hermitian matrix *A*.

Solves  $A * x[i] = w[i] * x[i]$ , the standard eigenvalue problem for *w*[*i*] eigenvalues with corresponding eigenvectors *x*[*i*].

If *M* is specified, solves  $A * x[i] = w[i] * M * x[i]$ , the generalized eigenvalue problem for *w*[*i*] eigenvalues with corresponding eigenvectors *x*[*i*]

**Parameters** *A* : An *N* x *N* matrix, array, sparse matrix, or LinearOperator representing the operation  $A * x$ , where *A* is a real symmetric matrix For buckling mode (see below) *A* must additionally be positive-definite

*k* : int, optional

The number of eigenvalues and eigenvectors desired. *k* must be smaller than *N*. It is not possible to compute all eigenvectors of a matrix.

**Returns** *w* : array

Array of *k* eigenvalues

*v* : array

An array representing the *k* eigenvectors. The column  $v[:, i]$  is the eigenvector corresponding to the eigenvalue *w*[*i*].

#### Other Parameters

*M* : An *N* x *N* matrix, array, sparse matrix, or linear operator representing the operation  $M * x$  for the generalized eigenvalue problem  $A * x = w * M * x$ .

*M* must represent a real, symmetric matrix if *A* is real, and must represent a complex, hermitian matrix if *A* is complex. For best results, the data type of *M* should be the same as that of *A*. Additionally:

If *sigma* is None, *M* is symmetric positive definite

If *sigma* is specified, *M* is symmetric positive semi-definite

In buckling mode, *M* is symmetric indefinite.

If *sigma* is None, `eigsh` requires an operator to compute the solution of the linear equation  $M * x = b$ . This is done internally via a (sparse) LU decomposition for an explicit matrix *M*, or via an iterative solver for a general linear operator. Alternatively, the user can supply the matrix or operator *Minv*, which gives  $x = Minv * b = M^{-1} * b$ .

*sigma* : real

Find eigenvalues near *sigma* using shift-invert mode. This requires an operator to compute the solution of the linear system  $[A - sigma * M] x = b$ , where *M* is the identity matrix if unspecified. This is computed internally via a (sparse) LU decomposition for explicit matrices *A* & *M*, or via an iterative solver if either *A* or *M* is a general linear operator. Alternatively, the user can supply the matrix or operator *OPinv*, which gives  $x = OPinv * b = [A - sigma * M]^{-1} * b$ . Note that when *sigma* is specified, the keyword 'which' refers to the shifted eigenvalues *w*' [*i*] where:

```

if mode == 'normal', w'[i] = 1 / (w[i] -
sigma).
if mode == 'cayley', w'[i] = (w[i] + sigma) /
(w[i] - sigma).
if mode == 'buckling', w'[i] = w[i] / (w[i] -
sigma).

```

(see further discussion in 'mode' below)

**v0** : ndarray, optional

Starting vector for iteration. Default: random

**ncv** : int, optional

The number of Lanczos vectors generated ncv must be greater than k and smaller than n; it is recommended that  $ncv > 2*k$ . Default:  $\min(n, \max(2*k + 1, 20))$

**which** : str ['LM' | 'SM' | 'LA' | 'SA' | 'BE']

If A is a complex hermitian matrix, 'BE' is invalid. Which k eigenvectors and eigenvalues to find:

```

'LM' : Largest (in magnitude) eigenvalues
'SM' : Smallest (in magnitude) eigenvalues
'LA' : Largest (algebraic) eigenvalues
'SA' : Smallest (algebraic) eigenvalues
'BE' : Half (k/2) from each end of the spectrum

```

When k is odd, return one more (k/2+1) from the high end. When sigma != None, 'which' refers to the shifted eigenvalues w'[i] (see discussion in 'sigma', above). ARPACK is generally better at finding large values than small values. If small eigenvalues are desired, consider using shift-invert mode for better performance.

**maxiter** : int, optional

Maximum number of Arnoldi update iterations allowed Default: n\*10

**tol** : float

Relative accuracy for eigenvalues (stopping criterion). The default value of 0 implies machine precision.

**Minv** : N x N matrix, array, sparse matrix, or LinearOperator

See notes in M, above

**OPinv** : N x N matrix, array, sparse matrix, or LinearOperator

See notes in sigma, above.

**return\_eigenvectors** : bool

Return eigenvectors (True) in addition to eigenvalues

**mode** : string ['normal' | 'buckling' | 'cayley']

Specify strategy to use for shift-invert mode. This argument applies only for real-valued A and sigma != None. For shift-invert mode, ARPACK internally solves the eigenvalue problem  $OP * x'[i] = w'[i] * B * x'[i]$  and transforms the resulting Ritz vectors x'[i] and Ritz values w'[i] into the desired eigenvectors and eigenvalues of the problem  $A * x[i] = w[i] * M * x[i]$ . The modes are as follows:

```

'normal' :   OP = [A - sigma * M]^-1 * M, B = M, w'[i]
             = 1 / (w[i] - sigma)
'buckling' : OP = [A - sigma * M]^-1 * A, B = A, w'[i] =
             w[i] / (w[i] - sigma)
'cayley' :   OP = [A - sigma * M]^-1 * [A + sigma * M],
             B = M, w'[i] = (w[i] + sigma) / (w[i] - sigma)

```

The choice of mode will affect which eigenvalues are selected by the keyword 'which', and can also impact the stability of convergence (see [2] for a discussion)

*Raises*

**ArpackNoConvergence**

When the requested convergence is not obtained.  
 The currently converged eigenvalues and eigenvectors can be found as `eigenvalues` and `eigenvectors` attributes of the exception object.

**See also:**

**eigs** eigenvalues and eigenvectors for a general (nonsymmetric) matrix A  
**svds** singular value decomposition for a matrix A

**Notes**

This function is a wrapper to the ARPACK [R371] SSEUPD and DSEUPD functions which use the Implicitly Restarted Lanczos Method to find the eigenvalues and eigenvectors [R372].

**References**

[R371], [R372]

**Examples**

```
>>> import scipy.sparse as sparse
>>> id = np.eye(13)
>>> vals, vecs = sparse.linalg.eigsh(id, k=6)
>>> vals
array([ 1.+0.j,  1.+0.j,  1.+0.j,  1.+0.j,  1.+0.j,  1.+0.j])
>>> vecs.shape
(13, 6)
```

`scipy.sparse.linalg.lobpcg(A, X, B=None, M=None, Y=None, tol=None, maxiter=20, largest=True, verbosityLevel=0, retLambdaHistory=False, retResidualNormsHistory=False)`

Locally Optimal Block Preconditioned Conjugate Gradient Method (LOBPCG)

LOBPCG is a preconditioned eigensolver for large symmetric positive definite (SPD) generalized eigenproblems.

- Parameters**
  - A** : {sparse matrix, dense matrix, LinearOperator}
 

The symmetric linear operator of the problem, usually a sparse matrix. Often called the “stiffness matrix”.
  - X** : array\_like
 

Initial approximation to the k eigenvectors. If A has shape=(n,n) then X should have shape shape=(n,k).
  - B** : {dense matrix, sparse matrix, LinearOperator}, optional
 

the right hand side operator in a generalized eigenproblem. by default, B = Identity often called the “mass matrix”
  - M** : {dense matrix, sparse matrix, LinearOperator}, optional
 

preconditioner to A; by default M = Identity M should approximate the inverse of A
  - Y** : array\_like, optional
 

n-by-sizeY matrix of constraints, sizeY < n The iterations will be performed in the B-orthogonal complement of the column-space of Y. Y must be full rank.
- Returns**
  - w** : array
 

Array of k eigenvalues
  - v** : array
 

An array of k eigenvectors. V has the same shape as X.
- Other Parameters**
  - tol** : scalar, optional
 

Solver tolerance (stopping criterion) by default: `tol=n*sqrt(eps)`

**maxiter** : integer, optional  
 maximum number of iterations by default: `maxiter=min(n,20)`

**largest** : bool, optional  
 when True, solve for the largest eigenvalues, otherwise the smallest

**verbosityLevel** : integer, optional  
 controls solver output. default: `verbosityLevel = 0`.

**retLambdaHistory** : boolean, optional  
 whether to return eigenvalue history

**retResidualNormsHistory** : boolean, optional  
 whether to return history of residual norms

### Notes

If both `retLambdaHistory` and `retResidualNormsHistory` are True, the return tuple has the following format (lambda, V, lambda history, residual norms history).

In the following `n` denotes the matrix size and `m` the number of required eigenvalues (smallest or largest).

The LOBPCG code internally solves eigenproblems of the size  $3 \times m$  on every iteration by calling the “standard” dense eigensolver, so if `m` is not small enough compared to `n`, it does not make sense to call the LOBPCG code, but rather one should use the “standard” eigensolver, e.g. `numpy` or `scipy` function in this case. If one calls the LOBPCG algorithm for  $5 \times m > n$ , it will most likely break internally, so the code tries to call the standard function instead.

It is not that `n` should be large for the LOBPCG to work, but rather the ratio `n/m` should be large. If you call the LOBPCG code with `m=1` and `n=10`, it should work, though `n` is small. The method is intended for extremely large `n/m`, see e.g., reference [28] in <http://arxiv.org/abs/0705.2626>

The convergence speed depends basically on two factors:

1. How well relatively separated the seeking eigenvalues are from the rest of the eigenvalues. One can try to vary `m` to make this better.
2. How well conditioned the problem is. This can be changed by using proper preconditioning. For example, a rod vibration test problem (under tests directory) is ill-conditioned for large `n`, so convergence will be slow, unless efficient preconditioning is used. For this specific problem, a good simple preconditioner function would be a linear solve for `A`, which is easy to code since `A` is tridiagonal.

### Acknowledgements

`lobpcg.py` code was written by Robert Cimrman. Many thanks belong to Andrew Knyazev, the author of the algorithm, for lots of advice and support.

### References

[R381], [R382], [R383]

### Examples

Solve  $Ax = \lambda Bx$  with constraints and preconditioning.

```
>>> from scipy.sparse import spdiags, issparse
>>> from scipy.sparse.linalg import lobpcg, LinearOperator
>>> n = 100
>>> vals = [np.arange(n, dtype=np.float64) + 1]
>>> A = spdiags(vals, 0, n, n)
>>> A.toarray()
array([[ 1.,  0.,  0., ...,  0.,  0.,  0.],
       [ 0.,  2.,  0., ...,  0.,  0.,  0.],
       [ 0.,  0.,  3., ...,  0.,  0.,  0.],
       ...,
       [ 0.,  0.,  0., ..., 98.,  0.,  0.]])
```

```
[ 0., 0., 0., ..., 0., 99., 0.],
 [ 0., 0., 0., ..., 0., 0., 100.]])
```

Constraints.

```
>>> Y = np.eye(n, 3)
```

Initial guess for eigenvectors, should have linearly independent columns. Column dimension = number of requested eigenvalues.

```
>>> X = np.random.rand(n, 3)
```

Preconditioner – inverse of A (as an abstract linear operator).

```
>>> invA = spdiags([1./vals[0]], 0, n, n)
>>> def precondition(x):
...     return invA * x
>>> M = LinearOperator(matvec=precond, shape=(n, n), dtype=float)
```

Here, invA could of course have been used directly as a preconditioner. Let us then solve the problem:

```
>>> eigs, vecs = lobpcg(A, X, Y=Y, M=M, tol=1e-4, maxiter=40, largest=False)
>>> eigs
array([ 4., 5., 6.])
```

Note that the vectors passed in Y are the eigenvectors of the 3 smallest eigenvalues. The results returned are orthogonal to those.

Singular values problems:

<code>svds(A[, k, ncv, tol, which, v0, maxiter, ...])</code>	Compute the largest k singular values/vectors for a sparse matrix.
--	--

`scipy.sparse.linalg.svds(A, k=6, ncv=None, tol=0, which='LM', v0=None, maxiter=None, return_singular_vectors=True)`

Compute the largest k singular values/vectors for a sparse matrix.

**Parameters**

- A** : {sparse matrix, LinearOperator}
  - Array to compute the SVD on, of shape (M, N)
- k** : int, optional
  - Number of singular values and vectors to compute. Must be  $1 \leq k < \min(A.shape)$ .
- ncv** : int, optional
  - The number of Lanczos vectors generated ncv must be greater than k+1 and smaller than n; it is recommended that  $ncv > 2*k$  Default:  $\min(n, \max(2*k + 1, 20))$
- tol** : float, optional
  - Tolerance for singular values. Zero (default) means machine precision.
- which** : str, ['LM' | 'SM'], optional
  - Which k singular values to find:
    - 'LM' : largest singular values
    - 'SM' : smallest singular values
  - New in version 0.12.0.
- v0** : ndarray, optional
  - Starting vector for iteration, of length  $\min(A.shape)$ . Should be an (approximate) left singular vector if  $N > M$  and a right singular vector otherwise.

Default: random  
 New in version 0.12.0.

**maxiter** : int, optional  
 Maximum number of iterations.  
 New in version 0.12.0.

**return\_singular\_vectors** : bool or str, optional

- True: return singular vectors (True) in addition to singular values.

New in version 0.12.0.

- "u": only return the u matrix, without computing vh (if  $N > M$ ).
- "vh": only return the vh matrix, without computing u (if  $N \leq M$ ).

**Returns**

**u** : ndarray, shape=(M, k)  
 New in version 0.16.0.  
 Unitary matrix having left singular vectors as columns. If *return\_singular\_vectors* is "vh", this variable is not computed, and None is returned instead.

**s** : ndarray, shape=(k,)  
 The singular values.

**vt** : ndarray, shape=(k, N)  
 Unitary matrix having right singular vectors as rows. If *return\_singular\_vectors* is "u", this variable is not computed, and None is returned instead.

**Notes**

This is a naive implementation using ARPACK as an eigensolver on  $A.H * A$  or  $A * A.H$ , depending on which one is more efficient.

**Examples**

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import svds, eigs
>>> A = csc_matrix([[1, 0, 0], [5, 0, 2], [0, -1, 0], [0, 0, 3]], dtype=float)
>>> u, s, vt = svds(A, k=2)
>>> s
array([ 2.75193379,  5.6059665 ])
>>> np.sqrt(eigs(A.dot(A.T), k=2)[0]).real
array([ 5.6059665 ,  2.75193379])
```

Complete or incomplete LU factorizations

<code>splu(A[, permc_spec, diag_pivot_thresh, ...])</code>	Compute the LU decomposition of a sparse, square matrix.
<code>spilu(A[, drop_tol, fill_factor, drop_rule, ...])</code>	Compute an incomplete LU decomposition for a sparse, square matrix.
<i>SuperLU</i>	LU factorization of a sparse matrix.

`scipy.sparse.linalg.splu(A, permc_spec=None, diag_pivot_thresh=None, relax=None, panel_size=None, options={})`  
 Compute the LU decomposition of a sparse, square matrix.

**Parameters**

**A** : sparse matrix  
 Sparse matrix to factorize. Should be in CSR or CSC format.

**permc\_spec** : str, optional  
 How to permute the columns of the matrix for sparsity preservation. (default: 'COLAMD')

- NATURAL: natural ordering.
- MMD\_ATA: minimum degree ordering on the structure of  $A^T A$ .
- MMD\_AT\_PLUS\_A: minimum degree ordering on the structure of  $A^T A + A$ .
- COLAMD: approximate minimum degree column ordering

**diag\_pivot\_thresh** : float, optional  
 Threshold used for a diagonal entry to be an acceptable pivot. See SuperLU user's guide for details [R394]

**relax** : int, optional  
 Expert option for customizing the degree of relaxing supernodes. See SuperLU user's guide for details [R394]

**panel\_size** : int, optional  
 Expert option for customizing the panel size. See SuperLU user's guide for details [R394]

**options** : dict, optional  
 Dictionary containing additional expert options to SuperLU. See SuperLU user guide [R394] (section 2.4 on the 'Options' argument) for more details. For example, you can specify `options=dict(Equil=False, IterRefine='SINGLE')` to turn equilibration off and perform a single iterative refinement.

**Returns** **invA** : `scipy.sparse.linalg.SuperLU`  
 Object, which has a `solve` method.

**See also:**

**spilu** incomplete LU decomposition

**Notes**

This function uses the SuperLU library.

**References**

[R394]

**Examples**

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import splu
>>> A = csc_matrix([[1., 0., 0.], [5., 0., 2.], [0., -1., 0.]], dtype=float)
>>> B = splu(A)
>>> x = np.array([1., 2., 3.], dtype=float)
>>> B.solve(x)
array([ 1. , -3. , -1.5])
>>> A.dot(B.solve(x))
array([ 1.,  2.,  3.])
>>> B.solve(A.dot(x))
array([ 1.,  2.,  3.])
```

`scipy.sparse.linalg.spilu`(A, *drop\_tol=None*, *fill\_factor=None*, *drop\_rule=None*, *perm\_spec=None*, *diag\_pivot\_thresh=None*, *relax=None*, *panel\_size=None*, *options=None*)

Compute an incomplete LU decomposition for a sparse, square matrix.

The resulting object is an approximation to the inverse of A.

**Parameters** **A** : (N, N) array\_like  
 Sparse matrix to factorize  
**drop\_tol** : float, optional

Drop tolerance ( $0 \leq \text{tol} \leq 1$ ) for an incomplete LU decomposition. (default:  $1e-4$ )

**fill\_factor** : float, optional  
Specifies the fill ratio upper bound ( $\geq 1.0$ ) for ILU. (default: 10)

**drop\_rule** : str, optional  
Comma-separated string of drop rules to use. Available rules: `basic`, `prows`, `column`, `area`, `secondary`, `dynamic`, `interp`. (Default: `basic, area`)  
See SuperLU documentation for details.

**Remaining other options**  
Same as for `splu`

**Returns** **invA\_approx** : `scipy.sparse.linalg.SuperLU`  
Object, which has a `solve` method.

**See also:**

**splu** complete LU decomposition

**Notes**

To improve the better approximation to the inverse, you may need to increase `fill_factor` AND decrease `drop_tol`.

This function uses the SuperLU library.

**Examples**

```
>>> from scipy.sparse import csc_matrix
>>> from scipy.sparse.linalg import splu
>>> A = csc_matrix([[1., 0., 0.], [5., 0., 2.], [0., -1., 0.]], dtype=float)
>>> B = splu(A)
>>> x = np.array([1., 2., 3.], dtype=float)
>>> B.solve(x)
array([ 1. , -3. , -1.5])
>>> A.dot(B.solve(x))
array([ 1.,  2.,  3.])
>>> B.solve(A.dot(x))
array([ 1.,  2.,  3.])
```

**class** `scipy.sparse.linalg.SuperLU`

LU factorization of a sparse matrix.

Factorization is represented as:

$$Pr * A * Pc = L * U$$

To construct these *SuperLU* objects, call the `splu` and `spilu` functions.

**Notes**

New in version 0.14.0.

**Examples**

The LU decomposition can be used to solve matrix equations. Consider:

```
>>> import numpy as np
>>> from scipy.sparse import csc_matrix, linalg as sla
>>> A = csc_matrix([[1,2,0,4],[1,0,0,1],[1,0,2,1],[2,2,1,0]])
```

This can be solved for a given right-hand side:

```
>>> lu = sla.splu(A)
>>> b = np.array([1, 2, 3, 4])
>>> x = lu.solve(b)
>>> A.dot(x)
array([ 1.,  2.,  3.,  4.]
```

The `lu` object also contains an explicit representation of the decomposition. The permutations are represented as mappings of indices:

```
>>> lu.perm_r
array([0, 2, 1, 3], dtype=int32)
>>> lu.perm_c
array([2, 0, 1, 3], dtype=int32)
```

The L and U factors are sparse matrices in CSC format:

```
>>> lu.L.A
array([[ 1. ,  0. ,  0. ,  0. ],
       [ 0. ,  1. ,  0. ,  0. ],
       [ 0. ,  0. ,  1. ,  0. ],
       [ 1. ,  0.5,  0.5,  1. ]])
>>> lu.U.A
array([[ 2.,  0.,  1.,  4.],
       [ 0.,  2.,  1.,  1.],
       [ 0.,  0.,  1.,  1.],
       [ 0.,  0.,  0., -5.]])
```

The permutation matrices can be constructed:

```
>>> Pr = csc_matrix((4, 4))
>>> Pr[lu.perm_r, np.arange(4)] = 1
>>> Pc = csc_matrix((4, 4))
>>> Pc[np.arange(4), lu.perm_c] = 1
```

We can reassemble the original matrix:

```
>>> (Pr.T * (lu.L * lu.U) * Pc.T).A
array([[ 1.,  2.,  0.,  4.],
       [ 1.,  0.,  0.,  1.],
       [ 1.,  0.,  2.,  1.],
       [ 2.,  2.,  1.,  0.]])
```

### Attributes

<i>shape</i>	Shape of the original matrix as a tuple of ints.
<i>nnz</i>	Number of nonzero elements in the matrix.
<i>perm_c</i>	Permutation Pc represented as an array of indices.
<i>perm_r</i>	Permutation Pr represented as an array of indices.
<i>L</i>	Lower triangular factor with unit diagonal as a <i>scipy.sparse.csc_matrix</i> .
<i>U</i>	Upper triangular factor as a <i>scipy.sparse.csc_matrix</i> .

### SuperLU. **shape**

Shape of the original matrix as a tuple of ints.

SuperLU.**nnz**

Number of nonzero elements in the matrix.

SuperLU.**perm\_c**

Permutation Pc represented as an array of indices.

The column permutation matrix can be reconstructed via:

```
>>> Pc = np.zeros((n, n))
>>> Pc[np.arange(n), perm_c] = 1
```

SuperLU.**perm\_r**

Permutation Pr represented as an array of indices.

The row permutation matrix can be reconstructed via:

```
>>> Pr = np.zeros((n, n))
>>> Pr[perm_r, np.arange(n)] = 1
```

SuperLU.**L**

Lower triangular factor with unit diagonal as a *scipy.sparse.csc\_matrix*.

New in version 0.14.0.

SuperLU.**U**

Upper triangular factor as a *scipy.sparse.csc\_matrix*.

New in version 0.14.0.

### Methods

<i>solve</i> (rhs[, trans])	Solves linear system of equations with one or several right-hand sides.
-----------------------------	---

SuperLU.**solve** (rhs[, trans])

Solves linear system of equations with one or several right-hand sides.

**Parameters** **rhs** : ndarray, shape (n,) or (n, k)  
 Right hand side(s) of equation  
**trans** : {'N', 'T', 'H'}, optional  
 Type of system to solve:

```
'N':  A   * x == rhs  (default)
'T':  A^T * x == rhs
'H':  A^H * x == rhs
```

**Returns** **x** : ndarray, shape rhs.shape  
 i.e., normal, transposed, and hermitian conjugate.  
 Solution vector(s)

## 5.22.6 Exceptions

<i>ArpackNoConvergence</i> (msg, eigenvalues, ...)	ARPACK iteration did not converge
<i>ArpackError</i> (info[, infodict])	ARPACK error

**exception** *scipy.sparse.linalg.ArpackNoConvergence* (msg, eigenvalues, eigenvectors)  
 ARPACK iteration did not converge

*Attributes*

eigenvalues	(ndarray) Partial result. Converged eigenvalues.
eigenvectors	(ndarray) Partial result. Converged eigenvectors.

**exception** `scipy.sparse.linalg.ArpackError` (*info*, *infodict*={*c*: {0: 'Normal exit.', 1: 'Maximum number of iterations taken. All possible eigenvalues of OP has been found. IPARAM(5) returns the number of wanted converged Ritz values.', 2: 'No longer an informational error. Deprecated starting with release 2 of ARPACK.', 3: 'No shifts could be applied during a cycle of the Implicitly restarted Arnoldi iteration. One possibility is to increase the size of NCV relative to NEV. ', -9999: 'Could not build an Arnoldi factorization. IPARAM(5) returns the size of the current Arnoldi factorization. The user is advised to check that enough workspace and array storage has been allocated.', -13: "NEV and WHICH = 'BE' are incompatible.", -12: 'IPARAM(1) must be equal to 0 or 1.', -1: 'N must be positive.', -10: 'IPARAM(7) must be 1, 2, 3.', -9: 'Starting vector is zero.', -8: 'Error return from LAPACK eigenvalue calculation;', -7: 'Length of private work array WORKL is not sufficient.', -6: "BMAT must be one of 'I' or 'G'."}, -5: " WHICH must be one of 'LM', 'SM', 'LR', 'SR', 'LI', 'SI'", -4: 'The maximum number of Arnoldi update iterations allowed must be greater than zero.', -3: 'NCV-NEV >= 2 and less than or equal to N.', -2: 'NEV must be positive.', -11: "IPARAM(7) = 1 and BMAT = 'G' are incompatible."}, *s*: {0: 'Normal exit.', 1: 'Maximum number of iterations taken. All possible eigenvalues of OP has been found. IPARAM(5) returns the number of wanted converged Ritz values.', 2: 'No longer an informational error. Deprecated starting with release 2 of ARPACK.', 3: 'No shifts could be applied during a cycle of the Implicitly restarted Arnoldi iteration. One possibility is to increase the size of NCV relative to NEV. ', -9999: 'Could not build an Arnoldi factorization. IPARAM(5) returns the size of the current Arnoldi factorization. The user is advised to check that enough workspace and array storage has been allocated.', -13: "NEV and WHICH = 'BE' are incompatible.", -12: 'IPARAM(1) must be equal to 0 or 1.', -2: 'NEV must be positive.', -10: 'IPARAM(7) must be 1, 2, 3, 4.', -9: 'Starting vector is zero.', -8: 'Error return from LAPACK eigenvalue calculation;', -7: 'Length of private work array WORKL is not sufficient.', -6: "BMAT must be one of 'I' or 'G'."}, -5: " WHICH must be one of 'LM', 'SM', 'LR', 'SR', 'LI', 'SI'", -4: 'The maximum number of Arnoldi update iterations allowed must be greater than zero.', -3: 'NCV-NEV >= 2 and less than or equal to N.', -1: 'N must be positive.', -11: "IPARAM(7) = 1 and BMAT = 'G' are incompatible."}, *z*: {0: 'Normal exit.', 1: 'Maximum number of iterations taken. All possible eigenvalues of OP has been found. IPARAM(5) returns the number of wanted converged Ritz values.', 2: 'No longer an informational error. Deprecated starting with release 2 of ARPACK.', 3: 'No shifts could be applied during a cycle of the Implicitly restarted Arnoldi iteration. One possibility is to increase the size of NCV relative to NEV. ', -9999: 'Could not build an Arnoldi factorization. IPARAM(5) returns the size

ARPACK error

## 5.23 Compressed Sparse Graph Routines (`scipy.sparse.csgraph`)

Fast graph algorithms based on sparse matrix representations.

### 5.23.1 Contents

<code>connected_components(csgraph[, directed, ...])</code>	Analyze the connected components of a sparse graph
<code>laplacian(csgraph[, normed, return_diag, ...])</code>	Return the Laplacian matrix of a directed graph.
<code>shortest_path(csgraph[, method, directed, ...])</code>	Perform a shortest-path graph search on a positive directed or undirected graph.
<code>dijkstra(csgraph[, directed, indices, ...])</code>	Dijkstra algorithm using Fibonacci Heaps
<code>floyd_warshall(csgraph[, directed, ...])</code>	Compute the shortest path lengths using the Floyd-Warshall algorithm
<code>bellman_ford(csgraph[, directed, indices, ...])</code>	Compute the shortest path lengths using the Bellman-Ford algorithm.
<code>johnson(csgraph[, directed, indices, ...])</code>	Compute the shortest path lengths using Johnson's algorithm.
<code>breadth_first_order(csgraph, i_start[, ...])</code>	Return a breadth-first ordering starting with specified node.
<code>depth_first_order(csgraph, i_start[, ...])</code>	Return a depth-first ordering starting with specified node.
<code>breadth_first_tree(csgraph, i_start[, directed])</code>	Return the tree generated by a breadth-first search
<code>depth_first_tree(csgraph, i_start[, directed])</code>	Return a tree generated by a depth-first search.
<code>minimum_spanning_tree(csgraph[, overwrite])</code>	Return a minimum spanning tree of an undirected graph
<code>reverse_cuthill_mckee(graph[, symmetric_mode])</code>	Returns the permutation array that orders a sparse CSR or CSC matrix in Reverse-Cuthill McKee ordering.
<code>maximum_bipartite_matching(graph[, perm_type])</code>	Returns an array of row or column permutations that makes the diagonal of a nonsingular square CSC sparse matrix zero free.
<code>structural_rank(graph)</code>	Compute the structural rank of a graph (matrix) with a given sparsity pattern.
<code>NegativeCycleError</code>	

`scipy.sparse.csgraph.connected_components` (*csgraph*, *directed=True*, *connection='weak'*, *return\_labels=True*)

Analyze the connected components of a sparse graph

New in version 0.11.0.

**Parameters** **csgraph** : array\_like or sparse matrix

The N x N matrix representing the compressed sparse graph. The input csgraph will be converted to csr format for the calculation.

**directed** : bool, optional

If True (default), then operate on a directed graph: only move from point i to point j along paths csgraph[i, j]. If False, then find the shortest path on an undirected graph: the algorithm can progress from point i to j along csgraph[i, j] or csgraph[j, i].

**connection** : str, optional

['weak'|'strong']. For directed graphs, the type of connection to use. Nodes i and j are strongly connected if a path exists both from i to j and from j to

i. Nodes i and j are weakly connected if only one of these paths exists. If `directed == False`, this keyword is not referenced.

**return\_labels** : bool, optional  
If True (default), then return the labels for each of the connected components.

**Returns**

**n\_components**: int  
The number of connected components.

**labels**: ndarray  
The length-N array of labels of the connected components.

### References

[R314]

`scipy.sparse.csgraph.laplacian` (*csgraph*, *normed=False*, *return\_diag=False*, *use\_out\_degree=False*)

Return the Laplacian matrix of a directed graph.

**Parameters**

**csgraph** : array\_like or sparse matrix, 2 dimensions  
compressed-sparse graph, with shape (N, N).

**normed** : bool, optional  
If True, then compute normalized Laplacian.

**return\_diag** : bool, optional  
If True, then also return an array related to vertex degrees.

**use\_out\_degree** : bool, optional  
If True, then use out-degree instead of in-degree. This distinction matters only if the graph is asymmetric. Default: False.

**Returns**

**lap** : ndarray or sparse matrix  
The N x N laplacian matrix of *csgraph*. It will be a numpy array (dense) if the input was dense, or a sparse matrix otherwise.

**diag** : ndarray, optional  
The length-N diagonal of the Laplacian matrix. For the normalized Laplacian, this is the array of square roots of vertex degrees or 1 if the degree is zero.

### Notes

The Laplacian matrix of a graph is sometimes referred to as the “Kirchoff matrix” or the “admittance matrix”, and is useful in many parts of spectral graph theory. In particular, the eigen-decomposition of the laplacian matrix can give insight into many properties of the graph.

### Examples

```
>>> from scipy.sparse import csgraph
>>> G = np.arange(5) * np.arange(5)[:, np.newaxis]
>>> G
array([[ 0,  0,  0,  0,  0],
       [ 0,  1,  2,  3,  4],
       [ 0,  2,  4,  6,  8],
       [ 0,  3,  6,  9, 12],
       [ 0,  4,  8, 12, 16]])
>>> csgraph.laplacian(G, normed=False)
array([[ 0,  0,  0,  0,  0],
       [ 0,  9, -2, -3, -4],
       [ 0, -2, 16, -6, -8],
       [ 0, -3, -6, 21, -12],
       [ 0, -4, -8, -12, 24]])
```

```
scipy.sparse.csgraph.shortest_path(csgraph, method='auto', directed=True,
                                     return_predecessors=False, unweighted=False,
                                     overwrite=False, indices=None)
```

Perform a shortest-path graph search on a positive directed or undirected graph.

New in version 0.11.0.

**Parameters**

- csgraph** : array, matrix, or sparse matrix, 2 dimensions  
The N x N array of distances representing the input graph.
- method** : string ['auto'|'FW'|'D'], optional  
Algorithm to use for shortest paths. Options are:
  - 'auto'** – (default) select the best among 'FW', 'D', 'BF', or 'J' based on the input data.
  - 'FW'** – *Floyd-Warshall algorithm. Computational cost is approximately  $O[N^3]$ . The input csgraph will be converted to a dense representation.*
  - 'D'** – *Dijkstra's algorithm with Fibonacci heaps. Computational cost is approximately  $O[N(N*k + N*\log(N))]$ , where k is the average number of connected edges per node. The input csgraph will be converted to a csr representation.*
  - 'BF'** – *Bellman-Ford algorithm. This algorithm can be used when weights are negative. If a negative cycle is encountered, an error will be raised. Computational cost is approximately  $O[N(N^2*k)]$ , where k is the average number of connected edges per node. The input csgraph will be converted to a csr representation.*
  - 'J'** – *Johnson's algorithm. Like the Bellman-Ford algorithm, Johnson's algorithm is designed for use when the weights are negative. It combines the Bellman-Ford algorithm with Dijkstra's algorithm for faster computation.*
- directed** : bool, optional  
If True (default), then find the shortest path on a directed graph: only move from point i to point j along paths csgraph[i, j]. If False, then find the shortest path on an undirected graph: the algorithm can progress from point i to j along csgraph[i, j] or csgraph[j, i]
- return\_predecessors** : bool, optional  
If True, return the size (N, N) predecessor matrix
- unweighted** : bool, optional  
If True, then find unweighted distances. That is, rather than finding the path between each point such that the sum of weights is minimized, find the path such that the number of edges is minimized.
- overwrite** : bool, optional  
If True, overwrite csgraph with the result. This applies only if method == 'FW' and csgraph is a dense, c-ordered array with dtype=float64.
- indices** : array\_like or int, optional  
If specified, only compute the paths for the points at the given indices. Incompatible with method == 'FW'.

**Returns**

- dist\_matrix** : ndarray

The  $N \times N$  matrix of distances between graph nodes. `dist_matrix[i,j]` gives the shortest distance from point  $i$  to point  $j$  along the graph.

**predecessors** : ndarray

Returned only if `return_predecessors == True`. The  $N \times N$  matrix of predecessors, which can be used to reconstruct the shortest paths. Row  $i$  of the predecessor matrix contains information on the shortest paths from point  $i$ : each entry `predecessors[i, j]` gives the index of the previous node in the path from point  $i$  to point  $j$ . If no path exists between point  $i$  and  $j$ , then `predecessors[i, j] = -9999`

**Raises**

**NegativeCycleError:**

if there are negative cycles in the graph

### Notes

As currently implemented, Dijkstra's algorithm and Johnson's algorithm do not work for graphs with direction-dependent distances when `directed == False`. i.e., if `csgraph[i,j]` and `csgraph[j,i]` are non-equal edges, `method='D'` may yield an incorrect result.

`scipy.sparse.csgraph.dijkstra(csgraph, directed=True, indices=None, return_predecessors=False, unweighted=False, limit=np.inf)`

Dijkstra algorithm using Fibonacci Heaps

New in version 0.11.0.

### Parameters

**csgraph** : array, matrix, or sparse matrix, 2 dimensions

The  $N \times N$  array of non-negative distances representing the input graph.

**directed** : bool, optional

If True (default), then find the shortest path on a directed graph: only move from point  $i$  to point  $j$  along paths `csgraph[i, j]`. If False, then find the shortest path on an undirected graph: the algorithm can progress from point  $i$  to  $j$  along `csgraph[i, j]` or `csgraph[j, i]`

**indices** : array\_like or int, optional

if specified, only compute the paths for the points at the given indices.

**return\_predecessors** : bool, optional

If True, return the size  $(N, N)$  predecessor matrix

**unweighted** : bool, optional

If True, then find unweighted distances. That is, rather than finding the path between each point such that the sum of weights is minimized, find the path such that the number of edges is minimized.

**limit** : float, optional

The maximum distance to calculate, must be  $\geq 0$ . Using a smaller limit will decrease computation time by aborting calculations between pairs that are separated by a distance  $> \text{limit}$ . For such pairs, the distance will be equal to `np.inf` (i.e., not connected).

### Returns

**dist\_matrix** : ndarray

New in version 0.14.0.  
The matrix of distances between graph nodes. `dist_matrix[i,j]` gives the shortest distance from point  $i$  to point  $j$  along the graph.

**predecessors** : ndarray

Returned only if `return_predecessors == True`. The matrix of predecessors, which can be used to reconstruct the shortest paths. Row  $i$  of the predecessor matrix contains information on the shortest paths from point  $i$ : each entry `predecessors[i, j]` gives the index of the previous node in the path from point  $i$  to point  $j$ . If no path exists between point  $i$  and  $j$ , then `predecessors[i, j] = -9999`

*Notes*

As currently implemented, Dijkstra’s algorithm does not work for graphs with direction-dependent distances when `directed == False`. i.e., if `csgraph[i,j]` and `csgraph[j,i]` are not equal and both are nonzero, setting `directed=False` will not yield the correct result.

Also, this routine does not work for graphs with negative distances. Negative distances can lead to infinite cycles that must be handled by specialized algorithms such as Bellman-Ford’s algorithm or Johnson’s algorithm.

`scipy.sparse.csgraph.floyd_warshall` (*csgraph*, *directed=True*, *return\_predecessors=False*, *unweighted=False*, *overwrite=False*)

Compute the shortest path lengths using the Floyd-Warshall algorithm

New in version 0.11.0.

- Parameters**
- csgraph** : array, matrix, or sparse matrix, 2 dimensions  
The N x N array of distances representing the input graph.
  - directed** : bool, optional  
If True (default), then find the shortest path on a directed graph: only move from point i to point j along paths `csgraph[i, j]`. If False, then find the shortest path on an undirected graph: the algorithm can progress from point i to j along `csgraph[i, j]` or `csgraph[j, i]`
  - return\_predecessors** : bool, optional  
If True, return the size (N, N) predecessor matrix
  - unweighted** : bool, optional  
If True, then find unweighted distances. That is, rather than finding the path between each point such that the sum of weights is minimized, find the path such that the number of edges is minimized.
  - overwrite** : bool, optional  
If True, overwrite `csgraph` with the result. This applies only if `csgraph` is a dense, c-ordered array with `dtype=float64`.
- Returns**
- dist\_matrix** : ndarray  
The N x N matrix of distances between graph nodes. `dist_matrix[i,j]` gives the shortest distance from point i to point j along the graph.
  - predecessors** : ndarray  
Returned only if `return_predecessors == True`. The N x N matrix of predecessors, which can be used to reconstruct the shortest paths. Row i of the predecessor matrix contains information on the shortest paths from point i: each entry `predecessors[i, j]` gives the index of the previous node in the path from point i to point j. If no path exists between point i and j, then `predecessors[i, j] = -9999`
- Raises**
- NegativeCycleError**:  
if there are negative cycles in the graph

`scipy.sparse.csgraph.bellman_ford` (*csgraph*, *directed=True*, *indices=None*, *return\_predecessors=False*, *unweighted=False*)

Compute the shortest path lengths using the Bellman-Ford algorithm.

The Bellman-ford algorithm can robustly deal with graphs with negative weights. If a negative cycle is detected, an error is raised. For graphs without negative edge weights, dijkstra’s algorithm may be faster.

New in version 0.11.0.

- Parameters**
- csgraph** : array, matrix, or sparse matrix, 2 dimensions  
The N x N array of distances representing the input graph.
  - directed** : bool, optional  
If True (default), then find the shortest path on a directed graph: only move from point i to point j along paths `csgraph[i, j]`. If False, then find the shortest path on an undirected graph: the algorithm can progress from point i to j along `csgraph[i, j]` or `csgraph[j, i]`

**indices** : array\_like or int, optional  
if specified, only compute the paths for the points at the given indices.

**return\_predecessors** : bool, optional  
If True, return the size (N, N) predecessor matrix

**unweighted** : bool, optional  
If True, then find unweighted distances. That is, rather than finding the path between each point such that the sum of weights is minimized, find the path such that the number of edges is minimized.

**Returns** **dist\_matrix** : ndarray  
The N x N matrix of distances between graph nodes. `dist_matrix[i,j]` gives the shortest distance from point `i` to point `j` along the graph.

**predecessors** : ndarray  
Returned only if `return_predecessors == True`. The N x N matrix of predecessors, which can be used to reconstruct the shortest paths. Row `i` of the predecessor matrix contains information on the shortest paths from point `i`: each entry `predecessors[i, j]` gives the index of the previous node in the path from point `i` to point `j`. If no path exists between point `i` and `j`, then `predecessors[i, j] = -9999`

**Raises** **NegativeCycleError**:  
if there are negative cycles in the graph

### Notes

This routine is specially designed for graphs with negative edge weights. If all edge weights are positive, then Dijkstra's algorithm is a better choice.

```
scipy.sparse.csgraph.johnson(csgraph, directed=True, indices=None, return_predecessors=False, unweighted=False)
```

Compute the shortest path lengths using Johnson's algorithm.

Johnson's algorithm combines the Bellman-Ford algorithm and Dijkstra's algorithm to quickly find shortest paths in a way that is robust to the presence of negative cycles. If a negative cycle is detected, an error is raised. For graphs without negative edge weights, `dijkstra()` may be faster.

New in version 0.11.0.

**Parameters** **csgraph** : array, matrix, or sparse matrix, 2 dimensions  
The N x N array of distances representing the input graph.

**directed** : bool, optional  
If True (default), then find the shortest path on a directed graph: only move from point `i` to point `j` along paths `csgraph[i, j]`. If False, then find the shortest path on an undirected graph: the algorithm can progress from point `i` to `j` along `csgraph[i, j]` or `csgraph[j, i]`

**indices** : array\_like or int, optional  
if specified, only compute the paths for the points at the given indices.

**return\_predecessors** : bool, optional  
If True, return the size (N, N) predecessor matrix

**unweighted** : bool, optional  
If True, then find unweighted distances. That is, rather than finding the path between each point such that the sum of weights is minimized, find the path such that the number of edges is minimized.

**Returns** **dist\_matrix** : ndarray  
The N x N matrix of distances between graph nodes. `dist_matrix[i,j]` gives the shortest distance from point `i` to point `j` along the graph.

**predecessors** : ndarray  
Returned only if `return_predecessors == True`. The N x N matrix of predecessors, which can be used to reconstruct the shortest paths. Row `i` of the predecessor matrix contains information on the shortest paths from point

**Raises** **NegativeCycleError:**  
*i*: each entry predecessors[*i*, *j*] gives the index of the previous node in the path from point *i* to point *j*. If no path exists between point *i* and *j*, then predecessors[*i*, *j*] = -9999  
 if there are negative cycles in the graph

**Notes**

This routine is specially designed for graphs with negative edge weights. If all edge weights are positive, then Dijkstra's algorithm is a better choice.

```
scipy.sparse.csgraph.breadth_first_order(csgraph, i_start, directed=True, return_predecessors=True)
```

Return a breadth-first ordering starting with specified node.

Note that a breadth-first order is not unique, but the tree which it generates is unique.

New in version 0.11.0.

**Parameters** **csgraph** : array\_like or sparse matrix  
 The N x N compressed sparse graph. The input csgraph will be converted to csr format for the calculation.

**i\_start** : int  
 The index of starting node.

**directed** : bool, optional  
 If True (default), then operate on a directed graph: only move from point *i* to point *j* along paths csgraph[*i*, *j*]. If False, then find the shortest path on an undirected graph: the algorithm can progress from point *i* to *j* along csgraph[*i*, *j*] or csgraph[*j*, *i*].

**return\_predecessors** : bool, optional  
 If True (default), then return the predecessor array (see below).

**Returns** **node\_array** : ndarray, one dimension  
 The breadth-first list of nodes, starting with specified node. The length of node\_array is the number of nodes reachable from the specified node.

**predecessors** : ndarray, one dimension  
 Returned only if return\_predecessors is True. The length-N list of predecessors of each node in a breadth-first tree. If node *i* is in the tree, then its parent is given by predecessors[*i*]. If node *i* is not in the tree (and for the parent node) then predecessors[*i*] = -9999.

```
scipy.sparse.csgraph.depth_first_order(csgraph, i_start, directed=True, return_predecessors=True)
```

Return a depth-first ordering starting with specified node.

Note that a depth-first order is not unique. Furthermore, for graphs with cycles, the tree generated by a depth-first search is not unique either.

New in version 0.11.0.

**Parameters** **csgraph** : array\_like or sparse matrix  
 The N x N compressed sparse graph. The input csgraph will be converted to csr format for the calculation.

**i\_start** : int  
 The index of starting node.

**directed** : bool, optional  
 If True (default), then operate on a directed graph: only move from point *i* to point *j* along paths csgraph[*i*, *j*]. If False, then find the shortest path on an undirected graph: the algorithm can progress from point *i* to *j* along csgraph[*i*, *j*] or csgraph[*j*, *i*].

**return\_predecessors** : bool, optional

**Returns**

**node\_array** : ndarray, one dimension  
If True (default), then return the predecessor array (see below).  
The depth-first list of nodes, starting with specified node. The length of node\_array is the number of nodes reachable from the specified node.

**predecessors** : ndarray, one dimension  
Returned only if return\_predecessors is True. The length-N list of predecessors of each node in a depth-first tree. If node *i* is in the tree, then its parent is given by predecessors[*i*]. If node *i* is not in the tree (and for the parent node) then predecessors[*i*] = -9999.

scipy.sparse.csgraph.breadth\_first\_tree (csgraph, i\_start, directed=True)

Return the tree generated by a breadth-first search

Note that a breadth-first tree from a specified node is unique.

New in version 0.11.0.

**Parameters**

**csgraph** : array\_like or sparse matrix  
The N x N matrix representing the compressed sparse graph. The input csgraph will be converted to csr format for the calculation.

**i\_start** : int  
The index of starting node.

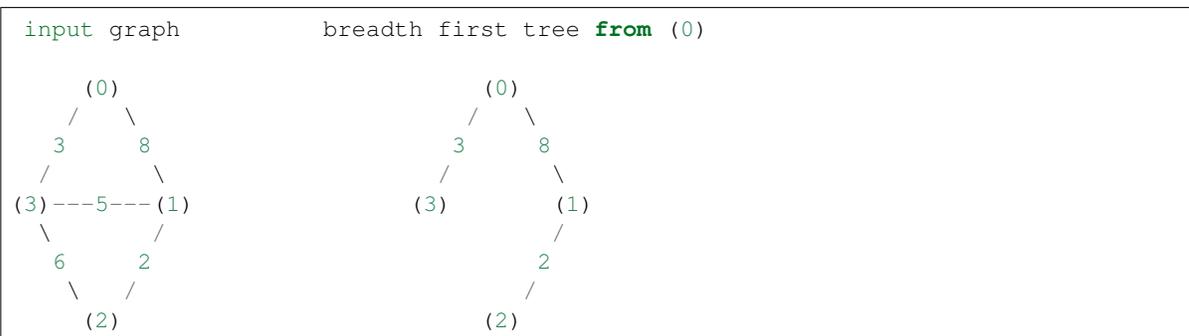
**directed** : bool, optional  
If True (default), then operate on a directed graph: only move from point *i* to point *j* along paths csgraph[*i*, *j*]. If False, then find the shortest path on an undirected graph: the algorithm can progress from point *i* to *j* along csgraph[*i*, *j*] or csgraph[*j*, *i*].

**Returns**

**csree** : csr matrix  
The N x N directed compressed-sparse representation of the breadth-first tree drawn from csgraph, starting at the specified node.

### Examples

The following example shows the computation of a depth-first tree over a simple four-component graph, starting at node 0:



In compressed sparse representation, the solution looks like this:

```

>>> from scipy.sparse import csr_matrix
>>> from scipy.sparse.csgraph import breadth_first_tree
>>> X = csr_matrix([[0, 8, 0, 3],
...                 [0, 0, 2, 5],
...                 [0, 0, 0, 6],
...                 [0, 0, 0, 0]])
>>> Tcsr = breadth_first_tree(X, 0, directed=False)
>>> Tcsr.toarray().astype(int)
array([[0, 8, 0, 3],

```

```
[0, 0, 2, 0],
[0, 0, 0, 0],
[0, 0, 0, 0]])
```

Note that the resulting graph is a Directed Acyclic Graph which spans the graph. A breadth-first tree from a given node is unique.

`scipy.sparse.csgraph.depth_first_tree(csgraph, i_start, directed=True)`

Return a tree generated by a depth-first search.

Note that a tree generated by a depth-first search is not unique: it depends on the order that the children of each node are searched.

New in version 0.11.0.

**Parameters**

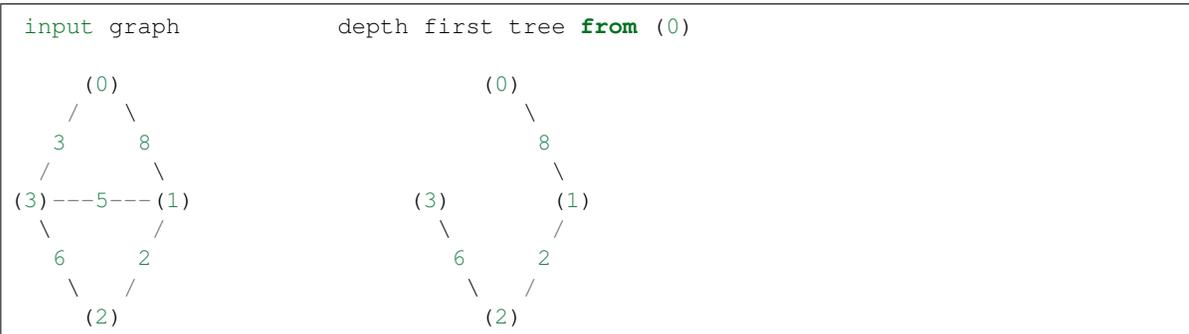
- csgraph** : array\_like or sparse matrix  
The N x N matrix representing the compressed sparse graph. The input csgraph will be converted to csr format for the calculation.
- i\_start** : int  
The index of starting node.
- directed** : bool, optional  
If True (default), then operate on a directed graph: only move from point i to point j along paths csgraph[i, j]. If False, then find the shortest path on an undirected graph: the algorithm can progress from point i to j along csgraph[i, j] or csgraph[j, i].

**Returns**

- csmtree** : csr matrix  
The N x N directed compressed-sparse representation of the depth- first tree drawn from csgraph, starting at the specified node.

### Examples

The following example shows the computation of a depth-first tree over a simple four-component graph, starting at node 0:



In compressed sparse representation, the solution looks like this:

```
>>> from scipy.sparse import csr_matrix
>>> from scipy.sparse.csgraph import depth_first_tree
>>> X = csr_matrix([[0, 8, 0, 3],
...                 [0, 0, 2, 5],
...                 [0, 0, 0, 6],
...                 [0, 0, 0, 0]])
>>> Tcsr = depth_first_tree(X, 0, directed=False)
>>> Tcsr.toarray().astype(int)
array([[0, 8, 0, 0],
       [0, 0, 2, 0],
```

```
[0, 0, 0, 6],
[0, 0, 0, 0]])
```

Note that the resulting graph is a Directed Acyclic Graph which spans the graph. Unlike a breadth-first tree, a depth-first tree of a given graph is not unique if the graph contains cycles. If the above solution had begun with the edge connecting nodes 0 and 3, the result would have been different.

`scipy.sparse.csgraph.minimum_spanning_tree(csgraph, overwrite=False)`

Return a minimum spanning tree of an undirected graph

A minimum spanning tree is a graph consisting of the subset of edges which together connect all connected nodes, while minimizing the total sum of weights on the edges. This is computed using the Kruskal algorithm.

New in version 0.11.0.

**Parameters**

- csgraph** : array\_like or sparse matrix, 2 dimensions  
The N x N matrix representing an undirected graph over N nodes (see notes below).
- overwrite** : bool, optional  
if true, then parts of the input graph will be overwritten for efficiency.

**Returns**

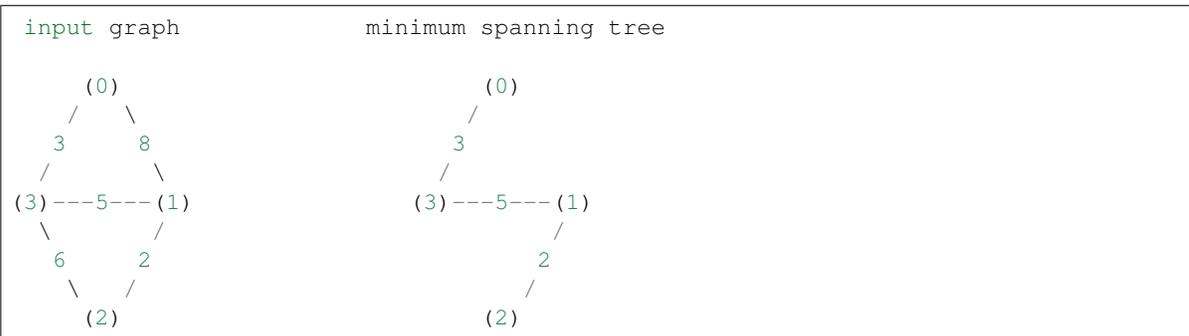
- span\_tree** : csr matrix  
The N x N compressed-sparse representation of the undirected minimum spanning tree over the input (see notes below).

### Notes

This routine uses undirected graphs as input and output. That is, if `graph[i, j]` and `graph[j, i]` are both zero, then nodes `i` and `j` do not have an edge connecting them. If either is nonzero, then the two are connected by the minimum nonzero value of the two.

### Examples

The following example shows the computation of a minimum spanning tree over a simple four-component graph:



It is easy to see from inspection that the minimum spanning tree involves removing the edges with weights 8 and 6. In compressed sparse representation, the solution looks like this:

```
>>> from scipy.sparse import csr_matrix
>>> from scipy.sparse.csgraph import minimum_spanning_tree
>>> X = csr_matrix([[0, 8, 0, 3],
...                [0, 0, 2, 5],
...                [0, 0, 0, 6],
...                [0, 0, 0, 0]])
>>> Tcsr = minimum_spanning_tree(X)
>>> Tcsr.toarray().astype(int)
array([[0, 0, 0, 3],
```

```
[0, 0, 2, 5],
[0, 0, 0, 0],
[0, 0, 0, 0]])
```

`scipy.sparse.csgraph.reverse_cuthill_mckee` (*graph*, *symmetric\_mode=False*)

Returns the permutation array that orders a sparse CSR or CSC matrix in Reverse-Cuthill McKee ordering.

It is assumed by default, `symmetric_mode=False`, that the input matrix is not symmetric and works on the matrix  $A+A.T$ . If you are guaranteed that the matrix is symmetric in structure (values of matrix elements do not matter) then set `symmetric_mode=True`.

**Parameters**

- graph** : sparse matrix  
Input sparse in CSC or CSR sparse matrix format.
- symmetric\_mode** : bool, optional  
Is input matrix guaranteed to be symmetric.

**Returns**

- perm** : ndarray  
Array of permuted row and column indices.

**Notes**

New in version 0.15.0.

**References**

E. Cuthill and J. McKee, “Reducing the Bandwidth of Sparse Symmetric Matrices”, ACM ‘69 Proceedings of the 1969 24th national conference, (1969).

`scipy.sparse.csgraph.maximum_bipartite_matching` (*graph*, *perm\_type='row'*)

Returns an array of row or column permutations that makes the diagonal of a nonsingular square CSC sparse matrix zero free.

Such a permutation is always possible provided that the matrix is nonsingular. This function looks at the structure of the matrix only. The input matrix will be converted to CSC matrix format if necessary.

**Parameters**

- graph** : sparse matrix  
Input sparse in CSC format
- perm\_type** : str, {'row', 'column'}  
Type of permutation to generate.

**Returns**

- perm** : ndarray  
Array of row or column permutations.

**Notes**

This function relies on a maximum cardinality bipartite matching algorithm based on a breadth-first search (BFS) of the underlying graph.

New in version 0.15.0.

**References**

I. S. Duff, K. Kaya, and B. Ucar, “Design, Implementation, and Analysis of Maximum Transversal Algorithms”, ACM Trans. Math. Softw. 38, no. 2, (2011).

`scipy.sparse.csgraph.structural_rank` (*graph*)

Compute the structural rank of a graph (matrix) with a given sparsity pattern.

The structural rank of a matrix is the number of entries in the maximum transversal of the corresponding bipartite graph, and is an upper bound on the numerical rank of the matrix. A graph has full structural rank if it is possible to permute the elements to make the diagonal zero-free.

**Parameters**

- graph** : sparse matrix  
Input sparse matrix.

**Returns**     **rank** : int  
                   The structural rank of the sparse graph.  
 New in version 0.19.0.

### References

[R315], [R316]

**exception** `scipy.sparse.csgraph.NegativeCycleError`

<code>construct_dist_matrix(graph, predecessors[, ...])</code>	Construct distance matrix from a predecessor matrix
<code>csgraph_from_dense(graph[, null_value, ...])</code>	Construct a CSR-format sparse graph from a dense matrix.
<code>csgraph_from_masked(graph)</code>	Construct a CSR-format graph from a masked array.
<code>csgraph_masked_from_dense(graph[, ...])</code>	Construct a masked array graph representation from a dense matrix.
<code>csgraph_to_dense(csgraph[, null_value])</code>	Convert a sparse graph representation to a dense representation
<code>csgraph_to_masked(csgraph)</code>	Convert a sparse graph representation to a masked array representation
<code>reconstruct_path(csgraph, predecessors[, ...])</code>	Construct a tree from a graph and a predecessor list.

`scipy.sparse.csgraph.construct_dist_matrix` (*graph*, *predecessors*, *directed=True*, *null\_value=np.inf*)

Construct distance matrix from a predecessor matrix

New in version 0.11.0.

**Parameters**   **graph** : array\_like or sparse  
                   The N x N matrix representation of a directed or undirected graph. If dense, then non-edges are indicated by zeros or infinities.

**predecessors** : array\_like  
                   The N x N matrix of predecessors of each node (see Notes below).

**directed** : bool, optional  
                   If True (default), then operate on a directed graph: only move from point *i* to point *j* along paths `csgraph[i, j]`. If False, then operate on an undirected graph: the algorithm can progress from point *i* to *j* along `csgraph[i, j]` or `csgraph[j, i]`.

**null\_value** : bool, optional  
                   value to use for distances between unconnected nodes. Default is `np.inf`

**Returns**       **dist\_matrix** : ndarray  
                   The N x N matrix of distances between nodes along the path specified by the predecessor matrix. If no path exists, the distance is zero.

### Notes

The predecessor matrix is of the form returned by `graph_shortest_path`. Row *i* of the predecessor matrix contains information on the shortest paths from point *i*: each entry `predecessors[i, j]` gives the index of the previous node in the path from point *i* to point *j*. If no path exists between point *i* and *j*, then `predecessors[i, j] = -9999`

`scipy.sparse.csgraph.csgraph_from_dense` (*graph*, *null\_value=0*, *nan\_null=True*, *infinity\_null=True*)

Construct a CSR-format sparse graph from a dense matrix.

New in version 0.11.0.

**Parameters**   **graph** : array\_like

Input graph. Shape should be (n\_nodes, n\_nodes).  
**null\_value** : float or None (optional)  
 Value that denotes non-edges in the graph. Default is zero.  
**infinity\_null** : bool  
 If True (default), then infinite entries (both positive and negative) are treated as null edges.  
**nan\_null** : bool  
 If True (default), then NaN entries are treated as non-edges  
**Returns** **csgraph** : csr\_matrix  
 Compressed sparse representation of graph,

`scipy.sparse.csgraph.csgraph_from_masked(graph)`  
 Construct a CSR-format graph from a masked array.

New in version 0.11.0.

**Parameters** **graph** : MaskedArray  
**Returns** **csgraph** : csr\_matrix  
 Input graph. Shape should be (n\_nodes, n\_nodes).  
 Compressed sparse representation of graph,

`scipy.sparse.csgraph.csgraph_masked_from_dense(graph, null_value=0, nan_null=True, infinity_null=True, copy=True)`  
 Construct a masked array graph representation from a dense matrix.

New in version 0.11.0.

**Parameters** **graph** : array\_like  
 Input graph. Shape should be (n\_nodes, n\_nodes).  
**null\_value** : float or None (optional)  
 Value that denotes non-edges in the graph. Default is zero.  
**infinity\_null** : bool  
 If True (default), then infinite entries (both positive and negative) are treated as null edges.  
**nan\_null** : bool  
 If True (default), then NaN entries are treated as non-edges  
**Returns** **csgraph** : MaskedArray  
 masked array representation of graph

`scipy.sparse.csgraph.csgraph_to_dense(csgraph, null_value=0)`  
 Convert a sparse graph representation to a dense representation

New in version 0.11.0.

**Parameters** **csgraph** : csr\_matrix, csc\_matrix, or lil\_matrix  
 Sparse representation of a graph.  
**null\_value** : float, optional  
 The value used to indicate null edges in the dense representation. Default is 0.  
**Returns** **graph** : ndarray  
 The dense representation of the sparse graph.

**Notes**

For normal sparse graph representations, calling `csgraph_to_dense` with `null_value=0` produces an equivalent result to using dense format conversions in the main sparse package. When the sparse representations have repeated values, however, the results will differ. The tools in `scipy.sparse` will add repeating values to obtain a final value. This function will select the minimum among repeating values to obtain a final value. For example, here we'll create a two-node directed sparse graph with multiple edges from node 0 to node 1, of weights 2 and 3. This illustrates the difference in behavior:

```

>>> from scipy.sparse import csr_matrix, csgraph
>>> data = np.array([2, 3])
>>> indices = np.array([1, 1])
>>> indptr = np.array([0, 2, 2])
>>> M = csr_matrix((data, indices, indptr), shape=(2, 2))
>>> M.toarray()
array([[0, 5],
       [0, 0]])
>>> csgraph.csgraph_to_dense(M)
array([[0., 2.],
       [0., 0.]])

```

The reason for this difference is to allow a compressed sparse graph to represent multiple edges between any two nodes. As most sparse graph algorithms are concerned with the single lowest-cost edge between any two nodes, the default `scipy.sparse` behavior of summing multiple weights does not make sense in this context.

The other reason for using this routine is to allow for graphs with zero-weight edges. Let's look at the example of a two-node directed graph, connected by an edge of weight zero:

```

>>> from scipy.sparse import csr_matrix, csgraph
>>> data = np.array([0.0])
>>> indices = np.array([1])
>>> indptr = np.array([0, 1, 1])
>>> M = csr_matrix((data, indices, indptr), shape=(2, 2))
>>> M.toarray()
array([[0, 0],
       [0, 0]])
>>> csgraph.csgraph_to_dense(M, np.inf)
array([[ inf,  0.],
       [ inf,  inf]])

```

In the first case, the zero-weight edge gets lost in the dense representation. In the second case, we can choose a different null value and see the true form of the graph.

`scipy.sparse.csgraph.csgraph_to_masked(csgraph)`

Convert a sparse graph representation to a masked array representation

New in version 0.11.0.

**Parameters** **csgraph** : `csr_matrix`, `csc_matrix`, or `lil_matrix`

**Returns** **graph** : `MaskedArray` Sparse representation of a graph.

The masked dense representation of the sparse graph.

`scipy.sparse.csgraph.reconstruct_path(csgraph, predecessors, directed=True)`

Construct a tree from a graph and a predecessor list.

New in version 0.11.0.

**Parameters** **csgraph** : `array_like` or sparse matrix

The  $N \times N$  matrix representing the directed or undirected graph from which the predecessors are drawn.

**predecessors** : `array_like`, one dimension

The length- $N$  array of indices of predecessors for the tree. The index of the parent of node  $i$  is given by `predecessors[i]`.

**directed** : `bool`, optional

If `True` (default), then operate on a directed graph: only move from point  $i$  to point  $j$  along paths `csgraph[i, j]`. If `False`, then operate on an undirected

**Returns** `cstree` : csr matrix  
 graph: the algorithm can progress from point  $i$  to  $j$  along `csgraph[i, j]` or `csgraph[j, i]`.  
 The  $N \times N$  directed compressed-sparse representation of the tree drawn from `csgraph` which is encoded by the predecessor list.

### 5.23.2 Graph Representations

This module uses graphs which are stored in a matrix format. A graph with  $N$  nodes can be represented by an  $(N \times N)$  adjacency matrix  $G$ . If there is a connection from node  $i$  to node  $j$ , then  $G[i, j] = w$ , where  $w$  is the weight of the connection. For nodes  $i$  and  $j$  which are not connected, the value depends on the representation:

- for dense array representations, non-edges are represented by  $G[i, j] = 0$ , infinity, or NaN.
- for dense masked representations (of type `np.ma.MaskedArray`), non-edges are represented by masked values. This can be useful when graphs with zero-weight edges are desired.
- for sparse array representations, non-edges are represented by non-entries in the matrix. This sort of sparse representation also allows for edges with zero weights.

As a concrete example, imagine that you would like to represent the following undirected graph:



This graph has three nodes, where node 0 and 1 are connected by an edge of weight 2, and nodes 0 and 2 are connected by an edge of weight 1. We can construct the dense, masked, and sparse representations as follows, keeping in mind that an undirected graph is represented by a symmetric matrix:

```

>>> G_dense = np.array([[0, 2, 1],
...                    [2, 0, 0],
...                    [1, 0, 0]])
>>> G_masked = np.ma.masked_values(G_dense, 0)
>>> from scipy.sparse import csr_matrix
>>> G_sparse = csr_matrix(G_dense)
  
```

This becomes more difficult when zero edges are significant. For example, consider the situation when we slightly modify the above graph:



This is identical to the previous graph, except nodes 0 and 2 are connected by an edge of zero weight. In this case, the dense representation above leads to ambiguities: how can non-edges be represented if zero is a meaningful value? In this case, either a masked or sparse representation must be used to eliminate the ambiguity:

```

>>> G2_data = np.array([[np.inf, 2, 0 ],
...                    [2, np.inf, np.inf],
...                    [0, np.inf, np.inf]])
  
```

```

... [0, np.inf, np.inf]])
>>> G2_masked = np.ma.masked_invalid(G2_data)
>>> from scipy.sparse.csgraph import csgraph_from_dense
>>> # G2_sparse = csr_matrix(G2_data) would give the wrong result
>>> G2_sparse = csgraph_from_dense(G2_data, null_value=np.inf)
>>> G2_sparse.data
array([ 2.,  0.,  2.,  0.])

```

Here we have used a utility routine from the `csgraph` submodule in order to convert the dense representation to a sparse representation which can be understood by the algorithms in submodule. By viewing the data array, we can see that the zero values are explicitly encoded in the graph.

## Directed vs. Undirected

Matrices may represent either directed or undirected graphs. This is specified throughout the `csgraph` module by a boolean keyword. Graphs are assumed to be directed by default. In a directed graph, traversal from node  $i$  to node  $j$  can be accomplished over the edge  $G[i, j]$ , but not the edge  $G[j, i]$ . In a non-directed graph, traversal from node  $i$  to node  $j$  can be accomplished over either  $G[i, j]$  or  $G[j, i]$ . If both edges are not null, and the two have unequal weights, then the smaller of the two is used. Note that a symmetric matrix will represent an undirected graph, regardless of whether the ‘directed’ keyword is set to `True` or `False`. In this case, using `directed=True` generally leads to more efficient computation.

The routines in this module accept as input either `scipy.sparse` representations (`csr`, `csc`, or `lil` format), masked representations, or dense representations with non-edges indicated by zeros, infinities, and NaN entries.

## 5.24 Spatial algorithms and data structures (`scipy.spatial`)

### 5.24.1 Nearest-neighbor Queries

<code>KDTree</code> ( <code>data</code> [, <code>leafsize</code> ])	kd-tree for quick nearest-neighbor lookup
<code>cKDTree</code>	kd-tree for quick nearest-neighbor lookup
<code>distance</code>	
<code>Rectangle</code> ( <code>maxes</code> , <code>mins</code> )	Hyperrectangle class.

**class** `scipy.spatial.KDTree`(`data`, `leafsize=10`)  
kd-tree for quick nearest-neighbor lookup

This class provides an index into a set of  $k$ -dimensional points which can be used to rapidly look up the nearest neighbors of any point.

**Parameters**

- data** : (N,K) array\_like  
The data points to be indexed. This array is not copied, and so modifying this data will result in bogus results.
- leafsize** : int, optional  
The number of points at which the algorithm switches over to brute-force. Has to be positive.

**Raises**

- RuntimeError**  
The maximum recursion limit can be exceeded for large data sets. If this happens, either increase the value for the `leafsize` parameter or increase the recursion limit by:

```
>>> import sys
>>> sys.setrecursionlimit(10000)
```

See also:

**cKDTree** Implementation of *KDTree* in Cython

**Notes**

The algorithm used is described in Maneewongvatana and Mount 1999. The general idea is that the kd-tree is a binary tree, each of whose nodes represents an axis-aligned hyperrectangle. Each node specifies an axis and splits the set of points based on whether their coordinate along that axis is greater than or less than a particular value.

During construction, the axis and splitting point are chosen by the “sliding midpoint” rule, which ensures that the cells do not all become long and thin.

The tree can be queried for the *r* closest neighbors of any given point (optionally returning only those within some maximum distance of the point). It can also be queried, with a substantial gain in efficiency, for the *r* approximate closest neighbors.

For large dimensions (20 is already large) do not expect this to run significantly faster than brute force. High-dimensional nearest-neighbor queries are a substantial open problem in computer science.

The tree also supports all-neighbors queries, both with arrays of points and with other kd-trees. These do use a reasonably efficient algorithm, but the kd-tree is not necessarily the best data structure for this sort of calculation.

**Methods**

<code>count_neighbors(other, r[, p])</code>	Count how many nearby pairs can be formed.
<code>innernode(split_dim, split, less, greater)</code>	
<code>leafnode(idx)</code>	
<code>node</code>	
<code>query(x[, k, eps, p, distance_upper_bound])</code>	Query the kd-tree for nearest neighbors
<code>query_ball_point(x, r[, p, eps])</code>	Find all points within distance <i>r</i> of point(s) <i>x</i> .
<code>query_ball_tree(other, r[, p, eps])</code>	Find all pairs of points whose distance is at most <i>r</i>
<code>query_pairs(r[, p, eps])</code>	Find all pairs of points within a distance.
<code>sparse_distance_matrix(other, max_distance)</code>	Compute a sparse distance matrix

`KDTree.count_neighbors` (*other*, *r*, *p*=2.0)

Count how many nearby pairs can be formed.

Count the number of pairs (*x*<sub>1</sub>,*x*<sub>2</sub>) can be formed, with *x*<sub>1</sub> drawn from self and *x*<sub>2</sub> drawn from *other*, and where `distance(x1, x2, p) <= r`. This is the “two-point correlation” described in Gray and Moore 2000, “N-body problems in statistical learning”, and the code here is based on their algorithm.

**Parameters**

- other** : KDTree instance  
The other tree to draw points from.
- r** : float or one-dimensional array of floats  
The radius to produce a count for. Multiple radii are searched with a single tree traversal.
- p** : float, 1<=p<=infinity, optional  
Which Minkowski p-norm to use

**Returns**

- result** : int or 1-D array of ints  
The number of pairs. Note that this is internally stored in a numpy int, and so may overflow if very large (2e9).

`KDTree.query(x, k=1, eps=0, p=2, distance_upper_bound=inf)`

Query the kd-tree for nearest neighbors

**Parameters**

- x** : array\_like, last dimension self.m  
An array of points to query.
- k** : int, optional  
The number of nearest neighbors to return.
- eps** : nonnegative float, optional  
Return approximate nearest neighbors; the kth returned value is guaranteed to be no further than (1+eps) times the distance to the real kth nearest neighbor.
- p** : float,  $1 \leq p \leq \text{infinity}$ , optional  
Which Minkowski p-norm to use. 1 is the sum-of-absolute-values “Manhattan” distance 2 is the usual Euclidean distance infinity is the maximum-coordinate-difference distance
- distance\_upper\_bound** : nonnegative float, optional  
Return only neighbors within this distance. This is used to prune tree searches, so if you are doing a series of nearest-neighbor queries, it may help to supply the distance to the nearest neighbor of the most recent point.

**Returns**

- d** : float or array of floats  
The distances to the nearest neighbors. If x has shape tuple+(self.m,), then d has shape tuple if k is one, or tuple+(k,) if k is larger than one. Missing neighbors (e.g. when  $k > n$  or `distance_upper_bound` is given) are indicated with infinite distances. If k is None, then d is an object array of shape tuple, containing lists of distances. In either case the hits are sorted by distance (nearest first).
- i** : integer or array of integers  
The locations of the neighbors in self.data. i is the same shape as d.

### Examples

```
>>> from scipy import spatial
>>> x, y = np.mgrid[0:5, 2:8]
>>> tree = spatial.KDTree(list(zip(x.ravel(), y.ravel())))
>>> tree.data
array([[0, 2],
       [0, 3],
       [0, 4],
       [0, 5],
       [0, 6],
       [0, 7],
       [1, 2],
       [1, 3],
       [1, 4],
       [1, 5],
       [1, 6],
       [1, 7],
       [2, 2],
       [2, 3],
       [2, 4],
       [2, 5],
       [2, 6],
       [2, 7],
       [3, 2],
       [3, 3],
       [3, 4],
```

```

        [3, 5],
        [3, 6],
        [3, 7],
        [4, 2],
        [4, 3],
        [4, 4],
        [4, 5],
        [4, 6],
        [4, 7]])
>>> pts = np.array([[0, 0], [2.1, 2.9]])
>>> tree.query(pts)
(array([ 2.          ,  0.14142136]), array([ 0, 13]))
>>> tree.query(pts[0])
(2.0, 0)

```

`KDTree.query_ball_point` ( $x$ ,  $r$ ,  $p=2.0$ ,  $eps=0$ )

Find all points within distance  $r$  of point(s)  $x$ .

**Parameters**

- x** : array\_like, shape tuple + (self.m.)  
The point or points to search for neighbors of.
- r** : positive float  
The radius of points to return.
- p** : float, optional  
Which Minkowski p-norm to use. Should be in the range [1, inf].
- eps** : nonnegative float, optional  
Approximate search. Branches of the tree are not explored if their nearest points are further than  $r / (1 + eps)$ , and branches are added in bulk if their furthest points are nearer than  $r * (1 + eps)$ .

**Returns**

- results** : list or array of lists  
If  $x$  is a single point, returns a list of the indices of the neighbors of  $x$ . If  $x$  is an array of points, returns an object array of shape tuple containing lists of neighbors.

### Notes

If you have many points whose neighbors you want to find, you may save substantial amounts of time by putting them in a KDTree and using `query_ball_tree`.

### Examples

```

>>> from scipy import spatial
>>> x, y = np.mgrid[0:5, 0:5]
>>> points = np.c_[x.ravel(), y.ravel()]
>>> tree = spatial.KDTree(points)
>>> tree.query_ball_point([2, 0], 1)
[5, 10, 11, 15]

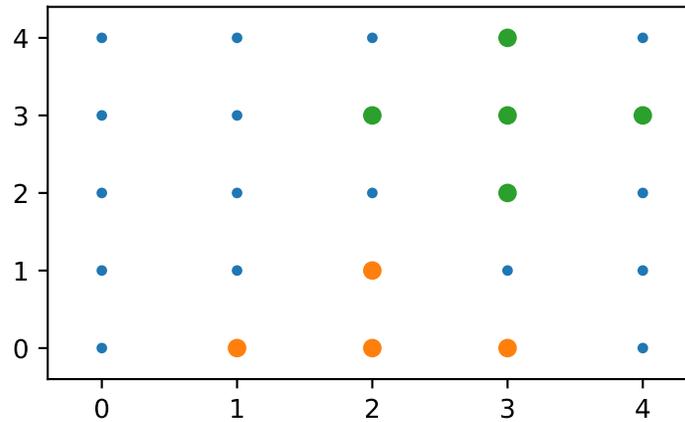
```

Query multiple points and plot the results:

```

>>> import matplotlib.pyplot as plt
>>> points = np.asarray(points)
>>> plt.plot(points[:,0], points[:,1], '.')
>>> for results in tree.query_ball_point([[2, 0], [3, 3]], 1):
...     nearby_points = points[results]
...     plt.plot(nearby_points[:,0], nearby_points[:,1], 'o')
>>> plt.margins(0.1, 0.1)
>>> plt.show()

```



`KDTree.query_ball_tree` (*other*, *r*, *p*=2.0, *eps*=0)

Find all pairs of points whose distance is at most *r*

**Parameters**

- other** : KDTree instance  
The tree containing points to search against.
- r** : float  
The maximum distance, has to be positive.
- p** : float, optional  
Which Minkowski norm to use. *p* has to meet the condition  $1 \leq p \leq \text{infinity}$ .
- eps** : float, optional  
Approximate search. Branches of the tree are not explored if their nearest points are further than  $r / (1 + \text{eps})$ , and branches are added in bulk if their furthest points are nearer than  $r * (1 + \text{eps})$ . *eps* has to be non-negative.

**Returns**

- results** : list of lists  
For each element `self.data[i]` of this tree, `results[i]` is a list of the indices of its neighbors in `other.data`.

`KDTree.query_pairs` (*r*, *p*=2.0, *eps*=0)

Find all pairs of points within a distance.

**Parameters**

- r** : positive float  
The maximum distance.
- p** : float, optional  
Which Minkowski norm to use. *p* has to meet the condition  $1 \leq p \leq \text{infinity}$ .
- eps** : float, optional  
Approximate search. Branches of the tree are not explored if their nearest points are further than  $r / (1 + \text{eps})$ , and branches are added in bulk if their furthest points are nearer than  $r * (1 + \text{eps})$ . *eps* has to be non-negative.

**Returns**

- results** : set  
Set of pairs  $(i, j)$ , with  $i < j$ , for which the corresponding positions are close.

`KDTree.sparse_distance_matrix` (*other*, *max\_distance*, *p=2.0*)

Compute a sparse distance matrix

Computes a distance matrix between two KDTrees, leaving as zero any distance greater than *max\_distance*.

**Parameters**    **other** : KDTree  
                   **max\_distance** : positive float

**Returns**        **p** : float, optional  
                   **result** : dok\_matrix

Sparse matrix representing the results in “dictionary of keys” format.

**class** `scipy.spatial.cKDTree`

kd-tree for quick nearest-neighbor lookup

This class provides an index into a set of k-dimensional points which can be used to rapidly look up the nearest neighbors of any point.

The algorithm used is described in Maneewongvatana and Mount 1999. The general idea is that the kd-tree is a binary trie, each of whose nodes represents an axis-aligned hyperrectangle. Each node specifies an axis and splits the set of points based on whether their coordinate along that axis is greater than or less than a particular value.

During construction, the axis and splitting point are chosen by the “sliding midpoint” rule, which ensures that the cells do not all become long and thin.

The tree can be queried for the *r* closest neighbors of any given point (optionally returning only those within some maximum distance of the point). It can also be queried, with a substantial gain in efficiency, for the *r* approximate closest neighbors.

For large dimensions (20 is already large) do not expect this to run significantly faster than brute force. High-dimensional nearest-neighbor queries are a substantial open problem in computer science.

**Parameters**    **data** : array\_like, shape (n,m)

The n data points of dimension m to be indexed. This array is not copied unless this is necessary to produce a contiguous array of doubles, and so modifying this data will result in bogus results. The data are also copied if the kd-tree is built with `copy_data=True`.

**leafsize** : positive int, optional

The number of points at which the algorithm switches over to brute-force. Default: 16.

**compact\_nodes** : bool, optional

If True, the kd-tree is built to shrink the hyperrectangles to the actual data range. This usually gives a more compact tree that is robust against degenerated input data and gives faster queries at the expense of longer build time. Default: True.

**copy\_data** : bool, optional

If True the data is always copied to protect the kd-tree against data corruption. Default: False.

**balanced\_tree** : bool, optional

If True, the median is used to split the hyperrectangles instead of the midpoint. This usually gives a more compact tree and faster queries at the expense of longer build time. Default: True.

**boxsize** : array\_like or scalar, optional

Apply a m-d toroidal topology to the KDTree.. The topology is generated by  $x_i + n_i L_i$  where  $n_i$  are integers and  $L_i$  is the boxsize along i-th dimension. The input data shall be wrapped into  $[0, L_i)$ . A ValueError is raised if any of the data is outside of this bound.

**See also:****KDTree** Implementation of *cKDTree* in pure Python**Attributes**

<code>data</code>	(ndarray, shape (n,m)) The n data points of dimension m to be indexed. This array is not copied unless this is necessary to produce a contiguous array of doubles. The data are also copied if the kd-tree is built with <i>copy_data=True</i> .
<code>leaf-size</code>	(positive int) The number of points at which the algorithm switches over to brute-force.
<code>m</code>	(int) The dimension of a single data-point.
<code>n</code>	(int) The number of data points.
<code>maxes</code>	(ndarray, shape (m,)) The maximum value in each dimension of the n data points.
<code>mins</code>	(ndarray, shape (m,)) The minimum value in each dimension of the n data points.
<code>tree</code>	(object, class <i>cKDTreeNode</i> ) This class exposes a Python view of the root node in the <i>cKDTree</i> object.
<code>size</code>	(int) The number of nodes in the tree.

**Methods**

<code>count_neighbors(self, other, r[, p, ...])</code>	Count how many nearby pairs can be formed.
<code>query(self, x[, k, eps, p, ...])</code>	Query the kd-tree for nearest neighbors
<code>query_ball_point(self, x, r[, p, eps])</code>	Find all points within distance r of point(s) x.
<code>query_ball_tree(self, other, r[, p, eps])</code>	Find all pairs of points whose distance is at most r
<code>query_pairs(self, r[, p, eps])</code>	Find all pairs of points whose distance is at most r.
<code>sparse_distance_matrix(self, other, max_distance)</code>	Compute a sparse distance matrix

`cKDTree.count_neighbors` (*self, other, r, p=2., weights=None, cumulative=True*)

Count how many nearby pairs can be formed. (pair-counting)

Count the number of pairs (x1,x2) can be formed, with x1 drawn from *self* and x2 drawn from *other*, and where `distance(x1, x2, p) <= r`.

Data points on *self* and *other* are optionally weighted by the *weights* argument. (See below)

The algorithm we implement here is based on [R401]. See notes for further discussion.

**Parameters** **other** : *cKDTree* instance

The other tree to draw points from, can be the same tree as *self*.

**r** : float or one-dimensional array of floats

The radius to produce a count for. Multiple radii are searched with a single tree traversal. If the count is non-cumulative (*cumulative=False*), *r* defines the edges of the bins, and must be non-decreasing.

**p** : float, optional

$1 \leq p \leq \infty$ . Which Minkowski p-norm to use. Default 2.0.

**weights** : tuple, array\_like, or None, optional

If None, the pair-counting is unweighted. If given as a tuple, `weights[0]` is the weights of points in *self*, and `weights[1]` is the weights of points in *other*; either can be None to indicate the points are unweighted. If given as an array\_like, *weights* is the weights of points in *self* and *other*. For this to make sense, *self* and *other* must be the same tree. If *self* and *other* are two different trees, a `ValueError` is raised. Default: None

**cumulative** : bool, optional  
 Whether the returned counts are cumulative. When `cumulative` is set to `False` the algorithm is optimized to work with a large number of bins (>10) specified by `r`. When `cumulative` is set to `True`, the algorithm is optimized to work with a small number of `r`. Default: `True`.

**Returns** **result** : scalar or 1-D array  
 The number of pairs. For unweighted counts, the result is integer. For weighted counts, the result is float. If `cumulative` is `False`, `result[i]` contains the counts with `(-inf if i == 0 else r[i-1]) < R <= r[i]`

**Notes**

Pair-counting is the basic operation used to calculate the two point correlation functions from a data set composed of position of objects.

Two point correlation function measures the clustering of objects and is widely used in cosmology to quantify the large scale structure in our Universe, but it may be useful for data analysis in other fields where self-similar assembly of objects also occur.

The Landy-Szalay estimator for the two point correlation function of `D` measures the clustering signal in `D`. [R402]

- For example, given the position of two sets of objects,
- objects `D` (data) contains the clustering signal, and
  - objects `R` (random) that contains no signal,

$$\xi(r) = \frac{\langle D, D \rangle - 2f \langle D, R \rangle + f^2 \langle R, R \rangle}{f^2 \langle R, R \rangle},$$

where the brackets represents counting pairs between two data sets in a finite bin around `r` (distance), corresponding to setting `cumulative=False`, and `f = float(len(D)) / float(len(R))` is the ratio between number of objects from data and random.

The algorithm implemented here is loosely based on the dual-tree algorithm described in [R401]. We switch between two different pair-cumulation scheme depending on the setting of `cumulative`. The computing time of the method we use when for `cumulative == False` does not scale with the total number of bins. The algorithm for `cumulative == True` scales linearly with the number of bins, though it is slightly faster when only 1 or 2 bins are used. [R405].

As an extension to the naive pair-counting, weighted pair-counting counts the product of weights instead of number of pairs. Weighted pair-counting is used to estimate marked correlation functions ([R403], section 2.2), or to properly calculate the average of data per distance bin (e.g. [R404], section 2.1 on redshift).

`ckdtree.query(self, x, k=1, eps=0, p=2, distance_upper_bound=np.inf, n_jobs=1)`

Query the kd-tree for nearest neighbors

**Parameters** **x** : array\_like, last dimension self.m  
 An array of points to query.

**k** : list of integer or integer  
 The list of k-th nearest neighbors to return. If `k` is an integer it is treated as a list of `[1, ... k]` (`range(1, k+1)`). Note that the counting starts from 1.

**eps** : non-negative float  
 Return approximate nearest neighbors; the k-th returned value is guaranteed to be no further than `(1+eps)` times the distance to the real k-th nearest neighbor.

**p** : float, `1 <= p <= infinity`

Which Minkowski  $p$ -norm to use. 1 is the sum-of-absolute-values “Manhattan” distance 2 is the usual Euclidean distance infinity is the maximum-coordinate-difference distance

**distance\_upper\_bound** : nonnegative float

Return only neighbors within this distance. This is used to prune tree searches, so if you are doing a series of nearest-neighbor queries, it may help to supply the distance to the nearest neighbor of the most recent point.

**n\_jobs** : int, optional

Number of jobs to schedule for parallel processing. If -1 is given all processors are used. Default: 1.

**Returns**

**d** : array of floats

The distances to the nearest neighbors. If  $x$  has shape `tuple+(self.m,)`, then  $d$  has shape `tuple+(k,)`. When  $k == 1$ , the last dimension of the output is squeezed. Missing neighbors are indicated with infinite distances.

**i** : ndarray of ints

The locations of the neighbors in `self.data`. If  $x$  has shape `tuple+(self.m,)`, then  $i$  has shape `tuple+(k,)`. When  $k == 1$ , the last dimension of the output is squeezed. Missing neighbors are indicated with `self.n`.

### Notes

If the KD-Tree is periodic, the position  $x$  is wrapped into the box.

When the input  $k$  is a list, a query for `arange(max(k))` is performed, but only columns that store the requested values of  $k$  are preserved. This is implemented in a manner that reduces memory usage.

### Examples

```
>>> import numpy as np
>>> from scipy.spatial import cKDTree
>>> x, y = np.mgrid[0:5, 2:8]
>>> tree = cKDTree(np.c_[x.ravel(), y.ravel()])
```

To query the nearest neighbours and return squeezed result, use

```
>>> dd, ii = tree.query([[0, 0], [2.1, 2.9]], k=1)
>>> print(dd, ii)
[ 2.          0.14142136] [ 0 13]
```

To query the nearest neighbours and return unsqueezed result, use

```
>>> dd, ii = tree.query([[0, 0], [2.1, 2.9]], k=[1])
>>> print(dd, ii)
[[ 2.          ]
 [ 0.14142136]] [[ 0]
 [13]]
```

To query the second nearest neighbours and return unsqueezed result, use

```
>>> dd, ii = tree.query([[0, 0], [2.1, 2.9]], k=[2])
>>> print(dd, ii)
[[ 2.23606798]
 [ 0.90553851]] [[ 6]
 [12]]
```

To query the first and second nearest neighbours, use

```
>>> dd, ii = tree.query([[0, 0], [2.1, 2.9]], k=2)
>>> print(dd, ii)
[[ 2.          2.23606798]
 [ 0.14142136  0.90553851]] [[ 0  6]
 [13 12]]
```

or, be more specific

```
>>> dd, ii = tree.query([[0, 0], [2.1, 2.9]], k=[1, 2])
>>> print(dd, ii)
[[ 2.          2.23606798]
 [ 0.14142136  0.90553851]] [[ 0  6]
 [13 12]]
```

`cKDTree.query_ball_point` (*self*, *x*, *r*, *p=2.*, *eps=0*)

Find all points within distance *r* of point(s) *x*.

**Parameters** **x** : array\_like, shape tuple + (self.m.)

The point or points to search for neighbors of.

**r** : positive float

The radius of points to return.

**p** : float, optional

Which Minkowski *p*-norm to use. Should be in the range [1, inf].

**eps** : nonnegative float, optional

Approximate search. Branches of the tree are not explored if their nearest points are further than  $r / (1 + \text{eps})$ , and branches are added in bulk if their furthest points are nearer than  $r * (1 + \text{eps})$ .

**n\_jobs** : int, optional

Number of jobs to schedule for parallel processing. If -1 is given all processors are used. Default: 1.

**Returns** **results** : list or array of lists

If *x* is a single point, returns a list of the indices of the neighbors of *x*. If *x* is an array of points, returns an object array of shape tuple containing lists of neighbors.

### Notes

If you have many points whose neighbors you want to find, you may save substantial amounts of time by putting them in a `cKDTree` and using `query_ball_tree`.

### Examples

```
>>> from scipy import spatial
>>> x, y = np.mgrid[0:4, 0:4]
>>> points = np.c_[x.ravel(), y.ravel()]
>>> tree = spatial.cKDTree(points)
>>> tree.query_ball_point([2, 0], 1)
[4, 8, 9, 12]
```

`cKDTree.query_ball_tree` (*self*, *other*, *r*, *p=2.*, *eps=0*)

Find all pairs of points whose distance is at most *r*

**Parameters** **other** : cKDTree instance

The tree containing points to search against.

**r** : float

The maximum distance, has to be positive.

**p** : float, optional  
Which Minkowski norm to use.  $p$  has to meet the condition  $1 \leq p \leq \text{infinity}$ .

**eps** : float, optional  
Approximate search. Branches of the tree are not explored if their nearest points are further than  $r / (1 + \text{eps})$ , and branches are added in bulk if their furthest points are nearer than  $r * (1 + \text{eps})$ .  $\text{eps}$  has to be non-negative.

**Returns** **results** : list of lists  
For each element `self.data[i]` of this tree, `results[i]` is a list of the indices of its neighbors in `other.data`.

`cKDTree.query_pairs` (*self*, *r*, *p=2.*, *eps=0*)  
Find all pairs of points whose distance is at most *r*.

**Parameters** **r** : positive float  
The maximum distance.

**p** : float, optional  
Which Minkowski norm to use.  $p$  has to meet the condition  $1 \leq p \leq \text{infinity}$ .

**eps** : float, optional  
Approximate search. Branches of the tree are not explored if their nearest points are further than  $r / (1 + \text{eps})$ , and branches are added in bulk if their furthest points are nearer than  $r * (1 + \text{eps})$ .  $\text{eps}$  has to be non-negative.

**output\_type** : string, optional  
Choose the output container, 'set' or 'ndarray'. Default: 'set'

**Returns** **results** : set or ndarray  
Set of pairs  $(i, j)$ , with  $i < j$ , for which the corresponding positions are close. If `output_type` is 'ndarray', an ndarray is returned instead of a set.

`cKDTree.sparse_distance_matrix` (*self*, *other*, *max\_distance*, *p=2.*)  
Compute a sparse distance matrix

Computes a distance matrix between two `cKDTree`s, leaving as zero any distance greater than `max_distance`.

**Parameters** **other** : `cKDTree`  
**max\_distance** : positive float  
**p** : float,  $1 \leq p \leq \text{infinity}$   
Which Minkowski  $p$ -norm to use.

**output\_type** : string, optional  
Which container to use for output data. Options: 'dok\_matrix', 'coo\_matrix', 'dict' or 'ndarray'. Default: 'dok\_matrix'.

**Returns** **result** : `dok_matrix`, `coo_matrix`, `dict` or `ndarray`  
Sparse matrix representing the results in "dictionary of keys" format. If a dict is returned the keys are  $(i, j)$  tuples of indices. If `output_type` is 'ndarray' a record array with fields 'i', 'j', and 'k' is returned,

### Distance computations (*scipy.spatial.distance*)

#### Function Reference

Distance matrix computation from a collection of raw observation vectors stored in a rectangular array.

<code>pdist(X[, metric])</code>	Pairwise distances between observations in n-dimensional space.
<code>cdist(XA, XB[, metric])</code>	Computes distance between each pair of the two collections of inputs.
<code>squareform(X[, force, checks])</code>	Converts a vector-form distance vector to a square-form distance matrix, and vice-versa.
<code>directed_hausdorff(u, v[, seed])</code>	Computes the directed Hausdorff distance between two N-D arrays.

`scipy.spatial.distance.pdist` (*X*, *metric*='euclidean', \*args, \*\*kwargs)

Pairwise distances between observations in n-dimensional space.

See Notes for common calling conventions.

**Parameters**    **X** : ndarray

An m by n array of m original observations in an n-dimensional space.

**metric** : str or function, optional

The distance metric to use. The distance function can be 'braycurtis', 'canberra', 'chebyshev', 'cityblock', 'correlation', 'cosine', 'dice', 'euclidean', 'hamming', 'jaccard', 'kulsinski', 'mahalanobis', 'matching', 'minkowski', 'rogerstanimoto', 'russellrao', 'seuclidean', 'sokalmichener', 'sokalsneath', 'sqeuclidean', 'yule'.

**\*args** : tuple. Deprecated.

Additional arguments should be passed as keyword arguments

**\*\*kwargs** : dict, optional

Extra arguments to *metric*: refer to each metric documentation for a list of all possible arguments.

Some possible arguments:

**p** : scalar The p-norm to apply for Minkowski, weighted and unweighted. Default: 2.

**w** : ndarray The weight vector for metrics that support weights (e.g., Minkowski).

**V** : ndarray The variance vector for standardized Euclidean. Default: var(X, axis=0, ddof=1)

**VI** : ndarray The inverse of the covariance matrix for Mahalanobis. Default: inv(cov(X.T)).T

**out** : ndarray. The output array If not None, condensed distance matrix Y is stored in this array. Note: metric independent, it will become a regular keyword arg in a future scipy version

**Returns**        **Y** : ndarray

Returns a condensed distance matrix Y. For each *i* and *j* (where  $i < j < m$ ), where *m* is the number of original observations. The metric `dist(u=X[i], v=X[j])` is computed and stored in entry `ij`.

**See also:**

**squareform** converts between condensed distance matrices and square distance matrices.

**Notes**

See `squareform` for information on how to calculate the index of this entry or to convert the condensed distance matrix to a redundant square matrix.

The following are common calling conventions.

1. `Y = pdist(X, 'euclidean')`

Computes the distance between  $m$  points using Euclidean distance (2-norm) as the distance metric between the points. The points are arranged as  $m$   $n$ -dimensional row vectors in the matrix  $X$ .

2. `Y = pdist(X, 'minkowski', p=2.)`

Computes the distances using the Minkowski distance  $\|u - v\|_p$  ( $p$ -norm) where  $p \geq 1$ .

3. `Y = pdist(X, 'cityblock')`

Computes the city block or Manhattan distance between the points.

4. `Y = pdist(X, 'seuclidean', V=None)`

Computes the standardized Euclidean distance. The standardized Euclidean distance between two  $n$ -vectors  $u$  and  $v$  is

$$\sqrt{\sum (u_i - v_i)^2 / V[x_i]}$$

$V$  is the variance vector;  $V[i]$  is the variance computed over all the  $i$ 'th components of the points. If not passed, it is automatically computed.

5. `Y = pdist(X, 'sqeuclidean')`

Computes the squared Euclidean distance  $\|u - v\|_2^2$  between the vectors.

6. `Y = pdist(X, 'cosine')`

Computes the cosine distance between vectors  $u$  and  $v$ ,

$$1 - \frac{u \cdot v}{\|u\|_2 \|v\|_2}$$

where  $\|* \|_2$  is the 2-norm of its argument  $*$ , and  $u \cdot v$  is the dot product of  $u$  and  $v$ .

7. `Y = pdist(X, 'correlation')`

Computes the correlation distance between vectors  $u$  and  $v$ . This is

$$1 - \frac{(u - \bar{u}) \cdot (v - \bar{v})}{\|(u - \bar{u})\|_2 \|(v - \bar{v})\|_2}$$

where  $\bar{v}$  is the mean of the elements of vector  $v$ , and  $x \cdot y$  is the dot product of  $x$  and  $y$ .

8. `Y = pdist(X, 'hamming')`

Computes the normalized Hamming distance, or the proportion of those vector elements between two  $n$ -vectors  $u$  and  $v$  which disagree. To save memory, the matrix  $X$  can be of type boolean.

9. `Y = pdist(X, 'jaccard')`

Computes the Jaccard distance between the points. Given two vectors,  $u$  and  $v$ , the Jaccard distance is the proportion of those elements  $u[i]$  and  $v[i]$  that disagree.

10. `Y = pdist(X, 'chebyshev')`

Computes the Chebyshev distance between the points. The Chebyshev distance between two  $n$ -vectors  $u$  and  $v$  is the maximum norm-1 distance between their respective elements. More precisely, the distance is given by

$$d(u, v) = \max_i |u_i - v_i|$$

11. `Y = pdist(X, 'canberra')`

Computes the Canberra distance between the points. The Canberra distance between two points  $u$  and  $v$  is

$$d(u, v) = \sum_i \frac{|u_i - v_i|}{|u_i| + |v_i|}$$

12.Y = pdist(X, 'braycurtis')

Computes the Bray-Curtis distance between the points. The Bray-Curtis distance between two points  $u$  and  $v$  is

$$d(u, v) = \frac{\sum_i |u_i - v_i|}{\sum_i |u_i + v_i|}$$

13.Y = pdist(X, 'mahalanobis', VI=None)

Computes the Mahalanobis distance between the points. The Mahalanobis distance between two points  $u$  and  $v$  is  $\sqrt{(u-v)(1/V)(u-v)^T}$  where  $(1/V)$  (the VI variable) is the inverse covariance. If VI is not None, VI will be used as the inverse covariance matrix.

14.Y = pdist(X, 'yule')

Computes the Yule distance between each pair of boolean vectors. (see yule function documentation)

15.Y = pdist(X, 'matching')

Synonym for 'hamming'.

16.Y = pdist(X, 'dice')

Computes the Dice distance between each pair of boolean vectors. (see dice function documentation)

17.Y = pdist(X, 'kulsinski')

Computes the Kulsinski distance between each pair of boolean vectors. (see kulsinski function documentation)

18.Y = pdist(X, 'rogerstanimoto')

Computes the Rogers-Tanimoto distance between each pair of boolean vectors. (see rogerstanimoto function documentation)

19.Y = pdist(X, 'russellrao')

Computes the Russell-Rao distance between each pair of boolean vectors. (see russellrao function documentation)

20.Y = pdist(X, 'sokalmichener')

Computes the Sokal-Michener distance between each pair of boolean vectors. (see sokalmichener function documentation)

21.Y = pdist(X, 'sokalsneath')

Computes the Sokal-Sneath distance between each pair of boolean vectors. (see sokalsneath function documentation)

22.Y = pdist(X, 'wminkowski', p=2, w=w)

Computes the weighted Minkowski distance between each pair of vectors. (see wminkowski function documentation)

23.Y = pdist(X, f)

Computes the distance between all pairs of vectors in X using the user supplied 2-arity function f. For example, Euclidean distance between the vectors could be computed as follows:

```
dm = pdist(X, lambda u, v: np.sqrt(((u-v)**2).sum()))
```

Note that you should avoid passing a reference to one of the distance functions defined in this library. For example,:

```
dm = pdist(X, sokalsneath)
```

would calculate the pair-wise distances between the vectors in  $X$  using the Python function `sokalsneath`. This would result in `sokalsneath` being called  $\binom{n}{2}$  times, which is inefficient. Instead, the optimized C version is more efficient, and we call it using the following syntax.:

```
dm = pdist(X, 'sokalsneath')
```

`scipy.spatial.distance.cdist` ( $XA, XB, metric='euclidean', *args, **kwargs$ )

Computes distance between each pair of the two collections of inputs.

See Notes for common calling conventions.

**Parameters**    **XA** : ndarray

An  $m_A$  by  $n$  array of  $m_A$  original observations in an  $n$ -dimensional space. Inputs are converted to float type.

**XB** : ndarray

An  $m_B$  by  $n$  array of  $m_B$  original observations in an  $n$ -dimensional space. Inputs are converted to float type.

**metric** : str or callable, optional

The distance metric to use. If a string, the distance function can be 'braycurtis', 'canberra', 'chebyshev', 'cityblock', 'correlation', 'cosine', 'dice', 'euclidean', 'hamming', 'jaccard', 'kulsinski', 'mahalanobis', 'matching', 'minkowski', 'rogerstanimoto', 'russellrao', 'seuclidean', 'sokalmichener', 'sokalsneath', 'sqeuclidean', 'wminkowski', 'yule'.

**\*args** : tuple. Deprecated.

Additional arguments should be passed as keyword arguments

**\*\*kwargs** : dict, optional

Extra arguments to *metric*: refer to each metric documentation for a list of all possible arguments.

Some possible arguments:

**p** : scalar The p-norm to apply for Minkowski, weighted and unweighted. Default: 2.

**w** : ndarray The weight vector for metrics that support weights (e.g., Minkowski).

**V** : ndarray The variance vector for standardized Euclidean. Default: `var(vstack([XA, XB]), axis=0, ddof=1)`

**VI** : ndarray The inverse of the covariance matrix for Mahalanobis. Default: `inv(cov(vstack([XA, XB].T))).T`

**out** : ndarray The output array If not None, the distance matrix  $Y$  is stored in this array. Note: metric independent, it will become a regular keyword arg in a future scipy version

**Returns**        **Y** : ndarray

A  $m_A$  by  $m_B$  distance matrix is returned. For each  $i$  and  $j$ , the metric `dist(u=XA[i], v=XB[j])` is computed and stored in the  $ij$  th entry.

**Raises**        **ValueError**

An exception is thrown if  $XA$  and  $XB$  do not have the same number of columns.

### Notes

The following are common calling conventions:

1.Y = cdist(XA, XB, 'euclidean')

Computes the distance between  $m$  points using Euclidean distance (2-norm) as the distance metric between the points. The points are arranged as  $m$   $n$ -dimensional row vectors in the matrix X.

2.Y = cdist(XA, XB, 'minkowski', p=2.)

Computes the distances using the Minkowski distance  $\|u - v\|_p$  ( $p$ -norm) where  $p \geq 1$ .

3.Y = cdist(XA, XB, 'cityblock')

Computes the city block or Manhattan distance between the points.

4.Y = cdist(XA, XB, 'seuclidean', V=None)

Computes the standardized Euclidean distance. The standardized Euclidean distance between two  $n$ -vectors  $u$  and  $v$  is

$$\sqrt{\sum (u_i - v_i)^2 / V[x_i]}.$$

$V$  is the variance vector;  $V[i]$  is the variance computed over all the  $i$ 'th components of the points. If not passed, it is automatically computed.

5.Y = cdist(XA, XB, 'sqeuclidean')

Computes the squared Euclidean distance  $\|u - v\|_2^2$  between the vectors.

6.Y = cdist(XA, XB, 'cosine')

Computes the cosine distance between vectors  $u$  and  $v$ ,

$$1 - \frac{u \cdot v}{\|u\|_2 \|v\|_2}$$

where  $\|* \|_2$  is the 2-norm of its argument  $*$ , and  $u \cdot v$  is the dot product of  $u$  and  $v$ .

7.Y = cdist(XA, XB, 'correlation')

Computes the correlation distance between vectors  $u$  and  $v$ . This is

$$1 - \frac{(u - \bar{u}) \cdot (v - \bar{v})}{\|(u - \bar{u})\|_2 \|(v - \bar{v})\|_2}$$

where  $\bar{v}$  is the mean of the elements of vector  $v$ , and  $x \cdot y$  is the dot product of  $x$  and  $y$ .

8.Y = cdist(XA, XB, 'hamming')

Computes the normalized Hamming distance, or the proportion of those vector elements between two  $n$ -vectors  $u$  and  $v$  which disagree. To save memory, the matrix X can be of type boolean.

9.Y = cdist(XA, XB, 'jaccard')

Computes the Jaccard distance between the points. Given two vectors,  $u$  and  $v$ , the Jaccard distance is the proportion of those elements  $u[i]$  and  $v[i]$  that disagree where at least one of them is non-zero.

10.Y = cdist(XA, XB, 'chebyshev')

Computes the Chebyshev distance between the points. The Chebyshev distance between two  $n$ -vectors  $u$  and  $v$  is the maximum norm-1 distance between their respective elements. More precisely, the distance is given by

$$d(u, v) = \max_i |u_i - v_i|.$$

11.Y = cdist(XA, XB, 'canberra')

Computes the Canberra distance between the points. The Canberra distance between two points  $u$  and  $v$  is

$$d(u, v) = \sum_i \frac{|u_i - v_i|}{|u_i| + |v_i|}.$$

```
12.Y = cdist(XA, XB, 'braycurtis')
```

Computes the Bray-Curtis distance between the points. The Bray-Curtis distance between two points  $u$  and  $v$  is

$$d(u, v) = \frac{\sum_i (|u_i - v_i|)}{\sum_i (|u_i + v_i|)}$$

```
13.Y = cdist(XA, XB, 'mahalanobis', VI=None)
```

Computes the Mahalanobis distance between the points. The Mahalanobis distance between two points  $u$  and  $v$  is  $\sqrt{(u-v)(1/V)(u-v)^T}$  where  $(1/V)$  (the `VI` variable) is the inverse covariance. If `VI` is not `None`, `VI` will be used as the inverse covariance matrix.

```
14.Y = cdist(XA, XB, 'yule')
```

Computes the Yule distance between the boolean vectors. (see `yule` function documentation)

```
15.Y = cdist(XA, XB, 'matching')
```

Synonym for ‘hamming’.

```
16.Y = cdist(XA, XB, 'dice')
```

Computes the Dice distance between the boolean vectors. (see `dice` function documentation)

```
17.Y = cdist(XA, XB, 'kulsinski')
```

Computes the Kulsinski distance between the boolean vectors. (see `kulsinski` function documentation)

```
18.Y = cdist(XA, XB, 'rogerstanimoto')
```

Computes the Rogers-Tanimoto distance between the boolean vectors. (see `rogerstanimoto` function documentation)

```
19.Y = cdist(XA, XB, 'russellrao')
```

Computes the Russell-Rao distance between the boolean vectors. (see `russellrao` function documentation)

```
20.Y = cdist(XA, XB, 'sokalmichener')
```

Computes the Sokal-Michener distance between the boolean vectors. (see `sokalmichener` function documentation)

```
21.Y = cdist(XA, XB, 'sokalsneath')
```

Computes the Sokal-Sneath distance between the vectors. (see `sokalsneath` function documentation)

```
22.Y = cdist(XA, XB, 'wminkowski', p=2., w=w)
```

Computes the weighted Minkowski distance between the vectors. (see `wminkowski` function documentation)

```
23.Y = cdist(XA, XB, f)
```

Computes the distance between all pairs of vectors in `X` using the user supplied 2-arity function `f`. For example, Euclidean distance between the vectors could be computed as follows:

```
dm = cdist(XA, XB, lambda u, v: np.sqrt(((u-v)**2).sum()))
```

Note that you should avoid passing a reference to one of the distance functions defined in this library. For example,:

```
dm = cdist(XA, XB, sokalsneath)
```

would calculate the pair-wise distances between the vectors in X using the Python function *sokalsneath*. This would result in *sokalsneath* being called  $\binom{n}{2}$  times, which is inefficient. Instead, the optimized C version is more efficient, and we call it using the following syntax:

```
dm = cdist(XA, XB, 'sokalsneath')
```

### Examples

Find the Euclidean distances between four 2-D coordinates:

```
>>> from scipy.spatial import distance
>>> coords = [(35.0456, -85.2672),
...           (35.1174, -89.9711),
...           (35.9728, -83.9422),
...           (36.1667, -86.7833)]
>>> distance.cdist(coords, coords, 'euclidean')
array([[ 0.         ,  4.7044,  1.6172,  1.8856],
       [ 4.7044,  0.         ,  6.0893,  3.3561],
       [ 1.6172,  6.0893,  0.         ,  2.8477],
       [ 1.8856,  3.3561,  2.8477,  0.         ]])
```

Find the Manhattan distance from a 3-D point to the corners of the unit cube:

```
>>> a = np.array([[0, 0, 0],
...               [0, 0, 1],
...               [0, 1, 0],
...               [0, 1, 1],
...               [1, 0, 0],
...               [1, 0, 1],
...               [1, 1, 0],
...               [1, 1, 1]])
>>> b = np.array([[0.1, 0.2, 0.4]])
>>> distance.cdist(a, b, 'cityblock')
array([[ 0.7],
       [ 0.9],
       [ 1.3],
       [ 1.5],
       [ 1.5],
       [ 1.7],
       [ 2.1],
       [ 2.3]])
```

`scipy.spatial.distance.squareform(X, force='no', checks=True)`

Converts a vector-form distance vector to a square-form distance matrix, and vice-versa.

**Parameters** **X** : ndarray

Either a condensed or redundant distance matrix.

**force** : str, optional

As with MATLAB(TM), if *force* is equal to 'tovector' or 'tomatrix', the input will be treated as a distance matrix or distance vector respectively.

**checks** : bool, optional

If set to False, no checks will be made for matrix symmetry nor zero diagonals. This is useful if it is known that  $X - X.T$  is small and  $\text{diag}(X)$  is close to zero. These values are ignored any way so they do not disrupt the squareform transformation.

**Returns** **Y** : ndarray

If a condensed distance matrix is passed, a redundant one is returned, or if a redundant one is passed, a condensed distance matrix is returned.

### Notes

1.  $v = \text{squareform}(X)$

Given a square  $d$ -by- $d$  symmetric distance matrix  $X$ ,  $v = \text{squareform}(X)$  returns a  $d * (d-1) / 2$  (or  $\binom{n}{2}$ ) sized vector  $v$ .

$v[\binom{n}{2} - \binom{n-i}{2} + (j-i-1)]$  is the distance between points  $i$  and  $j$ . If  $X$  is non-square or asymmetric, an error is returned.

2.  $X = \text{squareform}(v)$

Given a  $d * (d-1) / 2$  sized  $v$  for some integer  $d \geq 2$  encoding distances as described,  $X = \text{squareform}(v)$  returns a  $d$  by  $d$  distance matrix  $X$ . The  $X[i, j]$  and  $X[j, i]$  values are set to  $v[\binom{n}{2} - \binom{n-i}{2} + (j-i-1)]$  and all diagonal elements are zero.

In SciPy 0.19.0, `squareform` stopped casting all input types to float64, and started returning arrays of the same dtype as the input.

`scipy.spatial.distance.directed_hausdorff(u, v, seed=0)`

Computes the directed Hausdorff distance between two N-D arrays.

Distances between pairs are calculated using a Euclidean metric.

**Parameters** **u** : (M,N) ndarray

Input array.

**v** : (O,N) ndarray

Input array.

**seed** : int or None

Local `np.random.RandomState` seed. Default is 0, a random shuffling of  $u$  and  $v$  that guarantees reproducibility.

**Returns** **d** : double

The directed Hausdorff distance between arrays  $u$  and  $v$ ,

**index\_1** : int

index of point contributing to Hausdorff pair in  $u$

**index\_2** : int

index of point contributing to Hausdorff pair in  $v$

**See also:**

`scipy.spatial.procrustes`

Another similarity test for two data sets

### Notes

Uses the early break technique and the random sampling approach described by [R44]. Although worst-case performance is  $O(m * o)$  (as with the brute force algorithm), this is unlikely in practice as the input data would have to require the algorithm to explore every single point interaction, and after the algorithm shuffles the input points at that. The best case performance is  $O(m)$ , which is satisfied by selecting an inner loop distance

that is less than `cmax` and leads to an early break as often as possible. The authors have formally shown that the average runtime is closer to  $O(m)$ .

New in version 0.19.0.

### References

[R44]

### Examples

Find the directed Hausdorff distance between two 2-D arrays of coordinates:

```
>>> from scipy.spatial.distance import directed_hausdorff
>>> u = np.array([(1.0, 0.0),
...              (0.0, 1.0),
...              (-1.0, 0.0),
...              (0.0, -1.0)])
>>> v = np.array([(2.0, 0.0),
...              (0.0, 2.0),
...              (-2.0, 0.0),
...              (0.0, -4.0)])
```

```
>>> directed_hausdorff(u, v)[0]
2.23606797749979
>>> directed_hausdorff(v, u)[0]
3.0
```

Find the general (symmetric) Hausdorff distance between two 2-D arrays of coordinates:

```
>>> max(directed_hausdorff(u, v)[0], directed_hausdorff(v, u)[0])
3.0
```

Find the indices of the points that generate the Hausdorff distance (the Hausdorff pair):

```
>>> directed_hausdorff(v, u)[1:]
(3, 3)
```

Predicates for checking the validity of distance matrices, both condensed and redundant. Also contained in this module are functions for computing the number of observations in a distance matrix.

<code>is_valid_dm(D[, tol, throw, name, warning])</code>	Returns True if input array is a valid distance matrix.
<code>is_valid_y(y[, warning, throw, name])</code>	Returns True if the input array is a valid condensed distance matrix.
<code>num_obs_dm(d)</code>	Returns the number of original observations that correspond to a square, redundant distance matrix.
<code>num_obs_y(Y)</code>	Returns the number of original observations that correspond to a condensed distance matrix.

`scipy.spatial.distance.is_valid_dm(D, tol=0.0, throw=False, name='D', warning=False)`

Returns True if input array is a valid distance matrix.

Distance matrices must be 2-dimensional numpy arrays. They must have a zero-diagonal, and they must be symmetric.

**Parameters** **D**: ndarray

The candidate object to test for validity.

**tol** : float, optional  
The distance matrix should be symmetric. *tol* is the maximum difference between entries  $i_j$  and  $j_i$  for the distance metric to be considered symmetric.

**throw** : bool, optional  
An exception is thrown if the distance matrix passed is not valid.

**name** : str, optional  
The name of the variable to checked. This is useful if *throw* is set to True so the offending variable can be identified in the exception message when an exception is thrown.

**warning** : bool, optional  
Instead of throwing an exception, a warning message is raised.

**Returns** **valid** : bool  
True if the variable *D* passed is a valid distance matrix.

**Notes**

Small numerical differences in *D* and *D.T* and non-zerosness of the diagonal are ignored if they are within the tolerance specified by *tol*.

`scipy.spatial.distance.is_valid_y` (*y*, *warning=False*, *throw=False*, *name=None*)

Returns True if the input array is a valid condensed distance matrix.

Condensed distance matrices must be 1-dimensional numpy arrays. Their length must be a binomial coefficient  $\binom{n}{2}$  for some positive integer *n*.

**Parameters** **y** : ndarray  
The condensed distance matrix.

**warning** : bool, optional  
Invokes a warning if the variable passed is not a valid condensed distance matrix. The warning message explains why the distance matrix is not valid. *name* is used when referencing the offending variable.

**throw** : bool, optional  
Throws an exception if the variable passed is not a valid condensed distance matrix.

**name** : bool, optional  
Used when referencing the offending variable in the warning or exception message.

`scipy.spatial.distance.num_obs_dm` (*d*)

Returns the number of original observations that correspond to a square, redundant distance matrix.

**Parameters** **d** : ndarray  
The target distance matrix.

**Returns** **num\_obs\_dm** : int  
The number of observations in the redundant distance matrix.

`scipy.spatial.distance.num_obs_y` (*Y*)

Returns the number of original observations that correspond to a condensed distance matrix.

**Parameters** **Y** : ndarray  
Condensed distance matrix.

**Returns** **n** : int  
The number of observations in the condensed distance matrix *Y*.

Distance functions between two numeric vectors *u* and *v*. Computing distances over a large collection of vectors is inefficient for these functions. Use `pdist` for this purpose.

Continued on next page

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<code>braycurtis(u, v[, w])</code>	Computes the Bray-Curtis distance between two 1-D arrays.
<code>canberra(u, v[, w])</code>	Computes the Canberra distance between two 1-D arrays.
<code>chebyshev(u, v)</code>	Computes the Chebyshev distance.
<code>cityblock(u, v[, w])</code>	Computes the City Block (Manhattan) distance.
<code>correlation(u, v[, w, centered])</code>	Computes the correlation distance between two 1-D arrays.
<code>cosine(u, v[, w])</code>	Computes the Cosine distance between 1-D arrays.
<code>euclidean(u, v[, w])</code>	Computes the Euclidean distance between two 1-D arrays.
<code>mahalanobis(u, v, VI)</code>	Computes the Mahalanobis distance between two 1-D arrays.
<code>minkowski(u, v[, p, w])</code>	Computes the Minkowski distance between two 1-D arrays.
<code>seuclidean(u, v, V)</code>	Returns the standardized Euclidean distance between two 1-D arrays.
<code>squeuclidean(u, v[, w])</code>	Computes the squared Euclidean distance between two 1-D arrays.
<code>wminkowski(u, v, p, w)</code>	Computes the weighted Minkowski distance between two 1-D arrays.

`scipy.spatial.distance.braycurtis(u, v, w=None)`

Computes the Bray-Curtis distance between two 1-D arrays.

Bray-Curtis distance is defined as

$$\sum |u_i - v_i| / \sum |u_i + v_i|$$

The Bray-Curtis distance is in the range [0, 1] if all coordinates are positive, and is undefined if the inputs are of length zero.

**Parameters**

- u** : (N,) array\_like  
Input array.
- v** : (N,) array\_like  
Input array.
- w** : (N,) array\_like, optional  
The weights for each value in *u* and *v*. Default is None, which gives each value a weight of 1.0

**Returns**

- braycurtis** : double  
The Bray-Curtis distance between 1-D arrays *u* and *v*.

`scipy.spatial.distance.canberra(u, v, w=None)`

Computes the Canberra distance between two 1-D arrays.

The Canberra distance is defined as

$$d(u, v) = \sum_i \frac{|u_i - v_i|}{|u_i| + |v_i|}$$

**Parameters**

- u** : (N,) array\_like  
Input array.
- v** : (N,) array\_like  
Input array.
- w** : (N,) array\_like, optional  
The weights for each value in *u* and *v*. Default is None, which gives each value a weight of 1.0

**Returns**

- canberra** : double  
The Canberra distance between vectors *u* and *v*.

**Notes**

When  $u[i]$  and  $v[i]$  are 0 for given  $i$ , then the fraction  $0/0 = 0$  is used in the calculation.

`scipy.spatial.distance.chebyshev` ( $u, v$ )

Computes the Chebyshev distance.

Computes the Chebyshev distance between two 1-D arrays  $u$  and  $v$ , which is defined as

$$\max_i |u_i - v_i|.$$

**Parameters** **u** : (N,) array\_like  
Input vector.

**v** : (N,) array\_like

**Returns** **chebyshev** : double  
Input vector.

The Chebyshev distance between vectors  $u$  and  $v$ .

`scipy.spatial.distance.cityblock` ( $u, v, w=None$ )

Computes the City Block (Manhattan) distance.

Computes the Manhattan distance between two 1-D arrays  $u$  and  $v$ , which is defined as

$$\sum_i |u_i - v_i|.$$

**Parameters** **u** : (N,) array\_like  
Input array.

**v** : (N,) array\_like

Input array.

**w** : (N,) array\_like, optional

The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0

**Returns** **cityblock** : double

The City Block (Manhattan) distance between vectors  $u$  and  $v$ .

`scipy.spatial.distance.correlation` ( $u, v, w=None, centered=True$ )

Computes the correlation distance between two 1-D arrays. The correlation distance between  $u$  and  $v$ , is defined as

$$1 - \frac{(u - \bar{u}) \cdot (v - \bar{v})}{\|u - \bar{u}\|_2 \|v - \bar{v}\|_2}$$

where  $\bar{u}$  is the mean of the elements of  $u$  and  $x \cdot y$  is the dot product of  $x$  and  $y$ .

**Parameters** **u** : (N,) array\_like  
Input array.

**v** : (N,) array\_like

Input array.

**w** : (N,) array\_like, optional

The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0

**Returns** **correlation** : double

The correlation distance between 1-D array  $u$  and  $v$ .

`scipy.spatial.distance.cosine` ( $u, v, w=None$ )

Computes the Cosine distance between 1-D arrays. The Cosine distance between  $u$  and  $v$ , is defined as

$$1 - \frac{u \cdot v}{\|u\|_2 \|v\|_2}.$$

where  $u \cdot v$  is the dot product of  $u$  and  $v$ .

**Parameters**

- u** : (N,) array\_like  
Input array.
- v** : (N,) array\_like  
Input array.
- w** : (N,) array\_like, optional  
The weights for each value in *u* and *v*. Default is None, which gives each value a weight of 1.0

**Returns**

- cosine** : double  
The Cosine distance between vectors *u* and *v*.

`scipy.spatial.distance.euclidean` (*u*, *v*, *w=None*)

Computes the Euclidean distance between two 1-D arrays.

The Euclidean distance between 1-D arrays *u* and *v*, is defined as

$$\|u - v\|_2 = \left( \sum (w_i |u_i - v_i|^2) \right)^{1/2}$$

**Parameters**

- u** : (N,) array\_like  
Input array.
- v** : (N,) array\_like  
Input array.
- w** : (N,) array\_like, optional  
The weights for each value in *u* and *v*. Default is None, which gives each value a weight of 1.0

**Returns**

- euclidean** : double  
The Euclidean distance between vectors *u* and *v*.

`scipy.spatial.distance.mahalanobis` (*u*, *v*, *VI*)

Computes the Mahalanobis distance between two 1-D arrays.

The Mahalanobis distance between 1-D arrays *u* and *v*, is defined as

$$\sqrt{(u - v)V^{-1}(u - v)^T}$$

where *V* is the covariance matrix. Note that the argument *VI* is the inverse of *V*.

**Parameters**

- u** : (N,) array\_like  
Input array.
- v** : (N,) array\_like  
Input array.
- VI** : ndarray  
The inverse of the covariance matrix.

**Returns**

- mahalanobis** : double  
The Mahalanobis distance between vectors *u* and *v*.

`scipy.spatial.distance.minkowski` (*u*, *v*, *p=2*, *w=None*)

Computes the Minkowski distance between two 1-D arrays.

The Minkowski distance between 1-D arrays *u* and *v*, is defined as

$$\|u - v\|_p = \left( \sum |u_i - v_i|^p \right)^{1/p} = \left( \sum w_i (|u_i - v_i|^p) \right)^{1/p}$$

**Parameters**

- u** : (N,) array\_like  
Input array.
- v** : (N,) array\_like  
Input array.

**p** : int  
The order of the norm of the difference  $\|u - v\|_p$ .

**w** : (N,) array\_like, optional  
The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0

**Returns** **minkowski** : double  
The Minkowski distance between vectors  $u$  and  $v$ .

`scipy.spatial.distance.seuclidean(u, v, V)`  
Returns the standardized Euclidean distance between two 1-D arrays.

The standardized Euclidean distance between  $u$  and  $v$ .

**Parameters** **u** : (N,) array\_like  
Input array.

**v** : (N,) array\_like  
Input array.

**V** : (N,) array\_like  
 $V$  is an 1-D array of component variances. It is usually computed among a larger collection vectors.

**Returns** **seuclidean** : double  
The standardized Euclidean distance between vectors  $u$  and  $v$ .

`scipy.spatial.distance.sqeuclidean(u, v, w=None)`  
Computes the squared Euclidean distance between two 1-D arrays.

The squared Euclidean distance between  $u$  and  $v$  is defined as

$$\|u - v\|_2^2$$

$$\left( \sum (w_i |u_i - v_i|^2) \right)$$

**Parameters** **u** : (N,) array\_like  
Input array.

**v** : (N,) array\_like  
Input array.

**w** : (N,) array\_like, optional  
The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0

**Returns** **sqeuclidean** : double  
The squared Euclidean distance between vectors  $u$  and  $v$ .

`scipy.spatial.distance.wminkowski(u, v, p, w)`  
Computes the weighted Minkowski distance between two 1-D arrays. The weighted Minkowski distance between  $u$  and  $v$ , defined as

$$\left( \sum (|w_i(u_i - v_i)|^p) \right)^{1/p} .$$

**Parameters** **u** : (N,) array\_like  
Input array.

**v** : (N,) array\_like  
Input array.

**p** : int  
The order of the norm of the difference  $\|u - v\|_p$ .

**w** : (N,) array\_like  
The weight vector.

**Returns** **wminkowski** : double  
The weighted Minkowski distance between vectors  $u$  and  $v$ .

**Notes**

`wminkowski` is DEPRECATED. It implements a definition where weights are powered. It is recommended to use the weighted version of `minkowski` instead. This function will be removed in a future version of `scipy`.

Distance functions between two boolean vectors (representing sets)  $u$  and  $v$ . As in the case of numerical vectors, `pdist` is more efficient for computing the distances between all pairs.

<code>dice(u, v[, w])</code>	Computes the Dice dissimilarity between two boolean 1-D arrays.
<code>hamming(u, v[, w])</code>	Computes the Hamming distance between two 1-D arrays.
<code>jaccard(u, v[, w])</code>	Computes the Jaccard-Needham dissimilarity between two boolean 1-D arrays.
<code>kulsinski(u, v[, w])</code>	Computes the Kulsinski dissimilarity between two boolean 1-D arrays.
<code>rogerstanimoto(u, v[, w])</code>	Computes the Rogers-Tanimoto dissimilarity between two boolean 1-D arrays.
<code>russellrao(u, v[, w])</code>	Computes the Russell-Rao dissimilarity between two boolean 1-D arrays.
<code>sokalmichener(u, v[, w])</code>	Computes the Sokal-Michener dissimilarity between two boolean 1-D arrays.
<code>sokalsneath(u, v[, w])</code>	Computes the Sokal-Sneath dissimilarity between two boolean 1-D arrays.
<code>yule(u, v[, w])</code>	Computes the Yule dissimilarity between two boolean 1-D arrays.

`scipy.spatial.distance.dice(u, v, w=None)`

Computes the Dice dissimilarity between two boolean 1-D arrays.

The Dice dissimilarity between  $u$  and  $v$ , is

$$\frac{c_{TF} + c_{FT}}{2c_{TT} + c_{FT} + c_{TF}}$$

where  $c_{ij}$  is the number of occurrences of  $u[k] = i$  and  $v[k] = j$  for  $k < n$ .

**Parameters**

- u** : (N,) ndarray, bool  
Input 1-D array.
- v** : (N,) ndarray, bool  
Input 1-D array.
- w** : (N,) array\_like, optional  
The weights for each value in  $u$  and  $v$ . Default is `None`, which gives each value a weight of 1.0

**Returns**

- dice** : double  
The Dice dissimilarity between 1-D arrays  $u$  and  $v$ .

`scipy.spatial.distance.hamming(u, v, w=None)`

Computes the Hamming distance between two 1-D arrays.

The Hamming distance between 1-D arrays  $u$  and  $v$ , is simply the proportion of disagreeing components in  $u$  and  $v$ . If  $u$  and  $v$  are boolean vectors, the Hamming distance is

$$\frac{c_{01} + c_{10}}{n}$$

where  $c_{ij}$  is the number of occurrences of  $u[k] = i$  and  $v[k] = j$  for  $k < n$ .

**Parameters**

- u** : (N,) array\_like  
Input array.

**v** : (N,) array\_like  
Input array.

**w** : (N,) array\_like, optional  
The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0

**Returns** **hamming** : double  
The Hamming distance between vectors  $u$  and  $v$ .

`scipy.spatial.distance.jaccard` ( $u, v, w=None$ )

Computes the Jaccard-Needham dissimilarity between two boolean 1-D arrays.

The Jaccard-Needham dissimilarity between 1-D boolean arrays  $u$  and  $v$ , is defined as

$$\frac{c_{TF} + c_{FT}}{c_{TT} + c_{FT} + c_{TF}}$$

where  $c_{ij}$  is the number of occurrences of  $u[k] = i$  and  $v[k] = j$  for  $k < n$ .

**Parameters** **u** : (N,) array\_like, bool  
Input array.

**v** : (N,) array\_like, bool  
Input array.

**w** : (N,) array\_like, optional  
The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0

**Returns** **jaccard** : double  
The Jaccard distance between vectors  $u$  and  $v$ .

`scipy.spatial.distance.kulsinski` ( $u, v, w=None$ )

Computes the Kulsinski dissimilarity between two boolean 1-D arrays.

The Kulsinski dissimilarity between two boolean 1-D arrays  $u$  and  $v$ , is defined as

$$\frac{c_{TF} + c_{FT} - c_{TT} + n}{c_{FT} + c_{TF} + n}$$

where  $c_{ij}$  is the number of occurrences of  $u[k] = i$  and  $v[k] = j$  for  $k < n$ .

**Parameters** **u** : (N,) array\_like, bool  
Input array.

**v** : (N,) array\_like, bool  
Input array.

**w** : (N,) array\_like, optional  
The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0

**Returns** **kulsinski** : double  
The Kulsinski distance between vectors  $u$  and  $v$ .

`scipy.spatial.distance.rogerstanimoto` ( $u, v, w=None$ )

Computes the Rogers-Tanimoto dissimilarity between two boolean 1-D arrays.

The Rogers-Tanimoto dissimilarity between two boolean 1-D arrays  $u$  and  $v$ , is defined as

$$\frac{R}{c_{TT} + c_{FF} + R}$$

where  $c_{ij}$  is the number of occurrences of  $u[k] = i$  and  $v[k] = j$  for  $k < n$  and  $R = 2(c_{TF} + c_{FT})$ .

**Parameters** **u** : (N,) array\_like, bool  
Input array.

**v** : (N,) array\_like, bool  
Input array.

**Parameters** **w** : (N,) array\_like, optional  
 The weights for each value in *u* and *v*. Default is None, which gives each value a weight of 1.0

**Returns** **rogerstanimoto** : double  
 The Rogers-Tanimoto dissimilarity between vectors *u* and *v*.

`scipy.spatial.distance.russellrao` (*u*, *v*, *w=None*)  
 Computes the Russell-Rao dissimilarity between two boolean 1-D arrays.

The Russell-Rao dissimilarity between two boolean 1-D arrays, *u* and *v*, is defined as

$$\frac{n - c_{TT}}{n}$$

where  $c_{ij}$  is the number of occurrences of  $u[k] = i$  and  $v[k] = j$  for  $k < n$ .

**Parameters** **u** : (N,) array\_like, bool  
 Input array.

**v** : (N,) array\_like, bool  
 Input array.

**w** : (N,) array\_like, optional  
 The weights for each value in *u* and *v*. Default is None, which gives each value a weight of 1.0

**Returns** **russellrao** : double  
 The Russell-Rao dissimilarity between vectors *u* and *v*.

`scipy.spatial.distance.sokalmichener` (*u*, *v*, *w=None*)  
 Computes the Sokal-Michener dissimilarity between two boolean 1-D arrays.

The Sokal-Michener dissimilarity between boolean 1-D arrays *u* and *v*, is defined as

$$\frac{R}{S + R}$$

where  $c_{ij}$  is the number of occurrences of  $u[k] = i$  and  $v[k] = j$  for  $k < n$ ,  $R = 2 * (c_{TF} + c_{FT})$  and  $S = c_{FF} + c_{TT}$ .

**Parameters** **u** : (N,) array\_like, bool  
 Input array.

**v** : (N,) array\_like, bool  
 Input array.

**w** : (N,) array\_like, optional  
 The weights for each value in *u* and *v*. Default is None, which gives each value a weight of 1.0

**Returns** **sokalmichener** : double  
 The Sokal-Michener dissimilarity between vectors *u* and *v*.

`scipy.spatial.distance.sokalsneath` (*u*, *v*, *w=None*)  
 Computes the Sokal-Sneath dissimilarity between two boolean 1-D arrays.

The Sokal-Sneath dissimilarity between *u* and *v*,

$$\frac{R}{c_{TT} + R}$$

where  $c_{ij}$  is the number of occurrences of  $u[k] = i$  and  $v[k] = j$  for  $k < n$  and  $R = 2(c_{TF} + c_{FT})$ .

**Parameters** **u** : (N,) array\_like, bool  
 Input array.

**v** : (N,) array\_like, bool  
 Input array.

**w** : (N,) array\_like, optional

**Returns** `sokalsneath` : double  
 The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0  
 The Sokal-Sneath dissimilarity between vectors  $u$  and  $v$ .

`scipy.spatial.distance.yule` ( $u, v, w=None$ )  
 Computes the Yule dissimilarity between two boolean 1-D arrays.

The Yule dissimilarity is defined as

$$\frac{R}{c_{TT} * c_{FF} + \frac{R}{2}}$$

where  $c_{ij}$  is the number of occurrences of  $u[k] = i$  and  $v[k] = j$  for  $k < n$  and  $R = 2.0 * c_{TF} * c_{FT}$ .

**Parameters** `u` : (N,) array\_like, bool  
 Input array.  
`v` : (N,) array\_like, bool  
 Input array.  
`w` : (N,) array\_like, optional  
 The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0  
**Returns** `yule` : double  
 The Yule dissimilarity between vectors  $u$  and  $v$ .

`hamming` also operates over discrete numerical vectors.

**Functions**

<code>braycurtis(u, v[, w])</code>	Computes the Bray-Curtis distance between two 1-D arrays.
<code>callable(object) -&gt; bool</code>	Return whether the object is callable (i.e., some kind of function).
<code>canberra(u, v[, w])</code>	Computes the Canberra distance between two 1-D arrays.
<code>cdist(XA, XB[, metric])</code>	Computes distance between each pair of the two collections of inputs.
<code>chebyshev(u, v)</code>	Computes the Chebyshev distance.
<code>cityblock(u, v[, w])</code>	Computes the City Block (Manhattan) distance.
<code>correlation(u, v[, w, centered])</code>	Computes the correlation distance between two 1-D arrays.
<code>cosine(u, v[, w])</code>	Computes the Cosine distance between 1-D arrays.
<code>dice(u, v[, w])</code>	Computes the Dice dissimilarity between two boolean 1-D arrays.
<code>directed_hausdorff(u, v[, seed])</code>	Computes the directed Hausdorff distance between two N-D arrays.
<code>euclidean(u, v[, w])</code>	Computes the Euclidean distance between two 1-D arrays.
<code>hamming(u, v[, w])</code>	Computes the Hamming distance between two 1-D arrays.
<code>is_valid_dm(D[, tol, throw, name, warning])</code>	Returns True if input array is a valid distance matrix.
<code>is_valid_y(y[, warning, throw, name])</code>	Returns True if the input array is a valid condensed distance matrix.
<code>jaccard(u, v[, w])</code>	Computes the Jaccard-Needham dissimilarity between two boolean 1-D arrays.
<code>kulsinski(u, v[, w])</code>	Computes the Kulsinski dissimilarity between two boolean 1-D arrays.
<code>mahalanobis(u, v, VI)</code>	Computes the Mahalanobis distance between two 1-D arrays.
<code>matching(*args, **kwargs)</code>	<code>matching</code> is deprecated!

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<code>minkowski(u, v[, p, w])</code>	Computes the Minkowski distance between two 1-D arrays.
<code>namedtuple(typename, field_names[, verbose, ...])</code>	Returns a new subclass of tuple with named fields.
<code>norm(a[, ord, axis, keepdims])</code>	Matrix or vector norm.
<code>num_obs_dm(d)</code>	Returns the number of original observations that correspond to a square, redundant distance matrix.
<code>num_obs_y(Y)</code>	Returns the number of original observations that correspond to a condensed distance matrix.
<code>pdist(X[, metric])</code>	Pairwise distances between observations in n-dimensional space.
<code>rogerstanimoto(u, v[, w])</code>	Computes the Rogers-Tanimoto dissimilarity between two boolean 1-D arrays.
<code>russellrao(u, v[, w])</code>	Computes the Russell-Rao dissimilarity between two boolean 1-D arrays.
<code>seuclidean(u, v, V)</code>	Returns the standardized Euclidean distance between two 1-D arrays.
<code>sokalmichener(u, v[, w])</code>	Computes the Sokal-Michener dissimilarity between two boolean 1-D arrays.
<code>sokalsneath(u, v[, w])</code>	Computes the Sokal-Sneath dissimilarity between two boolean 1-D arrays.
<code>squeuclidean(u, v[, w])</code>	Computes the squared Euclidean distance between two 1-D arrays.
<code>squareform(X[, force, checks])</code>	Converts a vector-form distance vector to a square-form distance matrix, and vice-versa.
<code>wminkowski(u, v, p, w)</code>	Computes the weighted Minkowski distance between two 1-D arrays.
<code>yule(u, v[, w])</code>	Computes the Yule dissimilarity between two boolean 1-D arrays.

**Classes**

MetricInfo

**Attributes**

<code>partial</code>	<code>partial(func, *args, **keywords)</code> - new function with partial application
<code>xrange</code>	<code>xrange(start, stop[, step])</code> -> xrange object

**class** `scipy.spatial.Rectangle` (*maxes, mins*)  
 Hyperrectangle class.  
 Represents a Cartesian product of intervals.

**Methods**

<code>max_distance_point(x[, p])</code>	Return the maximum distance between input and points in the hyperrectangle.
<code>max_distance_rectangle(other[, p])</code>	Compute the maximum distance between points in the two hyperrectangles.
<code>min_distance_point(x[, p])</code>	Return the minimum distance between input and points in the hyperrectangle.

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<code>min_distance_rectangle(other[, p])</code>	Compute the minimum distance between points in the two hyperrectangles.
<code>split(d, split)</code>	Produce two hyperrectangles by splitting.
<code>volume()</code>	Total volume.

`Rectangle.max_distance_point` ( $x, p=2.0$ )

Return the maximum distance between input and points in the hyperrectangle.

**Parameters**

- x** : array\_like  
Input array.
- p** : float, optional  
Input.

`Rectangle.max_distance_rectangle` ( $other, p=2.0$ )

Compute the maximum distance between points in the two hyperrectangles.

**Parameters**

- other** : hyperrectangle  
Input.
- p** : float, optional  
Input.

`Rectangle.min_distance_point` ( $x, p=2.0$ )

Return the minimum distance between input and points in the hyperrectangle.

**Parameters**

- x** : array\_like  
Input.
- p** : float, optional  
Input.

`Rectangle.min_distance_rectangle` ( $other, p=2.0$ )

Compute the minimum distance between points in the two hyperrectangles.

**Parameters**

- other** : hyperrectangle  
Input.
- p** : float  
Input.

`Rectangle.split` ( $d, split$ )

Produce two hyperrectangles by splitting.

In general, if you need to compute maximum and minimum distances to the children, it can be done more efficiently by updating the maximum and minimum distances to the parent.

**Parameters**

- d** : int  
Axis to split hyperrectangle along.
- split** : float  
Position along axis  $d$  to split at.

`Rectangle.volume` ()

Total volume.

## 5.24.2 Delaunay Triangulation, Convex Hulls and Voronoi Diagrams

<code>Delaunay(points[, furthest_site, ...])</code>	Delaunay tessellation in N dimensions.
<code>ConvexHull(points[, incremental, qhull_options])</code>	Convex hulls in N dimensions.

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<code>Voronoi(points[, furthest_site, ...])</code>	Voronoi diagrams in N dimensions.
<code>SphericalVoronoi(points[, radius, center, ...])</code>	Voronoi diagrams on the surface of a sphere.
<code>HalfspaceIntersection(halfspaces, interior_point)</code>	Halfspace intersections in N dimensions.

**class** `scipy.spatial.Delaunay` (*points, furthest\_site=False, incremental=False, qhull\_options=None*)  
 Delaunay tessellation in N dimensions.

New in version 0.9.

**Parameters**

- points** : ndarray of floats, shape (npoints, ndim)  
 Coordinates of points to triangulate
- furthest\_site** : bool, optional  
 Whether to compute a furthest-site Delaunay triangulation. Default: False  
 New in version 0.12.0.
- incremental** : bool, optional  
 Allow adding new points incrementally. This takes up some additional resources.
- qhull\_options** : str, optional  
 Additional options to pass to Qhull. See Qhull manual for details. Option “Qt” is always enabled. Default: “Qbb Qc Qz Qx Q12” for ndim > 4 and “Qbb Qc Qz Q12” otherwise. Incremental mode omits “Qz”.  
 New in version 0.12.0.

**Raises**

- QhullError**  
 Raised when Qhull encounters an error condition, such as geometrical degeneracy when options to resolve are not enabled.
- ValueError**  
 Raised if an incompatible array is given as input.

**Notes**

The tessellation is computed using the Qhull library [Qhull library](#).

---

**Note:** Unless you pass in the Qhull option “QJ”, Qhull does not guarantee that each input point appears as a vertex in the Delaunay triangulation. Omitted points are listed in the *coplanar* attribute.

---

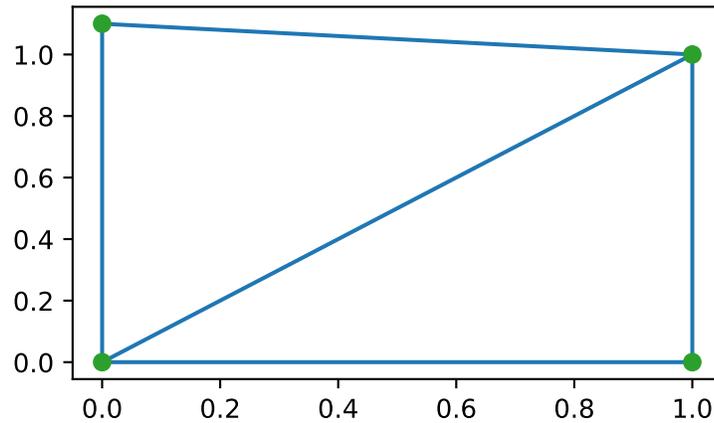
**Examples**

Triangulation of a set of points:

```
>>> points = np.array([[0, 0], [0, 1.1], [1, 0], [1, 1]])
>>> from scipy.spatial import Delaunay
>>> tri = Delaunay(points)
```

We can plot it:

```
>>> import matplotlib.pyplot as plt
>>> plt.triplot(points[:,0], points[:,1], tri.simplices.copy())
>>> plt.plot(points[:,0], points[:,1], 'o')
>>> plt.show()
```



Point indices and coordinates for the two triangles forming the triangulation:

```
>>> tri.simplices
array([[2, 3, 0],           # may vary
       [3, 1, 0]], dtype=int32)
```

Note that depending on how rounding errors go, the simplices may be in a different order than above.

```
>>> points[tri.simplices]
array([[ 1. ,  0. ],           # may vary
       [ 1. ,  1. ],
       [ 0. ,  0. ]],
      [[ 1. ,  1. ],
       [ 0. ,  1.1],
       [ 0. ,  0. ]])
```

Triangle 0 is the only neighbor of triangle 1, and it's opposite to vertex 1 of triangle 1:

```
>>> tri.neighbors[1]
array([-1,  0, -1], dtype=int32)
>>> points[tri.simplices[1,1]]
array([ 0. ,  1.1])
```

We can find out which triangle points are in:

```
>>> p = np.array([(0.1, 0.2), (1.5, 0.5), (0.5, 1.05)])
>>> tri.find_simplex(p)
array([ 1, -1,  1], dtype=int32)
```

The returned integers in the array are the indices of the simplex the corresponding point is in. If -1 is returned, the point is in no simplex. Be aware that the shortcut in the following example only works correctly for valid points as invalid points result in -1 which is itself a valid index for the last simplex in the list.

```
>>> p_valids = np.array([(0.1, 0.2), (0.5, 1.05)])
>>> tri.simplices[tri.find_simplex(p_valids)]
array([[3, 1, 0],           # may vary
       [3, 1, 0]], dtype=int32)
```

We can also compute barycentric coordinates in triangle 1 for these points:

```
>>> b = tri.transform[1,:2].dot(np.transpose(p - tri.transform[1,2]))
>>> np.c_[np.transpose(b), 1 - b.sum(axis=0)]
array([[ 0.1      ,  0.09090909,  0.80909091],
       [ 1.5      , -0.90909091,  0.40909091],
       [ 0.5      ,  0.5       ,  0.          ]])
```

The coordinates for the first point are all positive, meaning it is indeed inside the triangle. The third point is on a vertex, hence its null third coordinate.

**Attributes**

<code>transform</code>	Affine transform from $x$ to the barycentric coordinates $c$ .
<code>vertex_to_simplex</code>	Lookup array, from a vertex, to some simplex which it is a part of.
<code>convex_hull</code>	Vertices of facets forming the convex hull of the point set.
<code>vertex_neighbor_vertices</code>	Neighboring vertices of vertices.

**Delaunay.transform**

Affine transform from  $x$  to the barycentric coordinates  $c$ .

**Type** ndarray of double, shape (nsimplex, ndim+1, ndim)

This is defined by:

$$T c = x - r$$

At vertex  $j$ ,  $c_j = 1$  and the other coordinates zero.

For simplex  $i$ , `transform[i,:ndim,:ndim]` contains inverse of the matrix  $T$ , and `transform[i,ndim,:]` contains the vector  $r$ .

**Delaunay.vertex\_to\_simplex**

Lookup array, from a vertex, to some simplex which it is a part of.

**Type** ndarray of int, shape (npoints,)

**Delaunay.convex\_hull**

Vertices of facets forming the convex hull of the point set.

**Type** ndarray of int, shape (nfaces, ndim)

The array contains the indices of the points belonging to the (N-1)-dimensional facets that form the convex hull of the triangulation.

---

**Note:** Computing convex hulls via the Delaunay triangulation is inefficient and subject to increased numerical instability. Use `ConvexHull` instead.

---

**Delaunay.vertex\_neighbor\_vertices**

Neighboring vertices of vertices.

Tuple of two ndarrays of int: (indptr, indices). The indices of neighboring vertices of vertex  $k$  are `indices[indptr[k]:indptr[k+1]]`.

points	(ndarray of double, shape (npoints, ndim)) Coordinates of input points.
simplices	(ndarray of ints, shape (nsimplex, ndim+1)) Indices of the points forming the simplices in the triangulation. For 2-D, the points are oriented counterclockwise.
neighbors	(ndarray of ints, shape (nsimplex, ndim+1)) Indices of neighbor simplices for each simplex. The kth neighbor is opposite to the kth vertex. For simplices at the boundary, -1 denotes no neighbor.
equations	(ndarray of double, shape (nsimplex, ndim+2)) [normal, offset] forming the hyperplane equation of the facet on the paraboloid (see <a href="#">Qhull documentation</a> for more).
paraboloid_scale, paraboloid_shift	(float) Scale and shift for the extra paraboloid dimension (see <a href="#">Qhull documentation</a> for more).
coplanar	(ndarray of int, shape (ncoplanar, 3)) Indices of coplanar points and the corresponding indices of the nearest facet and the nearest vertex. Coplanar points are input points which were <i>not</i> included in the triangulation due to numerical precision issues. If option “Qc” is not specified, this list is not computed. .. versionadded:: 0.12.0
vertices	Same as <i>simplices</i> , but deprecated.

**Methods**

<code>add_points(points[, restart])</code>	Process a set of additional new points.
<code>close()</code>	Finish incremental processing.
<code>find_simplex(self, xi[, bruteforce, tol])</code>	Find the simplices containing the given points.
<code>lift_points(self, x)</code>	Lift points to the Qhull paraboloid.
<code>plane_distance(self, xi)</code>	Compute hyperplane distances to the point <i>xi</i> from all simplices.

`Delaunay.add_points (points, restart=False)`

Process a set of additional new points.

**Parameters**    **points** : ndarray

New points to add. The dimensionality should match that of the initial points.

**restart** : bool, optional

Whether to restart processing from scratch, rather than adding points incrementally.

**Raises**        **QhullError**

Raised when Qhull encounters an error condition, such as geometrical degeneracy when options to resolve are not enabled.

**See also:**

`close`

**Notes**

You need to specify `incremental=True` when constructing the object to be able to add points incrementally. Incremental addition of points is also not possible after `close` has been called.

`Delaunay.close ()`

Finish incremental processing.

Call this to free resources taken up by Qhull, when using the incremental mode. After calling this, adding more points is no longer possible.

`Delaunay.find_simplex (self, xi, bruteforce=False, tol=None)`

Find the simplices containing the given points.

**Parameters**    **tri** : DelaunayInfo

Delaunay triangulation  
**xi** : ndarray of double, shape (..., ndim)  
 Points to locate  
**bruteforce** : bool, optional  
 Whether to only perform a brute-force search  
**tol** : float, optional  
 Tolerance allowed in the inside-triangle check. Default is  $100 * \text{eps}$ .  
**Returns** **i** : ndarray of int, same shape as *xi*  
 Indices of simplices containing each point. Points outside the triangulation get the value -1.

**Notes**

This uses an algorithm adapted from Qhull's `qh_findbestfacet`, which makes use of the connection between a convex hull and a Delaunay triangulation. After finding the simplex closest to the point in  $N+1$  dimensions, the algorithm falls back to directed search in  $N$  dimensions.

`Delaunay.lift_points` (*self*, *x*)  
 Lift points to the Qhull paraboloid.

`Delaunay.plane_distance` (*self*, *xi*)  
 Compute hyperplane distances to the point *xi* from all simplices.

**class** `scipy.spatial.ConvexHull` (*points*, *incremental=False*, *qhull\_options=None*)  
 Convex hulls in  $N$  dimensions.

New in version 0.12.0.

**Parameters** **points** : ndarray of floats, shape (npoints, ndim)  
 Coordinates of points to construct a convex hull from  
**incremental** : bool, optional  
 Allow adding new points incrementally. This takes up some additional resources.  
**qhull\_options** : str, optional  
 Additional options to pass to Qhull. See Qhull manual for details. (Default: "Qx" for  $\text{ndim} > 4$  and "" otherwise) Option "Qt" is always enabled.  
**Raises** **QhullError**  
 Raised when Qhull encounters an error condition, such as geometrical degeneracy when options to resolve are not enabled.  
**ValueError**  
 Raised if an incompatible array is given as input.

**Notes**

The convex hull is computed using the [Qhull library](#).

**References**

[[Qhull](#)]

**Examples**

Convex hull of a random set of points:

```

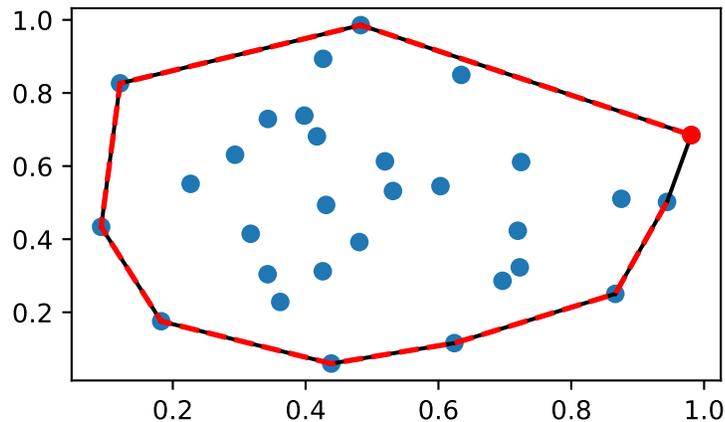
>>> from scipy.spatial import ConvexHull
>>> points = np.random.rand(30, 2) # 30 random points in 2-D
>>> hull = ConvexHull(points)
    
```

Plot it:

```
>>> import matplotlib.pyplot as plt
>>> plt.plot(points[:,0], points[:,1], 'o')
>>> for simplex in hull.simplices:
...     plt.plot(points[simplex, 0], points[simplex, 1], 'k-')
```

We could also have directly used the vertices of the hull, which for 2-D are guaranteed to be in counterclockwise order:

```
>>> plt.plot(points[hull.vertices,0], points[hull.vertices,1], 'r--', lw=2)
>>> plt.plot(points[hull.vertices[0],0], points[hull.vertices[0],1], 'ro')
>>> plt.show()
```



### Attributes

points	(ndarray of double, shape (npoints, ndim)) Coordinates of input points.
vertices	(ndarray of ints, shape (nvertices,)) Indices of points forming the vertices of the convex hull. For 2-D convex hulls, the vertices are in counterclockwise order. For other dimensions, they are in input order.
simplices	(ndarray of ints, shape (nfacet, ndim)) Indices of points forming the simplicial facets of the convex hull.
neighbors	(ndarray of ints, shape (nfacet, ndim)) Indices of neighbor facets for each facet. The kth neighbor is opposite to the kth vertex. -1 denotes no neighbor.
equations	(ndarray of double, shape (nfacet, ndim+1)) [normal, offset] forming the hyperplane equation of the facet (see <a href="#">Qhull documentation</a> for more).
coplanar	(ndarray of int, shape (ncoplanar, 3)) Indices of coplanar points and the corresponding indices of the nearest facets and nearest vertex indices. Coplanar points are input points which were <i>not</i> included in the triangulation due to numerical precision issues. If option “Qc” is not specified, this list is not computed.
area	(float) Area of the convex hull
volume	(float) Volume of the convex hull

### Methods

<code>add_points(points[, restart])</code>	Process a set of additional new points.
<code>close()</code>	Finish incremental processing.

`ConvexHull.add_points` (*points*, *restart=False*)

Process a set of additional new points.

<b>Parameters</b>	<b>points</b> : ndarray	New points to add. The dimensionality should match that of the initial points.
	<b>restart</b> : bool, optional	Whether to restart processing from scratch, rather than adding points incrementally.
<b>Raises</b>	<b>QhullError</b>	Raised when Qhull encounters an error condition, such as geometrical degeneracy when options to resolve are not enabled.

**See also:**

`close`

**Notes**

You need to specify `incremental=True` when constructing the object to be able to add points incrementally. Incremental addition of points is also not possible after `close` has been called.

`ConvexHull.close` ()

Finish incremental processing.

Call this to free resources taken up by Qhull, when using the incremental mode. After calling this, adding more points is no longer possible.

**class** `scipy.spatial.Voronoi` (*points*, *furthest\_site=False*, *incremental=False*, *qhull\_options=None*)

Voronoi diagrams in N dimensions.

New in version 0.12.0.

<b>Parameters</b>	<b>points</b> : ndarray of floats, shape (npoints, ndim)	Coordinates of points to construct a convex hull from
	<b>furthest_site</b> : bool, optional	Whether to compute a furthest-site Voronoi diagram. Default: False
	<b>incremental</b> : bool, optional	Allow adding new points incrementally. This takes up some additional resources.
	<b>qhull_options</b> : str, optional	Additional options to pass to Qhull. See Qhull manual for details. (Default: “Qbb Qc Qz Qx” for ndim > 4 and “Qbb Qc Qz” otherwise. Incremental mode omits “Qz”.)
<b>Raises</b>	<b>QhullError</b>	Raised when Qhull encounters an error condition, such as geometrical degeneracy when options to resolve are not enabled.
	<b>ValueError</b>	Raised if an incompatible array is given as input.

**Notes**

The Voronoi diagram is computed using the [Qhull library](#).

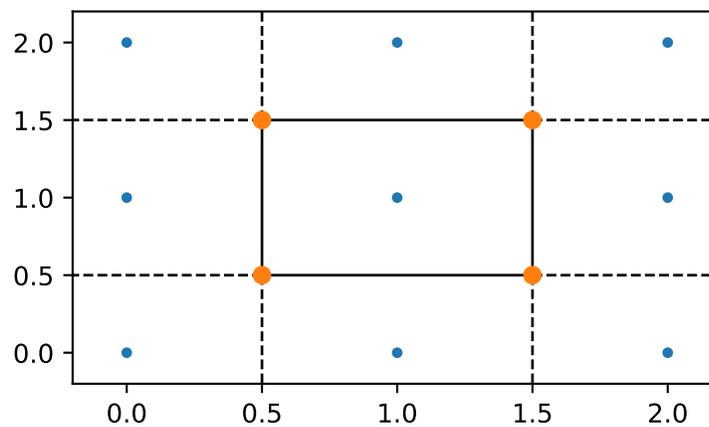
### Examples

Voronoi diagram for a set of point:

```
>>> points = np.array([[0, 0], [0, 1], [0, 2], [1, 0], [1, 1], [1, 2],
...                    [2, 0], [2, 1], [2, 2]])
>>> from scipy.spatial import Voronoi, voronoi_plot_2d
>>> vor = Voronoi(points)
```

Plot it:

```
>>> import matplotlib.pyplot as plt
>>> voronoi_plot_2d(vor)
>>> plt.show()
```



The Voronoi vertices:

```
>>> vor.vertices
array([[ 0.5,  0.5],
       [ 1.5,  0.5],
       [ 0.5,  1.5],
       [ 1.5,  1.5]])
```

There is a single finite Voronoi region, and four finite Voronoi ridges:

```
>>> vor.regions
[[[], [-1, 0], [-1, 1], [1, -1, 0], [3, -1, 2], [-1, 3], [-1, 2], [3, 2, 0, 1], [2,
↪ -1, 0], [3, -1, 1]]
>>> vor.ridge_vertices
[[-1, 0], [-1, 0], [-1, 1], [-1, 1], [0, 1], [-1, 3], [-1, 2], [2, 3], [-1, 3], [-
↪ 1, 2], [0, 2], [1, 3]]
```

The ridges are perpendicular between lines drawn between the following input points:

```
>>> vor.ridge_points
array([[0, 1],
       [0, 3],
       [6, 3],
       [6, 7],
```

```
[3, 4],
[5, 8],
[5, 2],
[5, 4],
[8, 7],
[2, 1],
[4, 1],
[4, 7]], dtype=int32)
```

**Attributes**

<code>points</code>	(ndarray of double, shape (npoints, ndim)) Coordinates of input points.
<code>vertices</code>	(ndarray of double, shape (nvertices, ndim)) Coordinates of the Voronoi vertices.
<code>ridge_points</code>	(ndarray of ints, shape (nridges, 2)) Indices of the points between which each Voronoi ridge lies.
<code>ridge_vertices</code>	(list of list of ints, shape (nridges, *)) Indices of the Voronoi vertices forming each Voronoi ridge.
<code>regions</code>	(list of list of ints, shape (nregions, *)) Indices of the Voronoi vertices forming each Voronoi region. -1 indicates vertex outside the Voronoi diagram.
<code>point_region</code>	(list of ints, shape (npoints)) Index of the Voronoi region for each input point. If qhull option "Qc" was not specified, the list will contain -1 for points that are not associated with a Voronoi region.

**Methods**

<code>add_points(points[, restart])</code>	Process a set of additional new points.
<code>close()</code>	Finish incremental processing.

`Voronoi.add_points` (*points*, *restart=False*)  
 Process a set of additional new points.

**Parameters**

- points** : ndarray  
 New points to add. The dimensionality should match that of the initial points.
- restart** : bool, optional  
 Whether to restart processing from scratch, rather than adding points incrementally.

**Raises**

- QhullError**  
 Raised when Qhull encounters an error condition, such as geometrical degeneracy when options to resolve are not enabled.

**See also:**

`close`

**Notes**

You need to specify `incremental=True` when constructing the object to be able to add points incrementally. Incremental addition of points is also not possible after `close` has been called.

`Voronoi.close` ()  
 Finish incremental processing.

Call this to free resources taken up by Qhull, when using the incremental mode. After calling this, adding more points is no longer possible.

**class** `scipy.spatial.SphericalVoronoi` (*points*, *radius=None*, *center=None*, *threshold=1e-06*)  
 Voronoi diagrams on the surface of a sphere.

New in version 0.18.0.

**Parameters**

- points** : ndarray of floats, shape (npoints, 3)  
 Coordinates of points to construct a spherical Voronoi diagram from
- radius** : float, optional  
 Radius of the sphere (Default: 1)
- center** : ndarray of floats, shape (3,)  
 Center of sphere (Default: origin)
- threshold** : float  
 Threshold for detecting duplicate points and mismatches between points and sphere parameters. (Default: 1e-06)

**Raises**

- ValueError**  
 If there are duplicates in *points*. If the provided *radius* is not consistent with *points*.

**See also:**

**Voronoi** Conventional Voronoi diagrams in N dimensions.

### Notes

The spherical Voronoi diagram algorithm proceeds as follows. The Convex Hull of the input points (generators) is calculated, and is equivalent to their Delaunay triangulation on the surface of the sphere [Caroli]. A 3D Delaunay tetrahedralization is obtained by including the origin of the coordinate system as the fourth vertex of each simplex of the Convex Hull. The circumcenters of all tetrahedra in the system are calculated and projected to the surface of the sphere, producing the Voronoi vertices. The Delaunay tetrahedralization neighbour information is then used to order the Voronoi region vertices around each generator. The latter approach is substantially less sensitive to floating point issues than angle-based methods of Voronoi region vertex sorting.

The surface area of spherical polygons is calculated by decomposing them into triangles and using L'Huilier's Theorem to calculate the spherical excess of each triangle [Weisstein]. The sum of the spherical excesses is multiplied by the square of the sphere radius to obtain the surface area of the spherical polygon. For nearly-degenerate spherical polygons an area of approximately 0 is returned by default, rather than attempting the unstable calculation.

Empirical assessment of spherical Voronoi algorithm performance suggests quadratic time complexity (loglinear is optimal, but algorithms are more challenging to implement). The reconstitution of the surface area of the sphere, measured as the sum of the surface areas of all Voronoi regions, is closest to 100 % for larger (>> 10) numbers of generators.

### References

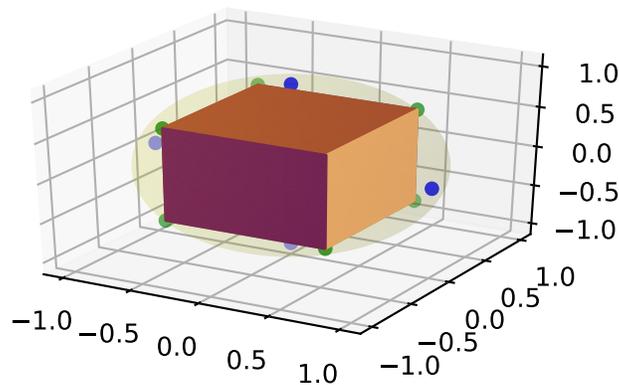
[Caroli], [Weisstein]

### Examples

```
>>> from matplotlib import colors
>>> from mpl_toolkits.mplot3d.art3d import Poly3DCollection
>>> import matplotlib.pyplot as plt
>>> from scipy.spatial import SphericalVoronoi
>>> from mpl_toolkits.mplot3d import proj3d
>>> # set input data
>>> points = np.array([[0, 0, 1], [0, 0, -1], [1, 0, 0],
...                   [0, 1, 0], [0, -1, 0], [-1, 0, 0], ])
>>> center = np.array([0, 0, 0])
>>> radius = 1
>>> # calculate spherical Voronoi diagram
```

```

>>> sv = SphericalVoronoi(points, radius, center)
>>> # sort vertices (optional, helpful for plotting)
>>> sv.sort_vertices_of_regions()
>>> # generate plot
>>> fig = plt.figure()
>>> ax = fig.add_subplot(111, projection='3d')
>>> # plot the unit sphere for reference (optional)
>>> u = np.linspace(0, 2 * np.pi, 100)
>>> v = np.linspace(0, np.pi, 100)
>>> x = np.outer(np.cos(u), np.sin(v))
>>> y = np.outer(np.sin(u), np.sin(v))
>>> z = np.outer(np.ones(np.size(u)), np.cos(v))
>>> ax.plot_surface(x, y, z, color='y', alpha=0.1)
>>> # plot generator points
>>> ax.scatter(points[:, 0], points[:, 1], points[:, 2], c='b')
>>> # plot Voronoi vertices
>>> ax.scatter(sv.vertices[:, 0], sv.vertices[:, 1], sv.vertices[:, 2],
...           c='g')
>>> # indicate Voronoi regions (as Euclidean polygons)
>>> for region in sv.regions:
...     random_color = colors.rgb2hex(np.random.rand(3))
...     polygon = Poly3DCollection([sv.vertices[region]], alpha=1.0)
...     polygon.set_color(random_color)
...     ax.add_collection3d(polygon)
>>> plt.show()
    
```



### Attributes

points	(double array of shape (npoints, 3)) the points in 3D to generate the Voronoi diagram from
radius	(double) radius of the sphere Default: None (forces estimation, which is less precise)
center	(double array of shape (3,)) center of the sphere Default: None (assumes sphere is centered at origin)
vertices	(double array of shape (nvertices, 3)) Voronoi vertices corresponding to points
regions	(list of list of integers of shape (npoints, _)) the n-th entry is a list consisting of the indices of the vertices belonging to the n-th point in points

**Methods**


---

<code>sort_vertices_of_regions()</code>	For each region in regions, it sorts the indices of the Voronoi vertices such that the resulting points are in a clockwise or counterclockwise order around the generator point.
---	--

---

**SphericalVoronoi.sort\_vertices\_of\_regions()**

For each region in regions, it sorts the indices of the Voronoi vertices such that the resulting points are in a clockwise or counterclockwise order around the generator point.

This is done as follows: Recall that the n-th region in regions surrounds the n-th generator in points and that the k-th Voronoi vertex in vertices is the projected circumcenter of the tetrahedron obtained by the k-th triangle in `_tri.simplices` (and the origin). For each region n, we choose the first triangle (=Voronoi vertex) in `_tri.simplices` and a vertex of that triangle not equal to the center n. These determine a unique neighbor of that triangle, which is then chosen as the second triangle. The second triangle will have a unique vertex not equal to the current vertex or the center. This determines a unique neighbor of the second triangle, which is then chosen as the third triangle and so forth. We proceed through all the triangles (=Voronoi vertices) belonging to the generator in points and obtain a sorted version of the vertices of its surrounding region.

**class** `scipy.spatial.HalfspaceIntersection` (*halfspaces*, *interior\_point*, *incremental=False*, *qhull\_options=None*)

Halfspace intersections in N dimensions.

New in version 0.19.0.

<b>Parameters</b>	<p><b>halfspaces</b> : ndarray of floats, shape (nineq, ndim+1) Stacked Inequalities of the form <math>Ax + b \leq 0</math> in format [A; b]</p> <p><b>interior_point</b> : ndarray of floats, shape (ndim,) Point clearly inside the region defined by halfspaces. Also called a feasible point, it can be obtained by linear programming.</p> <p><b>incremental</b> : bool, optional Allow adding new halfspaces incrementally. This takes up some additional resources.</p> <p><b>qhull_options</b> : str, optional Additional options to pass to Qhull. See Qhull manual for details. (Default: "Qx" for ndim &gt; 4 and "" otherwise) Option "H" is always enabled.</p>
<b>Raises</b>	<p><b>QhullError</b> Raised when Qhull encounters an error condition, such as geometrical degeneracy when options to resolve are not enabled.</p> <p><b>ValueError</b> Raised if an incompatible array is given as input.</p>

**Notes**

The intersections are computed using the [Qhull library](#). This reproduces the "qhalf" functionality of Qhull.

**References**

[[Qhull](#)], [[R395](#)]

**Examples**

Halfspace intersection of planes forming some polygon

```

>>> from scipy.spatial import HalfspaceIntersection
>>> import numpy as np
>>> halfspaces = np.array([[ -1,  0.,  0.],
...                       [ 0., -1.,  0.],
...                       [ 2.,  1., -4.],
...                       [-0.5, 1., -2.]])
>>> feasible_point = np.array([0.5, 0.5])
>>> hs = HalfspaceIntersection(halfspaces, feasible_point)

```

Plot halfspaces as filled regions and intersection points:

```

>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> ax = fig.add_subplot('111', aspect='equal')
>>> xlim, ylim = (-1, 3), (-1, 3)
>>> ax.set_xlim(xlim)
>>> ax.set_ylim(ylim)
>>> x = np.linspace(-1, 3, 100)
>>> symbols = ['- ', '+ ', 'x ', '* ']
>>> signs = [0, 0, -1, -1]
>>> fmt = {"color": None, "edgecolor": "b", "alpha": 0.5}
>>> for h, sym, sign in zip(halfspaces, symbols, signs):
...     hlist = h.tolist()
...     fmt["hatch"] = sym
...     if h[1]== 0:
...         ax.axvline(-h[2]/h[0], label='{}x+{}y+{}=0'.format(*hlist))
...         xi = np.linspace(xlim[sign], -h[2]/h[0], 100)
...         ax.fill_between(xi, ylim[0], ylim[1], **fmt)
...     else:
...         ax.plot(x, (-h[2]-h[0]*x)/h[1], label='{}x+{}y+{}=0'.format(*hlist))
...         ax.fill_between(x, (-h[2]-h[0]*x)/h[1], ylim[sign], **fmt)
>>> x, y = zip(*hs.intersections)
>>> ax.plot(x, y, 'o', markersize=8)

```

By default, qhull does not provide with a way to compute an interior point. This can easily be computed using linear programming. Considering halfspaces of the form  $Ax + b \leq 0$ , solving the linear program:

$$\begin{aligned} & \max y \\ & \text{s.t. } Ax + y||A_i|| \leq -b \end{aligned}$$

With  $A_i$  being the rows of  $A$ , i.e. the normals to each plane.

Will yield a point  $x$  that is furthest inside the convex polyhedron. To be precise, it is the center of the largest hypersphere of radius  $y$  inscribed in the polyhedron. This point is called the Chebyshev center of the polyhedron (see [R395] 4.3.1, pp148-149). The equations outputted by Qhull are always normalized.

```

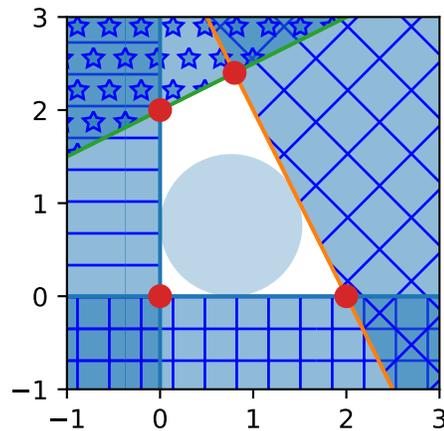
>>> from scipy.optimize import linprog
>>> from matplotlib.patches import Circle
>>> norm_vector = np.reshape(np.linalg.norm(halfspaces[:, :-1], axis=1),
...                          (halfspaces.shape[0], 1))
>>> c = np.zeros((halfspaces.shape[1],))
>>> c[-1] = -1
>>> A = np.hstack((halfspaces[:, :-1], norm_vector))
>>> b = - halfspaces[:, -1:]
>>> res = linprog(c, A_ub=A, b_ub=b)
>>> x = res.x[:-1]
>>> y = res.x[-1]
>>> circle = Circle(x, radius=y, alpha=0.3)

```

```

>>> ax.add_patch(circle)
>>> plt.legend(bbox_to_anchor=(1.6, 1.0))
>>> plt.show()

```



### Attributes

halfspaces	(ndarray of double, shape (nineq, ndim+1)) Input halfspaces.
interior_point :ndarray of floats, shape (ndim,)	Input interior point.
intersections	(ndarray of double, shape (ninter, ndim)) Intersections of all halfspaces.
dual_points	(ndarray of double, shape (nineq, ndim)) Dual points of the input halfspaces.
dual_facets	(list of lists of ints) Indices of points forming the (non necessarily simplicial) facets of the dual convex hull.
dual_vertices	(ndarray of ints, shape (nvertices,)) Indices of halfspaces forming the vertices of the dual convex hull. For 2-D convex hulls, the vertices are in counterclockwise order. For other dimensions, they are in input order.
dual_equations	(ndarray of double, shape (nfacet, ndim+1)) [normal, offset] forming the hyperplane equation of the dual facet (see <a href="#">Qhull documentation</a> for more).
dual_area	(float) Area of the dual convex hull
dual_volume	(float) Volume of the dual convex hull

### Methods

<code>add_halfspaces(halfspaces[, restart])</code>	Process a set of additional new halfspaces.
<code>close()</code>	Finish incremental processing.

`HalfspaceIntersection.add_halfspaces(halfspaces, restart=False)`

Process a set of additional new halfspaces.

**Parameters** `halfspaces` : ndarray

New halfspaces to add. The dimensionality should match that of the initial halfspaces.

`restart` : bool, optional

**Raises**

**QhullError**

Whether to restart processing from scratch, rather than adding halfspaces incrementally.

Raised when Qhull encounters an error condition, such as geometrical degeneracy when options to resolve are not enabled.

**See also:**

`close`

**Notes**

You need to specify `incremental=True` when constructing the object to be able to add halfspaces incrementally. Incremental addition of halfspaces is also not possible after `close` has been called.

`HalfspaceIntersection.close()`  
 Finish incremental processing.

Call this to free resources taken up by Qhull, when using the incremental mode. After calling this, adding more points is no longer possible.

### 5.24.3 Plotting Helpers

<code>del aunay_plot_2d(tri[, ax])</code>	Plot the given Delaunay triangulation in 2-D
<code>convex_hull_plot_2d(hull[, ax])</code>	Plot the given convex hull diagram in 2-D
<code>voronoi_plot_2d(vor[, ax])</code>	Plot the given Voronoi diagram in 2-D

`scipy.spatial.delaunay_plot_2d(tri, ax=None)`  
 Plot the given Delaunay triangulation in 2-D

**Parameters** **tri** : `scipy.spatial.Delaunay` instance  
 Triangulation to plot  
**ax** : `matplotlib.axes.Axes` instance, optional  
 Axes to plot on  
**Returns** **fig** : `matplotlib.figure.Figure` instance  
 Figure for the plot

**See also:**

`Delaunay`, `matplotlib.pyplot.triplot`

**Notes**

Requires Matplotlib.

`scipy.spatial.convex_hull_plot_2d(hull, ax=None)`  
 Plot the given convex hull diagram in 2-D

**Parameters** **hull** : `scipy.spatial.ConvexHull` instance  
 Convex hull to plot  
**ax** : `matplotlib.axes.Axes` instance, optional  
 Axes to plot on  
**Returns** **fig** : `matplotlib.figure.Figure` instance  
 Figure for the plot

**See also:**

`ConvexHull`

**Notes**

Requires Matplotlib.

```
scipy.spatial.voronoi_plot_2d(vor, ax=None, **kw)
```

Plot the given Voronoi diagram in 2-D

**Parameters**

- vor** : scipy.spatial.Voronoi instance  
Diagram to plot
- ax** : matplotlib.axes.Axes instance, optional  
Axes to plot on
- show\_points**: **bool, optional**  
Add the Voronoi points to the plot.
- show\_vertices** : bool, optional  
Add the Voronoi vertices to the plot.
- line\_colors** : string, optional  
Specifies the line color for polygon boundaries
- line\_width** : float, optional  
Specifies the line width for polygon boundaries
- line\_alpha**: **float, optional**  
Specifies the line alpha for polygon boundaries

**Returns**

- fig** : matplotlib.figure.Figure instance  
Figure for the plot

**See also:**

*Voronoi*

**Notes**

Requires Matplotlib.

**See also:**

*Tutorial*

## 5.24.4 Simplex representation

The simplices (triangles, tetrahedra, ...) appearing in the Delaunay tessellation (N-dim simplices), convex hull facets, and Voronoi ridges (N-1 dim simplices) are represented in the following scheme:

```
tess = Delaunay(points)
hull = ConvexHull(points)
voro = Voronoi(points)

# coordinates of the j-th vertex of the i-th simplex
tess.points[tess.simplices[i, j], :] # tessellation element
hull.points[hull.simplices[i, j], :] # convex hull facet
voro.vertices[voro.ridge_vertices[i, j], :] # ridge between Voronoi cells
```

For Delaunay triangulations and convex hulls, the neighborhood structure of the simplices satisfies the condition:

`tess.neighbors[i, j]` is the neighboring simplex of the i-th simplex, opposite to the j-vertex. It is -1 in case of no neighbor.

Convex hull facets also define a hyperplane equation:

```
(hull.equations[i, :-1] * coord).sum() + hull.equations[i, -1] == 0
```

Similar hyperplane equations for the Delaunay triangulation correspond to the convex hull facets on the corresponding  $N+1$  dimensional paraboloid.

The Delaunay triangulation objects offer a method for locating the simplex containing a given point, and barycentric coordinate computations.

## Functions

<code>tsearch(tri, xi)</code>	Find simplices containing the given points.
<code>distance_matrix(x, y[, p, threshold])</code>	Compute the distance matrix.
<code>minkowski_distance(x, y[, p])</code>	Compute the $L^{**p}$ distance between two arrays.
<code>minkowski_distance_p(x, y[, p])</code>	Compute the $p$ -th power of the $L^{**p}$ distance between two arrays.
<code>procrustes(data1, data2)</code>	Procrustes analysis, a similarity test for two data sets.

`scipy.spatial.tsearch(tri, xi)`

Find simplices containing the given points. This function does the same thing as `Delaunay.find_simplex`.

New in version 0.9.

**See also:**

`Delaunay.find_simplex`

`scipy.spatial.distance_matrix(x, y, p=2, threshold=1000000)`

Compute the distance matrix.

Returns the matrix of all pair-wise distances.

**Parameters** `x` : (M, K) array\_like

Matrix of M vectors in K dimensions.

`y` : (N, K) array\_like

Matrix of N vectors in K dimensions.

`p` : float,  $1 \leq p \leq \text{infinity}$

Which Minkowski  $p$ -norm to use.

**threshold** : positive int

If  $M * N * K > \text{threshold}$ , algorithm uses a Python loop instead of large

temporary arrays.

**Returns**

**result** : (M, N) ndarray

Matrix containing the distance from every vector in  $x$  to every vector in  $y$ .

### Examples

```
>>> from scipy.spatial import distance_matrix
>>> distance_matrix([[0,0], [0,1]], [[1,0], [1,1]])
array([[ 1.         ,  1.41421356],
       [ 1.41421356,  1.         ]])
```

`scipy.spatial.minkowski_distance(x, y, p=2)`

Compute the  $L^{**p}$  distance between two arrays.

**Parameters** `x` : (M, K) array\_like

Input array.

`y` : (N, K) array\_like

Input array.

`p` : float,  $1 \leq p \leq \text{infinity}$

Which Minkowski p-norm to use.

### Examples

```
>>> from scipy.spatial import minkowski_distance
>>> minkowski_distance([[0,0],[0,0]], [[1,1],[0,1]])
array([ 1.41421356,  1.         ])
```

`scipy.spatial.minkowski_distance_p(x, y, p=2)`

Compute the p-th power of the L\*\*p distance between two arrays.

For efficiency, this function computes the L\*\*p distance but does not extract the pth root. If  $p$  is 1 or infinity, this is equal to the actual L\*\*p distance.

**Parameters**

- x** : (M, K) array\_like  
Input array.
- y** : (N, K) array\_like  
Input array.
- p** : float,  $1 \leq p \leq \text{infinity}$   
Which Minkowski p-norm to use.

### Examples

```
>>> from scipy.spatial import minkowski_distance_p
>>> minkowski_distance_p([[0,0],[0,0]], [[1,1],[0,1]])
array([2, 1])
```

`scipy.spatial.procrustes(data1, data2)`

Procrustes analysis, a similarity test for two data sets.

Each input matrix is a set of points or vectors (the rows of the matrix). The dimension of the space is the number of columns of each matrix. Given two identically sized matrices, procrustes standardizes both such that:

- $\text{tr}(AA^T) = 1$ .
- Both sets of points are centered around the origin.

Procrustes ([R410], [R411]) then applies the optimal transform to the second matrix (including scaling/dilation, rotations, and reflections) to minimize  $M^2 = \sum (\text{data1} - \text{data2})^2$ , or the sum of the squares of the pointwise differences between the two input datasets.

This function was not designed to handle datasets with different numbers of datapoints (rows). If two data sets have different dimensionality (different number of columns), simply add columns of zeros to the smaller of the two.

**Parameters**

- data1** : array\_like  
Matrix, n rows represent points in k (columns) space *data1* is the reference data, after it is standardised, the data from *data2* will be transformed to fit the pattern in *data1* (must have >1 unique points).
- data2** : array\_like  
n rows of data in k space to be fit to *data1*. Must be the same shape (numrows, numcols) as *data1* (must have >1 unique points).

**Returns**

- mtx1** : array\_like  
A standardized version of *data1*.
- mtx2** : array\_like  
The orientation of *data2* that best fits *data1*. Centered, but not necessarily  $\text{tr}(AA^T) = 1$ .
- disparity** : float  
 $M^2$  as defined above.

**Raises**

- ValueError**  
If the input arrays are not two-dimensional. If the shape of the input arrays is different. If the input arrays have zero columns or zero rows.

**See also:**

`scipy.linalg.orthogonal_procrustes`  
**`scipy.spatial.distance.directed_hausdorff`**

Another similarity test for two data sets

**Notes**

- The disparity should not depend on the order of the input matrices, but the output matrices will, as only the first output matrix is guaranteed to be scaled such that  $tr(AA^T) = 1$ .
- Duplicate data points are generally ok, duplicating a data point will increase its effect on the procrustes fit.
- The disparity scales as the number of points per input matrix.

**References**

[R410], [R411]

**Examples**

```
>>> from scipy.spatial import procrustes
```

The matrix b is a rotated, shifted, scaled and mirrored version of a here:

```
>>> a = np.array([[1, 3], [1, 2], [1, 1], [2, 1]], 'd')
>>> b = np.array([[4, -2], [4, -4], [4, -6], [2, -6]], 'd')
>>> mtx1, mtx2, disparity = procrustes(a, b)
>>> round(disparity)
0.0
```

## 5.25 Distance computations (`scipy.spatial.distance`)

### 5.25.1 Function Reference

Distance matrix computation from a collection of raw observation vectors stored in a rectangular array.

<code>pdist(X[, metric])</code>	Pairwise distances between observations in n-dimensional space.
<code>cdist(XA, XB[, metric])</code>	Computes distance between each pair of the two collections of inputs.
<code>squareform(X[, force, checks])</code>	Converts a vector-form distance vector to a square-form distance matrix, and vice-versa.
<code>directed_hausdorff(u, v[, seed])</code>	Computes the directed Hausdorff distance between two N-D arrays.

`scipy.spatial.distance.pdist` (*X*, *metric*='euclidean', \*args, \*\*kwargs)

Pairwise distances between observations in n-dimensional space.

See Notes for common calling conventions.

- Parameters**
- X** : ndarray  
An m by n array of m original observations in an n-dimensional space.
  - metric** : str or function, optional  
The distance metric to use. The distance function can be 'braycurtis',

'canberra', 'chebyshev', 'cityblock', 'correlation', 'cosine', 'dice', 'euclidean', 'hamming', 'jaccard', 'kulsinski', 'mahalanobis', 'matching', 'minkowski', 'rogerstanimoto', 'russellrao', 'seuclidean', 'sokalmichener', 'sokalsneath', 'sqeuclidean', 'yule'.

**\*args** : tuple. Deprecated.

Additional arguments should be passed as keyword arguments

**\*\*kwargs** : dict, optional

Extra arguments to *metric*: refer to each metric documentation for a list of all possible arguments.

Some possible arguments:

**p** : scalar The p-norm to apply for Minkowski, weighted and unweighted. Default: 2.

**w** : ndarray The weight vector for metrics that support weights (e.g., Minkowski).

**V** : ndarray The variance vector for standardized Euclidean. Default: var(X, axis=0, ddof=1)

**VI** : ndarray The inverse of the covariance matrix for Mahalanobis. Default: inv(cov(X.T)).T

**out** : ndarray. The output array If not None, condensed distance matrix Y is stored in this array. Note: metric independent, it will become a regular keyword arg in a future scipy version

**Returns**     **Y** : ndarray

Returns a condensed distance matrix Y. For each *i* and *j* (where  $i < j < m$ ), where *m* is the number of original observations. The metric  $\text{dist}(u=X[i], v=X[j])$  is computed and stored in entry *ij*.

**See also:**

**squareform** converts between condensed distance matrices and square distance matrices.

**Notes**

See `squareform` for information on how to calculate the index of this entry or to convert the condensed distance matrix to a redundant square matrix.

The following are common calling conventions.

1. `Y = pdist(X, 'euclidean')`

Computes the distance between *m* points using Euclidean distance (2-norm) as the distance metric between the points. The points are arranged as *m* *n*-dimensional row vectors in the matrix *X*.

2. `Y = pdist(X, 'minkowski', p=2.)`

Computes the distances using the Minkowski distance  $\|u - v\|_p$  (p-norm) where  $p \geq 1$ .

3. `Y = pdist(X, 'cityblock')`

Computes the city block or Manhattan distance between the points.

4. `Y = pdist(X, 'seuclidean', V=None)`

Computes the standardized Euclidean distance. The standardized Euclidean distance between two *n*-vectors *u* and *v* is

$$\sqrt{\sum (u_i - v_i)^2 / V[x_i]}$$

*V* is the variance vector; *V*[*i*] is the variance computed over all the *i*'th components of the points. If not passed, it is automatically computed.

5. `Y = pdist(X, 'sqeuclidean')`

Computes the squared Euclidean distance  $\|u - v\|_2^2$  between the vectors.

6.Y = pdist(X, 'cosine')

Computes the cosine distance between vectors  $u$  and  $v$ ,

$$1 - \frac{u \cdot v}{\|u\|_2 \|v\|_2}$$

where  $\|*\|_2$  is the 2-norm of its argument  $*$ , and  $u \cdot v$  is the dot product of  $u$  and  $v$ .

7.Y = pdist(X, 'correlation')

Computes the correlation distance between vectors  $u$  and  $v$ . This is

$$1 - \frac{(u - \bar{u}) \cdot (v - \bar{v})}{\|(u - \bar{u})\|_2 \|(v - \bar{v})\|_2}$$

where  $\bar{v}$  is the mean of the elements of vector  $v$ , and  $x \cdot y$  is the dot product of  $x$  and  $y$ .

8.Y = pdist(X, 'hamming')

Computes the normalized Hamming distance, or the proportion of those vector elements between two  $n$ -vectors  $u$  and  $v$  which disagree. To save memory, the matrix  $X$  can be of type boolean.

9.Y = pdist(X, 'jaccard')

Computes the Jaccard distance between the points. Given two vectors,  $u$  and  $v$ , the Jaccard distance is the proportion of those elements  $u[i]$  and  $v[i]$  that disagree.

10.Y = pdist(X, 'chebyshev')

Computes the Chebyshev distance between the points. The Chebyshev distance between two  $n$ -vectors  $u$  and  $v$  is the maximum norm-1 distance between their respective elements. More precisely, the distance is given by

$$d(u, v) = \max_i |u_i - v_i|$$

11.Y = pdist(X, 'canberra')

Computes the Canberra distance between the points. The Canberra distance between two points  $u$  and  $v$  is

$$d(u, v) = \sum_i \frac{|u_i - v_i|}{|u_i| + |v_i|}$$

12.Y = pdist(X, 'braycurtis')

Computes the Bray-Curtis distance between the points. The Bray-Curtis distance between two points  $u$  and  $v$  is

$$d(u, v) = \frac{\sum_i |u_i - v_i|}{\sum_i |u_i + v_i|}$$

13.Y = pdist(X, 'mahalanobis', VI=None)

Computes the Mahalanobis distance between the points. The Mahalanobis distance between two points  $u$  and  $v$  is  $\sqrt{(u - v)(1/V)(u - v)^T}$  where  $(1/V)$  (the VI variable) is the inverse covariance. If VI is not None, VI will be used as the inverse covariance matrix.

14.Y = pdist(X, 'yule')

Computes the Yule distance between each pair of boolean vectors. (see yule function documentation)

15.Y = pdist(X, 'matching')

Synonym for 'hamming'.

```
16.Y = pdist(X, 'dice')
```

Computes the Dice distance between each pair of boolean vectors. (see dice function documentation)

```
17.Y = pdist(X, 'kulsinski')
```

Computes the Kulsinski distance between each pair of boolean vectors. (see kulsinski function documentation)

```
18.Y = pdist(X, 'rogerstanimoto')
```

Computes the Rogers-Tanimoto distance between each pair of boolean vectors. (see rogerstanimoto function documentation)

```
19.Y = pdist(X, 'russellrao')
```

Computes the Russell-Rao distance between each pair of boolean vectors. (see russellrao function documentation)

```
20.Y = pdist(X, 'sokalmichener')
```

Computes the Sokal-Michener distance between each pair of boolean vectors. (see sokalmichener function documentation)

```
21.Y = pdist(X, 'sokalsneath')
```

Computes the Sokal-Sneath distance between each pair of boolean vectors. (see sokalsneath function documentation)

```
22.Y = pdist(X, 'wminkowski', p=2, w=w)
```

Computes the weighted Minkowski distance between each pair of vectors. (see wminkowski function documentation)

```
23.Y = pdist(X, f)
```

Computes the distance between all pairs of vectors in X using the user supplied 2-arity function f. For example, Euclidean distance between the vectors could be computed as follows:

```
dm = pdist(X, lambda u, v: np.sqrt(((u-v)**2).sum()))
```

Note that you should avoid passing a reference to one of the distance functions defined in this library. For example,:

```
dm = pdist(X, sokalsneath)
```

would calculate the pair-wise distances between the vectors in X using the Python function sokalsneath. This would result in sokalsneath being called  $\binom{n}{2}$  times, which is inefficient. Instead, the optimized C version is more efficient, and we call it using the following syntax.:

```
dm = pdist(X, 'sokalsneath')
```

```
scipy.spatial.distance.cdist(XA, XB, metric='euclidean', *args, **kwargs)
```

Computes distance between each pair of the two collections of inputs.

See Notes for common calling conventions.

**Parameters**    **XA** : ndarray

An  $m_A$  by  $n$  array of  $m_A$  original observations in an  $n$ -dimensional space. Inputs are converted to float type.

**XB** : ndarray

An  $m_B$  by  $n$  array of  $m_B$  original observations in an  $n$ -dimensional space. Inputs are converted to float type.

**metric** : str or callable, optional

The distance metric to use. If a string, the distance function can be 'bray-curtis', 'canberra', 'chebyshev', 'cityblock', 'correlation', 'cosine', 'dice', 'euclidean', 'hamming', 'jaccard', 'kulsinski', 'mahalanobis', 'matching', 'minkowski', 'rogerstanimoto', 'russellrao', 'seuclidean', 'sokalmichener', 'sokalsneath', 'sqeuclidean', 'wminkowski', 'yule'.

**\*args** : tuple. Deprecated.

Additional arguments should be passed as keyword arguments

**\*\*kwargs** : dict, optional

Extra arguments to *metric*: refer to each metric documentation for a list of all possible arguments.

Some possible arguments:

**p** : scalar The p-norm to apply for Minkowski, weighted and unweighted. Default: 2.

**w** : ndarray The weight vector for metrics that support weights (e.g., Minkowski).

**V** : ndarray The variance vector for standardized Euclidean. Default: `var(vstack([XA, XB]), axis=0, ddof=1)`

**VI** : ndarray The inverse of the covariance matrix for Mahalanobis. Default: `inv(cov(vstack([XA, XB].T))).T`

**out** : ndarray The output array If not None, the distance matrix Y is stored in this array. Note: metric independent, it will become a regular keyword arg in a future scipy version

**Returns** **Y** : ndarray

A  $m_A$  by  $m_B$  distance matrix is returned. For each  $i$  and  $j$ , the metric `dist(u=XA[i], v=XB[j])` is computed and stored in the  $ij$  th entry.

**Raises** **ValueError**

An exception is thrown if *XA* and *XB* do not have the same number of columns.

### Notes

The following are common calling conventions:

1. `Y = cdist(XA, XB, 'euclidean')`

Computes the distance between  $m$  points using Euclidean distance (2-norm) as the distance metric between the points. The points are arranged as  $m$   $n$ -dimensional row vectors in the matrix *X*.

2. `Y = cdist(XA, XB, 'minkowski', p=2.)`

Computes the distances using the Minkowski distance  $\|u - v\|_p$  ( $p$ -norm) where  $p \geq 1$ .

3. `Y = cdist(XA, XB, 'cityblock')`

Computes the city block or Manhattan distance between the points.

4. `Y = cdist(XA, XB, 'seuclidean', V=None)`

Computes the standardized Euclidean distance. The standardized Euclidean distance between two vectors *u* and *v* is

$$\sqrt{\sum (u_i - v_i)^2 / V[x_i]}.$$

*V* is the variance vector; *V*[*i*] is the variance computed over all the *i*'th components of the points. If not passed, it is automatically computed.

5. `Y = cdist(XA, XB, 'sqeuclidean')`

Computes the squared Euclidean distance  $\|u - v\|_2^2$  between the vectors.

6.Y = cdist(XA, XB, 'cosine')

Computes the cosine distance between vectors  $u$  and  $v$ ,

$$1 - \frac{u \cdot v}{\|u\|_2 \|v\|_2}$$

where  $\|*\|_2$  is the 2-norm of its argument  $*$ , and  $u \cdot v$  is the dot product of  $u$  and  $v$ .

7.Y = cdist(XA, XB, 'correlation')

Computes the correlation distance between vectors  $u$  and  $v$ . This is

$$1 - \frac{(u - \bar{u}) \cdot (v - \bar{v})}{\|(u - \bar{u})\|_2 \|(v - \bar{v})\|_2}$$

where  $\bar{v}$  is the mean of the elements of vector  $v$ , and  $x \cdot y$  is the dot product of  $x$  and  $y$ .

8.Y = cdist(XA, XB, 'hamming')

Computes the normalized Hamming distance, or the proportion of those vector elements between two  $n$ -vectors  $u$  and  $v$  which disagree. To save memory, the matrix  $X$  can be of type boolean.

9.Y = cdist(XA, XB, 'jaccard')

Computes the Jaccard distance between the points. Given two vectors,  $u$  and  $v$ , the Jaccard distance is the proportion of those elements  $u[i]$  and  $v[i]$  that disagree where at least one of them is non-zero.

10.Y = cdist(XA, XB, 'chebyshev')

Computes the Chebyshev distance between the points. The Chebyshev distance between two  $n$ -vectors  $u$  and  $v$  is the maximum norm-1 distance between their respective elements. More precisely, the distance is given by

$$d(u, v) = \max_i |u_i - v_i|.$$

11.Y = cdist(XA, XB, 'canberra')

Computes the Canberra distance between the points. The Canberra distance between two points  $u$  and  $v$  is

$$d(u, v) = \sum_i \frac{|u_i - v_i|}{|u_i| + |v_i|}.$$

12.Y = cdist(XA, XB, 'braycurtis')

Computes the Bray-Curtis distance between the points. The Bray-Curtis distance between two points  $u$  and  $v$  is

$$d(u, v) = \frac{\sum_i (|u_i - v_i|)}{\sum_i (|u_i + v_i|)}$$

13.Y = cdist(XA, XB, 'mahalanobis', VI=None)

Computes the Mahalanobis distance between the points. The Mahalanobis distance between two points  $u$  and  $v$  is  $\sqrt{(u - v)(1/V)(u - v)^T}$  where  $(1/V)$  (the VI variable) is the inverse covariance. If VI is not None, VI will be used as the inverse covariance matrix.

14.Y = cdist(XA, XB, 'yule')

Computes the Yule distance between the boolean vectors. (see *yule* function documentation)

15.Y = cdist(XA, XB, 'matching')

Synonym for 'hamming'.

```
16.Y = cdist(XA, XB, 'dice')
```

Computes the Dice distance between the boolean vectors. (see *dice* function documentation)

```
17.Y = cdist(XA, XB, 'kulsinski')
```

Computes the Kulsinski distance between the boolean vectors. (see *kulsinski* function documentation)

```
18.Y = cdist(XA, XB, 'rogerstanimoto')
```

Computes the Rogers-Tanimoto distance between the boolean vectors. (see *rogerstanimoto* function documentation)

```
19.Y = cdist(XA, XB, 'russellrao')
```

Computes the Russell-Rao distance between the boolean vectors. (see *russellrao* function documentation)

```
20.Y = cdist(XA, XB, 'sokalmichener')
```

Computes the Sokal-Michener distance between the boolean vectors. (see *sokalmichener* function documentation)

```
21.Y = cdist(XA, XB, 'sokalsneath')
```

Computes the Sokal-Sneath distance between the vectors. (see *sokalsneath* function documentation)

```
22.Y = cdist(XA, XB, 'wminkowski', p=2., w=w)
```

Computes the weighted Minkowski distance between the vectors. (see *wminkowski* function documentation)

```
23.Y = cdist(XA, XB, f)
```

Computes the distance between all pairs of vectors in X using the user supplied 2-arity function f. For example, Euclidean distance between the vectors could be computed as follows:

```
dm = cdist(XA, XB, lambda u, v: np.sqrt(((u-v)**2).sum()))
```

Note that you should avoid passing a reference to one of the distance functions defined in this library. For example,:

```
dm = cdist(XA, XB, sokalsneath)
```

would calculate the pair-wise distances between the vectors in X using the Python function *sokalsneath*. This would result in *sokalsneath* being called  $\binom{n}{2}$  times, which is inefficient. Instead, the optimized C version is more efficient, and we call it using the following syntax:

```
dm = cdist(XA, XB, 'sokalsneath')
```

### Examples

Find the Euclidean distances between four 2-D coordinates:

```
>>> from scipy.spatial import distance
>>> coords = [(35.0456, -85.2672),
...          (35.1174, -89.9711),
...          (35.9728, -83.9422),
...          (36.1667, -86.7833)]
```

```
>>> distance.cdist(coords, coords, 'euclidean')
array([[ 0.        ,  4.7044,  1.6172,  1.8856],
       [ 4.7044,  0.        ,  6.0893,  3.3561],
       [ 1.6172,  6.0893,  0.        ,  2.8477],
       [ 1.8856,  3.3561,  2.8477,  0.        ]])
```

Find the Manhattan distance from a 3-D point to the corners of the unit cube:

```
>>> a = np.array([[0, 0, 0],
...              [0, 0, 1],
...              [0, 1, 0],
...              [0, 1, 1],
...              [1, 0, 0],
...              [1, 0, 1],
...              [1, 1, 0],
...              [1, 1, 1]])
>>> b = np.array([0.1, 0.2, 0.4])
>>> distance.cdist(a, b, 'cityblock')
array([[ 0.7],
       [ 0.9],
       [ 1.3],
       [ 1.5],
       [ 1.5],
       [ 1.7],
       [ 2.1],
       [ 2.3]])
```

`scipy.spatial.distance.squareform(X, force='no', checks=True)`

Converts a vector-form distance vector to a square-form distance matrix, and vice-versa.

**Parameters** **X** : ndarray

Either a condensed or redundant distance matrix.

**force** : str, optional

As with MATLAB(TM), if force is equal to 'tovector' or 'tomatrix', the input will be treated as a distance matrix or distance vector respectively.

**checks** : bool, optional

If set to False, no checks will be made for matrix symmetry nor zero diagonals. This is useful if it is known that  $X - X.T$  is small and  $\text{diag}(X)$  is close to zero. These values are ignored any way so they do not disrupt the squareform transformation.

**Returns** **Y** : ndarray

If a condensed distance matrix is passed, a redundant one is returned, or if a redundant one is passed, a condensed distance matrix is returned.

### Notes

1.  $v = \text{squareform}(X)$

Given a square  $d$ -by- $d$  symmetric distance matrix  $X$ ,  $v = \text{squareform}(X)$  returns a  $d * (d-1) / 2$  (or  $\binom{d}{2}$ ) sized vector  $v$ .

$v[\binom{d}{2} - \binom{d-i}{2} + (j-i-1)]$  is the distance between points  $i$  and  $j$ . If  $X$  is non-square or asymmetric, an error is returned.

2.  $X = \text{squareform}(v)$

Given a  $d*(d-1)/2$  sized  $v$  for some integer  $d \geq 2$  encoding distances as described,  $X = \text{squareform}(v)$  returns a  $d$  by  $d$  distance matrix  $X$ . The  $X[i, j]$  and  $X[j, i]$  values are set to  $v[\binom{n}{2} - \binom{n-i}{2} + (j-i-1)]$  and all diagonal elements are zero.

In SciPy 0.19.0, `squareform` stopped casting all input types to float64, and started returning arrays of the same dtype as the input.

`scipy.spatial.distance.directed_hausdorff(u, v, seed=0)`

Computes the directed Hausdorff distance between two N-D arrays.

Distances between pairs are calculated using a Euclidean metric.

**Parameters**

- u** : (M,N) ndarray  
Input array.
- v** : (O,N) ndarray  
Input array.
- seed** : int or None  
Local `np.random.RandomState` seed. Default is 0, a random shuffling of  $u$  and  $v$  that guarantees reproducibility.

**Returns**

- d** : double  
The directed Hausdorff distance between arrays  $u$  and  $v$ ,
- index\_1** : int  
index of point contributing to Hausdorff pair in  $u$
- index\_2** : int  
index of point contributing to Hausdorff pair in  $v$

See also:

`scipy.spatial.procrustes`

Another similarity test for two data sets

### Notes

Uses the early break technique and the random sampling approach described by [R409]. Although worst-case performance is  $O(m * o)$  (as with the brute force algorithm), this is unlikely in practice as the input data would have to require the algorithm to explore every single point interaction, and after the algorithm shuffles the input points at that. The best case performance is  $O(m)$ , which is satisfied by selecting an inner loop distance that is less than `cmax` and leads to an early break as often as possible. The authors have formally shown that the average runtime is closer to  $O(m)$ .

New in version 0.19.0.

### References

[R409]

### Examples

Find the directed Hausdorff distance between two 2-D arrays of coordinates:

```
>>> from scipy.spatial.distance import directed_hausdorff
>>> u = np.array([(1.0, 0.0),
...              (0.0, 1.0),
...              (-1.0, 0.0),
...              (0.0, -1.0)])
>>> v = np.array([(2.0, 0.0),
...              (0.0, 2.0),
...              (-2.0, 0.0),
...              (0.0, -4.0)])
```

```
>>> directed_hausdorff(u, v) [0]
2.23606797749979
>>> directed_hausdorff(v, u) [0]
3.0
```

Find the general (symmetric) Hausdorff distance between two 2-D arrays of coordinates:

```
>>> max(directed_hausdorff(u, v) [0], directed_hausdorff(v, u) [0])
3.0
```

Find the indices of the points that generate the Hausdorff distance (the Hausdorff pair):

```
>>> directed_hausdorff(v, u) [1:]
(3, 3)
```

Predicates for checking the validity of distance matrices, both condensed and redundant. Also contained in this module are functions for computing the number of observations in a distance matrix.

<code>is_valid_dm(D[, tol, throw, name, warning])</code>	Returns True if input array is a valid distance matrix.
<code>is_valid_y(y[, warning, throw, name])</code>	Returns True if the input array is a valid condensed distance matrix.
<code>num_obs_dm(d)</code>	Returns the number of original observations that correspond to a square, redundant distance matrix.
<code>num_obs_y(Y)</code>	Returns the number of original observations that correspond to a condensed distance matrix.

`scipy.spatial.distance.is_valid_dm(D, tol=0.0, throw=False, name='D', warning=False)`

Returns True if input array is a valid distance matrix.

Distance matrices must be 2-dimensional numpy arrays. They must have a zero-diagonal, and they must be symmetric.

<b>Parameters</b>	<b>D</b> : ndarray	The candidate object to test for validity.
	<b>tol</b> : float, optional	The distance matrix should be symmetric. <i>tol</i> is the maximum difference between entries $i_j$ and $j_i$ for the distance metric to be considered symmetric.
	<b>throw</b> : bool, optional	An exception is thrown if the distance matrix passed is not valid.
	<b>name</b> : str, optional	The name of the variable to checked. This is useful if <i>throw</i> is set to True so the offending variable can be identified in the exception message when an exception is thrown.
	<b>warning</b> : bool, optional	Instead of throwing an exception, a warning message is raised.
<b>Returns</b>	<b>valid</b> : bool	True if the variable <i>D</i> passed is a valid distance matrix.

#### Notes

Small numerical differences in *D* and *D.T* and non-zerosness of the diagonal are ignored if they are within the tolerance specified by *tol*.

`scipy.spatial.distance.is_valid_y(y, warning=False, throw=False, name=None)`

Returns True if the input array is a valid condensed distance matrix.

Condensed distance matrices must be 1-dimensional numpy arrays. Their length must be a binomial coefficient  $\binom{n}{2}$  for some positive integer  $n$ .

**Parameters** **y** : ndarray  
The condensed distance matrix.

**warning** : bool, optional  
Invokes a warning if the variable passed is not a valid condensed distance matrix. The warning message explains why the distance matrix is not valid. *name* is used when referencing the offending variable.

**throw** : bool, optional  
Throws an exception if the variable passed is not a valid condensed distance matrix.

**name** : bool, optional  
Used when referencing the offending variable in the warning or exception message.

`scipy.spatial.distance.num_obs_dm(d)`

Returns the number of original observations that correspond to a square, redundant distance matrix.

**Parameters** **d** : ndarray  
The target distance matrix.

**Returns** **num\_obs\_dm** : int  
The number of observations in the redundant distance matrix.

`scipy.spatial.distance.num_obs_y(Y)`

Returns the number of original observations that correspond to a condensed distance matrix.

**Parameters** **Y** : ndarray  
Condensed distance matrix.

**Returns** **n** : int  
The number of observations in the condensed distance matrix *Y*.

Distance functions between two numeric vectors *u* and *v*. Computing distances over a large collection of vectors is inefficient for these functions. Use `pdist` for this purpose.

<code>braycurtis(u, v[, w])</code>	Computes the Bray-Curtis distance between two 1-D arrays.
<code>canberra(u, v[, w])</code>	Computes the Canberra distance between two 1-D arrays.
<code>chebyshev(u, v)</code>	Computes the Chebyshev distance.
<code>cityblock(u, v[, w])</code>	Computes the City Block (Manhattan) distance.
<code>correlation(u, v[, w, centered])</code>	Computes the correlation distance between two 1-D arrays.
<code>cosine(u, v[, w])</code>	Computes the Cosine distance between 1-D arrays.
<code>euclidean(u, v[, w])</code>	Computes the Euclidean distance between two 1-D arrays.
<code>mahalanobis(u, v, VI)</code>	Computes the Mahalanobis distance between two 1-D arrays.
<code>minkowski(u, v[, p, w])</code>	Computes the Minkowski distance between two 1-D arrays.
<code>seuclidean(u, v, V)</code>	Returns the standardized Euclidean distance between two 1-D arrays.
<code>squeuclidean(u, v[, w])</code>	Computes the squared Euclidean distance between two 1-D arrays.
<code>wminkowski(u, v, p, w)</code>	Computes the weighted Minkowski distance between two 1-D arrays.

`scipy.spatial.distance.braycurtis(u, v, w=None)`

Computes the Bray-Curtis distance between two 1-D arrays.

Bray-Curtis distance is defined as

$$\sum |u_i - v_i| / \sum |u_i + v_i|$$

The Bray-Curtis distance is in the range [0, 1] if all coordinates are positive, and is undefined if the inputs are of length zero.

**Parameters**

- u** : (N,) array\_like  
Input array.
- v** : (N,) array\_like  
Input array.
- w** : (N,) array\_like, optional  
The weights for each value in *u* and *v*. Default is None, which gives each value a weight of 1.0

**Returns**

**braycurtis** : double  
The Bray-Curtis distance between 1-D arrays *u* and *v*.

`scipy.spatial.distance.canberra` (*u*, *v*, *w=None*)

Computes the Canberra distance between two 1-D arrays.

The Canberra distance is defined as

$$d(u, v) = \sum_i \frac{|u_i - v_i|}{|u_i| + |v_i|}$$

**Parameters**

- u** : (N,) array\_like  
Input array.
- v** : (N,) array\_like  
Input array.
- w** : (N,) array\_like, optional  
The weights for each value in *u* and *v*. Default is None, which gives each value a weight of 1.0

**Returns**

**canberra** : double  
The Canberra distance between vectors *u* and *v*.

#### Notes

When  $u[i]$  and  $v[i]$  are 0 for given *i*, then the fraction  $0/0 = 0$  is used in the calculation.

`scipy.spatial.distance.chebyshev` (*u*, *v*)

Computes the Chebyshev distance.

Computes the Chebyshev distance between two 1-D arrays *u* and *v*, which is defined as

$$\max_i |u_i - v_i|$$

**Parameters**

- u** : (N,) array\_like  
Input vector.
- v** : (N,) array\_like  
Input vector.

**Returns**

**chebyshev** : double  
The Chebyshev distance between vectors *u* and *v*.

`scipy.spatial.distance.cityblock` (*u*, *v*, *w=None*)

Computes the City Block (Manhattan) distance.

Computes the Manhattan distance between two 1-D arrays *u* and *v*, which is defined as

$$\sum_i |u_i - v_i|$$

**Parameters** **u** : (N,) array\_like  
 Input array.  
**v** : (N,) array\_like  
 Input array.  
**w** : (N,) array\_like, optional  
 The weights for each value in *u* and *v*. Default is None, which gives each value a weight of 1.0

**Returns** **cityblock** : double  
 The City Block (Manhattan) distance between vectors *u* and *v*.

`scipy.spatial.distance.correlation` (*u*, *v*, *w=None*, *centered=True*)

Computes the correlation distance between two 1-D arrays. The correlation distance between *u* and *v*, is defined as

$$1 - \frac{(u - \bar{u}) \cdot (v - \bar{v})}{\|u - \bar{u}\|_2 \|v - \bar{v}\|_2}$$

where  $\bar{u}$  is the mean of the elements of *u* and  $x \cdot y$  is the dot product of *x* and *y*.

**Parameters** **u** : (N,) array\_like  
 Input array.  
**v** : (N,) array\_like  
 Input array.  
**w** : (N,) array\_like, optional  
 The weights for each value in *u* and *v*. Default is None, which gives each value a weight of 1.0

**Returns** **correlation** : double  
 The correlation distance between 1-D array *u* and *v*.

`scipy.spatial.distance.cosine` (*u*, *v*, *w=None*)

Computes the Cosine distance between 1-D arrays. The Cosine distance between *u* and *v*, is defined as

$$1 - \frac{u \cdot v}{\|u\|_2 \|v\|_2}$$

where  $u \cdot v$  is the dot product of *u* and *v*.

**Parameters** **u** : (N,) array\_like  
 Input array.  
**v** : (N,) array\_like  
 Input array.  
**w** : (N,) array\_like, optional  
 The weights for each value in *u* and *v*. Default is None, which gives each value a weight of 1.0

**Returns** **cosine** : double  
 The Cosine distance between vectors *u* and *v*.

`scipy.spatial.distance.euclidean` (*u*, *v*, *w=None*)

Computes the Euclidean distance between two 1-D arrays.

The Euclidean distance between 1-D arrays *u* and *v*, is defined as

$$\|u - v\|_2 \left( \sum (w_i |(u_i - v_i)|^2) \right)^{1/2}$$

**Parameters** **u** : (N,) array\_like  
 Input array.  
**v** : (N,) array\_like  
 Input array.

**w** : (N,) array\_like, optional  
The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0

**Returns** **euclidean** : double  
The Euclidean distance between vectors  $u$  and  $v$ .

`scipy.spatial.distance.mahalanobis` ( $u, v, VI$ )

Computes the Mahalanobis distance between two 1-D arrays.

The Mahalanobis distance between 1-D arrays  $u$  and  $v$ , is defined as

$$\sqrt{(u - v)V^{-1}(u - v)^T}$$

where  $V$  is the covariance matrix. Note that the argument  $VI$  is the inverse of  $V$ .

**Parameters** **u** : (N,) array\_like  
Input array.  
**v** : (N,) array\_like  
Input array.  
**VI** : ndarray  
The inverse of the covariance matrix.

**Returns** **mahalanobis** : double  
The Mahalanobis distance between vectors  $u$  and  $v$ .

`scipy.spatial.distance.minkowski` ( $u, v, p=2, w=None$ )

Computes the Minkowski distance between two 1-D arrays.

The Minkowski distance between 1-D arrays  $u$  and  $v$ , is defined as

$$\|u - v\|_p = \left( \sum |u_i - v_i|^p \right)^{1/p}.$$

$$\left( \sum w_i (|u_i - v_i|^p) \right)^{1/p}.$$

**Parameters** **u** : (N,) array\_like  
Input array.  
**v** : (N,) array\_like  
Input array.  
**p** : int  
The order of the norm of the difference  $\|u - v\|_p$ .  
**w** : (N,) array\_like, optional  
The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0

**Returns** **minkowski** : double  
The Minkowski distance between vectors  $u$  and  $v$ .

`scipy.spatial.distance.seuclidean` ( $u, v, V$ )

Returns the standardized Euclidean distance between two 1-D arrays.

The standardized Euclidean distance between  $u$  and  $v$ .

**Parameters** **u** : (N,) array\_like  
Input array.  
**v** : (N,) array\_like  
Input array.  
**V** : (N,) array\_like  
 $V$  is an 1-D array of component variances. It is usually computed among a larger collection vectors.

**Returns** **seuclidean** : double  
The standardized Euclidean distance between vectors  $u$  and  $v$ .

`scipy.spatial.distance.sqeuclidean` (*u*, *v*, *w=None*)  
 Computes the squared Euclidean distance between two 1-D arrays.

The squared Euclidean distance between *u* and *v* is defined as

$$\|u - v\|_2^2$$

$$\left( \sum (w_i |u_i - v_i|^2) \right)$$

**Parameters**

- u** : (N,) array\_like  
Input array.
- v** : (N,) array\_like  
Input array.
- w** : (N,) array\_like, optional  
The weights for each value in *u* and *v*. Default is None, which gives each value a weight of 1.0

**Returns**

**sqeuclidean** : double  
The squared Euclidean distance between vectors *u* and *v*.

`scipy.spatial.distance.wminkowski` (*u*, *v*, *p*, *w*)  
 Computes the weighted Minkowski distance between two 1-D arrays. The weighted Minkowski distance between *u* and *v*, defined as

$$\left( \sum (|w_i (u_i - v_i)|^p) \right)^{1/p} .$$

**Parameters**

- u** : (N,) array\_like  
Input array.
- v** : (N,) array\_like  
Input array.
- p** : int  
The order of the norm of the difference  $\|u - v\|_p$ .
- w** : (N,) array\_like  
The weight vector.

**Returns**

**wminkowski** : double  
The weighted Minkowski distance between vectors *u* and *v*.

**Notes**

`wminkowski` is DEPRECATED. It implements a definition where weights are powered. It is recommended to use the weighted version of `minkowski` instead. This function will be removed in a future version of `scipy`.

Distance functions between two boolean vectors (representing sets) *u* and *v*. As in the case of numerical vectors, `pdist` is more efficient for computing the distances between all pairs.

<code>dice(u, v[, w])</code>	Computes the Dice dissimilarity between two boolean 1-D arrays.
<code>hamming(u, v[, w])</code>	Computes the Hamming distance between two 1-D arrays.
<code>jaccard(u, v[, w])</code>	Computes the Jaccard-Needham dissimilarity between two boolean 1-D arrays.
<code>kulsinski(u, v[, w])</code>	Computes the Kulsinski dissimilarity between two boolean 1-D arrays.
<code>rogerstanimoto(u, v[, w])</code>	Computes the Rogers-Tanimoto dissimilarity between two boolean 1-D arrays.
<code>russellrao(u, v[, w])</code>	Computes the Russell-Rao dissimilarity between two boolean 1-D arrays.
<code>sokalmichener(u, v[, w])</code>	Computes the Sokal-Michener dissimilarity between two boolean 1-D arrays.

Continued on next page

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<code>sokalsneath(u, v[, w])</code>	Computes the Sokal-Sneath dissimilarity between two boolean 1-D arrays.
<code>yule(u, v[, w])</code>	Computes the Yule dissimilarity between two boolean 1-D arrays.

`scipy.spatial.distance.dice` ( $u, v, w=None$ )

Computes the Dice dissimilarity between two boolean 1-D arrays.

The Dice dissimilarity between  $u$  and  $v$ , is

$$\frac{c_{TF} + c_{FT}}{2c_{TT} + c_{FT} + c_{TF}}$$

where  $c_{ij}$  is the number of occurrences of  $u[k] = i$  and  $v[k] = j$  for  $k < n$ .

**Parameters**

- u** : (N,) ndarray, bool  
Input 1-D array.
- v** : (N,) ndarray, bool  
Input 1-D array.
- w** : (N,) array\_like, optional  
The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0

**Returns**

**dice** : double  
The Dice dissimilarity between 1-D arrays  $u$  and  $v$ .

`scipy.spatial.distance.hamming` ( $u, v, w=None$ )

Computes the Hamming distance between two 1-D arrays.

The Hamming distance between 1-D arrays  $u$  and  $v$ , is simply the proportion of disagreeing components in  $u$  and  $v$ . If  $u$  and  $v$  are boolean vectors, the Hamming distance is

$$\frac{c_{01} + c_{10}}{n}$$

where  $c_{ij}$  is the number of occurrences of  $u[k] = i$  and  $v[k] = j$  for  $k < n$ .

**Parameters**

- u** : (N,) array\_like  
Input array.
- v** : (N,) array\_like  
Input array.
- w** : (N,) array\_like, optional  
The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0

**Returns**

**hamming** : double  
The Hamming distance between vectors  $u$  and  $v$ .

`scipy.spatial.distance.jaccard` ( $u, v, w=None$ )

Computes the Jaccard-Needham dissimilarity between two boolean 1-D arrays.

The Jaccard-Needham dissimilarity between 1-D boolean arrays  $u$  and  $v$ , is defined as

$$\frac{c_{TF} + c_{FT}}{c_{TT} + c_{FT} + c_{TF}}$$

where  $c_{ij}$  is the number of occurrences of  $u[k] = i$  and  $v[k] = j$  for  $k < n$ .

**Parameters**

- u** : (N,) array\_like, bool  
Input array.
- v** : (N,) array\_like, bool  
Input array.

**Returns** **w** : (N,) array\_like, optional  
 The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0  
**jaccard** : double  
 The Jaccard distance between vectors  $u$  and  $v$ .

`scipy.spatial.distance.kulsinski` ( $u, v, w=None$ )

Computes the Kulsinski dissimilarity between two boolean 1-D arrays.

The Kulsinski dissimilarity between two boolean 1-D arrays  $u$  and  $v$ , is defined as

$$\frac{c_{TF} + c_{FT} - c_{TT} + n}{c_{FT} + c_{TF} + n}$$

where  $c_{ij}$  is the number of occurrences of  $u[k] = i$  and  $v[k] = j$  for  $k < n$ .

**Parameters** **u** : (N,) array\_like, bool  
 Input array.  
**v** : (N,) array\_like, bool  
 Input array.  
**w** : (N,) array\_like, optional  
 The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0  
**Returns** **kulsinski** : double  
 The Kulsinski distance between vectors  $u$  and  $v$ .

`scipy.spatial.distance.rogerstanimoto` ( $u, v, w=None$ )

Computes the Rogers-Tanimoto dissimilarity between two boolean 1-D arrays.

The Rogers-Tanimoto dissimilarity between two boolean 1-D arrays  $u$  and  $v$ , is defined as

$$\frac{R}{c_{TT} + c_{FF} + R}$$

where  $c_{ij}$  is the number of occurrences of  $u[k] = i$  and  $v[k] = j$  for  $k < n$  and  $R = 2(c_{TF} + c_{FT})$ .

**Parameters** **u** : (N,) array\_like, bool  
 Input array.  
**v** : (N,) array\_like, bool  
 Input array.  
**w** : (N,) array\_like, optional  
 The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0  
**Returns** **rogerstanimoto** : double  
 The Rogers-Tanimoto dissimilarity between vectors  $u$  and  $v$ .

`scipy.spatial.distance.russellrao` ( $u, v, w=None$ )

Computes the Russell-Rao dissimilarity between two boolean 1-D arrays.

The Russell-Rao dissimilarity between two boolean 1-D arrays,  $u$  and  $v$ , is defined as

$$\frac{n - c_{TT}}{n}$$

where  $c_{ij}$  is the number of occurrences of  $u[k] = i$  and  $v[k] = j$  for  $k < n$ .

**Parameters** **u** : (N,) array\_like, bool  
 Input array.  
**v** : (N,) array\_like, bool  
 Input array.  
**w** : (N,) array\_like, optional  
 The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0

**Returns** **russellrao** : double  
The Russell-Rao dissimilarity between vectors  $u$  and  $v$ .

`scipy.spatial.distance.sokalmichener` ( $u, v, w=None$ )

Computes the Sokal-Michener dissimilarity between two boolean 1-D arrays.

The Sokal-Michener dissimilarity between boolean 1-D arrays  $u$  and  $v$ , is defined as

$$\frac{R}{S + R}$$

where  $c_{ij}$  is the number of occurrences of  $u[k] = i$  and  $v[k] = j$  for  $k < n$ ,  $R = 2 * (c_{TF} + c_{FT})$  and  $S = c_{FF} + c_{TT}$ .

**Parameters** **u** : (N,) array\_like, bool  
Input array.  
**v** : (N,) array\_like, bool  
Input array.  
**w** : (N,) array\_like, optional  
The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0

**Returns** **sokalmichener** : double  
The Sokal-Michener dissimilarity between vectors  $u$  and  $v$ .

`scipy.spatial.distance.sokalsneath` ( $u, v, w=None$ )

Computes the Sokal-Sneath dissimilarity between two boolean 1-D arrays.

The Sokal-Sneath dissimilarity between  $u$  and  $v$ ,

$$\frac{R}{c_{TT} + R}$$

where  $c_{ij}$  is the number of occurrences of  $u[k] = i$  and  $v[k] = j$  for  $k < n$  and  $R = 2(c_{TF} + c_{FT})$ .

**Parameters** **u** : (N,) array\_like, bool  
Input array.  
**v** : (N,) array\_like, bool  
Input array.  
**w** : (N,) array\_like, optional  
The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0

**Returns** **sokalsneath** : double  
The Sokal-Sneath dissimilarity between vectors  $u$  and  $v$ .

`scipy.spatial.distance.yule` ( $u, v, w=None$ )

Computes the Yule dissimilarity between two boolean 1-D arrays.

The Yule dissimilarity is defined as

$$\frac{R}{c_{TT} * c_{FF} + \frac{R}{2}}$$

where  $c_{ij}$  is the number of occurrences of  $u[k] = i$  and  $v[k] = j$  for  $k < n$  and  $R = 2.0 * c_{TF} * c_{FT}$ .

**Parameters** **u** : (N,) array\_like, bool  
Input array.  
**v** : (N,) array\_like, bool  
Input array.  
**w** : (N,) array\_like, optional  
The weights for each value in  $u$  and  $v$ . Default is None, which gives each value a weight of 1.0

**Returns** **yule** : double

The Yule dissimilarity between vectors  $u$  and  $v$ .

`hamming` also operates over discrete numerical vectors.

## 5.26 Special functions (`scipy.special`)

Nearly all of the functions below are universal functions and follow broadcasting and automatic array-looping rules. Exceptions are noted.

**See also:**

`scipy.special.cython_special` – Typed Cython versions of special functions

### 5.26.1 Error handling

Errors are handled by returning NaNs or other appropriate values. Some of the special function routines can emit warnings or raise exceptions when an error occurs. By default this is disabled; to query and control the current error handling state the following functions are provided.

<code>geterr</code>	Get the current way of handling special-function errors.
<code>seterr</code>	Set how special-function errors are handled.
<code>errstate</code>	Context manager for special-function error handling.
<code>SpecialFunctionWarning</code>	Warning that can be emitted by special functions.
<code>SpecialFunctionError</code>	Exception that can be raised by special functions.

`scipy.special.geterr()`

Get the current way of handling special-function errors.

**Returns** `err` : dict

A dictionary with keys “singular”, “underflow”, “overflow”, “slow”, “loss”, “no\_result”, “domain”, “arg”, and “other”, whose values are from the strings “ignore”, “warn”, and “raise”. The keys represent possible special-function errors, and the values define how these errors are handled.

**See also:**

- seterr** set how special-function errors are handled
- errstate** context manager for special-function error handling
- `numpy.geterr`** similar numpy function for floating-point errors

**Notes**

For complete documentation of the types of special-function errors and treatment options, see `seterr`.

**Examples**

By default all errors are ignored.

```

>>> import scipy.special as sc
>>> for key, value in sorted(sc.geterr().items()):
...     print("{}: {}".format(key, value))
...
arg: ignore
domain: ignore
    
```

```

loss: ignore
no_result: ignore
other: ignore
overflow: ignore
singular: ignore
slow: ignore
underflow: ignore

```

`scipy.special.seterr()`

Set how special-function errors are handled.

**Parameters** **all** : {'ignore', 'warn', 'raise'}, optional

Set treatment for all type of special-function errors at once. The options are:

- 'ignore' Take no action when the error occurs
- 'warn' Print a `SpecialFunctionWarning` when the error occurs (via the Python `warnings` module)
- 'raise' Raise a `SpecialFunctionError` when the error occurs.

The default is to not change the current behavior. If behaviors for additional categories of special-function errors are specified, then `all` is applied first, followed by the additional categories.

**singular** : {'ignore', 'warn', 'raise'}, optional

Treatment for singularities.

**underflow** : {'ignore', 'warn', 'raise'}, optional

Treatment for underflow.

**overflow** : {'ignore', 'warn', 'raise'}, optional

Treatment for overflow.

**slow** : {'ignore', 'warn', 'raise'}, optional

Treatment for slow convergence.

**loss** : {'ignore', 'warn', 'raise'}, optional

Treatment for loss of accuracy.

**no\_result** : {'ignore', 'warn', 'raise'}, optional

Treatment for failing to find a result.

**domain** : {'ignore', 'warn', 'raise'}, optional

Treatment for an invalid argument to a function.

**arg** : {'ignore', 'warn', 'raise'}, optional

Treatment for an invalid parameter to a function.

**other** : {'ignore', 'warn', 'raise'}, optional

Treatment for an unknown error.

**Returns**

**olderr** : dict

Dictionary containing the old settings.

See also:

**geterr** get the current way of handling special-function errors

**errstate** context manager for special-function error handling

**`numpy.seterr`**

similar numpy function for floating-point errors

**Examples**

```

>>> import scipy.special as sc
>>> from pytest import raises
>>> sc.gammaln(0)
inf
>>> olderr = sc.seterr(singular='raise')

```

```
>>> with raises(sc.SpecialFunctionError):
...     sc.gammaln(0)
...
>>> _ = sc.seterr(**olderr)
```

We can also raise for every category except one.

```
>>> olderr = sc.seterr(all='raise', singular='ignore')
>>> sc.gammaln(0)
inf
>>> with raises(sc.SpecialFunctionError):
...     sc.spence(-1)
...
>>> _ = sc.seterr(**olderr)
```

### class `scipy.special.errstate`

Context manager for special-function error handling.

Using an instance of `errstate` as a context manager allows statements in that context to execute with a known error handling behavior. Upon entering the context the error handling is set with `seterr`, and upon exiting it is restored to what it was before.

**Parameters** **kwargs** : {all, singular, underflow, overflow, slow, loss, no\_result, domain, arg, other}  
 Keyword arguments. The valid keywords are possible special-function errors. Each keyword should have a string value that defines the treatment for the particular type of error. Values must be 'ignore', 'warn', or 'other'. See `seterr` for details.

#### See also:

**geterr** get the current way of handling special-function errors  
**seterr** set how special-function errors are handled  
`numpy.errstate`  
 similar numpy function for floating-point errors

#### Examples

```
>>> import scipy.special as sc
>>> from pytest import raises
>>> sc.gammaln(0)
inf
>>> with sc.errstate(singular='raise'):
...     with raises(sc.SpecialFunctionError):
...         sc.gammaln(0)
...
>>> sc.gammaln(0)
inf
```

We can also raise on every category except one.

```
>>> with sc.errstate(all='raise', singular='ignore'):
...     sc.gammaln(0)
...     with raises(sc.SpecialFunctionError):
...         sc.spence(-1)
...
inf
```

**exception** `scipy.special.SpecialFunctionWarning`

Warning that can be emitted by special functions.

**exception** `scipy.special.SpecialFunctionError`

Exception that can be raised by special functions.

## 5.26.2 Available functions

### Airy functions

<code>airy(z)</code>	Airy functions and their derivatives.
<code>airye(z)</code>	Exponentially scaled Airy functions and their derivatives.
<code>ai_zeros(nt)</code>	Compute $nt$ zeros and values of the Airy function $Ai$ and its derivative.
<code>bi_zeros(nt)</code>	Compute $nt$ zeros and values of the Airy function $Bi$ and its derivative.
<code>itairy(x)</code>	Integrals of Airy functions

`scipy.special.airy(z) = <ufunc 'airy'>`

Airy functions and their derivatives.

**Parameters** `z` : array\_like

**Returns** `Ai, Aip, Bi, Bip` : ndarrays

Real or complex argument.

Airy functions  $Ai$  and  $Bi$ , and their derivatives  $Aip$  and  $Bip$ .

**See also:**

**airye** exponentially scaled Airy functions.

**Notes**

The Airy functions  $Ai$  and  $Bi$  are two independent solutions of

$$y''(x) = xy(x).$$

For real  $z$  in  $[-10, 10]$ , the computation is carried out by calling the Cephes [R413] `airy` routine, which uses power series summation for small  $z$  and rational minimax approximations for large  $z$ .

Outside this range, the AMOS [R414] `zairy` and `zbiry` routines are employed. They are computed using power series for  $|z| < 1$  and the following relations to modified Bessel functions for larger  $z$  (where  $t \equiv 2z^{3/2}/3$ ):

$$Ai(z) = \frac{1}{\pi\sqrt{3}}K_{1/3}(t)$$

$$Ai'(z) = -\frac{z}{\pi\sqrt{3}}K_{2/3}(t)$$

$$Bi(z) = \sqrt{\frac{z}{3}}(I_{-1/3}(t) + I_{1/3}(t))$$

$$Bi'(z) = \frac{z}{\sqrt{3}}(I_{-2/3}(t) + I_{2/3}(t))$$

**References**

[R413], [R414]

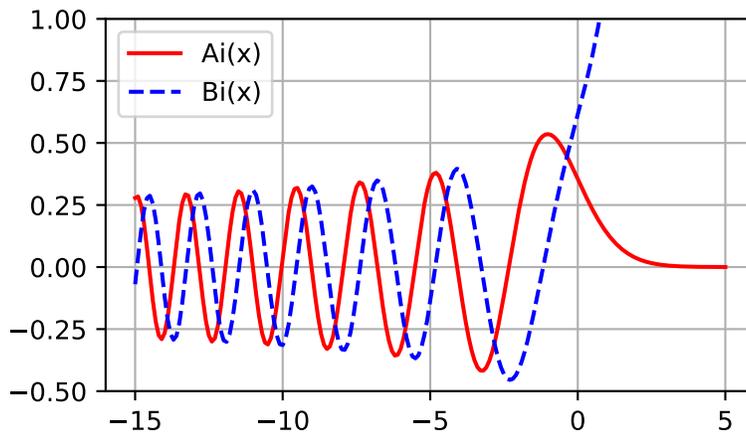
*Examples*

Compute the Airy functions on the interval [-15, 5].

```
>>> from scipy import special
>>> x = np.linspace(-15, 5, 201)
>>> ai, aip, bi, bip = special.airy(x)
```

Plot  $Ai(x)$  and  $Bi(x)$ .

```
>>> import matplotlib.pyplot as plt
>>> plt.plot(x, ai, 'r', label='Ai(x)')
>>> plt.plot(x, bi, 'b--', label='Bi(x)')
>>> plt.ylim(-0.5, 1.0)
>>> plt.grid()
>>> plt.legend(loc='upper left')
>>> plt.show()
```



`scipy.special.airye(z) = <ufunc 'airye'>`

Exponentially scaled Airy functions and their derivatives.

Scaling:

```
eAi = Ai * exp(2.0/3.0*z*sqrt(z))
eAip = Aip * exp(2.0/3.0*z*sqrt(z))
eBi = Bi * exp(-abs(2.0/3.0*(z*sqrt(z)).real))
eBip = Bip * exp(-abs(2.0/3.0*(z*sqrt(z)).real))
```

**Parameters** `z`: array\_like

**Returns** `eAi, eAip, eBi, eBip`: array\_like  
 Real or complex argument.  
 Airy functions  $Ai$  and  $Bi$ , and their derivatives  $Aip$  and  $Bip$

**See also:**

`airy`

**Notes**

Wrapper for the AMOS [R415] routines *zairy* and *zbiry*.

**References**

[R415]

`scipy.special.ai_zeros` (*nt*)

Compute *nt* zeros and values of the Airy function  $Ai$  and its derivative.

Computes the first *nt* zeros, *a*, of the Airy function  $Ai(x)$ ; first *nt* zeros, *ap*, of the derivative of the Airy function  $Ai'(x)$ ; the corresponding values  $Ai(a')$ ; and the corresponding values  $Ai'(a)$ .

<b>Parameters</b>	<b>nt</b> : int	Number of zeros to compute
<b>Returns</b>	<b>a</b> : ndarray	First <i>nt</i> zeros of $Ai(x)$
	<b>ap</b> : ndarray	First <i>nt</i> zeros of $Ai'(x)$
	<b>ai</b> : ndarray	Values of $Ai(x)$ evaluated at first <i>nt</i> zeros of $Ai'(x)$
	<b>aip</b> : ndarray	Values of $Ai'(x)$ evaluated at first <i>nt</i> zeros of $Ai(x)$

**References**

[R412]

`scipy.special.bi_zeros` (*nt*)

Compute *nt* zeros and values of the Airy function  $Bi$  and its derivative.

Computes the first *nt* zeros, *b*, of the Airy function  $Bi(x)$ ; first *nt* zeros, *b'*, of the derivative of the Airy function  $Bi'(x)$ ; the corresponding values  $Bi(b')$ ; and the corresponding values  $Bi'(b)$ .

<b>Parameters</b>	<b>nt</b> : int	Number of zeros to compute
<b>Returns</b>	<b>b</b> : ndarray	First <i>nt</i> zeros of $Bi(x)$
	<b>bp</b> : ndarray	First <i>nt</i> zeros of $Bi'(x)$
	<b>bi</b> : ndarray	Values of $Bi(x)$ evaluated at first <i>nt</i> zeros of $Bi'(x)$
	<b>bip</b> : ndarray	Values of $Bi'(x)$ evaluated at first <i>nt</i> zeros of $Bi(x)$

**References**

[R428]

`scipy.special.itairy` (*x*) = <ufunc 'itairy'>

Integrals of Airy functions

Calculates the integrals of Airy functions from 0 to *x*.

<b>Parameters</b>	<b>x</b> : array_like	Upper limit of integration (float).
<b>Returns</b>	<b>Apt</b>	Integral of $Ai(t)$ from 0 to <i>x</i> .
	<b>Bpt</b>	Integral of $Bi(t)$ from 0 to <i>x</i> .
	<b>Ant</b>	



`scipy.special.ellipk(m)`

Complete elliptic integral of the first kind.

This function is defined as

$$K(m) = \int_0^{\pi/2} [1 - m \sin(t)^2]^{-1/2} dt$$

**Parameters** **m** : array\_like  
**Returns** **K** : array\_like The parameter of the elliptic integral.  
 Value of the elliptic integral.

**See also:**

**ellipkm1** Complete elliptic integral of the first kind around  $m = 1$   
**ellipkinc** Incomplete elliptic integral of the first kind  
**ellipe** Complete elliptic integral of the second kind  
**ellipeinc** Incomplete elliptic integral of the second kind

**Notes**

For more precision around point  $m = 1$ , use `ellipkm1`, which this function calls.

The parameterization in terms of  $m$  follows that of section 17.2 in [R452]. Other parameterizations in terms of the complementary parameter  $1 - m$ , modular angle  $\sin^2(\alpha) = m$ , or modulus  $k^2 = m$  are also used, so be careful that you choose the correct parameter.

**References**

[R452]

`scipy.special.ellipkm1(p) = <ufunc 'ellipkm1'>`

Complete elliptic integral of the first kind around  $m = 1$

This function is defined as

$$K(p) = \int_0^{\pi/2} [1 - m \sin(t)^2]^{-1/2} dt$$

where  $m = 1 - p$ .

**Parameters** **p** : array\_like  
**Returns** **K** : ndarray Defines the parameter of the elliptic integral as  $m = 1 - p$ .  
 Value of the elliptic integral.

**See also:**

**ellipk** Complete elliptic integral of the first kind  
**ellipkinc** Incomplete elliptic integral of the first kind  
**ellipe** Complete elliptic integral of the second kind  
**ellipeinc** Incomplete elliptic integral of the second kind

**Notes**

Wrapper for the Cephes [R455] routine `ellpk`.

For  $p \leq 1$ , computation uses the approximation,

$$K(p) \approx P(p) - \log(p)Q(p),$$

where  $P$  and  $Q$  are tenth-order polynomials. The argument  $p$  is used internally rather than  $m$  so that the logarithmic singularity at  $m = 1$  will be shifted to the origin; this preserves maximum accuracy. For  $p > 1$ , the identity

$$K(p) = K(1/p)/\sqrt{p}$$

is used.

### References

[R455]

`scipy.special.ellipkinc(phi, m) = <ufunc 'ellipkinc'>`

Incomplete elliptic integral of the first kind

This function is defined as

$$K(\phi, m) = \int_0^\phi [1 - m \sin(t)^2]^{-1/2} dt$$

This function is also called  $F(\phi, m)$ .

<b>Parameters</b>	<b>phi</b> : array_like	amplitude of the elliptic integral
	<b>m</b> : array_like	parameter of the elliptic integral
<b>Returns</b>	<b>K</b> : ndarray	Value of the elliptic integral

See also:

<b>ellipkm1</b>	Complete elliptic integral of the first kind, near $m = 1$
<b>ellipk</b>	Complete elliptic integral of the first kind
<b>ellipe</b>	Complete elliptic integral of the second kind
<b>ellipeinc</b>	Incomplete elliptic integral of the second kind

### Notes

Wrapper for the Cephes [R453] routine *ellik*. The computation is carried out using the arithmetic-geometric mean algorithm.

The parameterization in terms of  $m$  follows that of section 17.2 in [R454]. Other parameterizations in terms of the complementary parameter  $1 - m$ , modular angle  $\sin^2(\alpha) = m$ , or modulus  $k^2 = m$  are also used, so be careful that you choose the correct parameter.

### References

[R453], [R454]

`scipy.special.ellipe(m) = <ufunc 'ellipe'>`

Complete elliptic integral of the second kind

This function is defined as

$$E(m) = \int_0^{\pi/2} [1 - m \sin(t)^2]^{1/2} dt$$

<b>Parameters</b>	<b>m</b> : array_like	Defines the parameter of the elliptic integral.
<b>Returns</b>	<b>E</b> : ndarray	Value of the elliptic integral.

See also:

**ellipkm1** Complete elliptic integral of the first kind, near  $m = 1$   
**ellipk** Complete elliptic integral of the first kind  
**ellipkinc** Incomplete elliptic integral of the first kind  
**ellipeinc** Incomplete elliptic integral of the second kind

**Notes**

Wrapper for the Cephes [R447] routine *ellpe*.

For  $m > 0$  the computation uses the approximation,

$$E(m) \approx P(1 - m) - (1 - m) \log(1 - m)Q(1 - m),$$

where  $P$  and  $Q$  are tenth-order polynomials. For  $m < 0$ , the relation

$$E(m) = E(m/(m - 1))\sqrt{1 - m}$$

is used.

The parameterization in terms of  $m$  follows that of section 17.2 in [R448]. Other parameterizations in terms of the complementary parameter  $1 - m$ , modular angle  $\sin^2(\alpha) = m$ , or modulus  $k^2 = m$  are also used, so be careful that you choose the correct parameter.

**References**

[R447], [R448]

`scipy.special.ellipeinc(phi, m) = <ufunc 'ellipeinc'>`  
 Incomplete elliptic integral of the second kind

This function is defined as

$$E(\phi, m) = \int_0^\phi [1 - m \sin(t)^2]^{1/2} dt$$

**Parameters**

- phi** : array\_like  
amplitude of the elliptic integral.
- m** : array\_like  
parameter of the elliptic integral.

**Returns**

- E** : ndarray  
Value of the elliptic integral.

**See also:**

**ellipkm1** Complete elliptic integral of the first kind, near  $m = 1$   
**ellipk** Complete elliptic integral of the first kind  
**ellipkinc** Incomplete elliptic integral of the first kind  
**ellipe** Complete elliptic integral of the second kind

**Notes**

Wrapper for the Cephes [R449] routine *ellie*.

Computation uses arithmetic-geometric means algorithm.

The parameterization in terms of  $m$  follows that of section 17.2 in [R450]. Other parameterizations in terms of the complementary parameter  $1 - m$ , modular angle  $\sin^2(\alpha) = m$ , or modulus  $k^2 = m$  are also used, so be careful that you choose the correct parameter.

**References**

[R449], [R450]

## Bessel Functions

$jv(v, z)$	Bessel function of the first kind of real order and complex argument.
$jn(v, z)$	Bessel function of the first kind of real order and complex argument.
$jve(v, z)$	Exponentially scaled Bessel function of order $v$ .
$yn(n, x)$	Bessel function of the second kind of integer order and real argument.
$yv(v, z)$	Bessel function of the second kind of real order and complex argument.
$yve(v, z)$	Exponentially scaled Bessel function of the second kind of real order.
$kn(n, x)$	Modified Bessel function of the second kind of integer order $n$
$kν(v, z)$	Modified Bessel function of the second kind of real order $v$
$kve(v, z)$	Exponentially scaled modified Bessel function of the second kind.
$iv(v, z)$	Modified Bessel function of the first kind of real order.
$ive(v, z)$	Exponentially scaled modified Bessel function of the first kind
$hankel1(v, z)$	Hankel function of the first kind
$hankel1e(v, z)$	Exponentially scaled Hankel function of the first kind
$hankel2(v, z)$	Hankel function of the second kind
$hankel2e(v, z)$	Exponentially scaled Hankel function of the second kind

`scipy.special.jv(v, z) = <ufunc 'jv'>`

Bessel function of the first kind of real order and complex argument.

**Parameters**

- v** : array\_like  
Order (float).
- z** : array\_like  
Argument (float or complex).

**Returns**

- J** : ndarray  
Value of the Bessel function,  $J_v(z)$ .

**See also:**

**jve**  $J_v$  with leading exponential behavior stripped off.

**spherical\_jn**  
spherical Bessel functions.

**Notes**

For positive  $v$  values, the computation is carried out using the AMOS [R511] *zbesj* routine, which exploits the connection to the modified Bessel function  $I_v$ ,

$$J_v(z) = \exp(v\pi i/2)I_v(-iz) \quad (\Im z > 0)$$

$$J_v(z) = \exp(-v\pi i/2)I_v(iz) \quad (\Im z < 0)$$

For negative  $v$  values the formula,

$$J_{-v}(z) = J_v(z) \cos(\pi v) - Y_v(z) \sin(\pi v)$$

is used, where  $Y_v(z)$  is the Bessel function of the second kind, computed using the AMOS routine *zbesy*. Note that the second term is exactly zero for integer  $v$ ; to improve accuracy the second term is explicitly omitted for  $v$  values such that  $v = \text{floor}(v)$ .

Not to be confused with the spherical Bessel functions (see *spherical\_jn*).

### References

[R511]

`scipy.special.jn`(*v*, *z*) = <ufunc 'jn'>

Bessel function of the first kind of real order and complex argument.

**Parameters**

- v** : array\_like  
Order (float).
- z** : array\_like  
Argument (float or complex).

**Returns**

- J** : ndarray  
Value of the Bessel function,  $J_v(z)$ .

See also:

**jve**  $J_v$  with leading exponential behavior stripped off.

**spherical\_jn**  
spherical Bessel functions.

### Notes

For positive *v* values, the computation is carried out using the AMOS [R506] *zbesj* routine, which exploits the connection to the modified Bessel function  $I_v$ ,

$$\begin{aligned} J_v(z) &= \exp(v\pi i/2) I_v(-iz) & (\Im z > 0) \\ J_v(z) &= \exp(-v\pi i/2) I_v(iz) & (\Im z < 0) \end{aligned}$$

For negative *v* values the formula,

$$J_{-v}(z) = J_v(z) \cos(\pi v) - Y_v(z) \sin(\pi v)$$

is used, where  $Y_v(z)$  is the Bessel function of the second kind, computed using the AMOS routine *zbesy*. Note that the second term is exactly zero for integer *v*; to improve accuracy the second term is explicitly omitted for *v* values such that  $v = \text{floor}(v)$ .

Not to be confused with the spherical Bessel functions (see *spherical\_jn*).

### References

[R506]

`scipy.special.jve`(*v*, *z*) = <ufunc 'jve'>

Exponentially scaled Bessel function of order *v*.

Defined as:

```
jve(v, z) = jv(v, z) * exp(-abs(z.imag))
```

**Parameters**

- v** : array\_like  
Order (float).
- z** : array\_like  
Argument (float or complex).

**Returns**

- J** : ndarray  
Value of the exponentially scaled Bessel function.



**Notes**

For positive  $\nu$  values, the computation is carried out using the AMOS [R597] *zbesy* routine, which exploits the connection to the Hankel Bessel functions  $H_\nu^{(1)}$  and  $H_\nu^{(2)}$ ,

$$Y_\nu(z) = \frac{1}{2i}(H_\nu^{(1)} - H_\nu^{(2)}).$$

For negative  $\nu$  values the formula,

$$Y_{-\nu}(z) = Y_\nu(z) \cos(\pi\nu) + J_\nu(z) \sin(\pi\nu)$$

is used, where  $J_\nu(z)$  is the Bessel function of the first kind, computed using the AMOS routine *zbesj*. Note that the second term is exactly zero for integer  $\nu$ ; to improve accuracy the second term is explicitly omitted for  $\nu$  values such that  $\nu = \text{floor}(\nu)$ .

**References**

[R597]

`scipy.special.yve` ( $\nu, z$ ) = <ufunc 'yve'>

Exponentially scaled Bessel function of the second kind of real order.

Returns the exponentially scaled Bessel function of the second kind of real order  $\nu$  at complex  $z$ :

```
yve( $\nu, z$ ) = yv( $\nu, z$ ) * exp(-abs( $z$ .imag))
```

**Parameters**  $\nu$  : array\_like

Order (float).

$z$  : array\_like

Argument (float or complex).

**Returns**  $Y$  : ndarray

Value of the exponentially scaled Bessel function.

**Notes**

For positive  $\nu$  values, the computation is carried out using the AMOS [R598] *zbesy* routine, which exploits the connection to the Hankel Bessel functions  $H_\nu^{(1)}$  and  $H_\nu^{(2)}$ ,

$$Y_\nu(z) = \frac{1}{2i}(H_\nu^{(1)} - H_\nu^{(2)}).$$

For negative  $\nu$  values the formula,

$$Y_{-\nu}(z) = Y_\nu(z) \cos(\pi\nu) + J_\nu(z) \sin(\pi\nu)$$

is used, where  $J_\nu(z)$  is the Bessel function of the first kind, computed using the AMOS routine *zbesj*. Note that the second term is exactly zero for integer  $\nu$ ; to improve accuracy the second term is explicitly omitted for  $\nu$  values such that  $\nu = \text{floor}(\nu)$ .

**References**

[R598]

`scipy.special.kn` ( $n, x$ ) = <ufunc 'kn'>

Modified Bessel function of the second kind of integer order  $n$

Returns the modified Bessel function of the second kind for integer order  $n$  at real  $z$ .

These are also sometimes called functions of the third kind, Basset functions, or Macdonald functions.

**Parameters**  $n$  : array\_like of int

Order of Bessel functions (floats will truncate with a warning)  
**z** : array\_like of float  
**Returns**     **out** : ndarray     Argument at which to evaluate the Bessel functions  
                                   The results

**See also:**

**kv**            Same function, but accepts real order and complex argument  
**kvp**          Derivative of this function

**Notes**

Wrapper for AMOS [R523] routine *zbesk*. For a discussion of the algorithm used, see [R524] and the references therein.

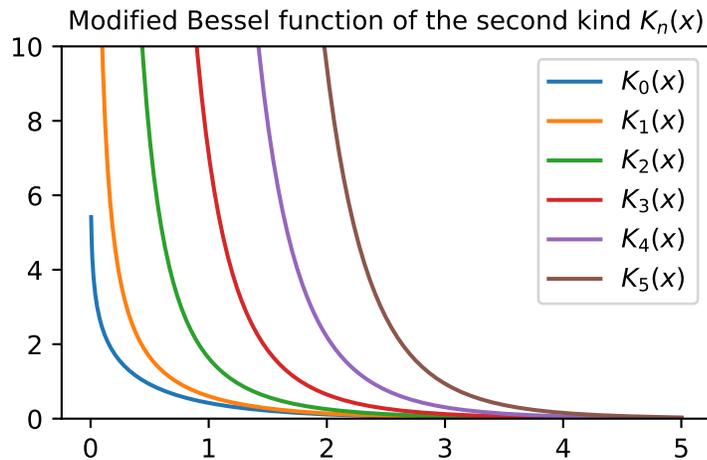
**References**

[R523], [R524]

**Examples**

Plot the function of several orders for real input:

```
>>> from scipy.special import kn
>>> import matplotlib.pyplot as plt
>>> x = np.linspace(0, 5, 1000)
>>> for N in range(6):
...     plt.plot(x, kn(N, x), label='$K_{%d}(x)$'.format(N))
>>> plt.ylim(0, 10)
>>> plt.legend()
>>> plt.title(r'Modified Bessel function of the second kind $K_n(x)$')
>>> plt.show()
```



Calculate for a single value at multiple orders:

```
>>> kn([4, 5, 6], 1)
array([ 44.23241585, 360.9605896, 3653.83831186])
```

`scipy.special.kv`( $\nu, z$ ) = <ufunc 'kv'>

Modified Bessel function of the second kind of real order  $\nu$

Returns the modified Bessel function of the second kind for real order  $\nu$  at complex  $z$ .

These are also sometimes called functions of the third kind, Basset functions, or Macdonald functions. They are defined as those solutions of the modified Bessel equation for which,

$$K_\nu(x) \sim \sqrt{\pi/(2x)} \exp(-x)$$

as  $x \rightarrow \infty$  [R527].

<b>Parameters</b>	<b>v</b> : array_like of float Order of Bessel functions
	<b>z</b> : array_like of complex Argument at which to evaluate the Bessel functions
<b>Returns</b>	<b>out</b> : ndarray The results. Note that input must be of complex type to get complex output, e.g. <code>kv(3, -2+0j)</code> instead of <code>kv(3, -2)</code> .

**See also:**

**kve** This function with leading exponential behavior stripped off.  
**kvp** Derivative of this function

**Notes**

Wrapper for AMOS [R525] routine `zbesk`. For a discussion of the algorithm used, see [R526] and the references therein.

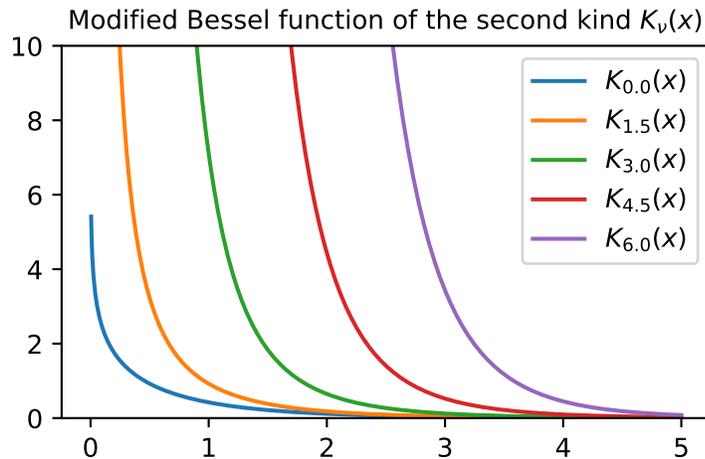
**References**

[R525], [R526], [R527]

**Examples**

Plot the function of several orders for real input:

```
>>> from scipy.special import kv
>>> import matplotlib.pyplot as plt
>>> x = np.linspace(0, 5, 1000)
>>> for N in np.linspace(0, 6, 5):
...     plt.plot(x, kv(N, x), label='$K_{%d}(x)$'.format(N))
>>> plt.ylim(0, 10)
>>> plt.legend()
>>> plt.title(r'Modified Bessel function of the second kind $K_{\nu}(x)$')
>>> plt.show()
```



Calculate for a single value at multiple orders:

```
>>> kv([4, 4.5, 5], 1+2j)
array([ 0.1992+2.3892j,  2.3493+3.6j    ,  7.2827+3.8104j])
```

`scipy.special.kve` ( $v, z$ ) = <ufunc 'kve'>

Exponentially scaled modified Bessel function of the second kind.

Returns the exponentially scaled, modified Bessel function of the second kind (sometimes called the third kind) for real order  $v$  at complex  $z$ :

```
kve(v, z) = kv(v, z) * exp(z)
```

**Parameters**

- v** : array\_like of float  
Order of Bessel functions
- z** : array\_like of complex  
Argument at which to evaluate the Bessel functions

**Returns**

- out** : ndarray  
The exponentially scaled modified Bessel function of the second kind.

#### Notes

Wrapper for AMOS [R528] routine *zbesk*. For a discussion of the algorithm used, see [R529] and the references therein.

#### References

[R528], [R529]

`scipy.special.iv` ( $v, z$ ) = <ufunc 'iv'>

Modified Bessel function of the first kind of real order.

**Parameters**

- v** : array\_like  
Order. If  $z$  is of real type and negative,  $v$  must be integer valued.
- z** : array\_like of float or complex  
Argument.

**Returns**

- out** : ndarray  
Values of the modified Bessel function.

**See also:**

**kve** This function with leading exponential behavior stripped off.

**Notes**

For real  $z$  and  $v \in [-50, 50]$ , the evaluation is carried out using Temme's method [R499]. For larger orders, uniform asymptotic expansions are applied.

For complex  $z$  and positive  $v$ , the AMOS [R500] *zbesi* routine is called. It uses a power series for small  $z$ , the asymptotic expansion for large  $abs(z)$ , the Miller algorithm normalized by the Wronskian and a Neumann series for intermediate magnitudes, and the uniform asymptotic expansions for  $I_v(z)$  and  $J_v(z)$  for large orders. Backward recurrence is used to generate sequences or reduce orders when necessary.

The calculations above are done in the right half plane and continued into the left half plane by the formula,

$$I_v(z \exp(\pm i\pi)) = \exp(\pm \pi v) I_v(z)$$

(valid when the real part of  $z$  is positive). For negative  $v$ , the formula

$$I_{-v}(z) = I_v(z) + \frac{2}{\pi} \sin(\pi v) K_v(z)$$

is used, where  $K_v(z)$  is the modified Bessel function of the second kind, evaluated using the AMOS routine *zbesk*.

**References**

[R499], [R500]

`scipy.special.ive(v, z) = <ufunc 'ive'>`

Exponentially scaled modified Bessel function of the first kind

Defined as:

```
ive(v, z) = iv(v, z) * exp(-abs(z.real))
```

**Parameters** **v** : array\_like of float  
Order.

**z** : array\_like of float or complex  
Argument.

**Returns** **out** : ndarray  
Values of the exponentially scaled modified Bessel function.

**Notes**

For positive  $v$ , the AMOS [R501] *zbesi* routine is called. It uses a power series for small  $z$ , the asymptotic expansion for large  $abs(z)$ , the Miller algorithm normalized by the Wronskian and a Neumann series for intermediate magnitudes, and the uniform asymptotic expansions for  $I_v(z)$  and  $J_v(z)$  for large orders. Backward recurrence is used to generate sequences or reduce orders when necessary.

The calculations above are done in the right half plane and continued into the left half plane by the formula,

$$I_v(z \exp(\pm i\pi)) = \exp(\pm \pi v) I_v(z)$$

(valid when the real part of  $z$  is positive). For negative  $v$ , the formula

$$I_{-v}(z) = I_v(z) + \frac{2}{\pi} \sin(\pi v) K_v(z)$$

is used, where  $K_v(z)$  is the modified Bessel function of the second kind, evaluated using the AMOS routine *zbesk*.



**References**

[R485]

`scipy.special.hankel2` ( $v, z$ ) = <ufunc 'hankel2'>

Hankel function of the second kind

**Parameters** **v** : array\_like  
Order (float).  
**z** : array\_like  
Argument (float or complex).

**Returns** **out** : Values of the Hankel function of the second kind.

**See also:****hankel2e** this function with leading exponential behavior stripped off.**Notes**A wrapper for the AMOS [R486] routine *zbesh*, which carries out the computation using the relation,

$$H_v^{(2)}(z) = -\frac{2}{i\pi} \exp(i\pi v/2) K_v(z \exp(i\pi/2))$$

where  $K_v$  is the modified Bessel function of the second kind. For negative orders, the relation

$$H_{-v}^{(2)}(z) = H_v^{(2)}(z) \exp(-i\pi v)$$

is used.

**References**

[R486]

`scipy.special.hankel2e` ( $v, z$ ) = <ufunc 'hankel2e'>

Exponentially scaled Hankel function of the second kind

Defined as:

<code>hankel2e(v, z) = hankel2(v, z) * exp(1j * z)</code>
---

**Parameters** **v** : array\_like  
Order (float).  
**z** : array\_like  
Argument (float or complex).

**Returns** **out** : Values of the exponentially scaled Hankel function of the second kind.

**Notes**A wrapper for the AMOS [R487] routine *zbesh*, which carries out the computation using the relation,

$$H_v^{(2)}(z) = -\frac{2}{i\pi} \exp\left(\frac{i\pi v}{2}\right) K_v\left(z \exp\left(\frac{i\pi}{2}\right)\right)$$

where  $K_v$  is the modified Bessel function of the second kind. For negative orders, the relation

$$H_{-v}^{(2)}(z) = H_v^{(2)}(z) \exp(-i\pi v)$$

is used.

**References**

[R487]

The following is not an universal function:

`lmbda(v, x)`

Jahnke-Emden Lambda function, `Lambdav(x)`.

---

`scipy.special.lmbda(v, x)`

Jahnke-Emden Lambda function, `Lambdav(x)`.

This function is defined as [R535],

$$\Lambda_v(x) = \Gamma(v + 1) \frac{J_v(x)}{(x/2)^v},$$

where  $\Gamma$  is the gamma function and  $J_v$  is the Bessel function of the first kind.

**Parameters**

- v** : float  
Order of the Lambda function
- x** : float  
Value at which to evaluate the function and derivatives

**Returns**

- vl** : ndarray  
Values of `Lambda_vi(x)`, for  $vi=v-\text{int}(v)$ ,  $vi=1+v-\text{int}(v)$ , ...,  $vi=v$ .
- dl** : ndarray  
Derivatives `Lambda_vi'(x)`, for  $vi=v-\text{int}(v)$ ,  $vi=1+v-\text{int}(v)$ , ...,  $vi=v$ .

**References**

[R534], [R535]

**Zeros of Bessel Functions**

These are not universal functions:

<code>jnjnp_zeros(nt)</code>	Compute zeros of integer-order Bessel functions $J_n$ and $J_n'$ .
<code>jny_n_zeros(n, nt)</code>	Compute $nt$ zeros of Bessel functions $J_n(x)$ , $J_n'(x)$ , $Y_n(x)$ , and $Y_n'(x)$ .
<code>jn_zeros(n, nt)</code>	Compute zeros of integer-order Bessel function $J_n(x)$ .
<code>jnp_zeros(n, nt)</code>	Compute zeros of integer-order Bessel function derivative $J_n'(x)$ .
<code>yn_zeros(n, nt)</code>	Compute zeros of integer-order Bessel function $Y_n(x)$ .
<code>ynp_zeros(n, nt)</code>	Compute zeros of integer-order Bessel function derivative $Y_n'(x)$ .
<code>y0_zeros(nt[, complex])</code>	Compute $nt$ zeros of Bessel function $Y_0(z)$ , and derivative at each zero.
<code>y1_zeros(nt[, complex])</code>	Compute $nt$ zeros of Bessel function $Y_1(z)$ , and derivative at each zero.
<code>y1p_zeros(nt[, complex])</code>	Compute $nt$ zeros of Bessel derivative $Y_1'(z)$ , and value at each zero.

`scipy.special.jnjnp_zeros(nt)`

Compute zeros of integer-order Bessel functions  $J_n$  and  $J_n'$ .

Results are arranged in order of the magnitudes of the zeros.

**Parameters**

- nt** : int  
Number ( $\leq 1200$ ) of zeros to compute

**Returns**

- zo[l-1]** : ndarray  
Value of the  $l$ th zero of  $J_n(x)$  and  $J_n'(x)$ . Of length  $nt$ .
- n[l-1]** : ndarray  
Order of the  $J_n(x)$  or  $J_n'(x)$  associated with  $l$ th zero. Of length  $nt$ .

**m[l-1]** : ndarray  
Serial number of the zeros of  $J_n(x)$  or  $J_n'(x)$  associated with  $l$ th zero. Of length  $nt$ .

**t[l-1]** : ndarray  
0 if  $l$ th zero in  $z_0$  is zero of  $J_n(x)$ , 1 if it is a zero of  $J_n'(x)$ . Of length  $nt$ .

**See also:***jn\_zeros, jnp\_zeros***References***[R508]*`scipy.special.jnyn_zeros(n, nt)`Compute  $nt$  zeros of Bessel functions  $J_n(x)$ ,  $J_n'(x)$ ,  $Y_n(x)$ , and  $Y_n'(x)$ .Returns 4 arrays of length  $nt$ , corresponding to the first  $nt$  zeros of  $J_n(x)$ ,  $J_n'(x)$ ,  $Y_n(x)$ , and  $Y_n'(x)$ , respectively.

**Parameters**

**n** : int  
Order of the Bessel functions

**nt** : int  
Number ( $\leq 1200$ ) of zeros to compute

See **`jn_zeros`**, **`jnp_zeros`**, **`yn_zeros`**, **`ynp_zeros`** to get separate arrays.

**References***[R510]*`scipy.special.jn_zeros(n, nt)`Compute zeros of integer-order Bessel function  $J_n(x)$ .

**Parameters**

**n** : int  
Order of Bessel function

**nt** : int  
Number of zeros to return

**References***[R507]*`scipy.special.jnp_zeros(n, nt)`Compute zeros of integer-order Bessel function derivative  $J_n'(x)$ .

**Parameters**

**n** : int  
Order of Bessel function

**nt** : int  
Number of zeros to return

**References***[R509]*`scipy.special.yn_zeros(n, nt)`Compute zeros of integer-order Bessel function  $Y_n(x)$ .

**Parameters**

**n** : int  
Order of Bessel function

**nt** : int  
Number of zeros to return

**References**

[R595]

`scipy.special.ynp_zeros` (*n*, *nt*)

Compute zeros of integer-order Bessel function derivative  $Y_n'(x)$ .

**Parameters**

- n** : int  
Order of Bessel function
- nt** : int  
Number of zeros to return

**References**

[R596]

`scipy.special.y0_zeros` (*nt*, *complex=False*)

Compute *nt* zeros of Bessel function  $Y_0(z)$ , and derivative at each zero.

The derivatives are given by  $Y_0'(z_0) = -Y_1(z_0)$  at each zero  $z_0$ .

**Parameters**

- nt** : int  
Number of zeros to return
- complex** : bool, default False  
Set to False to return only the real zeros; set to True to return only the complex zeros with negative real part and positive imaginary part. Note that the complex conjugates of the latter are also zeros of the function, but are not returned by this routine.

**Returns**

- z0n** : ndarray  
Location of *n*th zero of  $Y_0(z)$
- y0pz0n** : ndarray  
Value of derivative  $Y_0'(z_0)$  for *n*th zero

**References**

[R590]

`scipy.special.y1_zeros` (*nt*, *complex=False*)

Compute *nt* zeros of Bessel function  $Y_1(z)$ , and derivative at each zero.

The derivatives are given by  $Y_1'(z_1) = Y_0(z_1)$  at each zero  $z_1$ .

**Parameters**

- nt** : int  
Number of zeros to return
- complex** : bool, default False  
Set to False to return only the real zeros; set to True to return only the complex zeros with negative real part and positive imaginary part. Note that the complex conjugates of the latter are also zeros of the function, but are not returned by this routine.

**Returns**

- z1n** : ndarray  
Location of *n*th zero of  $Y_1(z)$
- y1pz1n** : ndarray  
Value of derivative  $Y_1'(z_1)$  for *n*th zero

**References**

[R592]

`scipy.special.y1p_zeros` (*nt*, *complex=False*)

Compute *nt* zeros of Bessel derivative  $Y_1'(z)$ , and value at each zero.

The values are given by  $Y_1(z_1)$  at each  $z_1$  where  $Y_1'(z_1)=0$ .

**Parameters**

**nt** : int  
Number of zeros to return

**complex** : bool, default False  
Set to False to return only the real zeros; set to True to return only the complex zeros with negative real part and positive imaginary part. Note that the complex conjugates of the latter are also zeros of the function, but are not returned by this routine.

**Returns**

**z1pn** : ndarray  
Location of nth zero of  $Y_1'(z)$

**y1z1pn** : ndarray  
Value of derivative  $Y_1(z_1)$  for nth zero

**References**

[R593]

**Faster versions of common Bessel Functions**

$j_0(x)$	Bessel function of the first kind of order 0.
$j_1(x)$	Bessel function of the first kind of order 1.
$y_0(x)$	Bessel function of the second kind of order 0.
$y_1(x)$	Bessel function of the second kind of order 1.
$i_0(x)$	Modified Bessel function of order 0.
$i_0e(x)$	Exponentially scaled modified Bessel function of order 0.
$i_1(x)$	Modified Bessel function of order 1.
$i_1e(x)$	Exponentially scaled modified Bessel function of order 1.
$k_0(x)$	Modified Bessel function of the second kind of order 0, $K_0$ .
$k_0e(x)$	Exponentially scaled modified Bessel function K of order 0
$k_1(x)$	Modified Bessel function of the second kind of order 1, $K_1(x)$ .
$k_1e(x)$	Exponentially scaled modified Bessel function K of order 1

`scipy.special.j0(x) = <ufunc 'j0'>`  
Bessel function of the first kind of order 0.

**Parameters** **x** : array\_like  
Argument (float).

**Returns** **J** : ndarray  
Value of the Bessel function of the first kind of order 0 at x.

**See also:****jv** Bessel function of real order and complex argument.**spherical\_jn**  
spherical Bessel functions.**Notes**

The domain is divided into the intervals  $[0, 5]$  and  $(5, \text{infinity})$ . In the first interval the following rational approximation is used:

$$J_0(x) \approx (w - r_1^2)(w - r_2^2) \frac{P_3(w)}{Q_8(w)},$$

where  $w = x^2$  and  $r_1, r_2$  are the zeros of  $J_0$ , and  $P_3$  and  $Q_8$  are polynomials of degrees 3 and 8, respectively.



**References***[R589]*

`scipy.special.y1(x) = <ufunc 'y1'>`  
 Bessel function of the second kind of order 1.

**Parameters** `x` : array\_like  
 Argument (float).  
**Returns** `Y` : ndarray  
 Value of the Bessel function of the second kind of order 1 at  $x$ .

**See also:***j1, yn, yv***Notes**

The domain is divided into the intervals  $[0, 8]$  and  $(8, \text{infinity})$ . In the first interval a 25 term Chebyshev expansion is used, and computing  $J_1$  (the Bessel function of the first kind) is required. In the second, the asymptotic trigonometric representation is employed using two rational functions of degree 5/5.

This function is a wrapper for the Cephes *[R591]* routine *y1*.

**References***[R591]*

`scipy.special.i0(x) = <ufunc 'i0'>`  
 Modified Bessel function of order 0.

Defined as,

$$I_0(x) = \sum_{k=0}^{\infty} \frac{(x^2/4)^k}{(k!)^2} = J_0(ix),$$

where  $J_0$  is the Bessel function of the first kind of order 0.

**Parameters** `x` : array\_like  
 Argument (float)  
**Returns** `I` : ndarray  
 Value of the modified Bessel function of order 0 at  $x$ .

**See also:***iv, i0e***Notes**

The range is partitioned into the two intervals  $[0, 8]$  and  $(8, \text{infinity})$ . Chebyshev polynomial expansions are employed in each interval.

This function is a wrapper for the Cephes *[R491]* routine *i0*.

**References***[R491]*

`scipy.special.i0e(x) = <ufunc 'i0e'>`  
 Exponentially scaled modified Bessel function of order 0.

Defined as:

$$i0e(x) = \exp(-\text{abs}(x)) * i0(x).$$

**Parameters** `x` : array\_like  
**Returns** `I` : ndarray     Argument (float)  
Value of the exponentially scaled modified Bessel function of order 0 at  $x$ .

**See also:**

`iv`, `i0`

**Notes**

The range is partitioned into the two intervals [0, 8] and (8, infinity). Chebyshev polynomial expansions are employed in each interval. The polynomial expansions used are the same as those in `i0`, but they are not multiplied by the dominant exponential factor.

This function is a wrapper for the Cephys [R492] routine `i0e`.

**References**

[R492]

`scipy.special.i1(x) = <ufunc 'i1'>`

Modified Bessel function of order 1.

Defined as,

$$I_1(x) = \frac{1}{2}x \sum_{k=0}^{\infty} \frac{(x^2/4)^k}{k!(k+1)!} = -iJ_1(ix),$$

where  $J_1$  is the Bessel function of the first kind of order 1.

**Parameters** `x` : array\_like  
**Returns** `I` : ndarray     Argument (float)  
Value of the modified Bessel function of order 1 at  $x$ .

**See also:**

`iv`, `ile`

**Notes**

The range is partitioned into the two intervals [0, 8] and (8, infinity). Chebyshev polynomial expansions are employed in each interval.

This function is a wrapper for the Cephys [R493] routine `i1`.

**References**

[R493]

`scipy.special.ile(x) = <ufunc 'ile'>`

Exponentially scaled modified Bessel function of order 1.

Defined as:

$$ile(x) = \exp(-abs(x)) * i1(x)$$

**Parameters** `x` : array\_like  
**Returns** `I` : ndarray     Argument (float)  
Value of the exponentially scaled modified Bessel function of order 1 at  $x$ .

**See also:***iv, i1***Notes**

The range is partitioned into the two intervals [0, 8] and (8, infinity). Chebyshev polynomial expansions are employed in each interval. The polynomial expansions used are the same as those in *i1*, but they are not multiplied by the dominant exponential factor.

This function is a wrapper for the Cephys [R494] routine *i1e*.

**References***[R494]*

`scipy.special.k0(x) = <ufunc 'k0'>`

Modified Bessel function of the second kind of order 0,  $K_0$ .

This function is also sometimes referred to as the modified Bessel function of the third kind of order 0.

**Parameters** **x** : array\_like  
Argument (float).

**Returns** **K** : ndarray  
Value of the modified Bessel function  $K_0$  at  $x$ .

**See also:***kv, k0e***Notes**

The range is partitioned into the two intervals [0, 2] and (2, infinity). Chebyshev polynomial expansions are employed in each interval.

This function is a wrapper for the Cephys [R515] routine *k0*.

**References***[R515]*

`scipy.special.k0e(x) = <ufunc 'k0e'>`

Exponentially scaled modified Bessel function K of order 0

Defined as:

$$k0e(x) = \exp(x) * k0(x).$$

**Parameters** **x** : array\_like  
Argument (float)

**Returns** **K** : ndarray  
Value of the exponentially scaled modified Bessel function K of order 0 at  $x$ .

**See also:***kv, k0***Notes**

The range is partitioned into the two intervals [0, 2] and (2, infinity). Chebyshev polynomial expansions are employed in each interval.

This function is a wrapper for the Cephys [R516] routine *k0e*.

**References**

[R516]

`scipy.special.k1(x) = <ufunc 'k1'>`

Modified Bessel function of the second kind of order 1,  $K_1(x)$ .

**Parameters** `x` : array\_like  
**Returns** `K` : ndarray

Argument (float)  
 Value of the modified Bessel function K of order 1 at  $x$ .

**See also:**

`kv`, `k1e`

**Notes**

The range is partitioned into the two intervals [0, 2] and (2, infinity). Chebyshev polynomial expansions are employed in each interval.

This function is a wrapper for the Cephes [R517] routine `k1`.

**References**

[R517]

`scipy.special.k1e(x) = <ufunc 'k1e'>`

Exponentially scaled modified Bessel function K of order 1

Defined as:

$k1e(x) = \exp(x) * k1(x)$
----------------------------

**Parameters** `x` : array\_like  
**Returns** `K` : ndarray

Argument (float)  
 Value of the exponentially scaled modified Bessel function K of order 1 at  $x$ .

**See also:**

`kv`, `k1`

**Notes**

The range is partitioned into the two intervals [0, 2] and (2, infinity). Chebyshev polynomial expansions are employed in each interval.

This function is a wrapper for the Cephes [R518] routine `k1e`.

**References**

[R518]

**Integrals of Bessel Functions**

<code>itj0y0(x)</code>	Integrals of Bessel functions of order 0
<code>it2j0y0(x)</code>	Integrals related to Bessel functions of order 0
<code>iti0k0(x)</code>	Integrals of modified Bessel functions of order 0
<code>it2i0k0(x)</code>	Integrals related to modified Bessel functions of order 0

Continued on next page

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<code>besselpoly(a, lmb, nu)</code>	Weighted integral of a Bessel function.
<code>scipy.special.itj0y0(x) = &lt;ufunc 'itj0y0'&gt;</code>	
Integrals of Bessel functions of order 0	
Returns simple integrals from 0 to $x$ of the zeroth order Bessel functions $j_0$ and $y_0$ .	
<b>Returns</b>	<code>ij0, iy0</code>
<code>scipy.special.it2j0y0(x) = &lt;ufunc 'it2j0y0'&gt;</code>	
Integrals related to Bessel functions of order 0	
<b>Returns</b>	<code>ij0</code>
	<code>integral((1-j0(t))/t, t=0..x)</code>
	<code>iy0</code>
	<code>integral(y0(t)/t, t=x..inf)</code>
<code>scipy.special.iti0k0(x) = &lt;ufunc 'iti0k0'&gt;</code>	
Integrals of modified Bessel functions of order 0	
Returns simple integrals from 0 to $x$ of the zeroth order modified Bessel functions $i_0$ and $k_0$ .	
<b>Returns</b>	<code>ii0, ik0</code>
<code>scipy.special.it2i0k0(x) = &lt;ufunc 'it2i0k0'&gt;</code>	
Integrals related to modified Bessel functions of order 0	
<b>Returns</b>	<code>ii0</code>
	<code>integral((i0(t)-1)/t, t=0..x)</code>
	<code>ik0</code>
	<code>int(k0(t)/t, t=x..inf)</code>
<code>scipy.special.besselpoly(a, lmb, nu) = &lt;ufunc 'besselpoly'&gt;</code>	
Weighted integral of a Bessel function.	

$$\int_0^1 x^\lambda J_\nu(2ax) dx$$

where  $J_\nu$  is a Bessel function and  $\lambda = lmb$ ,  $\nu = nu$ .

### Derivatives of Bessel Functions

<code>jvp(v, z[, n])</code>	Compute nth derivative of Bessel function $J_\nu(z)$ with respect to $z$ .
<code>yvp(v, z[, n])</code>	Compute nth derivative of Bessel function $Y_\nu(z)$ with respect to $z$ .
<code>kvp(v, z[, n])</code>	Compute nth derivative of real-order modified Bessel function $K_\nu(z)$
<code>ivp(v, z[, n])</code>	Compute nth derivative of modified Bessel function $I_\nu(z)$ with respect to $z$ .
<code>h1vp(v, z[, n])</code>	Compute nth derivative of Hankel function $H_{1\nu}(z)$ with respect to $z$ .
<code>h2vp(v, z[, n])</code>	Compute nth derivative of Hankel function $H_{2\nu}(z)$ with respect to $z$ .

`scipy.special.jvp(v, z, n=1)`

Compute nth derivative of Bessel function  $J_\nu(z)$  with respect to  $z$ .

**Parameters**

- v** : float  
Order of Bessel function
- z** : complex  
Argument at which to evaluate the derivative
- n** : int, default 1  
Order of derivative

**Notes**

The derivative is computed using the relation DLFM 10.6.7 [R514].

**References**

[R513], [R514]

`scipy.special.yvp(v, z, n=1)`

Compute nth derivative of Bessel function  $Y_v(z)$  with respect to  $z$ .

**Parameters**

- v** : float  
Order of Bessel function
- z** : complex  
Argument at which to evaluate the derivative
- n** : int, default 1  
Order of derivative

**Notes**

The derivative is computed using the relation DLFM 10.6.7 [R600].

**References**

[R599], [R600]

`scipy.special.kvp(v, z, n=1)`

Compute nth derivative of real-order modified Bessel function  $K_v(z)$

$K_v(z)$  is the modified Bessel function of the second kind. Derivative is calculated with respect to  $z$ .

**Parameters**

- v** : array\_like of float  
Order of Bessel function
- z** : array\_like of complex  
Argument at which to evaluate the derivative
- n** : int  
Order of derivative. Default is first derivative.

**Returns**

- out** : ndarray  
The results

**Notes**

The derivative is computed using the relation DLFM 10.29.5 [R531].

**References**

[R530], [R531]

**Examples**

Calculate multiple values at order 5:

```
>>> from scipy.special import kvp
>>> kvp(5, (1, 2, 3+5j))
array([-1849.0354+0.j      , -25.7735+0.j      , -0.0307+0.0875j])
```

Calculate for a single value at multiple orders:

```
>>> kvp((4, 4.5, 5), 1)
array([-184.0309, -568.9585, -1849.0354])
```

`scipy.special.ivp(v, z, n=1)`

Compute nth derivative of modified Bessel function  $I_v(z)$  with respect to  $z$ .

**Parameters**

- v** : array\_like of float  
Order of Bessel function
- z** : array\_like of complex  
Argument at which to evaluate the derivative
- n** : int, default 1  
Order of derivative

#### Notes

The derivative is computed using the relation DLFM 10.29.5 [R503].

#### References

[R502], [R503]

`scipy.special.h1vp(v, z, n=1)`

Compute nth derivative of Hankel function  $H_1v(z)$  with respect to  $z$ .

**Parameters**

- v** : float  
Order of Hankel function
- z** : complex  
Argument at which to evaluate the derivative
- n** : int, default 1  
Order of derivative

#### Notes

The derivative is computed using the relation DLFM 10.6.7 [R481].

#### References

[R480], [R481]

`scipy.special.h2vp(v, z, n=1)`

Compute nth derivative of Hankel function  $H_2v(z)$  with respect to  $z$ .

**Parameters**

- v** : float  
Order of Hankel function
- z** : complex  
Argument at which to evaluate the derivative
- n** : int, default 1  
Order of derivative

#### Notes

The derivative is computed using the relation DLFM 10.6.7 [R483].

**References**

[R482], [R483]

**Spherical Bessel Functions**

<code>spherical_jn(n, z[, derivative])</code>	Spherical Bessel function of the first kind or its derivative.
<code>spherical_yn(n, z[, derivative])</code>	Spherical Bessel function of the second kind or its derivative.
<code>spherical_in(n, z[, derivative])</code>	Modified spherical Bessel function of the first kind or its derivative.
<code>spherical_kn(n, z[, derivative])</code>	Modified spherical Bessel function of the second kind or its derivative.

`scipy.special.spherical_jn(n, z, derivative=False)`

Spherical Bessel function of the first kind or its derivative.

Defined as [R578],

$$j_n(z) = \sqrt{\frac{\pi}{2z}} J_{n+1/2}(z),$$

where  $J_n$  is the Bessel function of the first kind.

**Parameters** `n` : int, array\_like

Order of the Bessel function ( $n \geq 0$ ).

`z` : complex or float, array\_like

Argument of the Bessel function.

**derivative** : bool, optional

If True, the value of the derivative (rather than the function itself) is returned.

**Returns** `jn` : ndarray

**Notes**

For real arguments greater than the order, the function is computed using the ascending recurrence [R579]. For small real or complex arguments, the definitional relation to the cylindrical Bessel function of the first kind is used.

The derivative is computed using the relations [R580],

$$j'_n(z) = j_{n-1}(z) - \frac{n+1}{z} j_n(z).$$

$$j'_0(z) = -j_1(z)$$

New in version 0.18.0.

**References**

[R578], [R579], [R580]

`scipy.special.spherical_yn(n, z, derivative=False)`

Spherical Bessel function of the second kind or its derivative.

Defined as [R583],

$$y_n(z) = \sqrt{\frac{\pi}{2z}} Y_{n+1/2}(z),$$

where  $Y_n$  is the Bessel function of the second kind.

**Parameters** **n** : int, array\_like  
Order of the Bessel function ( $n \geq 0$ ).  
**z** : complex or float, array\_like  
Argument of the Bessel function.  
**derivative** : bool, optional  
If True, the value of the derivative (rather than the function itself) is returned.

**Returns** **yn** : ndarray

**Notes**

For real arguments, the function is computed using the ascending recurrence [R584]. For complex arguments, the definitional relation to the cylindrical Bessel function of the second kind is used.

The derivative is computed using the relations [R585],

$$y'_n = y_{n-1} - \frac{n+1}{2} y_n.$$

$$y'_0 = -y_1$$

New in version 0.18.0.

**References**

[R583], [R584], [R585]

`scipy.special.spherical_in` ( $n, z, derivative=False$ )  
Modified spherical Bessel function of the first kind or its derivative.

Defined as [R576],

$$i_n(z) = \sqrt{\frac{\pi}{2z}} I_{n+1/2}(z),$$

where  $I_n$  is the modified Bessel function of the first kind.

**Parameters** **n** : int, array\_like  
Order of the Bessel function ( $n \geq 0$ ).  
**z** : complex or float, array\_like  
Argument of the Bessel function.  
**derivative** : bool, optional  
If True, the value of the derivative (rather than the function itself) is returned.

**Returns** **in** : ndarray

**Notes**

The function is computed using its definitional relation to the modified cylindrical Bessel function of the first kind.

The derivative is computed using the relations [R577],

$$i'_n = i_{n-1} - \frac{n+1}{2} i_n.$$

$$i'_1 = i_0$$

New in version 0.18.0.

**References**

[R576], [R577]

`scipy.special.spherical_yn` (*n*, *z*, *derivative=False*)

Modified spherical Bessel function of the second kind or its derivative.

Defined as [R581],

$$k_n(z) = \sqrt{\frac{\pi}{2z}} K_{n+1/2}(z),$$

where  $K_n$  is the modified Bessel function of the second kind.

**Parameters**

- n** : int, array\_like  
Order of the Bessel function ( $n \geq 0$ ).
- z** : complex or float, array\_like  
Argument of the Bessel function.
- derivative** : bool, optional  
If True, the value of the derivative (rather than the function itself) is returned.

**Returns**

- kn** : ndarray

**Notes**

The function is computed using its definitional relation to the modified cylindrical Bessel function of the second kind.

The derivative is computed using the relations [R582],

$$k'_n = -k_{n-1} - \frac{n+1}{2} k_n.$$

$$k'_0 = -k_1$$

New in version 0.18.0.

**References**

[R581], [R582]

**Riccati-Bessel Functions**

These are not universal functions:

<code>riccati_jn</code> ( <i>n</i> , <i>x</i> )	Compute Riccati-Bessel function of the first kind and its derivative.
<code>riccati_yn</code> ( <i>n</i> , <i>x</i> )	Compute Riccati-Bessel function of the second kind and its derivative.

`scipy.special.riccati_jn` (*n*, *x*)

Compute Riccati-Bessel function of the first kind and its derivative.

The Riccati-Bessel function of the first kind is defined as  $xj_n(x)$ , where  $j_n$  is the spherical Bessel function of the first kind of order  $n$ .

This function computes the value and first derivative of the Riccati-Bessel function for all orders up to and including  $n$ .

**Parameters**

- n** : int  
Maximum order of function to compute
- x** : float

**Returns**

**jn** : ndarray     Argument at which to evaluate  
                          Value of  $j_0(x), \dots, j_n(x)$

**jnp** : ndarray  
                          First derivative  $j_0'(x), \dots, j_n'(x)$

**Notes**

The computation is carried out via backward recurrence, using the relation DLMF 10.51.1 [R565].

Wrapper for a Fortran routine created by Shanjie Zhang and Jianming Jin [R564].

**References**

[R564], [R565]

`scipy.special.riccati_yn` ( $n, x$ )

Compute Riccati-Bessel function of the second kind and its derivative.

The Riccati-Bessel function of the second kind is defined as  $xy_n(x)$ , where  $y_n$  is the spherical Bessel function of the second kind of order  $n$ .

This function computes the value and first derivative of the function for all orders up to and including  $n$ .

**Parameters**

**n** : int  
                          Maximum order of function to compute

**x** : float

**Returns**

**yn** : ndarray     Argument at which to evaluate  
                          Value of  $y_0(x), \dots, y_n(x)$

**ynp** : ndarray  
                          First derivative  $y_0'(x), \dots, y_n'(x)$

**Notes**

The computation is carried out via ascending recurrence, using the relation DLMF 10.51.1 [R567].

Wrapper for a Fortran routine created by Shanjie Zhang and Jianming Jin [R566].

**References**

[R566], [R567]

**Struve Functions**

<code>struve</code> ( $v, x$ )	Struve function.
<code>modstruve</code> ( $v, x$ )	Modified Struve function.
<code>itstruve0</code> ( $x$ )	Integral of the Struve function of order 0.
<code>it2struve0</code> ( $x$ )	Integral related to the Struve function of order 0.
<code>itmodstruve0</code> ( $x$ )	Integral of the modified Struve function of order 0.

`scipy.special.struve` ( $v, x$ ) = <ufunc 'struve'>

Struve function.

Return the value of the Struve function of order  $v$  at  $x$ . The Struve function is defined as,

$$H_v(x) = (z/2)^{v+1} \sum_{n=0}^{\infty} \frac{(-1)^n (z/2)^{2n}}{\Gamma(n + \frac{3}{2})\Gamma(n + v + \frac{3}{2})},$$

where  $\Gamma$  is the gamma function.

**Parameters** **v** : array\_like  
 Order of the Struve function (float).  
**x** : array\_like  
 Argument of the Struve function (float; must be positive unless  $v$  is an integer).  
**Returns** **H** : ndarray  
 Value of the Struve function of order  $v$  at  $x$ .

**See also:**

`modstruve`

**Notes**

Three methods discussed in [R586] are used to evaluate the Struve function:

- power series
- expansion in Bessel functions (if  $|z| < |v| + 20$ )
- asymptotic large- $z$  expansion (if  $z \geq 0.7v + 12$ )

Rounding errors are estimated based on the largest terms in the sums, and the result associated with the smallest error is returned.

**References**

[R586]

`scipy.special.modstruve` ( $v, x$ ) = <ufunc 'modstruve'>

Modified Struve function.

Return the value of the modified Struve function of order  $v$  at  $x$ . The modified Struve function is defined as,

$$L_v(x) = -i \exp(-\pi v/2) H_v(x),$$

where  $H_v$  is the Struve function.

**Parameters** **v** : array\_like  
 Order of the modified Struve function (float).  
**x** : array\_like  
 Argument of the Struve function (float; must be positive unless  $v$  is an integer).  
**Returns** **L** : ndarray  
 Value of the modified Struve function of order  $v$  at  $x$ .

**See also:**

`struve`

**Notes**

Three methods discussed in [R545] are used to evaluate the function:

- power series
- expansion in Bessel functions (if  $|z| < |v| + 20$ )
- asymptotic large- $z$  expansion (if  $z \geq 0.7v + 12$ )

Rounding errors are estimated based on the largest terms in the sums, and the result associated with the smallest error is returned.

**References**

[R545]

`scipy.special.itstruve0(x) = <ufunc 'itstruve0'>`

Integral of the Struve function of order 0.

$$I = \int_0^x H_0(t) dt$$

**Parameters** `x` : array\_like  
**Returns** `I` : ndarray      Upper limit of integration (float).  
 The integral of  $H_0$  from 0 to  $x$ .

**See also:**

`struve`

**Notes**

Wrapper for a Fortran routine created by Shanjie Zhang and Jianming Jin [R498].

**References**

[R498]

`scipy.special.it2struve0(x) = <ufunc 'it2struve0'>`

Integral related to the Struve function of order 0.

Returns the integral,

$$\int_x^\infty \frac{H_0(t)}{t} dt$$

where  $H_0$  is the Struve function of order 0.

**Parameters** `x` : array\_like  
**Returns** `I` : ndarray      Lower limit of integration.  
 The value of the integral.

**See also:**

`struve`

**Notes**

Wrapper for a Fortran routine created by Shanjie Zhang and Jianming Jin [R495].

**References**

[R495]

`scipy.special.itmodstruve0(x) = <ufunc 'itmodstruve0'>`

Integral of the modified Struve function of order 0.

$$I = \int_0^x L_0(t) dt$$

**Parameters** `x` : array\_like  
**Returns** `I` : ndarray      Upper limit of integration (float).  
 The integral of  $L_0$  from 0 to  $x$ .

**Notes**

Wrapper for a Fortran routine created by Shanjie Zhang and Jianming Jin [R497].

*References*

[R497]

**Raw Statistical Functions**

**See also:**

*scipy.stats*: Friendly versions of these functions.

<i>bdtr</i> (k, n, p)	Binomial distribution cumulative distribution function.
<i>bdtrc</i> (k, n, p)	Binomial distribution survival function.
<i>bdtri</i> (k, n, y)	Inverse function to <i>bdtr</i> with respect to <i>p</i> .
<i>bdtrik</i> (y, n, p)	Inverse function to <i>bdtr</i> with respect to <i>k</i> .
<i>bdtrin</i> (k, y, p)	Inverse function to <i>bdtr</i> with respect to <i>n</i> .
<i>bdtr</i> (a, b, x)	Cumulative density function of the beta distribution.
<i>bdtri</i> (a, b, p)	The <i>p</i> -th quantile of the beta distribution.
<i>bdtria</i> (p, b, x)	Inverse of <i>bdtr</i> with respect to <i>a</i> .
<i>bdtrib</i> (a, p, x)	Inverse of <i>bdtr</i> with respect to <i>b</i> .
<i>fdtr</i> (dfn, dfd, x)	F cumulative distribution function.
<i>fdtrc</i> (dfn, dfd, x)	F survival function.
<i>fdtri</i> (dfn, dfd, p)	The <i>p</i> -th quantile of the F-distribution.
<i>fdtridfd</i> (dfn, p, x)	Inverse to <i>fdtr</i> vs <i>dfd</i>
<i>gdtr</i> (a, b, x)	Gamma distribution cumulative density function.
<i>gdtrc</i> (a, b, x)	Gamma distribution survival function.
<i>gdtria</i> (p, b, x[, out])	Inverse of <i>gdtr</i> vs <i>a</i> .
<i>gdtrib</i> (a, p, x[, out])	Inverse of <i>gdtr</i> vs <i>b</i> .
<i>gdtrix</i> (a, b, p[, out])	Inverse of <i>gdtr</i> vs <i>x</i> .
<i>nbdtr</i> (k, n, p)	Negative binomial cumulative distribution function.
<i>nbdtrc</i> (k, n, p)	Negative binomial survival function.
<i>nbdtri</i> (k, n, y)	Inverse of <i>nbdtr</i> vs <i>p</i> .
<i>nbdtrik</i> (y, n, p)	Inverse of <i>nbdtr</i> vs <i>k</i> .
<i>nbdtrin</i> (k, y, p)	Inverse of <i>nbdtr</i> vs <i>n</i> .
<i>ncfdtr</i> (dfn, dfd, nc, f)	Cumulative distribution function of the non-central F distribution.
<i>ncfdtridfd</i> (dfn, p, nc, f)	Calculate degrees of freedom (denominator) for the non-central F-distribution.
<i>ncfdtridfn</i> (p, dfd, nc, f)	Calculate degrees of freedom (numerator) for the non-central F-distribution.
<i>ncfdtri</i> (dfn, dfd, nc, p)	Inverse with respect to <i>f</i> of the CDF of the non-central F distribution.
<i>ncfdtrinc</i> (dfn, dfd, p, f)	Calculate non-centrality parameter for non-central F distribution.
<i>nctdtr</i> (df, nc, t)	Cumulative distribution function of the non-central <i>t</i> distribution.
<i>nctdtridf</i> (p, nc, t)	Calculate degrees of freedom for non-central <i>t</i> distribution.
<i>nctdtrit</i> (df, nc, p)	Inverse cumulative distribution function of the non-central <i>t</i> distribution.
<i>nctdtrinc</i> (df, p, t)	Calculate non-centrality parameter for non-central <i>t</i> distribution.
<i>nrtrimn</i> (p, x, std)	Calculate mean of normal distribution given other params.

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<code>nrdrisd(p, x, mn)</code>	Calculate standard deviation of normal distribution given other params.
<code>pdtr(k, m)</code>	Poisson cumulative distribution function
<code>pdtrc(k, m)</code>	Poisson survival function
<code>pdtri(k, y)</code>	Inverse to <code>pdtr</code> vs <code>m</code>
<code>pdtrik(p, m)</code>	Inverse to <code>pdtr</code> vs <code>k</code>
<code>stdtr(df, t)</code>	Student t distribution cumulative density function
<code>stdtridf(p, t)</code>	Inverse of <code>stdtr</code> vs <code>df</code>
<code>stdtrit(df, p)</code>	Inverse of <code>stdtr</code> vs <code>t</code>
<code>chdtr(v, x)</code>	Chi square cumulative distribution function
<code>chdtrc(v, x)</code>	Chi square survival function
<code>chdtri(v, p)</code>	Inverse to <code>chdtrc</code>
<code>chdtriv(p, x)</code>	Inverse to <code>chdtr</code> vs <code>v</code>
<code>ndtr(x)</code>	Gaussian cumulative distribution function.
<code>log_ndtr(x)</code>	Logarithm of Gaussian cumulative distribution function.
<code>ndtri(y)</code>	Inverse of <code>ndtr</code> vs <code>x</code>
<code>chndtr(x, df, nc)</code>	Non-central chi square cumulative distribution function
<code>chndtridf(x, p, nc)</code>	Inverse to <code>chndtr</code> vs <code>df</code>
<code>chndtrinc(x, df, p)</code>	Inverse to <code>chndtr</code> vs <code>nc</code>
<code>chndtrix(p, df, nc)</code>	Inverse to <code>chndtr</code> vs <code>x</code>
<code>smirnov(n, e)</code>	Kolmogorov-Smirnov complementary cumulative distribution function
<code>smirnovi(n, y)</code>	Inverse to <code>smirnov</code>
<code>kolmogorov(y)</code>	Complementary cumulative distribution function of Kolmogorov distribution
<code>kolmogi(p)</code>	Inverse function to <code>kolmogorov</code>
<code>tklmbda(x, lmbda)</code>	Tukey-Lambda cumulative distribution function
<code>logit(x)</code>	Logit ufunc for ndarrays.
<code>expit(x)</code>	Expit ufunc for ndarrays.
<code>boxcox(x, lmbda)</code>	Compute the Box-Cox transformation.
<code>boxcox1p(x, lmbda)</code>	Compute the Box-Cox transformation of $1 + x$ .
<code>inv_boxcox(y, lmbda)</code>	Compute the inverse of the Box-Cox transformation.
<code>inv_boxcox1p(y, lmbda)</code>	Compute the inverse of the Box-Cox transformation.

`scipy.special.bdtr(k, n, p) = <ufunc 'bdtr'>`

Binomial distribution cumulative distribution function.

Sum of the terms 0 through  $k$  of the Binomial probability density.

$$\text{bdtr}(k, n, p) = \sum_{j=0}^k \binom{n}{j} p^j (1-p)^{n-j}$$

**Parameters** `k` : array\_like

Number of successes (int).

`n` : array\_like

Number of events (int).

`p` : array\_like

Probability of success in a single event (float).

**Returns** `y` : ndarray

Probability of  $k$  or fewer successes in  $n$  independent events with success probabilities of  $p$ .

**Notes**

The terms are not summed directly; instead the regularized incomplete beta function is employed, according to the formula,

$$\text{bdtr}(k, n, p) = I_{1-p}(n - k, k + 1).$$

Wrapper for the Cephes [R416] routine *bdt r*.

**References**

[R416]

`scipy.special.bdt rc(k, n, p) = <ufunc 'bdt rc'>`

Binomial distribution survival function.

Sum of the terms  $k + 1$  through  $n$  of the binomial probability density,

$$\text{bdtrc}(k, n, p) = \sum_{j=k+1}^n \binom{n}{j} p^j (1 - p)^{n-j}$$

<b>Parameters</b>	<b>k</b> : array_like Number of successes (int).
	<b>n</b> : array_like Number of events (int)
	<b>p</b> : array_like Probability of success in a single event.
<b>Returns</b>	<b>y</b> : ndarray Probability of $k + 1$ or more successes in $n$ independent events with success probabilities of $p$ .

**See also:**

*bdt r*, *betainc*

**Notes**

The terms are not summed directly; instead the regularized incomplete beta function is employed, according to the formula,

$$\text{bdtrc}(k, n, p) = I_p(k + 1, n - k).$$

Wrapper for the Cephes [R417] routine *bdt rc*.

**References**

[R417]

`scipy.special.bdt ri(k, n, y) = <ufunc 'bdt ri'>`

Inverse function to *bdt r* with respect to  $p$ .

Finds the event probability  $p$  such that the sum of the terms 0 through  $k$  of the binomial probability density is equal to the given cumulative probability  $y$ .

<b>Parameters</b>	<b>k</b> : array_like Number of successes (float).
	<b>n</b> : array_like Number of events (float)
	<b>y</b> : array_like Cumulative probability (probability of $k$ or fewer successes in $n$ events).
<b>Returns</b>	<b>p</b> : ndarray

The event probability such that  $bdtr(k, n, p) = y$ .

**See also:**

`bdtr`, `betaincinv`

**Notes**

The computation is carried out using the inverse beta integral function and the relation,:

$$1 - p = \text{betaincinv}(n - k, k + 1, y).$$

Wrapper for the Cephes [R418] routine `bdtri`.

**References**

[R418]

`scipy.special.bdtrik`( $y, n, p$ ) = <ufunc 'bdtrik'>

Inverse function to `bdtr` with respect to  $k$ .

Finds the number of successes  $k$  such that the sum of the terms 0 through  $k$  of the Binomial probability density for  $n$  events with probability  $p$  is equal to the given cumulative probability  $y$ .

**Parameters**

- y** : array\_like  
Cumulative probability (probability of  $k$  or fewer successes in  $n$  events).
- n** : array\_like  
Number of events (float).
- p** : array\_like  
Success probability (float).

**Returns**

- k** : ndarray  
The number of successes  $k$  such that  $bdtr(k, n, p) = y$ .

**See also:**

`bdtr`

**Notes**

Formula 26.5.24 of [R419] is used to reduce the binomial distribution to the cumulative incomplete beta distribution.

Computation of  $k$  involves a search for a value that produces the desired value of  $y$ . The search relies on the monotonicity of  $y$  with  $k$ .

Wrapper for the CDFLIB [R420] Fortran routine `cdfbin`.

**References**

[R419], [R420]

`scipy.special.bdtrin`( $k, y, p$ ) = <ufunc 'bdtrin'>

Inverse function to `bdtr` with respect to  $n$ .

Finds the number of events  $n$  such that the sum of the terms 0 through  $k$  of the Binomial probability density for events with probability  $p$  is equal to the given cumulative probability  $y$ .

**Parameters**

- k** : array\_like  
Number of successes (float).
- y** : array\_like  
Cumulative probability (probability of  $k$  or fewer successes in  $n$  events).
- p** : array\_like  
Success probability (float).

**Returns**

- n** : ndarray

The number of events  $n$  such that  $bctr(k, n, p) = y$ .

**See also:**

`bctr`

**Notes**

Formula 26.5.24 of [R421] is used to reduce the binomial distribution to the cumulative incomplete beta distribution.

Computation of  $n$  involves a search for a value that produces the desired value of  $y$ . The search relies on the monotonicity of  $y$  with  $n$ .

Wrapper for the CDFLIB [R422] Fortran routine `cdfbin`.

**References**

[R421], [R422]

`scipy.special.bctdtr(a, b, x) = <ufunc 'bctdtr'>`

Cumulative density function of the beta distribution.

Returns the integral from zero to  $x$  of the beta probability density function,

$$I = \int_0^x \frac{\Gamma(a+b)}{\Gamma(a)\Gamma(b)} t^{a-1} (1-t)^{b-1} dt$$

where  $\Gamma$  is the gamma function.

<b>Parameters</b>	<b>a</b> : array_like	Shape parameter ( $a > 0$ ).
	<b>b</b> : array_like	Shape parameter ( $b > 0$ ).
	<b>x</b> : array_like	Upper limit of integration, in $[0, 1]$ .
<b>Returns</b>	<b>I</b> : ndarray	Cumulative density function of the beta distribution with parameters $a$ and $b$ at $x$ .

**See also:**

`betainc`

**Notes**

This function is identical to the incomplete beta integral function `betainc`.

Wrapper for the Cephes [R429] routine `bctdtr`.

**References**

[R429]

`scipy.special.bctdtri(a, b, p) = <ufunc 'bctdtri'>`

The  $p$ -th quantile of the beta distribution.

This function is the inverse of the beta cumulative distribution function, `bctdtr`, returning the value of  $x$  for which `bctdtr(a, b, x) = p`, or

$$p = \int_0^x \frac{\Gamma(a+b)}{\Gamma(a)\Gamma(b)} t^{a-1} (1-t)^{b-1} dt$$

**Parameters** **a** : array\_like

**Returns**     **b** : array\_like     Shape parameter ( $a > 0$ ).  
                  **p** : array\_like     Shape parameter ( $b > 0$ ).  
                  **x** : ndarray       Cumulative probability, in  $[0, 1]$ .  
                                          The quantile corresponding to  $p$ .

**See also:**

*betaincinv*, *btdtr*

**Notes**

The value of  $x$  is found by interval halving or Newton iterations.

Wrapper for the Cephes [R430] routine *incbi*, which solves the equivalent problem of finding the inverse of the incomplete beta integral.

**References**

[R430]

`scipy.special.btdtria` ( $p, b, x$ ) = <ufunc 'btdtria'>  
Inverse of *btdtr* with respect to  $a$ .

This is the inverse of the beta cumulative distribution function, *btdtr*, considered as a function of  $a$ , returning the value of  $a$  for which  $btdtr(a, b, x) = p$ , or

$$p = \int_0^x \frac{\Gamma(a+b)}{\Gamma(a)\Gamma(b)} t^{a-1} (1-t)^{b-1} dt$$

**Parameters**   **p** : array\_like     Cumulative probability, in  $[0, 1]$ .  
                  **b** : array\_like     Shape parameter ( $b > 0$ ).  
                  **x** : array\_like     The quantile, in  $[0, 1]$ .  
**Returns**       **a** : ndarray             The value of the shape parameter  $a$  such that  $btdtr(a, b, x) = p$ .

**See also:**

**btdtr**           Cumulative density function of the beta distribution.  
**btdtri**          Inverse with respect to  $x$ .  
**btdtrib**        Inverse with respect to  $b$ .

**Notes**

Wrapper for the CDFLIB [R431] Fortran routine *cdfbet*.

The cumulative distribution function  $p$  is computed using a routine by DiDinato and Morris [R432]. Computation of  $a$  involves a search for a value that produces the desired value of  $p$ . The search relies on the monotonicity of  $p$  with  $a$ .

**References**

[R431], [R432]

`scipy.special.btdtrib` ( $a, p, x$ ) = <ufunc 'btdtrib'>  
Inverse of *btdtr* with respect to  $b$ .

This is the inverse of the beta cumulative distribution function, `btctr`, considered as a function of  $b$ , returning the value of  $b$  for which  $btctr(a, b, x) = p$ , or

$$p = \int_0^x \frac{\Gamma(a+b)}{\Gamma(a)\Gamma(b)} t^{a-1} (1-t)^{b-1} dt$$

**Parameters**

- a** : array\_like  
Shape parameter ( $a > 0$ ).
- p** : array\_like  
Cumulative probability, in  $[0, 1]$ .
- x** : array\_like  
The quantile, in  $[0, 1]$ .

**Returns**

- b** : ndarray  
The value of the shape parameter  $b$  such that  $btctr(a, b, x) = p$ .

**See also:**

**btctr** Cumulative density function of the beta distribution.  
**btctri** Inverse with respect to  $x$ .  
**btctria** Inverse with respect to  $a$ .

**Notes**

Wrapper for the CDFLIB [R433] Fortran routine `cdfbet`.

The cumulative distribution function  $p$  is computed using a routine by DiDinato and Morris [R434]. Computation of  $b$  involves a search for a value that produces the desired value of  $p$ . The search relies on the monotonicity of  $p$  with  $b$ .

**References**

[R433], [R434]

`scipy.special.fctrf` ( $dfn, dfd, x$ ) = <ufunc 'fctrf'>  
 F cumulative distribution function.

Returns the value of the cumulative density function of the F-distribution, also known as Snedecor's F-distribution or the Fisher-Snedecor distribution.

The F-distribution with parameters  $d_n$  and  $d_d$  is the distribution of the random variable,

$$X = \frac{U_n/d_n}{U_d/d_d},$$

where  $U_n$  and  $U_d$  are random variables distributed  $\chi^2$ , with  $d_n$  and  $d_d$  degrees of freedom, respectively.

**Parameters**

- dfn** : array\_like  
First parameter (positive float).
- dfd** : array\_like  
Second parameter (positive float).
- x** : array\_like  
Argument (nonnegative float).

**Returns**

- y** : ndarray  
The CDF of the F-distribution with parameters  $dfn$  and  $dfd$  at  $x$ .

**Notes**

The regularized incomplete beta function is used, according to the formula,

$$F(d_n, d_d; x) = I_{x d_n / (d_d + x d_n)}(d_n/2, d_d/2).$$

Wrapper for the Cephes [R464] routine `fctrf`.

**References**

[R464]

`scipy.special.fdtrc` (*dfn*, *dfd*, *x*) = <ufunc 'fdtrc'>

F survival function.

Returns the complemented F-distribution function (the integral of the density from *x* to infinity).

**Parameters**

- dfn** : array\_like  
First parameter (positive float).
- dfd** : array\_like  
Second parameter (positive float).
- x** : array\_like  
Argument (nonnegative float).

**Returns**

- y** : ndarray  
The complemented F-distribution function with parameters *dfn* and *dfd* at *x*.

**See also:***fdtr***Notes**

The regularized incomplete beta function is used, according to the formula,

$$F(d_n, d_d; x) = I_{d_d/(d_d+x d_n)}(d_d/2, d_n/2).$$

Wrapper for the Cephes [R465] routine *fdtrc*.**References**

[R465]

`scipy.special.fdttri` (*dfn*, *dfd*, *p*) = <ufunc 'fdtri'>The *p*-th quantile of the F-distribution.This function is the inverse of the F-distribution CDF, *fdtr*, returning the *x* such that *fdtr*(*dfn*, *dfd*, *x*) = *p*.

**Parameters**

- dfn** : array\_like  
First parameter (positive float).
- dfd** : array\_like  
Second parameter (positive float).
- p** : array\_like  
Cumulative probability, in [0, 1].

**Returns**

- x** : ndarray  
The quantile corresponding to *p*.

**Notes**The computation is carried out using the relation to the inverse regularized beta function,  $I_x^{-1}(a, b)$ . Let  $z = I_p^{-1}(d_d/2, d_n/2)$ . Then,

$$x = \frac{d_d(1-z)}{d_n z}.$$

If *p* is such that  $x < 0.5$ , the following relation is used instead for improved stability: let  $z' = I_{1-p}^{-1}(d_n/2, d_d/2)$ . Then,

$$x = \frac{d_d z'}{d_n(1-z')}.$$

Wrapper for the Cephes [R466] routine *fdtri*.

**References**

[R466]

`scipy.special.fdtroidfd(dfn, p, x) = <ufunc 'fdtridf'>`

Inverse to `fdtr` vs `dfd`

Finds the F density argument `dfd` such that `fdtr(dfn, dfd, x) == p`.

`scipy.special.gdtr(a, b, x) = <ufunc 'gdtr'>`

Gamma distribution cumulative density function.

Returns the integral from zero to  $x$  of the gamma probability density function,

$$F = \int_0^x \frac{a^b}{\Gamma(b)} t^{b-1} e^{-at} dt,$$

where  $\Gamma$  is the gamma function.

**Parameters** **a** : array\_like

The rate parameter of the gamma distribution, sometimes denoted  $\beta$  (float). It is also the reciprocal of the scale parameter  $\theta$ .

**b** : array\_like

The shape parameter of the gamma distribution, sometimes denoted  $\alpha$  (float).

**x** : array\_like

The quantile (upper limit of integration; float).

**Returns** **F** : ndarray

The CDF of the gamma distribution with parameters  $a$  and  $b$  evaluated at  $x$ .

**See also:**

**gdtrc** 1 - CDF of the gamma distribution.

**Notes**

The evaluation is carried out using the relation to the incomplete gamma integral (regularized gamma function).

Wrapper for the Cephes [R472] routine `gdtr`.

**References**

[R472]

`scipy.special.gdtrc(a, b, x) = <ufunc 'gdtrc'>`

Gamma distribution survival function.

Integral from  $x$  to infinity of the gamma probability density function,

$$F = \int_x^\infty \frac{a^b}{\Gamma(b)} t^{b-1} e^{-at} dt,$$

where  $\Gamma$  is the gamma function.

**Parameters** **a** : array\_like

The rate parameter of the gamma distribution, sometimes denoted  $\beta$  (float). It is also the reciprocal of the scale parameter  $\theta$ .

**b** : array\_like

The shape parameter of the gamma distribution, sometimes denoted  $\alpha$  (float).

**x** : array\_like

The quantile (lower limit of integration; float).

**Returns** **F** : ndarray

The survival function of the gamma distribution with parameters  $a$  and  $b$  evaluated at  $x$ .

**See also:**

`gdftr`, `gdftri`

**Notes**

The evaluation is carried out using the relation to the incomplete gamma integral (regularized gamma function). Wrapper for the Cephes [R473] routine `gdftrc`.

**References**

[R473]

`scipy.special.gdftria` ( $p, b, x, out=None$ ) = <ufunc 'gdftria'>

Inverse of `gdftr` vs  $a$ .

Returns the inverse with respect to the parameter  $a$  of  $p = \text{gdftr}(a, b, x)$ , the cumulative distribution function of the gamma distribution.

<b>Parameters</b>	<b>p</b> : array_like	Probability values.
	<b>b</b> : array_like	$b$ parameter values of $\text{gdftr}(a, b, x)$ . $b$ is the “shape” parameter of the gamma distribution.
	<b>x</b> : array_like	Nonnegative real values, from the domain of the gamma distribution.
	<b>out</b> : ndarray, optional	If a fourth argument is given, it must be a <code>numpy.ndarray</code> whose size matches the broadcast result of $a$ , $b$ and $x$ . <code>out</code> is then the array returned by the function.
<b>Returns</b>	<b>a</b> : ndarray	Values of the $a$ parameter such that $p = \text{gdftr}(a, b, x)$ . $1/a$ is the “scale” parameter of the gamma distribution.

**See also:**

<b>gdftr</b>	CDF of the gamma distribution.
<b>gdftrib</b>	Inverse with respect to $b$ of $\text{gdftr}(a, b, x)$ .
<b>gdftrix</b>	Inverse with respect to $x$ of $\text{gdftr}(a, b, x)$ .

**Notes**

Wrapper for the CDFLIB [R474] Fortran routine `cdfgam`.

The cumulative distribution function  $p$  is computed using a routine by DiDinato and Morris [R475]. Computation of  $a$  involves a search for a value that produces the desired value of  $p$ . The search relies on the monotonicity of  $p$  with  $a$ .

**References**

[R474], [R475]

**Examples**

First evaluate `gdftr`.

```
>>> from scipy.special import gdftr, gdftria
>>> p = gdftr(1.2, 3.4, 5.6)
>>> print(p)
0.94378087442
```

Verify the inverse.

```
>>> gdftria(p, 3.4, 5.6)
1.2
```

`scipy.special.gdftrib(a, p, x, out=None) = <ufunc 'gdftrib'>`

Inverse of `gdftr` vs `b`.

Returns the inverse with respect to the parameter `b` of `p = gdftr(a, b, x)`, the cumulative distribution function of the gamma distribution.

**Parameters**

- a** : array\_like  
`a` parameter values of `gdftr(a, b, x)`. `1/a` is the “scale” parameter of the gamma distribution.
- p** : array\_like  
Probability values.
- x** : array\_like  
Nonnegative real values, from the domain of the gamma distribution.
- out** : ndarray, optional  
If a fourth argument is given, it must be a `numpy.ndarray` whose size matches the broadcast result of `a`, `b` and `x`. `out` is then the array returned by the function.

**Returns**

- b** : ndarray  
Values of the `b` parameter such that `p = gdftr(a, b, x)`. `b` is the “shape” parameter of the gamma distribution.

**See also:**

**gdftr** CDF of the gamma distribution.  
**gdftria** Inverse with respect to `a` of `gdftr(a, b, x)`.  
**gdftrix** Inverse with respect to `x` of `gdftr(a, b, x)`.

**Notes**

Wrapper for the CDFLIB [R476] Fortran routine `cdfgam`.

The cumulative distribution function `p` is computed using a routine by DiDinato and Morris [R477]. Computation of `b` involves a search for a value that produces the desired value of `p`. The search relies on the monotonicity of `p` with `b`.

**References**

[R476], [R477]

**Examples**

First evaluate `gdftr`.

```
>>> from scipy.special import gdftr, gdftrib
>>> p = gdftr(1.2, 3.4, 5.6)
>>> print(p)
0.94378087442
```

Verify the inverse.

```
>>> gdtrib(1.2, p, 5.6)
3.3999999999723882
```

`scipy.special.gdtrix(a, b, p, out=None) = <ufunc 'gdtrix'>`

Inverse of `gdtr` vs `x`.

Returns the inverse with respect to the parameter `x` of  $p = \text{gdtr}(a, b, x)$ , the cumulative distribution function of the gamma distribution. This is also known as the  $p$ 'th quantile of the distribution.

**Parameters**

- a** : array\_like  
*a* parameter values of  $\text{gdtr}(a, b, x)$ .  $1/a$  is the “scale” parameter of the gamma distribution.
- b** : array\_like  
*b* parameter values of  $\text{gdtr}(a, b, x)$ . *b* is the “shape” parameter of the gamma distribution.
- p** : array\_like  
Probability values.
- out** : ndarray, optional  
If a fourth argument is given, it must be a `numpy.ndarray` whose size matches the broadcast result of *a*, *b* and *x*. *out* is then the array returned by the function.

**Returns**

- x** : ndarray  
Values of the *x* parameter such that  $p = \text{gdtr}(a, b, x)$ .

**See also:**

**gdtr** CDF of the gamma distribution.  
**gdtria** Inverse with respect to *a* of  $\text{gdtr}(a, b, x)$ .  
**gdtrib** Inverse with respect to *b* of  $\text{gdtr}(a, b, x)$ .

**Notes**

Wrapper for the CDFLIB [R478] Fortran routine `cdfgam`.

The cumulative distribution function *p* is computed using a routine by DiDinato and Morris [R479]. Computation of *x* involves a search for a value that produces the desired value of *p*. The search relies on the monotonicity of *p* with *x*.

**References**

[R478], [R479]

**Examples**

First evaluate `gdtr`.

```
>>> from scipy.special import gdtr, gdtrix
>>> p = gdtr(1.2, 3.4, 5.6)
>>> print(p)
0.94378087442
```

Verify the inverse.

```
>>> gdtrix(1.2, 3.4, p)
5.5999999999999996
```

`scipy.special.nbdtr(k, n, p) = <ufunc 'nbdtr'>`

Negative binomial cumulative distribution function.

Returns the sum of the terms 0 through  $k$  of the negative binomial distribution probability mass function,

$$F = \sum_{j=0}^k \binom{n+j-1}{j} p^n (1-p)^j.$$

In a sequence of Bernoulli trials with individual success probabilities  $p$ , this is the probability that  $k$  or fewer failures precede the  $n$ th success.

**Parameters**

- k** : array\_like  
The maximum number of allowed failures (nonnegative int).
- n** : array\_like  
The target number of successes (positive int).
- p** : array\_like  
Probability of success in a single event (float).

**Returns**

- F** : ndarray  
The probability of  $k$  or fewer failures before  $n$  successes in a sequence of events with individual success probability  $p$ .

**See also:**

`nbdtrc`

**Notes**

If floating point values are passed for  $k$  or  $n$ , they will be truncated to integers.

The terms are not summed directly; instead the regularized incomplete beta function is employed, according to the formula,

$$\text{nbdtr}(k, n, p) = I_p(n, k + 1).$$

Wrapper for the Cephes [R546] routine `nbdtr`.

**References**

[R546]

`scipy.special.nbdtrc(k, n, p) = <ufunc 'nbdtrc'>`

Negative binomial survival function.

Returns the sum of the terms  $k + 1$  to infinity of the negative binomial distribution probability mass function,

$$F = \sum_{j=k+1}^{\infty} \binom{n+j-1}{j} p^n (1-p)^j.$$

In a sequence of Bernoulli trials with individual success probabilities  $p$ , this is the probability that more than  $k$  failures precede the  $n$ th success.

**Parameters**

- k** : array\_like  
The maximum number of allowed failures (nonnegative int).
- n** : array\_like  
The target number of successes (positive int).
- p** : array\_like  
Probability of success in a single event (float).

**Returns**

- F** : ndarray  
The probability of  $k + 1$  or more failures before  $n$  successes in a sequence of events with individual success probability  $p$ .

**Notes**

If floating point values are passed for  $k$  or  $n$ , they will be truncated to integers.

The terms are not summed directly; instead the regularized incomplete beta function is employed, according to the formula,

$$\text{nbdtrc}(k, n, p) = I_{1-p}(k + 1, n).$$

Wrapper for the Cephes [R547] routine *nbdtrc*.

**References**

[R547]

`scipy.special.nbdtri`( $k, n, y$ ) = <ufunc 'nbdtri'>  
Inverse of *nbdt r* vs  $p$ .

Returns the inverse with respect to the parameter  $p$  of  $y = \text{nbdt r}(k, n, p)$ , the negative binomial cumulative distribution function.

<b>Parameters</b>	<b>k</b> : array_like	The maximum number of allowed failures (nonnegative int).
	<b>n</b> : array_like	The target number of successes (positive int).
	<b>y</b> : array_like	The probability of $k$ or fewer failures before $n$ successes (float).
<b>Returns</b>	<b>p</b> : ndarray	Probability of success in a single event (float) such that $\text{nbdt r}(k, n, p) = y$ .

**See also:**

**nbdt r** Cumulative distribution function of the negative binomial.  
**nbdt rik** Inverse with respect to  $k$  of  $\text{nbdt r}(k, n, p)$ .  
**nbdt rin** Inverse with respect to  $n$  of  $\text{nbdt r}(k, n, p)$ .

**Notes**

Wrapper for the Cephes [R548] routine *nbdt ri*.

**References**

[R548]

`scipy.special.nbdtrik`( $y, n, p$ ) = <ufunc 'nbdtrik'>  
Inverse of *nbdt r* vs  $k$ .

Returns the inverse with respect to the parameter  $k$  of  $y = \text{nbdt r}(k, n, p)$ , the negative binomial cumulative distribution function.

<b>Parameters</b>	<b>y</b> : array_like	The probability of $k$ or fewer failures before $n$ successes (float).
	<b>n</b> : array_like	The target number of successes (positive int).
	<b>p</b> : array_like	Probability of success in a single event (float).
<b>Returns</b>	<b>k</b> : ndarray	The maximum number of allowed failures such that $\text{nbdt r}(k, n, p) = y$ .

**See also:**

**nbdt r** Cumulative distribution function of the negative binomial.  
**nbdt ri** Inverse with respect to  $p$  of  $\text{nbdt r}(k, n, p)$ .

**nbdttrin** Inverse with respect to  $n$  of  $nbdtr(k, n, p)$ .

**Notes**

Wrapper for the CDFLIB [R549] Fortran routine *cdfnbn*.

Formula 26.5.26 of [R550],

$$\sum_{j=k+1}^{\infty} \binom{n+j-1}{j} p^n (1-p)^j = I_{1-p}(k+1, n),$$

is used to reduce calculation of the cumulative distribution function to that of a regularized incomplete beta  $I$ .

Computation of  $k$  involves a search for a value that produces the desired value of  $y$ . The search relies on the monotonicity of  $y$  with  $k$ .

**References**

[R549], [R550]

`scipy.special.nbdttrin(k, y, p) = <ufunc 'nbdttrin'>`

Inverse of *nbdtr* vs  $n$ .

Returns the inverse with respect to the parameter  $n$  of  $y = nbdtr(k, n, p)$ , the negative binomial cumulative distribution function.

**Parameters**

- k** : array\_like  
The maximum number of allowed failures (nonnegative int).
- y** : array\_like  
The probability of  $k$  or fewer failures before  $n$  successes (float).
- p** : array\_like  
Probability of success in a single event (float).

**Returns**

- n** : ndarray  
The number of successes  $n$  such that  $nbdttr(k, n, p) = y$ .

**See also:**

**nbdttr** Cumulative distribution function of the negative binomial.  
**nbdttri** Inverse with respect to  $p$  of  $nbdttr(k, n, p)$ .  
**nbdttrik** Inverse with respect to  $k$  of  $nbdttr(k, n, p)$ .

**Notes**

Wrapper for the CDFLIB [R551] Fortran routine *cdfnbn*.

Formula 26.5.26 of [R552],

$$\sum_{j=k+1}^{\infty} \binom{n+j-1}{j} p^n (1-p)^j = I_{1-p}(k+1, n),$$

is used to reduce calculation of the cumulative distribution function to that of a regularized incomplete beta  $I$ .

Computation of  $n$  involves a search for a value that produces the desired value of  $y$ . The search relies on the monotonicity of  $y$  with  $n$ .

**References**

[R551], [R552]

`scipy.special.ncfdtr(dfn, dfd, nc, f) = <ufunc 'ncfdtr'>`

Cumulative distribution function of the non-central F distribution.

The non-central F describes the distribution of,

$$Z = \frac{X/d_n}{Y/d_d}$$

where  $X$  and  $Y$  are independently distributed, with  $X$  distributed non-central  $\chi^2$  with noncentrality parameter  $nc$  and  $d_n$  degrees of freedom, and  $Y$  distributed  $\chi^2$  with  $d_d$  degrees of freedom.

**Parameters**

- dfn** : array\_like  
Degrees of freedom of the numerator sum of squares. Range (0, inf).
- dfd** : array\_like  
Degrees of freedom of the denominator sum of squares. Range (0, inf).
- nc** : array\_like  
Noncentrality parameter. Should be in range (0, 1e4).
- f** : array\_like  
Quantiles, i.e. the upper limit of integration.

**Returns**

- cdf** : float or ndarray  
The calculated CDF. If all inputs are scalar, the return will be a float. Otherwise it will be an array.

**See also:**

**ncfdtri** Quantile function; inverse of *ncfdtr* with respect to *f*.  
**ncfdtridf** Inverse of *ncfdtr* with respect to *dfd*.  
**ncfdtridf** Inverse of *ncfdtr* with respect to *dfn*.  
**ncfdtrinc** Inverse of *ncfdtr* with respect to *nc*.

**Notes**

Wrapper for the CDFLIB [R553] Fortran routine *cdffnc*.

The cumulative distribution function is computed using Formula 26.6.20 of [R554]:

$$F(d_n, d_d, n_c, f) = \sum_{j=0}^{\infty} e^{-n_c/2} \frac{(n_c/2)^j}{j!} I_x\left(\frac{d_n}{2} + j, \frac{d_d}{2}\right),$$

where  $I$  is the regularized incomplete beta function, and  $x = fd_n/(fd_n + d_d)$ .

The computation time required for this routine is proportional to the noncentrality parameter  $nc$ . Very large values of this parameter can consume immense computer resources. This is why the search range is bounded by 10,000.

**References**

[R553], [R554]

**Examples**

```
>>> from scipy import special
>>> from scipy import stats
>>> import matplotlib.pyplot as plt
```

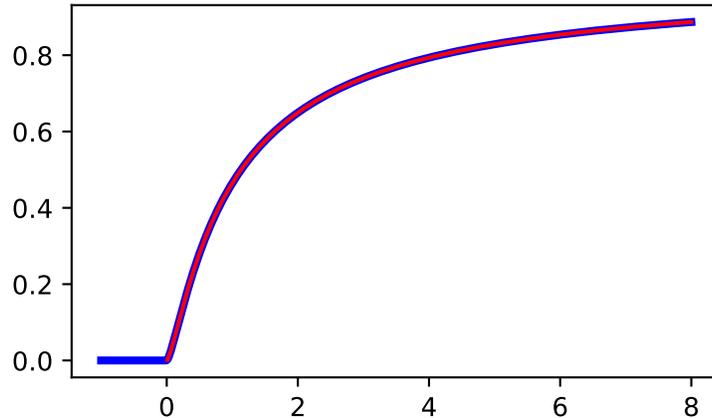
Plot the CDF of the non-central F distribution, for  $nc=0$ . Compare with the F-distribution from `scipy.stats`:

```
>>> x = np.linspace(-1, 8, num=500)
>>> dfn = 3
>>> dfd = 2
>>> ncf_stats = stats.f.cdf(x, dfn, dfd)
>>> ncf_special = special.ncfdtr(dfn, dfd, 0, x)
```

```

>>> fig = plt.figure()
>>> ax = fig.add_subplot(111)
>>> ax.plot(x, ncf_stats, 'b-', lw=3)
>>> ax.plot(x, ncf_special, 'r-')
>>> plt.show()

```



`scipy.special.ncfdtridfd(dfn, p, nc, f) = <ufunc 'ncfdtridfd'>`

Calculate degrees of freedom (denominator) for the noncentral F-distribution.

This is the inverse with respect to *dfd* of *ncfdtr*. See *ncfdtr* for more details.

**Parameters**

- dfn** : array\_like  
Degrees of freedom of the numerator sum of squares. Range (0, inf).
- p** : array\_like  
Value of the cumulative distribution function. Must be in the range [0, 1].
- nc** : array\_like  
Noncentrality parameter. Should be in range (0, 1e4).
- f** : array\_like  
Quantiles, i.e. the upper limit of integration.

**Returns**

- dfd** : float  
Degrees of freedom of the denominator sum of squares.

**See also:**

- ncfdtr** CDF of the non-central F distribution.
- ncfdtri** Quantile function; inverse of *ncfdtr* with respect to *f*.
- ncfdtridfn** Inverse of *ncfdtr* with respect to *dfn*.
- ncfdtrinc** Inverse of *ncfdtr* with respect to *nc*.

**Notes**

The value of the cumulative noncentral F distribution is not necessarily monotone in either degrees of freedom. There thus may be two values that provide a given CDF value. This routine assumes monotonicity and will find an arbitrary one of the two values.

**Examples**

```
>>> from scipy.special import ncfdtr, ncfdtridfd
```

Compute the CDF for several values of *dfd*:

```
>>> dfd = [1, 2, 3]
>>> p = ncfdtr(2, dfd, 0.25, 15)
>>> p
array([ 0.8097138 ,  0.93020416,  0.96787852])
```

Compute the inverse. We recover the values of *dfd*, as expected:

```
>>> ncfdtridfd(2, p, 0.25, 15)
array([ 1.,  2.,  3.])
```

`scipy.special.ncfdtridfn(p, dfd, nc, f) = <ufunc 'ncfdtridfn'>`

Calculate degrees of freedom (numerator) for the noncentral F-distribution.

This is the inverse with respect to *dfn* of *ncfdtr*. See *ncfdtr* for more details.

<b>Parameters</b>	<b>p</b> : array_like	Value of the cumulative distribution function. Must be in the range [0, 1].
	<b>dfd</b> : array_like	Degrees of freedom of the denominator sum of squares. Range (0, inf).
	<b>nc</b> : array_like	Noncentrality parameter. Should be in range (0, 1e4).
	<b>f</b> : float	Quantiles, i.e. the upper limit of integration.
<b>Returns</b>	<b>dfn</b> : float	Degrees of freedom of the numerator sum of squares.

**See also:**

**ncfdtr** CDF of the non-central F distribution.  
**ncfdtri** Quantile function; inverse of *ncfdtr* with respect to *f*.  
**ncfdtridfd** Inverse of *ncfdtr* with respect to *dfd*.  
**ncfdtrinc** Inverse of *ncfdtr* with respect to *nc*.

**Notes**

The value of the cumulative noncentral F distribution is not necessarily monotone in either degrees of freedom. There thus may be two values that provide a given CDF value. This routine assumes monotonicity and will find an arbitrary one of the two values.

**Examples**

```
>>> from scipy.special import ncfdtr, ncfdtridfn
```

Compute the CDF for several values of *dfn*:

```
>>> dfn = [1, 2, 3]
>>> p = ncfdtr(dfn, 2, 0.25, 15)
>>> p
array([ 0.92562363,  0.93020416,  0.93188394])
```

Compute the inverse. We recover the values of *dfn*, as expected:

```
>>> ncfdrtridf(p, 2, 0.25, 15)
array([ 1.,  2.,  3.])
```

`scipy.special.ncfdtri` (*dfn*, *dfd*, *nc*, *p*) = <ufunc 'ncfdtri'>

Inverse with respect to *f* of the CDF of the non-central F distribution.

See `ncfdtr` for more details.

<b>Parameters</b>	<b>dfn</b> : array_like	Degrees of freedom of the numerator sum of squares. Range (0, inf).
	<b>dfd</b> : array_like	Degrees of freedom of the denominator sum of squares. Range (0, inf).
	<b>nc</b> : array_like	Noncentrality parameter. Should be in range (0, 1e4).
	<b>p</b> : array_like	Value of the cumulative distribution function. Must be in the range [0, 1].
<b>Returns</b>	<b>f</b> : float	Quantiles, i.e. the upper limit of integration.

See also:

**ncfdtr** CDF of the non-central F distribution.

**ncfdtridf** Inverse of `ncfdtr` with respect to *dfd*.

**ncfdtridf** Inverse of `ncfdtr` with respect to *dfn*.

**ncfdtrinc** Inverse of `ncfdtr` with respect to *nc*.

**Examples**

```
>>> from scipy.special import ncfdrtr, ncfdrtri
```

Compute the CDF for several values of *f*:

```
>>> f = [0.5, 1, 1.5]
>>> p = ncfdrtr(2, 3, 1.5, f)
>>> p
array([ 0.20782291,  0.36107392,  0.47345752])
```

Compute the inverse. We recover the values of *f*, as expected:

```
>>> ncfdrtri(2, 3, 1.5, p)
array([ 0.5,  1. ,  1.5])
```

`scipy.special.ncfdtrinc` (*dfn*, *dfd*, *p*, *f*) = <ufunc 'ncfdtrinc'>

Calculate non-centrality parameter for non-central F distribution.

This is the inverse with respect to *nc* of `ncfdtr`. See `ncfdtr` for more details.

<b>Parameters</b>	<b>dfn</b> : array_like	Degrees of freedom of the numerator sum of squares. Range (0, inf).
	<b>dfd</b> : array_like	Degrees of freedom of the denominator sum of squares. Range (0, inf).
	<b>p</b> : array_like	Value of the cumulative distribution function. Must be in the range [0, 1].
	<b>f</b> : array_like	Quantiles, i.e. the upper limit of integration.
<b>Returns</b>	<b>nc</b> : float	Noncentrality parameter.

See also:

**ncfdtr** CDF of the non-central F distribution.  
**ncfdtri** Quantile function; inverse of *ncfdtr* with respect to *f*.  
**ncfdtridfd** Inverse of *ncfdtr* with respect to *dfd*.  
**ncfdtridfn** Inverse of *ncfdtr* with respect to *dfn*.

**Examples**

```
>>> from scipy.special import ncfdtr, ncftrin
```

Compute the CDF for several values of *nc*:

```
>>> nc = [0.5, 1.5, 2.0]
>>> p = ncfdtr(2, 3, nc, 15)
>>> p
array([ 0.96309246,  0.94327955,  0.93304098])
```

Compute the inverse. We recover the values of *nc*, as expected:

```
>>> ncftrin(2, 3, p, 15)
array([ 0.5,  1.5,  2. ])
```

`scipy.special.ncdtr(df, nc, t) = <ufunc 'ncdtr'>`

Cumulative distribution function of the non-central *t* distribution.

**Parameters**

- df**: array\_like  
Degrees of freedom of the distribution. Should be in range (0, inf).
- nc**: array\_like  
Noncentrality parameter. Should be in range (-1e6, 1e6).
- t**: array\_like  
Quantiles, i.e. the upper limit of integration.

**Returns**

- cdf**: float or ndarray  
The calculated CDF. If all inputs are scalar, the return will be a float. Otherwise it will be an array.

See also:

**ncdtrit** Inverse CDF (iCDF) of the non-central *t* distribution.  
**ncdtridf** Calculate degrees of freedom, given CDF and iCDF values.  
**ncdtrinc** Calculate non-centrality parameter, given CDF iCDF values.

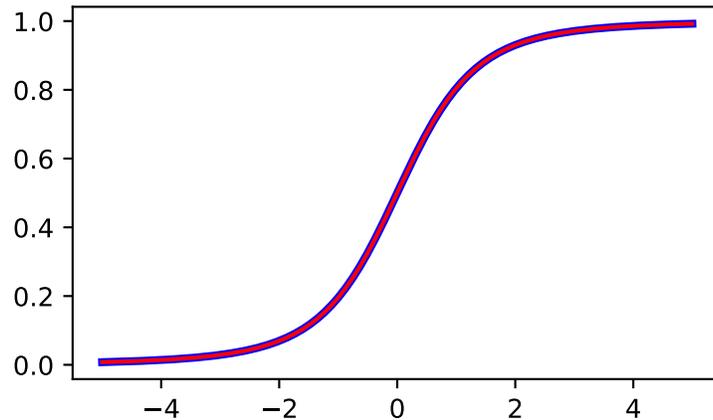
**Examples**

```
>>> from scipy import special
>>> from scipy import stats
>>> import matplotlib.pyplot as plt
```

Plot the CDF of the non-central *t* distribution, for *nc*=0. Compare with the *t*-distribution from `scipy.stats`:

```
>>> x = np.linspace(-5, 5, num=500)
>>> df = 3
>>> nct_stats = stats.t.cdf(x, df)
>>> nct_special = special.ncdtr(df, 0, x)
```

```
>>> fig = plt.figure()
>>> ax = fig.add_subplot(111)
>>> ax.plot(x, nct_stats, 'b-', lw=3)
>>> ax.plot(x, nct_special, 'r-')
>>> plt.show()
```



`scipy.special.nctdtridf` ( $p, nc, t$ ) = <ufunc 'nctdtridf'>

Calculate degrees of freedom for non-central t distribution.

See `nctdtr` for more details.

**Parameters**

- p** : array\_like  
CDF values, in range (0, 1].
- nc** : array\_like  
Noncentrality parameter. Should be in range (-1e6, 1e6).
- t** : array\_like  
Quantiles, i.e. the upper limit of integration.

`scipy.special.nctdtrit` ( $df, nc, p$ ) = <ufunc 'nctdtrit'>

Inverse cumulative distribution function of the non-central t distribution.

See `nctdtr` for more details.

**Parameters**

- df** : array\_like  
Degrees of freedom of the distribution. Should be in range (0, inf).
- nc** : array\_like  
Noncentrality parameter. Should be in range (-1e6, 1e6).
- p** : array\_like  
CDF values, in range (0, 1].

`scipy.special.nctdtrinc` ( $df, p, t$ ) = <ufunc 'nctdtrinc'>

Calculate non-centrality parameter for non-central t distribution.

See `nctdtr` for more details.

**Parameters**

- df** : array\_like  
Degrees of freedom of the distribution. Should be in range (0, inf).
- p** : array\_like  
CDF values, in range (0, 1].
- t** : array\_like  
Quantiles, i.e. the upper limit of integration.

`scipy.special.nrdtrimn` ( $p, x, std$ ) = <ufunc 'nrdtrimn'>

Calculate mean of normal distribution given other params.

**Parameters**

- p** : array\_like

**Returns** **mn** : float or ndarray  
 CDF values, in range (0, 1].  
**x** : array\_like  
 Quantiles, i.e. the upper limit of integration.  
**std** : array\_like  
 Standard deviation.  
 The mean of the normal distribution.

**See also:***nrtrimn, ndtr*

`scipy.special.nrdtrisd(p, x, mn) = <ufunc 'nrdtrisd'>`  
 Calculate standard deviation of normal distribution given other params.

**Parameters** **p** : array\_like  
 CDF values, in range (0, 1].  
**x** : array\_like  
 Quantiles, i.e. the upper limit of integration.  
**mn** : float or ndarray  
 The mean of the normal distribution.  
**Returns** **std** : array\_like  
 Standard deviation.

**See also:***nrdtristd, ndtr*

`scipy.special.pdtr(k, m) = <ufunc 'pdtr'>`  
 Poisson cumulative distribution function  
 Returns the sum of the first  $k$  terms of the Poisson distribution:  $\sum(\exp(-m) * m^{**j} / j!, j=0..k) = \text{gammaincc}(k+1, m)$ . Arguments must both be positive and  $k$  an integer.

`scipy.special.pdtrc(k, m) = <ufunc 'pdtrc'>`  
 Poisson survival function  
 Returns the sum of the terms from  $k+1$  to infinity of the Poisson distribution:  $\sum(\exp(-m) * m^{**j} / j!, j=k+1..inf) = \text{gammainc}(k+1, m)$ . Arguments must both be positive and  $k$  an integer.

`scipy.special.pdtri(k, y) = <ufunc 'pdtri'>`  
 Inverse to *pdtr* vs  $m$   
 Returns the Poisson variable  $m$  such that the sum from 0 to  $k$  of the Poisson density is equal to the given probability  $y$ : calculated by  $\text{gammaincinv}(k+1, y)$ .  $k$  must be a nonnegative integer and  $y$  between 0 and 1.

`scipy.special.pdtrik(p, m) = <ufunc 'pdtrik'>`  
 Inverse to *pdtr* vs  $k$   
 Returns the quantile  $k$  such that  $\text{pdtr}(k, m) = p$

`scipy.special.stdtr(df, t) = <ufunc 'stdtr'>`  
 Student t distribution cumulative density function  
 Returns the integral from minus infinity to  $t$  of the Student t distribution with  $df > 0$  degrees of freedom:

```
gamma((df+1)/2) / (sqrt(df*pi) * gamma(df/2)) *
integral((1+x**2/df)**(-df/2-1/2), x=-inf..t)
```

`scipy.special.stdtridf(p, t) = <ufunc 'stdtridf'>`  
 Inverse of *stdtr* vs  $df$   
 Returns the argument  $df$  such that  $\text{stdtr}(df, t)$  is equal to  $p$ .

`scipy.special.stdtrit(df, p) = <ufunc 'stdtrit'>`

Inverse of `stdtr` vs `t`

Returns the argument `t` such that `stdtr(df, t)` is equal to `p`.

`scipy.special.chdtr(v, x) = <ufunc 'chdtr'>`

Chi square cumulative distribution function

Returns the area under the left hand tail (from 0 to `x`) of the Chi square probability density function with `v` degrees of freedom:

$$1 / (2^{v/2} * \text{gamma}(v/2)) * \text{integral}(t^{v/2-1} * \exp(-t/2), t=0..x)$$

`scipy.special.chdtrc(v, x) = <ufunc 'chdtrc'>`

Chi square survival function

Returns the area under the right hand tail (from `x` to infinity) of the Chi square probability density function with `v` degrees of freedom:

$$1 / (2^{v/2} * \text{gamma}(v/2)) * \text{integral}(t^{v/2-1} * \exp(-t/2), t=x..inf)$$

`scipy.special.chdtri(v, p) = <ufunc 'chdtri'>`

Inverse to `chdtrc`

Returns the argument `x` such that `chdtrc(v, x) == p`.

`scipy.special.chdtriv(p, x) = <ufunc 'chdtriv'>`

Inverse to `chdtr` vs `v`

Returns the argument `v` such that `chdtr(v, x) == p`.

`scipy.special.ndtr(x) = <ufunc 'ndtr'>`

Gaussian cumulative distribution function.

Returns the area under the standard Gaussian probability density function, integrated from minus infinity to `x`

$$\frac{1}{\sqrt{2\pi}} \int_{-\infty}^x \exp(-t^2/2) dt$$

**Parameters** `x` : array\_like, real or complex

**Returns** ndarray Argument

The value of the normal CDF evaluated at `x`

**See also:**

`erf`, `erfc`, `scipy.stats.norm`, `log_ndtr`

`scipy.special.log_ndtr(x) = <ufunc 'log_ndtr'>`

Logarithm of Gaussian cumulative distribution function.

Returns the log of the area under the standard Gaussian probability density function, integrated from minus infinity to `x`:

$$\log(1/\text{sqrt}(2*\text{pi}) * \text{integral}(\exp(-t**2 / 2), t=-inf..x))$$

**Parameters** `x` : array\_like, real or complex

**Returns** ndarray Argument

The value of the log of the normal CDF evaluated at `x`

**See also:***erf, erfc, scipy.stats.norm, ndtr*`scipy.special.ndtri(y) = <ufunc 'ndtri'>`Inverse of *ndtr* vs *x*

Returns the argument *x* for which the area under the Gaussian probability density function (integrated from minus infinity to *x*) is equal to *y*.

`scipy.special.chndtr(x, df, nc) = <ufunc 'chndtr'>`

Non-central chi square cumulative distribution function

`scipy.special.chndtridf(x, p, nc) = <ufunc 'chndtridf'>`Inverse to *chndtr* vs *df*`scipy.special.chndtrinc(x, df, p) = <ufunc 'chndtrinc'>`Inverse to *chndtr* vs *nc*`scipy.special.chndtrix(p, df, nc) = <ufunc 'chndtrix'>`Inverse to *chndtr* vs *x*`scipy.special.smirnov(n, e) = <ufunc 'smirnov'>`

Kolmogorov-Smirnov complementary cumulative distribution function

Returns the exact Kolmogorov-Smirnov complementary cumulative distribution function (D<sub>n+</sub> or D<sub>n-</sub>) for a one-sided test of equality between an empirical and a theoretical distribution. It is equal to the probability that the maximum difference between a theoretical distribution and an empirical one based on *n* samples is greater than *e*.

`scipy.special.smirnovi(n, y) = <ufunc 'smirnovi'>`Inverse to *smirnov*

Returns *e* such that `smirnov(n, e) = y`.

`scipy.special.kolmogorov(y) = <ufunc 'kolmogorov'>`

Complementary cumulative distribution function of Kolmogorov distribution

Returns the complementary cumulative distribution function of Kolmogorov's limiting distribution (K<sub>n</sub>\* for large *n*) of a two-sided test for equality between an empirical and a theoretical distribution. It is equal to the (limit as *n*->infinity of the) probability that `sqrt(n) * max absolute deviation > y`.

`scipy.special.kolmogi(p) = <ufunc 'kolmogi'>`Inverse function to *kolmogorov*

Returns *y* such that `kolmogorov(y) == p`.

`scipy.special.tklmbda(x, lmbda) = <ufunc 'tklmbda'>`

Tukey-Lambda cumulative distribution function

`scipy.special.logit(x) = <ufunc 'logit'>`Logit ufunc for *ndarrays*.

The logit function is defined as `logit(p) = log(p/(1-p))`. Note that `logit(0) = -inf`, `logit(1) = inf`, and `logit(p)` for `p<0` or `p>1` yields `nan`.

**Parameters** *x* : *ndarray***Returns** *out* : *ndarray*The *ndarray* to apply *logit* to element-wise.

An *ndarray* of the same shape as *x*. Its entries are *logit* of the corresponding entry of *x*.

**See also:***expit*

**Notes**

As a ufunc `logit` takes a number of optional keyword arguments. For more information see [ufuncs](#)  
 New in version 0.10.0.

**Examples**

```
>>> from scipy.special import logit, expit
```

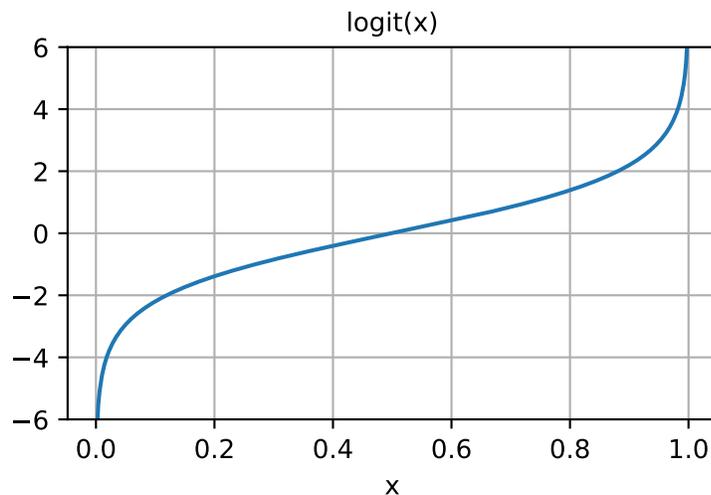
```
>>> logit([0, 0.25, 0.5, 0.75, 1])
array([-inf, -1.09861229, 0.          , 1.09861229,  inf])
```

`expit` is the inverse of `logit`:

```
>>> expit(logit([0.1, 0.75, 0.999]))
array([ 0.1   ,  0.75  ,  0.999])
```

Plot `logit(x)` for `x` in `[0, 1]`:

```
>>> import matplotlib.pyplot as plt
>>> x = np.linspace(0, 1, 501)
>>> y = logit(x)
>>> plt.plot(x, y)
>>> plt.grid()
>>> plt.ylim(-6, 6)
>>> plt.xlabel('x')
>>> plt.title('logit(x)')
>>> plt.show()
```



`scipy.special.expit(x) = <ufunc 'expit'>`

Expit ufunc for ndarrays.

The `expit` function, also known as the logistic function, is defined as  $\text{expit}(x) = 1/(1+\exp(-x))$ . It is the inverse of the `logit` function.

**Parameters** `x` : ndarray

**Returns** `out` : ndarray The ndarray to apply `expit` to element-wise.

An ndarray of the same shape as `x`. Its entries are `expit` of the corresponding entry of `x`.

**See also:**

`logit`

**Notes**

As a ufunc `expit` takes a number of optional keyword arguments. For more information see [ufuncs](#)

New in version 0.10.0.

**Examples**

```
>>> from scipy.special import expit, logit
```

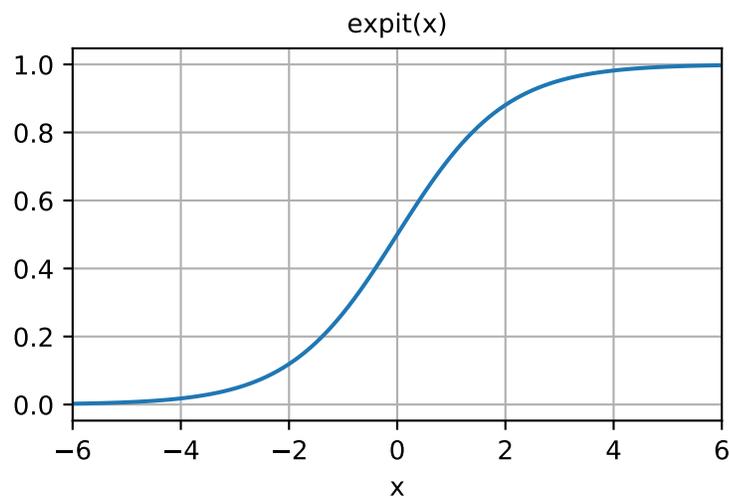
```
>>> expit([-np.inf, -1.5, 0, 1.5, np.inf])
array([ 0.          ,  0.18242552,  0.5          ,  0.81757448,  1.          ])
```

`logit` is the inverse of `expit`:

```
>>> logit(expit([-2.5, 0, 3.1, 5.0]))
array([-2.5,  0. ,  3.1,  5. ])
```

Plot `expit(x)` for `x` in `[-6, 6]`:

```
>>> import matplotlib.pyplot as plt
>>> x = np.linspace(-6, 6, 121)
>>> y = expit(x)
>>> plt.plot(x, y)
>>> plt.grid()
>>> plt.xlim(-6, 6)
>>> plt.xlabel('x')
>>> plt.title('expit(x)')
>>> plt.show()
```



`scipy.special.boxcox(x, lambda) = <ufunc 'boxcox'>`  
 Compute the Box-Cox transformation.

The Box-Cox transformation is:

```
y = (x**lmbda - 1) / lmbda  if lmbda != 0
    log(x)                  if lmbda == 0
```

Returns *nan* if  $x < 0$ . Returns *-inf* if  $x == 0$  and  $lmbda < 0$ .

**Parameters** **x** : array\_like  
Data to be transformed.  
**lmbda** : array\_like  
Power parameter of the Box-Cox transform.

**Returns** **y** : array  
Transformed data.

### Notes

New in version 0.14.0.

### Examples

```
>>> from scipy.special import boxcox
>>> boxcox([1, 4, 10], 2.5)
array([ 0.          , 12.4          , 126.09110641])
>>> boxcox(2, [0, 1, 2])
array([ 0.69314718, 1.          , 1.5          ])
```

`scipy.special.boxcox1p(x, lmbda) = <ufunc 'boxcox1p'>`  
Compute the Box-Cox transformation of  $1 + x$ .

The Box-Cox transformation computed by `boxcox1p` is:

```
y = ((1+x)**lmbda - 1) / lmbda  if lmbda != 0
    log(1+x)                    if lmbda == 0
```

Returns *nan* if  $x < -1$ . Returns *-inf* if  $x == -1$  and  $lmbda < 0$ .

**Parameters** **x** : array\_like  
Data to be transformed.  
**lmbda** : array\_like  
Power parameter of the Box-Cox transform.

**Returns** **y** : array  
Transformed data.

### Notes

New in version 0.14.0.

### Examples

```
>>> from scipy.special import boxcox1p
>>> boxcox1p(1e-4, [0, 0.5, 1])
array([ 9.99950003e-05,  9.99975001e-05,  1.00000000e-04])
>>> boxcox1p([0.01, 0.1], 0.25)
array([ 0.00996272,  0.09645476])
```

`scipy.special.inv_boxcox(y, lmbda) = <ufunc 'inv_boxcox'>`  
Compute the inverse of the Box-Cox transformation.

Find  $x$  such that:

```
y = (x**lmbda - 1) / lmbda if lmbda != 0
    log(x)                  if lmbda == 0
```

**Parameters** **y** : array\_like  
Data to be transformed.

**lmbda** : array\_like  
Power parameter of the Box-Cox transform.

**Returns** **x** : array  
Transformed data.

**Notes**

New in version 0.16.0.

**Examples**

```
>>> from scipy.special import boxcox, inv_boxcox
>>> y = boxcox([1, 4, 10], 2.5)
>>> inv_boxcox(y, 2.5)
array([1., 4., 10.]
```

`scipy.special.inv_boxcox1p(y, lmbda) = <ufunc 'inv_boxcox1p'>`  
Compute the inverse of the Box-Cox transformation.

Find  $x$  such that:

```
y = ((1+x)**lmbda - 1) / lmbda if lmbda != 0
    log(1+x)                  if lmbda == 0
```

**Parameters** **y** : array\_like  
Data to be transformed.

**lmbda** : array\_like  
Power parameter of the Box-Cox transform.

**Returns** **x** : array  
Transformed data.

**Notes**

New in version 0.16.0.

**Examples**

```
>>> from scipy.special import boxcox1p, inv_boxcox1p
>>> y = boxcox1p([1, 4, 10], 2.5)
>>> inv_boxcox1p(y, 2.5)
array([1., 4., 10.]
```

**Information Theory Functions**

<code>entr(x)</code>	Elementwise function for computing entropy.
<code>rel_entr(x, y)</code>	Elementwise function for computing relative entropy.
<code>kl_div(x, y)</code>	Elementwise function for computing Kullback-Leibler divergence.
<code>huber(delta, r)</code>	Huber loss function.

Continued on next page

Table 5.256 – continued from previous page

<code>pseudo_huber(delta, r)</code>	Pseudo-Huber loss function.
-------------------------------------	-----------------------------

`scipy.special.entr(x) = <ufunc 'entr'>`  
 Elementwise function for computing entropy.

$$\text{entr}(x) = \begin{cases} -x \log(x) & x > 0 \\ 0 & x = 0 \\ -\infty & \text{otherwise} \end{cases}$$

**Parameters** `x` : ndarray  
 Input array.

**Returns** `res` : ndarray  
 The value of the elementwise entropy function at the given points `x`.

**See also:**

`kl_div`, `rel_entr`

**Notes**

This function is concave.

New in version 0.15.0.

`scipy.special.rel_entr(x, y) = <ufunc 'rel_entr'>`  
 Elementwise function for computing relative entropy.

$$\text{rel_entr}(x, y) = \begin{cases} x \log(x/y) & x > 0, y > 0 \\ 0 & x = 0, y \geq 0 \\ \infty & \text{otherwise} \end{cases}$$

**Parameters** `x` : ndarray  
 First input array.

`y` : ndarray  
 Second input array.

**Returns** `res` : ndarray  
 Output array.

**See also:**

`entr`, `kl_div`

**Notes**

This function is jointly convex in `x` and `y`.

New in version 0.15.0.

`scipy.special.kl_div(x, y) = <ufunc 'kl_div'>`  
 Elementwise function for computing Kullback-Leibler divergence.

$$\text{kl_div}(x, y) = \begin{cases} x \log(x/y) - x + y & x > 0, y > 0 \\ y & x = 0, y \geq 0 \\ \infty & \text{otherwise} \end{cases}$$

**Parameters** `x` : ndarray  
 First input array.

`y` : ndarray

**Returns** **res** : ndarray Second input array.  
Output array.

**See also:**

*entr, rel\_entr*

**Notes**

This function is non-negative and is jointly convex in  $x$  and  $y$ .

New in version 0.15.0.

`scipy.special.huber` ( $\delta, r$ ) = <ufunc 'huber'>  
Huber loss function.

$$\text{huber}(\delta, r) = \begin{cases} \infty & \delta < 0 \\ \frac{1}{2}r^2 & 0 \leq \delta, |r| \leq \delta \\ \delta(|r| - \frac{1}{2}\delta) & \text{otherwise} \end{cases}$$

**Parameters** **delta** : ndarray Input array, indicating the quadratic vs. linear loss changepoint.  
**r** : ndarray Input array, possibly representing residuals.

**Returns** **res** : ndarray The computed Huber loss function values.

**Notes**

This function is convex in  $r$ .

New in version 0.15.0.

`scipy.special.pseudo_huber` ( $\delta, r$ ) = <ufunc 'pseudo\_huber'>  
Pseudo-Huber loss function.

$$\text{pseudo\_huber}(\delta, r) = \delta^2 \left( \sqrt{1 + \left(\frac{r}{\delta}\right)^2} - 1 \right)$$

**Parameters** **delta** : ndarray Input array, indicating the soft quadratic vs. linear loss changepoint.  
**r** : ndarray Input array, possibly representing residuals.

**Returns** **res** : ndarray The computed Pseudo-Huber loss function values.

**Notes**

This function is convex in  $r$ .

New in version 0.15.0.

**Gamma and Related Functions**

<i>gamma</i> (z)	Gamma function.
<i>gamma</i> ln(x, /[, out, where, casting, order, ...])	Logarithm of the absolute value of the Gamma function.
<i>loggamma</i> (z[, out])	Principal branch of the logarithm of the Gamma function.

Continued on next page

Table 5.257 – continued from previous page

<code>gammasgn(x)</code>	Sign of the gamma function.
<code>gammainc(a, x)</code>	Regularized lower incomplete gamma function.
<code>gammaincinv(a, y)</code>	Inverse to <code>gammainc</code>
<code>gammaincc(a, x)</code>	Regularized upper incomplete gamma function.
<code>gammainccinv(a, y)</code>	Inverse to <code>gammaincc</code>
<code>beta(a, b)</code>	Beta function.
<code>betaln(a, b)</code>	Natural logarithm of absolute value of beta function.
<code>betainc(a, b, x)</code>	Incomplete beta integral.
<code>betaincinv(a, b, y)</code>	Inverse function to beta integral.
<code>psi(z[, out])</code>	The digamma function.
<code>rgamma(z)</code>	Gamma function inverted
<code>polygamma(n, x)</code>	Polygamma function n.
<code>multigammaln(a, d)</code>	Returns the log of multivariate gamma, also sometimes called the generalized gamma.
<code>digamma(z[, out])</code>	The digamma function.
<code>poch(z, m)</code>	Rising factorial (z)_m

`scipy.special.gamma(z) = <ufunc 'gamma'>`  
 Gamma function.

$$\Gamma(z) = \int_0^{\infty} x^{z-1} e^{-x} dx = (z-1)!$$

The gamma function is often referred to as the generalized factorial since  $z \cdot \text{gamma}(z) = \text{gamma}(z+1)$  and  $\text{gamma}(n+1) = n!$  for natural number  $n$ .

**Parameters** `z`: float or complex array\_like  
**Returns** float or complex  
 The value(s) of `gamma(z)`

### Examples

```
>>> from scipy.special import gamma, factorial
```

```
>>> gamma([0, 0.5, 1, 5])
array([      inf,  1.77245385,  1.         ,  24.         ])
```

```
>>> z = 2.5 + 1j
>>> gamma(z)
(0.77476210455108352+0.70763120437959293j)
>>> gamma(z+1), z*gamma(z) # Recurrence property
((1.2292740569981171+2.5438401155000685j),
 (1.2292740569981158+2.5438401155000658j))
```

```
>>> gamma(0.5)**2 # gamma(0.5) = sqrt(pi)
3.1415926535897927
```

Plot `gamma(x)` for real `x`

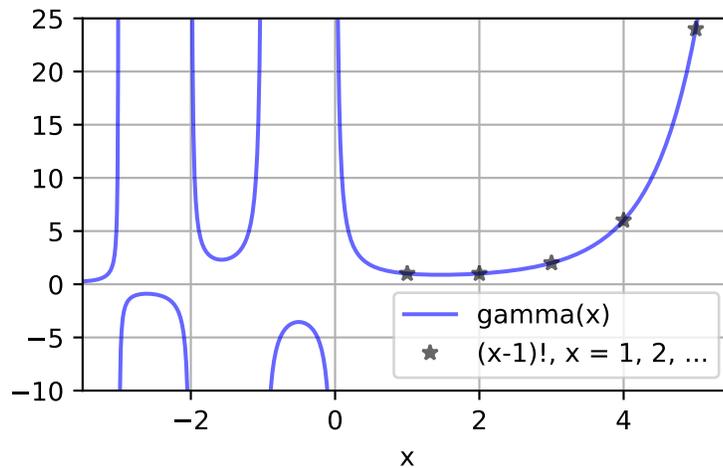
```
>>> x = np.linspace(-3.5, 5.5, 2251)
>>> y = gamma(x)
```

```
>>> import matplotlib.pyplot as plt
>>> plt.plot(x, y, 'b', alpha=0.6, label='gamma(x)')
```

```

>>> k = np.arange(1, 7)
>>> plt.plot(k, factorial(k-1), 'k*', alpha=0.6,
...         label='(x-1)!, x = 1, 2, ...')
>>> plt.xlim(-3.5, 5.5)
>>> plt.ylim(-10, 25)
>>> plt.grid()
>>> plt.xlabel('x')
>>> plt.legend(loc='lower right')
>>> plt.show()

```



`scipy.special.gammaln` (*x*, /, *out=None*, \*, *where=True*, *casting='same\_kind'*, *order='K'*, *dtype=None*, *subok=True*, [*signature*, *extobj*]) = <ufunc 'gammaln'>  
 Logarithm of the absolute value of the Gamma function.

**Parameters** *x*: array-like

**Returns** `gammaln`: ndarray  
 Values on the real line at which to compute `gammaln`  
 Values of `gammaln` at *x*.

**See also:**

`gamma` sign of the gamma function

`loggamma` principal branch of the logarithm of the gamma function

**Notes**

When used in conjunction with `gamma`, this function is useful for working in logspace on the real axis without having to deal with complex numbers, via the relation  $\exp(\text{gammaln}(x)) = \text{gamma}(x) * \text{gamma}(x)$ .

For complex-valued log-gamma, use `loggamma` instead of `gammaln`.

`scipy.special.loggamma` (*z*, *out=None*) = <ufunc 'loggamma'>

Principal branch of the logarithm of the Gamma function.

Defined to be  $\log(\Gamma(x))$  for  $x > 0$  and extended to the complex plane by analytic continuation. The function has a single branch cut on the negative real axis.

New in version 0.18.0.

**Parameters** *z*: array-like

Values in the complex plain at which to compute `loggamma`

**out** : ndarray, optional

**Returns** **loggamma** : ndarray  
 Output array for computed values of `loggamma`  
 Values of `loggamma` at `z`.

**See also:**

**gamma1n** logarithm of the absolute value of the Gamma function  
**gamma1sgn** sign of the gamma function

**Notes**

It is not generally true that  $\log \Gamma(z) = \log(\Gamma(z))$ , though the real parts of the functions do agree. The benefit of not defining `loggamma` as  $\log(\Gamma(z))$  is that the latter function has a complicated branch cut structure whereas `loggamma` is analytic except for on the negative real axis.

The identities

$$\begin{aligned} \exp(\log \Gamma(z)) &= \Gamma(z) \\ \log \Gamma(z + 1) &= \log(z) + \log \Gamma(z) \end{aligned}$$

make `loggamma` useful for working in complex logspace. However, `loggamma` necessarily returns complex outputs for real inputs, so if you want to work only with real numbers use `gamma1n`. On the real line the two functions are related by  $\exp(\loggamma(x)) = \text{gamma1sgn}(x) * \exp(\text{gamma1n}(x))$ , though in practice rounding errors will introduce small spurious imaginary components in  $\exp(\loggamma(x))$ .

The implementation here is based on [hare1997].

**References**

[hare1997]

`scipy.special.gamma1sgn(x)` = <ufunc 'gamma1sgn'>  
 Sign of the gamma function.

**See also:**

`gamma1n`, `loggamma`

`scipy.special.gammainc(a, x)` = <ufunc 'gammainc'>  
 Regularized lower incomplete gamma function.

Defined as

$$\frac{1}{\Gamma(a)} \int_0^x t^{a-1} e^{-t} dt$$

for  $a > 0$  and  $x \geq 0$ . The function satisfies the relation  $\text{gammainc}(a, x) + \text{gammaincc}(a, x) = 1$  where `gammaincc` is the regularized upper incomplete gamma function.

**See also:**

**gammaincc** regularized upper incomplete gamma function  
**gammaincinv**  
 inverse to `gammainc` versus `x`  
**gammainccinv**  
 inverse to `gammaincc` versus `x`

**Notes**

The implementation largely follows that of [R470].

**References***[R470]*`scipy.special.gammaincinv(a, y) = <ufunc 'gammaincinv'>`Inverse to *gammainc*Returns *x* such that `gammainc(a, x) = y`.`scipy.special.gammaincc(a, x) = <ufunc 'gammaincc'>`

Regularized upper incomplete gamma function.

Defined as

$$\frac{1}{\Gamma(a)} \int_x^{\infty} t^{a-1} e^{-t} dt$$

for  $a > 0$  and  $x \geq 0$ . The function satisfies the relation `gammainc(a, x) + gammaincc(a, x) = 1` where *gammainc* is the regularized lower incomplete gamma function.

**See also:****gammainc** regularized lower incomplete gamma function**gammaincinv**inverse to *gammainc* versus *x***gammainccinv**inverse to *gammaincc* versus *x***Notes**The implementation largely follows that of *[R471]*.**References***[R471]*`scipy.special.gammainccinv(a, y) = <ufunc 'gammainccinv'>`Inverse to *gammaincc*Returns *x* such that `gammaincc(a, x) == y`.`scipy.special.beta(a, b) = <ufunc 'beta'>`

Beta function.

$$\text{beta}(a, b) = \text{gamma}(a) * \text{gamma}(b) / \text{gamma}(a+b)$$

`scipy.special.betaln(a, b) = <ufunc 'betaln'>`

Natural logarithm of absolute value of beta function.

Computes `ln(abs(beta(a, b)))`.`scipy.special.betainc(a, b, x) = <ufunc 'betainc'>`

Incomplete beta integral.

Compute the incomplete beta integral of the arguments, evaluated from zero to *x*:

$$\text{gamma}(a+b) / (\text{gamma}(a) * \text{gamma}(b)) * \text{integral}(t^{a-1} (1-t)^{b-1}, t=0..x)$$

**Notes**

The incomplete beta is also sometimes defined without the terms in gamma, in which case the above definition is the so-called regularized incomplete beta. Under this definition, you can get the incomplete beta by multiplying the result of the scipy function by `beta(a, b)`.

`scipy.special.betaincinv(a, b, y) = <ufunc 'betaincinv'>`  
 Inverse function to beta integral.

Compute  $x$  such that  $\text{betainc}(a, b, x) = y$ .

`scipy.special.psi(z, out=None) = <ufunc 'psi'>`  
 The digamma function.

The logarithmic derivative of the gamma function evaluated at  $z$ .

**Parameters** `z` : array\_like  
 Real or complex argument.  
`out` : ndarray, optional  
 Array for the computed values of `psi`.  
**Returns** `digamma` : ndarray  
 Computed values of `psi`.

**Notes**

For large values not close to the negative real axis `psi` is computed using the asymptotic series (5.11.2) from [R562]. For small arguments not close to the negative real axis the recurrence relation (5.5.2) from [R562] is used until the argument is large enough to use the asymptotic series. For values close to the negative real axis the reflection formula (5.5.4) from [R562] is used first. Note that `psi` has a family of zeros on the negative real axis which occur between the poles at nonpositive integers. Around the zeros the reflection formula suffers from cancellation and the implementation loses precision. The sole positive zero and the first negative zero, however, are handled separately by precomputing series expansions using [R563], so the function should maintain full accuracy around the origin.

**References**

[R562], [R563]

`scipy.special.rgamma(z) = <ufunc 'rgamma'>`  
 Gamma function inverted

Returns  $1/\text{gamma}(x)$

`scipy.special.polygamma(n, x)`  
 Polygamma function  $n$ .

This is the  $n$ th derivative of the digamma (`psi`) function.

**Parameters** `n` : array\_like of int  
 The order of the derivative of `psi`.  
`x` : array\_like  
 Where to evaluate the polygamma function.  
**Returns** `polygamma` : ndarray  
 The result.

**Examples**

```
>>> from scipy import special
>>> x = [2, 3, 25.5]
>>> special.polygamma(1, x)
array([ 0.64493407,  0.39493407,  0.03999467])
>>> special.polygamma(0, x) == special.psi(x)
array([ True,  True,  True], dtype=bool)
```

`scipy.special.multigammaln(a, d)`  
 Returns the log of multivariate gamma, also sometimes called the generalized gamma.

**Parameters** `a` : ndarray

**Returns**

- d** : int The multivariate gamma is computed for each item of *a*.
- res** : ndarray The dimension of the space of integration.
- The values of the log multivariate gamma at the given points *a*.

**Notes**

The formal definition of the multivariate gamma of dimension *d* for a real *a* is

$$\Gamma_d(a) = \int_{A>0} e^{-tr(A)} |A|^{a-(d+1)/2} dA$$

with the condition  $a > (d - 1)/2$ , and  $A > 0$  being the set of all the positive definite matrices of dimension *d*. Note that *a* is a scalar: the integrand only is multivariate, the argument is not (the function is defined over a subset of the real set).

This can be proven to be equal to the much friendlier equation

$$\Gamma_d(a) = \pi^{d(d-1)/4} \prod_{i=1}^d \Gamma(a - (i - 1)/2).$$

**References**

R. J. Muirhead, Aspects of multivariate statistical theory (Wiley Series in probability and mathematical statistics).

`scipy.special.digamma` (*z*, *out=None*) = <ufunc 'psi'>

The digamma function.

The logarithmic derivative of the gamma function evaluated at *z*.

**Parameters**

- z** : array\_like Real or complex argument.
- out** : ndarray, optional

**Returns**

- digamma** : ndarray Array for the computed values of `psi`.
- Computed values of `psi`.

**Notes**

For large values not close to the negative real axis `psi` is computed using the asymptotic series (5.11.2) from [R441]. For small arguments not close to the negative real axis the recurrence relation (5.5.2) from [R441] is used until the argument is large enough to use the asymptotic series. For values close to the negative real axis the reflection formula (5.5.4) from [R441] is used first. Note that `psi` has a family of zeros on the negative real axis which occur between the poles at nonpositive integers. Around the zeros the reflection formula suffers from cancellation and the implementation loses precision. The sole positive zero and the first negative zero, however, are handled separately by precomputing series expansions using [R442], so the function should maintain full accuracy around the origin.

**References**

[R441], [R442]

`scipy.special.poch` (*z*, *m*) = <ufunc 'poch'>

Rising factorial (*z*)<sub>*m*</sub>

The Pochhammer symbol (rising factorial), is defined as

$$(z)_m = \frac{\Gamma(z + m)}{\Gamma(z)}$$

For positive integer  $m$  it reads

$$(z)_m = z(z + 1)\dots(z + m - 1)$$

**Parameters** **z** : array\_like  
(int or float)  
**m** : array\_like  
(int or float)

**Returns** **poch** : ndarray  
The value of the function.

## Error Function and Fresnel Integrals

<code>erf(z)</code>	Returns the error function of complex argument.
<code>erfc(x)</code>	Complementary error function, $1 - \text{erf}(x)$ .
<code>erfcx(x)</code>	Scaled complementary error function, $\exp(x^2) * \text{erfc}(x)$ .
<code>erfi(z)</code>	Imaginary error function, $-i \text{erf}(i z)$ .
<code>erfinv(y)</code>	Inverse function for erf.
<code>erfcinv(y)</code>	Inverse function for erfc.
<code>wofz(z)</code>	Faddeeva function
<code>dawson(x)</code>	Dawson's integral.
<code>fresnel(z)</code>	Fresnel sin and cos integrals
<code>fresnel_zeros(nt)</code>	Compute nt complex zeros of sine and cosine Fresnel integrals S(z) and C(z).
<code>modfresnelp(x)</code>	Modified Fresnel positive integrals
<code>modfresnelm(x)</code>	Modified Fresnel negative integrals

`scipy.special.erf(z) = <ufunc 'erf'>`

Returns the error function of complex argument.

It is defined as  $2/\sqrt{\pi} * \int_0^z \exp(-t^2) dt$ .

**Parameters** **x** : ndarray  
Input array.

**Returns** **res** : ndarray  
The values of the error function at the given points x.

**See also:**

`erfc`, `erfinv`, `erfcinv`, `wofz`, `erfcx`, `erfi`

**Notes**

The cumulative of the unit normal distribution is given by  $\Phi(z) = 1/2[1 + \text{erf}(z/\sqrt{2})]$ .

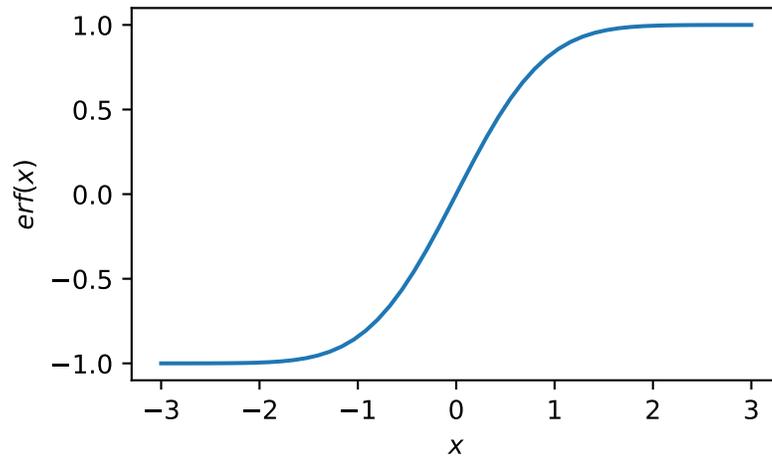
**References**

[R456], [R457], [R458]

**Examples**

```
>>> from scipy import special
>>> import matplotlib.pyplot as plt
>>> x = np.linspace(-3, 3)
>>> plt.plot(x, special.erf(x))
```

```
>>> plt.xlabel('$x$')
>>> plt.ylabel('$\text{erfc}(x)$')
>>> plt.show()
```



`scipy.special.erfc(x)` = <ufunc 'erfc'>  
Complementary error function,  $1 - \text{erf}(x)$ .

**See also:**

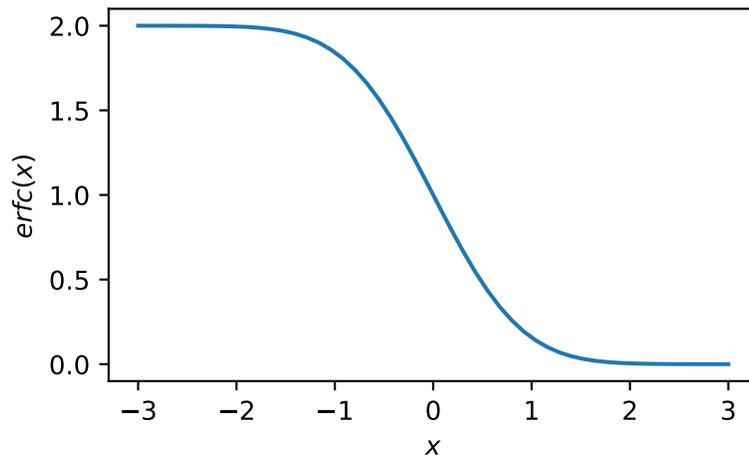
*erf, erfi, erfcx, dawson, wofz*

**References**

[R460]

**Examples**

```
>>> from scipy import special
>>> import matplotlib.pyplot as plt
>>> x = np.linspace(-3, 3)
>>> plt.plot(x, special.erfc(x))
>>> plt.xlabel('$x$')
>>> plt.ylabel('$\text{erfc}(x)$')
>>> plt.show()
```



`scipy.special.erfcx(x) = <ufunc 'erfcx'>`  
Scaled complementary error function,  $\exp(x**2) * \text{erfc}(x)$ .

**See also:**

*erf, erfc, erfi, dawson, wofz*

**Notes**

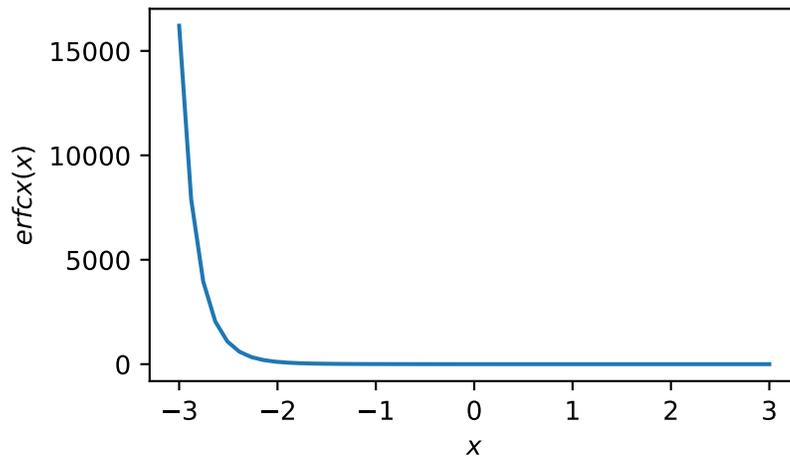
New in version 0.12.0.

**References**

[R461]

**Examples**

```
>>> from scipy import special
>>> import matplotlib.pyplot as plt
>>> x = np.linspace(-3, 3)
>>> plt.plot(x, special.erfcx(x))
>>> plt.xlabel('$x$')
>>> plt.ylabel('$\text{erfcx}(x)$')
>>> plt.show()
```



`scipy.special.erfi(z) = <ufunc 'erfi'>`  
Imaginary error function,  $-i \operatorname{erf}(i z)$ .

**See also:**

`erf`, `erfc`, `erfcx`, `dawsn`, `wofz`

**Notes**

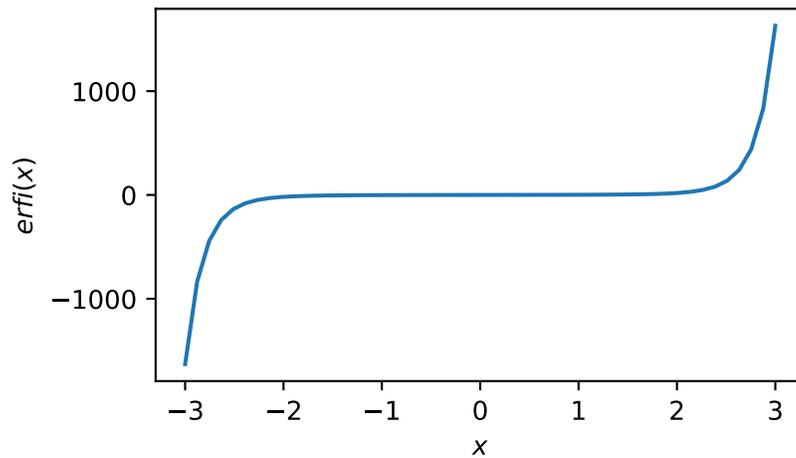
New in version 0.12.0.

**References**

[R462]

**Examples**

```
>>> from scipy import special
>>> import matplotlib.pyplot as plt
>>> x = np.linspace(-3, 3)
>>> plt.plot(x, special.erfi(x))
>>> plt.xlabel('$x$')
>>> plt.ylabel('$erfi(x)$')
>>> plt.show()
```



`scipy.special.erfinv`(y)  
Inverse function for erf.

`scipy.special.erfcinv`(y)  
Inverse function for erfc.

`scipy.special.wofz`(z) = <ufunc 'wofz'>  
Faddeeva function

Returns the value of the Faddeeva function for complex argument:

```
exp(-z**2) * erfc(-i*z)
```

**See also:**

*dawsn, erf, erfc, erfcx, erfi*

**References**

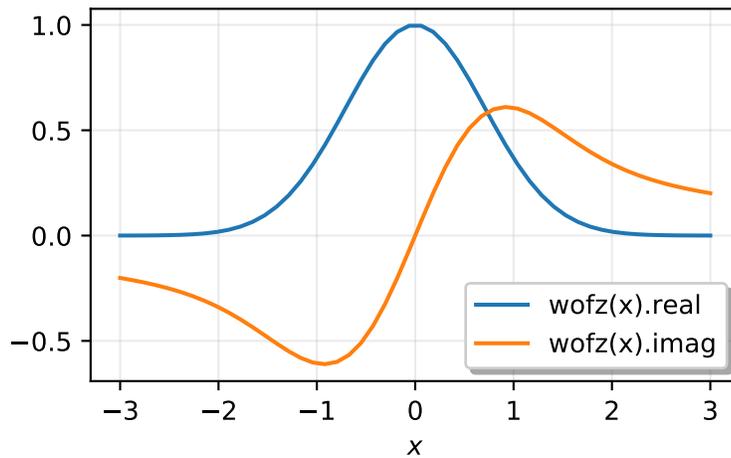
[R587]

**Examples**

```
>>> from scipy import special
>>> import matplotlib.pyplot as plt
```

```
>>> x = np.linspace(-3, 3)
>>> z = special.wofz(x)
```

```
>>> plt.plot(x, z.real, label='wofz(x).real')
>>> plt.plot(x, z.imag, label='wofz(x).imag')
>>> plt.xlabel('$x$')
>>> plt.legend(framealpha=1, shadow=True)
>>> plt.grid(alpha=0.25)
>>> plt.show()
```



`scipy.special.dawsn(x) = <ufunc 'dawsn'>`

Dawson's integral.

Computes:

```
exp(-x**2) * integral(exp(t**2), t=0..x).
```

**See also:**

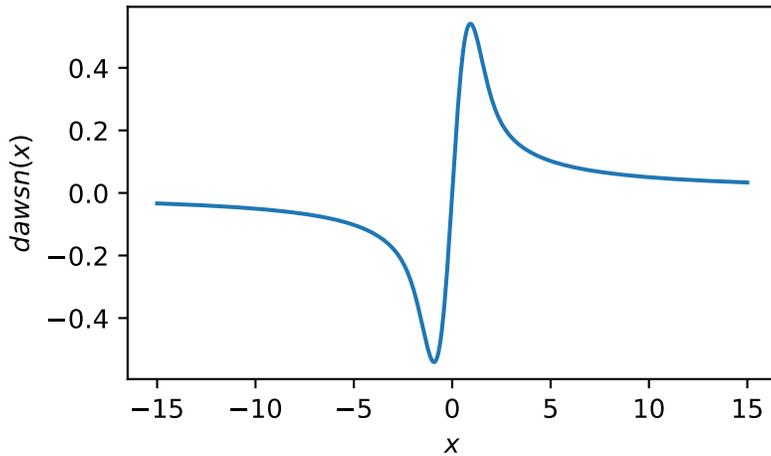
*wofz, erf, erfc, erfcx, erfi*

**References**

[R440]

**Examples**

```
>>> from scipy import special
>>> import matplotlib.pyplot as plt
>>> x = np.linspace(-15, 15, num=1000)
>>> plt.plot(x, special.dawsn(x))
>>> plt.xlabel('$x$')
>>> plt.ylabel('$dawsn(x)$')
>>> plt.show()
```



`scipy.special.fresnel(z) = <ufunc 'fresnel'>`

Fresnel sin and cos integrals

Defined as:

```
ssa = integral(sin(pi/2 * t**2), t=0..z)
csa = integral(cos(pi/2 * t**2), t=0..z)
```

**Parameters** **z** : float or complex array\_like  
Argument

**Returns** ssa, csa  
Fresnel sin and cos integral values

`scipy.special.fresnel_zeros(nt)`

Compute nt complex zeros of sine and cosine Fresnel integrals S(z) and C(z).

**References**

[R467]

`scipy.special.modfresnelp(x) = <ufunc 'modfresnelp'>`

Modified Fresnel positive integrals

**Returns** fp  
Integral  $F_+(x)$ :  $\text{integral}(\exp(1j*t*t), t=x..inf)$

kp  
Integral  $K_+(x)$ :  $1/\text{sqrt}(\pi) * \exp(-1j*(x*x+\pi/4)) * fp$

`scipy.special.modfresnelm(x) = <ufunc 'modfresnelm'>`

Modified Fresnel negative integrals

**Returns** fm  
Integral  $F_-(x)$ :  $\text{integral}(\exp(-1j*t*t), t=x..inf)$

km  
Integral  $K_-(x)$ :  $1/\text{sqrt}(\pi) * \exp(1j*(x*x+\pi/4)) * fp$

These are not universal functions:

Continued on next page

Table 5.259 – continued from previous page

<code>erf_zeros(nt)</code>	Compute <i>nt</i> complex zeros of error function erf( <i>z</i> ).
<code>fresnelc_zeros(nt)</code>	Compute <i>nt</i> complex zeros of cosine Fresnel integral C( <i>z</i> ).
<code>fresnels_zeros(nt)</code>	Compute <i>nt</i> complex zeros of sine Fresnel integral S( <i>z</i> ).

`scipy.special.erf_zeros` (*nt*)  
 Compute *nt* complex zeros of error function erf(*z*).

**References**

[R459]

`scipy.special.fresnelc_zeros` (*nt*)  
 Compute *nt* complex zeros of cosine Fresnel integral C(*z*).

**References**

[R468]

`scipy.special.fresnels_zeros` (*nt*)  
 Compute *nt* complex zeros of sine Fresnel integral S(*z*).

**References**

[R469]

**Legendre Functions**

<code>lpmv(m, v, x)</code>	Associated Legendre function of integer order and real degree.
<code>sph_harm(m, n, theta, phi)</code>	Compute spherical harmonics.

`scipy.special.lpmv` (*m*, *v*, *x*) = <ufunc 'lpmv'>  
 Associated Legendre function of integer order and real degree.

Defined as

$$P_v^m = (-1)^m (1 - x^2)^{m/2} \frac{d^m}{dx^m} P_v(x)$$

where

$$P_v = \sum_{k=0}^{\infty} \frac{(-v)_k (v+1)_k}{(k!)^2} \left( \frac{1-x}{2} \right)^k$$

is the Legendre function of the first kind. Here  $(\cdot)_k$  is the Pochhammer symbol; see `poch`.

**Parameters** **m** : array\_like

Order (int or float). If passed a float not equal to an integer the function returns NaN.

**v** : array\_like

Degree (float).

**x** : array\_likeArgument (float). Must have  $|x| \leq 1$ .**Returns****pmv** : ndarray

Value of the associated Legendre function.

**See also:**

- lpmn** Compute the associated Legendre function for all orders 0, ..., m and degrees 0, ..., n.
- clpmn** Compute the associated Legendre function at complex arguments.

**Notes**

Note that this implementation includes the Condon-Shortley phase.

**References**

[R538]

`scipy.special.sph_harm(m, n, theta, phi) = <ufunc 'sph_harm'>`

Compute spherical harmonics.

The spherical harmonics are defined as

$$Y_n^m(\theta, \phi) = \sqrt{\frac{2n+1}{4\pi} \frac{(n-m)!}{(n+m)!}} e^{im\theta} P_n^m(\cos(\phi))$$

where  $P_n^m$  are the associated Legendre functions; see *lpmv*.

- Parameters**
- m** : array\_like  
Order of the harmonic (int); must have  $|m| \leq n$ .
  - n** : array\_like  
Degree of the harmonic (int); must have  $n \geq 0$ . This is often denoted by  $l$  (lower case L) in descriptions of spherical harmonics.
  - theta** : array\_like  
Azimuthal (longitudinal) coordinate; must be in  $[0, 2\pi]$ .
  - phi** : array\_like  
Polar (colatitudinal) coordinate; must be in  $[0, \pi]$ .
- Returns**
- y\_mn** : complex float  
The harmonic  $Y_n^m$  sampled at `theta` and `phi`.

**Notes**

There are different conventions for the meanings of the input arguments `theta` and `phi`. In SciPy `theta` is the azimuthal angle and `phi` is the polar angle. It is common to see the opposite convention, that is, `theta` as the polar angle and `phi` as the azimuthal angle.

Note that SciPy's spherical harmonics include the Condon-Shortley phase [R575] because it is part of *lpmv*.

With SciPy's conventions, the first several spherical harmonics are

$$\begin{aligned}
 Y_0^0(\theta, \phi) &= \frac{1}{2} \sqrt{\frac{1}{\pi}} \\
 Y_1^{-1}(\theta, \phi) &= \frac{1}{2} \sqrt{\frac{3}{2\pi}} e^{-i\theta} \sin(\phi) \\
 Y_1^0(\theta, \phi) &= \frac{1}{2} \sqrt{\frac{3}{\pi}} \cos(\phi) \\
 Y_1^1(\theta, \phi) &= -\frac{1}{2} \sqrt{\frac{3}{2\pi}} e^{i\theta} \sin(\phi).
 \end{aligned}$$

**References**

[R574], [R575]

These are not universal functions:

<code>clpmn(m, n, z[, type])</code>	Associated Legendre function of the first kind for complex arguments.
<code>lpn(n, z)</code>	Legendre function of the first kind.
<code>lqn(n, z)</code>	Legendre function of the second kind.
<code>lpmn(m, n, z)</code>	Sequence of associated Legendre functions of the first kind.
<code>lqmn(m, n, z)</code>	Sequence of associated Legendre functions of the second kind.

`scipy.special.clpmn(m, n, z, type=3)`

Associated Legendre function of the first kind for complex arguments.

Computes the associated Legendre function of the first kind of order  $m$  and degree  $n$ ,  $P_{mn}(z) = P_n^m(z)$ , and its derivative,  $P_{mn}'(z)$ . Returns two arrays of size  $(m+1, n+1)$  containing  $P_{mn}(z)$  and  $P_{mn}'(z)$  for all orders from  $0 \dots m$  and degrees from  $0 \dots n$ .

**Parameters** **m** : int

$|m| \leq n$ ; the order of the Legendre function.

**n** : int

where  $n \geq 0$ ; the degree of the Legendre function. Often called  $l$  (lower case L) in descriptions of the associated Legendre function

**z** : float or complex

Input value.

**type** : int, optional

takes values 2 or 3 2: cut on the real axis  $|x| > 1$  3: cut on the real axis

**Returns** **Pmn\_z** :  $(m+1, n+1)$  array  $^{-1} \leq x \leq 1$  (default)

Values for all orders  $0 \dots m$  and degrees  $0 \dots n$

**Pmn\_d\_z** :  $(m+1, n+1)$  array

Derivatives for all orders  $0 \dots m$  and degrees  $0 \dots n$

**See also:**

**lpmn** associated Legendre functions of the first kind for real  $z$

**Notes**

By default, i.e. for `type=3`, phase conventions are chosen according to [R437] such that the function is analytic. The cut lies on the interval  $(-1, 1)$ . Approaching the cut from above or below in general yields a phase factor with respect to Ferrer's function of the first kind (cf. `lpmn`).

For `type=2` a cut at  $|x| > 1$  is chosen. Approaching the real values on the interval  $(-1, 1)$  in the complex plane yields Ferrer's function of the first kind.

**References**

[R437], [R438]

`scipy.special.lpn(n, z)`

Legendre function of the first kind.

Compute sequence of Legendre functions of the first kind (polynomials),  $P_n(z)$  and derivatives for all degrees from 0 to  $n$  (inclusive).

See also `special.legendre` for polynomial class.

**References**

[R539]

`scipy.special.lqgn` (*n*, *z*)

Legendre function of the second kind.

Compute sequence of Legendre functions of the second kind,  $Q_n(z)$  and derivatives for all degrees from 0 to *n* (inclusive).

**References**

[R541]

`scipy.special.lpmn` (*m*, *n*, *z*)

Sequence of associated Legendre functions of the first kind.

Computes the associated Legendre function of the first kind of order *m* and degree *n*,  $P_{mn}(z) = P_n^m(z)$ , and its derivative,  $P_{mn}'(z)$ . Returns two arrays of size (*m*+1, *n*+1) containing  $P_{mn}(z)$  and  $P_{mn}'(z)$  for all orders from 0..*m* and degrees from 0..*n*.

This function takes a real argument *z*. For complex arguments *z* use `clpmn` instead.

**Parameters**

**m** : int  
 |*m*| <= *n*; the order of the Legendre function.

**n** : int  
 where *n* >= 0; the degree of the Legendre function. Often called *l* (lower case L) in descriptions of the associated Legendre function

**z** : float

**Returns**

**Pmn\_z** : (*m*+1, *n*+1) array  
 Input value.  
 Values for all orders 0..*m* and degrees 0..*n*

**Pmn\_d\_z** : (*m*+1, *n*+1) array  
 Derivatives for all orders 0..*m* and degrees 0..*n*

**See also:**

**clpmn** associated Legendre functions of the first kind for complex *z*

**Notes**

In the interval (-1, 1), Ferrer's function of the first kind is returned. The phase convention used for the intervals (1, inf) and (-inf, -1) is such that the result is always real.

**References**

[R536], [R537]

`scipy.special.lqmn` (*m*, *n*, *z*)

Sequence of associated Legendre functions of the second kind.

Computes the associated Legendre function of the second kind of order *m* and degree *n*,  $Q_{mn}(z) = Q_n^m(z)$ , and its derivative,  $Q_{mn}'(z)$ . Returns two arrays of size (*m*+1, *n*+1) containing  $Q_{mn}(z)$  and  $Q_{mn}'(z)$  for all orders from 0..*m* and degrees from 0..*n*.

**Parameters**

**m** : int  
 |*m*| <= *n*; the order of the Legendre function.

**n** : int  
 where *n* >= 0; the degree of the Legendre function. Often called *l* (lower case L) in descriptions of the associated Legendre function

**z** : complex

**Returns**

**Qmn\_z** : (*m*+1, *n*+1) array  
 Input value.

Values for all orders 0..m and degrees 0..n  
**Qmn\_d\_z** : (m+1, n+1) array  
 Derivatives for all orders 0..m and degrees 0..n

### References

[R540]

## Ellipsoidal Harmonics

<code>ellip_harm(h2, k2, n, p, s[, signm, signn])</code>	Ellipsoidal harmonic functions $E^p_n(l)$
<code>ellip_harm_2(h2, k2, n, p, s)</code>	Ellipsoidal harmonic functions $F^p_n(l)$
<code>ellip_normal(h2, k2, n, p)</code>	Ellipsoidal harmonic normalization constants $\gamma^p_n$

`scipy.special.ellip_harm` (*h2, k2, n, p, s, signm=1, signn=1*)  
 Ellipsoidal harmonic functions  $E^p_n(l)$

These are also known as Lamé functions of the first kind, and are solutions to the Lamé equation:

$$(s^2 - h^2)(s^2 - k^2)E''(s) + s(2s^2 - h^2 - k^2)E'(s) + (a - qs^2)E(s) = 0$$

where  $q = (n + 1)n$  and  $a$  is the eigenvalue (not returned) corresponding to the solutions.

**Parameters**

- h2** : float  
h\*\*2
- k2** : float  
k\*\*2; should be larger than h\*\*2
- n** : int  
Degree
- s** : float  
Coordinate
- p** : int  
Order, can range between [1,2n+1]
- signm** : {1, -1}, optional  
Sign of prefactor of functions. Can be +/-1. See Notes.
- signn** : {1, -1}, optional  
Sign of prefactor of functions. Can be +/-1. See Notes.

**Returns**

- E** : float  
the harmonic  $E^p_n(s)$

### See also:

`ellip_harm_2`, `ellip_normal`

### Notes

The geometric interpretation of the ellipsoidal functions is explained in [R444], [R445], [R446]. The *signm* and *signn* arguments control the sign of prefactors for functions according to their type:

<pre>K : +1 L : signm M : signn N : signm*signn</pre>
---

New in version 0.15.0.

**References**

[R443], [R444], [R445], [R446]

**Examples**

```
>>> from scipy.special import ellip_harm
>>> w = ellip_harm(5, 8, 1, 1, 2.5)
>>> w
2.5
```

Check that the functions indeed are solutions to the Lamé equation:

```
>>> from scipy.interpolate import UnivariateSpline
>>> def eigenvalue(f, df, ddf):
...     r = ((s**2 - h**2)*(s**2 - k**2)*ddf + s*(2*s**2 - h**2 - k**2)*df -
->n*(n+1)*s**2*f)/f
...     return -r.mean(), r.std()
>>> s = np.linspace(0.1, 10, 200)
>>> k, h, n, p = 8.0, 2.2, 3, 2
>>> E = ellip_harm(h**2, k**2, n, p, s)
>>> E_spl = UnivariateSpline(s, E)
>>> a, a_err = eigenvalue(E_spl(s), E_spl(s,1), E_spl(s,2))
>>> a, a_err
(583.44366156701483, 6.4580890640310646e-11)
```

scipy.special.**ellip\_harm\_2** (*h2, k2, n, p, s*)

Ellipsoidal harmonic functions  $F^p_n(l)$

These are also known as Lamé functions of the second kind, and are solutions to the Lamé equation:

$$(s^2 - h^2)(s^2 - k^2)F''(s) + s(2s^2 - h^2 - k^2)F'(s) + (a - qs^2)F(s) = 0$$

where  $q = (n + 1)n$  and  $a$  is the eigenvalue (not returned) corresponding to the solutions.

<b>Parameters</b>	<b>h2</b> : float	$h^{*2}$
	<b>k2</b> : float	$k^{*2}$ ; should be larger than $h^{*2}$
	<b>n</b> : int	Degree.
	<b>p</b> : int	Order, can range between $[1, 2n+1]$ .
	<b>s</b> : float	Coordinate
<b>Returns</b>	<b>F</b> : float	The harmonic $F^p_n(s)$

**See also:**

*ellip\_harm, ellip\_normal*

**Notes**

Lamé functions of the second kind are related to the functions of the first kind:

$$F^p_n(s) = (2n + 1)E^p_n(s) \int_0^{1/s} \frac{du}{(E^p_n(1/u))^2 \sqrt{(1 - u^2k^2)(1 - u^2h^2)}}$$

New in version 0.15.0.

**Examples**

```
>>> from scipy.special import ellip_harm_2
>>> w = ellip_harm_2(5, 8, 2, 1, 10)
>>> w
0.00108056853382
```

`scipy.special.ellip_normal` (*h2*, *k2*, *n*, *p*)

Ellipsoidal harmonic normalization constants  $\gamma_n^p$

The normalization constant is defined as

$$\gamma_n^p = 8 \int_0^h dx \int_h^k dy \frac{(y^2 - x^2)(E_n^p(y)E_n^p(x))^2}{\sqrt{((k^2 - y^2)(y^2 - h^2)(h^2 - x^2)(k^2 - x^2))}}$$

**Parameters**

- h2** : float  
h\*\*2
- k2** : float  
k\*\*2; should be larger than h\*\*2
- n** : int  
Degree.
- p** : int  
Order, can range between [1,2n+1].

**Returns**

- gamma** : float  
The normalization constant  $\gamma_n^p$

**See also:**

`ellip_harm`, `ellip_harm_2`

**Notes**

New in version 0.15.0.

**Examples**

```
>>> from scipy.special import ellip_normal
>>> w = ellip_normal(5, 8, 3, 7)
>>> w
1723.38796997
```

**Orthogonal polynomials**

The following functions evaluate values of orthogonal polynomials:

<code>assoc_laguerre(x, n[, k])</code>	Compute the generalized (associated) Laguerre polynomial of degree <i>n</i> and order <i>k</i> .
<code>eval_legendre(n, x[, out])</code>	Evaluate Legendre polynomial at a point.
<code>eval_chebyt(n, x[, out])</code>	Evaluate Chebyshev polynomial of the first kind at a point.
<code>eval_chebyu(n, x[, out])</code>	Evaluate Chebyshev polynomial of the second kind at a point.
<code>eval_chebyc(n, x[, out])</code>	Evaluate Chebyshev polynomial of the first kind on [-2, 2] at a point.
<code>eval_chebys(n, x[, out])</code>	Evaluate Chebyshev polynomial of the second kind on [-2, 2] at a point.
<code>eval_jacobi(n, alpha, beta, x[, out])</code>	Evaluate Jacobi polynomial at a point.

Continued on next page

Table 5.263 – continued from previous page

<code>eval_laguerre(n, x[, out])</code>	Evaluate Laguerre polynomial at a point.
<code>eval_genlaguerre(n, alpha, x[, out])</code>	Evaluate generalized Laguerre polynomial at a point.
<code>eval_hermite(n, x[, out])</code>	Evaluate physicist's Hermite polynomial at a point.
<code>eval_hermitenorm(n, x[, out])</code>	Evaluate probabilist's (normalized) Hermite polynomial at a point.
<code>eval_gegenbauer(n, alpha, x[, out])</code>	Evaluate Gegenbauer polynomial at a point.
<code>eval_sh_legendre(n, x[, out])</code>	Evaluate shifted Legendre polynomial at a point.
<code>eval_sh_chebyt(n, x[, out])</code>	Evaluate shifted Chebyshev polynomial of the first kind at a point.
<code>eval_sh_chebyu(n, x[, out])</code>	Evaluate shifted Chebyshev polynomial of the second kind at a point.
<code>eval_sh_jacobi(n, p, q, x[, out])</code>	Evaluate shifted Jacobi polynomial at a point.

`scipy.special.assoc_laguerre(x, n, k=0.0)`

Compute the generalized (associated) Laguerre polynomial of degree  $n$  and order  $k$ .

The polynomial  $L_n^{(k)}(x)$  is orthogonal over  $[0, \infty)$ , with weighting function  $\exp(-x) * x^{**k}$  with  $k > -1$ .

**Notes**

`assoc_laguerre` is a simple wrapper around `eval_genlaguerre`, with reversed argument order  $(x, n, k=0.0) \rightarrow (n, k, x)$ .

`scipy.special.eval_legendre(n, x, out=None) = <ufunc 'eval_legendre'>`

Evaluate Legendre polynomial at a point.

The Legendre polynomials can be defined via the Gauss hypergeometric function  ${}_2F_1$  as

$$P_n(x) = {}_2F_1(-n, n + 1; 1; (1 - x)/2).$$

When  $n$  is an integer the result is a polynomial of degree  $n$ .

**Parameters** **n** : array\_like

Degree of the polynomial. If not an integer, the result is determined via the relation to the Gauss hypergeometric function.

**x** : array\_like

Points at which to evaluate the Legendre polynomial

**Returns**

**P** : ndarray

Values of the Legendre polynomial

See also:

**roots\_legendre**

roots and quadrature weights of Legendre polynomials

**legendre** Legendre polynomial object

**hyp2f1** Gauss hypergeometric function

**numpy.polynomial.legendre.Legendre**

Legendre series

`scipy.special.eval_chebyt(n, x, out=None) = <ufunc 'eval_chebyt'>`

Evaluate Chebyshev polynomial of the first kind at a point.

The Chebyshev polynomials of the first kind can be defined via the Gauss hypergeometric function  ${}_2F_1$  as

$$T_n(x) = {}_2F_1(n, -n; 1/2; (1 - x)/2).$$

When  $n$  is an integer the result is a polynomial of degree  $n$ .

**Parameters** **n** : array\_like  
Degree of the polynomial. If not an integer, the result is determined via the relation to the Gauss hypergeometric function.

**x** : array\_like  
Points at which to evaluate the Chebyshev polynomial

**Returns** **T** : ndarray  
Values of the Chebyshev polynomial

See also:

**roots\_chebyt**

roots and quadrature weights of Chebyshev polynomials of the first kind

**chebyu** Chebyshev polynomial object

**eval\_chebyu**

evaluate Chebyshev polynomials of the second kind

**hyp2f1** Gauss hypergeometric function

*numpy.polynomial.chebyshev.Chebyshev*

Chebyshev series

**Notes**

This routine is numerically stable for  $x$  in  $[-1, 1]$  at least up to order 10000.

`scipy.special.eval_chebyu(n, x, out=None) = <ufunc 'eval_chebyu'>`

Evaluate Chebyshev polynomial of the second kind at a point.

The Chebyshev polynomials of the second kind can be defined via the Gauss hypergeometric function  ${}_2F_1$  as

$$U_n(x) = (n+1) {}_2F_1(-n, n+2; 3/2; (1-x)/2).$$

When  $n$  is an integer the result is a polynomial of degree  $n$ .

**Parameters** **n** : array\_like  
Degree of the polynomial. If not an integer, the result is determined via the relation to the Gauss hypergeometric function.

**x** : array\_like  
Points at which to evaluate the Chebyshev polynomial

**Returns** **U** : ndarray  
Values of the Chebyshev polynomial

See also:

**roots\_chebyu**

roots and quadrature weights of Chebyshev polynomials of the second kind

**chebyu** Chebyshev polynomial object

**eval\_chebyt**

evaluate Chebyshev polynomials of the first kind

**hyp2f1** Gauss hypergeometric function

`scipy.special.eval_chebyc(n, x, out=None) = <ufunc 'eval_chebyc'>`

Evaluate Chebyshev polynomial of the first kind on  $[-2, 2]$  at a point.

These polynomials are defined as

$$S_n(x) = T_n(x/2)$$

where  $T_n$  is a Chebyshev polynomial of the first kind.

**Parameters** **n** : array\_like  
Degree of the polynomial. If not an integer, the result is determined via the relation to `eval_chebyt`.

**Returns** **x** : array\_like Points at which to evaluate the Chebyshev polynomial  
**C** : ndarray Values of the Chebyshev polynomial

See also:

**roots\_chebyc**

roots and quadrature weights of Chebyshev polynomials of the first kind on [-2, 2]

**chebyc** Chebyshev polynomial object

*numpy.polynomial.chebyshev.Chebyshev*

Chebyshev series

**eval\_chebyt**

evaluate Chebyshev polynomials of the first kind

`scipy.special.eval_chebys(n, x, out=None) = <ufunc 'eval_chebys'>`

Evaluate Chebyshev polynomial of the second kind on [-2, 2] at a point.

These polynomials are defined as

$$S_n(x) = U_n(x/2)$$

where  $U_n$  is a Chebyshev polynomial of the second kind.

**Parameters** **n** : array\_like

Degree of the polynomial. If not an integer, the result is determined via the relation to *eval\_chebyu*.

**x** : array\_like

**Returns**

**S** : ndarray

Points at which to evaluate the Chebyshev polynomial

Values of the Chebyshev polynomial

See also:

**roots\_chebys**

roots and quadrature weights of Chebyshev polynomials of the second kind on [-2, 2]

**chebys** Chebyshev polynomial object

**eval\_chebyu**

evaluate Chebyshev polynomials of the second kind

`scipy.special.eval_jacobi(n, alpha, beta, x, out=None) = <ufunc 'eval_jacobi'>`

Evaluate Jacobi polynomial at a point.

The Jacobi polynomials can be defined via the Gauss hypergeometric function  ${}_2F_1$  as

$$P_n^{(\alpha, \beta)}(x) = \frac{(\alpha + 1)_n}{\Gamma(n + 1)} {}_2F_1(-n, 1 + \alpha + \beta + n; \alpha + 1; (1 - z)/2)$$

where  $(\cdot)_n$  is the Pochhammer symbol; see *poch*. When  $n$  is an integer the result is a polynomial of degree  $n$ .

**Parameters** **n** : array\_like

Degree of the polynomial. If not an integer the result is determined via the relation to the Gauss hypergeometric function.

**alpha** : array\_like

Parameter

**beta** : array\_like

Parameter

**x** : array\_like

**Returns**

**P** : ndarray

Points at which to evaluate the polynomial

Values of the Jacobi polynomial

See also:

**roots\_jacobi** roots and quadrature weights of Jacobi polynomials  
**jacobi** Jacobi polynomial object  
**hyp2f1** Gauss hypergeometric function

`scipy.special.eval_laguerre` ( $n, x, out=None$ ) = <ufunc 'eval\_laguerre'>  
 Evaluate Laguerre polynomial at a point.

The Laguerre polynomials can be defined via the confluent hypergeometric function  ${}_1F_1$  as

$$L_n(x) = {}_1F_1(-n, 1, x).$$

When  $n$  is an integer the result is a polynomial of degree  $n$ .

**Parameters** **n** : array\_like  
 Degree of the polynomial. If not an integer the result is determined via the relation to the confluent hypergeometric function.  
**x** : array\_like  
 Points at which to evaluate the Laguerre polynomial  
**Returns** **L** : ndarray  
 Values of the Laguerre polynomial

See also:

**roots\_laguerre** roots and quadrature weights of Laguerre polynomials  
**laguerre** Laguerre polynomial object  
**numpy.polynomial.laguerre.Laguerre** Laguerre series  
**eval\_genlaguerre** evaluate generalized Laguerre polynomials

`scipy.special.eval_genlaguerre` ( $n, alpha, x, out=None$ ) = <ufunc 'eval\_genlaguerre'>  
 Evaluate generalized Laguerre polynomial at a point.

The generalized Laguerre polynomials can be defined via the confluent hypergeometric function  ${}_1F_1$  as

$$L_n^{(\alpha)}(x) = \binom{n+\alpha}{n} {}_1F_1(-n, \alpha+1, x).$$

When  $n$  is an integer the result is a polynomial of degree  $n$ . The Laguerre polynomials are the special case where  $\alpha = 0$ .

**Parameters** **n** : array\_like  
 Degree of the polynomial. If not an integer the result is determined via the relation to the confluent hypergeometric function.  
**alpha** : array\_like  
 Parameter; must have  $\alpha > -1$   
**x** : array\_like  
 Points at which to evaluate the generalized Laguerre polynomial  
**Returns** **L** : ndarray  
 Values of the generalized Laguerre polynomial

See also:

**roots\_genlaguerre** roots and quadrature weights of generalized Laguerre polynomials  
**genlaguerre** generalized Laguerre polynomial object

**hyp1f1** confluent hypergeometric function  
**eval\_laguerre**  
 evaluate Laguerre polynomials

`scipy.special.eval_hermite` (*n*, *x*, *out=None*) = <ufunc 'eval\_hermite'>  
 Evaluate physicist's Hermite polynomial at a point.

Defined by

$$H_n(x) = (-1)^n e^{x^2} \frac{d^n}{dx^n} e^{-x^2};$$

$H_n$  is a polynomial of degree  $n$ .

**Parameters**    **n** : array\_like                      Degree of the polynomial  
                   **x** : array\_like                      Points at which to evaluate the Hermite polynomial  
**Returns**        **H** : ndarray                                      Values of the Hermite polynomial

See also:

**roots\_hermite**  
 roots and quadrature weights of physicist's Hermite polynomials  
**hermite**        physicist's Hermite polynomial object  
[numpy.polynomial.hermite.Hermite](#)  
 Physicist's Hermite series  
**eval\_hermitenorm**  
 evaluate Probabilist's Hermite polynomials

`scipy.special.eval_hermitenorm` (*n*, *x*, *out=None*) = <ufunc 'eval\_hermitenorm'>  
 Evaluate probabilist's (normalized) Hermite polynomial at a point.

Defined by

$$He_n(x) = (-1)^n e^{x^2/2} \frac{d^n}{dx^n} e^{-x^2/2};$$

$He_n$  is a polynomial of degree  $n$ .

**Parameters**    **n** : array\_like                      Degree of the polynomial  
                   **x** : array\_like                      Points at which to evaluate the Hermite polynomial  
**Returns**        **He** : ndarray                                      Values of the Hermite polynomial

See also:

**roots\_hermitenorm**  
 roots and quadrature weights of probabilist's Hermite polynomials  
**hermitenorm**  
 probabilist's Hermite polynomial object  
[numpy.polynomial.hermite\\_e.HermiteE](#)  
 Probabilist's Hermite series  
**eval\_hermite**  
 evaluate physicist's Hermite polynomials

`scipy.special.eval_gegenbauer` (*n*, *alpha*, *x*, *out=None*) = <ufunc 'eval\_gegenbauer'>  
 Evaluate Gegenbauer polynomial at a point.

The Gegenbauer polynomials can be defined via the Gauss hypergeometric function  ${}_2F_1$  as

$$C_n^{(\alpha)} = \frac{(2\alpha)_n}{\Gamma(n+1)} {}_2F_1(-n, 2\alpha + n; \alpha + 1/2; (1-z)/2).$$

When  $n$  is an integer the result is a polynomial of degree  $n$ .

**Parameters** **n** : array\_like  
Degree of the polynomial. If not an integer, the result is determined via the relation to the Gauss hypergeometric function.

**alpha** : array\_like  
Parameter

**x** : array\_like  
Points at which to evaluate the Gegenbauer polynomial

**Returns** **C** : ndarray  
Values of the Gegenbauer polynomial

See also:

**roots\_gegenbauer**

roots and quadrature weights of Gegenbauer polynomials

**gegenbauer** Gegenbauer polynomial object

**hyp2f1** Gauss hypergeometric function

`scipy.special.eval_sh_legendre` ( $n, x, out=None$ ) = <ufunc 'eval\_sh\_legendre'>

Evaluate shifted Legendre polynomial at a point.

These polynomials are defined as

$$P_n^*(x) = P_n(2x - 1)$$

where  $P_n$  is a Legendre polynomial.

**Parameters** **n** : array\_like  
Degree of the polynomial. If not an integer, the value is determined via the relation to `eval_legendre`.

**x** : array\_like  
Points at which to evaluate the shifted Legendre polynomial

**Returns** **P** : ndarray  
Values of the shifted Legendre polynomial

See also:

**roots\_sh\_legendre**

roots and quadrature weights of shifted Legendre polynomials

**sh\_legendre**

shifted Legendre polynomial object

**eval\_legendre**

evaluate Legendre polynomials

**numpy.polynomial.legendre.Legendre**

Legendre series

`scipy.special.eval_sh_chebyt` ( $n, x, out=None$ ) = <ufunc 'eval\_sh\_chebyt'>

Evaluate shifted Chebyshev polynomial of the first kind at a point.

These polynomials are defined as

$$T_n^*(x) = T_n(2x - 1)$$

where  $T_n$  is a Chebyshev polynomial of the first kind.

**Parameters** **n** : array\_like

Degree of the polynomial. If not an integer, the result is determined via the relation to `eval_chebyt`.

**Returns** `x` : array\_like  
**T** : ndarray Points at which to evaluate the shifted Chebyshev polynomial  
Values of the shifted Chebyshev polynomial

See also:

**roots\_sh\_chebyt**

roots and quadrature weights of shifted Chebyshev polynomials of the first kind

**sh\_chebyt** shifted Chebyshev polynomial object

**eval\_chebyt**

evaluate Chebyshev polynomials of the first kind

*numpy.polynomial.chebyshev.Chebyshev*

Chebyshev series

`scipy.special.eval_sh_chebyu(n, x, out=None) = <ufunc 'eval_sh_chebyu'>`

Evaluate shifted Chebyshev polynomial of the second kind at a point.

These polynomials are defined as

$$U_n^*(x) = U_n(2x - 1)$$

where  $U_n$  is a Chebyshev polynomial of the first kind.

**Parameters** `n` : array\_like

Degree of the polynomial. If not an integer, the result is determined via the relation to `eval_chebyu`.

`x` : array\_like

**Returns** `U` : ndarray Points at which to evaluate the shifted Chebyshev polynomial  
Values of the shifted Chebyshev polynomial

See also:

**roots\_sh\_chebyu**

roots and quadrature weights of shifted Chebychev polynomials of the second kind

**sh\_chebyu** shifted Chebyshev polynomial object

**eval\_chebyu**

evaluate Chebyshev polynomials of the second kind

`scipy.special.eval_sh_jacobi(n, p, q, x, out=None) = <ufunc 'eval_sh_jacobi'>`

Evaluate shifted Jacobi polynomial at a point.

Defined by

$$G_n^{(p,q)}(x) = \binom{2n+p-1}{n}^{-1} P_n^{(p-q, q-1)}(2x-1),$$

where  $P_n^{(\cdot, \cdot)}$  is the n-th Jacobi polynomial.

**Parameters** `n` : int

Degree of the polynomial. If not an integer, the result is determined via the relation to `binom` and `eval_jacobi`.

`p` : float

Parameter

`q` : float

Parameter

**Returns** `G` : ndarray Values of the shifted Jacobi polynomial.

**See also:****roots\_sh\_jacobi**

roots and quadrature weights of shifted Jacobi polynomials

**sh\_jacobi** shifted Jacobi polynomial object**eval\_jacobi**

evaluate Jacobi polynomials

The following functions compute roots and quadrature weights for orthogonal polynomials:

<code>roots_legendre(n[, mu])</code>	Gauss-Legendre quadrature.
<code>roots_chebyt(n[, mu])</code>	Gauss-Chebyshev (first kind) quadrature.
<code>roots_chebyu(n[, mu])</code>	Gauss-Chebyshev (second kind) quadrature.
<code>roots_chebyc(n[, mu])</code>	Gauss-Chebyshev (first kind) quadrature.
<code>roots_chebys(n[, mu])</code>	Gauss-Chebyshev (second kind) quadrature.
<code>roots_jacobi(n, alpha, beta[, mu])</code>	Gauss-Jacobi quadrature.
<code>roots_laguerre(n[, mu])</code>	Gauss-Laguerre quadrature.
<code>roots_genlaguerre(n, alpha[, mu])</code>	Gauss-generalized Laguerre quadrature.
<code>roots_hermite(n[, mu])</code>	Gauss-Hermite (physicist's) quadrature.
<code>roots_hermitenorm(n[, mu])</code>	Gauss-Hermite (statistician's) quadrature.
<code>roots_gegenbauer(n, alpha[, mu])</code>	Gauss-Gegenbauer quadrature.
<code>roots_sh_legendre(n[, mu])</code>	Gauss-Legendre (shifted) quadrature.
<code>roots_sh_chebyt(n[, mu])</code>	Gauss-Chebyshev (first kind, shifted) quadrature.
<code>roots_sh_chebyu(n[, mu])</code>	Gauss-Chebyshev (second kind, shifted) quadrature.
<code>roots_sh_jacobi(n, p1, q1[, mu])</code>	Gauss-Jacobi (shifted) quadrature.

`scipy.special.roots_legendre` ( $n, mu=False$ )

Gauss-Legendre quadrature.

Computes the sample points and weights for Gauss-Legendre quadrature. The sample points are the roots of the  $n$ -th degree Legendre polynomial  $P_n(x)$ . These sample points and weights correctly integrate polynomials of degree  $2n - 1$  or less over the interval  $[-1, 1]$  with weight function  $f(x) = 1.0$ .

**Parameters**

- n** : int  
quadrature order
- mu** : bool, optional  
If True, return the sum of the weights, optional.

**Returns**

- x** : ndarray  
Sample points
- w** : ndarray  
Weights
- mu** : float  
Sum of the weights

**See also:**

`scipy.integrate.quadrature`, `scipy.integrate.fixed_quad`, `numpy.polynomial.legendre.leggauss`

`scipy.special.roots_chebyt` ( $n, mu=False$ )

Gauss-Chebyshev (first kind) quadrature.

Computes the sample points and weights for Gauss-Chebyshev quadrature. The sample points are the roots of the  $n$ -th degree Chebyshev polynomial of the first kind,  $T_n(x)$ . These sample points and weights correctly integrate polynomials of degree  $2n - 1$  or less over the interval  $[-1, 1]$  with weight function  $f(x) = 1/\sqrt{1 - x^2}$ .

**Parameters**

- n** : int  
quadrature order

**Returns**

<b>mu</b> : bool, optional	If True, return the sum of the weights, optional.
<b>x</b> : ndarray	Sample points
<b>w</b> : ndarray	Weights
<b>mu</b> : float	Sum of the weights

**See also:**

`scipy.integrate.quadrature`, `scipy.integrate.fixed_quad`, `numpy.polynomial.chebyshev.chebgauss`

`scipy.special.roots_chebyu` (*n*, *mu=False*)

Gauss-Chebyshev (second kind) quadrature.

Computes the sample points and weights for Gauss-Chebyshev quadrature. The sample points are the roots of the *n*-th degree Chebyshev polynomial of the second kind,  $U_n(x)$ . These sample points and weights correctly integrate polynomials of degree  $2n - 1$  or less over the interval  $[-1, 1]$  with weight function  $f(x) = \sqrt{1 - x^2}$ .

**Parameters**

<b>n</b> : int	quadrature order
<b>mu</b> : bool, optional	If True, return the sum of the weights, optional.

**Returns**

<b>x</b> : ndarray	Sample points
<b>w</b> : ndarray	Weights
<b>mu</b> : float	Sum of the weights

**See also:**

`scipy.integrate.quadrature`, `scipy.integrate.fixed_quad`

`scipy.special.roots_chebyc` (*n*, *mu=False*)

Gauss-Chebyshev (first kind) quadrature.

Computes the sample points and weights for Gauss-Chebyshev quadrature. The sample points are the roots of the *n*-th degree Chebyshev polynomial of the first kind,  $C_n(x)$ . These sample points and weights correctly integrate polynomials of degree  $2n - 1$  or less over the interval  $[-2, 2]$  with weight function  $f(x) = 1/\sqrt{1 - (x/2)^2}$ .

**Parameters**

<b>n</b> : int	quadrature order
<b>mu</b> : bool, optional	If True, return the sum of the weights, optional.

**Returns**

<b>x</b> : ndarray	Sample points
<b>w</b> : ndarray	Weights
<b>mu</b> : float	Sum of the weights

**See also:**

`scipy.integrate.quadrature`, `scipy.integrate.fixed_quad`

`scipy.special.roots_chebys` (*n*, *mu=False*)

Gauss-Chebyshev (second kind) quadrature.

Computes the sample points and weights for Gauss-Chebyshev quadrature. The sample points are the roots of the  $n$ -th degree Chebyshev polynomial of the second kind,  $S_n(x)$ . These sample points and weights correctly integrate polynomials of degree  $2n - 1$  or less over the interval  $[-2, 2]$  with weight function  $f(x) = \sqrt{1 - (x/2)^2}$ .

**Parameters**

- n** : int  
quadrature order
- mu** : bool, optional  
If True, return the sum of the weights, optional.

**Returns**

- x** : ndarray  
Sample points
- w** : ndarray  
Weights
- mu** : float  
Sum of the weights

**See also:**

`scipy.integrate.quadrature`, `scipy.integrate.fixed_quad`

`scipy.special.roots_jacobi` ( $n$ ,  $alpha$ ,  $beta$ ,  $mu=False$ )

Gauss-Jacobi quadrature.

Computes the sample points and weights for Gauss-Jacobi quadrature. The sample points are the roots of the  $n$ -th degree Jacobi polynomial,  $P_n^{\alpha, \beta}(x)$ . These sample points and weights correctly integrate polynomials of degree  $2n - 1$  or less over the interval  $[-1, 1]$  with weight function  $f(x) = (1 - x)^\alpha(1 + x)^\beta$ .

**Parameters**

- n** : int  
quadrature order
- alpha** : float  
alpha must be  $> -1$
- beta** : float  
beta must be  $> 0$
- mu** : bool, optional  
If True, return the sum of the weights, optional.

**Returns**

- x** : ndarray  
Sample points
- w** : ndarray  
Weights
- mu** : float  
Sum of the weights

**See also:**

`scipy.integrate.quadrature`, `scipy.integrate.fixed_quad`

`scipy.special.roots_laguerre` ( $n$ ,  $mu=False$ )

Gauss-Laguerre quadrature.

Computes the sample points and weights for Gauss-Laguerre quadrature. The sample points are the roots of the  $n$ -th degree Laguerre polynomial,  $L_n(x)$ . These sample points and weights correctly integrate polynomials of degree  $2n - 1$  or less over the interval  $[0, \infty]$  with weight function  $f(x) = e^{-x}$ .

**Parameters**

- n** : int  
quadrature order
- mu** : bool, optional  
If True, return the sum of the weights, optional.

**Returns**

- x** : ndarray  
Sample points
- w** : ndarray  
Weights
- mu** : float

Sum of the weights

**See also:**

`scipy.integrate.quadrature`, `scipy.integrate.fixed_quad`, `numpy.polynomial.laguerre.laggauss`

`scipy.special.roots_genlaguerre` (*n*, *alpha*, *mu=False*)

Gauss-generalized Laguerre quadrature.

Computes the sample points and weights for Gauss-generalized Laguerre quadrature. The sample points are the roots of the *n*-th degree generalized Laguerre polynomial,  $L_n^\alpha(x)$ . These sample points and weights correctly integrate polynomials of degree  $2n - 1$  or less over the interval  $[0, \infty]$  with weight function  $f(x) = x^\alpha e^{-x}$ .

<b>Parameters</b>	<b>n</b> : int	quadrature order
	<b>alpha</b> : float	alpha must be > -1
<b>Returns</b>	<b>mu</b> : bool, optional	If True, return the sum of the weights, optional.
	<b>x</b> : ndarray	Sample points
	<b>w</b> : ndarray	Weights
	<b>mu</b> : float	Sum of the weights

**See also:**

`scipy.integrate.quadrature`, `scipy.integrate.fixed_quad`

`scipy.special.roots_hermite` (*n*, *mu=False*)

Gauss-Hermite (physicst's) quadrature.

Computes the sample points and weights for Gauss-Hermite quadrature. The sample points are the roots of the *n*-th degree Hermite polynomial,  $H_n(x)$ . These sample points and weights correctly integrate polynomials of degree  $2n - 1$  or less over the interval  $[-\infty, \infty]$  with weight function  $f(x) = e^{-x^2}$ .

<b>Parameters</b>	<b>n</b> : int	quadrature order
	<b>mu</b> : bool, optional	If True, return the sum of the weights, optional.
<b>Returns</b>	<b>x</b> : ndarray	Sample points
	<b>w</b> : ndarray	Weights
	<b>mu</b> : float	Sum of the weights

**See also:**

`scipy.integrate.quadrature`, `scipy.integrate.fixed_quad`, `numpy.polynomial.hermite.hermgauss`, `roots_hermitenorm`

**Notes**

For small *n* up to 150 a modified version of the Golub-Welsch algorithm is used. Nodes are computed from the eigenvalue problem and improved by one step of a Newton iteration. The weights are computed from the well-known analytical formula.

For  $n$  larger than 150 an optimal asymptotic algorithm is applied which computes nodes and weights in a numerically stable manner. The algorithm has linear runtime making computation for very large  $n$  (several thousand or more) feasible.

### References

[townsend.trogdon.olver-2014], [townsend.trogdon.olver-2015]

`scipy.special.roots_hermitenorm` ( $n$ ,  $mu=False$ )

Gauss-Hermite (statistician's) quadrature.

Computes the sample points and weights for Gauss-Hermite quadrature. The sample points are the roots of the  $n$ -th degree Hermite polynomial,  $He_n(x)$ . These sample points and weights correctly integrate polynomials of degree  $2n - 1$  or less over the interval  $[-\infty, \infty]$  with weight function  $f(x) = e^{-x^2/2}$ .

<b>Parameters</b>	<b>n</b> : int	quadrature order
	<b>mu</b> : bool, optional	If True, return the sum of the weights, optional.
<b>Returns</b>	<b>x</b> : ndarray	Sample points
	<b>w</b> : ndarray	Weights
	<b>mu</b> : float	Sum of the weights

### See also:

`scipy.integrate.quadrature`, `scipy.integrate.fixed_quad`, `numpy.polynomial.hermite_e.hermegauss`

### Notes

For small  $n$  up to 150 a modified version of the Golub-Welsch algorithm is used. Nodes are computed from the eigenvalue problem and improved by one step of a Newton iteration. The weights are computed from the well-known analytical formula.

For  $n$  larger than 150 an optimal asymptotic algorithm is used which computes nodes and weights in a numerical stable manner. The algorithm has linear runtime making computation for very large  $n$  (several thousand or more) feasible.

`scipy.special.roots_gegenbauer` ( $n$ ,  $alpha$ ,  $mu=False$ )

Gauss-Gegenbauer quadrature.

Computes the sample points and weights for Gauss-Gegenbauer quadrature. The sample points are the roots of the  $n$ -th degree Gegenbauer polynomial,  $C_n^\alpha(x)$ . These sample points and weights correctly integrate polynomials of degree  $2n - 1$  or less over the interval  $[-1, 1]$  with weight function  $f(x) = (1 - x^2)^{\alpha-1/2}$ .

<b>Parameters</b>	<b>n</b> : int	quadrature order
	<b>alpha</b> : float	alpha must be > -0.5
<b>Returns</b>	<b>mu</b> : bool, optional	If True, return the sum of the weights, optional.
	<b>x</b> : ndarray	Sample points
	<b>w</b> : ndarray	Weights
	<b>mu</b> : float	Sum of the weights

**See also:**

`scipy.integrate.quadrature`, `scipy.integrate.fixed_quad`

`scipy.special.roots_sh_legendre` ( $n$ ,  $mu=False$ )

Gauss-Legendre (shifted) quadrature.

Computes the sample points and weights for Gauss-Legendre quadrature. The sample points are the roots of the  $n$ -th degree shifted Legendre polynomial  $P_n^*(x)$ . These sample points and weights correctly integrate polynomials of degree  $2n - 1$  or less over the interval  $[0, 1]$  with weight function  $f(x) = 1.0$ .

<b>Parameters</b>	<b>n</b> : int	quadrature order
	<b>mu</b> : bool, optional	If True, return the sum of the weights, optional.
<b>Returns</b>	<b>x</b> : ndarray	Sample points
	<b>w</b> : ndarray	Weights
	<b>mu</b> : float	Sum of the weights

**See also:**

`scipy.integrate.quadrature`, `scipy.integrate.fixed_quad`

`scipy.special.roots_sh_chebyt` ( $n$ ,  $mu=False$ )

Gauss-Chebyshev (first kind, shifted) quadrature.

Computes the sample points and weights for Gauss-Chebyshev quadrature. The sample points are the roots of the  $n$ -th degree shifted Chebyshev polynomial of the first kind,  $T_n(x)$ . These sample points and weights correctly integrate polynomials of degree  $2n - 1$  or less over the interval  $[0, 1]$  with weight function  $f(x) = 1/\sqrt{x - x^2}$ .

<b>Parameters</b>	<b>n</b> : int	quadrature order
	<b>mu</b> : bool, optional	If True, return the sum of the weights, optional.
<b>Returns</b>	<b>x</b> : ndarray	Sample points
	<b>w</b> : ndarray	Weights
	<b>mu</b> : float	Sum of the weights

**See also:**

`scipy.integrate.quadrature`, `scipy.integrate.fixed_quad`

`scipy.special.roots_sh_chebyu` ( $n$ ,  $mu=False$ )

Gauss-Chebyshev (second kind, shifted) quadrature.

Computes the sample points and weights for Gauss-Chebyshev quadrature. The sample points are the roots of the  $n$ -th degree shifted Chebyshev polynomial of the second kind,  $U_n(x)$ . These sample points and weights correctly integrate polynomials of degree  $2n - 1$  or less over the interval  $[0, 1]$  with weight function  $f(x) = \sqrt{x - x^2}$ .

<b>Parameters</b>	<b>n</b> : int	quadrature order
	<b>mu</b> : bool, optional	If True, return the sum of the weights, optional.
<b>Returns</b>	<b>x</b> : ndarray	Sample points
	<b>w</b> : ndarray	

**mu** : float  
Weights  
Sum of the weights

**See also:**

`scipy.integrate.quadrature`, `scipy.integrate.fixed_quad`

`scipy.special.roots_sh_jacobi` (*n*, *p1*, *q1*, *mu=False*)  
Gauss-Jacobi (shifted) quadrature.

Computes the sample points and weights for Gauss-Jacobi (shifted) quadrature. The sample points are the roots of the *n*-th degree shifted Jacobi polynomial,  $G_n^{p,q}(x)$ . These sample points and weights correctly integrate polynomials of degree  $2n - 1$  or less over the interval  $[0, 1]$  with weight function  $f(x) = (1 - x)^{p-q}x^{q-1}$

**Parameters**

- n** : int  
quadrature order
- p1** : float  
(p1 - q1) must be > -1
- q1** : float  
q1 must be > 0
- mu** : bool, optional  
If True, return the sum of the weights, optional.

**Returns**

- x** : ndarray  
Sample points
- w** : ndarray  
Weights
- mu** : float  
Sum of the weights

**See also:**

`scipy.integrate.quadrature`, `scipy.integrate.fixed_quad`

The functions below, in turn, return the polynomial coefficients in `orthopoly1d` objects, which function similarly as `numpy.poly1d`. The `orthopoly1d` class also has an attribute `weights` which returns the roots, weights, and total weights for the appropriate form of Gaussian quadrature. These are returned in an  $n \times 3$  array with roots in the first column, weights in the second column, and total weights in the final column. Note that `orthopoly1d` objects are converted to `poly1d` when doing arithmetic, and lose information of the original orthogonal polynomial.

<code>legendre</code> ( <i>n</i> [, <i>monic</i> ])	Legendre polynomial.
<code>chebyt</code> ( <i>n</i> [, <i>monic</i> ])	Chebyshev polynomial of the first kind.
<code>chebyu</code> ( <i>n</i> [, <i>monic</i> ])	Chebyshev polynomial of the second kind.
<code>chebyc</code> ( <i>n</i> [, <i>monic</i> ])	Chebyshev polynomial of the first kind on $[-2, 2]$ .
<code>chebys</code> ( <i>n</i> [, <i>monic</i> ])	Chebyshev polynomial of the second kind on $[-2, 2]$ .
<code>jacobi</code> ( <i>n</i> , <i>alpha</i> , <i>beta</i> [, <i>monic</i> ])	Jacobi polynomial.
<code>laguerre</code> ( <i>n</i> [, <i>monic</i> ])	Laguerre polynomial.
<code>genlaguerre</code> ( <i>n</i> , <i>alpha</i> [, <i>monic</i> ])	Generalized (associated) Laguerre polynomial.
<code>hermite</code> ( <i>n</i> [, <i>monic</i> ])	Physicist's Hermite polynomial.
<code>hermitenorm</code> ( <i>n</i> [, <i>monic</i> ])	Normalized (probabilist's) Hermite polynomial.
<code>gegenbauer</code> ( <i>n</i> , <i>alpha</i> [, <i>monic</i> ])	Gegenbauer (ultraspherical) polynomial.
<code>sh_legendre</code> ( <i>n</i> [, <i>monic</i> ])	Shifted Legendre polynomial.
<code>sh_chebyt</code> ( <i>n</i> [, <i>monic</i> ])	Shifted Chebyshev polynomial of the first kind.
<code>sh_chebyu</code> ( <i>n</i> [, <i>monic</i> ])	Shifted Chebyshev polynomial of the second kind.
<code>sh_jacobi</code> ( <i>n</i> , <i>p</i> , <i>q</i> [, <i>monic</i> ])	Shifted Jacobi polynomial.

`scipy.special.legendre` (*n*, *monic=False*)

Legendre polynomial.

Defined to be the solution of

$$\frac{d}{dx} \left[ (1 - x^2) \frac{d}{dx} P_n(x) \right] + n(n + 1)P_n(x) = 0;$$

$P_n(x)$  is a polynomial of degree  $n$ .

**Parameters** **n** : int  
Degree of the polynomial.  
**monic** : bool, optional  
If *True*, scale the leading coefficient to be 1. Default is *False*.

**Returns** **P** : orthopoly1d  
Legendre polynomial.

**Notes**

The polynomials  $P_n$  are orthogonal over  $[-1, 1]$  with weight function 1.

**Examples**

Generate the 3rd-order Legendre polynomial  $1/2*(5x^3 + 0x^2 - 3x + 0)$ :

```
>>> from scipy.special import legendre
>>> legendre(3)
poly1d([ 2.5,  0. , -1.5,  0. ])
```

`scipy.special.chebyt` ( $n$ , *monic=False*)

Chebyshev polynomial of the first kind.

Defined to be the solution of

$$(1 - x^2) \frac{d^2}{dx^2} T_n - x \frac{d}{dx} T_n + n^2 T_n = 0;$$

$T_n$  is a polynomial of degree  $n$ .

**Parameters** **n** : int  
Degree of the polynomial.  
**monic** : bool, optional  
If *True*, scale the leading coefficient to be 1. Default is *False*.

**Returns** **T** : orthopoly1d  
Chebyshev polynomial of the first kind.

**See also:**

**chebyu** Chebyshev polynomial of the second kind.

**Notes**

The polynomials  $T_n$  are orthogonal over  $[-1, 1]$  with weight function  $(1 - x^2)^{-1/2}$ .

`scipy.special.chebyu` ( $n$ , *monic=False*)

Chebyshev polynomial of the second kind.

Defined to be the solution of

$$(1 - x^2) \frac{d^2}{dx^2} U_n - 3x \frac{d}{dx} U_n + n(n + 2)U_n = 0;$$

$U_n$  is a polynomial of degree  $n$ .

**Parameters** **n** : int

**Returns** **U** : orthopoly1d  
 Degree of the polynomial.  
**monic** : bool, optional  
 If *True*, scale the leading coefficient to be 1. Default is *False*.  
 Chebyshev polynomial of the second kind.

**See also:**

**chebyt** Chebyshev polynomial of the first kind.

**Notes**

The polynomials  $U_n$  are orthogonal over  $[-1, 1]$  with weight function  $(1 - x^2)^{1/2}$ .

`scipy.special.chebyc` ( $n$ , *monic=False*)  
 Chebyshev polynomial of the first kind on  $[-2, 2]$ .

Defined as  $C_n(x) = 2T_n(x/2)$ , where  $T_n$  is the  $n$ th Chebychev polynomial of the first kind.

**Parameters** **n** : int  
 Degree of the polynomial.  
**monic** : bool, optional  
 If *True*, scale the leading coefficient to be 1. Default is *False*.  
**Returns** **C** : orthopoly1d  
 Chebyshev polynomial of the first kind on  $[-2, 2]$ .

**See also:**

**chebyt** Chebyshev polynomial of the first kind.

**Notes**

The polynomials  $C_n(x)$  are orthogonal over  $[-2, 2]$  with weight function  $1/\sqrt{1 - (x/2)^2}$ .

**References**

[R435]

`scipy.special.chebys` ( $n$ , *monic=False*)  
 Chebyshev polynomial of the second kind on  $[-2, 2]$ .

Defined as  $S_n(x) = U_n(x/2)$  where  $U_n$  is the  $n$ th Chebychev polynomial of the second kind.

**Parameters** **n** : int  
 Degree of the polynomial.  
**monic** : bool, optional  
 If *True*, scale the leading coefficient to be 1. Default is *False*.  
**Returns** **S** : orthopoly1d  
 Chebyshev polynomial of the second kind on  $[-2, 2]$ .

**See also:**

**chebyu** Chebyshev polynomial of the second kind

**Notes**

The polynomials  $S_n(x)$  are orthogonal over  $[-2, 2]$  with weight function  $\sqrt{1 - (x/2)^2}$ .

**References**

[R436]

`scipy.special.jacobi` (*n*, *alpha*, *beta*, *monic=False*)

Jacobi polynomial.

Defined to be the solution of

$$(1-x^2)\frac{d^2}{dx^2}P_n^{(\alpha,\beta)} + (\beta - \alpha - (\alpha + \beta + 2)x)\frac{d}{dx}P_n^{(\alpha,\beta)} + n(n + \alpha + \beta + 1)P_n^{(\alpha,\beta)} = 0$$

for  $\alpha, \beta > -1$ ;  $P_n^{(\alpha,\beta)}$  is a polynomial of degree  $n$ .

**Parameters**

- n** : int  
Degree of the polynomial.
- alpha** : float  
Parameter, must be greater than -1.
- beta** : float  
Parameter, must be greater than -1.
- monic** : bool, optional  
If *True*, scale the leading coefficient to be 1. Default is *False*.

**Returns**

**P** : orthopoly1d  
Jacobi polynomial.

**Notes**

For fixed  $\alpha, \beta$ , the polynomials  $P_n^{(\alpha,\beta)}$  are orthogonal over  $[-1, 1]$  with weight function  $(1-x)^\alpha(1+x)^\beta$ .

`scipy.special.laguerre` (*n*, *monic=False*)

Laguerre polynomial.

Defined to be the solution of

$$x\frac{d^2}{dx^2}L_n + (1-x)\frac{d}{dx}L_n + nL_n = 0;$$

$L_n$  is a polynomial of degree  $n$ .

**Parameters**

- n** : int  
Degree of the polynomial.
- monic** : bool, optional  
If *True*, scale the leading coefficient to be 1. Default is *False*.

**Returns**

**L** : orthopoly1d  
Laguerre Polynomial.

**Notes**

The polynomials  $L_n$  are orthogonal over  $[0, \infty)$  with weight function  $e^{-x}$ .

`scipy.special.genlaguerre` (*n*, *alpha*, *monic=False*)

Generalized (associated) Laguerre polynomial.

Defined to be the solution of

$$x\frac{d^2}{dx^2}L_n^{(\alpha)} + (\alpha + 1 - x)\frac{d}{dx}L_n^{(\alpha)} + nL_n^{(\alpha)} = 0,$$

where  $\alpha > -1$ ;  $L_n^{(\alpha)}$  is a polynomial of degree  $n$ .

**Parameters**

- n** : int  
Degree of the polynomial.
- alpha** : float  
Parameter, must be greater than -1.
- monic** : bool, optional  
If *True*, scale the leading coefficient to be 1. Default is *False*.

**Returns**

**L** : orthopoly1d

Generalized Laguerre polynomial.

**See also:**

**laguerre** Laguerre polynomial.

**Notes**

For fixed  $\alpha$ , the polynomials  $L_n^{(\alpha)}$  are orthogonal over  $[0, \infty)$  with weight function  $e^{-x}x^\alpha$ .

The Laguerre polynomials are the special case where  $\alpha = 0$ .

`scipy.special.hermite` ( $n$ , *monic=False*)

Physicist's Hermite polynomial.

Defined by

$$H_n(x) = (-1)^n e^{x^2} \frac{d^n}{dx^n} e^{-x^2};$$

$H_n$  is a polynomial of degree  $n$ .

**Parameters** **n** : int

Degree of the polynomial.

**monic** : bool, optional

**Returns** **H** : orthopoly1d If *True*, scale the leading coefficient to be 1. Default is *False*.  
Hermite polynomial.

**Notes**

The polynomials  $H_n$  are orthogonal over  $(-\infty, \infty)$  with weight function  $e^{-x^2}$ .

`scipy.special.hermite` ( $n$ , *monic=False*)

Normalized (probabilist's) Hermite polynomial.

Defined by

$$He_n(x) = (-1)^n e^{x^2/2} \frac{d^n}{dx^n} e^{-x^2/2};$$

$He_n$  is a polynomial of degree  $n$ .

**Parameters** **n** : int

Degree of the polynomial.

**monic** : bool, optional

**Returns** **He** : orthopoly1d If *True*, scale the leading coefficient to be 1. Default is *False*.  
Hermite polynomial.

**Notes**

The polynomials  $He_n$  are orthogonal over  $(-\infty, \infty)$  with weight function  $e^{-x^2/2}$ .

`scipy.special.gegenbauer` ( $n$ , *alpha*, *monic=False*)

Gegenbauer (ultraspherical) polynomial.

Defined to be the solution of

$$(1-x^2) \frac{d^2}{dx^2} C_n^{(\alpha)} - (2\alpha+1)x \frac{d}{dx} C_n^{(\alpha)} + n(n+2\alpha) C_n^{(\alpha)} = 0$$

for  $\alpha > -1/2$ ;  $C_n^{(\alpha)}$  is a polynomial of degree  $n$ .

**Parameters** **n** : int

**Returns** **C** : orthopoly1d  
 Degree of the polynomial.  
**monic** : bool, optional  
 If *True*, scale the leading coefficient to be 1. Default is *False*.  
 Gegenbauer polynomial.

**Notes**

The polynomials  $C_n^{(\alpha)}$  are orthogonal over  $[-1, 1]$  with weight function  $(1 - x^2)^{(\alpha-1/2)}$ .

`scipy.special.sh_legendre` (*n*, *monic=False*)  
 Shifted Legendre polynomial.

Defined as  $P_n^*(x) = P_n(2x - 1)$  for  $P_n$  the *n*th Legendre polynomial.

**Parameters** **n** : int  
 Degree of the polynomial.  
**monic** : bool, optional  
 If *True*, scale the leading coefficient to be 1. Default is *False*.  
**Returns** **P** : orthopoly1d  
 Shifted Legendre polynomial.

**Notes**

The polynomials  $P_n^*$  are orthogonal over  $[0, 1]$  with weight function 1.

`scipy.special.sh_chebyt` (*n*, *monic=False*)  
 Shifted Chebyshev polynomial of the first kind.

Defined as  $T_n^*(x) = T_n(2x - 1)$  for  $T_n$  the *n*th Chebyshev polynomial of the first kind.

**Parameters** **n** : int  
 Degree of the polynomial.  
**monic** : bool, optional  
 If *True*, scale the leading coefficient to be 1. Default is *False*.  
**Returns** **T** : orthopoly1d  
 Shifted Chebyshev polynomial of the first kind.

**Notes**

The polynomials  $T_n^*$  are orthogonal over  $[0, 1]$  with weight function  $(x - x^2)^{-1/2}$ .

`scipy.special.sh_chebyu` (*n*, *monic=False*)  
 Shifted Chebyshev polynomial of the second kind.

Defined as  $U_n^*(x) = U_n(2x - 1)$  for  $U_n$  the *n*th Chebyshev polynomial of the second kind.

**Parameters** **n** : int  
 Degree of the polynomial.  
**monic** : bool, optional  
 If *True*, scale the leading coefficient to be 1. Default is *False*.  
**Returns** **U** : orthopoly1d  
 Shifted Chebyshev polynomial of the second kind.

**Notes**

The polynomials  $U_n^*$  are orthogonal over  $[0, 1]$  with weight function  $(x - x^2)^{1/2}$ .

`scipy.special.sh_jacobi` (*n*, *p*, *q*, *monic=False*)  
 Shifted Jacobi polynomial.

Defined by

$$G_n^{(p,q)}(x) = \binom{2n+p-1}{n}^{-1} P_n^{(p-q, q-1)}(2x-1),$$

where  $P_n^{(\cdot, \cdot)}$  is the  $n$ th Jacobi polynomial.

**Parameters**

- n** : int  
Degree of the polynomial.
- p** : float  
Parameter, must have  $p > q - 1$ .
- q** : float  
Parameter, must be greater than 0.
- monic** : bool, optional  
If *True*, scale the leading coefficient to be 1. Default is *False*.

**Returns**

- G** : orthopoly1d  
Shifted Jacobi polynomial.

#### Notes

For fixed  $p, q$ , the polynomials  $G_n^{(p,q)}$  are orthogonal over  $[0, 1]$  with weight function  $(1-x)^{p-q}x^{q-1}$ .

**Warning:** Computing values of high-order polynomials (around `order > 20`) using polynomial coefficients is numerically unstable. To evaluate polynomial values, the `eval_*` functions should be used instead.

## Hypergeometric Functions

<code>hyp2f1(a, b, c, z)</code>	Gauss hypergeometric function 2F1(a, b; c; z)
<code>hyp1f1(a, b, x)</code>	Confluent hypergeometric function 1F1(a, b; x)
<code>hyperu(a, b, x)</code>	Confluent hypergeometric function U(a, b, x) of the second kind
<code>hyp0f1(v, x)</code>	Confluent hypergeometric limit function 0F1.
<code>hyp2f0(a, b, x, type)</code>	Hypergeometric function 2F0 in y and an error estimate
<code>hyp1f2(a, b, c, x)</code>	Hypergeometric function 1F2 and error estimate
<code>hyp3f0(a, b, c, x)</code>	Hypergeometric function 3F0 in y and an error estimate

`scipy.special.hyp2f1(a, b, c, z) = <ufunc 'hyp2f1'>`

Gauss hypergeometric function 2F1(a, b; c; z)

**Parameters**

- a, b, c** : array\_like  
Arguments, should be real-valued.
- z** : array\_like  
Argument, real or complex.

**Returns**

- hyp2f1** : scalar or ndarray  
The values of the gaussian hypergeometric function.

**See also:**

**hyp0f1** confluent hypergeometric limit function.  
**hyp1f1** Kummer's (confluent hypergeometric) function.

**Notes**

This function is defined for  $|z| < 1$  as

$$\text{hyp2f1}(a, b, c, z) = \sum_{n=0}^{\infty} \frac{(a)_n (b)_n}{(c)_n} \frac{z^n}{n!},$$

and defined on the rest of the complex  $z$ -plane by analytic continuation. Here  $(\cdot)_n$  is the Pochhammer symbol; see *poch*. When  $n$  is an integer the result is a polynomial of degree  $n$ .

The implementation for complex values of  $z$  is described in [R488].

**References**

[R488], [R489], [R490]

`scipy.special.hyp1f1(a, b, x) = <ufunc 'hyp1f1'>`  
 Confluent hypergeometric function 1F1(a, b; x)

`scipy.special.hyperu(a, b, x) = <ufunc 'hyperu'>`  
 Confluent hypergeometric function U(a, b, x) of the second kind

`scipy.special.hyp0f1(v, x) = <ufunc 'hyp0f1'>`  
 Confluent hypergeometric limit function 0F1.

**Parameters** `v, z` : array\_like  
 Input values.  
**Returns** `hyp0f1` : ndarray  
 The confluent hypergeometric limit function.

**Notes**

This function is defined as:

$${}_0F_1(v, z) = \sum_{k=0}^{\infty} \frac{z^k}{(v)_k k!}.$$

It's also the limit as  $q \rightarrow \infty$  of  ${}_1F_1(q; v; z/q)$ , and satisfies the differential equation  $f''(z) + v f'(z) = f(z)$ .

`scipy.special.hyp2f0(a, b, x, type) = <ufunc 'hyp2f0'>`  
 Hypergeometric function 2F0 in  $y$  and an error estimate

The parameter *type* determines a convergence factor and can be either 1 or 2.

**Returns** `y` Value of the function  
`err` Error estimate

`scipy.special.hyp1f2(a, b, c, x) = <ufunc 'hyp1f2'>`  
 Hypergeometric function 1F2 and error estimate

**Returns** `y` Value of the function  
`err` Error estimate

`scipy.special.hyp3f0(a, b, c, x) = <ufunc 'hyp3f0'>`  
 Hypergeometric function 3F0 in  $y$  and an error estimate

**Returns** `y` Value of the function  
`err` Error estimate

## Parabolic Cylinder Functions

<code>pbdv(v, x)</code>	Parabolic cylinder function D
<code>pbvv(v, x)</code>	Parabolic cylinder function V
<code>pbwa(a, x)</code>	Parabolic cylinder function W.

`scipy.special.pbdv(v, x) = <ufunc 'pbdv'>`

Parabolic cylinder function D

Returns (d, dp) the parabolic cylinder function  $Dv(x)$  in d and the derivative,  $Dv'(x)$  in dp.

**Returns**

d	Value of the function
dp	Value of the derivative vs x

`scipy.special.pbvv(v, x) = <ufunc 'pbvv'>`

Parabolic cylinder function V

Returns the parabolic cylinder function  $Vv(x)$  in v and the derivative,  $Vv'(x)$  in vp.

**Returns**

v	Value of the function
vp	Value of the derivative vs x

`scipy.special.pbwa(a, x) = <ufunc 'pbwa'>`

Parabolic cylinder function W.

The function is a particular solution to the differential equation

$$y'' + \left(\frac{1}{4}x^2 - a\right)y = 0,$$

for a full definition see section 12.14 in [R559].

**Parameters**

<b>a</b> : array_like	Real parameter
<b>x</b> : array_like	Real argument

**Returns**

<b>w</b> : scalar or ndarray	Value of the function
<b>wp</b> : scalar or ndarray	Value of the derivative in x

### Notes

The function is a wrapper for a Fortran routine by Zhang and Jin [R560]. The implementation is accurate only for  $|a|, |x| < 5$  and returns NaN outside that range.

### References

[R559], [R560]

These are not universal functions:

<code>pbdv_seq(v, x)</code>	Parabolic cylinder functions $Dv(x)$ and derivatives.
<code>pbvv_seq(v, x)</code>	Parabolic cylinder functions $Vv(x)$ and derivatives.
<code>pbdn_seq(n, z)</code>	Parabolic cylinder functions $Dn(z)$ and derivatives.

`scipy.special.pbdv_seq(v, x)`

Parabolic cylinder functions  $Dv(x)$  and derivatives.

**Parameters**

- v** : float  
Order of the parabolic cylinder function
- x** : float  
Value at which to evaluate the function and derivatives

**Returns**

- dv** : ndarray  
Values of  $D_{vi}(x)$ , for  $vi=v-int(v)$ ,  $vi=1+v-int(v)$ , ...,  $vi=v$ .
- dp** : ndarray  
Derivatives  $D_{vi}'(x)$ , for  $vi=v-int(v)$ ,  $vi=1+v-int(v)$ , ...,  $vi=v$ .

**References**

[R557]

`scipy.special.pbv_v_seq(v, x)`

Parabolic cylinder functions  $Vv(x)$  and derivatives.

**Parameters**

- v** : float  
Order of the parabolic cylinder function
- x** : float  
Value at which to evaluate the function and derivatives

**Returns**

- dv** : ndarray  
Values of  $V_{vi}(x)$ , for  $vi=v-int(v)$ ,  $vi=1+v-int(v)$ , ...,  $vi=v$ .
- dp** : ndarray  
Derivatives  $V_{vi}'(x)$ , for  $vi=v-int(v)$ ,  $vi=1+v-int(v)$ , ...,  $vi=v$ .

**References**

[R558]

`scipy.special.pbdn_seq(n, z)`

Parabolic cylinder functions  $Dn(z)$  and derivatives.

**Parameters**

- n** : int  
Order of the parabolic cylinder function
- z** : complex  
Value at which to evaluate the function and derivatives

**Returns**

- dv** : ndarray  
Values of  $D_i(z)$ , for  $i=0$ , ...,  $i=n$ .
- dp** : ndarray  
Derivatives  $D_i'(z)$ , for  $i=0$ , ...,  $i=n$ .

**References**

[R556]

**Mathieu and Related Functions**

---

<code>mathieu_a(m, q)</code>	Characteristic value of even Mathieu functions
<code>mathieu_b(m, q)</code>	Characteristic value of odd Mathieu functions

---

`scipy.special.mathieu_a(m, q) = <ufunc 'mathieu_a'>`

Characteristic value of even Mathieu functions

Returns the characteristic value for the even solution,  $ce_m(z, q)$ , of Mathieu's equation.

`scipy.special.mathieu_b(m, q) = <ufunc 'mathieu_b'>`

Characteristic value of odd Mathieu functions

Returns the characteristic value for the odd solution,  $se_m(z, q)$ , of Mathieu's equation.

These are not universal functions:

<code>mathieu_even_coef(m, q)</code>	Fourier coefficients for even Mathieu and modified Mathieu functions.
<code>mathieu_odd_coef(m, q)</code>	Fourier coefficients for even Mathieu and modified Mathieu functions.

`scipy.special.mathieu_even_coef(m, q)`

Fourier coefficients for even Mathieu and modified Mathieu functions.

The Fourier series of the even solutions of the Mathieu differential equation are of the form

$$ce_{2n}(z, q) = \sum_{k=0}^{\infty} A_{(2n)}^{(2k)} \cos 2kz$$

$$ce_{2n+1}(z, q) = \sum_{k=0}^{\infty} A_{(2n+1)}^{(2k+1)} \cos(2k+1)z$$

This function returns the coefficients  $A_{(2n)}^{(2k)}$  for even input  $m=2n$ , and the coefficients  $A_{(2n+1)}^{(2k+1)}$  for odd input  $m=2n+1$ .

**Parameters** **m** : int  
Order of Mathieu functions. Must be non-negative.

**q** : float (>=0)  
Parameter of Mathieu functions. Must be non-negative.

**Returns** **Ak** : ndarray  
Even or odd Fourier coefficients, corresponding to even or odd m.

### References

[R542], [R543]

`scipy.special.mathieu_odd_coef(m, q)`

Fourier coefficients for even Mathieu and modified Mathieu functions.

The Fourier series of the odd solutions of the Mathieu differential equation are of the form

$$se_{2n+1}(z, q) = \sum_{k=0}^{\infty} B_{(2n+1)}^{(2k+1)} \sin(2k+1)z$$

$$se_{2n+2}(z, q) = \sum_{k=0}^{\infty} B_{(2n+2)}^{(2k+2)} \sin(2k+2)z$$

This function returns the coefficients  $B_{(2n+2)}^{(2k+2)}$  for even input  $m=2n+2$ , and the coefficients  $B_{(2n+1)}^{(2k+1)}$  for odd input  $m=2n+1$ .

**Parameters** **m** : int  
Order of Mathieu functions. Must be non-negative.

**q** : float (>=0)  
Parameter of Mathieu functions. Must be non-negative.

**Returns** **Bk** : ndarray  
Even or odd Fourier coefficients, corresponding to even or odd m.

**References**

[R544]

The following return both function and first derivative:

<code>mathieu_cem(m, q, x)</code>	Even Mathieu function and its derivative
<code>mathieu_sem(m, q, x)</code>	Odd Mathieu function and its derivative
<code>mathieu_modcem1(m, q, x)</code>	Even modified Mathieu function of the first kind and its derivative
<code>mathieu_modcem2(m, q, x)</code>	Even modified Mathieu function of the second kind and its derivative
<code>mathieu_modsem1(m, q, x)</code>	Odd modified Mathieu function of the first kind and its derivative
<code>mathieu_modsem2(m, q, x)</code>	Odd modified Mathieu function of the second kind and its derivative

`scipy.special.mathieu_cem(m, q, x) = <ufunc 'mathieu_cem'>`

Even Mathieu function and its derivative

Returns the even Mathieu function,  $ce_m(x, q)$ , of order  $m$  and parameter  $q$  evaluated at  $x$  (given in degrees). Also returns the derivative with respect to  $x$  of  $ce_m(x, q)$

<b>Parameters</b>	<b>m</b>	Order of the function
	<b>q</b>	Parameter of the function
	<b>x</b>	Argument of the function, <i>given in degrees, not radians</i>
<b>Returns</b>	<b>y</b>	Value of the function
	<b>yp</b>	Value of the derivative vs $x$

`scipy.special.mathieu_sem(m, q, x) = <ufunc 'mathieu_sem'>`

Odd Mathieu function and its derivative

Returns the odd Mathieu function,  $se_m(x, q)$ , of order  $m$  and parameter  $q$  evaluated at  $x$  (given in degrees). Also returns the derivative with respect to  $x$  of  $se_m(x, q)$ .

<b>Parameters</b>	<b>m</b>	Order of the function
	<b>q</b>	Parameter of the function
	<b>x</b>	Argument of the function, <i>given in degrees, not radians</i> .
<b>Returns</b>	<b>y</b>	Value of the function
	<b>yp</b>	Value of the derivative vs $x$

`scipy.special.mathieu_modcem1(m, q, x) = <ufunc 'mathieu_modcem1'>`

Even modified Mathieu function of the first kind and its derivative

Evaluates the even modified Mathieu function of the first kind,  $Mc1m(x, q)$ , and its derivative at  $x$  for order  $m$  and parameter  $q$ .

<b>Returns</b>	<b>y</b>	Value of the function
----------------	----------	-----------------------

yp  
Value of the derivative vs x

`scipy.special.mathieu_modcem2(m, q, x) = <ufunc 'mathieu_modcem2'>`

Even modified Mathieu function of the second kind and its derivative

Evaluates the even modified Mathieu function of the second kind,  $Mc2m(x, q)$ , and its derivative at  $x$  (given in degrees) for order  $m$  and parameter  $q$ .

**Returns** y  
Value of the function  
yp  
Value of the derivative vs x

`scipy.special.mathieu_modsem1(m, q, x) = <ufunc 'mathieu_modsem1'>`

Odd modified Mathieu function of the first kind and its derivative

Evaluates the odd modified Mathieu function of the first kind,  $Ms1m(x, q)$ , and its derivative at  $x$  (given in degrees) for order  $m$  and parameter  $q$ .

**Returns** y  
Value of the function  
yp  
Value of the derivative vs x

`scipy.special.mathieu_modsem2(m, q, x) = <ufunc 'mathieu_modsem2'>`

Odd modified Mathieu function of the second kind and its derivative

Evaluates the odd modified Mathieu function of the second kind,  $Ms2m(x, q)$ , and its derivative at  $x$  (given in degrees) for order  $m$  and parameter  $q$ .

**Returns** y  
Value of the function  
yp  
Value of the derivative vs x

## Spheroidal Wave Functions

<code>pro_ang1(m, n, c, x)</code>	Prolate spheroidal angular function of the first kind and its derivative
<code>pro_rad1(m, n, c, x)</code>	Prolate spheroidal radial function of the first kind and its derivative
<code>pro_rad2(m, n, c, x)</code>	Prolate spheroidal radial function of the second kind and its derivative
<code>obl_ang1(m, n, c, x)</code>	Oblate spheroidal angular function of the first kind and its derivative
<code>obl_rad1(m, n, c, x)</code>	Oblate spheroidal radial function of the first kind and its derivative
<code>obl_rad2(m, n, c, x)</code>	Oblate spheroidal radial function of the second kind and its derivative.
<code>pro_cv(m, n, c)</code>	Characteristic value of prolate spheroidal function
<code>obl_cv(m, n, c)</code>	Characteristic value of oblate spheroidal function
<code>pro_cv_seq(m, n, c)</code>	Characteristic values for prolate spheroidal wave functions.
<code>obl_cv_seq(m, n, c)</code>	Characteristic values for oblate spheroidal wave functions.

`scipy.special.pro_ang1(m, n, c, x) = <ufunc 'pro_ang1'>`

Prolate spheroidal angular function of the first kind and its derivative

Computes the prolate spheroidal angular function of the first kind and its derivative (with respect to  $x$ ) for mode parameters  $m \geq 0$  and  $n \geq m$ , spheroidal parameter  $c$  and  $|x| < 1.0$ .

**Returns**

s	Value of the function
sp	Value of the derivative vs x

`scipy.special.pro_rad1(m, n, c, x) = <ufunc 'pro_rad1'>`

Prolate spheroidal radial function of the first kind and its derivative

Computes the prolate spheroidal radial function of the first kind and its derivative (with respect to  $x$ ) for mode parameters  $m \geq 0$  and  $n \geq m$ , spheroidal parameter  $c$  and  $|x| < 1.0$ .

**Returns**

s	Value of the function
sp	Value of the derivative vs x

`scipy.special.pro_rad2(m, n, c, x) = <ufunc 'pro_rad2'>`

Prolate spheroidal radial function of the second kind and its derivative

Computes the prolate spheroidal radial function of the second kind and its derivative (with respect to  $x$ ) for mode parameters  $m \geq 0$  and  $n \geq m$ , spheroidal parameter  $c$  and  $|x| < 1.0$ .

**Returns**

s	Value of the function
sp	Value of the derivative vs x

`scipy.special.obl_ang1(m, n, c, x) = <ufunc 'obl_ang1'>`

Oblate spheroidal angular function of the first kind and its derivative

Computes the oblate spheroidal angular function of the first kind and its derivative (with respect to  $x$ ) for mode parameters  $m \geq 0$  and  $n \geq m$ , spheroidal parameter  $c$  and  $|x| < 1.0$ .

**Returns**

s	Value of the function
sp	Value of the derivative vs x

`scipy.special.obl_rad1(m, n, c, x) = <ufunc 'obl_rad1'>`

Oblate spheroidal radial function of the first kind and its derivative

Computes the oblate spheroidal radial function of the first kind and its derivative (with respect to  $x$ ) for mode parameters  $m \geq 0$  and  $n \geq m$ , spheroidal parameter  $c$  and  $|x| < 1.0$ .

**Returns**

s	Value of the function
sp	Value of the derivative vs x

`scipy.special.obl_rad2(m, n, c, x) = <ufunc 'obl_rad2'>`

Oblate spheroidal radial function of the second kind and its derivative.

Computes the oblate spheroidal radial function of the second kind and its derivative (with respect to  $x$ ) for mode parameters  $m \geq 0$  and  $n \geq m$ , spheroidal parameter  $c$  and  $|x| < 1.0$ .

**Returns**

s	
---	--

Value of the function  
 sp Value of the derivative vs x

`scipy.special.pro_cv(m, n, c) = <ufunc 'pro_cv'>`

Characteristic value of prolate spheroidal function

Computes the characteristic value of prolate spheroidal wave functions of order  $m, n$  ( $n \geq m$ ) and spheroidal parameter  $c$ .

`scipy.special.obl_cv(m, n, c) = <ufunc 'obl_cv'>`

Characteristic value of oblate spheroidal function

Computes the characteristic value of oblate spheroidal wave functions of order  $m, n$  ( $n \geq m$ ) and spheroidal parameter  $c$ .

`scipy.special.pro_cv_seq(m, n, c)`

Characteristic values for prolate spheroidal wave functions.

Compute a sequence of characteristic values for the prolate spheroidal wave functions for mode  $m$  and  $n' = m..n$  and spheroidal parameter  $c$ .

**References**

[R561]

`scipy.special.obl_cv_seq(m, n, c)`

Characteristic values for oblate spheroidal wave functions.

Compute a sequence of characteristic values for the oblate spheroidal wave functions for mode  $m$  and  $n' = m..n$  and spheroidal parameter  $c$ .

**References**

[R555]

The following functions require pre-computed characteristic value:

<code>pro_ang1_cv(m, n, c, cv, x)</code>	Prolate spheroidal angular function <code>pro_ang1</code> for pre-computed characteristic value
<code>pro_rad1_cv(m, n, c, cv, x)</code>	Prolate spheroidal radial function <code>pro_rad1</code> for pre-computed characteristic value
<code>pro_rad2_cv(m, n, c, cv, x)</code>	Prolate spheroidal radial function <code>pro_rad2</code> for pre-computed characteristic value
<code>obl_ang1_cv(m, n, c, cv, x)</code>	Oblate spheroidal angular function <code>obl_ang1</code> for pre-computed characteristic value
<code>obl_rad1_cv(m, n, c, cv, x)</code>	Oblate spheroidal radial function <code>obl_rad1</code> for pre-computed characteristic value
<code>obl_rad2_cv(m, n, c, cv, x)</code>	Oblate spheroidal radial function <code>obl_rad2</code> for pre-computed characteristic value

`scipy.special.pro_ang1_cv(m, n, c, cv, x) = <ufunc 'pro_ang1_cv'>`

Prolate spheroidal angular function `pro_ang1` for pre-computed characteristic value

Computes the prolate spheroidal angular function of the first kind and its derivative (with respect to  $x$ ) for mode parameters  $m \geq 0$  and  $n \geq m$ , spheroidal parameter  $c$  and  $|x| < 1.0$ . Requires pre-computed characteristic value.

**Returns** s Value of the function

sp Value of the derivative vs x

`scipy.special.pro_rad1_cv(m, n, c, cv, x) = <ufunc 'pro_rad1_cv'>`  
 Prolate spheroidal radial function pro\_rad1 for precomputed characteristic value

Computes the prolate spheroidal radial function of the first kind and its derivative (with respect to  $x$ ) for mode parameters  $m \geq 0$  and  $n \geq m$ , spheroidal parameter  $c$  and  $|x| < 1.0$ . Requires pre-computed characteristic value.

**Returns** s Value of the function

sp Value of the derivative vs x

`scipy.special.pro_rad2_cv(m, n, c, cv, x) = <ufunc 'pro_rad2_cv'>`  
 Prolate spheroidal radial function pro\_rad2 for precomputed characteristic value

Computes the prolate spheroidal radial function of the second kind and its derivative (with respect to  $x$ ) for mode parameters  $m \geq 0$  and  $n \geq m$ , spheroidal parameter  $c$  and  $|x| < 1.0$ . Requires pre-computed characteristic value.

**Returns** s Value of the function

sp Value of the derivative vs x

`scipy.special.obl_ang1_cv(m, n, c, cv, x) = <ufunc 'obl_ang1_cv'>`  
 Oblate spheroidal angular function obl\_ang1 for precomputed characteristic value

Computes the oblate spheroidal angular function of the first kind and its derivative (with respect to  $x$ ) for mode parameters  $m \geq 0$  and  $n \geq m$ , spheroidal parameter  $c$  and  $|x| < 1.0$ . Requires pre-computed characteristic value.

**Returns** s Value of the function

sp Value of the derivative vs x

`scipy.special.obl_rad1_cv(m, n, c, cv, x) = <ufunc 'obl_rad1_cv'>`  
 Oblate spheroidal radial function obl\_rad1 for precomputed characteristic value

Computes the oblate spheroidal radial function of the first kind and its derivative (with respect to  $x$ ) for mode parameters  $m \geq 0$  and  $n \geq m$ , spheroidal parameter  $c$  and  $|x| < 1.0$ . Requires pre-computed characteristic value.

**Returns** s Value of the function

sp Value of the derivative vs x

`scipy.special.obl_rad2_cv(m, n, c, cv, x) = <ufunc 'obl_rad2_cv'>`  
 Oblate spheroidal radial function obl\_rad2 for precomputed characteristic value

Computes the oblate spheroidal radial function of the second kind and its derivative (with respect to  $x$ ) for mode parameters  $m \geq 0$  and  $n \geq m$ , spheroidal parameter  $c$  and  $|x| < 1.0$ . Requires pre-computed characteristic value.

**Returns** s Value of the function

sp

Value of the derivative vs x

## Kelvin Functions

<code>kelvin(x)</code>	Kelvin functions as complex numbers
<code>kelvin_zeros(nt)</code>	Compute nt zeros of all Kelvin functions.
<code>ber(x)</code>	Kelvin function <i>ber</i> .
<code>bei(x)</code>	Kelvin function <i>bei</i>
<code>berp(x)</code>	Derivative of the Kelvin function <i>ber</i>
<code>beip(x)</code>	Derivative of the Kelvin function <i>bei</i>
<code>ker(x)</code>	Kelvin function <i>ker</i>
<code>kei(x)</code>	Kelvin function <i>ker</i>
<code>kerp(x)</code>	Derivative of the Kelvin function <i>ker</i>
<code>keip(x)</code>	Derivative of the Kelvin function <i>kei</i>

`scipy.special.kelvin(x) = <ufunc 'kelvin'>`

Kelvin functions as complex numbers

**Returns** Be, Ke, Bep, Kep

The tuple (Be, Ke, Bep, Kep) contains complex numbers representing the real and imaginary Kelvin functions and their derivatives evaluated at *x*. For example, `kelvin(x)[0].real = ber x` and `kelvin(x)[0].imag = bei x` with similar relationships for *ker* and *kei*.

`scipy.special.kelvin_zeros(nt)`

Compute nt zeros of all Kelvin functions.

Returned in a length-8 tuple of arrays of length nt. The tuple contains the arrays of zeros of (*ber*, *bei*, *ker*, *kei*, *ber'*, *bei'*, *ker'*, *kei'*).

### References

[R520]

`scipy.special.ber(x) = <ufunc 'ber'>`

Kelvin function *ber*.

`scipy.special.bei(x) = <ufunc 'bei'>`

Kelvin function *bei*

`scipy.special.berp(x) = <ufunc 'berp'>`

Derivative of the Kelvin function *ber*

`scipy.special.beip(x) = <ufunc 'beip'>`

Derivative of the Kelvin function *bei*

`scipy.special.ker(x) = <ufunc 'ker'>`

Kelvin function *ker*

`scipy.special.kei(x) = <ufunc 'kei'>`

Kelvin function *ker*

`scipy.special.kerp(x) = <ufunc 'kerp'>`

Derivative of the Kelvin function *ker*

`scipy.special.keip(x) = <ufunc 'keip'>`

Derivative of the Kelvin function *kei*

These are not universal functions:

<code>ber_zeros(nt)</code>	Compute $nt$ zeros of the Kelvin function $\text{ber}(x)$ .
<code>bei_zeros(nt)</code>	Compute $nt$ zeros of the Kelvin function $\text{bei}(x)$ .
<code>berp_zeros(nt)</code>	Compute $nt$ zeros of the Kelvin function $\text{ber}'(x)$ .
<code>beip_zeros(nt)</code>	Compute $nt$ zeros of the Kelvin function $\text{bei}'(x)$ .
<code>ker_zeros(nt)</code>	Compute $nt$ zeros of the Kelvin function $\text{ker}(x)$ .
<code>kei_zeros(nt)</code>	Compute $nt$ zeros of the Kelvin function $\text{kei}(x)$ .
<code>kerp_zeros(nt)</code>	Compute $nt$ zeros of the Kelvin function $\text{ker}'(x)$ .
<code>keip_zeros(nt)</code>	Compute $nt$ zeros of the Kelvin function $\text{kei}'(x)$ .

`scipy.special.ber_zeros` ( $nt$ )  
 Compute  $nt$  zeros of the Kelvin function  $\text{ber}(x)$ .

**References**

[R425]

`scipy.special.bei_zeros` ( $nt$ )  
 Compute  $nt$  zeros of the Kelvin function  $\text{bei}(x)$ .

**References**

[R423]

`scipy.special.berp_zeros` ( $nt$ )  
 Compute  $nt$  zeros of the Kelvin function  $\text{ber}'(x)$ .

**References**

[R427]

`scipy.special.beip_zeros` ( $nt$ )  
 Compute  $nt$  zeros of the Kelvin function  $\text{bei}'(x)$ .

**References**

[R424]

`scipy.special.ker_zeros` ( $nt$ )  
 Compute  $nt$  zeros of the Kelvin function  $\text{ker}(x)$ .

**References**

[R521]

`scipy.special.kei_zeros` ( $nt$ )  
 Compute  $nt$  zeros of the Kelvin function  $\text{kei}(x)$ .

`scipy.special.kerp_zeros` ( $nt$ )  
 Compute  $nt$  zeros of the Kelvin function  $\text{ker}'(x)$ .

**References**

[R522]

`scipy.special.keip_zeros` ( $nt$ )  
 Compute  $nt$  zeros of the Kelvin function  $\text{kei}'(x)$ .

## References

[R519]

## Combinatorics

<code>comb(N, k[, exact, repetition])</code>	The number of combinations of N things taken k at a time.
<code>perm(N, k[, exact])</code>	Permutations of N things taken k at a time, i.e., k-permutations of N.

`scipy.special.comb(N, k, exact=False, repetition=False)`

The number of combinations of N things taken k at a time.

This is often expressed as “N choose k”.

<b>Parameters</b>	<b>N</b> : int, ndarray Number of things.
	<b>k</b> : int, ndarray Number of elements taken.
	<b>exact</b> : bool, optional If <i>exact</i> is False, then floating point precision is used, otherwise exact long integer is computed.
	<b>repetition</b> : bool, optional If <i>repetition</i> is True, then the number of combinations with repetition is computed.
<b>Returns</b>	<b>val</b> : int, float, ndarray The total number of combinations.

### See also:

**binom** Binomial coefficient ufunc

### Notes

- Array arguments accepted only for `exact=False` case.
- If  $k > N$ ,  $N < 0$ , or  $k < 0$ , then a 0 is returned.

### Examples

```
>>> from scipy.special import comb
>>> k = np.array([3, 4])
>>> n = np.array([10, 10])
>>> comb(n, k, exact=False)
array([ 120.,  210.])
>>> comb(10, 3, exact=True)
120L
>>> comb(10, 3, exact=True, repetition=True)
220L
```

`scipy.special.perm(N, k, exact=False)`

Permutations of N things taken k at a time, i.e., k-permutations of N.

It's also known as “partial permutations”.

<b>Parameters</b>	<b>N</b> : int, ndarray Number of things.
	<b>k</b> : int, ndarray Number of elements taken.

**exact** : bool, optional  
 If *exact* is False, then floating point precision is used, otherwise exact long integer is computed.

**Returns** **val** : int, ndarray  
 The number of k-permutations of N.

**Notes**

- Array arguments accepted only for exact=False case.
- If  $k > N$ ,  $N < 0$ , or  $k < 0$ , then a 0 is returned.

**Examples**

```
>>> from scipy.special import perm
>>> k = np.array([3, 4])
>>> n = np.array([10, 10])
>>> perm(n, k)
array([ 720., 5040.])
>>> perm(10, 3, exact=True)
720
```

**Lambert W and Related Functions**

<code>lambertw(z[, k, tol])</code>	Lambert W function.
<code>wrightomega(z[, out])</code>	Wright Omega function.

**Other Special Functions**

<code>agm(a, b)</code>	Compute the arithmetic-geometric mean of <i>a</i> and <i>b</i> .
<code>bernoulli(n)</code>	Bernoulli numbers B <sub>0</sub> ..B <sub>n</sub> (inclusive).
<code>binom(n, k)</code>	Binomial coefficient
<code>diric(x, n)</code>	Periodic sinc function, also called the Dirichlet function.
<code>euler(n)</code>	Euler numbers E <sub>0</sub> ..E <sub>n</sub> (inclusive).
<code>expn(n, x)</code>	Exponential integral E <sub>n</sub>
<code>expl(z)</code>	Exponential integral E <sub>1</sub> of complex argument <i>z</i>
<code>expi(x)</code>	Exponential integral E <sub>i</sub>
<code>factorial(n[, exact])</code>	The factorial of a number or array of numbers.
<code>factorial2(n[, exact])</code>	Double factorial.
<code>factorialk(n, k[, exact])</code>	Multifactorial of <i>n</i> of order <i>k</i> , $n(!\dots!)$ .
<code>shichi(x[, out])</code>	Hyperbolic sine and cosine integrals.
<code>sici(x[, out])</code>	Sine and cosine integrals.
<code>spence(z[, out])</code>	Spence's function, also known as the dilogarithm.
<code>zeta(x[, q, out])</code>	Riemann or Hurwitz zeta function.
<code>zetac(x)</code>	Riemann zeta function minus 1.

`scipy.special.agm(a, b) = <ufunc 'agm'>`  
 Compute the arithmetic-geometric mean of *a* and *b*.

Start with  $a_0 = a$  and  $b_0 = b$  and iteratively compute:

```
a_{n+1} = (a_n + b_n) / 2
b_{n+1} = sqrt(a_n * b_n)
```

`a_n` and `b_n` converge to the same limit as `n` increases; their common limit is `agm(a, b)`.

**Parameters** `a, b` : array\_like

Real values only. If the values are both negative, the result is negative. If one value is negative and the other is positive, `nan` is returned.

**Returns** float

The arithmetic-geometric mean of `a` and `b`.

### Examples

```
>>> from scipy.special import agm
>>> a, b = 24.0, 6.0
>>> agm(a, b)
13.458171481725614
```

Compare that result to the iteration:

```
>>> while a != b:
...     a, b = (a + b)/2, np.sqrt(a*b)
...     print("a = %19.16f b=%19.16f" % (a, b))
...
a = 15.000000000000000000 b=12.000000000000000000
a = 13.500000000000000000 b=13.4164078649987388
a = 13.4582039324993694 b=13.4581390309909850
a = 13.4581714817451772 b=13.4581714817060547
a = 13.4581714817256159 b=13.4581714817256159
```

When array-like arguments are given, broadcasting applies:

```
>>> a = np.array([[1.5], [3], [6]]) # a has shape (3, 1).
>>> b = np.array([6, 12, 24, 48]) # b has shape (4,).
>>> agm(a, b)
array([[ 3.36454287,  5.42363427,  9.05798751, 15.53650756],
       [ 4.37037309,  6.72908574, 10.84726853, 18.11597502],
       [ 6.          ,  8.74074619, 13.45817148, 21.69453707]])
```

`scipy.special.bernoulli` (`n`)

Bernoulli numbers  $B_0..B_n$  (inclusive).

### References

[R426]

`scipy.special.binom` (`n, k`) = <ufunc 'binom'>

Binomial coefficient

### See also:

**comb** The number of combinations of `N` things taken `k` at a time.

`scipy.special.diric` (`x, n`)

Periodic sinc function, also called the Dirichlet function.

The Dirichlet function is defined as:

$$\text{diric}(x) = \frac{\sin(x * n/2)}{(n * \sin(x / 2))},$$

where `n` is a positive integer.

**Parameters** `x` : array\_like

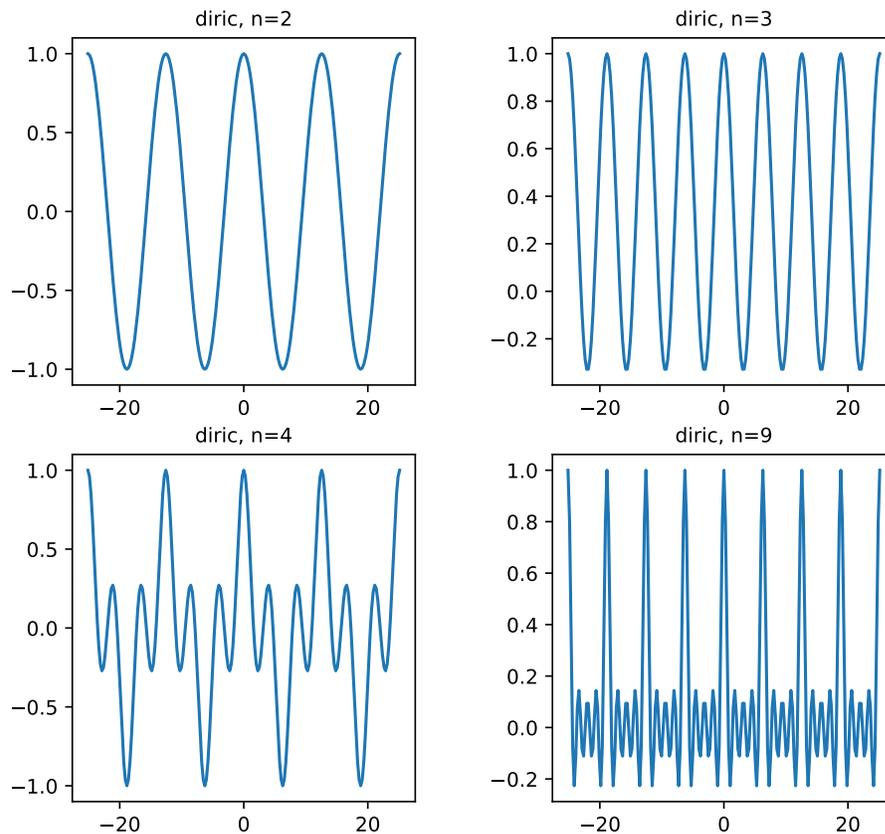
Input data

**Returns** `diric` : ndarray `n` : int  
 Integer defining the periodicity.

### Examples

```
>>> from scipy import special
>>> import matplotlib.pyplot as plt
```

```
>>> x = np.linspace(-8*np.pi, 8*np.pi, num=201)
>>> plt.figure(figsize=(8, 8));
>>> for idx, n in enumerate([2, 3, 4, 9]):
...     plt.subplot(2, 2, idx+1)
...     plt.plot(x, special.diric(x, n))
...     plt.title('diric, n={}'.format(n))
>>> plt.show()
```



The following example demonstrates that `diric` gives the magnitudes (modulo the sign and scaling) of the

Fourier coefficients of a rectangular pulse.

Suppress output of values that are effectively 0:

```
>>> np.set_printoptions(suppress=True)
```

Create a signal  $x$  of length  $m$  with  $k$  ones:

```
>>> m = 8
>>> k = 3
>>> x = np.zeros(m)
>>> x[:k] = 1
```

Use the FFT to compute the Fourier transform of  $x$ , and inspect the magnitudes of the coefficients:

```
>>> np.abs(np.fft.fft(x))
array([ 3.          ,  2.41421356,  1.          ,  0.41421356,  1.          ,
        0.41421356,  1.          ,  2.41421356])
```

Now find the same values (up to sign) using *diric*. We multiply by  $k$  to account for the different scaling conventions of `numpy.fft.fft` and *diric*:

```
>>> theta = np.linspace(0, 2*np.pi, m, endpoint=False)
>>> k * special.diric(theta, k)
array([ 3.          ,  2.41421356,  1.          , -0.41421356, -1.          ,
       -0.41421356,  1.          ,  2.41421356])
```

`scipy.special.euler` ( $n$ )  
Euler numbers E<sub>0</sub>..E<sub>n</sub> (inclusive).

### References

[R463]

`scipy.special.expn` ( $n, x$ ) = <ufunc 'expn'>  
Exponential integral E<sub>n</sub>

Returns the exponential integral for integer  $n$  and non-negative  $x$  and  $n$ :

```
integral(exp(-x*t) / t**n, t=1..inf).
```

`scipy.special.exp1` ( $z$ ) = <ufunc 'exp1'>  
Exponential integral E<sub>1</sub> of complex argument  $z$

```
integral(exp(-z*t)/t, t=1..inf).
```

`scipy.special.expi` ( $x$ ) = <ufunc 'expi'>  
Exponential integral E<sub>i</sub>

Defined as:

```
integral(exp(t)/t, t=-inf..x)
```

See *expn* for a different exponential integral.

`scipy.special.factorial` ( $n$ , *exact=False*)  
The factorial of a number or array of numbers.

The factorial of non-negative integer  $n$  is the product of all positive integers less than or equal to  $n$ :

$$n! = n * (n - 1) * (n - 2) * \dots * 1$$

**Parameters**

- n** : int or array\_like of ints  
Input values. If  $n < 0$ , the return value is 0.
- exact** : bool, optional  
If True, calculate the answer exactly using long integer arithmetic. If False, result is approximated in floating point rapidly using the *gamma* function.

**Returns**

- nf** : float or int or ndarray  
Default is False.  
Factorial of  $n$ , as integer or float depending on *exact*.

### Notes

For arrays with `exact=True`, the factorial is computed only once, for the largest input, with each other result computed in the process. The output dtype is increased to `int64` or `object` if necessary.

With `exact=False` the factorial is approximated using the gamma function:

$$n! = \Gamma(n + 1)$$

### Examples

```
>>> from scipy.special import factorial
>>> arr = np.array([3, 4, 5])
>>> factorial(arr, exact=False)
array([ 6., 24., 120.])
>>> factorial(arr, exact=True)
array([ 6, 24, 120])
>>> factorial(5, exact=True)
120L
```

`scipy.special.factorial2` ( $n$ , *exact=False*)

Double factorial.

This is the factorial with every second value skipped. E.g.,  $7!! = 7 * 5 * 3 * 1$ . It can be approximated numerically as:

$$\begin{aligned} n!! &= \text{special.gamma}(n/2+1) * 2^{*(m+1)/2} / \text{sqrt}(\text{pi}) && n \text{ odd} \\ &= 2^{*(n/2)} * (n/2)! && n \text{ even} \end{aligned}$$

**Parameters**

- n** : int or array\_like  
Calculate  $n!!$ . Arrays are only supported with *exact* set to False. If  $n < 0$ , the return value is 0.
- exact** : bool, optional  
The result can be approximated rapidly using the gamma-formula above (default). If *exact* is set to True, calculate the answer exactly using integer arithmetic.

**Returns**

- nff** : float or int  
Double factorial of  $n$ , as an int or a float depending on *exact*.

### Examples

```
>>> from scipy.special import factorial2
>>> factorial2(7, exact=False)
array(105.00000000000001)
>>> factorial2(7, exact=True)
105L
```

`scipy.special.factorialk` ( $n, k, exact=True$ )  
 Multifactorial of  $n$  of order  $k$ ,  $n(!\dots!)$ .

This is the multifactorial of  $n$  skipping  $k$  values. For example,

$$\text{factorialk}(17, 4) = 17!!!! = 17 * 13 * 9 * 5 * 1$$

In particular, for any integer  $n$ , we have

$$\begin{aligned}\text{factorialk}(n, 1) &= \text{factorial}(n) \\ \text{factorialk}(n, 2) &= \text{factorial2}(n)\end{aligned}$$

**Parameters**

- n** : int  
Calculate multifactorial. If  $n < 0$ , the return value is 0.
- k** : int  
Order of multifactorial.
- exact** : bool, optional  
If exact is set to True, calculate the answer exactly using integer arithmetic.

**Returns**

- val** : int  
Multifactorial of  $n$ .

**Raises**

- NotImplementedError**  
Raises when exact is False

### Examples

```
>>> from scipy.special import factorialk
>>> factorialk(5, 1, exact=True)
120L
>>> factorialk(5, 3, exact=True)
10L
```

`scipy.special.shichi` ( $x, out=None$ ) = <ufunc 'shichi'>  
 Hyperbolic sine and cosine integrals.

The hyperbolic sine integral is

$$\int_0^x \frac{\sinh t}{t} dt$$

and the hyperbolic cosine integral is

$$\gamma + \log(x) + \int_0^x \frac{\cosh t - 1}{t} dt$$

where  $\gamma$  is Euler's constant and  $\log$  is the principle branch of the logarithm.

**Parameters**

- x** : array\_like  
Real or complex points at which to compute the hyperbolic sine and cosine integrals.

**Returns**

- si** : ndarray  
Hyperbolic sine integral at  $x$
- ci** : ndarray  
Hyperbolic cosine integral at  $x$

### Notes

For real arguments with  $x < 0$ , `chi` is the real part of the hyperbolic cosine integral. For such points `chi(x)` and `chi(x + 0j)` differ by a factor of  $1j*\pi$ .

For real arguments the function is computed by calling Cephes' [R568] `shichi` routine. For complex arguments the algorithm is based on Mpmath's [R569] `shi` and `chi` routines.

**References**

[R568], [R569]

`scipy.special.sici(x, out=None) = <ufunc 'sici'>`

Sine and cosine integrals.

The sine integral is

$$\int_0^x \frac{\sin t}{t} dt$$

and the cosine integral is

$$\gamma + \log(x) + \int_0^x \frac{\cos t - 1}{t} dt$$

where  $\gamma$  is Euler's constant and  $\log$  is the principle branch of the logarithm.

**Parameters** `x` : array\_like

**Returns** `si` : ndarray Real or complex points at which to compute the sine and cosine integrals.

Sine integral at `x`

`ci` : ndarray

Cosine integral at `x`

**Notes**

For real arguments with  $x < 0$ , `ci` is the real part of the cosine integral. For such points `ci(x)` and `ci(x + 0j)` differ by a factor of  $1j\pi$ .

For real arguments the function is computed by calling Cephes' [R570] `sici` routine. For complex arguments the algorithm is based on Mpmath's [R571] `si` and `ci` routines.

**References**

[R570], [R571]

`scipy.special.spence(z, out=None) = <ufunc 'spence'>`

Spence's function, also known as the dilogarithm.

It is defined to be

$$\int_0^z \frac{\log(t)}{1-t} dt$$

for complex  $z$ , where the contour of integration is taken to avoid the branch cut of the logarithm. Spence's function is analytic everywhere except the negative real axis where it has a branch cut.

**Parameters** `z` : array\_like

**Returns** `s` : ndarray Points at which to evaluate Spence's function

Computed values of Spence's function

**Notes**

There is a different convention which defines Spence's function by the integral

$$-\int_0^z \frac{\log(1-t)}{t} dt;$$

this is our `spence(1 - z)`.

`scipy.special.zeta` ( $x, q=None, out=None$ )

Riemann or Hurwitz zeta function.

**Parameters**

- x** : array\_like of float  
Input data, must be real
- q** : array\_like of float, optional  
Input data, must be real. Defaults to Riemann zeta.
- out** : ndarray, optional  
Output array for the computed values.

**See also:**

`zetac`

**Notes**

The two-argument version is the Hurwitz zeta function:

$$\zeta(x, q) = \sum_{k=0}^{\infty} \frac{1}{(k+q)^x},$$

Riemann zeta function corresponds to  $q = 1$ .

`scipy.special.zetac` ( $x$ ) = <ufunc 'zetac'>

Riemann zeta function minus 1.

This function is defined as

$$\zeta(x) = \sum_{k=2}^{\infty} 1/k^x,$$

where  $x > 1$ .

**See also:**

`zeta`

## Convenience Functions

<code>cbrt(x)</code>	Element-wise cube root of $x$ .
<code>exp10(x)</code>	Compute $10^{**x}$ element-wise.
<code>exp2(x)</code>	Compute $2^{**x}$ element-wise.
<code>radian(d, m, s)</code>	Convert from degrees to radians
<code>cosdg(x)</code>	Cosine of the angle $x$ given in degrees.
<code>sindg(x)</code>	Sine of angle given in degrees
<code>tandg(x)</code>	Tangent of angle $x$ given in degrees.
<code>cotdg(x)</code>	Cotangent of the angle $x$ given in degrees.
<code>log1p(x)</code>	Calculates $\log(1+x)$ for use when $x$ is near zero
<code>expm1(x)</code>	Compute $\exp(x) - 1$ .
<code>cosm1(x)</code>	$\cos(x) - 1$ for use when $x$ is near zero.
<code>round(x)</code>	Round to nearest integer
<code>xlogy(x, y)</code>	Compute $x * \log(y)$ so that the result is 0 if $x = 0$ .
<code>xlog1py(x, y)</code>	Compute $x * \log1p(y)$ so that the result is 0 if $x = 0$ .
<code>logsumexp(a[, axis, b, keepdims, return_sign])</code>	Compute the log of the sum of exponentials of input elements.
<code>exprel(x)</code>	Relative error exponential, $(\exp(x) - 1) / x$ .
<code>sinc(x)</code>	Return the sinc function.

`scipy.special.cbrt(x) = <ufunc 'cbrt'>`

Element-wise cube root of  $x$ .

**Parameters** `x`: array\_like  
**Returns** float  
 $x$  must contain real numbers.  
The cube root of each value in  $x$ .

**Examples**

```
>>> from scipy.special import cbrt
```

```
>>> cbrt(8)
2.0
>>> cbrt([-8, -3, 0.125, 1.331])
array([-2.          , -1.44224957,  0.5          ,  1.1          ])
```

`scipy.special.exp10(x) = <ufunc 'exp10'>`

Compute  $10^{**x}$  element-wise.

**Parameters** `x`: array\_like  
**Returns** float  
 $x$  must contain real numbers.  
 $10^{**x}$ , computed element-wise.

**Examples**

```
>>> from scipy.special import exp10
```

```
>>> exp10(3)
1000.0
>>> x = np.array([[ -1, -0.5,  0], [ 0.5,  1,  1.5]])
>>> exp10(x)
array([[ 0.1          ,  0.31622777,  1.          ],
       [ 3.16227766,  10.          ,  31.6227766 ]])
```

`scipy.special.exp2(x) = <ufunc 'exp2'>`

Compute  $2^{**x}$  element-wise.

**Parameters** `x`: array\_like  
**Returns** float  
 $x$  must contain real numbers.  
 $2^{**x}$ , computed element-wise.

**Examples**

```
>>> from scipy.special import exp2
```

```
>>> exp2(3)
8.0
>>> x = np.array([[ -1, -0.5,  0], [ 0.5,  1,  1.5]])
>>> exp2(x)
array([[ 0.5          ,  0.70710678,  1.          ],
       [ 1.41421356,  2.          ,  2.82842712]])
```

`scipy.special.radians(d, m, s) = <ufunc 'radians'>`

Convert from degrees to radians

Returns the angle given in (d)egrees, (m)inutes, and (s)econds in radians.

`scipy.special.cosdg(x) = <ufunc 'cosdg'>`  
Cosine of the angle  $x$  given in degrees.

`scipy.special.sindg(x) = <ufunc 'sindg'>`  
Sine of angle given in degrees

`scipy.special.tandg(x) = <ufunc 'tandg'>`  
Tangent of angle  $x$  given in degrees.

`scipy.special.cotdg(x) = <ufunc 'cotdg'>`  
Cotangent of the angle  $x$  given in degrees.

`scipy.special.log1p(x) = <ufunc 'log1p'>`  
Calculates  $\log(1+x)$  for use when  $x$  is near zero

`scipy.special.expm1(x) = <ufunc 'expm1'>`  
Compute  $\exp(x) - 1$ .

When  $x$  is near zero,  $\exp(x)$  is near 1, so the numerical calculation of  $\exp(x) - 1$  can suffer from catastrophic loss of precision. `expm1(x)` is implemented to avoid the loss of precision that occurs when  $x$  is near zero.

**Parameters** `x`: array\_like  
`x` must contain real numbers.

**Returns** float  
 $\exp(x) - 1$  computed element-wise.

### Examples

```
>>> from scipy.special import expm1
```

```
>>> expm1(1.0)
1.7182818284590451
>>> expm1([-0.2, -0.1, 0, 0.1, 0.2])
array([-0.18126925, -0.09516258, 0.          , 0.10517092, 0.22140276])
```

The exact value of  $\exp(7.5e-13) - 1$  is:

```
7.5000000000028125000000007031250000001318...*10**-13.
```

Here is what `expm1(7.5e-13)` gives:

```
>>> expm1(7.5e-13)
7.5000000000028135e-13
```

Compare that to  $\exp(7.5e-13) - 1$ , where the subtraction results in a “catastrophic” loss of precision:

```
>>> np.exp(7.5e-13) - 1
7.5006667543675576e-13
```

`scipy.special.cosm1(x) = <ufunc 'cosm1'>`  
 $\cos(x) - 1$  for use when  $x$  is near zero.

`scipy.special.round(x) = <ufunc 'round'>`  
Round to nearest integer

Returns the nearest integer to  $x$  as a double precision floating point result. If  $x$  ends in 0.5 exactly, the nearest even integer is chosen.

`scipy.special.xlogy(x, y) = <ufunc 'xlogy'>`  
Compute  $x \cdot \log(y)$  so that the result is 0 if  $x = 0$ .

**Parameters** **x** : array\_like  
Multiplier  
**y** : array\_like  
**Returns** **z** : array\_like  
Argument  
Computed  $x \cdot \log(y)$

**Notes**

New in version 0.13.0.

`scipy.special.xlog1py(x, y) = <ufunc 'xlog1py'>`  
Compute  $x \cdot \log_1 p(y)$  so that the result is 0 if  $x = 0$ .

**Parameters** **x** : array\_like  
Multiplier  
**y** : array\_like  
**Returns** **z** : array\_like  
Argument  
Computed  $x \cdot \log_1 p(y)$

**Notes**

New in version 0.13.0.

`scipy.special.logsumexp(a, axis=None, b=None, keepdims=False, return_sign=False)`  
Compute the log of the sum of exponentials of input elements.

**Parameters** **a** : array\_like  
Input array.  
**axis** : None or int or tuple of ints, optional  
Axis or axes over which the sum is taken. By default *axis* is None, and all elements are summed.  
New in version 0.11.0.  
**keepdims** : bool, optional  
If this is set to True, the axes which are reduced are left in the result as dimensions with size one. With this option, the result will broadcast correctly against the original array.  
New in version 0.15.0.  
**b** : array-like, optional  
Scaling factor for  $\exp(a)$  must be of the same shape as *a* or broadcastable to *a*. These values may be negative in order to implement subtraction.  
New in version 0.12.0.  
**return\_sign** : bool, optional  
If this is set to True, the result will be a pair containing sign information; if False, results that are negative will be returned as NaN. Default is False (no sign information).  
New in version 0.16.0.

**Returns**

---

**res** : ndarray  
The result,  $\text{np.log}(\text{np.sum}(\text{np.exp}(a)))$  calculated in a numerically more stable way. If *b* is given then  $\text{np.log}(\text{np.sum}(b \cdot \text{np.exp}(a)))$  is returned.

**sgn** : ndarray  
If *return\_sign* is True, this will be an array of floating-point numbers matching *res* and +1, 0, or -1 depending on the sign of the result. If False, only one result is returned.

**See also:**

`numpy.logaddexp`, `numpy.logaddexp2`

**Notes**

Numpy has a `logaddexp` function which is very similar to `logsumexp`, but only handles two arguments. `logaddexp.reduce` is similar to this function, but may be less stable.

**Examples**

```
>>> from scipy.special import logsumexp
>>> a = np.arange(10)
>>> np.log(np.sum(np.exp(a)))
9.4586297444267107
>>> logsumexp(a)
9.4586297444267107
```

**With weights**

```
>>> a = np.arange(10)
>>> b = np.arange(10, 0, -1)
>>> logsumexp(a, b=b)
9.9170178533034665
>>> np.log(np.sum(b*np.exp(a)))
9.9170178533034647
```

**Returning a sign flag**

```
>>> logsumexp([1,2], b=[1,-1], return_sign=True)
(1.5413248546129181, -1.0)
```

Notice that `logsumexp` does not directly support masked arrays. To use it on a masked array, convert the mask into zero weights:

```
>>> a = np.ma.array([np.log(2), 2, np.log(3)],
...                 mask=[False, True, False])
>>> b = (~a.mask).astype(int)
>>> logsumexp(a.data, b=b), np.log(5)
1.6094379124341005, 1.6094379124341005
```

`scipy.special.exprel(x) = <ufunc 'exprel'>`

Relative error exponential,  $(\exp(x) - 1)/x$ .

When  $x$  is near zero,  $\exp(x)$  is near 1, so the numerical calculation of  $\exp(x) - 1$  can suffer from catastrophic loss of precision. `exprel(x)` is implemented to avoid the loss of precision that occurs when  $x$  is near zero.

**Parameters** `x`: ndarray

**Returns** float

Input array.  $x$  must contain real numbers.

$(\exp(x) - 1)/x$ , computed element-wise.

**See also:**

`expm1`

**Notes**

New in version 0.17.0.

*Examples*

```
>>> from scipy.special import exprel
```

```
>>> exprel(0.01)
1.0050167084168056
>>> exprel([-0.25, -0.1, 0, 0.1, 0.25])
array([ 0.88479687,  0.95162582,  1.          ,  1.05170918,  1.13610167])
```

Compare `exprel(5e-9)` to the naive calculation. The exact value is `1.00000000250000000416...`

```
>>> exprel(5e-9)
1.0000000025
```

```
>>> (np.exp(5e-9) - 1)/5e-9
0.99999999392252903
```

`scipy.special.sinc(x)`

Return the sinc function.

The sinc function is  $\sin(\pi x)/(\pi x)$ .

<b>Parameters</b>	<b>x</b> : ndarray	Array (possibly multi-dimensional) of values for which to calculate <code>sinc(x)</code> .
<b>Returns</b>	<b>out</b> : ndarray	<code>sinc(x)</code> , which has the same shape as the input.

*Notes*

`sinc(0)` is the limit value 1.

The name `sinc` is short for “sine cardinal” or “sinus cardinalis”.

The sinc function is used in various signal processing applications, including in anti-aliasing, in the construction of a Lanczos resampling filter, and in interpolation.

For bandlimited interpolation of discrete-time signals, the ideal interpolation kernel is proportional to the sinc function.

*References*

[R572], [R573]

*Examples*

```
>>> x = np.linspace(-4, 4, 41)
>>> np.sinc(x)
array([ -3.89804309e-17, -4.92362781e-02, -8.40918587e-02,
        -8.90384387e-02, -5.84680802e-02,  3.89804309e-17,
         6.68206631e-02,  1.16434881e-01,  1.26137788e-01,
         8.50444803e-02, -3.89804309e-17, -1.03943254e-01,
        -1.89206682e-01, -2.16236208e-01, -1.55914881e-01,
         3.89804309e-17,  2.33872321e-01,  5.04551152e-01,
         7.56826729e-01,  9.35489284e-01,  1.00000000e+00,
         9.35489284e-01,  7.56826729e-01,  5.04551152e-01,
         2.33872321e-01,  3.89804309e-17, -1.55914881e-01,
        -2.16236208e-01, -1.89206682e-01, -1.03943254e-01,
        -3.89804309e-17,  8.50444803e-02,  1.26137788e-01,
         1.16434881e-01,  6.68206631e-02,  3.89804309e-17,])
```

```
-5.84680802e-02, -8.90384387e-02, -8.40918587e-02,
-4.92362781e-02, -3.89804309e-17])
```

```
>>> plt.plot(x, np.sinc(x))
[<matplotlib.lines.Line2D object at 0x...>]
>>> plt.title("Sinc Function")
<matplotlib.text.Text object at 0x...>
>>> plt.ylabel("Amplitude")
<matplotlib.text.Text object at 0x...>
>>> plt.xlabel("X")
<matplotlib.text.Text object at 0x...>
>>> plt.show()
```

It works in 2-D as well:

```
>>> x = np.linspace(-4, 4, 401)
>>> xx = np.outer(x, x)
>>> plt.imshow(np.sinc(xx))
<matplotlib.image.AxesImage object at 0x...>
```

## 5.27 Statistical functions (`scipy.stats`)

This module contains a large number of probability distributions as well as a growing library of statistical functions.

Each univariate distribution is an instance of a subclass of `rv_continuous` (`rv_discrete` for discrete distributions):

<code>rv_continuous([momtype, a, b, xtol, ...])</code>	A generic continuous random variable class meant for subclassing.
<code>rv_discrete([a, b, name, badvalue, ...])</code>	A generic discrete random variable class meant for subclassing.
<code>rv_histogram(histogram, *args, **kwargs)</code>	Generates a distribution given by a histogram.

```
class scipy.stats.rv_continuous (momtype=1, a=None, b=None, xtol=1e-14, badvalue=None,
name=None, longname=None, shapes=None, extradoc=None,
seed=None)
```

A generic continuous random variable class meant for subclassing.

`rv_continuous` is a base class to construct specific distribution classes and instances for continuous random variables. It cannot be used directly as a distribution.

**Parameters**

- momtype** : int, optional  
The type of generic moment calculation to use: 0 for pdf, 1 (default) for ppf.
- a** : float, optional  
Lower bound of the support of the distribution, default is minus infinity.
- b** : float, optional  
Upper bound of the support of the distribution, default is plus infinity.
- xtol** : float, optional  
The tolerance for fixed point calculation for generic ppf.
- badvalue** : float, optional  
The value in a result arrays that indicates a value that for which some argument restriction is violated, default is `np.nan`.

- name** : str, optional  
The name of the instance. This string is used to construct the default example for distributions.
- longname** : str, optional  
This string is used as part of the first line of the docstring returned when a subclass has no docstring of its own. Note: *longname* exists for backwards compatibility, do not use for new subclasses.
- shapes** : str, optional  
The shape of the distribution. For example "m, n" for a distribution that takes two integers as the two shape arguments for all its methods. If not provided, shape parameters will be inferred from the signature of the private methods, `_pdf` and `_cdf` of the instance.
- extradoc** : str, optional, deprecated  
This string is used as the last part of the docstring returned when a subclass has no docstring of its own. Note: *extradoc* exists for backwards compatibility, do not use for new subclasses.
- seed** : None or int or `numpy.random.RandomState` instance, optional  
This parameter defines the `RandomState` object to use for drawing random variates. If None (or `np.random`), the global `np.random` state is used. If integer, it is used to seed the local `RandomState` instance. Default is None.

### Notes

Public methods of an instance of a distribution class (e.g., `pdf`, `cdf`) check their arguments and pass valid arguments to private, computational methods (`_pdf`, `_cdf`). For `pdf(x)`, `x` is valid if it is within the support of a distribution, `self.a <= x <= self.b`. Whether a shape parameter is valid is decided by an `_argcheck` method (which defaults to checking that its arguments are strictly positive.)

### Subclassing

New random variables can be defined by subclassing the `rv_continuous` class and re-defining at least the `_pdf` or the `_cdf` method (normalized to location 0 and scale 1).

If positive argument checking is not correct for your RV then you will also need to re-define the `_argcheck` method.

Correct, but potentially slow defaults exist for the remaining methods but for speed and/or accuracy you can over-ride:

```
_logpdf, _cdf, _logcdf, _ppf, _rvs, _isf, _sf, _logsf
```

Rarely would you override `_isf`, `_sf` or `_logsf`, but you could.

### Methods that can be overwritten by subclasses

```
_rvs
_pdf
_cdf
_sf
_ppf
_isf
_stats
_munp
_entropy
_argcheck
```

There are additional (internal and private) generic methods that can be useful for cross-checking and for debugging, but might work in all cases when directly called.

A note on `shapes`: subclasses need not specify them explicitly. In this case, `shapes` will be automatically deduced from the signatures of the overridden methods (`pdf`, `cdf` etc). If, for some reason, you prefer to avoid relying on introspection, you can specify `shapes` explicitly as an argument to the instance constructor.

### Frozen Distributions

Normally, you must provide shape parameters (and, optionally, location and scale parameters to each call of a method of a distribution.

Alternatively, the object may be called (as a function) to fix the shape, location, and scale parameters returning a “frozen” continuous RV object:

```
rv = generic(<shape(s)>, loc=0, scale=1)
```

frozen RV object with the same methods but holding the given shape, location, and scale fixed

### Statistics

Statistics are computed using numerical integration by default. For speed you can redefine this using `_stats`:

- take shape parameters and return `mu`, `mu2`, `g1`, `g2`
- If you can’t compute one of these, return it as `None`
- Can also be defined with a keyword argument `moments`, which is a string composed of “m”, “v”, “s”, and/or “k”. Only the components appearing in string should be computed and returned in the order “m”, “v”, “s”, or “k” with missing values returned as `None`.

Alternatively, you can override `_munp`, which takes `n` and shape parameters and returns the `n`-th non-central moment of the distribution.

### Examples

To create a new Gaussian distribution, we would do the following:

```
>>> from scipy.stats import rv_continuous
>>> class gaussian_gen(rv_continuous):
...     "Gaussian distribution"
...     def _pdf(self, x):
...         return np.exp(-x**2 / 2.) / np.sqrt(2.0 * np.pi)
>>> gaussian = gaussian_gen(name='gaussian')
```

`scipy.stats` distributions are *instances*, so here we subclass `rv_continuous` and create an instance. With this, we now have a fully functional distribution with all relevant methods automatically generated by the framework.

Note that above we defined a standard normal distribution, with zero mean and unit variance. Shifting and scaling of the distribution can be done by using `loc` and `scale` parameters: `gaussian.pdf(x, loc, scale)` essentially computes  $y = (x - \text{loc}) / \text{scale}$  and `gaussian._pdf(y) / scale`.

### Attributes

<code>random_state</code>	Get or set the <code>RandomState</code> object for generating random variates.
---------------------------	--

### `rv_continuous.random_state`

Get or set the `RandomState` object for generating random variates.

This can be either `None` or an existing `RandomState` object.

If `None` (or `np.random`), use the `RandomState` singleton used by `np.random`. If already a `RandomState` instance, use it. If an `int`, use a new `RandomState` instance seeded with `seed`.

### Methods

<code>rvs(*args, **kwargs)</code>	Random variates of given type.
<code>pdf(x, *args, **kwargs)</code>	Probability density function at x of the given RV.
<code>logpdf(x, *args, **kwargs)</code>	Log of the probability density function at x of the given RV.
<code>cdf(x, *args, **kwargs)</code>	Cumulative distribution function of the given RV.
<code>logcdf(x, *args, **kwargs)</code>	Log of the cumulative distribution function at x of the given RV.
<code>sf(x, *args, **kwargs)</code>	Survival function (1 - <i>cdf</i> ) at x of the given RV.
<code>logsf(x, *args, **kwargs)</code>	Log of the survival function of the given RV.
<code>ppf(q, *args, **kwargs)</code>	Percent point function (inverse of <i>cdf</i> ) at q of the given RV.
<code>isf(q, *args, **kwargs)</code>	Inverse survival function (inverse of <i>sf</i> ) at q of the given RV.
<code>moment(n, *args, **kwargs)</code>	n-th order non-central moment of distribution.
<code>stats(*args, **kwargs)</code>	Some statistics of the given RV.
<code>entropy(*args, **kwargs)</code>	Differential entropy of the RV.
<code>expect([func, args, loc, scale, lb, ub, ...])</code>	Calculate expected value of a function with respect to the distribution.
<code>median(*args, **kwargs)</code>	Median of the distribution.
<code>mean(*args, **kwargs)</code>	Mean of the distribution.
<code>std(*args, **kwargs)</code>	Standard deviation of the distribution.
<code>var(*args, **kwargs)</code>	Variance of the distribution.
<code>interval(alpha, *args, **kwargs)</code>	Confidence interval with equal areas around the median.
<code>__call__(*args, **kwargs)</code>	Freeze the distribution for the given arguments.
<code>fit(data, *args, **kwargs)</code>	Return MLEs for shape (if applicable), location, and scale parameters from data.
<code>fit_loc_scale(data, *args)</code>	Estimate loc and scale parameters from data using 1st and 2nd moments.
<code>nllf(theta, x)</code>	Return negative loglikelihood function.

`rv_continuous.rvs(*args, **kwargs)`

Random variates of given type.

**Parameters** `arg1, arg2, arg3,...` : array\_like

The shape parameter(s) for the distribution (see docstring of the instance object for more information).

`loc` : array\_like, optional

Location parameter (default=0).

`scale` : array\_like, optional

Scale parameter (default=1).

`size` : int or tuple of ints, optional

Defining number of random variates (default is 1).

`random_state` : None or int or `np.random.RandomState` instance, optional

If int or `RandomState`, use it for drawing the random variates. If None, rely on `self.random_state`. Default is None.

**Returns** `rvs` : ndarray or scalar

Random variates of given *size*.

`rv_continuous.pdf(x, *args, **kwargs)`

Probability density function at x of the given RV.

**Parameters** `x` : array\_like

quantiles

`arg1, arg2, arg3,...` : array\_like

The shape parameter(s) for the distribution (see docstring of the instance object for more information)

**loc** : array\_like, optional  
location parameter (default=0)

**scale** : array\_like, optional  
scale parameter (default=1)

**Returns** **pdf** : ndarray  
Probability density function evaluated at x

`rv_continuous.logpdf(x, *args, **kwargs)`  
Log of the probability density function at x of the given RV.

This uses a more numerically accurate calculation if available.

**Parameters** **x** : array\_like  
quantiles

**arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information)

**loc** : array\_like, optional  
location parameter (default=0)

**scale** : array\_like, optional  
scale parameter (default=1)

**Returns** **logpdf** : array\_like  
Log of the probability density function evaluated at x

`rv_continuous.cdf(x, *args, **kwargs)`  
Cumulative distribution function of the given RV.

**Parameters** **x** : array\_like  
quantiles

**arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information)

**loc** : array\_like, optional  
location parameter (default=0)

**scale** : array\_like, optional  
scale parameter (default=1)

**Returns** **cdf** : ndarray  
Cumulative distribution function evaluated at x

`rv_continuous.logcdf(x, *args, **kwargs)`  
Log of the cumulative distribution function at x of the given RV.

**Parameters** **x** : array\_like  
quantiles

**arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information)

**loc** : array\_like, optional  
location parameter (default=0)

**scale** : array\_like, optional  
scale parameter (default=1)

**Returns** **logcdf** : array\_like  
Log of the cumulative distribution function evaluated at x

`rv_continuous.sf(x, *args, **kwargs)`  
Survival function (1 - *cdf*) at x of the given RV.

**Parameters** **x** : array\_like

`quantiles`  
**arg1, arg2, arg3,...** : array\_like  
 The shape parameter(s) for the distribution (see docstring of the instance object for more information)  
**loc** : array\_like, optional  
 location parameter (default=0)  
**scale** : array\_like, optional  
 scale parameter (default=1)  
**Returns** **sf** : array\_like  
 Survival function evaluated at  $x$

`rv_continuous.logsf(x, *args, **kws)`  
 Log of the survival function of the given RV.  
 Returns the log of the “survival function,” defined as  $(1 - cdf)$ , evaluated at  $x$ .

**Parameters** **x** : array\_like  
`quantiles`  
**arg1, arg2, arg3,...** : array\_like  
 The shape parameter(s) for the distribution (see docstring of the instance object for more information)  
**loc** : array\_like, optional  
 location parameter (default=0)  
**scale** : array\_like, optional  
 scale parameter (default=1)  
**Returns** **logsf** : ndarray  
 Log of the survival function evaluated at  $x$ .

`rv_continuous.ppf(q, *args, **kws)`  
 Percent point function (inverse of  $cdf$ ) at  $q$  of the given RV.

**Parameters** **q** : array\_like  
 lower tail probability  
**arg1, arg2, arg3,...** : array\_like  
 The shape parameter(s) for the distribution (see docstring of the instance object for more information)  
**loc** : array\_like, optional  
 location parameter (default=0)  
**scale** : array\_like, optional  
 scale parameter (default=1)  
**Returns** **x** : array\_like  
 quantile corresponding to the lower tail probability  $q$ .

`rv_continuous.isf(q, *args, **kws)`  
 Inverse survival function (inverse of  $sf$ ) at  $q$  of the given RV.

**Parameters** **q** : array\_like  
 upper tail probability  
**arg1, arg2, arg3,...** : array\_like  
 The shape parameter(s) for the distribution (see docstring of the instance object for more information)  
**loc** : array\_like, optional  
 location parameter (default=0)  
**scale** : array\_like, optional  
 scale parameter (default=1)  
**Returns** **x** : ndarray or scalar  
 Quantile corresponding to the upper tail probability  $q$ .

`rv_continuous.moment(n, *args, **kws)`  
 $n$ -th order non-central moment of distribution.

**Parameters**

- n** : int,  $n \geq 1$   
Order of moment.
- arg1, arg2, arg3,...** : float  
The shape parameter(s) for the distribution (see docstring of the instance object for more information).
- loc** : array\_like, optional  
location parameter (default=0)
- scale** : array\_like, optional  
scale parameter (default=1)

`rv_continuous.stats` (\*args, \*\*kws)  
Some statistics of the given RV.

**Parameters**

- arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information)
- loc** : array\_like, optional  
location parameter (default=0)
- scale** : array\_like, optional (continuous RVs only)  
scale parameter (default=1)
- moments** : str, optional  
composed of letters ['mvsk'] defining which moments to compute: 'm' = mean, 'v' = variance, 's' = (Fisher's) skew, 'k' = (Fisher's) kurtosis. (default is 'mv')

**Returns**

- stats** : sequence  
of requested moments.

`rv_continuous.entropy` (\*args, \*\*kws)  
Differential entropy of the RV.

**Parameters**

- arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information).
- loc** : array\_like, optional  
Location parameter (default=0).
- scale** : array\_like, optional (continuous distributions only).  
Scale parameter (default=1).

### Notes

Entropy is defined base  $e$ :

```
>>> drv = rv_discrete(values=((0, 1), (0.5, 0.5)))
>>> np.allclose(drv.entropy(), np.log(2.0))
True
```

`rv_continuous.expect` (func=None, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, \*\*kws)

Calculate expected value of a function with respect to the distribution.

The expected value of a function  $f(x)$  with respect to a distribution `dist` is defined as:

$$E[x] = \int_{lb}^{ub} f(x) * dist.pdf(x)$$

**Parameters**

- func** : callable, optional

Function for which integral is calculated. Takes only one argument.  
The default is the identity mapping  $f(x) = x$ .

**args** : tuple, optional

Shape parameters of the distribution.

**loc** : float, optional

Location parameter (default=0).

**scale** : float, optional

Scale parameter (default=1).

**lb, ub** : scalar, optional

Lower and upper bound for integration. Default is set to the support of the distribution.

**conditional** : bool, optional

If True, the integral is corrected by the conditional probability of the integration interval. The return value is the expectation of the function, conditional on being in the given interval. Default is False.

**Returns** **Additional keyword arguments are passed to the integration routine.**

**expect** : float

The calculated expected value.

**Notes**

The integration behavior of this function is inherited from *integrate.quad*.

`rv_continuous.median(*args, **kws)`

Median of the distribution.

**Parameters** **arg1, arg2, arg3,...** : array\_like

The shape parameter(s) for the distribution (see docstring of the instance object for more information)

**loc** : array\_like, optional

Location parameter, Default is 0.

**scale** : array\_like, optional

Scale parameter, Default is 1.

**Returns** **median** : float

The median of the distribution.

**See also:**

***stats.distributions.rv\_discrete.ppf***

Inverse of the CDF

`rv_continuous.mean(*args, **kws)`

Mean of the distribution.

**Parameters** **arg1, arg2, arg3,...** : array\_like

The shape parameter(s) for the distribution (see docstring of the instance object for more information)

**loc** : array\_like, optional

location parameter (default=0)

**scale** : array\_like, optional

scale parameter (default=1)

**Returns** **mean** : float

the mean of the distribution

`rv_continuous.std(*args, **kws)`

Standard deviation of the distribution.

**Parameters** **arg1, arg2, arg3,...** : array\_like

The shape parameter(s) for the distribution (see docstring of the instance object for more information)

**loc** : array\_like, optional  
location parameter (default=0)  
**scale** : array\_like, optional  
scale parameter (default=1)  
**Returns** **std** : float  
standard deviation of the distribution

`rv_continuous.var(*args, **kws)`  
Variance of the distribution.

**Parameters** **arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information)  
**loc** : array\_like, optional  
location parameter (default=0)  
**scale** : array\_like, optional  
scale parameter (default=1)  
**Returns** **var** : float  
the variance of the distribution

`rv_continuous.interval(alpha, *args, **kws)`  
Confidence interval with equal areas around the median.

**Parameters** **alpha** : array\_like of float  
Probability that an rv will be drawn from the returned range. Each value should be in the range [0, 1].  
**arg1, arg2, ...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information).  
**loc** : array\_like, optional  
location parameter, Default is 0.  
**scale** : array\_like, optional  
scale parameter, Default is 1.  
**Returns** **a, b** : ndarray of float  
end-points of range that contain  $100 * \alpha$  % of the rv's possible values.

`rv_continuous.__call__(*args, **kws)`  
Freeze the distribution for the given arguments.

**Parameters** **arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution. Should include all the non-optional arguments, may include `loc` and `scale`.  
**Returns** **rv\_frozen** : rv\_frozen instance  
The frozen distribution.

`rv_continuous.fit(data, *args, **kws)`  
Return MLEs for shape (if applicable), location, and scale parameters from data.

MLE stands for Maximum Likelihood Estimate. Starting estimates for the fit are given by input arguments; for any arguments not provided with starting estimates, `self._fitstart(data)` is called to generate such.

One can hold some parameters fixed to specific values by passing in keyword arguments `f0`, `f1`, ..., `fn` (for shape parameters) and `floc` and `fscale` (for location and scale parameters, respectively).

**Parameters** **data** : array\_like  
Data to use in calculating the MLEs.  
**args** : floats, optional

Starting value(s) for any shape-characterizing arguments (those not provided will be determined by a call to `_fitstart(data)`). No default value.

**kwds** : floats, optional

Starting values for the location and scale parameters; no default. Special keyword arguments are recognized as holding certain parameters fixed:

- `f0...fn` : hold respective shape parameters fixed. Alternatively, shape parameters to fix can be specified by name. For example, if `self.shapes == "a, b"`, `fa` and `fix_a` are equivalent to `f0`, and `fb` and `fix_b` are equivalent to `f1`.
- `floc` : hold location parameter fixed to specified value.
- `fscale` : hold scale parameter fixed to specified value.
- `optimizer` : The optimizer to use. The optimizer must take `func`, and starting position as the first two arguments, plus `args` (for extra arguments to pass to the function to be optimized) and `disp=0` to suppress output as keyword arguments.

**Returns**

**mle\_tuple** : tuple of floats

MLEs for any shape parameters (if applicable), followed by those for location and scale. For most random variables, shape statistics will be returned, but there are exceptions (e.g. `norm`).

### Notes

This fit is computed by maximizing a log-likelihood function, with penalty applied for samples outside of range of the distribution. The returned answer is not guaranteed to be the globally optimal MLE, it may only be locally optimal, or the optimization may fail altogether.

### Examples

Generate some data to fit: draw random variates from the *beta* distribution

```
>>> from scipy.stats import beta
>>> a, b = 1., 2.
>>> x = beta.rvs(a, b, size=1000)
```

Now we can fit all four parameters (`a`, `b`, `loc` and `scale`):

```
>>> a1, b1, loc1, scale1 = beta.fit(x)
```

We can also use some prior knowledge about the dataset: let's keep `loc` and `scale` fixed:

```
>>> a1, b1, loc1, scale1 = beta.fit(x, floc=0, fscale=1)
>>> loc1, scale1
(0, 1)
```

We can also keep shape parameters fixed by using `f`-keywords. To keep the zero-th shape parameter `a` equal 1, use `f0=1` or, equivalently, `fa=1`:

```
>>> a1, b1, loc1, scale1 = beta.fit(x, fa=1, floc=0, fscale=1)
>>> a1
1
```

Not all distributions return estimates for the shape parameters. `norm` for example just returns estimates for location and scale:

```

>>> from scipy.stats import norm
>>> x = norm.rvs(a, b, size=1000, random_state=123)
>>> loc1, scale1 = norm.fit(x)
>>> loc1, scale1
(0.92087172783841631, 2.0015750750324668)

```

`rv_continuous.fit_loc_scale` (*data*, \**args*)

Estimate loc and scale parameters from data using 1st and 2nd moments.

**Parameters**

- data** : array\_like  
Data to fit.
- arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information).

**Returns**

- Lhat** : float  
Estimated location parameter for the data.
- Shat** : float  
Estimated scale parameter for the data.

`rv_continuous.nllf` (*theta*, *x*)

Return negative loglikelihood function.

#### Notes

This is  $-\text{sum}(\log \text{pdf}(x, \text{theta}), \text{axis}=0)$  where *theta* are the parameters (including loc and scale).

**class** `scipy.stats.rv_discrete` (*a=0*, *b=inf*, *name=None*, *badvalue=None*, *moment\_tol=1e-08*, *values=None*, *inc=1*, *longname=None*, *shaper=None*, *extradoc=None*, *seed=None*)

A generic discrete random variable class meant for subclassing.

*rv\_discrete* is a base class to construct specific distribution classes and instances for discrete random variables. It can also be used to construct an arbitrary distribution defined by a list of support points and corresponding probabilities.

**Parameters**

- a** : float, optional  
Lower bound of the support of the distribution, default: 0
- b** : float, optional  
Upper bound of the support of the distribution, default: plus infinity
- moment\_tol** : float, optional  
The tolerance for the generic calculation of moments.
- values** : tuple of two array\_like, optional  
(*xk*, *pk*) where *xk* are integers with non-zero probabilities *pk* with  $\text{sum}(pk) = 1$ .
- inc** : integer, optional  
Increment for the support of the distribution. Default is 1. (other values have not been tested)
- badvalue** : float, optional  
The value in a result arrays that indicates a value that for which some argument restriction is violated, default is `np.nan`.
- name** : str, optional  
The name of the instance. This string is used to construct the default example for distributions.
- longname** : str, optional  
This string is used as part of the first line of the docstring returned when a subclass has no docstring of its own. Note: *longname* exists for backwards compatibility, do not use for new subclasses.

**shapes** : str, optional

The shape of the distribution. For example “m, n” for a distribution that takes two integers as the two shape arguments for all its methods. If not provided, shape parameters will be inferred from the signatures of the private methods, `_pmf` and `_cdf` of the instance.

**extradoc** : str, optional

This string is used as the last part of the docstring returned when a subclass has no docstring of its own. Note: *extradoc* exists for backwards compatibility, do not use for new subclasses.

**seed** : None or int or `numpy.random.RandomState` instance, optional

This parameter defines the `RandomState` object to use for drawing random variates. If None, the global `np.random` state is used. If integer, it is used to seed the local `RandomState` instance. Default is None.

### Notes

This class is similar to `rv_continuous`. Whether a shape parameter is valid is decided by an `_argcheck` method (which defaults to checking that its arguments are strictly positive.) The main differences are:

- the support of the distribution is a set of integers
- instead of the probability density function, `pdf` (and the corresponding private `_pdf`), this class defines the *probability mass function*, `pmf` (and the corresponding private `_pmf`.)
- scale parameter is not defined.

To create a new discrete distribution, we would do the following:

```
>>> from scipy.stats import rv_discrete
>>> class poisson_gen(rv_discrete):
...     "Poisson distribution"
...     def _pmf(self, k, mu):
...         return exp(-mu) * mu**k / factorial(k)
```

and create an instance:

```
>>> poisson = poisson_gen(name="poisson")
```

Note that above we defined the Poisson distribution in the standard form. Shifting the distribution can be done by providing the `loc` parameter to the methods of the instance. For example, `poisson.pmf(x, mu, loc)` delegates the work to `poisson._pmf(x-loc, mu)`.

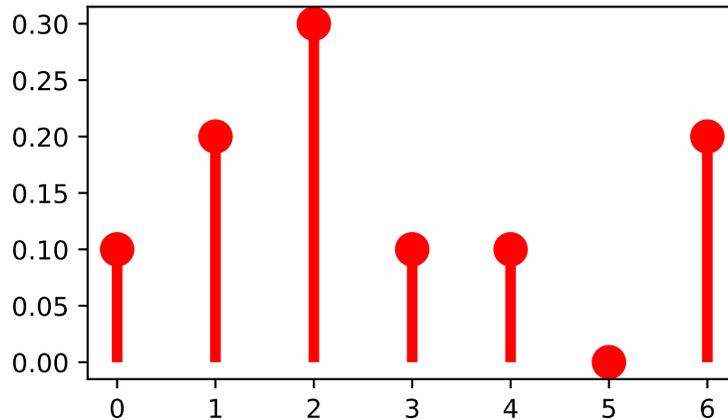
### Discrete distributions from a list of probabilities

Alternatively, you can construct an arbitrary discrete rv defined on a finite set of values  $x_k$  with  $\text{Prob}\{X=x_k\} = p_k$  by using the `values` keyword argument to the `rv_discrete` constructor.

### Examples

Custom made discrete distribution:

```
>>> from scipy import stats
>>> xk = np.arange(7)
>>> pk = (0.1, 0.2, 0.3, 0.1, 0.1, 0.0, 0.2)
>>> custm = stats.rv_discrete(name='custm', values=(xk, pk))
>>>
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
>>> ax.plot(xk, custm.pmf(xk), 'ro', ms=12, mec='r')
>>> ax.vlines(xk, 0, custm.pmf(xk), colors='r', lw=4)
>>> plt.show()
```



Random number generation:

```
>>> R = custom.rvs(size=100)
```

### Attributes

<code>random_state</code>	Get or set the RandomState object for generating random variates.
---------------------------	---

### `rv_discrete.random_state`

Get or set the RandomState object for generating random variates.

This can be either None or an existing RandomState object.

If None (or `np.random`), use the RandomState singleton used by `np.random`. If already a RandomState instance, use it. If an int, use a new RandomState instance seeded with `seed`.

### Methods

<code>rvs(*args, **kwargs)</code>	Random variates of given type.
<code>pmf(k, *args, **kwargs)</code>	Probability mass function at $k$ of the given RV.
<code>logpmf(k, *args, **kwargs)</code>	Log of the probability mass function at $k$ of the given RV.
<code>cdf(k, *args, **kwargs)</code>	Cumulative distribution function of the given RV.
<code>logcdf(k, *args, **kwargs)</code>	Log of the cumulative distribution function at $k$ of the given RV.
<code>sf(k, *args, **kwargs)</code>	Survival function ( $1 - cdf$ ) at $k$ of the given RV.
<code>logsf(k, *args, **kwargs)</code>	Log of the survival function of the given RV.
<code>ppf(q, *args, **kwargs)</code>	Percent point function (inverse of $cdf$ ) at $q$ of the given RV.
<code>isf(q, *args, **kwargs)</code>	Inverse survival function (inverse of $sf$ ) at $q$ of the given RV.
<code>moment(n, *args, **kwargs)</code>	$n$ -th order non-central moment of distribution.
<code>stats(*args, **kwargs)</code>	Some statistics of the given RV.

Continued on next page

Table 5.284 – continued from previous page

<code>entropy(*args, **kwargs)</code>	Differential entropy of the RV.
<code>expect([func, args, loc, lb, ub, ...])</code>	Calculate expected value of a function with respect to the distribution for discrete distribution.
<code>median(*args, **kwargs)</code>	Median of the distribution.
<code>mean(*args, **kwargs)</code>	Mean of the distribution.
<code>std(*args, **kwargs)</code>	Standard deviation of the distribution.
<code>var(*args, **kwargs)</code>	Variance of the distribution.
<code>interval(alpha, *args, **kwargs)</code>	Confidence interval with equal areas around the median.
<code>__call__(*args, **kwargs)</code>	Freeze the distribution for the given arguments.

`rv_discrete.rvs(*args, **kwargs)`

Random variates of given type.

**Parameters** `arg1, arg2, arg3,...` : array\_like  
 The shape parameter(s) for the distribution (see docstring of the instance object for more information).

`loc` : array\_like, optional  
 Location parameter (default=0).

`size` : int or tuple of ints, optional  
 Defining number of random variates (Default is 1). Note that *size* has to be given as keyword, not as positional argument.

`random_state` : None or int or `np.random.RandomState` instance, optional  
 If int or `RandomState`, use it for drawing the random variates. If None, rely on `self.random_state`. Default is None.

**Returns** `rvs` : ndarray or scalar  
 Random variates of given *size*.

`rv_discrete.pmf(k, *args, **kwargs)`

Probability mass function at k of the given RV.

**Parameters** `k` : array\_like  
 Quantiles.

`arg1, arg2, arg3,...` : array\_like  
 The shape parameter(s) for the distribution (see docstring of the instance object for more information)

`loc` : array\_like, optional  
 Location parameter (default=0).

**Returns** `pmf` : array\_like  
 Probability mass function evaluated at k

`rv_discrete.logpmf(k, *args, **kwargs)`

Log of the probability mass function at k of the given RV.

**Parameters** `k` : array\_like  
 Quantiles.

`arg1, arg2, arg3,...` : array\_like  
 The shape parameter(s) for the distribution (see docstring of the instance object for more information).

`loc` : array\_like, optional  
 Location parameter. Default is 0.

**Returns** `logpmf` : array\_like  
 Log of the probability mass function evaluated at k.

`rv_discrete.cdf(k, *args, **kwargs)`

Cumulative distribution function of the given RV.

**Parameters** `k` : array\_like, int

Quantiles.  
**arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information).  
**loc** : array\_like, optional  
Location parameter (default=0).  
**Returns** **cdf** : ndarray  
Cumulative distribution function evaluated at  $k$ .

`rv_discrete.logcdf(k, *args, **kws)`  
Log of the cumulative distribution function at  $k$  of the given RV.

**Parameters** **k** : array\_like, int  
Quantiles.  
**arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information).  
**loc** : array\_like, optional  
Location parameter (default=0).  
**Returns** **logcdf** : array\_like  
Log of the cumulative distribution function evaluated at  $k$ .

`rv_discrete.sf(k, *args, **kws)`  
Survival function ( $1 - cdf$ ) at  $k$  of the given RV.

**Parameters** **k** : array\_like  
Quantiles.  
**arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information).  
**loc** : array\_like, optional  
Location parameter (default=0).  
**Returns** **sf** : array\_like  
Survival function evaluated at  $k$ .

`rv_discrete.logsf(k, *args, **kws)`  
Log of the survival function of the given RV.  
Returns the log of the “survival function,” defined as  $1 - cdf$ , evaluated at  $k$ .

**Parameters** **k** : array\_like  
Quantiles.  
**arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information).  
**loc** : array\_like, optional  
Location parameter (default=0).  
**Returns** **logsf** : ndarray  
Log of the survival function evaluated at  $k$ .

`rv_discrete.ppf(q, *args, **kws)`  
Percent point function (inverse of  $cdf$ ) at  $q$  of the given RV.

**Parameters** **q** : array\_like  
Lower tail probability.  
**arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information).  
**loc** : array\_like, optional  
Location parameter (default=0).  
**Returns** **k** : array\_like

Quantile corresponding to the lower tail probability,  $q$ .

`rv_discrete.isf(q, *args, **kws)`

Inverse survival function (inverse of  $s_f$ ) at  $q$  of the given RV.

**Parameters** **q** : array\_like

Upper tail probability.

**arg1, arg2, arg3,...** : array\_like

The shape parameter(s) for the distribution (see docstring of the instance object for more information).

**loc** : array\_like, optional

Location parameter (default=0).

**Returns**

**k** : ndarray or scalar

Quantile corresponding to the upper tail probability,  $q$ .

`rv_discrete.moment(n, *args, **kws)`

$n$ -th order non-central moment of distribution.

**Parameters** **n** : int,  $n \geq 1$

Order of moment.

**arg1, arg2, arg3,...** : float

The shape parameter(s) for the distribution (see docstring of the instance object for more information).

**loc** : array\_like, optional

location parameter (default=0)

**scale** : array\_like, optional

scale parameter (default=1)

`rv_discrete.stats(*args, **kws)`

Some statistics of the given RV.

**Parameters** **arg1, arg2, arg3,...** : array\_like

The shape parameter(s) for the distribution (see docstring of the instance object for more information)

**loc** : array\_like, optional

location parameter (default=0)

**scale** : array\_like, optional (continuous RVs only)

scale parameter (default=1)

**moments** : str, optional

composed of letters ['mvsk'] defining which moments to compute: 'm' = mean, 'v' = variance, 's' = (Fisher's) skew, 'k' = (Fisher's)

kurtosis. (default is 'mv')

**Returns**

**stats** : sequence

of requested moments.

`rv_discrete.entropy(*args, **kws)`

Differential entropy of the RV.

**Parameters** **arg1, arg2, arg3,...** : array\_like

The shape parameter(s) for the distribution (see docstring of the instance object for more information).

**loc** : array\_like, optional

Location parameter (default=0).

**scale** : array\_like, optional (continuous distributions only).

Scale parameter (default=1).

**Notes**

Entropy is defined base  $e$ :

```
>>> drv = rv_discrete(values=((0, 1), (0.5, 0.5)))
>>> np.allclose(drv.entropy(), np.log(2.0))
True
```

`rv_discrete.expect` (*func=None, args=(), loc=0, lb=None, ub=None, conditional=False, maxcount=1000, tolerance=1e-10, chunksize=32*)

Calculate expected value of a function with respect to the distribution for discrete distribution.

**Parameters**

- func** : callable, optional  
Function for which the expectation value is calculated. Takes only one argument. The default is the identity mapping  $f(k) = k$ .
- args** : tuple, optional  
Shape parameters of the distribution.
- loc** : float, optional  
Location parameter. Default is 0.
- lb, ub** : int, optional  
Lower and upper bound for the summation, default is set to the support of the distribution, inclusive ( $ul \leq k \leq ub$ ).
- conditional** : bool, optional  
If true then the expectation is corrected by the conditional probability of the summation interval. The return value is the expectation of the function, *func*, conditional on being in the given interval ( $k$  such that  $ul \leq k \leq ub$ ). Default is False.
- maxcount** : int, optional  
Maximal number of terms to evaluate (to avoid an endless loop for an infinite sum). Default is 1000.
- tolerance** : float, optional  
Absolute tolerance for the summation. Default is 1e-10.
- chunksize** : int, optional  
Iterate over the support of a distributions in chunks of this size. Default is 32.

**Returns**

- expect** : float  
Expected value.

**Notes**

For heavy-tailed distributions, the expected value may or may not exist, depending on the function, *func*. If it does exist, but the sum converges slowly, the accuracy of the result may be rather low. For instance, for `zipf(4)`, accuracy for mean, variance in example is only 1e-5. increasing *maxcount* and/or *chunksize* may improve the result, but may also make `zipf` very slow.

The function is not vectorized.

`rv_discrete.median` (*\*args, \*\*kws*)

Median of the distribution.

**Parameters**

- arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information)
- loc** : array\_like, optional  
Location parameter, Default is 0.
- scale** : array\_like, optional  
Scale parameter, Default is 1.

**Returns**

- median** : float  
The median of the distribution.

See also:

***stats.distributions.rv\_discrete.ppf***

Inverse of the CDF

`rv_discrete.mean(*args, **kws)`

Mean of the distribution.

**Parameters** **arg1, arg2, arg3,...** : array\_like  
 The shape parameter(s) for the distribution (see docstring of the instance object for more information)  
**loc** : array\_like, optional  
 location parameter (default=0)  
**scale** : array\_like, optional  
 scale parameter (default=1)  
**Returns** **mean** : float  
 the mean of the distribution

`rv_discrete.std(*args, **kws)`

Standard deviation of the distribution.

**Parameters** **arg1, arg2, arg3,...** : array\_like  
 The shape parameter(s) for the distribution (see docstring of the instance object for more information)  
**loc** : array\_like, optional  
 location parameter (default=0)  
**scale** : array\_like, optional  
 scale parameter (default=1)  
**Returns** **std** : float  
 standard deviation of the distribution

`rv_discrete.var(*args, **kws)`

Variance of the distribution.

**Parameters** **arg1, arg2, arg3,...** : array\_like  
 The shape parameter(s) for the distribution (see docstring of the instance object for more information)  
**loc** : array\_like, optional  
 location parameter (default=0)  
**scale** : array\_like, optional  
 scale parameter (default=1)  
**Returns** **var** : float  
 the variance of the distribution

`rv_discrete.interval(alpha, *args, **kws)`

Confidence interval with equal areas around the median.

**Parameters** **alpha** : array\_like of float  
 Probability that an rv will be drawn from the returned range. Each value should be in the range [0, 1].  
**arg1, arg2, ...** : array\_like  
 The shape parameter(s) for the distribution (see docstring of the instance object for more information).  
**loc** : array\_like, optional  
 location parameter, Default is 0.  
**scale** : array\_like, optional  
 scale parameter, Default is 1.  
**Returns** **a, b** : ndarray of float  
 end-points of range that contain  $100 * \alpha$  % of the rv's possible values.

`rv_discrete.__call__(*args, **kwargs)`

Freeze the distribution for the given arguments.

**Parameters** `arg1, arg2, arg3,...` : array\_like

The shape parameter(s) for the distribution. Should include all the non-optional arguments, may include `loc` and `scale`.

**Returns** `rv_frozen` : `rv_frozen` instance

The frozen distribution.

**class** `scipy.stats.rv_histogram`(*histogram*, \*args, \*\*kwargs)

Generates a distribution given by a histogram. This is useful to generate a template distribution from a binned datasample.

As a subclass of the `rv_continuous` class, `rv_histogram` inherits from it a collection of generic methods (see `rv_continuous` for the full list), and implements them based on the properties of the provided binned datasample.

**Parameters** `histogram` : tuple of array\_like

Tuple containing two array\_like objects The first containing the content of n bins The second containing the (n+1) bin boundaries In particular the return value `np.histogram` is accepted

### Notes

There are no additional shape parameters except for the `loc` and `scale`. The pdf is defined as a stepwise function from the provided histogram The cdf is a linear interpolation of the pdf.

New in version 0.19.0.

### Examples

Create a `scipy.stats` distribution from a numpy histogram

```
>>> import scipy.stats
>>> import numpy as np
>>> data = scipy.stats.norm.rvs(size=100000, loc=0, scale=1.5, random_state=123)
>>> hist = np.histogram(data, bins=100)
>>> hist_dist = scipy.stats.rv_histogram(hist)
```

Behaves like an ordinary `scipy rv_continuous` distribution

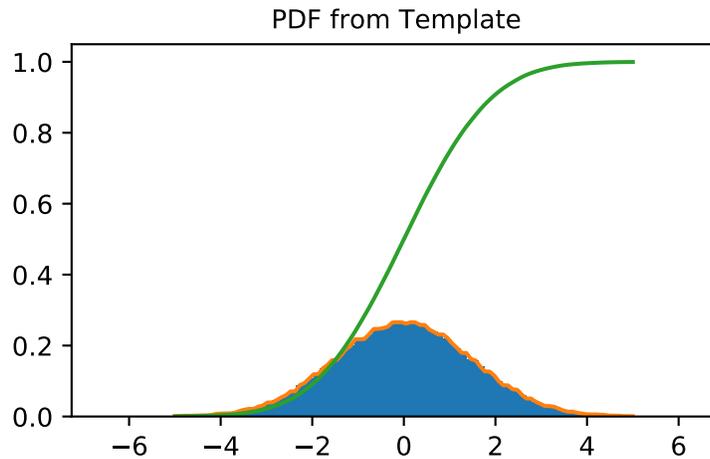
```
>>> hist_dist.pdf(1.0)
0.20538577847618705
>>> hist_dist.cdf(2.0)
0.90818568543056499
```

PDF is zero above (below) the highest (lowest) bin of the histogram, defined by the max (min) of the original dataset

```
>>> hist_dist.pdf(np.max(data))
0.0
>>> hist_dist.cdf(np.max(data))
1.0
>>> hist_dist.pdf(np.min(data))
7.7591907244498314e-05
>>> hist_dist.cdf(np.min(data))
0.0
```

PDF and CDF follow the histogram

```
>>> import matplotlib.pyplot as plt
>>> X = np.linspace(-5.0, 5.0, 100)
>>> plt.title("PDF from Template")
>>> plt.hist(data, normed=True, bins=100)
>>> plt.plot(X, hist_dist.pdf(X), label='PDF')
>>> plt.plot(X, hist_dist.cdf(X), label='CDF')
>>> plt.show()
```



**Attributes**

*random\_state* Get or set the RandomState object for generating random variates.

**rv\_histogram.random\_state**

Get or set the RandomState object for generating random variates.

This can be either None or an existing RandomState object.

If None (or np.random), use the RandomState singleton used by np.random. If already a RandomState instance, use it. If an int, use a new RandomState instance seeded with seed.

**Methods**

<i>__call__</i> (*args, **kwargs)	Freeze the distribution for the given arguments.
<i>cdf</i> (x, *args, **kwargs)	Cumulative distribution function of the given RV.
<i>entropy</i> (*args, **kwargs)	Differential entropy of the RV.
<i>expect</i> ([func, args, loc, scale, lb, ub, ...])	Calculate expected value of a function with respect to the distribution.
<i>fit</i> (data, *args, **kwargs)	Return MLEs for shape (if applicable), location, and scale parameters from data.
<i>fit_loc_scale</i> (data, *args)	Estimate loc and scale parameters from data using 1st and 2nd moments.
<i>freeze</i> (*args, **kwargs)	Freeze the distribution for the given arguments.
<i>interval</i> (alpha, *args, **kwargs)	Confidence interval with equal areas around the median.

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Table 5.286 – continued from previous page

<code>isf(q, *args, **kws)</code>	Inverse survival function (inverse of <i>sf</i> ) at <i>q</i> of the given RV.
<code>logcdf(x, *args, **kws)</code>	Log of the cumulative distribution function at <i>x</i> of the given RV.
<code>logpdf(x, *args, **kws)</code>	Log of the probability density function at <i>x</i> of the given RV.
<code>logsf(x, *args, **kws)</code>	Log of the survival function of the given RV.
<code>mean(*args, **kws)</code>	Mean of the distribution.
<code>median(*args, **kws)</code>	Median of the distribution.
<code>moment(n, *args, **kws)</code>	<i>n</i> -th order non-central moment of distribution.
<code>nllf(theta, x)</code>	Return negative loglikelihood function.
<code>pdf(x, *args, **kws)</code>	Probability density function at <i>x</i> of the given RV.
<code>ppf(q, *args, **kws)</code>	Percent point function (inverse of <i>cdf</i> ) at <i>q</i> of the given RV.
<code>rvs(*args, **kws)</code>	Random variates of given type.
<code>sf(x, *args, **kws)</code>	Survival function ( $1 - cdf$ ) at <i>x</i> of the given RV.
<code>stats(*args, **kws)</code>	Some statistics of the given RV.
<code>std(*args, **kws)</code>	Standard deviation of the distribution.
<code>var(*args, **kws)</code>	Variance of the distribution.

`rv_histogram.__call__(*args, **kws)`

Freeze the distribution for the given arguments.

**Parameters** `arg1, arg2, arg3,...` : array\_like

The shape parameter(s) for the distribution. Should include all the non-optional arguments, may include `loc` and `scale`.

**Returns** `rv_frozen` : `rv_frozen` instance

The frozen distribution.

`rv_histogram.cdf(x, *args, **kws)`

Cumulative distribution function of the given RV.

**Parameters** `x` : array\_like

quantiles

`arg1, arg2, arg3,...` : array\_like

The shape parameter(s) for the distribution (see docstring of the instance object for more information)

`loc` : array\_like, optional

location parameter (default=0)

`scale` : array\_like, optional

scale parameter (default=1)

**Returns** `cdf` : ndarray

Cumulative distribution function evaluated at *x*

`rv_histogram.entropy(*args, **kws)`

Differential entropy of the RV.

**Parameters** `arg1, arg2, arg3,...` : array\_like

The shape parameter(s) for the distribution (see docstring of the instance object for more information).

`loc` : array\_like, optional

Location parameter (default=0).

`scale` : array\_like, optional (continuous distributions only).

Scale parameter (default=1).

*Notes*

Entropy is defined base  $e$ :

```
>>> drv = rv_discrete(values=((0, 1), (0.5, 0.5)))
>>> np.allclose(drv.entropy(), np.log(2.0))
True
```

`rv_histogram.expect` (*func=None, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, \*\*kwds*)

Calculate expected value of a function with respect to the distribution.

The expected value of a function  $f(x)$  with respect to a distribution `dist` is defined as:

$$E[x] = \int_{lb}^{ub} f(x) * dist.pdf(x)$$

- Parameters**
- func** : callable, optional  
Function for which integral is calculated. Takes only one argument. The default is the identity mapping  $f(x) = x$ .
  - args** : tuple, optional  
Shape parameters of the distribution.
  - loc** : float, optional  
Location parameter (default=0).
  - scale** : float, optional  
Scale parameter (default=1).
  - lb, ub** : scalar, optional  
Lower and upper bound for integration. Default is set to the support of the distribution.
  - conditional** : bool, optional  
If True, the integral is corrected by the conditional probability of the integration interval. The return value is the expectation of the function, conditional on being in the given interval. Default is False.
- Returns**
- expect** : float  
**Additional keyword arguments are passed to the integration routine.**  
The calculated expected value.

*Notes*

The integration behavior of this function is inherited from `integrate.quad`.

`rv_histogram.fit` (*data, \*args, \*\*kwds*)

Return MLEs for shape (if applicable), location, and scale parameters from data.

MLE stands for Maximum Likelihood Estimate. Starting estimates for the fit are given by input arguments; for any arguments not provided with starting estimates, `self._fitstart(data)` is called to generate such.

One can hold some parameters fixed to specific values by passing in keyword arguments `f0, f1, ..., fn` (for shape parameters) and `floc` and `fscale` (for location and scale parameters, respectively).

- Parameters**
- data** : array\_like  
Data to use in calculating the MLEs.
  - args** : floats, optional  
Starting value(s) for any shape-characterizing arguments (those not provided will be determined by a call to `_fitstart(data)`). No default value.
  - kwds** : floats, optional

Starting values for the location and scale parameters; no default. Special keyword arguments are recognized as holding certain parameters fixed:

- `f0...fn` : hold respective shape parameters fixed. Alternatively, shape parameters to fix can be specified by name. For example, if `self.shapes == "a, b"`, `fa` and `fix_a` are equivalent to `f0`, and `fb` and `fix_b` are equivalent to `f1`.
- `floc` : hold location parameter fixed to specified value.
- `fscale` : hold scale parameter fixed to specified value.
- `optimizer` : The optimizer to use. The optimizer must take `func`, and starting position as the first two arguments, plus `args` (for extra arguments to pass to the function to be optimized) and `disp=0` to suppress output as keyword arguments.

**Returns** `mle_tuple` : tuple of floats

MLEs for any shape parameters (if applicable), followed by those for location and scale. For most random variables, shape statistics will be returned, but there are exceptions (e.g. `norm`).

### Notes

This fit is computed by maximizing a log-likelihood function, with penalty applied for samples outside of range of the distribution. The returned answer is not guaranteed to be the globally optimal MLE, it may only be locally optimal, or the optimization may fail altogether.

### Examples

Generate some data to fit: draw random variates from the *beta* distribution

```
>>> from scipy.stats import beta
>>> a, b = 1., 2.
>>> x = beta.rvs(a, b, size=1000)
```

Now we can fit all four parameters (`a`, `b`, `loc` and `scale`):

```
>>> a1, b1, loc1, scale1 = beta.fit(x)
```

We can also use some prior knowledge about the dataset: let's keep `loc` and `scale` fixed:

```
>>> a1, b1, loc1, scale1 = beta.fit(x, floc=0, fscale=1)
>>> loc1, scale1
(0, 1)
```

We can also keep shape parameters fixed by using `f`-keywords. To keep the zero-th shape parameter `a` equal 1, use `f0=1` or, equivalently, `fa=1`:

```
>>> a1, b1, loc1, scale1 = beta.fit(x, fa=1, floc=0, fscale=1)
>>> a1
1
```

Not all distributions return estimates for the shape parameters. `norm` for example just returns estimates for location and scale:

```
>>> from scipy.stats import norm
>>> x = norm.rvs(a, b, size=1000, random_state=123)
>>> loc1, scale1 = norm.fit(x)
>>> loc1, scale1
(0.92087172783841631, 2.0015750750324668)
```

`rv_histogram.fit_loc_scale` (*data*, \**args*)

Estimate loc and scale parameters from data using 1st and 2nd moments.

**Parameters**

- data** : array\_like  
Data to fit.
- arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information).

**Returns**

- Lhat** : float  
Estimated location parameter for the data.
- Shat** : float  
Estimated scale parameter for the data.

`rv_histogram.freeze` (\**args*, \*\**kws*)

Freeze the distribution for the given arguments.

**Parameters**

- arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution. Should include all the non-optional arguments, may include `loc` and `scale`.

**Returns**

- rv\_frozen** : `rv_frozen` instance  
The frozen distribution.

`rv_histogram.interval` (*alpha*, \**args*, \*\**kws*)

Confidence interval with equal areas around the median.

**Parameters**

- alpha** : array\_like of float  
Probability that an rv will be drawn from the returned range. Each value should be in the range [0, 1].
- arg1, arg2, ...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information).
- loc** : array\_like, optional  
location parameter, Default is 0.
- scale** : array\_like, optional  
scale parameter, Default is 1.

**Returns**

- a, b** : ndarray of float  
end-points of range that contain  $100 * \alpha$  % of the rv's possible values.

`rv_histogram.isf` (*q*, \**args*, \*\**kws*)

Inverse survival function (inverse of  $s_f$ ) at *q* of the given RV.

**Parameters**

- q** : array\_like  
upper tail probability
- arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information)
- loc** : array\_like, optional  
location parameter (default=0)
- scale** : array\_like, optional  
scale parameter (default=1)

**Returns**

- x** : ndarray or scalar  
Quantile corresponding to the upper tail probability *q*.

`rv_histogram.logcdf` (*x*, \**args*, \*\**kws*)

Log of the cumulative distribution function at *x* of the given RV.

**Parameters**

- x** : array\_like  
quantiles
- arg1, arg2, arg3,...** : array\_like

The shape parameter(s) for the distribution (see docstring of the instance object for more information)

**loc** : array\_like, optional  
location parameter (default=0)

**scale** : array\_like, optional  
scale parameter (default=1)

**Returns** **logcdf** : array\_like  
Log of the cumulative distribution function evaluated at x

`rv_histogram.logpdf(x, *args, **kwargs)`  
Log of the probability density function at x of the given RV.  
This uses a more numerically accurate calculation if available.

**Parameters** **x** : array\_like  
quantiles

**arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information)

**loc** : array\_like, optional  
location parameter (default=0)

**scale** : array\_like, optional  
scale parameter (default=1)

**Returns** **logpdf** : array\_like  
Log of the probability density function evaluated at x

`rv_histogram.logsf(x, *args, **kwargs)`  
Log of the survival function of the given RV.  
Returns the log of the “survival function,” defined as  $(1 - cdf)$ , evaluated at x.

**Parameters** **x** : array\_like  
quantiles

**arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information)

**loc** : array\_like, optional  
location parameter (default=0)

**scale** : array\_like, optional  
scale parameter (default=1)

**Returns** **logsf** : ndarray  
Log of the survival function evaluated at x.

`rv_histogram.mean(*args, **kwargs)`  
Mean of the distribution.

**Parameters** **arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information)

**loc** : array\_like, optional  
location parameter (default=0)

**scale** : array\_like, optional  
scale parameter (default=1)

**Returns** **mean** : float  
the mean of the distribution

`rv_histogram.median(*args, **kwargs)`  
Median of the distribution.

**Parameters** **arg1, arg2, arg3,...** : array\_like

The shape parameter(s) for the distribution (see docstring of the instance object for more information)

**loc** : array\_like, optional  
Location parameter, Default is 0.

**scale** : array\_like, optional  
Scale parameter, Default is 1.

**Returns** **median** : float  
The median of the distribution.

**See also:**

***stats.distributions.rv\_discrete.ppf***

Inverse of the CDF

`rv_histogram.moment` (*n*, \*args, \*\*kwargs)  
n-th order non-central moment of distribution.

**Parameters** **n** : int, n >= 1  
Order of moment.

**arg1, arg2, arg3,...** : float  
The shape parameter(s) for the distribution (see docstring of the instance object for more information).

**loc** : array\_like, optional  
location parameter (default=0)

**scale** : array\_like, optional  
scale parameter (default=1)

`rv_histogram.nnlf` (*theta*, *x*)  
Return negative loglikelihood function.

**Notes**

This is  $-\text{sum}(\log \text{pdf}(x, \text{theta}), \text{axis}=0)$  where *theta* are the parameters (including loc and scale).

`rv_histogram.pdf` (*x*, \*args, \*\*kwargs)  
Probability density function at x of the given RV.

**Parameters** **x** : array\_like  
quantiles

**arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information)

**loc** : array\_like, optional  
location parameter (default=0)

**scale** : array\_like, optional  
scale parameter (default=1)

**Returns** **pdf** : ndarray  
Probability density function evaluated at x

`rv_histogram.ppf` (*q*, \*args, \*\*kwargs)  
Percent point function (inverse of *cdf*) at q of the given RV.

**Parameters** **q** : array\_like  
lower tail probability

**arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information)

**loc** : array\_like, optional  
location parameter (default=0)

**Returns** **scale** : array\_like, optional  
 scale parameter (default=1)  
**x** : array\_like  
 quantile corresponding to the lower tail probability  $q$ .

`rv_histogram.rvs (*args, **kws)`  
 Random variates of given type.

**Parameters** **arg1, arg2, arg3,...** : array\_like  
 The shape parameter(s) for the distribution (see docstring of the instance object for more information).  
**loc** : array\_like, optional  
 Location parameter (default=0).  
**scale** : array\_like, optional  
 Scale parameter (default=1).  
**size** : int or tuple of ints, optional  
 Defining number of random variates (default is 1).  
**random\_state** : None or int or `np.random.RandomState` instance, optional  
 If int or `RandomState`, use it for drawing the random variates. If None, rely on `self.random_state`. Default is None.  
**Returns** **rvs** : ndarray or scalar  
 Random variates of given *size*.

`rv_histogram.sf (x, *args, **kws)`  
 Survival function ( $1 - cdf$ ) at  $x$  of the given RV.

**Parameters** **x** : array\_like  
 quantiles  
**arg1, arg2, arg3,...** : array\_like  
 The shape parameter(s) for the distribution (see docstring of the instance object for more information)  
**loc** : array\_like, optional  
 location parameter (default=0)  
**scale** : array\_like, optional  
 scale parameter (default=1)  
**Returns** **sf** : array\_like  
 Survival function evaluated at  $x$

`rv_histogram.stats (*args, **kws)`  
 Some statistics of the given RV.

**Parameters** **arg1, arg2, arg3,...** : array\_like  
 The shape parameter(s) for the distribution (see docstring of the instance object for more information)  
**loc** : array\_like, optional  
 location parameter (default=0)  
**scale** : array\_like, optional (continuous RVs only)  
 scale parameter (default=1)  
**moments** : str, optional  
 composed of letters ['mvsk'] defining which moments to compute: 'm' = mean, 'v' = variance, 's' = (Fisher's) skew, 'k' = (Fisher's) kurtosis. (default is 'mv')  
**Returns** **stats** : sequence  
 of requested moments.

`rv_histogram.std (*args, **kws)`  
 Standard deviation of the distribution.

**Parameters** **arg1, arg2, arg3,...** : array\_like

The shape parameter(s) for the distribution (see docstring of the instance object for more information)

**loc** : array\_like, optional  
location parameter (default=0)

**scale** : array\_like, optional  
scale parameter (default=1)

**Returns** **std** : float  
standard deviation of the distribution

`rv_histogram.var(*args, **kws)`  
Variance of the distribution.

**Parameters** **arg1, arg2, arg3,...** : array\_like  
The shape parameter(s) for the distribution (see docstring of the instance object for more information)

**loc** : array\_like, optional  
location parameter (default=0)

**scale** : array\_like, optional  
scale parameter (default=1)

**Returns** **var** : float  
the variance of the distribution

### 5.27.1 Continuous distributions

<i>alpha</i>	An alpha continuous random variable.
<i>anglit</i>	An anglit continuous random variable.
<i>arcsine</i>	An arcsine continuous random variable.
<i>argus</i>	Argus distribution
<i>beta</i>	A beta continuous random variable.
<i>betaprime</i>	A beta prime continuous random variable.
<i>bradford</i>	A Bradford continuous random variable.
<i>burr</i>	A Burr (Type III) continuous random variable.
<i>burr12</i>	A Burr (Type XII) continuous random variable.
<i>cauchy</i>	A Cauchy continuous random variable.
<i>chi</i>	A chi continuous random variable.
<i>chi2</i>	A chi-squared continuous random variable.
<i>cosine</i>	A cosine continuous random variable.
<i>crystalball</i>	Crystalball distribution
<i>dgamma</i>	A double gamma continuous random variable.
<i>dweibull</i>	A double Weibull continuous random variable.
<i>erlang</i>	An Erlang continuous random variable.
<i>expon</i>	An exponential continuous random variable.
<i>exponnorm</i>	An exponentially modified Normal continuous random variable.
<i>exponweib</i>	An exponentiated Weibull continuous random variable.
<i>exponpow</i>	An exponential power continuous random variable.
<i>f</i>	An F continuous random variable.
<i>fatiguelife</i>	A fatigue-life (Birnbau-Saunders) continuous random variable.
<i>fisk</i>	A Fisk continuous random variable.
<i>foldcauchy</i>	A folded Cauchy continuous random variable.
<i>foldnorm</i>	A folded normal continuous random variable.

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Table 5.287 – continued from previous page

<i>frechet_r</i>	A frechet_r continuous random variable.
<i>frechet_l</i>	A frechet_l continuous random variable.
<i>genlogistic</i>	A generalized logistic continuous random variable.
<i>gennorm</i>	A generalized normal continuous random variable.
<i>genpareto</i>	A generalized Pareto continuous random variable.
<i>genexpon</i>	A generalized exponential continuous random variable.
<i>genextreme</i>	A generalized extreme value continuous random variable.
<i>gausshyper</i>	A Gauss hypergeometric continuous random variable.
<i>gamma</i>	A gamma continuous random variable.
<i>gengamma</i>	A generalized gamma continuous random variable.
<i>genhalflogistic</i>	A generalized half-logistic continuous random variable.
<i>gilbrat</i>	A Gilbrat continuous random variable.
<i>gompertz</i>	A Gompertz (or truncated Gumbel) continuous random variable.
<i>gumbel_r</i>	A right-skewed Gumbel continuous random variable.
<i>gumbel_l</i>	A left-skewed Gumbel continuous random variable.
<i>halfcauchy</i>	A Half-Cauchy continuous random variable.
<i>halflogistic</i>	A half-logistic continuous random variable.
<i>halfnorm</i>	A half-normal continuous random variable.
<i>halfgennorm</i>	The upper half of a generalized normal continuous random variable.
<i>hypsecant</i>	A hyperbolic secant continuous random variable.
<i>invgamma</i>	An inverted gamma continuous random variable.
<i>invgauss</i>	An inverse Gaussian continuous random variable.
<i>invweibull</i>	An inverted Weibull continuous random variable.
<i>johnsonsb</i>	A Johnson SB continuous random variable.
<i>johnsonsu</i>	A Johnson SU continuous random variable.
<i>kappa4</i>	Kappa 4 parameter distribution.
<i>kappa3</i>	Kappa 3 parameter distribution.
<i>ksone</i>	General Kolmogorov-Smirnov one-sided test.
<i>kstwobign</i>	Kolmogorov-Smirnov two-sided test for large N.
<i>laplace</i>	A Laplace continuous random variable.
<i>levy</i>	A Levy continuous random variable.
<i>levy_l</i>	A left-skewed Levy continuous random variable.
<i>levy_stable</i>	A Levy-stable continuous random variable.
<i>logistic</i>	A logistic (or Sech-squared) continuous random variable.
<i>loggamma</i>	A log gamma continuous random variable.
<i>loglaplace</i>	A log-Laplace continuous random variable.
<i>lognorm</i>	A lognormal continuous random variable.
<i>lomax</i>	A Lomax (Pareto of the second kind) continuous random variable.
<i>maxwell</i>	A Maxwell continuous random variable.
<i>mielke</i>	A Mielke's Beta-Kappa continuous random variable.
<i>nakagami</i>	A Nakagami continuous random variable.
<i>ncx2</i>	A non-central chi-squared continuous random variable.
<i>ncf</i>	A non-central F distribution continuous random variable.
<i>nct</i>	A non-central Student's T continuous random variable.
<i>norm</i>	A normal continuous random variable.
<i>pareto</i>	A Pareto continuous random variable.
<i>pearson3</i>	A pearson type III continuous random variable.

Continued on next page

Table 5.287 – continued from previous page

<i>powerlaw</i>	A power-function continuous random variable.
<i>powerlognorm</i>	A power log-normal continuous random variable.
<i>powernorm</i>	A power normal continuous random variable.
<i>rdist</i>	An R-distributed continuous random variable.
<i>reciprocal</i>	A reciprocal continuous random variable.
<i>rayleigh</i>	A Rayleigh continuous random variable.
<i>rice</i>	A Rice continuous random variable.
<i>recipinvgauss</i>	A reciprocal inverse Gaussian continuous random variable.
<i>semicircular</i>	A semicircular continuous random variable.
<i>skewnorm</i>	A skew-normal random variable.
<i>t</i>	A Student's T continuous random variable.
<i>trapz</i>	A trapezoidal continuous random variable.
<i>triang</i>	A triangular continuous random variable.
<i>truncexpon</i>	A truncated exponential continuous random variable.
<i>truncnorm</i>	A truncated normal continuous random variable.
<i>tukeylambda</i>	A Tukey-Lambda continuous random variable.
<i>uniform</i>	A uniform continuous random variable.
<i>vonmises</i>	A Von Mises continuous random variable.
<i>vonmises_line</i>	A Von Mises continuous random variable.
<i>wald</i>	A Wald continuous random variable.
<i>weibull_min</i>	Weibull minimum continuous random variable.
<i>weibull_max</i>	Weibull maximum continuous random variable.
<i>wrapcauchy</i>	A wrapped Cauchy continuous random variable.

`scipy.stats.alpha = <scipy.stats.continuous_distns.alpha_gen object>`

An alpha continuous random variable.

As an instance of the `rv_continuous` class, `alpha` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for `alpha` is:

$$f(x, a) = \frac{1}{x^2 \Phi(a) \sqrt{2\pi}} * \exp\left(-\frac{1}{2}(a - 1/x)^2\right)$$

where  $\Phi(a)$  is the normal CDF,  $x > 0$ , and  $a > 0$ .

`alpha` takes `a` as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `alpha.pdf(x, a, loc, scale)` is identically equivalent to `alpha.pdf(y, a) / scale` with `y = (x - loc) / scale`.

### Examples

```
>>> from scipy.stats import alpha
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a = 3.57
>>> mean, var, skew, kurt = alpha.stats(a, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(alpha.ppf(0.01, a),
...                 alpha.ppf(0.99, a), 100)
>>> ax.plot(x, alpha.pdf(x, a),
...         'r-', lw=5, alpha=0.6, label='alpha pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = alpha(a)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

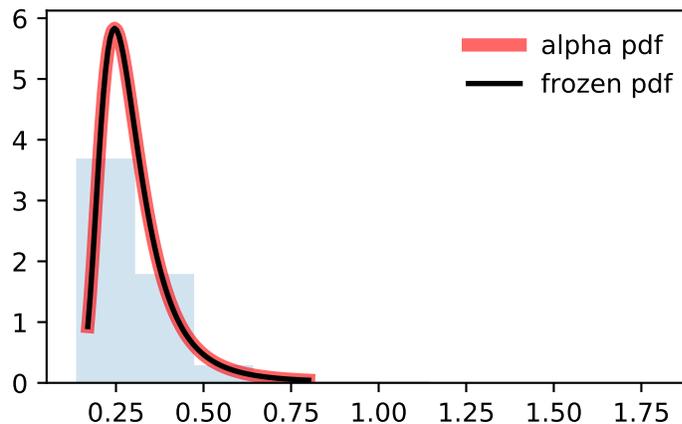
```
>>> vals = alpha.ppf([0.001, 0.5, 0.999], a)
>>> np.allclose([0.001, 0.5, 0.999], alpha.cdf(vals, a))
True
```

Generate random numbers:

```
>>> r = alpha.rvs(a, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(a, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, a, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, a, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, a, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, a, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, a, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, a, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, a, loc=0, scale=1)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, a, loc=0, scale=1)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>moment(n, a, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(a, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, a, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(a,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(a, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(a, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(a, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.anqlit = <scipy.stats.continuous_distns.anqlit_gen object>`

An `anqlit` continuous random variable.

As an instance of the `rv_continuous` class, `anqlit` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for `anqlit` is:

$$f(x) = \sin(2x + \pi/2) = \cos(2x)$$

for  $-\pi/4 \leq x \leq \pi/4$ .

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `anqlit.pdf(x, loc, scale)` is identically equivalent to `anqlit.pdf(y) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import anqlit
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = anglit.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(anglit.ppf(0.01),
...                 anglit.ppf(0.99), 100)
>>> ax.plot(x, anglit.pdf(x),
...         'r-', lw=5, alpha=0.6, label='anglit pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = anglit()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

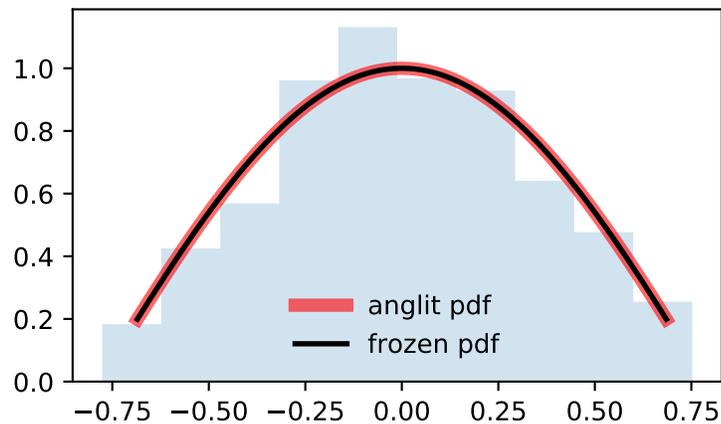
```
>>> vals = anglit.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], anglit.cdf(vals))
True
```

Generate random numbers:

```
>>> r = anglit.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.arcsine` = <scipy.stats\_continuous\_distns.arcsine\_gen object>

An arcsine continuous random variable.

As an instance of the `rv_continuous` class, `arcsine` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for `arcsine` is:

$$f(x) = \frac{1}{\pi\sqrt{x(1-x)}}$$

for  $0 \leq x \leq 1$ .

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `arcsine.pdf(x, loc, scale)` is identically equivalent to `arcsine.pdf(y) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import arcsine
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = arcsine.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(arcsine.ppf(0.01),
...                 arcsine.ppf(0.99), 100)
>>> ax.plot(x, arcsine.pdf(x),
...         'r-', lw=5, alpha=0.6, label='arcsine pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = arcsine()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

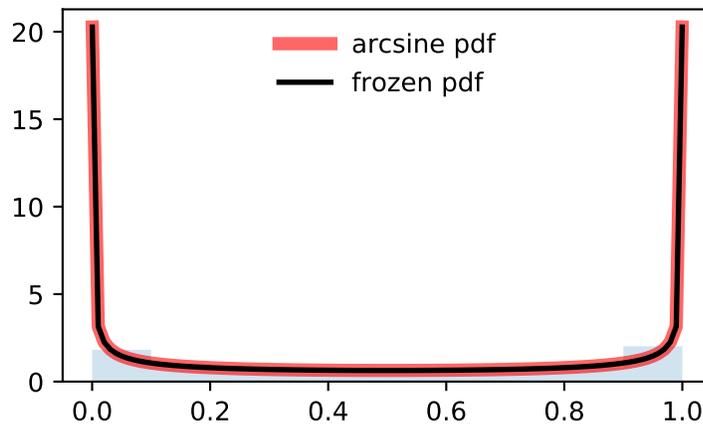
```
>>> vals = arcsine.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], arcsine.cdf(vals))
True
```

Generate random numbers:

```
>>> r = arcsine.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.argus = <scipy.stats._continuous_distns.argus_gen object>`

Argus distribution

As an instance of the `rv_continuous` class, `argus` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for `argus` is:

$$f(x, \chi) = \frac{\chi^3}{\sqrt{2\pi}\Psi(\chi)} x \sqrt{1-x^2} \exp(-0.5\chi^2(1-x^2))$$

where :

$$\Psi(\chi) = \Phi(\chi) - \chi\phi(\chi) - 1/2$$

with  $\Phi$  and  $\phi$  being the CDF and PDF of a standard normal distribution, respectively.

`argus` takes  $\chi$  as shape a parameter.

**References**

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `argus.pdf(x, chi, loc, scale)` is identically equivalent to `argus.pdf(y, chi) / scale` with  $y = (x - loc) / scale$ .

New in version 0.19.0.

[R609]

*Examples*

```
>>> from scipy.stats import argus
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> chi = 1
>>> mean, var, skew, kurt = argus.stats(chi, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(argus.ppf(0.01, chi),
...                 argus.ppf(0.99, chi), 100)
>>> ax.plot(x, argus.pdf(x, chi),
...         'r-', lw=5, alpha=0.6, label='argus pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = argus(chi)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

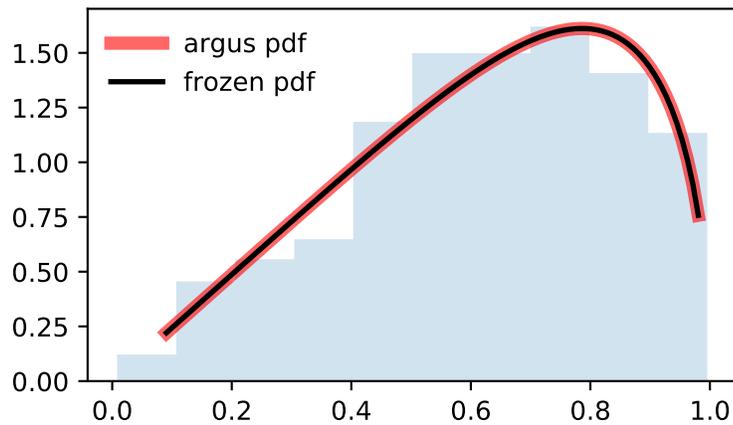
```
>>> vals = argus.ppf([0.001, 0.5, 0.999], chi)
>>> np.allclose([0.001, 0.5, 0.999], argus.cdf(vals, chi))
True
```

Generate random numbers:

```
>>> r = argus.rvs(chi, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(chi, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, chi, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, chi, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, chi, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, chi, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, chi, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, chi, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, chi, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, chi, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, chi, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(chi, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(chi, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, chi, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(chi,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(chi, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(chi, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(chi, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(chi, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, chi, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.beta = <scipy.stats_continuous_distns.beta_gen object>`

A beta continuous random variable.

As an instance of the *rv\_continuous* class, *beta* object inherits from it a collection of generic methods

(see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *beta* is:

$$f(x, a, b) = \frac{\gamma(a+b)x^{a-1}(1-x)^{b-1}}{\gamma(a)\gamma(b)}$$

for  $0 < x < 1$ ,  $a > 0$ ,  $b > 0$ , where  $\gamma(z)$  is the gamma function (`scipy.special.gamma`).

*beta* takes *a* and *b* as shape parameters.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `beta.pdf(x, a, b, loc, scale)` is identically equivalent to `beta.pdf(y, a, b) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import beta
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a, b = 2.31, 0.627
>>> mean, var, skew, kurt = beta.stats(a, b, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(beta.ppf(0.01, a, b),
...                 beta.ppf(0.99, a, b), 100)
>>> ax.plot(x, beta.pdf(x, a, b),
...        'r-', lw=5, alpha=0.6, label='beta pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = beta(a, b)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

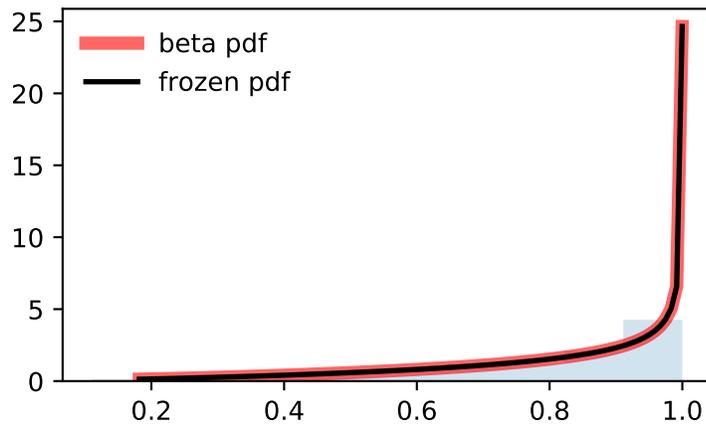
```
>>> vals = beta.ppf([0.001, 0.5, 0.999], a, b)
>>> np.allclose([0.001, 0.5, 0.999], beta.cdf(vals, a, b))
True
```

Generate random numbers:

```
>>> r = beta.rvs(a, b, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(a, b, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, a, b, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, a, b, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, a, b, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, a, b, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, a, b, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, a, b, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, a, b, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, a, b, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, a, b, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(a, b, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, b, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, a, b, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(a, b), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, b, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(a, b, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(a, b, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(a, b, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, b, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.betaprime = <scipy.stats.continuous_distns.betaprime_gen object>`

A beta prime continuous random variable.

As an instance of the *rv\_continuous* class, *betaprime* object inherits from it a collection of generic

methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *betaprime* is:

$$f(x, a, b) = \frac{x^{a-1}(1+x)^{-a-b}}{\beta(a, b)}$$

for  $x > 0, a > 0, b > 0$ , where  $\beta(a, b)$  is the beta function (see `scipy.special.beta`).

*betaprime* takes *a* and *b* as shape parameters.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `betaprime.pdf(x, a, b, loc, scale)` is identically equivalent to `betaprime.pdf(y, a, b) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import betaprime
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a, b = 5, 6
>>> mean, var, skew, kurt = betaprime.stats(a, b, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(betaprime.ppf(0.01, a, b),
...                 betaprime.ppf(0.99, a, b), 100)
>>> ax.plot(x, betaprime.pdf(x, a, b),
...         'r-', lw=5, alpha=0.6, label='betaprime pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = betaprime(a, b)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

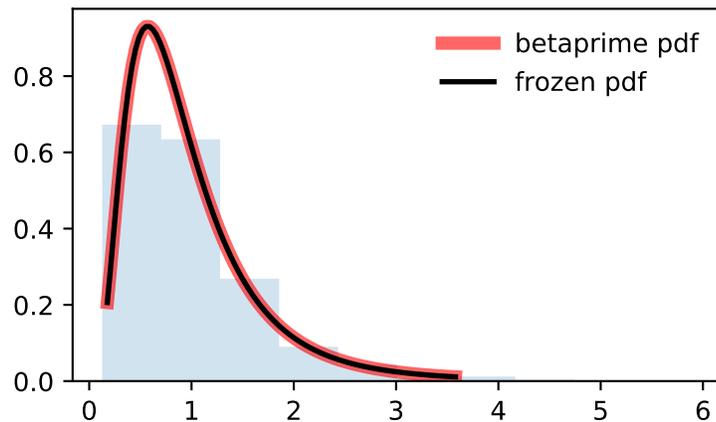
```
>>> vals = betaprime.ppf([0.001, 0.5, 0.999], a, b)
>>> np.allclose([0.001, 0.5, 0.999], betaprime.cdf(vals, a, b))
True
```

Generate random numbers:

```
>>> r = betaprime.rvs(a, b, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(a, b, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, a, b, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, a, b, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, a, b, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, a, b, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, a, b, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, a, b, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, a, b, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, a, b, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, a, b, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(a, b, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, b, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, a, b, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(a, b), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, b, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(a, b, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(a, b, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(a, b, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, b, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.bradford` = <scipy.stats.continuous\_distns.bradford\_gen object>

A Bradford continuous random variable.

As an instance of the *rv\_continuous* class, *bradford* object inherits from it a collection of generic meth-

ods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *bradford* is:

$$f(x, c) = \frac{c}{k(1 + cx)}$$

for  $0 < x < 1, c > 0$  and  $k = \log(1 + c)$ .

*bradford* takes *c* as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `bradford.pdf(x, c, loc, scale)` is identically equivalent to `bradford.pdf(y, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import bradford
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 0.299
>>> mean, var, skew, kurt = bradford.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(bradford.ppf(0.01, c),
...                 bradford.ppf(0.99, c), 100)
>>> ax.plot(x, bradford.pdf(x, c),
...         'r-', lw=5, alpha=0.6, label='bradford pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = bradford(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

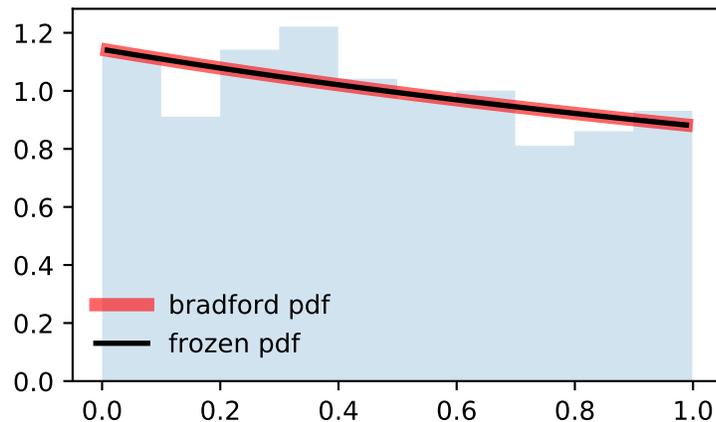
```
>>> vals = bradford.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], bradford.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = bradford.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.burr = <scipy.stats._continuous_distns.burr_gen object>`

A Burr (Type III) continuous random variable.

As an instance of the *rv\_continuous* class, *burr* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**See also:**

**fisk** a special case of either *burr* or *burr12* with  $d = 1$   
**burr12** Burr Type XII distribution

**Notes**

The probability density function for *burr* is:

$$f(x, c, d) = cdx^{-c-1}(1+x^{-c})^{-d-1}$$

for  $x > 0$ .

*burr* takes  $c$  and  $d$  as shape parameters.

This is the PDF corresponding to the third CDF given in Burr's list; specifically, it is equation (11) in Burr's paper [R615].

The probability density above is defined in the "standardized" form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `burr.pdf(x, c, d, loc, scale)` is identically equivalent to `burr.pdf(y, c, d) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**References**

[R615]

**Examples**

```
>>> from scipy.stats import burr
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c, d = 10.5, 4.3
>>> mean, var, skew, kurt = burr.stats(c, d, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(burr.ppf(0.01, c, d),
...                 burr.ppf(0.99, c, d), 100)
>>> ax.plot(x, burr.pdf(x, c, d),
...        'r-', lw=5, alpha=0.6, label='burr pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a "frozen" RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = burr(c, d)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

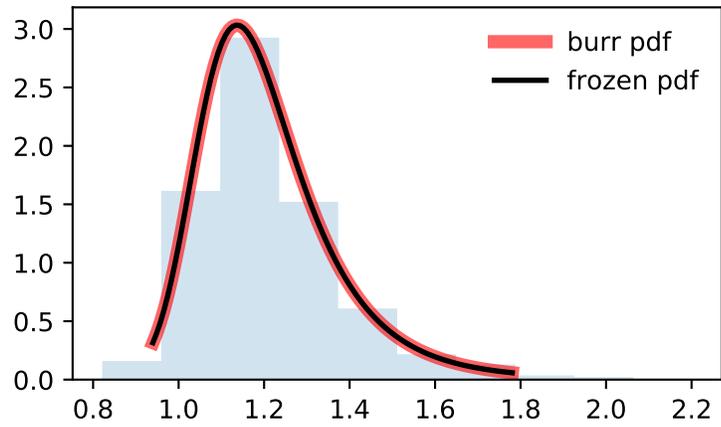
```
>>> vals = burr.ppf([0.001, 0.5, 0.999], c, d)
>>> np.allclose([0.001, 0.5, 0.999], burr.cdf(vals, c, d))
True
```

Generate random numbers:

```
>>> r = burr.rvs(c, d, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(c, d, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, d, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, d, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, d, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, d, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, d, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, d, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, d, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, d, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, d, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, d, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, d, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, d, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c, d), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, d, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, d, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, d, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, d, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, d, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.burr12 = <scipy.stats._continuous_distns.burr12_gen object>`

A Burr (Type XII) continuous random variable.

As an instance of the *rv\_continuous* class, *burr12* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**See also:**

**fisk** a special case of either *burr* or *burr12* with  $d = 1$   
**burr** Burr Type III distribution

**Notes**

The probability density function for *burr* is:

$$f(x, c, d) = cdx^{c-1}(1+x^c)^{-d-1}$$

for  $x > 0$ .

*burr12* takes *c* and *d* as shape parameters.

This is the PDF corresponding to the twelfth CDF given in Burr's list; specifically, it is equation (20) in Burr's paper [R616].

The probability density above is defined in the "standardized" form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `burr12.pdf(x, c, d, loc, scale)` is identically equivalent to `burr12.pdf(y, c, d) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

The Burr type 12 distribution is also sometimes referred to as the Singh-Maddala distribution from NIST [R617].

### References

[R616], [R617]

### Examples

```
>>> from scipy.stats import burr12
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c, d = 10, 4
>>> mean, var, skew, kurt = burr12.stats(c, d, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(burr12.ppf(0.01, c, d),
...                 burr12.ppf(0.99, c, d), 100)
>>> ax.plot(x, burr12.pdf(x, c, d),
...        'r-', lw=5, alpha=0.6, label='burr12 pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = burr12(c, d)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

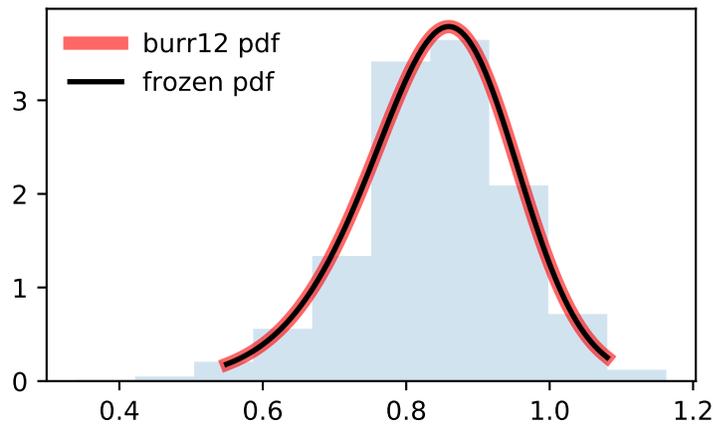
```
>>> vals = burr12.ppf([0.001, 0.5, 0.999], c, d)
>>> np.allclose([0.001, 0.5, 0.999], burr12.cdf(vals, c, d))
True
```

Generate random numbers:

```
>>> r = burr12.rvs(c, d, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, d, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, d, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, d, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, d, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, d, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, d, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, d, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, d, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, d, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, d, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, d, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, d, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, d, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c, d), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, d, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, d, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, d, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, d, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, d, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.cauchy` = <scipy.stats.continuous\_distns.cauchy\_gen object>

A Cauchy continuous random variable.

As an instance of the *rv\_continuous* class, *cauchy* object inherits from it a collection of generic methods

(see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *cauchy* is:

$$f(x) = \frac{1}{\pi(1+x^2)}$$

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `cauchy.pdf(x, loc, scale)` is identically equivalent to `cauchy.pdf(y) / scale` with `y = (x - loc) / scale`.

### Examples

```
>>> from scipy.stats import cauchy
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = cauchy.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(cauchy.ppf(0.01),
...                 cauchy.ppf(0.99), 100)
>>> ax.plot(x, cauchy.pdf(x),
...         'r-', lw=5, alpha=0.6, label='cauchy pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = cauchy()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

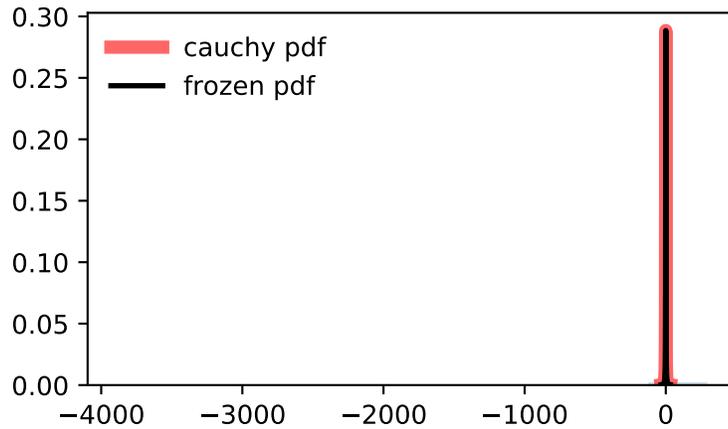
```
>>> vals = cauchy.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], cauchy.cdf(vals))
True
```

Generate random numbers:

```
>>> r = cauchy.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.chi = <scipy.stats.continuous_distns.chi_gen object>`

A chi continuous random variable.

As an instance of the *rv\_continuous* class, *chi* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *chi* is:

$$f(x, df) = \frac{x^{df-1} \exp(-x^2/2)}{2^{df/2-1} \Gamma(df/2)}$$

for  $x > 0$ .

Special cases of *chi* are:

- `chi(1, loc, scale)` is equivalent to *halfnorm*
- `chi(2, 0, scale)` is equivalent to *rayleigh*
- `chi(3, 0, scale)` is equivalent to *maxwell*

*chi* takes `df` as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `chi.pdf(x, df, loc, scale)` is identically equivalent to `chi.pdf(y, df) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import chi
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> df = 78
>>> mean, var, skew, kurt = chi.stats(df, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(chi.ppf(0.01, df),
...                 chi.ppf(0.99, df), 100)
>>> ax.plot(x, chi.pdf(x, df),
...         'r-', lw=5, alpha=0.6, label='chi pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = chi(df)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

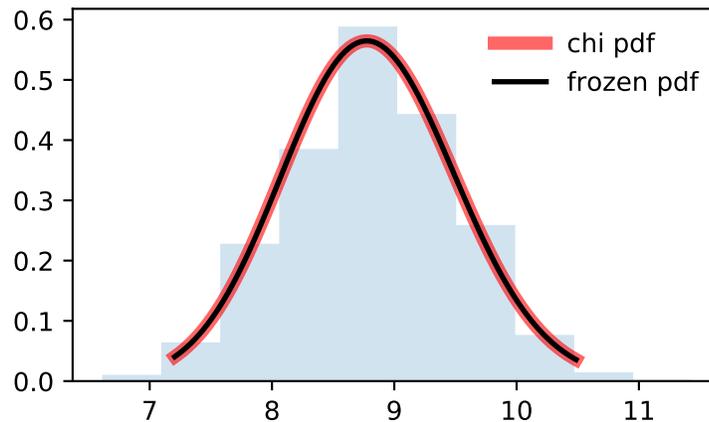
```
>>> vals = chi.ppf([0.001, 0.5, 0.999], df)
>>> np.allclose([0.001, 0.5, 0.999], chi.cdf(vals, df))
True
```

Generate random numbers:

```
>>> r = chi.rvs(df, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(df, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, df, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, df, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, df, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, df, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, df, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, df, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, df, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, df, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, df, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(df, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(df, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, df, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(df,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(df, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(df, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(df, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(df, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, df, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.chi2` = <scipy.stats.continuous\_distns.chi2\_gen object>

A chi-squared continuous random variable.

As an instance of the *rv\_continuous* class, *chi2* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *chi2* is:

$$f(x, df) = \frac{1}{(2\gamma(df/2))} (x/2)^{df/2-1} \exp(-x/2)$$

*chi2* takes *df* as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `chi2.pdf(x, df, loc, scale)` is identically equivalent to `chi2.pdf(y, df) / scale` with `y = (x - loc) / scale`.

### Examples

```
>>> from scipy.stats import chi2
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> df = 55
>>> mean, var, skew, kurt = chi2.stats(df, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(chi2.ppf(0.01, df),
...                 chi2.ppf(0.99, df), 100)
>>> ax.plot(x, chi2.pdf(x, df),
...         'r-', lw=5, alpha=0.6, label='chi2 pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = chi2(df)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

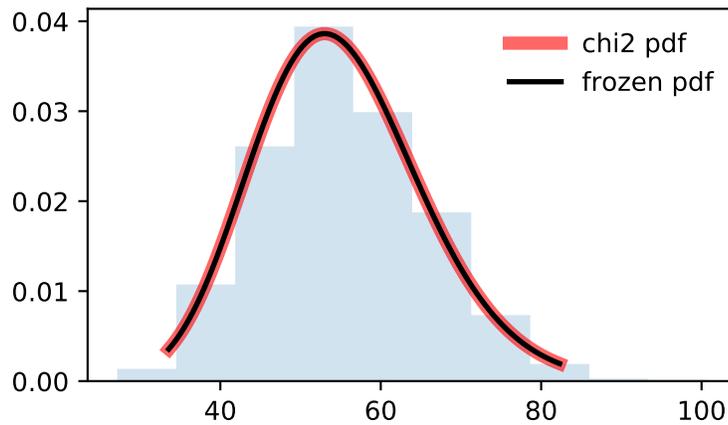
```
>>> vals = chi2.ppf([0.001, 0.5, 0.999], df)
>>> np.allclose([0.001, 0.5, 0.999], chi2.cdf(vals, df))
True
```

Generate random numbers:

```
>>> r = chi2.rvs(df, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(df, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, df, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, df, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, df, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, df, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, df, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, df, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, df, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, df, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, df, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(df, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(df, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, df, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(df,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(df, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(df, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(df, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(df, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, df, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.cosine = <scipy.stats.continuous_distns.cosine_gen object>`

A cosine continuous random variable.

As an instance of the *rv\_continuous* class, *cosine* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The cosine distribution is an approximation to the normal distribution. The probability density function for *cosine* is:

$$f(x) = \frac{1}{2\pi}(1 + \cos(x))$$

for  $-\pi \leq x \leq \pi$ .

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `cosine.pdf(x, loc, scale)` is identically equivalent to `cosine.pdf(y) / scale` with `y = (x - loc) / scale`.

### Examples

```
>>> from scipy.stats import cosine
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = cosine.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(cosine.ppf(0.01),
...                 cosine.ppf(0.99), 100)
>>> ax.plot(x, cosine.pdf(x),
...        'r-', lw=5, alpha=0.6, label='cosine pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = cosine()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

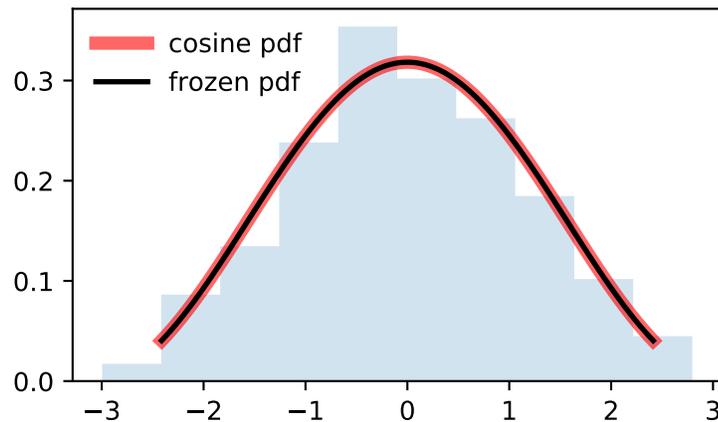
```
>>> vals = cosine.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], cosine.cdf(vals))
True
```

Generate random numbers:

```
>>> r = cosine.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.crystalball = <scipy.stats.continuous_distns.crystalball_gen object>`

Crystalball distribution

As an instance of the *rv\_continuous* class, *crystalball* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for `crystalball` is:

$$f(x, \beta, m) = \begin{cases} N \exp(-x^2/2), & \text{for } x > -\beta \\ NA(B - x)^{-m} & \text{for } x \leq -\beta \end{cases}$$

where  $A = (m/|\beta|) * n * \exp(-\beta^2/2)$ ,  $B = m/|\beta| - |\beta|$  and  $N$  is a normalisation constant.

`crystalball` takes  $\beta$  and  $m$  as shape parameters.  $\beta$  defines the point where the pdf changes from a power-law to a gaussian distribution  $m$  is power of the power-law tail.

### References

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `crystalball.pdf(x, beta, m, loc, scale)` is identically equivalent to `crystalball.pdf(y, beta, m) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

[R628]

### Examples

```
>>> from scipy.stats import crystalball
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> beta, m = 2, 3
>>> mean, var, skew, kurt = crystalball.stats(beta, m, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(crystalball.ppf(0.01, beta, m),
...                 crystalball.ppf(0.99, beta, m), 100)
>>> ax.plot(x, crystalball.pdf(x, beta, m),
...         'r-', lw=5, alpha=0.6, label='crystalball pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = crystalball(beta, m)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

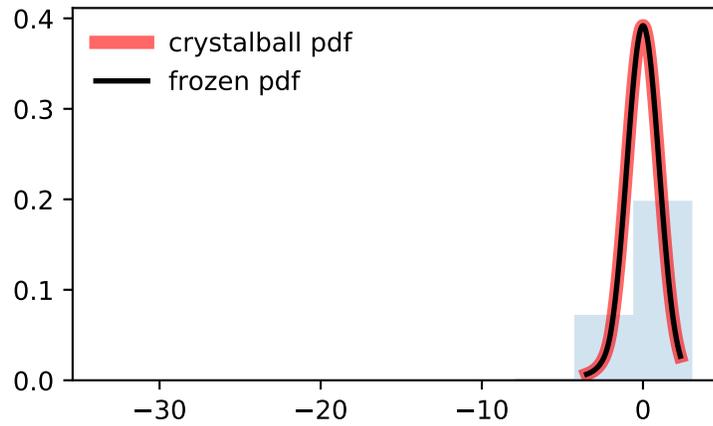
```
>>> vals = crystalball.ppf([0.001, 0.5, 0.999], beta, m)
>>> np.allclose([0.001, 0.5, 0.999], crystalball.cdf(vals, beta, m))
True
```

Generate random numbers:

```
>>> r = crystalball.rvs(beta, m, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(beta, m, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, beta, m, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, beta, m, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, beta, m, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, beta, m, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, beta, m, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, beta, m, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, beta, m, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, beta, m, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, beta, m, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(beta, m, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(beta, m, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, beta, m, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(beta, m), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(beta, m, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(beta, m, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(beta, m, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(beta, m, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, beta, m, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.dgamma = <scipy.stats._continuous_distns.dgamma_gen object>`

A double gamma continuous random variable.

As an instance of the `rv_continuous` class, `dgamma` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for `dgamma` is:

$$f(x, a) = \frac{1}{2\gamma(a)} |x|^{a-1} \exp(-|x|)$$

for  $a > 0$ .

`dgamma` takes  $a$  as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `dgamma.pdf(x, a, loc, scale)` is identically equivalent to `dgamma.pdf(y, a) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import dgamma
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a = 1.1
>>> mean, var, skew, kurt = dgamma.stats(a, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(dgamma.ppf(0.01, a),
...                 dgamma.ppf(0.99, a), 100)
>>> ax.plot(x, dgamma.pdf(x, a),
...         'r-', lw=5, alpha=0.6, label='dgamma pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = dgamma(a)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

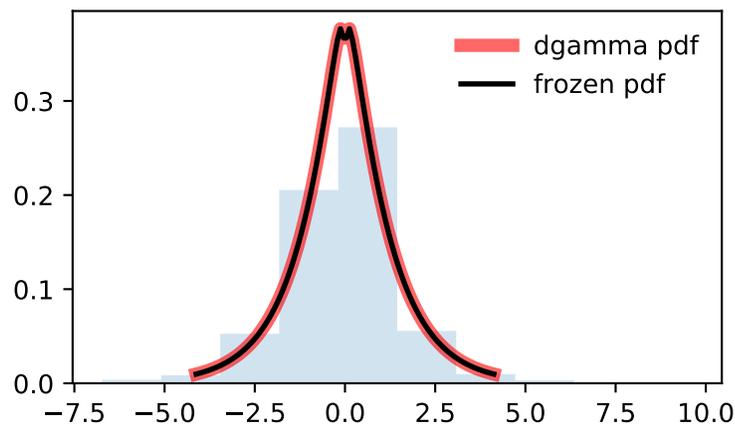
```
>>> vals = dgamma.ppf([0.001, 0.5, 0.999], a)
>>> np.allclose([0.001, 0.5, 0.999], dgamma.cdf(vals, a))
True
```

Generate random numbers:

```
>>> r = dgamma.rvs(a, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(a, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, a, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, a, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, a, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, a, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, a, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, a, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, a, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, a, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, a, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(a, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, a, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(a,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(a, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(a, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(a, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.dweibull = <scipy.stats._continuous_distns.dweibull_gen object>`

A double Weibull continuous random variable.

As an instance of the *rv\_continuous* class, *dweibull* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *dweibull* is:

$$f(x, c) = c/2|x|^{c-1} \exp(-|x|^c)$$

*dweibull* takes *d* as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `dweibull.pdf(x, c, loc, scale)` is identically equivalent to `dweibull.pdf(y, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import dweibull
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 2.07
>>> mean, var, skew, kurt = dweibull.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(dweibull.ppf(0.01, c),
...                 dweibull.ppf(0.99, c), 100)
>>> ax.plot(x, dweibull.pdf(x, c),
...         'r-', lw=5, alpha=0.6, label='dweibull pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = dweibull(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

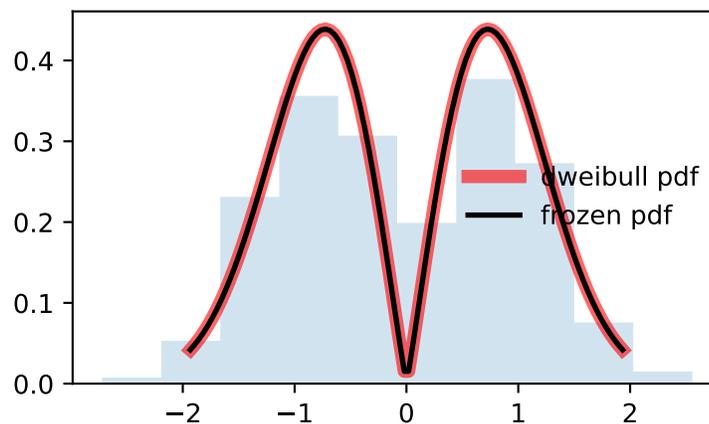
```
>>> vals = dweibull.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], dweibull.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = dweibull.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.erlang = <scipy.stats_continuous_distns.erlang_gen object>`

An Erlang continuous random variable.

As an instance of the *rv\_continuous* class, *erlang* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**See also:**

*gamma*

**Notes**

The Erlang distribution is a special case of the Gamma distribution, with the shape parameter *a* an integer. Note that this restriction is not enforced by *erlang*. It will, however, generate a warning the first time a non-integer value is used for the shape parameter.

Refer to *gamma* for examples.

**Methods**

<code>rvs(a, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, a, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, a, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, a, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, a, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, a, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, a, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, a, loc=0, scale=1)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, a, loc=0, scale=1)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>moment(n, a, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(a, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, a, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(a,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(a, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(a, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(a, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.expon` = <scipy.stats.continuous\_distns.expon\_gen object>

An exponential continuous random variable.

As an instance of the `rv_continuous` class, `expon` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for `expon` is:

$$f(x) = \exp(-x)$$

for  $x \geq 0$ .

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `expon.pdf(x, loc, scale)` is identically equivalent to `expon.pdf(y) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

A common parameterization for `expon` is in terms of the rate parameter `lambda`, such that `pdf = lambda * exp(-lambda * x)`. This parameterization corresponds to using `scale = 1 / lambda`.

**Examples**

```
>>> from scipy.stats import expon
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = expon.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(expon.ppf(0.01),
...                 expon.ppf(0.99), 100)
>>> ax.plot(x, expon.pdf(x),
...         'r-', lw=5, alpha=0.6, label='expon pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = expon()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

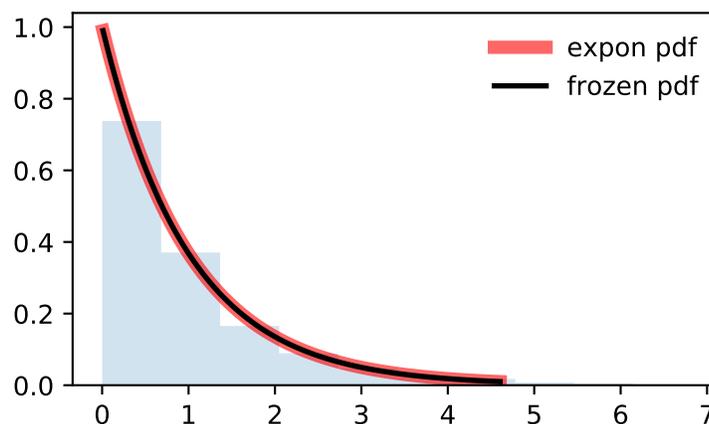
```
>>> vals = expon.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], expon.cdf(vals))
True
```

Generate random numbers:

```
>>> r = expon.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.exponnorm` = <scipy.stats.continuous\_distns.exponnorm\_gen object>

An exponentially modified Normal continuous random variable.

As an instance of the *rv\_continuous* class, *exponnorm* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *exponnorm* is:

$$f(x, K) = \frac{1}{2K} \exp\left(\frac{1}{2K^2}\right) \exp(-x/K) \operatorname{erfc} - \frac{x - 1/K}{\sqrt{2}}$$

where the shape parameter  $K > 0$ .

It can be thought of as the sum of a normally distributed random value with mean *loc* and sigma *scale* and an exponentially distributed random number with a pdf proportional to  $\exp(-\text{lambda} * x)$  where  $\text{lambda} = (K * \text{scale})^{**}(-1)$ .

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `exponnorm.pdf(x, K, loc, scale)` is identically equivalent to `exponnorm.pdf(y, K) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

An alternative parameterization of this distribution (for example, in [Wikipedia](#)) involves three parameters,  $\mu$ ,  $\lambda$  and  $\sigma$ . In the present parameterization this corresponds to having *loc* and *scale* equal to  $\mu$  and  $\sigma$ , respectively, and shape parameter  $K = 1/\sigma\lambda$ .

New in version 0.16.0.

### Examples

```
>>> from scipy.stats import exponnorm
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> K = 1.5
>>> mean, var, skew, kurt = exponnorm.stats(K, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(exponnorm.ppf(0.01, K),
...                 exponnorm.ppf(0.99, K), 100)
>>> ax.plot(x, exponnorm.pdf(x, K),
...        'r-', lw=5, alpha=0.6, label='exponnorm pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = exponnorm(K)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

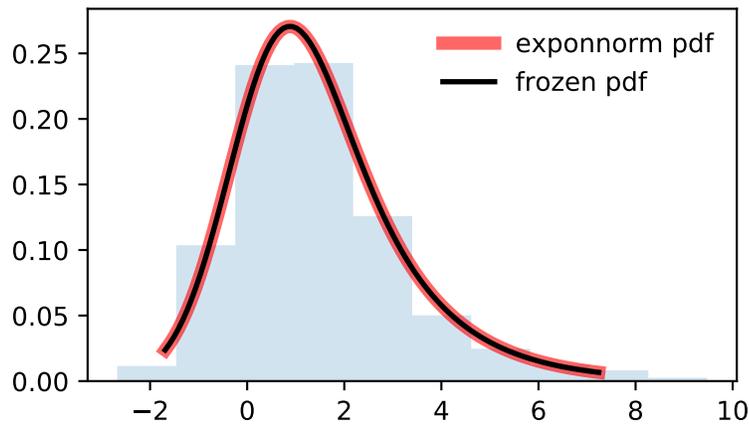
```
>>> vals = exponnorm.ppf([0.001, 0.5, 0.999], K)
>>> np.allclose([0.001, 0.5, 0.999], exponnorm.cdf(vals, K))
True
```

Generate random numbers:

```
>>> r = exponnorm.rvs(K, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(K, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, K, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, K, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, K, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, K, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, K, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, K, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, K, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, K, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, K, loc=0, scale=1)</code>	Non-central moment of order <i>n</i> .
<code>stats(K, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(K, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, K, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(K,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(K, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(K, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(K, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(K, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, K, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution.

`scipy.stats.exponweib` = <scipy.stats.continuous\_distns.exponweib\_gen object>

An exponentiated Weibull continuous random variable.

As an instance of the `rv_continuous` class, `exponweib` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *exponweib* is:

$$f(x, a, c) = ac(1 - \exp(-x^c))^{a-1} \exp(-x^c)x^{c-1}$$

for  $x > 0, a > 0, c > 0$ .

*exponweib* takes *a* and *c* as shape parameters.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `exponweib.pdf(x, a, c, loc, scale)` is identically equivalent to `exponweib.pdf(y, a, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import exponweib
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a, c = 2.89, 1.95
>>> mean, var, skew, kurt = exponweib.stats(a, c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(exponweib.ppf(0.01, a, c),
...                 exponweib.ppf(0.99, a, c), 100)
>>> ax.plot(x, exponweib.pdf(x, a, c),
...         'r-', lw=5, alpha=0.6, label='exponweib pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = exponweib(a, c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

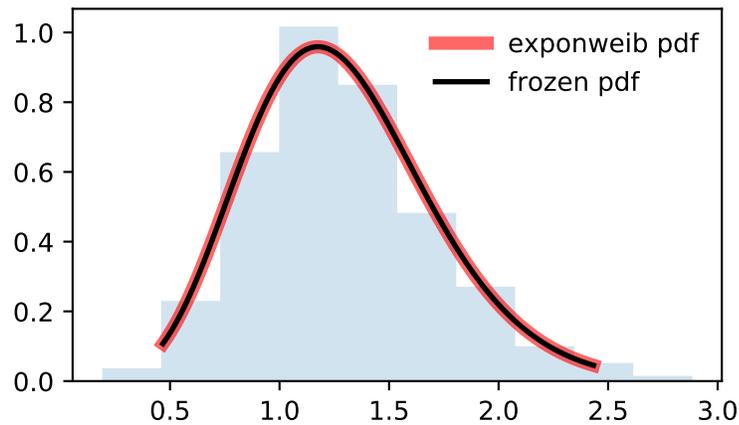
```
>>> vals = exponweib.ppf([0.001, 0.5, 0.999], a, c)
>>> np.allclose([0.001, 0.5, 0.999], exponweib.cdf(vals, a, c))
True
```

Generate random numbers:

```
>>> r = exponweib.rvs(a, c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(a, c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, a, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, a, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, a, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, a, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, a, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, a, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, a, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, a, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, a, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(a, c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, a, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(a, c), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(a, c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(a, c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(a, c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.exponpow = <scipy.stats.continuous_distns.exponpow_gen object>`

An exponential power continuous random variable.

As an instance of the *rv\_continuous* class, *exponpow* object inherits from it a collection of generic meth-

ods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for `exponpow` is:

$$f(x, b) = bx^{b-1} \exp(1 + x^b - \exp(x^b))$$

for  $x \geq 0, b > 0$ . Note that this is a different distribution from the exponential power distribution that is also known under the names “generalized normal” or “generalized Gaussian”.

`exponpow` takes  $b$  as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `exponpow.pdf(x, b, loc, scale)` is identically equivalent to `exponpow.pdf(y, b) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### References

<http://www.math.wm.edu/~leemis/chart/UDR/PDFs/Exponentialpower.pdf>

### Examples

```
>>> from scipy.stats import exponpow
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> b = 2.7
>>> mean, var, skew, kurt = exponpow.stats(b, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(exponpow.ppf(0.01, b),
...                 exponpow.ppf(0.99, b), 100)
>>> ax.plot(x, exponpow.pdf(x, b),
...         'r-', lw=5, alpha=0.6, label='exponpow pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = exponpow(b)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

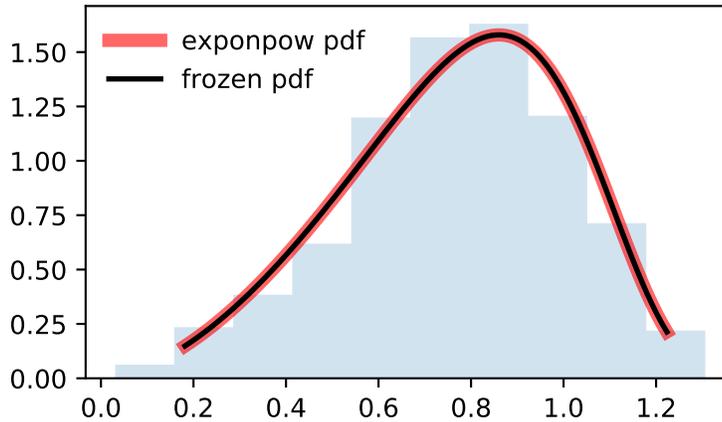
```
>>> vals = exponpow.ppf([0.001, 0.5, 0.999], b)
>>> np.allclose([0.001, 0.5, 0.999], exponpow.cdf(vals, b))
True
```

Generate random numbers:

```
>>> r = exponpow.rvs(b, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(b, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, b, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, b, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, b, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, b, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, b, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, b, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, b, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, b, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, b, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(b, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(b, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, b, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(b,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwargs)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(b, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(b, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(b, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(b, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, b, loc=0, scale=1)</code>	Endpoints of the range that contains <i>alpha</i> percent of the distribution

`scipy.stats.f` = <scipy.stats\_continuous\_distns.f\_gen object>

An F continuous random variable.

As an instance of the `rv_continuous` class, `f` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for `f` is:

$$f(x, df_1, df_2) = \frac{df_2^{df_2/2} df_1^{df_1/2} x^{df_1/2-1}}{(df_2 + df_1 x)^{(df_1+df_2)/2} B(df_1/2, df_2/2)}$$

for  $x > 0$ .

`f` takes `dfn` and `dfd` as shape parameters.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `f.pdf(x, dfn, dfd, loc, scale)` is identically equivalent to `f.pdf(y, dfn, dfd) / scale` with `y = (x - loc) / scale`.

### Examples

```
>>> from scipy.stats import f
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> dfn, dfd = 29, 18
>>> mean, var, skew, kurt = f.stats(dfn, dfd, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(f.ppf(0.01, dfn, dfd),
...                 f.ppf(0.99, dfn, dfd), 100)
>>> ax.plot(x, f.pdf(x, dfn, dfd),
...         'r-', lw=5, alpha=0.6, label='f pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = f(dfn, dfd)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

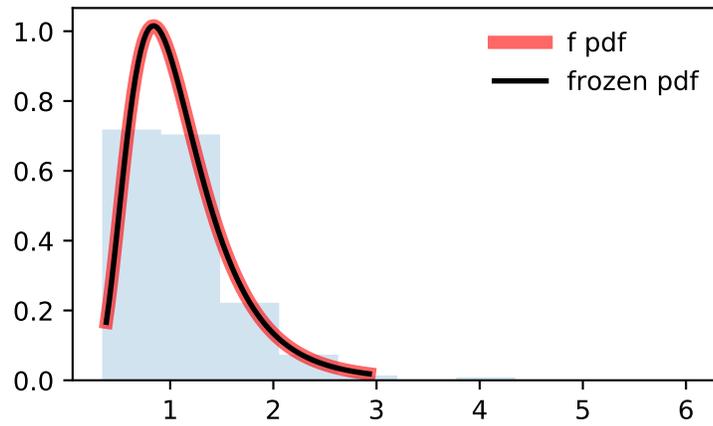
```
>>> vals = f.ppf([0.001, 0.5, 0.999], dfn, dfd)
>>> np.allclose([0.001, 0.5, 0.999], f.cdf(vals, dfn, dfd))
True
```

Generate random numbers:

```
>>> r = f.rvs(dfn, dfd, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(dfn, dfd, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, dfn, dfd, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, dfn, dfd, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, dfn, dfd, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, dfn, dfd, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, dfn, dfd, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, dfn, dfd, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, dfn, dfd, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, dfn, dfd, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, dfn, dfd, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(dfn, dfd, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(dfn, dfd, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, dfn, dfd, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(dfn, dfd), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(dfn, dfd, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(dfn, dfd, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(dfn, dfd, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(dfn, dfd, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, dfn, dfd, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.fatiguelife = <scipy.stats.continuous_distns.fatiguelife_gen object>`

A fatigue-life (Birnbbaum-Saunders) continuous random variable.

As an instance of the *rv\_continuous* class, *fatiguelife* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *fatiguelife* is:

$$f(x, c) = \frac{x + 1}{2c\sqrt{2\pi}x^3 \exp\left(-\frac{(x-1)^2}{2xc^2}\right)}$$

for  $x > 0$ .

*fatiguelife* takes *c* as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `fatiguelife.pdf(x, c, loc, scale)` is identically equivalent to `fatiguelife.pdf(y, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**References**

[R636]

*Examples*

```
>>> from scipy.stats import fatiguelife
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 29
>>> mean, var, skew, kurt = fatiguelife.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(fatiguelife.ppf(0.01, c),
...                 fatiguelife.ppf(0.99, c), 100)
>>> ax.plot(x, fatiguelife.pdf(x, c),
...         'r-', lw=5, alpha=0.6, label='fatiguelife pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = fatiguelife(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

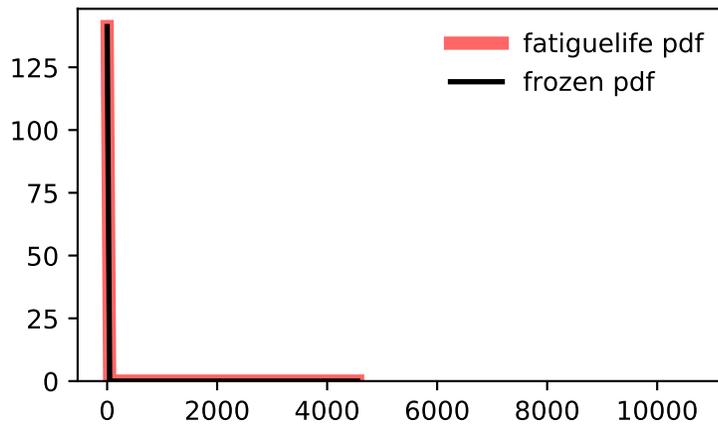
```
>>> vals = fatiguelife.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], fatiguelife.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = fatiguelife.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.fisk = <scipy.stats.continuous_distns.fisk_gen object>`

A Fisk continuous random variable.

The Fisk distribution is also known as the log-logistic distribution, and equals the Burr distribution with  $d == 1$ .

*fisk* takes *c* as a shape parameter.

As an instance of the *rv\_continuous* class, *fisk* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**See also:**

*burr*

**Notes**

The probability density function for *fisk* is:

$$f(x, c) = cx^{-c-1}(1 + x^{-c})^{-2}$$

for  $x > 0$ .

*fisk* takes *c* as a shape parameters.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `fisk.pdf(x, c, loc, scale)` is identically equivalent to `fisk.pdf(y, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import fisk
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 3.09
>>> mean, var, skew, kurt = fisk.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(fisk.ppf(0.01, c),
...                 fisk.ppf(0.99, c), 100)
>>> ax.plot(x, fisk.pdf(x, c),
...         'r-', lw=5, alpha=0.6, label='fisk pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = fisk(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

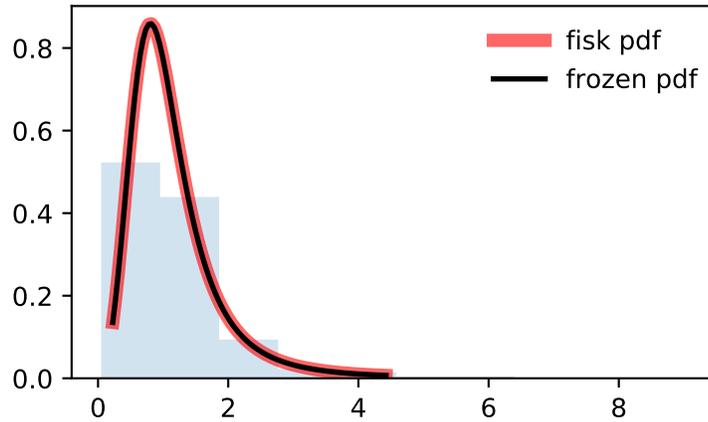
```
>>> vals = fisk.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], fisk.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = fisk.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwargs)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.foldcauchy = <scipy.stats_continuous_distns.foldcauchy_gen object>`

A folded Cauchy continuous random variable.

As an instance of the `rv_continuous` class, `foldcauchy` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for `foldcauchy` is:

$$f(x, c) = \frac{1}{\pi(1 + (x - c)^2)} + \frac{1}{\pi(1 + (x + c)^2)}$$

for  $x \geq 0$ .

`foldcauchy` takes `c` as a shape parameter.

### Examples

```
>>> from scipy.stats import foldcauchy
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 4.72
>>> mean, var, skew, kurt = foldcauchy.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(foldcauchy.ppf(0.01, c),
...                 foldcauchy.ppf(0.99, c), 100)
>>> ax.plot(x, foldcauchy.pdf(x, c),
...         'r-', lw=5, alpha=0.6, label='foldcauchy pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = foldcauchy(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

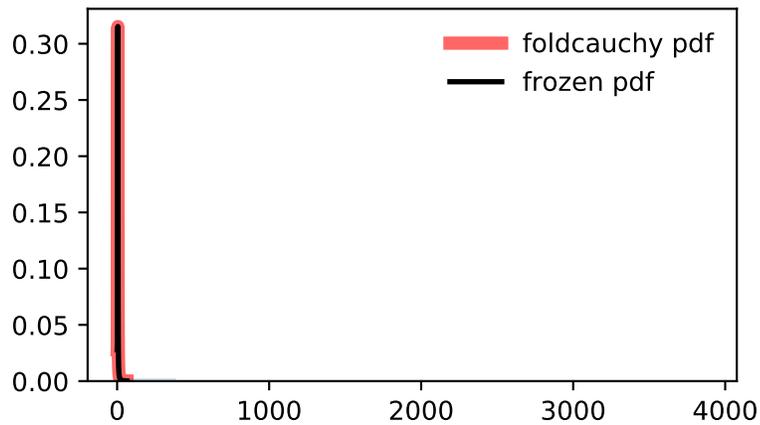
```
>>> vals = foldcauchy.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], foldcauchy.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = foldcauchy.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i> .
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution.

`scipy.stats.foldnorm = <scipy.stats._continuous_distns.foldnorm_gen object>`

A folded normal continuous random variable.

As an instance of the `rv_continuous` class, `foldnorm` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for `foldnorm` is:

$$f(x, c) = \sqrt{2/\pi} \cosh(cx) \exp\left(-\frac{x^2 + c^2}{2}\right)$$

for  $c \geq 0$ .

`foldnorm` takes  $c$  as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `foldnorm.pdf(x, c, loc, scale)` is identically equivalent to `foldnorm.pdf(y, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import foldnorm
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 1.95
>>> mean, var, skew, kurt = foldnorm.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(foldnorm.ppf(0.01, c),
...                 foldnorm.ppf(0.99, c), 100)
>>> ax.plot(x, foldnorm.pdf(x, c),
...         'r-', lw=5, alpha=0.6, label='foldnorm pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = foldnorm(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

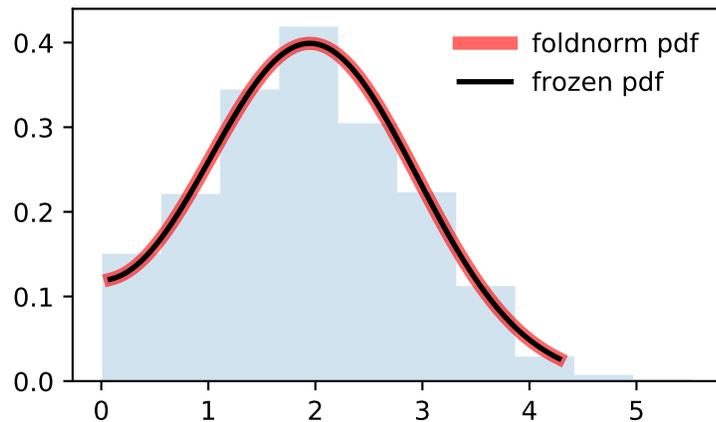
```
>>> vals = foldnorm.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], foldnorm.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = foldnorm.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.frechet_r = <scipy.stats.continuous_distns.frechet_r_gen object>`

A `frechet_r` continuous random variable.

As an instance of the `rv_continuous` class, `frechet_r` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

*Examples*

```
>>> from scipy.stats import frechet_r
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c =
>>> mean, var, skew, kurt = frechet_r.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(frechet_r.ppf(0.01, c),
...                 frechet_r.ppf(0.99, c), 100)
>>> ax.plot(x, frechet_r.pdf(x, c),
...         'r-', lw=5, alpha=0.6, label='frechet_r pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = frechet_r(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

```
>>> vals = frechet_r.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], frechet_r.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = frechet_r.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```

### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.frechet_1 = <scipy.stats.continuous_distns.frechet_1_gen object>`

A *frechet\_1* continuous random variable.

As an instance of the *rv\_continuous* class, *frechet\_1* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Examples

```
>>> from scipy.stats import frechet_1
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c =
>>> mean, var, skew, kurt = frechet_1.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(frechet_1.ppf(0.01, c),
...                 frechet_1.ppf(0.99, c), 100)
>>> ax.plot(x, frechet_1.pdf(x, c),
...         'r-', lw=5, alpha=0.6, label='frechet_1 pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = frechet_1(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

```
>>> vals = frechet_1.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], frechet_1.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = frechet_1.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```

### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwargs)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.genlogistic` = <scipy.stats.continuous\_distns.genlogistic\_gen object>

A generalized logistic continuous random variable.

As an instance of the `rv_continuous` class, `genlogistic` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *genlogistic* is:

$$f(x, c) = c \frac{\exp(-x)}{(1 + \exp(-x))^{c+1}}$$

for  $x > 0, c > 0$ .

*genlogistic* takes  $c$  as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `genlogistic.pdf(x, c, loc, scale)` is identically equivalent to `genlogistic.pdf(y, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import genlogistic
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 0.412
>>> mean, var, skew, kurt = genlogistic.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(genlogistic.ppf(0.01, c),
...                 genlogistic.ppf(0.99, c), 100)
>>> ax.plot(x, genlogistic.pdf(x, c),
...        'r-', lw=5, alpha=0.6, label='genlogistic pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = genlogistic(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

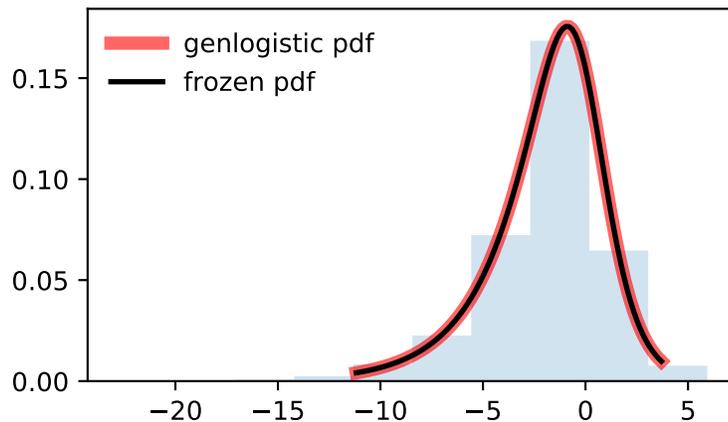
```
>>> vals = genlogistic.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], genlogistic.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = genlogistic.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.gennorm` = <scipy.stats.continuous\_distns.gennorm\_gen object>

A generalized normal continuous random variable.

As an instance of the `rv_continuous` class, `gennorm` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

See also:

**laplace** Laplace distribution  
**norm** normal distribution

*Notes*

The probability density function for *gennorm* is [R646]:

$$\text{gennorm.pdf}(x, \text{beta}) = \frac{\text{beta}}{2 \text{ gamma}(1/\text{beta})} \exp(-|x|**\text{beta})$$

*gennorm* takes  $\beta$  as a shape parameter. For  $\beta = 1$ , it is identical to a Laplace distribution. For  $\beta = 2$ , it is identical to a normal distribution (with *scale* =  $1/\sqrt{2}$ ).

*References*

[R646]

*Examples*

```
>>> from scipy.stats import gennorm
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> beta = 1.3
>>> mean, var, skew, kurt = gennorm.stats(beta, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(gennorm.ppf(0.01, beta),
...                 gennorm.ppf(0.99, beta), 100)
>>> ax.plot(x, gennorm.pdf(x, beta),
...         'r-', lw=5, alpha=0.6, label='gennorm pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = gennorm(beta)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

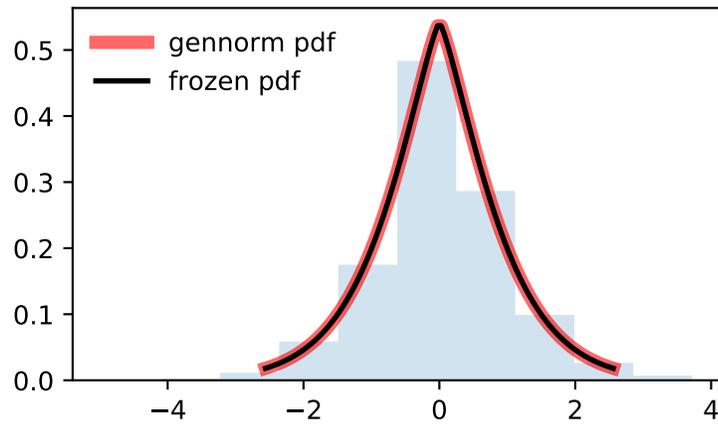
```
>>> vals = gennorm.ppf([0.001, 0.5, 0.999], beta)
>>> np.allclose([0.001, 0.5, 0.999], gennorm.cdf(vals, beta))
True
```

Generate random numbers:

```
>>> r = gennorm.rvs(beta, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(beta, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, beta, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, beta, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, beta, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, beta, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, beta, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, beta, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, beta, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, beta, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, beta, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(beta, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(beta, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, beta, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(beta,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(beta, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(beta, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(beta, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(beta, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, beta, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.genpareto` = <scipy.stats.continuous\_distns.genpareto\_gen object>

A generalized Pareto continuous random variable.

As an instance of the *rv\_continuous* class, *genpareto* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *genpareto* is:

$$f(x, c) = (1 + cx)^{-1-1/c}$$

defined for  $x \geq 0$  if  $c \geq 0$ , and for  $0 \leq x \leq -1/c$  if  $c < 0$ .

*genpareto* takes *c* as a shape parameter.

For  $c == 0$ , *genpareto* reduces to the exponential distribution, *expon*:

$$f(x, c = 0) = \exp(-x)$$

For  $c == -1$ , *genpareto* is uniform on  $[0, 1]$ :

$$f(x, c = -1) = x$$

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `genpareto.pdf(x, c, loc, scale)` is identically equivalent to `genpareto.pdf(y, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

*Examples*

```
>>> from scipy.stats import genpareto
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 0.1
>>> mean, var, skew, kurt = genpareto.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(genpareto.ppf(0.01, c),
...                 genpareto.ppf(0.99, c), 100)
>>> ax.plot(x, genpareto.pdf(x, c),
...         'r-', lw=5, alpha=0.6, label='genpareto pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = genpareto(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

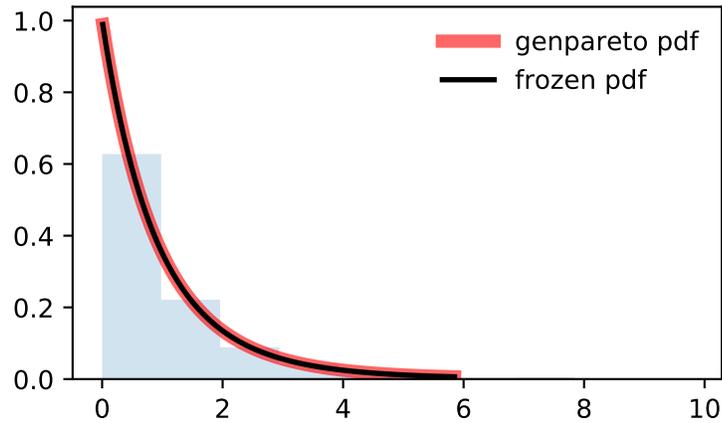
```
>>> vals = genpareto.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], genpareto.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = genpareto.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.genexpon = <scipy.stats._continuous_distns.genexpon_gen object>`

A generalized exponential continuous random variable.

As an instance of the `rv_continuous` class, `genexpon` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *genexpon* is:

$$f(x, a, b, c) = (a + b(1 - \exp(-cx))) \exp(-ax - bx + \frac{b}{c}(1 - \exp(-cx)))$$

for  $x \geq 0, a, b, c > 0$ .

*genexpon* takes *a*, *b* and *c* as shape parameters.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `genexpon.pdf(x, a, b, c, loc, scale)` is identically equivalent to `genexpon.pdf(y, a, b, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### References

H.K. Ryu, “An Extension of Marshall and Olkin’s Bivariate Exponential Distribution”, Journal of the American Statistical Association, 1993.

N. Balakrishnan, “The Exponential Distribution: Theory, Methods and Applications”, Asit P. Basu.

### Examples

```
>>> from scipy.stats import genexpon
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a, b, c = 9.13, 16.2, 3.28
>>> mean, var, skew, kurt = genexpon.stats(a, b, c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(genexpon.ppf(0.01, a, b, c),
...                 genexpon.ppf(0.99, a, b, c), 100)
>>> ax.plot(x, genexpon.pdf(x, a, b, c),
...        'r-', lw=5, alpha=0.6, label='genexpon pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = genexpon(a, b, c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

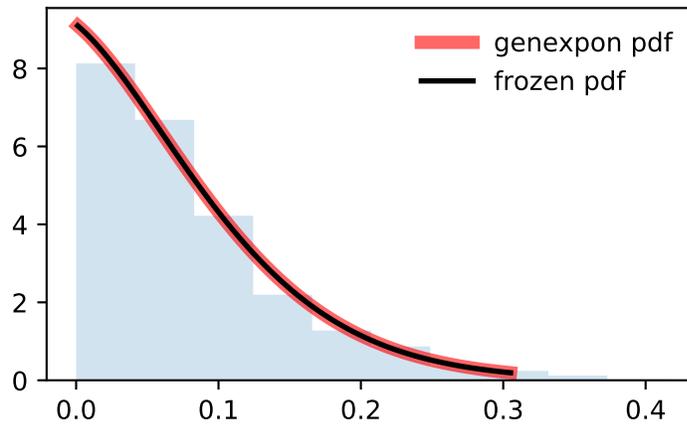
```
>>> vals = genexpon.ppf([0.001, 0.5, 0.999], a, b, c)
>>> np.allclose([0.001, 0.5, 0.999], genexpon.cdf(vals, a, b, c))
True
```

Generate random numbers:

```
>>> r = genexpon.rvs(a, b, c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(a, b, c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, a, b, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, a, b, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, a, b, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, a, b, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, a, b, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, a, b, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, a, b, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, a, b, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, a, b, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(a, b, c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, b, c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, a, b, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(a, b, c), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, b, c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(a, b, c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(a, b, c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(a, b, c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, b, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.genextreme = <scipy.stats.continuous_distns.genextreme_gen object>`

A generalized extreme value continuous random variable.

As an instance of the *rv\_continuous* class, *genextreme* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**See also:**

*gumbel\_r*

**Notes**

For  $c = 0$ , *genextreme* is equal to *gumbel\_r*. The probability density function for *genextreme* is:

$$f(x, c) = \begin{cases} \exp(-\exp(-x)) \exp(-x) & \text{for } c = 0 \\ \exp(-(1 - cx)^{1/c})(1 - cx)^{1/c-1} & \text{for } x \leq 1/c, c > 0 \end{cases}$$

Note that several sources and software packages use the opposite convention for the sign of the shape parameter *c*.

*genextreme* takes *c* as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `genextreme.pdf(x, c, loc, scale)` is identically equivalent to `genextreme.pdf(y, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import genextreme
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = -0.1
>>> mean, var, skew, kurt = genextreme.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(genextreme.ppf(0.01, c),
...                 genextreme.ppf(0.99, c), 100)
>>> ax.plot(x, genextreme.pdf(x, c),
...        'r-', lw=5, alpha=0.6, label='genextreme pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = genextreme(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

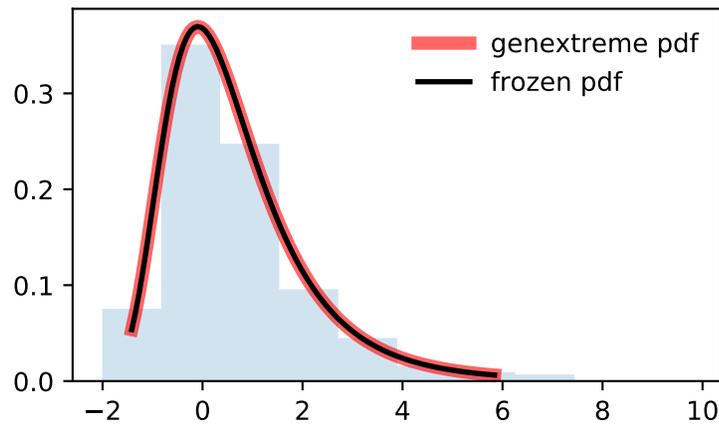
```
>>> vals = genextreme.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], genextreme.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = genextreme.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i> .
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution.

`scipy.stats.gausshyper = <scipy.stats._continuous_distns.gausshyper_gen object>`

A Gauss hypergeometric continuous random variable.

As an instance of the `rv_continuous` class, `gausshyper` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *gausshyper* is:

$$f(x, a, b, c, z) = Cx^{a-1}(1-x)^{b-1}(1+zx)^{-c}$$

for  $0 \leq x \leq 1$ ,  $a > 0$ ,  $b > 0$ , and  $C = \frac{1}{B(a,b)F[2,1](c,a;a+b;-z)}$

*gausshyper* takes *a*, *b*, *c* and *z* as shape parameters.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `gausshyper.pdf(x, a, b, c, z, loc, scale)` is identically equivalent to `gausshyper.pdf(y, a, b, c, z) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import gausshyper
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a, b, c, z = 13.8, 3.12, 2.51, 5.18
>>> mean, var, skew, kurt = gausshyper.stats(a, b, c, z, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(gausshyper.ppf(0.01, a, b, c, z),
...                 gausshyper.ppf(0.99, a, b, c, z), 100)
>>> ax.plot(x, gausshyper.pdf(x, a, b, c, z),
...         'r-', lw=5, alpha=0.6, label='gausshyper pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = gausshyper(a, b, c, z)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

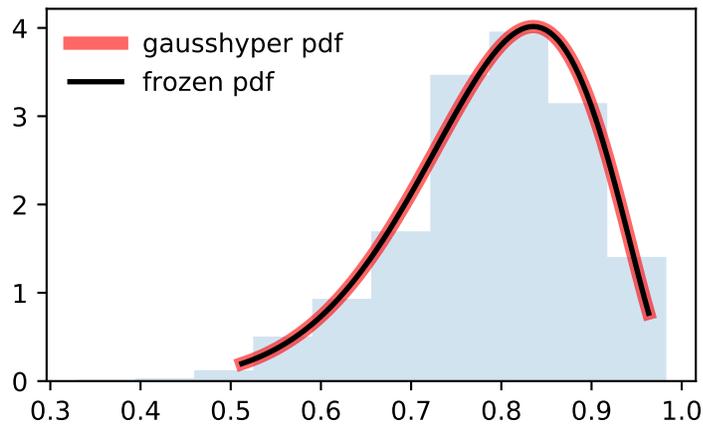
```
>>> vals = gausshyper.ppf([0.001, 0.5, 0.999], a, b, c, z)
>>> np.allclose([0.001, 0.5, 0.999], gausshyper.cdf(vals, a, b, c, z))
True
```

Generate random numbers:

```
>>> r = gausshyper.rvs(a, b, c, z, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(a, b, c, z, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, a, b, c, z, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, a, b, c, z, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, a, b, c, z, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, a, b, c, z, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, a, b, c, z, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, a, b, c, z, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, a, b, c, z, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, a, b, c, z, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, a, b, c, z, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(a, b, c, z, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, b, c, z, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, a, b, c, z, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(a, b, c, z), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, b, c, z, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(a, b, c, z, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(a, b, c, z, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(a, b, c, z, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, b, c, z, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.gamma` = <scipy.stats\_continuous\_distns.gamma\_gen object>

A gamma continuous random variable.

As an instance of the `rv_continuous` class, `gamma` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**See also:**

`erlang`, `expon`

**Notes**

The probability density function for `gamma` is:

$$f(x, a) = \frac{x^{a-1} \exp(-x)}{\gamma(a)}$$

for  $x \geq 0$ ,  $a > 0$ . Here  $\gamma(a)$  refers to the gamma function.

`gamma` has a shape parameter  $a$  which needs to be set explicitly.

When  $a$  is an integer,  $\gamma$  reduces to the Erlang distribution, and when  $a = 1$  to the exponential distribution.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `gamma.pdf(x, a, loc, scale)` is identically equivalent to `gamma.pdf(y, a) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import gamma
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a = 1.99
>>> mean, var, skew, kurt = gamma.stats(a, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(gamma.ppf(0.01, a),
...                 gamma.ppf(0.99, a), 100)
>>> ax.plot(x, gamma.pdf(x, a),
...         'r-', lw=5, alpha=0.6, label='gamma pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = gamma(a)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

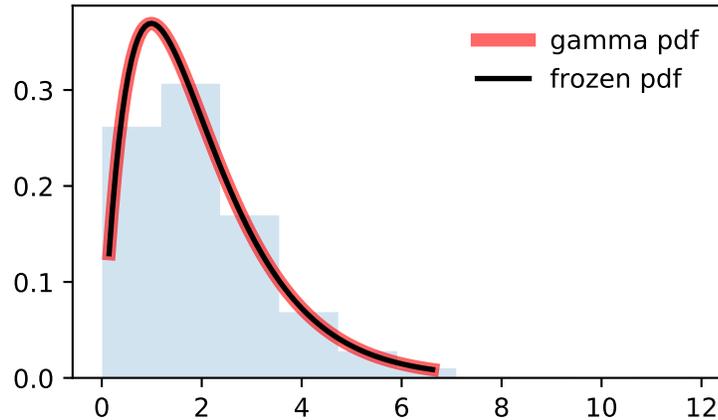
```
>>> vals = gamma.ppf([0.001, 0.5, 0.999], a)
>>> np.allclose([0.001, 0.5, 0.999], gamma.cdf(vals, a))
True
```

Generate random numbers:

```
>>> r = gamma.rvs(a, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(a, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, a, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, a, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, a, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, a, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, a, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, a, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, a, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, a, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, a, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(a, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, a, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(a,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwargs)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(a, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(a, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(a, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.gengamma = <scipy.stats._continuous_distns.gengamma_gen object>`

A generalized gamma continuous random variable.

As an instance of the `rv_continuous` class, `gengamma` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for `gengamma` is:

$$f(x, a, c) = \frac{|c|x^{ca-1} \exp(-x^c)}{\gamma(a)}$$

for  $x \geq 0$ ,  $a > 0$ , and  $c \neq 0$ .

`gengamma` takes  $a$  and  $c$  as shape parameters.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `gengamma.pdf(x, a, c, loc, scale)` is identically equivalent to `gengamma.pdf(y, a, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import gengamma
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a, c = 4.42, -3.12
>>> mean, var, skew, kurt = gengamma.stats(a, c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(gengamma.ppf(0.01, a, c),
...                 gengamma.ppf(0.99, a, c), 100)
>>> ax.plot(x, gengamma.pdf(x, a, c),
...         'r-', lw=5, alpha=0.6, label='gengamma pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = gengamma(a, c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

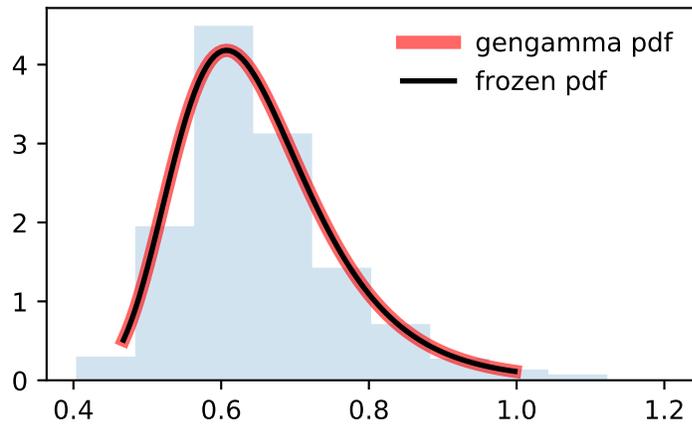
```
>>> vals = gengamma.ppf([0.001, 0.5, 0.999], a, c)
>>> np.allclose([0.001, 0.5, 0.999], gengamma.cdf(vals, a, c))
True
```

Generate random numbers:

```
>>> r = gengamma.rvs(a, c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(a, c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, a, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, a, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, a, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, a, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, a, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, a, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, a, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, a, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, a, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(a, c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, a, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(a, c), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(a, c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(a, c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(a, c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.genhalflogistic = <scipy.stats.continuous_distns.genhalflogistic_gen object>`

A generalized half-logistic continuous random variable.

As an instance of the *rv\_continuous* class, *genhalflogistic* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *genhalflogistic* is:

$$f(x, c) = \frac{2(1 - cx)^{1/(c-1)}}{[1 + (1 - cx)^{1/c}]^2}$$

for  $0 \leq x \leq 1/c$ , and  $c > 0$ .

*genhalflogistic* takes *c* as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `genhalflogistic.pdf(x, c, loc, scale)` is identically equivalent to `genhalflogistic.pdf(y, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

*Examples*

```
>>> from scipy.stats import genhalflogistic
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 0.773
>>> mean, var, skew, kurt = genhalflogistic.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(genhalflogistic.ppf(0.01, c),
...                 genhalflogistic.ppf(0.99, c), 100)
>>> ax.plot(x, genhalflogistic.pdf(x, c),
...         'r-', lw=5, alpha=0.6, label='genhalflogistic pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = genhalflogistic(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

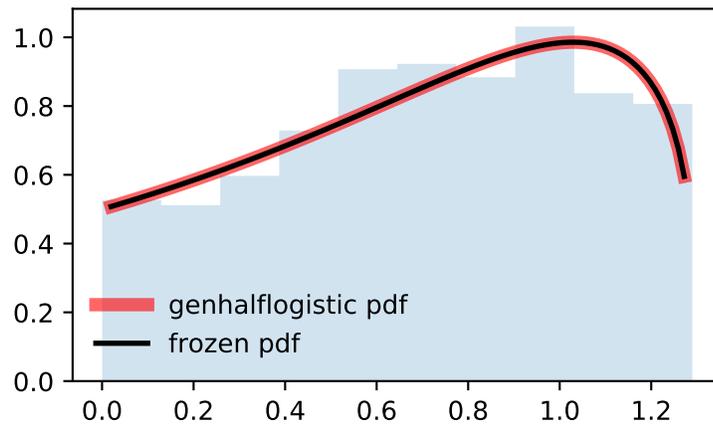
```
>>> vals = genhalflogistic.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], genhalflogistic.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = genhalflogistic.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.gilbrat` = <scipy.stats.continuous\_distns.gilbrat\_gen object>

A Gilbrat continuous random variable.

As an instance of the *rv\_continuous* class, *gilbrat* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *gilbrat* is:

$$f(x) = \frac{1}{x\sqrt{2\pi}} \exp\left(-\frac{1}{2}(\log(x))^2\right)$$

*gilbrat* is a special case of *lognorm* with  $s = 1$ .

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `gilbrat.pdf(x, loc, scale)` is identically equivalent to `gilbrat.pdf(y) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import gilbrat
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = gilbrat.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(gilbrat.ppf(0.01),
...                 gilbrat.ppf(0.99), 100)
>>> ax.plot(x, gilbrat.pdf(x),
...         'r-', lw=5, alpha=0.6, label='gilbrat pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = gilbrat()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

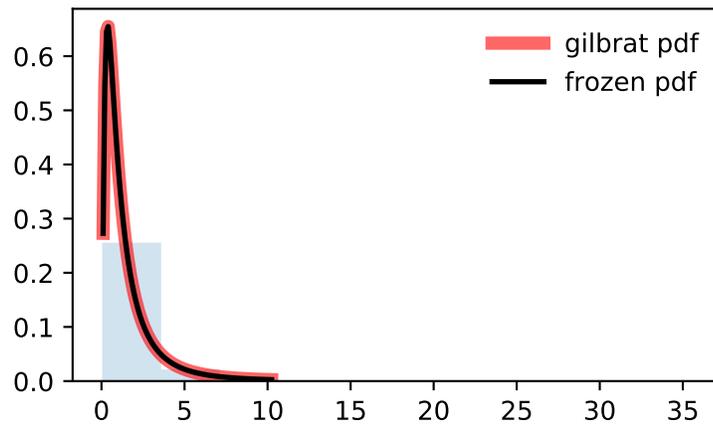
```
>>> vals = gilbrat.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], gilbrat.cdf(vals))
True
```

Generate random numbers:

```
>>> r = gilbrat.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.gompertz = <scipy.stats.continuous_distns.gompertz_gen object>`

A Gompertz (or truncated Gumbel) continuous random variable.

As an instance of the `rv_continuous` class, `gompertz` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *gompertz* is:

$$f(x, c) = c \exp(x) \exp(-c(e^x - 1))$$

for  $x \geq 0, c > 0$ .

*gompertz* takes  $c$  as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `gompertz.pdf(x, c, loc, scale)` is identically equivalent to `gompertz.pdf(y, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import gompertz
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 0.947
>>> mean, var, skew, kurt = gompertz.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(gompertz.ppf(0.01, c),
...                 gompertz.ppf(0.99, c), 100)
>>> ax.plot(x, gompertz.pdf(x, c),
...        'r-', lw=5, alpha=0.6, label='gompertz pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = gompertz(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

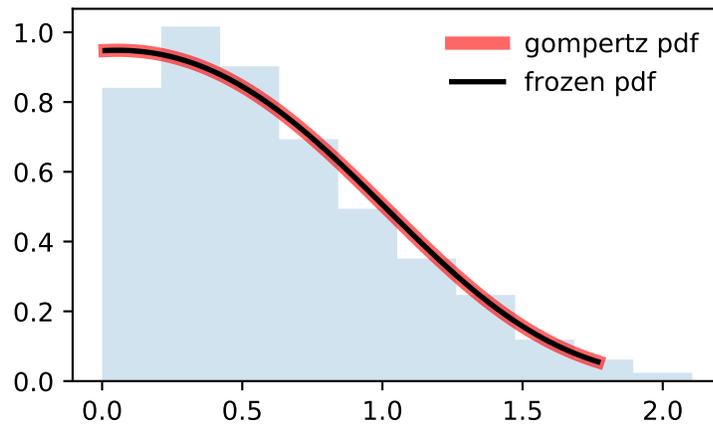
```
>>> vals = gompertz.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], gompertz.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = gompertz.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.gumbel_r` = <scipy.stats.continuous\_distns.gumbel\_r\_gen object>

A right-skewed Gumbel continuous random variable.

As an instance of the *rv\_continuous* class, *gumbel\_r* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**See also:**

*gumbel\_l*, *gompertz*, *genextreme*

**Notes**

The probability density function for *gumbel\_r* is:

$$f(x) = \exp(-(x + e^{-x}))$$

The Gumbel distribution is sometimes referred to as a type I Fisher-Tippett distribution. It is also related to the extreme value distribution, log-Weibull and Gompertz distributions.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `gumbel_r.pdf(x, loc, scale)` is identically equivalent to `gumbel_r.pdf(y) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import gumbel_r
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = gumbel_r.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(gumbel_r.ppf(0.01),
...                 gumbel_r.ppf(0.99), 100)
>>> ax.plot(x, gumbel_r.pdf(x),
...         'r-', lw=5, alpha=0.6, label='gumbel_r pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = gumbel_r()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

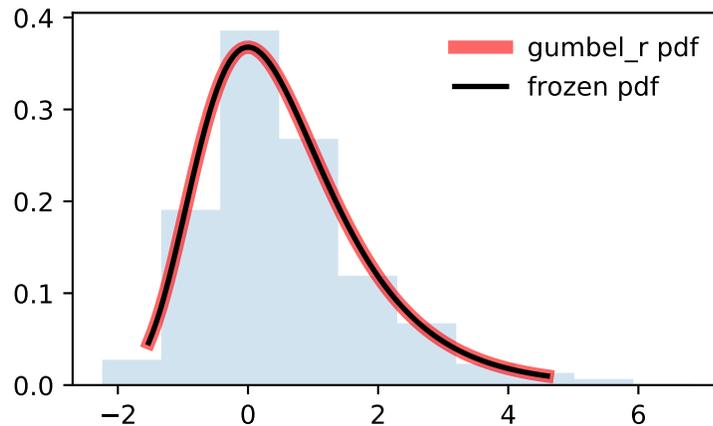
```
>>> vals = gumbel_r.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], gumbel_r.cdf(vals))
True
```

Generate random numbers:

```
>>> r = gumbel_r.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.gumbel_1 = <scipy.stats.continuous_distns.gumbel_1_gen object>`

A left-skewed Gumbel continuous random variable.

As an instance of the *rv\_continuous* class, *gumbel\_1* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**See also:**

`gumbel_r`, `gompertz`, `genextreme`

**Notes**

The probability density function for `gumbel_l` is:

$$f(x) = \exp(x - e^x)$$

The Gumbel distribution is sometimes referred to as a type I Fisher-Tippett distribution. It is also related to the extreme value distribution, log-Weibull and Gompertz distributions.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `gumbel_l.pdf(x, loc, scale)` is identically equivalent to `gumbel_l.pdf(y) / scale` with `y = (x - loc) / scale`.

**Examples**

```
>>> from scipy.stats import gumbel_l
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = gumbel_l.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(gumbel_l.ppf(0.01),
...                 gumbel_l.ppf(0.99), 100)
>>> ax.plot(x, gumbel_l.pdf(x),
...         'r-', lw=5, alpha=0.6, label='gumbel_l pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = gumbel_l()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

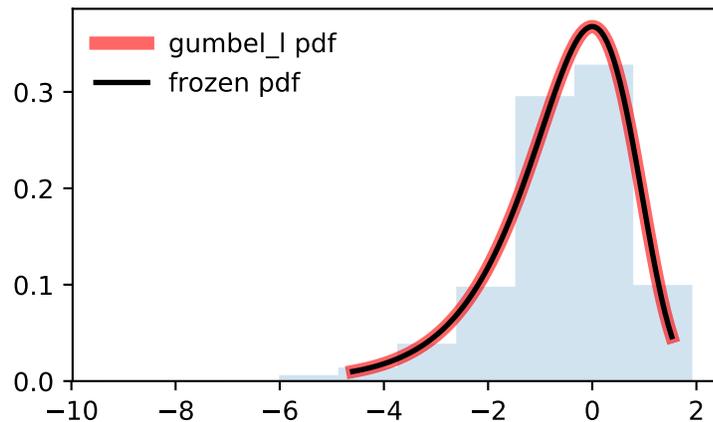
```
>>> vals = gumbel_l.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], gumbel_l.cdf(vals))
True
```

Generate random numbers:

```
>>> r = gumbel_l.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.halfcauchy = <scipy.stats._continuous_distns.halfcauchy_gen object>`

A Half-Cauchy continuous random variable.

As an instance of the *rv\_continuous* class, *halfcauchy* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *halfcauchy* is:

$$f(x) = \frac{2}{\pi(1+x^2)}$$

for  $x \geq 0$ .

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `halfcauchy.pdf(x, loc, scale)` is identically equivalent to `halfcauchy.pdf(y) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import halfcauchy
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = halfcauchy.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(halfcauchy.ppf(0.01),
...                 halfcauchy.ppf(0.99), 100)
>>> ax.plot(x, halfcauchy.pdf(x),
...         'r-', lw=5, alpha=0.6, label='halfcauchy pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = halfcauchy()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

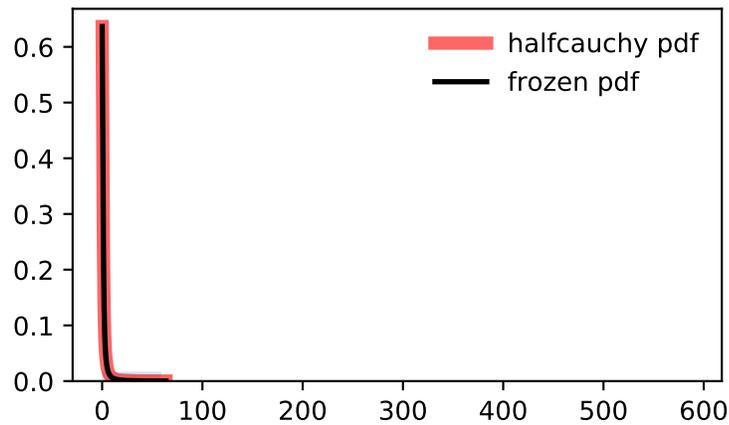
```
>>> vals = halfcauchy.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], halfcauchy.cdf(vals))
True
```

Generate random numbers:

```
>>> r = halfcauchy.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.halflogistic = <scipy.stats._continuous_distns.halflogistic_gen object>`

A half-logistic continuous random variable.

As an instance of the `rv_continuous` class, `halflogistic` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *halflogistic* is:

$$f(x) = \frac{2e^{-x}}{(1+e^{-x})^2} = \frac{1}{2} \operatorname{sech}(x/2)^2$$

for  $x \geq 0$ .

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `halflogistic.pdf(x, loc, scale)` is identically equivalent to `halflogistic.pdf(y) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import halflogistic
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = halflogistic.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(halflogistic.ppf(0.01),
...                 halflogistic.ppf(0.99), 100)
>>> ax.plot(x, halflogistic.pdf(x),
...         'r-', lw=5, alpha=0.6, label='halflogistic pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = halflogistic()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

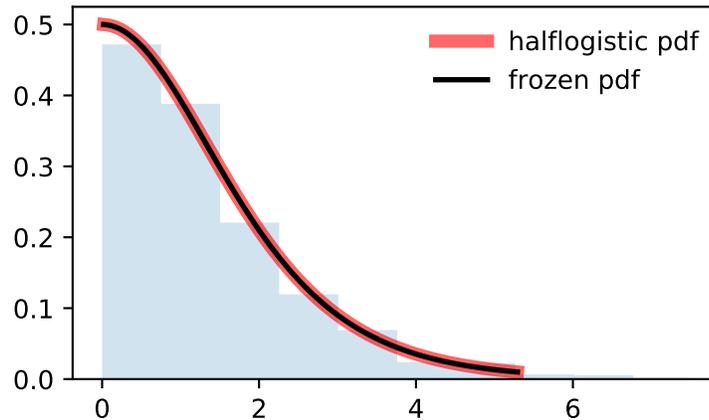
```
>>> vals = halflogistic.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], halflogistic.cdf(vals))
True
```

Generate random numbers:

```
>>> r = halflogistic.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.halfnorm = <scipy.stats._continuous_distns.halfnorm_gen object>`

A half-normal continuous random variable.

As an instance of the `rv_continuous` class, `halfnorm` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *halfnorm* is:

$$f(x) = \sqrt{2/\pi} e^{-\frac{x^2}{2}}$$

for  $x > 0$ .

*halfnorm* is a special case of `math:chi` with `df == 1`.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `halfnorm.pdf(x, loc, scale)` is identically equivalent to `halfnorm.pdf(y) / scale` with `y = (x - loc) / scale`.

### Examples

```
>>> from scipy.stats import halfnorm
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = halfnorm.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(halfnorm.ppf(0.01),
...                 halfnorm.ppf(0.99), 100)
>>> ax.plot(x, halfnorm.pdf(x),
...         'r-', lw=5, alpha=0.6, label='halfnorm pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = halfnorm()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

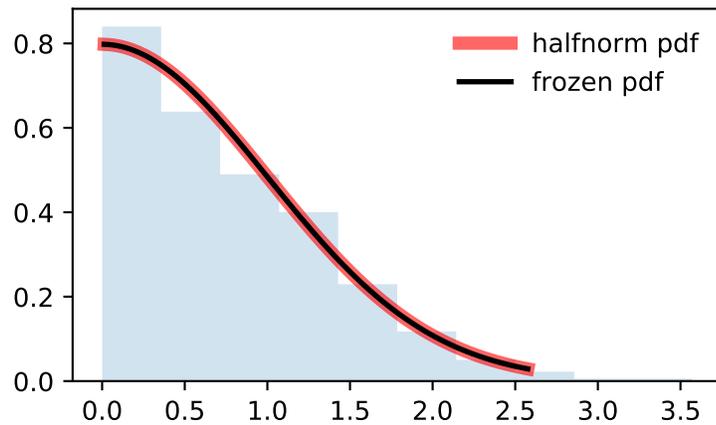
```
>>> vals = halfnorm.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], halfnorm.cdf(vals))
True
```

Generate random numbers:

```
>>> r = halfnorm.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.halfgennorm = <scipy.stats.continuous_distns.halfgennorm_gen object>`

The upper half of a generalized normal continuous random variable.

As an instance of the *rv\_continuous* class, *halfgennorm* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**See also:**

**gennorm**    generalized normal distribution  
**expon**     exponential distribution  
**halfnorm**   half normal distribution

**Notes**

The probability density function for *halfgennorm* is:

$$f(x, \beta) = \frac{\beta}{\gamma(1/\beta)} \exp(-|x|^\beta)$$

*gennorm* takes  $\beta$  as a shape parameter. For  $\beta = 1$ , it is identical to an exponential distribution. For  $\beta = 2$ , it is identical to a half normal distribution (with *scale* =  $1/\sqrt{2}$ ).

**References**

[R647]

**Examples**

```
>>> from scipy.stats import halfgennorm
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> beta = 0.675
>>> mean, var, skew, kurt = halfgennorm.stats(beta, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(halfgennorm.ppf(0.01, beta),
...                 halfgennorm.ppf(0.99, beta), 100)
>>> ax.plot(x, halfgennorm.pdf(x, beta),
...         'r-', lw=5, alpha=0.6, label='halfgennorm pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = halfgennorm(beta)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

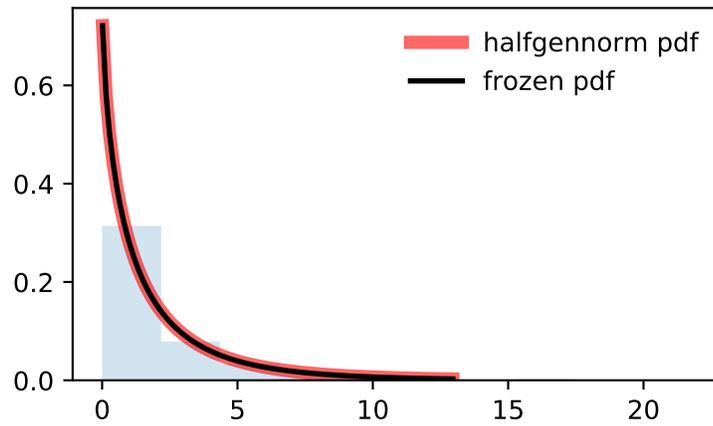
```
>>> vals = halfgennorm.ppf([0.001, 0.5, 0.999], beta)
>>> np.allclose([0.001, 0.5, 0.999], halfgennorm.cdf(vals, beta))
True
```

Generate random numbers:

```
>>> r = halfgennorm.rvs(beta, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(beta, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, beta, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, beta, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, beta, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, beta, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, beta, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, beta, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, beta, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, beta, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, beta, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(beta, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(beta, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, beta, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(beta,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwargs)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(beta, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(beta, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(beta, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(beta, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, beta, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.hypsecant` = <scipy.stats.continuous\_distns.hypsecant\_gen object>

A hyperbolic secant continuous random variable.

As an instance of the *rv\_continuous* class, *hypsecant* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *hypsecant* is:

$$f(x) = \frac{1}{\pi} \operatorname{sech}(x)$$

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `hypsecant.pdf(x, loc, scale)` is identically equivalent to `hypsecant.pdf(y) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import hypsecant
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = hypsecant.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(hypsecant.ppf(0.01),
...                 hypsecant.ppf(0.99), 100)
>>> ax.plot(x, hypsecant.pdf(x),
...         'r-', lw=5, alpha=0.6, label='hypsecant pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = hypsecant()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

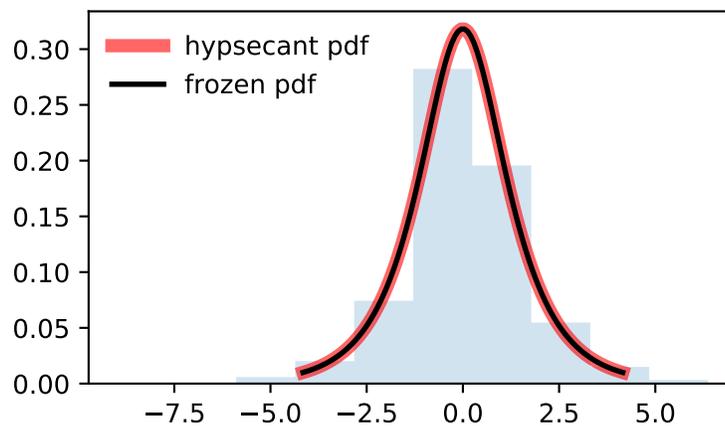
```
>>> vals = hypsecant.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], hypsecant.cdf(vals))
True
```

Generate random numbers:

```
>>> r = hypsecant.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kws)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.invgamma = <scipy.stats._continuous_distns.invgamma_gen object>`

An inverted gamma continuous random variable.

As an instance of the `rv_continuous` class, `invgamma` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for `invgamma` is:

$$f(x, a) = \frac{x^{-a-1}}{\gamma(a)} \exp\left(-\frac{1}{x}\right)$$

for  $x > 0, a > 0$ .

`invgamma` takes *a* as a shape parameter.

`invgamma` is a special case of `gengamma` with `c == -1`.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `invgamma.pdf(x, a, loc, scale)` is identically equivalent to `invgamma.pdf(y, a) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import invgamma
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a = 4.07
>>> mean, var, skew, kurt = invgamma.stats(a, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(invgamma.ppf(0.01, a),
...                 invgamma.ppf(0.99, a), 100)
>>> ax.plot(x, invgamma.pdf(x, a),
...         'r-', lw=5, alpha=0.6, label='invgamma pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = invgamma(a)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

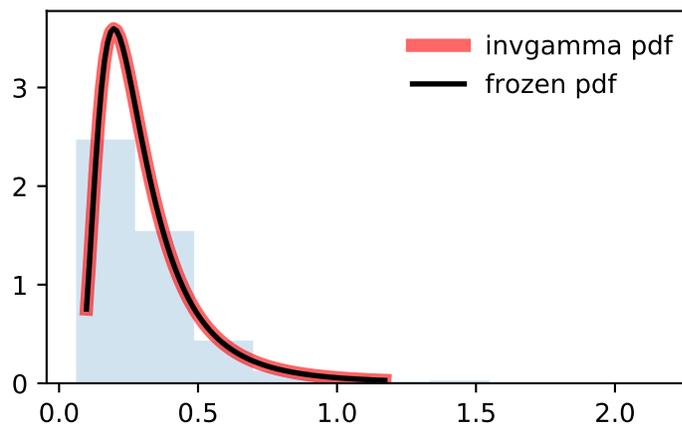
```
>>> vals = invgamma.ppf([0.001, 0.5, 0.999], a)
>>> np.allclose([0.001, 0.5, 0.999], invgamma.cdf(vals, a))
True
```

Generate random numbers:

```
>>> r = invgamma.rvs(a, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(a, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, a, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, a, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, a, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, a, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, a, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, a, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, a, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, a, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, a, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(a, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, a, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(a,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(a, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(a, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(a, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.invgauss = <scipy.stats.continuous_distns.invgauss_gen object>`

An inverse Gaussian continuous random variable.

As an instance of the *rv\_continuous* class, *invgauss* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *invgauss* is:

$$f(x, \mu) = \frac{1}{\sqrt{2\pi x^3}} \exp\left(-\frac{(x - \mu)^2}{2x\mu^2}\right)$$

for  $x > 0$ .

*invgauss* takes  $\mu$  as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `invgauss.pdf(x, mu, loc, scale)` is identically equivalent to `invgauss.pdf(y, mu) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

When  $\mu$  is too small, evaluating the cumulative distribution function will be inaccurate due to `cdf(mu -> 0) = inf * 0`. NaNs are returned for  $\mu \leq 0.0028$ .

**Examples**

```
>>> from scipy.stats import invgauss
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mu = 0.145
>>> mean, var, skew, kurt = invgauss.stats(mu, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(invgauss.ppf(0.01, mu),
...                 invgauss.ppf(0.99, mu), 100)
>>> ax.plot(x, invgauss.pdf(x, mu),
...         'r-', lw=5, alpha=0.6, label='invgauss pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = invgauss(mu)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

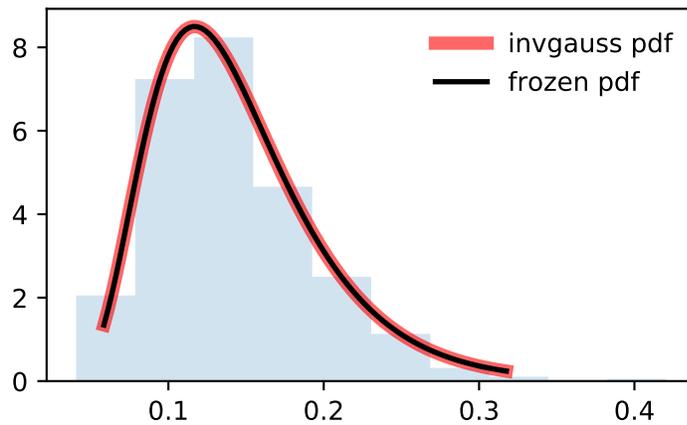
```
>>> vals = invgauss.ppf([0.001, 0.5, 0.999], mu)
>>> np.allclose([0.001, 0.5, 0.999], invgauss.cdf(vals, mu))
True
```

Generate random numbers:

```
>>> r = invgauss.rvs(mu, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(mu, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, mu, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, mu, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, mu, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, mu, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, mu, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, mu, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, mu, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, mu, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, mu, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(mu, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(mu, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, mu, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(mu,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(mu, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(mu, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(mu, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(mu, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, mu, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.invweibull = <scipy.stats._continuous_distns.invweibull_gen object>`

An inverted Weibull continuous random variable.

As an instance of the *rv\_continuous* class, *invweibull* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *invweibull* is:

$$f(x, c) = cx^{-c-1} \exp(-x^{-c})$$

for  $x > 0$ ,  $c > 0$ .

*invweibull* takes  $c$  as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `invweibull.pdf(x, c, loc, scale)` is identically equivalent to `invweibull.pdf(y, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**References**

F.R.S. de Gusmao, E.M.M Ortega and G.M. Cordeiro, “The generalized inverse Weibull distribution”, Stat. Papers, vol. 52, pp. 591-619, 2011.

**Examples**

```
>>> from scipy.stats import invweibull
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 10.6
>>> mean, var, skew, kurt = invweibull.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(invweibull.ppf(0.01, c),
...                 invweibull.ppf(0.99, c), 100)
>>> ax.plot(x, invweibull.pdf(x, c),
...         'r-', lw=5, alpha=0.6, label='invweibull pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = invweibull(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

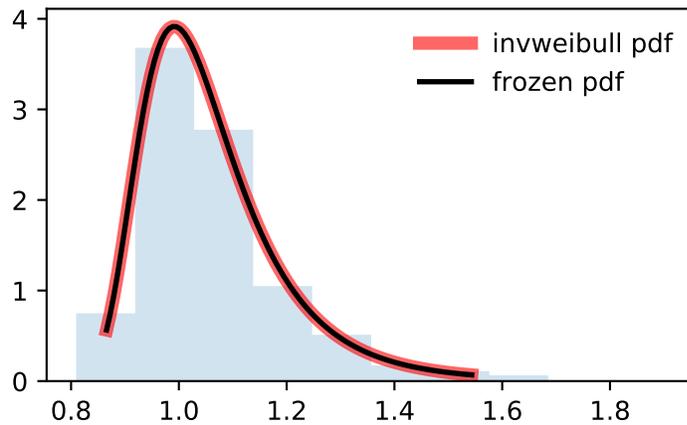
```
>>> vals = invweibull.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], invweibull.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = invweibull.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.johnsonsb` = <scipy.stats.continuous\_distns.johnsonsb\_gen object>

A Johnson SB continuous random variable.

As an instance of the *rv\_continuous* class, *johnsonsb* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**See also:***johnsonsu***Notes**

The probability density function for *johnsonsb* is:

$$f(x, a, b) = \frac{b}{x(1-x)} \phi\left(a + b \log \frac{x}{1-x}\right)$$

for  $0 < x < 1$  and  $a, b > 0$ , and  $\phi$  is the normal pdf.

*johnsonsb* takes *a* and *b* as shape parameters.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `johnsonsb.pdf(x, a, b, loc, scale)` is identically equivalent to `johnsonsb.pdf(y, a, b) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import johnsonsb
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a, b = 4.32, 3.18
>>> mean, var, skew, kurt = johnsonsb.stats(a, b, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(johnsonsb.ppf(0.01, a, b),
...                 johnsonsb.ppf(0.99, a, b), 100)
>>> ax.plot(x, johnsonsb.pdf(x, a, b),
...         'r-', lw=5, alpha=0.6, label='johnsonsb pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = johnsonsb(a, b)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

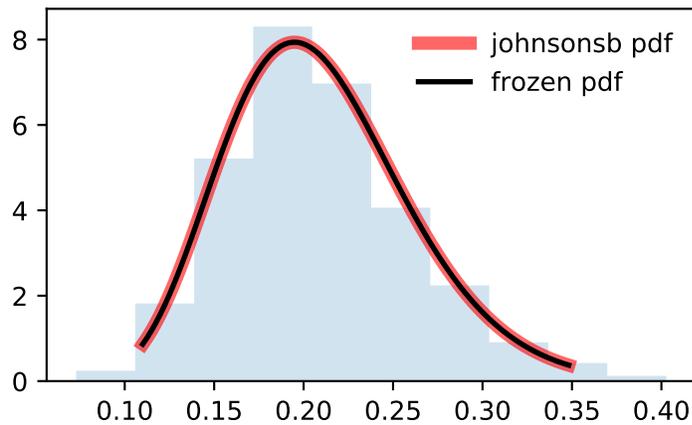
```
>>> vals = johnsonsb.ppf([0.001, 0.5, 0.999], a, b)
>>> np.allclose([0.001, 0.5, 0.999], johnsonsb.cdf(vals, a, b))
True
```

Generate random numbers:

```
>>> r = johnsonsb.rvs(a, b, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(a, b, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, a, b, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, a, b, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, a, b, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, a, b, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, a, b, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, a, b, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, a, b, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, a, b, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, a, b, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(a, b, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, b, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, a, b, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(a, b), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, b, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(a, b, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(a, b, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(a, b, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, b, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.johnsonsu` = <scipy.stats\_continuous\_distns.johnsonsu\_gen object>

A Johnson SU continuous random variable.

As an instance of the *rv\_continuous* class, *johnsonsu* object inherits from it a collection of generic

methods (see below for the full list), and completes them with details specific for this particular distribution.

**See also:**

*johnsonsb*

**Notes**

The probability density function for *johnsonsu* is:

$$f(x, a, b) = \frac{b}{\sqrt{x^2 + 1}} \phi(a + b \log(x + \sqrt{x^2 + 1}))$$

for all  $x, a, b > 0$ , and  $\phi$  is the normal pdf.

*johnsonsu* takes *a* and *b* as shape parameters.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `johnsonsu.pdf(x, a, b, loc, scale)` is identically equivalent to `johnsonsu.pdf(y, a, b) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import johnsonsu
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a, b = 2.55, 2.25
>>> mean, var, skew, kurt = johnsonsu.stats(a, b, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(johnsonsu.ppf(0.01, a, b),
...                 johnsonsu.ppf(0.99, a, b), 100)
>>> ax.plot(x, johnsonsu.pdf(x, a, b),
...         'r-', lw=5, alpha=0.6, label='johnsonsu pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = johnsonsu(a, b)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

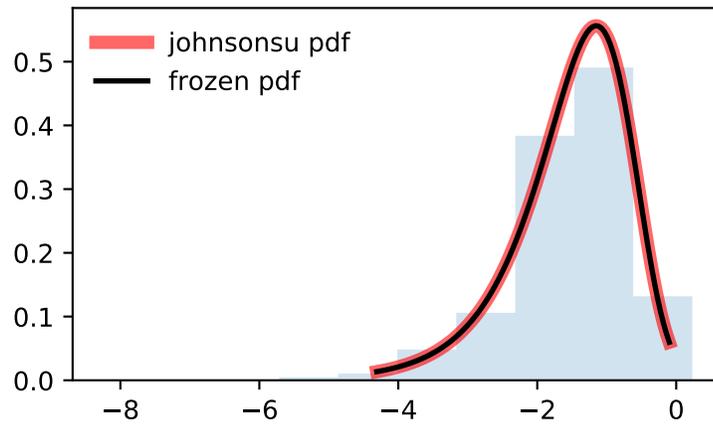
```
>>> vals = johnsonsu.ppf([0.001, 0.5, 0.999], a, b)
>>> np.allclose([0.001, 0.5, 0.999], johnsonsu.cdf(vals, a, b))
True
```

Generate random numbers:

```
>>> r = johnsonsu.rvs(a, b, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(a, b, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, a, b, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, a, b, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, a, b, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, a, b, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, a, b, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, a, b, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, a, b, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, a, b, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, a, b, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(a, b, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, b, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, a, b, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(a, b), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, b, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(a, b, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(a, b, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(a, b, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, b, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.kappa4 = <scipy.stats._continuous_distns.kappa4_gen object>`

Kappa 4 parameter distribution.

As an instance of the *rv\_continuous* class, *kappa4* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *kappa4* is:

$$f(x, h, k) = (1 - kx)^{1/k-1} (1 - h(1 - kx)^{1/k})^{1/h-1}$$

if *h* and *k* are not equal to 0.

If *h* or *k* are zero then the pdf can be simplified:

*h* = 0 and *k* != 0:

```
kappa4.pdf(x, h, k) = (1.0 - k*x)**(1.0/k - 1.0)*
                    exp(-(1.0 - k*x)**(1.0/k))
```

*h* != 0 and *k* = 0:

```
kappa4.pdf(x, h, k) = exp(-x)*(1.0 - h*exp(-x))**(1.0/h - 1.0)
```

$h = 0$  and  $k = 0$ :

```
kappa4.pdf(x, h, k) = exp(-x)*exp(-exp(-x))
```

`kappa4` takes  $h$  and  $k$  as shape parameters.

The `kappa4` distribution returns other distributions when certain  $h$  and  $k$  values are used.

h	k=0.0	k=1.0	-inf<=k<=inf
-1.0	Logistic logistic(x)		Generalized Logistic(1)
0.0	Gumbel gumbel_r(x)	Reverse Exponential(2)	Generalized Extreme Value genextreme(x, k)
1.0	Exponential expon(x)	Uniform uniform(x)	Generalized Pareto genpareto(x, -k)

1. There are at least five generalized logistic distributions. Four are described here: [https://en.wikipedia.org/wiki/Generalized\\_logistic\\_distribution](https://en.wikipedia.org/wiki/Generalized_logistic_distribution) The “fifth” one is the one `kappa4` should match which currently isn’t implemented in `scipy`: [https://en.wikipedia.org/wiki/Talk:Generalized\\_logistic\\_distribution](https://en.wikipedia.org/wiki/Talk:Generalized_logistic_distribution) [http://www.mathwave.com/help/easyfit/html/analyses/distributions/gen\\_logistic.html](http://www.mathwave.com/help/easyfit/html/analyses/distributions/gen_logistic.html)

2. This distribution is currently not in `scipy`.

### References

J.C. Finney, “Optimization of a Skewed Logistic Distribution With Respect to the Kolmogorov-Smirnov Test”, A Dissertation Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College, (August, 2004), [http://digitalcommons.lsu.edu/cgi/viewcontent.cgi?article=4671&context=gradschool\\_dissertations](http://digitalcommons.lsu.edu/cgi/viewcontent.cgi?article=4671&context=gradschool_dissertations)

J.R.M. Hosking, “The four-parameter kappa distribution”. IBM J. Res. Develop. 38 (3), 25 1-258 (1994).

B. Kumphon, A. Kaew-Man, P. Seenoi, “A Rainfall Distribution for the Lampao Site in the Chi River Basin, Thailand”, Journal of Water Resource and Protection, vol. 4, 866-869, (2012). [http://file.scirp.org/pdf/JWARP20121000009\\_14676002.pdf](http://file.scirp.org/pdf/JWARP20121000009_14676002.pdf)

C. Winchester, “On Estimation of the Four-Parameter Kappa Distribution”, A Thesis Submitted to Dalhousie University, Halifax, Nova Scotia, (March 2000). <http://www.nlc-bnc.ca/obj/s4/f2/dsk2/ftp01/MQ57336.pdf>

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `kappa4.pdf(x, h, k, loc, scale)` is identically equivalent to `kappa4.pdf(y, h, k) / scale` with  $y = (x - loc) / scale$ .

### Examples

```
>>> from scipy.stats import kappa4
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> h, k = 0.1, 0
>>> mean, var, skew, kurt = kappa4.stats(h, k, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(kappa4.ppf(0.01, h, k),
...                 kappa4.ppf(0.99, h, k), 100)
>>> ax.plot(x, kappa4.pdf(x, h, k),
...         'r-', lw=5, alpha=0.6, label='kappa4 pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = kappa4(h, k)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

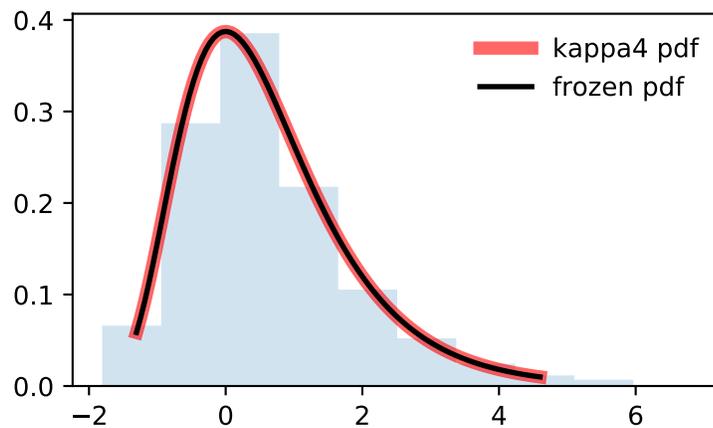
```
>>> vals = kappa4.ppf([0.001, 0.5, 0.999], h, k)
>>> np.allclose([0.001, 0.5, 0.999], kappa4.cdf(vals, h, k))
True
```

Generate random numbers:

```
>>> r = kappa4.rvs(h, k, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(h, k, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, h, k, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, h, k, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, h, k, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, h, k, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, h, k, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, h, k, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, h, k, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, h, k, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, h, k, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(h, k, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(h, k, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, h, k, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(h, k), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwargs)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(h, k, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(h, k, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(h, k, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(h, k, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, h, k, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.kappa3 = <scipy.stats._continuous_distns.kappa3_gen object>`

Kappa 3 parameter distribution.

As an instance of the `rv_continuous` class, `kappa3` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *kappa* is:

$$f(x, a) = \begin{cases} a[a + x^a]^{-(a+1)/a}, & \text{for } x > 0 \\ 0.0, & \text{for } x \leq 0 \end{cases}$$

`kappa3` takes *a* as a shape parameter and  $a > 0$ .

**References**

P.W. Mielke and E.S. Johnson, “Three-Parameter Kappa Distribution Maximum Likelihood and Likelihood Ratio Tests”, *Methods in Weather Research*, 701-707, (September, 1973), <http://docs.lib.noaa.gov/rescue/mwr/101/mwr-101-09-0701.pdf>

B. Kumphon, “Maximum Entropy and Maximum Likelihood Estimation for the Three-Parameter Kappa Distribution”, *Open Journal of Statistics*, vol 2, 415-419 (2012) [http://file.scirp.org/pdf/OJS20120400011\\_95789012.pdf](http://file.scirp.org/pdf/OJS20120400011_95789012.pdf)

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `kappa3.pdf(x, a, loc, scale)` is identically equivalent to `kappa3.pdf(y, a) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import kappa3
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a = 1
>>> mean, var, skew, kurt = kappa3.stats(a, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(kappa3.ppf(0.01, a),
...                 kappa3.ppf(0.99, a), 100)
>>> ax.plot(x, kappa3.pdf(x, a),
...         'r-', lw=5, alpha=0.6, label='kappa3 pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = kappa3(a)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

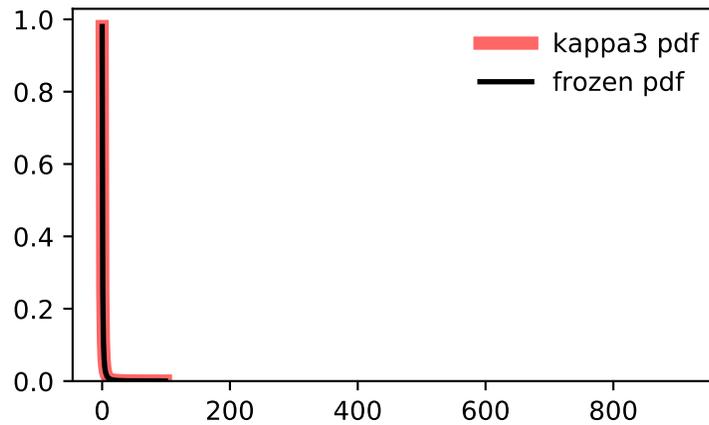
```
>>> vals = kappa3.ppf([0.001, 0.5, 0.999], a)
>>> np.allclose([0.001, 0.5, 0.999], kappa3.cdf(vals, a))
True
```

Generate random numbers:

```
>>> r = kappa3.rvs(a, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(a, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, a, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, a, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, a, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, a, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, a, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, a, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, a, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, a, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, a, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(a, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, a, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(a,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(a, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(a, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(a, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.kstone = <scipy.stats.continuous_distns.kstone_gen object>`

General Kolmogorov-Smirnov one-sided test.

As an instance of the *rv\_continuous* class, *kstone* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Examples

```
>>> from scipy.stats import ksone
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> n = 1e+03
>>> mean, var, skew, kurt = ksone.stats(n, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(ksone.ppf(0.01, n),
...                 ksone.ppf(0.99, n), 100)
>>> ax.plot(x, ksone.pdf(x, n),
...         'r-', lw=5, alpha=0.6, label='ksone pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = ksone(n)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

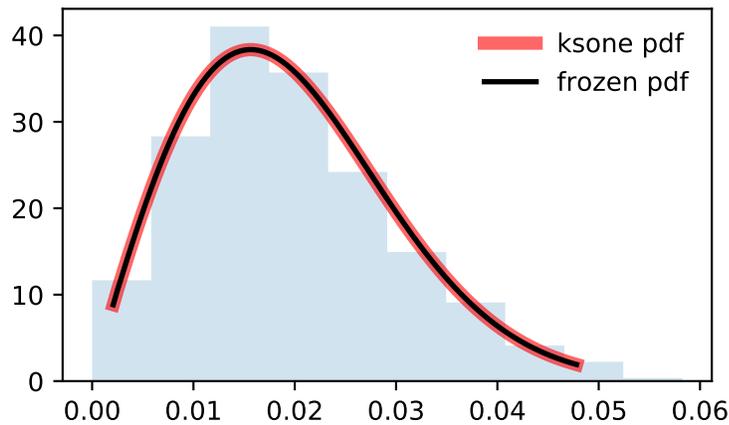
```
>>> vals = ksone.ppf([0.001, 0.5, 0.999], n)
>>> np.allclose([0.001, 0.5, 0.999], ksone.cdf(vals, n))
True
```

Generate random numbers:

```
>>> r = ksone.rvs(n, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(n, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, n, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, n, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, n, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, n, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, n, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, n, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, n, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, n, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(n, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(n, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, n, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(n,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(n, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(n, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(n, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(n, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, n, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.kstwobign` = <scipy.stats.\_continuous\_distns.kstwobign\_gen object>

Kolmogorov-Smirnov two-sided test for large *N*.

As an instance of the *rv\_continuous* class, *kstwobign* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Examples

```
>>> from scipy.stats import kstwobign
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = kstwobign.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(kstwobign.ppf(0.01),
...                 kstwobign.ppf(0.99), 100)
>>> ax.plot(x, kstwobign.pdf(x),
...         'r-', lw=5, alpha=0.6, label='kstwobign pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = kstwobign()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

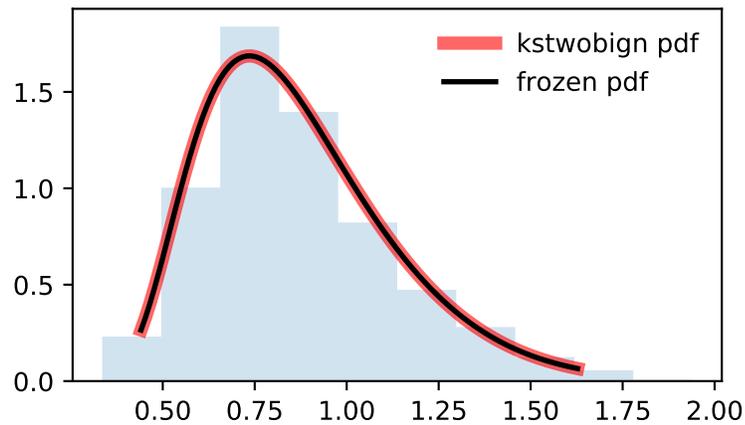
```
>>> vals = kstwobign.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], kstwobign.cdf(vals))
True
```

Generate random numbers:

```
>>> r = kstwobign.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.laplace` = <scipy.stats.continuous\_distns.laplace\_gen object>

A Laplace continuous random variable.

As an instance of the *rv\_continuous* class, *laplace* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for `laplace` is:

$$f(x) = \frac{1}{2} \exp(-|x|)$$

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `laplace.pdf(x, loc, scale)` is identically equivalent to `laplace.pdf(y) / scale` with `y = (x - loc) / scale`.

### Examples

```
>>> from scipy.stats import laplace
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = laplace.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(laplace.ppf(0.01),
...                 laplace.ppf(0.99), 100)
>>> ax.plot(x, laplace.pdf(x),
...         'r-', lw=5, alpha=0.6, label='laplace pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = laplace()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

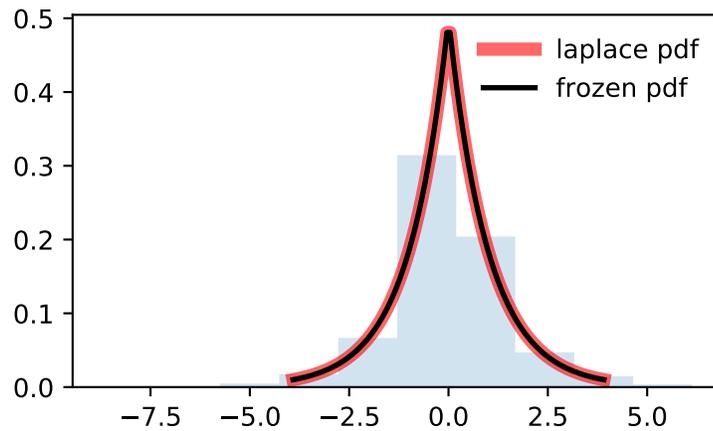
```
>>> vals = laplace.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], laplace.cdf(vals))
True
```

Generate random numbers:

```
>>> r = laplace.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.levy` = <scipy.stats.continuous\_distns.levy\_gen object>

A Levy continuous random variable.

As an instance of the *rv\_continuous* class, *levy* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**See also:**`levy_stable, levy_l`**Notes**

The probability density function for `levy` is:

$$f(x) = \frac{1}{x\sqrt{2\pi x}} \exp\left(-\frac{1}{2x}\right)$$

for  $x > 0$ .

This is the same as the Levy-stable distribution with  $a = 1/2$  and  $b = 1$ .

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `levy.pdf(x, loc, scale)` is identically equivalent to `levy.pdf(y) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import levy
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = levy.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(levy.ppf(0.01),
...                 levy.ppf(0.99), 100)
>>> ax.plot(x, levy.pdf(x),
...         'r-', lw=5, alpha=0.6, label='levy pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = levy()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

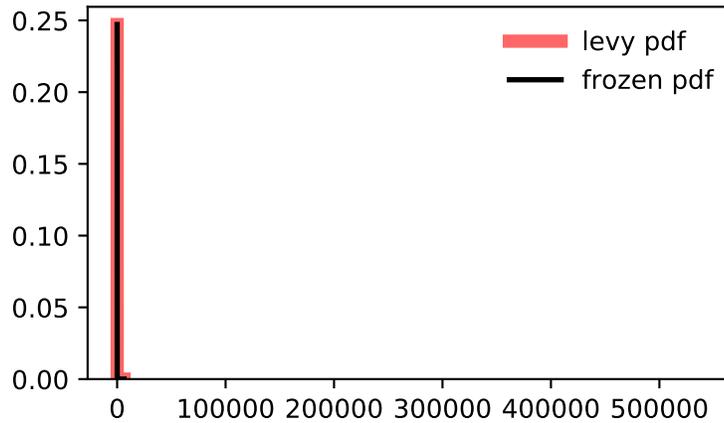
```
>>> vals = levy.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], levy.cdf(vals))
True
```

Generate random numbers:

```
>>> r = levy.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.levy_1 = <scipy.stats._continuous_distns.levy_1_gen object>`

A left-skewed Levy continuous random variable.

As an instance of the *rv\_continuous* class, *levy\_1* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**See also:**`levy, levy_stable`**Notes**

The probability density function for `levy_l` is:

$$f(x) = \frac{1}{|x|\sqrt{2\pi|x|}} \exp\left(-\frac{1}{2|x|}\right)$$

for  $x < 0$ .

This is the same as the Levy-stable distribution with  $a = 1/2$  and  $b = -1$ .

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `levy_l.pdf(x, loc, scale)` is identically equivalent to `levy_l.pdf(y) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import levy_l
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = levy_l.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(levy_l.ppf(0.01),
...                 levy_l.ppf(0.99), 100)
>>> ax.plot(x, levy_l.pdf(x),
...         'r-', lw=5, alpha=0.6, label='levy_l pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = levy_l()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

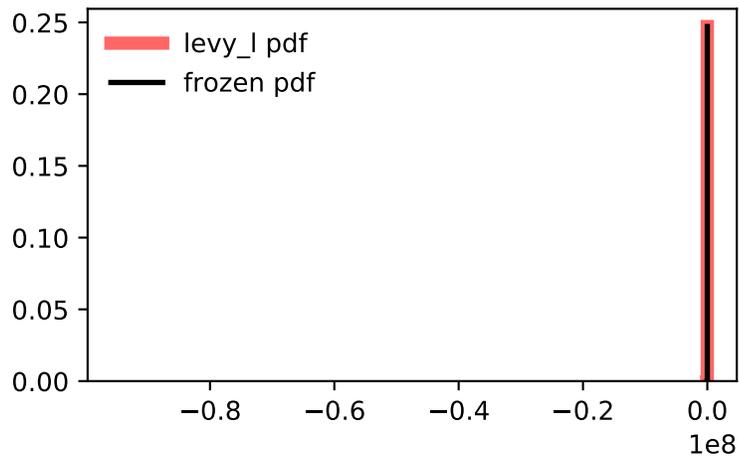
```
>>> vals = levy_l.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], levy_l.cdf(vals))
True
```

Generate random numbers:

```
>>> r = levy_l.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.levy_stable` = <scipy.stats.continuous\_distns.levy\_stable\_gen object>

A Levy-stable continuous random variable.

As an instance of the *rv\_continuous* class, *levy\_stable* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**See also:**

`levy`, `levy_l`

**Notes**

Levy-stable distribution (only random variates available – ignore other docs)

**Methods**

<code>rvs(alpha, beta, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, alpha, beta, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, alpha, beta, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, alpha, beta, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, alpha, beta, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, alpha, beta, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, alpha, beta, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, alpha, beta, loc=0, scale=1)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, alpha, beta, loc=0, scale=1)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>moment(n, alpha, beta, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(alpha, beta, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(alpha, beta, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, alpha, beta, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(alpha, beta), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(alpha, beta, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(alpha, beta, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(alpha, beta, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(alpha, beta, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, alpha, beta, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.logistic = <scipy.stats.continuous_distns.logistic_gen object>`

A logistic (or Sech-squared) continuous random variable.

As an instance of the `rv_continuous` class, `logistic` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for `logistic` is:

$$f(x) = \frac{\exp(-x)}{(1 + \exp(-x))^2}$$

`logistic` is a special case of `genlogistic` with `c == 1`.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `logistic.pdf(x, loc, scale)` is identically equivalent

to `logistic.pdf(y) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import logistic
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = logistic.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(logistic.ppf(0.01),
...                 logistic.ppf(0.99), 100)
>>> ax.plot(x, logistic.pdf(x),
...        'r-', lw=5, alpha=0.6, label='logistic pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = logistic()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

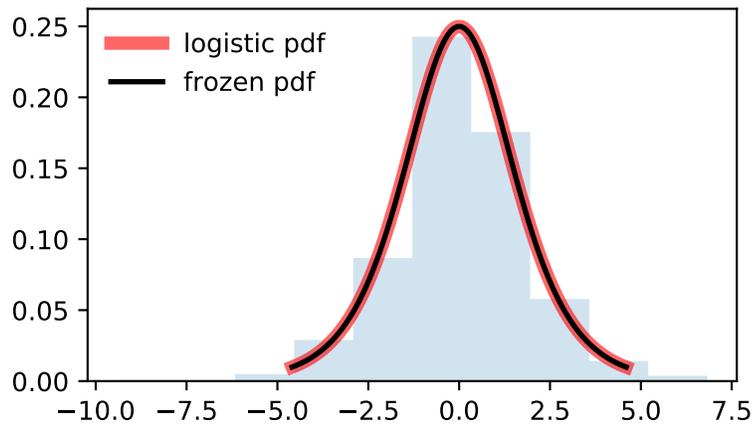
```
>>> vals = logistic.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], logistic.cdf(vals))
True
```

Generate random numbers:

```
>>> r = logistic.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.loggamma = <scipy.stats.continuous_distns.loggamma_gen object>`

A log gamma continuous random variable.

As an instance of the `rv_continuous` class, `loggamma` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *loggamma* is:

$$f(x, c) = \frac{\exp(cx - \exp(x))}{\gamma(c)}$$

for all  $x, c > 0$ .

*loggamma* takes  $c$  as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `loggamma.pdf(x, c, loc, scale)` is identically equivalent to `loggamma.pdf(y, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import loggamma
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 0.414
>>> mean, var, skew, kurt = loggamma.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(loggamma.ppf(0.01, c),
...                 loggamma.ppf(0.99, c), 100)
>>> ax.plot(x, loggamma.pdf(x, c),
...        'r-', lw=5, alpha=0.6, label='loggamma pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = loggamma(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

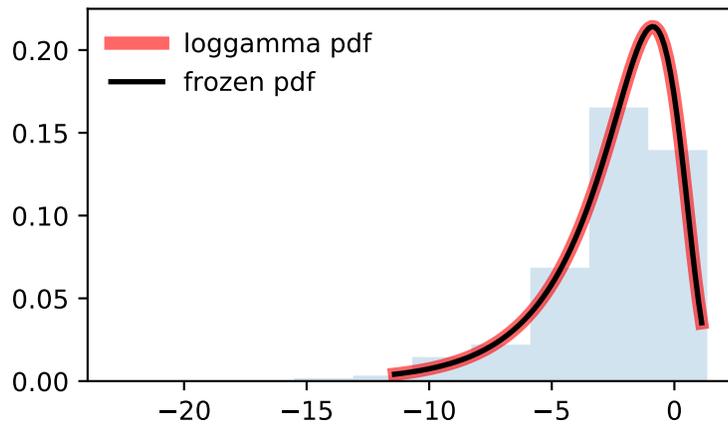
```
>>> vals = loggamma.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], loggamma.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = loggamma.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.loglaplace = <scipy.stats.continuous_distns.loglaplace_gen object>`

A log-Laplace continuous random variable.

As an instance of the *rv\_continuous* class, *loglaplace* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for `loglaplace` is:

$$f(x, c) = \begin{cases} \frac{c}{2}x^{c-1} & \text{for } 0 < x < 1 \\ \frac{c}{2}x^{-c-1} & \text{for } x \geq 1 \end{cases}$$

for  $c > 0$ .

`loglaplace` takes  $c$  as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `loglaplace.pdf(x, c, loc, scale)` is identically equivalent to `loglaplace.pdf(y, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**References**

T.J. Kozubowski and K. Podgorski, “A log-Laplace growth rate model”, *The Mathematical Scientist*, vol. 28, pp. 49-60, 2003.

**Examples**

```
>>> from scipy.stats import loglaplace
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 3.25
>>> mean, var, skew, kurt = loglaplace.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(loglaplace.ppf(0.01, c),
...                 loglaplace.ppf(0.99, c), 100)
>>> ax.plot(x, loglaplace.pdf(x, c),
...        'r-', lw=5, alpha=0.6, label='loglaplace pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = loglaplace(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

```
>>> vals = loglaplace.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], loglaplace.cdf(vals, c))
True
```

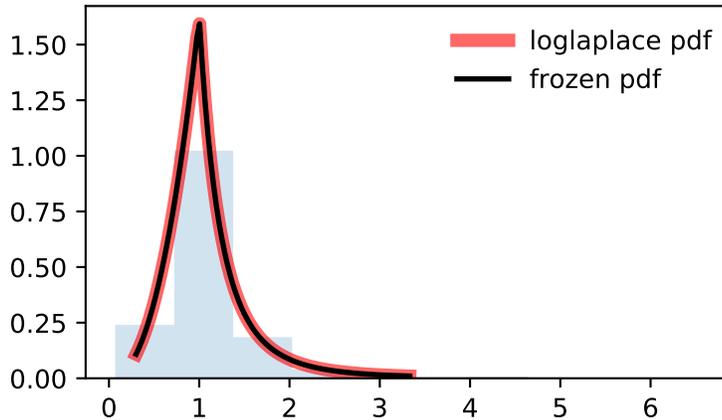
Generate random numbers:

```
>>> r = loglaplace.rvs(c, size=1000)
```

And compare the histogram:

```

>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
    
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwargs)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains <i>alpha</i> percent of the distribution

`scipy.stats.lognorm` = <scipy.stats.continuous\_distns.lognorm\_gen object>

A lognormal continuous random variable.

As an instance of the `rv_continuous` class, `lognorm` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for `lognorm` is:

$$f(x, s) = \frac{1}{sx\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{\log(x)}{s}\right)^2\right)$$

for  $x > 0, s > 0$ .

`lognorm` takes `s` as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `lognorm.pdf(x, s, loc, scale)` is identically equivalent to `lognorm.pdf(y, s) / scale` with `y = (x - loc) / scale`.

A common parametrization for a lognormal random variable  $Y$  is in terms of the mean, `mu`, and standard deviation, `sigma`, of the unique normally distributed random variable  $X$  such that  $\exp(X) = Y$ . This parametrization corresponds to setting `s = sigma` and `scale = exp(mu)`.

### Examples

```
>>> from scipy.stats import lognorm
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> s = 0.954
>>> mean, var, skew, kurt = lognorm.stats(s, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(lognorm.ppf(0.01, s),
...                 lognorm.ppf(0.99, s), 100)
>>> ax.plot(x, lognorm.pdf(x, s),
...         'r-', lw=5, alpha=0.6, label='lognorm pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = lognorm(s)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

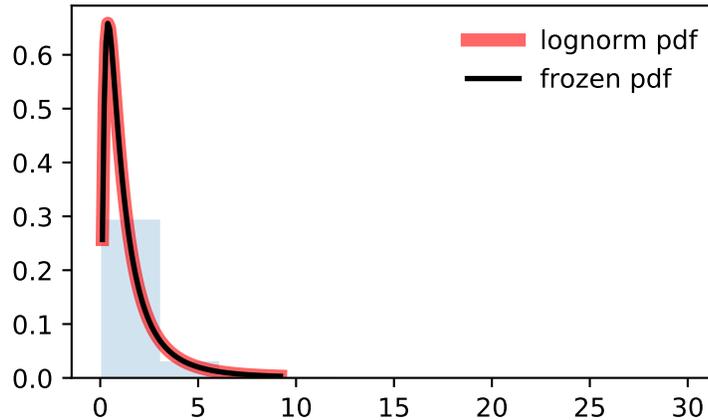
```
>>> vals = lognorm.ppf([0.001, 0.5, 0.999], s)
>>> np.allclose([0.001, 0.5, 0.999], lognorm.cdf(vals, s))
True
```

Generate random numbers:

```
>>> r = lognorm.rvs(s, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(s, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, s, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, s, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, s, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, s, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, s, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, s, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, s, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, s, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, s, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(s, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(s, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, s, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(s,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwargs)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(s, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(s, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(s, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(s, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, s, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.lomax = <scipy.stats._continuous_distns.lomax_gen object>`

A Lomax (Pareto of the second kind) continuous random variable.

As an instance of the `rv_continuous` class, `lomax` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The Lomax distribution is a special case of the Pareto distribution, with (`loc=-1.0`).

The probability density function for `lomax` is:

$$f(x, c) = \frac{c}{(1+x)^{c+1}}$$

for  $x \geq 0, c > 0$ .

`lomax` takes `c` as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `lomax.pdf(x, c, loc, scale)` is identically equivalent to `lomax.pdf(y, c) / scale` with `y = (x - loc) / scale`.

### Examples

```
>>> from scipy.stats import lomax
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 1.88
>>> mean, var, skew, kurt = lomax.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(lomax.ppf(0.01, c),
...                 lomax.ppf(0.99, c), 100)
>>> ax.plot(x, lomax.pdf(x, c),
...         'r-', lw=5, alpha=0.6, label='lomax pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = lomax(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

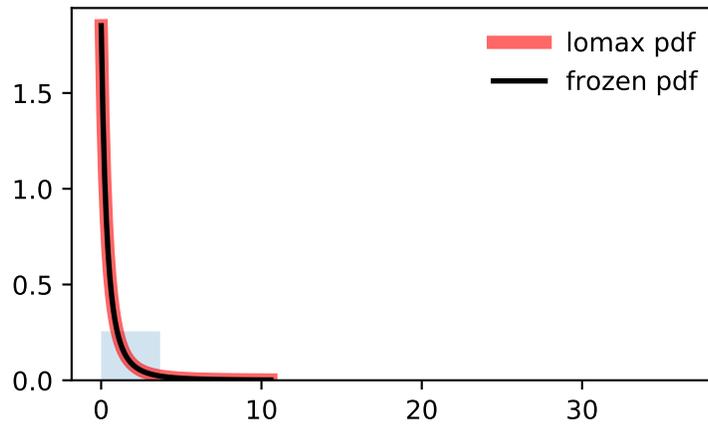
```
>>> vals = lomax.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], lomax.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = lomax.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwargs)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains <i>alpha</i> percent of the distribution

`scipy.stats.maxwell = <scipy.stats.continuous_distns.maxwell_gen object>`

A Maxwell continuous random variable.

As an instance of the `rv_continuous` class, `maxwell` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

A special case of a `chi` distribution, with `df = 3`, `loc = 0.0`, and given `scale = a`, where `a` is the parameter used in the Mathworld description [R667].

The probability density function for `maxwell` is:

$$f(x) = \sqrt{2/\pi} x^2 \exp(-x^2/2)$$

for  $x > 0$ .

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `maxwell.pdf(x, loc, scale)` is identically equivalent to `maxwell.pdf(y) / scale` with `y = (x - loc) / scale`.

### References

[R667]

### Examples

```
>>> from scipy.stats import maxwell
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = maxwell.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(maxwell.ppf(0.01),
...                 maxwell.ppf(0.99), 100)
>>> ax.plot(x, maxwell.pdf(x),
...        'r-', lw=5, alpha=0.6, label='maxwell pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = maxwell()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

```
>>> vals = maxwell.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], maxwell.cdf(vals))
True
```

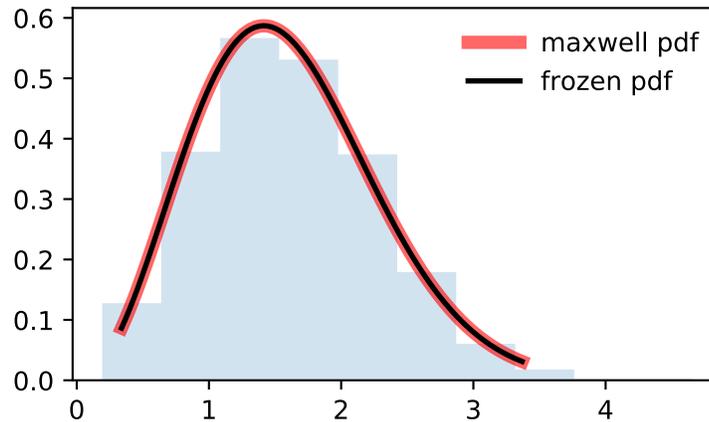
Generate random numbers:

```
>>> r = maxwell.rvs(size=1000)
```

And compare the histogram:

```

>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
    
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains <i>alpha</i> percent of the distribution

`scipy.stats.mielke = <scipy.stats_continuous_distns.mielke_gen object>`

A Mielke’s Beta-Kappa continuous random variable.

As an instance of the `rv_continuous` class, `mielke` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for `mielke` is:

$$f(x, k, s) = \frac{kx^{k-1}}{(1+x^s)^{1+k/s}}$$

for  $x > 0$ .

`mielke` takes `k` and `s` as shape parameters.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `mielke.pdf(x, k, s, loc, scale)` is identically equivalent to `mielke.pdf(y, k, s) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import mielke
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> k, s = 10.4, 3.6
>>> mean, var, skew, kurt = mielke.stats(k, s, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(mielke.ppf(0.01, k, s),
...                 mielke.ppf(0.99, k, s), 100)
>>> ax.plot(x, mielke.pdf(x, k, s),
...         'r-', lw=5, alpha=0.6, label='mielke pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = mielke(k, s)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

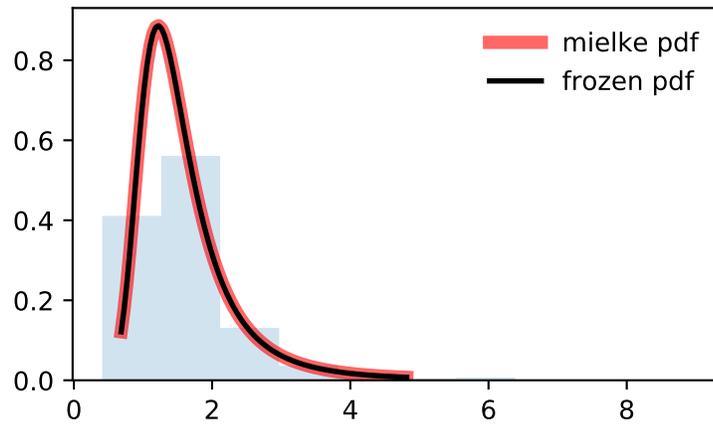
```
>>> vals = mielke.ppf([0.001, 0.5, 0.999], k, s)
>>> np.allclose([0.001, 0.5, 0.999], mielke.cdf(vals, k, s))
True
```

Generate random numbers:

```
>>> r = mielke.rvs(k, s, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(k, s, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, k, s, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, k, s, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, k, s, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, k, s, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, k, s, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, k, s, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, k, s, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, k, s, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, k, s, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(k, s, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(k, s, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, k, s, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(k, s), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwargs)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(k, s, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(k, s, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(k, s, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(k, s, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, k, s, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.nakagami` = <scipy.stats.continuous\_distns.nakagami\_gen object>

A Nakagami continuous random variable.

As an instance of the *rv\_continuous* class, *nakagami* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *nakagami* is:

$$f(x, nu) = \frac{2\nu^\nu}{\gamma(\nu)} x^{2\nu-1} \exp(-\nu x^2)$$

for  $x > 0, nu > 0$ .

*nakagami* takes *nu* as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `nakagami.pdf(x, nu, loc, scale)` is identically equivalent to `nakagami.pdf(y, nu) / scale` with  $y = (x - loc) / scale$ .

**Examples**

```
>>> from scipy.stats import nakagami
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> nu = 4.97
>>> mean, var, skew, kurt = nakagami.stats(nu, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(nakagami.ppf(0.01, nu),
...                 nakagami.ppf(0.99, nu), 100)
>>> ax.plot(x, nakagami.pdf(x, nu),
...         'r-', lw=5, alpha=0.6, label='nakagami pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = nakagami(nu)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

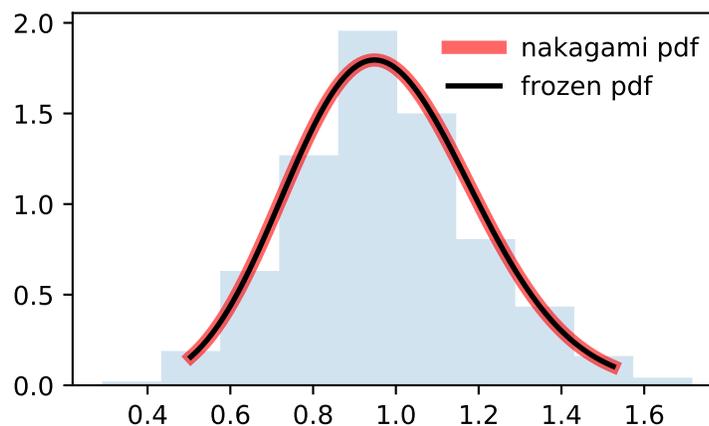
```
>>> vals = nakagami.ppf([0.001, 0.5, 0.999], nu)
>>> np.allclose([0.001, 0.5, 0.999], nakagami.cdf(vals, nu))
True
```

Generate random numbers:

```
>>> r = nakagami.rvs(nu, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(nu, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, nu, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, nu, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, nu, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, nu, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, nu, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, nu, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, nu, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, nu, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, nu, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(nu, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(nu, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, nu, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(nu,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(nu, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(nu, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(nu, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(nu, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, nu, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.ncx2 = <scipy.stats.continuous_distns.ncx2_gen object>`

A non-central chi-squared continuous random variable.

As an instance of the *rv\_continuous* class, *ncx2* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *ncx2* is:

$$f(x, df, nc) = \exp\left(-\frac{nc + x}{2}\right) \frac{1}{2} (x/nc)^{(df-2)/4} I_{[(df-2)/2]}(\sqrt{ncx})$$

for  $x > 0$ .

*ncx2* takes *df* and *nc* as shape parameters.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `ncx2.pdf(x, df, nc, loc, scale)` is identically equivalent to `ncx2.pdf(y, df, nc) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import ncx2
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> df, nc = 21, 1.06
>>> mean, var, skew, kurt = ncx2.stats(df, nc, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(ncx2.ppf(0.01, df, nc),
...                 ncx2.ppf(0.99, df, nc), 100)
>>> ax.plot(x, ncx2.pdf(x, df, nc),
...         'r-', lw=5, alpha=0.6, label='ncx2 pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = ncx2(df, nc)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

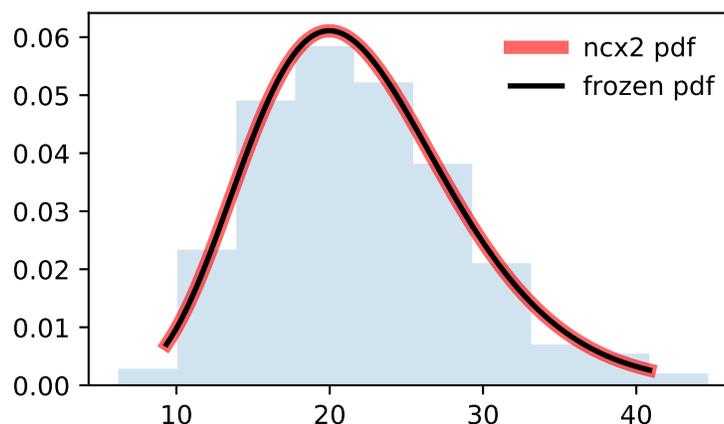
```
>>> vals = ncx2.ppf([0.001, 0.5, 0.999], df, nc)
>>> np.allclose([0.001, 0.5, 0.999], ncx2.cdf(vals, df, nc))
True
```

Generate random numbers:

```
>>> r = ncx2.rvs(df, nc, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(df, nc, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, df, nc, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, df, nc, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, df, nc, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, df, nc, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, df, nc, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, df, nc, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, df, nc, loc=0, scale=1)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, df, nc, loc=0, scale=1)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>moment(n, df, nc, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(df, nc, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(df, nc, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, df, nc, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(df, nc), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwargs)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(df, nc, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(df, nc, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(df, nc, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(df, nc, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, df, nc, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.ncf` = <scipy.stats.continuous\_distns.ncf\_gen object>

A non-central F distribution continuous random variable.

As an instance of the `rv_continuous` class, `ncf` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for `ncf` is:

$$f(x, n_1, n_2, \lambda) = \exp\left(\frac{\lambda}{2} + \lambda n_1 \frac{x}{2(n_1 x + n_2)}\right) n_1^{n_1/2} n_2^{n_2/2} x^{n_1/2-1} \\ (n_2 + n_1 x)^{-(n_1+n_2)/2} \gamma(n_1/2) \gamma(1 + n_2/2) \\ \frac{L_{\frac{v_1}{2}-1}(-\lambda v_1 \frac{x}{2(v_1 x + v_2)})}{(B(v_1/2, v_2/2) \gamma(\frac{v_1+v_2}{2}))}$$

for  $n_1 > 1$ ,  $n_2, \lambda > 0$ . Here  $n_1$  is the degrees of freedom in the numerator,  $n_2$  the degrees of freedom in the denominator,  $\lambda$  the non-centrality parameter,  $\gamma$  is the logarithm of the Gamma function,  $L_n^k$  is a generalized Laguerre polynomial and  $B$  is the beta function.

`ncf` takes `df1`, `df2` and `nc` as shape parameters.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `ncf.pdf(x, dfn, dfd, nc, loc, scale)` is identically

equivalent to `ncf.pdf(y, dfn, dfd, nc) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import ncf
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> dfn, dfd, nc = 27, 27, 0.416
>>> mean, var, skew, kurt = ncf.stats(dfn, dfd, nc, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(ncf.ppf(0.01, dfn, dfd, nc),
...                 ncf.ppf(0.99, dfn, dfd, nc), 100)
>>> ax.plot(x, ncf.pdf(x, dfn, dfd, nc),
...         'r-', lw=5, alpha=0.6, label='ncf pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = ncf(dfn, dfd, nc)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

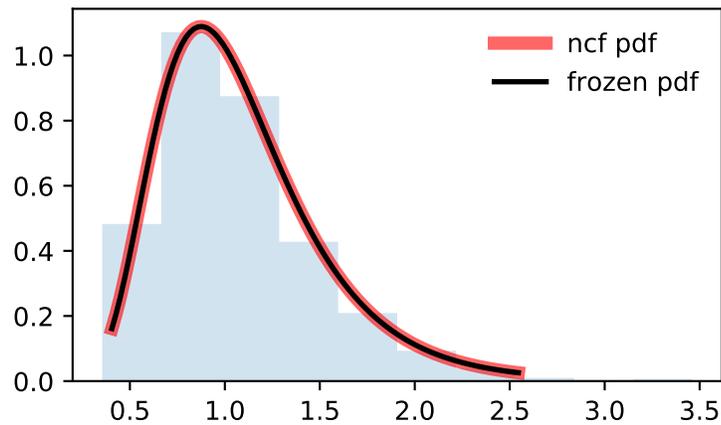
```
>>> vals = ncf.ppf([0.001, 0.5, 0.999], dfn, dfd, nc)
>>> np.allclose([0.001, 0.5, 0.999], ncf.cdf(vals, dfn, dfd, nc))
True
```

Generate random numbers:

```
>>> r = ncf.rvs(dfn, dfd, nc, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(dfn, dfd, nc, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, dfn, dfd, nc, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, dfn, dfd, nc, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, dfn, dfd, nc, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, dfn, dfd, nc, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, dfn, dfd, nc, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, dfn, dfd, nc, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, dfn, dfd, nc, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, dfn, dfd, nc, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, dfn, dfd, nc, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(dfn, dfd, nc, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(dfn, dfd, nc, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, dfn, dfd, nc, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(dfn, dfd, nc), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(dfn, dfd, nc, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(dfn, dfd, nc, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(dfn, dfd, nc, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(dfn, dfd, nc, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, dfn, dfd, nc, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.nct` = <`scipy.stats.continuous_distns.nct_gen` object>

A non-central Student's T continuous random variable.

As an instance of the `rv_continuous` class, `nct` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for `nct` is:

$$f(x, df, nc) = \frac{df^{df/2} \gamma(df + 1)}{2^{df} \exp(nc^2/2) (df + x^2)^{df/2} \gamma(df/2)}$$

for  $df > 0$ .

`nct` takes `df` and `nc` as shape parameters.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `nct.pdf(x, df, nc, loc, scale)` is identically equivalent to `nct.pdf(y, df, nc) / scale` with  $y = (x - loc) / scale$ .

### Examples

```
>>> from scipy.stats import nct
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> df, nc = 14, 0.24
>>> mean, var, skew, kurt = nct.stats(df, nc, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(nct.ppf(0.01, df, nc),
...                 nct.ppf(0.99, df, nc), 100)
>>> ax.plot(x, nct.pdf(x, df, nc),
...         'r-', lw=5, alpha=0.6, label='nct pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = nct(df, nc)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

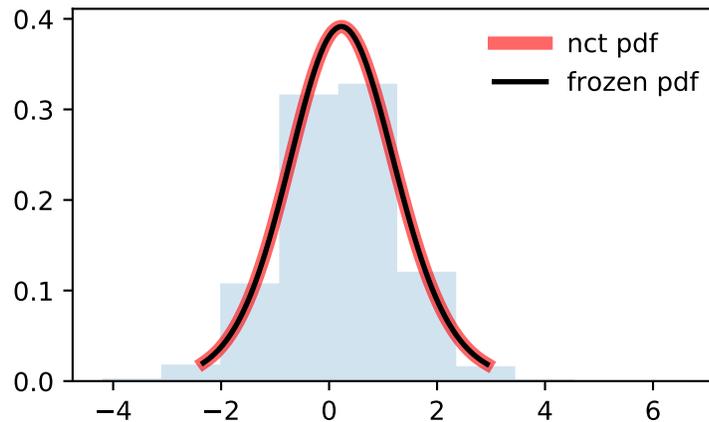
```
>>> vals = nct.ppf([0.001, 0.5, 0.999], df, nc)
>>> np.allclose([0.001, 0.5, 0.999], nct.cdf(vals, df, nc))
True
```

Generate random numbers:

```
>>> r = nct.rvs(df, nc, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(df, nc, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, df, nc, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, df, nc, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, df, nc, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, df, nc, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, df, nc, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, df, nc, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, df, nc, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, df, nc, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, df, nc, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(df, nc, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(df, nc, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, df, nc, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(df, nc), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(df, nc, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(df, nc, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(df, nc, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(df, nc, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, df, nc, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.norm = <scipy.stats.continuous_distns.norm_gen object>`

A normal continuous random variable.

The location (*loc*) keyword specifies the mean. The scale (*scale*) keyword specifies the standard deviation.

As an instance of the `rv_continuous` class, `norm` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for `norm` is:

$$f(x) = \frac{\exp(-x^2/2)}{\sqrt{2\pi}}$$

The survival function, `norm.sf`, is also referred to as the Q-function in some contexts (see, e.g., [Wikipedia's definition](#)).

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `norm.pdf(x, loc, scale)` is identically equivalent to `norm.pdf(y) / scale` with `y = (x - loc) / scale`.

### Examples

```
>>> from scipy.stats import norm
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = norm.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(norm.ppf(0.01),
...                 norm.ppf(0.99), 100)
>>> ax.plot(x, norm.pdf(x),
...         'r-', lw=5, alpha=0.6, label='norm pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = norm()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

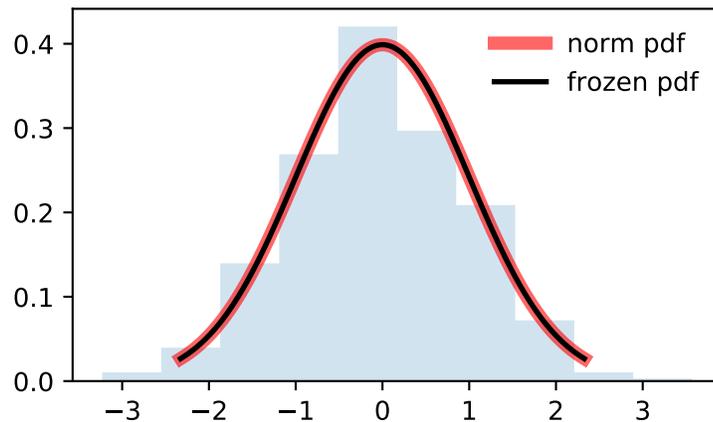
```
>>> vals = norm.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], norm.cdf(vals))
True
```

Generate random numbers:

```
>>> r = norm.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.pareto` = <scipy.stats.continuous\_distns.pareto\_gen object>

A Pareto continuous random variable.

As an instance of the *rv\_continuous* class, *pareto* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *pareto* is:

$$f(x, b) = \frac{b}{x^{b+1}}$$

for  $x \geq 1, b > 0$ .

*pareto* takes *b* as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `pareto.pdf(x, b, loc, scale)` is identically equivalent to `pareto.pdf(y, b) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import pareto
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> b = 2.62
>>> mean, var, skew, kurt = pareto.stats(b, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(pareto.ppf(0.01, b),
...                 pareto.ppf(0.99, b), 100)
>>> ax.plot(x, pareto.pdf(x, b),
...         'r-', lw=5, alpha=0.6, label='pareto pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = pareto(b)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

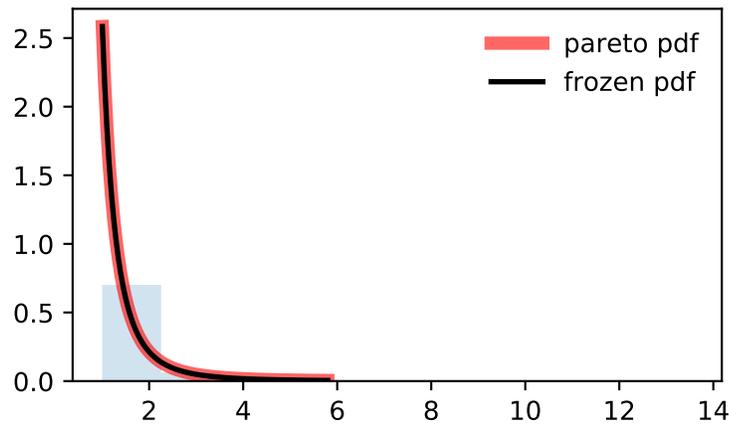
```
>>> vals = pareto.ppf([0.001, 0.5, 0.999], b)
>>> np.allclose([0.001, 0.5, 0.999], pareto.cdf(vals, b))
True
```

Generate random numbers:

```
>>> r = pareto.rvs(b, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(b, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, b, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, b, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, b, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, b, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, b, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, b, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, b, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, b, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, b, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(b, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(b, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, b, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(b,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(b, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(b, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(b, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(b, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, b, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.pearson3 = <scipy.stats.continuous_distns.pearson3_gen object>`

A pearson type III continuous random variable.

As an instance of the `rv_continuous` class, `pearson3` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for `pearson3` is:

$$f(x, skew) = \frac{|\beta|}{\gamma(\alpha)} (\beta(x - \zeta))^{\alpha-1} \exp(-\beta(x - \zeta))$$

where:

$$\beta = \frac{2}{skewstddev} \alpha = (stddev\beta)^2 \zeta = loc - \frac{\alpha}{\beta}$$

`pearson3` takes `skew` as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `pearson3.pdf(x, skew, loc, scale)` is identically equivalent to `pearson3.pdf(y, skew) / scale` with `y = (x - loc) / scale`.

### References

R.W. Vogel and D.E. McMartin, “Probability Plot Goodness-of-Fit and Skewness Estimation Procedures for the Pearson Type 3 Distribution”, *Water Resources Research*, Vol.27, 3149-3158 (1991).

L.R. Salvosa, “Tables of Pearson’s Type III Function”, *Ann. Math. Statist.*, Vol.1, 191-198 (1930).

“Using Modern Computing Tools to Fit the Pearson Type III Distribution to Aviation Loads Data”, Office of Aviation Research (2003).

### Examples

```
>>> from scipy.stats import pearson3
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> skew = 0.1
>>> mean, var, skew, kurt = pearson3.stats(skew, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(pearson3.ppf(0.01, skew),
...                 pearson3.ppf(0.99, skew), 100)
>>> ax.plot(x, pearson3.pdf(x, skew),
...         'r-', lw=5, alpha=0.6, label='pearson3 pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = pearson3(skew)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

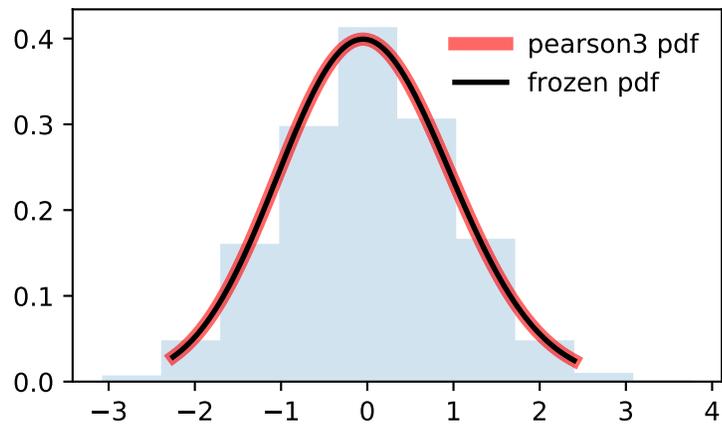
```
>>> vals = pearson3.ppf([0.001, 0.5, 0.999], skew)
>>> np.allclose([0.001, 0.5, 0.999], pearson3.cdf(vals, skew))
True
```

Generate random numbers:

```
>>> r = pearson3.rvs(skew, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(skew, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, skew, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, skew, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, skew, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, skew, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, skew, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, skew, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, skew, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, skew, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, skew, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(skew, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(skew, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, skew, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(skew,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(skew, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(skew, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(skew, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(skew, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, skew, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.powerlaw = <scipy.stats.continuous_distns.powerlaw_gen object>`

A power-function continuous random variable.

As an instance of the *rv\_continuous* class, *powerlaw* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *powerlaw* is:

$$f(x, a) = ax^{a-1}$$

for  $0 \leq x \leq 1, a > 0$ .

*powerlaw* takes *a* as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `powerlaw.pdf(x, a, loc, scale)` is identically equivalent to `powerlaw.pdf(y, a) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

*powerlaw* is a special case of *beta* with  $b == 1$ .

**Examples**

```
>>> from scipy.stats import powerlaw
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a = 1.66
>>> mean, var, skew, kurt = powerlaw.stats(a, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(powerlaw.ppf(0.01, a),
...                 powerlaw.ppf(0.99, a), 100)
>>> ax.plot(x, powerlaw.pdf(x, a),
...         'r-', lw=5, alpha=0.6, label='powerlaw pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = powerlaw(a)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

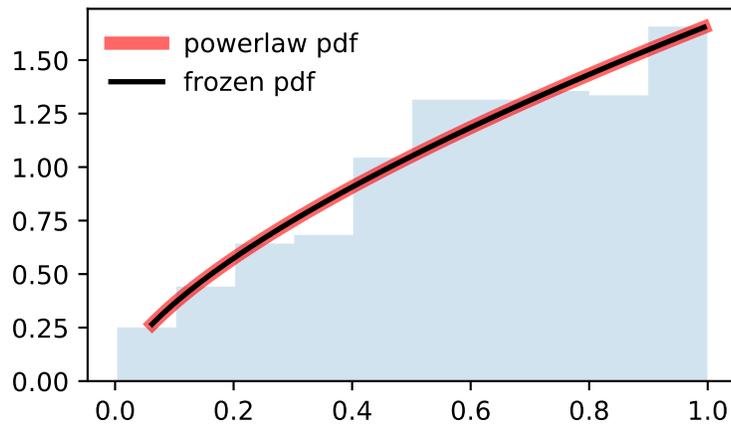
```
>>> vals = powerlaw.ppf([0.001, 0.5, 0.999], a)
>>> np.allclose([0.001, 0.5, 0.999], powerlaw.cdf(vals, a))
True
```

Generate random numbers:

```
>>> r = powerlaw.rvs(a, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(a, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, a, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, a, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, a, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, a, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, a, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, a, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, a, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, a, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, a, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(a, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, a, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(a,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(a, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(a, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(a, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.powerlognorm = <scipy.stats._continuous_distns.powerlognorm_gen object>`

A power log-normal continuous random variable.

As an instance of the `rv_continuous` class, `powerlognorm` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for `powerlognorm` is:

$$f(x, c, s) = \frac{c}{xs} \phi(\log(x)/s) (\Phi(-\log(x)/s))^{c-1}$$

where  $\phi$  is the normal pdf, and  $\Phi$  is the normal cdf, and  $x > 0, s, c > 0$ .

`powerlognorm` takes  $c$  and  $s$  as shape parameters.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `powerlognorm.pdf(x, c, s, loc, scale)` is identically equivalent to `powerlognorm.pdf(y, c, s) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import powerlognorm
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c, s = 2.14, 0.446
>>> mean, var, skew, kurt = powerlognorm.stats(c, s, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(powerlognorm.ppf(0.01, c, s),
...                 powerlognorm.ppf(0.99, c, s), 100)
>>> ax.plot(x, powerlognorm.pdf(x, c, s),
...         'r-', lw=5, alpha=0.6, label='powerlognorm pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = powerlognorm(c, s)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

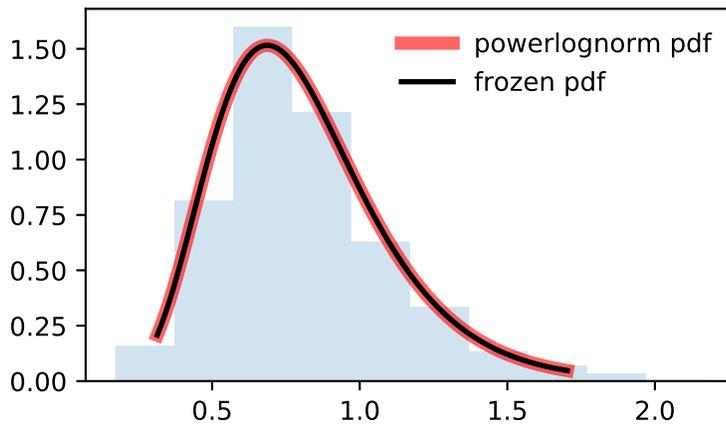
```
>>> vals = powerlognorm.ppf([0.001, 0.5, 0.999], c, s)
>>> np.allclose([0.001, 0.5, 0.999], powerlognorm.cdf(vals, c, s))
True
```

Generate random numbers:

```
>>> r = powerlognorm.rvs(c, s, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, s, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, s, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, s, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, s, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, s, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, s, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, s, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, s, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, s, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, s, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, s, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, s, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, s, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c, s), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, s, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, s, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, s, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, s, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, s, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.powernorm = <scipy.stats.continuous_distns.powernorm_gen object>`

A power normal continuous random variable.

As an instance of the *rv\_continuous* class, *powernorm* object inherits from it a collection of generic

methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *powernorm* is:

$$f(x, c) = c\phi(x)(\Phi(-x))^{c-1}$$

where  $\phi$  is the normal pdf, and  $\Phi$  is the normal cdf, and  $x > 0, c > 0$ .

*powernorm* takes *c* as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `powernorm.pdf(x, c, loc, scale)` is identically equivalent to `powernorm.pdf(y, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import powernorm
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 4.45
>>> mean, var, skew, kurt = powernorm.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(powernorm.ppf(0.01, c),
...                 powernorm.ppf(0.99, c), 100)
>>> ax.plot(x, powernorm.pdf(x, c),
...         'r-', lw=5, alpha=0.6, label='powernorm pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = powernorm(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

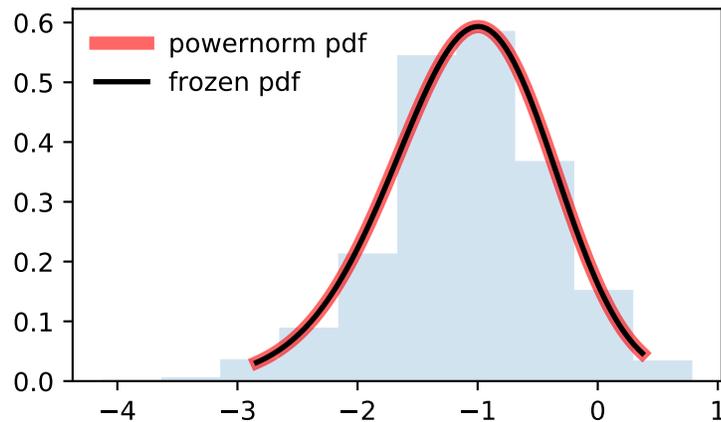
```
>>> vals = powernorm.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], powernorm.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = powernorm.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.rdist = <scipy.stats.continuous_distns.rdist_gen object>`

An R-distributed continuous random variable.

As an instance of the `rv_continuous` class, `rdist` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *rdist* is:

$$f(x, c) = \frac{(1 - x^2)^{c/2-1}}{B(1/2, c/2)}$$

for  $-1 \leq x \leq 1, c > 0$ .

*rdist* takes *c* as a shape parameter.

This distribution includes the following distribution kernels as special cases:

```
c = 2: uniform
c = 4: Epanechnikov (parabolic)
c = 6: quartic (biweight)
c = 8: triweight
```

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `rdist.pdf(x, c, loc, scale)` is identically equivalent to `rdist.pdf(y, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import rdist
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 0.9
>>> mean, var, skew, kurt = rdist.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(rdist.ppf(0.01, c),
...                 rdist.ppf(0.99, c), 100)
>>> ax.plot(x, rdist.pdf(x, c),
...         'r-', lw=5, alpha=0.6, label='rdist pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = rdist(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

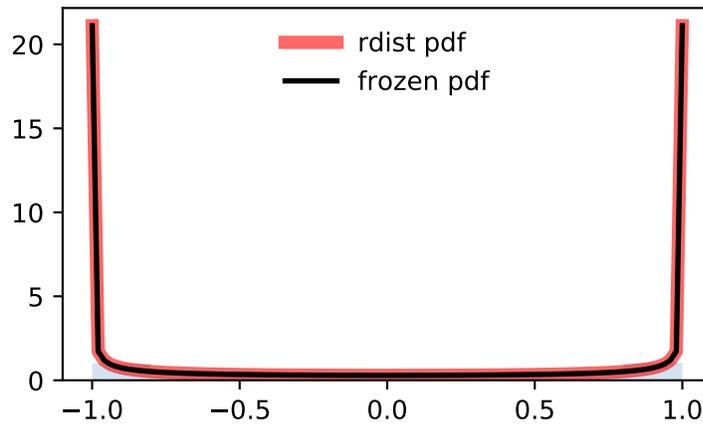
```
>>> vals = rdist.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], rdist.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = rdist.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwargs)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains <i>alpha</i> percent of the distribution

`scipy.stats.reciprocal` = <scipy.stats\_continuous\_distns.reciprocal\_gen object>

A reciprocal continuous random variable.

As an instance of the *rv\_continuous* class, *reciprocal* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *reciprocal* is:

$$f(x, a, b) = \frac{1}{x \log(b/a)}$$

for  $a \leq x \leq b, a, b > 0$ .

*reciprocal* takes *a* and *b* as shape parameters.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `reciprocal.pdf(x, a, b, loc, scale)` is identically equivalent to `reciprocal.pdf(y, a, b) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import reciprocal
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a, b = 0.00623, 1.01
>>> mean, var, skew, kurt = reciprocal.stats(a, b, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(reciprocal.ppf(0.01, a, b),
...                 reciprocal.ppf(0.99, a, b), 100)
>>> ax.plot(x, reciprocal.pdf(x, a, b),
...         'r-', lw=5, alpha=0.6, label='reciprocal pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = reciprocal(a, b)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

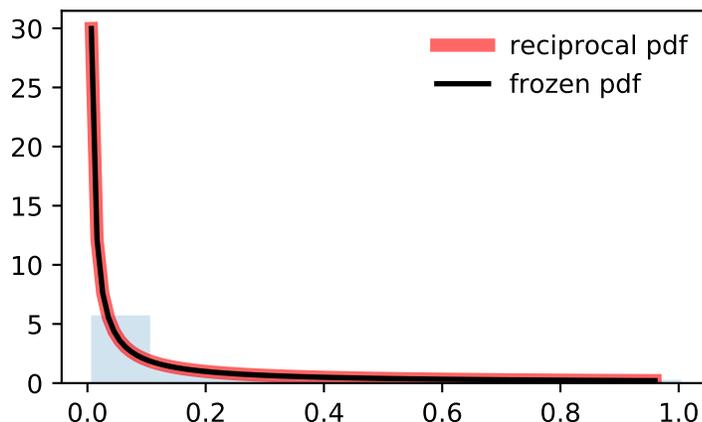
```
>>> vals = reciprocal.ppf([0.001, 0.5, 0.999], a, b)
>>> np.allclose([0.001, 0.5, 0.999], reciprocal.cdf(vals, a, b))
True
```

Generate random numbers:

```
>>> r = reciprocal.rvs(a, b, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(a, b, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, a, b, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, a, b, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, a, b, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, a, b, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, a, b, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, a, b, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, a, b, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, a, b, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, a, b, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(a, b, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, b, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, a, b, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(a, b), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, b, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(a, b, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(a, b, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(a, b, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, b, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.rayleigh = <scipy.stats.continuous_distns.rayleigh_gen object>`

A Rayleigh continuous random variable.

As an instance of the *rv\_continuous* class, *rayleigh* object inherits from it a collection of generic meth-

ods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for `rayleigh` is:

$$f(r) = r \exp(-r^2/2)$$

for  $x \geq 0$ .

`rayleigh` is a special case of `chi` with `df == 2`.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `rayleigh.pdf(x, loc, scale)` is identically equivalent to `rayleigh.pdf(y) / scale` with `y = (x - loc) / scale`.

### Examples

```
>>> from scipy.stats import rayleigh
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = rayleigh.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(rayleigh.ppf(0.01),
...                 rayleigh.ppf(0.99), 100)
>>> ax.plot(x, rayleigh.pdf(x),
...         'r-', lw=5, alpha=0.6, label='rayleigh pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = rayleigh()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

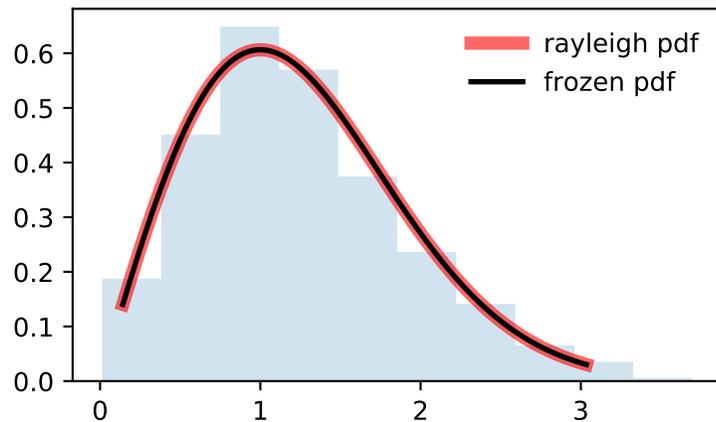
```
>>> vals = rayleigh.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], rayleigh.cdf(vals))
True
```

Generate random numbers:

```
>>> r = rayleigh.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.rice = <scipy.stats_continuous_distns.rice_gen object>`

A Rice continuous random variable.

As an instance of the `rv_continuous` class, *rice* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *rice* is:

$$f(x, b) = x \exp\left(-\frac{x^2 + b^2}{2}\right) I_0(xb)$$

for  $x > 0, b > 0$ .

*rice* takes *b* as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `rice.pdf(x, b, loc, scale)` is identically equivalent to `rice.pdf(y, b) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

The Rice distribution describes the length, *r*, of a 2-D vector with components  $(U + u, V + v)$ , where *U, V* are constant, *u, v* are independent Gaussian random variables with standard deviation *s*. Let  $R = \sqrt{U^2 + V^2}$ . Then the pdf of *r* is `rice.pdf(x, R/s, scale=s)`.

### Examples

```
>>> from scipy.stats import rice
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> b = 0.775
>>> mean, var, skew, kurt = rice.stats(b, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(rice.ppf(0.01, b),
...                 rice.ppf(0.99, b), 100)
>>> ax.plot(x, rice.pdf(x, b),
...         'r-', lw=5, alpha=0.6, label='rice pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = rice(b)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

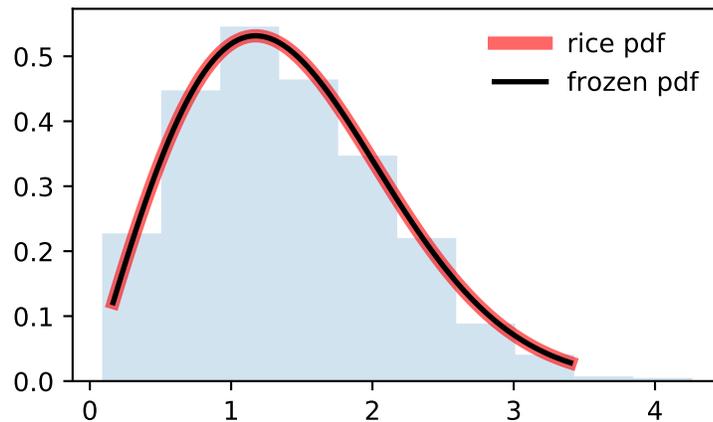
```
>>> vals = rice.ppf([0.001, 0.5, 0.999], b)
>>> np.allclose([0.001, 0.5, 0.999], rice.cdf(vals, b))
True
```

Generate random numbers:

```
>>> r = rice.rvs(b, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(b, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, b, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, b, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, b, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, b, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, b, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, b, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, b, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, b, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, b, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(b, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(b, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, b, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(b,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(b, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(b, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(b, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(b, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, b, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.recipinvgauss = <scipy.stats.continuous_distns.recipinvgauss_gen object>`

A reciprocal inverse Gaussian continuous random variable.

As an instance of the *rv\_continuous* class, *recipinvgauss* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *recipinvgauss* is:

$$f(x, \mu) = \frac{1}{\sqrt{2\pi x}} \frac{\exp(-(1 - \mu x)^2)}{2x\mu^2}$$

for  $x \geq 0$ .

*recipinvgauss* takes  $\mu$  as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `recipinvgauss.pdf(x, mu, loc, scale)` is identically equivalent to `recipinvgauss.pdf(y, mu) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import recipinvgauss
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mu = 0.63
>>> mean, var, skew, kurt = recipinvgauss.stats(mu, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(recipinvgauss.ppf(0.01, mu),
...                 recipinvgauss.ppf(0.99, mu), 100)
>>> ax.plot(x, recipinvgauss.pdf(x, mu),
...         'r-', lw=5, alpha=0.6, label='recipinvgauss pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = recipinvgauss(mu)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

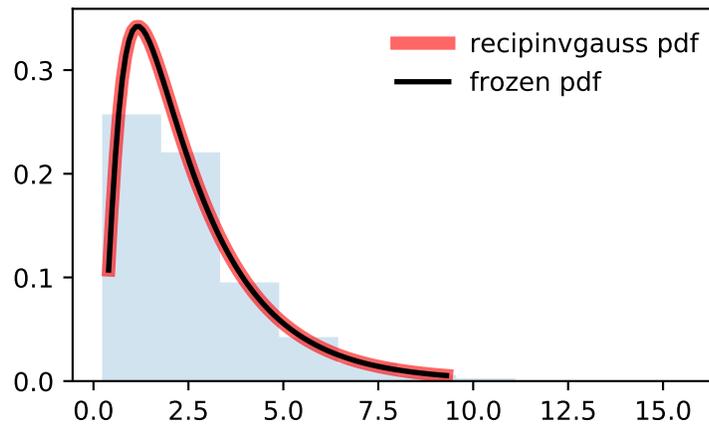
```
>>> vals = recipinvgauss.ppf([0.001, 0.5, 0.999], mu)
>>> np.allclose([0.001, 0.5, 0.999], recipinvgauss.cdf(vals, mu))
True
```

Generate random numbers:

```
>>> r = recipinvgauss.rvs(mu, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(mu, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, mu, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, mu, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, mu, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, mu, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, mu, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, mu, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, mu, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, mu, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, mu, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(mu, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(mu, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, mu, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(mu,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(mu, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(mu, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(mu, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(mu, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, mu, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.semicircular = <scipy.stats._continuous_distns.semicircular_gen object>`

A semicircular continuous random variable.

As an instance of the `rv_continuous` class, `semicircular` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *semicircular* is:

$$f(x) = \frac{2}{\pi} \sqrt{1 - x^2}$$

for  $-1 \leq x \leq 1$ .

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `semicircular.pdf(x, loc, scale)` is identically equivalent to `semicircular.pdf(y) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import semicircular
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = semicircular.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(semicircular.ppf(0.01),
...                 semicircular.ppf(0.99), 100)
>>> ax.plot(x, semicircular.pdf(x),
...         'r-', lw=5, alpha=0.6, label='semicircular pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = semicircular()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

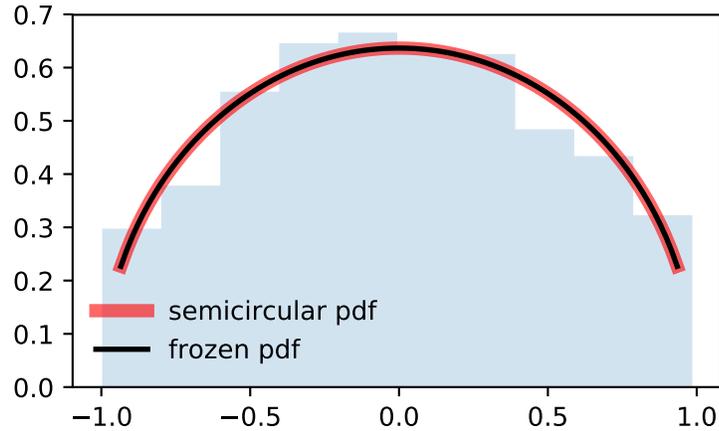
```
>>> vals = semicircular.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], semicircular.cdf(vals))
True
```

Generate random numbers:

```
>>> r = semicircular.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.skewnorm` = <scipy.stats.continuous\_distns.skew\_norm\_gen object>

A skew-normal random variable.

As an instance of the `rv_continuous` class, `skewnorm` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The pdf is:

```
skewnorm.pdf(x, a) = 2 * norm.pdf(x) * norm.cdf(a*x)
```

*skewnorm* takes *a* as a skewness parameter. When *a* = 0 the distribution is identical to a normal distribution. *rvs* implements the method of [R697].

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `skewnorm.pdf(x, a, loc, scale)` is identically equivalent to `skewnorm.pdf(y, a) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### References

[R697]

### Examples

```
>>> from scipy.stats import skewnorm
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a = 4
>>> mean, var, skew, kurt = skewnorm.stats(a, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(skewnorm.ppf(0.01, a),
...                 skewnorm.ppf(0.99, a), 100)
>>> ax.plot(x, skewnorm.pdf(x, a),
...        'r-', lw=5, alpha=0.6, label='skewnorm pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = skewnorm(a)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

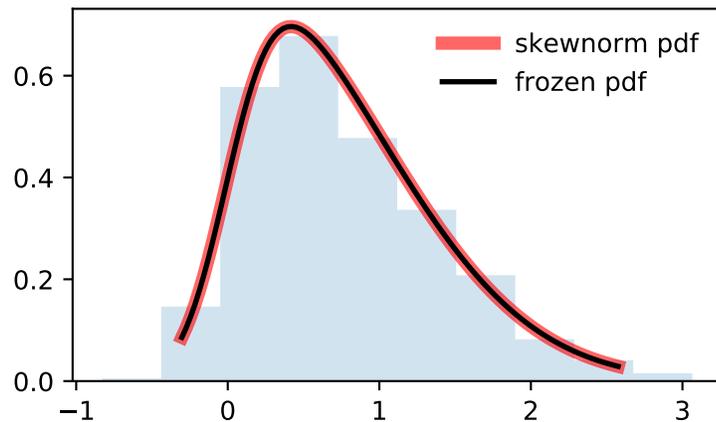
```
>>> vals = skewnorm.ppf([0.001, 0.5, 0.999], a)
>>> np.allclose([0.001, 0.5, 0.999], skewnorm.cdf(vals, a))
True
```

Generate random numbers:

```
>>> r = skewnorm.rvs(a, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(a, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, a, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, a, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, a, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, a, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, a, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, a, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, a, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, a, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, a, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(a, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, a, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(a,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(a, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(a, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(a, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.t` = <scipy.stats.continuous\_distns.t\_gen object>

A Student's T continuous random variable.

As an instance of the *rv\_continuous* class, *t* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for  $t$  is:

$$f(x, df) = \frac{\gamma((df + 1)/2)}{\sqrt{\pi * df} \gamma(df/2) (1 + x^2/df)^{(df+1)/2}}$$

for  $df > 0$ .

$t$  takes  $df$  as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `t.pdf(x, df, loc, scale)` is identically equivalent to `t.pdf(y, df) / scale` with  $y = (x - loc) / scale$ .

**Examples**

```
>>> from scipy.stats import t
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> df = 2.74
>>> mean, var, skew, kurt = t.stats(df, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(t.ppf(0.01, df),
...                 t.ppf(0.99, df), 100)
>>> ax.plot(x, t.pdf(x, df),
...         'r-', lw=5, alpha=0.6, label='t pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = t(df)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

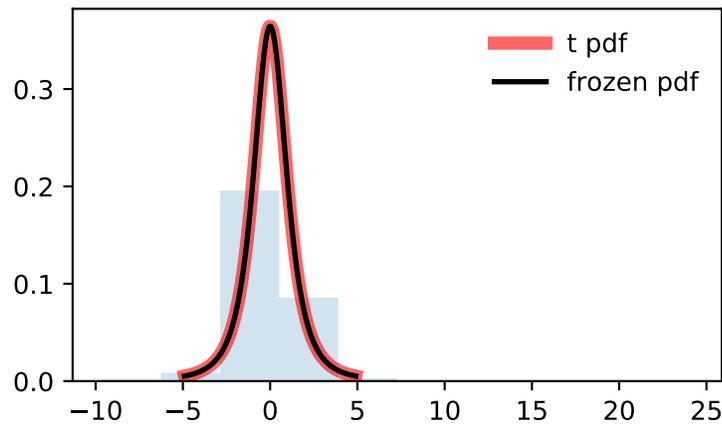
```
>>> vals = t.ppf([0.001, 0.5, 0.999], df)
>>> np.allclose([0.001, 0.5, 0.999], t.cdf(vals, df))
True
```

Generate random numbers:

```
>>> r = t.rvs(df, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(df, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, df, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, df, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, df, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, df, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, df, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, df, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, df, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, df, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, df, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(df, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(df, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, df, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(df,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(df, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(df, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(df, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(df, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, df, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.trapz = <scipy.stats.continuous_distns.trapz_gen object>`

A trapezoidal continuous random variable.

As an instance of the *rv\_continuous* class, *trapz* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The trapezoidal distribution can be represented with an up-sloping line from `loc` to `(loc + c*scale)`, then constant to `(loc + d*scale)` and then downsloping from `(loc + d*scale)` to `(loc+scale)`.

`trapz` takes `c` and `d` as shape parameters.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `trapz.pdf(x, c, d, loc, scale)` is identically equivalent to `trapz.pdf(y, c, d) / scale` with `y = (x - loc) / scale`.

The standard form is in the range `[0, 1]` with `c` the mode. The location parameter shifts the start to `loc`. The scale parameter changes the width from 1 to `scale`.

**Examples**

```
>>> from scipy.stats import trapz
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c, d = 0.2, 0.8
>>> mean, var, skew, kurt = trapz.stats(c, d, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(trapz.ppf(0.01, c, d),
...                 trapz.ppf(0.99, c, d), 100)
>>> ax.plot(x, trapz.pdf(x, c, d),
...         'r-', lw=5, alpha=0.6, label='trapz pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = trapz(c, d)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

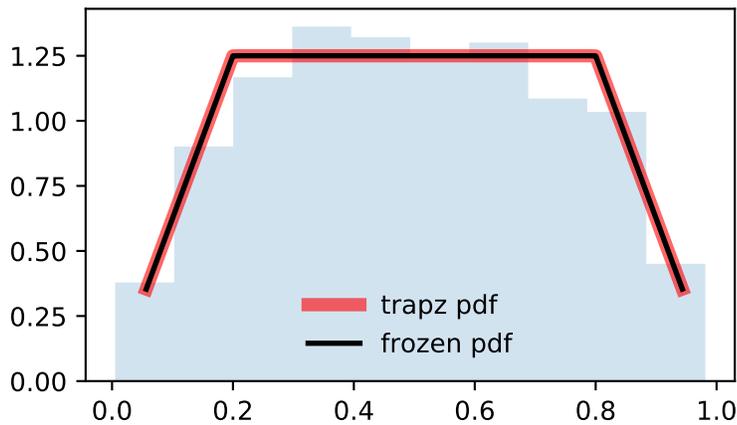
```
>>> vals = trapz.ppf([0.001, 0.5, 0.999], c, d)
>>> np.allclose([0.001, 0.5, 0.999], trapz.cdf(vals, c, d))
True
```

Generate random numbers:

```
>>> r = trapz.rvs(c, d, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, d, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, d, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, d, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, d, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, d, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, d, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, d, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, d, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, d, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, d, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, d, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, d, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, d, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c, d), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, d, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, d, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, d, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, d, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, d, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.triang = <scipy.stats.continuous_distns.triang_gen object>`

A triangular continuous random variable.

As an instance of the *rv\_continuous* class, *triang* object inherits from it a collection of generic methods

(see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The triangular distribution can be represented with an up-sloping line from `loc` to `(loc + c*scale)` and then downsloping for `(loc + c*scale)` to `(loc+scale)`.

`triang` takes `c` as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `triang.pdf(x, c, loc, scale)` is identically equivalent to `triang.pdf(y, c) / scale` with `y = (x - loc) / scale`.

The standard form is in the range `[0, 1]` with `c` the mode. The location parameter shifts the start to `loc`. The scale parameter changes the width from 1 to `scale`.

### Examples

```
>>> from scipy.stats import triang
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 0.158
>>> mean, var, skew, kurt = triang.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(triang.ppf(0.01, c),
...                 triang.ppf(0.99, c), 100)
>>> ax.plot(x, triang.pdf(x, c),
...         'r-', lw=5, alpha=0.6, label='triang pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = triang(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

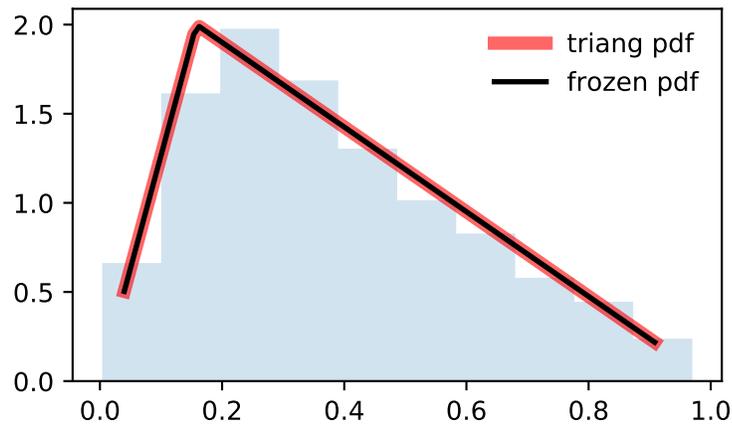
```
>>> vals = triang.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], triang.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = triang.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.truncexpon = <scipy.stats.continuous_distns.truncexpon_gen object>`

A truncated exponential continuous random variable.

As an instance of the *rv\_continuous* class, *truncexpon* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *truncexpon* is:

$$f(x, b) = \frac{\exp(-x)}{1 - \exp(-b)}$$

for  $0 < x < b$ .

*truncexpon* takes *b* as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `truncexpon.pdf(x, b, loc, scale)` is identically equivalent to `truncexpon.pdf(y, b) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import truncexpon
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> b = 4.69
>>> mean, var, skew, kurt = truncexpon.stats(b, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(truncexpon.ppf(0.01, b),
...                 truncexpon.ppf(0.99, b), 100)
>>> ax.plot(x, truncexpon.pdf(x, b),
...         'r-', lw=5, alpha=0.6, label='truncexpon pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = truncexpon(b)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

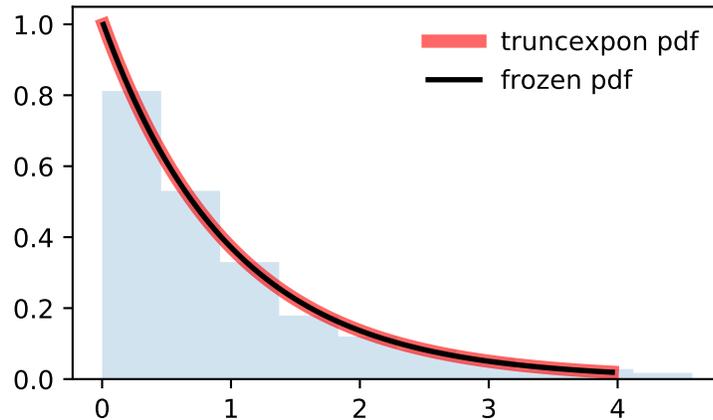
```
>>> vals = truncexpon.ppf([0.001, 0.5, 0.999], b)
>>> np.allclose([0.001, 0.5, 0.999], truncexpon.cdf(vals, b))
True
```

Generate random numbers:

```
>>> r = truncexpon.rvs(b, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(b, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, b, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, b, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, b, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, b, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, b, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, b, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, b, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, b, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, b, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(b, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(b, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, b, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(b,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(b, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(b, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(b, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(b, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, b, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.truncnorm` = <scipy.stats.continuous\_distns.truncnorm\_gen object>

A truncated normal continuous random variable.

As an instance of the *rv\_continuous* class, *truncnorm* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The standard form of this distribution is a standard normal truncated to the range  $[a, b]$  — notice that  $a$  and  $b$  are defined over the domain of the standard normal. To convert clip values for a specific mean and standard deviation, use:

```
a, b = (myclip_a - my_mean) / my_std, (myclip_b - my_mean) / my_std
```

`truncnorm` takes  $a$  and  $b$  as shape parameters.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `truncnorm.pdf(x, a, b, loc, scale)` is identically equivalent to `truncnorm.pdf(y, a, b) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import truncnorm
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a, b = 0.1, 2
>>> mean, var, skew, kurt = truncnorm.stats(a, b, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(truncnorm.ppf(0.01, a, b),
...                 truncnorm.ppf(0.99, a, b), 100)
>>> ax.plot(x, truncnorm.pdf(x, a, b),
...         'r-', lw=5, alpha=0.6, label='truncnorm pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = truncnorm(a, b)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

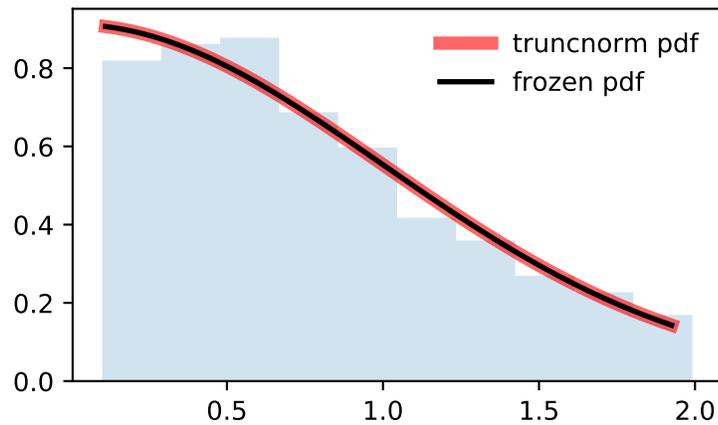
```
>>> vals = truncnorm.ppf([0.001, 0.5, 0.999], a, b)
>>> np.allclose([0.001, 0.5, 0.999], truncnorm.cdf(vals, a, b))
True
```

Generate random numbers:

```
>>> r = truncnorm.rvs(a, b, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(a, b, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, a, b, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, a, b, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, a, b, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, a, b, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, a, b, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, a, b, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, a, b, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, a, b, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, a, b, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(a, b, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, b, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, a, b, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(a, b), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, b, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(a, b, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(a, b, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(a, b, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, b, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.tukeylambda = <scipy.stats.continuous_distns.tukeylambda_gen object>`

A Tukey-Lambda continuous random variable.

As an instance of the *rv\_continuous* class, *tukeylambda* object inherits from it a collection of generic

methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

A flexible distribution, able to represent and interpolate between the following distributions:

- Cauchy (lam=-1)
- logistic (lam=0.0)
- approx Normal (lam=0.14)
- u-shape (lam = 0.5)
- uniform from -1 to 1 (lam = 1)

`tukeylambda` takes `lam` as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `tukeylambda.pdf(x, lam, loc, scale)` is identically equivalent to `tukeylambda.pdf(y, lam) / scale` with  $y = (x - loc) / scale$ .

### Examples

```
>>> from scipy.stats import tukeylambda
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> lam = 3.13
>>> mean, var, skew, kurt = tukeylambda.stats(lam, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(tukeylambda.ppf(0.01, lam),
...                 tukeylambda.ppf(0.99, lam), 100)
>>> ax.plot(x, tukeylambda.pdf(x, lam),
...         'r-', lw=5, alpha=0.6, label='tukeylambda pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = tukeylambda(lam)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

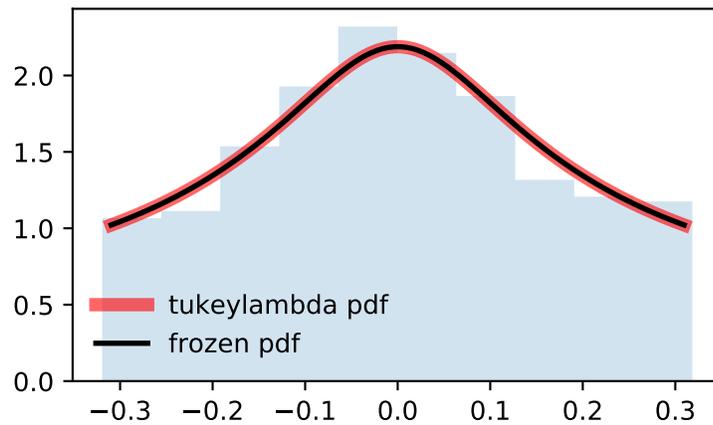
```
>>> vals = tukeylambda.ppf([0.001, 0.5, 0.999], lam)
>>> np.allclose([0.001, 0.5, 0.999], tukeylambda.cdf(vals, lam))
True
```

Generate random numbers:

```
>>> r = tukeylambda.rvs(lam, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(lam, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, lam, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, lam, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, lam, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, lam, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, lam, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, lam, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, lam, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, lam, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, lam, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(lam, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(lam, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, lam, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(lam,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(lam, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(lam, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(lam, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(lam, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, lam, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.uniform` = <scipy.stats.continuous\_distns.uniform\_gen object>

A uniform continuous random variable.

This distribution is constant between *loc* and *loc* + *scale*.

As an instance of the `rv_continuous` class, `uniform` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Examples

```
>>> from scipy.stats import uniform
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = uniform.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(uniform.ppf(0.01),
...                 uniform.ppf(0.99), 100)
>>> ax.plot(x, uniform.pdf(x),
...        'r-', lw=5, alpha=0.6, label='uniform pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = uniform()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

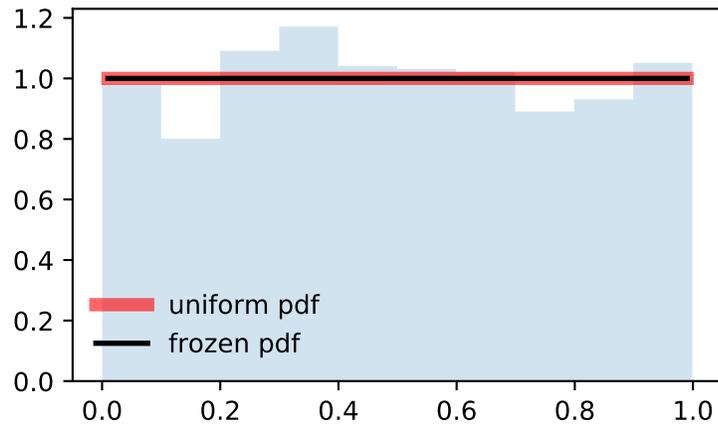
```
>>> vals = uniform.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], uniform.cdf(vals))
True
```

Generate random numbers:

```
>>> r = uniform.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.vonmises = <scipy.stats.continuous_distns.vonmises_gen object>`

A Von Mises continuous random variable.

As an instance of the `rv_continuous` class, `vonmises` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

See also:

### `vonmises_line`

The same distribution, defined on a  $[-\pi, \pi]$  segment of the real line.

### Notes

If  $x$  is not in range or  $loc$  is not in range it assumes they are angles and converts them to  $[-\pi, \pi]$  equivalents.

The probability density function for `vonmises` is:

$$f(x, \kappa) = \frac{\exp(\kappa \cos(x))}{2\pi I_0(\kappa)}$$

for  $-\pi \leq x \leq \pi, \kappa > 0$ .

`vonmises` takes  $\kappa$  as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `vonmises.pdf(x, kappa, loc, scale)` is identically equivalent to `vonmises.pdf(y, kappa) / scale` with  $y = (x - loc) / scale$ .

### Examples

```
>>> from scipy.stats import vonmises
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> kappa = 3.99
>>> mean, var, skew, kurt = vonmises.stats(kappa, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(vonmises.ppf(0.01, kappa),
...                 vonmises.ppf(0.99, kappa), 100)
>>> ax.plot(x, vonmises.pdf(x, kappa),
...         'r-', lw=5, alpha=0.6, label='vonmises pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = vonmises(kappa)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

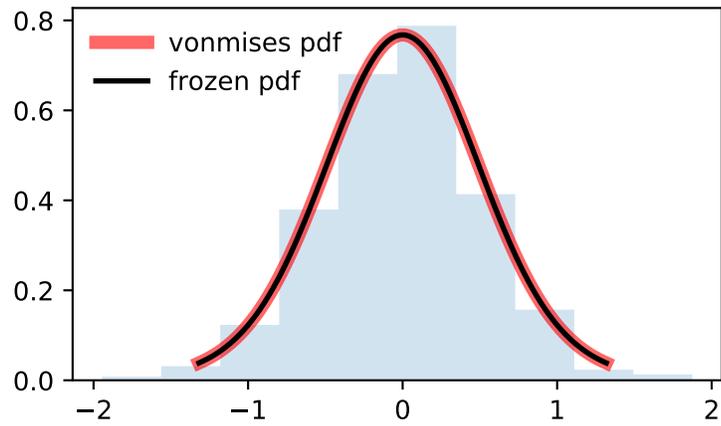
```
>>> vals = vonmises.ppf([0.001, 0.5, 0.999], kappa)
>>> np.allclose([0.001, 0.5, 0.999], vonmises.cdf(vals, kappa))
True
```

Generate random numbers:

```
>>> r = vonmises.rvs(kappa, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



**Methods**

<code>rvs(kappa, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, kappa, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, kappa, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, kappa, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, kappa, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, kappa, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, kappa, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, kappa, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, kappa, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, kappa, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(kappa, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(kappa, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, kappa, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(kappa,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwargs)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(kappa, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(kappa, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(kappa, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(kappa, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, kappa, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.vonmises_line = <scipy.stats.continuous_distns.vonmises_gen object>`

A Von Mises continuous random variable.

As an instance of the *rv\_continuous* class, *vonmises\_line* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**See also:****vonmises\_line**

The same distribution, defined on a  $[-\pi, \pi]$  segment of the real line.

**Notes**

If *x* is not in range or *loc* is not in range it assumes they are angles and converts them to  $[-\pi, \pi]$  equivalents.

The probability density function for *vonmises* is:

$$f(x, \kappa) = \frac{\exp(\kappa \cos(x))}{2\pi I_0(\kappa)}$$

for  $-\pi \leq x \leq \pi, \kappa > 0$ .

*vonmises* takes  $\kappa$  as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `vonmises_line.pdf(x, kappa, loc, scale)` is identically equivalent to `vonmises_line.pdf(y, kappa) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

### Examples

```
>>> from scipy.stats import vonmises_line
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> kappa = 3.99
>>> mean, var, skew, kurt = vonmises_line.stats(kappa, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(vonmises_line.ppf(0.01, kappa),
...                 vonmises_line.ppf(0.99, kappa), 100)
>>> ax.plot(x, vonmises_line.pdf(x, kappa),
...         'r-', lw=5, alpha=0.6, label='vonmises_line pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = vonmises_line(kappa)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

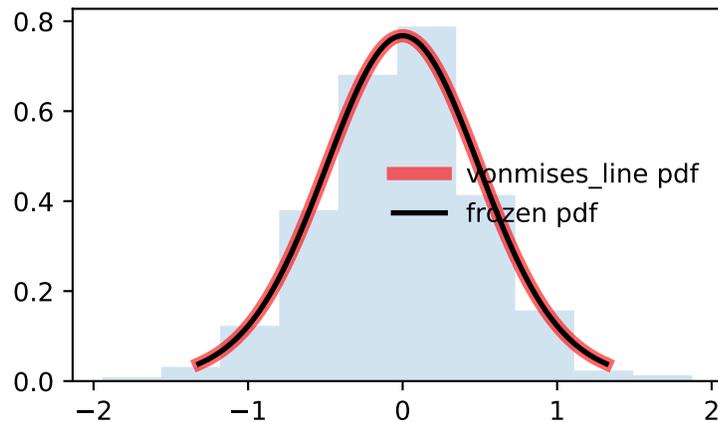
```
>>> vals = vonmises_line.ppf([0.001, 0.5, 0.999], kappa)
>>> np.allclose([0.001, 0.5, 0.999], vonmises_line.cdf(vals, kappa))
True
```

Generate random numbers:

```
>>> r = vonmises_line.rvs(kappa, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(kappa, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, kappa, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, kappa, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, kappa, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, kappa, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, kappa, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, kappa, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, kappa, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, kappa, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, kappa, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(kappa, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(kappa, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, kappa, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(kappa,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(kappa, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(kappa, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(kappa, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(kappa, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, kappa, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.wald = <scipy.stats_continuous_distns.wald_gen object>`

A Wald continuous random variable.

As an instance of the *rv\_continuous* class, *wald* object inherits from it a collection of generic methods

(see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability density function for *wald* is:

$$f(x) = \frac{1}{\sqrt{2\pi x^3}} \exp\left(-\frac{(x-1)^2}{2x}\right)$$

for  $x > 0$ .

*wald* is a special case of *invgauss* with `mu == 1`.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `wald.pdf(x, loc, scale)` is identically equivalent to `wald.pdf(y) / scale` with `y = (x - loc) / scale`.

### Examples

```
>>> from scipy.stats import wald
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mean, var, skew, kurt = wald.stats(moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(wald.ppf(0.01),
...                 wald.ppf(0.99), 100)
>>> ax.plot(x, wald.pdf(x),
...         'r-', lw=5, alpha=0.6, label='wald pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = wald()
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

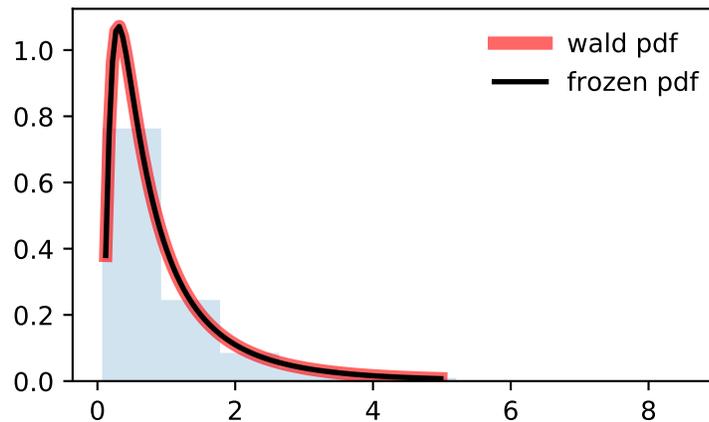
```
>>> vals = wald.ppf([0.001, 0.5, 0.999])
>>> np.allclose([0.001, 0.5, 0.999], wald.cdf(vals))
True
```

Generate random numbers:

```
>>> r = wald.rvs(size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(loc=0, scale=1)</code>	Median of the distribution.
<code>mean(loc=0, scale=1)</code>	Mean of the distribution.
<code>var(loc=0, scale=1)</code>	Variance of the distribution.
<code>std(loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.weibull_min = <scipy.stats.continuous_distns.weibull_min_gen object>`

Weibull minimum continuous random variable.

As an instance of the *rv\_continuous* class, *weibull\_min* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**See also:**`weibull_max`**Notes**

The probability density function for `weibull_min` is:

$$f(x, c) = cx^{c-1} \exp(-x^c)$$

for  $x > 0, c > 0$ .

`weibull_min` takes  $c$  as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `weibull_min.pdf(x, c, loc, scale)` is identically equivalent to `weibull_min.pdf(y, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import weibull_min
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 1.79
>>> mean, var, skew, kurt = weibull_min.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(weibull_min.ppf(0.01, c),
...                 weibull_min.ppf(0.99, c), 100)
>>> ax.plot(x, weibull_min.pdf(x, c),
...         'r-', lw=5, alpha=0.6, label='weibull_min pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = weibull_min(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

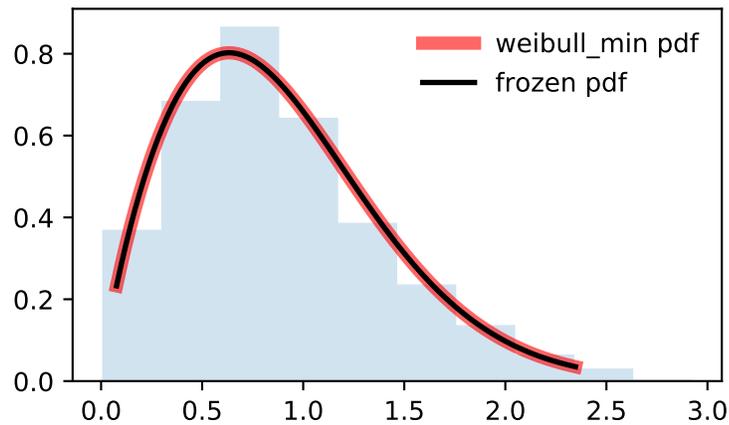
```
>>> vals = weibull_min.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], weibull_min.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = weibull_min.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.weibull_max = <scipy.stats.continuous_distns.weibull_max_gen object>`

Weibull maximum continuous random variable.

As an instance of the *rv\_continuous* class, *weibull\_max* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**See also:**`weibull_min`**Notes**

The probability density function for `weibull_max` is:

$$f(x, c) = c(-x)^{c-1} \exp(-(-x)^c)$$

for  $x < 0, c > 0$ .

`weibull_max` takes  $c$  as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the `loc` and `scale` parameters. Specifically, `weibull_max.pdf(x, c, loc, scale)` is identically equivalent to `weibull_max.pdf(y, c) / scale` with  $y = (x - loc) / scale$ .

**Examples**

```
>>> from scipy.stats import weibull_max
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 2.87
>>> mean, var, skew, kurt = weibull_max.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(weibull_max.ppf(0.01, c),
...                 weibull_max.ppf(0.99, c), 100)
>>> ax.plot(x, weibull_max.pdf(x, c),
...         'r-', lw=5, alpha=0.6, label='weibull_max pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = weibull_max(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

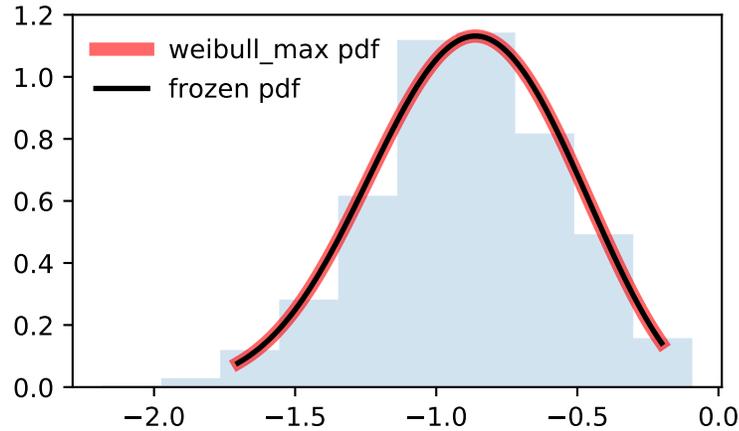
```
>>> vals = weibull_max.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], weibull_max.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = weibull_max.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.wrapcauchy = <scipy.stats.continuous_distns.wrapcauchy_gen object>`

A wrapped Cauchy continuous random variable.

As an instance of the *rv\_continuous* class, *wrapcauchy* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

**Notes**

The probability density function for *wrapcauchy* is:

$$f(x, c) = \frac{1 - c^2}{2\pi(1 + c^2 - 2c \cos(x))}$$

for  $0 \leq x \leq 2\pi$ ,  $0 < c < 1$ .

*wrapcauchy* takes *c* as a shape parameter.

The probability density above is defined in the “standardized” form. To shift and/or scale the distribution use the *loc* and *scale* parameters. Specifically, `wrapcauchy.pdf(x, c, loc, scale)` is identically equivalent to `wrapcauchy.pdf(y, c) / scale` with  $y = (x - \text{loc}) / \text{scale}$ .

**Examples**

```
>>> from scipy.stats import wrapcauchy
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> c = 0.0311
>>> mean, var, skew, kurt = wrapcauchy.stats(c, moments='mvsk')
```

Display the probability density function (pdf):

```
>>> x = np.linspace(wrapcauchy.ppf(0.01, c),
...                 wrapcauchy.ppf(0.99, c), 100)
>>> ax.plot(x, wrapcauchy.pdf(x, c),
...         'r-', lw=5, alpha=0.6, label='wrapcauchy pdf')
```

Alternatively, the distribution object can be called (as a function) to fix the shape, location and scale parameters. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pdf:

```
>>> rv = wrapcauchy(c)
>>> ax.plot(x, rv.pdf(x), 'k-', lw=2, label='frozen pdf')
```

Check accuracy of cdf and ppf:

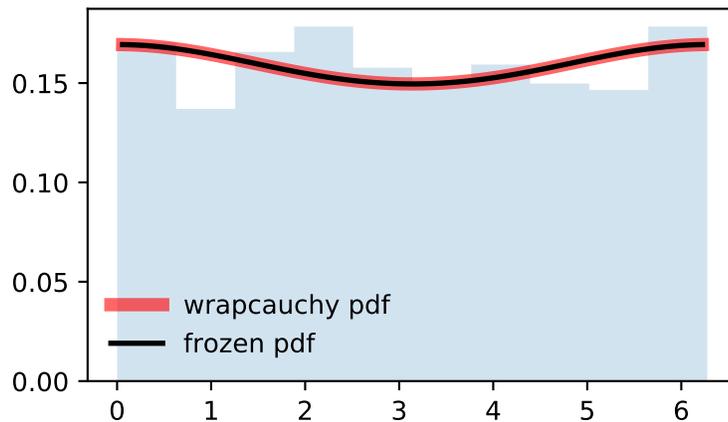
```
>>> vals = wrapcauchy.ppf([0.001, 0.5, 0.999], c)
>>> np.allclose([0.001, 0.5, 0.999], wrapcauchy.cdf(vals, c))
True
```

Generate random numbers:

```
>>> r = wrapcauchy.rvs(c, size=1000)
```

And compare the histogram:

```
>>> ax.hist(r, normed=True, histtype='stepfilled', alpha=0.2)
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



### Methods

<code>rvs(c, loc=0, scale=1, size=1, random_state=None)</code>	Random variates.
<code>pdf(x, c, loc=0, scale=1)</code>	Probability density function.
<code>logpdf(x, c, loc=0, scale=1)</code>	Log of the probability density function.
<code>cdf(x, c, loc=0, scale=1)</code>	Cumulative distribution function.
<code>logcdf(x, c, loc=0, scale=1)</code>	Log of the cumulative distribution function.
<code>sf(x, c, loc=0, scale=1)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(x, c, loc=0, scale=1)</code>	Log of the survival function.
<code>ppf(q, c, loc=0, scale=1)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, c, loc=0, scale=1)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>moment(n, c, loc=0, scale=1)</code>	Non-central moment of order <i>n</i>
<code>stats(c, loc=0, scale=1, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(c, loc=0, scale=1)</code>	(Differential) entropy of the RV.
<code>fit(data, c, loc=0, scale=1)</code>	Parameter estimates for generic data.
<code>expect(func, args=(c,), loc=0, scale=1, lb=None, ub=None, conditional=False, **kwds)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(c, loc=0, scale=1)</code>	Median of the distribution.
<code>mean(c, loc=0, scale=1)</code>	Mean of the distribution.
<code>var(c, loc=0, scale=1)</code>	Variance of the distribution.
<code>std(c, loc=0, scale=1)</code>	Standard deviation of the distribution.
<code>interval(alpha, c, loc=0, scale=1)</code>	Endpoints of the range that contains alpha percent of the distribution

## 5.27.2 Multivariate distributions

<code>multivariate_normal</code>	A multivariate normal random variable.
<code>matrix_normal</code>	A matrix normal random variable.
<code>dirichlet</code>	A Dirichlet random variable.
<code>wishart</code>	A Wishart random variable.
<code>invwishart</code>	An inverse Wishart random variable.
<code>multinomial</code>	A multinomial random variable.
<code>special_ortho_group</code>	A matrix-valued SO(N) random variable.
<code>ortho_group</code>	A matrix-valued O(N) random variable.
<code>unitary_group</code>	A matrix-valued U(N) random variable.
<code>random_correlation</code>	A random correlation matrix.

`scipy.stats.multivariate_normal` = <scipy.stats.\_multivariate.multivariate\_normal\_gen object>  
 A multivariate normal random variable.

The *mean* keyword specifies the mean. The *cov* keyword specifies the covariance matrix.

**Parameters** `x` : array\_like

Quantiles, with the last axis of *x* denoting the components.

**mean** : array\_like, optional

Mean of the distribution (default zero)

**cov** : array\_like, optional

Covariance matrix of the distribution (default one)

**allow\_singular** : bool, optional

Whether to allow a singular covariance matrix. (Default: False)

**random\_state** : None or int or np.random.RandomState instance, optional

If int or RandomState, use it for drawing the random variates. If None (or np.random), the global np.random state is used. Default is None.

**Alternatively, the object may be called (as a function) to fix the mean and covariance parameters, returning a “frozen” multivariate normal random variable:**

**rv = multivariate\_normal(mean=None, cov=1, allow\_singular=False)**

•Frozen object with the same methods but holding the given mean and covariance fixed.

### Notes

#### Setting the parameter mean to None is equivalent to having mean

be the zero-vector. The parameter *cov* can be a scalar, in which case the covariance matrix is the identity times that value, a vector of diagonal entries for the covariance matrix, or a two-dimensional array\_like.

The covariance matrix *cov* must be a (symmetric) positive semi-definite matrix. The determinant and inverse of *cov* are computed as the pseudo-determinant and pseudo-inverse, respectively, so that *cov* does not need to have full rank.

The probability density function for *multivariate\_normal* is

$$f(x) = \frac{1}{\sqrt{(2\pi)^k \det \Sigma}} \exp\left(-\frac{1}{2}(x - \mu)^T \Sigma^{-1}(x - \mu)\right),$$

where  $\mu$  is the mean,  $\Sigma$  the covariance matrix, and  $k$  is the dimension of the space where  $x$  takes values.

New in version 0.14.0.

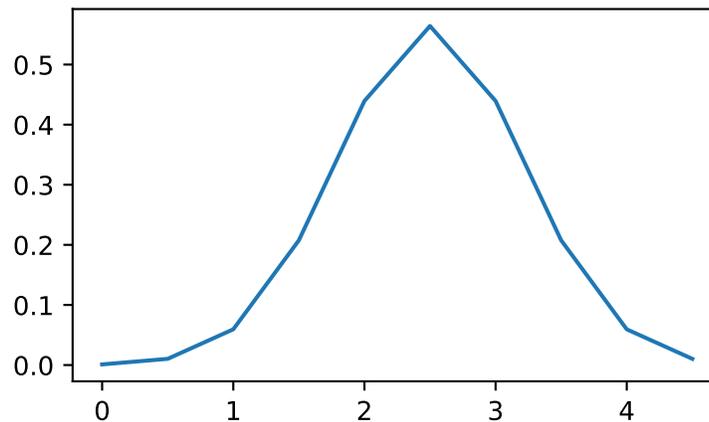
*Examples*

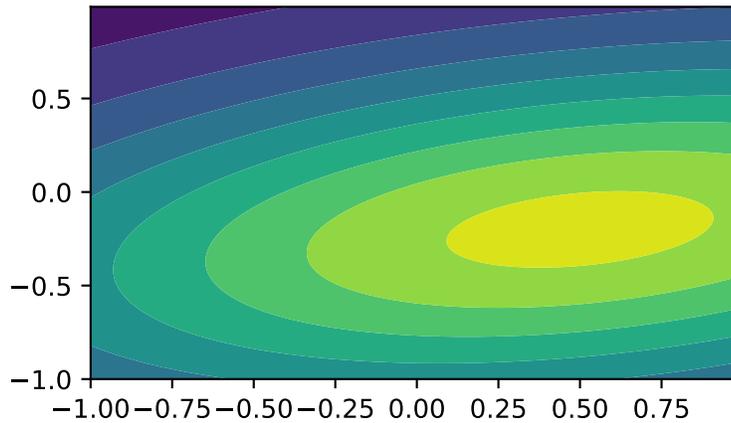
```
>>> import matplotlib.pyplot as plt
>>> from scipy.stats import multivariate_normal
```

```
>>> x = np.linspace(0, 5, 10, endpoint=False)
>>> y = multivariate_normal.pdf(x, mean=2.5, cov=0.5); y
array([ 0.00108914,  0.01033349,  0.05946514,  0.20755375,  0.43939129,
         0.56418958,  0.43939129,  0.20755375,  0.05946514,  0.01033349])
>>> fig1 = plt.figure()
>>> ax = fig1.add_subplot(111)
>>> ax.plot(x, y)
```

The input quantiles can be any shape of array, as long as the last axis labels the components. This allows us for instance to display the frozen pdf for a non-isotropic random variable in 2D as follows:

```
>>> x, y = np.mgrid[-1:1:.01, -1:1:.01]
>>> pos = np.dstack((x, y))
>>> rv = multivariate_normal([0.5, -0.2], [[2.0, 0.3], [0.3, 0.5]])
>>> fig2 = plt.figure()
>>> ax2 = fig2.add_subplot(111)
>>> ax2.contourf(x, y, rv.pdf(pos))
```





### Methods

<code>pdf(x, mean=None, cov=1, allow_singular=False)</code>	Probability density function.
<code>logpdf(x, mean=None, cov=1, allow_singular=False)</code>	Log of the probability density function.
<code>cdf(x, mean=None, cov=1, allow_singular=False, maxpts=1000000*dim, abseps=1e-5, releps=1e-5)</code>	Cumulative distribution function.
<code>logcdf(x, mean=None, cov=1, allow_singular=False, maxpts=1000000*dim, abseps=1e-5, releps=1e-5)</code>	Log of the cumulative distribution function.
<code>rvs(mean=None, cov=1, size=1, random_state=None)</code>	Draw random samples from a multivariate normal distribution.
<code>entropy()</code>	Compute the differential entropy of the multivariate normal.

`scipy.stats.matrix_normal = <scipy.stats.multivariate.matrix_normal_gen object>`

A matrix normal random variable.

The *mean* keyword specifies the mean. The *rowcov* keyword specifies the among-row covariance matrix. The *colcov* keyword specifies the among-column covariance matrix.

**Parameters** **X** : array\_like

Quantiles, with the last two axes of *X* denoting the components.

**mean** : array\_like, optional

Mean of the distribution (default: *None*)

**rowcov** : array\_like, optional

Among-row covariance matrix of the distribution (default: *I*)

**colcov** : array\_like, optional

Among-column covariance matrix of the distribution (default: *I*)

**random\_state** : None or int or `np.random.RandomState` instance, optional

If int or `RandomState`, use it for drawing the random variates. If *None* (or `np.random`), the global `np.random` state is used. Default is *None*.

**Alternatively, the object may be called (as a function) to fix the mean and covariance parameters, returning a “frozen” matrix normal**

**random variable:**

**rv = matrix\_normal(mean=None, rowcov=1, colcov=1)**

- Frozen object with the same methods but holding the given mean and covariance fixed.

### Notes

**If mean is set to None then a matrix of zeros is used for the mean.**

The dimensions of this matrix are inferred from the shape of *rowcov* and *colcov*, if these are provided, or set to 1 if ambiguous.

*rowcov* and *colcov* can be two-dimensional array\_likes specifying the covariance matrices directly. Alternatively, a one-dimensional array will be interpreted as the entries of a diagonal matrix, and a scalar or zero-dimensional array will be interpreted as this value times the identity matrix.

The covariance matrices specified by *rowcov* and *colcov* must be (symmetric) positive definite. If the samples in *X* are  $m \times n$ , then *rowcov* must be  $m \times m$  and *colcov* must be  $n \times n$ . *mean* must be the same shape as *X*.

The probability density function for *matrix\_normal* is

$$f(X) = (2\pi)^{-\frac{mn}{2}} |U|^{-\frac{n}{2}} |V|^{-\frac{m}{2}} \exp\left(-\frac{1}{2} \text{Tr} [U^{-1}(X - M)V^{-1}(X - M)^T]\right),$$

where *M* is the mean, *U* the among-row covariance matrix, *V* the among-column covariance matrix.

The *allow\_singular* behaviour of the *multivariate\_normal* distribution is not currently supported. Covariance matrices must be full rank.

The *matrix\_normal* distribution is closely related to the *multivariate\_normal* distribution. Specifically,  $\text{Vec}(X)$  (the vector formed by concatenating the columns of *X*) has a multivariate normal distribution with mean  $\text{Vec}(M)$  and covariance  $V \otimes U$  (where  $\otimes$  is the Kronecker product). Sampling and pdf evaluation are  $\mathcal{O}(m^3 + n^3 + m^2n + mn^2)$  for the matrix normal, but  $\mathcal{O}(m^3n^3)$  for the equivalent multivariate normal, making this equivalent form algorithmically inefficient.

New in version 0.17.0.

### Examples

```
>>> from scipy.stats import matrix_normal
```

```
>>> M = np.arange(6).reshape(3,2); M
array([[0, 1],
       [2, 3],
       [4, 5]])
>>> U = np.diag([1,2,3]); U
array([[1, 0, 0],
       [0, 2, 0],
       [0, 0, 3]])
>>> V = 0.3*np.identity(2); V
array([[ 0.3,  0. ],
       [ 0. ,  0.3]])
>>> X = M + 0.1; X
array([[ 0.1,  1.1],
       [ 2.1,  3.1],
       [ 4.1,  5.1]])
>>> matrix_normal.pdf(X, mean=M, rowcov=U, colcov=V)
0.023410202050005054
```

```

>>> # Equivalent multivariate normal
>>> from scipy.stats import multivariate_normal
>>> vectorised_X = X.T.flatten()
>>> equiv_mean = M.T.flatten()
>>> equiv_cov = np.kron(V,U)
>>> multivariate_normal.pdf(vectorised_X, mean=equiv_mean, cov=equiv_cov)
0.023410202050005054
    
```

### Methods

<code>pdf(X, mean=None, rowcov=1, colcov=1)</code>	Probability density function.
<code>logpdf(X, mean=None, rowcov=1, colcov=1)</code>	Log of the probability density function.
<code>rvs(mean=None, rowcov=1, colcov=1, size=1, random_state=None)</code>	Draw random samples.

`scipy.stats.dirichlet` = <scipy.stats.\_multivariate.dirichlet\_gen object>

A Dirichlet random variable.

The *alpha* keyword specifies the concentration parameters of the distribution.

New in version 0.15.0.

**Parameters** `x`: array\_like

Quantiles, with the last axis of *x* denoting the components.

**alpha**: array\_like

The concentration parameters. The number of entries determines the dimensionality of the distribution.

**random\_state**: None or int or np.random.RandomState instance, optional

If int or RandomState, use it for drawing the random variates. If None (or np.random), the global np.random state is used. Default is None.

**Alternatively, the object may be called (as a function) to fix concentration parameters, returning a “frozen” Dirichlet random variable:**

**rv = dirichlet(alpha)**

- Frozen object with the same methods but holding the given concentration parameters fixed.

### Notes

Each  $\alpha$  entry must be positive. The distribution has only support on the simplex defined by

$$\sum_{i=1}^K x_i \leq 1$$

The probability density function for *dirichlet* is

$$f(x) = \frac{1}{B(\boldsymbol{\alpha})} \prod_{i=1}^K x_i^{\alpha_i - 1}$$

where

$$B(\boldsymbol{\alpha}) = \frac{\prod_{i=1}^K \Gamma(\alpha_i)}{\Gamma(\sum_{i=1}^K \alpha_i)}$$

and  $\boldsymbol{\alpha} = (\alpha_1, \dots, \alpha_K)$ , the concentration parameters and *K* is the dimension of the space where *x* takes values.

Note that the dirichlet interface is somewhat inconsistent. The array returned by the rvs function is transposed with respect to the format expected by the pdf and logpdf.

**Methods**

<code>pdf(x, alpha)</code>	Probability density function.
<code>logpdf(x, alpha)</code>	Log of the probability density function.
<code>rvs(alpha, size=1, random_state=None)</code>	Draw random samples from a Dirichlet distribution.
<code>mean(alpha)</code>	The mean of the Dirichlet distribution
<code>var(alpha)</code>	The variance of the Dirichlet distribution
<code>entropy(alpha)</code>	Compute the differential entropy of the Dirichlet distribution.

`scipy.stats.wishart` = <`scipy.stats._multivariate.wishart_gen` object>

A Wishart random variable.

The *df* keyword specifies the degrees of freedom. The *scale* keyword specifies the scale matrix, which must be symmetric and positive definite. In this context, the scale matrix is often interpreted in terms of a multivariate normal precision matrix (the inverse of the covariance matrix).

**Parameters** `x` : array\_like

Quantiles, with the last axis of *x* denoting the components.

**df** : int

Degrees of freedom, must be greater than or equal to dimension of the scale matrix

**scale** : array\_like

Symmetric positive definite scale matrix of the distribution

**random\_state** : None or int or `np.random.RandomState` instance, optional

If int or `RandomState`, use it for drawing the random variates. If None (or `np.random`), the global `np.random` state is used. Default is None.

**Alternatively, the object may be called (as a function) to fix the degrees of freedom and scale parameters, returning a “frozen” Wishart random variable:**

**rv = wishart(df=1, scale=1)**

•Frozen object with the same methods but holding the given degrees of freedom and scale fixed.

**See also:**

`invwishart`, `chi2`

**Notes**

The scale matrix *scale* must be a symmetric positive definite matrix. Singular matrices, including the symmetric positive semi-definite case, are not supported.

The Wishart distribution is often denoted

$$W_p(\nu, \Sigma)$$

where  $\nu$  is the degrees of freedom and  $\Sigma$  is the  $p \times p$  scale matrix.

The probability density function for *wishart* has support over positive definite matrices *S*; if  $S \sim W_p(\nu, \Sigma)$ , then its PDF is given by:

$$f(S) = \frac{|S|^{\frac{\nu-p-1}{2}}}{2^{\frac{\nu p}{2}} |\Sigma|^{\frac{p}{2}} \Gamma_p\left(\frac{\nu}{2}\right)} \exp(-tr(\Sigma^{-1}S)/2)$$

If  $S \sim W_p(\nu, \Sigma)$  (Wishart) then  $S^{-1} \sim W_p^{-1}(\nu, \Sigma^{-1})$  (inverse Wishart).

If the scale matrix is 1-dimensional and equal to one, then the Wishart distribution  $W_1(\nu, 1)$  collapses to the  $\chi^2(\nu)$  distribution.

New in version 0.16.0.

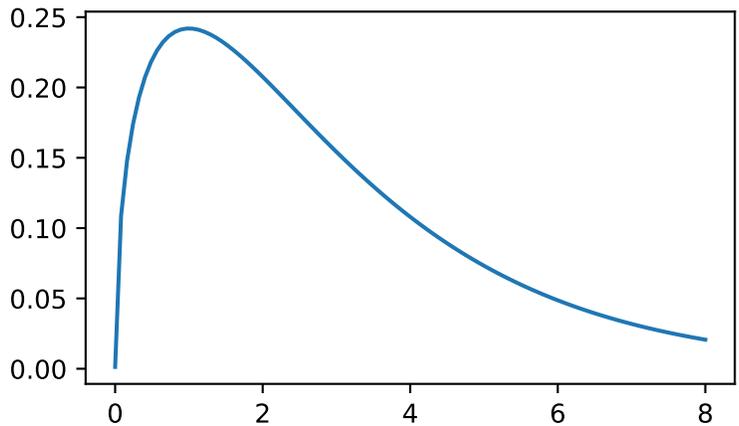
**References**

[R716], [R717]

**Examples**

```
>>> import matplotlib.pyplot as plt
>>> from scipy.stats import wishart, chi2
>>> x = np.linspace(1e-5, 8, 100)
>>> w = wishart.pdf(x, df=3, scale=1); w[:5]
array([ 0.00126156,  0.10892176,  0.14793434,  0.17400548,  0.1929669  ])
>>> c = chi2.pdf(x, 3); c[:5]
array([ 0.00126156,  0.10892176,  0.14793434,  0.17400548,  0.1929669  ])
>>> plt.plot(x, w)
```

The input quantiles can be any shape of array, as long as the last axis labels the components.



**Methods**

pdf(x, df, scale)	Probability density function.
logpdf(x, df, scale)	Log of the probability density function.
rvs(df, scale, size=1, random_state=None)	Draw random samples from a Wishart distribution.
entropy()	Compute the differential entropy of the Wishart distribution.

scipy.stats.invwishart = <scipy.stats.\_multivariate.invwishart\_gen object>

An inverse Wishart random variable.

The *df* keyword specifies the degrees of freedom. The *scale* keyword specifies the scale matrix, which must be symmetric and positive definite. In this context, the scale matrix is often interpreted in terms of a multivariate normal covariance matrix.

**Parameters** *x* : array\_like  
Quantiles, with the last axis of *x* denoting the components.  
*df* : int

Degrees of freedom, must be greater than or equal to dimension of the scale matrix

**scale** : array\_like

Symmetric positive definite scale matrix of the distribution

**random\_state** : None or int or np.random.RandomState instance, optional

If int or RandomState, use it for drawing the random variates. If None (or np.random), the global np.random state is used. Default is None.

**Alternatively, the object may be called (as a function) to fix the degrees of freedom and scale parameters, returning a “frozen” inverse Wishart random variable:**

**rv = invwishart(df=1, scale=1)**

- Frozen object with the same methods but holding the given degrees of freedom and scale fixed.

**See also:**

*wishart*

**Notes**

The scale matrix *scale* must be a symmetric positive definite matrix. Singular matrices, including the symmetric positive semi-definite case, are not supported.

The inverse Wishart distribution is often denoted

$$W_p^{-1}(\nu, \Psi)$$

where  $\nu$  is the degrees of freedom and  $\Psi$  is the  $p \times p$  scale matrix.

The probability density function for *invwishart* has support over positive definite matrices  $S$ ; if  $S \sim W_p^{-1}(\nu, \Sigma)$ , then its PDF is given by:

$$f(S) = \frac{|\Sigma|^{\frac{\nu}{2}}}{2^{\frac{\nu p}{2}} |S|^{\frac{\nu+p+1}{2}} \Gamma_p\left(\frac{\nu}{2}\right)} \exp(-tr(\Sigma S^{-1})/2)$$

If  $S \sim W_p^{-1}(\nu, \Psi)$  (inverse Wishart) then  $S^{-1} \sim W_p(\nu, \Psi^{-1})$  (Wishart).

If the scale matrix is 1-dimensional and equal to one, then the inverse Wishart distribution  $W_1(\nu, 1)$  collapses to the inverse Gamma distribution with parameters shape =  $\frac{\nu}{2}$  and scale =  $\frac{1}{2}$ .

New in version 0.16.0.

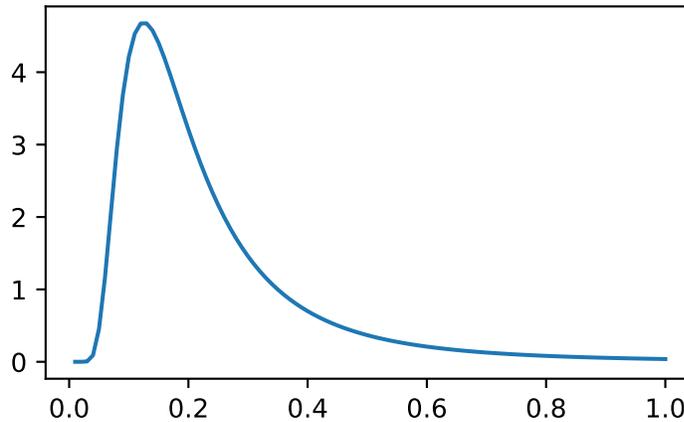
**References**

[R648], [R649]

**Examples**

```
>>> import matplotlib.pyplot as plt
>>> from scipy.stats import invwishart, invgamma
>>> x = np.linspace(0.01, 1, 100)
>>> iw = invwishart.pdf(x, df=6, scale=1)
>>> iw[:3]
array([ 1.20546865e-15,  5.42497807e-06,  4.45813929e-03])
>>> ig = invgamma.pdf(x, 6/2., scale=1./2)
>>> ig[:3]
array([ 1.20546865e-15,  5.42497807e-06,  4.45813929e-03])
>>> plt.plot(x, iw)
```

The input quantiles can be any shape of array, as long as the last axis labels the components.



**Methods**

<code>pdf(x, df, scale)</code>	Probability density function.
<code>logpdf(x, df, scale)</code>	Log of the probability density function.
<code>rvs(df, scale, size=1, random_state=None)</code>	Draw random samples from an inverse Wishart distribution.

`scipy.stats.multinomial` = <scipy.stats.\_multivariate.multinomial\_gen object>

A multinomial random variable.

- Parameters**
- x** : array\_like  
Quantiles, with the last axis of *x* denoting the components.
  - n** : int  
Number of trials
  - p** : array\_like  
Probability of a trial falling into each category; should sum to 1
  - random\_state** : None or int or np.random.RandomState instance, optional  
If int or RandomState, use it for drawing the random variates. If None (or np.random), the global np.random state is used. Default is None.

**See also:**

- `scipy.stats.binom`  
The binomial distribution.
- `numpy.random.multinomial`  
Sampling from the multinomial distribution.

**Notes**

*n* should be a positive integer. Each element of *p* should be in the interval [0, 1] and the elements should sum to 1. If they do not sum to 1, the last element of the *p* array is not used and is replaced with the remaining probability left over from the earlier elements.

Alternatively, the object may be called (as a function) to fix the *n* and *p* parameters, returning a “frozen” multinomial random variable:

The probability mass function for *multinomial* is

$$f(x) = \frac{n!}{x_1! \cdots x_k!} p_1^{x_1} \cdots p_k^{x_k},$$

supported on  $x = (x_1, \dots, x_k)$  where each  $x_i$  is a nonnegative integer and their sum is  $n$ .

New in version 0.19.0.

### Examples

```
>>> from scipy.stats import multinomial
>>> rv = multinomial(8, [0.3, 0.2, 0.5])
>>> rv.pmf([1, 3, 4])
0.0420000000000000072
```

The multinomial distribution for  $k = 2$  is identical to the corresponding binomial distribution (tiny numerical differences notwithstanding):

```
>>> from scipy.stats import binom
>>> multinomial.pmf([3, 4], n=7, p=[0.4, 0.6])
0.29030399999999973
>>> binom.pmf(3, 7, 0.4)
0.29030400000000012
```

The functions `pmf`, `logpmf`, `entropy`, and `cov` support broadcasting, under the convention that the vector parameters (`x` and `p`) are interpreted as if each row along the last axis is a single object. For instance:

```
>>> multinomial.pmf([[3, 4], [3, 5]], n=[7, 8], p=[.3, .7])
array([0.2268945, 0.25412184])
```

Here, `x.shape == (2, 2)`, `n.shape == (2,)`, and `p.shape == (2,)`, but following the rules mentioned above they behave as if the rows `[3, 4]` and `[3, 5]` in `x` and `[.3, .7]` in `p` were a single object, and as if we had `x.shape = (2,)`, `n.shape = (2,)`, and `p.shape = ()`. To obtain the individual elements without broadcasting, we would do this:

```
>>> multinomial.pmf([3, 4], n=7, p=[.3, .7])
0.2268945
>>> multinomial.pmf([3, 5], 8, p=[.3, .7])
0.25412184
```

This broadcasting also works for `cov`, where the output objects are square matrices of size `p.shape[-1]`. For example:

```
>>> multinomial.cov([4, 5], [[.3, .7], [.4, .6]])
array([[ [ 0.84, -0.84],
        [-0.84, 0.84]],
       [[ 1.2, -1.2 ],
        [-1.2, 1.2 ]]])
```

In this example, `n.shape == (2,)` and `p.shape == (2, 2)`, and following the rules above, these broadcast as if `p.shape == (2,)`. Thus the result should also be of shape `(2,)`, but since each output is a  $2 \times 2$  matrix, the result in fact has shape `(2, 2, 2)`, where `result[0]` is equal to `multinomial.cov(n=4, p=[.3, .7])` and `result[1]` is equal to `multinomial.cov(n=5, p=[.4, .6])`.



**Notes**

This class is closely related to `special_ortho_group`.

Some care is taken to avoid numerical error, as per the paper by Mezzadri.

**References**

[R678]

**Examples**

```
>>> from scipy.stats import ortho_group
>>> x = ortho_group.rvs(3)
```

```
>>> np.dot(x, x.T)
array([[ 1.00000000e+00,  1.13231364e-17, -2.86852790e-16],
       [ 1.13231364e-17,  1.00000000e+00, -1.46845020e-16],
       [-2.86852790e-16, -1.46845020e-16,  1.00000000e+00]])
```

```
>>> import scipy.linalg
>>> np.fabs(scipy.linalg.det(x))
1.0
```

This generates one random matrix from  $O(3)$ . It is orthogonal and has a determinant of +1 or -1.

**Methods**

<code>rvs(dim=None, size=1, random_state=None)</code>	Draw random samples from $O(N)$ .
---	-----------------------------------

`scipy.stats.unitary_group = <scipy.stats.multivariate.unitary_group_gen object>`

A matrix-valued  $U(N)$  random variable.

Return a random unitary matrix.

The *dim* keyword specifies the dimension  $N$ .

**Parameters** **dim** : scalar  
Dimension of matrices

**Notes**

This class is similar to `ortho_group`.

**References**

[R708]

**Examples**

```
>>> from scipy.stats import unitary_group
>>> x = unitary_group.rvs(3)
```

```
>>> np.dot(x, x.conj().T)
array([[ 1.00000000e+00,  1.13231364e-17, -2.86852790e-16],
       [ 1.13231364e-17,  1.00000000e+00, -1.46845020e-16],
       [-2.86852790e-16, -1.46845020e-16,  1.00000000e+00]])
```

This generates one random matrix from  $U(3)$ . The dot product confirms that it is unitary up to machine precision.

**Methods**

<code>rvs(dim=None, size=1, random_state=None)</code>	Draw random samples from U(N).
---	--------------------------------

`scipy.stats.random_correlation = <scipy.stats.multivariate.random_correlation_gen object>`

A random correlation matrix.

Return a random correlation matrix, given a vector of eigenvalues.

The *eigs* keyword specifies the eigenvalues of the correlation matrix, and implies the dimension.

**Parameters** *eigs* : 1d ndarray  
Eigenvalues of correlation matrix.

**Notes**

Generates a random correlation matrix following a numerically stable algorithm spelled out by Davies & Higham. This algorithm uses a single O(N) similarity transformation to construct a symmetric positive semi-definite matrix, and applies a series of Givens rotations to scale it to have ones on the diagonal.

**References**

[R689]

**Examples**

```
>>> from scipy.stats import random_correlation
>>> np.random.seed(514)
>>> x = random_correlation.rvs((.5, .8, 1.2, 1.5))
>>> x
array([[ 1.          , -0.20387311,  0.18366501, -0.04953711],
       [-0.20387311,  1.          , -0.24351129,  0.06703474],
       [ 0.18366501, -0.24351129,  1.          ,  0.38530195],
       [-0.04953711,  0.06703474,  0.38530195,  1.          ]])
```

```
>>> import scipy.linalg
>>> e, v = scipy.linalg.eigh(x)
>>> e
array([ 0.5,  0.8,  1.2,  1.5])
```

**Methods**

<code>rvs(eigs=None, random_state=None)</code>	Draw random correlation matrices, all with eigenvalues <i>eigs</i> .
--	--

**5.27.3 Discrete distributions**

<i>bernoulli</i>	A Bernoulli discrete random variable.
<i>binom</i>	A binomial discrete random variable.
<i>boltzmann</i>	A Boltzmann (Truncated Discrete Exponential) random variable.
<i>dlaplace</i>	A Laplacian discrete random variable.
<i>geom</i>	A geometric discrete random variable.
<i>hypergeom</i>	A hypergeometric discrete random variable.
<i>logser</i>	A Logarithmic (Log-Series, Series) discrete random variable.

Continued on next page

Table 5.289 – continued from previous page

<i>nbinom</i>	A negative binomial discrete random variable.
<i>planck</i>	A Planck discrete exponential random variable.
<i>poisson</i>	A Poisson discrete random variable.
<i>randint</i>	A uniform discrete random variable.
<i>skellam</i>	A Skellam discrete random variable.
<i>zipf</i>	A Zipf discrete random variable.

`scipy.stats.bernoulli` = <`scipy.stats.discrete_distns.bernoulli_gen` object>

A Bernoulli discrete random variable.

As an instance of the *rv\_discrete* class, *bernoulli* object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability mass function for *bernoulli* is:

$$\begin{aligned} \text{bernoulli.pmf}(k) &= 1-p && \text{if } k = 0 \\ &= p && \text{if } k = 1 \end{aligned}$$

for  $k$  in  $\{0, 1\}$ .

*bernoulli* takes  $p$  as shape parameter.

The probability mass function above is defined in the “standardized” form. To shift distribution use the `loc` parameter. Specifically, `bernoulli.pmf(k, p, loc)` is identically equivalent to `bernoulli.pmf(k - loc, p)`.

### Examples

```
>>> from scipy.stats import bernoulli
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> p = 0.3
>>> mean, var, skew, kurt = bernoulli.stats(p, moments='mvsk')
```

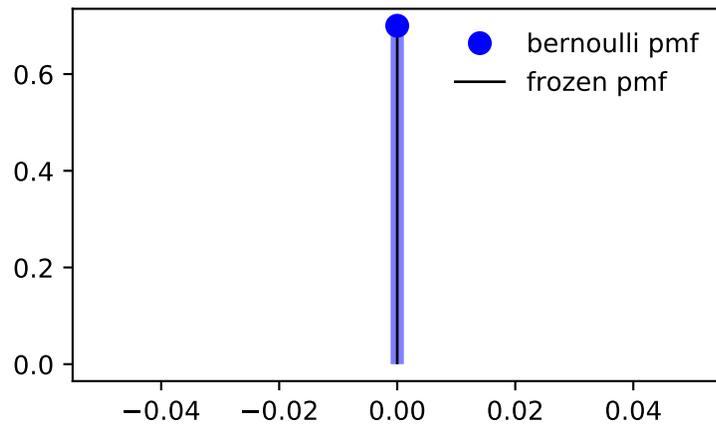
Display the probability mass function (pmf):

```
>>> x = np.arange(bernoulli.ppf(0.01, p),
...               bernoulli.ppf(0.99, p))
>>> ax.plot(x, bernoulli.pmf(x, p), 'bo', ms=8, label='bernoulli pmf')
>>> ax.vlines(x, 0, bernoulli.pmf(x, p), colors='b', lw=5, alpha=0.5)
```

Alternatively, the distribution object can be called (as a function) to fix the shape and location. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pmf:

```
>>> rv = bernoulli(p)
>>> ax.vlines(x, 0, rv.pmf(x), colors='k', linestyle='-', lw=1,
...          label='frozen pmf')
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



Check accuracy of cdf and ppf:

```
>>> prob = bernoulli.cdf(x, p)
>>> np.allclose(x, bernoulli.ppf(prob, p))
True
```

Generate random numbers:

```
>>> r = bernoulli.rvs(p, size=1000)
```

### Methods

<code>rvs(p, loc=0, size=1, random_state=None)</code>	Random variates.
<code>pmf(k, p, loc=0)</code>	Probability mass function.
<code>logpmf(k, p, loc=0)</code>	Log of the probability mass function.
<code>cdf(k, p, loc=0)</code>	Cumulative distribution function.
<code>logcdf(k, p, loc=0)</code>	Log of the cumulative distribution function.
<code>sf(k, p, loc=0)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(k, p, loc=0)</code>	Log of the survival function.
<code>ppf(q, p, loc=0)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, p, loc=0)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>stats(p, loc=0, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(p, loc=0)</code>	(Differential) entropy of the RV.
<code>expect(func, args=(p,), loc=0, lb=None, ub=None, conditional=False)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(p, loc=0)</code>	Median of the distribution.
<code>mean(p, loc=0)</code>	Mean of the distribution.
<code>var(p, loc=0)</code>	Variance of the distribution.
<code>std(p, loc=0)</code>	Standard deviation of the distribution.
<code>interval(alpha, p, loc=0)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.binom` = <`scipy.stats._discrete_distns.binom_gen` object>

A binomial discrete random variable.

As an instance of the `rv_discrete` class, `binom` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability mass function for `binom` is:

```
binom.pmf(k) = choose(n, k) * p**k * (1-p)**(n-k)
```

for `k` in  $\{0, 1, \dots, n\}$ .

`binom` takes `n` and `p` as shape parameters.

The probability mass function above is defined in the “standardized” form. To shift distribution use the `loc` parameter. Specifically, `binom.pmf(k, n, p, loc)` is identically equivalent to `binom.pmf(k - loc, n, p)`.

### Examples

```
>>> from scipy.stats import binom
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> n, p = 5, 0.4
>>> mean, var, skew, kurt = binom.stats(n, p, moments='mvsk')
```

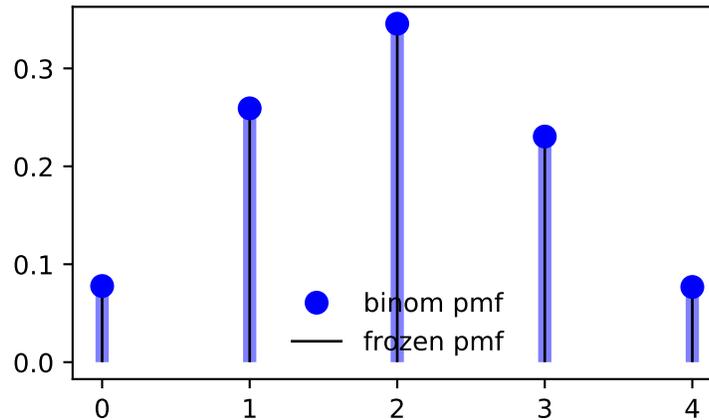
Display the probability mass function (pmf):

```
>>> x = np.arange(binom.ppf(0.01, n, p),
...               binom.ppf(0.99, n, p))
>>> ax.plot(x, binom.pmf(x, n, p), 'bo', ms=8, label='binom pmf')
>>> ax.vlines(x, 0, binom.pmf(x, n, p), colors='b', lw=5, alpha=0.5)
```

Alternatively, the distribution object can be called (as a function) to fix the shape and location. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pmf:

```
>>> rv = binom(n, p)
>>> ax.vlines(x, 0, rv.pmf(x), colors='k', linestyle='-', lw=1,
...          label='frozen pmf')
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



Check accuracy of cdf and ppf:

```
>>> prob = binom.cdf(x, n, p)
>>> np.allclose(x, binom.ppf(prob, n, p))
True
```

Generate random numbers:

```
>>> r = binom.rvs(n, p, size=1000)
```

### Methods

<code>rvs(n, p, loc=0, size=1, random_state=None)</code>	Random variates.
<code>pmf(k, n, p, loc=0)</code>	Probability mass function.
<code>logpmf(k, n, p, loc=0)</code>	Log of the probability mass function.
<code>cdf(k, n, p, loc=0)</code>	Cumulative distribution function.
<code>logcdf(k, n, p, loc=0)</code>	Log of the cumulative distribution function.
<code>sf(k, n, p, loc=0)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(k, n, p, loc=0)</code>	Log of the survival function.
<code>ppf(q, n, p, loc=0)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, n, p, loc=0)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>stats(n, p, loc=0, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(n, p, loc=0)</code>	(Differential) entropy of the RV.
<code>expect(func, args=(n, p), loc=0, lb=None, ub=None, conditional=False)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(n, p, loc=0)</code>	Median of the distribution.
<code>mean(n, p, loc=0)</code>	Mean of the distribution.
<code>var(n, p, loc=0)</code>	Variance of the distribution.
<code>std(n, p, loc=0)</code>	Standard deviation of the distribution.
<code>interval(alpha, n, p, loc=0)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.boltzmann = <scipy.stats._discrete_distns.boltzmann_gen object>`

A Boltzmann (Truncated Discrete Exponential) random variable.

As an instance of the `rv_discrete` class, `boltzmann` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability mass function for `boltzmann` is:

$$\text{boltzmann.pmf}(k) = (1 - \exp(-\lambda)) \exp(-\lambda * k) / (1 - \exp(-\lambda * N))$$

for  $k = 0, \dots, N-1$ .

`boltzmann` takes `lambda_` and `N` as shape parameters.

The probability mass function above is defined in the “standardized” form. To shift distribution use the `loc` parameter. Specifically, `boltzmann.pmf(k, lambda_, N, loc)` is identically equivalent to `boltzmann.pmf(k - loc, lambda_, N)`.

### Examples

```
>>> from scipy.stats import boltzmann
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> lambda_, N = 1.4, 19
>>> mean, var, skew, kurt = boltzmann.stats(lambda_, N, moments='mvsk')
```

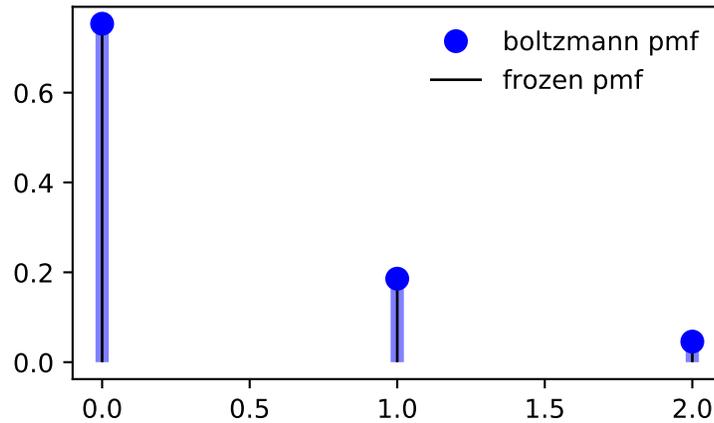
Display the probability mass function (pmf):

```
>>> x = np.arange(boltzmann.ppf(0.01, lambda_, N),
...               boltzmann.ppf(0.99, lambda_, N))
>>> ax.plot(x, boltzmann.pmf(x, lambda_, N), 'bo', ms=8, label='boltzmann pmf')
>>> ax.vlines(x, 0, boltzmann.pmf(x, lambda_, N), colors='b', lw=5, alpha=0.5)
```

Alternatively, the distribution object can be called (as a function) to fix the shape and location. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pmf:

```
>>> rv = boltzmann(lambda_, N)
>>> ax.vlines(x, 0, rv.pmf(x), colors='k', linestyle='-', lw=1,
...          label='frozen pmf')
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



Check accuracy of cdf and ppf:

```
>>> prob = boltzmann.cdf(x, lambda_, N)
>>> np.allclose(x, boltzmann.ppf(prob, lambda_, N))
True
```

Generate random numbers:

```
>>> r = boltzmann.rvs(lambda_, N, size=1000)
```

### Methods

<code>rvs(lambda_, N, loc=0, size=1, random_state=None)</code>	Random variates.
<code>pmf(k, lambda_, N, loc=0)</code>	Probability mass function.
<code>logpmf(k, lambda_, N, loc=0)</code>	Log of the probability mass function.
<code>cdf(k, lambda_, N, loc=0)</code>	Cumulative distribution function.
<code>logcdf(k, lambda_, N, loc=0)</code>	Log of the cumulative distribution function.
<code>sf(k, lambda_, N, loc=0)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(k, lambda_, N, loc=0)</code>	Log of the survival function.
<code>ppf(q, lambda_, N, loc=0)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, lambda_, N, loc=0)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>stats(lambda_, N, loc=0, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(lambda_, N, loc=0)</code>	(Differential) entropy of the RV.
<code>expect(func, args=(lambda_, N), loc=0, lb=None, ub=None, conditional=False)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(lambda_, N, loc=0)</code>	Median of the distribution.
<code>mean(lambda_, N, loc=0)</code>	Mean of the distribution.
<code>var(lambda_, N, loc=0)</code>	Variance of the distribution.
<code>std(lambda_, N, loc=0)</code>	Standard deviation of the distribution.
<code>interval(alpha, lambda_, N, loc=0)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.dlaplace = <scipy.stats._discrete_distns.dlaplace_gen object>`

A Laplacian discrete random variable.

As an instance of the `rv_discrete` class, `dlaplace` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability mass function for `dlaplace` is:

$$\text{dlaplace.pmf}(k) = \tanh(a/2) * \exp(-a*abs(k))$$

for  $a > 0$ .

`dlaplace` takes `a` as shape parameter.

The probability mass function above is defined in the “standardized” form. To shift distribution use the `loc` parameter. Specifically, `dlaplace.pmf(k, a, loc)` is identically equivalent to `dlaplace.pmf(k - loc, a)`.

### Examples

```
>>> from scipy.stats import dlaplace
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a = 0.8
>>> mean, var, skew, kurt = dlaplace.stats(a, moments='mvsk')
```

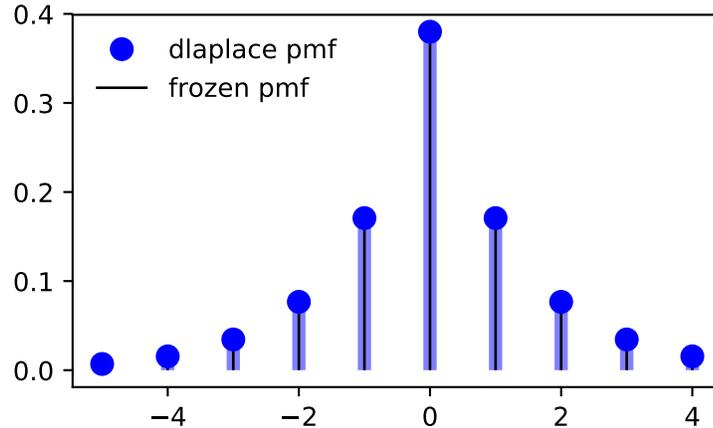
Display the probability mass function (pmf):

```
>>> x = np.arange(dlaplace.ppf(0.01, a),
...               dlaplace.ppf(0.99, a))
>>> ax.plot(x, dlaplace.pmf(x, a), 'bo', ms=8, label='dlaplace pmf')
>>> ax.vlines(x, 0, dlaplace.pmf(x, a), colors='b', lw=5, alpha=0.5)
```

Alternatively, the distribution object can be called (as a function) to fix the shape and location. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pmf:

```
>>> rv = dlaplace(a)
>>> ax.vlines(x, 0, rv.pmf(x), colors='k', linestyle='-', lw=1,
...           label='frozen pmf')
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



Check accuracy of cdf and ppf:

```
>>> prob = dlaplace.cdf(x, a)
>>> np.allclose(x, dlaplace.ppf(prob, a))
True
```

Generate random numbers:

```
>>> r = dlaplace.rvs(a, size=1000)
```

### Methods

<code>rvs(a, loc=0, size=1, random_state=None)</code>	Random variates.
<code>pmf(k, a, loc=0)</code>	Probability mass function.
<code>logpmf(k, a, loc=0)</code>	Log of the probability mass function.
<code>cdf(k, a, loc=0)</code>	Cumulative distribution function.
<code>logcdf(k, a, loc=0)</code>	Log of the cumulative distribution function.
<code>sf(k, a, loc=0)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(k, a, loc=0)</code>	Log of the survival function.
<code>ppf(q, a, loc=0)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, a, loc=0)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>stats(a, loc=0, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, loc=0)</code>	(Differential) entropy of the RV.
<code>expect(func, args=(a,), loc=0, lb=None, ub=None, conditional=False)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, loc=0)</code>	Median of the distribution.
<code>mean(a, loc=0)</code>	Mean of the distribution.
<code>var(a, loc=0)</code>	Variance of the distribution.
<code>std(a, loc=0)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, loc=0)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.geom` = <`scipy.stats._discrete_distns.geom_gen` object>

A geometric discrete random variable.

As an instance of the `rv_discrete` class, `geom` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability mass function for `geom` is:

$$\text{geom.pmf}(k) = (1-p)^{k-1} * p$$

for  $k \geq 1$ .

`geom` takes `p` as shape parameter.

The probability mass function above is defined in the “standardized” form. To shift distribution use the `loc` parameter. Specifically, `geom.pmf(k, p, loc)` is identically equivalent to `geom.pmf(k - loc, p)`.

### Examples

```
>>> from scipy.stats import geom
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> p = 0.5
>>> mean, var, skew, kurt = geom.stats(p, moments='mvsk')
```

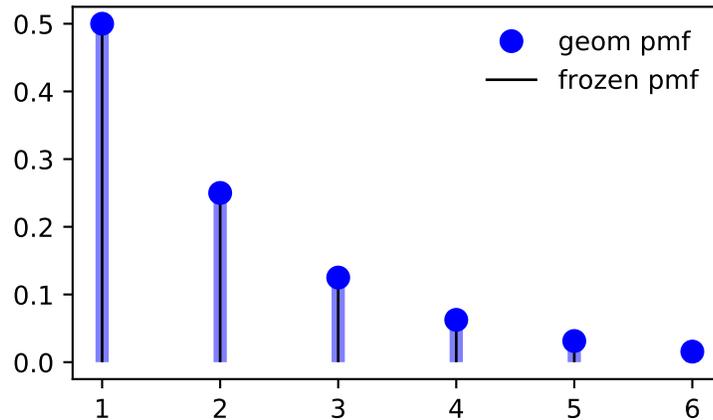
Display the probability mass function (pmf):

```
>>> x = np.arange(geom.ppf(0.01, p),
...               geom.ppf(0.99, p))
>>> ax.plot(x, geom.pmf(x, p), 'bo', ms=8, label='geom pmf')
>>> ax.vlines(x, 0, geom.pmf(x, p), colors='b', lw=5, alpha=0.5)
```

Alternatively, the distribution object can be called (as a function) to fix the shape and location. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pmf:

```
>>> rv = geom(p)
>>> ax.vlines(x, 0, rv.pmf(x), colors='k', linestyle='-', lw=1,
...          label='frozen pmf')
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



Check accuracy of cdf and ppf:

```
>>> prob = geom.cdf(x, p)
>>> np.allclose(x, geom.ppf(prob, p))
True
```

Generate random numbers:

```
>>> r = geom.rvs(p, size=1000)
```

### Methods

<code>rvs(p, loc=0, size=1, random_state=None)</code>	Random variates.
<code>pmf(k, p, loc=0)</code>	Probability mass function.
<code>logpmf(k, p, loc=0)</code>	Log of the probability mass function.
<code>cdf(k, p, loc=0)</code>	Cumulative distribution function.
<code>logcdf(k, p, loc=0)</code>	Log of the cumulative distribution function.
<code>sf(k, p, loc=0)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(k, p, loc=0)</code>	Log of the survival function.
<code>ppf(q, p, loc=0)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, p, loc=0)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>stats(p, loc=0, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(p, loc=0)</code>	(Differential) entropy of the RV.
<code>expect(func, args=(p,), loc=0, lb=None, ub=None, conditional=False)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(p, loc=0)</code>	Median of the distribution.
<code>mean(p, loc=0)</code>	Mean of the distribution.
<code>var(p, loc=0)</code>	Variance of the distribution.
<code>std(p, loc=0)</code>	Standard deviation of the distribution.
<code>interval(alpha, p, loc=0)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.hypergeom` = <scipy.stats.\_discrete\_distns.hypergeom\_gen object>

A hypergeometric discrete random variable.

The hypergeometric distribution models drawing objects from a bin.  $M$  is the total number of objects,  $n$  is total number of Type I objects. The random variate represents the number of Type I objects in  $N$  drawn without replacement from the total population.

As an instance of the `rv_discrete` class, `hypergeom` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The symbols used to denote the shape parameters ( $M$ ,  $n$ , and  $N$ ) are not universally accepted. See the Examples for a clarification of the definitions used here.

The probability mass function is defined as,

$$p(k, M, n, N) = \frac{\binom{n}{k} \binom{M-n}{N-k}}{\binom{M}{N}}$$

for  $k \in [\max(0, N - M + n), \min(n, N)]$ , where the binomial coefficients are defined as,

$$\binom{n}{k} \equiv \frac{n!}{k!(n-k)!}$$

The probability mass function above is defined in the “standardized” form. To shift distribution use the `loc` parameter. Specifically, `hypergeom.pmf(k, M, n, N, loc)` is identically equivalent to `hypergeom.pmf(k - loc, M, n, N)`.

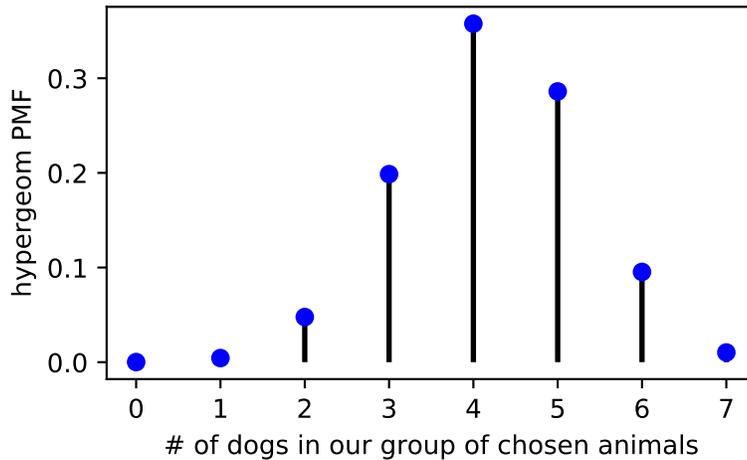
### Examples

```
>>> from scipy.stats import hypergeom
>>> import matplotlib.pyplot as plt
```

Suppose we have a collection of 20 animals, of which 7 are dogs. Then if we want to know the probability of finding a given number of dogs if we choose at random 12 of the 20 animals, we can initialize a frozen distribution and plot the probability mass function:

```
>>> [M, n, N] = [20, 7, 12]
>>> rv = hypergeom(M, n, N)
>>> x = np.arange(0, n+1)
>>> pmf_dogs = rv.pmf(x)
```

```
>>> fig = plt.figure()
>>> ax = fig.add_subplot(111)
>>> ax.plot(x, pmf_dogs, 'bo')
>>> ax.vlines(x, 0, pmf_dogs, lw=2)
>>> ax.set_xlabel('# of dogs in our group of chosen animals')
>>> ax.set_ylabel('hypergeom PMF')
>>> plt.show()
```



Instead of using a frozen distribution we can also use *hypergeom* methods directly. To for example obtain the cumulative distribution function, use:

```
>>> prb = hypergeom.cdf(x, M, n, N)
```

And to generate random numbers:

```
>>> R = hypergeom.rvs(M, n, N, size=10)
```

### Methods

<code>rvs(M, n, N, loc=0, size=1, random_state=None)</code>	Random variates.
<code>pmf(k, M, n, N, loc=0)</code>	Probability mass function.
<code>logpmf(k, M, n, N, loc=0)</code>	Log of the probability mass function.
<code>cdf(k, M, n, N, loc=0)</code>	Cumulative distribution function.
<code>logcdf(k, M, n, N, loc=0)</code>	Log of the cumulative distribution function.
<code>sf(k, M, n, N, loc=0)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(k, M, n, N, loc=0)</code>	Log of the survival function.
<code>ppf(q, M, n, N, loc=0)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, M, n, N, loc=0)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>stats(M, n, N, loc=0, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(M, n, N, loc=0)</code>	(Differential) entropy of the RV.
<code>expect(func, args=(M, n, N), loc=0, lb=None, ub=None, conditional=False)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(M, n, N, loc=0)</code>	Median of the distribution.
<code>mean(M, n, N, loc=0)</code>	Mean of the distribution.
<code>var(M, n, N, loc=0)</code>	Variance of the distribution.
<code>std(M, n, N, loc=0)</code>	Standard deviation of the distribution.
<code>interval(alpha, M, n, N, loc=0)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.logser = <scipy.stats_discrete_distns.logser_gen object>`

A Logarithmic (Log-Series, Series) discrete random variable.

As an instance of the `rv_discrete` class, `logser` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability mass function for `logser` is:

```
logser.pmf(k) = - p**k / (k*log(1-p))
```

for  $k \geq 1$ .

`logser` takes `p` as shape parameter.

The probability mass function above is defined in the “standardized” form. To shift distribution use the `loc` parameter. Specifically, `logser.pmf(k, p, loc)` is identically equivalent to `logser.pmf(k - loc, p)`.

### Examples

```
>>> from scipy.stats import logser
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> p = 0.6
>>> mean, var, skew, kurt = logser.stats(p, moments='mvsk')
```

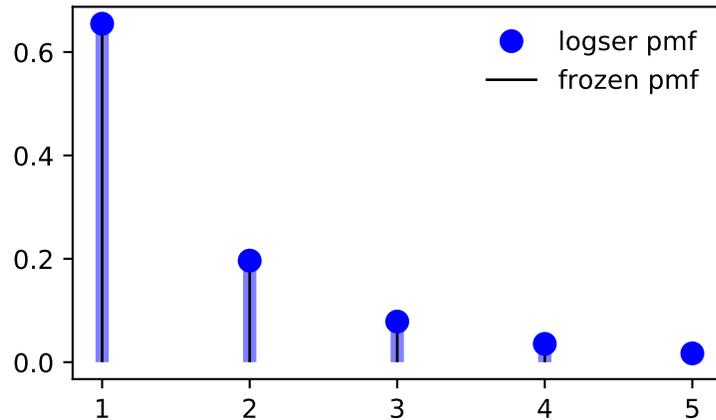
Display the probability mass function (pmf):

```
>>> x = np.arange(logser.ppf(0.01, p),
...               logser.ppf(0.99, p))
>>> ax.plot(x, logser.pmf(x, p), 'bo', ms=8, label='logser pmf')
>>> ax.vlines(x, 0, logser.pmf(x, p), colors='b', lw=5, alpha=0.5)
```

Alternatively, the distribution object can be called (as a function) to fix the shape and location. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pmf:

```
>>> rv = logser(p)
>>> ax.vlines(x, 0, rv.pmf(x), colors='k', linestyle='-', lw=1,
...          label='frozen pmf')
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



Check accuracy of cdf and ppf:

```
>>> prob = logser.cdf(x, p)
>>> np.allclose(x, logser.ppf(prob, p))
True
```

Generate random numbers:

```
>>> r = logser.rvs(p, size=1000)
```

### Methods

<code>rvs(p, loc=0, size=1, random_state=None)</code>	Random variates.
<code>pmf(k, p, loc=0)</code>	Probability mass function.
<code>logpmf(k, p, loc=0)</code>	Log of the probability mass function.
<code>cdf(k, p, loc=0)</code>	Cumulative distribution function.
<code>logcdf(k, p, loc=0)</code>	Log of the cumulative distribution function.
<code>sf(k, p, loc=0)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(k, p, loc=0)</code>	Log of the survival function.
<code>ppf(q, p, loc=0)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, p, loc=0)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>stats(p, loc=0, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(p, loc=0)</code>	(Differential) entropy of the RV.
<code>expect(func, args=(p,), loc=0, lb=None, ub=None, conditional=False)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(p, loc=0)</code>	Median of the distribution.
<code>mean(p, loc=0)</code>	Mean of the distribution.
<code>var(p, loc=0)</code>	Variance of the distribution.
<code>std(p, loc=0)</code>	Standard deviation of the distribution.
<code>interval(alpha, p, loc=0)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.nbinom` = <`scipy.stats._discrete_distns.nbinom_gen` object>

A negative binomial discrete random variable.

As an instance of the `rv_discrete` class, `nbinom` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

Negative binomial distribution describes a sequence of i.i.d. Bernoulli trials, repeated until a predefined, non-random number of successes occurs.

The probability mass function of the number of failures for `nbinom` is:

$$\text{nbinom.pmf}(k) = \text{choose}(k+n-1, n-1) * p^{**n} * (1-p)^{**k}$$

for  $k \geq 0$ .

`nbinom` takes `n` and `p` as shape parameters where `n` is the number of successes, whereas `p` is the probability of a single success.

The probability mass function above is defined in the “standardized” form. To shift distribution use the `loc` parameter. Specifically, `nbinom.pmf(k, n, p, loc)` is identically equivalent to `nbinom.pmf(k - loc, n, p)`.

### Examples

```
>>> from scipy.stats import nbinom
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> n, p = 0.4, 0.4
>>> mean, var, skew, kurt = nbinom.stats(n, p, moments='mvsk')
```

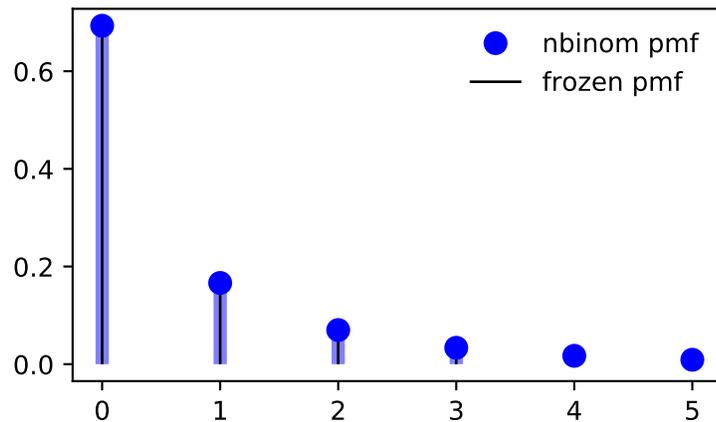
Display the probability mass function (pmf):

```
>>> x = np.arange(nbinom.ppf(0.01, n, p),
...               nbinom.ppf(0.99, n, p))
>>> ax.plot(x, nbinom.pmf(x, n, p), 'bo', ms=8, label='nbinom pmf')
>>> ax.vlines(x, 0, nbinom.pmf(x, n, p), colors='b', lw=5, alpha=0.5)
```

Alternatively, the distribution object can be called (as a function) to fix the shape and location. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pmf:

```
>>> rv = nbinom(n, p)
>>> ax.vlines(x, 0, rv.pmf(x), colors='k', linestyle='-', lw=1,
...          label='frozen pmf')
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



Check accuracy of cdf and ppf:

```
>>> prob = nbinom.cdf(x, n, p)
>>> np.allclose(x, nbinom.ppf(prob, n, p))
True
```

Generate random numbers:

```
>>> r = nbinom.rvs(n, p, size=1000)
```

### Methods

<code>rvs(n, p, loc=0, size=1, random_state=None)</code>	Random variates.
<code>pmf(k, n, p, loc=0)</code>	Probability mass function.
<code>logpmf(k, n, p, loc=0)</code>	Log of the probability mass function.
<code>cdf(k, n, p, loc=0)</code>	Cumulative distribution function.
<code>logcdf(k, n, p, loc=0)</code>	Log of the cumulative distribution function.
<code>sf(k, n, p, loc=0)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(k, n, p, loc=0)</code>	Log of the survival function.
<code>ppf(q, n, p, loc=0)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, n, p, loc=0)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>stats(n, p, loc=0, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(n, p, loc=0)</code>	(Differential) entropy of the RV.
<code>expect(func, args=(n, p), loc=0, lb=None, ub=None, conditional=False)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(n, p, loc=0)</code>	Median of the distribution.
<code>mean(n, p, loc=0)</code>	Mean of the distribution.
<code>var(n, p, loc=0)</code>	Variance of the distribution.
<code>std(n, p, loc=0)</code>	Standard deviation of the distribution.
<code>interval(alpha, n, p, loc=0)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.planck = <scipy.stats._discrete_distns.planck_gen object>`

A Planck discrete exponential random variable.

As an instance of the `rv_discrete` class, `planck` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability mass function for `planck` is:

```
planck.pmf(k) = (1-exp(-lambda_)) * exp(-lambda_*k)
```

for  $k * \text{lambda\_} \geq 0$ .

`planck` takes `lambda_` as shape parameter.

The probability mass function above is defined in the “standardized” form. To shift distribution use the `loc` parameter. Specifically, `planck.pmf(k, lambda_, loc)` is identically equivalent to `planck.pmf(k - loc, lambda_)`.

### Examples

```
>>> from scipy.stats import planck
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> lambda_ = 0.51
>>> mean, var, skew, kurt = planck.stats(lambda_, moments='mvsk')
```

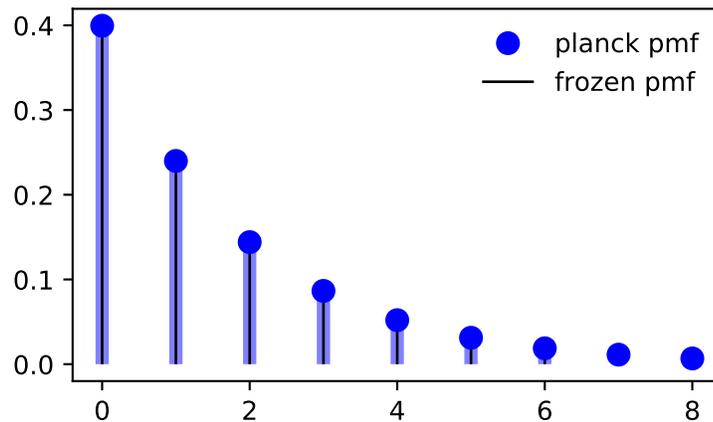
Display the probability mass function (pmf):

```
>>> x = np.arange(planck.ppf(0.01, lambda_),
...               planck.ppf(0.99, lambda_))
>>> ax.plot(x, planck.pmf(x, lambda_), 'bo', ms=8, label='planck pmf')
>>> ax.vlines(x, 0, planck.pmf(x, lambda_), colors='b', lw=5, alpha=0.5)
```

Alternatively, the distribution object can be called (as a function) to fix the shape and location. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pmf:

```
>>> rv = planck(lambda_)
>>> ax.vlines(x, 0, rv.pmf(x), colors='k', linestyle='-', lw=1,
...          label='frozen pmf')
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



Check accuracy of cdf and ppf:

```
>>> prob = planck.cdf(x, lambda_)
>>> np.allclose(x, planck.ppf(prob, lambda_))
True
```

Generate random numbers:

```
>>> r = planck.rvs(lambda_, size=1000)
```

### Methods

<code>rvs(lambda_, loc=0, size=1, random_state=None)</code>	Random variates.
<code>pmf(k, lambda_, loc=0)</code>	Probability mass function.
<code>logpmf(k, lambda_, loc=0)</code>	Log of the probability mass function.
<code>cdf(k, lambda_, loc=0)</code>	Cumulative distribution function.
<code>logcdf(k, lambda_, loc=0)</code>	Log of the cumulative distribution function.
<code>sf(k, lambda_, loc=0)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(k, lambda_, loc=0)</code>	Log of the survival function.
<code>ppf(q, lambda_, loc=0)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, lambda_, loc=0)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>stats(lambda_, loc=0, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(lambda_, loc=0)</code>	(Differential) entropy of the RV.
<code>expect(func, args=(lambda_,), loc=0, lb=None, ub=None, conditional=False)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(lambda_, loc=0)</code>	Median of the distribution.
<code>mean(lambda_, loc=0)</code>	Mean of the distribution.
<code>var(lambda_, loc=0)</code>	Variance of the distribution.
<code>std(lambda_, loc=0)</code>	Standard deviation of the distribution.
<code>interval(alpha, lambda_, loc=0)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.poisson` = <`scipy.stats._discrete_distns.poisson_gen` object>

A Poisson discrete random variable.

As an instance of the `rv_discrete` class, `poisson` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability mass function for `poisson` is:

```
poisson.pmf(k) = exp(-mu) * mu**k / k!
```

for  $k \geq 0$ .

`poisson` takes `mu` as shape parameter.

The probability mass function above is defined in the “standardized” form. To shift distribution use the `loc` parameter. Specifically, `poisson.pmf(k, mu, loc)` is identically equivalent to `poisson.pmf(k - loc, mu)`.

### Examples

```
>>> from scipy.stats import poisson
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mu = 0.6
>>> mean, var, skew, kurt = poisson.stats(mu, moments='mvsk')
```

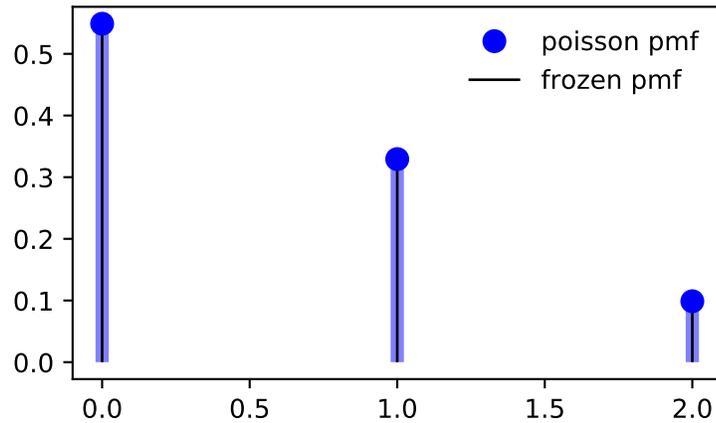
Display the probability mass function (pmf):

```
>>> x = np.arange(poisson.ppf(0.01, mu),
...               poisson.ppf(0.99, mu))
>>> ax.plot(x, poisson.pmf(x, mu), 'bo', ms=8, label='poisson pmf')
>>> ax.vlines(x, 0, poisson.pmf(x, mu), colors='b', lw=5, alpha=0.5)
```

Alternatively, the distribution object can be called (as a function) to fix the shape and location. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pmf:

```
>>> rv = poisson(mu)
>>> ax.vlines(x, 0, rv.pmf(x), colors='k', linestyle='-', lw=1,
...          label='frozen pmf')
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



Check accuracy of cdf and ppf:

```
>>> prob = poisson.cdf(x, mu)
>>> np.allclose(x, poisson.ppf(prob, mu))
True
```

Generate random numbers:

```
>>> r = poisson.rvs(mu, size=1000)
```

### Methods

<code>rvs(mu, loc=0, size=1, random_state=None)</code>	Random variates.
<code>pmf(k, mu, loc=0)</code>	Probability mass function.
<code>logpmf(k, mu, loc=0)</code>	Log of the probability mass function.
<code>cdf(k, mu, loc=0)</code>	Cumulative distribution function.
<code>logcdf(k, mu, loc=0)</code>	Log of the cumulative distribution function.
<code>sf(k, mu, loc=0)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(k, mu, loc=0)</code>	Log of the survival function.
<code>ppf(q, mu, loc=0)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, mu, loc=0)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>stats(mu, loc=0, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(mu, loc=0)</code>	(Differential) entropy of the RV.
<code>expect(func, args=(mu,), loc=0, lb=None, ub=None, conditional=False)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(mu, loc=0)</code>	Median of the distribution.
<code>mean(mu, loc=0)</code>	Mean of the distribution.
<code>var(mu, loc=0)</code>	Variance of the distribution.
<code>std(mu, loc=0)</code>	Standard deviation of the distribution.
<code>interval(alpha, mu, loc=0)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.randint` = <`scipy.stats._discrete_distns.randint_gen` object>

A uniform discrete random variable.

As an instance of the `rv_discrete` class, `randint` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability mass function for `randint` is:

```
randint.pmf(k) = 1./(high - low)
```

for `k = low, ..., high - 1`.

`randint` takes `low` and `high` as shape parameters.

The probability mass function above is defined in the “standardized” form. To shift distribution use the `loc` parameter. Specifically, `randint.pmf(k, low, high, loc)` is identically equivalent to `randint.pmf(k - loc, low, high)`.

### Examples

```
>>> from scipy.stats import randint
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> low, high = 7, 31
>>> mean, var, skew, kurt = randint.stats(low, high, moments='mvsk')
```

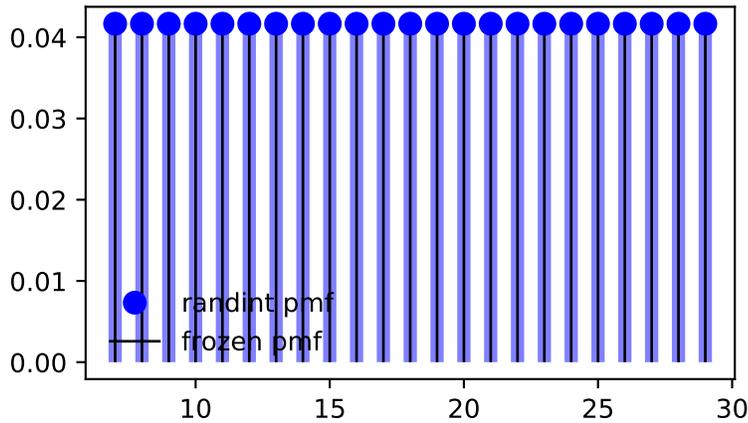
Display the probability mass function (pmf):

```
>>> x = np.arange(randint.ppf(0.01, low, high),
...               randint.ppf(0.99, low, high))
>>> ax.plot(x, randint.pmf(x, low, high), 'bo', ms=8, label='randint pmf')
>>> ax.vlines(x, 0, randint.pmf(x, low, high), colors='b', lw=5, alpha=0.5)
```

Alternatively, the distribution object can be called (as a function) to fix the shape and location. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pmf:

```
>>> rv = randint(low, high)
>>> ax.vlines(x, 0, rv.pmf(x), colors='k', linestyle='-', lw=1,
...          label='frozen pmf')
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



Check accuracy of cdf and ppf:

```
>>> prob = randint.cdf(x, low, high)
>>> np.allclose(x, randint.ppf(prob, low, high))
True
```

Generate random numbers:

```
>>> r = randint.rvs(low, high, size=1000)
```

### Methods

<code>rvs(low, high, loc=0, size=1, random_state=None)</code>	Random variates.
<code>pmf(k, low, high, loc=0)</code>	Probability mass function.
<code>logpmf(k, low, high, loc=0)</code>	Log of the probability mass function.
<code>cdf(k, low, high, loc=0)</code>	Cumulative distribution function.
<code>logcdf(k, low, high, loc=0)</code>	Log of the cumulative distribution function.
<code>sf(k, low, high, loc=0)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(k, low, high, loc=0)</code>	Log of the survival function.
<code>ppf(q, low, high, loc=0)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, low, high, loc=0)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>stats(low, high, loc=0, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(low, high, loc=0)</code>	(Differential) entropy of the RV.
<code>expect(func, args=(low, high), loc=0, lb=None, ub=None, conditional=False)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(low, high, loc=0)</code>	Median of the distribution.
<code>mean(low, high, loc=0)</code>	Mean of the distribution.
<code>var(low, high, loc=0)</code>	Variance of the distribution.
<code>std(low, high, loc=0)</code>	Standard deviation of the distribution.
<code>interval(alpha, low, high, loc=0)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.skellam` = <`scipy.stats_discrete_distns.skellam_gen` object>

A Skellam discrete random variable.

As an instance of the `rv_discrete` class, `skellam` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

Probability distribution of the difference of two correlated or uncorrelated Poisson random variables.

Let  $k_1$  and  $k_2$  be two Poisson-distributed r.v. with expected values  $\lambda_1$  and  $\lambda_2$ . Then,  $k_1 - k_2$  follows a Skellam distribution with parameters  $\mu_1 = \lambda_1 - \rho \cdot \sqrt{\lambda_1 \lambda_2}$  and  $\mu_2 = \lambda_2 - \rho \cdot \sqrt{\lambda_1 \lambda_2}$ , where  $\rho$  is the correlation coefficient between  $k_1$  and  $k_2$ . If the two Poisson-distributed r.v. are independent then  $\rho = 0$ .

Parameters  $\mu_1$  and  $\mu_2$  must be strictly positive.

For details see: [http://en.wikipedia.org/wiki/Skellam\\_distribution](http://en.wikipedia.org/wiki/Skellam_distribution)

`skellam` takes  $\mu_1$  and  $\mu_2$  as shape parameters.

The probability mass function above is defined in the “standardized” form. To shift distribution use the `loc` parameter. Specifically, `skellam.pmf(k, mu1, mu2, loc)` is identically equivalent to `skellam.pmf(k - loc, mu1, mu2)`.

### Examples

```
>>> from scipy.stats import skellam
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> mu1, mu2 = 15, 8
>>> mean, var, skew, kurt = skellam.stats(mu1, mu2, moments='mvsk')
```

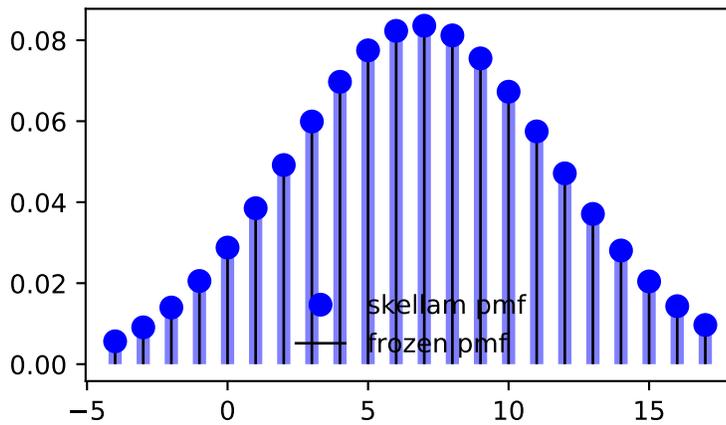
Display the probability mass function (pmf):

```
>>> x = np.arange(skellam.ppf(0.01, mu1, mu2),
...               skellam.ppf(0.99, mu1, mu2))
>>> ax.plot(x, skellam.pmf(x, mu1, mu2), 'bo', ms=8, label='skellam pmf')
>>> ax.vlines(x, 0, skellam.pmf(x, mu1, mu2), colors='b', lw=5, alpha=0.5)
```

Alternatively, the distribution object can be called (as a function) to fix the shape and location. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pmf:

```
>>> rv = skellam(mu1, mu2)
>>> ax.vlines(x, 0, rv.pmf(x), colors='k', linestyle='-', lw=1,
...          label='frozen pmf')
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



Check accuracy of cdf and ppf:

```
>>> prob = skellam.cdf(x, mu1, mu2)
>>> np.allclose(x, skellam.ppf(prob, mu1, mu2))
True
```

Generate random numbers:

```
>>> r = skellam.rvs(mu1, mu2, size=1000)
```

### Methods

<code>rvs(mu1, mu2, loc=0, size=1, random_state=None)</code>	Random variates.
<code>pmf(k, mu1, mu2, loc=0)</code>	Probability mass function.
<code>logpmf(k, mu1, mu2, loc=0)</code>	Log of the probability mass function.
<code>cdf(k, mu1, mu2, loc=0)</code>	Cumulative distribution function.
<code>logcdf(k, mu1, mu2, loc=0)</code>	Log of the cumulative distribution function.
<code>sf(k, mu1, mu2, loc=0)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(k, mu1, mu2, loc=0)</code>	Log of the survival function.
<code>ppf(q, mu1, mu2, loc=0)</code>	Percent point function (inverse of <i>cdf</i> — percentiles).
<code>isf(q, mu1, mu2, loc=0)</code>	Inverse survival function (inverse of <i>sf</i> ).
<code>stats(mu1, mu2, loc=0, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(mu1, mu2, loc=0)</code>	(Differential) entropy of the RV.
<code>expect(func, args=(mu1, mu2), loc=0, lb=None, ub=None, conditional=False)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(mu1, mu2, loc=0)</code>	Median of the distribution.
<code>mean(mu1, mu2, loc=0)</code>	Mean of the distribution.
<code>var(mu1, mu2, loc=0)</code>	Variance of the distribution.
<code>std(mu1, mu2, loc=0)</code>	Standard deviation of the distribution.
<code>interval(alpha, mu1, mu2, loc=0)</code>	Endpoints of the range that contains alpha percent of the distribution

`scipy.stats.zipf` = <scipy.stats.\_discrete\_distns.zipf\_gen object>

A Zipf discrete random variable.

As an instance of the `rv_discrete` class, `zipf` object inherits from it a collection of generic methods (see below for the full list), and completes them with details specific for this particular distribution.

### Notes

The probability mass function for `zipf` is:

```
zipf.pmf(k, a) = 1/(zeta(a) * k**a)
```

for  $k \geq 1$ .

`zipf` takes `a` as shape parameter.

The probability mass function above is defined in the “standardized” form. To shift distribution use the `loc` parameter. Specifically, `zipf.pmf(k, a, loc)` is identically equivalent to `zipf.pmf(k - loc, a)`.

### Examples

```
>>> from scipy.stats import zipf
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots(1, 1)
```

Calculate a few first moments:

```
>>> a = 6.5
>>> mean, var, skew, kurt = zipf.stats(a, moments='mvsk')
```

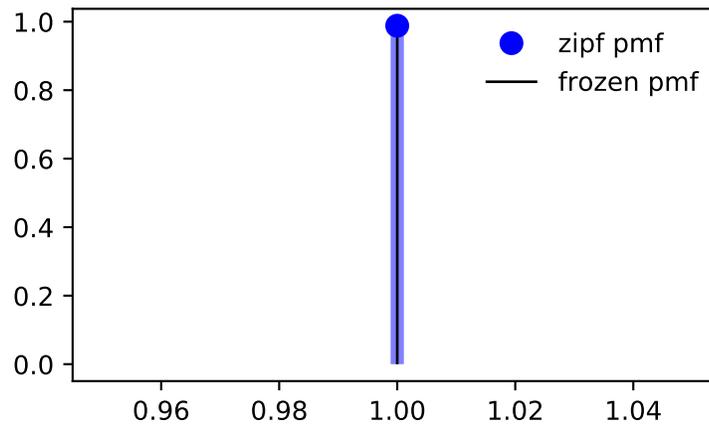
Display the probability mass function (pmf):

```
>>> x = np.arange(zipf.ppf(0.01, a),
...               zipf.ppf(0.99, a))
>>> ax.plot(x, zipf.pmf(x, a), 'bo', ms=8, label='zipf pmf')
>>> ax.vlines(x, 0, zipf.pmf(x, a), colors='b', lw=5, alpha=0.5)
```

Alternatively, the distribution object can be called (as a function) to fix the shape and location. This returns a “frozen” RV object holding the given parameters fixed.

Freeze the distribution and display the frozen pmf:

```
>>> rv = zipf(a)
>>> ax.vlines(x, 0, rv.pmf(x), colors='k', linestyle='-', lw=1,
...          label='frozen pmf')
>>> ax.legend(loc='best', frameon=False)
>>> plt.show()
```



Check accuracy of cdf and ppf:

```
>>> prob = zipf.cdf(x, a)
>>> np.allclose(x, zipf.ppf(prob, a))
True
```

Generate random numbers:

```
>>> r = zipf.rvs(a, size=1000)
```

### Methods

<code>rvs(a, loc=0, size=1, random_state=None)</code>	Random variates.
<code>pmf(k, a, loc=0)</code>	Probability mass function.
<code>logpmf(k, a, loc=0)</code>	Log of the probability mass function.
<code>cdf(k, a, loc=0)</code>	Cumulative distribution function.
<code>logcdf(k, a, loc=0)</code>	Log of the cumulative distribution function.
<code>sf(k, a, loc=0)</code>	Survival function (also defined as $1 - \text{cdf}$ , but <i>sf</i> is sometimes more accurate).
<code>logsf(k, a, loc=0)</code>	Log of the survival function.
<code>ppf(q, a, loc=0)</code>	Percent point function (inverse of <code>cdf</code> — percentiles).
<code>isf(q, a, loc=0)</code>	Inverse survival function (inverse of <code>sf</code> ).
<code>stats(a, loc=0, moments='mv')</code>	Mean('m'), variance('v'), skew('s'), and/or kurtosis('k').
<code>entropy(a, loc=0)</code>	(Differential) entropy of the RV.
<code>expect(func, args=(a,), loc=0, lb=None, ub=None, conditional=False)</code>	Expected value of a function (of one argument) with respect to the distribution.
<code>median(a, loc=0)</code>	Median of the distribution.
<code>mean(a, loc=0)</code>	Mean of the distribution.
<code>var(a, loc=0)</code>	Variance of the distribution.
<code>std(a, loc=0)</code>	Standard deviation of the distribution.
<code>interval(alpha, a, loc=0)</code>	Endpoints of the range that contains alpha percent of the distribution

## 5.27.4 Statistical functions

Several of these functions have a similar version in `scipy.stats.mstats` which work for masked arrays.

<code>describe(a[, axis, ddof, bias, nan_policy])</code>	Compute several descriptive statistics of the passed array.
<code>gmean(a[, axis, dtype])</code>	Compute the geometric mean along the specified axis.
<code>hmean(a[, axis, dtype])</code>	Calculate the harmonic mean along the specified axis.
<code>kurtosis(a[, axis, fisher, bias, nan_policy])</code>	Compute the kurtosis (Fisher or Pearson) of a dataset.
<code>kurtosistest(a[, axis, nan_policy])</code>	Test whether a dataset has normal kurtosis.
<code>mode(a[, axis, nan_policy])</code>	Return an array of the modal (most common) value in the passed array.
<code>moment(a[, moment, axis, nan_policy])</code>	Calculate the nth moment about the mean for a sample.
<code>normaltest(a[, axis, nan_policy])</code>	Test whether a sample differs from a normal distribution.
<code>skew(a[, axis, bias, nan_policy])</code>	Compute the skewness of a data set.
<code>skewtest(a[, axis, nan_policy])</code>	Test whether the skew is different from the normal distribution.
<code>kstat(data[, n])</code>	Return the nth k-statistic ( $1 \leq n \leq 4$ so far).
<code>kstatvar(data[, n])</code>	Returns an unbiased estimator of the variance of the k-statistic.
<code>tmean(a[, limits, inclusive, axis])</code>	Compute the trimmed mean.
<code>tvar(a[, limits, inclusive, axis, ddof])</code>	Compute the trimmed variance.
<code>tmin(a[, lowerlimit, axis, inclusive, ...])</code>	Compute the trimmed minimum.
<code>tmax(a[, upperlimit, axis, inclusive, ...])</code>	Compute the trimmed maximum.
<code>tstd(a[, limits, inclusive, axis, ddof])</code>	Compute the trimmed sample standard deviation.
<code>tsem(a[, limits, inclusive, axis, ddof])</code>	Compute the trimmed standard error of the mean.
<code>variation(a[, axis, nan_policy])</code>	Compute the coefficient of variation, the ratio of the biased standard deviation to the mean.
<code>find_repeats(arr)</code>	Find repeats and repeat counts.
<code>trim_mean(a, proportiontocut[, axis])</code>	Return mean of array after trimming distribution from both tails.

`scipy.stats.describe(a, axis=0, ddof=1, bias=True, nan_policy='propagate')`

Compute several descriptive statistics of the passed array.

**Parameters** **a** : array\_like

Input data.

**axis** : int or None, optional

Axis along which statistics are calculated. Default is 0. If None, compute over the whole array *a*.

**ddof** : int, optional

Delta degrees of freedom (only for variance). Default is 1.

**bias** : bool, optional

If False, then the skewness and kurtosis calculations are corrected for statistical bias.

**nan\_policy** : { 'propagate', 'raise', 'omit' }, optional

Defines how to handle when input contains nan. 'propagate' returns nan, 'raise' throws an error, 'omit' performs the calculations ignoring nan values. Default is 'propagate'.

**Returns**

**nobs** : int or ndarray of ints

Number of observations (length of data along *axis*). When 'omit' is chosen as *nan\_policy*, each column is counted separately.

**minmax**: tuple of ndarrays or floats

Minimum and maximum value of data array.

- mean** : ndarray or float  
Arithmetic mean of data along axis.
- variance** : ndarray or float  
Unbiased variance of the data along axis, denominator is number of observations minus one.
- skewness** : ndarray or float  
Skewness, based on moment calculations with denominator equal to the number of observations, i.e. no degrees of freedom correction.
- kurtosis** : ndarray or float  
Kurtosis (Fisher). The kurtosis is normalized so that it is zero for the normal distribution. No degrees of freedom are used.

**See also:**

*skew, kurtosis*

**Examples**

```
>>> from scipy import stats
>>> a = np.arange(10)
>>> stats.describe(a)
DescribeResult(nobs=10, minmax=(0, 9), mean=4.5, variance=9.1666666666666661,
              skewness=0.0, kurtosis=-1.2242424242424244)
>>> b = [[1, 2], [3, 4]]
>>> stats.describe(b)
DescribeResult(nobs=2, minmax=(array([1, 2]), array([3, 4])),
              mean=array([ 2., 3.]), variance=array([ 2., 2.]),
              skewness=array([ 0., 0.]), kurtosis=array([-2., -2.]))
```

`scipy.stats.gmean(a, axis=0, dtype=None)`

Compute the geometric mean along the specified axis.

Return the geometric average of the array elements. That is: n-th root of (x1 \* x2 \* ... \* xn)

- Parameters**

  - a** : array\_like  
Input array or object that can be converted to an array.
  - axis** : int or None, optional  
Axis along which the geometric mean is computed. Default is 0. If None, compute over the whole array *a*.
  - dtype** : dtype, optional  
Type of the returned array and of the accumulator in which the elements are summed. If dtype is not specified, it defaults to the dtype of *a*, unless *a* has an integer dtype with a precision less than that of the default platform integer. In that case, the default platform integer is used.

- Returns**

  - gmean** : ndarray  
see dtype parameter above

**See also:**

- numpy.mean* Arithmetic average
- numpy.average*  
Weighted average
- hmean** Harmonic mean

**Notes**

The geometric average is computed over a single dimension of the input array, axis=0 by default, or all values in the array if axis=None. float64 intermediate and return values are used for integer inputs.

Use masked arrays to ignore any non-finite values in the input or that arise in the calculations such as Not a Number and infinity because masked arrays automatically mask any non-finite values.

### Examples

```
>>> from scipy.stats import gmean
>>> gmean([1, 4])
2.0
>>> gmean([1, 2, 3, 4, 5, 6, 7])
3.3800151591412964
```

`scipy.stats.hmean(a, axis=0, dtype=None)`

Calculate the harmonic mean along the specified axis.

That is:  $n / (1/x_1 + 1/x_2 + \dots + 1/x_n)$

**Parameters**    **a** : array\_like

Input array, masked array or object that can be converted to an array.

**axis** : int or None, optional

Axis along which the harmonic mean is computed. Default is 0. If None, compute over the whole array *a*.

**dtype** : dtype, optional

Type of the returned array and of the accumulator in which the elements are summed. If *dtype* is not specified, it defaults to the dtype of *a*, unless *a* has an integer *dtype* with a precision less than that of the default platform integer. In that case, the default platform integer is used.

**Returns**

**hmean** : ndarray

see *dtype* parameter above

See also:

`numpy.mean` Arithmetic average

`numpy.average`

Weighted average

`gmean`

Geometric mean

### Notes

The harmonic mean is computed over a single dimension of the input array, `axis=0` by default, or all values in the array if `axis=None`. float64 intermediate and return values are used for integer inputs.

Use masked arrays to ignore any non-finite values in the input or that arise in the calculations such as Not a Number and infinity.

### Examples

```
>>> from scipy.stats import hmean
>>> hmean([1, 4])
1.6000000000000001
>>> hmean([1, 2, 3, 4, 5, 6, 7])
2.6997245179063363
```

`scipy.stats.kurtosis(a, axis=0, fisher=True, bias=True, nan_policy='propagate')`

Compute the kurtosis (Fisher or Pearson) of a dataset.

Kurtosis is the fourth central moment divided by the square of the variance. If Fisher's definition is used, then 3.0 is subtracted from the result to give 0.0 for a normal distribution.

If `bias` is False then the kurtosis is calculated using *k* statistics to eliminate bias coming from biased moment estimators

Use `kurtosistest` to see if result is close enough to normal.

**Parameters**

- a** : array  
data for which the kurtosis is calculated
- axis** : int or None, optional  
Axis along which the kurtosis is calculated. Default is 0. If None, compute over the whole array *a*.
- fisher** : bool, optional  
If True, Fisher's definition is used (normal ==> 0.0). If False, Pearson's definition is used (normal ==> 3.0).
- bias** : bool, optional  
If False, then the calculations are corrected for statistical bias.
- nan\_policy** : {'propagate', 'raise', 'omit'}, optional  
Defines how to handle when input contains nan. 'propagate' returns nan, 'raise' throws an error, 'omit' performs the calculations ignoring nan values. Default is 'propagate'.

**Returns**

- kurtosis** : array  
The kurtosis of values along an axis. If all values are equal, return -3 for Fisher's definition and 0 for Pearson's definition.

**References**

[R660]

**Examples**

```
>>> from scipy.stats import kurtosis
>>> kurtosis([1, 2, 3, 4, 5])
-1.3
```

`scipy.stats.kurtosistest` (*a*, *axis*=0, *nan\_policy*='propagate')

Test whether a dataset has normal kurtosis.

This function tests the null hypothesis that the kurtosis of the population from which the sample was drawn is that of the normal distribution:  $kurtosis = 3(n-1)/(n+1)$ .

**Parameters**

- a** : array  
array of the sample data
- axis** : int or None, optional  
Axis along which to compute test. Default is 0. If None, compute over the whole array *a*.
- nan\_policy** : {'propagate', 'raise', 'omit'}, optional  
Defines how to handle when input contains nan. 'propagate' returns nan, 'raise' throws an error, 'omit' performs the calculations ignoring nan values. Default is 'propagate'.

**Returns**

- statistic** : float  
The computed z-score for this test.
- pvalue** : float  
The 2-sided p-value for the hypothesis test

**Notes**

Valid only for  $n > 20$ . The Z-score is set to 0 for bad entries. This function uses the method described in [R661].

**References**

[R661]

**Examples**

```
>>> from scipy.stats import kurtosistest
>>> kurtosistest(list(range(20)))
KurtosistestResult(statistic=-1.7058104152122062, pvalue=0.088043383325283484)
```

```
>>> np.random.seed(28041990)
>>> s = np.random.normal(0, 1, 1000)
>>> kurtosistest(s)
KurtosistestResult(statistic=1.2317590987707365, pvalue=0.21803908613450895)
```

`scipy.stats.mode` (*a*, *axis=0*, *nan\_policy='propagate'*)

Return an array of the modal (most common) value in the passed array.

If there is more than one such value, only the smallest is returned. The bin-count for the modal bins is also returned.

**Parameters**

- a** : array\_like  
n-dimensional array of which to find mode(s).
- axis** : int or None, optional  
Axis along which to operate. Default is 0. If None, compute over the whole array *a*.
- nan\_policy** : {'propagate', 'raise', 'omit'}, optional  
Defines how to handle when input contains nan. 'propagate' returns nan, 'raise' throws an error, 'omit' performs the calculations ignoring nan values. Default is 'propagate'.

**Returns**

- mode** : ndarray  
Array of modal values.
- count** : ndarray  
Array of counts for each mode.

**Examples**

```
>>> a = np.array([[6, 8, 3, 0],
...              [3, 2, 1, 7],
...              [8, 1, 8, 4],
...              [5, 3, 0, 5],
...              [4, 7, 5, 9]])
>>> from scipy import stats
>>> stats.mode(a)
(array([[3, 1, 0, 0]]), array([[1, 1, 1, 1]]))
```

To get mode of whole array, specify *axis=None*:

```
>>> stats.mode(a, axis=None)
(array([3]), array([3]))
```

`scipy.stats.moment` (*a*, *moment=1*, *axis=0*, *nan\_policy='propagate'*)

Calculate the *n*th moment about the mean for a sample.

A moment is a specific quantitative measure of the shape of a set of points. It is often used to calculate coefficients of skewness and kurtosis due to its close relationship with them.

**Parameters**

- a** : array\_like  
data
- moment** : int or array\_like of ints, optional  
order of central moment that is returned. Default is 1.
- axis** : int or None, optional

Axis along which the central moment is computed. Default is 0. If None, compute over the whole array *a*.

**nan\_policy** : { 'propagate', 'raise', 'omit' }, optional  
 Defines how to handle when input contains nan. 'propagate' returns nan, 'raise' throws an error, 'omit' performs the calculations ignoring nan values. Default is 'propagate'.

**Returns** **n-th central moment** : ndarray or float  
 The appropriate moment along the given axis or over all values if axis is None. The denominator for the moment calculation is the number of observations, no degrees of freedom correction is done.

**See also:**

*kurtosis*, *skew*, *describe*

**Notes**

The k-th central moment of a data sample is:

$$m_k = \frac{1}{n} \sum_{i=1}^n (x_i - \bar{x})^k$$

Where n is the number of samples and x-bar is the mean. This function uses exponentiation by squares [R670] for efficiency.

**References**

[R670]

**Examples**

```
>>> from scipy.stats import moment
>>> moment([1, 2, 3, 4, 5], moment=1)
0.0
>>> moment([1, 2, 3, 4, 5], moment=2)
2.0
```

`scipy.stats.normaltest` (*a*, *axis*=0, *nan\_policy*='propagate')

Test whether a sample differs from a normal distribution.

This function tests the null hypothesis that a sample comes from a normal distribution. It is based on D'Agostino and Pearson's [R675], [R676] test that combines skew and kurtosis to produce an omnibus test of normality.

**Parameters** **a** : array\_like  
 The array containing the sample to be tested.

**axis** : int or None, optional  
 Axis along which to compute test. Default is 0. If None, compute over the whole array *a*.

**nan\_policy** : { 'propagate', 'raise', 'omit' }, optional  
 Defines how to handle when input contains nan. 'propagate' returns nan, 'raise' throws an error, 'omit' performs the calculations ignoring nan values. Default is 'propagate'.

**Returns** **statistic** : float or array  
 $s^2 + k^2$ , where *s* is the z-score returned by *skewtest* and *k* is the z-score returned by *kurtosistest*.

**pvalue** : float or array  
 A 2-sided chi squared probability for the hypothesis test.

**References**

[R675], [R676]

**Examples**

```

>>> from scipy import stats
>>> pts = 1000
>>> np.random.seed(28041990)
>>> a = np.random.normal(0, 1, size=pts)
>>> b = np.random.normal(2, 1, size=pts)
>>> x = np.concatenate((a, b))
>>> k2, p = stats.normaltest(x)
>>> alpha = 1e-3
>>> print("p = {:g}".format(p))
p = 3.27207e-11
>>> if p < alpha: # null hypothesis: x comes from a normal distribution
...     print("The null hypothesis can be rejected")
... else:
...     print("The null hypothesis cannot be rejected")
The null hypothesis can be rejected

```

`scipy.stats.skew` (*a*, *axis*=0, *bias*=True, *nan\_policy*='propagate')

Compute the skewness of a data set.

For normally distributed data, the skewness should be about 0. For unimodal continuous distributions, a skewness value > 0 means that there is more weight in the right tail of the distribution. The function `skewtest` can be used to determine if the skewness value is close enough to 0, statistically speaking.

**Parameters** **a** : ndarray

data

**axis** : int or None, optional

Axis along which skewness is calculated. Default is 0. If None, compute over the whole array *a*.

**bias** : bool, optional

If False, then the calculations are corrected for statistical bias.

**nan\_policy** : {'propagate', 'raise', 'omit'}, optional

Defines how to handle when input contains nan. 'propagate' returns nan, 'raise' throws an error, 'omit' performs the calculations ignoring nan values. Default is 'propagate'.

**Returns**

**skewness** : ndarray

The skewness of values along an axis, returning 0 where all values are equal.

**References**

[R696]

**Examples**

```

>>> from scipy.stats import skew
>>> skew([1, 2, 3, 4, 5])
0.0
>>> skew([2, 8, 0, 4, 1, 9, 9, 0])
0.2650554122698573

```

`scipy.stats.skewtest` (*a*, *axis*=0, *nan\_policy*='propagate')

Test whether the skew is different from the normal distribution.

This function tests the null hypothesis that the skewness of the population that the sample was drawn from is the same as that of a corresponding normal distribution.

**Parameters**

- a** : array  
The data to be tested
- axis** : int or None, optional  
Axis along which statistics are calculated. Default is 0. If None, compute over the whole array *a*.
- nan\_policy** : {'propagate', 'raise', 'omit'}, optional  
Defines how to handle when input contains nan. 'propagate' returns nan, 'raise' throws an error, 'omit' performs the calculations ignoring nan values. Default is 'propagate'.

**Returns**

- statistic** : float  
The computed z-score for this test.
- pvalue** : float  
a 2-sided p-value for the hypothesis test

**Notes**

The sample size must be at least 8.

**References**

[R698]

**Examples**

```
>>> from scipy.stats import skewtest
>>> skewtest([1, 2, 3, 4, 5, 6, 7, 8])
SkewtestResult(statistic=1.0108048609177787, pvalue=0.31210983614218968)
>>> skewtest([2, 8, 0, 4, 1, 9, 9, 0])
SkewtestResult(statistic=0.44626385374196975, pvalue=0.65540666312754592)
>>> skewtest([1, 2, 3, 4, 5, 6, 7, 8000])
SkewtestResult(statistic=3.5717735103604071, pvalue=0.00035457199058231331)
>>> skewtest([100, 100, 100, 100, 100, 100, 100, 101])
SkewtestResult(statistic=3.5717766638478072, pvalue=0.000354567720281634)
```

`scipy.stats.kstat` (*data*, *n=2*)  
Return the *n*th k-statistic (1<=*n*<=4 so far).

The *n*th k-statistic *k<sub>n</sub>* is the unique symmetric unbiased estimator of the *n*th cumulant *kappa<sub>n</sub>*.

**Parameters**

- data** : array\_like  
Input array. Note that n-D input gets flattened.
- n** : int, {1, 2, 3, 4}, optional  
Default is equal to 2.

**Returns**

- kstat** : float  
The *n*th k-statistic.

**See also:**

**kstatvar** Returns an unbiased estimator of the variance of the k-statistic.  
**moment** Returns the *n*-th central moment about the mean for a sample.

**Notes**

For a sample size *n*, the first few k-statistics are given by:

$$k_1 = \mu k_2 = \frac{n}{n-1} m_2 k_3 = \frac{n^2}{(n-1)(n-2)} m_3 k_4 = \frac{n^2[(n+1)m_4 - 3(n-1)m_2^2]}{(n-1)(n-2)(n-3)}$$

where  $\mu$  is the sample mean,  $m_2$  is the sample variance, and  $m_i$  is the *i*-th sample central moment.

## References

<http://mathworld.wolfram.com/k-Statistic.html>

<http://mathworld.wolfram.com/Cumulant.html>

## Examples

```
>>> from scipy import stats
>>> rndm = np.random.RandomState(1234)
```

As sample size increases, n-th moment and n-th k-statistic converge to the same number (although they aren't identical). In the case of the normal distribution, they converge to zero.

```
>>> for n in [2, 3, 4, 5, 6, 7]:
...     x = rndm.normal(size=10**n)
...     m, k = stats.moment(x, 3), stats.kstat(x, 3)
...     print("%.3g %.3g %.3g" % (m, k, m-k))
-0.631 -0.651 0.0194
0.0282 0.0283 -8.49e-05
-0.0454 -0.0454 1.36e-05
7.53e-05 7.53e-05 -2.26e-09
0.00166 0.00166 -4.99e-09
-2.88e-06 -2.88e-06 8.63e-13
```

`scipy.stats.kstatvar` (*data*, *n*=2)

Returns an unbiased estimator of the variance of the k-statistic.

See *kstat* for more details of the k-statistic.

**Parameters**

- data** : array\_like  
Input array. Note that n-D input gets flattened.
- n** : int, {1, 2}, optional  
Default is equal to 2.

**Returns**

- kstatvar** : float  
The nth k-statistic variance.

See also:

**kstat** Returns the n-th k-statistic.  
**moment** Returns the n-th central moment about the mean for a sample.

## Notes

The variances of the first few k-statistics are given by:

$$\text{var}(k_1) = \frac{\kappa^2}{n} \text{var}(k_2) = \frac{\kappa^4}{n} + \frac{2\kappa_2^2}{n-1} \text{var}(k_3) = \frac{\kappa^6}{n} + \frac{9\kappa_2\kappa_4}{n-1} + \frac{9\kappa_3^2}{n-1} + \frac{6n\kappa_2^3}{(n-1)(n-2)} \text{var}(k_4) = \frac{\kappa^8}{n} + \frac{16\kappa_2\kappa_6}{n-1} + \frac{48\kappa_3\kappa_5}{n-1}$$

`scipy.stats.tmean` (*a*, *limits*=None, *inclusive*=(True, True), *axis*=None)

Compute the trimmed mean.

This function finds the arithmetic mean of given values, ignoring values outside the given *limits*.

**Parameters**

- a** : array\_like  
Array of values.
- limits** : None or (lower limit, upper limit), optional  
Values in the input array less than the lower limit or greater than the upper limit will be ignored. When *limits* is None (default), then all values are used. Either of the limit values in the tuple can also be None representing a half-open interval.

**inclusive** : (bool, bool), optional  
 A tuple consisting of the (lower flag, upper flag). These flags determine whether values exactly equal to the lower or upper limits are included. The default value is (True, True).

**axis** : int or None, optional  
 Axis along which to compute test. Default is None.

**Returns** **tmean** : float

**See also:**

**trim\_mean** returns mean after trimming a proportion from both tails.

**Examples**

```
>>> from scipy import stats
>>> x = np.arange(20)
>>> stats.tmean(x)
9.5
>>> stats.tmean(x, (3,17))
10.0
```

`scipy.stats.tvar(a, limits=None, inclusive=(True, True), axis=0, ddof=1)`

Compute the trimmed variance.

This function computes the sample variance of an array of values, while ignoring values which are outside of given *limits*.

**Parameters** **a** : array\_like

Array of values.

**limits** : None or (lower limit, upper limit), optional

Values in the input array less than the lower limit or greater than the upper limit will be ignored. When *limits* is None, then all values are used. Either of the limit values in the tuple can also be None representing a half-open interval. The default value is None.

**inclusive** : (bool, bool), optional

A tuple consisting of the (lower flag, upper flag). These flags determine whether values exactly equal to the lower or upper limits are included. The default value is (True, True).

**axis** : int or None, optional

Axis along which to operate. Default is 0. If None, compute over the whole array *a*.

**ddof** : int, optional

Delta degrees of freedom. Default is 1.

**Returns** **tvar** : float

Trimmed variance.

**Notes**

*tvar* computes the unbiased sample variance, i.e. it uses a correction factor  $n / (n - 1)$ .

**Examples**

```
>>> from scipy import stats
>>> x = np.arange(20)
>>> stats.tvar(x)
35.0
>>> stats.tvar(x, (3,17))
20.0
```

`scipy.stats.tmin(a, lowerlimit=None, axis=0, inclusive=True, nan_policy='propagate')`

Compute the trimmed minimum.

This function finds the minimum value of an array *a* along the specified axis, but only considering values greater than a specified lower limit.

**Parameters**

- a** : array\_like  
array of values
- lowerlimit** : None or float, optional  
Values in the input array less than the given limit will be ignored. When lowerlimit is None, then all values are used. The default value is None.
- axis** : int or None, optional  
Axis along which to operate. Default is 0. If None, compute over the whole array *a*.
- inclusive** : {True, False}, optional  
This flag determines whether values exactly equal to the lower limit are included. The default value is True.
- nan\_policy** : {'propagate', 'raise', 'omit'}, optional  
Defines how to handle when input contains nan. 'propagate' returns nan, 'raise' throws an error, 'omit' performs the calculations ignoring nan values. Default is 'propagate'.

**Returns**

- tmin** : float, int or ndarray

#### Examples

```
>>> from scipy import stats
>>> x = np.arange(20)
>>> stats.tmin(x)
0
```

```
>>> stats.tmin(x, 13)
13
```

```
>>> stats.tmin(x, 13, inclusive=False)
14
```

`scipy.stats.tmax(a, upperlimit=None, axis=0, inclusive=True, nan_policy='propagate')`

Compute the trimmed maximum.

This function computes the maximum value of an array along a given axis, while ignoring values larger than a specified upper limit.

**Parameters**

- a** : array\_like  
array of values
- upperlimit** : None or float, optional  
Values in the input array greater than the given limit will be ignored. When upperlimit is None, then all values are used. The default value is None.
- axis** : int or None, optional  
Axis along which to operate. Default is 0. If None, compute over the whole array *a*.
- inclusive** : {True, False}, optional  
This flag determines whether values exactly equal to the upper limit are included. The default value is True.
- nan\_policy** : {'propagate', 'raise', 'omit'}, optional  
Defines how to handle when input contains nan. 'propagate' returns nan, 'raise' throws an error, 'omit' performs the calculations ignoring nan values. Default is 'propagate'.

**Returns** `tmax` : float, int or ndarray

### Examples

```
>>> from scipy import stats
>>> x = np.arange(20)
>>> stats.tmax(x)
19
```

```
>>> stats.tmax(x, 13)
13
```

```
>>> stats.tmax(x, 13, inclusive=False)
12
```

`scipy.stats.tstd(a, limits=None, inclusive=(True, True), axis=0, ddof=1)`

Compute the trimmed sample standard deviation.

This function finds the sample standard deviation of given values, ignoring values outside the given *limits*.

**Parameters** `a` : array\_like

array of values

**limits** : None or (lower limit, upper limit), optional

Values in the input array less than the lower limit or greater than the upper limit will be ignored. When *limits* is None, then all values are used. Either of the limit values in the tuple can also be None representing a half-open interval. The default value is None.

**inclusive** : (bool, bool), optional

A tuple consisting of the (lower flag, upper flag). These flags determine whether values exactly equal to the lower or upper limits are included. The default value is (True, True).

**axis** : int or None, optional

Axis along which to operate. Default is 0. If None, compute over the whole array *a*.

**ddof** : int, optional

Delta degrees of freedom. Default is 1.

**Returns** `tstd` : float

### Notes

*tstd* computes the unbiased sample standard deviation, i.e. it uses a correction factor  $n / (n - 1)$ .

### Examples

```
>>> from scipy import stats
>>> x = np.arange(20)
>>> stats.tstd(x)
5.9160797830996161
>>> stats.tstd(x, (3, 17))
4.4721359549995796
```

`scipy.stats.tsem(a, limits=None, inclusive=(True, True), axis=0, ddof=1)`

Compute the trimmed standard error of the mean.

This function finds the standard error of the mean for given values, ignoring values outside the given *limits*.

**Parameters** `a` : array\_like

array of values

**limits** : None or (lower limit, upper limit), optional  
 Values in the input array less than the lower limit or greater than the upper limit will be ignored. When limits is None, then all values are used. Either of the limit values in the tuple can also be None representing a half-open interval. The default value is None.

**inclusive** : (bool, bool), optional  
 A tuple consisting of the (lower flag, upper flag). These flags determine whether values exactly equal to the lower or upper limits are included. The default value is (True, True).

**axis** : int or None, optional  
 Axis along which to operate. Default is 0. If None, compute over the whole array *a*.

**ddof** : int, optional  
 Delta degrees of freedom. Default is 1.

**Returns** **tsem** : float

### Notes

*tsem* uses unbiased sample standard deviation, i.e. it uses a correction factor  $n / (n - 1)$ .

### Examples

```
>>> from scipy import stats
>>> x = np.arange(20)
>>> stats.tsem(x)
1.3228756555322954
>>> stats.tsem(x, (3, 17))
1.1547005383792515
```

`scipy.stats.variation` (*a*, *axis*=0, *nan\_policy*='propagate')

Compute the coefficient of variation, the ratio of the biased standard deviation to the mean.

**Parameters** **a** : array\_like  
 Input array.

**axis** : int or None, optional  
 Axis along which to calculate the coefficient of variation. Default is 0. If None, compute over the whole array *a*.

**nan\_policy** : {'propagate', 'raise', 'omit'}, optional  
 Defines how to handle when input contains nan. 'propagate' returns nan, 'raise' throws an error, 'omit' performs the calculations ignoring nan values. Default is 'propagate'.

**Returns** **variation** : ndarray  
 The calculated variation along the requested axis.

### References

[R709]

### Examples

```
>>> from scipy.stats import variation
>>> variation([1, 2, 3, 4, 5])
0.47140452079103173
```

`scipy.stats.find_repeats` (*arr*)

Find repeats and repeat counts.

**Parameters** **arr** : array\_like  
 Input array. This is cast to float64.



<code>cumfreq(a[, numbins, defaultreallimits, weights])</code>	Return a cumulative frequency histogram, using the histogram function.
<code>itemfreq(a)</code>	Return a 2-D array of item frequencies.
<code>percentileofscore(a, score[, kind])</code>	The percentile rank of a score relative to a list of scores.
<code>scoreatpercentile(a, per[, limit, ...])</code>	Calculate the score at a given percentile of the input sequence.
<code>relfreq(a[, numbins, defaultreallimits, weights])</code>	Return a relative frequency histogram, using the histogram function.

`scipy.stats.cumfreq(a, numbins=10, defaultreallimits=None, weights=None)`

Return a cumulative frequency histogram, using the histogram function.

A cumulative histogram is a mapping that counts the cumulative number of observations in all of the bins up to the specified bin.

**Parameters** **a** : array\_like

Input array.

**numbins** : int, optional

The number of bins to use for the histogram. Default is 10.

**defaultreallimits** : tuple (lower, upper), optional

The lower and upper values for the range of the histogram. If no value is given, a range slightly larger than the range of the values in *a* is used. Specifically  $(a.\text{min}() - s, a.\text{max}() + s)$ , where  $s = (1/2)(a.\text{max}() - a.\text{min}()) / (\text{numbins} - 1)$ .

**weights** : array\_like, optional

The weights for each value in *a*. Default is None, which gives each value a weight of 1.0

**Returns**

**cumcount** : ndarray

Binned values of cumulative frequency.

**lowerlimit** : float

Lower real limit

**binsize** : float

Width of each bin.

**extrapoints** : int

Extra points.

### Examples

```
>>> import matplotlib.pyplot as plt
>>> from scipy import stats
>>> x = [1, 4, 2, 1, 3, 1]
>>> res = stats.cumfreq(x, numbins=4, defaultreallimits=(1.5, 5))
>>> res.cumcount
array([ 1.,  2.,  3.,  3.])
>>> res.extrapoints
3
```

Create a normal distribution with 1000 random values

```
>>> rng = np.random.RandomState(seed=12345)
>>> samples = stats.norm.rvs(size=1000, random_state=rng)
```

Calculate cumulative frequencies

```
>>> res = stats.cumfreq(samples, numbins=25)
```

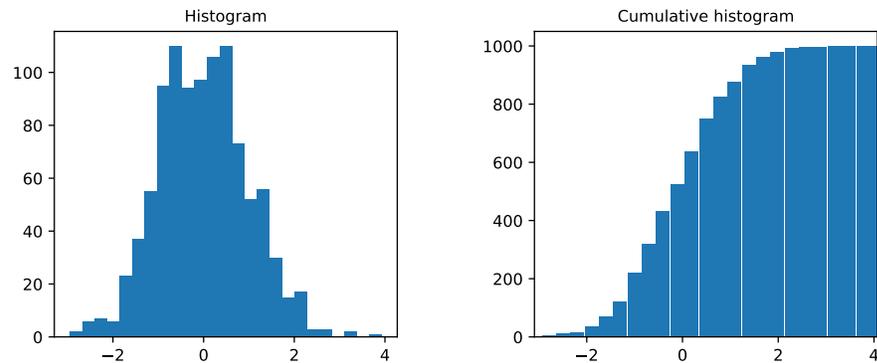
Calculate space of values for x

```
>>> x = res.lowerlimit + np.linspace(0, res.binsize*res.cumcount.size,
...
                                   res.cumcount.size)
```

Plot histogram and cumulative histogram

```
>>> fig = plt.figure(figsize=(10, 4))
>>> ax1 = fig.add_subplot(1, 2, 1)
>>> ax2 = fig.add_subplot(1, 2, 2)
>>> ax1.hist(samples, bins=25)
>>> ax1.set_title('Histogram')
>>> ax2.bar(x, res.cumcount, width=res.binsize)
>>> ax2.set_title('Cumulative histogram')
>>> ax2.set_xlim([x.min(), x.max()])
```

```
>>> plt.show()
```



`scipy.stats.itemfreq(a)`

Return a 2-D array of item frequencies.

**Parameters** `a`: (N,) array\_like

**Returns** `itemfreq`: (K, 2)<sup>Input array.</sup> ndarray

A 2-D frequency table. Column 1 contains sorted, unique values from `a`, column 2 contains their respective counts.

**Examples**

```
>>> from scipy import stats
>>> a = np.array([1, 1, 5, 0, 1, 2, 2, 0, 1, 4])
>>> stats.itemfreq(a)
array([[ 0.,  2.],
       [ 1.,  4.],
       [ 2.,  2.],
       [ 4.,  1.],
       [ 5.,  1.]])
>>> np.bincount(a)
array([2, 4, 2, 0, 1, 1])
```

```
>>> stats.itemfreq(a/10.)
array([[ 0. ,  2. ],
       [ 0.1,  4. ],
       [ 0.2,  2. ],
       [ 0.4,  1. ],
       [ 0.5,  1. ]])
```

`scipy.stats.percentileofscore` (*a*, *score*, *kind*='rank')

The percentile rank of a score relative to a list of scores.

A *percentileofscore* of, for example, 80% means that 80% of the scores in *a* are below the given score. In the case of gaps or ties, the exact definition depends on the optional keyword, *kind*.

**Parameters**    **a** : array\_like

Array of scores to which *score* is compared.

**score** : int or float

Score that is compared to the elements in *a*.

**kind** : {'rank', 'weak', 'strict', 'mean'}, optional

This optional parameter specifies the interpretation of the resulting score:

- “**rank**”: *Average percentage ranking of score. In case of multiple matches, average the percentage rankings of all matching scores.*
- “**weak**”: *This kind corresponds to the definition of a cumulative*

*distribution function. A percentileofscore of 80% means that 80% of values are less than or equal to the provided score.*

- “**strict**”: *Similar to “weak”, except that only values that are*

*strictly less than the given score are counted.*

- “**mean**”: *The average of the “weak” and “strict” scores, often used in*

*testing. See*

[http://en.wikipedia.org/wiki/Percentile\\_rank](http://en.wikipedia.org/wiki/Percentile_rank)

**Returns**        **pcos** : float

Percentile-position of score (0-100) relative to *a*.

**See also:**

`numpy.percentile`

**Examples**

Three-quarters of the given values lie below a given score:

```
>>> from scipy import stats
>>> stats.percentileofscore([1, 2, 3, 4], 3)
75.0
```

With multiple matches, note how the scores of the two matches, 0.6 and 0.8 respectively, are averaged:

```
>>> stats.percentileofscore([1, 2, 3, 3, 4], 3)
70.0
```

Only 2/5 values are strictly less than 3:

```
>>> stats.percentileofscore([1, 2, 3, 3, 4], 3, kind='strict')
40.0
```

But 4/5 values are less than or equal to 3:

```
>>> stats.percentileofscore([1, 2, 3, 3, 4], 3, kind='weak')
80.0
```

The average between the weak and the strict scores is

```
>>> stats.percentileofscore([1, 2, 3, 3, 4], 3, kind='mean')
60.0
```

`scipy.stats.scoreatpercentile` (*a*, *per*, *limit*=(), *interpolation\_method*='fraction', *axis*=None)  
 Calculate the score at a given percentile of the input sequence.

For example, the score at *per*=50 is the median. If the desired quantile lies between two data points, we interpolate between them, according to the value of *interpolation*. If the parameter *limit* is provided, it should be a tuple (lower, upper) of two values.

**Parameters**

- a** : array\_like  
A 1-D array of values from which to extract score.
- per** : array\_like  
Percentile(s) at which to extract score. Values should be in range [0,100].
- limit** : tuple, optional  
Tuple of two scalars, the lower and upper limits within which to compute the percentile. Values of *a* outside this (closed) interval will be ignored.
- interpolation\_method** : {'fraction', 'lower', 'higher'}, optional  
This optional parameter specifies the interpolation method to use, when the desired quantile lies between two data points *i* and *j*
  - fraction:  $i + (j - i) * \text{fraction}$  where *fraction* is the fractional part of the index surrounded by *i* and *j*.
  - lower: *i*.
  - higher: *j*.
- axis** : int, optional  
Axis along which the percentiles are computed. Default is None. If None, compute over the whole array *a*.

**Returns**

- score** : float or ndarray  
Score at percentile(s).

**See also:**

`percentileofscore`, `numpy.percentile`

**Notes**

This function will become obsolete in the future. For Numpy 1.9 and higher, `numpy.percentile` provides all the functionality that `scoreatpercentile` provides. And it's significantly faster. Therefore it's recommended to use `numpy.percentile` for users that have numpy >= 1.9.

**Examples**

```
>>> from scipy import stats
>>> a = np.arange(100)
>>> stats.scoreatpercentile(a, 50)
49.5
```

`scipy.stats.relfreq` (*a*, *numbins*=10, *defaultreallimits*=None, *weights*=None)  
 Return a relative frequency histogram, using the histogram function.

A relative frequency histogram is a mapping of the number of observations in each of the bins relative to the total of observations.

**Parameters**

- a** : array\_like  
Input array.
- numbins** : int, optional  
The number of bins to use for the histogram. Default is 10.
- defaultreallimits** : tuple (lower, upper), optional  
The lower and upper values for the range of the histogram. If no value is given, a range slightly larger than the range of the values in *a* is used. Specifically  $(a.\text{min}() - s, a.\text{max}() + s)$ , where  $s = (1/2)(a.\text{max}() - a.\text{min}()) / (\text{numbins} - 1)$ .
- weights** : array\_like, optional  
The weights for each value in *a*. Default is None, which gives each value a weight of 1.0

**Returns**

- frequency** : ndarray  
Binned values of relative frequency.
- lowerlimit** : float  
Lower real limit
- binsize** : float  
Width of each bin.
- extrapoints** : int  
Extra points.

### Examples

```
>>> import matplotlib.pyplot as plt
>>> from scipy import stats
>>> a = np.array([2, 4, 1, 2, 3, 2])
>>> res = stats.relfreq(a, numbins=4)
>>> res.frequency
array([ 0.16666667, 0.5          , 0.16666667, 0.16666667])
>>> np.sum(res.frequency) # relative frequencies should add up to 1
1.0
```

Create a normal distribution with 1000 random values

```
>>> rng = np.random.RandomState(seed=12345)
>>> samples = stats.norm.rvs(size=1000, random_state=rng)
```

Calculate relative frequencies

```
>>> res = stats.relfreq(samples, numbins=25)
```

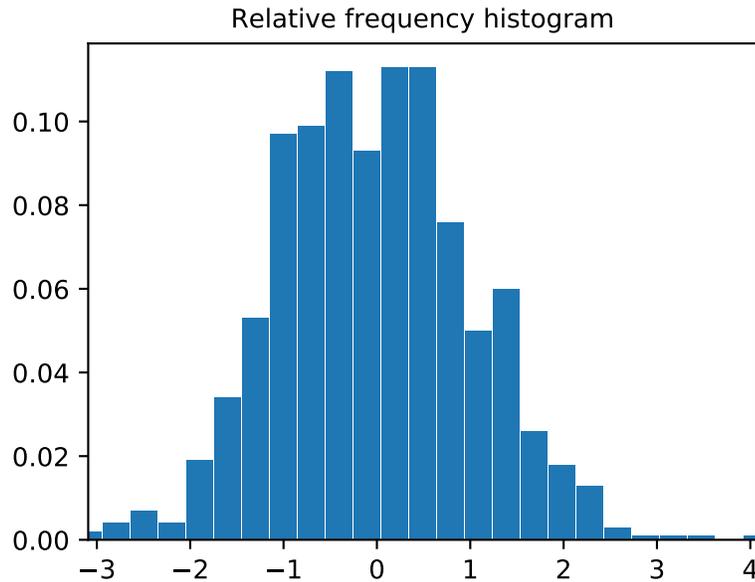
Calculate space of values for x

```
>>> x = res.lowerlimit + np.linspace(0, res.binsize*res.frequency.size,
...                                 res.frequency.size)
```

Plot relative frequency histogram

```
>>> fig = plt.figure(figsize=(5, 4))
>>> ax = fig.add_subplot(1, 1, 1)
>>> ax.bar(x, res.frequency, width=res.binsize)
>>> ax.set_title('Relative frequency histogram')
>>> ax.set_xlim([x.min(), x.max()])
```

```
>>> plt.show()
```



<code>binned_statistic(x, values[, statistic, ...])</code>	Compute a binned statistic for one or more sets of data.
<code>binned_statistic_2d(x, y, values[, ...])</code>	Compute a bidimensional binned statistic for one or more sets of data.
<code>binned_statistic_dd(sample, values[, ...])</code>	Compute a multidimensional binned statistic for a set of data.

`scipy.stats.binned_statistic(x, values, statistic='mean', bins=10, range=None)`

Compute a binned statistic for one or more sets of data.

This is a generalization of a histogram function. A histogram divides the space into bins, and returns the count of the number of points in each bin. This function allows the computation of the sum, mean, median, or other statistic of the values (or set of values) within each bin.

**Parameters** `x` : (N,) array\_like

A sequence of values to be binned.

**values** : (N,) array\_like or list of (N,) array\_like

The data on which the statistic will be computed. This must be the same shape as `x`, or a set of sequences - each the same shape as `x`. If `values` is a set of sequences, the statistic will be computed on each independently.

**statistic** : string or callable, optional

The statistic to compute (default is 'mean'). The following statistics are available:

- 'mean' : compute the mean of values for points within each bin. Empty bins will be represented by NaN.
- 'median' : compute the median of values for points within each bin. Empty bins will be represented by NaN.
- 'count' : compute the count of points within each bin. This is identical to an unweighted histogram. `values` array is not referenced.
- 'sum' : compute the sum of values for points within each bin. This is identical to a weighted histogram.

- `'min'` : compute the minimum of values for points within each bin. Empty bins will be represented by NaN.
- `'max'` : compute the maximum of values for point within each bin. Empty bins will be represented by NaN.
- `function` : a user-defined function which takes a 1-D array of values, and outputs a single numerical statistic. This function will be called on the values in each bin. Empty bins will be represented by `function([])`, or NaN if this returns an error.

**bins** : int or sequence of scalars, optional

If *bins* is an int, it defines the number of equal-width bins in the given range (10 by default). If *bins* is a sequence, it defines the bin edges, including the rightmost edge, allowing for non-uniform bin widths. Values in *x* that are smaller than lowest bin edge are assigned to bin number 0, values beyond the highest bin are assigned to `bins[-1]`. If the bin edges are specified, the number of bins will be,  $(nx = \text{len}(\text{bins})-1)$ .

**range** : (float, float) or [(float, float)], optional

The lower and upper range of the bins. If not provided, range is simply  $(x.\text{min}(), x.\text{max}())$ . Values outside the range are ignored.

**Returns**

**statistic** : array  
The values of the selected statistic in each bin.

**bin\_edges** : array of dtype float

Return the bin edges (`length(statistic)+1`).

**binnumber**: 1-D ndarray of ints

Indices of the bins (corresponding to *bin\_edges*) in which each value of *x* belongs. Same length as *values*. A binnumber of *i* means the corresponding value is between `(bin_edges[i-1], bin_edges[i])`.

**See also:**

`numpy.digitize`, `numpy.histogram`, `binned_statistic_2d`, `binned_statistic_dd`

**Notes**

All but the last (righthand-most) bin is half-open. In other words, if *bins* is `[1, 2, 3, 4]`, then the first bin is `[1, 2)` (including 1, but excluding 2) and the second `[2, 3)`. The last bin, however, is `[3, 4]`, which includes 4.

New in version 0.11.0.

**Examples**

```
>>> from scipy import stats
>>> import matplotlib.pyplot as plt
```

First some basic examples:

Create two evenly spaced bins in the range of the given sample, and sum the corresponding values in each of those bins:

```
>>> values = [1.0, 1.0, 2.0, 1.5, 3.0]
>>> stats.binned_statistic([1, 1, 2, 5, 7], values, 'sum', bins=2)
(array([ 4. ,  4.5]), array([ 1.,  4.,  7.]), array([1, 1, 1, 2, 2]))
```

Multiple arrays of values can also be passed. The statistic is calculated on each set independently:

```
>>> values = [[1.0, 1.0, 2.0, 1.5, 3.0], [2.0, 2.0, 4.0, 3.0, 6.0]]
>>> stats.binned_statistic([1, 1, 2, 5, 7], values, 'sum', bins=2)
```

```
(array([[ 4. ,  4.5], [ 8. ,  9. ]]), array([ 1.,  4.,  7.]),
      array([1, 1, 1, 2, 2]))
```

```
>>> stats.binned_statistic([1, 2, 1, 2, 4], np.arange(5), statistic='mean',
...                        bins=3)
(array([ 1.,  2.,  4.]), array([ 1.,  2.,  3.,  4.]),
      array([1, 2, 1, 2, 3]))
```

As a second example, we now generate some random data of sailing boat speed as a function of wind speed, and then determine how fast our boat is for certain wind speeds:

```
>>> windspeed = 8 * np.random.rand(500)
>>> boatspeed = .3 * windspeed**.5 + .2 * np.random.rand(500)
>>> bin_means, bin_edges, binnumber = stats.binned_statistic(windspeed,
...                 boatspeed, statistic='median', bins=[1,2,3,4,5,6,7])
>>> plt.figure()
>>> plt.plot(windspeed, boatspeed, 'b.', label='raw data')
>>> plt.hlines(bin_means, bin_edges[:-1], bin_edges[1:], colors='g', lw=5,
...           label='binned statistic of data')
>>> plt.legend()
```

Now we can use `binnumber` to select all datapoints with a windspeed below 1:

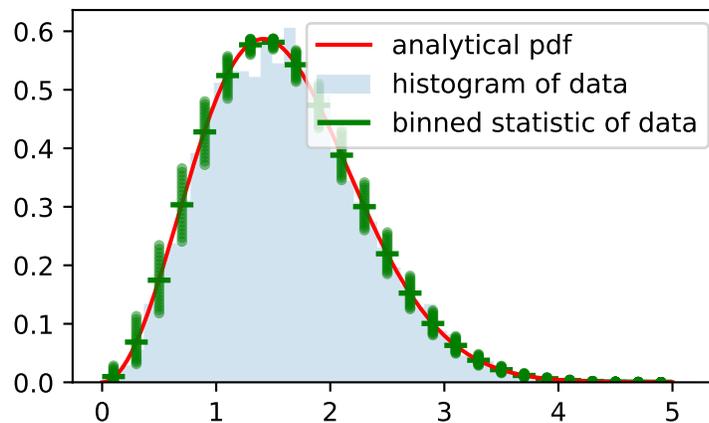
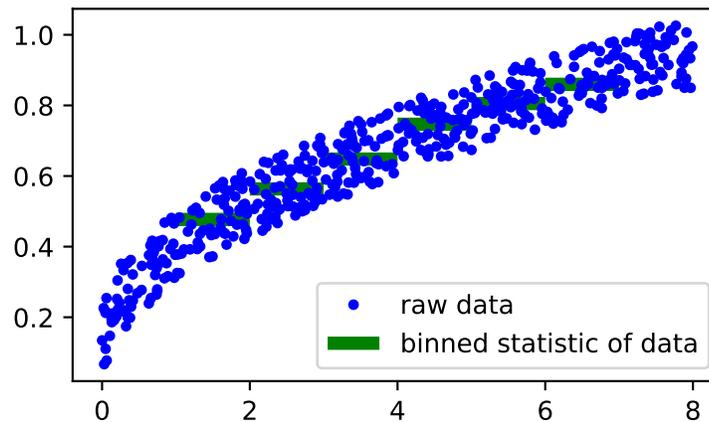
```
>>> low_boatspeed = boatspeed[binnumber == 0]
```

As a final example, we will use `bin_edges` and `binnumber` to make a plot of a distribution that shows the mean and distribution around that mean per bin, on top of a regular histogram and the probability distribution function:

```
>>> x = np.linspace(0, 5, num=500)
>>> x_pdf = stats.maxwell.pdf(x)
>>> samples = stats.maxwell.rvs(size=10000)
```

```
>>> bin_means, bin_edges, binnumber = stats.binned_statistic(x, x_pdf,
...                 statistic='mean', bins=25)
>>> bin_width = (bin_edges[1] - bin_edges[0])
>>> bin_centers = bin_edges[1:] - bin_width/2
```

```
>>> plt.figure()
>>> plt.hist(samples, bins=50, normed=True, histtype='stepfilled',
...         alpha=0.2, label='histogram of data')
>>> plt.plot(x, x_pdf, 'r-', label='analytical pdf')
>>> plt.hlines(bin_means, bin_edges[:-1], bin_edges[1:], colors='g', lw=2,
...           label='binned statistic of data')
>>> plt.plot((binnumber - 0.5) * bin_width, x_pdf, 'g.', alpha=0.5)
>>> plt.legend(fontsize=10)
>>> plt.show()
```



```
scipy.stats.binned_statistic_2d(x, y, values, statistic='mean', bins=10, range=None, expand_binnumbers=False)
```

Compute a bidimensional binned statistic for one or more sets of data.

This is a generalization of a `histogram2d` function. A histogram divides the space into bins, and returns the count of the number of points in each bin. This function allows the computation of the sum, mean, median, or other statistic of the values (or set of values) within each bin.

**Parameters** `x` : (N,) array\_like

A sequence of values to be binned along the first dimension.

`y` : (N,) array\_like

A sequence of values to be binned along the second dimension.

**values** : (N,) array\_like or list of (N,) array\_like

The data on which the statistic will be computed. This must be the same shape as `x`, or a list of sequences - each with the same shape as `x`. If `values` is such a list, the statistic will be computed on each independently.

**statistic** : string or callable, optional

The statistic to compute (default is ‘mean’). The following statistics are available:

- ‘mean’ : compute the mean of values for points within each bin. Empty bins will be represented by NaN.
- ‘median’ : compute the median of values for points within each bin. Empty bins will be represented by NaN.
- ‘count’ : compute the count of points within each bin. This is identical to an unweighted histogram. *values* array is not referenced.
- ‘sum’ : compute the sum of values for points within each bin. This is identical to a weighted histogram.
- ‘min’ : compute the minimum of values for points within each bin. Empty bins will be represented by NaN.
- ‘max’ : compute the maximum of values for point within each bin. Empty bins will be represented by NaN.
- ‘function’ : a user-defined function which takes a 1D array of values, and outputs a single numerical statistic. This function will be called on the values in each bin. Empty bins will be represented by function([]), or NaN if this returns an error.

**bins** : int or [int, int] or array\_like or [array, array], optional

The bin specification:

- the number of bins for the two dimensions ( $nx = ny = bins$ ),
- the number of bins in each dimension ( $nx, ny = bins$ ),
- the bin edges for the two dimensions ( $x\_edge = y\_edge = bins$ ),
- the bin edges in each dimension ( $x\_edge, y\_edge = bins$ ).

If the bin edges are specified, the number of bins will be, ( $nx = len(x\_edge) - 1$ ,  $ny = len(y\_edge) - 1$ ).

**range** : (2,2) array\_like, optional

The leftmost and rightmost edges of the bins along each dimension (if not specified explicitly in the *bins* parameters): `[[xmin, xmax], [ymin, ymax]]`. All values outside of this range will be considered outliers and not tallied in the histogram.

**expand\_binnumbers** : bool, optional

‘False’ (default): the returned *binnumber* is a shape (N,) array of linearized bin indices. ‘True’: the returned *binnumber* is ‘unraveled’ into a shape (2,N) ndarray, where each row gives the bin numbers in the corresponding dimension. See the *binnumber* returned value, and the *Examples* section.

New in version 0.17.0.

**Returns**

**statistic** : (nx, ny) ndarray

The values of the selected statistic in each two-dimensional bin.

**x\_edge** : (nx + 1) ndarray

The bin edges along the first dimension.

**y\_edge** : (ny + 1) ndarray

The bin edges along the second dimension.

**binnumber** : (N,) array of ints or (2,N) ndarray of ints

This assigns to each element of *sample* an integer that represents the bin in which this observation falls. The representation depends on the *expand\_binnumbers* argument. See *Notes* for details.

**See also:**

`numpy.digitize`, `numpy.histogram2d`, `binned_statistic`, `binned_statistic_dd`

**Notes**

Binedges: All but the last (righthand-most) bin is half-open. In other words, if *bins* is `[1, 2, 3, 4]`, then the first bin is `[1, 2)` (including 1, but excluding 2) and the second `[2, 3)`. The last bin, however, is `[3, 4]`, which *includes* 4.

*binnumber*: This returned argument assigns to each element of *sample* an integer that represents the bin in which it belongs. The representation depends on the *expand\_binnumbers* argument. If 'False' (default): The returned *binnumber* is a shape (N,) array of linearized indices mapping each element of *sample* to its corresponding bin (using row-major ordering). If 'True': The returned *binnumber* is a shape (2,N) ndarray where each row indicates bin placements for each dimension respectively. In each dimension, a binnumber of *i* means the corresponding value is between (D\_edge[i-1], D\_edge[i]), where 'D' is either 'x' or 'y'.

New in version 0.11.0.

### Examples

```
>>> from scipy import stats
```

Calculate the counts with explicit bin-edges:

```
>>> x = [0.1, 0.1, 0.1, 0.6]
>>> y = [2.1, 2.6, 2.1, 2.1]
>>> binx = [0.0, 0.5, 1.0]
>>> biny = [2.0, 2.5, 3.0]
>>> ret = stats.binned_statistic_2d(x, y, None, 'count', bins=[binx,biny])
>>> ret.statistic
array([[ 2.,  1.],
       [ 1.,  0.]])
```

The bin in which each sample is placed is given by the *binnumber* returned parameter. By default, these are the linearized bin indices:

```
>>> ret.binnumber
array([5, 6, 5, 9])
```

The bin indices can also be expanded into separate entries for each dimension using the *expand\_binnumbers* parameter:

```
>>> ret = stats.binned_statistic_2d(x, y, None, 'count', bins=[binx,biny],
...                                 expand_binnumbers=True)
>>> ret.binnumber
array([[1, 1, 1, 2],
       [1, 2, 1, 1]])
```

Which shows that the first three elements belong in the xbin 1, and the fourth into xbin 2; and so on for y.

`scipy.stats.binned_statistic_dd`(*sample*, *values*, *statistic*='mean', *bins*=10, *range*=None, *expand\_binnumbers*=False)

Compute a multidimensional binned statistic for a set of data.

This is a generalization of a histogramdd function. A histogram divides the space into bins, and returns the count of the number of points in each bin. This function allows the computation of the sum, mean, median, or other statistic of the values within each bin.

**Parameters** **sample** : array\_like

Data to histogram passed as a sequence of D arrays of length N, or as an (N,D) array.

**values** : (N,) array\_like or list of (N,) array\_like

The data on which the statistic will be computed. This must be the same shape as *x*, or a list of sequences - each with the same shape as *x*. If *values* is such a list, the statistic will be computed on each independently.

**statistic** : string or callable, optional

The statistic to compute (default is 'mean'). The following statistics are available:

- ‘mean’ : compute the mean of values for points within each bin. Empty bins will be represented by NaN.
- ‘median’ : compute the median of values for points within each bin. Empty bins will be represented by NaN.
- ‘count’ : compute the count of points within each bin. This is identical to an unweighted histogram. *values* array is not referenced.
- ‘sum’ : compute the sum of values for points within each bin. This is identical to a weighted histogram.
- ‘min’ : compute the minimum of values for points within each bin. Empty bins will be represented by NaN.
- ‘max’ : compute the maximum of values for point within each bin. Empty bins will be represented by NaN.
- *function* : a user-defined function which takes a 1D array of values, and outputs a single numerical statistic. This function will be called on the values in each bin. Empty bins will be represented by `function([])`, or NaN if this returns an error.

**bins** : sequence or int, optional

The bin specification must be in one of the following forms:

- A sequence of arrays describing the bin edges along each dimension.
- The number of bins for each dimension (`nx, ny, ... = bins`).
- The number of bins for all dimensions (`nx = ny = ... = bins`).

**range** : sequence, optional

A sequence of lower and upper bin edges to be used if the edges are not given explicitly in *bins*. Defaults to the minimum and maximum values along each dimension.

**expand\_binnumbers** : bool, optional

‘False’ (default): the returned *binnumber* is a shape (N,) array of linearized bin indices. ‘True’: the returned *binnumber* is ‘unraveled’ into a shape (D,N) ndarray, where each row gives the bin numbers in the corresponding dimension. See the *binnumber* returned value, and the *Examples* section of *binned\_statistic\_2d*.

**Returns**

**statistic** : ndarray, shape(nx1, nx2, nx3,...)

The values of the selected statistic in each two-dimensional bin.

**bin\_edges** : list of ndarrays

A list of D arrays describing the (nxi + 1) bin edges for each dimension.

**binnumber** : (N,) array of ints or (D,N) ndarray of ints

This assigns to each element of *sample* an integer that represents the bin in which this observation falls. The representation depends on the *expand\_binnumbers* argument. See *Notes* for details.

**See also:**

`numpy.digitize`, `numpy.histogramdd`, `binned_statistic`, `binned_statistic_2d`

**Notes**

**Binedges:** All but the last (righthand-most) bin is half-open in each dimension. In other words, if *bins* is [1, 2, 3, 4], then the first bin is [1, 2) (including 1, but excluding 2) and the second [2, 3). The last bin, however, is [3, 4], which *includes* 4.

**binnumber:** This returned argument assigns to each element of *sample* an integer that represents the bin in which it belongs. The representation depends on the *expand\_binnumbers* argument. If ‘False’ (default): The returned *binnumber* is a shape (N,) array of linearized indices mapping each element of *sample* to its corresponding bin (using row-major ordering). If ‘True’: The returned *binnumber* is a shape (D,N) ndarray where each row indicates bin placements for each dimension respectively. In each dimension, a binnumber of *i* means the corresponding value is between (bin\_edges[D][i-1], bin\_edges[D][i]), for each dimension ‘D’.

New in version 0.11.0.

<code>obrientransform(*args)</code>	Compute the O'Brien transform on input data (any number of arrays).
<code>bayes_mvs(data[, alpha])</code>	Bayesian confidence intervals for the mean, var, and std.
<code>mvsdist(data)</code>	'Frozen' distributions for mean, variance, and standard deviation of data.
<code>sem(a[, axis, ddof, nan_policy])</code>	Calculate the standard error of the mean (or standard error of measurement) of the values in the input array.
<code>zmap(scores, compare[, axis, ddof])</code>	Calculate the relative z-scores.
<code>zscore(a[, axis, ddof])</code>	Calculate the z score of each value in the sample, relative to the sample mean and standard deviation.
<code>iqr(x[, axis, rng, scale, nan_policy, ...])</code>	Compute the interquartile range of the data along the specified axis.

`scipy.stats.obrientransform(*args)`

Compute the O'Brien transform on input data (any number of arrays).

Used to test for homogeneity of variance prior to running one-way stats. Each array in `*args` is one level of a factor. If `f_oneway` is run on the transformed data and found significant, the variances are unequal. From Maxwell and Delaney [R677], p.112.

**Parameters** `args`: tuple of array\_like

**Returns** `obrientransform`: ndarray

Any number of arrays.  
Transformed data for use in an ANOVA. The first dimension of the result corresponds to the sequence of transformed arrays. If the arrays given are all 1-D of the same length, the return value is a 2-D array; otherwise it is a 1-D array of type object, with each element being an ndarray.

### References

[R677]

### Examples

We'll test the following data sets for differences in their variance.

```
>>> x = [10, 11, 13, 9, 7, 12, 12, 9, 10]
>>> y = [13, 21, 5, 10, 8, 14, 10, 12, 7, 15]
```

Apply the O'Brien transform to the data.

```
>>> from scipy.stats import obrientransform
>>> tx, ty = obrientransform(x, y)
```

Use `scipy.stats.f_oneway` to apply a one-way ANOVA test to the transformed data.

```
>>> from scipy.stats import f_oneway
>>> F, p = f_oneway(tx, ty)
>>> p
0.1314139477040335
```

If we require that  $p < 0.05$  for significance, we cannot conclude that the variances are different.

`scipy.stats.bayes_mvs(data, alpha=0.9)`

Bayesian confidence intervals for the mean, var, and std.

**Parameters** **data** : array\_like  
 Input data, if multi-dimensional it is flattened to 1-D by *bayes\_mvs*. Requires 2 or more data points.

**alpha** : float, optional  
 Probability that the returned confidence interval contains the true parameter.

**Returns** **mean\_cntr, var\_cntr, std\_cntr** : tuple  
 The three results are for the mean, variance and standard deviation, respectively. Each result is a tuple of the form:

```
(center, (lower, upper))
```

with *center* the mean of the conditional pdf of the value given the data, and (*lower, upper*) a confidence interval, centered on the median, containing the estimate to a probability *alpha*.

**See also:**

*mvsdist*

**Notes**

Each tuple of mean, variance, and standard deviation estimates represent the (center, (lower, upper)) with center the mean of the conditional pdf of the value given the data and (lower, upper) is a confidence interval centered on the median, containing the estimate to a probability *alpha*.

Converts data to 1-D and assumes all data has the same mean and variance. Uses Jeffrey’s prior for variance and std.

Equivalent to `tuple((x.mean(), x.interval(alpha)) for x in mvsdist(dat))`

**References**

T.E. Oliphant, “A Bayesian perspective on estimating mean, variance, and standard-deviation from data”, <http://scholarsarchive.byu.edu/facpub/278>, 2006.

**Examples**

First a basic example to demonstrate the outputs:

```
>>> from scipy import stats
>>> data = [6, 9, 12, 7, 8, 8, 13]
>>> mean, var, std = stats.bayes_mvs(data)
>>> mean
Mean(statistic=9.0, minmax=(7.1036502226125329, 10.896349777387467))
>>> var
Variance(statistic=10.0, minmax=(3.176724206..., 24.45910382...))
>>> std
Std_dev(statistic=2.9724954732045084, minmax=(1.7823367265645143, 4.
↪9456146050146295))
```

Now we generate some normally distributed random data, and get estimates of mean and standard deviation with 95% confidence intervals for those estimates:

```
>>> n_samples = 100000
>>> data = stats.norm.rvs(size=n_samples)
>>> res_mean, res_var, res_std = stats.bayes_mvs(data, alpha=0.95)
```

```
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure()
>>> ax = fig.add_subplot(111)
```

```

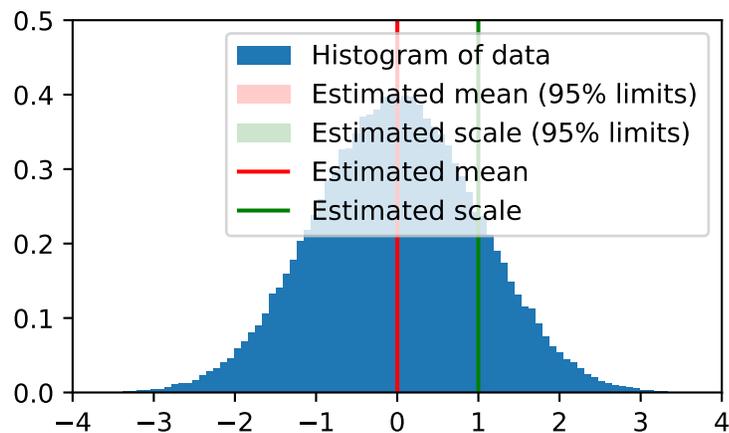
>>> ax.hist(data, bins=100, normed=True, label='Histogram of data')
>>> ax.vlines(res_mean.statistic, 0, 0.5, colors='r', label='Estimated mean')
>>> ax.axvspan(res_mean.minmax[0], res_mean.minmax[1], facecolor='r',
...           alpha=0.2, label=r'Estimated mean (95% limits)')
>>> ax.vlines(res_std.statistic, 0, 0.5, colors='g', label='Estimated scale')
>>> ax.axvspan(res_std.minmax[0], res_std.minmax[1], facecolor='g', alpha=0.2,
...           label=r'Estimated scale (95% limits)')

```

```

>>> ax.legend(fontsize=10)
>>> ax.set_xlim([-4, 4])
>>> ax.set_ylim([0, 0.5])
>>> plt.show()

```



`scipy.stats.mvstdist` (*data*)

‘Frozen’ distributions for mean, variance, and standard deviation of data.

**Parameters** **data** : array\_like

Input array. Converted to 1-D using `ravel`. Requires 2 or more data-points.

**Returns** **mdist** : “frozen” distribution object

Distribution object representing the mean of the data

**vdist** : “frozen” distribution object

Distribution object representing the variance of the data

**sdist** : “frozen” distribution object

Distribution object representing the standard deviation of the data

**See also:**

`bayes_mvs`

**Notes**

The return values from `bayes_mvs(data)` is equivalent to `tuple((x.mean(), x.interval(0.90)) for x in mvstdist(data))`.

In other words, calling `<dist>.mean()` and `<dist>.interval(0.90)` on the three distribution objects returned from this function will give the same results that are returned from `bayes_mvs`.

### References

T.E. Oliphant, “A Bayesian perspective on estimating mean, variance, and standard-deviation from data”, <http://scholarsarchive.byu.edu/facpub/278>, 2006.

### Examples

```
>>> from scipy import stats
>>> data = [6, 9, 12, 7, 8, 8, 13]
>>> mean, var, std = stats.mvstdist(data)
```

We now have frozen distribution objects “mean”, “var” and “std” that we can examine:

```
>>> mean.mean()
9.0
>>> mean.interval(0.95)
(6.6120585482655692, 11.387941451734431)
>>> mean.std()
1.1952286093343936
```

`scipy.stats.sem(a, axis=0, ddof=1, nan_policy='propagate')`

Calculate the standard error of the mean (or standard error of measurement) of the values in the input array.

**Parameters** **a** : array\_like

An array containing the values for which the standard error is returned.

**axis** : int or None, optional

Axis along which to operate. Default is 0. If None, compute over the whole array *a*.

**ddof** : int, optional

Delta degrees-of-freedom. How many degrees of freedom to adjust for bias in limited samples relative to the population estimate of variance. Defaults to 1.

**nan\_policy** : {‘propagate’, ‘raise’, ‘omit’}, optional

Defines how to handle when input contains nan. ‘propagate’ returns nan, ‘raise’ throws an error, ‘omit’ performs the calculations ignoring nan values. Default is ‘propagate’.

**Returns** **s** : ndarray or float

The standard error of the mean in the sample(s), along the input axis.

### Notes

The default value for *ddof* is different to the default (0) used by other *ddof* containing routines, such as `np.std` and `np.nanstd`.

### Examples

Find standard error along the first axis:

```
>>> from scipy import stats
>>> a = np.arange(20).reshape(5, 4)
>>> stats.sem(a)
array([ 2.8284,  2.8284,  2.8284,  2.8284])
```

Find standard error across the whole array, using *n* degrees of freedom:

```
>>> stats.sem(a, axis=None, ddof=0)
1.2893796958227628
```

`scipy.stats.zmap` (*scores*, *compare*, *axis=0*, *ddof=0*)

Calculate the relative z-scores.

Return an array of z-scores, i.e., scores that are standardized to zero mean and unit variance, where mean and variance are calculated from the comparison array.

**Parameters**

- scores** : array\_like  
The input for which z-scores are calculated.
- compare** : array\_like  
The input from which the mean and standard deviation of the normalization are taken; assumed to have the same dimension as *scores*.
- axis** : int or None, optional  
Axis over which mean and variance of *compare* are calculated. Default is 0. If None, compute over the whole array *scores*.
- ddof** : int, optional  
Degrees of freedom correction in the calculation of the standard deviation. Default is 0.

**Returns**

- zscore** : array\_like  
Z-scores, in the same shape as *scores*.

### Notes

This function preserves ndarray subclasses, and works also with matrices and masked arrays (it uses *asanyarray* instead of *asarray* for parameters).

### Examples

```
>>> from scipy.stats import zmap
>>> a = [0.5, 2.0, 2.5, 3]
>>> b = [0, 1, 2, 3, 4]
>>> zmap(a, b)
array([-1.06066017,  0.          ,  0.35355339,  0.70710678])
```

`scipy.stats.zscore` (*a*, *axis=0*, *ddof=0*)

Calculate the z score of each value in the sample, relative to the sample mean and standard deviation.

**Parameters**

- a** : array\_like  
An array like object containing the sample data.
- axis** : int or None, optional  
Axis along which to operate. Default is 0. If None, compute over the whole array *a*.
- ddof** : int, optional  
Degrees of freedom correction in the calculation of the standard deviation. Default is 0.

**Returns**

- zscore** : array\_like  
The z-scores, standardized by mean and standard deviation of input array *a*.

### Notes

This function preserves ndarray subclasses, and works also with matrices and masked arrays (it uses *asanyarray* instead of *asarray* for parameters).

### Examples

```
>>> a = np.array([ 0.7972,  0.0767,  0.4383,  0.7866,  0.8091,
...              0.1954,  0.6307,  0.6599,  0.1065,  0.0508])
>>> from scipy import stats
>>> stats.zscore(a)
```

```
array([ 1.1273, -1.247 , -0.0552,  1.0923,  1.1664, -0.8559,  0.5786,
        0.6748, -1.1488, -1.3324])
```

Computing along a specified axis, using  $n-1$  degrees of freedom (`ddof=1`) to calculate the standard deviation:

```
>>> b = np.array([[ 0.3148,  0.0478,  0.6243,  0.4608],
...               [ 0.7149,  0.0775,  0.6072,  0.9656],
...               [ 0.6341,  0.1403,  0.9759,  0.4064],
...               [ 0.5918,  0.6948,  0.904 ,  0.3721],
...               [ 0.0921,  0.2481,  0.1188,  0.1366]])
>>> stats.zscore(b, axis=1, ddof=1)
array([[ -0.19264823, -1.28415119,  1.07259584,  0.40420358],
       [  0.33048416, -1.37380874,  0.04251374,  1.00081084],
       [  0.26796377, -1.12598418,  1.23283094, -0.37481053],
       [ -0.22095197,  0.24468594,  1.19042819, -1.21416216],
       [ -0.82780366,  1.4457416 , -0.43867764, -0.1792603 ]])
```

`scipy.stats.iqr(x, axis=None, rng=(25, 75), scale='raw', nan_policy='propagate', interpolation='linear', keepdims=False)`

Compute the interquartile range of the data along the specified axis.

The interquartile range (IQR) is the difference between the 75th and 25th percentile of the data. It is a measure of the dispersion similar to standard deviation or variance, but is much more robust against outliers [R651].

The `rng` parameter allows this function to compute other percentile ranges than the actual IQR. For example, setting `rng=(0, 100)` is equivalent to `numpy.ptp`.

The IQR of an empty array is `np.nan`.

New in version 0.18.0.

**Parameters** `x`: array\_like

Input array or object that can be converted to an array.

**axis**: int or sequence of int, optional

Axis along which the range is computed. The default is to compute the IQR for the entire array.

**rng**: Two-element sequence containing floats in range of [0,100] optional

Percentiles over which to compute the range. Each must be between 0 and 100, inclusive. The default is the true IQR: (25, 75). The order of the elements is not important.

**scale**: scalar or str, optional

The numerical value of scale will be divided out of the final result. The following string values are recognized:

‘raw’: No scaling, just return the raw IQR. ‘normal’: Scale by  $2\sqrt{2}erf^{-1}(\frac{1}{2}) \approx 1.349$ .

The default is ‘raw’. Array-like scale is also allowed, as long as it broadcasts correctly to the output such that `out / scale` is a valid operation. The output dimensions depend on the input array, `x`, the `axis` argument, and the `keepdims` flag.

**nan\_policy**: {‘propagate’, ‘raise’, ‘omit’}, optional

Defines how to handle when input contains nan. ‘propagate’ returns nan, ‘raise’ throws an error, ‘omit’ performs the calculations ignoring nan values. Default is ‘propagate’.

**interpolation**: {‘linear’, ‘lower’, ‘higher’, ‘midpoint’, ‘nearest’}, optional

Specifies the interpolation method to use when the percentile boundaries lie between two data points `i` and `j`:

- **'linear'**  $[i + (j - i) * fraction]$ , where *fraction* is the fractional part of the index surrounded by *i* and *j*.
- **'lower'**: *i*,
- **'higher'**: *j*,
- **'nearest'**: *i* or *j* whichever is nearest.
- **'midpoint'**:  $(i + j) / 2$ .

Default is 'linear'.

**keepdims** : bool, optional

If this is set to *True*, the reduced axes are left in the result as dimensions with size one. With this option, the result will broadcast correctly against the original array *x*.

**Returns**

**iqr** : scalar or ndarray

If *axis=None*, a scalar is returned. If the input contains integers or floats of smaller precision than `np.float64`, then the output data-type is `np.float64`. Otherwise, the output data-type is the same as that of the input.

**See also:**

`numpy.std`, `numpy.var`

**Notes**

This function is heavily dependent on the version of `numpy` that is installed. Versions greater than 1.11.0b3 are highly recommended, as they include a number of enhancements and fixes to `numpy.percentile` and `numpy.nanpercentile` that affect the operation of this function. The following modifications apply:

**Below 1.10.0** [*nan\_policy* is poorly defined.] The default behavior of `numpy.percentile` is used for 'propagate'. This is a hybrid of 'omit' and 'propagate' that mostly yields a skewed version of 'omit' since NaNs are sorted to the end of the data. A warning is raised if there are NaNs in the data.

**Below 1.9.0:** `numpy.nanpercentile` does not exist.

This means that `numpy.percentile` is used regardless of *nan\_policy* and a warning is issued. See previous item for a description of the behavior.

**Below 1.9.0:** **keepdims and interpolation are not supported.**

The keywords get ignored with a warning if supplied with non-default values. However, multiple axes are still supported.

**References**

[R650], [R651], [R652]

**Examples**

```
>>> from scipy.stats import iqr
>>> x = np.array([[10, 7, 4], [3, 2, 1]])
>>> x
array([[10,  7,  4],
       [ 3,  2,  1]])
>>> iqr(x)
4.0
>>> iqr(x, axis=0)
array([ 3.5,  2.5,  1.5])
>>> iqr(x, axis=1)
array([ 3.,  1.])
>>> iqr(x, axis=1, keepdims=True)
array([[ 3.],
       [ 1.]])
```

`sigmaclip(a[, low, high])`

Iterative sigma-clipping of array elements.

`trimboth(a, proportiontocut[, axis])`

Slices off a proportion of items from both ends of an array.

Continued on next page

Table 5.294 – continued from previous page

<code>triml(a, proportiontocut[, tail, axis])</code>	Slices off a proportion from ONE end of the passed array distribution.
--	--

`scipy.stats.sigmaclip(a, low=4.0, high=4.0)`

Iterative sigma-clipping of array elements.

The output array contains only those elements of the input array *c* that satisfy the conditions

$$\text{mean}(c) - \text{std}(c) * \text{low} < c < \text{mean}(c) + \text{std}(c) * \text{high}$$

Starting from the full sample, all elements outside the critical range are removed. The iteration continues with a new critical range until no elements are outside the range.

**Parameters**

- a** : array\_like  
Data array, will be raveled if not 1-D.
- low** : float, optional  
Lower bound factor of sigma clipping. Default is 4.
- high** : float, optional  
Upper bound factor of sigma clipping. Default is 4.

**Returns**

- clipped** : ndarray  
Input array with clipped elements removed.
- lower** : float  
Lower threshold value use for clipping.
- upper** : float  
Upper threshold value use for clipping.

**Examples**

```
>>> from scipy.stats import sigmaclip
>>> a = np.concatenate((np.linspace(9.5, 10.5, 31),
...                     np.linspace(0, 20, 5)))
>>> fact = 1.5
>>> c, low, upp = sigmaclip(a, fact, fact)
>>> c
array([ 9.96666667, 10.          , 10.03333333, 10.          ])
>>> c.var(), c.std()
(0.00055555555555555165, 0.023570226039551501)
>>> low, c.mean() - fact*c.std(), c.min()
(9.9646446609406727, 9.9646446609406727, 9.9666666666666668)
>>> upp, c.mean() + fact*c.std(), c.max()
(10.035355339059327, 10.035355339059327, 10.033333333333333)
```

```
>>> a = np.concatenate((np.linspace(9.5, 10.5, 11),
...                     np.linspace(-100, -50, 3)))
>>> c, low, upp = sigmaclip(a, 1.8, 1.8)
>>> (c == np.linspace(9.5, 10.5, 11)).all()
True
```

`scipy.stats.trimboth(a, proportiontocut, axis=0)`

Slices off a proportion of items from both ends of an array.

Slices off the passed proportion of items from both ends of the passed array (i.e., with *proportiontocut* = 0.1, slices leftmost 10% and rightmost 10% of scores). The trimmed values are the lowest and highest ones. Slices off less if proportion results in a non-integer slice index (i.e., conservatively slices off ‘proportiontocut’).

**Parameters**

- a** : array\_like  
Data to trim.

**proportiontocut** : float  
 Proportion (in range 0-1) of total data set to trim of each end.

**axis** : int or None, optional  
 Axis along which to trim data. Default is 0. If None, compute over the whole array *a*.

**Returns** **out** : ndarray  
 Trimmed version of array *a*. The order of the trimmed content is undefined.

**See also:**

`trim_mean`

**Examples**

```
>>> from scipy import stats
>>> a = np.arange(20)
>>> b = stats.trimboth(a, 0.1)
>>> b.shape
(16,)
```

`scipy.stats.trim1(a, proportiontocut, tail='right', axis=0)`  
 Slices off a proportion from ONE end of the passed array distribution.

If *proportiontocut* = 0.1, slices off 'leftmost' or 'rightmost' 10% of scores. The lowest or highest values are trimmed (depending on the tail). Slices off less if proportion results in a non-integer slice index (i.e., conservatively slices off *proportiontocut* ).

**Parameters** **a** : array\_like  
 Input array

**proportiontocut** : float  
 Fraction to cut off of 'left' or 'right' of distribution

**tail** : {'left', 'right'}, optional  
 Defaults to 'right'.

**axis** : int or None, optional  
 Axis along which to trim data. Default is 0. If None, compute over the whole array *a*.

**Returns** **trim1** : ndarray  
 Trimmed version of array *a*. The order of the trimmed content is undefined.

<code>f_oneway(*args)</code>	Performs a 1-way ANOVA.
<code>pearsonr(x, y)</code>	Calculate a Pearson correlation coefficient and the p-value for testing non-correlation.
<code>spearmanr(a[, b, axis, nan_policy])</code>	Calculate a Spearman rank-order correlation coefficient and the p-value to test for non-correlation.
<code>pointbiserialr(x, y)</code>	Calculate a point biserial correlation coefficient and its p-value.
<code>kendalltau(x, y[, initial_lexsort, nan_policy])</code>	Calculate Kendall's tau, a correlation measure for ordinal data.
<code>weightedtau(x, y[, rank, weigher, additive])</code>	Compute a weighted version of Kendall's $\tau$ .
<code>linregress(x[, y])</code>	Calculate a linear least-squares regression for two sets of measurements.
<code>theilslopes(y[, x, alpha])</code>	Computes the Theil-Sen estimator for a set of points (x, y).

`scipy.stats.f_oneway(*args)`  
 Performs a 1-way ANOVA.

The one-way ANOVA tests the null hypothesis that two or more groups have the same population mean. The

test is applied to samples from two or more groups, possibly with differing sizes.

**Parameters** `sample1, sample2, ...` : array\_like  
 The sample measurements for each group.

**Returns** `statistic` : float  
 The computed F-value of the test.

`pvalue` : float  
 The associated p-value from the F-distribution.

**Notes**

The ANOVA test has important assumptions that must be satisfied in order for the associated p-value to be valid.

- 1.The samples are independent.
- 2.Each sample is from a normally distributed population.
- 3.The population standard deviations of the groups are all equal. This property is known as homoscedasticity.

If these assumptions are not true for a given set of data, it may still be possible to use the Kruskal-Wallis H-test (`scipy.stats.kruskal`) although with some loss of power.

The algorithm is from Heiman[2], pp.394-7.

**References**

[R633], [R634], [R635]

**Examples**

```
>>> import scipy.stats as stats
```

[R635] Here are some data on a shell measurement (the length of the anterior adductor muscle scar, standardized by dividing by length) in the mussel *Mytilus trossulus* from five locations: Tillamook, Oregon; Newport, Oregon; Petersburg, Alaska; Magadan, Russia; and Tvarminne, Finland, taken from a much larger data set used in McDonald et al. (1991).

```
>>> tillamook = [0.0571, 0.0813, 0.0831, 0.0976, 0.0817, 0.0859, 0.0735,
...             0.0659, 0.0923, 0.0836]
>>> newport = [0.0873, 0.0662, 0.0672, 0.0819, 0.0749, 0.0649, 0.0835,
...            0.0725]
>>> petersburg = [0.0974, 0.1352, 0.0817, 0.1016, 0.0968, 0.1064, 0.105]
>>> magadan = [0.1033, 0.0915, 0.0781, 0.0685, 0.0677, 0.0697, 0.0764,
...            0.0689]
>>> tvarminne = [0.0703, 0.1026, 0.0956, 0.0973, 0.1039, 0.1045]
>>> stats.f_oneway(tillamook, newport, petersburg, magadan, tvarminne)
(7.1210194716424473, 0.00028122423145345439)
```

`scipy.stats.pearsonr(x, y)`

Calculate a Pearson correlation coefficient and the p-value for testing non-correlation.

The Pearson correlation coefficient measures the linear relationship between two datasets. Strictly speaking, Pearson’s correlation requires that each dataset be normally distributed, and not necessarily zero-mean. Like other correlation coefficients, this one varies between -1 and +1 with 0 implying no correlation. Correlations of -1 or +1 imply an exact linear relationship. Positive correlations imply that as x increases, so does y. Negative correlations imply that as x increases, y decreases.

The p-value roughly indicates the probability of an uncorrelated system producing datasets that have a Pearson correlation at least as extreme as the one computed from these datasets. The p-values are not entirely reliable but are probably reasonable for datasets larger than 500 or so.

**Parameters** `x` : (N,) array\_like  
 Input

**Returns**

- y** : (N,) array\_like
- r** : float      Input
- Pearson's correlation coefficient
- p-value** : float
- 2-tailed p-value

**Notes**

The correlation coefficient is calculated as follows:

$$r_{pb} = \frac{\sum(x - m_x)(y - m_y)}{\sqrt{\sum(x - m_x)^2(y - m_y)^2}}$$

where  $m_x$  is the mean of the vector  $x$  and  $m_y$  is the mean of the vector  $y$ .

**References**

<http://www.statsoft.com/textbook/glosp.html#Pearson%20Correlation>

**Examples**

```
>>> from scipy import stats
>>> a = np.array([0, 0, 0, 1, 1, 1, 1])
>>> b = np.arange(7)
>>> stats.pearsonr(a, b)
(0.8660254037844386, 0.011724811003954654)
```

```
>>> stats.pearsonr([1, 2, 3, 4, 5], [5, 6, 7, 8, 7])
(0.83205029433784372, 0.080509573298498519)
```

`scipy.stats.spearmanr` (*a*, *b=None*, *axis=0*, *nan\_policy='propagate'*)

Calculate a Spearman rank-order correlation coefficient and the p-value to test for non-correlation.

The Spearman correlation is a nonparametric measure of the monotonicity of the relationship between two datasets. Unlike the Pearson correlation, the Spearman correlation does not assume that both datasets are normally distributed. Like other correlation coefficients, this one varies between -1 and +1 with 0 implying no correlation. Correlations of -1 or +1 imply an exact monotonic relationship. Positive correlations imply that as  $x$  increases, so does  $y$ . Negative correlations imply that as  $x$  increases,  $y$  decreases.

The p-value roughly indicates the probability of an uncorrelated system producing datasets that have a Spearman correlation at least as extreme as the one computed from these datasets. The p-values are not entirely reliable but are probably reasonable for datasets larger than 500 or so.

**Parameters**    **a, b** : 1D or 2D array\_like, b is optional

One or two 1-D or 2-D arrays containing multiple variables and observations. When these are 1-D, each represents a vector of observations of a single variable. For the behavior in the 2-D case, see under `axis`, below. Both arrays need to have the same length in the `axis` dimension.

**axis** : int or None, optional

If `axis=0` (default), then each column represents a variable, with observations in the rows. If `axis=1`, the relationship is transposed: each row represents a variable, while the columns contain observations. If `axis=None`, then both arrays will be raveled.

**nan\_policy** : { 'propagate', 'raise', 'omit' }, optional

Defines how to handle when input contains nan. 'propagate' returns nan, 'raise' throws an error, 'omit' performs the calculations ignoring nan values. Default is 'propagate'.

**Returns**        **correlation** : float or ndarray (2-D square)

Spearman correlation matrix or correlation coefficient (if only 2 variables are given as parameters. Correlation matrix is square with length equal to total number of variables (columns or rows) in a and b combined.

**pvalue** : float

The two-sided p-value for a hypothesis test whose null hypothesis is that two sets of data are uncorrelated, has same dimension as rho.

**Notes**

Changes in scipy 0.8.0: rewrite to add tie-handling, and axis.

**References**

[R699]

**Examples**

```
>>> from scipy import stats
>>> stats.spearmanr([1,2,3,4,5], [5,6,7,8,7])
(0.82078268166812329, 0.088587005313543798)
>>> np.random.seed(1234321)
>>> x2n = np.random.randn(100, 2)
>>> y2n = np.random.randn(100, 2)
>>> stats.spearmanr(x2n)
(0.059969996999699973, 0.55338590803773591)
>>> stats.spearmanr(x2n[:,0], x2n[:,1])
(0.059969996999699973, 0.55338590803773591)
>>> rho, pval = stats.spearmanr(x2n, y2n)
>>> rho
array([[ 1.          ,  0.05997   ,  0.18569457,  0.06258626],
       [ 0.05997   ,  1.          ,  0.110003  ,  0.02534653],
       [ 0.18569457,  0.110003  ,  1.          ,  0.03488749],
       [ 0.06258626,  0.02534653,  0.03488749,  1.          ]])
>>> pval
array([[ 0.          ,  0.55338591,  0.06435364,  0.53617935],
       [ 0.55338591,  0.          ,  0.27592895,  0.80234077],
       [ 0.06435364,  0.27592895,  0.          ,  0.73039992],
       [ 0.53617935,  0.80234077,  0.73039992,  0.          ]])
>>> rho, pval = stats.spearmanr(x2n.T, y2n.T, axis=1)
>>> rho
array([[ 1.          ,  0.05997   ,  0.18569457,  0.06258626],
       [ 0.05997   ,  1.          ,  0.110003  ,  0.02534653],
       [ 0.18569457,  0.110003  ,  1.          ,  0.03488749],
       [ 0.06258626,  0.02534653,  0.03488749,  1.          ]])
>>> stats.spearmanr(x2n, y2n, axis=None)
(0.10816770419260482, 0.1273562188027364)
>>> stats.spearmanr(x2n.ravel(), y2n.ravel())
(0.10816770419260482, 0.1273562188027364)
```

```
>>> xint = np.random.randint(10, size=(100, 2))
>>> stats.spearmanr(xint)
(0.052760927029710199, 0.60213045837062351)
```

scipy.stats.**pointbiserialr**(x, y)

Calculate a point biserial correlation coefficient and its p-value.

The point biserial correlation is used to measure the relationship between a binary variable, x, and a continuous variable, y. Like other correlation coefficients, this one varies between -1 and +1 with 0 implying no correlation. Correlations of -1 or +1 imply a deterministic relationship.

This function uses a shortcut formula but produces the same result as `pearsonr`.

**Parameters** `x` : array\_like of bools  
                   Input array.  
`y` : array\_like  
                   Input array.  
**Returns** `correlation` : float  
                   R value  
`pvalue` : float  
                   2-tailed p-value

### Notes

`pointbiserialr` uses a t-test with  $n-1$  degrees of freedom. It is equivalent to `pearsonr`.

The value of the point-biserial correlation can be calculated from:

$$r_{pb} = \frac{\bar{Y}_1 - \bar{Y}_0}{s_y} \sqrt{\frac{N_1 N_2}{N(N-1)}}$$

Where  $Y_0$  and  $Y_1$  are means of the metric observations coded 0 and 1 respectively;  $N_0$  and  $N_1$  are number of observations coded 0 and 1 respectively;  $N$  is the total number of observations and  $s_y$  is the standard deviation of all the metric observations.

A value of  $r_{pb}$  that is significantly different from zero is completely equivalent to a significant difference in means between the two groups. Thus, an independent groups t Test with  $N - 2$  degrees of freedom may be used to test whether  $r_{pb}$  is nonzero. The relation between the t-statistic for comparing two independent groups and  $r_{pb}$  is given by:

$$t = \sqrt{N - 2} \frac{r_{pb}}{\sqrt{1 - r_{pb}^2}}$$

### References

[R679], [R680], [R681]

### Examples

```
>>> from scipy import stats
>>> a = np.array([0, 0, 0, 1, 1, 1, 1])
>>> b = np.arange(7)
>>> stats.pointbiserialr(a, b)
(0.8660254037844386, 0.011724811003954652)
>>> stats.pearsonr(a, b)
(0.86602540378443871, 0.011724811003954626)
>>> np.corrcoef(a, b)
array([[ 1.          ,  0.8660254 ],
       [ 0.8660254 ,  1.          ]])
```

`scipy.stats.kendalltau` ( $x, y, initial\_lexsort=None, nan\_policy='propagate'$ )

Calculate Kendall's tau, a correlation measure for ordinal data.

Kendall's tau is a measure of the correspondence between two rankings. Values close to 1 indicate strong agreement, values close to -1 indicate strong disagreement. This is the 1945 "tau-b" version of Kendall's tau [R655], which can account for ties and which reduces to the 1938 "tau-a" version [R654] in absence of ties.

**Parameters** `x, y` : array\_like  
                   Arrays of rankings, of the same shape. If arrays are not 1-D, they will be flattened to 1-D.

**initial\_lexsort** : bool, optional  
 Unused (deprecated).

**nan\_policy** : { 'propagate', 'raise', 'omit' }, optional  
 Defines how to handle when input contains nan. 'propagate' returns nan, 'raise' throws an error, 'omit' performs the calculations ignoring nan values. Default is 'propagate'. Note that if the input contains nan 'omit' delegates to `mstats_basic.kendalltau()`, which has a different implementation.

**Returns**

**correlation** : float  
 The tau statistic.

**pvalue** : float  
 The two-sided p-value for a hypothesis test whose null hypothesis is an absence of association,  $\tau = 0$ .

#### See also:

**spearmanr** Calculates a Spearman rank-order correlation coefficient.

#### theilslopes

Computes the Theil-Sen estimator for a set of points  $(x, y)$ .

#### weightedtau

Computes a weighted version of Kendall's tau.

#### Notes

The definition of Kendall's tau that is used is [R655]:

$$\tau = (P - Q) / \sqrt{((P + Q + T) * (P + Q + U))}$$

where  $P$  is the number of concordant pairs,  $Q$  the number of discordant pairs,  $T$  the number of ties only in  $x$ , and  $U$  the number of ties only in  $y$ . If a tie occurs for the same pair in both  $x$  and  $y$ , it is not added to either  $T$  or  $U$ .

#### References

[R654], [R655], [R656], [R657]

#### Examples

```

>>> from scipy import stats
>>> x1 = [12, 2, 1, 12, 2]
>>> x2 = [1, 4, 7, 1, 0]
>>> tau, p_value = stats.kendalltau(x1, x2)
>>> tau
-0.47140452079103173
>>> p_value
0.2827454599327748
    
```

`scipy.stats.weightedtau` ( $x, y, rank=True, weigher=None, additive=True$ )

Compute a weighted version of Kendall's  $\tau$ .

The weighted  $\tau$  is a weighted version of Kendall's  $\tau$  in which exchanges of high weight are more influential than exchanges of low weight. The default parameters compute the additive hyperbolic version of the index,  $\tau_h$ , which has been shown to provide the best balance between important and unimportant elements [R712].

The weighting is defined by means of a rank array, which assigns a nonnegative rank to each element, and a weigher function, which assigns a weight based from the rank to each element. The weight of an exchange is then the sum or the product of the weights of the ranks of the exchanged elements. The default parameters compute  $\tau_h$ : an exchange between elements with rank  $r$  and  $s$  (starting from zero) has weight  $1/(r + 1) + 1/(s + 1)$ .

Specifying a rank array is meaningful only if you have in mind an external criterion of importance. If, as it usually happens, you do not have in mind a specific rank, the weighted  $\tau$  is defined by averaging the values

obtained using the decreasing lexicographical rank by  $(x, y)$  and by  $(y, x)$ . This is the behavior with default parameters.

Note that if you are computing the weighted  $\tau$  on arrays of ranks, rather than of scores (i.e., a larger value implies a lower rank) you must negate the ranks, so that elements of higher rank are associated with a larger value.

**Parameters**

**x, y** : array\_like  
Arrays of scores, of the same shape. If arrays are not 1-D, they will be flattened to 1-D.

**rank** : array\_like of ints or bool, optional  
A nonnegative rank assigned to each element. If it is None, the decreasing lexicographical rank by  $(x, y)$  will be used: elements of higher rank will be those with larger  $x$ -values, using  $y$ -values to break ties (in particular, swapping  $x$  and  $y$  will give a different result). If it is False, the element indices will be used directly as ranks. The default is True, in which case this function returns the average of the values obtained using the decreasing lexicographical rank by  $(x, y)$  and by  $(y, x)$ .

**weigher** : callable, optional  
The weigher function. Must map nonnegative integers (zero representing the most important element) to a nonnegative weight. The default, None, provides hyperbolic weighing, that is, rank  $r$  is mapped to weight  $1/(r+1)$ .

**additive** : bool, optional  
If True, the weight of an exchange is computed by adding the weights of the ranks of the exchanged elements; otherwise, the weights are multiplied. The default is True.

**Returns**

**correlation** : float  
The weighted  $\tau$  correlation index.

**pvalue** : float  
Presently `np.nan`, as the null statistics is unknown (even in the additive hyperbolic case).

See also:

**kendalltau** Calculates Kendall's tau.

**spearmanr** Calculates a Spearman rank-order correlation coefficient.

**theilslopes**

Computes the Theil-Sen estimator for a set of points  $(x, y)$ .

**Notes**

This function uses an  $O(n \log n)$ , mergesort-based algorithm [R712] that is a weighted extension of Knight's algorithm for Kendall's  $\tau$  [R713]. It can compute Shieh's weighted  $\tau$  [R714] between rankings without ties (i.e., permutations) by setting *additive* and *rank* to False, as the definition given in [R712] is a generalization of Shieh's.

NaNs are considered the smallest possible score.

New in version 0.19.0.

**References**

[R712], [R713], [R714]

**Examples**

```
>>> from scipy import stats
>>> x = [12, 2, 1, 12, 2]
>>> y = [1, 4, 7, 1, 0]
```

```
>>> tau, p_value = stats.weightedtau(x, y)
>>> tau
-0.56694968153682723
>>> p_value
nan
>>> tau, p_value = stats.weightedtau(x, y, additive=False)
>>> tau
-0.62205716951801038
```

NaNs are considered the smallest possible score:

```
>>> x = [12, 2, 1, 12, 2]
>>> y = [1, 4, 7, 1, np.nan]
>>> tau, _ = stats.weightedtau(x, y)
>>> tau
-0.56694968153682723
```

This is exactly Kendall's tau:

```
>>> x = [12, 2, 1, 12, 2]
>>> y = [1, 4, 7, 1, 0]
>>> tau, _ = stats.weightedtau(x, y, weigher=lambda x: 1)
>>> tau
-0.47140452079103173
```

```
>>> x = [12, 2, 1, 12, 2]
>>> y = [1, 4, 7, 1, 0]
>>> stats.weightedtau(x, y, rank=None)
WeightedTauResult(correlation=-0.4157652301037516, pvalue=nan)
>>> stats.weightedtau(y, x, rank=None)
WeightedTauResult(correlation=-0.71813413296990281, pvalue=nan)
```

`scipy.stats.linregress(x,y=None)`

Calculate a linear least-squares regression for two sets of measurements.

**Parameters** `x, y` : array\_like

Two sets of measurements. Both arrays should have the same length. If only `x` is given (and `y=None`), then it must be a two-dimensional array where one dimension has length 2. The two sets of measurements are then found by splitting the array along the length-2 dimension.

**Returns** `slope` : float

slope of the regression line

`intercept` : float

intercept of the regression line

`rvalue` : float

correlation coefficient

`pvalue` : float

two-sided p-value for a hypothesis test whose null hypothesis is that the slope is zero, using Wald Test with t-distribution of the test statistic.

`stderr` : float

Standard error of the estimated gradient.

See also:

`scipy.optimize.curve_fit`

Use non-linear least squares to fit a function to data.

`scipy.optimize.leastsq`

Minimize the sum of squares of a set of equations.

**Examples**

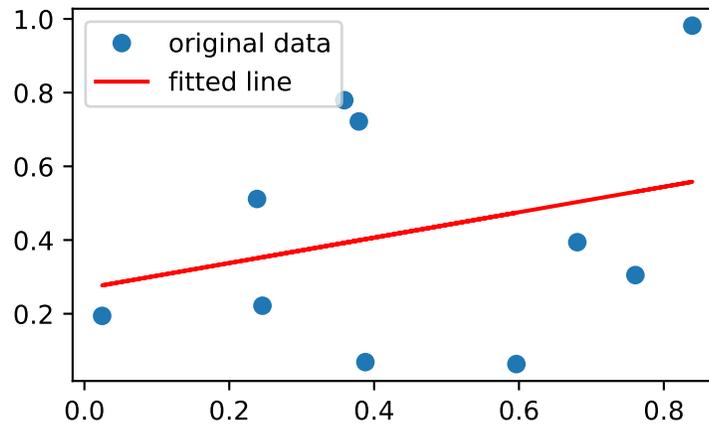
```
>>> import matplotlib.pyplot as plt
>>> from scipy import stats
>>> np.random.seed(12345678)
>>> x = np.random.random(10)
>>> y = np.random.random(10)
>>> slope, intercept, r_value, p_value, std_err = stats.linregress(x, y)
```

To get coefficient of determination (`r_squared`)

```
>>> print("r-squared:", r_value**2)
r-squared: 0.080402268539
```

Plot the data along with the fitted line

```
>>> plt.plot(x, y, 'o', label='original data')
>>> plt.plot(x, intercept + slope*x, 'r', label='fitted line')
>>> plt.legend()
>>> plt.show()
```



`scipy.stats.theilslopes` (`y`, `x=None`, `alpha=0.95`)

Computes the Theil-Sen estimator for a set of points (`x`, `y`).

`theilslopes` implements a method for robust linear regression. It computes the slope as the median of all slopes between paired values.

**Parameters** `y`: array\_like

Dependent variable.

`x`: array\_like or None, optional

Independent variable. If None, use `arange(len(y))` instead.

**alpha**: float, optional

Confidence degree between 0 and 1. Default is 95% confidence. Note that `alpha` is symmetric around 0.5, i.e. both 0.1 and 0.9 are interpreted as “find the 90% confidence interval”.

**Returns** `medslope`: float

Theil slope.

`medintercept`: float

Intercept of the Theil line, as  $\text{median}(y) - \text{medslope} * \text{median}(x)$ .

**lo\_slope** : float  
Lower bound of the confidence interval on *medslope*.

**up\_slope** : float  
Upper bound of the confidence interval on *medslope*.

### Notes

The implementation of *theilslopes* follows [R700]. The intercept is not defined in [R700], and here it is defined as  $\text{median}(y) - \text{medslope} * \text{median}(x)$ , which is given in [R702]. Other definitions of the intercept exist in the literature. A confidence interval for the intercept is not given as this question is not addressed in [R700].

### References

[R700], [R701], [R702]

### Examples

```
>>> from scipy import stats
>>> import matplotlib.pyplot as plt
```

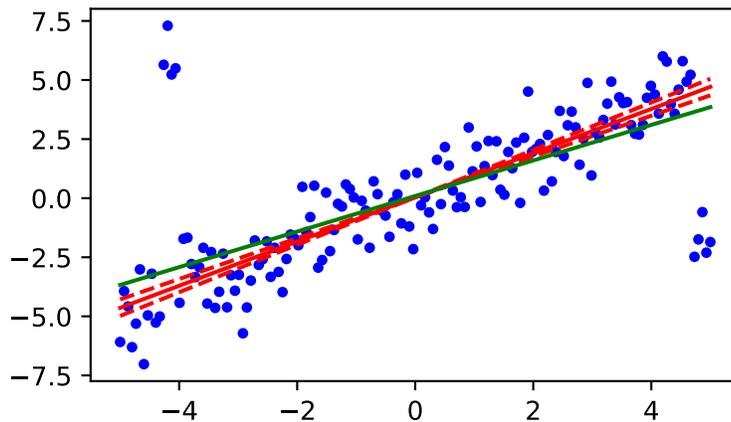
```
>>> x = np.linspace(-5, 5, num=150)
>>> y = x + np.random.normal(size=x.size)
>>> y[11:15] += 10 # add outliers
>>> y[-5:] -= 7
```

Compute the slope, intercept and 90% confidence interval. For comparison, also compute the least-squares fit with *linregress*:

```
>>> res = stats.theilslopes(y, x, 0.90)
>>> lsq_res = stats.linregress(x, y)
```

Plot the results. The Theil-Sen regression line is shown in red, with the dashed red lines illustrating the confidence interval of the slope (note that the dashed red lines are not the confidence interval of the regression as the confidence interval of the intercept is not included). The green line shows the least-squares fit for comparison.

```
>>> fig = plt.figure()
>>> ax = fig.add_subplot(111)
>>> ax.plot(x, y, 'b.')
>>> ax.plot(x, res[1] + res[0] * x, 'r-')
>>> ax.plot(x, res[1] + res[2] * x, 'r--')
>>> ax.plot(x, res[1] + res[3] * x, 'r--')
>>> ax.plot(x, lsq_res[1] + lsq_res[0] * x, 'g-')
>>> plt.show()
```



<code>ttest_1samp(a, popmean[, axis, nan_policy])</code>	Calculate the T-test for the mean of ONE group of scores.
<code>ttest_ind(a, b[, axis, equal_var, nan_policy])</code>	Calculate the T-test for the means of <i>two independent</i> samples of scores.
<code>ttest_ind_from_stats(mean1, std1, nobs1, ...)</code>	T-test for means of two independent samples from descriptive statistics.
<code>ttest_rel(a, b[, axis, nan_policy])</code>	Calculate the T-test on TWO RELATED samples of scores, a and b.
<code>kstest(rvs, cdf[, args, N, alternative, mode])</code>	Perform the Kolmogorov-Smirnov test for goodness of fit.
<code>chisquare(f_obs[, f_exp, ddof, axis])</code>	Calculate a one-way chi square test.
<code>power_divergence(f_obs[, f_exp, ddof, axis, ...])</code>	Cressie-Read power divergence statistic and goodness of fit test.
<code>ks_2samp(data1, data2)</code>	Compute the Kolmogorov-Smirnov statistic on 2 samples.
<code>mannwhitneyu(x, y[, use_continuity, alternative])</code>	Compute the Mann-Whitney rank test on samples x and y.
<code>tiecorrect(rankvals)</code>	Tie correction factor for ties in the Mann-Whitney U and Kruskal-Wallis H tests.
<code>rankdata(a[, method])</code>	Assign ranks to data, dealing with ties appropriately.
<code>ranksums(x, y)</code>	Compute the Wilcoxon rank-sum statistic for two samples.
<code>wilcoxon(x[, y, zero_method, correction])</code>	Calculate the Wilcoxon signed-rank test.
<code>kruskal(*args, **kwargs)</code>	Compute the Kruskal-Wallis H-test for independent samples
<code>friedmanchisquare(*args)</code>	Compute the Friedman test for repeated measurements
<code>combine_pvalues(pvalues[, method, weights])</code>	Methods for combining the p-values of independent tests bearing upon the same hypothesis.
<code>jarque_bera(x)</code>	Perform the Jarque-Bera goodness of fit test on sample data.

`scipy.stats.ttest_1samp(a, popmean, axis=0, nan_policy='propagate')`

Calculate the T-test for the mean of ONE group of scores.

This is a two-sided test for the null hypothesis that the expected value (mean) of a sample of independent observations *a* is equal to the given population mean, *popmean*.

**Parameters**

- a** : array\_like  
sample observation
- popmean** : float or array\_like

expected value in null hypothesis, if `array_like` than it must have the same shape as `a` excluding the axis dimension

**axis** : int or None, optional  
Axis along which to compute test. If None, compute over the whole array `a`.

**nan\_policy** : {'propagate', 'raise', 'omit'}, optional  
Defines how to handle when input contains nan. 'propagate' returns nan, 'raise' throws an error, 'omit' performs the calculations ignoring nan values. Default is 'propagate'.

**Returns**

**statistic** : float or array  
t-statistic

**pvalue** : float or array  
two-tailed p-value

*Examples*

```
>>> from scipy import stats
```

```
>>> np.random.seed(7654567) # fix seed to get the same result
>>> rvs = stats.norm.rvs(loc=5, scale=10, size=(50,2))
```

Test if mean of random sample is equal to true mean, and different mean. We reject the null hypothesis in the second case and don't reject it in the first case.

```
>>> stats.ttest_1samp(rvs, 5.0)
(array([-0.68014479, -0.04323899]), array([ 0.49961383,  0.96568674]))
>>> stats.ttest_1samp(rvs, 0.0)
(array([ 2.77025808,  4.11038784]), array([ 0.00789095,  0.00014999]))
```

Examples using axis and non-scalar dimension for population mean.

```
>>> stats.ttest_1samp(rvs, [5.0, 0.0])
(array([-0.68014479,  4.11038784]), array([ 4.99613833e-01,  1.49986458e-04]))
>>> stats.ttest_1samp(rvs.T, [5.0, 0.0], axis=1)
(array([-0.68014479,  4.11038784]), array([ 4.99613833e-01,  1.49986458e-04]))
>>> stats.ttest_1samp(rvs, [[5.0], [0.0]])
(array([[ -0.68014479, -0.04323899],
        [ 2.77025808,  4.11038784]]), array([[ 4.99613833e-01,  9.65686743e-01],
        [ 7.89094663e-03,  1.49986458e-04]]))
```

`scipy.stats.ttest_ind(a, b, axis=0, equal_var=True, nan_policy='propagate')`

Calculate the T-test for the means of *two independent* samples of scores.

This is a two-sided test for the null hypothesis that 2 independent samples have identical average (expected) values. This test assumes that the populations have identical variances by default.

**Parameters**

**a, b** : array\_like  
The arrays must have the same shape, except in the dimension corresponding to *axis* (the first, by default).

**axis** : int or None, optional  
Axis along which to compute test. If None, compute over the whole arrays, *a*, and *b*.

**equal\_var** : bool, optional  
If True (default), perform a standard independent 2 sample test that assumes equal population variances [R704]. If False, perform Welch's t-test, which does not assume equal population variance [R705].  
New in version 0.11.0.

	<b>nan_policy</b> : { 'propagate', 'raise', 'omit' }, optional
	Defines how to handle when input contains nan. 'propagate' returns nan, 'raise' throws an error, 'omit' performs the calculations ignoring nan values. Default is 'propagate'.
<b>Returns</b>	<b>statistic</b> : float or array
	The calculated t-statistic.
	<b>pvalue</b> : float or array
	The two-tailed p-value.

### Notes

We can use this test, if we observe two independent samples from the same or different population, e.g. exam scores of boys and girls or of two ethnic groups. The test measures whether the average (expected) value differs significantly across samples. If we observe a large p-value, for example larger than 0.05 or 0.1, then we cannot reject the null hypothesis of identical average scores. If the p-value is smaller than the threshold, e.g. 1%, 5% or 10%, then we reject the null hypothesis of equal averages.

### References

[R704], [R705]

### Examples

```
>>> from scipy import stats
>>> np.random.seed(12345678)
```

Test with sample with identical means:

```
>>> rvs1 = stats.norm.rvs(loc=5, scale=10, size=500)
>>> rvs2 = stats.norm.rvs(loc=5, scale=10, size=500)
>>> stats.ttest_ind(rvs1, rvs2)
(0.26833823296239279, 0.78849443369564776)
>>> stats.ttest_ind(rvs1, rvs2, equal_var = False)
(0.26833823296239279, 0.78849452749500748)
```

*ttest\_ind* underestimates p for unequal variances:

```
>>> rvs3 = stats.norm.rvs(loc=5, scale=20, size=500)
>>> stats.ttest_ind(rvs1, rvs3)
(-0.46580283298287162, 0.64145827413436174)
>>> stats.ttest_ind(rvs1, rvs3, equal_var = False)
(-0.46580283298287162, 0.64149646246569292)
```

When  $n1 \neq n2$ , the equal variance t-statistic is no longer equal to the unequal variance t-statistic:

```
>>> rvs4 = stats.norm.rvs(loc=5, scale=20, size=100)
>>> stats.ttest_ind(rvs1, rvs4)
(-0.99882539442782481, 0.3182832709103896)
>>> stats.ttest_ind(rvs1, rvs4, equal_var = False)
(-0.69712570584654099, 0.48716927725402048)
```

T-test with different means, variance, and n:

```
>>> rvs5 = stats.norm.rvs(loc=8, scale=20, size=100)
>>> stats.ttest_ind(rvs1, rvs5)
(-1.4679669854490653, 0.14263895620529152)
>>> stats.ttest_ind(rvs1, rvs5, equal_var = False)
(-0.94365973617132992, 0.34744170334794122)
```

`scipy.stats.ttest_ind_from_stats` (*mean1*, *std1*, *nobs1*, *mean2*, *std2*, *nobs2*, *equal\_var=True*)  
 T-test for means of two independent samples from descriptive statistics.

This is a two-sided test for the null hypothesis that two independent samples have identical average (expected) values.

**Parameters**

- mean1** : array\_like  
The mean(s) of sample 1.
- std1** : array\_like  
The standard deviation(s) of sample 1.
- nobs1** : array\_like  
The number(s) of observations of sample 1.
- mean2** : array\_like  
The mean(s) of sample 2
- std2** : array\_like  
The standard deviations(s) of sample 2.
- nobs2** : array\_like  
The number(s) of observations of sample 2.
- equal\_var** : bool, optional  
If True (default), perform a standard independent 2 sample test that assumes equal population variances [R706]. If False, perform Welch's t-test, which does not assume equal population variance [R707].

**Returns**

- statistic** : float or array  
The calculated t-statistics
- pvalue** : float or array  
The two-tailed p-value.

**See also:**

`scipy.stats.ttest_ind`

**Notes**

New in version 0.16.0.

**References**

[R706], [R707]

**Examples**

Suppose we have the summary data for two samples, as follows:

	Size	Sample Mean	Sample Variance
Sample 1	13	15.0	87.5
Sample 2	11	12.0	39.0

Apply the t-test to this data (with the assumption that the population variances are equal):

```
>>> from scipy.stats import ttest_ind_from_stats
>>> ttest_ind_from_stats(mean1=15.0, std1=np.sqrt(87.5), nobs1=13,
...                      mean2=12.0, std2=np.sqrt(39.0), nobs2=11)
Ttest_indResult(statistic=0.90513580933102689, pvalue=0.37519967975814872)
```

For comparison, here is the data from which those summary statistics were taken. With this data, we can compute the same result using `scipy.stats.ttest_ind`:

```

>>> a = np.array([1, 3, 4, 6, 11, 13, 15, 19, 22, 24, 25, 26, 26])
>>> b = np.array([2, 4, 6, 9, 11, 13, 14, 15, 18, 19, 21])
>>> from scipy.stats import ttest_ind
>>> ttest_ind(a, b)
Ttest_indResult(statistic=0.905135809331027, pvalue=0.37519967975814861)

```

`scipy.stats.ttest_rel(a, b, axis=0, nan_policy='propagate')`

Calculate the T-test on TWO RELATED samples of scores, a and b.

This is a two-sided test for the null hypothesis that 2 related or repeated samples have identical average (expected) values.

**Parameters** **a, b** : array\_like

The arrays must have the same shape.

**axis** : int or None, optional

Axis along which to compute test. If None, compute over the whole arrays, *a*, and *b*.

**nan\_policy** : {'propagate', 'raise', 'omit'}, optional

Defines how to handle when input contains nan. 'propagate' returns nan, 'raise' throws an error, 'omit' performs the calculations ignoring nan values. Default is 'propagate'.

**Returns**

**statistic** : float or array  
t-statistic

**pvalue** : float or array  
two-tailed p-value

### Notes

Examples for the use are scores of the same set of student in different exams, or repeated sampling from the same units. The test measures whether the average score differs significantly across samples (e.g. exams). If we observe a large p-value, for example greater than 0.05 or 0.1 then we cannot reject the null hypothesis of identical average scores. If the p-value is smaller than the threshold, e.g. 1%, 5% or 10%, then we reject the null hypothesis of equal averages. Small p-values are associated with large t-statistics.

### References

[https://en.wikipedia.org/wiki/T-test#Dependent\\_t-test\\_for\\_paired\\_samples](https://en.wikipedia.org/wiki/T-test#Dependent_t-test_for_paired_samples)

### Examples

```

>>> from scipy import stats
>>> np.random.seed(12345678) # fix random seed to get same numbers

```

```

>>> rvs1 = stats.norm.rvs(loc=5, scale=10, size=500)
>>> rvs2 = (stats.norm.rvs(loc=5, scale=10, size=500) +
...         stats.norm.rvs(scale=0.2, size=500))
>>> stats.ttest_rel(rvs1, rvs2)
(0.24101764965300962, 0.80964043445811562)
>>> rvs3 = (stats.norm.rvs(loc=8, scale=10, size=500) +
...         stats.norm.rvs(scale=0.2, size=500))
>>> stats.ttest_rel(rvs1, rvs3)
(-3.9995108708727933, 7.3082402191726459e-005)

```

`scipy.stats.kstest(rvs, cdf, args=(), N=20, alternative='two-sided', mode='approx')`

Perform the Kolmogorov-Smirnov test for goodness of fit.

This performs a test of the distribution  $G(x)$  of an observed random variable against a given distribution  $F(x)$ . Under the null hypothesis the two distributions are identical,  $G(x)=F(x)$ . The alternative hypothesis can be either

‘two-sided’ (default), ‘less’ or ‘greater’. The KS test is only valid for continuous distributions.

**Parameters**

**rvs** : str, array or callable  
 If a string, it should be the name of a distribution in *scipy.stats*. If an array, it should be a 1-D array of observations of random variables. If a callable, it should be a function to generate random variables; it is required to have a keyword argument *size*.

**cdf** : str or callable  
 If a string, it should be the name of a distribution in *scipy.stats*. If *rvs* is a string then *cdf* can be False or the same as *rvs*. If a callable, that callable is used to calculate the cdf.

**args** : tuple, sequence, optional  
 Distribution parameters, used if *rvs* or *cdf* are strings.

**N** : int, optional  
 Sample size if *rvs* is string or callable. Default is 20.

**alternative** : {‘two-sided’, ‘less’, ‘greater’}, optional  
 Defines the alternative hypothesis (see explanation above). Default is ‘two-sided’.

**mode** : ‘approx’ (default) or ‘asympt’, optional  
 Defines the distribution used for calculating the p-value.
 

- ‘approx’ : use approximation to exact distribution of test statistic,
- ‘asympt’ : use asymptotic distribution of test statistic

**Returns**

**statistic** : float  
 KS test statistic, either D, D+ or D-.

**pvalue** : float  
 One-tailed or two-tailed p-value.

**Notes**

In the one-sided test, the alternative is that the empirical cumulative distribution function of the random variable is “less” or “greater” than the cumulative distribution function  $F(x)$  of the hypothesis,  $G(x) \leq F(x)$ , resp.  $G(x) \geq F(x)$ .

**Examples**

```
>>> from scipy import stats
```

```
>>> x = np.linspace(-15, 15, 9)
>>> stats.kstest(x, 'norm')
(0.44435602715924361, 0.038850142705171065)
```

```
>>> np.random.seed(987654321) # set random seed to get the same result
>>> stats.kstest('norm', False, N=100)
(0.058352892479417884, 0.88531190944151261)
```

The above lines are equivalent to:

```
>>> np.random.seed(987654321)
>>> stats.kstest(stats.norm.rvs(size=100), 'norm')
(0.058352892479417884, 0.88531190944151261)
```

*Test against one-sided alternative hypothesis*

Shift distribution to larger values, so that  $\text{cdf\_dgp}(x) < \text{norm.cdf}(x)$ :

```
>>> np.random.seed(987654321)
>>> x = stats.norm.rvs(loc=0.2, size=100)
>>> stats.kstest(x, 'norm', alternative = 'less')
(0.12464329735846891, 0.040989164077641749)
```

Reject equal distribution against alternative hypothesis: less

```
>>> stats.kstest(x, 'norm', alternative = 'greater')
(0.0072115233216311081, 0.98531158590396395)
```

Don't reject equal distribution against alternative hypothesis: greater

```
>>> stats.kstest(x, 'norm', mode='asympt')
(0.12464329735846891, 0.08944488871182088)
```

*Testing t distributed random variables against normal distribution*

With 100 degrees of freedom the t distribution looks close to the normal distribution, and the K-S test does not reject the hypothesis that the sample came from the normal distribution:

```
>>> np.random.seed(987654321)
>>> stats.kstest(stats.t.rvs(100, size=100), 'norm')
(0.072018929165471257, 0.67630062862479168)
```

With 3 degrees of freedom the t distribution looks sufficiently different from the normal distribution, that we can reject the hypothesis that the sample came from the normal distribution at the 10% level:

```
>>> np.random.seed(987654321)
>>> stats.kstest(stats.t.rvs(3, size=100), 'norm')
(0.131016895759829, 0.058826222555312224)
```

`scipy.stats.chisquare` (*f\_obs*, *f\_exp*=None, *ddof*=0, *axis*=0)

Calculate a one-way chi square test.

The chi square test tests the null hypothesis that the categorical data has the given frequencies.

**Parameters**

- f\_obs** : array\_like  
Observed frequencies in each category.
- f\_exp** : array\_like, optional  
Expected frequencies in each category. By default the categories are assumed to be equally likely.
- ddof** : int, optional  
“Delta degrees of freedom”: adjustment to the degrees of freedom for the p-value. The p-value is computed using a chi-squared distribution with  $k - 1 - \text{ddof}$  degrees of freedom, where  $k$  is the number of observed frequencies. The default value of *ddof* is 0.
- axis** : int or None, optional  
The axis of the broadcast result of *f\_obs* and *f\_exp* along which to apply the test. If axis is None, all values in *f\_obs* are treated as a single data set. Default is 0.

**Returns**

- chisq** : float or ndarray  
The chi-squared test statistic. The value is a float if *axis* is None or *f\_obs* and *f\_exp* are 1-D.
- p** : float or ndarray  
The p-value of the test. The value is a float if *ddof* and the return value *chisq* are scalars.

**See also:**

`power_divergence`, `mstats.chisquare`

**Notes**

This test is invalid when the observed or expected frequencies in each category are too small. A typical rule is that all of the observed and expected frequencies should be at least 5.

The default degrees of freedom,  $k-1$ , are for the case when no parameters of the distribution are estimated. If  $p$  parameters are estimated by efficient maximum likelihood then the correct degrees of freedom are  $k-1-p$ . If the parameters are estimated in a different way, then the dof can be between  $k-1-p$  and  $k-1$ . However, it is also possible that the asymptotic distribution is not a chisquare, in which case this test is not appropriate.

**References**

[R621], [R622]

**Examples**

When just `f_obs` is given, it is assumed that the expected frequencies are uniform and given by the mean of the observed frequencies.

```
>>> from scipy.stats import chisquare
>>> chisquare([16, 18, 16, 14, 12, 12])
(2.0, 0.84914503608460956)
```

With `f_exp` the expected frequencies can be given.

```
>>> chisquare([16, 18, 16, 14, 12, 12], f_exp=[16, 16, 16, 16, 16, 8])
(3.5, 0.62338762774958223)
```

When `f_obs` is 2-D, by default the test is applied to each column.

```
>>> obs = np.array([[16, 18, 16, 14, 12, 12], [32, 24, 16, 28, 20, 24]]).T
>>> obs.shape
(6, 2)
>>> chisquare(obs)
(array([ 2.          ,  6.66666667]), array([ 0.84914504,  0.24663415]))
```

By setting `axis=None`, the test is applied to all data in the array, which is equivalent to applying the test to the flattened array.

```
>>> chisquare(obs, axis=None)
(23.31034482758621, 0.015975692534127565)
>>> chisquare(obs.ravel())
(23.31034482758621, 0.015975692534127565)
```

`ddof` is the change to make to the default degrees of freedom.

```
>>> chisquare([16, 18, 16, 14, 12, 12], ddof=1)
(2.0, 0.73575888234288467)
```

The calculation of the p-values is done by broadcasting the chi-squared statistic with `ddof`.

```
>>> chisquare([16, 18, 16, 14, 12, 12], ddof=[0,1,2])
(2.0, array([ 0.84914504,  0.73575888,  0.5724067 ]))
```

$f_{obs}$  and  $f_{exp}$  are also broadcast. In the following,  $f_{obs}$  has shape (6,) and  $f_{exp}$  has shape (2, 6), so the result of broadcasting  $f_{obs}$  and  $f_{exp}$  has shape (2, 6). To compute the desired chi-squared statistics, we use `axis=1`:

```
>>> chisquare([16, 18, 16, 14, 12, 12],
...           f_exp=[[16, 16, 16, 16, 16, 8], [8, 20, 20, 16, 12, 12]],
...           axis=1)
(array([ 3.5 ,  9.25]), array([ 0.62338763,  0.09949846]))
```

`scipy.stats.power_divergence` ( $f_{obs}$ ,  $f_{exp}=None$ ,  $ddof=0$ ,  $axis=0$ ,  $lambda_=None$ )

Cressie-Read power divergence statistic and goodness of fit test.

This function tests the null hypothesis that the categorical data has the given frequencies, using the Cressie-Read power divergence statistic.

**Parameters** `f_obs` : array\_like

Observed frequencies in each category.

`f_exp` : array\_like, optional

Expected frequencies in each category. By default the categories are assumed to be equally likely.

`ddof` : int, optional

“Delta degrees of freedom”: adjustment to the degrees of freedom for the p-value. The p-value is computed using a chi-squared distribution with  $k - 1 - ddof$  degrees of freedom, where  $k$  is the number of observed frequencies. The default value of `ddof` is 0.

`axis` : int or None, optional

The axis of the broadcast result of  $f_{obs}$  and  $f_{exp}$  along which to apply the test. If axis is None, all values in  $f_{obs}$  are treated as a single data set. Default is 0.

`lambda_` : float or str, optional

`lambda_` gives the power in the Cressie-Read power divergence statistic. The default is 1. For convenience, `lambda_` may be assigned one of the following strings, in which case the corresponding numerical value is used:

String	Value	Description
"pearson"	1	Pearson's chi-squared <code>statistic</code> . In this case, the function <code>is chisquare`</code> is equivalent to <code>stats.log-likelihood`</code> .
"log-likelihood"	0	Log-likelihood ratio. Also known as the G-test [R684].
"freeman-tukey"	-1/2	Freeman-Tukey statistic.
"mod-log-likelihood"	-1	Modified log-likelihood <code>ratio</code> .
"neyman"	-2	Neyman's statistic.
"cressie-read"	2/3	The power recommended in [R686].

**Returns** `statistic` : float or ndarray

The Cressie-Read power divergence test statistic. The value is a float if `axis` is None or if  $f_{obs}$  and  $f_{exp}$  are 1-D.

`pvalue` : float or ndarray

The p-value of the test. The value is a float if `ddof` and the return value `stat` are scalars.

**See also:**

*chisquare*

**Notes**

This test is invalid when the observed or expected frequencies in each category are too small. A typical rule is that all of the observed and expected frequencies should be at least 5.

When *lambda\_* is less than zero, the formula for the statistic involves dividing by *f\_obs*, so a warning or error may be generated if any value in *f\_obs* is 0.

Similarly, a warning or error may be generated if any value in *f\_exp* is zero when *lambda\_*  $\geq$  0.

The default degrees of freedom, *k*-1, are for the case when no parameters of the distribution are estimated. If *p* parameters are estimated by efficient maximum likelihood then the correct degrees of freedom are *k*-1-*p*. If the parameters are estimated in a different way, then the dof can be between *k*-1-*p* and *k*-1. However, it is also possible that the asymptotic distribution is not a chisquare, in which case this test is not appropriate.

This function handles masked arrays. If an element of *f\_obs* or *f\_exp* is masked, then data at that position is ignored, and does not count towards the size of the data set.

New in version 0.13.0.

**References**

[R682], [R683], [R684], [R685], [R686]

**Examples**

(See *chisquare* for more examples.)

When just *f\_obs* is given, it is assumed that the expected frequencies are uniform and given by the mean of the observed frequencies. Here we perform a G-test (i.e. use the log-likelihood ratio statistic):

```
>>> from scipy.stats import power_divergence
>>> power_divergence([16, 18, 16, 14, 12, 12], lambda_='log-likelihood')
(2.006573162632538, 0.84823476779463769)
```

The expected frequencies can be given with the *f\_exp* argument:

```
>>> power_divergence([16, 18, 16, 14, 12, 12],
...                  f_exp=[16, 16, 16, 16, 16, 8],
...                  lambda_='log-likelihood')
(3.3281031458963746, 0.6495419288047497)
```

When *f\_obs* is 2-D, by default the test is applied to each column.

```
>>> obs = np.array([[16, 18, 16, 14, 12, 12], [32, 24, 16, 28, 20, 24]])
>>> obs.shape
(6, 2)
>>> power_divergence(obs, lambda_="log-likelihood")
(array([ 2.00657316,  6.77634498]), array([ 0.84823477,  0.23781225]))
```

By setting *axis=None*, the test is applied to all data in the array, which is equivalent to applying the test to the flattened array.

```
>>> power_divergence(obs, axis=None)
(23.31034482758621, 0.015975692534127565)
>>> power_divergence(obs.ravel())
(23.31034482758621, 0.015975692534127565)
```

*ddof* is the change to make to the default degrees of freedom.

```
>>> power_divergence([16, 18, 16, 14, 12, 12], ddof=1)
(2.0, 0.73575888234288467)
```

The calculation of the p-values is done by broadcasting the test statistic with *ddof*.

```
>>> power_divergence([16, 18, 16, 14, 12, 12], ddof=[0,1,2])
(2.0, array([ 0.84914504,  0.73575888,  0.5724067 ]))
```

*f\_obs* and *f\_exp* are also broadcast. In the following, *f\_obs* has shape (6,) and *f\_exp* has shape (2, 6), so the result of broadcasting *f\_obs* and *f\_exp* has shape (2, 6). To compute the desired chi-squared statistics, we must use `axis=1`:

```
>>> power_divergence([16, 18, 16, 14, 12, 12],
...                  f_exp=[[16, 16, 16, 16, 16, 8],
...                         [8, 20, 20, 16, 12, 12]],
...                  axis=1)
(array([ 3.5 ,  9.25]), array([ 0.62338763,  0.09949846]))
```

`scipy.stats.ks_2samp` (*data1*, *data2*)

Compute the Kolmogorov-Smirnov statistic on 2 samples.

This is a two-sided test for the null hypothesis that 2 independent samples are drawn from the same continuous distribution.

<b>Parameters</b>	<b>data1, data2</b> : sequence of 1-D ndarrays
	two arrays of sample observations assumed to be drawn from a continuous distribution, sample sizes can be different
<b>Returns</b>	<b>statistic</b> : float
	KS statistic
	<b>pvalue</b> : float
	two-tailed p-value

### Notes

This tests whether 2 samples are drawn from the same distribution. Note that, like in the case of the one-sample K-S test, the distribution is assumed to be continuous.

This is the two-sided test, one-sided tests are not implemented. The test uses the two-sided asymptotic Kolmogorov-Smirnov distribution.

If the K-S statistic is small or the p-value is high, then we cannot reject the hypothesis that the distributions of the two samples are the same.

### Examples

```
>>> from scipy import stats
>>> np.random.seed(12345678) #fix random seed to get the same result
>>> n1 = 200 # size of first sample
>>> n2 = 300 # size of second sample
```

For a different distribution, we can reject the null hypothesis since the pvalue is below 1%:

```
>>> rvs1 = stats.norm.rvs(size=n1, loc=0., scale=1)
>>> rvs2 = stats.norm.rvs(size=n2, loc=0.5, scale=1.5)
>>> stats.ks_2samp(rvs1, rvs2)
(0.20833333333333337, 4.6674975515806989e-005)
```

For a slightly different distribution, we cannot reject the null hypothesis at a 10% or lower alpha since the p-value at 0.144 is higher than 10%

```
>>> rvs3 = stats.norm.rvs(size=n2, loc=0.01, scale=1.0)
>>> stats.ks_2samp(rvs1, rvs3)
(0.10333333333333333, 0.14498781825751686)
```

For an identical distribution, we cannot reject the null hypothesis since the p-value is high, 41%:

```
>>> rvs4 = stats.norm.rvs(size=n2, loc=0.0, scale=1.0)
>>> stats.ks_2samp(rvs1, rvs4)
(0.079999999999999996, 0.41126949729859719)
```

`scipy.stats.mannwhitneyu(x, y, use_continuity=True, alternative=None)`

Compute the Mann-Whitney rank test on samples x and y.

**Parameters**

- x, y** : array\_like  
Array of samples, should be one-dimensional.
- use\_continuity** : bool, optional  
Whether a continuity correction (1/2.) should be taken into account. Default is True.
- alternative** : None (deprecated), 'less', 'two-sided', or 'greater'  
Whether to get the p-value for the one-sided hypothesis ('less' or 'greater') or for the two-sided hypothesis ('two-sided'). Defaults to None, which results in a p-value half the size of the 'two-sided' p-value and a different U statistic. The default behavior is not the same as using 'less' or 'greater': it only exists for backward compatibility and is deprecated.

**Returns**

- statistic** : float  
The Mann-Whitney U statistic, equal to  $\min(U \text{ for } x, U \text{ for } y)$  if *alternative* is equal to None (deprecated; exists for backward compatibility), and U for y otherwise.
- pvalue** : float  
p-value assuming an asymptotic normal distribution. One-sided or two-sided, depending on the choice of *alternative*.

**Notes**

Use only when the number of observation in each sample is > 20 and you have 2 independent samples of ranks. Mann-Whitney U is significant if the u-obtained is LESS THAN or equal to the critical value of U.

This test corrects for ties and by default uses a continuity correction.

**References**

[R665], [R666]

`scipy.stats.tiecorrect(rankvals)`

Tie correction factor for ties in the Mann-Whitney U and Kruskal-Wallis H tests.

**Parameters**

- rankvals** : array\_like  
A 1-D sequence of ranks. Typically this will be the array returned by `stats.rankdata`.

**Returns**

- factor** : float  
Correction factor for U or H.

**See also:**

**rankdata** Assign ranks to the data  
**mannwhitneyu** Mann-Whitney rank test

**kruskal** Kruskal-Wallis H test

### References

[R703]

### Examples

```
>>> from scipy.stats import tiecorrect, rankdata
>>> tiecorrect([1, 2.5, 2.5, 4])
0.9
>>> ranks = rankdata([1, 3, 2, 4, 5, 7, 2, 8, 4])
>>> ranks
array([ 1. ,  4. ,  2.5,  5.5,  7. ,  8. ,  2.5,  9. ,  5.5])
>>> tiecorrect(ranks)
0.9833333333333333
```

`scipy.stats.rankdata` (*a*, *method*='average')

Assign ranks to data, dealing with ties appropriately.

Ranks begin at 1. The *method* argument controls how ranks are assigned to equal values. See [R690] for further discussion of ranking methods.

**Parameters** **a** : array\_like

The array of values to be ranked. The array is first flattened.

**method** : str, optional

The method used to assign ranks to tied elements. The options are 'average', 'min', 'max', 'dense' and 'ordinal'.

**'average'**: The average of the ranks that would have been assigned to all the tied values is assigned to each value.

**'min'**: The minimum of the ranks that would have been assigned to all the tied values is assigned to each value. (This is also referred to as "competition" ranking.)

**'max'**: The maximum of the ranks that would have been assigned to all the tied values is assigned to each value.

**'dense'**: Like 'min', but the rank of the next highest element is assigned the rank immediately after those assigned to the tied elements.

**'ordinal'**: All values are given a distinct rank, corresponding to the order that the values occur in *a*.

**Returns** **ranks** : ndarray

The default is 'average'.

An array of length equal to the size of *a*, containing rank scores.

### References

[R690]

### Examples

```
>>> from scipy.stats import rankdata
>>> rankdata([0, 2, 3, 2])
array([ 1. ,  2.5,  4. ,  2.5])
>>> rankdata([0, 2, 3, 2], method='min')
array([ 1,  2,  4,  2])
>>> rankdata([0, 2, 3, 2], method='max')
array([ 1,  3,  4,  3])
>>> rankdata([0, 2, 3, 2], method='dense')
array([ 1,  2,  3,  2])
>>> rankdata([0, 2, 3, 2], method='ordinal')
array([ 1,  2,  4,  3])
```

`scipy.stats.ranksums(x, y)`

Compute the Wilcoxon rank-sum statistic for two samples.

The Wilcoxon rank-sum test tests the null hypothesis that two sets of measurements are drawn from the same distribution. The alternative hypothesis is that values in one sample are more likely to be larger than the values in the other sample.

This test should be used to compare two samples from continuous distributions. It does not handle ties between measurements in  $x$  and  $y$ . For tie-handling and an optional continuity correction see `scipy.stats.mannwhitneyu`.

**Parameters** `x,y` : array\_like  
 The data from the two samples

**Returns** `statistic` : float  
 The test statistic under the large-sample approximation that the rank sum statistic is normally distributed

`pvalue` : float  
 The two-sided p-value of the test

**References**

[R691]

`scipy.stats.wilcoxon(x, y=None, zero_method='wilcox', correction=False)`

Calculate the Wilcoxon signed-rank test.

The Wilcoxon signed-rank test tests the null hypothesis that two related paired samples come from the same distribution. In particular, it tests whether the distribution of the differences  $x - y$  is symmetric about zero. It is a non-parametric version of the paired T-test.

**Parameters** `x` : array\_like  
 The first set of measurements.

`y` : array\_like, optional  
 The second set of measurements. If  $y$  is not given, then the  $x$  array is considered to be the differences between the two sets of measurements.

**zero\_method** : string, {"pratt", "wilcox", "zsplit"}, optional  
 "pratt": Pratt treatment: includes zero-differences in the ranking process (more conservative)  
 "wilcox": Wilcox treatment: discards all zero-differences  
 "zsplit": Zero rank split: just like Pratt, but splitting the zero rank between positive and negative ones

**correction** : bool, optional  
 If True, apply continuity correction by adjusting the Wilcoxon rank statistic by 0.5 towards the mean value when computing the z-statistic. Default is False.

**Returns** `statistic` : float  
 The sum of the ranks of the differences above or below zero, whichever is smaller.

`pvalue` : float  
 The two-sided p-value for the test.

**Notes**

Because the normal approximation is used for the calculations, the samples used should be large. A typical rule is to require that  $n > 20$ .

**References**

[R715]

`scipy.stats.kruskal(*args, **kwargs)`

Compute the Kruskal-Wallis H-test for independent samples

The Kruskal-Wallis H-test tests the null hypothesis that the population median of all of the groups are equal. It is a non-parametric version of ANOVA. The test works on 2 or more independent samples, which may have different sizes. Note that rejecting the null hypothesis does not indicate which of the groups differs. Post-hoc comparisons between groups are required to determine which groups are different.

<b>Parameters</b>	<b>sample1, sample2, ...</b> : array_like Two or more arrays with the sample measurements can be given as arguments.
	<b>nan_policy</b> : {'propagate', 'raise', 'omit'}, optional Defines how to handle when input contains nan. 'propagate' returns nan, 'raise' throws an error, 'omit' performs the calculations ignoring nan values. Default is 'propagate'.
<b>Returns</b>	<b>statistic</b> : float The Kruskal-Wallis H statistic, corrected for ties
	<b>pvalue</b> : float The p-value for the test using the assumption that H has a chi square distribution

**See also:**

**f\_oneway** 1-way ANOVA

**mannwhitneyu**

Mann-Whitney rank test on two samples.

**friedmanchisquare**

Friedman test for repeated measurements

**Notes**

Due to the assumption that H has a chi square distribution, the number of samples in each group must not be too small. A typical rule is that each sample must have at least 5 measurements.

**References**

[R658], [R659]

**Examples**

```
>>> from scipy import stats
>>> x = [1, 3, 5, 7, 9]
>>> y = [2, 4, 6, 8, 10]
>>> stats.kruskal(x, y)
KruskalResult(statistic=0.27272727272727337, pvalue=0.60150813444058948)
```

```
>>> x = [1, 1, 1]
>>> y = [2, 2, 2]
>>> z = [2, 2]
>>> stats.kruskal(x, y, z)
KruskalResult(statistic=7.0, pvalue=0.030197383422318501)
```

`scipy.stats.friedmanchisquare(*args)`

Compute the Friedman test for repeated measurements

The Friedman test tests the null hypothesis that repeated measurements of the same individuals have the same distribution. It is often used to test for consistency among measurements obtained in different ways. For example, if two measurement techniques are used on the same set of individuals, the Friedman test can be used to determine if the two measurement techniques are consistent.

**Parameters** **measurements1, measurements2, measurements3...** : array\_like  
 Arrays of measurements. All of the arrays must have the same number of elements. At least 3 sets of measurements must be given.

**Returns** **statistic** : float  
 the test statistic, correcting for ties

**pvalue** : float  
 the associated p-value assuming that the test statistic has a chi squared distribution

**Notes**

Due to the assumption that the test statistic has a chi squared distribution, the p-value is only reliable for  $n > 10$  and more than 6 repeated measurements.

**References**

[R641]

`scipy.stats.combine_pvalues` (*pvalues*, *method='fisher'*, *weights=None*)

Methods for combining the p-values of independent tests bearing upon the same hypothesis.

**Parameters** **pvalues** : array\_like, 1-D  
 Array of p-values assumed to come from independent tests.

**method** : {'fisher', 'stouffer'}, optional  
 Name of method to use to combine p-values. The following methods are available:

- “fisher”: Fisher’s method (Fisher’s combined probability test), the default.
- stouffer: Stouffer’s Z-score method.

**weights** : array\_like, 1-D, optional  
 Optional array of weights used only for Stouffer’s Z-score method.

**Returns** **statistic**: float  
 The statistic calculated by the specified method: - “fisher”: The chi-squared statistic - “stouffer”: The Z-score

**pval**: float  
 The combined p-value.

**Notes**

Fisher’s method (also known as Fisher’s combined probability test) [R623] uses a chi-squared statistic to compute a combined p-value. The closely related Stouffer’s Z-score method [R624] uses Z-scores rather than p-values. The advantage of Stouffer’s method is that it is straightforward to introduce weights, which can make Stouffer’s method more powerful than Fisher’s method when the p-values are from studies of different size [R625] [R626].

Fisher’s method may be extended to combine p-values from dependent tests [R627]. Extensions such as Brown’s method and Kost’s method are not currently implemented.

New in version 0.15.0.

**References**

[R623], [R624], [R625], [R626], [R627]

`scipy.stats.jarque_bera` (*x*)

Perform the Jarque-Bera goodness of fit test on sample data.

The Jarque-Bera test tests whether the sample data has the skewness and kurtosis matching a normal distribution.

Note that this test only works for a large enough number of data samples (>2000) as the test statistic asymptotically has a Chi-squared distribution with 2 degrees of freedom.

**Parameters** `x` : array\_like  
**Returns** `jb_value` : float Observations of a random variable.  
The test statistic.  
`p` : float  
The p-value for the hypothesis test.

**References**

[R653]

**Examples**

```
>>> from scipy import stats
>>> np.random.seed(987654321)
>>> x = np.random.normal(0, 1, 100000)
>>> y = np.random.rayleigh(1, 100000)
>>> stats.jarque_bera(x)
(4.7165707989581342, 0.09458225503041906)
>>> stats.jarque_bera(y)
(6713.7098548143422, 0.0)
```

<code>ansari(x, y)</code>	Perform the Ansari-Bradley test for equal scale parameters
<code>bartlett(*args)</code>	Perform Bartlett's test for equal variances
<code>levene(*args, **kwds)</code>	Perform Levene test for equal variances.
<code>shapiro(x)</code>	Perform the Shapiro-Wilk test for normality.
<code>anderson(x[, dist])</code>	Anderson-Darling test for data coming from a particular distribution
<code>anderson_ksamp(samples[, midrank])</code>	The Anderson-Darling test for k-samples.
<code>binom_test(x[, n, p, alternative])</code>	Perform a test that the probability of success is p.
<code>fligner(*args, **kwds)</code>	Perform Fligner-Killeen test for equality of variance.
<code>median_test(*args, **kwds)</code>	Mood's median test.
<code>mood(x, y[, axis])</code>	Perform Mood's test for equal scale parameters.

`scipy.stats.ansari(x, y)`

Perform the Ansari-Bradley test for equal scale parameters

The Ansari-Bradley test is a non-parametric test for the equality of the scale parameter of the distributions from which two samples were drawn.

**Parameters** `x, y` : array\_like  
**Returns** `statistic` : float arrays of sample data  
The Ansari-Bradley test statistic  
`pvalue` : float  
The p-value of the hypothesis test

**See also:**

**fligner** A non-parametric test for the equality of k variances  
**mood** A non-parametric test for the equality of two scale parameters

**Notes**

The p-value given is exact when the sample sizes are both less than 55 and there are no ties, otherwise a normal approximation for the p-value is used.

### References

[R608]

`scipy.stats.bartlett` (\*args)

Perform Bartlett's test for equal variances

Bartlett's test tests the null hypothesis that all input samples are from populations with equal variances. For samples from significantly non-normal populations, Levene's test `levene` is more robust.

**Parameters** `sample1, sample2,...` : array\_like  
arrays of sample data. May be different lengths.

**Returns** `statistic` : float  
The test statistic.

`pvalue` : float  
The p-value of the test.

### See also:

**fligner** A non-parametric test for the equality of k variances  
**levene** A robust parametric test for equality of k variances

### Notes

Conover et al. (1981) examine many of the existing parametric and nonparametric tests by extensive simulations and they conclude that the tests proposed by Fligner and Killeen (1976) and Levene (1960) appear to be superior in terms of robustness of departures from normality and power [R612].

### References

[R610], [R611], [R612], [R613]

`scipy.stats.levene` (\*args, \*\*kwds)

Perform Levene test for equal variances.

The Levene test tests the null hypothesis that all input samples are from populations with equal variances. Levene's test is an alternative to Bartlett's test `bartlett` in the case where there are significant deviations from normality.

**Parameters** `sample1, sample2, ...` : array\_like  
The sample data, possibly with different lengths

`center` : {'mean', 'median', 'trimmed'}, optional  
Which function of the data to use in the test. The default is 'median'.

`proportiontocut` : float, optional  
When `center` is 'trimmed', this gives the proportion of data points to cut from each end. (See `scipy.stats.trim_mean`.) Default is 0.05.

**Returns** `statistic` : float  
The test statistic.

`pvalue` : float  
The p-value for the test.

### Notes

Three variations of Levene's test are possible. The possibilities and their recommended usages are:

- 'median' : Recommended for skewed (non-normal) distributions>
- 'mean' : Recommended for symmetric, moderate-tailed distributions.
- 'trimmed' : Recommended for heavy-tailed distributions.

**References**

[R662], [R663], [R664]

`scipy.stats.shapiro(x)`

Perform the Shapiro-Wilk test for normality.

The Shapiro-Wilk test tests the null hypothesis that the data was drawn from a normal distribution.

**Parameters** `x` : array\_like  
 Array of sample data.

**Returns** `W` : float  
 The test statistic.

`p-value` : float  
 The p-value for the hypothesis test.

**See also:**

**anderson** The Anderson-Darling test for normality

**kstest** The Kolmogorov-Smirnov test for goodness of fit.

**Notes**

The algorithm used is described in [R695] but censoring parameters as described are not implemented. For  $N > 5000$  the  $W$  test statistic is accurate but the p-value may not be.

The chance of rejecting the null hypothesis when it is true is close to 5% regardless of sample size.

**References**

[R692], [R693], [R694], [R695]

**Examples**

```
>>> from scipy import stats
>>> np.random.seed(12345678)
>>> x = stats.norm.rvs(loc=5, scale=3, size=100)
>>> stats.shapiro(x)
(0.9772805571556091, 0.08144091814756393)
```

`scipy.stats.anderson(x, dist='norm')`

Anderson-Darling test for data coming from a particular distribution

The Anderson-Darling test is a modification of the Kolmogorov-Smirnov test `kstest` for the null hypothesis that a sample is drawn from a population that follows a particular distribution. For the Anderson-Darling test, the critical values depend on which distribution is being tested against. This function works for normal, exponential, logistic, or Gumbel (Extreme Value Type I) distributions.

**Parameters** `x` : array\_like  
 array of sample data

**dist** : {'norm', 'expon', 'logistic', 'gumbel', 'gumbel\_l', 'gumbel\_r', 'extreme1'}, optional the type of distribution to test against. The default is 'norm' and 'extreme1', 'gumbel\_l' and 'gumbel' are synonyms.

**Returns** **statistic** : float  
 The Anderson-Darling test statistic

**critical\_values** : list  
 The critical values for this distribution

**significance\_level** : list  
 The significance levels for the corresponding critical values in percents. The function returns critical values for a differing set of significance levels depending on the distribution that is being tested against.

*Notes*

Critical values provided are for the following significance levels:

**normal/exponential**

15%, 10%, 5%, 2.5%, 1%

**logistic** 25%, 10%, 5%, 2.5%, 1%, 0.5%

**Gumbel** 25%, 10%, 5%, 2.5%, 1%

If  $A_2$  is larger than these critical values then for the corresponding significance level, the null hypothesis that the data come from the chosen distribution can be rejected.

*References*

[R601], [R602], [R603], [R604], [R605], [R606]

`scipy.stats.anderson_ksamp` (*samples*, *midrank=True*)

The Anderson-Darling test for k-samples.

The k-sample Anderson-Darling test is a modification of the one-sample Anderson-Darling test. It tests the null hypothesis that k-samples are drawn from the same population without having to specify the distribution function of that population. The critical values depend on the number of samples.

<b>Parameters</b>	<p><b>samples</b> : sequence of 1-D array_like Array of sample data in arrays.</p> <p><b>midrank</b> : bool, optional Type of Anderson-Darling test which is computed. Default (True) is the midrank test applicable to continuous and discrete populations. If False, the right side empirical distribution is used.</p>
<b>Returns</b>	<p><b>statistic</b> : float Normalized k-sample Anderson-Darling test statistic.</p> <p><b>critical_values</b> : array The critical values for significance levels 25%, 10%, 5%, 2.5%, 1%.</p> <p><b>significance_level</b> : float An approximate significance level at which the null hypothesis for the provided samples can be rejected.</p>
<b>Raises</b>	<p><b>ValueError</b> If less than 2 samples are provided, a sample is empty, or no distinct observations are in the samples.</p>

**See also:**

**ks\_2samp** 2 sample Kolmogorov-Smirnov test

**anderson** 1 sample Anderson-Darling test

*Notes*

[R607] Defines three versions of the k-sample Anderson-Darling test: one for continuous distributions and two for discrete distributions, in which ties between samples may occur. The default of this routine is to compute the version based on the midrank empirical distribution function. This test is applicable to continuous and discrete data. If midrank is set to False, the right side empirical distribution is used for a test for discrete data. According to [R607], the two discrete test statistics differ only slightly if a few collisions due to round-off errors occur in the test not adjusted for ties between samples.

New in version 0.14.0.

*References*

[R607]

### Examples

```
>>> from scipy import stats
>>> np.random.seed(314159)
```

The null hypothesis that the two random samples come from the same distribution can be rejected at the 5% level because the returned test value is greater than the critical value for 5% (1.961) but not at the 2.5% level. The interpolation gives an approximate significance level of 3.1%:

```
>>> stats.anderson_ksamp([np.random.normal(size=50),
... np.random.normal(loc=0.5, size=30)])
(2.4615796189876105,
 array([ 0.325,  1.226,  1.961,  2.718,  3.752]),
 0.03134990135800783)
```

The null hypothesis cannot be rejected for three samples from an identical distribution. The approximate p-value (87%) has to be computed by extrapolation and may not be very accurate:

```
>>> stats.anderson_ksamp([np.random.normal(size=50),
... np.random.normal(size=30), np.random.normal(size=20)])
(-0.73091722665244196,
 array([ 0.44925884,  1.3052767 ,  1.9434184 ,  2.57696569,  3.41634856]),
 0.8789283903979661)
```

`scipy.stats.binom_test(x, n=None, p=0.5, alternative='two-sided')`

Perform a test that the probability of success is  $p$ .

This is an exact, two-sided test of the null hypothesis that the probability of success in a Bernoulli experiment is  $p$ .

**Parameters**

- x** : integer or array\_like  
the number of successes, or if x has length 2, it is the number of successes and the number of failures.
- n** : integer  
the number of trials. This is ignored if x gives both the number of successes and failures
- p** : float, optional  
The hypothesized probability of success.  $0 \leq p \leq 1$ . The default value is  $p = 0.5$
- alternative** : {'two-sided', 'greater', 'less'}, optional  
Indicates the alternative hypothesis. The default value is 'two-sided'.

**Returns**

- p-value** : float  
The p-value of the hypothesis test

### References

[R614]

`scipy.stats.fligner(*args, **kws)`

Perform Fligner-Killeen test for equality of variance.

Fligner's test tests the null hypothesis that all input samples are from populations with equal variances. Fligner-Killeen's test is distribution free when populations are identical [R638].

**Parameters**

- sample1, sample2, ...** : array\_like  
Arrays of sample data. Need not be the same length.
- center** : {'mean', 'median', 'trimmed'}, optional  
Keyword argument controlling which function of the data is used in computing the test statistic. The default is 'median'.

**Returns**

- proportiontocut** : float, optional  
When *center* is ‘trimmed’, this gives the proportion of data points to cut from each end. (See `scipy.stats.trim_mean`.) Default is 0.05.
- statistic** : float  
The test statistic.
- pvalue** : float  
The p-value for the hypothesis test.

**See also:**

**bartlett** A parametric test for equality of k variances in normal samples  
**levene** A robust parametric test for equality of k variances

**Notes**

As with Levene’s test there are three variants of Fligner’s test that differ by the measure of central tendency used in the test. See *levene* for more information.

Conover et al. (1981) examine many of the existing parametric and nonparametric tests by extensive simulations and they conclude that the tests proposed by Fligner and Killeen (1976) and Levene (1960) appear to be superior in terms of robustness of departures from normality and power [R639].

**References**

[R637], [R638], [R639], [R640]

`scipy.stats.median_test` (\*args, \*\*kws)  
 Mood’s median test.

Test that two or more samples come from populations with the same median.

Let  $n = \text{len}(\text{args})$  be the number of samples. The “grand median” of all the data is computed, and a contingency table is formed by classifying the values in each sample as being above or below the grand median. The contingency table, along with *correction* and *lambda\_*, are passed to `scipy.stats.chi2_contingency` to compute the test statistic and p-value.

**Parameters**

- sample1, sample2, ...** : array\_like  
The set of samples. There must be at least two samples. Each sample must be a one-dimensional sequence containing at least one value. The samples are not required to have the same length.
- ties** : str, optional  
Determines how values equal to the grand median are classified in the contingency table. The string must be one of:

```

"below":
    Values equal to the grand median are counted as
    ↳"below".
"above":
    Values equal to the grand median are counted as
    ↳"above".
"ignore":
    Values equal to the grand median are not counted.
```

The default is “below”.

- correction** : bool, optional  
If True, *and* there are just two samples, apply Yates’ correction for continuity when computing the test statistic associated with the contingency table. Default is True.
- lambda\_** : float or str, optional.

By default, the statistic computed in this test is Pearson’s chi-squared statistic. *lambda\_* allows a statistic from the Cressie-Read power divergence family to be used instead. See *power\_divergence* for details. Default is 1 (Pearson’s chi-squared statistic).

	<b>nan_policy</b> :	{‘propagate’, ‘raise’, ‘omit’}, optional	Defines how to handle when input contains nan. ‘propagate’ returns nan, ‘raise’ throws an error, ‘omit’ performs the calculations ignoring nan values. Default is ‘propagate’.
<b>Returns</b>	<b>stat</b> :	float	The test statistic. The statistic that is returned is determined by <i>lambda_</i> . The default is Pearson’s chi-squared statistic.
	<b>p</b> :	float	The p-value of the test.
	<b>m</b> :	float	The grand median.
	<b>table</b> :	ndarray	The contingency table. The shape of the table is (2, n), where n is the number of samples. The first row holds the counts of the values above the grand median, and the second row holds the counts of the values below the grand median. The table allows further analysis with, for example, <i>scipy.stats.chi2_contingency</i> , or with <i>scipy.stats.fisher_exact</i> if there are two samples, without having to recompute the table. If <i>nan_policy</i> is “propagate” and there are nans in the input, the return value for <i>table</i> is None.

#### See also:

**kruskal** Compute the Kruskal-Wallis H-test for independent samples.

**mannwhitneyu**

Computes the Mann-Whitney rank test on samples x and y.

#### Notes

New in version 0.15.0.

#### References

[R668], [R669]

#### Examples

A biologist runs an experiment in which there are three groups of plants. Group 1 has 16 plants, group 2 has 15 plants, and group 3 has 17 plants. Each plant produces a number of seeds. The seed counts for each group are:

```
Group 1: 10 14 14 18 20 22 24 25 31 31 32 39 43 43 48 49
Group 2: 28 30 31 33 34 35 36 40 44 55 57 61 91 92 99
Group 3:  0  3  9 22 23 25 25 33 34 34 40 45 46 48 62 67 84
```

The following code applies Mood’s median test to these samples.

```
>>> g1 = [10, 14, 14, 18, 20, 22, 24, 25, 31, 31, 32, 39, 43, 43, 48, 49]
>>> g2 = [28, 30, 31, 33, 34, 35, 36, 40, 44, 55, 57, 61, 91, 92, 99]
>>> g3 = [0, 3, 9, 22, 23, 25, 25, 33, 34, 34, 40, 45, 46, 48, 62, 67, 84]
>>> from scipy.stats import median_test
>>> stat, p, med, tbl = median_test(g1, g2, g3)
```

The median is

```
>>> med
34.0
```

and the contingency table is

```
>>> tbl
array([[ 5, 10,  7],
       [11,  5, 10]])
```

$p$  is too large to conclude that the medians are not the same:

```
>>> p
0.12609082774093244
```

The “G-test” can be performed by passing `lambda_="log-likelihood"` to `median_test`.

```
>>> g, p, med, tbl = median_test(g1, g2, g3, lambda_="log-likelihood")
>>> p
0.12224779737117837
```

The median occurs several times in the data, so we’ll get a different result if, for example, `ties="above"` is used:

```
>>> stat, p, med, tbl = median_test(g1, g2, g3, ties="above")
>>> p
0.063873276069553273
```

```
>>> tbl
array([[ 5, 11,  9],
       [11,  4,  8]])
```

This example demonstrates that if the data set is not large and there are values equal to the median, the  $p$ -value can be sensitive to the choice of *ties*.

`scipy.stats.mood(x, y, axis=0)`

Perform Mood’s test for equal scale parameters.

Mood’s two-sample test for scale parameters is a non-parametric test for the null hypothesis that two samples are drawn from the same distribution with the same scale parameter.

**Parameters** `x, y` : array\_like  
 Arrays of sample data.

`axis` : int, optional  
 The axis along which the samples are tested.  $x$  and  $y$  can be of different length along *axis*. If *axis* is None,  $x$  and  $y$  are flattened and the test is done on all values in the flattened arrays.

**Returns** `z` : scalar or ndarray  
 The z-score for the hypothesis test. For 1-D inputs a scalar is returned.

**p-value** : scalar ndarray  
 The p-value for the hypothesis test.

See also:

**fligner** A non-parametric test for the equality of  $k$  variances  
**ansari** A non-parametric test for the equality of 2 variances  
**bartlett** A parametric test for equality of  $k$  variances in normal samples  
**levene** A parametric test for equality of  $k$  variances

**Notes**

The data are assumed to be drawn from probability distributions  $f(x)$  and  $f(x/s) / s$  respectively, for some probability density function  $f$ . The null hypothesis is that  $s == 1$ .

For multi-dimensional arrays, if the inputs are of shapes  $(n_0, n_1, n_2, n_3)$  and  $(n_0, m_1, n_2, n_3)$ , then if `axis=1`, the resulting `z` and `p` values will have shape  $(n_0, n_2, n_3)$ . Note that `n1` and `m1` don't have to be equal, but the other dimensions do.

**Examples**

```
>>> from scipy import stats
>>> np.random.seed(1234)
>>> x2 = np.random.randn(2, 45, 6, 7)
>>> x1 = np.random.randn(2, 30, 6, 7)
>>> z, p = stats.mood(x1, x2, axis=1)
>>> p.shape
(2, 6, 7)
```

Find the number of points where the difference in scale is not significant:

```
>>> (p > 0.1).sum()
74
```

Perform the test with different scales:

```
>>> x1 = np.random.randn(2, 30)
>>> x2 = np.random.randn(2, 35) * 10.0
>>> stats.mood(x1, x2, axis=1)
(array([-5.7178125 , -5.25342163]), array([ 1.07904114e-08,  1.49299218e-07]))
```

<code>boxcox(x[, lmbda, alpha])</code>	Return a positive dataset transformed by a Box-Cox power transformation.
<code>boxcox_normmax(x[, brack, method])</code>	Compute optimal Box-Cox transform parameter for input data.
<code>boxcox_llf(lmb, data)</code>	The boxcox log-likelihood function.
<code>entropy(pk[, qk, base])</code>	Calculate the entropy of a distribution for given probability values.

`scipy.stats.boxcox(x, lmbda=None, alpha=None)`

Return a positive dataset transformed by a Box-Cox power transformation.

**Parameters** `x` : ndarray

Input array. Should be 1-dimensional.

**lmbda** : {None, scalar}, optional

If `lmbda` is not None, do the transformation for that value.

If `lmbda` is None, find the lambda that maximizes the log-likelihood function and return it as the second output argument.

**alpha** : {None, float}, optional

If `alpha` is not None, return the  $100 * (1-\alpha)\%$  confidence interval for `lmbda` as the third output argument. Must be between 0.0 and 1.0.

**Returns**

**boxcox** : ndarray

Box-Cox power transformed array.

**maxlog** : float, optional

If the `lmbda` parameter is None, the second returned argument is the lambda that maximizes the log-likelihood function.

**(min\_ci, max\_ci)** : tuple of float, optional

If *lambda* parameter is None and *alpha* is not None, this returned tuple of floats represents the minimum and maximum confidence limits given *alpha*.

**See also:**

*probplot*, *boxcox\_normplot*, *boxcox\_normmax*, *boxcox\_llf*

**Notes**

The Box-Cox transform is given by:

```
y = (x**lambda - 1) / lambda,   for lambda > 0
    log(x),                    for lambda = 0
```

*boxcox* requires the input data to be positive. Sometimes a Box-Cox transformation provides a shift parameter to achieve this; *boxcox* does not. Such a shift parameter is equivalent to adding a positive constant to *x* before calling *boxcox*.

The confidence limits returned when *alpha* is provided give the interval where:

$$llf(\hat{\lambda}) - llf(\lambda) < \frac{1}{2}\chi^2(1 - \alpha, 1),$$

with *llf* the log-likelihood function and  $\chi^2$  the chi-squared function.

**References**

G.E.P. Box and D.R. Cox, “An Analysis of Transformations”, Journal of the Royal Statistical Society B, 26, 211-252 (1964).

**Examples**

```
>>> from scipy import stats
>>> import matplotlib.pyplot as plt
```

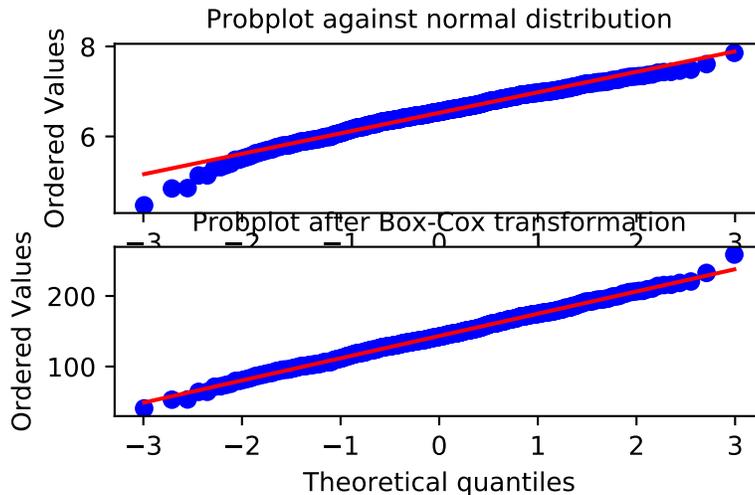
We generate some random variates from a non-normal distribution and make a probability plot for it, to show it is non-normal in the tails:

```
>>> fig = plt.figure()
>>> ax1 = fig.add_subplot(211)
>>> x = stats.loggamma.rvs(5, size=500) + 5
>>> prob = stats.probplot(x, dist=stats.norm, plot=ax1)
>>> ax1.set_xlabel('')
>>> ax1.set_title('Probplot against normal distribution')
```

We now use *boxcox* to transform the data so it’s closest to normal:

```
>>> ax2 = fig.add_subplot(212)
>>> xt, _ = stats.boxcox(x)
>>> prob = stats.probplot(xt, dist=stats.norm, plot=ax2)
>>> ax2.set_title('Probplot after Box-Cox transformation')
```

```
>>> plt.show()
```



```
scipy.stats.boxcox_normmax(x, brack=(-2.0, 2.0), method='pearsonr')
```

Compute optimal Box-Cox transform parameter for input data.

**Parameters** `x` : array\_like

Input array.

**brack** : 2-tuple, optional

The starting interval for a downhill bracket search with *optimize.brent*. Note that this is in most cases not critical; the final result is allowed to be outside this bracket.

**method** : str, optional

The method to determine the optimal transform parameter (*boxcox* lambda parameter). Options are:

**'pearsonr'** (default)

Maximizes the Pearson correlation coefficient between  $y = \text{boxcox}(x)$  and the expected values for  $y$  if  $x$  would be normally-distributed.

**'mle'**

Minimizes the log-likelihood *boxcox\_llf*. This is the method used in *boxcox*.

**'all'**

Use all optimization methods available, and return all results. Useful to compare different methods.

**Returns** `maxlog` : float or ndarray

The optimal transform parameter found. An array instead of a scalar for `method='all'`.

**See also:**

*boxcox*, *boxcox\_llf*, *boxcox\_normplot*

**Examples**

```
>>> from scipy import stats
>>> import matplotlib.pyplot as plt
>>> np.random.seed(1234) # make this example reproducible
```

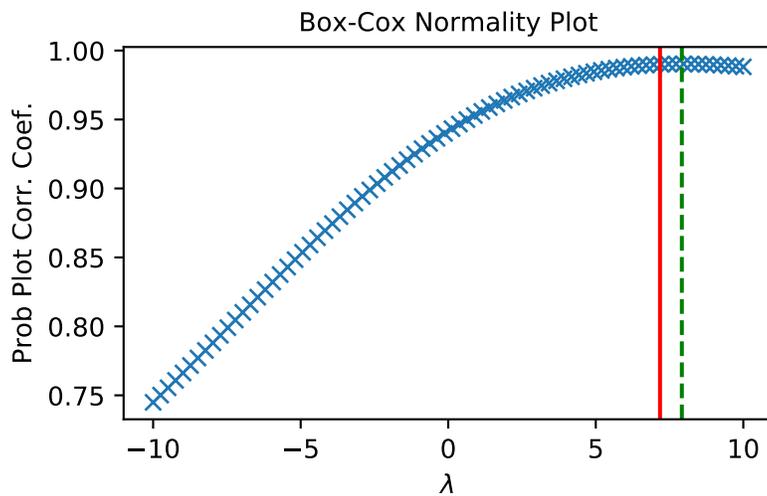
Generate some data and determine optimal lambda in various ways:

```
>>> x = stats.loggamma.rvs(5, size=30) + 5
>>> y, lmax_mle = stats.boxcox(x)
>>> lmax_pearsonr = stats.boxcox_normmax(x)
```

```
>>> lmax_mle
7.177...
>>> lmax_pearsonr
7.916...
>>> stats.boxcox_normmax(x, method='all')
array([ 7.91667384,  7.17718692])
```

```
>>> fig = plt.figure()
>>> ax = fig.add_subplot(111)
>>> prob = stats.boxcox_normplot(x, -10, 10, plot=ax)
>>> ax.axvline(lmax_mle, color='r')
>>> ax.axvline(lmax_pearsonr, color='g', ls='--')
```

```
>>> plt.show()
```



`scipy.stats.boxcox_llf(lmb, data)`

The boxcox log-likelihood function.

**Parameters** **lmb** : scalar

Parameter for Box-Cox transformation. See `boxcox` for details.

**data** : array\_like

Data to calculate Box-Cox log-likelihood for. If `data` is multi-dimensional, the log-likelihood is calculated along the first axis.

**Returns** **llf** : float or ndarray

Box-Cox log-likelihood of `data` given `lmb`. A float for 1-D `data`, an array otherwise.

**See also:**

`boxcox`, `probplot`, `boxcox_normplot`, `boxcox_normmax`

**Notes**

The Box-Cox log-likelihood function is defined here as

$$llf = (\lambda - 1) \sum_i (\log(x_i)) - N/2 \log(\sum_i (y_i - \bar{y})^2 / N),$$

where `y` is the Box-Cox transformed input data `x`.

### Examples

```
>>> from scipy import stats
>>> import matplotlib.pyplot as plt
>>> from mpl_toolkits.axes_grid1.inset_locator import inset_axes
>>> np.random.seed(1245)
```

Generate some random variates and calculate Box-Cox log-likelihood values for them for a range of lambda values:

```
>>> x = stats.loggamma.rvs(5, loc=10, size=1000)
>>> lmbdas = np.linspace(-2, 10)
>>> llf = np.zeros(lmbdas.shape, dtype=float)
>>> for ii, lambda in enumerate(lmbdas):
...     llf[ii] = stats.boxcox_llf(lambda, x)
```

Also find the optimal lambda value with `boxcox`:

```
>>> x_most_normal, lambda_optimal = stats.boxcox(x)
```

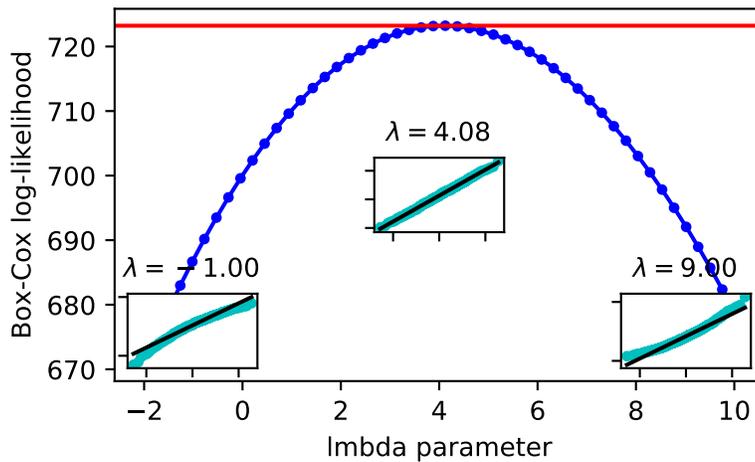
Plot the log-likelihood as function of lambda. Add the optimal lambda as a horizontal line to check that that's really the optimum:

```
>>> fig = plt.figure()
>>> ax = fig.add_subplot(111)
>>> ax.plot(lmbdas, llf, 'b.-')
>>> ax.axhline(stats.boxcox_llf(lambda_optimal, x), color='r')
>>> ax.set_xlabel('lambda parameter')
>>> ax.set_ylabel('Box-Cox log-likelihood')
```

Now add some probability plots to show that where the log-likelihood is maximized the data transformed with `boxcox` looks closest to normal:

```
>>> locs = [3, 10, 4] # 'lower left', 'center', 'lower right'
>>> for lambda, loc in zip([-1, lambda_optimal, 9], locs):
...     xt = stats.boxcox(x, lambda=lambda)
...     (osm, osr), (slope, intercept, r_sq) = stats.probplot(xt)
...     ax_inset = inset_axes(ax, width="20%", height="20%", loc=loc)
...     ax_inset.plot(osm, osr, 'c.', osm, slope*osm + intercept, 'k-')
...     ax_inset.set_xticklabels([])
...     ax_inset.set_yticklabels([])
...     ax_inset.set_title('$\lambda=%1.2f$' % lambda)
```

```
>>> plt.show()
```



`scipy.stats.entropy(pk, qk=None, base=None)`

Calculate the entropy of a distribution for given probability values.

If only probabilities  $pk$  are given, the entropy is calculated as  $S = -\sum(pk * \log(pk), axis=0)$ .

If  $qk$  is not None, then compute the Kullback-Leibler divergence  $S = \sum(pk * \log(pk / qk), axis=0)$ .

This routine will normalize  $pk$  and  $qk$  if they don't sum to 1.

**Parameters**

- pk** : sequence  
Defines the (discrete) distribution.  $pk[i]$  is the (possibly unnormalized) probability of event  $i$ .
- qk** : sequence, optional  
Sequence against which the relative entropy is computed. Should be in the same format as  $pk$ .
- base** : float, optional  
The logarithmic base to use, defaults to  $e$  (natural logarithm).

**Returns**

- S** : float  
The calculated entropy.

---

`wasserstein_distance(u_values, v_values[, ...])`      Compute the first Wasserstein distance between two 1D distributions.

---

`energy_distance(u_values, v_values[, ...])`      Compute the energy distance between two 1D distributions.

---

`scipy.stats.wasserstein_distance(u_values, v_values, u_weights=None, v_weights=None)`

Compute the first Wasserstein distance between two 1D distributions.

This distance is also known as the earth mover's distance, since it can be seen as the minimum amount of "work" required to transform  $u$  into  $v$ , where "work" is measured as the amount of distribution weight that must be moved, multiplied by the distance it has to be moved.

New in version 1.0.0.

**Parameters**

- u\_values, v\_values** : array\_like  
Values observed in the (empirical) distribution.
- u\_weights, v\_weights** : array\_like, optional  
Weight for each value. If unspecified, each value is assigned the same weight.  $u\_weights$  (resp.  $v\_weights$ ) must have the same length as  $u\_values$

**Returns** **distance** : float (resp. *v\_values*). If the weight sum differs from 1, it must still be positive and finite so that the weights can be normalized to sum to 1.  
The computed distance between the distributions.

**Notes**

The first Wasserstein distance between the distributions  $u$  and  $v$  is:

$$l_1(u, v) = \inf_{\pi \in \Gamma(u, v)} \int_{\mathbb{R} \times \mathbb{R}} |x - y| d\pi(x, y)$$

where  $\Gamma(u, v)$  is the set of (probability) distributions on  $\mathbb{R} \times \mathbb{R}$  whose marginals are  $u$  and  $v$  on the first and second factors respectively.

If  $U$  and  $V$  are the respective CDFs of  $u$  and  $v$ , this distance also equals to:

$$l_1(u, v) = \int_{-\infty}^{+\infty} |U - V|$$

See [R711] for a proof of the equivalence of both definitions.

The input distributions can be empirical, therefore coming from samples whose values are effectively inputs of the function, or they can be seen as generalized functions, in which case they are weighted sums of Dirac delta functions located at the specified values.

**References**

[R710], [R711]

**Examples**

```
>>> from scipy.stats import wasserstein_distance
>>> wasserstein_distance([0, 1, 3], [5, 6, 8])
5.0
>>> wasserstein_distance([0, 1], [0, 1], [3, 1], [2, 2])
0.25
>>> wasserstein_distance([3.4, 3.9, 7.5, 7.8], [4.5, 1.4],
...                       [1.4, 0.9, 3.1, 7.2], [3.2, 3.5])
4.0781331438047861
```

`scipy.stats.energy_distance` (*u\_values*, *v\_values*, *u\_weights=None*, *v\_weights=None*)

Compute the energy distance between two 1D distributions.

New in version 1.0.0.

**Parameters** **u\_values, v\_values** : array\_like  
Values observed in the (empirical) distribution.  
**u\_weights, v\_weights** : array\_like, optional  
Weight for each value. If unspecified, each value is assigned the same weight. *u\_weights* (resp. *v\_weights*) must have the same length as *u\_values* (resp. *v\_values*). If the weight sum differs from 1, it must still be positive and finite so that the weights can be normalized to sum to 1.

**Returns** **distance** : float  
The computed distance between the distributions.

**Notes**

The energy distance between two distributions  $u$  and  $v$ , whose respective CDFs are  $U$  and  $V$ , equals to:

$$D(u, v) = (2\mathbb{E}|X - Y| - \mathbb{E}|X - X'| - \mathbb{E}|Y - Y'|)^{1/2}$$

where  $X$  and  $X'$  (resp.  $Y$  and  $Y'$ ) are independent random variables whose probability distribution is  $u$  (resp.  $v$ ).

As shown in [R630], for one-dimensional real-valued variables, the energy distance is linked to the non-distribution-free version of the Cramer-von Mises distance:

$$D(u, v) = \sqrt{2}l_2(u, v) = \left( 2 \int_{-\infty}^{+\infty} (U - V)^2 \right)^{1/2}$$

Note that the common Cramer-von Mises criterion uses the distribution-free version of the distance. See [R630] (section 2), for more details about both versions of the distance.

The input distributions can be empirical, therefore coming from samples whose values are effectively inputs of the function, or they can be seen as generalized functions, in which case they are weighted sums of Dirac delta functions located at the specified values.

**References**

[R629], [R630], [R631], [R632]

**Examples**

```
>>> from scipy.stats import energy_distance
>>> energy_distance([0], [2])
2.0000000000000004
>>> energy_distance([0, 8], [0, 8], [3, 1], [2, 2])
1.0000000000000002
>>> energy_distance([0.7, 7.4, 2.4, 6.8], [1.4, 8. ],
...                 [2.1, 4.2, 7.4, 8. ], [7.6, 8.8])
0.88003340976158217
```

### 5.27.5 Circular statistical functions

<code>circmean(samples[, high, low, axis])</code>	Compute the circular mean for samples in a range.
<code>circvar(samples[, high, low, axis])</code>	Compute the circular variance for samples assumed to be in a range
<code>circstd(samples[, high, low, axis])</code>	Compute the circular standard deviation for samples assumed to be in the range [low to high].

`scipy.stats.circmean` (*samples, high=6.283185307179586, low=0, axis=None*)

Compute the circular mean for samples in a range.

**Parameters**

- samples** : array\_like  
Input array.
- high** : float or int, optional  
High boundary for circular mean range. Default is  $2 * \pi$ .
- low** : float or int, optional  
Low boundary for circular mean range. Default is 0.
- axis** : int, optional  
Axis along which means are computed. The default is to compute the mean of the flattened array.

**Returns**

- circmean** : float  
Circular mean.

**Examples**

```
>>> from scipy.stats import circmean
>>> circmean([0.1, 2*np.pi+0.2, 6*np.pi+0.3])
0.2
```

```
>>> from scipy.stats import circmean
>>> circmean([0.2, 1.4, 2.6], high = 1, low = 0)
0.4
```

`scipy.stats.circvar` (*samples*, *high*=6.283185307179586, *low*=0, *axis*=None)

Compute the circular variance for samples assumed to be in a range

**Parameters**

- samples** : array\_like  
Input array.
- low** : float or int, optional  
Low boundary for circular variance range. Default is 0.
- high** : float or int, optional  
High boundary for circular variance range. Default is  $2\pi$ .
- axis** : int, optional  
Axis along which variances are computed. The default is to compute the variance of the flattened array.

**Returns**

- circvar** : float  
Circular variance.

**Notes**

This uses a definition of circular variance that in the limit of small angles returns a number close to the ‘linear’ variance.

**Examples**

```
>>> from scipy.stats import circvar
>>> circvar([0, 2*np.pi/3, 5*np.pi/3])
2.19722457734
```

`scipy.stats.circstd` (*samples*, *high*=6.283185307179586, *low*=0, *axis*=None)

Compute the circular standard deviation for samples assumed to be in the range [low to high].

**Parameters**

- samples** : array\_like  
Input array.
- low** : float or int, optional  
Low boundary for circular standard deviation range. Default is 0.
- high** : float or int, optional  
High boundary for circular standard deviation range. Default is  $2\pi$ .
- axis** : int, optional  
Axis along which standard deviations are computed. The default is to compute the standard deviation of the flattened array.

**Returns**

- circstd** : float  
Circular standard deviation.

**Notes**

This uses a definition of circular standard deviation that in the limit of small angles returns a number close to the ‘linear’ standard deviation.

*Examples*

```
>>> from scipy.stats import circstd
>>> circstd([0, 0.1*np.pi/2, 0.001*np.pi, 0.03*np.pi/2])
0.063564063306
```

### 5.27.6 Contingency table functions

<code>chi2_contingency(observed[, correction, lambda_])</code>	Chi-square test of independence of variables in a contingency table.
<code>contingency.expected_freq(observed)</code>	Compute the expected frequencies from a contingency table.
<code>contingency.margins(a)</code>	Return a list of the marginal sums of the array <i>a</i> .
<code>fisher_exact(table[, alternative])</code>	Performs a Fisher exact test on a 2x2 contingency table.

`scipy.stats.chi2_contingency` (*observed*, *correction=True*, *lambda\_=None*)

Chi-square test of independence of variables in a contingency table.

This function computes the chi-square statistic and p-value for the hypothesis test of independence of the observed frequencies in the contingency table [R618] *observed*. The expected frequencies are computed based on the marginal sums under the assumption of independence; see `scipy.stats.contingency.expected_freq`. The number of degrees of freedom is (expressed using numpy functions and attributes):

```
dof = observed.size - sum(observed.shape) + observed.ndim - 1
```

**Parameters** **observed** : array\_like

The contingency table. The table contains the observed frequencies (i.e. number of occurrences) in each category. In the two-dimensional case, the table is often described as an “R x C table”.

**correction** : bool, optional

If True, *and* the degrees of freedom is 1, apply Yates’ correction for continuity. The effect of the correction is to adjust each observed value by 0.5 towards the corresponding expected value.

**lambda\_** : float or str, optional.

By default, the statistic computed in this test is Pearson’s chi-squared statistic [R619]. *lambda\_* allows a statistic from the Cressie-Read power divergence family [R620] to be used instead. See `power_divergence` for details.

**Returns** **chi2** : float

The test statistic.

**p** : float

The p-value of the test

**dof** : int

Degrees of freedom

**expected** : ndarray, same shape as *observed*

The expected frequencies, based on the marginal sums of the table.

**See also:**

`contingency.expected_freq`, `fisher_exact`, `chisquare`, `power_divergence`

### Notes

An often quoted guideline for the validity of this calculation is that the test should be used only if the observed and expected frequency in each cell is at least 5.

This is a test for the independence of different categories of a population. The test is only meaningful when the dimension of *observed* is two or more. Applying the test to a one-dimensional table will always result in *expected* equal to *observed* and a chi-square statistic equal to 0.

This function does not handle masked arrays, because the calculation does not make sense with missing values.

Like `stats.chisquare`, this function computes a chi-square statistic; the convenience this function provides is to figure out the expected frequencies and degrees of freedom from the given contingency table. If these were already known, and if the Yates' correction was not required, one could use `stats.chisquare`. That is, if one calls:

```
chi2, p, dof, ex = chi2_contingency(obs, correction=False)
```

then the following is true:

```
(chi2, p) == stats.chisquare(obs.ravel(), f_exp=ex.ravel(),
                             ddof=obs.size - 1 - dof)
```

The `lambda_` argument was added in version 0.13.0 of `scipy`.

### References

[R618], [R619], [R620]

### Examples

A two-way example (2 x 3):

```
>>> from scipy.stats import chi2_contingency
>>> obs = np.array([[10, 10, 20], [20, 20, 20]])
>>> chi2_contingency(obs)
(2.7777777777777777,
 0.24935220877729619,
 2,
 array([[ 12.,  12.,  16.],
        [ 18.,  18.,  24.]])
```

Perform the test using the log-likelihood ratio (i.e. the “G-test”) instead of Pearson’s chi-squared statistic.

```
>>> g, p, dof, expctd = chi2_contingency(obs, lambda_="log-likelihood")
>>> g, p
(2.7688587616781319, 0.25046668010954165)
```

A four-way example (2 x 2 x 2 x 2):

```
>>> obs = np.array(
...     [[[[12, 17],
...         [11, 16]],
...        [[11, 12],
...         [15, 16]]],
...     [[[[23, 15],
...         [30, 22]],
...        [[14, 17],
...         [15, 16]]]])
>>> chi2_contingency(obs)
(8.7584514426741897,
```

```

0.64417725029295503,
11,
array([[[[ 14.15462386,  14.15462386],
          [ 16.49423111,  16.49423111]],
        [[ 11.2461395 ,  11.2461395 ],
          [ 13.10500554,  13.10500554]]],
       [[ 19.5591166 ,  19.5591166 ],
          [ 22.79202844,  22.79202844]],
       [[ 15.54012004,  15.54012004],
          [ 18.10873492,  18.10873492]]]])
    
```

`scipy.stats.contingency.expected_freq(observed)`

Compute the expected frequencies from a contingency table.

Given an  $n$ -dimensional contingency table of observed frequencies, compute the expected frequencies for the table based on the marginal sums under the assumption that the groups associated with each dimension are independent.

**Parameters**    **observed** : array\_like

The table of observed frequencies. (While this function can handle a 1-D array, that case is trivial. Generally *observed* is at least 2-D.)

**Returns**        **expected** : ndarray of float64

The expected frequencies, based on the marginal sums of the table. Same shape as *observed*.

### Examples

```

>>> observed = np.array([[10, 10, 20],[20, 20, 20]])
>>> from scipy.stats import expected_freq
>>> expected_freq(observed)
array([[ 12.,  12.,  16.],
       [ 18.,  18.,  24.]])
    
```

`scipy.stats.contingency.margins(a)`

Return a list of the marginal sums of the array *a*.

**Parameters**    **a** : ndarray

The array for which to compute the marginal sums.

**Returns**        **margsums** : list of ndarrays

A list of length *a.ndim*. *margsums[k]* is the result of summing *a* over all axes except *k*; it has the same number of dimensions as *a*, but the length of each axis except axis *k* will be 1.

### Examples

```

>>> a = np.arange(12).reshape(2, 6)
>>> a
array([[ 0,  1,  2,  3,  4,  5],
       [ 6,  7,  8,  9, 10, 11]])
>>> m0, m1 = margins(a)
>>> m0
array([[15],
       [51]])
>>> m1
array([[ 6,  8, 10, 12, 14, 16]])
    
```

```

>>> b = np.arange(24).reshape(2, 3, 4)
>>> m0, m1, m2 = margins(b)
    
```

```

>>> m0
array([[ 66]],
      [[210]])
>>> m1
array([[ 60],
      [ 92],
      [124]])
>>> m2
array([[60, 66, 72, 78]])

```

`scipy.stats.fisher_exact` (*table*, *alternative='two-sided'*)

Performs a Fisher exact test on a 2x2 contingency table.

**Parameters**

- table** : array\_like of ints  
A 2x2 contingency table. Elements should be non-negative integers.
- alternative** : {'two-sided', 'less', 'greater'}, optional  
Which alternative hypothesis to the null hypothesis the test uses. Default is 'two-sided'.

**Returns**

- oddsratio** : float  
This is prior odds ratio and not a posterior estimate.
- p\_value** : float  
P-value, the probability of obtaining a distribution at least as extreme as the one that was actually observed, assuming that the null hypothesis is true.

**See also:**

**chi2\_contingency**

Chi-square test of independence of variables in a contingency table.

**Notes**

The calculated odds ratio is different from the one R uses. This scipy implementation returns the (more common) “unconditional Maximum Likelihood Estimate”, while R uses the “conditional Maximum Likelihood Estimate”.

For tables with large numbers, the (inexact) chi-square test implemented in the function `chi2_contingency` can also be used.

**Examples**

Say we spend a few days counting whales and sharks in the Atlantic and Indian oceans. In the Atlantic ocean we find 8 whales and 1 shark, in the Indian ocean 2 whales and 5 sharks. Then our contingency table is:

	Atlantic	Indian
whales	8	2
sharks	1	5

We use this table to find the p-value:

```

>>> import scipy.stats as stats
>>> oddsratio, pvalue = stats.fisher_exact([[8, 2], [1, 5]])
>>> pvalue
0.0349...

```

The probability that we would observe this or an even more imbalanced ratio by chance is about 3.5%. A commonly used significance level is 5%—if we adopt that, we can therefore conclude that our observed imbalance is statistically significant; whales prefer the Atlantic while sharks prefer the Indian ocean.

## 5.27.7 Plot-tests

<code>ppcc_max(x[, brack, dist])</code>	Calculate the shape parameter that maximizes the PPCC
<code>ppcc_plot(x, a, b[, dist, plot, N])</code>	Calculate and optionally plot probability plot correlation coefficient.
<code>probplot(x[, sparams, dist, fit, plot, rvalue])</code>	Calculate quantiles for a probability plot, and optionally show the plot.
<code>boxcox_normplot(x, la, lb[, plot, N])</code>	Compute parameters for a Box-Cox normality plot, optionally show it.

`scipy.stats.ppcc_max(x, brack=(0.0, 1.0), dist='tukeylambda')`

Calculate the shape parameter that maximizes the PPCC

The probability plot correlation coefficient (PPCC) plot can be used to determine the optimal shape parameter for a one-parameter family of distributions. `ppcc_max` returns the shape parameter that would maximize the probability plot correlation coefficient for the given data to a one-parameter family of distributions.

**Parameters** `x` : array\_like

Input array.

**brack** : tuple, optional

Triple (a,b,c) where (a<b<c). If bracket consists of two numbers (a, c) then they are assumed to be a starting interval for a downhill bracket search (see `scipy.optimize.brent`).

**dist** : str or stats.distributions instance, optional

Distribution or distribution function name. Objects that look enough like a stats.distributions instance (i.e. they have a `ppf` method) are also accepted. The default is 'tukeylambda'.

**Returns**

**shape\_value** : float

The shape parameter at which the probability plot correlation coefficient reaches its max value.

**See also:**

`ppcc_plot`, `probplot`, `boxcox`

**Notes**

The `brack` keyword serves as a starting point which is useful in corner cases. One can use a plot to obtain a rough visual estimate of the location for the maximum to start the search near it.

**References**

[R687], [R688]

**Examples**

First we generate some random data from a Tukey-Lambda distribution, with shape parameter -0.7:

```
>>> from scipy import stats
>>> x = stats.tukeylambda.rvs(-0.7, loc=2, scale=0.5, size=10000,
...                          random_state=1234567) + 1e4
```

Now we explore this data with a PPCC plot as well as the related probability plot and Box-Cox normplot. A red line is drawn where we expect the PPCC value to be maximal (at the shape parameter -0.7 used above):

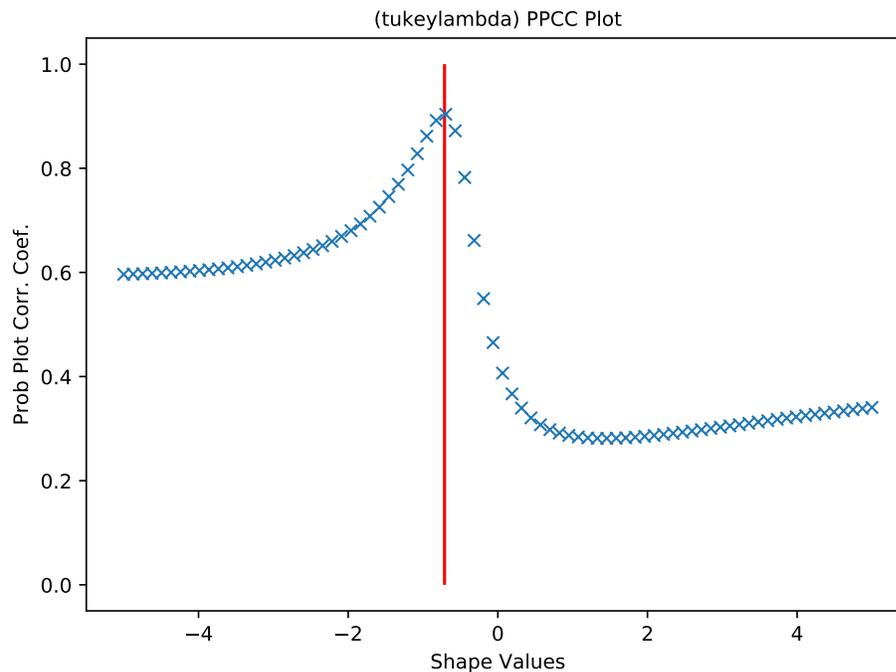
```
>>> import matplotlib.pyplot as plt
>>> fig = plt.figure(figsize=(8, 6))
```

```
>>> ax = fig.add_subplot(111)
>>> res = stats.ppcc_plot(x, -5, 5, plot=ax)
```

We calculate the value where the shape should reach its maximum and a red line is drawn there. The line should coincide with the highest point in the ppcc\_plot.

```
>>> max = stats.ppcc_max(x)
>>> ax.vlines(max, 0, 1, colors='r', label='Expected shape value')
```

```
>>> plt.show()
```



`scipy.stats.ppcc_plot(x, a, b, dist='tukeylambda', plot=None, N=80)`

Calculate and optionally plot probability plot correlation coefficient.

The probability plot correlation coefficient (PPCC) plot can be used to determine the optimal shape parameter for a one-parameter family of distributions. It cannot be used for distributions without shape parameters (like the normal distribution) or with multiple shape parameters.

By default a Tukey-Lambda distribution (`stats.tukeylambda`) is used. A Tukey-Lambda PPCC plot interpolates from long-tailed to short-tailed distributions via an approximately normal one, and is therefore particularly useful in practice.

**Parameters** `x`: array\_like

Input array.

**a, b**: scalar

Lower and upper bounds of the shape parameter to use.

**dist**: str or `stats.distributions` instance, optional

Distribution or distribution function name. Objects that look enough like a `stats.distributions` instance (i.e. they have a `ppf` method) are also accepted. The default is `'tukeylambda'`.

**plot** : object, optional

If given, plots PPCC against the shape parameter. *plot* is an object that has to have methods “plot” and “text”. The `matplotlib.pyplot` module or a Matplotlib Axes object can be used, or a custom object with the same methods. Default is `None`, which means that no plot is created.

**N** : int, optional

Number of points on the horizontal axis (equally distributed from *a* to *b*).

**Returns**

**svals** : ndarray

The shape values for which *ppcc* was calculated.

**ppcc** : ndarray

The calculated probability plot correlation coefficient values.

**See also:**

`ppcc_max`, `probplot`, `boxcox_normplot`, `tukeylambda`

### References

J.J. Filliben, “The Probability Plot Correlation Coefficient Test for Normality”, *Technometrics*, Vol. 17, pp. 111-117, 1975.

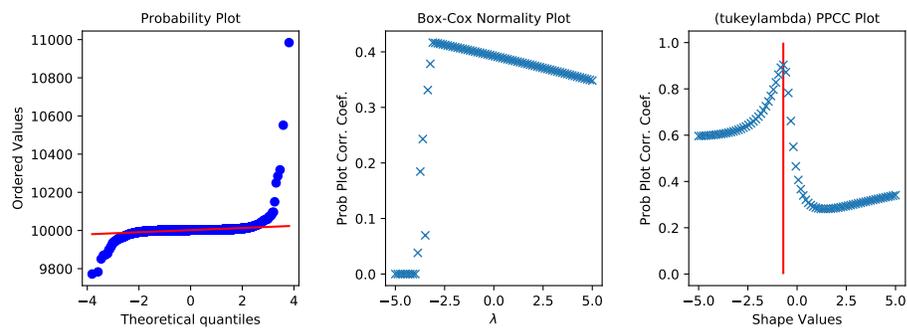
### Examples

First we generate some random data from a Tukey-Lambda distribution, with shape parameter -0.7:

```
>>> from scipy import stats
>>> import matplotlib.pyplot as plt
>>> np.random.seed(1234567)
>>> x = stats.tukeylambda.rvs(-0.7, loc=2, scale=0.5, size=10000) + 1e4
```

Now we explore this data with a PPCC plot as well as the related probability plot and Box-Cox normplot. A red line is drawn where we expect the PPCC value to be maximal (at the shape parameter -0.7 used above):

```
>>> fig = plt.figure(figsize=(12, 4))
>>> ax1 = fig.add_subplot(131)
>>> ax2 = fig.add_subplot(132)
>>> ax3 = fig.add_subplot(133)
>>> res = stats.probplot(x, plot=ax1)
>>> res = stats.boxcox_normplot(x, -5, 5, plot=ax2)
>>> res = stats.ppcc_plot(x, -5, 5, plot=ax3)
>>> ax3.vlines(-0.7, 0, 1, colors='r', label='Expected shape value')
>>> plt.show()
```



`scipy.stats.probplot(x, sparams=(), dist='norm', fit=True, plot=None, rvalue=False)`

Calculate quantiles for a probability plot, and optionally show the plot.

Generates a probability plot of sample data against the quantiles of a specified theoretical distribution (the normal distribution by default). `probplot` optionally calculates a best-fit line for the data and plots the results using Matplotlib or a given plot function.

**Parameters** `x` : array\_like

Sample/response data from which `probplot` creates the plot.

`sparams` : tuple, optional

Distribution-specific shape parameters (shape parameters plus location and scale).

`dist` : str or stats.distributions instance, optional

Distribution or distribution function name. The default is 'norm' for a normal probability plot. Objects that look enough like a stats.distributions instance (i.e. they have a `ppf` method) are also accepted.

`fit` : bool, optional

Fit a least-squares regression (best-fit) line to the sample data if True (default).

`plot` : object, optional

If given, plots the quantiles and least squares fit. `plot` is an object that has to have methods "plot" and "text". The `matplotlib.pyplot` module or a Matplotlib Axes object can be used, or a custom object with the same methods. Default is None, which means that no plot is created.

**Returns**

`(osm, osr)` : tuple of ndarrays

Tuple of theoretical quantiles (`osm`, or order statistic medians) and ordered responses (`osr`). `osr` is simply sorted input `x`. For details on how `osm` is calculated see the Notes section.

`(slope, intercept, r)` : tuple of floats, optional

Tuple containing the result of the least-squares fit, if that is performed by `probplot`. `r` is the square root of the coefficient of determination. If `fit=False` and `plot=None`, this tuple is not returned.

### Notes

Even if `plot` is given, the figure is not shown or saved by `probplot`; `plt.show()` or `plt.savefig('figname.png')` should be used after calling `probplot`.

`probplot` generates a probability plot, which should not be confused with a Q-Q or a P-P plot. Statsmodels has more extensive functionality of this type, see `statsmodels.api.ProbPlot`.

The formula used for the theoretical quantiles (horizontal axis of the probability plot) is Filliben's estimate:

```
quantiles = dist.ppf(val), for
    0.5**(1/n), for i = n
    val = (i - 0.3175) / (n + 0.365), for i = 2, ..., n-1
    1 - 0.5**(1/n), for i = 1
```

where `i` indicates the `i`-th ordered value and `n` is the total number of values.

### Examples

```
>>> from scipy import stats
>>> import matplotlib.pyplot as plt
>>> nsample = 100
>>> np.random.seed(7654321)
```

A t distribution with small degrees of freedom:

```
>>> ax1 = plt.subplot(221)
>>> x = stats.t.rvs(3, size=nsample)
>>> res = stats.probplot(x, plot=plt)
```

A t distribution with larger degrees of freedom:

```
>>> ax2 = plt.subplot(222)
>>> x = stats.t.rvs(25, size=nsample)
>>> res = stats.probplot(x, plot=plt)
```

A mixture of two normal distributions with broadcasting:

```
>>> ax3 = plt.subplot(223)
>>> x = stats.norm.rvs(loc=[0,5], scale=[1,1.5],
...                   size=(nsample//2,2)).ravel()
>>> res = stats.probplot(x, plot=plt)
```

A standard normal distribution:

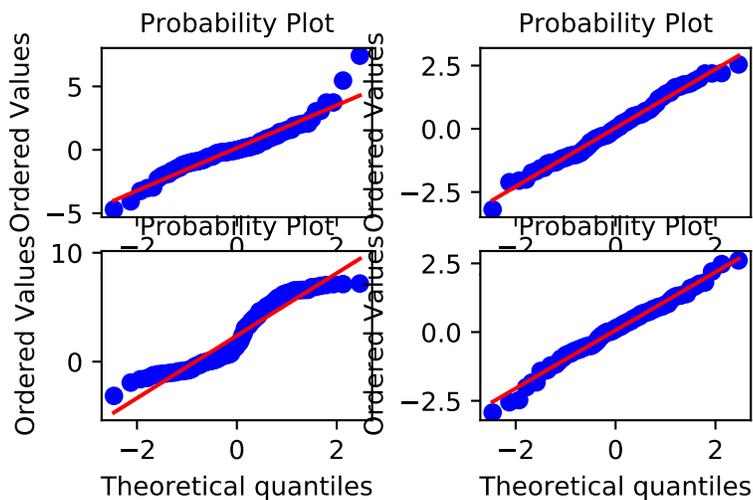
```
>>> ax4 = plt.subplot(224)
>>> x = stats.norm.rvs(loc=0, scale=1, size=nsample)
>>> res = stats.probplot(x, plot=plt)
```

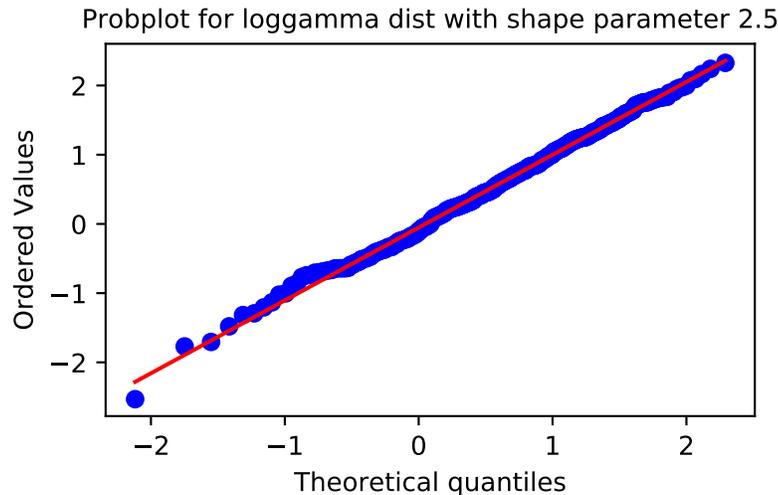
Produce a new figure with a loggamma distribution, using the `dist` and `sparams` keywords:

```
>>> fig = plt.figure()
>>> ax = fig.add_subplot(111)
>>> x = stats.loggamma.rvs(c=2.5, size=500)
>>> res = stats.probplot(x, dist=stats.loggamma, sparams=(2.5,), plot=ax)
>>> ax.set_title("Probplot for loggamma dist with shape parameter 2.5")
```

Show the results with Matplotlib:

```
>>> plt.show()
```





`scipy.stats.boxcox_normplot` (*x*, *la*, *lb*, *plot=None*, *N=80*)

Compute parameters for a Box-Cox normality plot, optionally show it.

A Box-Cox normality plot shows graphically what the best transformation parameter is to use in `boxcox` to obtain a distribution that is close to normal.

**Parameters** `x` : array\_like

Input array.

`la`, `lb` : scalar

The lower and upper bounds for the `lambda` values to pass to `boxcox` for Box-Cox transformations. These are also the limits of the horizontal axis of the plot if that is generated.

`plot` : object, optional

If given, plots the quantiles and least squares fit. `plot` is an object that has to have methods “plot” and “text”. The `matplotlib.pyplot` module or a Matplotlib Axes object can be used, or a custom object with the same methods. Default is None, which means that no plot is created.

`N` : int, optional

Number of points on the horizontal axis (equally distributed from `la` to `lb`).

**Returns** `lmbdas` : ndarray

The `lambda` values for which a Box-Cox transform was done.

`ppcc` : ndarray

Probability Plot Correlation Coefficient, as obtained from `probplot` when fitting the Box-Cox transformed input `x` against a normal distribution.

**See also:**

`probplot`, `boxcox`, `boxcox_normmax`, `boxcox_llf`, `ppcc_max`

**Notes**

Even if `plot` is given, the figure is not shown or saved by `boxcox_normplot`; `plt.show()` or `plt.savefig('figname.png')` should be used after calling `probplot`.

**Examples**

```
>>> from scipy import stats
>>> import matplotlib.pyplot as plt
```

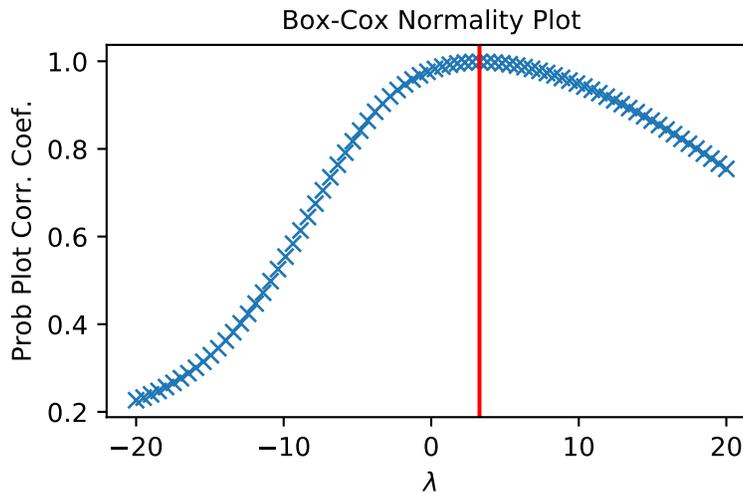
Generate some non-normally distributed data, and create a Box-Cox plot:

```
>>> x = stats.loggamma.rvs(5, size=500) + 5
>>> fig = plt.figure()
>>> ax = fig.add_subplot(111)
>>> prob = stats.boxcox_normplot(x, -20, 20, plot=ax)
```

Determine and plot the optimal lambda to transform x and plot it in the same plot:

```
>>> _, maxlog = stats.boxcox(x)
>>> ax.axvline(maxlog, color='r')
```

```
>>> plt.show()
```



## 5.27.8 Masked statistics functions

### Statistical functions for masked arrays (`scipy.stats.mstats`)

This module contains a large number of statistical functions that can be used with masked arrays.

Most of these functions are similar to those in `scipy.stats` but might have small differences in the API or in the algorithm used. Since this is a relatively new package, some API changes are still possible.

<code>argstoarray(*args)</code>	Constructs a 2D array from a group of sequences.
<code>chisquare(f_obs[, f_exp, ddof, axis])</code>	Calculate a one-way chi square test.
<code>count_tied_groups(x[, use_missing])</code>	Counts the number of tied values.
<code>describe(a[, axis, ddof, bias])</code>	Computes several descriptive statistics of the passed array.
<code>f_oneway(*args)</code>	Performs a 1-way ANOVA, returning an F-value and probability given any number of groups.
<code>find_repeats(arr)</code>	Find repeats in arr and return a tuple (repeats, repeat_count).
<code>friedmanchisquare(*args)</code>	Friedman Chi-Square is a non-parametric, one-way within-subjects ANOVA.

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<code>kendalltau(x, y[, use_ties, use_missing])</code>	Computes Kendall's rank correlation tau on two variables $x$ and $y$ .
<code>kendalltau_seasonal(x)</code>	Computes a multivariate Kendall's rank correlation tau, for seasonal data.
<code>kruskalwallis(*args)</code>	Compute the Kruskal-Wallis H-test for independent samples
<code>ks_twosamp(data1, data2[, alternative])</code>	Computes the Kolmogorov-Smirnov test on two samples.
<code>kurtosis(a[, axis, fisher, bias])</code>	Computes the kurtosis (Fisher or Pearson) of a dataset.
<code>kurtosistest(a[, axis])</code>	Tests whether a dataset has normal kurtosis
<code>linregress(x[, y])</code>	Calculate a linear least-squares regression for two sets of measurements.
<code>mannwhitneyu(x, y[, use_continuity])</code>	Computes the Mann-Whitney statistic
<code>plotting_positions(data[, alpha, beta])</code>	Returns plotting positions (or empirical percentile points) for the data.
<code>mode(a[, axis])</code>	Returns an array of the modal (most common) value in the passed array.
<code>moment(a[, moment, axis])</code>	Calculates the $n$ th moment about the mean for a sample.
<code>mquantiles(a[, prob, alphap, betap, axis, limit])</code>	Computes empirical quantiles for a data array.
<code>msign(x)</code>	Returns the sign of $x$ , or 0 if $x$ is masked.
<code>normaltest(a[, axis])</code>	Tests whether a sample differs from a normal distribution.
<code>obrientransform(*args)</code>	Computes a transform on input data (any number of columns).
<code>pearsonr(x, y)</code>	Calculates a Pearson correlation coefficient and the p-value for testing non-correlation.
<code>plotting_positions(data[, alpha, beta])</code>	Returns plotting positions (or empirical percentile points) for the data.
<code>pointbiserialr(x, y)</code>	Calculates a point biserial correlation coefficient and its p-value.
<code>rankdata(data[, axis, use_missing])</code>	Returns the rank (also known as order statistics) of each data point along the given axis.
<code>scoreatpercentile(data, per[, limit, ...])</code>	Calculate the score at the given 'per' percentile of the sequence $a$ .
<code>sem(a[, axis, ddof])</code>	Calculates the standard error of the mean of the input array.
<code>skew(a[, axis, bias])</code>	Computes the skewness of a data set.
<code>skewtest(a[, axis])</code>	Tests whether the skew is different from the normal distribution.
<code>spearmanr(x, y[, use_ties])</code>	Calculates a Spearman rank-order correlation coefficient and the p-value to test for non-correlation.
<code>theilslopes(y[, x, alpha])</code>	Computes the Theil-Sen estimator for a set of points $(x, y)$ .
<code>tmax(a[, upperlimit, axis, inclusive])</code>	Compute the trimmed maximum
<code>tmean(a[, limits, inclusive, axis])</code>	Compute the trimmed mean.
<code>tmin(a[, lowerlimit, axis, inclusive])</code>	Compute the trimmed minimum
<code>trim(a[, limits, inclusive, relative, axis])</code>	Trims an array by masking the data outside some given limits.
<code>trima(a[, limits, inclusive])</code>	Trims an array by masking the data outside some given limits.
<code>trimboth(data[, proportiontocut, inclusive, ...])</code>	Trims the smallest and largest data values.
<code>trimmed_stde(a[, limits, inclusive, axis])</code>	Returns the standard error of the trimmed mean along the given axis.
<code>trimr(a[, limits, inclusive, axis])</code>	Trims an array by masking some proportion of the data on each end.

Continued on next page

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<code>trimtail(data[, proportiontocut, tail, ...])</code>	Trims the data by masking values from one tail.
<code>tsem(a[, limits, inclusive, axis, ddof])</code>	Compute the trimmed standard error of the mean.
<code>ttest_onesamp(a, popmean[, axis])</code>	Calculates the T-test for the mean of ONE group of scores.
<code>ttest_ind(a, b[, axis, equal_var])</code>	Calculates the T-test for the means of TWO INDEPENDENT samples of scores.
<code>ttest_onesamp(a, popmean[, axis])</code>	Calculates the T-test for the mean of ONE group of scores.
<code>ttest_rel(a, b[, axis])</code>	Calculates the T-test on TWO RELATED samples of scores, a and b.
<code>tvar(a[, limits, inclusive, axis, ddof])</code>	Compute the trimmed variance
<code>variation(a[, axis])</code>	Computes the coefficient of variation, the ratio of the biased standard deviation to the mean.
<code>winsorize(a[, limits, inclusive, inplace, axis])</code>	Returns a Winsorized version of the input array.
<code>zmap(scores, compare[, axis, ddof])</code>	Calculate the relative z-scores.
<code>zscore(a[, axis, ddof])</code>	Calculate the z score of each value in the sample, relative to the sample mean and standard deviation.
<code>compare_medians_ms(group_1, group_2[, axis])</code>	Compares the medians from two independent groups along the given axis.
<code>gmean(a[, axis, dtype])</code>	Compute the geometric mean along the specified axis.
<code>hdmedian(data[, axis, var])</code>	Returns the Harrell-Davis estimate of the median along the given axis.
<code>hdquantiles(data[, prob, axis, var])</code>	Computes quantile estimates with the Harrell-Davis method.
<code>hdquantiles_sd(data[, prob, axis])</code>	The standard error of the Harrell-Davis quantile estimates by jackknife.
<code>hmean(a[, axis, dtype])</code>	Calculate the harmonic mean along the specified axis.
<code>idealfourths(data[, axis])</code>	Returns an estimate of the lower and upper quartiles.
<code>kruskal(*args)</code>	Compute the Kruskal-Wallis H-test for independent samples
<code>ks_2samp(data1, data2[, alternative])</code>	Computes the Kolmogorov-Smirnov test on two samples.
<code>median_cihs(data[, alpha, axis])</code>	Computes the alpha-level confidence interval for the median of the data.
<code>meppf(data[, alpha, beta])</code>	Returns plotting positions (or empirical percentile points) for the data.
<code>mjci(data[, prob, axis])</code>	Returns the Maritz-Jarrett estimators of the standard error of selected experimental quantiles of the data.
<code>mquantiles_cimj(data[, prob, alpha, axis])</code>	Computes the alpha confidence interval for the selected quantiles of the data, with Maritz-Jarrett estimators.
<code>rsh(data[, points])</code>	Evaluates Rosenblatt's shifted histogram estimators for each data point.
<code>sen_seasonal_slopes(x)</code>	
<code>trimmed_mean(a[, limits, inclusive, ...])</code>	
<code>trimmed_mean_ci(data[, limits, inclusive, ...])</code>	Selected confidence interval of the trimmed mean along the given axis.
<code>trimmed_std(a[, limits, inclusive, ...])</code>	
<code>trimmed_var(a[, limits, inclusive, ...])</code>	
<code>ttest_1samp(a, popmean[, axis])</code>	Calculates the T-test for the mean of ONE group of scores.

`scipy.stats.mstats.argstoarray(*args)`

Constructs a 2D array from a group of sequences.

Sequences are filled with missing values to match the length of the longest sequence.

**Parameters** `args` : sequences

**Returns** `argstoarray` : `MaskedArray` Group of sequences.

A ( $m \times n$ ) masked array, where  $m$  is the number of arguments and  $n$  the length of the longest argument.

### Notes

`numpy.ma.row_stack` has identical behavior, but is called with a sequence of sequences.

`scipy.stats.mstats.chisquare(f_obs, f_exp=None, ddof=0, axis=0)`

Calculate a one-way chi square test.

The chi square test tests the null hypothesis that the categorical data has the given frequencies.

**Parameters** `f_obs` : array\_like

Observed frequencies in each category.

`f_exp` : array\_like, optional

Expected frequencies in each category. By default the categories are assumed to be equally likely.

`ddof` : int, optional

“Delta degrees of freedom”: adjustment to the degrees of freedom for the p-value. The p-value is computed using a chi-squared distribution with  $k - 1 - \text{ddof}$  degrees of freedom, where  $k$  is the number of observed frequencies. The default value of `ddof` is 0.

`axis` : int or None, optional

The axis of the broadcast result of `f_obs` and `f_exp` along which to apply the test. If `axis` is None, all values in `f_obs` are treated as a single data set.

**Returns** `chisq` : float or ndarray Default is 0.

The chi-squared test statistic. The value is a float if `axis` is None or `f_obs` and `f_exp` are 1-D.

`p` : float or ndarray

The p-value of the test. The value is a float if `ddof` and the return value `chisq` are scalars.

### See also:

`power_divergence`, `mstats.chisquare`

### Notes

This test is invalid when the observed or expected frequencies in each category are too small. A typical rule is that all of the observed and expected frequencies should be at least 5.

The default degrees of freedom,  $k-1$ , are for the case when no parameters of the distribution are estimated. If  $p$  parameters are estimated by efficient maximum likelihood then the correct degrees of freedom are  $k-1-p$ . If the parameters are estimated in a different way, then the dof can be between  $k-1-p$  and  $k-1$ . However, it is also possible that the asymptotic distribution is not a chisquare, in which case this test is not appropriate.

### References

[R671], [R672]

### Examples

When just `f_obs` is given, it is assumed that the expected frequencies are uniform and given by the mean of the observed frequencies.

```
>>> from scipy.stats import chisquare
>>> chisquare([16, 18, 16, 14, 12, 12])
(2.0, 0.84914503608460956)
```

With *f\_exp* the expected frequencies can be given.

```
>>> chisquare([16, 18, 16, 14, 12, 12], f_exp=[16, 16, 16, 16, 16, 8])
(3.5, 0.62338762774958223)
```

When *f\_obs* is 2-D, by default the test is applied to each column.

```
>>> obs = np.array([[16, 18, 16, 14, 12, 12], [32, 24, 16, 28, 20, 24]]).T
>>> obs.shape
(6, 2)
>>> chisquare(obs)
(array([ 2.          ,  6.66666667]), array([ 0.84914504,  0.24663415]))
```

By setting *axis=None*, the test is applied to all data in the array, which is equivalent to applying the test to the flattened array.

```
>>> chisquare(obs, axis=None)
(23.31034482758621, 0.015975692534127565)
>>> chisquare(obs.ravel())
(23.31034482758621, 0.015975692534127565)
```

*ddof* is the change to make to the default degrees of freedom.

```
>>> chisquare([16, 18, 16, 14, 12, 12], ddof=1)
(2.0, 0.73575888234288467)
```

The calculation of the p-values is done by broadcasting the chi-squared statistic with *ddof*.

```
>>> chisquare([16, 18, 16, 14, 12, 12], ddof=[0,1,2])
(2.0, array([ 0.84914504,  0.73575888,  0.5724067 ]))
```

*f\_obs* and *f\_exp* are also broadcast. In the following, *f\_obs* has shape (6,) and *f\_exp* has shape (2, 6), so the result of broadcasting *f\_obs* and *f\_exp* has shape (2, 6). To compute the desired chi-squared statistics, we use *axis=1*:

```
>>> chisquare([16, 18, 16, 14, 12, 12],
...          f_exp=[[16, 16, 16, 16, 16, 8], [8, 20, 20, 16, 12, 12]],
...          axis=1)
(array([ 3.5 ,  9.25]), array([ 0.62338763,  0.09949846]))
```

`scipy.stats.mstats.count_tied_groups(x, use_missing=False)`

Counts the number of tied values.

**Parameters**

- x**: sequence
- Sequence of data on which to counts the ties
- use\_missing**: bool, optional
- Whether to consider missing values as tied.

**Returns**

- count\_tied\_groups**: dict
- Returns a dictionary (nb of ties: nb of groups).

*Examples*

```
>>> from scipy.stats import mstats
>>> z = [0, 0, 0, 2, 2, 2, 3, 3, 4, 5, 6]
>>> mstats.count_tied_groups(z)
{2: 1, 3: 2}
```

In the above example, the ties were 0 (3x), 2 (3x) and 3 (2x).

```
>>> z = np.ma.array([0, 0, 1, 2, 2, 2, 3, 3, 4, 5, 6])
>>> mstats.count_tied_groups(z)
{2: 2, 3: 1}
>>> z[[1,-1]] = np.ma.masked
>>> mstats.count_tied_groups(z, use_missing=True)
{2: 2, 3: 1}
```

`scipy.stats.mstats.describe` (*a*, *axis=0*, *ddof=0*, *bias=True*)

Computes several descriptive statistics of the passed array.

<b>Parameters</b>	<b>a</b> : array_like	Data array
	<b>axis</b> : int or None, optional	Axis along which to calculate statistics. Default 0. If None, compute over the whole array <i>a</i> .
	<b>ddof</b> : int, optional	degree of freedom (default 0); note that default ddof is different from the same routine in <code>stats.describe</code>
	<b>bias</b> : bool, optional	If False, then the skewness and kurtosis calculations are corrected for statistical bias.
<b>Returns</b>	<b>nobs</b> : int	(size of the data (discarding missing values))
	<b>minmax</b> : (int, int)	min, max
	<b>mean</b> : float	arithmetic mean
	<b>variance</b> : float	unbiased variance
	<b>skewness</b> : float	biased skewness
	<b>kurtosis</b> : float	biased kurtosis

### Examples

```
>>> from scipy.stats.mstats import describe
>>> ma = np.ma.array(range(6), mask=[0, 0, 0, 1, 1, 1])
>>> describe(ma)
DescribeResult(nobs=3, minmax=(masked_array(data = 0,
      mask = False,
      fill_value = 999999)
, masked_array(data = 2,
      mask = False,
      fill_value = 999999)
), mean=1.0, variance=0.66666666666666663, skewness=masked_array(data = 0.0,
      mask = False,
      fill_value = 1e+20)
, kurtosis=-1.5)
```

`scipy.stats.mstats.f_oneway(*args)`

Performs a 1-way ANOVA, returning an F-value and probability given any number of groups. From Heiman, pp.394-7.

Usage: `f_oneway(*args)`, where `*args` is 2 or more arrays, one per treatment group.

**Returns**

- statistic** : float  
The computed F-value of the test.
- pvalue** : float  
The associated p-value from the F-distribution.

`scipy.stats.mstats.find_repeats(arr)`

Find repeats in `arr` and return a tuple (`repeats`, `repeat_count`).

The input is cast to float64. Masked values are discarded.

**Parameters**

- arr** : sequence  
Input array. The array is flattened if it is not 1D.

**Returns**

- repeats** : ndarray  
Array of repeated values.
- counts** : ndarray  
Array of counts.

`scipy.stats.mstats.friedmanchisquare(*args)`

Friedman Chi-Square is a non-parametric, one-way within-subjects ANOVA. This function calculates the Friedman Chi-square test for repeated measures and returns the result, along with the associated probability value.

Each input is considered a given group. Ideally, the number of treatments among each group should be equal. If this is not the case, only the first `n` treatments are taken into account, where `n` is the number of treatments of the smallest group. If a group has some missing values, the corresponding treatments are masked in the other groups. The test statistic is corrected for ties.

Masked values in one group are propagated to the other groups.

**Returns**

- statistic** : float  
the test statistic.
- pvalue** : float  
the associated p-value.

`scipy.stats.mstats.kendalltau(x, y, use_ties=True, use_missing=False)`

Computes Kendall's rank correlation tau on two variables `x` and `y`.

**Parameters**

- x** : sequence  
First data list (for example, time).
- y** : sequence  
Second data list.
- use\_ties** : {True, False}, optional  
Whether ties correction should be performed.
- use\_missing** : {False, True}, optional  
Whether missing data should be allocated a rank of 0 (False) or the average rank (True)

**Returns**

- correlation** : float  
Kendall tau
- pvalue** : float  
Approximate 2-side p-value.

`scipy.stats.mstats.kendalltau_seasonal(x)`

Computes a multivariate Kendall's rank correlation tau, for seasonal data.

**Parameters**

- x** : 2-D ndarray

Array of seasonal data, with seasons in columns.

`scipy.stats.mstats.kruskalwallis(*args)`

Compute the Kruskal-Wallis H-test for independent samples

**Parameters** **sample1, sample2, ...** : array\_like  
Two or more arrays with the sample measurements can be given as arguments.

**Returns** **statistic** : float  
The Kruskal-Wallis H statistic, corrected for ties

**pvalue** : float  
The p-value for the test using the assumption that H has a chi square distribution

#### Notes

For more details on *kruskal*, see *stats.kruskal*.

`scipy.stats.mstats.ks_twosamp(data1, data2, alternative='two-sided')`

Computes the Kolmogorov-Smirnov test on two samples.

Missing values are discarded.

**Parameters** **data1** : array\_like  
First data set

**data2** : array\_like  
Second data set

**alternative** : {'two-sided', 'less', 'greater'}, optional  
Indicates the alternative hypothesis. Default is 'two-sided'.

**Returns** **d** : float  
Value of the Kolmogorov Smirnov test

**p** : float  
Corresponding p-value.

`scipy.stats.mstats.kurtosis(a, axis=0, fisher=True, bias=True)`

Computes the kurtosis (Fisher or Pearson) of a dataset.

Kurtosis is the fourth central moment divided by the square of the variance. If Fisher's definition is used, then 3.0 is subtracted from the result to give 0.0 for a normal distribution.

If bias is False then the kurtosis is calculated using k statistics to eliminate bias coming from biased moment estimators

Use *kurtosistest* to see if result is close enough to normal.

**Parameters** **a** : array  
data for which the kurtosis is calculated

**axis** : int or None, optional  
Axis along which the kurtosis is calculated. Default is 0. If None, compute over the whole array *a*.

**fisher** : bool, optional  
If True, Fisher's definition is used (normal ==> 0.0). If False, Pearson's definition is used (normal ==> 3.0).

**bias** : bool, optional  
If False, then the calculations are corrected for statistical bias.

**Returns** **kurtosis** : array  
The kurtosis of values along an axis. If all values are equal, return -3 for Fisher's definition and 0 for Pearson's definition.

*Notes*

For more details about *kurtosis*, see *stats.kurtosis*.

`scipy.stats.mstats.kurtosistest` (*a*, *axis=0*)

Tests whether a dataset has normal kurtosis

<b>Parameters</b>	<b>a</b> : array	array of the sample data
	<b>axis</b> : int or None, optional	Axis along which to compute test. Default is 0. If None, compute over the whole array <i>a</i> .
<b>Returns</b>	<b>statistic</b> : float	The computed z-score for this test.
	<b>pvalue</b> : float	The 2-sided p-value for the hypothesis test

*Notes*

For more details about *kurtosistest*, see *stats.kurtosistest*.

`scipy.stats.mstats.linregress` (*x*, *y=None*)

Calculate a linear least-squares regression for two sets of measurements.

<b>Parameters</b>	<b>x, y</b> : array_like	Two sets of measurements. Both arrays should have the same length. If only <i>x</i> is given (and <i>y=None</i> ), then it must be a two-dimensional array where one dimension has length 2. The two sets of measurements are then found by splitting the array along the length-2 dimension.
<b>Returns</b>	<b>slope</b> : float	slope of the regression line
	<b>intercept</b> : float	intercept of the regression line
	<b>rvalue</b> : float	correlation coefficient
	<b>pvalue</b> : float	two-sided p-value for a hypothesis test whose null hypothesis is that the slope is zero, using Wald Test with t-distribution of the test statistic.
	<b>stderr</b> : float	Standard error of the estimated gradient.

See also:

`scipy.optimize.curve_fit`

Use non-linear least squares to fit a function to data.

`scipy.optimize.leastsq`

Minimize the sum of squares of a set of equations.

*Notes*

Missing values are considered pair-wise: if a value is missing in *x*, the corresponding value in *y* is masked.

*Examples*

```

>>> import matplotlib.pyplot as plt
>>> from scipy import stats
>>> np.random.seed(12345678)
>>> x = np.random.random(10)
>>> y = np.random.random(10)
>>> slope, intercept, r_value, p_value, std_err = stats.linregress(x, y)

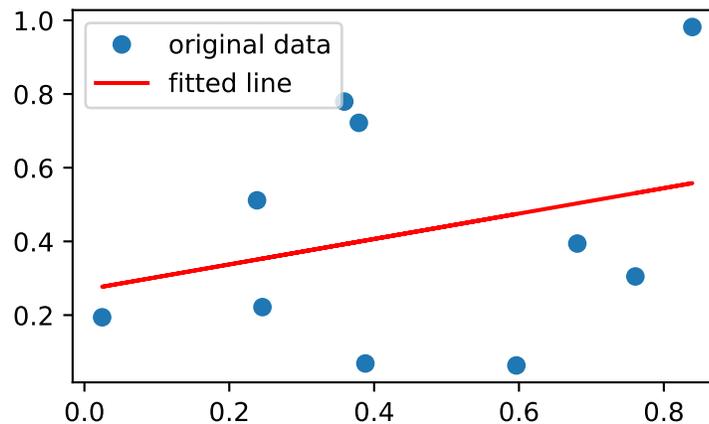
```

To get coefficient of determination (`r_squared`)

```
>>> print("r-squared:", r_value**2)
r-squared: 0.080402268539
```

Plot the data along with the fitted line

```
>>> plt.plot(x, y, 'o', label='original data')
>>> plt.plot(x, intercept + slope*x, 'r', label='fitted line')
>>> plt.legend()
>>> plt.show()
```



`scipy.stats.mstats.mannwhitneyu(x, y, use_continuity=True)`

Computes the Mann-Whitney statistic

Missing values in *x* and/or *y* are discarded.

**Parameters**

- x** : sequence  
Input
- y** : sequence  
Input
- use\_continuity** : {True, False}, optional  
Whether a continuity correction (1/2.) should be taken into account.

**Returns**

- statistic** : float  
The Mann-Whitney statistics
- pvalue** : float  
Approximate p-value assuming a normal distribution.

`scipy.stats.mstats.plotting_positions(data, alpha=0.4, beta=0.4)`

Returns plotting positions (or empirical percentile points) for the data.

*Plotting positions are defined as  $(i-\alpha)/(n+1-\alpha-\beta)$ , where:*

- *i* is the rank order statistics
- *n* is the number of unmasked values along the given axis
- *alpha* and *beta* are two parameters.

*Typical values for alpha and beta are:*

- (0,1) :  $p(k) = k/n$ , linear interpolation of cdf (R, type 4)

- (.5,.5) :  $p(k) = (k-1/2.) / n$ , piecewise linear function (R, type 5)
- (0,0) :  $p(k) = k / (n+1)$ , Weibull (R type 6)
- (1,1) :  $p(k) = (k-1) / (n-1)$ , in this case,  $p(k) = \text{mode}[F(x[k])]$ . That's R default (R type 7)
- (1/3,1/3):  $p(k) = (k-1/3) / (n+1/3)$ , then  $p(k) \sim \text{median}[F(x[k])]$ . The resulting quantile estimates are approximately median-unbiased regardless of the distribution of  $x$ . (R type 8)
- (3/8,3/8):  $p(k) = (k-3/8) / (n+1/4)$ , Blom. The resulting quantile estimates are approximately unbiased if  $x$  is normally distributed (R type 9)
- (.4,.4) : approximately quantile unbiased (Cunnane)
- (.35,.35): APL, used with PWM
- (.3175, .3175): used in `scipy.stats.probplot`

**Parameters**

**data** : array\_like  
Input data, as a sequence or array of dimension at most 2.

**alpha** : float, optional  
Plotting positions parameter. Default is 0.4.

**beta** : float, optional  
Plotting positions parameter. Default is 0.4.

**Returns**

**positions** : MaskedArray  
The calculated plotting positions.

`scipy.stats.mstats.mode(a, axis=0)`

Returns an array of the modal (most common) value in the passed array.

**Parameters**

**a** : array\_like  
n-dimensional array of which to find mode(s).

**axis** : int or None, optional  
Axis along which to operate. Default is 0. If None, compute over the whole array  $a$ .

**Returns**

**mode** : ndarray  
Array of modal values.

**count** : ndarray  
Array of counts for each mode.

**Notes**

For more details, see `stats.mode`.

`scipy.stats.mstats.moment(a, moment=1, axis=0)`

Calculates the  $n$ th moment about the mean for a sample.

**Parameters**

**a** : array\_like  
data

**moment** : int, optional  
order of central moment that is returned

**axis** : int or None, optional  
Axis along which the central moment is computed. Default is 0. If None, compute over the whole array  $a$ .

**Returns**

**$n$ -th central moment** : ndarray or float  
The appropriate moment along the given axis or over all values if axis is None. The denominator for the moment calculation is the number of observations, no degrees of freedom correction is done.

**Notes**

For more details about `moment`, see `stats.moment`.

`scipy.stats.mstats.mquantiles(a, prob=[0.25, 0.5, 0.75], alphap=0.4, betap=0.4, axis=None, limit=())`

Computes empirical quantiles for a data array.

Samples quantile are defined by  $Q(p) = (1-\gamma) * x[j] + \gamma * x[j+1]$ , where  $x[j]$  is the  $j$ -th order statistic, and  $\gamma$  is a function of  $j = \text{floor}(n * p + m)$ ,  $m = \text{alphap} + p * (1 - \text{alphap} - \text{betap})$  and  $g = n * p + m - j$ .

Reinterpreting the above equations to compare to **R** lead to the equation:  $p(k) = (k - \text{alphap}) / (n + 1 - \text{alphap} - \text{betap})$

*Typical values of (alphap,betap) are:*

- (0,1):  $p(k) = k/n$ : linear interpolation of cdf (**R** type 4)
- (.5,.5):  $p(k) = (k - 1/2.) / n$ : piecewise linear function (**R** type 5)
- (0,0):  $p(k) = k / (n+1)$ : (**R** type 6)
- (1,1):  $p(k) = (k-1) / (n-1)$ :  $p(k) = \text{mode}[F(x[k])]$ . (**R** type 7, **R** default)
- (1/3,1/3):  $p(k) = (k-1/3) / (n+1/3)$ : Then  $p(k) \sim \text{median}[F(x[k])]$ . The resulting quantile estimates are approximately median-unbiased regardless of the distribution of  $x$ . (**R** type 8)
- (3/8,3/8):  $p(k) = (k-3/8) / (n+1/4)$ : Blom. The resulting quantile estimates are approximately unbiased if  $x$  is normally distributed (**R** type 9)
- (.4,.4): approximately quantile unbiased (Cunnane)
- (.35,.35): APL, used with PWM

**Parameters** **a**: array\_like

Input data, as a sequence or array of dimension at most 2.

**prob**: array\_like, optional

List of quantiles to compute.

**alphap**: float, optional

Plotting positions parameter, default is 0.4.

**betap**: float, optional

Plotting positions parameter, default is 0.4.

**axis**: int, optional

Axis along which to perform the trimming. If None (default), the input array is first flattened.

**limit**: tuple, optional

Tuple of (lower, upper) values. Values of  $a$  outside this open interval are ignored.

**Returns** **mquantiles**: `MaskedArray`

An array containing the calculated quantiles.

### Notes

This formulation is very similar to **R** except the calculation of  $m$  from `alphap` and `betap`, where in **R**  $m$  is defined with each type.

### References

[R673], [R674]

### Examples

```
>>> from scipy.stats.mstats import mquantiles
>>> a = np.array([6., 47., 49., 15., 42., 41., 7., 39., 43., 40., 36.])
>>> mquantiles(a)
array([ 19.2,  40. ,  42.8])
```

Using a 2D array, specifying axis and limit.

```
>>> data = np.array([[ 6.,  7.,  1.],
...                  [ 47., 15.,  2.],
...                  [ 49., 36.,  3.],
...                  [ 15., 39.,  4.],
...                  [ 42., 40., -999.],
...                  [ 41., 41., -999.],
...                  [  7., -999., -999.],
...                  [ 39., -999., -999.],
...                  [ 43., -999., -999.],
...                  [ 40., -999., -999.],
...                  [ 36., -999., -999.]])
>>> print(mquantiles(data, axis=0, limit=(0, 50)))
[[ 19.2  14.6  1.45]
 [ 40.   37.5  2.5 ]
 [ 42.8  40.05 3.55]]
```

```
>>> data[:, 2] = -999.
>>> print(mquantiles(data, axis=0, limit=(0, 50)))
[[19.200000000000003 14.6 --]
 [40.0 37.5 --]
 [42.800000000000004 40.05 --]]
```

`scipy.stats.mstats.msign(x)`

Returns the sign of x, or 0 if x is masked.

`scipy.stats.mstats.normaltest(a, axis=0)`

Tests whether a sample differs from a normal distribution.

**Parameters** **a** : array\_like

The array containing the data to be tested.

**axis** : int or None, optional

Axis along which to compute test. Default is 0. If None, compute over the

**Returns** **statistic** : float or array

whole array *a*.  
 $s^2 + k^2$ , where *s* is the z-score returned by *skewtest* and *k* is the z-score returned by *kurtosistest*.

**pvalue** : float or array

A 2-sided chi squared probability for the hypothesis test.

**Notes**

For more details about *normaltest*, see *stats.normaltest*.

`scipy.stats.mstats.obrientransform(*args)`

Computes a transform on input data (any number of columns). Used to test for homogeneity of variance prior to running one-way stats. Each array in *\*args* is one level of a factor. If an *f\_oneway()* run on the transformed data and found significant, variances are unequal. From Maxwell and Delaney, p.112.

Returns: transformed data for use in an ANOVA

`scipy.stats.mstats.pearsonr(x, y)`

Calculates a Pearson correlation coefficient and the p-value for testing non-correlation.

The Pearson correlation coefficient measures the linear relationship between two datasets. Strictly speaking, Pearson's correlation requires that each dataset be normally distributed. Like other correlation coefficients, this one varies between -1 and +1 with 0 implying no correlation. Correlations of -1 or +1 imply an exact linear relationship. Positive correlations imply that as *x* increases, so does *y*. Negative correlations imply that as *x* increases, *y* decreases.

The p-value roughly indicates the probability of an uncorrelated system producing datasets that have a Pearson correlation at least as extreme as the one computed from these datasets. The p-values are not entirely reliable but are probably reasonable for datasets larger than 500 or so.

**Parameters** **x** : 1-D array\_like  
Input  
**y** : 1-D array\_like  
Input  
**Returns** **pearsonr** : float  
Pearson's correlation coefficient, 2-tailed p-value.

### References

<http://www.statsoft.com/textbook/glosp.html#Pearson%20Correlation>

`scipy.stats.mstats.pointbiserialr` (*x*, *y*)

Calculates a point biserial correlation coefficient and its p-value.

**Parameters** **x** : array\_like of bools  
Input array.  
**y** : array\_like  
Input array.  
**Returns** **correlation** : float  
R value  
**pvalue** : float  
2-tailed p-value

### Notes

Missing values are considered pair-wise: if a value is missing in *x*, the corresponding value in *y* is masked.

For more details on `pointbiserialr`, see `stats.pointbiserialr`.

`scipy.stats.mstats.rankdata` (*data*, *axis=None*, *use\_missing=False*)

Returns the rank (also known as order statistics) of each data point along the given axis.

If some values are tied, their rank is averaged. If some values are masked, their rank is set to 0 if `use_missing` is False, or set to the average rank of the unmasked values if `use_missing` is True.

**Parameters** **data** : sequence  
Input data. The data is transformed to a masked array  
**axis** : {None,int}, optional  
Axis along which to perform the ranking. If None, the array is first flattened. An exception is raised if the axis is specified for arrays with a dimension larger than 2  
**use\_missing** : bool, optional  
Whether the masked values have a rank of 0 (False) or equal to the average rank of the unmasked values (True).

`scipy.stats.mstats.scoreatpercentile` (*data*, *per*, *limit=()*, *alphap=0.4*, *betap=0.4*)

Calculate the score at the given 'per' percentile of the sequence *a*. For example, the score at `per=50` is the median.

This function is a shortcut to `mquantile`

`scipy.stats.mstats.sem` (*a*, *axis=0*, *ddof=1*)

Calculates the standard error of the mean of the input array.

Also sometimes called standard error of measurement.

**Parameters** **a** : array\_like  
An array containing the values for which the standard error is returned.

**axis** : int or None, optional  
 If axis is None, ravel *a* first. If axis is an integer, this will be the axis over which to operate. Defaults to 0.

**ddof** : int, optional  
 Delta degrees-of-freedom. How many degrees of freedom to adjust for bias in limited samples relative to the population estimate of variance. Defaults to 1.

**Returns** **s** : ndarray or float  
 The standard error of the mean in the sample(s), along the input axis.

**Notes**

The default value for *ddof* changed in scipy 0.15.0 to be consistent with *stats.sem* as well as with the most common definition used (like in the R documentation).

**Examples**

Find standard error along the first axis:

```
>>> from scipy import stats
>>> a = np.arange(20).reshape(5, 4)
>>> print(stats.mstats.sem(a))
[2.8284271247461903  2.8284271247461903  2.8284271247461903
 2.8284271247461903]
```

Find standard error across the whole array, using n degrees of freedom:

```
>>> print(stats.mstats.sem(a, axis=None, ddof=0))
1.2893796958227628
```

`scipy.stats.mstats.skew(a, axis=0, bias=True)`

Computes the skewness of a data set.

**Parameters** **a** : ndarray  
 data

**axis** : int or None, optional  
 Axis along which skewness is calculated. Default is 0. If None, compute over the whole array *a*.

**bias** : bool, optional  
 If False, then the calculations are corrected for statistical bias.

**Returns** **skewness** : ndarray  
 The skewness of values along an axis, returning 0 where all values are equal.

**Notes**

For more details about *skew*, see *stats.skew*.

`scipy.stats.mstats.skewtest(a, axis=0)`

Tests whether the skew is different from the normal distribution.

**Parameters** **a** : array  
 The data to be tested

**axis** : int or None, optional  
 Axis along which statistics are calculated. Default is 0. If None, compute over the whole array *a*.

**Returns** **statistic** : float  
 The computed z-score for this test.

**pvalue** : float  
 a 2-sided p-value for the hypothesis test

**Notes**

For more details about `skewtest`, see `stats.skewtest`.

`scipy.stats.mstats.spearmanr(x, y, use_ties=True)`

Calculates a Spearman rank-order correlation coefficient and the p-value to test for non-correlation.

The Spearman correlation is a nonparametric measure of the linear relationship between two datasets. Unlike the Pearson correlation, the Spearman correlation does not assume that both datasets are normally distributed. Like other correlation coefficients, this one varies between -1 and +1 with 0 implying no correlation. Correlations of -1 or +1 imply a monotonic relationship. Positive correlations imply that as  $x$  increases, so does  $y$ . Negative correlations imply that as  $x$  increases,  $y$  decreases.

Missing values are discarded pair-wise: if a value is missing in  $x$ , the corresponding value in  $y$  is masked.

The p-value roughly indicates the probability of an uncorrelated system producing datasets that have a Spearman correlation at least as extreme as the one computed from these datasets. The p-values are not entirely reliable but are probably reasonable for datasets larger than 500 or so.

<b>Parameters</b>	<b>x</b> : array_like	The length of $x$ must be $> 2$ .
	<b>y</b> : array_like	The length of $y$ must be $> 2$ .
<b>Returns</b>	<b>use_ties</b> : bool, optional	Whether the correction for ties should be computed.
	<b>correlation</b> : float	Spearman correlation coefficient
	<b>pvalue</b> : float	2-tailed p-value.

**References**

[CRCProbStat2000] section 14.7

`scipy.stats.mstats.theilslopes(y, x=None, alpha=0.95)`

Computes the Theil-Sen estimator for a set of points  $(x, y)$ .

`theilslopes` implements a method for robust linear regression. It computes the slope as the median of all slopes between paired values.

<b>Parameters</b>	<b>y</b> : array_like	Dependent variable.
	<b>x</b> : array_like or None, optional	Independent variable. If None, use <code>arange(len(y))</code> instead.
<b>Returns</b>	<b>alpha</b> : float, optional	Confidence degree between 0 and 1. Default is 95% confidence. Note that $\alpha$ is symmetric around 0.5, i.e. both 0.1 and 0.9 are interpreted as “find the 90% confidence interval”.
	<b>medslope</b> : float	Theil slope.
	<b>medintercept</b> : float	Intercept of the Theil line, as $\text{median}(y) - \text{medslope} * \text{median}(x)$ .
	<b>lo_slope</b> : float	Lower bound of the confidence interval on <code>medslope</code> .
	<b>up_slope</b> : float	Upper bound of the confidence interval on <code>medslope</code> .

*Notes*

For more details on *theilslopes*, see *stats.theilslopes*.

`scipy.stats.mstats.tmax` (*a*, *upperlimit=None*, *axis=0*, *inclusive=True*)

Compute the trimmed maximum

This function computes the maximum value of an array along a given axis, while ignoring values larger than a specified upper limit.

**Parameters**

- a** : array\_like  
array of values
- upperlimit** : None or float, optional  
Values in the input array greater than the given limit will be ignored. When upperlimit is None, then all values are used. The default value is None.
- axis** : int or None, optional  
Axis along which to operate. Default is 0. If None, compute over the whole array *a*.
- inclusive** : {True, False}, optional  
This flag determines whether values exactly equal to the upper limit are included. The default value is True.

**Returns**

- tmax** : float, int or ndarray

*Notes*

For more details on *tmax*, see *stats.tmax*.

`scipy.stats.mstats.tmean` (*a*, *limits=None*, *inclusive=(True, True)*, *axis=None*)

Compute the trimmed mean.

**Parameters**

- a** : array\_like  
Array of values.
- limits** : None or (lower limit, upper limit), optional  
Values in the input array less than the lower limit or greater than the upper limit will be ignored. When limits is None (default), then all values are used. Either of the limit values in the tuple can also be None representing a half-open interval.
- inclusive** : (bool, bool), optional  
A tuple consisting of the (lower flag, upper flag). These flags determine whether values exactly equal to the lower or upper limits are included. The default value is (True, True).
- axis** : int or None, optional  
Axis along which to operate. If None, compute over the whole array. Default is None.

**Returns**

- tmean** : float

*Notes*

For more details on *tmean*, see *stats.tmean*.

`scipy.stats.mstats.tmin` (*a*, *lowerlimit=None*, *axis=0*, *inclusive=True*)

Compute the trimmed minimum

**Parameters**

- a** : array\_like  
array of values
- lowerlimit** : None or float, optional  
Values in the input array less than the given limit will be ignored. When lowerlimit is None, then all values are used. The default value is None.
- axis** : int or None, optional

Axis along which to operate. Default is 0. If None, compute over the whole array *a*.

**inclusive** : {True, False}, optional

This flag determines whether values exactly equal to the lower limit are included. The default value is True.

**Returns** **tmin** : float, int or ndarray

### Notes

For more details on *tmin*, see *stats.tmin*.

`scipy.stats.mstats.trim(a, limits=None, inclusive=(True, True), relative=False, axis=None)`

Trims an array by masking the data outside some given limits.

Returns a masked version of the input array.

**Parameters** **a** : sequence

Input array

**limits** : {None, tuple}, optional

If *relative* is False, tuple (lower limit, upper limit) in absolute values. Values of the input array lower (greater) than the lower (upper) limit are masked.

If *relative* is True, tuple (lower percentage, upper percentage) to cut on each side of the array, with respect to the number of unmasked data.

Noting *n* the number of unmasked data before trimming, the (*n*\*limits[0])th smallest data and the (*n*\*limits[1])th largest data are masked, and the total number of unmasked data after trimming is *n*\*(1.-sum(limits)) In each case, the value of one limit can be set to None to indicate an open interval.

If limits is None, no trimming is performed

**inclusive** : {(bool, bool) tuple}, optional

If *relative* is False, tuple indicating whether values exactly equal to the absolute limits are allowed. If *relative* is True, tuple indicating whether the number of data being masked on each side should be rounded (True) or truncated (False).

**relative** : bool, optional

Whether to consider the limits as absolute values (False) or proportions to cut (True).

**axis** : int, optional

Axis along which to trim.

### Examples

```
>>> from scipy.stats.mstats import trim
>>> z = [ 1, 2, 3, 4, 5, 6, 7, 8, 9,10]
>>> print(trim(z, (3,8)))
[-- -- 3 4 5 6 7 8 -- --]
>>> print(trim(z, (0.1,0.2), relative=True))
[-- 2 3 4 5 6 7 8 -- --]
```

`scipy.stats.mstats.trima(a, limits=None, inclusive=(True, True))`

Trims an array by masking the data outside some given limits.

Returns a masked version of the input array.

**Parameters** **a** : array\_like

Input array.

**limits** : {None, tuple}, optional

Tuple of (lower limit, upper limit) in absolute values. Values of the input array lower (greater) than the lower (upper) limit will be masked. A limit is None indicates an open interval.

**inclusive** : (bool, bool) tuple, optional

Tuple of (lower flag, upper flag), indicating whether values exactly equal to the lower (upper) limit are allowed.

`scipy.stats.mstats.trimboth` (*data*, *proportiontocut*=0.2, *inclusive*=(*True*, *True*), *axis*=*None*)

Trims the smallest and largest data values.

Trims the *data* by masking the `int`(`proportiontocut * n`) smallest and `int`(`proportiontocut * n`) largest values of data along the given axis, where *n* is the number of unmasked values before trimming.

**Parameters**    **data** : ndarray

Data to trim.

**proportiontocut** : float, optional

Percentage of trimming (as a float between 0 and 1). If *n* is the number of unmasked values before trimming, the number of values after trimming is  $(1 - 2 * \text{proportiontocut}) * n$ . Default is 0.2.

**inclusive** : {(bool, bool) tuple}, optional

Tuple indicating whether the number of data being masked on each side should be rounded (*True*) or truncated (*False*).

**axis** : int, optional

Axis along which to perform the trimming. If *None*, the input array is first flattened.

`scipy.stats.mstats.trimmed_stde` (*a*, *limits*=(0.1, 0.1), *inclusive*=(1, 1), *axis*=*None*)

Returns the standard error of the trimmed mean along the given axis.

**Parameters**    **a** : sequence

Input array

**limits** : {(0.1,0.1), tuple of float}, optional

tuple (lower percentage, upper percentage) to cut on each side of the array, with respect to the number of unmasked data.

If *n* is the number of unmasked data before trimming, the values smaller than  $n * \text{limits}[0]$  and the values larger than  $n * \text{limits}[1]$  are masked, and the total number of unmasked data after trimming is  $n * (1 - \text{sum}(\text{limits}))$ . In each case, the value of one limit can be set to *None* to indicate an open interval. If *limits* is *None*, no trimming is performed.

**inclusive** : {(bool, bool) tuple} optional

Tuple indicating whether the number of data being masked on each side should be rounded (*True*) or truncated (*False*).

**axis** : int, optional

Axis along which to trim.

**Returns**    **trimmed\_stde** : scalar or ndarray

`scipy.stats.mstats.trimr` (*a*, *limits*=*None*, *inclusive*=(*True*, *True*), *axis*=*None*)

Trims an array by masking some proportion of the data on each end. Returns a masked version of the input array.

**Parameters**    **a** : sequence

Input array.

**limits** : {None, tuple}, optional

Tuple of the percentages to cut on each side of the array, with respect to the number of unmasked data, as floats between 0. and 1. Noting *n* the number of unmasked data before trimming, the  $(n * \text{limits}[0])$ th smallest data and the  $(n * \text{limits}[1])$ th largest data are masked, and the total number of unmasked

data after trimming is  $n*(1.-\text{sum}(\text{limits}))$ . The value of one limit can be set to None to indicate an open interval.

**inclusive** : {(True,True) tuple}, optional

Tuple of flags indicating whether the number of data being masked on the left (right) end should be truncated (True) or rounded (False) to integers.

**axis** : {None,int}, optional

Axis along which to trim. If None, the whole array is trimmed, but its shape is maintained.

`scipy.stats.mstats.trimtail` (*data*, *proportiontocut*=0.2, *tail*='left', *inclusive*=(True, True), *axis*=None)

Trims the data by masking values from one tail.

**Parameters** **data** : array\_like

Data to trim.

**proportiontocut** : float, optional

Percentage of trimming. If *n* is the number of unmasked values before trimming, the number of values after trimming is  $(1 - \text{proportiontocut}) * n$ . Default is 0.2.

**tail** : {'left','right'}, optional

If 'left' the *proportiontocut* lowest values will be masked. If 'right' the *proportiontocut* highest values will be masked. Default is 'left'.

**inclusive** : {(bool, bool) tuple}, optional

Tuple indicating whether the number of data being masked on each side should be rounded (True) or truncated (False). Default is (True, True).

**axis** : int, optional

Axis along which to perform the trimming. If None, the input array is first flattened. Default is None.

**Returns** **trimtail** : ndarray

Returned array of same shape as *data* with masked tail values.

`scipy.stats.mstats.tsem` (*a*, *limits*=None, *inclusive*=(True, True), *axis*=0, *ddof*=1)

Compute the trimmed standard error of the mean.

This function finds the standard error of the mean for given values, ignoring values outside the given *limits*.

**Parameters** **a** : array\_like

array of values

**limits** : None or (lower limit, upper limit), optional

Values in the input array less than the lower limit or greater than the upper limit will be ignored. When *limits* is None, then all values are used. Either of the limit values in the tuple can also be None representing a half-open interval. The default value is None.

**inclusive** : (bool, bool), optional

A tuple consisting of the (lower flag, upper flag). These flags determine whether values exactly equal to the lower or upper limits are included. The default value is (True, True).

**axis** : int or None, optional

Axis along which to operate. If None, compute over the whole array. Default is zero.

**ddof** : int, optional

Delta degrees of freedom. Default is 1.

**Returns** **tsem** : float

### Notes

For more details on *tsem*, see *stats.tsem*.

`scipy.stats.mstats.ttest_onesamp` (*a*, *popmean*, *axis=0*)

Calculates the T-test for the mean of ONE group of scores.

**Parameters**

- a** : array\_like  
sample observation
- popmean** : float or array\_like  
expected value in null hypothesis, if array\_like than it must have the same shape as *a* excluding the axis dimension
- axis** : int or None, optional  
Axis along which to compute test. If None, compute over the whole array

**Returns**

- statistic** : float or array  
*a*.  
t-statistic
- pvalue** : float or array  
two-tailed p-value

**Notes**

For more details on `ttest_1samp`, see `stats.ttest_1samp`.

`scipy.stats.mstats.ttest_ind` (*a*, *b*, *axis=0*, *equal\_var=True*)

Calculates the T-test for the means of TWO INDEPENDENT samples of scores.

**Parameters**

- a, b** : array\_like  
The arrays must have the same shape, except in the dimension corresponding to *axis* (the first, by default).
- axis** : int or None, optional  
Axis along which to compute test. If None, compute over the whole arrays, *a*, and *b*.
- equal\_var** : bool, optional  
If True, perform a standard independent 2 sample test that assumes equal population variances. If False, perform Welch's t-test, which does not assume equal population variance. .. versionadded:: 0.17.0

**Returns**

- statistic** : float or array  
The calculated t-statistic.
- pvalue** : float or array  
The two-tailed p-value.

**Notes**

For more details on `ttest_ind`, see `stats.ttest_ind`.

`scipy.stats.mstats.ttest_rel` (*a*, *b*, *axis=0*)

Calculates the T-test on TWO RELATED samples of scores, *a* and *b*.

**Parameters**

- a, b** : array\_like  
The arrays must have the same shape.
- axis** : int or None, optional  
Axis along which to compute test. If None, compute over the whole arrays, *a*, and *b*.

**Returns**

- statistic** : float or array  
t-statistic
- pvalue** : float or array  
two-tailed p-value

**Notes**

For more details on `ttest_rel`, see `stats.ttest_rel`.

`scipy.stats.mstats.tvar` (*a*, *limits=None*, *inclusive=(True, True)*, *axis=0*, *ddof=1*)

Compute the trimmed variance

This function computes the sample variance of an array of values, while ignoring values which are outside of given *limits*.

**Parameters**

- a** : array\_like  
Array of values.
- limits** : None or (lower limit, upper limit), optional  
Values in the input array less than the lower limit or greater than the upper limit will be ignored. When *limits* is None, then all values are used. Either of the limit values in the tuple can also be None representing a half-open interval. The default value is None.
- inclusive** : (bool, bool), optional  
A tuple consisting of the (lower flag, upper flag). These flags determine whether values exactly equal to the lower or upper limits are included. The default value is (True, True).
- axis** : int or None, optional  
Axis along which to operate. If None, compute over the whole array. Default is zero.
- ddof** : int, optional  
Delta degrees of freedom. Default is 1.

**Returns**

- tvar** : float  
Trimmed variance.

#### Notes

For more details on *tvar*, see *stats.tvar*.

`scipy.stats.mstats.variation` (*a*, *axis=0*)

Computes the coefficient of variation, the ratio of the biased standard deviation to the mean.

**Parameters**

- a** : array\_like  
Input array.
- axis** : int or None, optional  
Axis along which to calculate the coefficient of variation. Default is 0. If None, compute over the whole array *a*.

**Returns**

- variation** : ndarray  
The calculated variation along the requested axis.

#### Notes

For more details about *variation*, see *stats.variation*.

`scipy.stats.mstats.winsorize` (*a*, *limits=None*, *inclusive=(True, True)*, *inplace=False*, *axis=None*)

Returns a Winsorized version of the input array.

The (*limits*[0])th lowest values are set to the (*limits*[0])th percentile, and the (*limits*[1])th highest values are set to the (1 - *limits*[1])th percentile. Masked values are skipped.

**Parameters**

- a** : sequence  
Input array.
- limits** : {None, tuple of float}, optional  
Tuple of the percentages to cut on each side of the array, with respect to the number of unmasked data, as floats between 0. and 1. Noting *n* the number of unmasked data before trimming, the (*n*\**limits*[0])th smallest data and the (*n*\**limits*[1])th largest data are masked, and the total number of unmasked data after trimming is *n*\*(1.-sum(*limits*)). The value of one limit can be set to None to indicate an open interval.

**inclusive** : {(True, True) tuple}, optional  
 Tuple indicating whether the number of data being masked on each side should be rounded (True) or truncated (False).

**inplace** : {False, True}, optional  
 Whether to winsorize in place (True) or to use a copy (False)

**axis** : {None, int}, optional  
 Axis along which to trim. If None, the whole array is trimmed, but its shape is maintained.

**Notes**

This function is applied to reduce the effect of possibly spurious outliers by limiting the extreme values.

`scipy.stats.mstats.zmap(scores, compare, axis=0, ddof=0)`

Calculate the relative z-scores.

Return an array of z-scores, i.e., scores that are standardized to zero mean and unit variance, where mean and variance are calculated from the comparison array.

**Parameters**

- scores** : array\_like  
 The input for which z-scores are calculated.
- compare** : array\_like  
 The input from which the mean and standard deviation of the normalization are taken; assumed to have the same dimension as *scores*.
- axis** : int or None, optional  
 Axis over which mean and variance of *compare* are calculated. Default is 0. If None, compute over the whole array *scores*.
- ddof** : int, optional  
 Degrees of freedom correction in the calculation of the standard deviation. Default is 0.

**Returns**

- zscore** : array\_like  
 Z-scores, in the same shape as *scores*.

**Notes**

This function preserves ndarray subclasses, and works also with matrices and masked arrays (it uses *asanyarray* instead of *asarray* for parameters).

**Examples**

```

>>> from scipy.stats import zmap
>>> a = [0.5, 2.0, 2.5, 3]
>>> b = [0, 1, 2, 3, 4]
>>> zmap(a, b)
array([-1.06066017,  0.          ,  0.35355339,  0.70710678])
    
```

`scipy.stats.mstats.zscore(a, axis=0, ddof=0)`

Calculate the z score of each value in the sample, relative to the sample mean and standard deviation.

**Parameters**

- a** : array\_like  
 An array like object containing the sample data.
- axis** : int or None, optional  
 Axis along which to operate. Default is 0. If None, compute over the whole array *a*.
- ddof** : int, optional  
 Degrees of freedom correction in the calculation of the standard deviation. Default is 0.

**Returns**

- zscore** : array\_like  
 The z-scores, standardized by mean and standard deviation of input array *a*.

**Notes**

This function preserves ndarray subclasses, and works also with matrices and masked arrays (it uses *asanyarray* instead of *asarray* for parameters).

**Examples**

```
>>> a = np.array([ 0.7972,  0.0767,  0.4383,  0.7866,  0.8091,
...               0.1954,  0.6307,  0.6599,  0.1065,  0.0508])
>>> from scipy import stats
>>> stats.zscore(a)
array([ 1.1273, -1.247 , -0.0552,  1.0923,  1.1664, -0.8559,  0.5786,
        0.6748, -1.1488, -1.3324])
```

Computing along a specified axis, using n-1 degrees of freedom (ddof=1) to calculate the standard deviation:

```
>>> b = np.array([[ 0.3148,  0.0478,  0.6243,  0.4608],
...               [ 0.7149,  0.0775,  0.6072,  0.9656],
...               [ 0.6341,  0.1403,  0.9759,  0.4064],
...               [ 0.5918,  0.6948,  0.904 ,  0.3721],
...               [ 0.0921,  0.2481,  0.1188,  0.1366]])
>>> stats.zscore(b, axis=1, ddof=1)
array([[ -0.19264823, -1.28415119,  1.07259584,  0.40420358],
       [  0.33048416, -1.37380874,  0.04251374,  1.00081084],
       [  0.26796377, -1.12598418,  1.23283094, -0.37481053],
       [ -0.22095197,  0.24468594,  1.19042819, -1.21416216],
       [ -0.82780366,  1.4457416 , -0.43867764, -0.1792603 ]])
```

`scipy.stats.mstats.compare_medians_ms(group_1, group_2, axis=None)`

Compares the medians from two independent groups along the given axis.

The comparison is performed using the McKean-Schrader estimate of the standard error of the medians.

**Parameters** **group\_1** : array\_like

First dataset. Has to be of size  $\geq 7$ .

**group\_2** : array\_like

Second dataset. Has to be of size  $\geq 7$ .

**axis** : int, optional

Axis along which the medians are estimated. If None, the arrays are flattened. If *axis* is not None, then *group\_1* and *group\_2* should have the same

**Returns** **compare\_medians\_ms** : {float, ndarray}

If *axis* is None, then returns a float, otherwise returns a 1-D ndarray of floats with a length equal to the length of *group\_1* along *axis*.

`scipy.stats.mstats.gmean(a, axis=0, dtype=None)`

Compute the geometric mean along the specified axis.

Return the geometric average of the array elements. That is:  $n$ -th root of  $(x_1 * x_2 * \dots * x_n)$

**Parameters** **a** : array\_like

Input array or object that can be converted to an array.

**axis** : int or None, optional

Axis along which the geometric mean is computed. Default is 0. If None, compute over the whole array *a*.

**dtype** : dtype, optional

Type of the returned array and of the accumulator in which the elements are summed. If dtype is not specified, it defaults to the dtype of *a*, unless a

**Returns** **gmean** : ndarray  
 has an integer dtype with a precision less than that of the default platform integer. In that case, the default platform integer is used.  
 see dtype parameter above

**See also:**

**numpy.mean** Arithmetic average  
**numpy.average** Weighted average  
**hmean** Harmonic mean

**Notes**

The geometric average is computed over a single dimension of the input array, axis=0 by default, or all values in the array if axis=None. float64 intermediate and return values are used for integer inputs.

Use masked arrays to ignore any non-finite values in the input or that arise in the calculations such as Not a Number and infinity because masked arrays automatically mask any non-finite values.

**Examples**

```
>>> from scipy.stats import gmean
>>> gmean([1, 4])
2.0
>>> gmean([1, 2, 3, 4, 5, 6, 7])
3.3800151591412964
```

scipy.stats.mstats.**hdmedian** (*data, axis=-1, var=False*)

Returns the Harrell-Davis estimate of the median along the given axis.

**Parameters** **data** : ndarray  
 Data array.  
**axis** : int, optional  
 Axis along which to compute the quantiles. If None, use a flattened array.  
**var** : bool, optional  
 Whether to return the variance of the estimate.  
**Returns** **hdmedian** : MaskedArray  
 The median values. If var=True, the variance is returned inside the masked array. E.g. for a 1-D array the shape change from (1,) to (2,).

scipy.stats.mstats.**hdquantiles** (*data, prob=[0.25, 0.5, 0.75], axis=None, var=False*)

Computes quantile estimates with the Harrell-Davis method.

The quantile estimates are calculated as a weighted linear combination of order statistics.

**Parameters** **data** : array\_like  
 Data array.  
**prob** : sequence, optional  
 Sequence of quantiles to compute.  
**axis** : int or None, optional  
 Axis along which to compute the quantiles. If None, use a flattened array.  
**var** : bool, optional  
 Whether to return the variance of the estimate.  
**Returns** **hdquantiles** : MaskedArray  
 A (p,) array of quantiles (if var is False), or a (2,p) array of quantiles and variances (if var is True), where p is the number of quantiles.

**See also:**

*hdquantiles\_sd*

`scipy.stats.mstats.hdquantiles_sd` (*data*, *prob*=[0.25, 0.5, 0.75], *axis*=None)

The standard error of the Harrell-Davis quantile estimates by jackknife.

**Parameters**

- data** : array\_like  
Data array.
- prob** : sequence, optional  
Sequence of quantiles to compute.
- axis** : int, optional  
Axis along which to compute the quantiles. If None, use a flattened array.

**Returns**

- hdquantiles\_sd** : MaskedArray  
Standard error of the Harrell-Davis quantile estimates.

**See also:**

`hdquantiles`

`scipy.stats.mstats.hmean` (*a*, *axis*=0, *dtype*=None)

Calculate the harmonic mean along the specified axis.

That is:  $n / (1/x_1 + 1/x_2 + \dots + 1/x_n)$

**Parameters**

- a** : array\_like  
Input array, masked array or object that can be converted to an array.
- axis** : int or None, optional  
Axis along which the harmonic mean is computed. Default is 0. If None, compute over the whole array *a*.
- dtype** : dtype, optional  
Type of the returned array and of the accumulator in which the elements are summed. If *dtype* is not specified, it defaults to the dtype of *a*, unless *a* has an integer *dtype* with a precision less than that of the default platform integer. In that case, the default platform integer is used.

**Returns**

- hmean** : ndarray  
see *dtype* parameter above

**See also:**

`numpy.mean` Arithmetic average

`numpy.average`

Weighted average

`gmean` Geometric mean

**Notes**

The harmonic mean is computed over a single dimension of the input array, *axis*=0 by default, or all values in the array if *axis*=None. float64 intermediate and return values are used for integer inputs.

Use masked arrays to ignore any non-finite values in the input or that arise in the calculations such as Not a Number and infinity.

**Examples**

```
>>> from scipy.stats import hmean
>>> hmean([1, 4])
1.6000000000000001
>>> hmean([1, 2, 3, 4, 5, 6, 7])
2.6997245179063363
```

`scipy.stats.mstats.idealfourths` (*data*, *axis*=None)

Returns an estimate of the lower and upper quartiles.

Uses the ideal fourths algorithm.

**Parameters** **data** : array\_like  
 Input array.  
**axis** : int, optional  
 Axis along which the quartiles are estimated. If None, the arrays are flattened.

**Returns** **idealfourths** : {list of floats, masked array}  
 Returns the two internal values that divide *data* into four parts using the ideal fourths algorithm either along the flattened array (if *axis* is None) or along *axis* of *data*.

`scipy.stats.mstats.kruskal(*args)`  
 Compute the Kruskal-Wallis H-test for independent samples

**Parameters** **sample1, sample2, ...** : array\_like  
 Two or more arrays with the sample measurements can be given as arguments.

**Returns** **statistic** : float  
 The Kruskal-Wallis H statistic, corrected for ties  
**pvalue** : float  
 The p-value for the test using the assumption that H has a chi square distribution

**Notes**

For more details on *kruskal*, see *stats.kruskal*.

`scipy.stats.mstats.ks_2samp(data1, data2, alternative='two-sided')`  
 Computes the Kolmogorov-Smirnov test on two samples.

Missing values are discarded.

**Parameters** **data1** : array\_like  
 First data set  
**data2** : array\_like  
 Second data set  
**alternative** : {‘two-sided’, ‘less’, ‘greater’}, optional  
 Indicates the alternative hypothesis. Default is ‘two-sided’.

**Returns** **d** : float  
 Value of the Kolmogorov Smirnov test  
**p** : float  
 Corresponding p-value.

`scipy.stats.mstats.median_cihs(data, alpha=0.05, axis=None)`  
 Computes the alpha-level confidence interval for the median of the data.

Uses the Hettmasperger-Sheather method.

**Parameters** **data** : array\_like  
 Input data. Masked values are discarded. The input should be 1D only, or *axis* should be set to None.  
**alpha** : float, optional  
 Confidence level of the intervals.  
**axis** : int or None, optional  
 Axis along which to compute the quantiles. If None, use a flattened array.

**Returns** **median\_cihs**  
 Alpha level confidence interval.

`scipy.stats.mstats.meppf(data, alpha=0.4, beta=0.4)`  
 Returns plotting positions (or empirical percentile points) for the data.  
 Plotting positions are defined as  $(i - \alpha) / (n + 1 - \alpha - \beta)$ , where:

- $i$  is the rank order statistics
- $n$  is the number of unmasked values along the given axis
- $\alpha$  and  $\beta$  are two parameters.

*Typical values for alpha and beta are:*

- (0,1) :  $p(k) = k/n$ , linear interpolation of cdf (R, type 4)
- (.5,.5) :  $p(k) = (k-1/2)/n$ , piecewise linear function (R, type 5)
- (0,0) :  $p(k) = k/(n+1)$ , Weibull (R type 6)
- (1,1) :  $p(k) = (k-1)/(n-1)$ , in this case,  $p(k) = \text{mode}[F(x[k])]$ . That's R default (R type 7)
- (1/3,1/3):  $p(k) = (k-1/3)/(n+1/3)$ , then  $p(k) \sim \text{median}[F(x[k])]$ . The resulting quantile estimates are approximately median-unbiased regardless of the distribution of  $x$ . (R type 8)
- (3/8,3/8):  $p(k) = (k-3/8)/(n+1/4)$ , Blom. The resulting quantile estimates are approximately unbiased if  $x$  is normally distributed (R type 9)
- (.4,.4) : approximately quantile unbiased (Cunnane)
- (.35,.35): APL, used with PWM
- (.3175, .3175): used in `scipy.stats.probplot`

**Parameters**

**data** : array\_like  
Input data, as a sequence or array of dimension at most 2.

**alpha** : float, optional  
Plotting positions parameter. Default is 0.4.

**beta** : float, optional  
Plotting positions parameter. Default is 0.4.

**Returns**

**positions** : MaskedArray  
The calculated plotting positions.

`scipy.stats.mstats.mjci` (*data*, *prob*=[0.25, 0.5, 0.75], *axis*=None)

Returns the Maritz-Jarrett estimators of the standard error of selected experimental quantiles of the data.

**Parameters**

**data** : ndarray  
Data array.

**prob** : sequence, optional  
Sequence of quantiles to compute.

**axis** : int or None, optional  
Axis along which to compute the quantiles. If None, use a flattened array.

`scipy.stats.mstats.mquantiles_cimj` (*data*, *prob*=[0.25, 0.5, 0.75], *alpha*=0.05, *axis*=None)

Computes the alpha confidence interval for the selected quantiles of the data, with Maritz-Jarrett estimators.

**Parameters**

**data** : ndarray  
Data array.

**prob** : sequence, optional  
Sequence of quantiles to compute.

**alpha** : float, optional  
Confidence level of the intervals.

**axis** : int or None, optional  
Axis along which to compute the quantiles. If None, use a flattened array.

**Returns**

**ci\_lower** : ndarray  
The lower boundaries of the confidence interval. Of the same length as *prob*.

**ci\_upper** : ndarray  
The upper boundaries of the confidence interval. Of the same length as *prob*.

`scipy.stats.mstats.rsh` (*data*, *points=None*)

Evaluates Rosenblatt's shifted histogram estimators for each data point.

Rosenblatt's estimator is a centered finite-difference approximation to the derivative of the empirical cumulative distribution function.

**Parameters** **data** : sequence

Input data, should be 1-D. Masked values are ignored.

**points** : sequence or None, optional

Sequence of points where to evaluate Rosenblatt shifted histogram. If None, use the data.

`scipy.stats.mstats.sen_seasonal_slopes` (*x*)

`scipy.stats.mstats.trimmed_mean` (*a*, *limits=(0.1, 0.1)*, *inclusive=(1, 1)*, *relative=True*, *axis=None*)

`scipy.stats.mstats.trimmed_mean_ci` (*data*, *limits=(0.2, 0.2)*, *inclusive=(True, True)*, *alpha=0.05*, *axis=None*)

Selected confidence interval of the trimmed mean along the given axis.

**Parameters** **data** : array\_like

Input data.

**limits** : {None, tuple}, optional

None or a two item tuple. Tuple of the percentages to cut on each side of the array, with respect to the number of unmasked data, as floats between 0. and 1. If *n* is the number of unmasked data before trimming, then (*n* \* *limits*[0])th smallest data and (*n* \* *limits*[1])th largest data are masked. The total number of unmasked data after trimming is *n* \* (1. - sum(*limits*)). The value of one limit can be set to None to indicate an open interval.

Defaults to (0.2, 0.2).

**inclusive** : (2,) tuple of boolean, optional

If *relative==False*, tuple indicating whether values exactly equal to the absolute limits are allowed. If *relative==True*, tuple indicating whether the number of data being masked on each side should be rounded (True) or truncated (False).

Defaults to (True, True).

**alpha** : float, optional

Confidence level of the intervals.

Defaults to 0.05.

**axis** : int, optional

Axis along which to cut. If None, uses a flattened version of *data*.

Defaults to None.

**Returns** **trimmed\_mean\_ci** : (2,) ndarray

The lower and upper confidence intervals of the trimmed data.

`scipy.stats.mstats.trimmed_std` (*a*, *limits=(0.1, 0.1)*, *inclusive=(1, 1)*, *relative=True*, *axis=None*, *ddof=0*)

`scipy.stats.mstats.trimmed_var` (*a*, *limits=(0.1, 0.1)*, *inclusive=(1, 1)*, *relative=True*, *axis=None*, *ddof=0*)

`scipy.stats.mstats.ttest_1samp` (*a*, *popmean*, *axis=0*)

Calculates the T-test for the mean of ONE group of scores.

**Parameters** **a** : array\_like

sample observation

**popmean** : float or array\_like  
 expected value in null hypothesis, if array\_like than it must have the same shape as *a* excluding the axis dimension

**axis** : int or None, optional  
 Axis along which to compute test. If None, compute over the whole array

**Returns**

**statistic** : float or array  
<sup>*a*</sup>  
 t-statistic

**pvalue** : float or array  
 two-tailed p-value

**Notes**

For more details on `ttest_1samp`, see `stats.ttest_1samp`.

### 5.27.9 Univariate and multivariate kernel density estimation (`scipy.stats.kde`)

`gaussian_kde(dataset[, bw_method])` Representation of a kernel-density estimate using Gaussian kernels.

**class** `scipy.stats.gaussian_kde` (*dataset*, *bw\_method=None*)  
 Representation of a kernel-density estimate using Gaussian kernels.

Kernel density estimation is a way to estimate the probability density function (PDF) of a random variable in a non-parametric way. `gaussian_kde` works for both uni-variate and multi-variate data. It includes automatic bandwidth determination. The estimation works best for a unimodal distribution; bimodal or multi-modal distributions tend to be oversmoothed.

**Parameters**

**dataset** : array\_like  
 Datapoints to estimate from. In case of univariate data this is a 1-D array, otherwise a 2-D array with shape (# of dims, # of data).

**bw\_method** : str, scalar or callable, optional  
 The method used to calculate the estimator bandwidth. This can be ‘scott’, ‘silverman’, a scalar constant or a callable. If a scalar, this will be used directly as `kde.factor`. If a callable, it should take a `gaussian_kde` instance as only parameter and return a scalar. If None (default), ‘scott’ is used. See Notes for more details.

**Notes**

Bandwidth selection strongly influences the estimate obtained from the KDE (much more so than the actual shape of the kernel). Bandwidth selection can be done by a “rule of thumb”, by cross-validation, by “plug-in methods” or by other means; see [R644], [R645] for reviews. `gaussian_kde` uses a rule of thumb, the default is Scott’s Rule.

Scott’s Rule [R642], implemented as `scotts_factor`, is:

```
n**(-1./ (d+4)),
```

with *n* the number of data points and *d* the number of dimensions. Silverman’s Rule [R643], implemented as `silverman_factor`, is:

```
(n * (d + 2) / 4.)**(-1. / (d + 4)).
```

Good general descriptions of kernel density estimation can be found in [R642] and [R643], the mathematics for this multi-dimensional implementation can be found in [R642].

### References

[R642], [R643], [R644], [R645]

### Examples

Generate some random two-dimensional data:

```
>>> from scipy import stats
>>> def measure(n):
...     "Measurement model, return two coupled measurements."
...     m1 = np.random.normal(size=n)
...     m2 = np.random.normal(scale=0.5, size=n)
...     return m1+m2, m1-m2
```

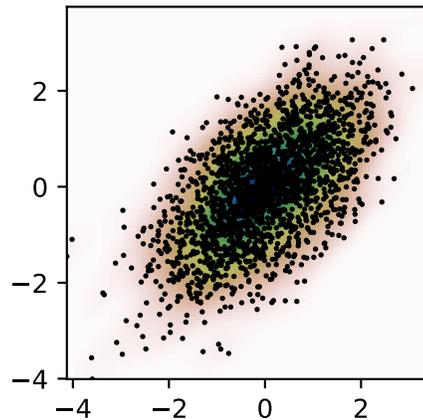
```
>>> m1, m2 = measure(2000)
>>> xmin = m1.min()
>>> xmax = m1.max()
>>> ymin = m2.min()
>>> ymax = m2.max()
```

Perform a kernel density estimate on the data:

```
>>> X, Y = np.mgrid[xmin:xmax:100j, ymin:ymax:100j]
>>> positions = np.vstack([X.ravel(), Y.ravel()])
>>> values = np.vstack([m1, m2])
>>> kernel = stats.gaussian_kde(values)
>>> Z = np.reshape(kernel(positions).T, X.shape)
```

Plot the results:

```
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots()
>>> ax.imshow(np.rot90(Z), cmap=plt.cm.gist_earth_r,
...          extent=[xmin, xmax, ymin, ymax])
>>> ax.plot(m1, m2, 'k.', markersize=2)
>>> ax.set_xlim([xmin, xmax])
>>> ax.set_ylim([ymin, ymax])
>>> plt.show()
```



### Attributes

dataset	(ndarray) The dataset with which <i>gaussian_kde</i> was initialized.
d	(int) Number of dimensions.
n	(int) Number of datapoints.
factor	(float) The bandwidth factor, obtained from <i>kde.covariance_factor</i> , with which the covariance matrix is multiplied.
covariance	(ndarray) The covariance matrix of <i>dataset</i> , scaled by the calculated bandwidth ( <i>kde.factor</i> ).
inv_cov	(ndarray) The inverse of <i>covariance</i> .

### Methods

<i>evaluate</i> (points)	Evaluate the estimated pdf on a set of points.
<i>__call__</i> (points)	Evaluate the estimated pdf on a set of points.
<i>integrate_gaussian</i> (mean, cov)	Multiply estimated density by a multivariate Gaussian and integrate over the whole space.
<i>integrate_box_1d</i> (low, high)	Computes the integral of a 1D pdf between two bounds.
<i>integrate_box</i> (low_bounds, high_bounds[, maxpts])	Computes the integral of a pdf over a rectangular interval.
<i>integrate_kde</i> (other)	Computes the integral of the product of this kernel density estimate with another.
<i>pdf</i> (x)	Evaluate the estimated pdf on a provided set of points.
<i>logpdf</i> (x)	Evaluate the log of the estimated pdf on a provided set of points.
<i>resample</i> ([size])	Randomly sample a dataset from the estimated pdf.
<i>set_bandwidth</i> ([bw_method])	Compute the estimator bandwidth with given method.
<i>covariance_factor</i> ()	Computes the coefficient ( <i>kde.factor</i> ) that multiplies the data covariance matrix to obtain the kernel covariance matrix.

`gaussian_kde.evaluate`(points)  
Evaluate the estimated pdf on a set of points.

**Parameters** **points** : (# of dimensions, # of points)-array  
 Alternatively, a (# of dimensions,) vector can be passed in and treated as a single point.

**Returns** **values** : (# of points,)-array  
 The values at each point.

**Raises** **ValueError** : if the dimensionality of the input points is different than the dimensionality of the KDE.

`gaussian_kde.__call__(points)`

Evaluate the estimated pdf on a set of points.

**Parameters** **points** : (# of dimensions, # of points)-array  
 Alternatively, a (# of dimensions,) vector can be passed in and treated as a single point.

**Returns** **values** : (# of points,)-array  
 The values at each point.

**Raises** **ValueError** : if the dimensionality of the input points is different than the dimensionality of the KDE.

`gaussian_kde.integrate_gaussian(mean, cov)`

Multiply estimated density by a multivariate Gaussian and integrate over the whole space.

**Parameters** **mean** : array\_like  
 A 1-D array, specifying the mean of the Gaussian.

**cov** : array\_like  
 A 2-D array, specifying the covariance matrix of the Gaussian.

**Returns** **result** : scalar  
 The value of the integral.

**Raises** **ValueError**  
 If the mean or covariance of the input Gaussian differs from the KDE's dimensionality.

`gaussian_kde.integrate_box_1d(low, high)`

Computes the integral of a 1D pdf between two bounds.

**Parameters** **low** : scalar  
 Lower bound of integration.

**high** : scalar  
 Upper bound of integration.

**Returns** **value** : scalar  
 The result of the integral.

**Raises** **ValueError**  
 If the KDE is over more than one dimension.

`gaussian_kde.integrate_box(low_bounds, high_bounds, maxpts=None)`

Computes the integral of a pdf over a rectangular interval.

**Parameters** **low\_bounds** : array\_like  
 A 1-D array containing the lower bounds of integration.

**high\_bounds** : array\_like  
 A 1-D array containing the upper bounds of integration.

**maxpts** : int, optional  
 The maximum number of points to use for integration.

**Returns** **value** : scalar  
 The result of the integral.

`gaussian_kde.integrate_kde(other)`

Computes the integral of the product of this kernel density estimate with another.

**Parameters** **other** : gaussian\_kde instance  
 The other kde.

**Returns** **value** : scalar  
 The result of the integral.

**Raises** **ValueError**

If the KDEs have different dimensionality.

`gaussian_kde.pdf(x)`

Evaluate the estimated pdf on a provided set of points.

#### Notes

This is an alias for `gaussian_kde.evaluate`. See the `evaluate` docstring for more details.

`gaussian_kde.logpdf(x)`

Evaluate the log of the estimated pdf on a provided set of points.

`gaussian_kde.resample(size=None)`

Randomly sample a dataset from the estimated pdf.

**Parameters** `size` : int, optional

The number of samples to draw. If not provided, then the size is the same as the underlying dataset.

**Returns** `resample` : (self.d, size) ndarray

The sampled dataset.

`gaussian_kde.set_bandwidth(bw_method=None)`

Compute the estimator bandwidth with given method.

The new bandwidth calculated after a call to `set_bandwidth` is used for subsequent evaluations of the estimated density.

**Parameters** `bw_method` : str, scalar or callable, optional

The method used to calculate the estimator bandwidth. This can be 'scott', 'silverman', a scalar constant or a callable. If a scalar, this will be used directly as `kde.factor`. If a callable, it should take a `gaussian_kde` instance as only parameter and return a scalar. If None (default), nothing happens; the current `kde.covariance_factor` method is kept.

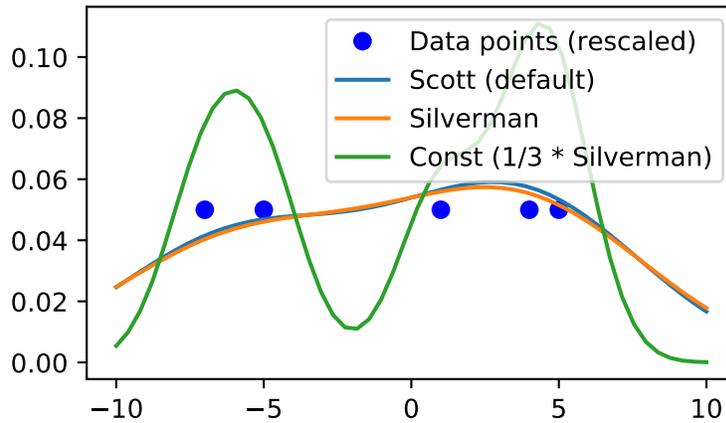
#### Notes

New in version 0.11.

#### Examples

```
>>> import scipy.stats as stats
>>> x1 = np.array([-7, -5, 1, 4, 5.])
>>> kde = stats.gaussian_kde(x1)
>>> xs = np.linspace(-10, 10, num=50)
>>> y1 = kde(xs)
>>> kde.set_bandwidth(bw_method='silverman')
>>> y2 = kde(xs)
>>> kde.set_bandwidth(bw_method=kde.factor / 3.)
>>> y3 = kde(xs)
```

```
>>> import matplotlib.pyplot as plt
>>> fig, ax = plt.subplots()
>>> ax.plot(x1, np.ones(x1.shape) / (4. * x1.size), 'bo',
...        label='Data points (rescaled)')
>>> ax.plot(xs, y1, label='Scott (default)')
>>> ax.plot(xs, y2, label='Silverman')
>>> ax.plot(xs, y3, label='Const (1/3 * Silverman)')
>>> ax.legend()
>>> plt.show()
```



`gaussian_kde.covariance_factor()`

Computes the coefficient (*kde.factor*) that multiplies the data covariance matrix to obtain the kernel covariance matrix. The default is `scotts_factor`. A subclass can overwrite this method to provide a different method, or set it through a call to `kde.set_bandwidth`.

For many more stat related functions install the software R and the interface package rpy.

## 5.28 Low-level callback functions

Some functions in SciPy take as arguments callback functions, which can either be python callables or low-level compiled functions. Using compiled callback functions can improve performance somewhat by avoiding wrapping data in Python objects.

Such low-level functions in Scipy are wrapped in *LowLevelCallable* objects, which can be constructed from function pointers obtained from ctypes, cffi, Cython, or contained in Python *PyCapsule* objects.

*LowLevelCallable*

Low-level callback function.

**class** `scipy.LowLevelCallable`

Low-level callback function.

**Parameters**

- function** : {PyCapsule, ctypes function pointer, cffi function pointer}  
Low-level callback function.
- user\_data** : {PyCapsule, ctypes void pointer, cffi void pointer}  
User data to pass on to the callback function.
- signature** : str, optional  
Signature of the function. If omitted, determined from *function*, if possible.

### Notes

The argument *function* can be one of:

- PyCapsule, whose name contains the C function signature
- ctypes function pointer
- cffi function pointer

The signature of the low-level callback must match one of those expected by the routine it is passed to.

If constructing low-level functions from a PyCapsule, the name of the capsule must be the corresponding signature, in the format:

```
return_type (arg1_type, arg2_type, ...)
```

For example:

```
"void (double)"
"double (double, int *, void *)"
```

The context of a PyCapsule passed in as `function` is used as `user_data`, if an explicit value for `user_data` was not given.

**Attributes**

<code>function</code>	Callback function given
<code>user_data</code>	User data given
<code>signature</code>	Signature of the function.

**Methods**

`from_cython(module, name[, user_data, signature])` Create a low-level callback function from an exported Cython function.

**classmethod** `LowLevelCallable.from_cython(module, name, user_data=None, signature=None)`

Create a low-level callback function from an exported Cython function.

**Parameters**

- module** : module  
Cython module where the exported function resides
- name** : str  
Name of the exported function
- user\_data** : {PyCapsule, ctypes void pointer, cffi void pointer}, optional  
User data to pass on to the callback function.
- signature** : str, optional  
Signature of the function. If omitted, determined from *function*.

**See also:**

Functions accepting low-level callables:

`scipy.integrate.quad`, `scipy.ndimage.generic_filter`, `scipy.ndimage.generic_filter1d`, `scipy.ndimage.geometric_transform`

Usage examples:

*Extending scipy.ndimage in C, Faster integration using low-level callback functions*



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