Toward a Common Model for Highly Concurrent Applications

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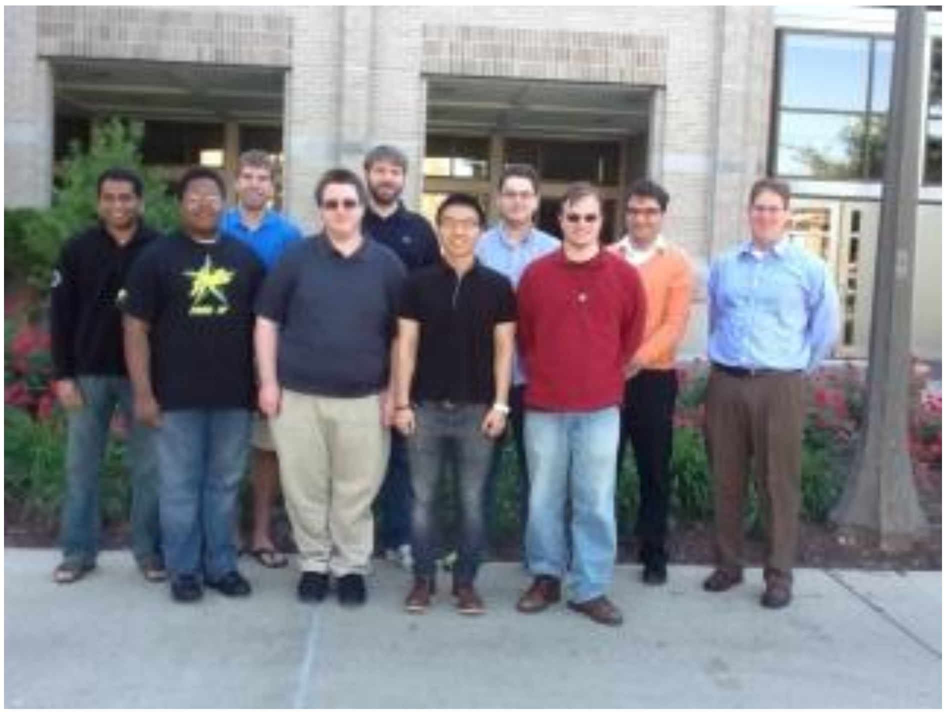
MTAGS Workshop
17 November 2013

Overview

- **Experience with Concurrent Applications**
  - **Makeflow, Weaver, Work Queue**
- Thesis: Convergence of Models
  - Declarative Language
  - Directed Graphs of Tasks and Data
  - Shared Nothing Architecture
- Open Problems
  - Transaction Granularity
  - Where to Parallelize?
  - Resource Management
- Concluding Thoughts

The Cooperative Computing Lab

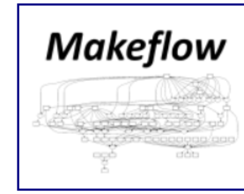
University of Notre Dame



http://www.nd.edu/~ccl

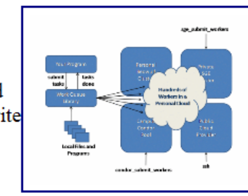
Makeflow

Makeflow is a workflow system for parallel and distributed computing that uses a language very similar to Make. Using Makeflow, you can write simple scripts that easily execute on hundreds or thousands of machines.



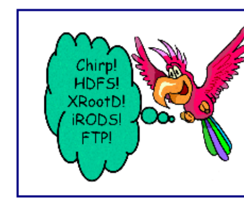
Work Queue

Work Queue is a system and library for creating and managing scalable master-worker style programs that scale up to thousands machines on clusters, clouds, and grids. Work Queue programs are easy to write in C, Python or Perl.



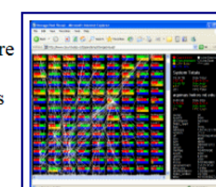
Parrot

Parrot is a transparent user-level virtual filesystem that allows any ordinary program to be attached to many different remote storage systems, including HDFS, iRODS, Chirp, and FTP.



Chirp

Chirp is a personal user-level distributed filesystem that allows unprivileged users to share space securely, efficiently, and conveniently. When combined with Parrot, Chirp allows users to create custom wide-area distributed filesystems.



The Cooperative Computing Lab

- We *collaborate with people* who have large scale computing problems in science, engineering, and other fields.
- We *operate computer systems* on the O(10,000) cores: clusters, clouds, grids.
- We *conduct computer science* research in the context of real people and problems.
- We *release open source software* for large scale distributed computing.

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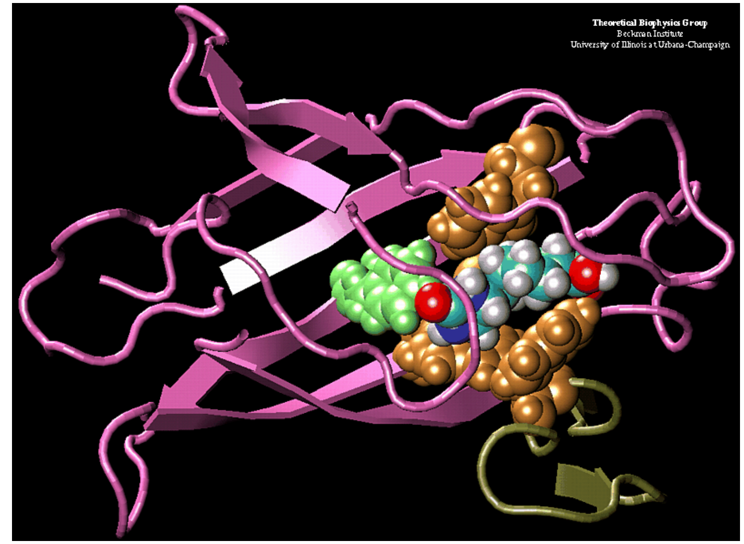
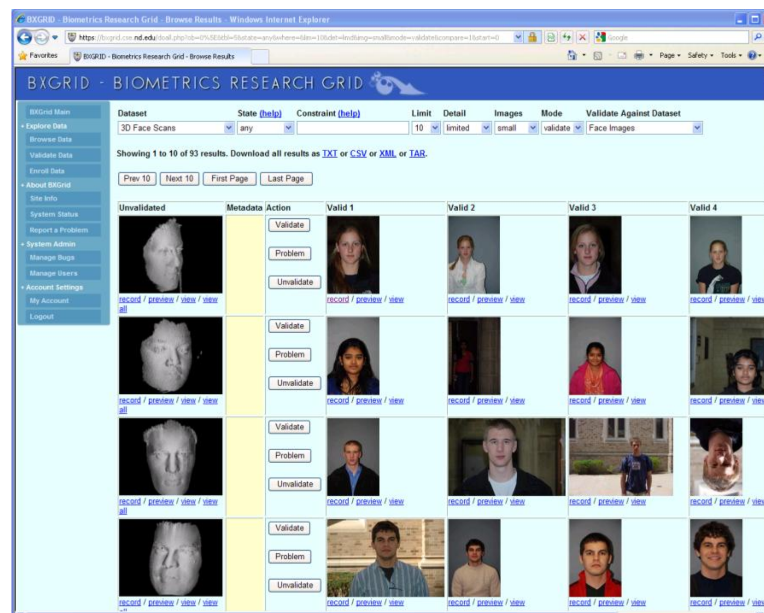
Our Collaborators

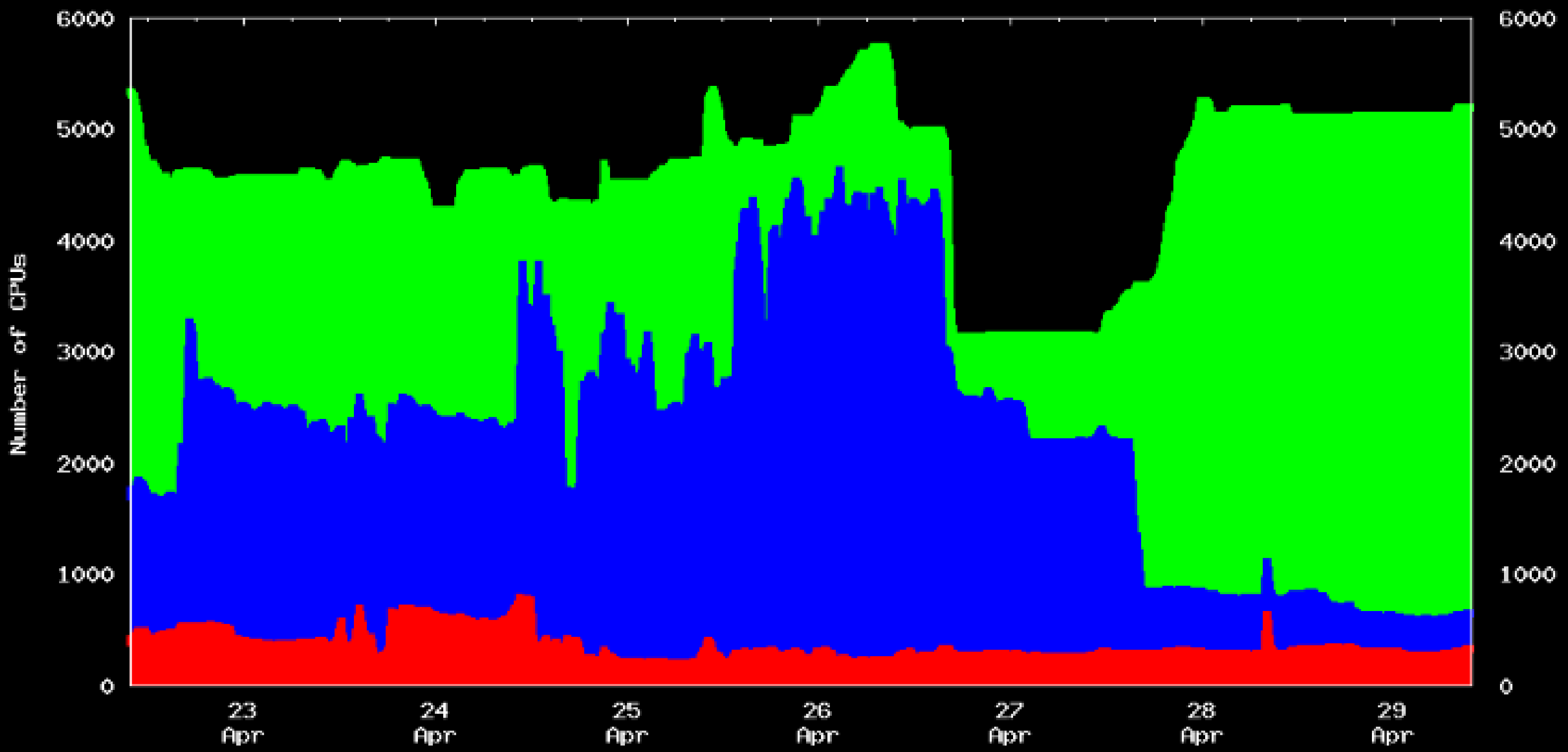


AGTCCGTACGATGCTATTAGCGAGCGTGA...



Good News:
Computing is Plentiful

CPU Utilization for the Last Week



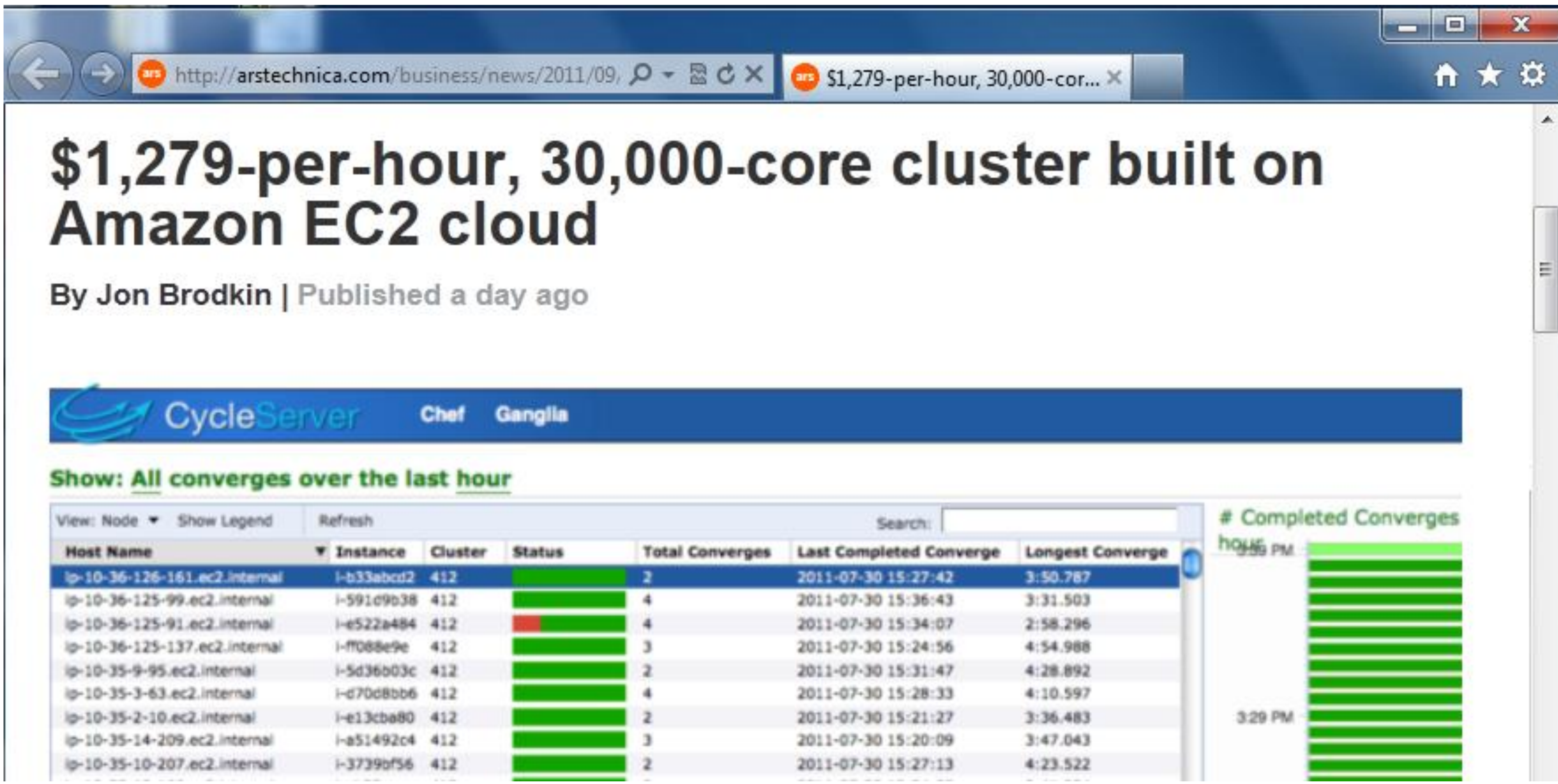
404855 (51%) CPU-Hours Unused

328960 (41%) CPU-Hours Used by Condor

58935 (7%) CPU-Hours Used by Owner

792750 (100%) CPU-Hours Total

Superclusters by the Hour



http://arstechnica.com/business/news/2011/09/30000-core-cluster-built-on-amazon-ec2-cloud.ars

The Bad News:
It is inconvenient.

End User Challenges

- System Properties:
  - Wildly varying resource availability.
  - Heterogeneous resources.
  - Unpredictable preemption.
  - Unexpected resource limits.
- User Considerations:
  - Jobs can’t run for too long... but, they can’t run too quickly, either!
  - I/O operations must be carefully matched to the capacity of clients, servers, and networks.
  - Users often do not even have access to the necessary information to make good choices!

I have a standard, debugged, trusted application that runs on my laptop.

A toy problem completes in one hour.
A real problem will take a month (I think.)

Can I get a single result faster?
Can I get more results in the same time?

Last year,
I heard about
this grid thing.

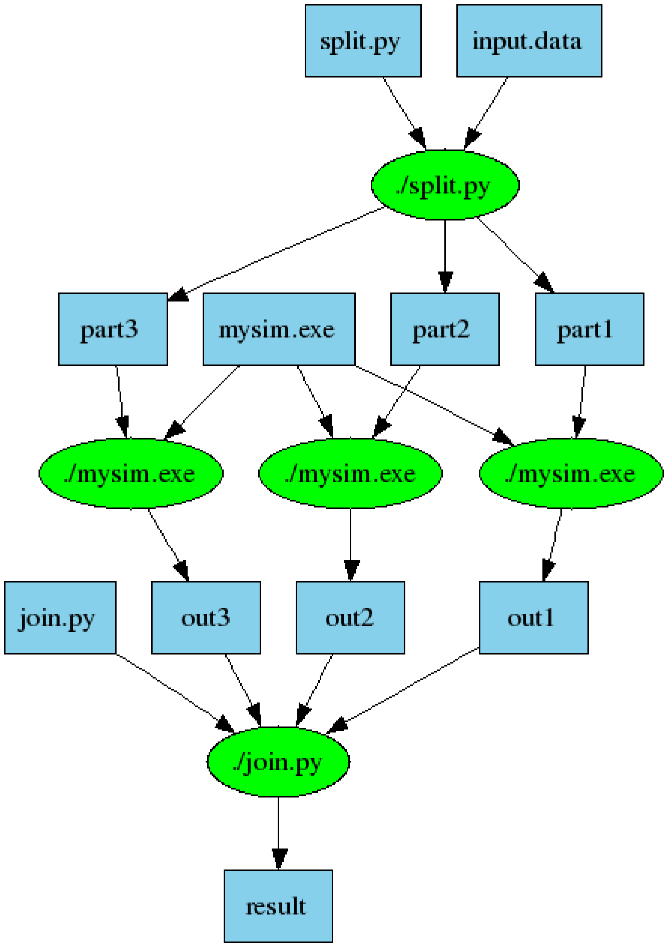
This year,
I heard about
this cloud thing.

What do I do next?

Our Philosophy:

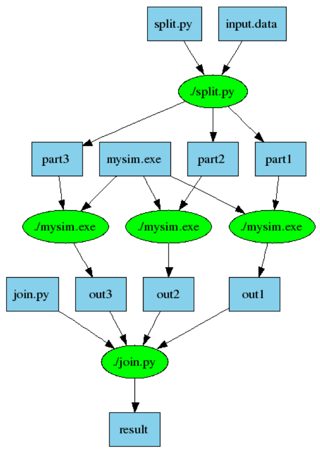
- Harness all the resources that are available: desktops, clusters, clouds, and grids.
- Make it easy to scale up from one desktop to national scale infrastructure.
- Provide familiar interfaces that make it easy to connect existing apps together.
- Allow portability across operating systems, storage systems, middleware…
- Make simple things easy, and complex things possible.
- ***No special privileges required.***

An Old Idea: Makefiles

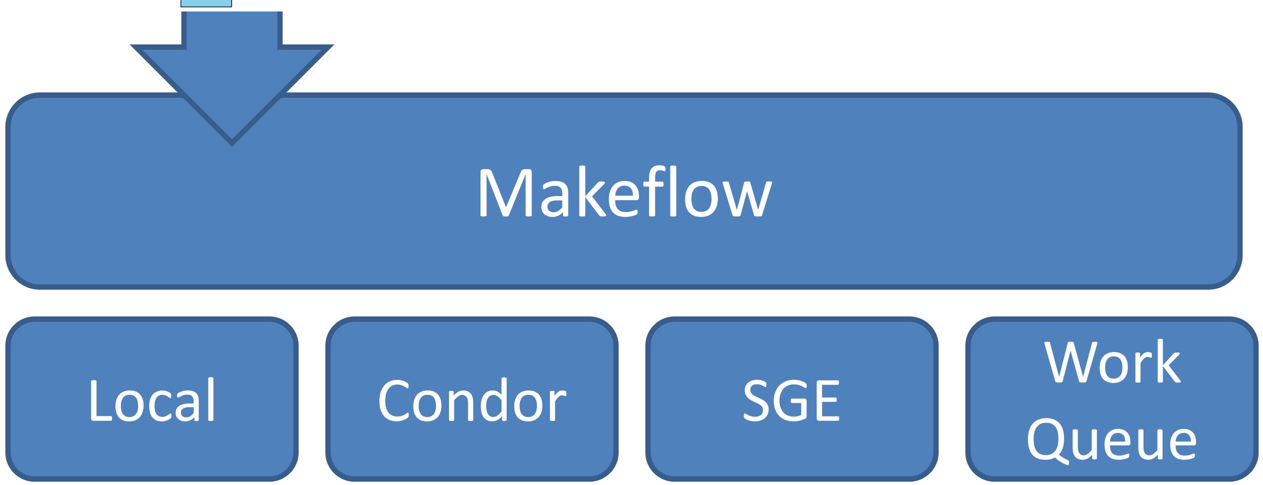



```
part1 part2 part3: input.data split.py
    ./split.py input.data

out1: part1 mysim.exe
    ./mysim.exe part1 >out1

out2: part2 mysim.exe
    ./mysim.exe part2 >out2

out3: part3 mysim.exe
    ./mysim.exe part3 >out3

result: out1 out2 out3 join.py
    ./join.py out1 out2 out3 > result
```

Makeflow = Make + Workflow

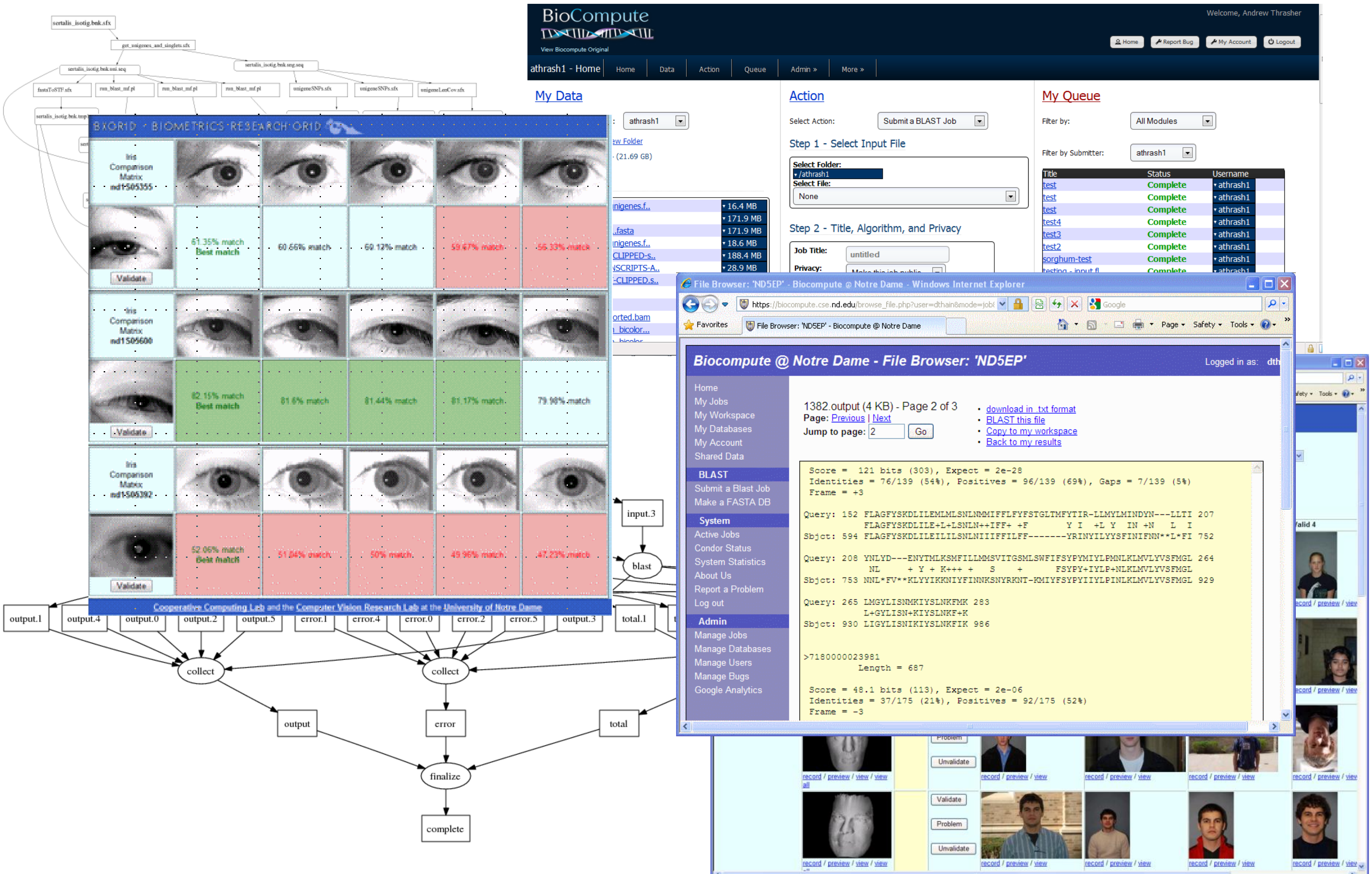


- Provides portability across batch systems.
- Enable parallelism (but not too much!)
- Fault tolerance at multiple scales.
- Data and resource management.

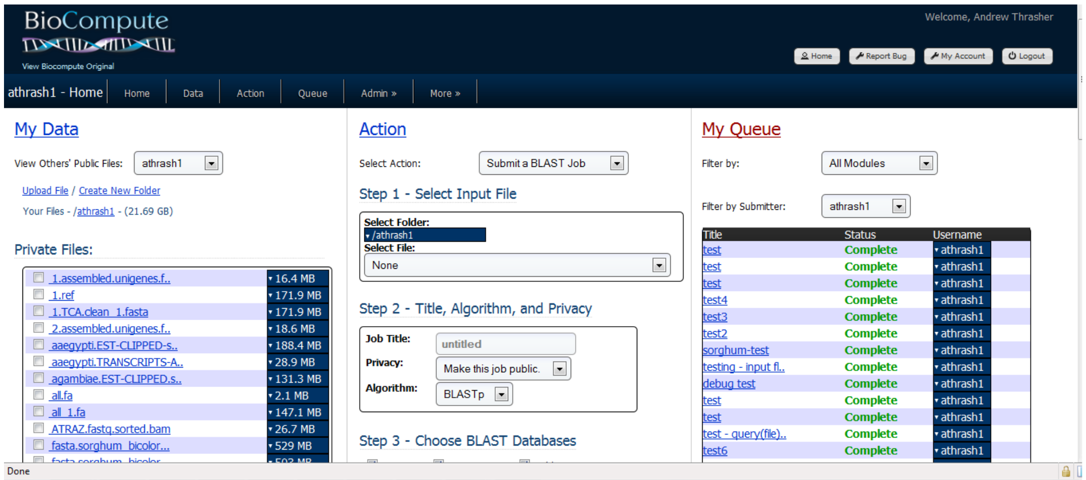


http://www.nd.edu/~ccl/software/makeflow

Makeflow Applications

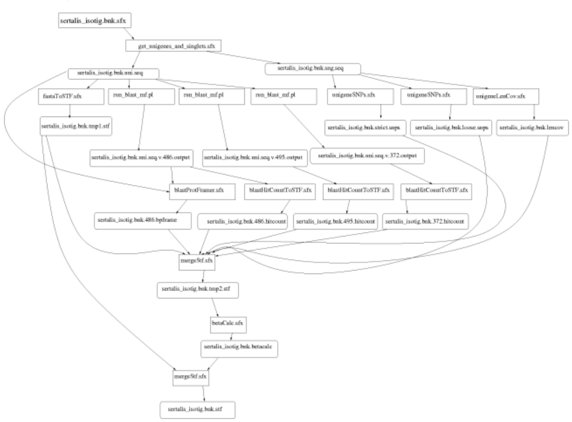


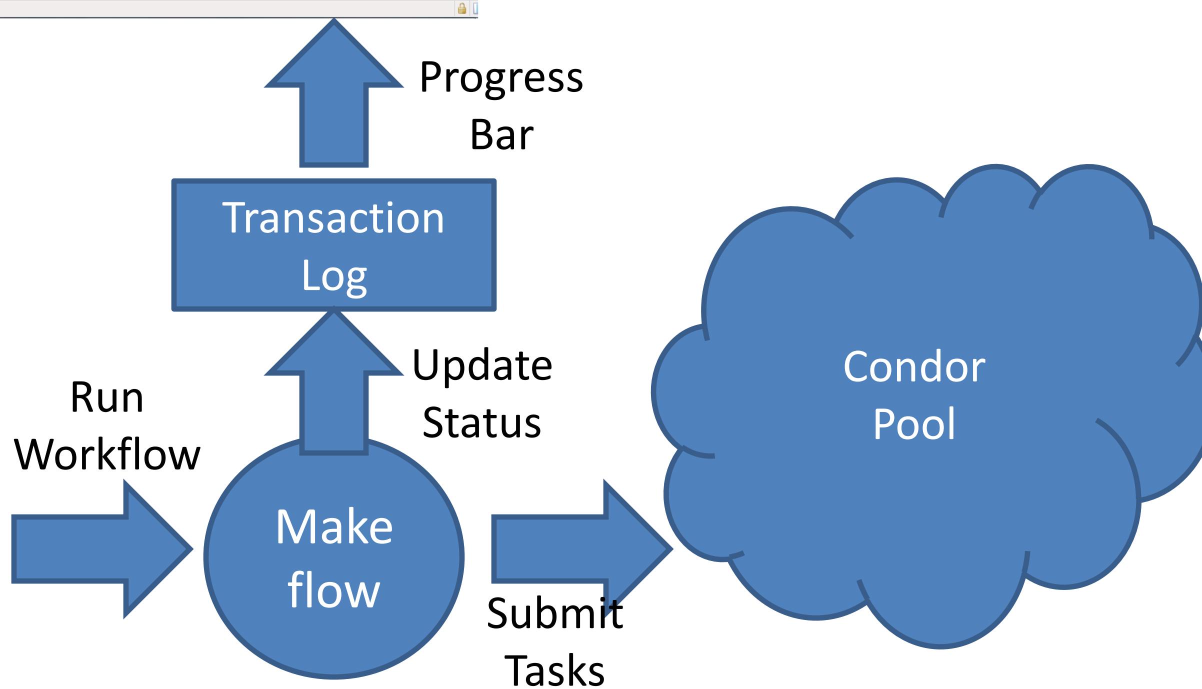
Example: Biocompute Portal



BLAST
SSAHA
SHRIMP
EST
MAKER
...

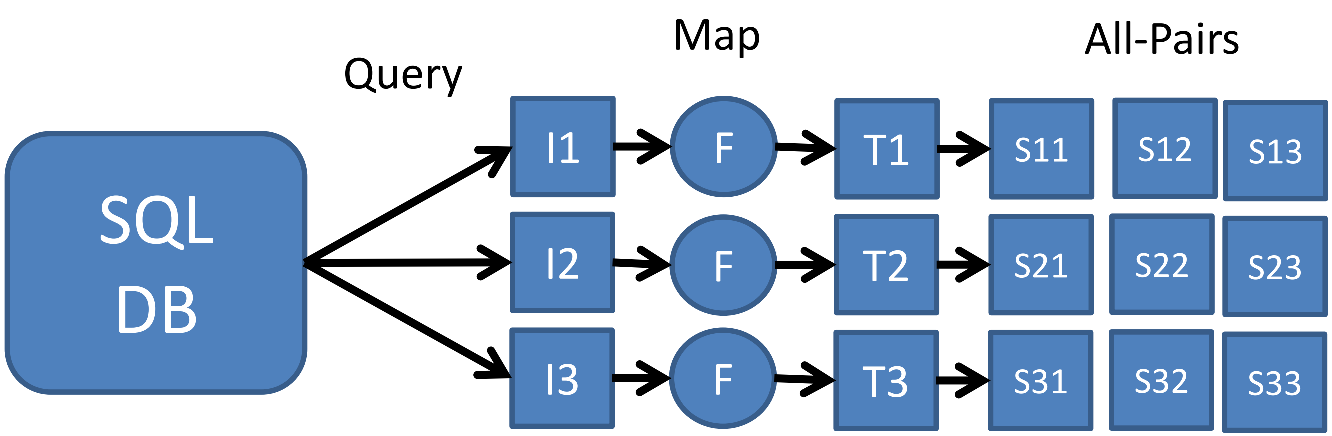
Generate Makefile





Generating Workflows with Weaver

```
db      = SQLDataSet('db', 'biometrics', 'irises');
irises = Query(db,color==‘Blue’)

iris_to_bit  = SimpleFunction('convert_iris_to_template‘)
compare_bits = SimpleFunction('compare_iris_templates')

bits = Map(iris_to_bit, irises)
AllPairs(compare_bits, bits, bits, output='scores.txt')
```

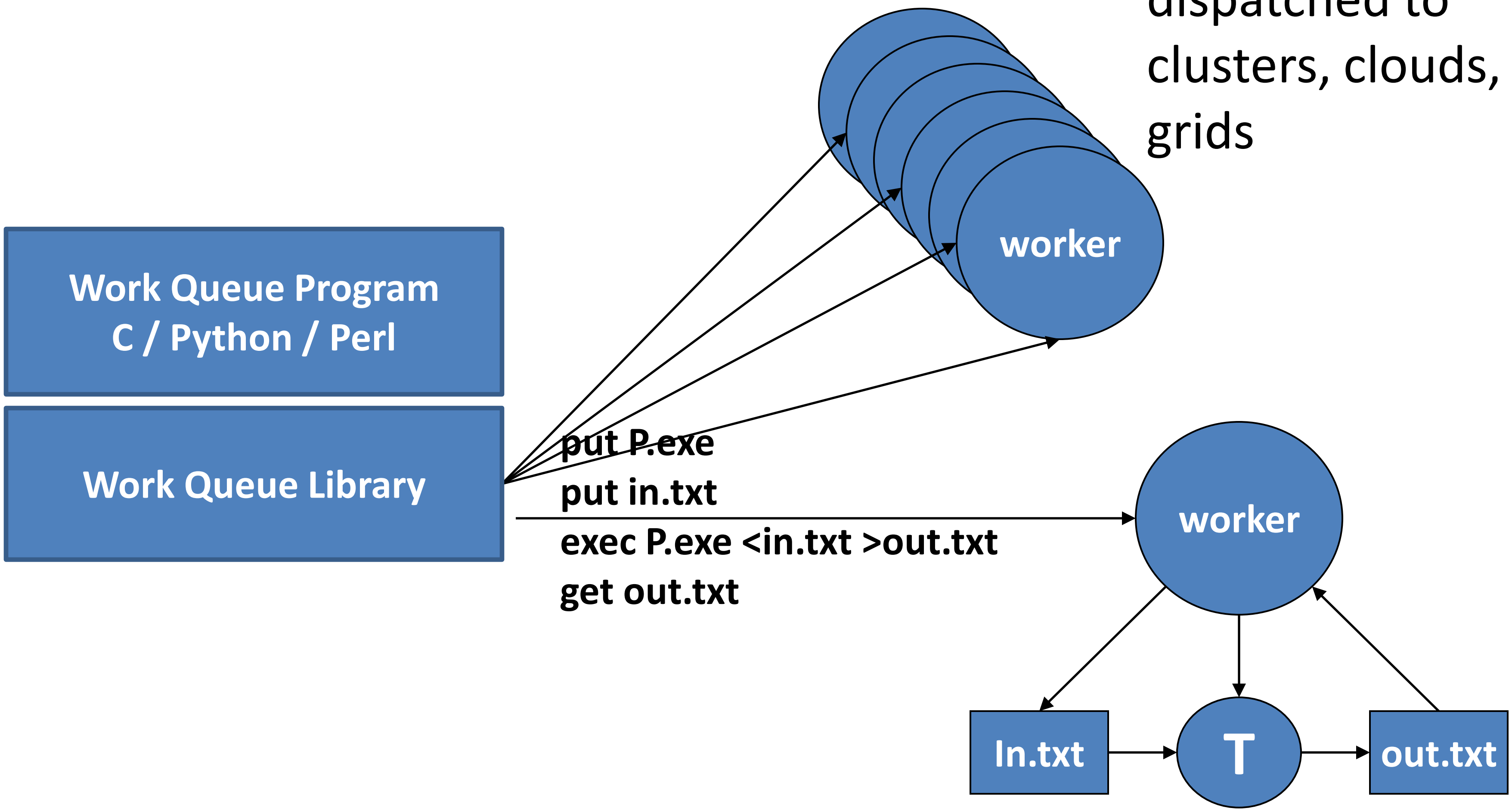


Weaver + Makeflow + Batch System

- A good starting point:
  - Simple representation is easy to pick up.
  - Value provided by DAG analysis tools.
  - Easy to move apps between batch systems.
- But, the shared filesystem remains a problem.
  - Relaxed consistency confuses the coordinator.
  - Too easy for Makeflow to overload the FS.
- And the batch system was designed for large jobs.
  - Nobody likes seeing 1M entries in qstat.
  - 30-second rule applies to most batch systems

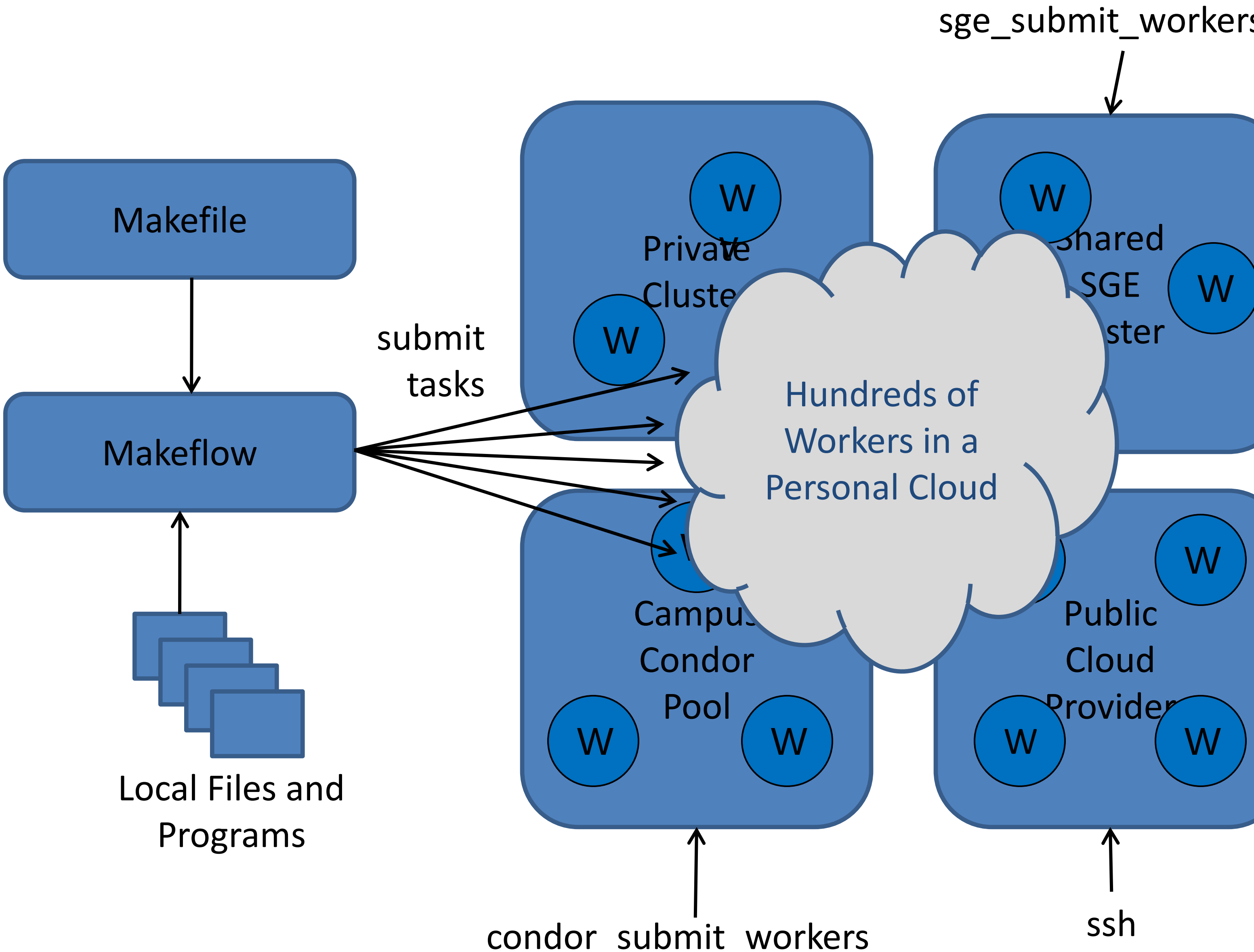
Work Queue System

1000s of workers dispatched to clusters, clouds, and grids

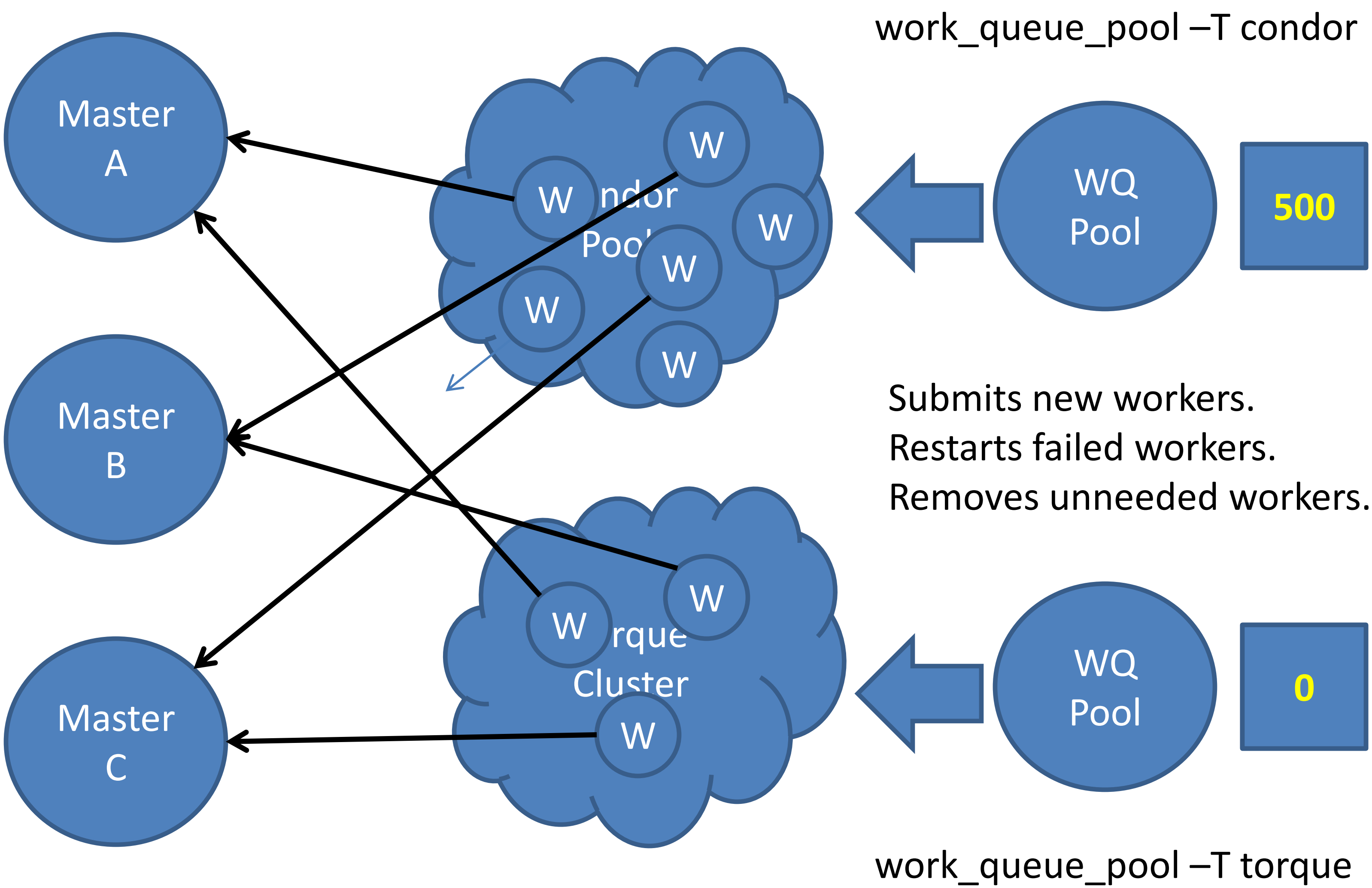


http://www.nd.edu/~ccl/software/workqueue

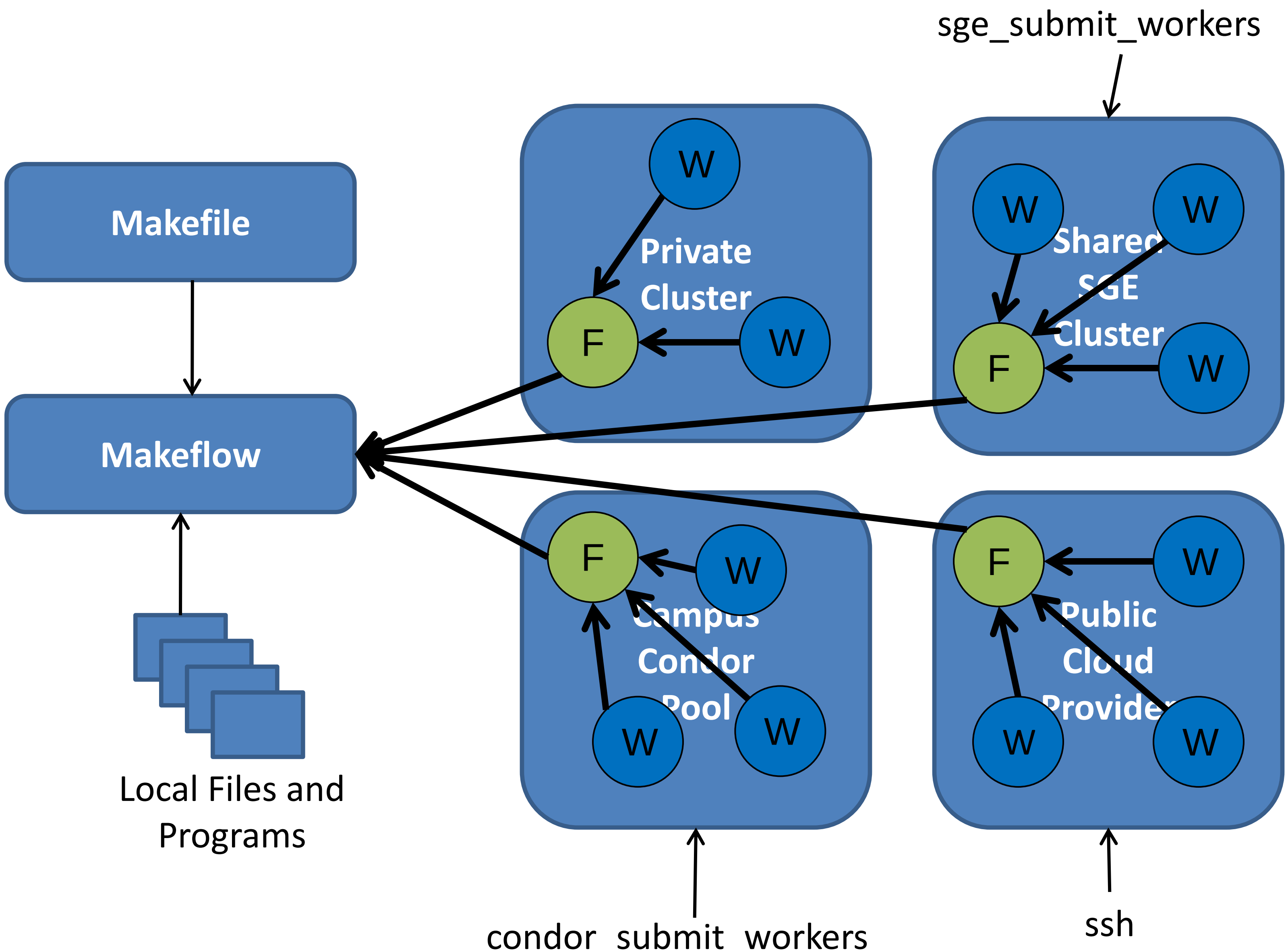
Makeflow + Work Queue



Managing Your Workforce



Hierarchical Work Queue



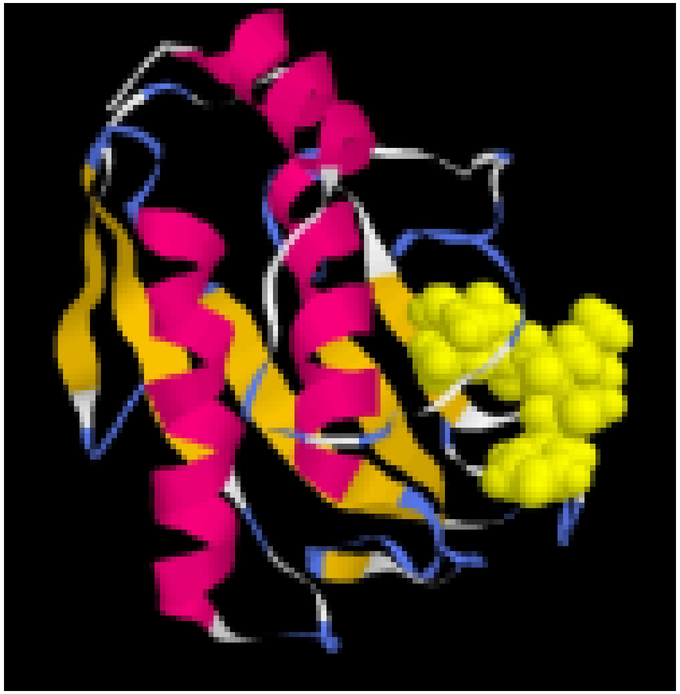
Work Queue Library

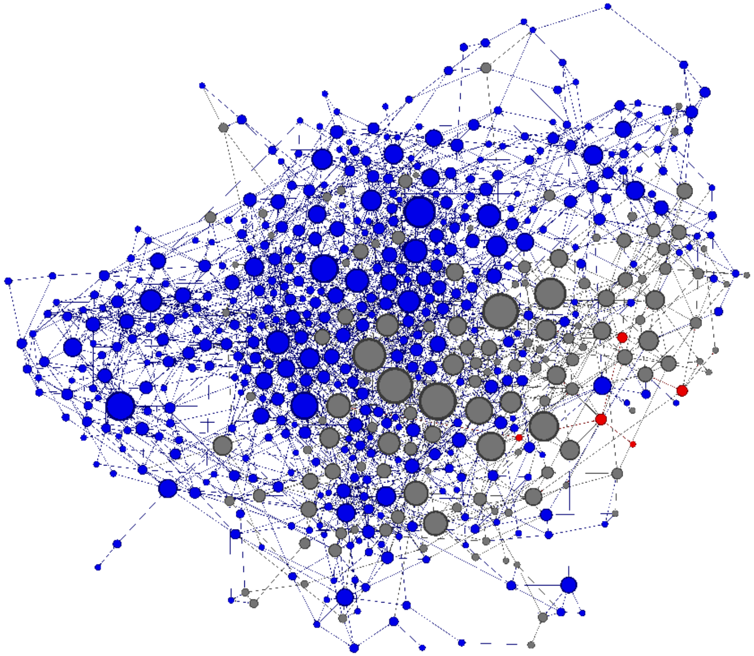
```
#include  "work_queue.h"

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://www.nd.edu/~ccl/software/workqueue

Adaptive Weighted Ensemble

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



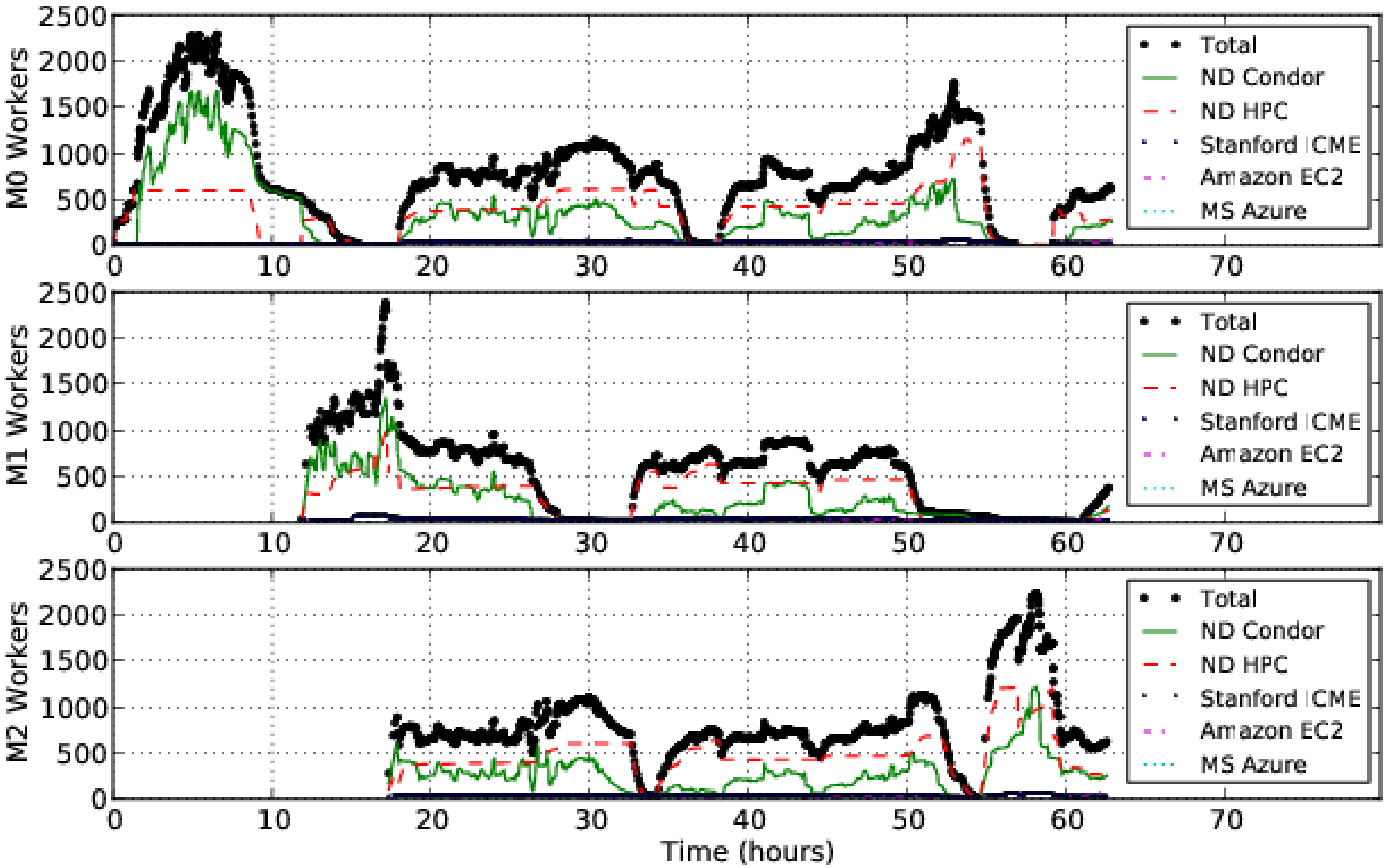


How common is each state?
How does the protein transition between states?
How common are those transitions?

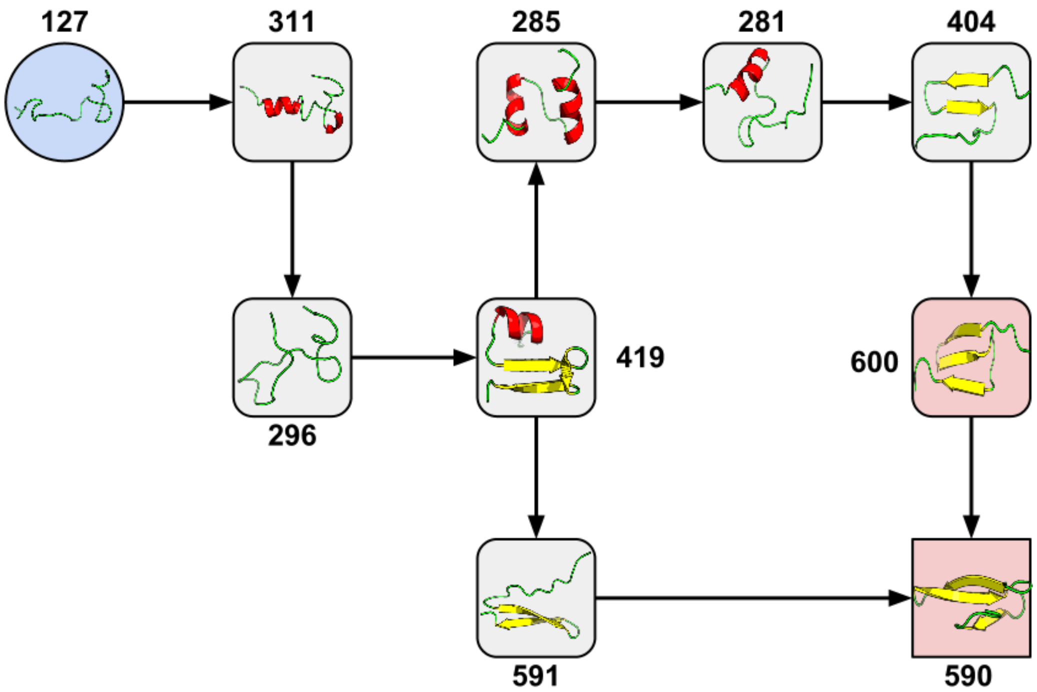
AWE Using Work Queue

- Simplified Algorithm:
  - Submit N short simulations in various states.
  - Wait for them to finish.
  - When done, record all state transitions.
  - If too many are in one state, redistribute them.
  - Stop if enough data has been collected.
  - Continue back at step 2.

AWE on Clusters, Clouds, and Grids



New Pathway Found!



Credit: Joint work in progress with Badi Abdul-Wahid, Dinesh Rajan, Haoyun Feng, Jesus Izaguirre, and Eric Darve.

Software as a Social Lever

- User and app accustomed to a particular system with standalone executables.
- Introduce Makeflow as an aid for expression, debugging, performance monitoring.
- When ready, use Makeflow + Work Queue to gain more direct control of I/O operations on the existing cluster.
- When ready, deploy Work Queue to multiple systems across the wide area.
- When ready, write new apps to target the Work Queue API directly.

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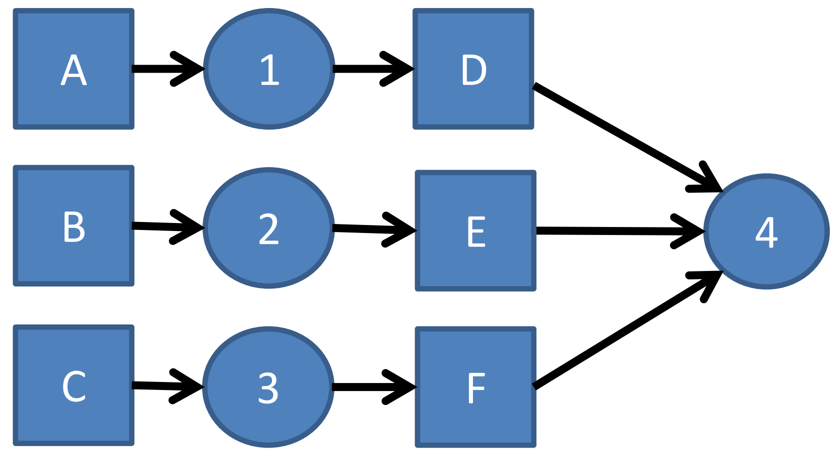
Scalable Computing Model

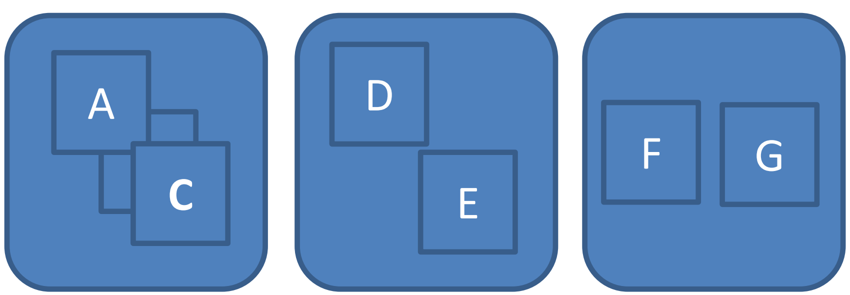
Makeflow



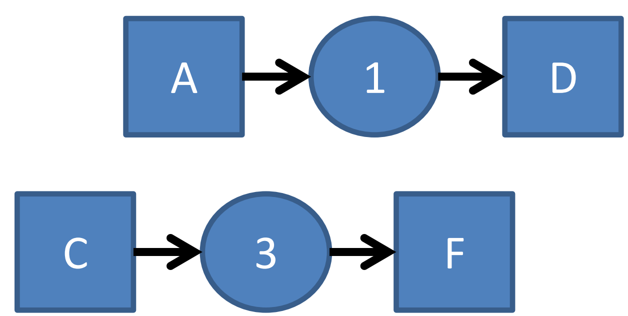
Weaver

for x in list f(g(x))

Shared-Nothing Cluster



Work Queue

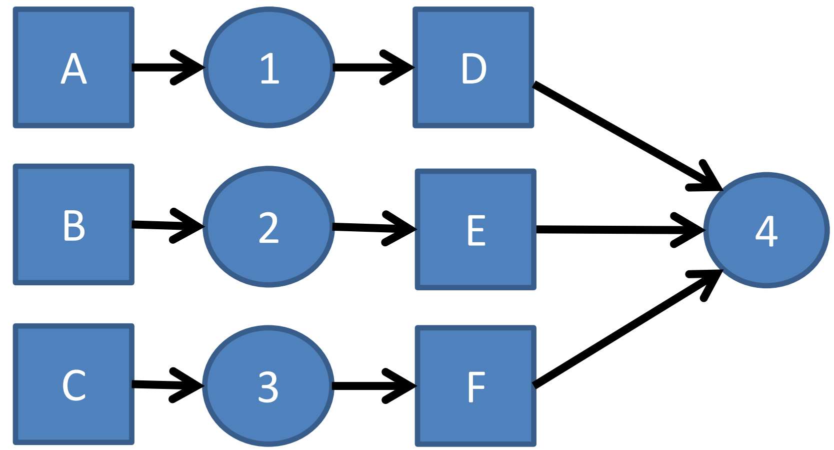


Scalable Computing Model

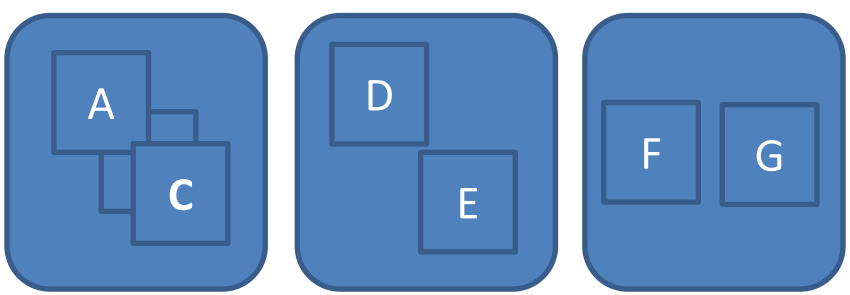
Declarative Language

for x in list f(g(x))

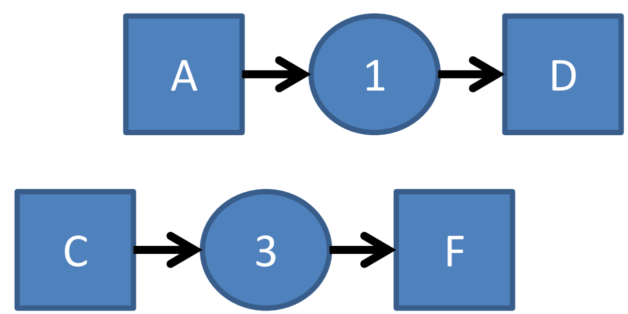
Dependency Graph



Shared-Nothing Cluster



Independent Tasks



Convergence of Worlds

- Scientific Computing
  - Weaver, Makeflow, Work Queue, Cluster
  - Pegasus, DAGMan, Condor, Cluster
  - Swift-K, (?), Karajan, Cluster
- High Performance Computing
  - SMPSS->JDF->DAGue->NUMA Architecture
  - Swift-T, (?), Turbine, MPI Application
- Databases and Clouds
  - Pig, Map-Reduce, Hadoop, HDFS
  - JSON, Map-Reduce, MongoDB, Storage Cluster
  - LINQ, Dryad, Map-Reduce, Storage Cluster

Thoughts on the Layers

- Declarative languages.
  - Pros: Compact, expressive, easy to use.
  - Cons: Intractable to analyze in the general case.
- Directed graphs.
  - Pros: Finite structures with discrete components are easily analyzed.
  - Cons: Cannot represent dynamic applications.
- Independent tasks and data.
  - Pros: Simple submit/wait APIs, data dependencies can be exploited by layers above below.
  - Cons: In most general case, scheduling is intractable.
- Shared-nothing clusters.
  - Pros: Can support many disparate systems. Performance is readily apparent.
  - Cons: requires knowledge of dependencies.

Common Model of Compilers

- Scanner detects single tokens.
  - Finite state machine is fast and compact.
- Parser detects syntactic elements.
  - Grammar + push down automata. LL(k), LR(k)
- Abstract syntax tree for semantic analysis.
  - Type analysis and high level optimization.
- Intermediate Representation
  - Register allocation and low level optimization.
- Assembly Language
  - Generated by tree-matching algorithm.

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  - **Transaction Granularity**
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  - **Resource Management**
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Observation:

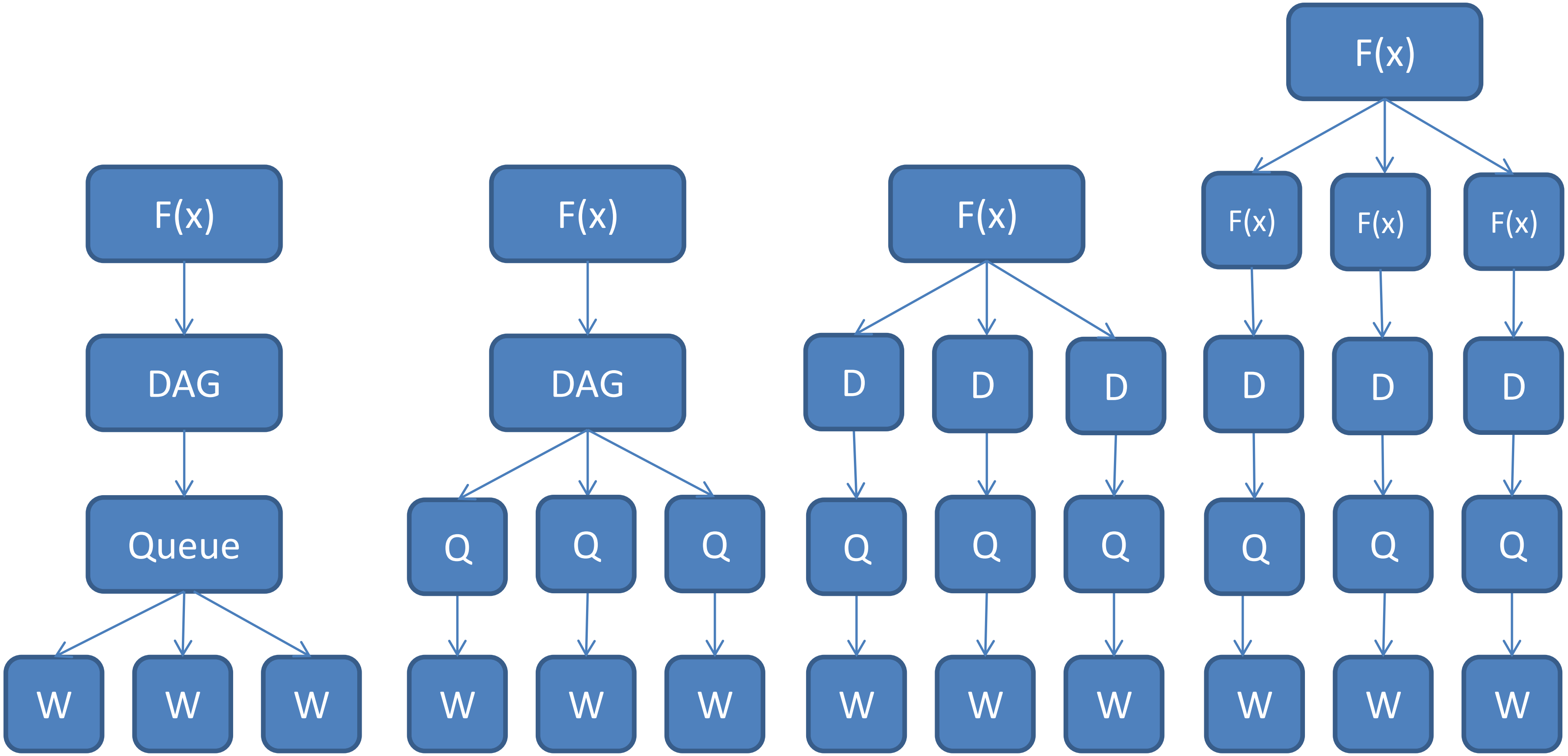
Generating parallelism is easy but making it ***predictable*** is hard!

Challenge: Transaction Granularity

- Commit every action to disk. (Condor)
  - \+ Makes recovery from any point possible.
  - \- Significant overhead on small tasks.
- Commit only completed tasks to disk. (Falkon)
  - \- Cannot recover tasks in progress after a failure.
  - \+ Fast for very small tasks.

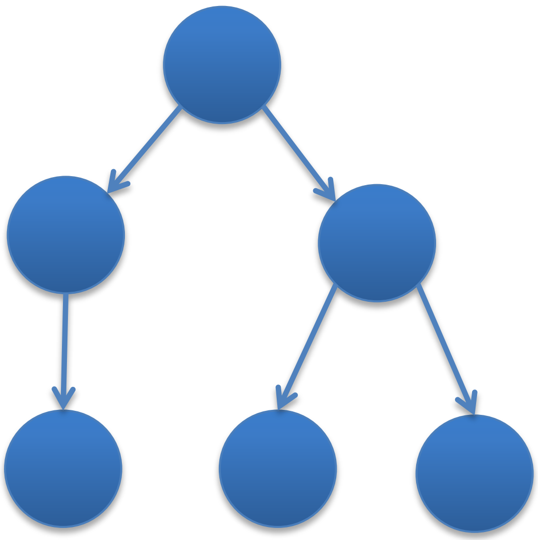
- Extreme: Commit only completed DAG.
- Problem: Choice changes with workload!

Challenge: Where to Parallelize?

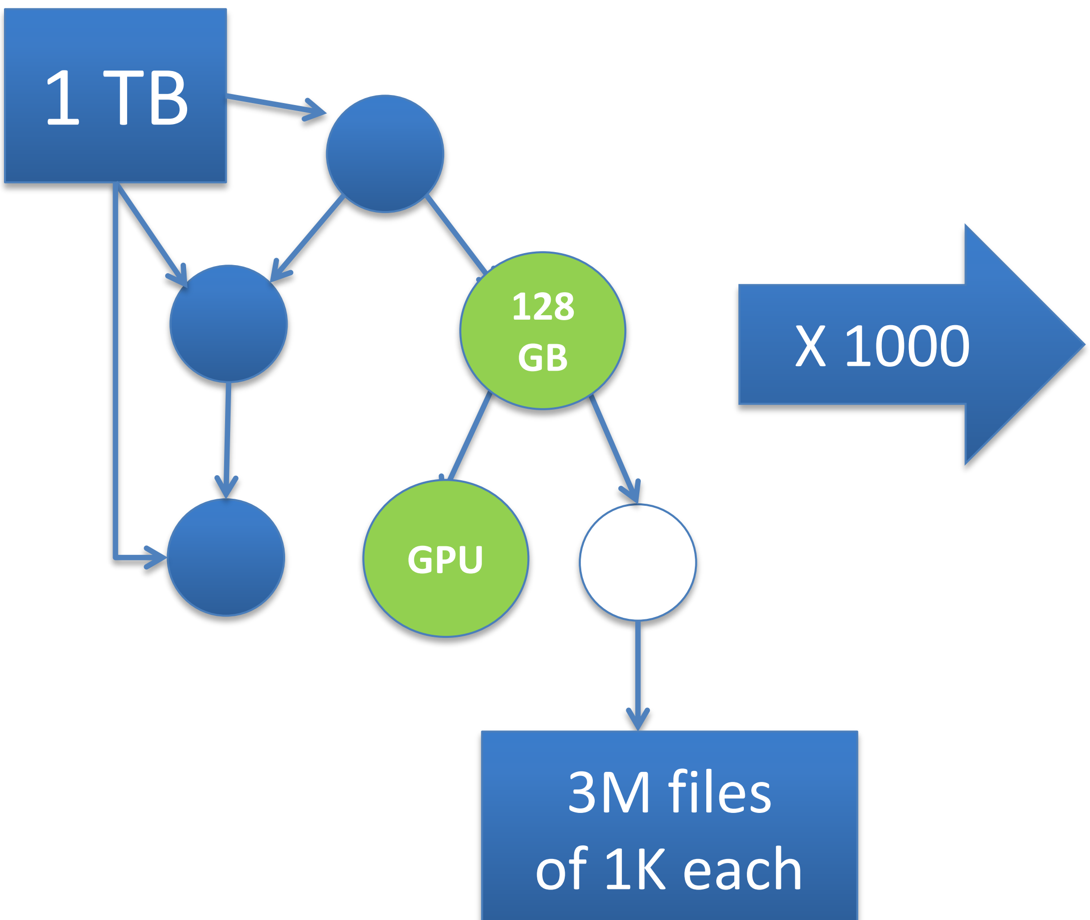


Challenge: Resource Management

The Ideal Picture



What actually happens:



Some reasonable questions:

- Will this workload **at all** on machine X?
- How many workloads can I run simultaneously without running out of storage space?
- Did this workload actually behave as expected when run on a new machine?
- How is run X different from run Y?
- If my workload wasn't able to run on this machine, where can I run it?

End users have **no idea** what resources their applications actually need.

and…

Computer systems are **terrible** at describing their capabilities and limits.

and…

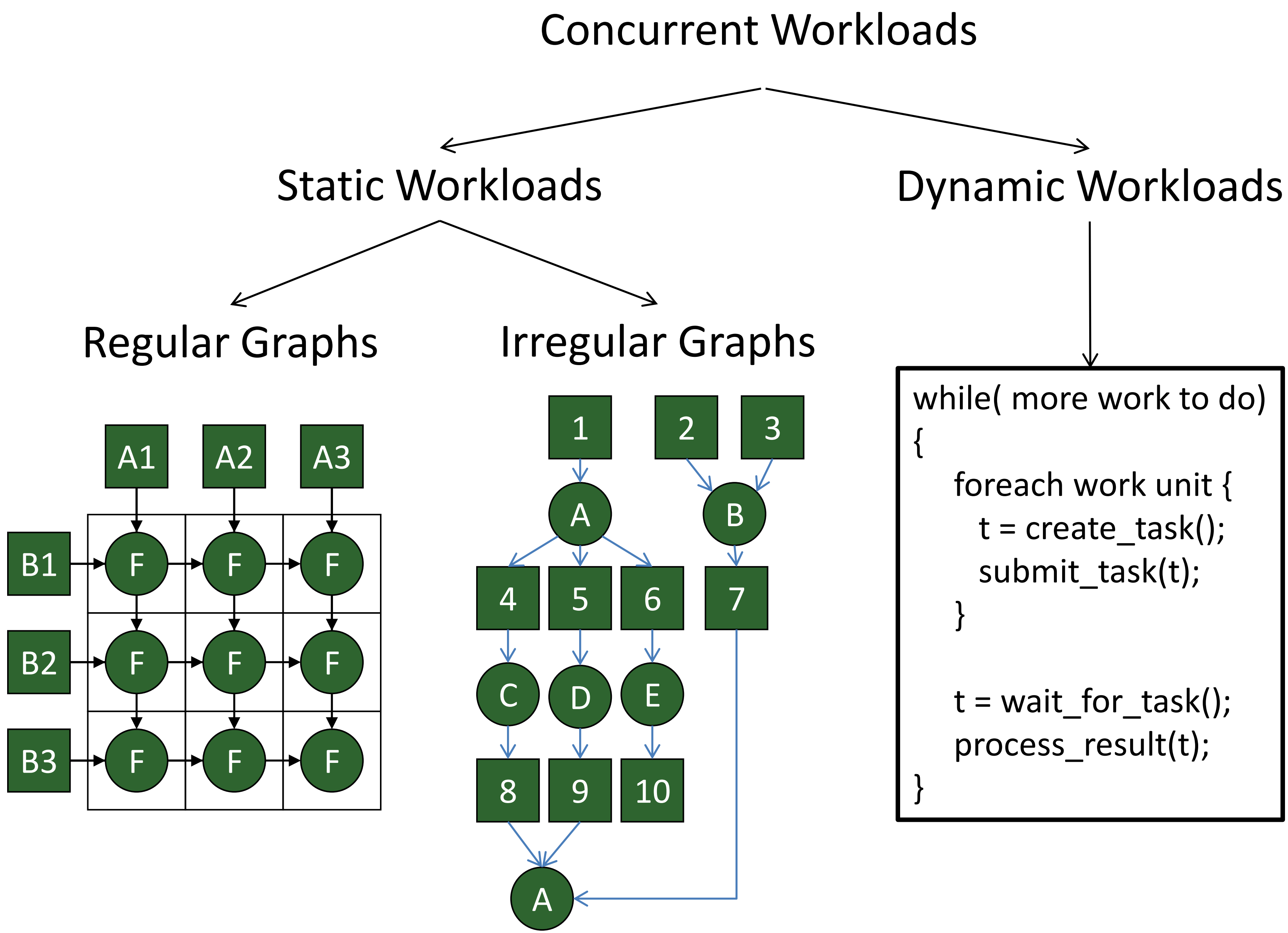
They don’t know when to say **NO**.

dV/dt : **Accelerating the Rate of Progress Towards Extreme Scale Collaborative Science**

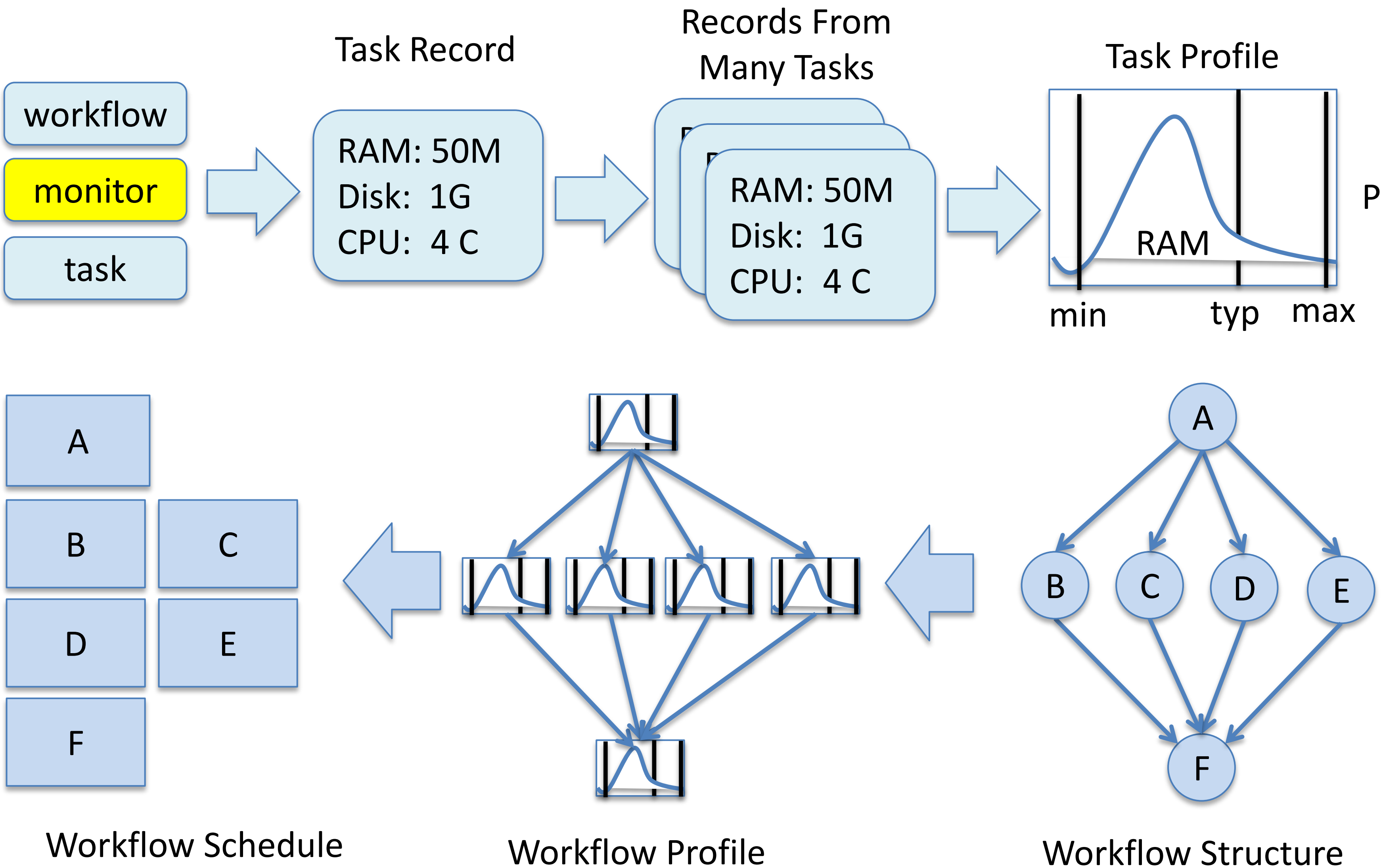
Miron Livny (UW), Ewa Deelman (USC/ISI), Douglas Thain (ND), Frank Wuerthwein (UCSD), Bill Allcock (ANL)

… make it easier for scientists to conduct large-scale computational tasks that use the power of computing resources they do not own to process data they did not collect with applications they did not develop …

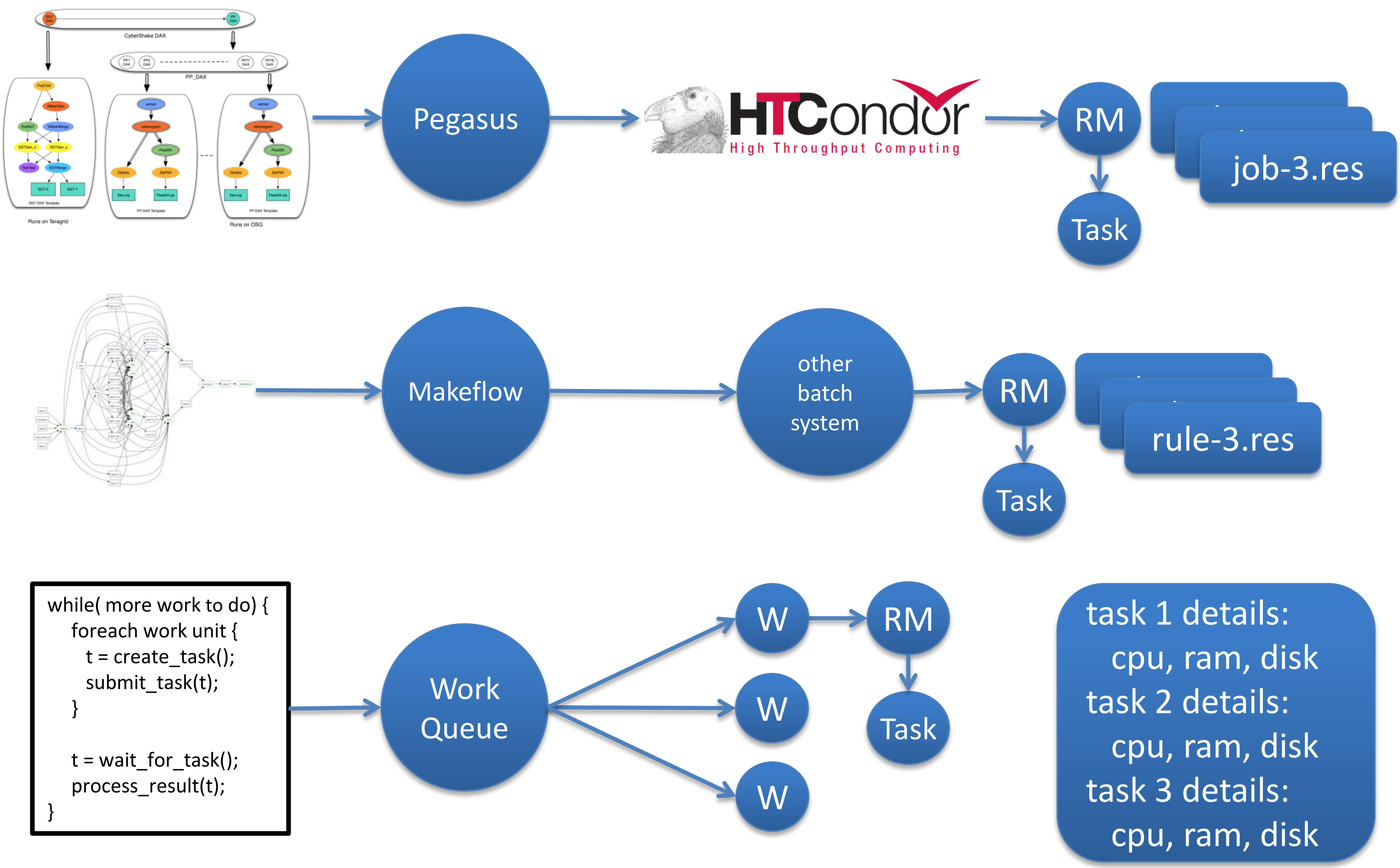
Categories of Applications



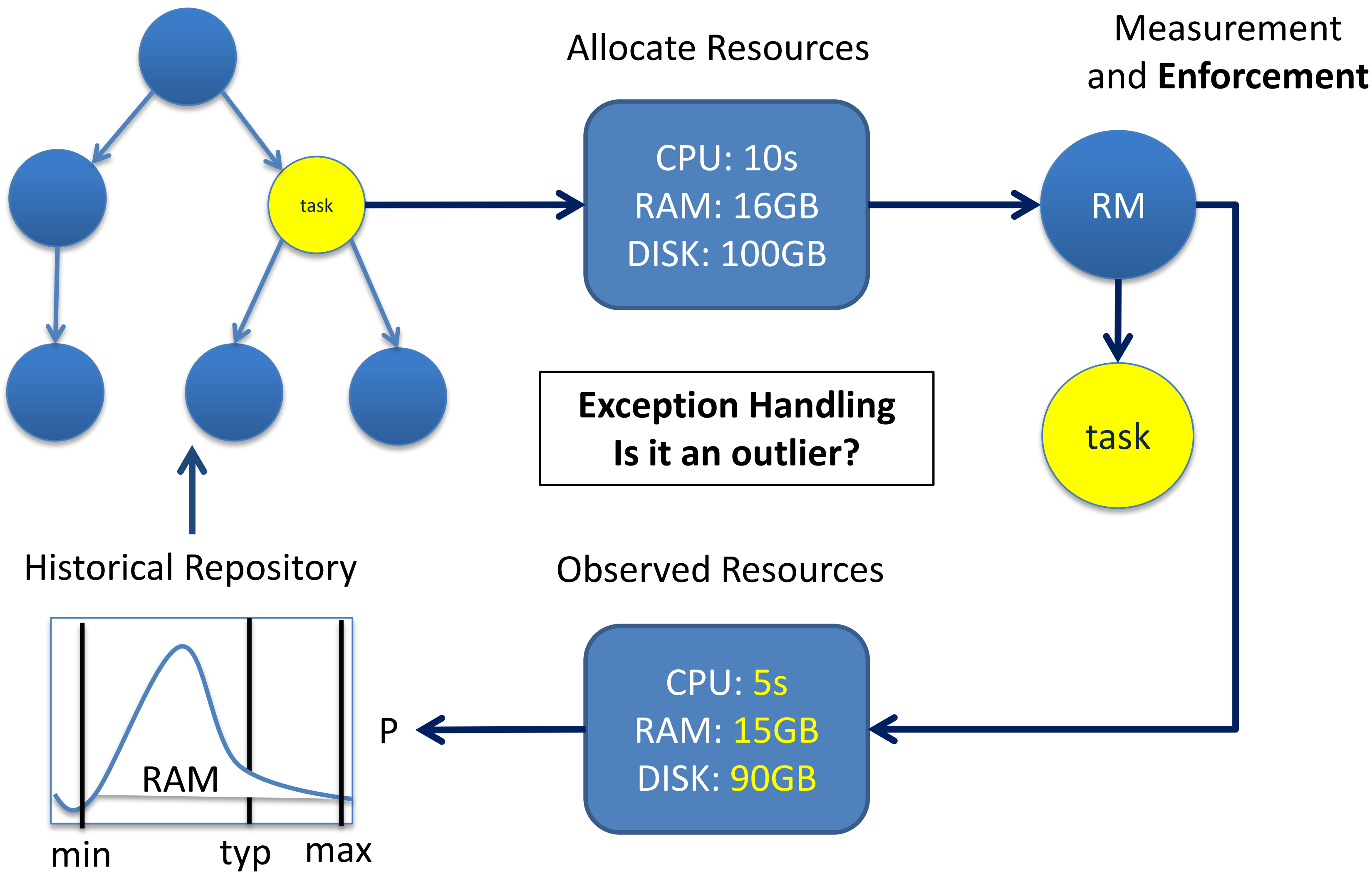
Data Collection and Modeling



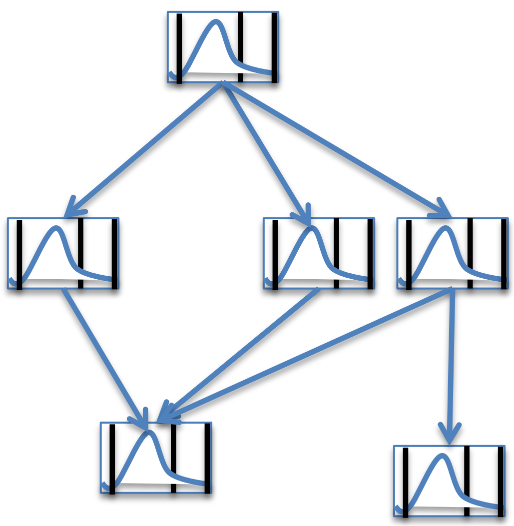
Portable Resource Management



Completing the Cycle



Complete Workload Characterization



128 GB
32 cores

X 1

16 GB
4 cores

X 10

12 hours
500 Gb/s I/O

128 GB
32 cores

X 1

16 GB
4 cores

X 100

1 hour
5 Tb/s I/O

X 1000

We can approach the question:
Can it run on this particular machine?
What machines could it run on?

At what levels of the model can resource management be done?

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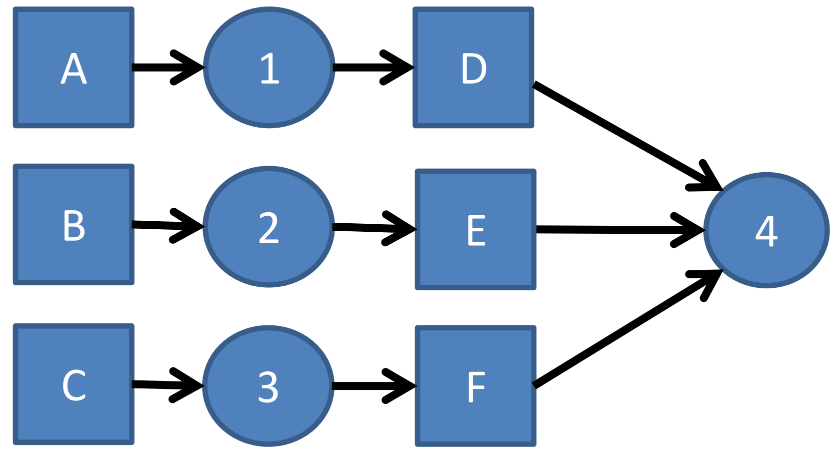

Weaver

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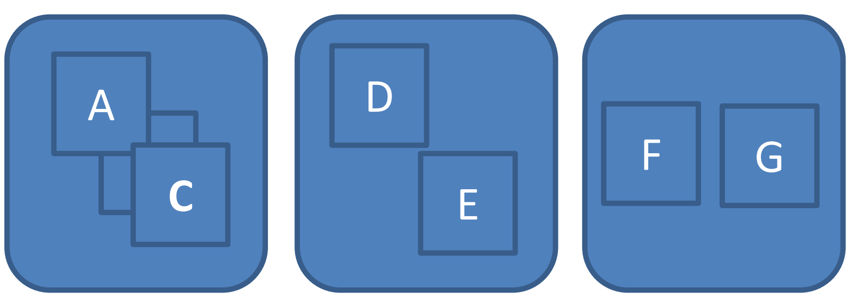
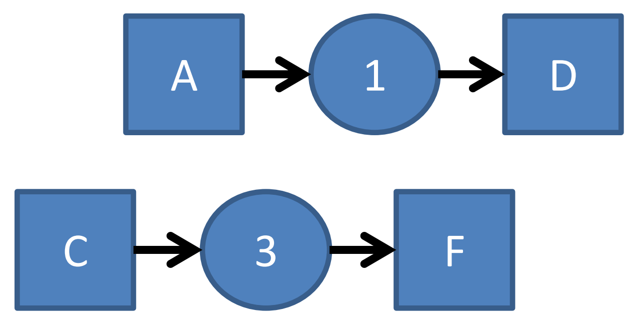
Work Queue Workers



Work Queue Master



An exciting time to work
in distributed systems!

Talks by CCL Students This Weekend

- Casey Robinson,
  Automated Packaging of Bioinformatics Workflows for Portability and Durability Using Makeflow,
  WORKS Workshop, 4pm on Sunday.
- Patrick Donnelly,
  Design of an Active Storage Cluster File System for DAG Workflows,
  DISCS Workshop on Monday.

Acknowledgements

dV/dT Project PIs

- Bill Allcock (ALCF)
- Ewa Deelman (USC)
- Miron Livny (UW)
- Frank Weurthwein (UCSD)

CCL Staff

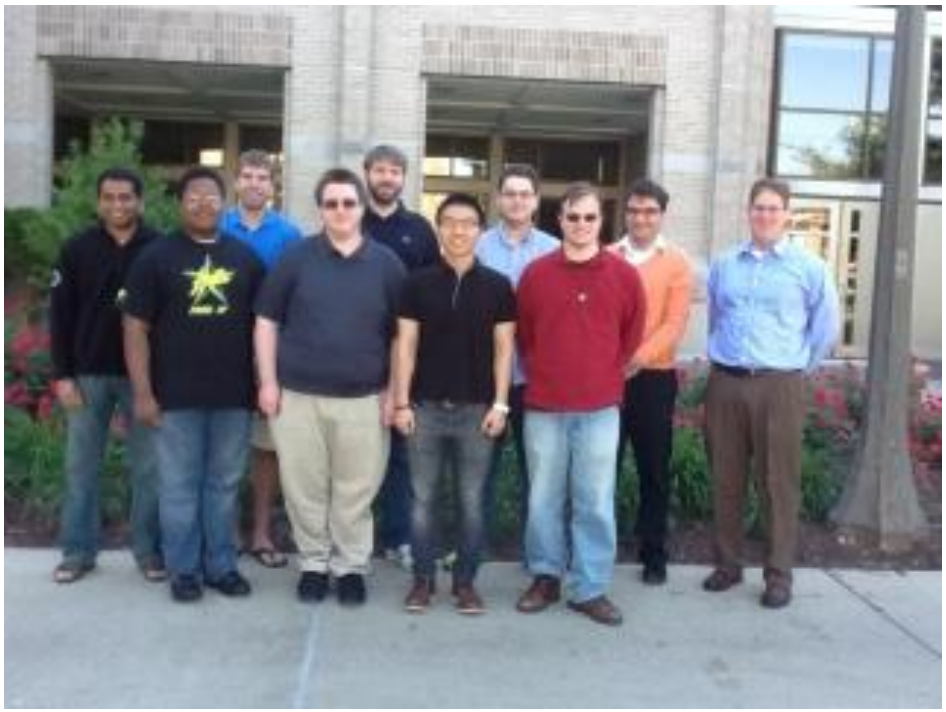
- Ben Tovar

CCL Graduate Students:

- Michael Albrecht
- Patrick Donnelly
- Dinesh Rajan
- Casey Robinson
- Peter Sempolinski
- Nick Hazekamp
- Haiyan Meng
- Peter Ivie

The Cooperative Computing Lab

University of Notre Dame



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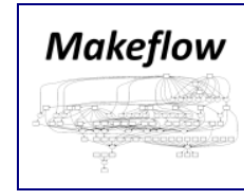
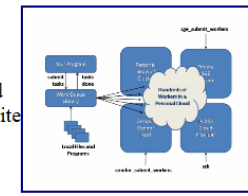
Makeflow

Makeflow is a workflow system for parallel and distributed computing that uses a language very similar to Make. Using Makeflow, you can write simple scripts that easily execute on hundreds or thousands of machines.



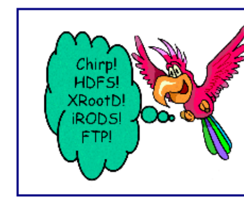
Work Queue

Work Queue is a system and library for creating and managing scalable master-worker style programs that scale up to thousands machines on clusters, clouds, and grids. Work Queue programs are easy to write in C, Python or Perl.



Parrot

Parrot is a transparent user-level virtual filesystem that allows any ordinary program to be attached to many different remote storage systems, including HDFS, iRODS, Chirp, and FTP.



Chirp

Chirp is a personal user-level distributed filesystem that allows unprivileged users to share space securely, efficiently, and conveniently. When combined with Parrot, Chirp allows users to create custom wide-area distributed filesystems.