
Dask.distributed Documentation

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Getting Started

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Dask.distributed is a lightweight library for distributed computing in Python. It extends both the `concurrent.futures` and `dask` APIs to moderate sized clusters.

See [the quickstart](#) to get started.

Motivation

`Distributed` serves to complement the existing PyData analysis stack. In particular it meets the following needs:

- **Low latency:** Each task suffers about 1ms of overhead. A small computation and network roundtrip can complete in less than 10ms.
- **Peer-to-peer data sharing:** Workers communicate with each other to share data. This removes central bottlenecks for data transfer.
- **Complex Scheduling:** Supports complex workflows (not just map/filter/reduce) which are necessary for sophisticated algorithms used in nd-arrays, machine learning, image processing, and statistics.
- **Pure Python:** Built in Python using well-known technologies. This eases installation, improves efficiency (for Python users), and simplifies debugging.
- **Data Locality:** Scheduling algorithms cleverly execute computations where data lives. This minimizes network traffic and improves efficiency.
- **Familiar APIs:** Compatible with the `concurrent.futures` API in the Python standard library. Compatible with `dask` API for parallel algorithms
- **Easy Setup:** As a Pure Python package `distributed` is `pip` installable and easy to *set up* on your own cluster.

CHAPTER 2

Architecture

Dask.distributed is a centrally managed, distributed, dynamic task scheduler. The central `dask-scheduler` process coordinates the actions of several `dask-worker` processes spread across multiple machines and the concurrent requests of several clients.

The scheduler is asynchronous and event driven, simultaneously responding to requests for computation from multiple clients and tracking the progress of multiple workers. The event-driven and asynchronous nature makes it flexible to concurrently handle a variety of workloads coming from multiple users at the same time while also handling a fluid worker population with failures and additions. Workers communicate amongst each other for bulk data transfer over TCP.

Internally the scheduler tracks all work as a constantly changing directed acyclic graph of tasks. A task is a Python function operating on Python objects, which can be the results of other tasks. This graph of tasks grows as users submit more computations, fills out as workers complete tasks, and shrinks as users leave or become disinterested in previous results.

Users interact by connecting a local Python session to the scheduler and submitting work, either by individual calls to the simple interface `client.submit(function, *args, **kwargs)` or by using the large data collections and parallel algorithms of the parent `dask` library. The collections in the `dask` library like `dask.array` and `dask.dataframe` provide easy access to sophisticated algorithms and familiar APIs like NumPy and Pandas, while the simple `client.submit` interface provides users with custom control when they want to break out of canned “big data” abstractions and submit fully custom workloads.

3.1 Install Dask.Distributed

You can install `dask.distributed` with `conda`, with `pip`, or by installing from source.

3.1.1 Conda

To install the latest version of `dask.distributed` from the [conda-forge](#) repository using `conda`:

```
conda install dask distributed -c conda-forge
```

3.1.2 Pip

Or install distributed with `pip`:

```
pip install dask distributed --upgrade
```

3.1.3 Source

To install distributed from source, clone the repository from [github](#):

```
git clone https://github.com/dask/distributed.git
cd distributed
python setup.py install
```

3.1.4 Notes

Note for Macports users: There is a [known issue](#), with python from macports that makes executables be placed in a location that is not available by default. A simple solution is to extend the `PATH` environment variable to the location where python from macports install the binaries:

```
$ export PATH=/opt/local/Library/Frameworks/Python.framework/Versions/3.5/bin:$PATH  
or  
$ export PATH=/opt/local/Library/Frameworks/Python.framework/Versions/2.7/bin:$PATH
```

3.2 Quickstart

3.2.1 Install

```
$ pip install dask distributed --upgrade
```

See [installation](#) document for more information.

3.2.2 Setup Dask.distributed the Easy Way

If you create an client without providing an address it will start up a local scheduler and worker for you.

```
>>> from dask.distributed import Client  
>>> client = Client() # set up local cluster on your laptop  
>>> client  
<Client: scheduler="127.0.0.1:8786" processes=8 cores=8>
```

3.2.3 Setup Dask.distributed the Hard Way

This allows dask.distributed to use multiple machines as workers.

Set up scheduler and worker processes on your local computer:

```
$ dask-scheduler  
Scheduler started at 127.0.0.1:8786  
  
$ dask-worker 127.0.0.1:8786  
$ dask-worker 127.0.0.1:8786  
$ dask-worker 127.0.0.1:8786
```

Note: At least one `dask-worker` must be running after launching a scheduler.

Launch an Client and point it to the IP/port of the scheduler.

```
>>> from dask.distributed import Client  
>>> client = Client('127.0.0.1:8786')
```

See [setup](#) for advanced use.

Map and Submit Functions

Use the `map` and `submit` methods to launch computations on the cluster. The `map/submit` functions send the function and arguments to the remote workers for processing. They return `Future` objects that refer to remote data on the cluster. The `Future` returns immediately while the computations run remotely in the background.

```
>>> def square(x):
    return x ** 2

>>> def neg(x):
    return -x

>>> A = client.map(square, range(10))
>>> B = client.map(neg, A)
>>> total = client.submit(sum, B)
>>> total.result()
-285
```

Gather

The `map/submit` functions return `Future` objects, lightweight tokens that refer to results on the cluster. By default the results of computations *stay on the cluster*.

```
>>> total # Function hasn't yet completed
<Future: status: waiting, key: sum-58999c52e0fa35c7d7346c098f5085c7>

>>> total # Function completed, result ready on remote worker
<Future: status: finished, key: sum-58999c52e0fa35c7d7346c098f5085c7>
```

Gather results to your local machine either with the `Future.result` method for a single future, or with the `Client.gather` method for many futures at once.

```
>>> total.result() # result for single future
-285
>>> client.gather(A) # gather for many futures
[0, 1, 4, 9, 16, 25, 36, 49, 64, 81]
```

Restart

When things go wrong, or when you want to reset the cluster state, call the `restart` method.

```
>>> client.restart()
```

See [client](#) for advanced use.

3.3 Setup Network

A `dask.distributed` network consists of one `Scheduler` node and several `Worker` nodes. One can set these up in a variety of ways

3.3.1 Using the Command Line

We launch the `dask-scheduler` executable in one process and the `dask-worker` executable in several processes, possibly on different machines.

Launch `dask-scheduler` on one node:

```
$ dask-scheduler
Start scheduler at 192.168.0.1:8786
```

Then launch `dask-worker` on the rest of the nodes, providing the address to the node that hosts `dask-scheduler`:

```
$ dask-worker 192.168.0.1:8786
Start worker at:          192.168.0.2:12345
Registered with center at: 192.168.0.1:8786

$ dask-worker 192.168.0.1:8786
Start worker at:          192.168.0.3:12346
Registered with center at: 192.168.0.1:8786

$ dask-worker 192.168.0.1:8786
Start worker at:          192.168.0.4:12347
Registered with center at: 192.168.0.1:8786
```

There are various mechanisms to deploy these executables on a cluster, ranging from manually SSH-ing into all of the nodes to more automated systems like SGE/SLURM/Torque or Yarn/Mesos. Additionally, cluster SSH tools exist to send the same commands to many machines. One example is [tmux-cssh](#).

Note:

- The scheduler and worker both need to accept TCP connections. By default the scheduler uses port 8786 and the worker binds to a random open port. If you are behind a firewall then you may have to open particular ports or tell Dask to use particular ports with the `--port` and `-worker-port` keywords. Other ports like 8787, 8788, and 8789 are also useful to keep open for the diagnostic web interfaces.
 - More information about relevant ports is available by looking at the help pages with `dask-scheduler --help` and `dask-worker --help`
-

3.3.2 Using SSH

The convenience script `dask-ssh` opens several SSH connections to your target computers and initializes the network accordingly. You can give it a list of hostnames or IP addresses:

```
$ dask-ssh 192.168.0.1 192.168.0.2 192.168.0.3 192.168.0.4
```

Or you can use normal UNIX grouping:

```
$ dask-ssh 192.168.0.{1,2,3,4}
```

Or you can specify a hostfile that includes a list of hosts:

```
$ cat hostfile.txt
192.168.0.1
192.168.0.2
```

```
192.168.0.3
192.168.0.4

$ dask-ssh --hostfile hostfile.txt
```

The `dask-ssh` utility depends on the `paramiko`:

```
pip install paramiko
```

3.3.3 Using a Shared Network File System and a Job Scheduler

Some clusters benefit from a shared network file system (NFS) and can use this to communicate the scheduler location to the workers:

```
dask-scheduler --scheduler-file /path/to/scheduler.json

dask-worker --scheduler-file /path/to/scheduler.json
dask-worker --scheduler-file /path/to/scheduler.json
```

```
>>> client = Client(scheduler_file='/path/to/scheduler.json')
```

This can be particularly useful when deploying `dask-scheduler` and `dask-worker` processes using a job scheduler like SGE/SLURM/Torque/etc. . Here is an example using SGE's `qsub` command:

```
# Start a dask-scheduler somewhere and write connection information to file
qsub -b y /path/to/dask-scheduler --scheduler-file /path/to/scheduler.json

# Start 100 dask-worker processes in an array job pointing to the same file
qsub -b y -t 1-100 /path/to/dask-worker --scheduler-file /path/to/scheduler.json
```

Note, the `--scheduler-file` option is *only* valuable if your scheduler and workers share a standard POSIX file system.

3.3.4 Using MPI

You can launch a Dask network using `mpirun` or `mpiexec` and the `dask-mpi` command line executable.

```
mpirun --np 4 dask-mpi --scheduler-file /path/to/scheduler.json
```

```
from dask.distributed import Client
client = Client(scheduler_file='/path/to/scheduler.json')
```

This depends on the `mpi4py` library. It only uses MPI to start the Dask cluster, and not for inter-node communication. You may want to specify a high-bandwidth network interface like infiniband using the `--interface` keyword

```
mpirun --np 4 dask-mpi --nthreads 1 \
    --interface ib0 \
    --scheduler-file /path/to/scheduler.json
```

3.3.5 Using the Python API

Alternatively you can start up the `distributed.scheduler.Scheduler` and `distributed.worker.Worker` objects within a Python session manually.

Start the Scheduler, provide the listening port (defaults to 8786) and Tornado IOLoop (defaults to `IOLoop.current()`)

```
from distributed import Scheduler
from tornado.ioloop import IOLoop
from threading import Thread

loop = IOLoop.current()
t = Thread(target=loop.start, daemon=True)
t.start()

s = Scheduler(loop=loop)
s.start('tcp://:8786')    # Listen on TCP port 8786
```

On other nodes start worker processes that point to the URL of the scheduler.

```
from distributed import Worker
from tornado.ioloop import IOLoop
from threading import Thread

loop = IOLoop.current()
t = Thread(target=loop.start, daemon=True)
t.start()

w = Worker('tcp://127.0.0.1:8786', loop=loop)
w.start()    # choose randomly assigned port
```

Alternatively, replace `Worker` with `Nanny` if you want your workers to be managed in a separate process by a local nanny process. This allows workers to restart themselves in case of failure, provides some additional monitoring, and is useful when coordinating many workers that should live in different processes to avoid the [GIL](#).

3.3.6 Using LocalCluster

You can do the work above easily using *LocalCluster*.

```
from distributed import LocalCluster
c = LocalCluster(processes=False)
```

A scheduler will be available under `c.scheduler` and a list of workers under `c.workers`. There is an `IOLoop` running in a background thread.

3.3.7 Using Amazon EC2

See the [EC2 quickstart](#) for information on the `dask-ec2` easy setup script to launch a canned cluster on EC2.

3.3.8 Using Google Cloud

See the [dask-kubernetes](#) project to easily launch clusters on [Google Kubernetes Engine](#).

3.3.9 Cluster Resource Managers

Dask.distributed has been deployed on dozens of different cluster resource managers. This section contains links to some external projects, scripts, and instructions that may serve as useful starting points.

Kubernetes

- <https://github.com/martindurant/dask-kubernetes>
- <https://github.com/ogrisel/docker-distributed>
- <https://github.com/hammerlab/dask-distributed-on-kubernetes/>

Marathon

- <https://github.com/mrocklin/dask-marathon>

DRMAA (SGE, SLURM, Torque, etc..)

- <https://github.com/dask/dask-drmaa>
- <https://github.com/mfouesneau/dasksgsge>

YARN

- <https://github.com/dask/dask-yarn>
- <https://knit.readthedocs.io/en/latest/>

3.3.10 Software Environment

The workers and clients should all share the same software environment. That means that they should all have access to the same libraries and that those libraries should be the same version. Dask generally assumes that it can call a function on any worker with the same outcome (unless explicitly told otherwise.)

This is typically enforced through external means, such as by having a network file system (NFS) mount for libraries, by starting the `dask-worker` processes in equivalent [Docker](#) containers, using [Conda](#) environments, or through any of the other means typically employed by cluster administrators.

Windows

Note:

- Running a `dask-scheduler` on Windows architectures is supported for only a limited number of workers (roughly 100). This is a detail of the underlying tcp server implementation and is discussed [here](#).
 - Running `dask-worker` processes on Windows is well supported, performant, and without limit.
-

If you wish to run in a primarily Windows environment, it is recommended to run a `dask-scheduler` on a linux or MacOSX environment, with `dask-worker` workers on the Windows boxes. This works because the scheduler environment is de-coupled from that of the workers.

3.3.11 Customizing initialization

Both `dask-scheduler` and `dask-worker` support a `--preload` option that allows custom initialization of each scheduler/worker respectively. A module or python file passed as a `--preload` value is guaranteed to be imported before establishing any connection. A `dask_setup(service)` function is called if found, with a `Scheduler` or `Worker` instance as the argument. As the service stops, `dask_teardown(service)` is called if present.

As an example, consider the following file that creates a *scheduler plugin* and registers it with the scheduler

```
# scheduler-setup.py
from distributed.diagnostics.plugin import SchedulerPlugin

class MyPlugin(SchedulerPlugin):
    def add_worker(self, scheduler=None, worker=None, **kwargs):
        print("Added a new worker at", worker)

def dask_setup(scheduler):
    plugin = MyPlugin()
    scheduler.add_plugin(plugin)
```

We can then run this preload script by referring to its filename (or module name if it is on the path) when we start the scheduler:

```
dask-scheduler --preload scheduler-setup.py
```

3.4 Client

The Client is the primary entry point for users of `dask.distributed`.

After we *setup a cluster*, we initialize a `Client` by pointing it to the address of a `Scheduler`:

```
>>> from distributed import Client
>>> client = Client('127.0.0.1:8786')
```

There are a few different ways to interact with the cluster through the client:

1. The Client satisfies most of the standard `concurrent.futures` - PEP-3148 interface with `.submit`, `.map` functions and `Future` objects, allowing the immediate and direct submission of tasks.
2. The Client registers itself as the default `Dask` scheduler, and so runs all dask collections like `dask.array`, `dask.bag`, `dask.dataframe` and `dask.delayed`
3. The Client has additional methods for manipulating data remotely. See the full *API* for a thorough list.

3.4.1 Concurrent.futures

We can submit individual function calls with the `client.submit` method or many function calls with the `client.map` method

```
>>> def inc(x):
    return x + 1

>>> x = client.submit(inc, 10)
>>> x
<Future - key: inc-e4853cffcc2f51909cdb69d16dacd1a5>
```

```
>>> L = client.map(inc, range(1000))
>>> L
[<Future - key: inc-e4853cfffcc2f51909cdb69d16dacd1a5>,
 <Future - key: inc-...>,
 <Future - key: inc-...>,
 <Future - key: inc-...>, ...]
```

These results live on distributed workers.

We can submit tasks on futures. The function will go to the machine where the futures are stored and run on the result once it has completed.

```
>>> y = client.submit(inc, x)      # Submit on x, a Future
>>> total = client.submit(sum, L)  # Map on L, a list of Futures
```

We gather back the results using either the `Future.result` method for single futures or `client.gather` method for many futures at once.

```
>>> x.result()
11

>>> client.gather(L)
[1, 2, 3, 4, 5, ...]
```

But, as always, we want to minimize communicating results back to the local process. It's often best to leave data on the cluster and operate on it remotely with functions like `submit`, `map`, `get` and `compute`. See [efficiency](#) for more information on efficient use of distributed.

3.4.2 Dask

The parent library `Dask` contains objects like `dask.array`, `dask.dataframe`, `dask.bag`, and `dask.delayed`, which automatically produce parallel algorithms on larger datasets. All dask collections work smoothly with the distributed scheduler.

When we create a `Client` object it registers itself as the default Dask scheduler. All `.compute()` methods will automatically start using the distributed system.

```
client = Client('scheduler:8786')

my_dataframe.sum().compute()  # Now uses the distributed system by default
```

We can stop this behavior by using the `set_as_default=False` keyword argument when starting the `Client`.

Dask's normal `.compute()` methods are *synchronous*, meaning that they block the interpreter until they complete. Dask.distributed allows the new ability of *asynchronous* computing, we can trigger computations to occur in the background and persist in memory while we continue doing other work. This is typically handled with the `Client.persist` and `Client.compute` methods which are used for larger and smaller result sets respectively.

```
>>> df = client.persist(df)  # trigger all computations, keep df in memory
>>> type(df)
dask.DataFrame
```

For more information see the page on [Managing Computation](#).

3.4.3 Pure Functions by Default

By default we assume that all functions are `pure`. If this is not the case we should use the `pure=False` keyword argument.

The client associates a key to all computations. This key is accessible on the Future object.

```
>>> from operator import add
>>> x = client.submit(add, 1, 2)
>>> x.key
'add-ebf39f96ad7174656f97097d658f3fa2'
```

This key should be the same across all computations with the same inputs and across all machines. If we run the computation above on any computer with the same environment then we should get the exact same key.

The scheduler avoids redundant computations. If the result is already in memory from a previous call then that old result will be used rather than recomputing it. Calls to `submit` or `map` are idempotent in the common case.

While convenient, this feature may be undesired for impure functions, like `random`. In these cases two calls to the same function with the same inputs should produce different results. We accomplish this with the `pure=False` keyword argument. In this case keys are randomly generated (by `uuid4`.)

```
>>> import numpy as np
>>> client.submit(np.random.random, 1000, pure=False).key
'random_sample-fc814a39-ee00-42f3-8b6f-cac65bcb5556'
>>> client.submit(np.random.random, 1000, pure=False).key
'random_sample-a24e7220-a113-47f2-a030-72209439f093'
```

3.4.4 Tornado Coroutines

If we are operating in an asynchronous environment then the blocking functions listed above become asynchronous equivalents. You must start your client with the `asynchronous=True` keyword and `yield` or `await` blocking functions.

```
@gen.coroutine
def f():
    client = yield Client(asynchronous=True)
    future = client.submit(func, *args)
    result = yield future
    return result
```

If you want to reuse the same client in asynchronous and synchronous environments you can apply the `asynchronous=True` keyword at each method call.

```
client = Client() # normal blocking client

@gen.coroutine
def f():
    futures = client.map(func, L)
    results = yield client.gather(futures, asynchronous=True)
    return results
```

See the [Asynchronous](#) documentation for more information.

3.4.5 Additional Links

For more information on how to use dask.distributed you may want to look at the following pages:

- [Managing Memory](#)
- [Managing Computation](#)
- [Data Locality](#)
- [API](#)

3.5 API

Client

<code>Client([address, loop, timeout, ...])</code>	Connect to and drive computation on a distributed Dask cluster
<code>Client.call_stack([futures, keys])</code>	The actively running call stack of all relevant keys
<code>Client.cancel(futures[, asynchronous, force])</code>	Cancel running futures
<code>Client.close([timeout])</code>	Close this client
<code>Client.compute(collections[, sync, ...])</code>	Compute dask collections on cluster
<code>Client.gather(futures[, errors, maxsize, ...])</code>	Gather futures from distributed memory
<code>Client.get(dsk, keys[, restrictions, ...])</code>	Compute dask graph
<code>Client.get_dataset(name, **kwargs)</code>	Get named dataset from the scheduler
<code>Client.get_executor(**kwargs)</code>	Return a concurrent.futures Executor for submitting tasks on this Client.
<code>Client.get_metadata(keys[, default])</code>	Get arbitrary metadata from scheduler
<code>Client.get_scheduler_logs([n])</code>	Get logs from scheduler
<code>Client.get_worker_logs([n, workers])</code>	Get logs from workers
<code>Client.has_what([workers])</code>	Which keys are held by which workers
<code>Client.list_datasets(**kwargs)</code>	List named datasets available on the scheduler
<code>Client.map(func, *iterables, **kwargs)</code>	Map a function on a sequence of arguments
<code>Client.ncores([workers])</code>	The number of threads/cores available on each worker node
<code>Client.persist(collections[, ...])</code>	Persist dask collections on cluster
<code>Client.publish_dataset(**kwargs)</code>	Publish named datasets to scheduler
<code>Client.profile([key, start, stop, workers, ...])</code>	Collect statistical profiling information about recent work
<code>Client.rebalance([futures, workers])</code>	Rebalance data within network
<code>Client.replicate(futures[, n, workers, ...])</code>	Set replication of futures within network
<code>Client.restart(**kwargs)</code>	Restart the distributed network
<code>Client.run(function, *args, **kwargs)</code>	Run a function on all workers outside of task scheduling system
<code>Client.run_on_scheduler(function, *args, ...)</code>	Run a function on the scheduler process
<code>Client.scatter(data[, workers, broadcast, ...])</code>	Scatter data into distributed memory
<code>Client.scheduler_info(**kwargs)</code>	Basic information about the workers in the cluster
<code>Client.set_metadata(key, value)</code>	Set arbitrary metadata in the scheduler
<code>Client.start_ipython_workers([workers, ...])</code>	Start IPython kernels on workers
<code>Client.start_ipython_scheduler([magic_name, ...])</code>	Start IPython kernel on the scheduler
<code>Client.submit(func, *args, **kwargs)</code>	Submit a function application to the scheduler
<code>Client.unpublish_dataset(name, **kwargs)</code>	Remove named datasets from scheduler
<code>Client.upload_file(filename, **kwargs)</code>	Upload local package to workers

Continued on next page

Table 3.1 – continued from previous page

<code>Client.who_has([futures])</code>	The workers storing each future’s data
<code>worker_client(*args, **kwargs)</code>	Get client for this thread
<code>get_worker()</code>	Get the worker currently running this task
<code>get_client([address, timeout])</code>	Get a client while within a task
<code>secede()</code>	Have this task secede from the worker’s thread pool
<code>rejoin()</code>	Have this thread rejoin the ThreadPoolExecutor
<code>Reschedule</code>	Reschedule this task
<code>ReplayExceptionClient.get_futures_error(future)</code>	Ask the scheduler details of the sub-task of the given failed future
<code>ReplayExceptionClient.recreate_error_locally(future)</code>	For a failed calculation, perform the blamed task locally for debugging.

Future

<code>Future(key[, client, inform, state])</code>	A remotely running computation
<code>Future.add_done_callback(fn)</code>	Call callback on future when callback has finished
<code>Future.cancel(**kwargs)</code>	Cancel request to run this future
<code>Future.cancelled()</code>	Returns True if the future has been cancelled
<code>Future.done()</code>	Is the computation complete?
<code>Future.exception([timeout])</code>	Return the exception of a failed task
<code>Future.result([timeout])</code>	Wait until computation completes, gather result to local process.
<code>Future.traceback([timeout])</code>	Return the traceback of a failed task

Client Coordination

<code>Lock([name, client])</code>	Distributed Centralized Lock
<code>Queue([name, client, maxsize])</code>	Distributed Queue
<code>Variable([name, client, maxsize])</code>	Distributed Global Variable

Other

<code>as_completed([futures, loop, with_results])</code>	Return futures in the order in which they complete
<code>distributed.diagnostics.progress(*futures, ...)</code>	Track progress of futures
<code>wait(fs[, timeout, return_when])</code>	Wait until all futures are complete
<code>fire_and_forget(obj)</code>	Run tasks at least once, even if we release the futures

3.5.1 Asynchronous methods

Most methods and functions can be used equally well within a blocking or asynchronous environment using Tornado coroutines. If used within a Tornado IOLoop then you should yield or await otherwise blocking operations appropriately.

You must tell the client that you intend to use it within an asynchronous environment by passing the `asynchronous=True` keyword

```
# blocking
client = Client()
future = client.submit(func, *args) # immediate, no blocking/async difference
result = client.gather(future) # blocking

# asynchronous Python 2/3
client = yield Client(asynchronous=True)
future = client.submit(func, *args) # immediate, no blocking/async difference
result = yield client.gather(future) # non-blocking/asynchronous

# asynchronous Python 3
client = await Client(asynchronous=True)
future = client.submit(func, *args) # immediate, no blocking/async difference
result = await client.gather(future) # non-blocking/asynchronous
```

The asynchronous variants must be run within a Tornado coroutine. See the [Asynchronous](#) documentation for more information.

3.5.2 Client

```
class distributed.client.Client (address=None, loop=None, timeout=5, set_as_default=True,
                                scheduler_file=None, security=None, asynchronous=False,
                                name=None, heartbeat_interval=None, **kwargs)
```

Connect to and drive computation on a distributed Dask cluster

The Client connects users to a dask.distributed compute cluster. It provides an asynchronous user interface around functions and futures. This class resembles executors in `concurrent.futures` but also allows Future objects within `submit/map` calls.

Parameters **address: string, or Cluster**

This can be the address of a Scheduler server like a string `'127.0.0.1:8786'` or a cluster object like `LocalCluster()`

timeout: int

Timeout duration for initial connection to the scheduler

set_as_default: bool (True)

Claim this scheduler as the global dask scheduler

scheduler_file: string (optional)

Path to a file with scheduler information if available

security: (optional)

Optional security information

asynchronous: bool (False by default)

Set to True if this client will be used within a Tornado event loop

name: string (optional)

Gives the client a name that will be included in logs generated on the scheduler for matters relating to this client

heartbeat_interval: int

Time in milliseconds between heartbeats to scheduler

See also:

`distributed.scheduler.Scheduler` Internal scheduler

Examples

Provide cluster's scheduler node address on initialization:

```
>>> client = Client('127.0.0.1:8786')
```

Use submit method to send individual computations to the cluster

```
>>> a = client.submit(add, 1, 2)
>>> b = client.submit(add, 10, 20)
```

Continue using submit or map on results to build up larger computations

```
>>> c = client.submit(add, a, b)
```

Gather results with the gather method.

```
>>> client.gather(c)
33
```

asynchronous

Are we running in the event loop?

This is true if the user signaled that we might be when creating the client as in the following:

```
client = Client(asynchronous=True)
```

However, we override this expectation if we can definitively tell that we are running from a thread that is not the event loop. This is common when calling `get_client()` from within a worker task. Even though the client was originally created in asynchronous mode we may find ourselves in contexts when it is better to operate synchronously.

call_stack (*futures=None, keys=None*)

The actively running call stack of all relevant keys

You can specify data of interest either by providing futures or collections in the `futures=` keyword or a list of explicit keys in the `keys=` keyword. If neither are provided then all call stacks will be returned.

Parameters **futures:** list (optional)

List of futures, defaults to all data

keys: list (optional)

List of key names, defaults to all data

Examples

```
>>> df = dd.read_parquet(...).persist()
>>> client.call_stack(df)  # call on collections
```



```
>>> client.call_stack() # Or call with no arguments for all activity
```

cancel (*futures, asynchronous=None, force=False*)

Cancel running futures

This stops future tasks from being scheduled if they have not yet run and deletes them if they have already run. After calling, this result and all dependent results will no longer be accessible

Parameters **futures:** list of Futures

force: boolean (False)

Cancel this future even if other clients desire it

close (*timeout=10*)

Close this client

Clients will also close automatically when your Python session ends

If you started a client without arguments like `Client()` then this will also close the local cluster that was started at the same time.

See also:

`Client.restart`

compute (*collections, sync=False, optimize_graph=True, workers=None, allow_other_workers=False, resources=None, retries=0, **kwargs*)

Compute dask collections on cluster

Parameters **collections:** iterable of dask objects or single dask object

Collections like `dask.array` or `dataframe` or `dask.value` objects

sync: bool (optional)

Returns Futures if False (default) or concrete values if True

optimize_graph: bool

Whether or not to optimize the underlying graphs

workers: str, list, dict

Which workers can run which parts of the computation If a string a list then the output collections will run on the listed

workers, but other sub-computations can run anywhere

If a dict then keys should be (tuples of) collections and values should be addresses or lists.

allow_other_workers: bool, list

If True then all restrictions in `workers=` are considered loose If a list then only the keys for the listed collections are loose

retries: int (default to 0)

Number of allowed automatic retries if computing a result fails

****kwargs:**

Options to pass to the graph optimize calls

Returns List of Futures if input is a sequence, or a single future otherwise

See also:

Client.get Normal synchronous dask.get function

Examples

```
>>> from dask import delayed
>>> from operator import add
>>> x = delayed(add)(1, 2)
>>> y = delayed(add)(x, x)
>>> xx, yy = client.compute([x, y])
>>> xx
<Future: status: finished, key: add-8f6e709446674bad78ea8aeecfee188e>
>>> xx.result()
3
>>> yy.result()
6
```

Also support single arguments

```
>>> xx = client.compute(x)
```

classmethod `current()`

Return global client if one exists, otherwise raise `ValueError`

gather (*futures*, *errors*='raise', *maxsize*=0, *direct*=None, *asynchronous*=None)

Gather futures from distributed memory

Accepts a future, nested container of futures, iterator, or queue. The return type will match the input type.

Parameters **futures:** Collection of futures

This can be a possibly nested collection of Future objects. Collections can be lists, sets, iterators, queues or dictionaries

errors: string

Either 'raise' or 'skip' if we should raise if a future has erred or skip its inclusion in the output collection

maxsize: int

If the input is a queue then this produces an output queue with a maximum size.

Returns results: a collection of the same type as the input, but now with

gathered results rather than futures

See also:

Client.scatter Send data out to cluster

Examples

```
>>> from operator import add
>>> c = Client('127.0.0.1:8787')
>>> x = c.submit(add, 1, 2)
>>> c.gather(x)
```

```
3
>>> c.gather([x, [x], x]) # support lists and dicts
[3, [3], 3]
```

```
>>> seq = c.gather(iter([x, x])) # support iterators
>>> next(seq)
3
```

get (*dsk*, *keys*, *restrictions=None*, *loose_restrictions=None*, *resources=None*, *sync=True*, *asynchronous=None*, ***kwargs*)
 Compute dask graph

Parameters *dsk*: dict

keys: object, or nested lists of objects

restrictions: dict (optional)

A mapping of {key: {set of worker hostnames}} that restricts where jobs can take place

sync: bool (optional)

Returns Futures if False or concrete values if True (default).

See also:

[*Client.compute*](#) Compute asynchronous collections

Examples

```
>>> from operator import add
>>> c = Client('127.0.0.1:8787')
>>> c.get({'x': (add, 1, 2)}, 'x')
3
```

get_dataset (*name*, ***kwargs*)
 Get named dataset from the scheduler

See also:

[*Client.publish_dataset*](#), [*Client.list_datasets*](#)

get_executor (***kwargs*)
 Return a concurrent.futures Executor for submitting tasks on this Client.

Parameters ***kwargs*:

Any submit()- or map()- compatible arguments, such as *workers* or *resources*.

Returns An Executor object that's fully compatible with the concurrent.futures

API.

get_metadata (*keys*, *default='__no_default__'*)
 Get arbitrary metadata from scheduler
 See [*set_metadata*](#) for the full docstring with examples

See also:

[*Client.set_metadata*](#)

classmethod `get_restrictions` (*collections, workers, allow_other_workers*)

Get restrictions from inputs to compute/persist

get_scheduler_logs (*n=None*)

Get logs from scheduler

Parameters *n*: int

Number of logs to retrieve. Maxes out at 10000 by default, configurable in `config.yaml::log-length`

Returns Logs in reversed order (newest first)

get_versions (*check=False*)

Return version info for the scheduler, all workers and myself

Parameters *check*: boolean, default False

raise `ValueError` if all required & optional packages do not match

Examples

```
>>> c.get_versions()
```

get_worker_logs (*n=None, workers=None*)

Get logs from workers

Parameters *n*: int

Number of logs to retrieve. Maxes out at 10000 by default, configurable in `config.yaml::log-length`

workers: iterable

List of worker addresses to retrieve. Gets all workers by default.

Returns Dictionary mapping worker address to logs.

Logs are returned in reversed order (newest first)

has_what (*workers=None, **kwargs*)

Which keys are held by which workers

Parameters *workers*: list (optional)

A list of worker addresses, defaults to all

See also:

`Client.who_has`, `Client.ncores`

Examples

```
>>> x, y, z = c.map(inc, [1, 2, 3])
>>> wait([x, y, z])
>>> c.has_what()
{'192.168.1.141:46784': ['inc-1c8dd6be1c21646c71f76c16d09304ea',
                       'inc-fd65c238a7ea60f6a01bf4c8a5fcf44b',
                       'inc-1e297fc27658d7b67b3a758f16bcf47a']}
```

list_datasets (***kwargs*)

List named datasets available on the scheduler

See also:

Client.publish_dataset, *Client.get_dataset*

map (*func*, **iterables*, ***kwargs*)

Map a function on a sequence of arguments

Arguments can be normal objects or Futures

Parameters **func**: callable

iterables: Iterables, Iterators, or Queues

key: str, list

Prefix for task names if string. Explicit names if list.

pure: bool (defaults to True)

Whether or not the function is pure. Set `pure=False` for impure functions like `np.random.random`.

workers: set, iterable of sets

A set of worker hostnames on which computations may be performed. Leave empty to default to all workers (common case)

retries: int (default to 0)

Number of allowed automatic retries if a task fails

Returns List, iterator, or Queue of futures, depending on the type of the inputs.

See also:

Client.submit Submit a single function

Examples

```
>>> L = client.map(func, sequence)
```

nbytes (*keys=None*, *summary=True*, ***kwargs*)

The bytes taken up by each key on the cluster

This is as measured by `sys.getsizeof` which may not accurately reflect the true cost.

Parameters **keys**: list (optional)

A list of keys, defaults to all keys

summary: boolean, (optional)

Summarize keys into key types

See also:

Client.who_has

Examples

```
>>> x, y, z = c.map(inc, [1, 2, 3])
>>> c.nbytes(summary=False)
{'inc-1c8dd6be1c21646c71f76c16d09304ea': 28,
 'inc-1e297fc27658d7b67b3a758f16bcf47a': 28,
 'inc-fd65c238a7ea60f6a01bf4c8a5fcf44b': 28}
```

```
>>> c.nbytes(summary=True)
{'inc': 84}
```

ncores (*workers=None, **kwargs*)

The number of threads/cores available on each worker node

Parameters **workers**: list (optional)

A list of workers that we care about specifically. Leave empty to receive information about all workers.

See also:

Client.who_has, Client.has_what

Examples

```
>>> c.ncores()
{'192.168.1.141:46784': 8,
 '192.167.1.142:47548': 8,
 '192.167.1.143:47329': 8,
 '192.167.1.144:37297': 8}
```

normalize_collection (*collection*)

Replace collection's tasks by already existing futures if they exist

This normalizes the tasks within a collection's task graph against the known futures within the scheduler. It returns a copy of the collection with a task graph that includes the overlapping futures.

See also:

Client.persist trigger computation of collection's tasks

Examples

```
>>> len(x.__dask_graph__()) # x is a dask collection with 100 tasks
100
>>> set(client.futures).intersection(x.__dask_graph__()) # some overlap_
↪exists
10
```

```
>>> x = client.normalize_collection(x)
>>> len(x.__dask_graph__()) # smaller computational graph
20
```

persist (*collections*, *optimize_graph=True*, *workers=None*, *allow_other_workers=None*, *re-sources=None*, *retries=None*, ***kwargs*)

Persist dask collections on cluster

Starts computation of the collection on the cluster in the background. Provides a new dask collection that is semantically identical to the previous one, but now based off of futures currently in execution.

Parameters collections: sequence or single dask object

Collections like `dask.array` or `dataframe` or `dask.value` objects

optimize_graph: bool

Whether or not to optimize the underlying graphs

workers: str, list, dict

Which workers can run which parts of the computation If a string a list then the output collections will run on the listed

workers, but other sub-computations can run anywhere

If a dict then keys should be (tuples of) collections and values should be addresses or lists.

allow_other_workers: bool, list

If True then all restrictions in `workers=` are considered loose If a list then only the keys for the listed collections are loose

retries: int (default to 0)

Number of allowed automatic retries if computing a result fails

kwargs:

Options to pass to the graph optimize calls

Returns List of collections, or single collection, depending on type of input.

See also:

`Client.compute`

Examples

```
>>> xx = client.persist(x)
>>> xx, yy = client.persist([x, y])
```

processing (*workers=None*)

The tasks currently running on each worker

Parameters workers: list (optional)

A list of worker addresses, defaults to all

See also:

`Client.stacks`, `Client.who_has`, `Client.has_what`, `Client.ncores`

Examples

```
>>> x, y, z = c.map(inc, [1, 2, 3])
>>> c.processing()
{'192.168.1.141:46784': ['inc-1c8dd6be1c21646c71f76c16d09304ea',
                      'inc-fd65c238a7ea60f6a01bf4c8a5fcf44b',
                      'inc-1e297fc27658d7b67b3a758f16bcf47a']}
```

profile (*key=None, start=None, stop=None, workers=None, merge_workers=True*)

Collect statistical profiling information about recent work

Parameters **key: str**

Key prefix to select, this is typically a function name like ‘inc’ Leave as None to collect all data

start: time

stop: time

workers: list

List of workers to restrict profile information

Examples

```
>>> client.profile() # call on collections
```

publish_dataset (***kwargs*)

Publish named datasets to scheduler

This stores a named reference to a dask collection or list of futures on the scheduler. These references are available to other Clients which can download the collection or futures with `get_dataset`.

Datasets are not immediately computed. You may wish to call `Client.persist` prior to publishing a dataset.

Parameters **kwargs: dict**

named collections to publish on the scheduler

Returns None

See also:

`Client.list_datasets`, `Client.get_dataset`, `Client.unpublish_dataset`,
`Client.persist`

Examples

Publishing client:

```
>>> df = dd.read_csv('s3://...')
>>> df = c.persist(df)
>>> c.publish_dataset(my_dataset=df)
```

Receiving client:


```
>>> c.list_datasets()
['my_dataset']
>>> df2 = c.get_dataset('my_dataset')
```

rebalance (*futures=None, workers=None, **kwargs*)

Rebalance data within network

Move data between workers to roughly balance memory burden. This either affects a subset of the keys/workers or the entire network, depending on keyword arguments.

This operation is generally not well tested against normal operation of the scheduler. It is not recommended to use it while waiting on computations.

Parameters futures: list, optional

A list of futures to balance, defaults all data

workers: list, optional

A list of workers on which to balance, defaults to all workers

replicate (*futures, n=None, workers=None, branching_factor=2, **kwargs*)

Set replication of futures within network

Copy data onto many workers. This helps to broadcast frequently accessed data and it helps to improve resilience.

This performs a tree copy of the data throughout the network individually on each piece of data. This operation blocks until complete. It does not guarantee replication of data to future workers.

Parameters futures: list of futures

Futures we wish to replicate

n: int, optional

Number of processes on the cluster on which to replicate the data. Defaults to all.

workers: list of worker addresses

Workers on which we want to restrict the replication. Defaults to all.

branching_factor: int, optional

The number of workers that can copy data in each generation

See also:

`Client.rebalance`

Examples

```
>>> x = c.submit(func, *args)
>>> c.replicate([x]) # send to all workers
>>> c.replicate([x], n=3) # send to three workers
>>> c.replicate([x], workers=['alice', 'bob']) # send to specific
>>> c.replicate([x], n=1, workers=['alice', 'bob']) # send to one of
↳ specific workers
>>> c.replicate([x], n=1) # reduce replications
```

restart (***kwargs*)

Restart the distributed network

This kills all active work, deletes all data on the network, and restarts the worker processes.

run (*function*, **args*, ***kwargs*)

Run a function on all workers outside of task scheduling system

This calls a function on all currently known workers immediately, blocks until those results come back, and returns the results asynchronously as a dictionary keyed by worker address. This method is generally used for side effects, such as collecting diagnostic information or installing libraries.

If your function takes an input argument named `dask_worker` then that variable will be populated with the worker itself.

Parameters **function:** callable

***args:** arguments for remote function

****kwargs:** keyword arguments for remote function

workers: list

Workers on which to run the function. Defaults to all known workers.

Examples

```
>>> c.run(os.getpid)
{'192.168.0.100:9000': 1234,
 '192.168.0.101:9000': 4321,
 '192.168.0.102:9000': 5555}
```

Restrict computation to particular workers with the `workers=` keyword argument.

```
>>> c.run(os.getpid, workers=['192.168.0.100:9000',
...                           '192.168.0.101:9000'])
{'192.168.0.100:9000': 1234,
 '192.168.0.101:9000': 4321}
```

```
>>> def get_status(dask_worker):
...     return dask_worker.status
```

```
>>> c.run(get_hostname)
{'192.168.0.100:9000': 'running',
 '192.168.0.101:9000': 'running'}
```

run_coroutine (*function*, **args*, ***kwargs*)

Spawn a coroutine on all workers.

This spawns a coroutine on all currently known workers and then waits for the coroutine on each worker. The coroutines' results are returned as a dictionary keyed by worker address.

Parameters **function:** a coroutine function

(typically a function wrapped in `gen.coroutine` or a Python 3.5+ `async` function)

***args:** arguments for remote function

****kwargs:** keyword arguments for remote function

wait: boolean (default `True`)

Whether to wait for coroutines to end.

workers: list

Workers on which to run the function. Defaults to all known workers.

run_on_scheduler (*function, *args, **kwargs*)

Run a function on the scheduler process

This is typically used for live debugging. The function should take a keyword argument `dask_scheduler=`, which will be given the scheduler object itself.

See also:

`Client.run` Run a function on all workers

`Client.start_ipython_scheduler` Start an IPython session on scheduler

Examples

```
>>> def get_number_of_tasks(dask_scheduler=None):
...     return len(dask_scheduler.tasks)
```

```
>>> client.run_on_scheduler(get_number_of_tasks)
100
```

scatter (*data, workers=None, broadcast=False, direct=None, hash=True, maxsize=0, timeout=3, asynchronous=None*)

Scatter data into distributed memory

This moves data from the local client process into the workers of the distributed scheduler. Note that it is often better to submit jobs to your workers to have them load the data rather than loading data locally and then scattering it out to them.

Parameters data: list, iterator, dict, Queue, or object

Data to scatter out to workers. Output type matches input type.

workers: list of tuples (optional)

Optionally constrain locations of data. Specify workers as hostname/port pairs, e.g. `('127.0.0.1', 8787)`.

broadcast: bool (defaults to False)

Whether to send each data element to all workers. By default we round-robin based on number of cores.

direct: bool (defaults to automatically check)

Send data directly to workers, bypassing the central scheduler. This avoids burdening the scheduler but assumes that the client is able to talk directly with the workers.

maxsize: int (optional)

Maximum size of queue if using queues, 0 implies infinite

hash: bool (optional)

Whether or not to hash data to determine key. If False then this uses a random key

Returns List, dict, iterator, or queue of futures matching the type of input.

See also:

`Client.gather` Gather data back to local process

Examples

```
>>> c = Client('127.0.0.1:8787')
>>> c.scatter(1)
<Future: status: finished, key: c0a8a20f903a4915b94db8de3ea63195>
```

```
>>> c.scatter([1, 2, 3])
[<Future: status: finished, key: c0a8a20f903a4915b94db8de3ea63195>,
 <Future: status: finished, key: 58e78e1b34eb49a68c65b54815d1b158>,
 <Future: status: finished, key: d3395e15f605bc35ab1bac6341a285e2>]
```

```
>>> c.scatter({'x': 1, 'y': 2, 'z': 3})
{'x': <Future: status: finished, key: x>,
 'y': <Future: status: finished, key: y>,
 'z': <Future: status: finished, key: z>}
```

Constrain location of data to subset of workers

```
>>> c.scatter([1, 2, 3], workers=[('hostname', 8788)])
```

Handle streaming sequences of data with iterators or queues

```
>>> seq = c.scatter(iter([1, 2, 3]))
>>> next(seq)
<Future: status: finished, key: c0a8a20f903a4915b94db8de3ea63195>,
```

Broadcast data to all workers

```
>>> [future] = c.scatter([element], broadcast=True)
```

`scheduler_info` (***kwargs*)

Basic information about the workers in the cluster

Examples

```
>>> c.scheduler_info()
{'id': '2de2b6da-69ee-11e6-ab6a-e82aea155996',
 'services': {},
 'type': 'Scheduler',
 'workers': {'127.0.0.1:40575': {'active': 0,
                                'last-seen': 1472038237.4845693,
                                'name': '127.0.0.1:40575',
                                'services': {},
                                'stored': 0,
                                'time-delay': 0.0061032772064208984}}}
```

`set_metadata` (*key, value*)

Set arbitrary metadata in the scheduler

This allows you to store small amounts of data on the central scheduler process for administrative purposes. Data should be msgpack serializable (ints, strings, lists, dicts)

If the key corresponds to a task then that key will be cleaned up when the task is forgotten by the scheduler.

If the key is a list then it will be assumed that you want to index into a nested dictionary structure using those keys. For example if you call the following:

```
>>> client.set_metadata(['a', 'b', 'c'], 123)
```

Then this is the same as setting

```
>>> scheduler.task_metadata['a']['b']['c'] = 123
```

The lower level dictionaries will be created on demand.

See also:

get_metadata

Examples

```
>>> client.set_metadata('x', 123)
>>> client.get_metadata('x')
123
```

```
>>> client.set_metadata(['x', 'y'], 123)
>>> client.get_metadata('x')
{'y': 123}
```

```
>>> client.set_metadata(['x', 'w', 'z'], 456)
>>> client.get_metadata('x')
{'y': 123, 'w': {'z': 456}}
```

```
>>> client.get_metadata(['x', 'w'])
{'z': 456}
```

shutdown (*args, **kwargs)

Deprecated, see close instead

This was deprecated because “shutdown” was sometimes confusingly thought to refer to the cluster rather than the client

stacks (workers=None)

The task queues on each worker

Parameters **workers**: list (optional)

A list of worker addresses, defaults to all

See also:

Client.processing, Client.who_has, Client.has_what, Client.ncores

Examples

```
>>> x, y, z = c.map(inc, [1, 2, 3])
>>> c.stacks()
{'192.168.1.141:46784': ['inc-1c8dd6be1c21646c71f76c16d09304ea',
                      'inc-fd65c238a7ea60f6a01bf4c8a5fcf44b',
                      'inc-1e297fc27658d7b67b3a758f16bcf47a']}
```

start (***kwargs*)

Start scheduler running in separate thread

start_ipython_scheduler (*magic_name='scheduler_if_ipython', qtconsole=False, qtconsole_args=None*)

Start IPython kernel on the scheduler

Parameters *magic_name*: str or None (optional)

If defined, register IPython magic with this name for executing code on the scheduler.

If not defined, register `%scheduler` magic if IPython is running.

qtconsole: bool (optional)

If True, launch a Jupyter QtConsole connected to the worker(s).

qtconsole_args: list(str) (optional)

Additional arguments to pass to the qtconsole on startup.

Returns *connection_info*: dict

connection_info dict containing info necessary to connect Jupyter clients to the scheduler.

See also:

Client.start_ipython_workers Start IPython on the workers

Examples

```
>>> c.start_ipython_scheduler()
>>> %scheduler scheduler.processing
{'127.0.0.1:3595': {'inc-1', 'inc-2'},
 '127.0.0.1:53589': {'inc-2', 'add-5'}}
```

```
>>> c.start_ipython_scheduler(qtconsole=True)
```

start_ipython_workers (*workers=None, magic_names=False, qtconsole=False, qtconsole_args=None*)

Start IPython kernels on workers

Parameters *workers*: list (optional)

A list of worker addresses, defaults to all

magic_names: str or list(str) (optional)

If defined, register IPython magics with these names for executing code on the workers.

If string has asterix then expand asterix into 0, 1, ..., n for n workers

qtconsole: bool (optional)

If True, launch a Jupyter QtConsole connected to the worker(s).

qtconsole_args: list(str) (optional)

Additional arguments to pass to the qtconsole on startup.

Returns *iter_connection_info*: list

List of *connection_info* dicts containing info necessary to connect Jupyter clients to the workers.

See also:

`Client.start_ipython_scheduler` start ipython on the scheduler

Examples

```
>>> info = c.start_ipython_workers()
>>> %remote info['192.168.1.101:5752'] worker.data
{'x': 1, 'y': 100}
```

```
>>> c.start_ipython_workers('192.168.1.101:5752', magic_names='w')
>>> %w worker.data
{'x': 1, 'y': 100}
```

```
>>> c.start_ipython_workers('192.168.1.101:5752', qtconsole=True)
```

Add asterisk `*` in magic names to add one magic per worker

```
>>> c.start_ipython_workers(magic_names='w_*')
>>> %w_0 worker.data
{'x': 1, 'y': 100}
>>> %w_1 worker.data
{'z': 5}
```

submit (*func*, **args*, ***kwargs*)

Submit a function application to the scheduler

Parameters **func:** callable

***args:**

****kwargs:**

pure: bool (defaults to True)

Whether or not the function is pure. Set `pure=False` for impure functions like `np.random.random`.

workers: set, iterable of sets

A set of worker hostnames on which computations may be performed. Leave empty to default to all workers (common case)

key: str

Unique identifier for the task. Defaults to function-name and hash

allow_other_workers: bool (defaults to False)

Used with *workers*. Indicates whether or not the computations may be performed on workers that are not in the *workers* set(s).

retries: int (default to 0)

Number of allowed automatic retries if the task fails

Returns Future

See also:

`Client.map` Submit on many arguments at once

Examples

```
>>> c = client.submit(add, a, b)
```

unpublish_dataset (*name*, ***kwargs*)
Remove named datasets from scheduler

See also:

Client.publish_dataset

Examples

```
>>> c.list_datasets()
['my_dataset']
>>> c.unpublish_datasets('my_dataset')
>>> c.list_datasets()
[]
```

upload_file (*filename*, ***kwargs*)
Upload local package to workers

This sends a local file up to all worker nodes. This file is placed into a temporary directory on Python's system path so any .py, .pyc, .egg or .zip files will be importable.

Parameters filename: string

Filename of .py, .pyc, .egg or .zip file to send to workers

Examples

```
>>> client.upload_file('mylibrary.egg')
>>> from mylibrary import myfunc
>>> L = c.map(myfunc, seq)
```

who_has (*futures=None*, ***kwargs*)
The workers storing each future's data

Parameters futures: list (optional)

A list of futures, defaults to all data

See also:

Client.has_what, *Client.ncores*

Examples

```
>>> x, y, z = c.map(inc, [1, 2, 3])
>>> wait([x, y, z])
>>> c.who_has()
{'inc-1c8dd6be1c21646c71f76c16d09304ea': ['192.168.1.141:46784'],
 'inc-1e297fc27658d7b67b3a758f16bcf47a': ['192.168.1.141:46784'],
 'inc-fd65c238a7ea60f6a01bf4c8a5fcf44b': ['192.168.1.141:46784']}
```



```
>>> c.who_has([x, y])
{'inc-1c8dd6be1c21646c71f76c16d09304ea': ['192.168.1.141:46784'],
 'inc-1e297fc27658d7b67b3a758f16bcf47a': ['192.168.1.141:46784']}
```

class `distributed.recreate_exceptions.ReplayExceptionClient` (*client*)

A plugin for the client allowing replay of remote exceptions locally

Adds the following methods (and their async variants) to the given client:

- `recreate_error_locally`: main user method
- **`get_futures_error`**: gets the task, its details and dependencies, responsible for failure of the given future.

`get_futures_error` (*future*)

Ask the scheduler details of the sub-task of the given failed future

When a future evaluates to a status of “error”, i.e., an exception was raised in a task within its graph, we can get information from the scheduler. This function gets the details of the specific task that raised the exception and led to the error, but does not fetch data from the cluster or execute the function.

Parameters *future* : future that failed, having `status=="error"`, typically after an attempt to `gather()` shows a stack-`trace`.

Returns Tuple:

- the function that raised an exception
- argument list (a tuple), may include values and keys
- keyword arguments (a dictionary), may include values and keys
- list of keys that the function requires to be fetched to run

See also:

`ReplayExceptionClient.recreate_error_locally`

`recreate_error_locally` (*future*)

For a failed calculation, perform the blamed task locally for debugging.

This operation should be performed after a future (result of `gather`, `compute`, etc) comes back with a status of “error”, if the stack-`trace` is not informative enough to diagnose the problem. The specific task (part of the graph pointing to the future) responsible for the error will be fetched from the scheduler, together with the values of its inputs. The function will then be executed, so that `pdb` can be used for debugging.

Parameters *future* : future or collection that failed

The same thing as was given to `gather`, but came back with an exception/stack-`trace`. Can also be a (persisted) dask collection containing any errored futures.

Returns Nothing; the function runs and should raise an exception, allowing the debugger to run.

Examples

```
>>> future = c.submit(div, 1, 0)
>>> future.status
'error'
```

```
>>> c.recreate_error_locally(future)
ZeroDivisionError: division by zero
```

If you're in IPython you might take this opportunity to use pdb

```
>>> %pdb
Automatic pdb calling has been turned ON
```

```
>>> c.recreate_error_locally(future)
ZeroDivisionError: division by zero
      1 def div(x, y):
----> 2     return x / y
      ipdb>
```

3.5.3 Future

class `distributed.client.Future` (*key*, *client=None*, *inform=True*, *state=None*)

A remotely running computation

A Future is a local proxy to a result running on a remote worker. A user manages future objects in the local Python process to determine what happens in the larger cluster.

Parameters **key:** str, or tuple

Key of remote data to which this future refers

client: Client

Client that should own this future. Defaults to `_get_global_client()`

inform: bool

Do we inform the scheduler that we need an update on this future

See also:

[`Client`](#) Creates futures

Examples

Futures typically emerge from Client computations

```
>>> my_future = client.submit(add, 1, 2)
```

We can track the progress and results of a future

```
>>> my_future
<Future: status: finished, key: add-8f6e709446674bad78ea8aeecfee188e>
```

We can get the result or the exception and traceback from the future

```
>>> my_future.result()
```

add_done_callback (*fn*)

Call callback on future when callback has finished

The callback `fn` should take the future as its only argument. This will be called regardless of if the future completes successfully, errs, or is cancelled

The callback is executed in a separate thread.

cancel (***kwargs*)

Cancel request to run this future

See also:

`Client.cancel`

cancelled ()

Returns True if the future has been cancelled

done ()

Is the computation complete?

exception (*timeout=None, **kwargs*)

Return the exception of a failed task

If *timeout* seconds are elapsed before returning, a `TimeoutError` is raised.

See also:

`Future.traceback`

result (*timeout=None*)

Wait until computation completes, gather result to local process.

If *timeout* seconds are elapsed before returning, a `TimeoutError` is raised.

traceback (*timeout=None, **kwargs*)

Return the traceback of a failed task

This returns a traceback object. You can inspect this object using the `traceback` module. Alternatively if you call `future.result()` this traceback will accompany the raised exception.

If *timeout* seconds are elapsed before returning, a `TimeoutError` is raised.

See also:

`Future.exception`

Examples

```
>>> import traceback
>>> tb = future.traceback()
>>> traceback.export_tb(tb)
[...]
```

3.5.4 Other

`distributed.client.as_completed` (*futures=None, loop=None, with_results=False*)

Return futures in the order in which they complete

This returns an iterator that yields the input future objects in the order in which they complete. Calling `next` on the iterator will block until the next future completes, irrespective of order.

Additionally, you can also add more futures to this object during computation with the `.add` method

Examples

```
>>> x, y, z = client.map(inc, [1, 2, 3])
>>> for future in as_completed([x, y, z]):
...     print(future.result())
3
2
4
```

Add more futures during computation

```
>>> x, y, z = client.map(inc, [1, 2, 3])
>>> ac = as_completed([x, y, z])
>>> for future in ac:
...     print(future.result())
...     if random.random() < 0.5:
...         ac.add(c.submit(double, future))
4
2
8
3
6
12
24
```

Optionally wait until the result has been gathered as well

```
>>> ac = as_completed([x, y, z], with_results=True)
>>> for future, result in ac:
...     print(result)
2
4
3
```

`distributed.diagnostics.progress(*futures, **kwargs)`

Track progress of futures

This operates differently in the notebook and the console

- Notebook: This returns immediately, leaving an IPython widget on screen
- Console: This blocks until the computation completes

Parameters futures: Futures

A list of futures or keys to track

notebook: bool (optional)

Running in the notebook or not (defaults to guess)

multi: bool (optional)

Track different functions independently (defaults to True)

complete: bool (optional)

Track all keys (True) or only keys that have not yet run (False) (defaults to True)

Notes

In the notebook, the output of *progress* must be the last statement in the cell. Typically, this means calling *progress* at the end of a cell.

Examples

```
>>> progress(futures)
[#####] | 100% Completed | 1.7s
```

`distributed.client.wait(fs, timeout=None, return_when='ALL_COMPLETED')`

Wait until all futures are complete

Parameters `fs`: list of futures

timeout: number, optional

Time in seconds after which to raise a `gen.TimeoutError`

Returns Named tuple of completed, not completed

`distributed.worker_client(*args, **kws)`

Get client for this thread

This context manager is intended to be called within functions that we run on workers. When run as a context manager it delivers a client `Client` object that can submit other tasks directly from that worker.

Parameters `timeout`: Number

Timeout after which to err

separate_thread: bool, optional

Whether to run this function outside of the normal thread pool defaults to `True`

See also:

`get_worker`, `get_client`, `secede`

Examples

```
>>> def func(x):
...     with worker_client() as c: # connect from worker back to scheduler
...         a = c.submit(inc, x)   # this task can submit more tasks
...         b = c.submit(dec, x)
...         result = c.gather([a, b]) # and gather results
...     return result
```

```
>>> future = client.submit(func, 1) # submit func(1) on cluster
```

`distributed.get_worker()`

Get the worker currently running this task

See also:

`get_client`, `worker_client`

Examples

```
>>> def f():
...     worker = get_worker() # The worker on which this task is running
...     return worker.address
```

```
>>> future = client.submit(f)
>>> future.result()
'tcp://127.0.0.1:47373'
```

`distributed.get_client(address=None, timeout=3)`

Get a client while within a task

This client connects to the same scheduler to which the worker is connected

See also:

`get_worker`, `worker_client`, `secede`

Examples

```
>>> def f():
...     client = get_client()
...     futures = client.map(lambda x: x + 1, range(10)) # spawn many tasks
...     results = client.gather(futures)
...     return sum(results)
```

```
>>> future = client.submit(f)
>>> future.result()
55
```

`distributed.secede()`

Have this task secede from the worker's thread pool

This opens up a new scheduling slot and a new thread for a new task. This enables the client to schedule tasks on this node, which is especially useful while waiting for other jobs to finish (e.g., with `client.gather`).

See also:

`get_client`, `get_worker`

Examples

```
>>> def mytask(x):
...     # do some work
...     client = get_client()
...     futures = client.map(...) # do some remote work
...     secede() # while that work happens, remove ourself from the pool
...     return client.gather(futures) # return gathered results
```

`distributed.rejoin()`

Have this thread rejoin the `ThreadPoolExecutor`

This will block until a new slot opens up in the executor. The next thread to finish a task will leave the pool to allow this one to join.

See also:

[*secede*](#) leave the thread pool

class `distributed.Lock` (*name=None, client=None*)
Distributed Centralized Lock

Parameters **name:** string

Name of the lock to acquire. Choosing the same name allows two disconnected processes to coordinate a lock.

Examples

```
>>> lock = Lock('x')
>>> lock.acquire(timeout=1)
>>> # do things with protected resource
>>> lock.release()
```

acquire (*timeout=None*)
Acquire the lock

Parameters **timeout:** number

Seconds to wait on the lock in the scheduler. This does not include local coroutine time, network transfer time, etc..

Returns True or False whether or not it successfully acquired the lock

Examples

```
>>> lock = Lock('x')
>>> lock.acquire(timeout=1)
```

release ()
Release the lock if already acquired

class `distributed.Queue` (*name=None, client=None, maxsize=0*)
Distributed Queue

This allows multiple clients to share futures or small bits of data between each other with a multi-producer/multi-consumer queue. All metadata is sequentialized through the scheduler.

Elements of the Queue must be either Futures or msgpack-encodable data (ints, strings, lists, dicts). All data is sent through the scheduler so it is wise not to send large objects. To share large objects scatter the data and share the future instead.

Warning: This object is experimental and has known issues in Python 2

See also:

[*Variable*](#) shared variable between clients

Examples

```
>>> from dask.distributed import Client, Queue
>>> client = Client()
>>> queue = Queue('x')
>>> future = client.submit(f, x)
>>> queue.put(future)
```

get (*timeout=None, batch=False, **kwargs*)
Get data from the queue

Parameters **timeout**: Number (optional)

Time in seconds to wait before timing out

batch: boolean, int (optional)

If True then return all elements currently waiting in the queue. If an integer then return that many elements from the queue If False (default) then return one item at a time

put (*value, timeout=None, **kwargs*)
Put data into the queue

qsize (***kwargs*)
Current number of elements in the queue

class `dask.distributed.Variable` (*name=None, client=None, maxsize=0*)
Distributed Global Variable

This allows multiple clients to share futures and data between each other with a single mutable variable. All metadata is sequentialized through the scheduler. Race conditions can occur.

Values must be either Futures or msgpack-encodable data (ints, lists, strings, etc..) All data will be kept and sent through the scheduler, so it is wise not to send too much. If you want to share a large amount of data then `scatter` it and share the future instead.

Warning: This object is experimental and has known issues in Python 2

See also:

[`Queue`](#) shared multi-producer/multi-consumer queue between clients

Examples

```
>>> from dask.distributed import Client, Variable
>>> client = Client()
>>> x = Variable('x')
>>> x.set(123) # doctest: +SKIP
>>> x.get() # doctest: +SKIP
123
>>> future = client.submit(f, x)
>>> x.set(future)
```

delete ()
Delete this variable
Caution, this affects all clients currently pointing to this variable.

get (*timeout=None, **kwargs*)
Get the value of this variable

set (*value, **kwargs*)
Set the value of this variable

Parameters value: Future or object

Must be either a Future or a msgpack-encodable value

3.5.5 Asyncio Client

3.5.6 Adaptive

class `distributed.deploy.Adaptive` (*scheduler, cluster, interval=1000, startup_cost=1, scale_factor=2, **kwargs*)

Adaptively allocate workers based on scheduler load. A superclass.

Contains logic to dynamically resize a Dask cluster based on current use.

Parameters scheduler: `distributed.Scheduler`

cluster: object

Must have `scale_up` and `scale_down` methods/coroutines

startup_cost : int, default 1

Factor representing how costly it is to start an additional worker. Affects quickly to adapt to high tasks per worker loads

scale_factor : int, default 2

Factor to scale by when it's determined additional workers are needed

****kwargs:**

Extra parameters to pass to `Scheduler.workers_to_close`

Notes

Subclasses can override `Adaptive.should_scale_up()` and `Adaptive.should_scale_down()` to control when the cluster should be resized. The default implementation checks if there are too many tasks per worker or too little memory available (see `Adaptive.needs_cpu()` and `Adaptive.needs_memory()`).

`Adaptive.get_scale_up_kwargs()` method controls the arguments passed to the cluster's `scale_up` method.

Examples

```
>>> class MyCluster(object):
...     def scale_up(self, n):
...         """ Bring worker count up to n """
...     def scale_down(self, workers):
...         """ Remove worker addresses from cluster """
```

get_scale_up_kwargs()

Get the arguments to be passed to `self.cluster.scale_up`.

See also:

`LocalCluster.scale_up`

Notes

By default the desired number of total workers is returned (`n`). Subclasses should ensure that the return dictionary includes a key- value pair for `n`, either by implementing it or by calling the parent's `get_scale_up_kwargs`.

needs_cpu()

Check if the cluster is CPU constrained (too many tasks per core)

Notes

Returns `True` if the occupancy per core is some factor larger than `startup_cost`.

needs_memory()

Check if the cluster is RAM constrained

Notes

Returns `True` if the required bytes in distributed memory is some factor larger than the actual distributed memory available.

should_scale_down()

Determine whether any workers should potentially be removed from the cluster.

Returns `scale_down` : bool

See also:

`Scheduler.workers_to_close`

Notes

`Adaptive.should_scale_down` defaults to dispatching to `Adaptive.workers_to_close`, returning `True` if any workers to close are specified.

should_scale_up()

Determine whether additional workers should be added to the cluster

Returns `scale_up` : bool

Notes

Additional workers are added whenever

1. There are unrunnable tasks and no workers
2. The cluster is CPU constrained
3. The cluster is RAM constrained

See also:

needs_cpu, needs_memory

workers_to_close (***kwargs*)

Determine which, if any, workers should potentially be removed from the cluster.

Returns workers: [worker_name]

See also:

`Scheduler.workers_to_close`

Notes

`Adaptive.workers_to_close` dispatches to `Scheduler.workers_to_close()`, but may be overridden in subclasses.

3.6 Frequently Asked Questions

More questions can be found on StackOverflow at <http://stackoverflow.com/search?tab=votes&q=dask%20distributed>

3.6.1 How do I use external modules?

Use `client.upload_file`. For more detail, see the [API docs](#) and a StackOverflow question “[Can I use functions imported from .py files in Dask/Distributed?](#)” This function supports both standalone file and `setuptools`’s `.egg` files for larger modules.

3.6.2 Too many open file descriptors?

Your operating system imposes a limit to how many open files or open network connections any user can have at once. Depending on the scale of your cluster the `dask-scheduler` may run into this limit.

By default most Linux distributions set this limit at 1024 open files/connections and OS-X at 128 or 256. Each worker adds a few open connections to a running scheduler (somewhere between one and ten, depending on how contentious things get.)

If you are on a managed cluster you can usually ask whoever manages your cluster to increase this limit. If you have root access and know what you are doing you can change the limits on Linux by editing `/etc/security/limits.conf`. Instructions are here under the heading “User Level FD Limits”: <http://www.cyberciti.biz/faq/linux-increase-the-maximum-number-of-open-files/>

3.6.3 Error when running dask-worker about OMP_NUM_THREADS

For more problems with `OMP_NUM_THREADS`, see <http://stackoverflow.com/questions/39422092/error-with-omp-num-threads-when-using-dask-distributed>

3.6.4 Does Dask handle Data Locality?

Yes, both data locality in memory and data locality on disk.

Often it's *much* cheaper to move computations to where data lives. If one of your tasks creates a large array and a future task computes the sum of that array, you want to be sure that the sum runs on the same worker that has the array in the first place, otherwise you'll wait for a long while as the data moves between workers. Needless communication can easily dominate costs if we're sloppy.

The Dask Scheduler tracks the location and size of every intermediate value produced by every worker and uses this information when assigning future tasks to workers. Dask tries to make computations more efficient by minimizing data movement.

Sometimes your data is on a hard drive or other remote storage that isn't controlled by Dask. In this case the scheduler is unaware of exactly where your data lives, so you have to do a bit more work. You can tell Dask to preferentially run a task on a particular worker or set of workers.

For example Dask developers use this ability to build in data locality when we communicate to data-local storage systems like the Hadoop File System. When users use high-level functions like `dask.dataframe.read_csv('hdfs:///path/to/files/*.csv')` Dask talks to the HDFS name node, finds the locations of all of the blocks of data, and sends that information to the scheduler so that it can make smarter decisions and improve load times for users.

3.6.5 PermissionError [Errno 13] Permission Denied: '/root/.dask'

This error can be seen when starting distributed through the standard process control tool `supervisor` and running as a non-root user. This is caused by `supervisor` not passing the shell environment variables through to the subprocess, head to [this section](#) of the supervisor documentation to see how to pass the `$HOME` and `$USER` variables through.

3.7 Diagnosing Performance

Understanding the performance of a distributed computation can be difficult. This is due in part to the many components of a distributed computer that may impact performance:

1. Compute time
2. Memory bandwidth
3. Network bandwidth
4. Disk bandwidth
5. Scheduler overhead
6. Serialization costs

This difficulty is compounded because the information about these costs is spread among many machines and so there is no central place to collect data to identify performance issues.

Fortunately, Dask collects a variety of diagnostic information during execution. It does this both to provide performance feedback to users, but also for its own internal scheduling decisions. The primary place to observe this feedback is the [diagnostic dashboard](#). This document describes the various pieces of performance information available and how to access them.

3.7.1 Task start and stop times

Workers capture durations associated to tasks. For each task that passes through a worker we record start and stop times for each of the following:

1. Serialization (gray)
2. Dependency gathering from peers (red)
3. Disk I/O to collect local data (orange)
4. Execution times (colored by task)

The main way to observe these times is with the task stream plot on the scheduler's `/status` page where the colors of the bars correspond to the colors listed above.

Alternatively if you want to do your own diagnostics on every task event you might want to create a *Scheduler plugin*. All of this information will be available when a task transitions from processing to memory or erred.

3.7.2 Statistical Profiling

For single-threaded profiling Python users typically depend on the CProfile module in the standard library (Dask developers recommend the *snakeviz* tool for single-threaded profiling). Unfortunately the standard CProfile module does not work with multi-threaded or distributed computations.

To address this Dask implements its own distributed *statistical profiler*. Every 10ms each worker process checks what each of its worker threads are doing. It captures the call stack and adds this stack to a counting data structure. This counting data structure is recorded and cleared every second in order to establish a record of performance over time.

Users typically observe this data through the `/profile` plot on either the worker or scheduler diagnostic dashboards. On the scheduler page they observe the total profile aggregated over all workers over all threads. Clicking on any of the bars in the profile will zoom the user into just that section, as is typical with most profiling tools. There is a timeline at the bottom of the page to allow users to select different periods in time.

Profiles are also grouped by the task that was being run at the time. You can select a task name from the selection menu at the top of the page. You can also click on the rectangle corresponding to the task in the main task stream plot on the `/status` page.

Users can also query this data directly using the *Client.profile* function. This will deliver the raw data structure used to produce these plots.

The 10ms and 1s parameters can be controlled by the `profile-interval` and `profile-cycle-interval` entries in the `config.yaml` file.

3.7.3 Bandwidth

Dask workers track every incoming and outgoing transfer in the `Worker.outgoing_transfer_log` and `Worker.incoming_transfer_log` attributes including

1. Total bytes transferred
2. Compressed bytes transferred
3. Start/stop times
4. Keys moved

5. Peer

These are made available to users through the `/main` page of the Worker's diagnostic dashboard. You can capture their state explicitly by running a command on the workers:

```
client.run(lambda dask_worker: dask_worker.outgoing_transfer_log)
client.run(lambda dask_worker: dask_worker.incoming_transfer_log)
```

3.7.4 A note about times

Different computers maintain different clocks which may not match perfectly. To address this the Dask scheduler sends its current time in response to every worker heartbeat. Workers compare their local time against this time to obtain an estimate of differences. All times recorded in workers take this estimated delay into account. This helps, but still, imprecise measurements may exist.

All times are intended to be from the scheduler's perspective.

3.8 Efficiency

Parallel computing done well is responsive and rewarding. However, several speed-bumps can get in the way. This section describes common ways to ensure performance.

3.8.1 Leave data on the cluster

Wait as long as possible to gather data locally. If you want to ask a question of a large piece of data on the cluster it is often faster to submit a function onto that data then to bring the data down to your local computer.

For example if we have a numpy array on the cluster and we want to know its shape we might choose one of the following options:

1. **Slow:** Gather the numpy array to the local process, access the `.shape` attribute
2. **Fast:** Send a lambda function up to the cluster to compute the shape

```
>>> x = client.submit(np.random.random, (1000, 1000))
>>> type(x)
Future
```

Slow

```
>>> x.result().shape() # Slow from lots of data transfer
(1000, 1000)
```

Fast

```
>>> client.submit(lambda a: a.shape, x).result() # fast
(1000, 1000)
```

3.8.2 Use larger tasks

The scheduler adds about *one millisecond* of overhead per task or Future object. While this may sound fast it's quite slow if you run a billion tasks. If your functions run faster than 100ms or so then you might not see any speedup from using distributed computing.

A common solution is to batch your input into larger chunks.

Slow

```
>>> futures = client.map(f, seq)
>>> len(futures)  # avoid large numbers of futures
1000000000
```

Fast

```
>>> def f_many(chunk):
...     return [f(x) for x in chunk]

>>> from toolz import partition_all
>>> chunks = partition_all(1000000, seq)  # Collect into groups of size 1000

>>> futures = client.map(f_many, chunks)
>>> len(futures)  # Compute on larger pieces of your data at once
1000
```

3.8.3 Adjust between Threads and Processes

By default a single `Worker` runs many computations in parallel using as many threads as your compute node has cores. When using pure Python functions this may not be optimal and you may instead want to run several separate worker processes on each node, each using one thread. When configuring your cluster you may want to use the options to the `dask-worker` executable as follows:

```
$ dask-worker ip:port --nprocs 8 --nthreads 1
```

Note that if you're primarily using NumPy, Pandas, SciPy, Scikit Learn, Numba, or other C/Fortran/LLVM/Cython-accelerated libraries then this is not an issue for you. Your code is likely optimal for use with multi-threading.

3.8.4 Don't go distributed

Consider the `dask` and `concurrent.futures` modules, which have similar APIs to distributed but operate on a single machine. It may be that your problem performs well enough on a laptop or large workstation.

Consider accelerating your code through other means than parallelism. Better algorithms, data structures, storage formats, or just a little bit of C/Fortran/Numba code might be enough to give you the 10x speed boost that you're looking for. Parallelism and distributed computing are expensive ways to accelerate your application.

3.9 Limitations

Dask.distributed has limitations. Understanding these can help you to reliably create efficient distributed computations.

3.9.1 Performance

- The central scheduler spends a few hundred microseconds on every task. For optimal performance, task durations should be greater than 10-100ms.
- Dask can not parallelize within individual tasks. Individual tasks should be a comfortable size so as not to overwhelm any particular worker.

- Dask assigns tasks to workers heuristically. It *usually* makes the right decision, but non-optimal situations do occur.
- The workers are just Python processes, and inherit all capabilities and limitations of Python. They do not bound or limit themselves in any way. In production you may wish to run dask-workers within containers.

3.9.2 Assumptions on Functions and Data

Dask assumes the following about your functions and your data:

- All functions must be serializable either with pickle or `cloudpickle`. This is *usually* the case except in fairly exotic situations. The following should work:

```
from cloudpickle import dumps, loads
loads(dumps(my_object))
```

- All data must be serializable either with pickle, cloudpickle, or using Dask's custom serialization system.
- Dask may run your functions multiple times, such as if a worker holding an intermediate result dies. Any side effects should be *idempotent*.
-

3.9.3 Security

As a distributed computing framework, Dask enables the remote execution of arbitrary code. You should only host dask-workers within networks that you trust. This is standard among distributed computing frameworks, but is worth repeating.

3.10 Data Locality

Data movement often needlessly limits performance.

This is especially true for analytic computations. Dask.distributed minimizes data movement when possible and enables the user to take control when necessary. This document describes current scheduling policies and user API around data locality.

3.10.1 Current Policies

Task Submission

In the common case distributed runs tasks on workers that already hold dependent data. If you have a task $f(x)$ that requires some data x then that task will very likely be run on the worker that already holds x .

If a task requires data split among multiple workers, then the scheduler chooses to run the task on the worker that requires the least data transfer to it. The size of each data element is measured by the workers using the `sys.getsizeof` function, which depends on the `__sizeof__` protocol generally available on most relevant Python objects.

Data Scatter

When a user scatters data from their local process to the distributed network this data is distributed in a round-robin fashion grouping by number of cores. So for example If we have two workers Alice and Bob, each with two cores and we scatter out the list `range(10)` as follows:

```
futures = client.scatter(range(10))
```

Then Alice and Bob receive the following data

- Alice: [0, 1, 4, 5, 8, 9]
- Bob: [2, 3, 6, 7]

3.10.2 User Control

Complex algorithms may require more user control.

For example the existence of specialized hardware such as GPUs or database connections may restrict the set of valid workers for a particular task.

In these cases use the `workers=` keyword argument to the `submit`, `map`, or `scatter` functions, providing a hostname, IP address, or alias as follows:

```
future = client.submit(func, *args, workers=['Alice'])
```

- Alice: [0, 1, 4, 5, 8, 9, new_result]
- Bob: [2, 3, 6, 7]

Required data will always be moved to these workers, even if the volume of that data is significant. If this restriction is only a preference and not a strict requirement, then add the `allow_other_workers` keyword argument to signal that in extreme cases such as when no valid worker is present, another may be used.

```
future = client.submit(func, *args, workers=['Alice'],
                       allow_other_workers=True)
```

Additionally the `scatter` function supports a `broadcast=` keyword argument to enforce that the all data is sent to all workers rather than round-robin. If new workers arrive they will not automatically receive this data.

```
futures = client.scatter([1, 2, 3], broadcast=True)  # send data to all workers
```

- Alice: [1, 2, 3]
- Bob: [1, 2, 3]

Valid arguments for `workers=` include the following:

- A single IP addresses, IP/Port pair, or hostname like the following:

```
192.168.1.100, 192.168.1.100:8989, alice, alice:8989
```

- A list or set of the above:

```
['alice'], ['192.168.1.100', '192.168.1.101:9999']
```

If only a hostname or IP is given then any worker on that machine will be considered valid. Additionally, you can provide aliases to workers upon creation.:

```
$ dask-worker scheduler_address:8786 --name worker_1
```

And then use this name when specifying workers instead.

```
client.map(func, sequence, workers='worker_1')
```

3.10.3 Specify workers with Compute/Persist

The `workers=` keyword in `scatter`, `submit`, and `map` is fairly straightforward, taking either a worker hostname, host:port pair or a sequence of those as valid inputs:

```
client.submit(f, x, workers='127.0.0.1')
client.submit(f, x, workers='127.0.0.1:55852')
client.submit(f, x, workers=['192.168.1.101', '192.168.1.100'])
```

For more complex computations, such as occur with dask collections like `dask.dataframe` or `dask.delayed`, we sometimes want to specify that certain parts of the computation run on certain workers while other parts run on other workers.

```
x = delayed(f)(1)
y = delayed(f)(2)
z = delayed(g)(x, y)

future = client.compute(z, workers={z: '127.0.0.1',
                                     x: '192.168.0.1'})
```

Here the values of the dictionary are of the same form as before, a host, a host:port pair, or a list of these. The keys in this case are either dask collections or tuples of dask collections. All of the *final* keys of these collections will run on the specified machines; dependencies can run anywhere unless they are also listed in `workers=`. We explore this through a set of examples:

The computation `z = f(x, y)` runs on the host `127.0.0.1`. The other two computations for `x` and `y` can run anywhere.

```
future = client.compute(z, workers={z: '127.0.0.1'})
```

The computations for both `z` and `x` must run on `127.0.0.1`

```
future = client.compute(z, workers={z: '127.0.0.1',
                                     x: '127.0.0.1'})
```

Use a tuple to group collections. This is shorthand for the above.

```
future = client.compute(z, workers={(x, y): '127.0.0.1'})
```

Recall that all options for `workers=` in `scatter`/`submit`/`map` hold here as well.

```
future = client.compute(z, workers={(x, y): ['192.168.1.100', '192.168.1.101:9999']})
```

Set `allow_other_workers=True` to make these loose restrictions rather than hard requirements.

```
future = client.compute(z, workers={(x, y): '127.0.0.1'},
                        allow_other_workers=True)
```

Provide a collection to `allow_other_workers=[...]` to say that the keys for only some of the collections are loose. In the case below `z` *must* run on `127.0.0.1` while `x` *should* run on `127.0.0.1` but can run elsewhere if necessary:

```
future = client.compute(z, workers={(x, y): '127.0.0.1'},
                        allow_other_workers=[x])
```

This works fine with `persist` and with any dask collection (any object with a `.__dask_graph__()` method):

```
df = dd.read_csv('s3://...')
df = client.persist(df, workers={df: ...})
```

See the [efficiency](#) page to learn about best practices.

3.11 Managing Computation

Data and Computation in Dask.distributed are always in one of three states

1. Concrete values in local memory. Example include the integer 1 or a numpy array in the local process.
2. Lazy computations in a dask graph, perhaps stored in a `dask.delayed` or `dask.dataframe` object.
3. Running computations or remote data, represented by `Future` objects pointing to computations currently in flight.

All three of these forms are important and there are functions that convert between all three states.

3.11.1 Dask Collections to Concrete Values

You can turn any dask collection into a concrete value by calling the `.compute()` method or `dask.compute(...)` function. This function will block until the computation is finished, going straight from a lazy dask collection to a concrete value in local memory.

This approach is the most familiar and straightforward, especially for people coming from the standard single-machine Dask experience or from just normal programming. It is great when you have data already in memory and want to get small fast results right to your local process.

```
>>> df = dd.read_csv('s3://...')
>>> df.value.sum().compute()
100000000
```

However, this approach often breaks down if you try to bring the entire dataset back to local RAM

```
>>> df.compute()
MemoryError(...)
```

It also forces you to wait until the computation finishes before handing back control of the interpreter.

3.11.2 Dask Collections to Futures

You can asynchronously submit lazy dask graphs to run on the cluster with the `client.compute` and `client.persist` methods. These functions return `Future` objects immediately. These futures can then be queried to determine the state of the computation.

client.compute

The `.compute` method takes a collection and returns a single future.

```
>>> df = dd.read_csv('s3://...')
>>> total = client.compute(df.sum()) # Return a single future
>>> total
Future(..., status='pending')

>>> total.result() # Block until finished
100000000
```

Because this is a single future the result must fit on a single worker machine. Like `dask.compute` above, the `client.compute` method is only appropriate when results are small and should fit in memory. The following would likely fail:

```
>>> future = client.compute(df) # Blows up memory
```

Instead, you should use `client.persist`

client.persist

The `.persist` method submits the task graph behind the Dask collection to the scheduler, obtaining Futures for all of the top-most tasks (for example one Future for each Pandas DataFrame in a Dask DataFrame). It then returns a copy of the collection pointing to these futures instead of the previous graph. This new collection is semantically equivalent but now points to actively running data rather than a lazy graph. If you look at the dask graph within the collection you will see the Future objects directly:

```
>>> df = dd.read_csv('s3://...')
>>> df.dask # Recipe to compute df in chunks
{('read', 0): (load_s3_bytes, ...),
 ('parse', 0): (pd.read_csv, ('read', 0)),
 ('read', 1): (load_s3_bytes, ...),
 ('parse', 1): (pd.read_csv, ('read', 1)),
 ...
}

>>> df = client.persist(df) # Start computation
>>> df.dask # Now points to running futures
{('parse', 0): Future(..., status='finished'),
 ('parse', 1): Future(..., status='pending'),
 ...
}
```

The collection is returned immediately and the computation happens in the background on the cluster. Eventually all of the futures of this collection will be completed at which point further queries on this collection will likely be very fast.

Typically the workflow is to define a computation with a tool like `dask.dataframe` or `dask.delayed` until a point where you have a nice dataset to work from, then persist that collection to the cluster and then perform many fast queries off of the resulting collection.

3.11.3 Concrete Values to Futures

We obtain futures through a few different ways. One is the mechanism above, by wrapping Futures within Dask collections. Another is by submitting data or tasks directly to the cluster with `client.scatter`, `client.submit`

or `client.map`.

```
futures = client.scatter(args)           # Send data
future = client.submit(function, *args, **kwargs) # Send single task
futures = client.map(function, sequence, **kwargs) # Send many tasks
```

In this case `*args` or `**kwargs` can be normal Python objects, like `1` or `'hello'`, or they can be other `Future` objects if you want to link tasks together with dependencies.

Unlike Dask collections like `dask.delayed` these task submissions happen immediately. The `concurrent.futures` interface is very similar to `dask.delayed` except that execution is immediate rather than lazy.

3.11.4 Futures to Concrete Values

You can turn an individual `Future` into a concrete value in the local process by calling the `Future.result()` method. You can convert a collection of futures into concrete values by calling the `client.gather` method.

```
>>> future.result()
1

>>> client.gather(futures)
[1, 2, 3, 4, ...]
```

3.11.5 Futures to Dask Collections

As seen in the `Collection to futures` section it is common to have currently computing `Future` objects within Dask graphs. This lets us build further computations on top of currently running computations. This is most often done with `dask.delayed` workflows on custom computations:

```
>>> x = delayed(sum)(futures)
>>> y = delayed(product)(futures)
>>> future = client.compute(x + y)
```

Mixing the two forms allow you to build and submit a computation in stages like `sum(...) + product(...)`. This is often valuable if you want to wait to see the values of certain parts of the computation before determining how to proceed. Submitting many computations at once allows the scheduler to be slightly more intelligent when determining what gets run.

If this page interests you then you may also want to check out the doc page on [Managing Memory](#)

3.12 Managing Memory

Dask.distributed stores the results of tasks in the distributed memory of the worker nodes. The central scheduler tracks all data on the cluster and determines when data should be freed. Completed results are usually cleared from memory as quickly as possible in order to make room for more computation. The result of a task is kept in memory if either of the following conditions hold:

1. A client holds a future pointing to this task. The data should stay in RAM so that the client can gather the data on demand.
2. The task is necessary for ongoing computations that are working to produce the final results pointed to by futures. These tasks will be removed once no ongoing tasks require them.

When users hold Future objects or persisted collections (which contain many such Futures inside their `.dask` attribute) they pin those results to active memory. When the user deletes futures or collections from their local Python process the scheduler removes the associated data from distributed RAM. Because of this relationship, distributed memory reflects the state of local memory. A user may free distributed memory on the cluster by deleting persisted collections in the local session.

3.12.1 Creating Futures

The following functions produce Futures

<code>Client.submit(func, *args, **kwargs)</code>	Submit a function application to the scheduler
<code>Client.map(func, *iterables, **kwargs)</code>	Map a function on a sequence of arguments
<code>Client.compute(collections[, sync, ...])</code>	Compute dask collections on cluster
<code>Client.persist(collections[, ...])</code>	Persist dask collections on cluster
<code>Client.scatter(data[, workers, broadcast, ...])</code>	Scatter data into distributed memory

The `submit` and `map` methods handle raw Python functions. The `compute` and `persist` methods handle Dask collections like arrays, bags, delayed values, and dataframes. The `scatter` method sends data directly from the local process.

3.12.2 Persisting Collections

Calls to `Client.compute` or `Client.persist` submit task graphs to the cluster and return Future objects that point to particular output tasks.

`Compute` returns a single future per input, `persist` returns a copy of the collection with each block or partition replaced by a single future. In short, use `persist` to keep full collection on the cluster and use `compute` when you want a small result as a single future.

`Persist` is more common and is often used as follows with collections:

```
>>> # Construct dataframe, no work happens
>>> df = dd.read_csv(...)
>>> df = df[df.x > 0]
>>> df = df.assign(z = df.x + df.y)

>>> # Pin data in distributed ram, this triggers computation
>>> df = client.persist(df)

>>> # continue operating on df
```

Note for Spark users: this differs from what you're accustomed to. `Persist` is an immediate action. However, you'll get control back immediately as computation occurs in the background.

In this example we build a computation by parsing CSV data, filtering rows, and then adding a new column. Up until this point all work is lazy; we've just built up a recipe to perform the work as a graph in the `df` object.

When we call `df = client.persist(df)` we cut this graph off of the `df` object, send it up to the scheduler, receive Future objects in return and create a new dataframe with a very shallow graph that points directly to these futures. This happens more or less immediately (as long as it takes to serialize and send the graph) and we can continue working on our new `df` object while the cluster works to evaluate the graph in the background.

3.12.3 Difference with `dask.compute`

The operations `client.persist(df)` and `client.compute(df)` are asynchronous and so differ from the traditional `df.compute()` method or `dask.compute` function, which blocks until a result is available. The `.compute()` method does not persist any data on the cluster. The `.compute()` method also brings the entire result back to the local machine, so it is unwise to use it on large datasets. However, `.compute()` is very convenient for smaller results particularly because it does return concrete results in a way that most other tools expect.

Typically we use asynchronous methods like `client.persist` to set up large collections and then use `df.compute()` for fast analyses.

```
>>> # df.compute() # This is bad and would likely flood local memory
>>> df = client.persist(df) # This is good and asynchronously pins df
>>> df.x.sum().compute() # This is good because the result is small
>>> future = client.compute(df.x.sum()) # This is also good but less intuitive
```

3.12.4 Clearing data

We remove data from distributed ram by removing the collection from our local process. Remote data is removed once all Futures pointing to that data are removed from all client machines.

```
>>> del df # Deleting local data often deletes remote data
```

If this is the only copy then this will likely trigger the cluster to delete the data as well.

However if we have multiple copies or other collections based on this one then we'll have to delete them all.

```
>>> df2 = df[df.x < 10]
>>> del df # would not delete data, because df2 still tracks the futures
```

3.12.5 Aggressively Clearing Data

To definitely remove a computation and all computations that depend on it you can always `cancel` the futures/collection.

```
>>> client.cancel(df) # kills df, df2, and every other dependent computation
```

Alternatively, if you want a clean slate, you can restart the cluster. This clears all state and does a hard restart of all worker processes. It generally completes in around a second.

```
>>> client.restart()
```

3.12.6 Resilience

Results are not intentionally copied unless necessary for computations on other worker nodes. Resilience is achieved through recomputation by maintaining the provenance of any result. If a worker node goes down the scheduler is able to recompute all of its results. The complete graph for any desired Future is maintained until no references to that future exist.

For more information see [Resilience](#).

3.12.7 Advanced techniques

At first the result of a task is not intentionally copied, but only persists on the node where it was originally computed or scattered. However result may be copied to another worker node in the course of normal computation if that result is required by another task that is intended to be run by a different worker. This occurs if a task requires two pieces of data on different machines (at least one must move) or through work stealing. In these cases it is the policy for the second machine to maintain its redundant copy of the data. This helps to organically spread around data that is in high demand.

However, advanced users may want to control the location, replication, and balancing of data more directly throughout the cluster. They may know ahead of time that certain data should be broadcast throughout the network or that their data has become particularly imbalanced, or that they want certain pieces of data to live on certain parts of their network. These considerations are not usually necessary.

<code>Client.rebalance([futures, workers])</code>	Rebalance data within network
<code>Client.replicate(futures[, n, workers, ...])</code>	Set replication of futures within network
<code>Client.scatter(data[, workers, broadcast, ...])</code>	Scatter data into distributed memory

3.13 Related Work

Writing the “related work” for a project called “distributed”, is a Sisyphean task. We’ll list a few notable projects that you’ve probably already heard of down below.

You may also find the [dask comparison with spark](#) of interest.

3.13.1 Big Data World

- The venerable [Hadoop](#) provides batch processing with the MapReduce programming paradigm. Python users typically use [Hadoop Streaming](#) or [MRJob](#).
- Spark builds on top of HDFS systems with a nicer API and in-memory processing. Python users typically use [PySpark](#).
- [Storm](#) provides streaming computation. Python users typically use [streamparse](#).

This is a woefully inadequate representation of the excellent work blossoming in this space. A variety of projects have come into this space and rival or complement the projects above. Still, most “Big Data” processing hype probably centers around the three projects above, or their derivatives.

3.13.2 Python Projects

There are dozens of Python projects for distributed computing. Here we list a few of the more prominent projects that we see in active use today.

Task scheduling

- [Celery](#): An asynchronous task scheduler, focusing on real-time processing.
- [Luigi](#): A bulk big-data/batch task scheduler, with hooks to a variety of interesting data sources.

Ad hoc computation

- [IPython Parallel](#): Allows for stateful remote control of several running ipython sessions.
- [Scoop](#): Implements the `concurrent.futures` API on distributed workers. Notably allows tasks to spawn more tasks.

Direct Communication

- [MPI4Py](#): Wraps the Message Passing Interface popular in high performance computing.
- [PyZMQ](#): Wraps ZeroMQ, the gentleman's socket.

Venerable

There are a couple of older projects that often get mentioned

- [Dispy](#): Embarrassingly parallel function evaluation
- [Pyro](#): Remote objects / RPC

3.13.3 Relationship

In relation to these projects `distributed`...

- Supports data-local computation like Hadoop and Spark
- Uses a task graph with data dependencies abstraction like Luigi
- In support of ad-hoc applications, like IPython Parallel and Scoop

3.13.4 In depth comparison to particular projects

IPython Parallel

Short Description

[IPython Parallel](#) is a distributed computing framework from the IPython project. It uses a centralized hub to farm out jobs to several `ipengine` processes running on remote workers. It communicates over ZeroMQ sockets and centralizes communication through the central hub.

IPython parallel has been around for a while and, while not particularly fancy, is quite stable and robust.

IPython Parallel offers `parallel map` and `remote apply` functions that route computations to remote workers

```
>>> view = Client(...)[:]
>>> results = view.map(func, sequence)
>>> result = view.apply(func, *args, **kwargs)
>>> future = view.apply_async(func, *args, **kwargs)
```

It also provides direct execution of code in the remote process and collection of data from the remote namespace.

```
>>> view.execute('x = 1 + 2')
>>> view['x']
[3, 3, 3, 3, 3, 3]
```

Brief Comparison

Distributed and IPython Parallel are similar in that they provide `map` and `apply/submit` abstractions over distributed worker processes running Python. Both manage the remote namespaces of those worker processes.

They are dissimilar in terms of their maturity, how worker nodes communicate to each other, and in the complexity of algorithms that they enable.

Distributed Advantages

The primary advantages of `distributed` over IPython Parallel include

1. Peer-to-peer communication between workers
2. Dynamic task scheduling

Distributed workers share data in a peer-to-peer fashion, without having to send intermediate results through a central bottleneck. This allows `distributed` to be more effective for more complex algorithms and to manage larger datasets in a more natural manner. IPython parallel does not provide a mechanism for workers to communicate with each other, except by using the central node as an intermediary for data transfer or by relying on some other medium, like a shared file system. Data transfer through the central node can easily become a bottleneck and so IPython parallel has been mostly helpful in embarrassingly parallel work (the bulk of applications) but has not been used extensively for more sophisticated algorithms that require non-trivial communication patterns.

The distributed client includes a dynamic task scheduler capable of managing deep data dependencies between tasks. The IPython parallel docs include a [recipe](#) for executing task graphs with data dependencies. This same idea is core to all of `distributed`, which uses a dynamic task scheduler for all operations. Notably, `distributed.Future` objects can be used within `submit/map/get` calls before they have completed.

```
>>> x = client.submit(f, 1)  # returns a future
>>> y = client.submit(f, 2)  # returns a future
>>> z = client.submit(add, x, y) # consumes futures
```

The ability to use futures cheaply within `submit` and `map` methods enables the construction of very sophisticated data pipelines with simple code. Additionally, `distributed` can serve as a full dask task scheduler, enabling support for distributed arrays, dataframes, machine learning pipelines, and any other application build on dask graphs. The dynamic task schedulers within `distributed` are adapted from the [dask](#) task schedulers and so are fairly sophisticated/efficient.

IPython Parallel Advantages

IPython Parallel has the following advantages over `distributed`

1. Maturity: IPython Parallel has been around for a while.
2. Explicit control over the worker processes: IPython parallel allows you to execute arbitrary statements on the workers, allowing it to serve in system administration tasks.
3. Deployment help: IPython Parallel has mechanisms built-in to aid deployment on SGE, MPI, etc.. Distributed does not have any such sugar, though is fairly simple to [set up](#) by hand.
4. Various other advantages: Over the years IPython parallel has accrued a variety of helpful features like IPython interaction magics, `@parallel` decorators, etc..

concurrent.futures

The `distributed.Client` API is modeled after `concurrent.futures` and [PEP 3184](#). It has a few notable differences:

- `distributed` accepts `Future` objects within calls to `submit/map`. When chaining computations, it is preferable to submit Future objects directly rather than wait on them before submission.

- The `map()` method returns `Future` objects, not concrete results. The `map()` method returns immediately.
- Despite sharing a similar API, distributed `Future` objects cannot always be substituted for `concurrent.futures.Future` objects, especially when using `wait()` or `as_completed()`.
- Distributed generally does not support callbacks.

If you need full compatibility with the `concurrent.futures.Executor` API, use the object returned by the `get_executor()` method.

3.14 Resilience

Software fails, Hardware fails, network connections fail, user code fails. This document describes how `dask.distributed` responds in the face of these failures and other known bugs.

3.14.1 User code failures

When a function raises an error that error is kept and transmitted to the client on request. Any attempt to gather that result *or any dependent result* will raise that exception.

```
>>> def div(a, b):
...     return a / b

>>> x = client.submit(div, 1, 0)
>>> x.result()
ZeroDivisionError: division by zero

>>> y = client.submit(add, x, 10)
>>> y.result() # same error as above
ZeroDivisionError: division by zero
```

This does not affect the smooth operation of the scheduler or worker in any way.

3.14.2 Closed Network Connections

If the connection to a remote worker unexpectedly closes and the local process appropriately raises an `IOError` then the scheduler will reroute all pending computations to other workers.

If the lost worker was the only worker to hold vital results necessary for future computations then those results will be recomputed by surviving workers. The scheduler maintains a full history of how each result was produced and so is able to reproduce those same computations on other workers.

This has some fail cases.

1. If results depend on impure functions then you may get a different (although still entirely accurate) result
2. If the worker failed due to a bad function, for example a function that causes a segmentation fault, then that bad function will repeatedly be called on other workers. This function will be marked as “bad” after it kills a fixed number of workers (defaults to three).
3. Data scattered out to the workers is not kept in the scheduler (it is often quite large) and so the loss of this data is irreparable. You may wish to call `Client.replicate` on the data with a suitable replication factor to ensure that it remains long-lived or else back the data off of some resilient store, like a file system.

3.14.3 Hardware Failures

It is not clear under which circumstances the local process will know that the remote worker has closed the connection. If the socket does not close cleanly then the system will wait for a timeout, roughly three seconds, before marking the worker as failed and resuming smooth operation.

3.14.4 Scheduler Failure

The process containing the scheduler might die. There is currently no persistence mechanism to record and recover the scheduler state.

The workers and clients will all reconnect to the scheduler after it comes back online but records of ongoing computations will be lost.

3.14.5 Restart and Nanny Processes

The client provides a mechanism to restart all of the workers in the cluster. This is convenient if, during the course of experimentation, you find your workers in an inconvenient state that makes them unresponsive. The `Client.restart` method kills all workers, flushes all scheduler state, and then brings all workers back online, resulting in a clean cluster.

3.15 Scheduling Policies

This document describes the policies used to select the preference of tasks and to select the preference of workers used by Dask's distributed scheduler. For more information on how these policies are enacted efficiently see [Scheduling State](#).

3.15.1 Choosing Workers

When a task transitions from waiting to a processing state we decide a suitable worker for that task. If the task has significant data dependencies or if the workers are under heavy load then this choice of worker can strongly impact global performance. Currently workers for tasks are determined as follows:

1. If the task has no major dependencies and no restrictions then we find the least occupied worker.
2. Otherwise, if a task has user-provided restrictions (for example it must run on a machine with a GPU) then we restrict the available pool of workers to just that set, otherwise we consider all workers
3. From among this pool of workers we determine the workers to whom the least amount of data would need to be transferred.
4. We break ties by choosing the worker that currently has the fewest tasks, counting both those tasks in memory and those tasks processing currently.

This process is easy to change (and indeed this document may be outdated). We encourage readers to inspect the `decide_worker` function in `scheduler.py`

`decide_worker(ts, all_workers, ...)`Decide which worker should take task *ts*.

3.15.2 Choosing Tasks

We often have a choice between running many valid tasks. There are a few competing interests that might motivate our choice:

1. Run tasks on a first-come-first-served basis for fairness between multiple clients
2. Run tasks that are part of the critical path in an effort to reduce total running time and minimize straggler workloads
3. Run tasks that allow us to release many dependencies in an effort to keep the memory footprint small
4. Run tasks that are related so that large chunks of work can be completely eliminated before running new chunks of work

Accomplishing all of these objectives simultaneously is impossible. Optimizing for any of these objectives perfectly can result in costly overhead. The heuristics with the scheduler do a decent but imperfect job of optimizing for all of these (they all come up in important workloads) quickly.

Last in, first out

When a worker finishes a task the immediate dependencies of that task get top priority. This encourages a behavior of finishing ongoing work immediately before starting new work. This often conflicts with the first-come-first-served objective but often results in shorter total runtimes and significantly reduced memory footprints.

Break ties with children and depth

Often a task has multiple dependencies and we need to break ties between them with some other objective. Breaking these ties has a surprisingly strong impact on performance and memory footprint.

When a client submits a graph we perform a few linear scans over the graph to determine something like the number of descendants of each node (not quite, because it's a DAG rather than a tree, but this is a close proxy). This number can be used to break ties and helps us to prioritize nodes with longer critical paths and nodes with many children. The actual algorithms used are somewhat more complex and are described in detail in [dask/order.py](#)

Initial Task Placement

When a new large batch of tasks come in and there are many idle workers then we want to give each worker a set of tasks that are close together/related and unrelated from the tasks given to other workers. This usually avoids inter-worker communication down the line. The same depth-first-with-child-weights priority given to workers described above can usually be used to properly segment the leaves of a graph into decently well separated sub-graphs with relatively low inter-sub-graph connectedness.

First-Come-First-Served, Coarsely

The last-in-first-out behavior used by the workers to minimize memory footprint can distort the task order provided by the clients. Tasks submitted recently may run sooner than tasks submitted long ago because they happen to be more convenient given the current data in memory. This behavior can be *unfair* but improves global runtimes and system efficiency, sometimes quite significantly.

However, workers inevitably run out of tasks that were related to tasks they were just working on and the last-in-first-out policy eventually exhausts itself. In these cases workers often pull tasks from the common task pool. The tasks in this pool *are* ordered in a first-come-first-served basis and so workers do behave in a fair scheduling manner at a *coarse* level if not a fine grained one.

Dask's scheduling policies are short-term-efficient and long-term-fair.

Where these decisions are made

The objectives above are mostly followed by small decisions made by the client, scheduler, and workers at various points in the computation.

1. As we submit a graph from the client to the scheduler we assign a numeric priority to each task of that graph. This priority focuses on computing deeply before broadly, preferring critical paths, preferring nodes with many dependencies, etc.. This is the same logic used by the single-machine scheduler and lives in [dask/order.py](#).
2. When the graph reaches the scheduler the scheduler changes each of these numeric priorities into a tuple of two numbers, the first of which is an increasing counter, the second of which is the client-generated priority described above. This per-graph counter encourages a first-in-first-out policy between computations. All tasks from a previous call to compute have a higher priority than all tasks from a subsequent call to compute (or submit, persist, map, or any operation that generates futures).
3. Whenever a task is ready to run the scheduler assigns it to a worker. The scheduler does not wait based on priority.
4. However when the worker receives these tasks it considers their priorities when determining which tasks to prioritize for communication or for computation. The worker maintains a heap of all ready-to-run tasks ordered by this priority.

3.16 Scheduling State

3.16.1 Overview

The life of a computation with Dask can be described in the following stages:

1. The user authors a graph using some library, perhaps `dask.delayed` or `dask.dataframe` or the `submit/map` functions on the client. They submit these tasks to the scheduler.
2. The scheduler assimilates these tasks into its graph of all tasks to track, and as their dependencies become available it asks workers to run each of these tasks in turn.
3. The worker receives information about how to run the task, communicates with its peer workers to collect data dependencies, and then runs the relevant function on the appropriate data. It reports back to the scheduler that it has finished, keeping the result stored in the worker where it was computed.
4. The scheduler reports back to the user that the task has completed. If the user desires, it then fetches the data from the worker through the scheduler.

Most relevant logic is in tracking tasks as they evolve from newly submitted, to waiting for dependencies, to actively running on some worker, to finished in memory, to garbage collected. Tracking this process, and tracking all effects that this task has on other tasks that might depend on it, is the majority of the complexity of the dynamic task scheduler. This section describes the system used to perform this tracking.

For more abstract information about the policies used by the scheduler, see [Scheduling Policies](#).

The scheduler keeps internal state about several kinds of entities:

- Individual tasks known to the scheduler
- Workers connected to the scheduler
- Clients connected to the scheduler

Note: Everything listed in this page is an internal detail of how Dask operates. It may change between versions and you should probably avoid relying on it in user code (including on any APIs explained here).

3.16.2 Task State

Internally, the scheduler moves tasks between a fixed set of states, notably `released`, `waiting`, `no-worker`, `processing`, `memory`, `erred`.

Tasks flow along the following states with the following allowed transitions:

- *Released*: Known but not actively computing or in memory
- *Waiting*: On track to be computed, waiting on dependencies to arrive in memory
- *No-worker*: Ready to be computed, but no appropriate worker exists (for example because of resource restrictions, or because no worker is connected at all).
- *Processing*: Actively being computed by one or more workers
- *Memory*: In memory on one or more workers
- *Erred*: Task computation, or one of its dependencies, has encountered an error
- *Forgotten* (not actually a state): Task is no longer needed by any client or dependent task

In addition to the literal state, though, other information needs to be kept and updated about each task. Individual task state is stored in an object named `TaskState` and consists of the following information:

class `distributed.scheduler.TaskState` (*key*, *run_spec*)

A simple object holding information about a task.

key: `str`

The key is the unique identifier of a task, generally formed from the name of the function, followed by a hash of the function and arguments, like `'inc-ab31c010444977004d656610d2d421ec'`.

prefix: `str`

The key prefix, used in certain calculations to get an estimate of the task’s duration based on the duration of other tasks in the same “family” (for example `'inc'`).

run_spec: `object`

A specification of how to run the task. The type and meaning of this value is opaque to the scheduler, as it is only interpreted by the worker to which the task is sent for executing.

As a special case, this attribute may also be `None`, in which case the task is “pure data” (such as, for example, a piece of data loaded in the scheduler using `Client.scatter()`). A “pure data” task cannot be computed again if its value is lost.

priority: `tuple`

The priority provides each task with a relative ranking which is used to break ties when many tasks are being considered for execution.

This ranking is generally a 2-item tuple. The first (and dominant) item corresponds to when it was submitted. Generally, earlier tasks take precedence. The second item is determined by the client, and is a way to prioritize tasks within a large graph that may be important, such as if they are on the critical path, or good to run in order to release many dependencies. This is explained further in [Scheduling Policy](#).

state: `str`

This task’s current state. Valid states include `released`, `waiting`, `no-worker`, `processing`, `memory`, `erred` and `forgotten`. If it is `forgotten`, the task isn’t stored in the `tasks` dictionary anymore and will probably disappear soon from memory.

dependencies: {TaskState}

The set of tasks this task depends on for proper execution. Only tasks still alive are listed in this set. If, for whatever reason, this task also depends on a forgotten task, the `has_lost_dependencies` flag is set.

A task can only be executed once all its dependencies have already been successfully executed and have their result stored on at least one worker. This is tracked by progressively draining the `waiting_on` set.

dependents: {TaskState}

The set of tasks which depend on this task. Only tasks still alive are listed in this set.

This is the reverse mapping of `dependencies`.

has_lost_dependencies: bool

Whether any of the dependencies of this task has been forgotten. For memory consumption reasons, forgotten tasks are not kept in memory even though they may have dependent tasks. When a task is forgotten, therefore, each of its dependents has their `has_lost_dependencies` attribute set to `True`.

If `has_lost_dependencies` is `true`, this task cannot go into the “processing” state anymore.

waiting_on: {TaskState}

The set of tasks this task is waiting on *before* it can be executed. This is always a subset of `dependencies`. Each time one of the dependencies has finished processing, it is removed from the `waiting_on` set.

Once `waiting_on` becomes empty, this task can move from the “waiting” state to the “processing” state (unless one of the dependencies errored out, in which case this task is instead marked “erred”).

waiters: {TaskState}

The set of tasks which need this task to remain alive. This is always a subset of `dependents`. Each time one of the dependents has finished processing, it is removed from the `waiters` set.

Once both `waiters` and `who_wants` become empty, this task can be released (if it has a non-empty `run_spec`) or forgotten (otherwise) by the scheduler, and by any workers in `who_has`.

Note: Counter-intuitively, `waiting_on` and `waiters` are not reverse mappings of each other.

who_wants: {ClientState}

The set of clients who want this task’s result to remain alive. This is the reverse mapping of `ClientState.wants_what`.

When a client submits a graph to the scheduler it also specifies which output tasks it desires, such that their results are not released from memory.

Once a task has finished executing (i.e. moves into the “memory” or “erred” state), the clients in `who_wants` are notified.

Once both `waiters` and `who_wants` become empty, this task can be released (if it has a non-empty `run_spec`) or forgotten (otherwise) by the scheduler, and by any workers in `who_has`.

who_has: {WorkerState}

The set of workers who have this task’s result in memory. It is non-empty iff the task is in the “memory” state. There can be more than one worker in this set if, for example, `Client.scatter()` or `Client.replicate()` was used.

This is the reverse mapping of `WorkerState.has_what`.

processing_on: WorkerState (or None)

If this task is in the “processing” state, which worker is currently processing it. Otherwise this is `None`.

This attribute is kept in sync with `WorkerState.processing`.

retries: int

The number of times this task can automatically be retried in case of failure. If a task fails executing (the worker returns with an error), its `retries` attribute is checked. If it is equal to 0, the task is marked “erred”. If it is greater than 0, the `retries` attribute is decremented and execution is attempted again.

nbytes: int (or None)

The number of bytes, as determined by `sizeof`, of the result of a finished task. This number is used for diagnostics and to help prioritize work.

exception: object

If this task failed executing, the exception object is stored here. Otherwise this is `None`.

traceback: object

If this task failed executing, the traceback object is stored here. Otherwise this is `None`.

exception_blame: TaskState (or None)

If this task or one of its dependencies failed executing, the failed task is stored here (possibly itself). Otherwise this is `None`.

suspicious: int

The number of times this task has been involved in a worker death.

Some tasks may cause workers to die (such as calling `os._exit(0)`). When a worker dies, all of the tasks on that worker are reassigned to others. This combination of behaviors can cause a bad task to catastrophically destroy all workers on the cluster, one after another. Whenever a worker dies, we mark each task currently processing on that worker (as recorded by `WorkerState.processing`) as suspicious.

If a task is involved in three deaths (or some other fixed constant) then we mark the task as `erred`.

host_restrictions: {hostnames}

A set of hostnames where this task can be run (or `None` if empty). Usually this is empty unless the task has been specifically restricted to only run on certain hosts. A hostname may correspond to one or several connected workers.

worker_restrictions: {worker addresses}

A set of complete worker addresses where this can be run (or `None` if empty). Usually this is empty unless the task has been specifically restricted to only run on certain workers.

Note this is tracking worker addresses, not worker states, since the specific workers may not be connected at this time.

resource_restrictions: {resource: quantity}

Resources required by this task, such as `{'gpu': 1}` or `{'memory': 1e9}` (or `None` if empty). These are user-defined names and are matched against the contents of each `WorkerState.resources` dictionary.

loose_restrictions: bool

If `False`, each of `host_restrictions`, `worker_restrictions` and `resource_restrictions` is a hard constraint: if no worker is available satisfying those restrictions, the task cannot go into the “processing” state and will instead go into the “no-worker” state.

If `True`, the above restrictions are mere preferences: if no worker is available satisfying those restrictions, the task can still go into the “processing” state and be sent for execution to another connected worker.

The scheduler keeps track of all the `TaskState` objects (those not in the “forgotten” state) using several containers:

tasks: {str: TaskState}

A dictionary mapping task keys (usually strings) to `TaskState` objects. Task keys are how information about

tasks is communicated between the scheduler and clients, or the scheduler and workers; this dictionary is then used to find the corresponding *TaskState* object.

unrunnable: {TaskState}

A set of *TaskState* objects in the “no-worker” state. These tasks already have all their dependencies satisfied (their *waiting_on* set is empty), and are waiting for an appropriate worker to join the network before computing.

3.16.3 Worker State

Each worker’s current state is stored in a *WorkerState* object. This information is involved in deciding *which worker to run a task on*.

class `distributed.scheduler.WorkerState` (*worker, ncores, memory_limit, name=None*)

A simple object holding information about a worker.

address

This worker’s unique key. This can be its connected address (such as `'tcp://127.0.0.1:8891'`) or an alias (such as `'alice'`).

processing: {TaskState: cost}

A dictionary of tasks that have been submitted to this worker. Each task state is associated with the expected cost in seconds of running that task, summing both the task’s expected computation time and the expected communication time of its result.

Multiple tasks may be submitted to a worker in advance and the worker will run them eventually, depending on its execution resources (but see *Work Stealing*).

All the tasks here are in the “processing” state.

This attribute is kept in sync with `TaskState.processing_on`.

has_what: {TaskState}

The set of tasks which currently reside on this worker. All the tasks here are in the “memory” state.

This is the reverse mapping of `TaskState.who_has`.

nbytes: int

The total memory size, in bytes, used by the tasks this worker holds in memory (i.e. the tasks in this worker’s *has_what*).

ncores: int

The number of CPU cores made available on this worker.

resources: {str: Number}

The available resources on this worker like `{ 'gpu': 2 }`. These are abstract quantities that constrain certain tasks from running at the same time on this worker.

used_resources: {str: Number}

The sum of each resource used by all tasks allocated to this worker. The numbers in this dictionary can only be less or equal than those in this worker’s *resources*.

occupancy: Number

The total expected runtime, in seconds, of all tasks currently processing on this worker. This is the sum of all the costs in this worker’s *processing* dictionary.

In addition to individual worker state, the scheduler maintains two containers to help with scheduling tasks:

Scheduler.saturated: {WorkerState}

A set of workers whose computing power (as measured by `WorkerState.ncores`) is fully exploited by processing tasks, and whose current *occupancy* is a lot greater than the average.

Scheduler.idle: {WorkerState}

A set of workers whose computing power is not fully exploited. These workers are assumed to be able to start computing new tasks immediately.

These two sets are disjoint. Also, some workers may be *neither* “idle” nor “saturated”. “Idle” workers will be preferred when *deciding a suitable worker* to run a new task on. Conversely, “saturated” workers may see their workload lightened through *Work Stealing*.

3.16.4 Client State

Information about each individual client is kept in a *ClientState* object:

```
class distributed.scheduler.ClientState(client)
```

A simple object holding information about a client.

client_key: str

A unique identifier for this client. This is generally an opaque string generated by the client itself.

wants_what: {TaskState}

A set of tasks this client wants kept in memory, so that it can download its result when desired. This is the reverse mapping of `TaskState.who_wants`.

Tasks are typically removed from this set when the corresponding object in the client’s space (for example a `Future` or a Dask collection) gets garbage-collected.

3.16.5 Understanding a Task’s Flow

As seen above, there are numerous pieces of information pertaining to task and worker state, and some of them can be computed, updated or removed during a task’s transitions.

The table below shows which state variable a task is in, depending on the task’s state. Cells with a check mark (✓) indicate the task key *must* be present in the given state variable; cells with an question mark (?) indicate the task key *may* be present in the given state variable.

State variable	Re- leased	Wait- ing	No- worker	Process- ing	Mem- ory	Erred
<code>TaskState.dependencies</code>	✓	✓	✓	✓	✓	✓
<code>TaskState.dependents</code>	✓	✓	✓	✓	✓	✓
<code>TaskState.host_restrictions</code>	?	?	?	?	?	?
<code>TaskState.worker_restrictions</code>	?	?	?	?	?	?
<code>TaskState.resource_restrictions</code>	?	?	?	?	?	?
<code>TaskState.loose_restrictions</code>	?	?	?	?	?	?
<code>TaskState.waiting_on</code>		✓		✓		
<code>TaskState.waiters</code>		✓		✓		
<code>TaskState.processing_on</code>				✓		
<code>WorkerState.processing</code>				✓		
<code>TaskState.who_has</code>					✓	
<code>WorkerState.has_what</code>					✓	
<code>TaskState.nbytes (1)</code>	?	?	?	?	✓	?
<code>TaskState.exception (2)</code>						?
<code>TaskState.traceback (2)</code>						?
<code>TaskState.exception_blame</code>						✓
<code>TaskState.retries</code>	?	?	?	?	?	?
<code>TaskState.suspicious_tasks</code>	?	?	?	?	?	?

Notes:

1. `TaskState.nbytes`: this attribute can be known as long as a task has already been computed, even if it has been later released.
2. `TaskState.exception` and `TaskState.traceback` should be looked up on the `TaskState.exception_blame` task.

The table below shows which worker state variables are updated on each task state transition.

Transition	Affected worker state
released → waiting	occupancy, idle, saturated
waiting → processing	occupancy, idle, saturated, used_resources
waiting → memory	idle, saturated, nbytes
processing → memory	occupancy, idle, saturated, used_resources, nbytes
processing → erred	occupancy, idle, saturated, used_resources
processing → released	occupancy, idle, saturated, used_resources
memory → released	nbytes
memory → forgotten	nbytes

Note: Another way of understanding this table is to observe that entering or exiting a specific task state updates a well-defined set of worker state variables. For example, entering and exiting the “memory” state updates `WorkerState.nbytes`.

3.16.6 Implementation

Every transition between states is a separate method in the scheduler. These task transition functions are prefixed with `transition` and then have the name of the start and finish task state like the following.

```
def transition_released_waiting(self, key):

def transition_processing_memory(self, key):

def transition_processing_erred(self, key):
```

These functions each have three effects.

1. They perform the necessary transformations on the scheduler state (the 20 dicts/lists/sets) to move one key between states.
2. They return a dictionary of recommended `{key: state}` transitions to enact directly afterwards on other keys. For example after we transition a key into memory we may find that many waiting keys are now ready to transition from waiting to a ready state.
3. Optionally they include a set of validation checks that can be turned on for testing.

Rather than call these functions directly we call the central function `transition`:

```
def transition(self, key, final_state):
    """ Transition key to the suggested state """
```

This transition function finds the appropriate path from the current to the final state. It also serves as a central point for logging and diagnostics.

Often we want to enact several transitions at once or want to continually respond to new transitions recommended by initial transitions until we reach a steady state. For that we use the `transitions` function (note the plural `s`).

```
def transitions(self, recommendations):
    recommendations = recommendations.copy()
    while recommendations:
        key, finish = recommendations.popitem()
        new = self.transition(key, finish)
        recommendations.update(new)
```

This function runs `transition`, takes the recommendations and runs them as well, repeating until no further task-transitions are recommended.

3.16.7 Stimuli

Transitions occur from stimuli, which are state-changing messages to the scheduler from workers or clients. The scheduler responds to the following stimuli:

- **Workers**
 - Task finished: A task has completed on a worker and is now in memory
 - Task erred: A task ran and erred on a worker
 - Task missing data: A task tried to run but was unable to find necessary data on other workers
 - Worker added: A new worker was added to the network
 - Worker removed: An existing worker left the network
- **Clients**

- Update graph: The client sends more tasks to the scheduler
- Release keys: The client no longer desires the result of certain keys

Stimuli functions are prepended with the text `stimulus`, and take a variety of keyword arguments from the message as in the following examples:

```
def stimulus_task_finished(self, key=None, worker=None, nbytes=None,
                           type=None, compute_start=None, compute_stop=None,
                           transfer_start=None, transfer_stop=None):

def stimulus_task_erred(self, key=None, worker=None,
                        exception=None, traceback=None)
```

These functions change some non-essential administrative state and then call transition functions.

Note that there are several other non-state-changing messages that we receive from the workers and clients, such as messages requesting information about the current state of the scheduler. These are not considered stimuli.

3.16.8 API

```
class distributed.scheduler.Scheduler (center=None, loop=None, delete_interval=500, syn-
                                     chronize_worker_interval=60000, services=None, al-
                                     lowed_failures=3, extensions=None, validate=False,
                                     scheduler_file=None, security=None, **kwargs)
```

Dynamic distributed task scheduler

The scheduler tracks the current state of workers, data, and computations. The scheduler listens for events and responds by controlling workers appropriately. It continuously tries to use the workers to execute an ever growing dask graph.

All events are handled quickly, in linear time with respect to their input (which is often of constant size) and generally within a millisecond. To accomplish this the scheduler tracks a lot of state. Every operation maintains the consistency of this state.

The scheduler communicates with the outside world through Comm objects. It maintains a consistent and valid view of the world even when listening to several clients at once.

A Scheduler is typically started either with the `dask-scheduler` executable:

```
$ dask-scheduler
Scheduler started at 127.0.0.1:8786
```

Or within a LocalCluster a Client starts up without connection information:

```
>>> c = Client()
>>> c.cluster.scheduler
Scheduler(...)
```

Users typically do not interact with the scheduler directly but rather with the client object `Client`.

State

The scheduler contains the following state variables. Each variable is listed along with what it stores and a brief description.

- **tasks:** {**task key:** **TaskState**} Tasks currently known to the scheduler
- **unrunnable:** {**TaskState**} Tasks in the “no-worker” state
- **workers:** {**worker key:** **WorkerState**} Workers currently connected to the scheduler

- **idle: {WorkerState}**: Set of workers that are not fully utilized
- **saturated: {WorkerState}**: Set of workers that are not over-utilized
- **host_info: {hostname: dict}**: Information about each worker host
- **clients: {client key: ClientState}** Workers currently connected to the scheduler
- **services: {str: port}**: Other services running on this scheduler, like Bokeh
- **loop: IOLoop**: The running Tornado IOLoop
- **client_comms: {client key: Comm}** For each client, a Comm object used to receive task requests and report task status updates.
- **worker_comms: {worker key: Comm}** For each worker, a Comm object from which we both accept stimuli and report results
- **task_duration: {key-prefix: time}** Time we expect certain functions to take, e.g. `{ 'sum': 0.25 }`
- **coroutines: [Futures]**: A list of active futures that control operation

add_client (*args, **kwargs)

Add client to network

We listen to all future messages from this Comm.

add_keys (comm=None, worker=None, keys=())

Learn that a worker has certain keys

This should not be used in practice and is mostly here for legacy reasons. However, it is sent by workers from time to time.

add_plugin (plugin)

Add external plugin to scheduler

See <https://distributed.readthedocs.io/en/latest/plugins.html>

add_worker (comm=None, address=None, keys=(), ncores=None, name=None, resolve_address=True, nbytes=None, now=None, resources=None, host_info=None, memory_limit=None, **info)

Add a new worker to the cluster

broadcast (*args, **kwargs)

Broadcast message to workers, return all results

cancel_key (key, client, retries=5, force=False)

Cancel a particular key and all dependents

cleanup (*args, **kwargs)

Clean up queues and coroutines, prepare to stop

client_heartbeat (client=None)

Handle heartbeats from Client

client_releases_keys (keys=None, client=None)

Remove keys from client desired list

close (*args, **kwargs)

Send cleanup signal to all coroutines then wait until finished

See also:

[`Scheduler.cleanup`](#)

close_comms ()

Close all active Comms.

close_worker (*args, **kwargs)

Remove a worker from the cluster

This both removes the worker from our local state and also sends a signal to the worker to shut down. This works regardless of whether or not the worker has a nanny process restarting it

coerce_address (addr, resolve=True)

Coerce possible input addresses to canonical form. *resolve* can be disabled for testing with fake hostnames.

Handles strings, tuples, or aliases.

coerce_hostname (host)

Coerce the hostname of a worker.

decide_worker (ts)

Decide on a worker for task *ts*. Return a WorkerState.

feed (*args, **kwargs)

Provides a data Comm to external requester

Caution: this runs arbitrary Python code on the scheduler. This should eventually be phased out. It is mostly used by diagnostics.

finished (*args, **kwargs)

Wait until all coroutines have ceased

gather (*args, **kwargs)

Collect data in from workers

get_comm_cost (ts, ws)

Get the estimated communication cost (in s.) to compute the task on the given worker.

get_task_duration (ts, default=0.5)

Get the estimated computation cost of the given task (not including any communication cost).

get_versions (comm)

Basic information about ourselves and our cluster

get_worker_service_addr (worker, service_name)

Get the (host, port) address of the named service on the *worker*. Returns None if the service doesn't exist.

handle_client (*args, **kwargs)

Listen and respond to messages from clients

This runs once per Client Comm or Queue.

See also:

Scheduler.worker_stream The equivalent function for workers

handle_long_running (key=None, worker=None, compute_duration=None)

A task has seceded from the thread pool

We stop the task from being stolen in the future, and change task duration accounting as if the task has stopped.

handle_worker (*args, **kwargs)

Listen to responses from a single worker

This is the main loop for scheduler-worker interaction

See also:

[`Scheduler.handle_client`](#) Equivalent coroutine for clients

identity (*comm=None*)

Basic information about ourselves and our cluster

rebalance (**args, **kwargs*)

Rebalance keys so that each worker stores roughly equal bytes

Policy

This orders the workers by what fraction of bytes of the existing keys they have. It walks down this list from most-to-least. At each worker it sends the largest results it can find and sends them to the least occupied worker until either the sender or the recipient are at the average expected load.

reevaluate_occupancy (*worker_index=0*)

Periodically reassess task duration time

The expected duration of a task can change over time. Unfortunately we don't have a good constant-time way to propagate the effects of these changes out to the summaries that they affect, like the total expected runtime of each of the workers, or what tasks are stealable.

In this coroutine we walk through all of the workers and re-align their estimates with the current state of tasks. We do this periodically rather than at every transition, and we only do it if the scheduler process isn't under load (using `psutil.Process.cpu_percent()`). This lets us avoid this fringe optimization when we have better things to think about.

remove_client (*client=None*)

Remove client from network

remove_plugin (*plugin*)

Remove external plugin from scheduler

remove_worker (*comm=None, address=None, safe=False, close=True*)

Remove worker from cluster

We do this when a worker reports that it plans to leave or when it appears to be unresponsive. This may send its tasks back to a released state.

replicate (**args, **kwargs*)

Replicate data throughout cluster

This performs a tree copy of the data throughout the network individually on each piece of data.

Parameters keys: Iterable

list of keys to replicate

n: int

Number of replications we expect to see within the cluster

branching_factor: int, optional

The number of workers that can copy data in each generation. The larger the branching factor, the more data we copy in a single step, but the more a given worker risks being swamped by data requests.

See also:

[`Scheduler.rebalance`](#)

report (*msg, ts=None, client=None*)

Publish updates to all listening Queues and Comms

If the message contains a key then we only send the message to those comms that care about the key.

reschedule (*key=None, worker=None*)

Reschedule a task

Things may have shifted and this task may now be better suited to run elsewhere

restart (**args, **kwargs*)

Restart all workers. Reset local state.

retire_workers (**args, **kwargs*)

Gracefully retire workers from cluster

Parameters **workers: list (optional)**

List of worker IDs to retire. If not provided we call `workers_to_close` which finds a good set

remove: bool (defaults to True)

Whether or not to remove the worker metadata immediately or else wait for the worker to contact us

close_workers: bool (defaults to False)

Whether or not to actually close the worker explicitly from here. Otherwise we expect some external job scheduler to finish off the worker.

Returns Dictionary mapping worker ID/address to dictionary of information about that worker for each retired worker.

run_function (*stream, function, args=(), kwargs={}*)

Run a function within this process

See also:

`Client.run_on_scheduler`

scatter (**args, **kwargs*)

Send data out to workers

See also:

`Scheduler.broadcast`

send_task_to_worker (*worker, key*)

Send a single computational task to a worker

start (*addr_or_port=8786, start_queues=True*)

Clear out old state and restart all running coroutines

start_ipython (*comm=None*)

Start an IPython kernel

Returns Jupyter connection info dictionary.

stimulus_cancel (*comm, keys=None, client=None, force=False*)

Stop execution on a list of keys

stimulus_missing_data (*cause=None, key=None, worker=None, ensure=True, **kwargs*)

Mark that certain keys have gone missing. Recover.

stimulus_task_erred (*key=None, worker=None, exception=None, traceback=None, **kwargs*)

Mark that a task has erred on a particular worker

stimulus_task_finished (*key=None, worker=None, **kwargs*)

Mark that a task has finished execution on a particular worker

story (**keys*)

Get all transitions that touch one of the input keys

transition (*key, finish, *args, **kwargs*)

Transition a key from its current state to the finish state

Returns Dictionary of recommendations for future transitions

See also:

[*Scheduler.transitions*](#) transitive version of this function

Examples

```
>>> self.transition('x', 'waiting')
{'x': 'processing'}
```

transition_story (**keys*)

Get all transitions that touch one of the input keys

transitions (*recommendations*)

Process transitions until none are left

This includes feedback from previous transitions and continues until we reach a steady state

update_data (*comm=None, who_has=None, nbytes=None, client=None*)

Learn that new data has entered the network from an external source

See also:

[*Scheduler.mark_key_in_memory*](#)

update_graph (*client=None, tasks=None, keys=None, dependencies=None, restrictions=None, priority=None, loose_restrictions=None, resources=None, submitting_task=None, retries=None*)

Add new computations to the internal dask graph

This happens whenever the Client calls submit, map, get, or compute.

valid_workers (*ts*)

Return set of currently valid workers for key

If all workers are valid then this returns `True`. This checks tracks the following state:

- `worker_restrictions`
- `host_restrictions`
- `resource_restrictions`

worker_objective (*ts, ws*)

Objective function to determine which worker should get the task

Minimize expected start time. If a tie then break with data storage.

worker_send (*worker, msg*)

Send message to worker

This also handles connection failures by adding a callback to remove the worker on the next cycle.

workers_list (*workers*)

List of qualifying workers

Takes a list of worker addresses or hostnames. Returns a list of all worker addresses that match

workers_to_close (*memory_ratio=2, key=None*)

Find workers that we can close with low cost

This returns a list of workers that are good candidates to retire. These workers are not running anything and are storing relatively little data relative to their peers. If all workers are idle then we still maintain enough workers to have enough RAM to store our data, with a comfortable buffer.

This is for use with systems like `distributed.deploy.adaptive`.

Parameters **memory_factor**: Number

Amount of extra space we want to have for our stored data. Defaults two 2, or that we want to have twice as much memory as we currently have data.

key: Callable(**WorkerState**)

An optional callable mapping a **WorkerState** object to a group affiliation. Groups will be closed together. This is useful when closing workers must be done collectively, such as by hostname.

Returns `to_close`: list of worker addresses that are OK to close

Examples

```
>>> scheduler.workers_to_close()
['tcp://192.168.0.1:1234', 'tcp://192.168.0.2:1234']
```

Group workers by hostname prior to closing

```
>>> scheduler.workers_to_close(key=lambda ws: ws.host)
['tcp://192.168.0.1:1234', 'tcp://192.168.0.1:4567']
```

`distributed.scheduler.decide_worker` (*ts, all_workers, valid_workers, objective*)

Decide which worker should take task *ts*.

We choose the worker that has the data on which *ts* depends.

If several workers have dependencies then we choose the less-busy worker.

Optionally provide *valid_workers* of where jobs are allowed to occur (if all workers are allowed to take the task, pass `True` instead).

If the task requires data communication because no eligible worker has all the dependencies already, then we choose to minimize the number of bytes sent between workers. This is determined by calling the *objective* function.

3.17 Worker

3.17.1 Overview

Workers provide two functions:

1. Compute tasks as directed by the scheduler
2. Store and serve computed results to other workers or clients

Each worker contains a `ThreadPool` that it uses to evaluate tasks as requested by the scheduler. It stores the results of these tasks locally and serves them to other workers or clients on demand. If the worker is asked to evaluate a task for which it does not have all of the necessary data then it will reach out to its peer workers to gather the necessary dependencies.

A typical conversation between a scheduler and two workers Alice and Bob may look like the following:

```
Scheduler -> Alice: Compute ``x <- add(1, 2)``!
Alice -> Scheduler: I've computed x and am holding on to it!

Scheduler -> Bob:   Compute ``y <- add(x, 10)``!
                   You will need x.  Alice has x.
Bob -> Alice:       Please send me x.
Alice -> Bob:       Sure.  x is 3!
Bob -> Scheduler:   I've computed y and am holding on to it!
```

3.17.2 Storing Data

Data is stored locally in a dictionary in the `.data` attribute that maps keys to the results of function calls.

```
>>> worker.data
{'x': 3,
 'y': 13,
 ...
 '(df, 0)': pd.DataFrame(...),
 ...
 }
```

This `.data` attribute is a `MutableMapping` that is typically a combination of in-memory and on-disk storage with an LRU policy to move data between them.

3.17.3 Thread Pool

Each worker sends computations to a thread in a `concurrent.futures.ThreadPoolExecutor` for computation. These computations occur in the same process as the Worker communication server so that they can access and share data efficiently between each other. For the purposes of data locality all threads within a worker are considered the same worker.

If your computations are mostly numeric in nature (for example NumPy and Pandas computations) and release the GIL entirely then it is advisable to run `dask-worker` processes with many threads and one process. This reduces communication costs and generally simplifies deployment.

If your computations are mostly Python code and don't release the GIL then it is advisable to run `dask-worker` processes with many processes and one thread per core:

```
$ dask-worker scheduler:8786 --nprocs 8
```

If your computations are external to Python and long-running and don't release the GIL then beware that while the computation is running the worker process will not be able to communicate to other workers or to the scheduler. This situation should be avoided. If you don't link in your own custom C/Fortran code then this topic probably doesn't apply to you.

3.17.4 Command Line tool

Use the `dask-worker` command line tool to start an individual worker. Here are the available options:

```
$ dask-worker --help
Usage: dask-worker [OPTIONS] SCHEDULER

Options:
  --worker-port INTEGER  Serving worker port, defaults to randomly assigned
  --http-port INTEGER    Serving http port, defaults to randomly assigned
  --nanny-port INTEGER    Serving nanny port, defaults to randomly assigned
  --port INTEGER          Deprecated, see --nanny-port
  --host TEXT             Serving host. Defaults to an ip address that can
                           hopefully be visible from the scheduler network.
  --nthreads INTEGER      Number of threads per process. Defaults to number of
                           cores
  --nprocs INTEGER        Number of worker processes. Defaults to one.
  --name TEXT             Alias
  --memory-limit TEXT     Number of bytes before spilling data to disk
  --no-nanny
  --help                  Show this message and exit.
```

3.17.5 Internal Scheduling

Internally tasks that come to the scheduler proceed through the following pipeline:

The worker also tracks data dependencies that are required to run the tasks above. These follow through a simpler pipeline:

As tasks arrive they are prioritized and put into a heap. They are then taken from this heap in turn to have any remote dependencies collected. For each dependency we select a worker at random that has that data and collect the dependency from that worker. To improve bandwidth we opportunistically gather other dependencies of other tasks that are known to be on that worker, up to a maximum of 200MB of data (too little data and bandwidth suffers, too much data and responsiveness suffers). We use a fixed number of connections (around 10-50) so as to avoid overly-fragmenting our network bandwidth. After all dependencies for a task are in memory we transition the task to the ready state and put the task again into a heap of tasks that are ready to run.

We collect from this heap and put the task into a thread from a local thread pool to execute.

Optionally, this task may identify itself as a long-running task (see [Tasks launching tasks](#)), at which point it secedes from the thread pool.

A task either errs or its result is put into memory. In either case a response is sent back to the scheduler.

3.17.6 Memory Management

Workers are given a target memory limit to stay under with the command line `--memory-limit` keyword or the `memory_limit=` Python keyword argument.:

```
$ dask-worker tcp://scheduler:port --memory-limit=auto # total available RAM
$ dask-worker tcp://scheduler:port --memory-limit=4e9 # four gigabytes
```

Workers use a few different policies to keep memory use beneath this limit:

1. At 60% of memory load (as estimated by `sizeof`), spill least recently used data to disk
2. At 70% of memory load, spill least recently used data to disk regardless of what is reported by `sizeof`
3. At 80% of memory load, stop accepting new work on local thread pool
4. At 95% of memory load, terminate and restart the worker

These values can be configured by modifying the `~/.dask/config.yaml` file

```
# Fractions of worker memory at which we take action to avoid memory blowup
# Set any of the lower three values to False to turn off the behavior entirely
worker-memory-target: 0.60 # target fraction to stay below
worker-memory-spill: 0.70 # fraction at which we spill to disk
worker-memory-pause: 0.80 # fraction at which we pause worker threads
worker-memory-terminate: 0.95 # fraction at which we terminate the worker
```

Spill data to Disk

Every time the worker finishes a task it estimates the size in bytes that the result costs to keep in memory using the `sizeof` function. This function defaults to `sys.getsizeof` for arbitrary objects which uses the standard Python `__sizeof__` protocol, but also has special-cased implementations for common data types like NumPy arrays and Pandas dataframes.

When the sum of the number of bytes of the data in memory exceeds 60% of the available threshold the worker will begin to dump the least recently used data to disk. You can control this location with the `--local-directory` keyword.:

```
$ dask-worker tcp://scheduler:port --memory-limit 4e9 --local-directory /scratch
```

That data is still available and will be read back from disk when necessary. On the diagnostic dashboard status page disk I/O will show up in the task stream plot as orange blocks. Additionally the memory plot in the upper left will become orange and then red.

Monitor process memory load

The approach above can fail for a few reasons

1. Custom objects may not report their memory size accurately
2. User functions may take up more RAM than expected
3. Significant amounts of data may accumulate in network I/O buffers

To address this we periodically monitor the memory of the worker process every 200 ms. If the system reported memory use is above 70% of the target memory usage then the worker will start dumping unused data to disk, even if internal `sizeof` recording hasn't yet reached the normal 60% limit.

Halt worker threads

At 80% load the worker's thread pool will stop accepting new tasks. This gives time for the write-to-disk functionality to take effect even in the face of rapidly accumulating data.

Kill Worker

At 95% memory load a worker's nanny process will terminate it. This is to avoid having our worker job being terminated by an external job scheduler (like YARN, Mesos, SGE, etc..). After termination the nanny will restart the worker in a fresh state.

3.17.7 API Documentation

class `distributed.worker.Worker(*args, **kwargs)`

Worker node in a Dask distributed cluster

Workers perform two functions:

1. **Serve data** from a local dictionary
2. **Perform computation** on that data and on data from peers

Workers keep the scheduler informed of their data and use that scheduler to gather data from other workers when necessary to perform a computation.

You can start a worker with the `dask-worker` command line application:

```
$ dask-worker scheduler-ip:port
```

Use the `--help` flag to see more options

```
$ dask-worker --help
```

The rest of this docstring is about the internal state the the worker uses to manage and track internal computations.

State

Informational State

These attributes don't change significantly during execution.

- **ncores: int:** Number of cores used by this worker process
- **executor: concurrent.futures.ThreadPoolExecutor:** Executor used to perform computation
- **local_dir: path:** Path on local machine to store temporary files
- **scheduler: rpc:** Location of scheduler. See `.ip/.port` attributes.
- **name: string:** Alias
- **services: {str: Server}:** Auxiliary web servers running on this worker
- **service_ports: {str: port}:**
- **total_connections: int** The maximum number of concurrent connections we want to see
- **total_comm_nbytes: int**
- **batched_stream: BatchedSend** A batched stream along which we communicate to the scheduler

- **log:** [(message)] A structured and queryable log. See `Worker.story`

Volatile State

This attributes track the progress of tasks that this worker is trying to complete. In the descriptions below a `key` is the name of a task that we want to compute and `dep` is the name of a piece of dependent data that we want to collect from others.

- **data:** {key: object}: Dictionary mapping keys to actual values
- **task_state:** {key: string}: The state of all tasks that the scheduler has asked us to compute. Valid states include waiting, constrained, executing, memory, erred
- **tasks:** {key: dict} The function, args, kwargs of a task. We run this when appropriate
- **dependencies:** {key: {deps}} The data needed by this key to run
- **dependents:** {dep: {keys}} The keys that use this dependency
- **data_needed:** deque(keys) The keys whose data we still lack, arranged in a deque
- **waiting_for_data:** {key: {deps}} A dynamic version of dependencies. All dependencies that we still don't have for a particular key.
- **ready:** [keys] Keys that are ready to run. Stored in a LIFO stack
- **constrained:** [keys] Keys for which we have the data to run, but are waiting on abstract resources like GPUs. Stored in a FIFO deque
- **executing:** [keys] Keys that are currently executing
- **executed_count:** int A number of tasks that this worker has run in its lifetime
- **long_running:** {keys} A set of keys of tasks that are running and have started their own long-running clients.
- **dep_state:** {dep: string}: The state of all dependencies required by our tasks Valid states include waiting, flight, and memory
- **who_has:** {dep: {worker}} Workers that we believe have this data
- **has_what:** {worker: {deps}} The data that we care about that we think a worker has
- **pending_data_per_worker:** {worker: [dep]} The data on each worker that we still want, prioritized as a deque
- **in_flight_tasks:** {task: worker} All dependencies that are coming to us in current peer-to-peer connections and the workers from which they are coming.
- **in_flight_workers:** {worker: {task}} The workers from which we are currently gathering data and the dependencies we expect from those connections
- **comm_bytes:** int The total number of bytes in flight
- **suspicious_deps:** {dep: int} The number of times a dependency has not been where we expected it
- **nbytes:** {key: int} The size of a particular piece of data
- **types:** {key: type} The type of a particular piece of data
- **threads:** {key: int} The ID of the thread on which the task ran
- **active_threads:** {int: key} The keys currently running on active threads
- **exceptions:** {key: exception} The exception caused by running a task if it erred
- **tracebacks:** {key: traceback} The exception caused by running a task if it erred

- **startstops:** {key: [(str, float, float)]} Log of transfer, load, and compute times for a task
- **priorities:** {key: tuple} The priority of a key given by the scheduler. Determines run order.
- **durations:** {key: float} Expected duration of a task
- **resource_restrictions:** {key: {str: number}} Abstract resources required to run a task

Parameters scheduler_ip: str

scheduler_port: int

ip: str, optional

ncores: int, optional

loop: tornado.ioloop.IOLoop

local_dir: str, optional

Directory where we place local resources

name: str, optional

heartbeat_interval: int

Milliseconds between heartbeats to scheduler

memory_limit: int, float, string

Number of bytes of memory that this worker should use. Set to zero for no limit. Set to 'auto' for 60% of memory use. Use strings or numbers like 5GB or 5e9

memory_target_fraction: float

Fraction of memory to try to stay beneath

memory_spill_fraction: float

Fraction of memory at which we start spilling to disk

memory_pause_fraction: float

Fraction of memory at which we stop running new tasks

executor: concurrent.futures.Executor

resources: dict

Resources that this worker has like {'GPU': 2}

See also:

[`distributed.scheduler.Scheduler`](#), [`distributed.nanny.Nanny`](#)

Examples

Use the command line to start a worker:

```
$ dask-scheduler
Start scheduler at 127.0.0.1:8786

$ dask-worker 127.0.0.1:8786
```

```
Start worker at:           127.0.0.1:1234
Registered with scheduler at: 127.0.0.1:8786
```

3.18 Work Stealing

Some tasks prefer to run on certain workers. This may be because that worker holds data dependencies of the task or because the user has expressed a loose desire that the task run in a particular place. Occasionally this results in a few very busy workers and several idle workers. In this situation the idle workers may choose to steal work from the busy workers, even if stealing work requires the costly movement of data.

This is a performance optimization and not required for correctness. Work stealing provides robustness in many ad-hoc cases, but can also backfire when we steal the wrong tasks and reduce performance.

3.18.1 Criteria for stealing

Computation to Communication Ratio

Stealing is profitable when the computation time for a task is much longer than the communication time of the task's dependencies.

Bad example

We do not want to steal tasks that require moving a large dependent piece of data across a wire from the victim to the thief if the computation is fast. We end up spending far more time in communication than just waiting a bit longer and giving up on parallelism.

```
[data] = client.scatter([np.arange(1000000000)])
x = client.submit(np.sum, data)
```

Good example

We do want to steal task tasks that only need to move dependent pieces of data, especially when the computation time is expensive (here 100 seconds.)

```
[data] = client.scatter([100])
x = client.submit(sleep, data)
```

Fortunately we often know both the number of bytes of dependencies (as reported by calling `sys.getsizeof` on the workers) and the runtime cost of previously seen functions, which is maintained as an exponentially weighted moving average.

Saturated Worker Burden

Stealing may be profitable even when the computation-time to communication-time ratio is poor. This occurs when the saturated workers have a very long backlog of tasks and there are a large number of idle workers. We determine if it acceptable to steal a task if the last task to be run by the saturated workers would finish more quickly if stolen or if it remains on the original/victim worker.

The longer the backlog of stealable tasks, and the smaller the number of active workers we have both increase our willingness to steal. This is balanced against the compute-to-communicate cost ratio.

Replicate Popular Data

It is also good long term if stealing causes highly-sought-after data to be replicated on more workers.

Steal from the Rich

We would like to steal tasks from particularly over-burdened workers rather than workers with just a few excess tasks.

Restrictions

If a task has been specifically restricted to run on particular workers (such as is the case when special hardware is required) then we do not steal.

3.18.2 Choosing tasks to steal

We maintain a list of sets of stealable tasks, ordered into bins by computation-to-communication time ratio. The first bin contains all tasks with a compute-to-communicate ratio greater than or equal to 8 (considered high enough to always steal), the next bin with a ratio of 4, the next bin with a ratio of 2, etc., all the way down to a ratio of 1/256, which we will never steal.

This data structure provides a somewhat-ordered view of all stealable tasks that we can add to and remove from in constant time, rather than $\log(n)$ as with more traditional data structures, like a heap.

During any stage when we submit tasks to workers we check if there are both idle and saturated workers and if so we quickly run through this list of sets, selecting tasks from the best buckets first, working our way down to the buckets of less desirable stealable tasks. We stop either when there are no more stealable tasks, no more idle workers, or when the quality of the task-to-be-stolen is not high enough given the current backlog.

This approach is fast, optimizes to steal the tasks with the best computation-to-communication cost ratio (up to a factor of two) and tends to steal from the workers that have the largest backlogs, just by nature that random selection tends to draw from the largest population.

3.18.3 Transactional Work Stealing

To avoid running the same task twice, Dask implements transactional work stealing. When the scheduler identifies a task that should be moved it first sends a request to the busy worker. The worker inspects its current state of the task and sends a response to the scheduler:

1. If the task is not yet running, then the worker cancels the task and informs the scheduler that it can reroute the task elsewhere.
2. If the task is already running or complete then the worker tells the scheduler that it should not replicate the task elsewhere.

This avoids redundant work, and also the duplication of side effects for more exotic tasks. However, concurrent or repeated execution of the same task *is still possible* in the event of worker death or a disrupted network connection.

3.19 Adaptive Deployments

It is possible to grow and shrink Dask clusters based on current use. This allows you to run Dask permanently on your cluster and have it only take up resources when necessary. Dask contains the logic about when to grow and shrink but relies on external cluster managers to launch and kill `dask-worker` jobs. This page describes the policies about

adaptively resizing Dask clusters based on load, how to connect these policies to a particular job scheduler, and an example implementation.

Dynamically scaling a Dask cluster up and down requires tight integration with an external cluster management system that can deploy `dask-worker` jobs throughout the cluster. Several systems are in wide use today, including common examples like SGE, SLURM, Torque, Condor, LSF, Yarn, Mesos, Marathon, Kubernetes, etc. . . These systems can be quite different from each other, but all are used to manage distributed services throughout different kinds of clusters.

The large number of relevant systems, the challenges of rigorously testing each, and finite development time precludes the systematic inclusion of all solutions within the `dask/distributed` repository. Instead, we include a generic interface that can be extended by someone with basic understanding of their cluster management tool. We encourage these as third party modules.

3.19.1 Policies

We control the number of workers based on current load and memory use. The scheduler checks itself periodically to determine if more or fewer workers are needed.

If there are excess unclaimed tasks, or if the memory of the current workers is more nearing full then the scheduler tries to increase the number of workers by a fixed factor, defaulting to 2. This causes exponential growth while growth is useful.

If there are idle workers and if the memory of the current workers is nearing empty then we gracefully retire the idle workers with the least amount of data in memory. We first move these results to the surviving workers and then remove the idle workers from the cluster. This shrinks the cluster while gracefully preserving intermediate results, shrinking the cluster when excess size is not useful.

3.19.2 Adaptive class interface

The `distributed.deploy.Adaptive` class contains the logic about when to ask for new workers, and when to close idle ones. This class requires both a scheduler and a cluster object.

The cluster object must support two methods, `scale_up(n, **kwargs)`, which takes in a target number of total workers for the cluster and `scale_down(workers)`, which takes in a list of addresses to remove from the cluster. The `Adaptive` class will call these methods with the correct values at the correct times.

```
class MyCluster(object):
    @gen.coroutine
    def scale_up(self, n, **kwargs):
        """
        Bring the total count of workers up to ``n``

        This function/coroutine should bring the total number of workers up to
        the number ``n``.

        This can be implemented either as a function or as a Tornado coroutine.
        """
        raise NotImplementedError()

    @gen.coroutine
    def scale_down(self, workers):
        """
        Remove ``workers`` from the cluster

        Given a list of worker addresses this function should remove those
        workers from the cluster. This may require tracking which jobs are
```

```
associated to which worker address.
```

```
This can be implemented either as a function or as a Tornado coroutine.
"""
```

```
from distributed.deploy import Adaptive

scheduler = Scheduler()
cluster = MyCluster()
adaptive_cluster = Adaptive(scheduler, cluster)
scheduler.start()
```

Implementing these `scale_up` and `scale_down` functions depends strongly on the cluster management system. See *LocalCluster* for an example.

3.19.3 Marathon: an example

We now present an example project that implements this cluster interface backed by the Marathon cluster management tool on Mesos. Full source code and testing apparatus is available here: <http://github.com/mrocklin/dask-marathon>

The implementation is small. It uses the Marathon HTTP API through the *marathon* Python client library. We reproduce the full body of the implementation below as an example:

```
from marathon import MarathonClient, MarathonApp
from marathon.models.container import MarathonContainer

class MarathonCluster(object):
    def __init__(self, scheduler,
                 executable='dask-worker',
                 docker_image='mrocklin/dask-distributed',
                 marathon_address='http://localhost:8080',
                 name=None, **kwargs):
        self.scheduler = scheduler

        # Create Marathon App to run dask-worker
        args = [executable, scheduler.address,
                '--name', '$MESOS_TASK_ID'] # use Mesos task ID as worker name
        if 'mem' in kwargs:
            args.extend(['--memory-limit',
                        str(int(kwargs['mem'] * 0.6 * 1e6))])
        kwargs['cmd'] = ' '.join(args)
        container = MarathonContainer({'image': docker_image})

        app = MarathonApp(instances=0, container=container, **kwargs)

        # Connect and register app
        self.client = MarathonClient(marathon_address)
        self.app = self.client.create_app(name or 'dask-%s' % uuid.uuid4(), app)

    def scale_up(self, instances):
        self.marathon_client.scale_app(self.app.id, instances=instances)

    def scale_down(self, workers):
        for w in workers:
            self.marathon_client.kill_task(self.app.id,
                                           self.scheduler.worker_info[w]['name'],
                                           scale=True)
```

3.19.4 Subclassing Adaptive

The default behaviors of `Adaptive` controlling when to scale up or down, and by how much, may not be appropriate for your cluster manager or workload. For example, you may have tasks that require a worker with more memory than usual. This means we need to pass through some additional keyword arguments to `cluster.scale_up` call.

```
from distributed.deploy import Adaptive

class MyAdaptive(Adaptive):
    def get_scale_up_kwargs(self):
        kwargs = super(Adaptive, self).get_scale_up_kwargs()
        # resource_restrictions maps task keys to a dict of restrictions
        restrictions = self.scheduler.resource_restrictions.values()
        memory_restrictions = [x.get('memory') for x in restrictions
                               if 'memory' in x]

        if memory_restrictions:
            kwargs['memory'] = max(memory_restrictions)

        return kwargs
```

So if there are any tasks that are waiting to be run on a worker with enough memory, the `kwargs` dictionary passed to `cluster.scale_up` will include a key and value for `'memory'` (your `Cluster.scale_up` method needs to be able to support this).

3.20 Asynchronous Operation

Dask.distributed can operate as a fully asynchronous framework and so interoperate with other highly concurrent applications. Internally Dask is built on top of Tornado coroutines but also has a compatibility layer for `asyncio` (see below).

3.20.1 Basic Operation

When starting a client provide the `asynchronous=True` keyword to tell Dask that you intend to use this client within an asynchronous context.

```
client = await Client(asynchronous=True)
```

Operations that used to block now provide Tornado coroutines on which you can `await`.

Fast functions that only submit work remain fast and don't need to be awaited. This includes all functions that submit work to the cluster, like `submit`, `map`, `compute`, and `persist`.

```
future = client.submit(lambda x: x + 1, 10)
```

You can `await` futures directly

```
result = await future

>>> print(result)
11
```

Or you can use the normal client methods. Any operation that waited until it received information from the scheduler should now be `await`'ed.

```
result = await client.gather(future)
```

If you want to reuse the same client in asynchronous and synchronous environments you can apply the `asynchronous=True` keyword at each method call.

```
client = Client()  # normal blocking client

async def f():
    futures = client.map(func, L)
    results = await client.gather(futures, asynchronous=True)
    return results
```

3.20.2 AsyncIO

If you prefer to use the Asyncio event loop over the Tornado event loop you should use the `AioClient`.

```
from distributed.asyncio import AioClient
client = await AioClient()
```

All other operations remain the same:

```
future = client.submit(lambda x: x + 1, 10)
result = await future
# or
result = await client.gather(future)
```

3.20.3 Python 2 Compatibility

Everything here works with Python 2 if you replace `await` with `yield`. See more extensive comparison in the example below.

3.20.4 Example

This self-contained example starts an asynchronous client, submits a trivial job, waits on the result, and then shuts down the client. You can see implementations for Python 2 and 3 and for Asyncio and Tornado.

Python 3 with Tornado

```
from dask.distributed import Client

async def f():
    client = await Client(asynchronous=True)
    future = client.submit(lambda x: x + 1, 10)
    result = await future
    await client.close()
    return result

from tornado.ioloop import IOLoop
IOLoop().run_sync(f)
```


Python 2/3 with Tornado

```
from dask.distributed import Client
from tornado import gen

@gen.coroutine
def f():
    client = yield Client(asynchronous=True)
    future = client.submit(lambda x: x + 1, 10)
    result = yield future
    yield client.close()
    raise gen.Result(result)

from tornado.ioloop import IOLoop
IOLoop().run_sync(f)
```

Python 3 with Asyncio

```
from distributed.asyncio import AioClient

async def f():
    client = await AioClient()
    future = client.submit(lambda x: x + 1, 10)
    result = await future
    await client.close()
    return result

from asyncio import get_event_loop
get_event_loop().run_until_complete(f())
```

3.20.5 Use Cases

Historically this has been used in a few kinds of applications:

1. To integrate Dask into other asynchronous services (such as web backends), supplying a computational engine similar to Celery, but while still maintaining a high degree of concurrency and not blocking needlessly.
2. For computations that change or update state very rapidly, such as is common in some advanced machine learning workloads.
3. To develop the internals of Dask's distributed infrastructure, which is written entirely in this style.
4. For complex control and data structures in advanced applications.

3.21 Configuration

As with any distributed computation system, taking full advantage of Dask distributed sometimes requires configuration. Some options can be passed as *API* parameters and/or command line options to the various Dask executables. However, some options can also be entered in the Dask configuration file.

3.21.1 User-wide configuration

Dask accepts some configuration options in a configuration file, which by default is a `.dask/config.yaml` file located in your home directory. The file path can be overridden using the `DASK_CONFIG` environment variable. In order to parse this configuration file, the `pyyaml` module needs to be installed. If the `pyyaml` module is not installed, the configuration file is ignored.

The file is written in the YAML format, which allows for a human-readable hierarchical key-value configuration. All keys in the configuration file are optional, though Dask will create a default configuration file for you on its first launch.

Here is a synopsis of the configuration file:

```
logging:
  distributed: info
  distributed.client: warning
  bokeh: critical

# Scheduler options
bandwidth: 100000000      # 100 MB/s estimated worker-worker bandwidth
allowed-failures: 3       # number of retries before a task is considered bad
pdb-on-err: False        # enter debug mode on scheduling error
transition-log-length: 10000

# Worker options
multiprocessing-method: forkserver

# Communication options
compression: auto
tcp-timeout: 30           # seconds delay before calling an unresponsive connection dead
default-scheme: tcp
require-encryption: False # whether to require encryption on non-local comms
tls:
  ca-file: myca.pem
  scheduler:
    cert: mycert.pem
    key: mykey.pem
  worker:
    cert: mycert.pem
    key: mykey.pem
  client:
    cert: mycert.pem
    key: mykey.pem
# ciphers:
# ECDHE-ECDSA-AES128-GCM-SHA256

# Bokeh web dashboard
bokeh-export-tool: False
```

We will review some of those options hereafter.

Communication options

compression

This key configures the desired compression scheme when transferring data over the network. The default value, “auto”, applies heuristics to try and select the best compression scheme for each piece of data.

`default-scheme`

The *communication* scheme used by default. You can override the default (“tcp”) here, but it is recommended to use explicit URIs for the various endpoints instead (for example `tls://` if you want to enable *TLS* communications).

`require-encryption`

Whether to require that all non-local communications be encrypted. If true, then Dask will refuse establishing any clear-text communications (for example over TCP without TLS), forcing you to use a secure transport such as *TLS*.

`tcp-timeout`

The default “timeout” on TCP sockets. If a remote endpoint is unresponsive (at the TCP layer, not at the distributed layer) for at least the specified number of seconds, the communication is considered closed. This helps detect endpoints that have been killed or have disconnected abruptly.

`tls`

This key configures *TLS* communications. Several sub-keys are recognized:

- `ca-file` configures the CA certificate file used to authenticate and authorize all endpoints.
- `ciphers` restricts allowed ciphers on TLS communications.

Each kind of endpoint has a dedicated endpoint sub-key: `scheduler`, `worker` and `client`. Each endpoint sub-key also supports several sub-keys:

- `cert` configures the certificate file for the endpoint.
- `key` configures the private key file for the endpoint.

Scheduler options

`allowed-failures`

The number of retries before a “suspicious” task is considered bad. A task is considered “suspicious” if the worker died while executing it.

`bandwidth`

The estimated network bandwidth, in bytes per second, from worker to worker. This value is used to estimate the time it takes to ship data from one node to another, and balance tasks and data accordingly.

Misc options

`logging`

This key configures the logging settings. There are two possible formats. The simple, recommended format configures the desired verbosity level for each logger. It also sets default values for several loggers such as `distributed` unless explicitly configured.

A more extended format is possible following the `logging` module's [Configuration dictionary schema](#). To enable this extended format, there must be a `version` sub-key as mandated by the schema. The extended format does not set any default values.

Note: Python's `logging` module uses a hierarchical logger tree. For example, configuring the logging level for the distributed logger will also affect its children such as `distributed.scheduler`, unless explicitly overridden.

logging-file-config

As an alternative to the two logging settings formats discussed above, you can specify a logging config file. Its format adheres to the `logging` module's [Configuration file format](#).

Note: The configuration options `logging-file-config` and `logging` are mutually exclusive.

3.22 EC2 Startup Script

First, add your AWS credentials to `~/.aws/credentials` like this:

```
[default]
aws_access_key_id = YOUR_ACCESS_KEY
aws_secret_access_key = YOUR_SECRET_KEY
```

For other ways to manage or troubleshoot credentials, see the [boto3 docs](#).

Now, you can quickly deploy a scheduler and workers on EC2 using the `dask-ec2` quickstart application:

```
pip install dask-ec2
dask-ec2 up --keyname YOUR-AWS-KEY --keypair ~/.ssh/YOUR-AWS-SSH-KEY.pem
```

This provisions a cluster on Amazon's EC2 cloud service, installs Anaconda, and sets up a scheduler and workers. It then prints out instructions on how to connect to the cluster.

3.22.1 Options

The `dask-ec2` startup script comes with the following options for creating a cluster:

```
$ dask-ec2 up --help
Usage: dask-ec2 up [OPTIONS]

Options:
  --keyname TEXT           Keyname on EC2 console [required]
  --keypair PATH           Path to the keypair that matches the keyname,
  ↪ [required]
  --name TEXT              Tag name on EC2
  --region-name TEXT       AWS region [default: us-east-1]
  --ami TEXT               EC2 AMI [default: ami-d05e75b8]
  --username TEXT          User to SSH to the AMI [default: ubuntu]
  --type TEXT              EC2 Instance Type [default: m3.2xlarge]
  --count INTEGER          Number of nodes [default: 4]
  --security-group TEXT    Security Group Name [default: dask-ec2-default]
```

<code>--volume-type TEXT</code>	Root volume type [default: gp2]
<code>--volume-size INTEGER</code>	Root volume size (GB) [default: 500]
<code>--file PATH</code>	File to save the metadata [default: cluster.yaml]
<code>--provision / --no-provision</code>	Provision salt on the nodes [default: True]
<code>--dask / --no-dask</code>	Install Dask.Distributed in the cluster [default: <code>True</code>]
<code>--nprocs INTEGER</code>	Number of processes per worker [default: 1]
<code>-h, --help</code>	Show this message and exit.

3.22.2 Connect

Connection instructions follow successful completion of the `dask-ec2 up` command. The involve the following:

```
dask-ec2 ssh 0      # SSH into head node
ipython           # Start IPython console on head node
```

```
>>> from distributed import Client
>>> c = Client('127.0.0.1:8786')
```

This client now has access to all the cores of your cluster.

3.22.3 Destroy

You can destroy your cluster from your local machine with the `destroy` command:

```
dask-ec2 destroy
```

3.23 Local Cluster

For convenience you can start a local cluster from your Python session.

```
>>> from distributed import Client, LocalCluster
>>> cluster = LocalCluster()
LocalCluster("127.0.0.1:8786", workers=8, ncores=8)
>>> client = Client(cluster)
<Client: scheduler=127.0.0.1:8786 processes=8 cores=8>
```

You can dynamically scale this cluster up and down:

```
>>> worker = cluster.add_worker()
>>> cluster.remove_worker(worker)
```

Alternatively, a `LocalCluster` is made for you automatically if you create an `Client` with no arguments:

```
>>> from distributed import Client
>>> client = Client()
>>> client
<Client: scheduler=127.0.0.1:8786 processes=8 cores=8>
```

3.23.1 API

```
class distributed.deploy.local.LocalCluster(n_workers=None,
                                             threads_per_worker=None, processes=True,
                                             loop=None, start=True, ip=None,
                                             scheduler_port=0, silence_logs=50,
                                             diagnostics_port=8787, services={},
                                             worker_services={}, service_kwargs=None,
                                             **worker_kwargs)
```

Create local Scheduler and Workers

This creates a “cluster” of a scheduler and workers running on the local machine.

Parameters **n_workers: int**

Number of workers to start

processes: bool

Whether to use processes (True) or threads (False). Defaults to True

threads_per_worker: int

Number of threads per each worker

scheduler_port: int

Port of the scheduler. 8786 by default, use 0 to choose a random port

silence_logs: logging level

Level of logs to print out to stdout. `logging.CRITICAL` by default. Use a falsey value like `False` or `None` for no change.

ip: string

IP address on which the scheduler will listen, defaults to only localhost

kwargs: dict

Extra worker arguments, will be passed to the Worker constructor.

service_kwargs: Dict[str, Dict]

Extra keywords to hand to the running services

Examples

```
>>> c = LocalCluster() # Create a local cluster with as many workers as cores
>>> c
LocalCluster("127.0.0.1:8786", workers=8, ncores=8)
```

```
>>> c = Client(c) # connect to local cluster
```

Add a new worker to the cluster >>> `w = c.start_worker(ncores=2)` # doctest: +SKIP

Shut down the extra worker >>> `c.remove_worker(w)` # doctest: +SKIP

Pass extra keyword arguments to Bokeh >>> `LocalCluster(service_kwargs={'bokeh': {'prefix': '/foo'}})` # doctest: +SKIP

close (timeout=20)

Close the cluster

scale_down (*args, **kwargs)

Remove workers from the cluster

Given a list of worker addresses this function should remove those workers from the cluster. This may require tracking which jobs are associated to which worker address.

This can be implemented either as a function or as a Tornado coroutine.

scale_up (*args, **kwargs)

Bring the total count of workers up to n

This function/coroutine should bring the total number of workers up to the number n.

This can be implemented either as a function or as a Tornado coroutine.

start_worker (ncores=0, **kwargs)

Add a new worker to the running cluster

Parameters **port: int (optional)**

Port on which to serve the worker, defaults to 0 or random

ncores: int (optional)

Number of threads to use. Defaults to number of logical cores

Returns The created Worker or Nanny object. Can be discarded.

Examples

```
>>> c = LocalCluster()
>>> c.start_worker(ncores=2)
```

stop_worker (w)

Stop a running worker

Examples

```
>>> c = LocalCluster()
>>> w = c.start_worker(ncores=2)
>>> c.stop_worker(w)
```

3.24 IPython Integration

Dask.distributed integrates with IPython in three ways:

1. You can launch a Dask.distributed cluster from an [IPyParallel](#) cluster
2. You can launch IPython kernels from Dask Workers and Schedulers to assist with debugging
3. They both support the common [concurrent.futures](#) interface

3.24.1 Launch Dask from IPyParallel

IPyParallel is IPython's distributed computing framework that allows you to easily manage many IPython engines on different computers.

An IPyParallel Client can launch a `dask.distributed` Scheduler and Workers on those IPython engines, effectively launching a full `dask.distributed` system.

This is possible with the `Client.become_dask` method:

```
$ ipcluster start
```

```
>>> from ipyparallel import Client
>>> c = Client() # connect to IPyParallel cluster

>>> e = c.become_dask() # start dask on top of IPyParallel
>>> e
<Client: scheduler="127.0.0.1:59683" processes=8 cores=8>
```

3.24.2 Launch IPython within Dask Workers

It is sometimes convenient to inspect the Worker or Scheduler process interactively. Fortunately IPython gives us a way to launch interactive sessions within Python processes. This is available through the following methods:

<code>Client.start_ipython_workers([workers, ...])</code>	Start IPython kernels on workers
<code>Client.start_ipython_scheduler([magic_name, ...])</code>	Start IPython kernel on the scheduler

These methods start IPython kernels running in a separate thread within the specified Worker or Schedulers. These kernels are accessible either through IPython magics or a QT-Console.

Example with IPython Magics

```
>>> e.start_ipython_scheduler()
>>> %scheduler scheduler.processing
{'127.0.0.1:3595': ['inc-1', 'inc-2'],
 '127.0.0.1:53589': ['inc-2', 'add-5']}

>>> info = e.start_ipython_workers()
>>> %remote info['127.0.0.1:3595'] worker.active
{'inc-1', 'inc-2'}
```

Example with qt-console

You can also open up a full interactive IPython qt-console on the scheduler or each of the workers:

```
>>> e.start_ipython_scheduler(qtconsole=True)
>>> e.start_ipython_workers(qtconsole=True)
```


3.25 Joblib Integration

Dask.distributed integrates with [Joblib](#) by providing an alternative cluster-computing backend, alongside Joblib's builtin threading and multiprocessing backends.

[Joblib](#) is a library for simple parallel programming primarily developed and used by the Scikit Learn community. As of version 0.10.0 it contains a plugin mechanism to allow Joblib code to use other parallel frameworks to execute computations. The `dask.distributed` scheduler implements such a plugin in the `distributed.joblib` module and registers it appropriately with Joblib. As a result, any joblib code (including many scikit-learn algorithms) will run on the distributed scheduler if you enclose it in a context manager as follows:

```
import distributed.joblib
from joblib import Parallel, parallel_backend

with parallel_backend('dask.distributed', scheduler_host='HOST:PORT'):
    # normal Joblib code
```

Note that scikit-learn bundles joblib internally, so if you want to specify the joblib backend you'll need to import `parallel_backend` from `scikit-learn` instead of `joblib`. As an example you might distributed a randomized cross validated parameter search as follows.

```
import distributed.joblib
# Scikit-learn bundles joblib, so you need to import from
# `sklearn.externals.joblib` instead of `joblib` directly
from sklearn.externals.joblib import parallel_backend
from sklearn.datasets import load_digits
from sklearn.grid_search import RandomizedSearchCV
from sklearn.svm import SVC
import numpy as np

digits = load_digits()

param_space = {
    'C': np.logspace(-6, 6, 13),
    'gamma': np.logspace(-8, 8, 17),
    'tol': np.logspace(-4, -1, 4),
    'class_weight': [None, 'balanced'],
}

model = SVC(kernel='rbf')
search = RandomizedSearchCV(model, param_space, cv=3, n_iter=50, verbose=10)

with parallel_backend('dask.distributed', scheduler_host='localhost:8786'):
    search.fit(digits.data, digits.target)
```

For large arguments that are used by multiple tasks, it may be more efficient to pre-scatter the data to every worker, rather than serializing it once for every task. This can be done using the `scatter` keyword argument, which takes an iterable of objects to send to each worker.

```
# Serialize the training data only once to each worker
with parallel_backend('dask.distributed', scheduler_host='localhost:8786',
                      scatter=[digits.data, digits.target]):
    search.fit(digits.data, digits.target)
```

3.26 Publish Datasets

A *published dataset* is a named reference to a Dask collection or list of futures that has been published to the cluster. It is available for any client to see and persists beyond the scope of an individual session.

Publishing datasets is useful in the following cases:

- You want to share computations with colleagues
- You want to persist results on the cluster between interactive sessions

3.26.1 Motivating Example

In this example we load a `dask.dataframe` from S3, manipulate it, and then publish the result.

Connect and Load

```
from dask.distributed import Client
client = Client('scheduler-address:8786')

import dask.dataframe as dd
df = dd.read_csv('s3://my-bucket/*.csv')
df2 = df[df.balance < 0]
df2 = client.persist(df2)

>>> df2.head()
   name  balance
0  Alice    -100
1   Bob    -200
2 Charlie    -300
3  Dennis    -400
4  Edith    -500
```

Publish

To share this collection with a colleague we publish it under the name `'negative_accounts'`

```
client.publish_dataset(negative_accounts=df2)
```

Load published dataset from different client

Now any other client can connect to the scheduler and retrieve this published dataset.

```
>>> from dask.distributed import Client
>>> client = Client('scheduler-address:8786')

>>> client.list_datasets()
['negative_accounts']

>>> df = client.get_dataset('negative_accounts')
>>> df.head()
   name  balance
0  Alice    -100
1   Bob    -200
2 Charlie    -300
3  Dennis    -400
4  Edith    -500
```

This allows users to easily share results. It also allows for the persistence of important and commonly used datasets beyond a single session. Published datasets continue to reside in distributed memory even after all clients requesting them have disconnected.

3.26.2 Dictionary interface

Alternatively you can use the `.datasets` mapping on the client to publish, list, get, and delete global datasets.

```
>>> client.datasets['negative_accounts'] = df

>>> list(client.datasets)
['negative_accounts']
>>> df = client.datasets['negative_accounts']
```

This mapping is globally shared among all clients connected to the same scheduler.

3.26.3 Notes

Published collections are not automatically persisted. If you publish an un-persisted collection then others will still be able to get the collection from the scheduler, but operations on that collection will start from scratch. This allows you to publish views on data that do not permanently take up cluster memory but can be surprising if you expect “publishing” to automatically make a computed dataset rapidly available.

Any client can publish or unpublish a dataset.

Publishing too many large datasets can quickly consume a cluster’s RAM.

3.26.4 API

<code>Client.publish_dataset(**kwargs)</code>	Publish named datasets to scheduler
<code>Client.list_datasets(**kwargs)</code>	List named datasets available on the scheduler
<code>Client.get_dataset(name, **kwargs)</code>	Get named dataset from the scheduler
<code>Client.unpublish_dataset(name, **kwargs)</code>	Remove named datasets from scheduler

3.27 Data Streams with Queues

The `Client` methods `scatter`, `map`, and `gather` can consume and produce standard Python `Queue` objects. This is useful for processing continuous streams of data. However, it does not constitute a full streaming data processing pipeline like Storm.

3.27.1 Example

We connect to a local Client.

```
>>> from distributed import Client
>>> client = Client('127.0.0.1:8786')
>>> client
<Client: scheduler=127.0.0.1:8786 workers=1 threads=4>
```

We build a couple of toy data processing functions:

```
from time import sleep
from random import random

def inc(x):
    from random import random
    sleep(random() * 2)
    return x + 1

def double(x):
    from random import random
    sleep(random())
    return 2 * x
```

And we set up an input Queue and map our functions across it.

```
>>> from queue import Queue
>>> input_q = Queue()
>>> remote_q = client.scatter(input_q)
>>> inc_q = client.map(inc, remote_q)
>>> double_q = client.map(double, inc_q)
```

We will fill the `input_q` with local data from some stream, and then `remote_q`, `inc_q` and `double_q` will fill with Future objects as data gets moved around.

We gather the futures from the `double_q` back to a queue holding local data in the local process.

```
>>> result_q = client.gather(double_q)
```

Insert Data Manually

Because we haven't placed any data into any of the queues everything is empty, including the final output, `result_q`.

```
>>> result_q.qsize()
0
```

But when we insert an entry into the `input_q`, it starts to make its way through the pipeline and ends up in the `result_q`.

```
>>> input_q.put(10)
>>> result_q.get()
22
```

Insert data in a separate thread

We simulate a slightly more realistic situation by dumping data into the `input_q` in a separate thread. This simulates what you might get if you were to read from an active data source.

```
def load_data(q):
    i = 0
    while True:
        q.put(i)
        sleep(random())
        i += 1

>>> from threading import Thread
```

```
>>> load_thread = Thread(target=load_data, args=(input_q,))
>>> load_thread.start()

>>> result_q.qsize()
4
>>> result_q.qsize()
9
```

We consume data from the `result_q` and print results to the screen.

```
>>> while True:
...     item = result_q.get()
...     print(item)
2
4
6
8
10
12
...
```

3.27.2 Limitations

- This doesn't do any sort of auto-batching of computations, so ideally you batch your data to take significantly longer than 1ms to run.
- This isn't a proper streaming system. There is no support outside of what you see here. In particular there are no policies for dropping data, joining over time windows, etc..

3.27.3 Extensions

We can extend this small example to more complex systems that have buffers, split queues, merge queues, etc. all by manipulating normal Python Queues.

Here are a couple of useful function to multiplex and merge queues:

```
from queue import Queue
from threading import Thread

def multiplex(n, q, **kwargs):
    """ Convert one queue into several equivalent Queues

    >>> q1, q2, q3 = multiplex(3, in_q)
    """
    out_queues = [Queue(**kwargs) for i in range(n)]
    def f():
        while True:
            x = q.get()
            for out_q in out_queues:
                out_q.put(x)
    t = Thread(target=f)
    t.daemon = True
    t.start()
    return out_queues
```

```
def push(in_q, out_q):
    while True:
        x = in_q.get()
        out_q.put(x)

def merge(*in_qs, **kwargs):
    """ Merge multiple queues together

    >>> out_q = merge(q1, q2, q3)
    """
    out_q = Queue(**kwargs)
    threads = [Thread(target=push, args=(q, out_q)) for q in in_qs]
    for t in threads:
        t.daemon = True
        t.start()
    return out_q
```

With useful functions like these we can build out more sophisticated data processing pipelines that split off and join back together. By creating queues with `maxsize=` we can control buffering and apply back pressure.

3.28 Worker Resources

Access to scarce resources like memory, GPUs, or special hardware may constrain how many of certain tasks can run on particular machines.

For example, we may have a cluster with ten computers, four of which have two GPUs each. We may have a thousand tasks, a hundred of which require a GPU and ten of which require two GPUs at once. In this case we want to balance tasks across the cluster with these resource constraints in mind, allocating GPU-constrained tasks to GPU-enabled workers. Additionally we need to be sure to constrain the number of GPU tasks that run concurrently on any given worker to ensure that we respect the provided limits.

This situation arises not only for GPUs but for many resources like tasks that require a large amount of memory at runtime, special disk access, or access to special hardware. Dask allows you to specify abstract arbitrary resources to constrain how your tasks run on your workers. Dask does not model these resources in any particular way (Dask does not know what a GPU is) and it is up to the user to specify resource availability on workers and resource demands on tasks.

3.28.1 Example

We consider a computation where we load data from many files, process each one with a function that requires a GPU, and then aggregate all of the intermediate results with a task that takes up 70GB of memory.

We operate on a three-node cluster that has two machines with two GPUs each and one machine with 100GB of RAM.

When we set up our cluster we define resources per worker:

```
dask-worker scheduler:8786 --resources "GPU=2"
dask-worker scheduler:8786 --resources "GPU=2"
dask-worker scheduler:8786 --resources "MEMORY=100e9"
```

When we submit tasks to the cluster we specify constraints per task

```
from distributed import Client
client = Client('scheduler:8786')
```

```
data = [client.submit(load, fn) for fn in filenames]
processed = [client.submit(process, d, resources={'GPU': 1}) for d in data]
final = client.submit(aggregate, processed, resources={'MEMORY': 70e9})
```

3.28.2 Resources are Abstract

Resources listed in this way are just abstract quantities. We could equally well have used terms “mem”, “memory”, “bytes” etc. above because, from Dask’s perspective, this is just an abstract term. You can choose any term as long as you are consistent across workers and clients.

It’s worth noting that Dask separately track number of cores and available memory as actual resources and uses these in normal scheduling operation.

3.28.3 Resources with collections

You can also use resources with Dask collections, like arrays, dataframes, and delayed objects. You can pass a dictionary mapping keys of the collection to resource requirements during compute or persist calls.

```
x = dd.read_csv(...)
y = x.map_partitions(func1)
z = y.map_partitions(func2)

z.compute(resources={tuple(y.__dask_keys__()): {'GPU': 1}})
```

In some cases (such as the case above) the keys for `y` may be optimized away before execution. You can avoid that either by requiring them as an explicit output, or by passing the `optimize_graph=False` keyword.

```
z.compute(resources={tuple(y.__dask_keys__()): {'GPU': 1}}, optimize_graph=False)
```

3.29 Submitting Applications

The `dask-submit` cli can be used to submit an application to the dask cluster running remotely. If your code depends on resources that can only be access from cluster running dask, `dask-submit` provides a mechanism to send the script to the cluster for execution from a different machine.

For example, S3 buckets could not be visible from your local machine and hence any attempt to create a dask graph from local machine may not work.

3.29.1 Submitting dask Applications with *dask-submit*

In order to remotely submit scripts to the cluster from a local machine or a CI/CD environment, we need to run a remote client on the same machine as the scheduler:

```
#scheduler machine
dask-remote --port 8788
```

After making sure the `dask-remote` is running, you can submit a script by:

```
#local machine
dask-submit <dask-remote-address>:<port> <script.py>
```

Some of the commonly used arguments are:

- `REMOTE_CLIENT_ADDRESS`: host name where dask-remote client is running
- `FILEPATH`: Local path to file containing dask application

For example, given the following dask application saved in a file called `script.py`:

```
from distributed import Client

def inc(x):
    return x + 1

if __name__ == '__main__':
    client = Client('127.0.0.1:8786')
    x = client.submit(inc, 10)
    print(x.result())
```

We can submit this application from a local machine by running:

```
dask-submit <remote-client-address>:<port> script.py
```

3.30 Launch Tasks from Tasks

Sometimes it is convenient to launch tasks from other tasks. For example you may not know what computations to run until you have the results of some initial computations.

3.30.1 Motivating example

We want to download one piece of data and turn it into a list. Then we want to submit one task for every element of that list. We don't know how long the list will be until we have the data.

So we send off our original `download_and_convert_to_list` function, which downloads the data and converts it to a list on one of our worker machines:

```
future = client.submit(download_and_convert_to_list, uri)
```

But now we need to submit new tasks for individual parts of this data. We have three options.

1. Gather the data back to the local process and then submit new jobs from the local process
2. Gather only enough information about the data back to the local process and submit jobs from the local process
3. Submit a task to the cluster that will submit other tasks directly from that worker

3.30.2 Gather the data locally

If the data is not large then we can bring it back to the client to perform the necessary logic on our local machine:

```
>>> data = future.result()                                # gather data to local process
>>> data                                           # data is a list
[...]

>>> futures = e.map(process_element, data)           # submit new tasks on data
>>> analysis = e.submit(aggregate, futures)          # submit final aggregation task
```


This is straightforward and, if data is small then it is probably the simplest, and therefore correct choice. However, if data is large then we have to choose another option.

3.30.3 Submit tasks from client

We can run small functions on our remote data to determine enough to submit the right kinds of tasks. In the following example we compute the `len` function on data remotely and then break up data into its various elements.

```
>>> n = client.submit(len, data)           # compute number of elements
>>> n = n.result()                         # gather n (small) locally

>>> from operator import getitem
>>> elements = [client.submit(getitem, data, i) for i in range(n)] # split data

>>> futures = client.map(process_element, elements)
>>> analysis = client.submit(aggregate, futures)
```

We compute the length remotely, gather back this very small result, and then use it to submit more tasks to break up the data and process on the cluster. This is more complex because we had to go back and forth a couple of times between the cluster and the local process, but the data moved was very small, and so this only added a few milliseconds to our total processing time.

Extended Example

Computing the Fibonacci numbers creates involves a recursive function. When the function is run, it calls itself using values it computed. We will use this as an example throughout this documentation to illustrate different techniques of submitting tasks from tasks.

```
def fib(n):
    if n < 2:
        return n
    a = fib(n - 1)
    b = fib(n - 2)
    return a + b

print(fib(10)) # prints "55"
```

We will use this example to show the different interfaces.

3.30.4 Submit tasks from worker

Note: this interface is new and experimental. It may be changed without warning in future versions.

We can submit tasks from other tasks. This allows us to make decisions while on worker nodes.

To submit new tasks from a worker that worker must first create a new client object that connects to the scheduler. There are three options for this:

1. `dask.delayed` and `dask.compute`
2. `get_client` with `secede` and `rejoin`
3. `worker_client`

dask.delayed

The Dask delayed behaves as normal: it submits the functions to the graph, optimizes for less bandwidth/computation and gathers the results. For more detail, see [dask.delayed](#).

```
from distributed import Client
from dask import delayed, compute

@delayed
def fib(n):
    if n < 2:
        return n
    # We can use dask.delayed and dask.compute to launch
    # computation from within tasks
    a = fib(n - 1) # these calls are delayed
    b = fib(n - 2)
    a, b = compute(a, b) # execute both in parallel
    return a + b

if __name__ == "__main__":
    # these features require the dask.distributed scheduler
    client = Client()

    result = fib(10).compute()
    print(result) # prints "55"
```

Getting the client on a worker

The `get_client` function provides a normal Client object that gives full access to the dask cluster, including the ability to submit, scatter, and gather results.

```
from distributed import Client, get_client, secede, rejoin

def fib(n):
    if n < 2:
        return n
    client = get_client()
    a_future = client.submit(fib, n - 1)
    b_future = client.submit(fib, n - 2)
    a, b = client.gather([a_future, b_future])
    return a + b

if __name__ == "__main__":
    client = Client()
    future = client.submit(fib, 10)
    result = future.result()
    print(result) # prints "55"
```

However, this can deadlock the scheduler if too many tasks request jobs at once. Each task does not communicate to the scheduler that they are waiting on results and are free to compute other tasks. This can deadlock the cluster if every scheduling slot is running a task and they all request more tasks.

To avoid this deadlocking issue we can use `secede` and `rejoin`. These functions will remove and rejoin the current task from the cluster respectively.

```
def fib(n):
    if n < 2:
        return n
    client = get_client()
    a_future = client.submit(fib, n - 1)
    b_future = client.submit(fib, n - 2)
    secede()
    a, b = client.gather([a_future, b_future])
    rejoin()
    return a + b
```

Connection with context manager

The `worker_client` function performs the same task as `get_client`, but is implemented as a context manager. Using `worker_client` as a context manager ensures proper cleanup on the worker.

```
from dask.distributed import worker_client

def fib(n):
    if n < 2:
        return n
    with worker_client() as client:
        a_future = client.submit(fib, n - 1)
        b_future = client.submit(fib, n - 2)
        a, b = client.gather([a_future, b_future])
    return a + b

if __name__ == "__main__":
    client = Client()
    future = client.submit(fib, 10)
    result = future.result()
    print(result)  # prints "55"
```

Tasks that invoke `worker_client` are conservatively assumed to be *long running*. They can take a long time, waiting for other tasks to finish, gathering results, etc. In order to avoid having them take up processing slots the following actions occur whenever a task invokes `worker_client`.

1. The thread on the worker running this function *secedes* from the thread pool and goes off on its own. This allows the thread pool to populate that slot with a new thread and continue processing additional tasks without counting this long running task against its normal quota.
2. The Worker sends a message back to the scheduler temporarily increasing its allowed number of tasks by one. This likewise lets the scheduler allocate more tasks to this worker, not counting this long running task against it.

Establishing a connection to the scheduler takes a few milliseconds and so it is wise for computations that use this feature to be at least a few times longer in duration than this.

3.31 TLS/SSL

Currently dask distributed has experimental support for TLS/SSL communication, providing mutual authentication and encryption of communications between cluster endpoints (Clients, Schedulers and Workers).

TLS is enabled by using a `tls` address such as `tls://` (the default being `tcp`, which sends data unauthenticated and unencrypted). In TLS mode, all cluster endpoints must present a valid TLS certificate signed by a given Certificate

Authority (CA). It is generally recommended to use a custom CA for your organization, as it will allow signing certificates for internal hostnames or IP addresses.

3.31.1 Parameters

When using TLS, one has to provide additional parameters:

- a *CA certificate(s) file*, which allows TLS to decide whether an endpoint's certificate has been signed by the correct authority;
- a *certificate file* for each endpoint, which is presented to other endpoints so as to achieve mutual authentication;
- a *private key file*, which is the cryptographic means to prove to other endpoints that you are the authorized user of a given certificate.

Note: As per OpenSSL's requirements, all those files should be in PEM format. Also, it is allowed to concatenate the certificate and private key into a single file (you can then just specify the *certificate* parameter and leave the *private key* parameter absent).

It is up to you whether each endpoint uses a different certificate and private key, or whether all endpoints share the same, or whether each endpoint kind (Client, Scheduler, Worker) gets its own certificate / key pair. Unless you have extraordinary requirements, however, the CA certificate should probably be the same for all endpoints.

One can also pass additional parameters:

- a set of allowed *ciphers*, if you have strong requirements as to which algorithms are considered secure; this setting's value should be an [OpenSSL cipher string](#);
- whether to *require encryption*, to avoid using plain TCP communications by mistake.

All those parameters can be passed in several ways:

- through the Dask *configuration file*;
- if using the command line, through options to `dask-scheduler` and `dask-worker`;
- if using the API, through a `Security` object. For example, here is how you might configure a `Security` object for client use:

```
from distributed import Client
from distributed.security import Security

sec = Security(tls_ca_file='cluster_ca.pem',
              tls_client_cert='cli_cert.pem',
              tls_client_key='cli_key.pem',
              require_encryption=True)

client = Client(..., security=sec)
```

3.31.2 Security policy

Dask always verifies the certificate presented by a remote endpoint against the configured CA certificate(s). Certificates are verified for both “client” and “server” endpoints (in the TCP sense), ensuring the endpoints are mutually authenticated. The hostname or IP address for which a certificate has been issued is not checked; this should not be an issue if you are using your own internal Certificate Authority.

It is not possible to disable certificate verification, as it would render the communications vulnerable to Man-in-the-Middle attacks.

3.31.3 Performance implications

Encryption is fast on recent CPUs, most of which have hardware acceleration for AES-based encryption. AES is normally selected by the TLS layer unless you have forced the `ciphers` parameter to something else. However, encryption may still have a non-negligible overhead if you are transferring very large data over very high speed network links.

See also:

A [study of AES-NI acceleration](#) shows recent x86 CPUs can AES-encrypt more than 1 GB per second on each CPU core.

3.32 Web Interface

Information about the current state of the network helps to track progress, identify performance issues, and debug failures.

Dask.distributed includes a web interface to help deliver this information over a normal web page in real time. This web interface is launched by default wherever the scheduler is launched if the scheduler machine has [Bokeh](#) installed (`conda install bokeh -c bokeh`).

3.32.1 List of Servers

There are a few sets of diagnostic pages served at different ports:

- Main Scheduler pages at `http://scheduler-address:8787`. These pages, particularly the `/status` page are the main page that most people associate with Dask. These pages are served from a separate standalone Bokeh server application running in a separate process.
- Debug Scheduler pages at `http://scheduler-address:8788`. These pages have more detailed diagnostic information about the scheduler. They are more often used by developers than by users, but may still be of interest to the performance-conscious. These pages run from inside the scheduler process, and so compete for resources with the main scheduler.
- Debug Worker pages for each worker at `http://worker-address:8789`. These pages have detailed diagnostic information about the worker. Like the diagnostic scheduler pages they are of more utility to developers or to people looking to understand the performance of their underlying cluster. If port 8789 is unavailable (for example it is in use by another worker) then a random port is chosen. A list of all ports can be obtained from looking at the service ports for each worker in the result of calling `client.scheduler_info()`

The rest of this document will be about the main pages at `http://scheduler-address:8787`.

The available pages are `http://scheduler-address:8787/<page>/` where `<page>` is one of

- `status`: a stream of recently run tasks, progress bars, resource use
- `tasks`: a larger stream of the last 100k tasks
- `workers`: basic information about workers and their current load

3.32.2 Plots

Example Computation

The following plots show a trace of the following computation:

```
from distributed import Client
from time import sleep
import random

def inc(x):
    sleep(random.random() / 10)
    return x + 1

def dec(x):
    sleep(random.random() / 10)
    return x - 1

def add(x, y):
    sleep(random.random() / 10)
    return x + y

client = Client('127.0.0.1:8786')

incs = client.map(inc, range(100))
decs = client.map(dec, range(100))
adds = client.map(add, incs, decs)
total = client.submit(sum, adds)

del incs, decs, adds
total.result()
```

Progress

The interface shows the progress of the various computations as well as the exact number completed.

Each bar is assigned a color according to the function being run. Each bar has a few components. On the left the lighter shade is the number of tasks that have both completed and have been released from memory. The darker shade to the right corresponds to the tasks that are completed and whose data still reside in memory. If errors occur then they appear as a black colored block to the right.

Typical computations may involve dozens of kinds of functions. We handle this visually with the following approaches:

1. Functions are ordered by the number of total tasks
2. The colors are assigned in a round-robin fashion from a standard palette
3. The progress bars shrink horizontally to make space for more functions
4. Only the largest functions (in terms of number of tasks) are displayed

Counts of tasks processing, waiting for dependencies, processing, etc.. are displayed in the title bar.

Memory Use

The interface shows the relative memory use of each function with a horizontal bar sorted by function name.

The title shows the number of total bytes in use. Hovering over any bar tells you the specific function and how many bytes its results are actively taking up in memory. This does not count data that has been released.

Task Stream

The task stream plot shows when tasks complete on which workers. Worker cores are on the y-axis and time is on the x-axis. As a worker completes a task its start and end times are recorded and a rectangle is added to this plot accordingly.

If data transfer occurs between workers a *red* bar appears preceding the task bar showing the duration of the transfer. If an error occurs than a *black* bar replaces the normal color. This plot show the last 1000 tasks. It resets if there is a delay greater than 10 seconds.

For a full history of the last 100,000 tasks see the `tasks/` page.

Resources

The resources plot show the average CPU and Memory use over time as well as average network traffic. More detailed information on a per-worker basis is available in the `workers/` page.

3.32.3 Connecting to Web Interface

Default

By default, `dask-scheduler` prints out the address of the web interface:

```
INFO - Bokeh UI at:  http://10.129.39.91:8787/status
...
INFO - Starting Bokeh server on port 8787 with applications at paths ['/status', '/
↪tasks']
```

The machine hosting the scheduler runs an HTTP server serving at that address.

3.32.4 Troubleshooting

Some clusters restrict the ports that are visible to the outside world. These ports may include the default port for the web interface, 8787. There are a few ways to handle this:

1. Open port 8787 to the outside world. Often this involves asking your cluster administrator.
2. Use a different port that is publicly accessible using the `--bokeh-port PORT` option on the `dask-scheduler` command.
3. Use fancier techniques, like [Port Forwarding](#)

Running distributed on a remote machine can cause issues with viewing the web UI – this depends on the remote machines network configuration.

Port Forwarding

If you have SSH access then one way to gain access to a blocked port is through SSH port forwarding. A typical use case looks like the following:

```
local$ ssh -L 8000:localhost:8787 user@remote
remote$ dask-scheduler # now, the web UI is visible at localhost:8000
remote$ # continue to set up dask if needed -- add workers, etc
```

It is then possible to go to `localhost:8000` and see Dask Web UI. This same approach is not specific to `dask.distributed`, but can be used by any service that operates over a network, such as Jupyter notebooks. For example, if we chose to do this we could forward port 8888 (the default Jupyter port) to port 8001 with `ssh -L 8001:localhost:8888 user@remote`.

3.33 Changelog

3.33.1 1.20.2 - 2017-12-07

- Clear deque handlers after each test (GH#1586) Antoine Pitrou
- Handle deserialization in `FutureState.set_error` (GH#1592) Matthew Rocklin
- Add process leak checker to tests (GH#1596) Antoine Pitrou
- Customize process title for subprocess (GH#1590) Antoine Pitrou
- Make linting a separate CI job (GH#1599) Antoine Pitrou
- Fix error from `get_client()` with no global client (GH#1595) Daniel Li
- Remove `Worker.host_health`, correct `WorkerTable` metrics (GH#1600) Matthew Rocklin
- Don't mark tasks as suspicious when `retire_workers` called. Addresses (GH#1607) **'Russ Bubley'**
- Do not include processing workers in `workers_to_close` (GH#1609) **'Russ Bubley'**
- Disallow simultaneous scale up and down in `Adaptive` (GH#1608) **'Russ Bubley'**
- Parse bytestrings in `--memory-limit` (GH#1615) Matthew Rocklin
- Use environment variable for scheduler address if present (GH#1610) Matthew Rocklin
- Fix deprecation warning from `logger.warn` (GH#1616) Brett Naul

3.33.2 1.20.1 - 2017-11-26

- Wrap `import ssl` statements with `try-except` block for ssl-crippled environments, (GH#1570) Xander Johnson
- Support zero `memory-limit` in `Nanny` (GH#1571) Matthew Rocklin
- Avoid `PeriodicCallback` double starts (GH#1573) Matthew Rocklin
- Add disposable workspace facility (GH#1543) Antoine Pitrou
- Use `format_time` in `task_stream` plots (GH#1575) Matthew Rocklin

- Avoid delayed finalize calls in compute (GH#1577) Matthew Rocklin
- Doc fix about secede (GH#1583) Scott Sievert
- Add tracemalloc option when tracking test leaks (GH#1585) Antoine Pitrou
- Add JSON routes to Bokeh server (GH#1584) Matthew Rocklin
- Handle exceptions cleanly in Variables and Queues (GH#1580) Matthew Rocklin

3.33.3 1.20.0 - 2017-11-17

- Drop use of pandas.msgpack (GH#1473) Matthew Rocklin
- Add methods to get/set scheduler metadata Matthew Rocklin
- Add distributed lock Matthew Rocklin
- Add reschedule exception for worker tasks Matthew Rocklin
- Fix `nbytes()` for `bytearrays` Matthew Rocklin
- Capture scheduler and worker logs Matthew Rocklin
- Garbage collect after data eviction on high worker memory usage (GH#1488) Olivier Grisel
- Add scheduler HTML routes to bokeh server (GH#1478) (GH#1514) Matthew Rocklin
- Add pytest plugin to test for resource leaks (GH#1499) Antoine Pitrou
- Improve documentation for scheduler states (GH#1498) Antoine Pitrou
- Correct `warn_if_longer` timeout in `ThrottledGC` (GH#1496) Fabian Keller
- Catch race condition in `as_completed` on cancelled futures (GH#1507) Matthew Rocklin
- Transactional work stealing (GH#1489) (GH#1528) Matthew Rocklin
- Avoid forserver in PyPy (GH#1509) Matthew Rocklin
- Add dict access to get/set datasets (GH#1508) Mike DePalatis
- Support Tornado 5 (GH#1509) (GH#1512) (GH#1518) (GH#1534) Antoine Pitrou
- Move `thread_state` in Dask (GH#1523) Jim Crist
- Use new Dask collections interface (GH#1513) Matthew Rocklin
- Add nanny flag to `dask-mpi` Matthew Rocklin
- Remove JSON-based HTTP servers Matthew Rocklin
- Avoid doing I/O in `repr/str` (GH#1536) Matthew Rocklin
- Fix URL for MPI4Py project (GH#1546) Ian Hopkinson
- Allow automatic retries of a failed task (GH#1524) Antoine Pitrou
- Clean and accelerate tests (GH#1548) (GH#1549) (GH#1552) (GH#1553) (GH#1560) (GH#1564) Antoine Pitrou
- Move HDFS functionality to the `hdfs3` library (GH#1561) Jim Crist
- Fix bug when using events page with no events (GH#1562) @rbubley
- Improve diagnostic naming of tasks within tuples (GH#1566) Kelvyn Yang

3.33.4 1.19.3 - 2017-10-16

- Handle None case in profile.identity (GH#1456)
- Asyncio rewrite (GH#1458)
- Add rejoin function partner to secede (GH#1462)
- Nested compute (GH#1465)
- Use LooseVersion when comparing Bokeh versions (GH#1470)

3.33.5 1.19.2 - 2017-10-06

- as_completed doesn't block on cancelled futures (GH#1436)
- Notify waiting threads/coroutines on cancellation (GH#1438)
- Set Future(inform=True) as default (GH#1437)
- Rename Scheduler.transition_story to story (GH#1445)
- Future uses default client by default (GH#1449)
- Add keys= keyword to Client.call_stack (GH#1446)
- Add get_current_task to worker (GH#1444)
- Ensure that Client remains asynchronuous before ioloop starts (GH#1452)
- Remove “click for worker page” in bokeh plot (GH#1453)
- Add Client.current() (GH#1450)
- Clean handling of restart timeouts (GH#1442)

3.33.6 1.19.1 - September 25th, 2017

- Fix tool issues with TaskStream plot (GH#1425)
- Move profile module to top level (GH#1423)

3.33.7 1.19.0 - September 24th, 2017

- Avoid storing messages in message log (GH#1361)
- fileConfig does not disable existing loggers (GH#1380)
- Offload upload_file disk I/O to separate thread (GH#1383)
- Add missing SSLContext (GH#1385)
- Collect worker thread information from sys._current_frames (GH#1387)
- Add nanny timeout (GH#1395)
- Restart worker if memory use goes above 95% (GH#1397)
- Track workers memory use with psutil (GH#1398)
- Track scheduler delay times in workers (GH#1400)
- Add time slider to profile plot (GH#1403)

- Change memory-limit keyword to refer to maximum number of bytes ([GH#1405](#))
- Add `cancel(force=)` keyword ([GH#1408](#))

3.33.8 1.18.2 - September 2nd, 2017

- Silently pass on cancelled futures in `as_completed` ([GH#1366](#))
- Fix unicode keys error in Python 2 ([GH#1370](#))
- Support numeric worker names
- Add `dask-mpi` executable ([GH#1367](#))

3.33.9 1.18.1 - August 25th, 2017

- Clean up forgotten keys in fire-and-forget workloads ([GH#1250](#))
- Handle missing extensions ([GH#1263](#))
- Allow `recreate_exception` on persisted collections ([GH#1253](#))
- Add `asynchronous=` keyword to blocking client methods ([GH#1272](#))
- Restrict to horizontal panning in bokeh plots ([GH#1274](#))
- Rename `client.shutdown` to `client.close` ([GH#1275](#))
- Avoid blocking on event loop ([GH#1270](#))
- Avoid cloudpickle errors for `Client.get_versions` ([GH#1279](#))
- Yield on Tornado `IOStream.write` futures ([GH#1289](#))
- Assume async behavior if inside a sync statement ([GH#1284](#))
- Avoid error messages on closing ([GH#1297](#)), ([GH#1296](#)) ([GH#1318](#)) ([GH#1319](#))
- Add `timeout=` keyword to `get_client` ([GH#1290](#))
- Respect timeouts when restarting ([GH#1304](#))
- Clean file descriptor and memory leaks in tests ([GH#1317](#))
- Deprecate `Executor` ([GH#1302](#))
- Add `timeout` to `ThreadPoolExecutor.shutdown` ([GH#1330](#))
- Clean up `AsyncProcess` handling ([GH#1324](#))
- Allow unicode keys in Python 2 scheduler ([GH#1328](#))
- Avoid leaking stolen data ([GH#1326](#))
- Improve error handling on failed nanny starts ([GH#1337](#)), ([GH#1331](#))
- Make `Adaptive` more flexible
- Support `--contact-address` and `--listen-address` in worker ([GH#1278](#))
- Remove old `dworker`, `dscheduler` executables ([GH#1355](#))
- Exit workers if nanny process fails ([GH#1345](#))
- Auto pep8 and flake ([GH#1353](#))

3.33.10 1.18.0 - July 8th, 2017

- Multi-threading safety (GH#1191), (GH#1228), (GH#1229)
- Improve handling of byte counting (GH#1198) (GH#1224)
- Add `get_client`, `secede` functions, refactor worker-client relationship (GH#1201)
- Allow logging configuraiton using `logging.dictConfig()` (GH#1206) (GH#1211)
- Offload serialization and deserialization to separate thread (GH#1218)
- Support fire-and-forget tasks (GH#1221)
- Support bytestrings as keys (for Julia) (GH#1234)
- Resolve testing corner-cases (GH#1236), (GH#1237), (GH#1240), (GH#1241), (GH#1242), (GH#1244)
- Automatic use of `scatter/gather(direct=True)` in more cases (GH#1239)

3.33.11 1.17.1 - June 14th, 2017

- Remove Python 3.4 testing from travis-ci (GH#1157)
- Remove ZMQ Support (GH#1160)
- Fix `memoryview` `nbytes` issue in Python 2.7 (GH#1165)
- Re-enable counters (GH#1168)
- Improve `scheduler.restart` (GH#1175)

3.33.12 1.17.0 - June 9th, 2017

- Reevaluate worker occupancy periodically during scheduler downtime (GH#1038) (GH#1101)
- Add `AioClient` `asyncio`-compatible client API (GH#1029) (GH#1092) (GH#1099)
- Update Keras serializer (GH#1067)
- Support TLS/SSL connections for security (GH#866) (GH#1034)
- Always create new worker directory when passed `--local-directory` (GH#1079)
- Support pre-scattering data when using `jupyterlab` frontend (GH#1022)
- Make workers more robust to failure of `sizeof` function (GH#1108) and writing to disk (GH#1096)
- Add `is_empty` and `update` methods to `as_completed` (GH#1113)
- Remove `_get` coroutine and replace with `get(..., sync=False)` (GH#1109)
- Improve API compatibility with `async/await` syntax (GH#1115) (GH#1124)
- Add distributed `Queues` (GH#1117) and shared `Variables` (GH#1128) to enable inter-client coordination
- Support direct client-to-worker scattering and gathering (GH#1130) as well as performance enhancements when scattering data
- Style improvements for bokeh web dashboards (GH#1126) (GH#1141) as well as a removal of the external bokeh process
- HTML reprs for `Future` and `Client` objects (GH#1136)

- Support nested collections in `client.compute` (GH#1144)
- Use normal client API in asynchronous mode (GH#1152)
- Remove old `distributed.collections` submodule (GH#1153)

3.33.13 1.16.3 - May 5th, 2017

- Add bokeh template files to MANIFEST (GH#1063)
- Don't set `worker_client.get` as default `get` (GH#1061)
- Clean up logging on `Client().shutdown()` (GH#1055)

3.33.14 1.16.2 - May 3rd, 2017

- Support `async` with `Client` syntax (GH#1053)
- Use internal bokeh server for default diagnostics server (GH#1047)
- Improve styling of bokeh plots when empty (GH#1046) (GH#1037)
- Support efficient serialization for sparse arrays (GH#1040)
- Prioritize newly arrived work in worker (GH#1035)
- Prescatter data with joblib backend (GH#1022)
- Make `client.restart` more robust to worker failure (GH#1018)
- Support preloading a module or script in `dask-worker` or `dask-scheduler` processes (GH#1016)
- Specify network interface in command line interface (GH#1007)
- `Client.scatter` supports a single element (GH#1003)
- Use `blosc` compression on all memoryviews passing through comms (GH#998)
- Add `concurrent.futures-compatible` `Executor` (GH#997)
- Add `as_completed.batches` method and return results (GH#994) (GH#971)
- Allow `worker_clients` to optionally stay within the thread pool (GH#993)
- Add bytes-stored and tasks-processing diagnostic histograms (GH#990)
- `Run` supports non-msgpack-serializable results (GH#965)

3.33.15 1.16.1 - March 22nd, 2017

- Use `inproc` transport in `LocalCluster` (GH#919)
- Add structured and queryable cluster event logs (GH#922)
- Use connection pool for inter-worker communication (GH#935)
- Robustly shut down spawned worker processes at shutdown (GH#928)
- Worker death timeout (GH#940)
- More visual reporting of exceptions in progressbar (GH#941)
- Render disk and serialization events to task stream visual (GH#943)

- Support async for / await protocol ([GH#952](#))
- Ensure random generators are re-seeded in worker processes ([GH#953](#))
- Upload sourcecode as zip module ([GH#886](#))
- Replay remote exceptions in local process ([GH#894](#))

3.33.16 1.16.0 - February 24th, 2017

- First come first served priorities on client submissions ([GH#840](#))
- Can specify Bokeh internal ports ([GH#850](#))
- Allow stolen tasks to return from either worker ([GH#853](#)), ([GH#875](#))
- Add worker resource constraints during execution ([GH#857](#))
- Send small data through Channels ([GH#858](#))
- Better estimates for SciPy sparse matrix memory costs ([GH#863](#))
- Avoid stealing long running tasks ([GH#873](#))
- Maintain fortran ordering of NumPy arrays ([GH#876](#))
- Add `--scheduler-file` keyword to dask-scheduler ([GH#877](#))
- Add serializer for Keras models ([GH#878](#))
- Support uploading modules from zip files ([GH#886](#))
- Improve titles of Bokeh dashboards ([GH#895](#))

3.33.17 1.15.2 - January 27th, 2017

- Fix a bug where arrays with large dtypes or shapes were being improperly compressed ([GH#830](#) [GH#832](#) [GH#833](#))
- Extend `as_completed` to accept new futures during iteration ([GH#829](#))
- Add `--nohost` keyword to dask-ssh startup utility ([GH#827](#))
- Support scheduler shutdown of remote workers, useful for adaptive clusters (:pr: 811 [GH#816](#) [GH#821](#))
- Add `Client.run_on_scheduler` method for running debug functions on the scheduler ([GH#808](#))

3.33.18 1.15.1 - January 11th, 2017

- Make compatible with Bokeh 0.12.4 ([GH#803](#))
- Avoid compressing arrays if not helpful ([GH#777](#))
- Optimize inter-worker data transfer ([GH#770](#)) ([GH#790](#))
- Add `-local-directory` keyword to worker ([GH#788](#))
- Enable workers to arrive to the cluster with their own data. Useful if a worker leaves and comes back ([GH#785](#))
- Resolve thread safety bug when using `local_client` ([GH#802](#))
- Resolve scheduling issues in worker ([GH#804](#))

3.33.19 1.15.0 - January 2nd, 2017

- Major Worker refactor ([GH#704](#))
- Major Scheduler refactor ([GH#717](#)) ([GH#722](#)) ([GH#724](#)) ([GH#742](#)) ([GH#743](#))
- Add `check` (default is `False`) option to `Client.get_versions` to raise if the versions don't match on client, scheduler & workers ([GH#664](#))
- `Future.add_done_callback` executes in separate thread ([GH#656](#))
- Clean up numpy serialization ([GH#670](#))
- Support serialization of Tornado v4.5 coroutines ([GH#673](#))
- Use CPickle instead of Pickle in Python 2 ([GH#684](#))
- Use Forkserver rather than Fork on Unix in Python 3 ([GH#687](#))
- Support abstract resources for per-task constraints ([GH#694](#)) ([GH#720](#)) ([GH#737](#))
- Add TCP timeouts ([GH#697](#))
- Add embedded Bokeh server to workers ([GH#709](#)) ([GH#713](#)) ([GH#738](#))
- Add embedded Bokeh server to scheduler ([GH#724](#)) ([GH#736](#)) ([GH#738](#))
- Add more precise timers for Windows ([GH#713](#))
- Add Versioneer ([GH#715](#))
- Support inter-client channels ([GH#729](#)) ([GH#749](#))
- Scheduler Performance improvements ([GH#740](#)) ([GH#760](#))
- Improve load balancing and work stealing ([GH#747](#)) ([GH#754](#)) ([GH#757](#))
- Run Tornado coroutines on workers
- Avoid slow `sizeof` call on Pandas dataframes ([GH#758](#))

3.33.20 1.14.3 - November 13th, 2016

- Remove custom Bokeh export tool that implicitly relied on nodejs ([GH#655](#))
- Clean up scheduler logging ([GH#657](#))

3.33.21 1.14.2 - November 11th, 2016

- Support more numpy dtypes in custom serialization, ([GH#627](#)), ([GH#630](#)), ([GH#636](#))
- Update Bokeh plots ([GH#628](#))
- Improve spill to disk heuristics ([GH#633](#))
- Add Export tool to Task Stream plot
- Reverse frame order in loads for very many frames ([GH#651](#))
- Add timeout when waiting on write ([GH#653](#))

3.33.22 1.14.0 - November 3rd, 2016

- Add `Client.get_versions()` function to return software and package information from the scheduler, workers, and client ([GH#595](#))
- Improved windows support ([GH#577](#)) ([GH#590](#)) ([GH#583](#)) ([GH#597](#))
- Clean up rpc objects explicitly ([GH#584](#))
- Normalize collections against known futures ([GH#587](#))
- Add `key=` keyword to `map` to specify keynames ([GH#589](#))
- Custom data serialization ([GH#606](#))
- Refactor the web interface ([GH#608](#)) ([GH#615](#)) ([GH#621](#))
- Allow user-supplied Executor in Worker ([GH#609](#))
- Pass Worker kwargs through LocalCluster

3.33.23 1.13.3 - October 15th, 2016

- Schedulers can retire workers cleanly
- Add `Future.add_done_callback` for `concurrent.futures` compatibility
- Update web interface to be consistent with Bokeh 0.12.3
- Close streams explicitly, avoiding race conditions and supporting more robust restarts on Windows.
- Improved shuffled performance for `dask.dataframe`
- Add adaptive allocation cluster manager
- Reduce administrative overhead when dealing with many workers
- `dask-ssh --log-directory .` no longer errors
- Microperformance tuning for the scheduler

3.33.24 1.13.2

- Revert `dask_worker` to use `fork` rather than `subprocess` by default
- Scatter retains type information
- Bokeh always uses `subprocess` rather than `spawn`

3.33.25 1.13.1

- Fix critical Windows error with `dask_worker` executable

3.33.26 1.13.0

- Rename Executor to Client ([GH#492](#))
- Add `--memory-limit` option to `dask-worker`, enabling spill-to-disk behavior when running out of memory ([GH#485](#))

- Add `--pid-file` option to `dask-worker` and `--dask-scheduler` (GH#496)
- Add `upload_environment` function to distribute conda environments. This is experimental, undocumented, and may change without notice. (GH#494)
- Add `workers=` keyword argument to `Client.compute` and `Client.persist`, supporting location-restricted workloads with Dask collections (GH#484)
- Add `upload_environment` function to distribute conda environments. This is experimental, undocumented, and may change without notice. (GH#494)
 - Add optional `dask_worker=` keyword to `client.run` functions that gets provided the worker or nanny object
 - Add `nanny=False` keyword to `Client.run`, allowing for the execution of arbitrary functions on the nannies as well as normal workers

3.33.27 1.12.2

This release adds some new features and removes dead code

- Publish and share datasets on the scheduler between many clients (GH#453). See *Publish Datasets*.
- Launch tasks from other tasks (experimental) (GH#471). See *Launch Tasks from Tasks*.
- Remove unused code, notably the `Center` object and older client functions (GH#478)
- `Executor()` and `LocalCluster()` is now robust to Bokeh's absence (GH#481)
- Removed `s3fs` and `boto3` from requirements. These have moved to Dask.

3.33.28 1.12.1

This release is largely a bugfix release, recovering from the previous large refactor.

- **Fixes from previous refactor**
 - Ensure idempotence across clients
 - Stress test losing scattered data permanently
- **IPython fixes**
 - Add `start_ipython_scheduler` method to `Executor`
 - Add `%remote` magic for workers
 - Clean up code and tests
- Pool connects to maintain reuse and reduce number of open file handles
- Re-implement work stealing algorithm
- Support cancellation of tuple keys, such as occur in `dask.arrays`
- Start synchronizing against worker data that may be superfluous
- **Improve bokeh plots styling**
 - Add memory plot tracking number of bytes
 - Make the progress bars more compact and align colors
 - Add `workers/` page with workers table, stacks/processing plot, and memory

- Add this release notes document

3.33.29 1.12.0

This release was largely a refactoring release. Internals were changed significantly without many new features.

- Major refactor of the scheduler to use transitions system
- Tweak protocol to traverse down complex messages in search of large bytestrings
- Add dask-submit and dask-remote
- Refactor HDFS writing to align with changes in the dask library
- Executor reconnects to scheduler on broken connection or failed scheduler
- Support sklearn.external.joblib as well as normal joblib

3.34 Communications

Workers, the Scheduler, and Clients communicate by sending each other Python objects (such as *Protocol* messages or user data). The communication layer handles appropriate encoding and shipping of those Python objects between the distributed endpoints. The communication layer is able to select between different transport implementations, depending on user choice or (possibly) internal optimizations.

The communication layer lives in the `distributed.comm` package.

3.34.1 Addresses

Communication addresses are canonically represented as URIs, such as `tcp://127.0.0.1:1234`. For compatibility with existing code, if the URI scheme is omitted, a default scheme of `tcp` is assumed (so `127.0.0.1:456` is really the same as `tcp://127.0.0.1:456`). The default scheme may change in the future.

The following schemes are currently implemented in the `distributed` source tree:

- `tcp` is the main transport; it uses TCP sockets and allows for IPv4 and IPv6 addresses.
- `tls` is a secure transport using the well-known *TLS protocol* over TCP sockets. Using it requires specifying keys and certificates as outlined in *TLS/SSL*.
- `inproc` is an in-process transport using simple object queues; it eliminates serialization and I/O overhead, providing almost zero-cost communication between endpoints as long as they are situated in the same process.

Some URIs may be valid for listening but not for connecting. For example, the URI `tcp://` will listen on all IPv4 and IPv6 addresses and on an arbitrary port, but you cannot connect to that address.

Higher-level APIs in `distributed` may accept other address formats for convenience or compatibility, for example a `(host, port)` pair. However, the abstract communications layer always deals with URIs.

Functions

There are a number of top-level functions in `distributed.comm` to help deal with addresses:

`distributed.comm.parse_address(addr, strict=False)`
Split address into its scheme and scheme-dependent location string.

```
>>> parse_address('tcp://127.0.0.1')
('tcp', '127.0.0.1')
```

If strict is set to true the address must have a scheme.

`distributed.comm.unparse_address(scheme, loc)`
Undo `parse_address()`.

```
>>> unparse_address('tcp', '127.0.0.1')
'tcp://127.0.0.1'
```

`distributed.comm.normalize_address(addr)`
Canonicalize address, adding a default scheme if necessary.

```
>>> normalize_address('tls://[::1]')
'tls://[::1]'
>>> normalize_address('[::1]')
'tcp://[::1]'
```

`distributed.comm.resolve_address(addr)`
Apply scheme-specific address resolution to *addr*, replacing all symbolic references with concrete location specifiers.

In practice, this can mean hostnames are resolved to IP addresses.

```
>>> resolve_address('tcp://localhost:8786')
'tcp://127.0.0.1:8786'
```

`distributed.comm.get_address_host(addr)`
Return a hostname / IP address identifying the machine this address is located on.
In contrast to `get_address_host_port()`, this function should always succeed for well-formed addresses.

```
>>> get_address_host('tcp://1.2.3.4:80')
'1.2.3.4'
```

3.34.2 Communications API

The basic unit for dealing with established communications is the `Comm` object:

class `distributed.comm.Comm`

A message-oriented communication object, representing an established communication channel. There should be only one reader and one writer at a time: to manage current communications, even with a single peer, you must create distinct `Comm` objects.

Messages are arbitrary Python objects. Concrete implementations of this class can implement different serialization mechanisms depending on the underlying transport's characteristics.

abort()

Close the communication immediately and abruptly. Useful in destructors or generators' `finally` blocks.

close()

Close the communication cleanly. This will attempt to flush outgoing buffers before actually closing the underlying transport.

This method is a coroutine.

closed()

Return whether the stream is closed.

extra_info

Return backend-specific information about the communication, as a dict. Typically, this is information which is initialized when the communication is established and doesn't vary afterwards.

local_address

The local address. For logging and debugging purposes only.

peer_address

The peer's address. For logging and debugging purposes only.

read()

Read and return a message (a Python object).

This method is a coroutine.

write(msg)

Write a message (a Python object).

This method is a coroutine.

You don't create `Comm` objects directly: you either `listen` for incoming communications, or `connect` to a peer listening for connections:

`distributed.comm.connect(*args, **kwargs)`

Connect to the given address (a URI such as `tcp://127.0.0.1:1234`) and yield a `Comm` object. If the connection attempt fails, it is retried until the *timeout* is expired.

`distributed.comm.listen(addr, handle_comm, deserialize=True, connection_args=None)`

Create a listener object with the given parameters. When its `start()` method is called, the listener will listen on the given address (a URI such as `tcp://0.0.0.0`) and call *handle_comm* with a `Comm` object for each incoming connection.

handle_comm can be a regular function or a coroutine.

Listener objects expose the following interface:

class `distributed.comm.core.Listener`

contact_address

An address this listener can be contacted on. This can be different from *listen_address* if the latter is some wildcard address such as `'tcp://0.0.0.0:123'`.

listen_address

The listening address as a URI string.

start()

Start listening for incoming connections.

stop()

Stop listening. This does not shutdown already established communications, but prevents accepting new ones.

3.34.3 Extending the Communication Layer

Each transport is represented by a URI scheme (such as `tcp`) and backed by a dedicated `Backend` implementation, which provides entry points into all transport-specific routines.

class distributed.comm.registry.**Backend**

A communication backend, selected by a given URI scheme (e.g. 'tcp').

get_address_host (*loc*)

Get a host name (normally an IP address) identifying the host the address is located on. *loc* is a scheme-less address.

get_address_host_port (*loc*)

Get the (host, port) tuple of the scheme-less address *loc*. This should only be implemented by IP-based transports.

get_connector ()

Get a connector object usable for connecting to addresses.

get_listener (*loc*, *handle_comm*, *deserialize*, ***connection_args*)

Get a listener object for the scheme-less address *loc*.

get_local_address_for (*loc*)

Get the local listening address suitable for reaching *loc*.

resolve_address (*loc*)

Resolve the address into a canonical form. *loc* is a scheme-less address.

Simple implementations may return *loc* unchanged.

3.35 Development Guidelines

This repository is part of the [Dask](#) projects. General development guidelines including where to ask for help, a layout of repositories, testing practices, and documentation and style standards are available at the [Dask developer guidelines](#) in the main documentation.

3.35.1 Install

After setting up an environment as described in the [Dask developer guidelines](#) you can clone this repository with git:

```
git clone git@github.com:dask/distributed.git
```

and install it from source:

```
cd distributed
python setup.py install
```

3.35.2 Test

Test using `py.test`:

```
py.test distributed --verbose
```

3.35.3 Tornado

Dask.distributed is a Tornado TCP application. Tornado provides us with both a communication layer on top of sockets, as well as a syntax for writing asynchronous coroutines, similar to `asyncio`. You can make modest changes to the policies within this library without understanding much about Tornado, however moderate changes will probably

require you to understand Tornado IO loops, coroutines, and a little about non-blocking communication.. The Tornado API documentation is quite good and we recommend that you read the following resources:

- <http://www.tornadoweb.org/en/stable/gen.html>
- <http://www.tornadoweb.org/en/stable/ioloop.html>

Additionally, if you want to interact at a low level with the communication between workers and scheduler then you should understand the Tornado `TCPServer` and `IOStream` available here:

- <http://www.tornadoweb.org/en/stable/networking.html>

Dask.distributed wraps a bit of logic around Tornado. See *Foundations* for more information.

3.35.4 Writing Tests

Testing distributed systems is normally quite difficult because it is difficult to inspect the state of all components when something goes wrong. Fortunately, the non-blocking asynchronous model within Tornado allows us to run a scheduler, multiple workers, and multiple clients all within a single thread. This gives us predictable performance, clean shutdowns, and the ability to drop into any point of the code during execution. At the same time, sometimes we want everything to run in different processes in order to simulate a more realistic setting.

The test suite contains three kinds of tests

1. `@gen_cluster`: Fully asynchronous tests where all components live in the same event loop in the main thread. These are good for testing complex logic and inspecting the state of the system directly. They are also easier to debug and cause the fewest problems with shutdowns.
2. `with cluster()`: Tests with multiple processes forked from the master process. These are good for testing the synchronous (normal user) API and when triggering hard failures for resilience tests.
3. `popen`: Tests that call out to the command line to start the system. These are rare and mostly for testing the command line interface.

If you are comfortable with the Tornado interface then you will be happiest using the `@gen_cluster` style of test

```
@gen_cluster(client=True)
def test_submit(c, s, a, b):
    assert isinstance(c, Client)
    assert isinstance(s, Scheduler)
    assert isinstance(a, Worker)
    assert isinstance(b, Worker)

    future = c.submit(inc, 1)
    assert future.key in c.futures

    # result = future.result() # This synchronous API call would block
    result = yield future
    assert result == 2

    assert future.key in s.tasks
    assert future.key in a.data or future.key in b.data
```

The `@gen_cluster` decorator sets up a scheduler, client, and workers for you and cleans them up after the test. It also allows you to directly inspect the state of every element of the cluster directly. However, you can not use the normal synchronous API (doing so will cause the test to wait forever) and instead you need to use the coroutine API, where all blocking functions are prepended with an underscore (`_`). Beware, it is a common mistake to use the blocking interface within these tests.

If you want to test the normal synchronous API you can use a `with cluster` style test, which sets up a scheduler and workers for you in different forked processes:

```
def test_submit_sync(loop):
    with cluster() as (s, [a, b]):
        with Client(('127.0.0.1', s['port']), loop=loop) as c:
            future = c.submit(inc, 1)
            assert future.key in c.futures

            result = future.result() # use the synchronous/blocking API here
            assert result == 2

            a['proc'].terminate() # kill one of the workers

            result = future.result() # test that future remains valid
            assert result == 2
```

In this style of test you do not have access to the scheduler or workers. The variables `s`, `a`, `b` are now dictionaries holding a `multiprocessing.Process` object and a port integer. However, you can now use the normal synchronous API (never use `yield` in this style of test) and you can close processes easily by terminating them.

Typically for most user-facing functions you will find both kinds of tests. The `@gen_cluster` tests test particular logic while the `with cluster` tests test basic interface and resilience.

You should avoid `popen` style tests unless absolutely necessary, such as if you need to test the command line interface.

3.36 Foundations

You should read through the [quickstart](#) before reading this document.

Distributed computing is hard for two reasons:

1. Consistent coordination of distributed systems requires sophistication
2. Concurrent network programming is tricky and error prone

The foundations of `dask.distributed` provide abstractions to hide some complexity of concurrent network programming (#2). These abstractions ease the construction of sophisticated parallel systems (#1) in a safer environment. However, as with all layered abstractions, ours has flaws. Critical feedback is welcome.

3.36.1 Concurrency with Tornado Coroutines

Worker and Scheduler nodes operate concurrently. They serve several overlapping requests and perform several overlapping computations at the same time without blocking. There are several approaches for concurrent programming, we've chosen to use Tornado for the following reasons:

1. Developing and debugging is more comfortable without threads
2. [Tornado's documentation](#) is excellent
3. Stackoverflow coverage is excellent
4. Performance is satisfactory

3.36.2 Endpoint-to-endpoint Communication

The various distributed endpoints (Client, Scheduler, Worker) communicate by sending each other arbitrary Python objects. Encoding, sending and then decoding those objects is the job of the *communication layer*.

Ancillary services such as a Bokeh-based Web interface, however, have their own implementation and semantics.

3.36.3 Protocol Handling

While the abstract communication layer can transfer arbitrary Python objects (as long as they are serializable), participants in a `distributed` cluster concretely obey the distributed *Protocol*, which specifies request-response semantics using a well-defined message format.

Dedicated infrastructure in `distributed` handles the various aspects of the protocol, such as dispatching the various operations supported by an endpoint.

Servers

Worker, Scheduler, and Nanny objects all inherit from a `Server` class.

```
class distributed.core.Server (handlers,          connection_limit=512,          deserialize=True,
                               io_loop=None)
```

Distributed TCP Server

Superclass for endpoints in a distributed cluster, such as Worker and Scheduler objects.

Handlers

Servers define operations with a `handlers` dict mapping operation names to functions. The first argument of a handler function will be a `Comm` for the communication established with the client. Other arguments will receive inputs from the keys of the incoming message which will always be a dictionary.

```
>>> def pingpong(comm):
...     return b'pong'
```

```
>>> def add(comm, x, y):
...     return x + y
```

```
>>> handlers = {'ping': pingpong, 'add': add}
>>> server = Server(handlers)
>>> server.listen('tcp://0.0.0.0:8000')
```

Message Format

The server expects messages to be dictionaries with a special key, `'op'` that corresponds to the name of the operation, and other key-value pairs as required by the function.

So in the example above the following would be good messages.

- `{ 'op': 'ping' }`
- `{ 'op': 'add', 'x': 10, 'y': 20 }`

RPC

To interact with remote servers we typically use `rpc` objects which expose a familiar method call interface to invoke remote operations.

class distributed.core.rpc (arg=None, comm=None, deserialize=True, timeout=None, connection_args=None)

Conveniently interact with a remote server

```
>>> remote = rpc(address)
>>> response = yield remote.add(x=10, y=20)
```

One rpc object can be reused for several interactions. Additionally, this object creates and destroys many comms as necessary and so is safe to use in multiple overlapping communications.

When done, close comms explicitly.

```
>>> remote.close_comms()
```

3.36.4 Examples

Here is a small example using distributed.core to create and interact with a custom server.

Server Side

```
from tornado import gen
from tornado.ioloop import IOLoop
from distributed.core import Server

def add(comm, x=None, y=None): # simple handler, just a function
    return x + y

@gen.coroutine
def stream_data(comm, interval=1): # complex handler, multiple responses
    data = 0
    while True:
        yield gen.sleep(interval)
        data += 1
        yield comm.write(data)

s = Server({'add': add, 'stream_data': stream_data})
s.listen('tcp://:8888') # listen on TCP port 8888

IOLoop.current().start()
```

Client Side

```
from tornado import gen
from tornado.ioloop import IOLoop
from distributed.core import connect

@gen.coroutine
def f():
    comm = yield connect('tcp://127.0.0.1:8888')
    yield comm.write({'op': 'add', 'x': 1, 'y': 2})
    result = yield comm.read()
    yield comm.close()
    print(result)
```

```
>>> IOLoop().run_sync(f)
3

@gen.coroutine
def g():
    comm = yield connect('tcp://127.0.0.1:8888')
    yield comm.write({'op': 'stream_data', 'interval': 1})
    while True:
        result = yield comm.read()
        print(result)

>>> IOLoop().run_sync(g)
1
2
3
...
```

Client Side with rpc

RPC provides a more pythonic interface. It also provides other benefits, such as using multiple streams in concurrent cases. Most distributed code uses `rpc`. The exception is when we need to perform multiple reads or writes, as with the stream data case above.

```
from tornado import gen
from tornado.ioloop import IOLoop
from distributed.core import rpc

@gen.coroutine
def f():
    # comm = yield connect('tcp://127.0.0.1', 8888)
    # yield comm.write({'op': 'add', 'x': 1, 'y': 2})
    # result = yield comm.read()
    r = rpc('tcp://127.0.0.1:8888')
    result = yield r.add(x=1, y=2)
    r.close_comms()

    print(result)

>>> IOLoop().run_sync(f)
3
```

3.37 Journey of a Task

We follow a single task through the user interface, scheduler, worker nodes, and back. Hopefully this helps to illustrate the inner workings of the system.

3.37.1 User code

A user computes the addition of two variables already on the cluster, then pulls the result back to the local process.

```
client = Client('host:port')
x = e.submit(...)
```

```
y = e.submit(...)

z = client.submit(add, x, y) # we follow z

print(z.result())
```

3.37.2 Step 1: Client

`z` begins its life when the `Client.submit` function sends the following message to the Scheduler:

```
{'op': 'update-graph',
 'tasks': {'z': (add, x, y)},
 'keys': ['z']}
```

The client then creates a `Future` object with the key `'z'` and returns that object back to the user. This happens even before the message has been received by the scheduler. The status of the future says `'pending'`.

3.37.3 Step 2: Arrive in the Scheduler

A few milliseconds later, the scheduler receives this message on an open socket.

The scheduler updates its state with this little graph that shows how to compute `z`:

```
scheduler.tasks.update(msg['tasks'])
```

The scheduler also updates *a lot* of other state. Notably, it has to identify that `x` and `y` are themselves variables, and connect all of those dependencies. This is a long and detail oriented process that involves updating roughly 10 sets and dictionaries. Interested readers should investigate `distributed/scheduler.py::update_state()`. While this is fairly complex and tedious to describe rest assured that it all happens in constant time and in about a millisecond.

3.37.4 Step 3: Select a Worker

Once the latter of `x` and `y` finishes, the scheduler notices that all of `z`'s dependencies are in memory and that `z` itself may now run. Which worker should `z` select? We consider a sequence of criteria:

1. First, we quickly downselect to only those workers that have either `x` or `y` in local memory.
2. Then, we select the worker that would have to gather the least number of bytes in order to get both `x` and `y` locally. E.g. if two different workers have `x` and `y` and if `y` takes up more bytes than `x` then we select the machine that holds `y` so that we don't have to communicate as much.
3. If there are multiple workers that require the minimum number of communication bytes then we select the worker that is the least busy

`z` considers the workers and chooses one based on the above criteria. In the common case the choice is pretty obvious after step 1. `z` waits on a stack associated with the chosen worker. The worker may still be busy though, so `z` may wait a while.

Note: This policy is under flux and this part of this document is quite possibly out of date.

3.37.5 Step 4: Transmit to the Worker

Eventually the worker finishes a task, has a spare core, and `z` finds itself at the top of the stack (note, that this may be some time after the last section if other tasks placed themselves on top of the worker's stack in the meantime.)

We place `z` into a `worker_queue` associated with that worker and a `worker_core` coroutine pulls it out. `z`'s function, the keys associated to its arguments, and the locations of workers that hold those keys are packed up into a message that looks like this:

```
{'op': 'compute',
 'function': execute_task,
 'args': ((add, 'x', 'y'),),
 'who_has': {'x': {(worker_host, port)},
             'y': {(worker_host, port), (worker_host, port)}},
 'key': 'z'}
```

This message is serialized and sent across a TCP socket to the worker.

3.37.6 Step 5: Execute on the Worker

The worker unpacks the message, and notices that it needs to have both `x` and `y`. If the worker does not already have both of these then it gathers them from the workers listed in the `who_has` dictionary also in the message. For each key that it doesn't have it selects a valid worker from `who_has` at random and gathers data from it.

After this exchange, the worker has both the value for `x` and the value for `y`. So it launches the computation `add(x, y)` in a local `ThreadPoolExecutor` and waits on the result.

In the mean time the worker repeats this process concurrently for other tasks. Nothing blocks.

Eventually the computation completes. The Worker stores this result in its local memory:

```
data['x'] = ...
```

And transmits back a success, and the number of bytes of the result:

```
Worker: Hey Scheduler, 'z' worked great.
       I'm holding onto it.
       It takes up 64 bytes.
```

The worker does not transmit back the actual value for `z`.

3.37.7 Step 6: Scheduler Aftermath

The scheduler receives this message and does a few things:

1. It notes that the worker has a free core, and sends up another task if available
2. If `x` or `y` are no longer needed then it sends a message out to relevant workers to delete them from local memory.
3. It sends a message to all of the clients that `z` is ready and so all client `Future` objects that are currently waiting should, wake up. In particular, this wakes up the `z.result()` command executed by the user originally.

3.37.8 Step 7: Gather

When the user calls `z.result()` they wait both on the completion of the computation and for the computation to be sent back over the wire to the local process. Usually this isn't necessary, usually you don't want to move data back to the local process but instead want to keep in on the cluster.

But perhaps the user really wanted to actually know this value, so they called `z.result()`.

The scheduler checks who has `z` and sends them a message asking for the result. This message doesn't wait in a queue or for other jobs to complete, it starts instantly. The value gets serialized, sent over TCP, and then deserialized and returned to the user (passing through a queue or two on the way.)

3.37.9 Step 8: Garbage Collection

The user leaves this part of their code and the local variable `z` goes out of scope. The Python garbage collector cleans it up. This triggers a decremented reference on the client (we didn't mention this, but when we created the `Future` we also started a reference count.) If this is the only instance of a `Future` pointing to `z` then we send a message up to the scheduler that it is OK to release `z`. The user no longer requires it to persist.

The scheduler receives this message and, if there are no computations that might depend on `z` in the immediate future, it removes elements of this key from local scheduler state and adds the key to a list of keys to be deleted periodically. Every 500 ms a message goes out to relevant workers telling them which keys they can delete from their local memory. The graph/recipe to create the result of `z` persists in the scheduler for all time.

3.37.10 Overhead

The user experiences this in about 10 milliseconds, depending on network latency.

3.38 Protocol

The scheduler, workers, and clients pass messages between each other. Semantically these messages encode commands, status updates, and data, like the following:

- Please compute the function `sum` on the data `x` and store in `y`
- The computation `y` has been completed
- Be advised that a new worker named `alice` is available for use
- Here is the data for the keys `'x'`, and `'y'`

In practice we represent these messages with dictionaries/mappings:

```
{'op': 'compute',
 'function': ...
 'args': ['x']}

{'op': 'task-complete',
 'key': 'y',
 'nbytes': 26}

{'op': 'register-worker',
 'address': '192.168.1.42',
 'name': 'alice',
 'ncores': 4}

{'x': b'...',
 'y': b'...'}
```

When we communicate these messages between nodes we need to serialize these messages down to a string of bytes that can then be deserialized on the other end to their in-memory dictionary form. For simple cases several options exist like JSON, MsgPack, Protobuffers, and Thrift. The situation is made more complex by concerns like serializing Python functions and Python objects, optional compression, cross-language support, large messages, and efficiency.

This document describes the protocol used by `dask.distributed` today. Be advised that this protocol changes rapidly as we continue to optimize for performance.

3.38.1 Overview

We may split a single message into multiple message-part to suit different protocols. Generally small bits of data are encoded with `MsgPack` while large bytestrings and complex datatypes are handled by a custom format. Each message-part gets its own header, which is always encoded as `msgpack`. After serializing all message parts we have a sequence of bytestrings or *frames* which we send along the wire, prepended with length information.

The application doesn't know any of this, it just sends us Python dictionaries with various datatypes and we produce a list of bytestrings that get written to a socket. This format is fast both for many frequent messages and for large messages.

3.38.2 MsgPack for Messages

Most messages are encoded with `MsgPack`, a self describing semi-structured serialization format that is very similar to JSON, but smaller, faster, not human-readable, and supporting of bytestrings and (soon) timestamps. We chose `MsgPack` as a base serialization format for the following reasons:

- It does not require separate headers, and so is easy and flexible to use which is particularly important in an early stage project like `dask.distributed`
- It is very fast, much faster than JSON, and there are nicely optimized implementations. With few exceptions (described later) `MsgPack` does not come anywhere near being a bottleneck, even under heavy use.
- Unlike JSON it supports bytestrings
- It covers the standard set of types necessary to encode most information
- It is widely implemented in a number of languages (see cross language section below)

However, `MsgPack` fails (correctly) in the following ways:

- It does not provide any way for us to encode Python functions or user defined data types
- It does not support bytestrings greater than 4GB and is generally inefficient for very large messages.

Because of these failings we supplement it with a language-specific protocol and a special case for large bytestrings.

3.38.3 CloudPickle for Functions and Some Data

Pickle and `CloudPickle` are Python libraries to serialize almost any Python object, including functions. We use these libraries to transform the users' functions and data into bytes before we include them in the dictionary/map that we pass off to `msgpack`. In the introductory example you may have noticed that we skipped providing an example for the function argument:

```
{ 'op': 'compute',  
  'function': ...  
  'args': ['x'] }
```

That is because this value `...` will actually be the result of calling `cloudpickle.dumps(myfunction)`. Those bytes will then be included in the dictionary that we send off to `msgpack`, which will only have to deal with bytes rather than obscure Python functions.

Note: we actually call some combination of `pickle` and `cloudpickle`, depending on the situation. This is for performance reasons.

3.38.4 Cross Language Specialization

The Client and Workers must agree on a language-specific serialization format. In the standard `dask.distributed` client and worker objects this ends up being the following:

```
bytes = cloudpickle.dumps(obj, protocol=pickle.HIGHEST_PROTOCOL)
obj = cloudpickle.loads(bytes)
```

This varies between Python 2 and 3 and so your client and workers must match their Python versions and software environments.

However, the Scheduler never uses the language-specific serialization and instead only deals with `MsgPack`. If the client sends a pickled function up to the scheduler the scheduler will not unpack function but will instead keep it as bytes. Eventually those bytes will be sent to a worker, which will then unpack the bytes into a proper Python function. Because the Scheduler never unpacks language-specific serialized bytes it may be in a different language.

The client and workers must share the same language and software environment, the scheduler may differ.

This has a few advantages:

1. The Scheduler is protected from unpickling unsafe code
2. The Scheduler can be run under `pypy` for improved performance. This is only useful for larger clusters.
3. We could conceivably implement workers and clients for other languages (like R or Julia) and reuse the Python scheduler. The worker and client code is fairly simple and much easier to reimplement than the scheduler, which is complex.
4. The scheduler might some day be rewritten in more heavily optimized C or Go

3.38.5 Compression

Fast compression libraries like LZ4 or Snappy may increase effective bandwidth by compressing data before sending and decompressing it after reception. This is especially valuable on lower-bandwidth networks.

If either of these libraries is available (we prefer LZ4 to Snappy) then for every message greater than 1kB we try to compress the message and, if the compression is at least a 10% improvement, we send the compressed bytes rather than the original payload. We record the compression used within the header as a string like `'lz4'` or `'snappy'`.

To avoid compressing large amounts of uncompressable data we first try to compress a sample. We take 10kB chunks from five locations in the dataset, arrange them together, and try compressing the result. If this doesn't result in significant compression then we don't try to compress the full result.

3.38.6 Header

The header is a small dictionary encoded in `msgpack` that includes some metadata about the message, such as compression.

3.38.7 Serializing Data

For administrative messages like updating status `msgpack` is sufficient. However for large results or Python specific data, like NumPy arrays or Pandas Dataframes, or for larger results we need to use something else to convert Python objects to bytestrings. Exactly how we do this is described more in the [Serialization documentation](#).

The application code marks Python specific results with the `to_serialize` function:

```
>>> import numpy as np
>>> x = np.ones(5)

>>> from distributed.protocol import to_serialize
>>> msg = {'status': 'OK', 'data': to_serialize(x)}
>>> msg
{'data': <Serialize: [ 1.  1.  1.  1.  1.]>, 'status': 'OK'}
```

We separate the message into two messages, one encoding all of the data to be serialized and, and one encoding everything else:

```
{'key': 'x', 'address': 'alice'}
{'data': <Serialize: [ 1.  1.  1.  1.  1.]>}
```

The first message we pass normally with msgpack. The second we pass in multiple parts, one part for each serialized piece of data (see *serialization*) and one header including types, compression, etc. used for each value:

```
{'keys': ['data'],
 'compression': ['lz4']}
b'...'
b'...'
```

3.38.8 Frames

At the end of the pipeline we have a sequence of bytestrings or frames. We need to tell the receiving end how many frames there are and how long each these frames are. We order the frames and lengths of frames as follows:

1. The number of frames, stored as an 8 byte unsigned integer
2. The length of each frame, each stored as an 8 byte unsigned integer
3. Each of the frames

In the following sections we describe how we create these frames.

3.38.9 Technical Version

A message is broken up into the following components:

1. 8 bytes encoding how many frames there are in the message (N) as a `uint64`
2. $8 * N$ frames encoding the length of each frame as `uint64`s
3. Header for the administrative message
4. The administrative message, msgpack encoded, possibly compressed
5. Header for all payload messages
6. Payload messages

Header for Administrative Message

The administrative message is arbitrary msgpack-encoded data. Usually a dictionary. It may optionally be compressed. If so the compression type will be in the header.

to be faster on common formats like NumPy and Pandas and gives power-users more control about how their objects get moved around on the network if they want to extend the system.

We include a small example and then follow with the full API documentation describing the `serialize` and `deserialize` functions, which convert objects into a msgpack header and a list of bytestrings and back.

3.39.1 Example

Here is how we special case handling raw Python bytes objects. In this case there is no need to call `pickle.dumps` on the object. The object is already a sequence of bytes.

```
def serialize_bytes(obj):
    header = {} # no special metadata
    frames = [obj]
    return header, frames

def deserialize_bytes(header, frames):
    return frames[0]

register_serialization(bytes, serialize_bytes, deserialize_bytes)
```

3.39.2 API

<code>register_serialization(cls, serialize, ...)</code>	Register a new class for custom serialization
<code>serialize(x)</code>	Convert object to a header and list of bytestrings
<code>deserialize(header, frames)</code>	Convert serialized header and list of bytestrings back to a Python object

`distributed.protocol.serialize.register_serialization(cls, serialize, deserialize)`

Register a new class for custom serialization

Parameters `cls`: type

serialize: function

deserialize: function

See also:

`serialize`, `deserialize`

Examples

```
>>> class Human(object):
...     def __init__(self, name):
...         self.name = name
```

```
>>> def serialize(human):
...     header = {}
...     frames = [human.name.encode()]
...     return header, frames
```

```
>>> def deserialize(header, frames):
...     return Human(frames[0].decode())
```

```
>>> register_serialization(Human, serialize, deserialize)
>>> serialize(Human('Alice'))
({}, [b'Alice'])
```

`distributed.protocol.serialize.serialize(x)`

Convert object to a header and list of bytestrings

This takes in an arbitrary Python object and returns a msgpack serializable header and a list of bytes or memoryview objects. By default this uses pickle/cloudpickle but can use special functions if they have been pre-registered.

Returns header: dictionary containing any msgpack-serializable metadata

frames: list of bytes or memoryviews, commonly of length one

See also:

deserialize Convert header and frames back to object

to_serialize Mark that data in a message should be serialized

register_serialization Register custom serialization functions

Examples

```
>>> serialize(1)
({}, [b'\x80\x04\x95\x03\x00\x00\x00\x00\x00\x00K\x01.'])
```

```
>>> serialize(b'123') # some special types get custom treatment
({'type': 'builtins.bytes'}, [b'123'])
```

```
>>> deserialize(*serialize(1))
1
```

`distributed.protocol.serialize.deserialize(header, frames)`

Convert serialized header and list of bytestrings back to a Python object

Parameters header: dict

frames: list of bytes

See also:

serialize

3.40 Scheduler Plugins

class `distributed.diagnostics.plugin.SchedulerPlugin`

Interface to extend the Scheduler

The scheduler operates by triggering and responding to events like `task_finished`, `update_graph`, `task_erred`, etc..

A plugin enables custom code to run at each of those same events. The scheduler will run the analogous methods on this class when each event is triggered. This runs user code within the scheduler thread that can perform arbitrary operations in synchrony with the scheduler itself.

Plugins are often used for diagnostics and measurement, but have full access to the scheduler and could in principle affect core scheduling.

To implement a plugin implement some of the methods of this class and add the plugin to the scheduler with `Scheduler.add_plugin(myplugin)`.

Examples

```
>>> class Counter(SchedulerPlugin):
...     def __init__(self):
...         self.counter = 0
...
...     def transition(self, key, start, finish, *args, **kwargs):
...         if start == 'processing' and finish == 'memory':
...             self.counter += 1
...
...     def restart(self, scheduler):
...         self.counter = 0
```

```
>>> c = Counter()
>>> scheduler.add_plugin(c)
```

add_worker (*scheduler=None, worker=None, **kwargs*)

Run when a new worker enters the cluster

remove_worker (*scheduler=None, worker=None, **kwargs*)

Run when a worker leaves the cluster

restart (*scheduler, **kwargs*)

Run when the scheduler restarts itself

transition (*key, start, finish, *args, **kwargs*)

Run whenever a task changes state

Parameters **key:** string

start: string

Start state of the transition. One of released, waiting, processing, memory, error.

finish: string

Final state of the transition.

***args, **kwargs:** More options passed when transitioning

This may include worker ID, compute time, etc.

update_graph (*scheduler, dsk=None, keys=None, restrictions=None, **kwargs*)

Run when a new graph / tasks enter the scheduler

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