Introduction to Work Queue Applications

CSE 40822 – Cloud Computing – Spring 2016

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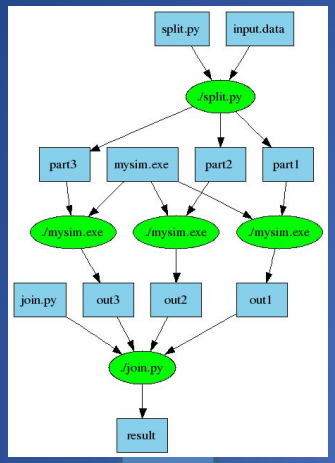
Quick Recap

Makeflow = Make + Workflow



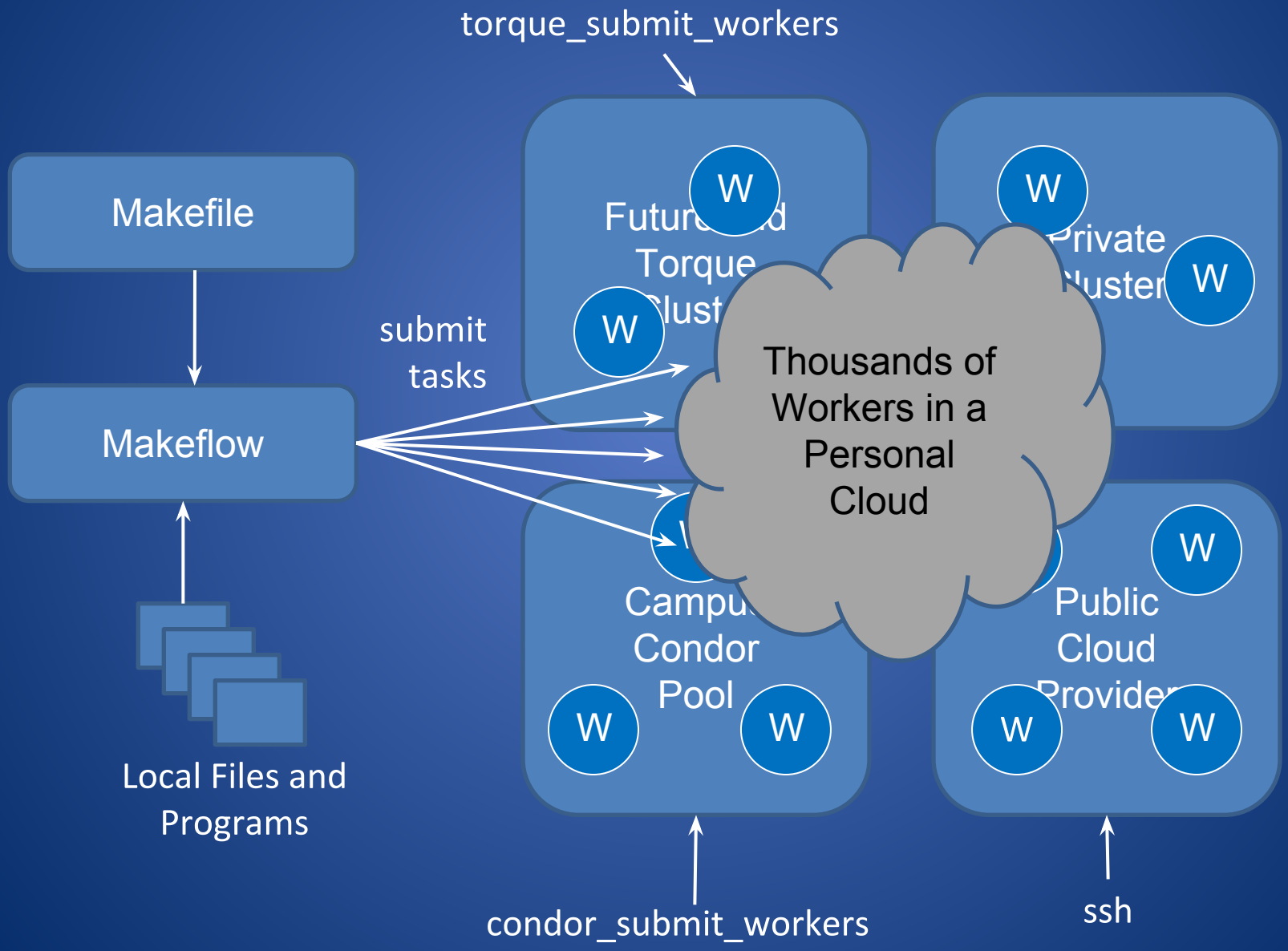
- Provides portability across batch systems.
- Enable parallelism (but not too much!)
- Trickle out work to batch system.
- Fault tolerance at multiple scales.
- Data and resource management.

Makeflow

Local | Condor | Torque | Work Queue

http://ccl.cse.nd.edu/software/makeflow

Makeflow + Work Queue



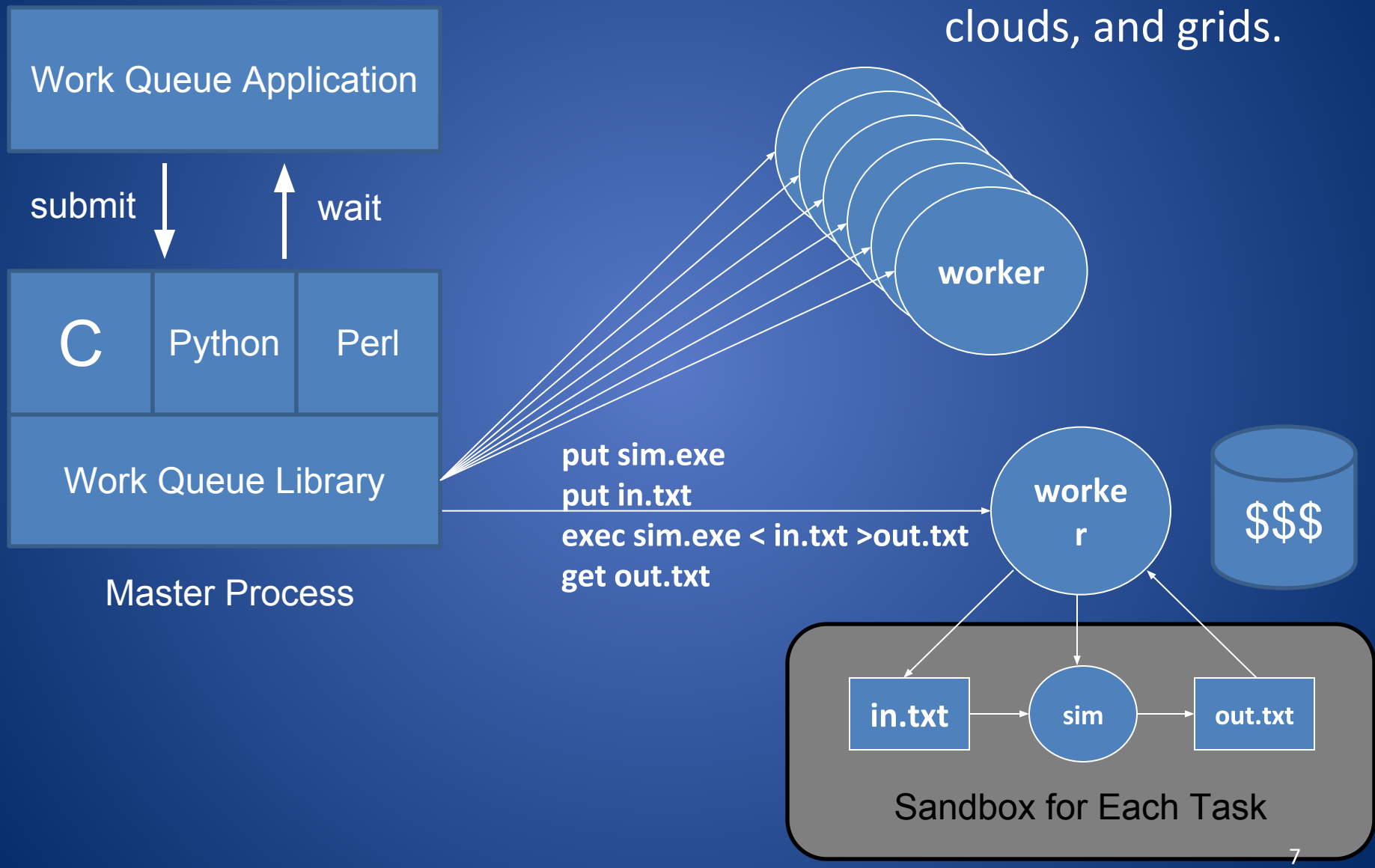
Today:
How to write Work Queue applications directly, without using Makeflow.

Makeflow vs. Work Queue

- Makeflow
  - Directed Acyclic Graph programming model.
  - Static structure known in advance.
  - All communication through files on disk.
- Work Queue
  - Submit-Wait programming model.
  - Dynamic structure decided at run-time.
  - Communicate through buffers or files.
  - More detailed knowledge of how tasks ran.

Work Queue System

X O(1000) workers running on clusters, clouds, and grids.



Work Queue API

```
#include “work_queue.h”

queue = work_queue_create();

while( not done ) {
    while (more work ready) {
        task = work_queue_task_create();
        // add some details to the task
        work_queue_submit(queue, task);
    }

    task = work_queue_wait(queue);
    // process the completed task
}
```

http://ccl.cse.nd.edu/software/workqueue

Basic Queue Operations

```
#include “work_queue.h”
struct work_queue *queue;
struct work_queue_task *task;

// Creates a new queue listening on a port, use zero to pick any port.
queue = work_queue_create( port );
// Submits a task into a queue.  (non-blocking)
work_queue_submit( queue, task );
// Waits for a task to complete, returns the complete task.
task = work_queue_wait( queue, timeout );
// Returns true if there are no tasks left in the queue.
work_queue_empty( queue );
// Returns true if the queue is hungry for more tasks.
work_queue_hungry( queue );
```

Basic Task Operations

```
#include “work_queue.h”
struct work_queue_task *task;

// Create a task that will run a given Unix command.
task = work_queue_task_create( command );

// Indicate an input or output file needed by the task.
work_queue_task_specify_file( task, name, remote_name, type, flags );

// Indicate an input buffer needed by the task.
work_queue_task_specify_buffer( task, data, length, remote_name, flags);

// Destroy the task object.
work_queue_task_delete( task );
```

Run One Task in C

```
#include “work_queue.h”

struct work_queue *queue;
struct work_queue_task *task;

queue = work_queue_create( 0 );

work_queue_specify_name( “myproject” );

task = work_queue_task_create(“sim.exe –p 50 in.dat >out.txt”);

/// Missing: Specify files needed by the task.

work_queue_submit( queue, task );

while(!work_queue_empty(queue)) {
    task = work_queue_wait( queue, 60 );
    if(task) work_queue_task_delete( task );
}
```

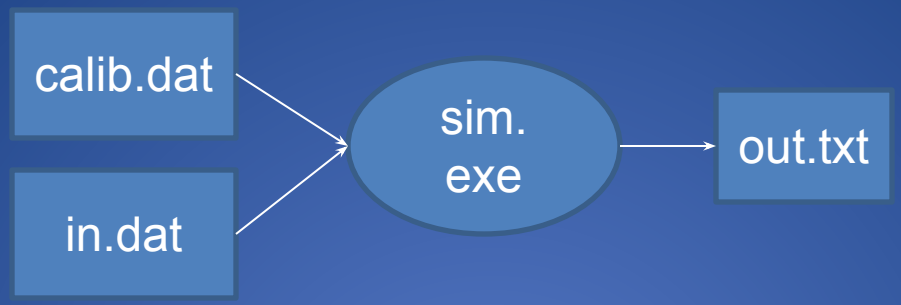
Run One Task in Perl

```
use Work_Queue;

$queue = Work_Queue->new( 0 );

$queue->specify_name( “myproject” );

$task = Work_Queue::Task->new(“sim.exe –p 50 in.dat >out.txt”);

### Missing: Specify files needed by the task.

$queue->submit( $task );

while(!$queue->empty()) {
    $task = $queue->wait( 60 );
   ### Missing: Do something with the task's results
}
```

Run One Task in Python

```
from work_queue import *

queue = WorkQueue( port = 0 )

queue.specify_name( “myproject” );

task = Task(“sim.exe –p 50 in.dat >out.txt”)

### Missing: Specify files needed by the task.

queue.submit( task )

While not queue.empty():
    task = queue.wait(60)
```

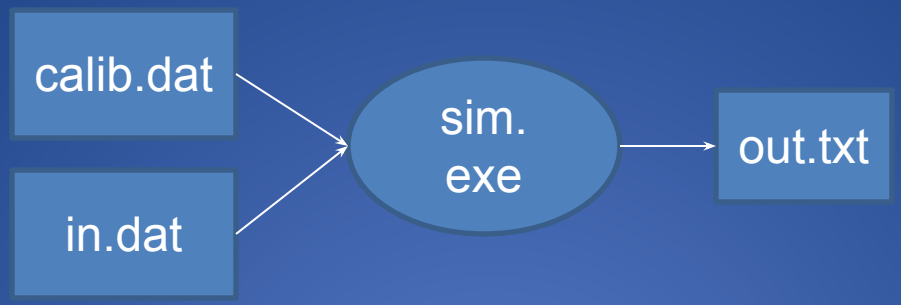
C: Specify Files for a Task



sim.exe in.dat –p 50 > out.txt

```
work_queue_task_specify_file( task,“in.dat”,”in.dat”,
            WORK_QUEUE_INPUT, WORK_QUEUE_NOCACHE );

work_queue_task_specify_file( task,“calib.dat”,”calib.dat”,
          WORK_QUEUE_INPUT, WORK_QUEUE_CACHE );

work_queue_task_specify_file( task,“out.txt”,”out.txt”,
          WORK_QUEUE_OUTPUT, WORK_QUEUE_NOCACHE );

work_queue_task_specify_file( task,“sim.exe”,”sim.exe”,
            WORK_QUEUE_INPUT, WORK_QUEUE_CACHE );
```

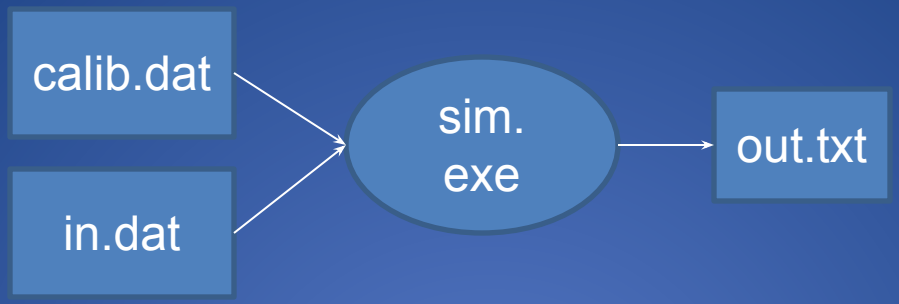
Perl: Specify Files for a Task



sim.exe in.dat –p 50 > out.txt

```
$task->specify_input_file(“in.dat”);

$task->specify_input_file(“calib.dat”);

$task->specify_output_file(“out.txt”);

$task->specify_input_file(local_name => “sim.exe”,
remote_name => "sim.exe",
flags => $Work_Queue::WORK_QUEUE_CACHE );
```

Python: Specify Files for a Task




```
sim.exe  in.dat  –p 50  >  out.txt
```

```
task.specify_file( “in.dat”, ”in.dat”,
           WORK_QUEUE_INPUT, cache = False )

task.specify_input_file( “calib.dat” )

task.specify_output_file( “out.txt” )

task.specify_input_file( “sim.exe”, cache = True )
```


You must state
all the files
needed by the command.

Running a Work Queue Program

```
gcc  work_queue_example.c   -o work_queue_example
      -I $HOME/cctools/include/cctools
      -L $HOME/cctools/lib
      -lwork_queue -ldttools  -lm

./work_queue_example
Listening on port 8374 …
```

In another window:

```
./work_queue_worker studentXX.cse.nd.edu 8374
```

… for Python

setenv PYTHONPATH ${PYTHONPATH}: (no line break)
    ${HOME}/cctools/lib/python2.6/site-package

./work_queue_example.py
Listening on port 8374 …

In another window:
./work_queue_worker studentXX.cse.nd.edu 8374

… for Perl

setenv PERL5LIB ${PERL5LIB}: (no line break)
    ${HOME}/cctools/lib/perl5/site_perl

./work_queue_example.py
Listening on port 8374 …

In another window:
./work_queue_worker studentXX.cse.nd.edu 8374

Start Workers Everywhere

Submit workers to Condor:

condor_submit_workers studentXX.cse.nd.edu 8374 25

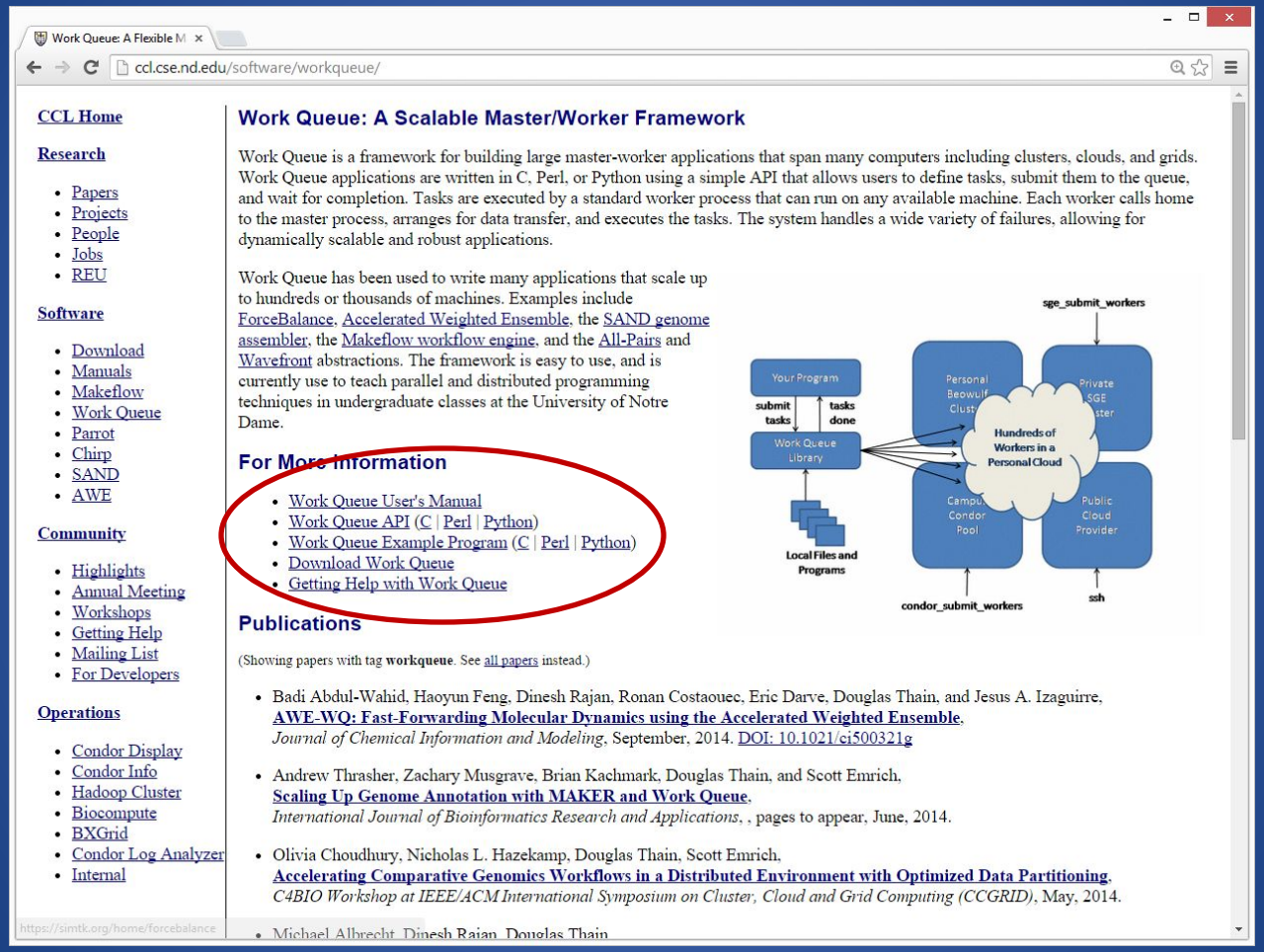
Submit workers to SGE:

sge_submit_workers studentXX.cse.nd.edu 8374 25

Submit workers to Torque:

torque_submit_workers studentXX.cse.nd.edu 8374 25

http://ccl.cse.nd.edu/software/workqueue

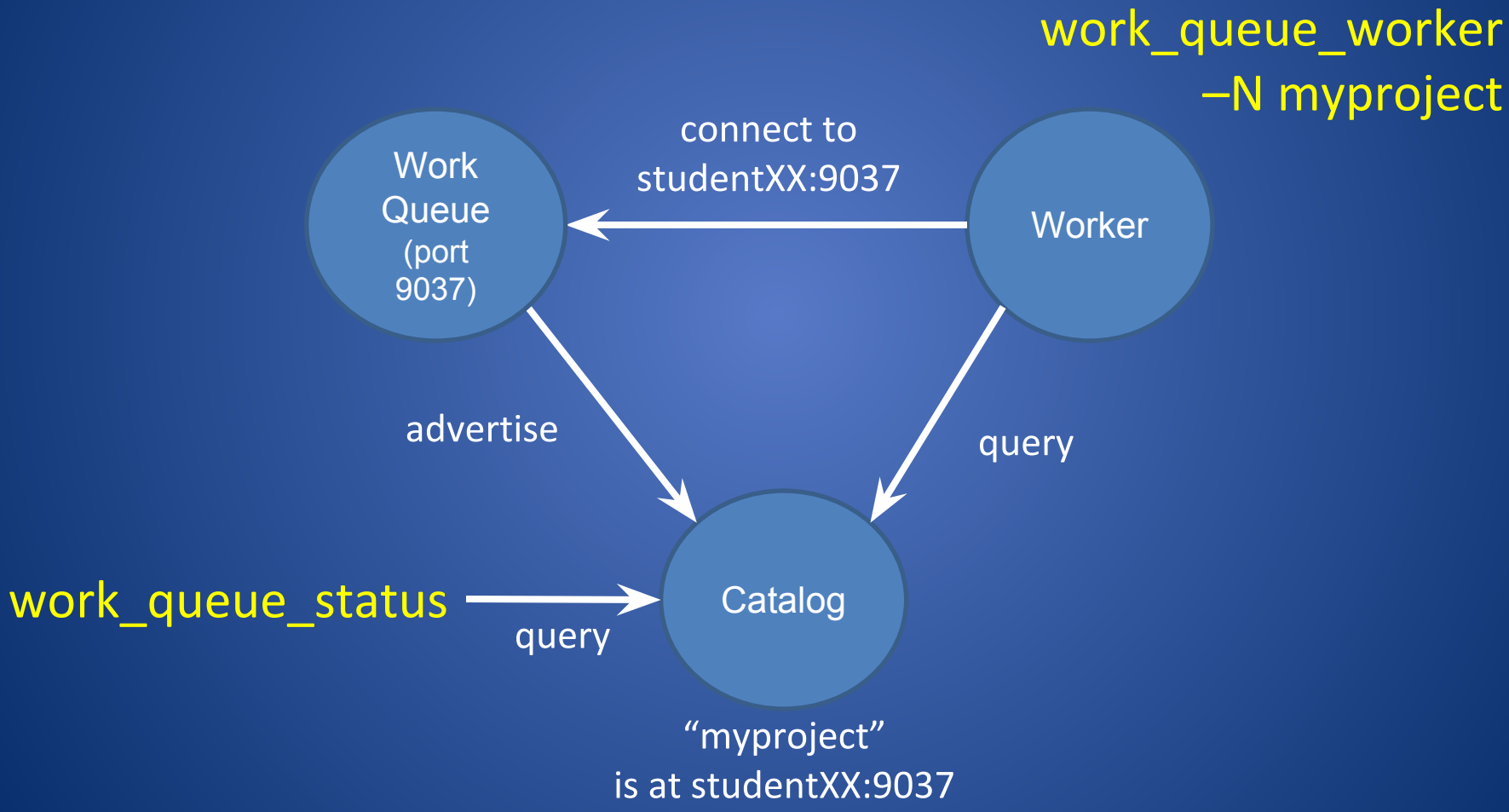


Possible Programming Styles

- Bite off a Piece
- Run Until Convergence
- Scatter-Gather
- Heuristic Tree Search
- Hill Climbing

More Advanced Features

Use Project Names



Specify Project Names in Work Queue

Specify Project Name for Work Queue master:

Python:

```
q.specify_name (“myproject”)
```

Perl:

```
work_queue_specify_name ($q, “myproject”);
```

C:

```
work_queue_specify_name (q, “myproject”);
```

Start Workers with Project Names

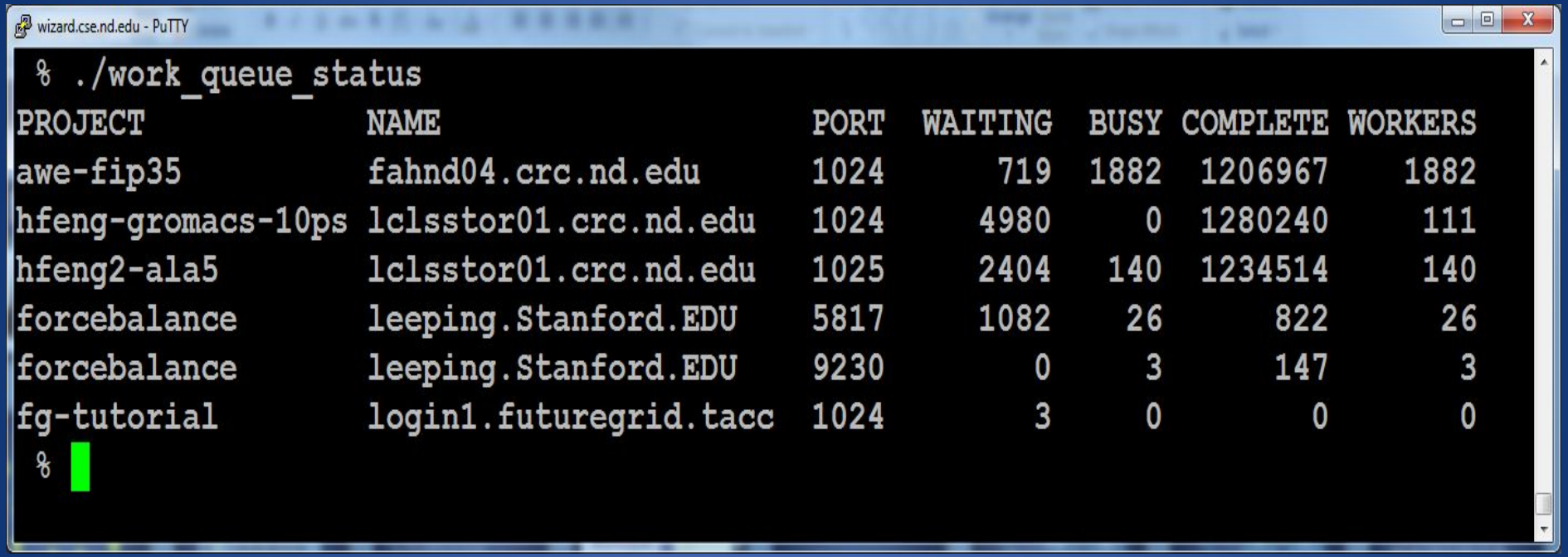
Start one worker:

```
$ work_queue_worker  -N myproject
```

Start many workers:

```
$ sge_submit_workers -N myproject  5
$ condor_submit_workers -N myproject  5
$ torque_submit_workers -N myproject  5
```

work_queue_status



Tag a Work Queue task

- You can specify a tag for a task
  - Batch together related tasks with a tag
  - Add a unique identifier as tag to quickly identify on completed.

Python:

```
t.specify_tag("iteration_1")
```

Perl:

```
work_queue_task_specify_tag($t, "iteration_1");
```

C:

```
work_queue_task_specify_tag(t, "iteration_1");
```

Cancel Work Queue task

- You can cancel any task anytime after it has been submitted to Work Queue as follows:

Python:

```
q.cancel_by_taskid(q, cancel_taskid)
q.cancel_by_tasktag(q, “redudant_task”)
```

Perl:

```
work_queue_cancel_by_taskid($q, $cancel_taskid);
work_queue_cancel_by_tasktag($q, “redudant_task”);
```

C:

```
work_queue_cancel_by_taskid(q, cancel_taskid);
work_queue_cancel_by_tasktag(q, “redudant_task”);
```

Retry “slow” Work Queue tasks

- Running on large number of resources
  - High probability of stragglers
  - These stragglers slow down completion of your computation
- Work Queue has a “fast abort” feature to detect stragglers and migrate tasks to other available resources.
  - It keeps running average of the task execution times.
  - Activate fast abort by specifying a multiple of the average task execution time
  - Work Queue will abort any task executing beyond the specified multiple of the task execution time.
  - The aborted task will then be retried for execution on another available machine.

Activating fast abort in Work Queue

Python:

```
#abort if task exceeds 2.5 * avg execution time
q.activate_fast_abort (2.5)
```

Perl:

```
work_queue_activate_fast_abort ($q, 2.5);
```

C:

```
work_queue_activate_fast_abort (q, 2.5);
```

Send intermediate buffer data as input file for Work Queue Task

- You may have data stored in a buffer (e.g., output of a computation) that will serve as input for a work queue task.
- To send buffer data as input to a task:

Python:

```
buffer = “This is intermediate data”
t.specify_buffer(buffer, input.txt, WORK_QUEUE_INPUT, cache=True)
```

Send intermediate buffer data as input file for Work Queue Task

Perl:

```
my $buffer = “This is intermediate buffer data”
my $buff_len = length($buffer);
work_queue_task_specify_buffer($t,$buffer,$buf_len, “input.txt”, $WORK_QUEUE_CACHE);
```

C:

```
const char * buffer = “This is intermediate buffer data”;
int buff_len = strlen(buffer);
work_queue_task_specify_buffer(t, buffer, buff_len,  “input.txt”, WORK_QUEUE_CACHE);
```

Work Queue Task Structure

- The Work Queue task structure contains information about the task and its execution.
- The following information is available in the task structure:
  - Task command (command line arguments)
  - Task output (stdout)
  - Task return status (exit code of command)
  - Task host (hostname and port on which it ran)
  - Task submit time, Task completion time
  - Task execution time (command)
  - And more..

Accessing Work Queue Task structure

Python:

```
# After ‘t’  has been retrieved through q.wait()
print % t.output
print  % t.host
```

Perl:

```
# After ‘t’ has been retrieved through work_queue_wait()
print “$t->{output}\n”;
print “$t->{host})\n”:
```

C:

```
// After ‘t’ has been retrieved through work_queue_wait()
printf (“%s\n”, t->output);
printf (“%s\n”, t->host):
```

Work Queue Statistics

- Work Queue collects statistics on tasks & workers during run time
- The statistics can be retrieved anytime during run time
- Global statistics
  - Total bytes sent, Total send time
  - Total bytes received, Total receive time
  - Total tasks dispatched, Total tasks complete
  - Total workers joined, Total workers removed
- Statistics on Tasks
  - Tasks running, Tasks complete, Tasks waiting
- Statistics on Workers
  - Workers ready, workers busy, workers cancelling
- And more…

Accessing Work Queue Statistics

- You can access the Work Queue statistics anytime during run time as follows:

Python:

```
print  q.stats
print  q.stats.tasks_running
```

Perl:

```
my $work_queue_stats = work_queue_stats->new();
work_queue_get_stats ($q, $work_queue_stats);
print “$work_queue_stats->{tasks_running}”;
```

Work Queue Statistics

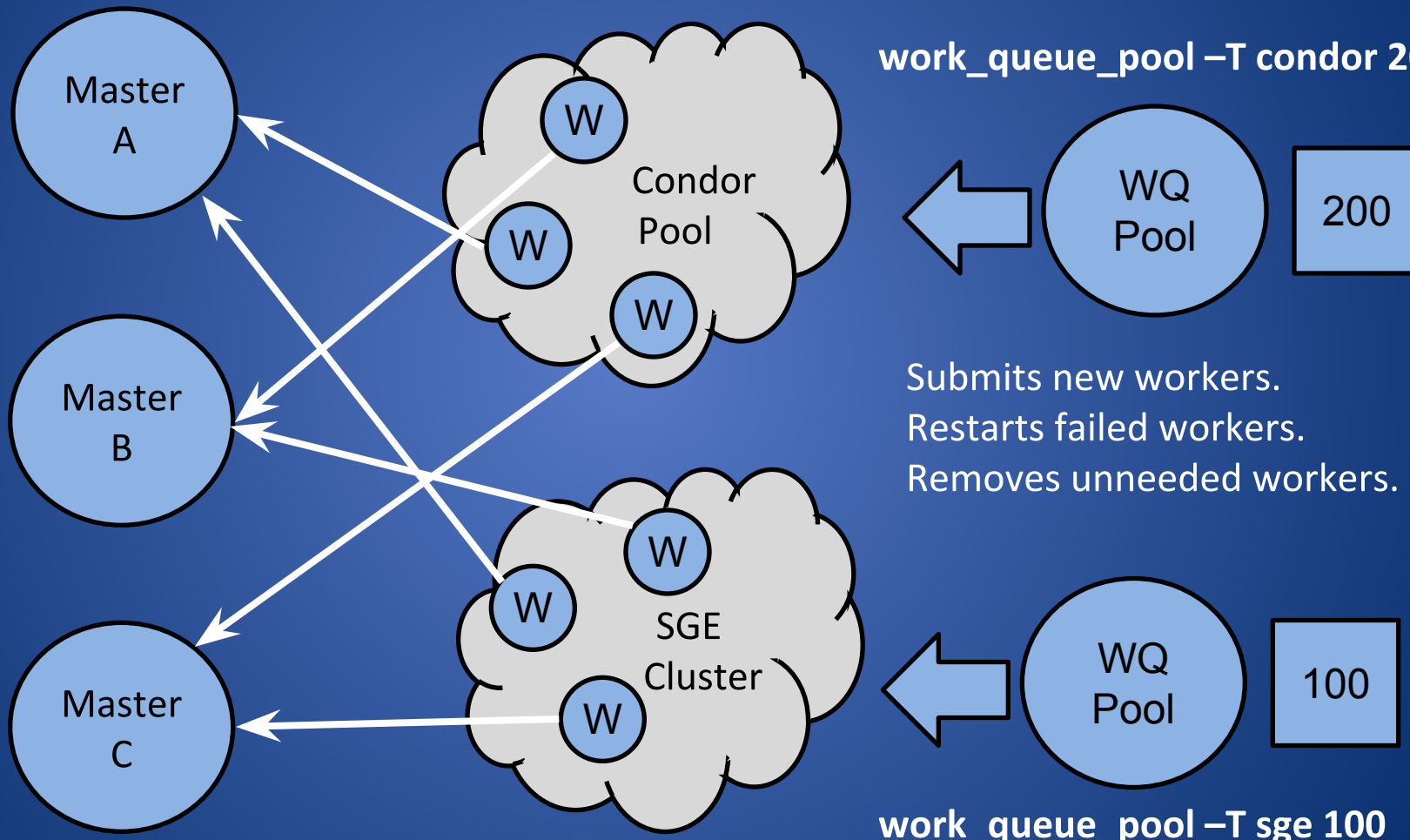
- You can access the Work Queue statistics anytime during run time as follows:

C:

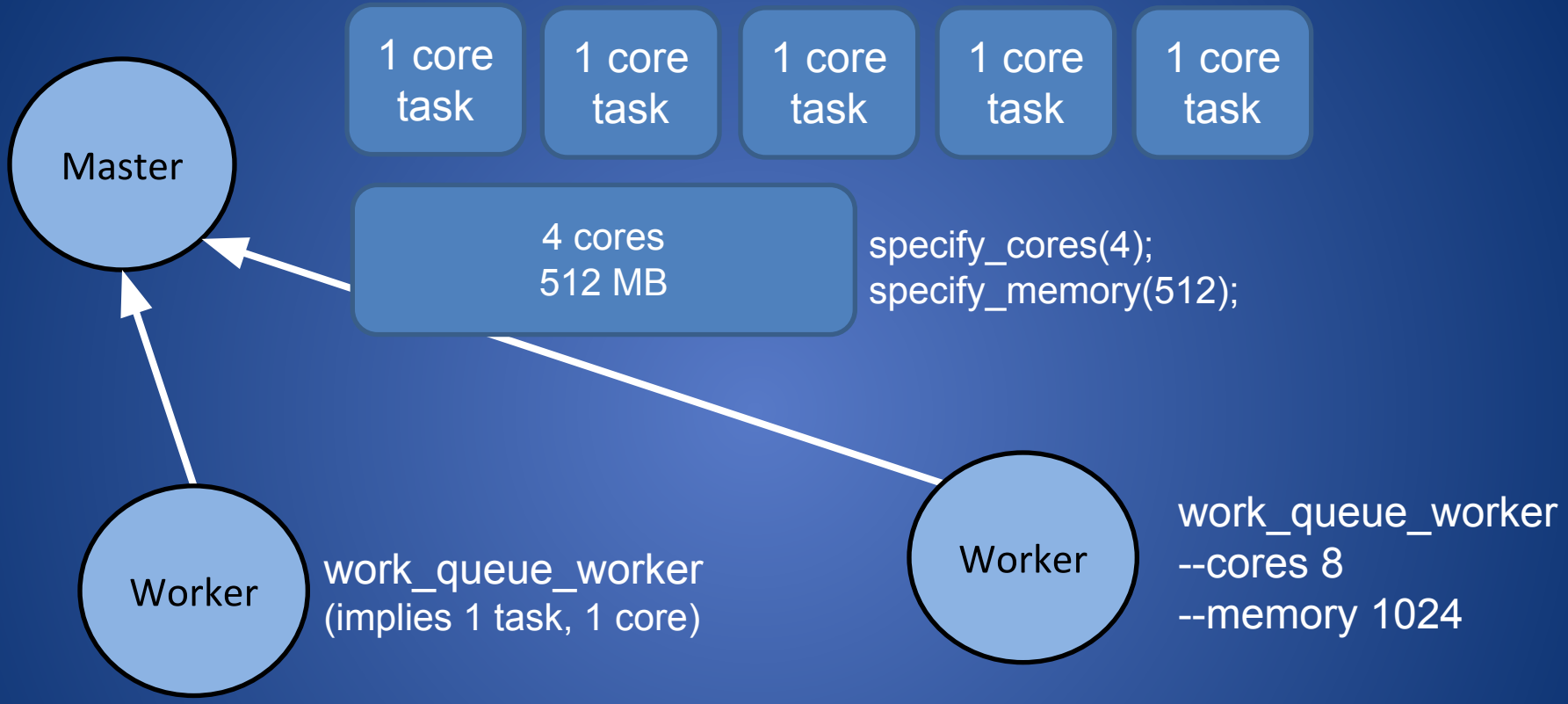
```
struct work_queue_stats *wq_stats;
work_queue_get_stats (q, wq_stats);
printf (“%d”, work_queue_stats->tasks_running);
```

Thinking Even BIGGER

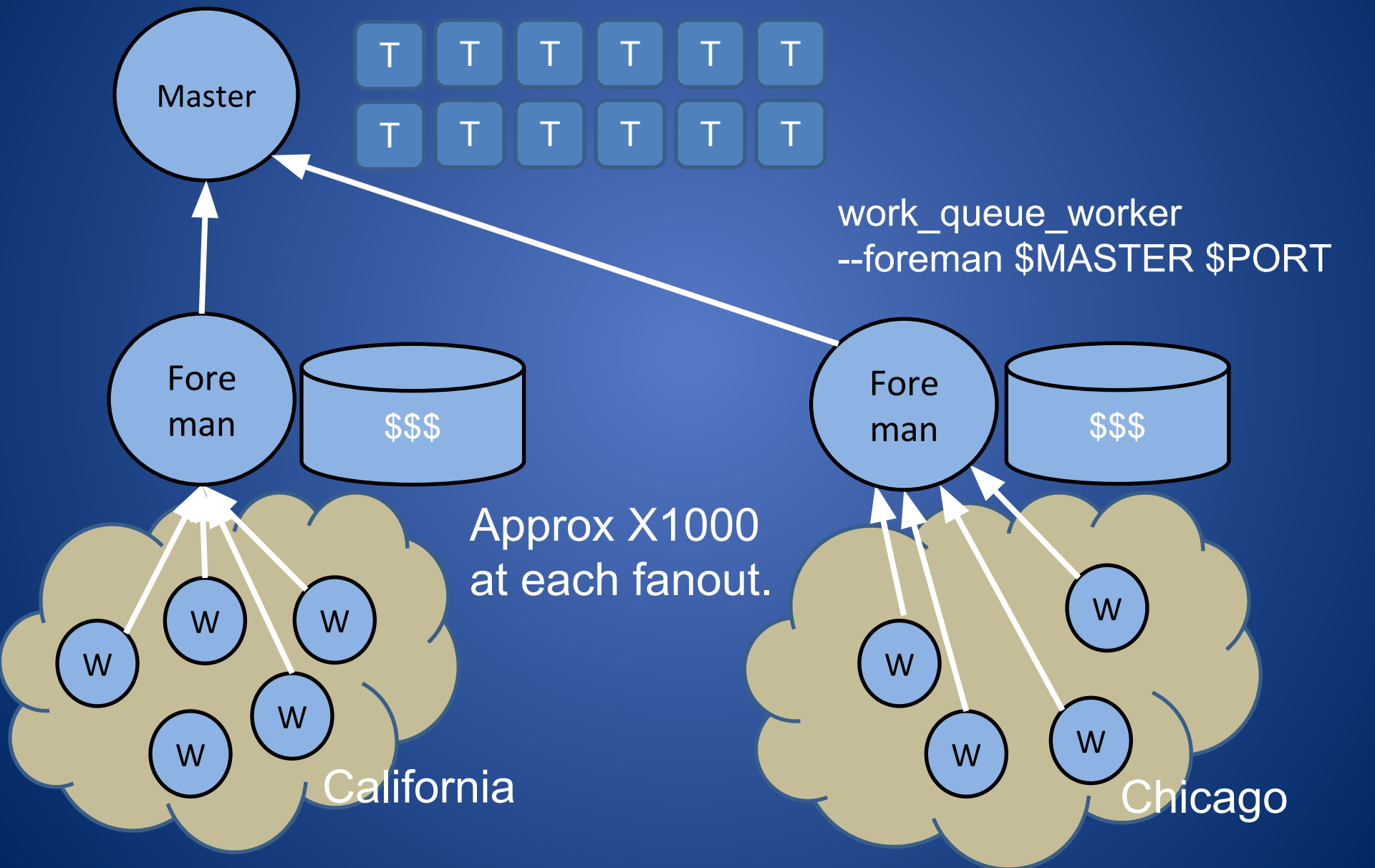
Managing Your Workforce



Multi-Slot Workers



Using Foremen

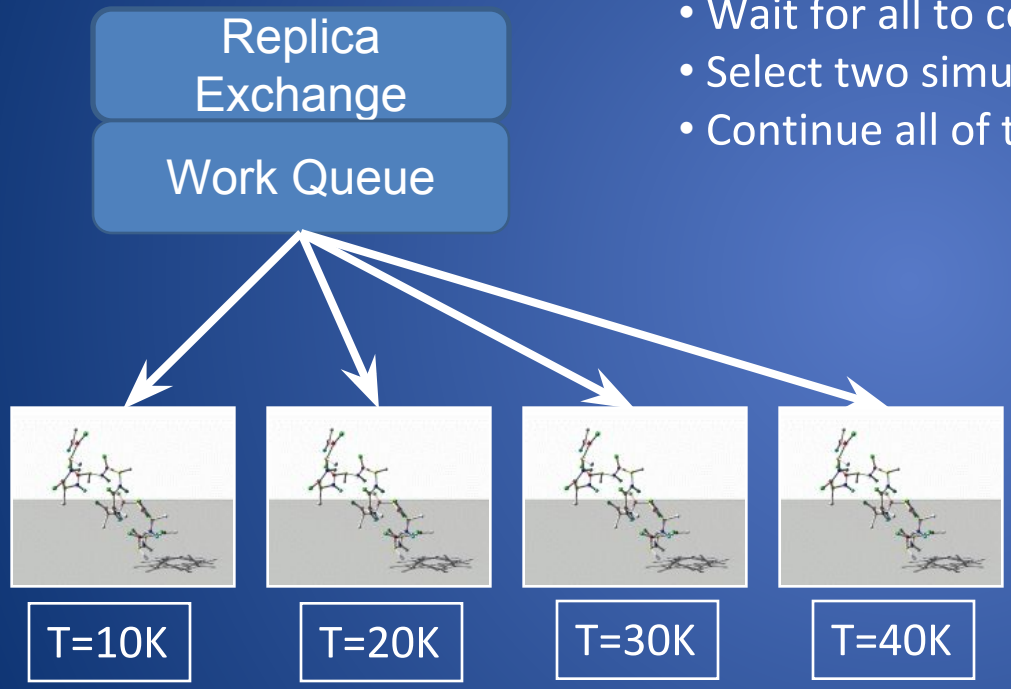


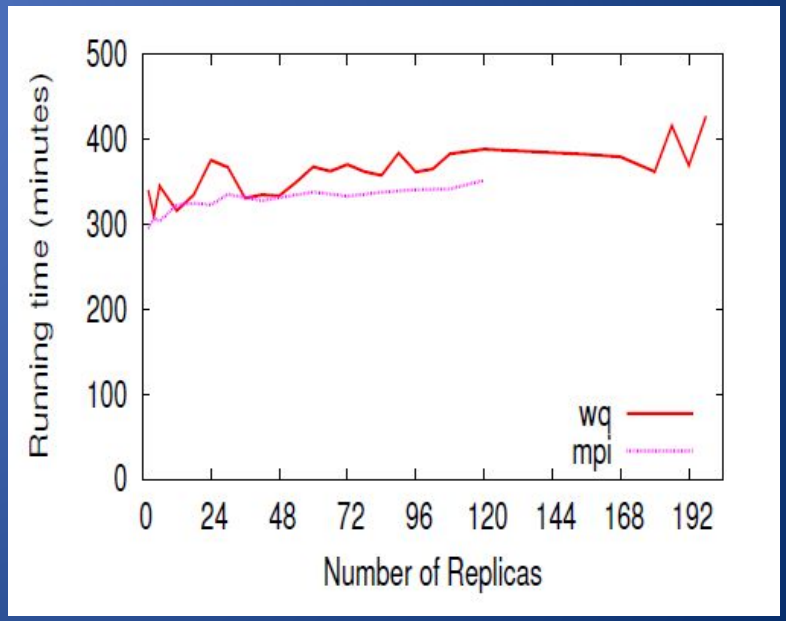
Sample Applications of Work Queue

Replica Exchange

Simplified Algorithm:

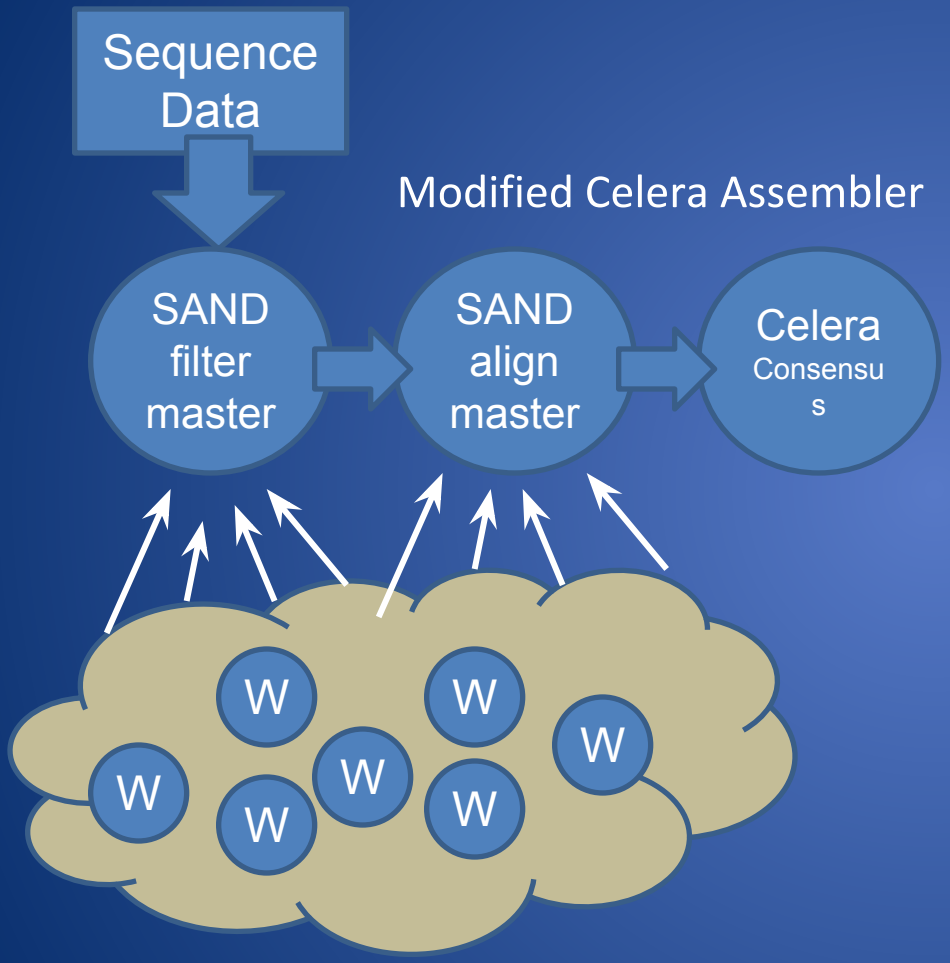
- Submit N short simulations at different temps.
- Wait for all to complete.
- Select two simulations to swap.
- Continue all of the simulations.

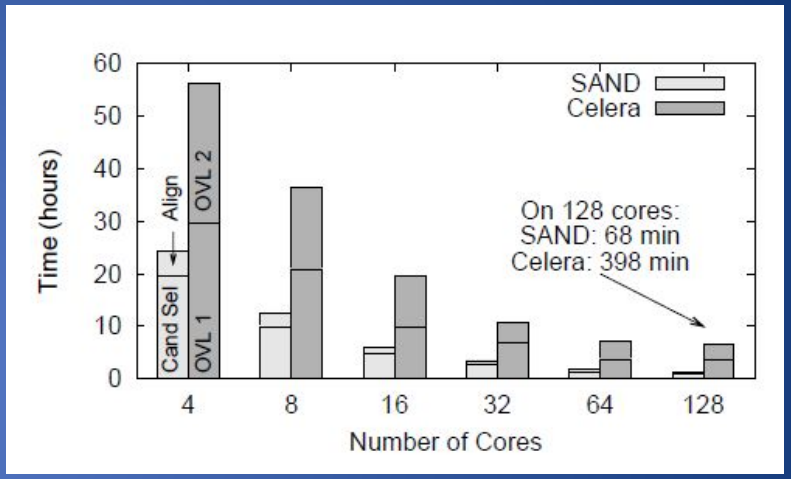




Dinesh Rajan, Anthony Canino, Jesus A Izaguirre, and Douglas Thain,
Converting A High Performance Application to an Elastic Cloud Application, Cloud Com 2011

Genome Assembly



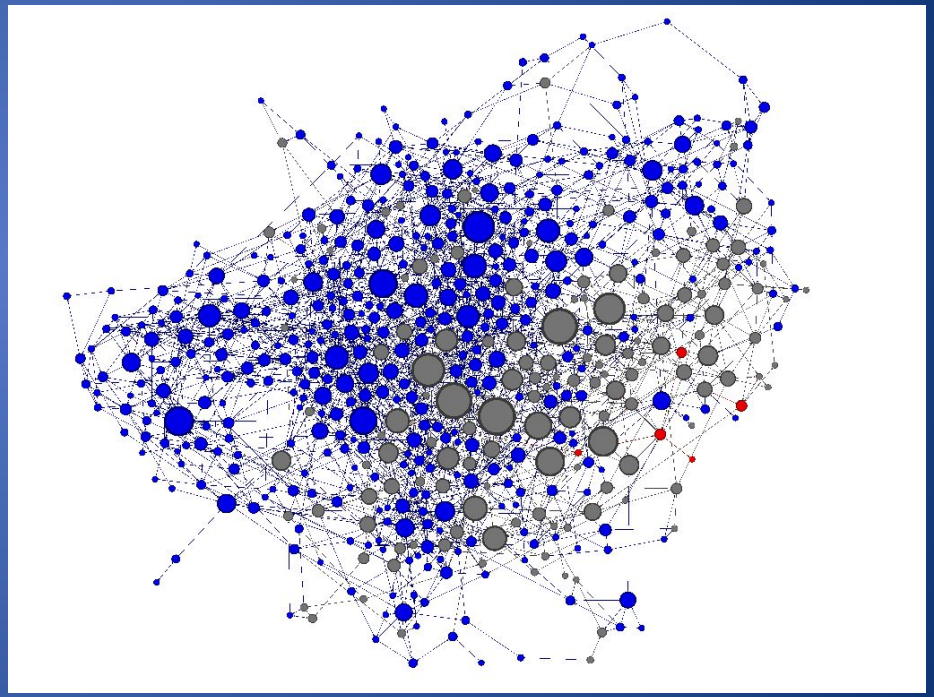


Using WQ, we could assemble a human genome in 2.5 hours on a collection of clusters, clouds, and grids with a speedup of 952X.

Christopher Moretti, Andrew Thrasher, Li Yu, Michael Olson, Scott Emrich, and Douglas Thain, **A Framework for Scalable Genome Assembly on Clusters, Clouds, and Grids**, *IEEE Transactions on Parallel and Distributed Systems*, **2012**

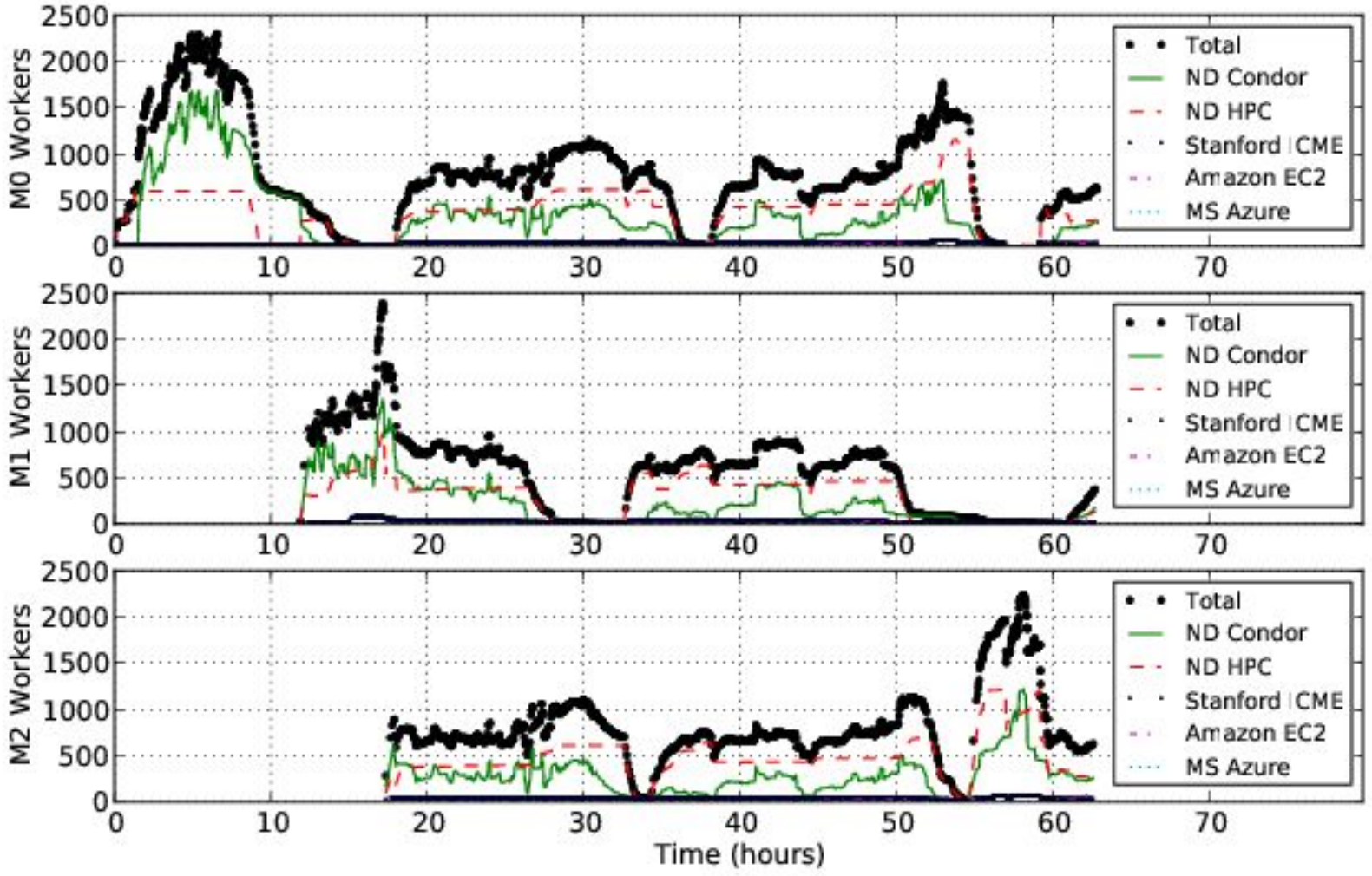
Adaptive Weighted Ensemble

Proteins fold into a number of distinctive states, each of which affects its function in the organism.



How common is each state?
How does the protein transition between states?
How common are those transitions?

AWE on Clusters, Clouds, and Grids



Work Queue provides the Submit-Wait programming model using a Master-Worker architecture.