Using Condor
An Introduction

Condor Week 2011

Condor Project
Computer Sciences Department
University of Wisconsin-Madison

The Condor Project (Established '85)

- Research and Development in the Distributed High Throughput Computing field
- Our team of ~35 faculty, full time staff, and students
  - face software engineering challenges in a distributed UNIX/Linux/NT environment.
  - are involved in national and international grid collaborations.
  - actively interact with academic and commercial entities and users.
  - maintain and support large, distributed, production environments.
  - educate and train students.

The Condor Team

Some Free Software produced by the Condor Project

- Condor System
- VDT
- Metronome
- ClassAd Library
- DAGMan
- CCB
- Master Worker (MW)

And others… all as Open Source

- Licensed under the Apache License, Version 2.0
- OSI Approved
- Free as in Beer, Free as in Speech

High-Throughput Computing

- Allows for many computational tasks to be done over a long period of time
- Is concerned largely with the number of compute resources that are available to people who wish to use the system
- A very useful system for researchers and other users who are more concerned with the number of computations they can do over long spans of time, than they are with short-burst computations

Condor

What is Condor?

- Classic High-Throughput Computing system
- An integral part of many computational grids around the world

Full featured system

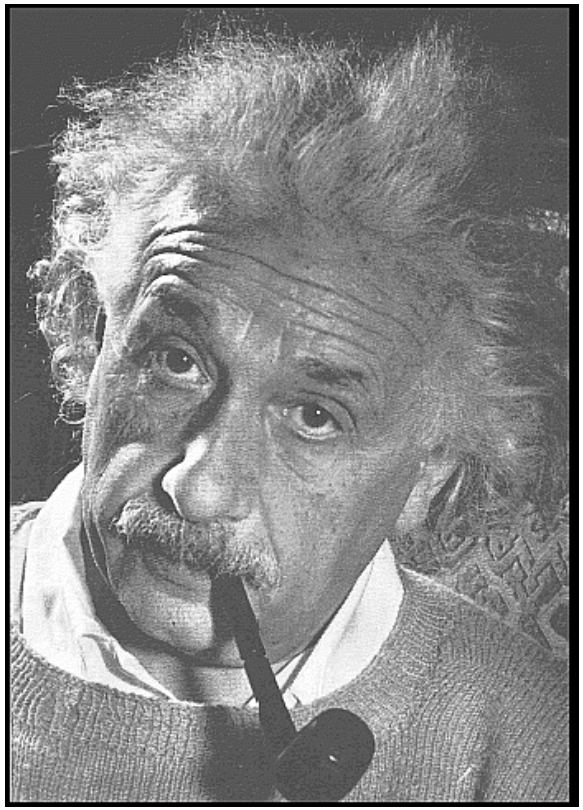
- Flexible scheduling policy engine via ClassAds
  - Preemption, suspension, requirements, preferences, groups, quotas, settable fair-share, system hold…
- Facilities to manage *both* dedicated CPUs (clusters) and non-dedicated resources (desktops)
- Transparent Checkpoint/Migration for many types of serial jobs
- No shared file system required
- Federate clusters with a wide array of Grid Middleware

More features

- Workflow management (inter-dependencies)
- Support for many job types: serial, parallel, etc.
- Fault-tolerant: can survive crashes, network outages, any single point of failure.
- Development APIs: via SOAP / web services, DRMAA (C), Perl package, GAHP, flexible command-line tools, MW
- Supported platforms:
  - Linux on i386 / X86-64
  - Windows XP / Vista / 7
  - MacOS X

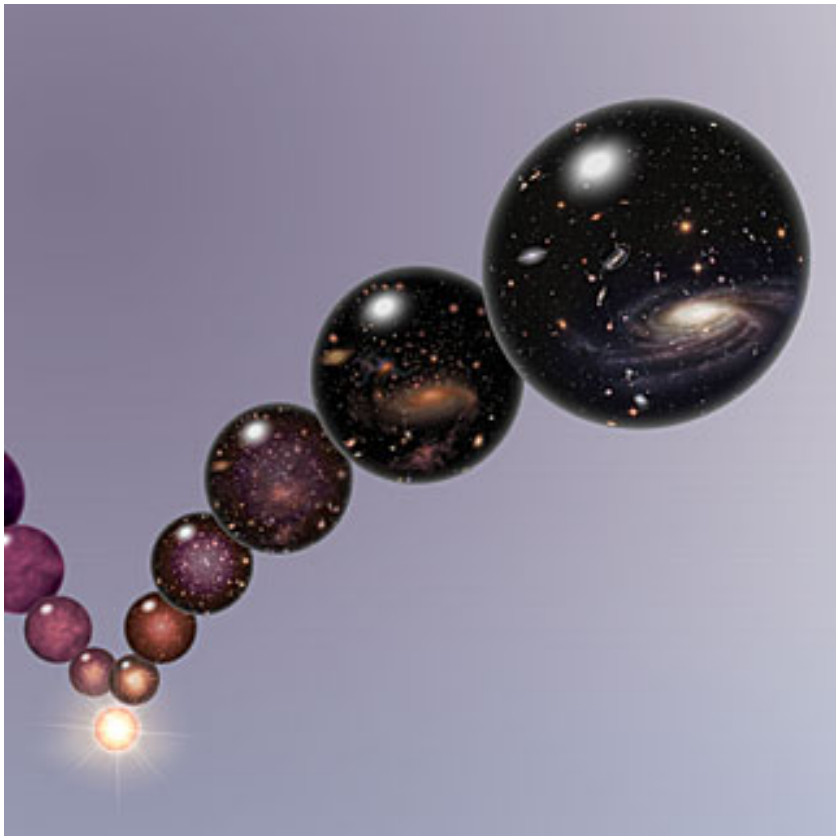
The Problem

Our esteemed scientist, while visiting Madison, needs to run a *small* * simulation.



* Depends on your definition of "small"

Einstein's Simulation



Simulate the evolution of the cosmos, with various properties.

The Simulation Details

Varying values for each of:

- G (the gravitational constant): 100 values
- $\mathcal{R}_{\mu\nu}$ (the cosmological constant): 100 values
- c (the speed of light): 100 values

`100 × 100 × 100 = 1,000,000 jobs`

Running the Simulation

Each point (job) within the simulation:

- Requires up to 4GB of RAM
- Requires 20MB of input
- Requires 2 – 500 hours of computing time
- Produces up to 10GB of output

Estimated total:

- 15,000,000 hours!
- 1,700 compute YEARS
- 10 Petabytes of output

NSF didn't fund the requested Blue Gene

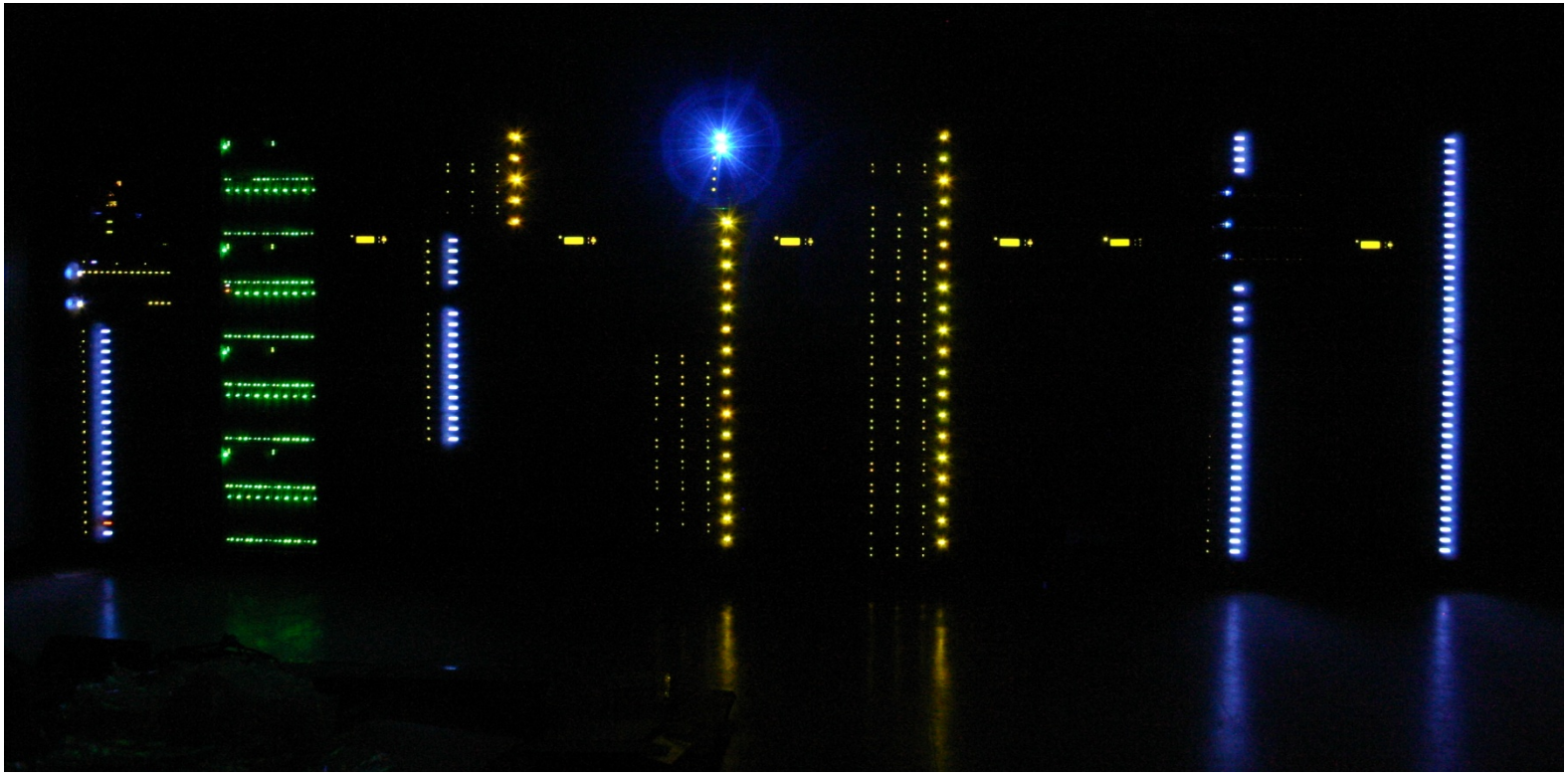
While sharing a beverage with some colleagues, Carl asks "Have you tried Condor? It's free, available for you to use, and you can use our CHTC pool. Condor has been used to run billions and billions of jobs."

CHTC

Center for High Throughput Computing

- Approved in August 2006
- Numerous resources at its disposal to keep up with the computational needs of UW-Madison
- These resources are being funded by:
  - National Institute of Health (NIH)
  - Department of Energy (DOE)
  - National Science Foundation (NSF)
  - Various grants from the University itself

B240
One of the CTHC Clusters



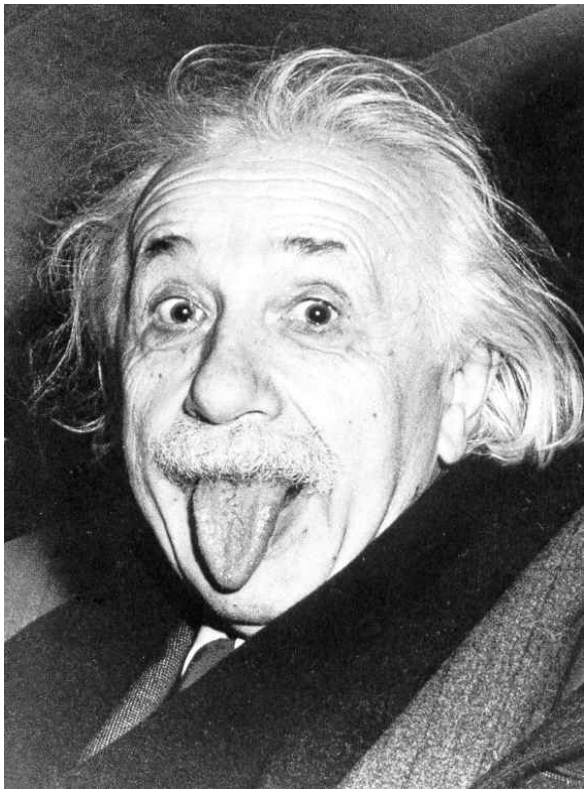
But... will my jobs be safe?

- No worries!!
  - Jobs are queued in a safe way
    - More details later
  - Condor will make sure that your jobs run, return output, etc.
    - You can even specify what defines "OK"
- Like money in the (FDIC insured) bank

Condor will ...

- Keep an eye on your jobs and will keep you posted on their progress
- Implement your policy on the execution order of the jobs
- Log your job's activities
- Add fault tolerance to your jobs
- Implement your policy as to when the jobs can run on your workstation

Condor Doesn't Play Dice with My Universes!



Definitions

- Job
  - The Condor representation of your work
  - Condor's quanta of work
  - Like a Unix process
  - Can be an element of a workflow
- ClassAd
  - Condor's internal data representation
- Machine or Resource
  - The Condor representation of computers that can do the processing

More Definitions

- Match Making
  - Associating a job with a machine resource
- Central Manager
  - Central repository for the whole pool
  - Does match making
- Submit Host
  - The computer from which you submit your jobs to Condor
- Execute Host
  - The computer that actually runs your job

Jobs Have Wants & Needs

- Jobs state their requirements and preferences:
  - Requirements:
    - I **require** a Linux x86-64 platform
  - Rank (Preferences):
    - I **prefer** the machine with the most memory
    - I **prefer** a machine in the chemistry department

Machines Do Too!

- Machines specify:
  - Requirements:
    - **Require** that jobs run only when there is no keyboard activity
    - **Never** run jobs belonging to Dr. Heisenberg
  - Rank (Preferences):
    - I **prefer** to run Albert's jobs
  - Custom Attributes:
    - I am a machine in the physics department

Condor ClassAds

What is a ClassAd?

- Condor's internal data representation
  - Similar to a classified ad in a paper
    - Their namesake
  - Represent an object & its attributes
    - Usually many attributes
  - Can also describe what an object matches with

ClassAd Types

- Condor has many types of ClassAds
  - A Job ClassAd represents a job to Condor
  - A Machine ClassAd represents the various compute resources within the Condor pool
  - Other ClassAds represent other pieces of the Condor pool

ClassAds Explained

- ClassAds can contain a lot of details
  - The job's executable is `"cosmos"`
  - The machine's load average is 5.6
- ClassAds can specify requirements
  - My job requires a machine with Linux
- ClassAds can specify rank
  - This machine prefers to run jobs from the physics group

ClassAd Structure

- ClassAds are:
  - semi-structured
  - user-extensible
  - schema-free
- ClassAd contents:
  - Attribute = Value

  or
  - Attribute = Expression

The Pet Exchange

Pet Ad

```
Type   = "Dog"
Color = "Brown"
Price = 75
Sex = "Male"
AgeWeeks = 8
Breed = "Saint Bernard"
Size = "Very Large"
Weight = 30
Name = "Ralph"
```

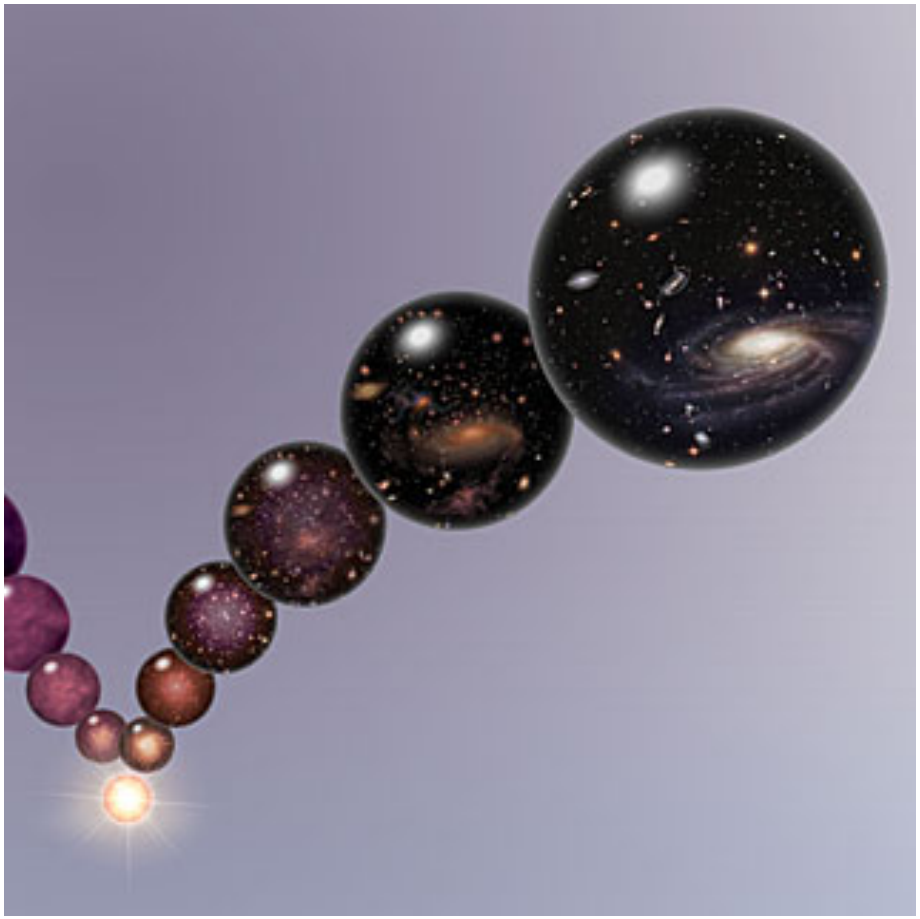
Buyer Ad

```
. . .
Requirements =
  (Type == "Dog")      &&
  (Price <= 100)       &&
  ( Size == "Large" ||
    Size == "Very Large" )
Rank =
  (Breed == "Saint Bernard")
. . .
```

The Magic of Matchmaking

- The Condor match maker matches Job Ads with Machine Ads, taking into account:
  - Requirements
    - Enforces both machine *and* job requirements expressions
  - Preferences
    - Considers both job *and* machine rank expressions
  - Priorities
    - Takes into account user and group priorities

Back to Albert's simulation...



Getting Started:

1. Get access to submit host
2. Make sure your program runs stand-alone
3. Choose a universe for your job
4. Make your job batch-ready
   - Includes making your data available to your job
5. Create a submit description file
6. Run `condor_submit` to put the job(s) in the queue
7. Relax while Condor manages and watches over your job(s) for you

1. Access to CHTC (UW Specific)

- Send email to **chtc@cs.wisc.edu**
- An account will be set up for you
- **ssh** into our submit head node:
  - From Unix / Linux:
    - **ssh einstein@submit.chtc.wisc.edu**
  - From Windows:
    - Install Putty or similar SSH client
    - Use Putty to ssh into **submit.chtc.wisc.edu**

If You're not at UW…

- Work with your Condor Administrator to get access
- Login to your Condor submit host…

2. Make Sure Your Program Runs stand-alone

- Before you try to submit your program to Condor, you should verify that it runs on it's own.
- Log into the submit node, and try to run your program (by hand) there.
- If it doesn't work here, it's not going to work under Condor!

3. Choose the Universe

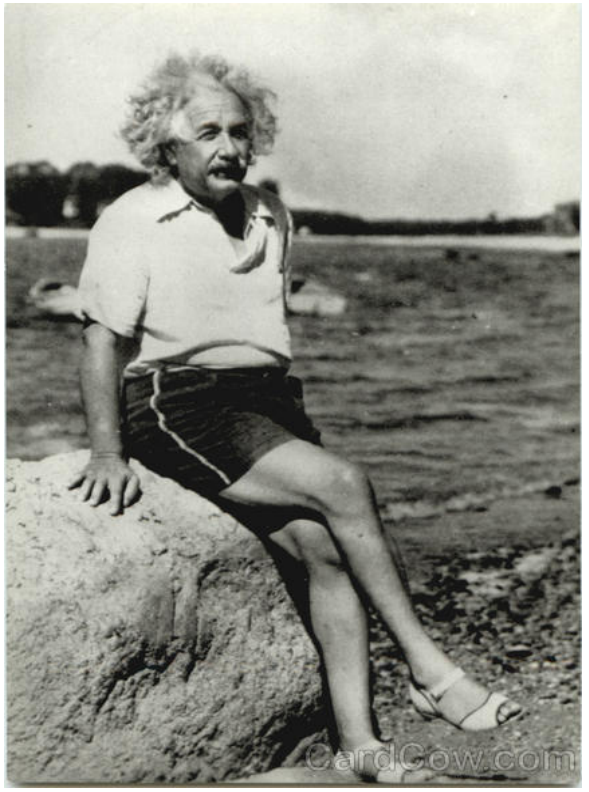
- Controls how Condor handles jobs
- Condor's many universes include:
  - vanilla
  - standard
  - grid
  - java
  - parallel
  - vm

Using the Vanilla Universe

- Allows running almost any "serial" job
- Provides automatic file transfer, etc.
- Like vanilla ice cream
  - Can be used in just about any situation

4. Make the job batch-ready

- Must be able to run in the background
- No interactive input
- No GUI/window clicks
  - We don't need no stinkin' mouse!
- No music ;^)



Batch-Ready: Standard Input & Output

- Job can still use **STDIN**, **STDOUT**, and **STDERR** (the keyboard and the screen), but files are used for these instead of the actual devices
- Similar to Unix shell:

```
$ ./myprogram <input.txt >output.txt
```

Make your Data Available

- Condor can
  - Transfer data files *to* your job
  - Transfer results files *back from* your job
- You need to place your data files in a place where Condor can access them

5. Create a Submit Description File

- Most people just call it a "submit file"
- A plain ASCII text file
- Condor does ***not*** care about file extensions
  - Many use `.sub` or `.submit` as suffixes
- Tells Condor about the job:
  - Executable to run
  - The Job's Universe
  - Input, output and error files to use
  - Command-line arguments, environment variables
  - Job requirements and/or rank expressions (more on this later)
- Can describe many jobs at once (a cluster), each with different input, arguments, output, etc.

Input, output & error files

- Controlled by the submit file settings
- Read job's standard input from `in_file`:
  - `Input = in_file.txt`
  - Shell: `$ program < in_file.txt`
- Write job's standard output to `out_file`:
  - `Output  = out_file.txt`
  - Shell: `$ program > out_file.txt`
- Write job's standard error to `error_file`:
  - `Error = error_file.txt`
  - Shell: `$ program 2> error_file.txt`

Simple Submit Description File

```
# simple submit description file
# (Lines beginning with # are comments)
# NOTE: the words on the left side are not
#   case sensitive, but filenames are!

Universe   = vanilla
Executable = cosmos       Job's executable
Input      = cosmos.in    Job's STDIN
Output     = cosmos.out   Job's STDOUT
Log        = cosmos.log   Log the job's activities
Queue                     Put the job in the queue
```

Logging the Job's Activities

- Creates a log of job events
- In the submit description file:

```
log = cosmos.log
```

- The Life Story of a Job
  - Shows all events in the life of a job
- Always have a log file

Sample Job Log

```
000 (0101.000.000) 05/25 19:10:03 Job submitted from host:
<128.105.146.14:1816>
...
001 (0101.000.000) 05/25 19:12:17 Job executing on host:
<128.105.146.14:1026>
...
005 (0101.000.000) 05/25 19:13:06 Job terminated.
    (1) Normal termination (return value 0)
...
```

6. Submit the Job to Condor

- Run `condor_submit`:
  - Provide the name of the submit file :

```
$ condor_submit cosmos.sub
```

- `condor_submit`:
  - Parses the submit file, checks for errors
  - Creates one or more job ClassAd(s) that describes your job(s)
  - Hands the job ClassAd(s) off to the Condor scheduler daemon

The Job ClassAd

```
MyType          = "Job"
TargetType      = "Machine"
ClusterId       = 1
ProcId          = 0
IsPhysics       = True
Owner           = "einstein"
Cmd             = "cosmos"
Requirements    = (Arch == "INTEL")
.
.
.
```

String

Integer

Boolean

Boolean Expression

Submitting The Job

```
[einstein@submit ~]$ condor_submit cosmos.sub
Submitting job(s).
1 job(s) submitted to cluster 100.
[einstein@submit ~]$ condor_q
-- Submitter: submit.chtc.wisc.edu : <128.104.55.9:51883> : submit.chtc.wisc.edu
 ID          OWNER            SUBMITTED     RUN_TIME ST PRI SIZE CMD
1.0          sagan           7/22 14:19 172+21:28:36 H  0   22.0 checkprogress.cron
2.0          heisenberg      1/13 13:59   0+00:00:00 I  0   0.0  env
3.0          hawking         1/15 19:18   0+04:29:33 H  0   0.0  script.sh
4.0          hawking         1/15 19:33   0+00:00:00 H  0   0.0  script.sh
5.0          hawking         1/15 19:33   0+00:00:00 H  0   0.0  script.sh
6.0          hawking         1/15 19:34   0+00:00:00 H  0   0.0  script.sh
...
96.0         bohr            4/5  13:46   0+00:00:00 I  0   0.0  c2b_dops.sh
97.0         bohr            4/5  13:46   0+00:00:00 I  0   0.0  c2b_dops.sh
98.0         bohr            4/5  13:52   0+00:00:00 I  0   0.0  c2b_dopc.sh
99.0         bohr            4/5  13:52   0+00:00:00 I  0   0.0  c2b_dopc.sh
100.0        einstein        4/5  13:55   0+00:00:00 I  0   0.0  cosmos

557 jobs; 402 idle, 145 running, 10 held
```

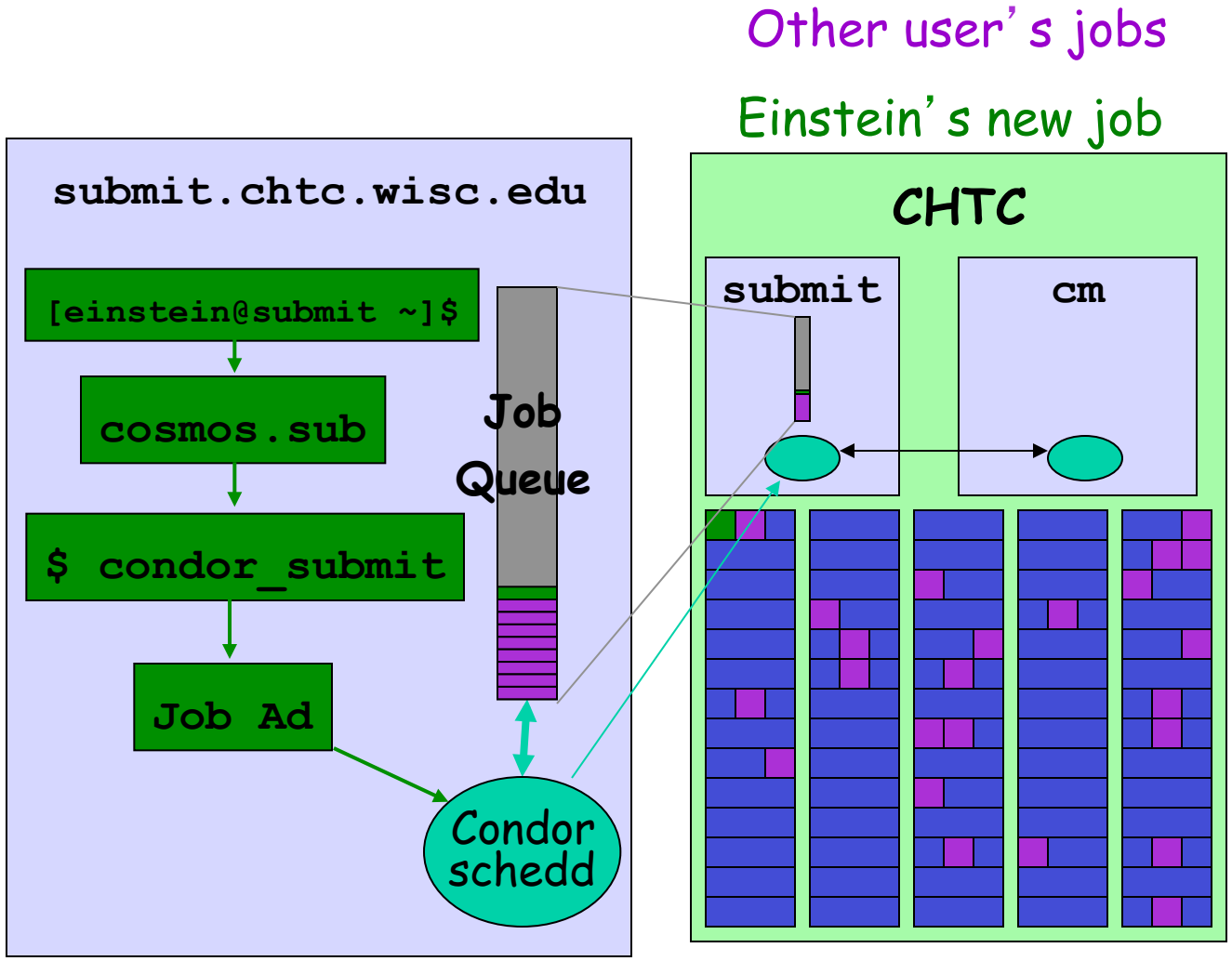
The Job Queue

- `condor_submit` sends the job's ClassAd(s) to the schedd (a daemon)
- The schedd (more details later):
  - Manages the local job queue
  - Stores the job in the job queue
    - Atomic operation, two-phase commit
    - "Like money in the (*FDIC insured*) bank"
- View the queue with `condor_q`

Baby Steps

- Wait for your **one** job to complete
  - It won't run any faster than it does running it by hand
- Verify that your job performed as expected:
  - Look at the standard output and error files
  - Examine any other results files
- Problems?
  - Look in the job log for hints

CHTC Condor Pool



File Transfer

- If your job needs data files, you'll need to have Condor transfer them for you
- Likewise, Condor can transfer results files back for you
- You need to place your data files in a place where Condor can access them
- Sounds Great! What do I need to do?

Specify File Transfer Lists

In your submit file:

- **`Transfer_Input_Files`**
  - List of files for Condor to transfer from the submit machine to the execute machine
- **`Transfer_Output_Files`**
  - List of files for Condor to *transfer back from* the execute machine to the submit machine
  - If not specified, Condor will transfer back all "new" files in the execute directory

Condor File Transfer Controls

Should_Transfer_Files

- **YES**: Always transfer files to execution site
- **NO**: Always rely on a shared file system
- **IF_NEEDED**: Condor will automatically transfer the files, if the submit and execute machine are not in the same **FileSystemDomain**
  - Translation: Use shared file system if available

When_To_Transfer_Output

- **ON_EXIT**: Transfer the job's output files back to the submitting machine only when the job completes
- **ON_EXIT_OR_EVICT**: Like above, but also when the job is evicted

File Transfer Example

```
# Example using file transfer
Universe                    = vanilla
Executable                   = cosmos
Log                         = cosmos.log
ShouldTransferFiles         = IF_NEEDED
Transfer_input_files         = cosmos.dat
Transfer_output_files       = results.dat
When_To_Transfer_Output     = ON_EXIT
Queue
```

Transfer Time

- File transfer (both input and output) requires network bandwidth and time
  - Limit the amount of I/O Condor needs to do for your job
  - If your produces 1TB of output, but you only need 10M of it, only bring back the 10M that you need!
  - Less data means shorter data transfer times

Command Line Arguments

In the submit file:

```
arguments = -arg1 -arg2 foo
```

```
# Example with command line arguments
Universe   = vanilla
Executable = cosmos
Arguments  = -c 299792458 -G 6.67300e-112
log        = cosmos.log
Input      = cosmos.in
Output     = cosmos.out
Error      = cosmos.err
Queue
```

InitialDir

- Identifies a directory for file input and output.
- Also provides a directory (on the submit machine) for the user log, when a full path is not specified.
- **Note:** `Executable` is **not** relative to `InitialDir`

```
# Example with InitialDir
Universe   = vanilla
InitialDir = /home/einstein/cosmos/run
Executable = cosmos
Log        = cosmos.log
Input      = cosmos.in
Output     = cosmos.out
Error      = cosmos.err

Transfer_Input_Files=cosmos.dat
Arguments  = -f cosmos.dat
Queue
```

NOT Relative to `InitialDir`

Is Relative to `InitialDir`

Need More Feedback?

- Condor sends email about job events to the submitting user
- Specify one of these in the submit description file:

```
Notification = complete
Notification = never
Notification = error
Notification = always
```

Jobs, Clusters, and Processes

- If the submit description file describes multiple jobs, it is called a cluster
- Each cluster has a cluster number, where the cluster number is unique to the job queue on a machine
- Each individual job within a cluster is called a process, and process numbers always start at zero
- A Condor Job ID is the cluster number, a period, and the process number (i.e. 2.1)
  - A cluster can have a single process
    - Job ID = 20.0 - **Cluster 20, process 0**
  - Or, a cluster can have more than one process
    - Job IDs: 21.0, 21.1, 21.2 - **Cluster 21, process 0, 1, 2**

Submit File for a Cluster

```
# Example submit file for a cluster of 2 jobs
# with separate input, output, error and log files
Universe   = vanilla
Executable = cosmos

Arguments  = -f cosmos_0.dat
log        = cosmos_0.log
Input      = cosmos_0.in
Output     = cosmos_0.out
Error      = cosmos_0.err
Queue                  ·Job 102.0 (cluster 102, process 0)

Arguments  = -f cosmos_1.dat
log        = cosmos_1.log
Input      = cosmos_1.in
Output     = cosmos_1.out
Error      = cosmos_1.err
Queue                  ·Job 102.1 (cluster 102, process 1)
```

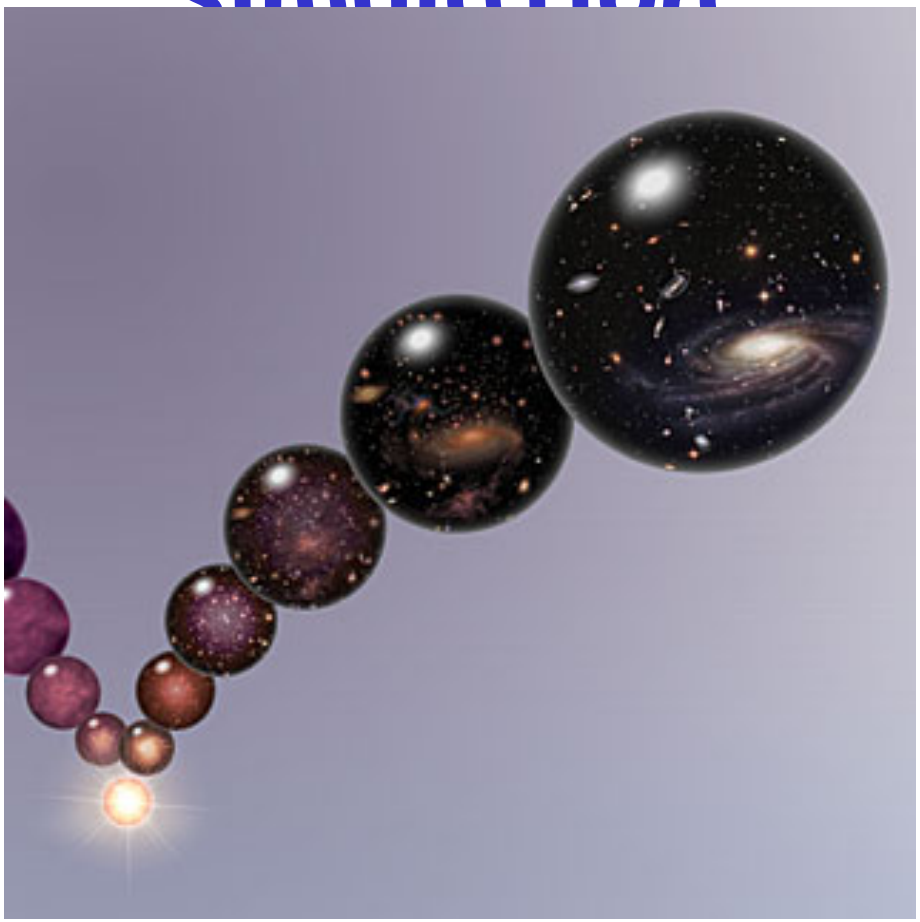
Submitting a Couple Jobs

```
[einstein@submit ~]$ condor_submit cosmos.sub
Submitting job(s).
2 job(s) submitted to cluster 102.
[einstein@submit ~]$ condor_q
-- Submitter: submit.chtc.wisc.edu : <128.104.55.9:51883> : submit.chtc.wisc.edu
 ID      OWNER            SUBMITTED     RUN_TIME ST PRI SIZE CMD
1.0      sagan           7/22 14:19 172+21:28:36 H  0   22.0 checkprogress.cron
2.0      heisenberg      1/13 13:59   0+00:00:00 I  0   0.0  env
3.0      hawking         1/15 19:18   0+04:29:33 H  0   0.0  script.sh
4.0      hawking         1/15 19:33   0+00:00:00 H  0   0.0  script.sh
5.0      hawking         1/15 19:33   0+00:00:00 H  0   0.0  script.sh
6.0      hawking         1/15 19:34   0+00:00:00 H  0   0.0  script.sh
...
102.0    einstein        4/5  13:55   0+00:00:00 I  0   0.0  cosmos -f cosmos.dat
102.1    einstein        4/5  13:55   0+00:00:00 I  0   0.0  cosmos -f cosmos.dat

557 jobs; 402 idle, 145 running, 10 held

[einstein@submit ~]$
```

One Step at a Time!

- ***Before*** trying to submit a large batch of jobs:
  - Submit a single job
    - (See "Baby Steps" slide)
    - Verify that it works
  - Then, submit a small number (5 - 10)
  - Verify that they all work as expected
- ***Now***, you're ready to move on to bigger & better..

Back to Albert's simulation



Files for the 1,000,000 jobs...

- We could put all input, output, error & log files in the one directory
  - One of each type for each job
  - 4,000,000+ files (4 files × 1,000,000 jobs)
  - Submit description file: 6,000,000+ lines, ~128M
  - Difficult (at best) to sort through
- *Better:* create a subdirectory for each run
  - Take advantage of `InitialDir` directive

Organization for big runs

- Create subdirectories for each run
  - `run_0`, `run_1`, … `run_999999`
- Create input files in each of these
  - `run_0/(cosmos.in,cosmos.dat)`
  - `run_1/(cosmos.in,cosmos.dat)`
  - …
  - `run_999999/(cosmos.in,cosmos.dat)`

- The output, error & log files for each job will be created by Condor from the job's output
- Can easily be done with a simple Python program (or even Perl)

More Data Files

- We'll create a new data file, and store the values of G, c & $\mathcal{R}\mu\nu$ for each run to a data file
  - I named this new file "`cosmos.in`"
  - Each run directory contains a unique `cosmos.in` file
    - Probably created by our Python program
- The common `cosmos.dat` file could be shared by all runs
  - Can be symbolic links to a common file

cosmos.in files

These cosmos.in files can easily be generated programmatically using Python or Perl

```
run_0/cosmos.in
c = 299792408
G = 6.67300e-112
R = 10.00e-29
```

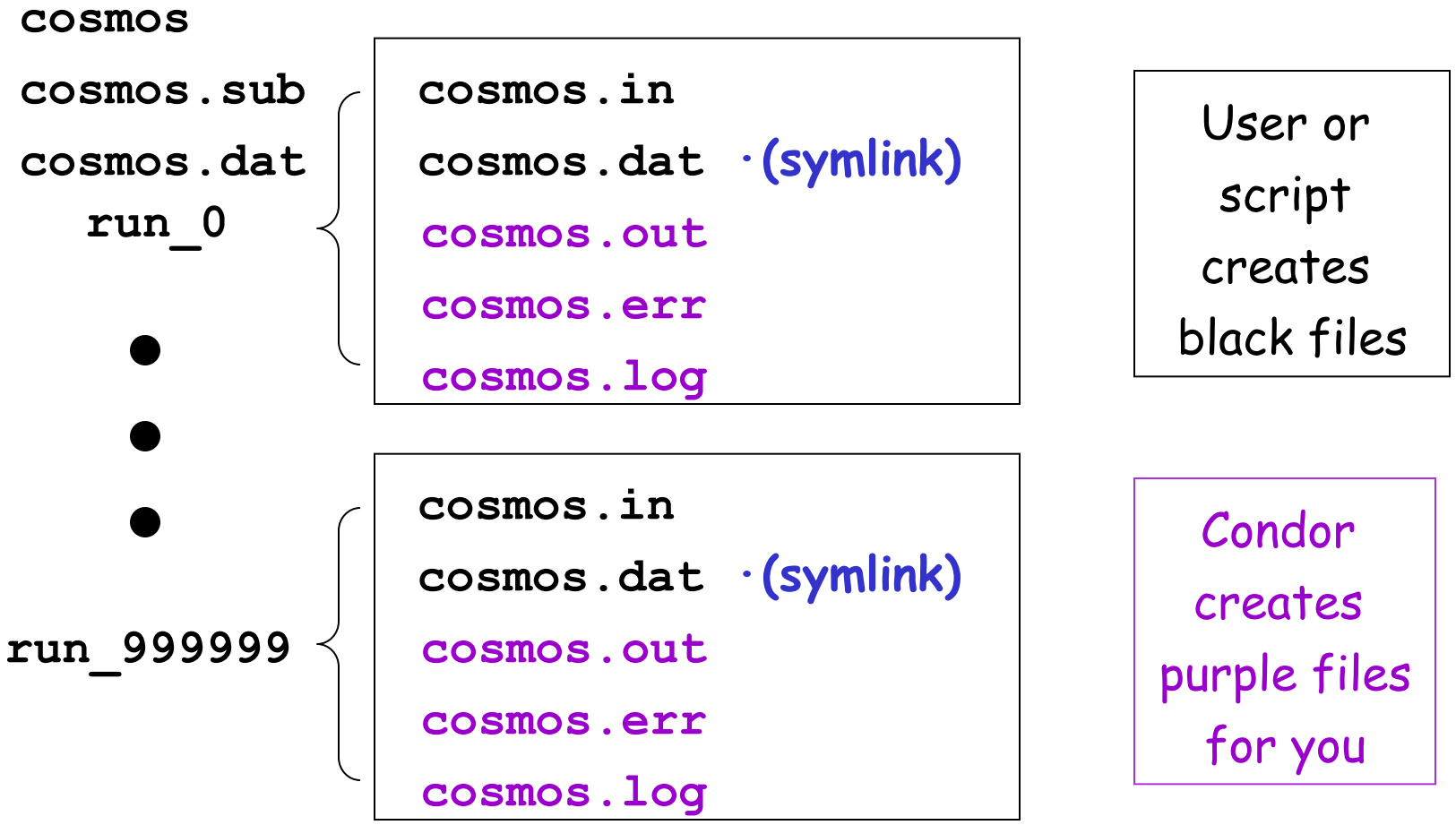
```
run_1/cosmos.in
c = 299792409
G = 6.67300e-112
R = 10.00e-29
```

...

```
run_999998/cosmos.in
c = 299792508
G = 6.67300e-100
R = 10.49e-29
```

```
run_999999/cosmos.in
c = 299792508
G = 6.67300e-100
R = 10.50e-29
```

Einstein's simulation directory



Submit File

```
# Cluster of 1,000,000 jobs with
# different directories
Universe                = vanilla
Executable              = cosmos
Log                     = cosmos.log
Output                  = cosmos.out
Input                   = cosmos.in
Arguments               = -f cosmos.dat
Transfer_Input_Files    = cosmos.dat
...

InitialDir = run_0
Queue

InitialDir = run_1
Queue
```

- Log, in, out & error files -> run_0
- Job 103.0 (Cluster 103, Process 0)

- Log, in, out & error files -> run_1
- Job 103.1 (Cluster 103, Process 1)

- Do this 999,998 more times……

1,000,000 Proc Cluster!!

- With this submit file, we can now submit a single cluster with 1,000,000 processes in it
- All the input/output files are organized within directories
- The submit description file is quite large, though
  - 2,000,000+ lines, ~32M
- Surely, there must be a better way
  - I am serious… and don't call me Shirley

The Better Way

- Queue all 1,000,000 processes with a single command:

```
Queue 1000000
```

- Condor provides
  - `$(Process)` will be expanded to the process number for each job in the cluster
    - 0, 1, … 999999

Using $(Process)

- The initial directory for each job can be specified using `$(Process)`
  - `InitialDir = run_$(Process)`
  - Condor will expand these directories to:
    - `run_0`, `run_1`, … `run_999999`
- Similarly, arguments can be variable
  - `Arguments = -n $(Process)`
  - Condor will expand these to:

```
-n 0
-n 1
…
-n 999999
```

Better Submit File

All 1,000,000 jobs described in a ten line submit file!!!

```
# Example Condor submit file that defines
# a cluster of 1,000,000 jobs with different
# directories
Universe   = vanilla
Executable = cosmos
Log        = cosmos.log
Input      = cosmos.in
Output     = cosmos.out
Error      = cosmos.err
Transfer_Input_Files = cosmos.dat
Arguments  = -f cosmos.dat
InitialDir = run_$(Process)
Queue 1000000
```

- All share arguments
- run_0 … run_999999
- Jobs 104.0 … 104.999999

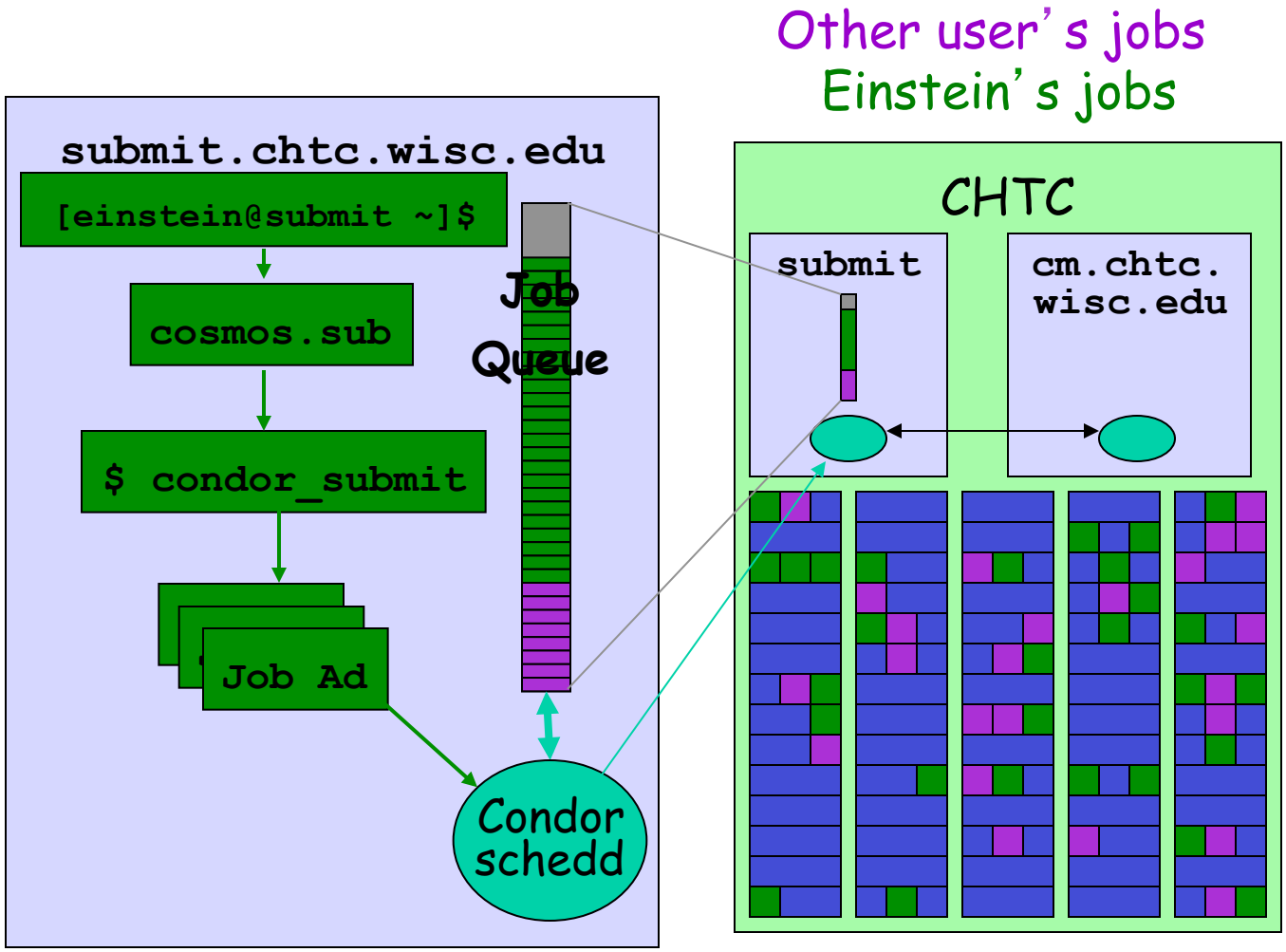
Finally, we submit them all. Be patient, it'll take a while…

```
[einstein@submit ~]$ condor_submit cosmos.sub
Submitting job
   (s) ..........................................
   ..........................................
   ..........................................
   ..........................................
   ..........................................
   ..................
Logging submit event
   (s) ..........................................
   ..........................................
   ..........................................
   ..........................................
   ..........................................
   ..................
1000000 job(s) submitted to cluster 104.
```

The Job Queue

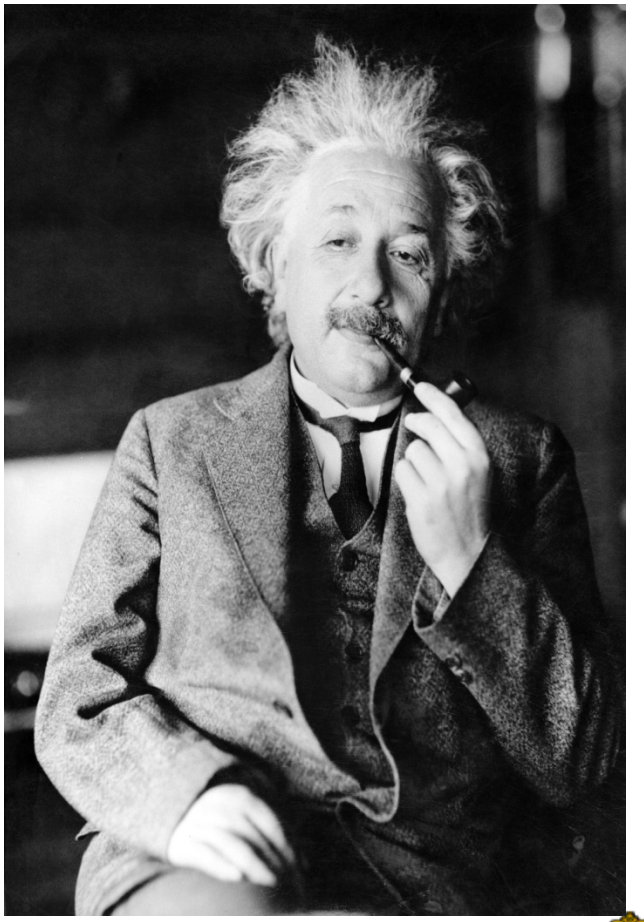
```
[einstein@submit ~]$ condor_q
-- Submitter: submit.chtc.wisc.edu : <128.104.55.9:51883> :
   submit.chtc.wisc.edu
ID       OWNER   SUBMITTED   RUN_TIME  ST PRI SIZE CMD
104.0      einstein 4/20 12:08 0+00:00:05 R 0 9.8 cosmos -f cosmos.dat
104.1      einstein 4/20 12:08 0+00:00:03 I 0 9.8 cosmos -f cosmos.dat
104.2      einstein 4/20 12:08 0+00:00:01 I 0 9.8 cosmos -f cosmos.dat
104.3      einstein 4/20 12:08 0+00:00:00 I 0 9.8 cosmos -f cosmos.dat
...
104.999998 einstein 4/20 12:08 0+00:00:00 I 0 9.8 cosmos -f cosmos.dat
104.999999 einstein 4/20 12:08 0+00:00:00 I 0 9.8 cosmos -f cosmos.dat

999999 jobs; 999998 idle, 1 running, 0 held
```

CHTC Condor Pool

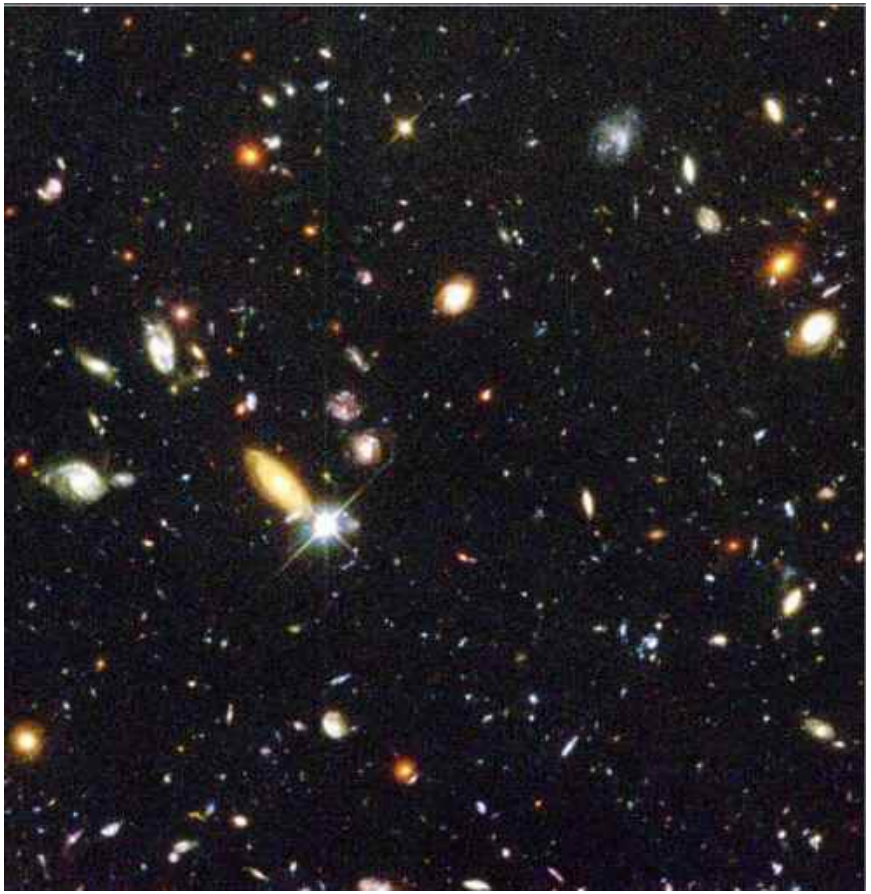


7. Relax

- Condor is watching over your jobs
  - Will restart them if required, etc.
- Time for a cold one!
- While I'm waiting…
  - Is there more that I can do with Condor?

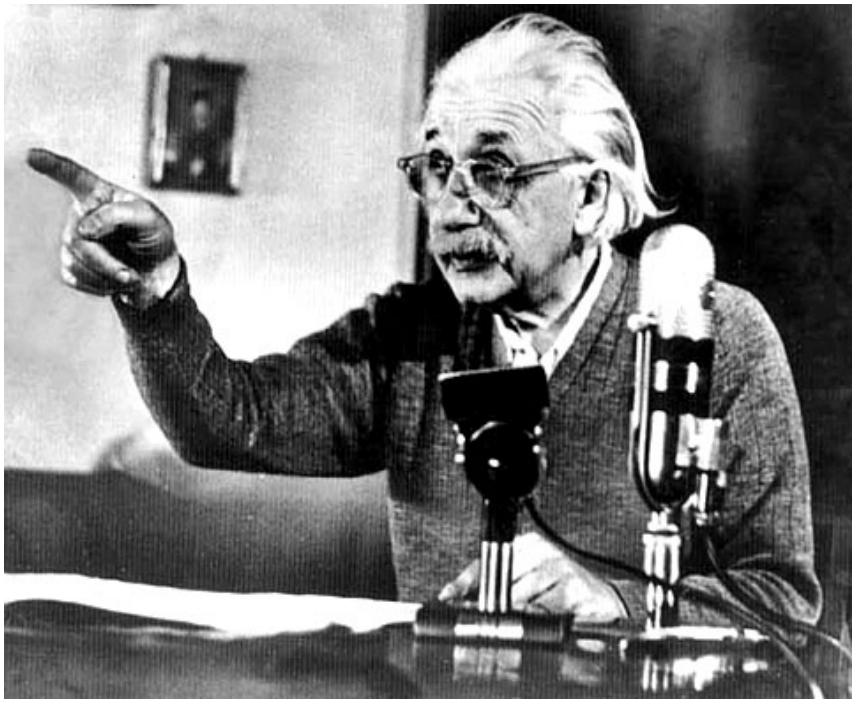


Looking Deeper



Oh <censored>!!! My Biggest Blunder Ever

- Albert removes $\mathcal{R}\mu\nu$ (Cosmological Constant) from his equations, and needs to remove his running jobs
- We'll just ignore that modern cosmologists may have re-introduced $\mathcal{R}\mu\nu$ (so called "dark energy")



Removing Jobs

- If you want to remove a job from the Condor queue, you use *condor_rm*
- You can only remove jobs that you own
- Privileged user can remove any jobs
  - "root" on UNIX / Linux
  - "administrator" on Windows

Removing jobs (continued)

- Remove an entire cluster:
  - `condor_rm 4` - Removes the whole cluster
- Remove a specific job from a cluster:
  - `condor_rm 4.0` - Removes a single job
- Or, remove **all** of your jobs with "*-a*"
  - DANGEROUS!!
  - `condor_rm -a` - Removes all jobs / clusters

How can I tell Condor that my jobs are Physics related?

- In the submit description file, introduce an attribute for the job

```
+Department = "physics"
```

Causes the Job Ad to contain:

```
Department = "physics"
```

Matching Machine Configuration

- Machines can be configured to:
  - Give higher rank to physics jobs
  - Pre-empt non-physics jobs when a physics job comes along
  - See Alan's "Basic Condor Administration" tutorial @ 1:15 today for more about machine policy expressions

How Can I Control Where my Jobs Run?

- Some of the machines in the pool can't successfully run my jobs
  - Not enough RAM
  - Not enough scratch disk space
  - Required software not installed
  - Etc.

Specify Job Requirements

- A boolean expression (syntax similar to C or Java)
- Evaluated with attributes from machine ad(s)
- **Must** evaluate to True for a match to be made

```
Universe        = vanilla
Executable      = cosmos
Log             = cosmos.log
InitialDir      = run_$(Process)
Input           = cosmos.in
Output          = cosmos.out
Error           = cosmos.err
Requirements = ( (Memory >= 4096) && \
                 (Disk > 10000)    )
Queue 1000000
```

Advanced Requirements

- Requirements can match custom attributes in your Machine Ad
  - Can be added by hand to each machine
  - Or, automatically using the ~~Hawkeye~~ ClassAd Daemon Hooks mechanism

```
Universe        = vanilla
Executable      = cosmos
Log             = cosmos.log
InitialDir      = run_$(Process)
Input           = cosmos.in
Output          = cosmos.out
Error           = cosmos.err
Requirements    = ( (Memory >= 4096) && \
                      (Disk > 10000)   && \
                      (CosmosData =!=
UNDEFINED) )
Queue 1000000
```

CosmosData =!= UNDEFINED ???

- What's this "=!=" and "**UNDEFINED**" **business?**
  - Is this like the state of Schrödinger's Cat?
- Introducing ClassAd Meta Operators:
  - Allow you to test if a attribute is in a ClassAd
  - Is identical to operator: "=?="
  - Is not identical to operator: "=!="
  - Behave similar to == and !=, but are not strict
  - Somewhat akin to Python's "**is NONE**" and "**is not NONE**"
  - Without these, ANY expression with an **UNDEFINED** in it will always evaluate to **UNDEFINED**

Meta Operator Examples

Expression	Evaluates to
`10 == UNDEFINED`	`UNDEFINED`
`UNDEFINED == UNDEFINED`	`UNDEFINED`
`10 =?= UNDEFINED`	`False`
`UNDEFINED =?= UNDEFINED`	`True`
`UNDEFINED =!= UNDEFINED`	`False`

More Meta Operator Examples

Expression	X	Evaluates to
X == 10	10	True
	5	False
	"ABC"	ERROR
	*	UNDEFINED
X =!= UNDEFINED	5	True
	10	True
	"ABC"	True
	*	False

*: X is not present in the ClassAd

One Last Meta Example

Expression	X	Evaluates to

`( (X =!= UNDEFINED) && (X == 10) )`
Is logically equivalent to:
`(X =?= 10)`
	10	True

	5	False
	11	False
	*	False

`( (X =?= UNDEFINED) || (X != 10) )`
Is logically equivalent to:
`(X =!= 10)`
	10	False

	5	True
	11	True
	*	True

*: X is not present in the ClassAd

Using Attributes from the Machine Ad

- You can use attributes from the matched Machine Ad in your job submit file
  - `$$(<attribute>)` will be replaced by the value of the specified attribute in the Machine Ad
- **Example:**
  - Matching Machine Ad has:

```
CosmosData      = "/local/cosmos/data"
```

  - Submit file has:

```
Executable      = cosmos
Requirements    = (CosmosData =!= UNDEFINED)
Arguments       = -d $$(CosmosData)
```

  - Resulting command line:

```
cosmos -d /local/cosmos/data
```

Specify Job Rank

- All matches which meet the requirements can be sorted by preference with a **Rank** expression
  - Numerical
  - Higher rank values match first
- Like **Requirements**, is evaluated with attributes from machine ads

```
Universe        = vanilla
Executable      = cosmos
Log             = cosmos.log
Arguments       = -arg1 -arg2
InitialDir      = run_$(Process)
Requirements    = (Memory >= 4096) && (Disk > 10000)
Rank            = (KFLOPS*10000) + Memory
Queue 1000000
```

Need More Control of Your Job?

- Exit status isn't always a good indicator of job success
- What if my job gets a signal?
  - `SIGSEGV`
  - `SIGBUS`
- ...

Job Policy Expressions

- User can supply job policy expressions in the submit file.
- Can be used to describe a successful run.

```
on_exit_remove   = <expression>
on_exit_hold     = <expression>
periodic_remove  = <expression>
periodic_hold    = <expression>
```

Job Policy Examples

- Do not remove if exits with a signal:

```
on_exit_remove = ExitBySignal == False
```

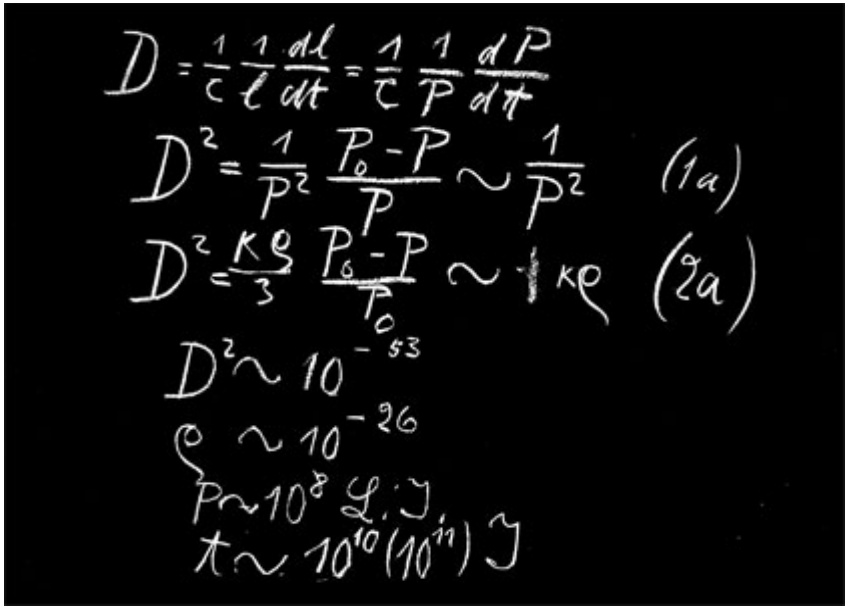
- Place on hold if exits with nonzero status or ran for less than an hour:

```
on_exit_hold =
  ( (ExitBySignal==False) && (ExitSignal != 0) ) ||
  ( (ServerStartTime - JobStartDate) < 3600)
```

- Place on hold if job has spent more than 50% of its time suspended:

```
periodic_hold =
  ( CumulativeSuspensionTime >
    (RemoteWallClockTime / 2.0) )
```

How can my jobs access their data files?



Access to Data in Condor

- Condor can transfer files
  - We've already seen examples of this
  - Can automatically send back changed files
  - Atomic transfer of multiple files
  - The files can be encrypted over the wire
  - **New**: Condor can now transfer directories
- Shared file system (NFS / AFS)
- HDFS
- Remote I/O Socket (parrot)
- Standard Universe can use remote system calls (more on this later)

NFS / AFS

- Condor can be configured to allow access to NFS and AFS shared resources
- AFS is available on most of CHTC
- Your program can access /afs/...
- Note: Condor runs your job without your AFS credentials
  - At UW Computer Sciences, you must grant net:cs access to all Condor job input, output, and log files stored in AFS directories.
  - Elsewhere, you'll have to do something similar

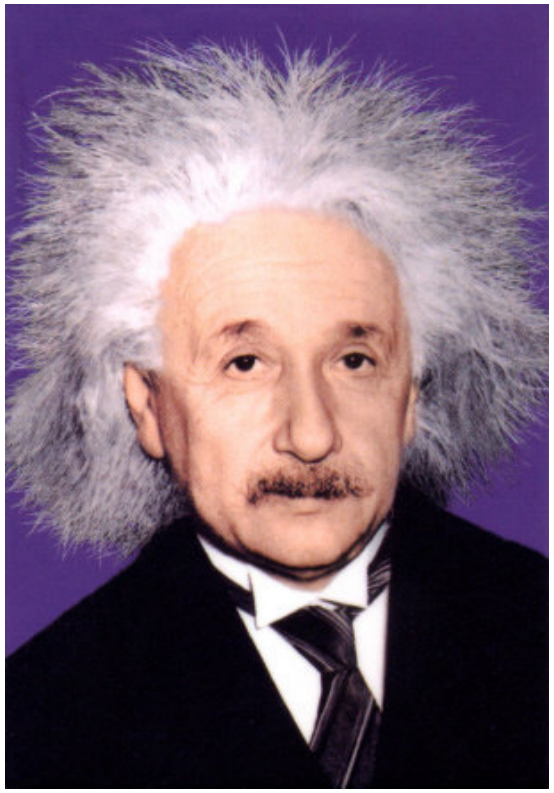
I Need to run lots of Short-Running Jobs

- First: Condor is a High Throughput system, designed for long running jobs
  - Starting a job in Condor is somewhat expensive
- Batch your short jobs together
  - Write a wrapper script that will run a number of them in series
  - Submit your wrapper script as your job
- Explore Condor's parallel universe
- There are some configuration parameters that may be able to help
  - Contact a Condor staff person for more info

Need to Learn Scripting?

- CS 368 / Summer 2011
- Introduction to Scripting Languages
- Two Sections
  - Both taught by Condor Staff Members
  - Section 1
    - Perl
    - Instructor: Tim Cartwright (Condor Staff)
  - Section 2
    - Advanced Python
    - Instructor: Nick LeRoy (me)

I Need Help!



My Jobs Are Idle

- Our scientist runs `condor_q` and finds all his jobs are idle

```
[einstein@submit ~]$ condor_q
-- Submitter: x.cs.wisc.edu : <128.105.121.53:510> :x.cs.wisc.edu
ID  OWNER    SUBMITTED     RUN_TIME ST PRI SIZE CMD
4.0 einstein  4/20 13:22  0+00:00:00 I 0   9.8  cosmos -arg1 -arg2
5.0 einstein  4/20 12:23  0+00:00:00 I 0   9.8  cosmos -arg1 -n 0
5.1 einstein  4/20 12:23  0+00:00:00 I 0   9.8  cosmos -arg1 -n 1
5.2 einstein  4/20 12:23  0+00:00:00 I 0   9.8  cosmos -arg1 -n 2
5.3 einstein  4/20 12:23  0+00:00:00 I 0   9.8  cosmos -arg1 -n 3
5.4 einstein  4/20 12:23  0+00:00:00 I 0   9.8  cosmos -arg1 -n 4
5.5 einstein  4/20 12:23  0+00:00:00 I 0   9.8  cosmos -arg1 -n 5
5.6 einstein  4/20 12:23  0+00:00:00 I 0   9.8  cosmos -arg1 -n 6
5.7 einstein  4/20 12:23  0+00:00:00 I 0   9.8  cosmos -arg1 -n 7
8 jobs; 8 idle, 0 running, 0 held
```

Exercise a little patience

- On a busy pool, it can take a while to match and start your jobs
- Wait at least a negotiation cycle or two (typically a few minutes)

Check Machine's Status

```
[einstein@submit ~]$ condor_status
Name                OpSys      Arch   State     Activity LoadAv Mem   ActvtyTime
slot1@c002.chtc.wi LINUX      X86_64 Claimed   Busy     1.000  4599  0+00:10:13
slot2@c002.chtc.wi LINUX      X86_64 Claimed   Busy     1.000  1024  1+19:10:36
slot3@c002.chtc.wi LINUX      X86_64 Claimed   Busy     0.990  1024  1+22:42:20
slot4@c002.chtc.wi LINUX      X86_64 Claimed   Busy     1.000  1024  0+03:22:10
slot5@c002.chtc.wi LINUX      X86_64 Claimed   Busy     1.000  1024  0+03:17:00
slot6@c002.chtc.wi LINUX      X86_64 Claimed   Busy     1.000  1024  0+03:09:14
slot7@c002.chtc.wi LINUX      X86_64 Claimed   Busy     1.000  1024  0+19:13:49
...
vm1@INFOLABS-SML65 WINNT51    INTEL  Owner     Idle     0.000   511   [Unknown]
vm2@INFOLABS-SML65 WINNT51    INTEL  Owner     Idle     0.030   511   [Unknown]
vm1@INFOLABS-SML66 WINNT51    INTEL  Unclaimed Idle     0.000   511   [Unknown]
vm2@INFOLABS-SML66 WINNT51    INTEL  Unclaimed Idle     0.010   511   [Unknown]
vm1@infolabs-smlde WINNT51    INTEL  Claimed   Busy     1.130   511   [Unknown]
vm2@infolabs-smlde WINNT51    INTEL  Claimed   Busy     1.090   511   [Unknown]
                     Total Owner Claimed Unclaimed Matched Preempting Backfill

       INTEL/WINNT51   104    78      16        10       0          0        0
        X86_64/LINUX   759   170     587         0       0          1        0

               Total   863   248     603        10       0          1        0
```

Not Matching at All? condor_q -analyze

```
[einstein@submit ~]$ condor_q -ana 29
The Requirements expression for your job is:

( (target.Memory > 8192) ) && (target.Arch == "INTEL") &&
(target.OpSys == "LINUX") && (target.Disk >= DiskUsage) &&
(TARGET.FileSystemDomain == MY.FileSystemDomain)
Condition                Machines    Matched  Suggestion
---------                ----------- -------- -----------
1 ( ( target.Memory > 8192 ) )  0          MODIFY TO 4000
2 ( TARGET.FileSystemDomain == "cs.wisc.edu" )584
3   ( target.Arch == "INTEL" )  1078
4   ( target.OpSys == "LINUX" ) 1100
5   ( target.Disk >= 13 )       1243
```

Learn about available resources:

```
[einstein@submit ~]$ condor_status -const 'Memory > 8192'
(no output means no matches)
[einstein@submit ~]$ condor_status -const 'Memory > 4096'
Name               OpSys   Arch   State     Activ LoadAv Mem   ActvtyTime
vm1@s0-03.cs.  LINUX   X86_64 Unclaimed Idle  0.000  5980  1+05:35:05
vm2@s0-03.cs.  LINUX   X86_64 Unclaimed Idle  0.000  5980 13+05:37:03
vm1@s0-04.cs.  LINUX   X86_64 Unclaimed Idle  0.000  7988  1+06:00:05
vm2@s0-04.cs.  LINUX   X86_64 Unclaimed Idle  0.000  7988 13+06:03:47

                     Total Owner Claimed Unclaimed Matched Preempting
   X86_64/LINUX          4     0       0         4       0          0
          Total          4     0       0         4       0          0
```

Held Jobs

- Now he discovers that his jobs are in the 'H' state…

```
[einstein@submit ~]$ condor_q
-- Submitter: x.cs.wisc.edu : <128.105.121.53:510> :x.cs.wisc.edu
ID  OWNER    SUBMITTED     RUN_TIME ST PRI SIZE CMD
4.0 einstein  4/20 13:22  0+00:00:00 H 0   9.8  cosmos -arg1 -arg2
5.0 einstein  4/20 12:23  0+00:00:00 H 0   9.8  cosmos -arg1 -n 0
5.1 einstein  4/20 12:23  0+00:00:00 H 0   9.8  cosmos -arg1 -n 1
5.2 einstein  4/20 12:23  0+00:00:00 H 0   9.8  cosmos -arg1 -n 2
5.3 einstein  4/20 12:23  0+00:00:00 H 0   9.8  cosmos -arg1 -n 3
5.4 einstein  4/20 12:23  0+00:00:00 H 0   9.8  cosmos -arg1 -n 4
5.5 einstein  4/20 12:23  0+00:00:00 H 0   9.8  cosmos -arg1 -n 5
5.6 einstein  4/20 12:23  0+00:00:00 H 0   9.8  cosmos -arg1 -n 6
5.7 einstein  4/20 12:23  0+00:00:00 H 0   9.8  cosmos -arg1 -n 7
8 jobs; 0 idle, 0 running, 8 held
```

Look at jobs on hold

```
[einstein@submit ~]$ condor_q -hold
-- Submiter: submit.chtc.wisc.edu :
  <128.105.121.53:510> :submit.chtc.wisc.edu
 ID      OWNER            HELD_SINCE HOLD_REASON
 6.0   einstein           4/20 13:23 Error from starter
  on skywalker.cs.wisc.edu

9 jobs; 8 idle, 0 running, 1 held
```

Or, see full details for a job

```
[einstein@submit ~]$ condor_q -l 6.0
…
HoldReason = "Error from starter"
…
```

Look in the Job Log

- The job log will likely contain clues:

```
[einstein@submit ~]$ cat cosmos.log
000 (031.000.000) 04/20 14:47:31 Job submitted from
  host: <128.105.121.53:48740>
...
007 (031.000.000) 04/20 15:02:00 Shadow exception!
        Error from starter on gig06.stat.wisc.edu:
  Failed to open '/scratch.1/einstein/workspace/v67/
  condor-test/test3/run_0/cosmos.in' as standard
  input: No such file or directory (errno 2)
        0  -  Run Bytes Sent By Job
        0  -  Run Bytes Received By Job
...
```

Interact With Your Job

- Why is my job still running?
  - Is it stuck accessing a file?
  - Is it in an infinite loop?
- Try `condor_ssh_to_job`
  - Interactive debugging in UNIX
  - Use ps, top, gdb, strace, lsof, …
  - Forward ports, X, transfer files, etc.
  - Currently not available on Windows

Interactive Debug Example

```
einstein@phy:~$ condor_q

-- Submitter: cosmos.phy.wisc.edu : <128.105.165.34:1027> :
ID      OWNER          SUBMITTED     RUN_TIME  ST PRI SIZE CMD
 1.0    einstein       4/15 06:52  1+12:10:05 R 0    10.0 cosmos

1 jobs; 0 idle, 1 running, 0 held

[einstein@submit ~]$ condor_ssh_to_job 1.0

Welcome to slot4@c025.chtc.wisc.edu!
Your condor job is running with pid(s) 15603.

$ gdb -p 15603
  …
```

It's Still not Working!!!!

- Go back and verify that your program runs stand alone
  - We've had **many** cases in which users blame Condor, but haven't tried running it outside of Condor (See "Baby Steps")
- Help is but an email away:
  - **chtc@cs.wisc.edu** for CHTC help
  - **condor-admin@cs.wisc.edu** for Condor-specific help

Parallel Universes

MW: A Master-Worker Grid Toolkit

- Provides a mechanism for controlling parallel algorithms
  - Fault tolerant
  - Allows for resources to come and go
  - Ideal for Computational Grid settings
- To use, write your software using the MW API
- **http://www.cs.wisc.edu/condor/mw/**

MPI jobs

Note: Condor will probably not schedule all of your jobs on the same machine

Try using whole machine slots

- Talk to a Condor staff member for details

```
# Example submit input file that for an MPI job
universe = parallel
executable = mp1script
arguments = my_mpich_linked_executable arg1 arg2
machine_count = 4
should_transfer_files = yes
when_to_transfer_output = on_exit
transfer_input_files = my_mpich_linked_executable
queue
```

Map Reduce

- Condor provides a powerful execution environment for running parallel applications like MPI.
  - The Parallel Universe (PU) of Condor is built specifically for this purpose
  - The Map-Reduce (MR) is a relatively recent programming model particularly suitable for applications that require processing a large set of data on cluster of computers.
- A popular open-source implementation of MR framework is provided by Hadoop project by Apache Software Foundation.

Map Reduce On Condor

- Uses Condor's Parallel Universe resource manager to select a subset of machines within a cluster
  - Sets up a Hadoop MR cluster on these machines
  - Submits a MR job and clean-up once the job is finished
  - These machines will be available as dedicated resources for the duration of the job
  - User can choose which machine should act as a master and communication channels between masters and slave nodes are also established

http://condor-wiki.cs.wisc.edu/index.cgi/wiki?p=MapReduce

Human Genome Sequencing

- A team of computer scientists from the University of Wisconsin-Madison and the University of Maryland recently assembled a full human genome from millions of pieces of data — stepping up from commonly assembled genomes several orders of magnitude less complex — and they did it without a big-ticket supercomputer.
  - July 19, 2010 -- UW Press Release
  - `http://www.news.wisc.edu/18240`
- This computation was done using Condor & Hadoop on CHTC

Accessing Large Data Sets via HDFS

- HDFS
  - Allows disk space to be pooled into one resource
  - For the CS CHTC cluster, that is on the order of a couple hundred terabytes
- Can enable jobs with large I/O to run without filling up the spool on submit machine
- However, HDFS has no security so should not be used for sensitive data
  - Condor adds basic host-based security (better than nothing)
  - The Hadoop people are adding better security, but not yet available

HDFS @ CHTC

- Command line tools are available to move files in and out of the HDFS
- The Human Genome Sequencing from a couple of slides ago used HDFS
  - However, it's the only real job that's exercised our HDFS setup so far…

We've seen how Condor can:

- Keep an eye on your jobs
  - Keep you posted on their progress
- Implement your policy on the execution order of the jobs
- Keep a log of your job activities

More User Issues...

- We need more disk space for our jobs
- We have users that come and go

Your own Submit Host

- Benefits:
  - As much disk space as you need (or can afford)
  - Manage your own users
- Getting Started:
  - Download & install appropriate Condor binaries
  - "Flock" into CHTC and other campus pools

Getting Condor

- Available as a free download from
  http://www.cs.wisc.edu/condor
- Download Condor for your operating system
  - Available for most modern UNIX platforms (including Linux and Apple's OS/X)
  - Also for Windows XP / Vista / Windows 7
- Repositories
  - YUM: RHEL 4 & 5
    - `$ yum install condor`
  - APT: Debian 4 & 5
    - `$ apt-get install condor`

Condor Releases

- Stable / Developer Releases
  - Version numbering scheme similar to that of the (pre 2.6) Linux kernels …
- Major.minor.release
  - If minor is even (a.b.c): Stable series
    - Very stable, mostly bug fixes
    - Current: 7.6
    - Examples: 7.4.5, 7.6.0
      - 7.6.0 just released
  - If minor is odd (a.b.c): Developer series
    - New features, may have some bugs
    - Current: 7.7
    - Examples: 7.5.2, 7.7.0
      - 7.7.0 in the works

Condor Installation

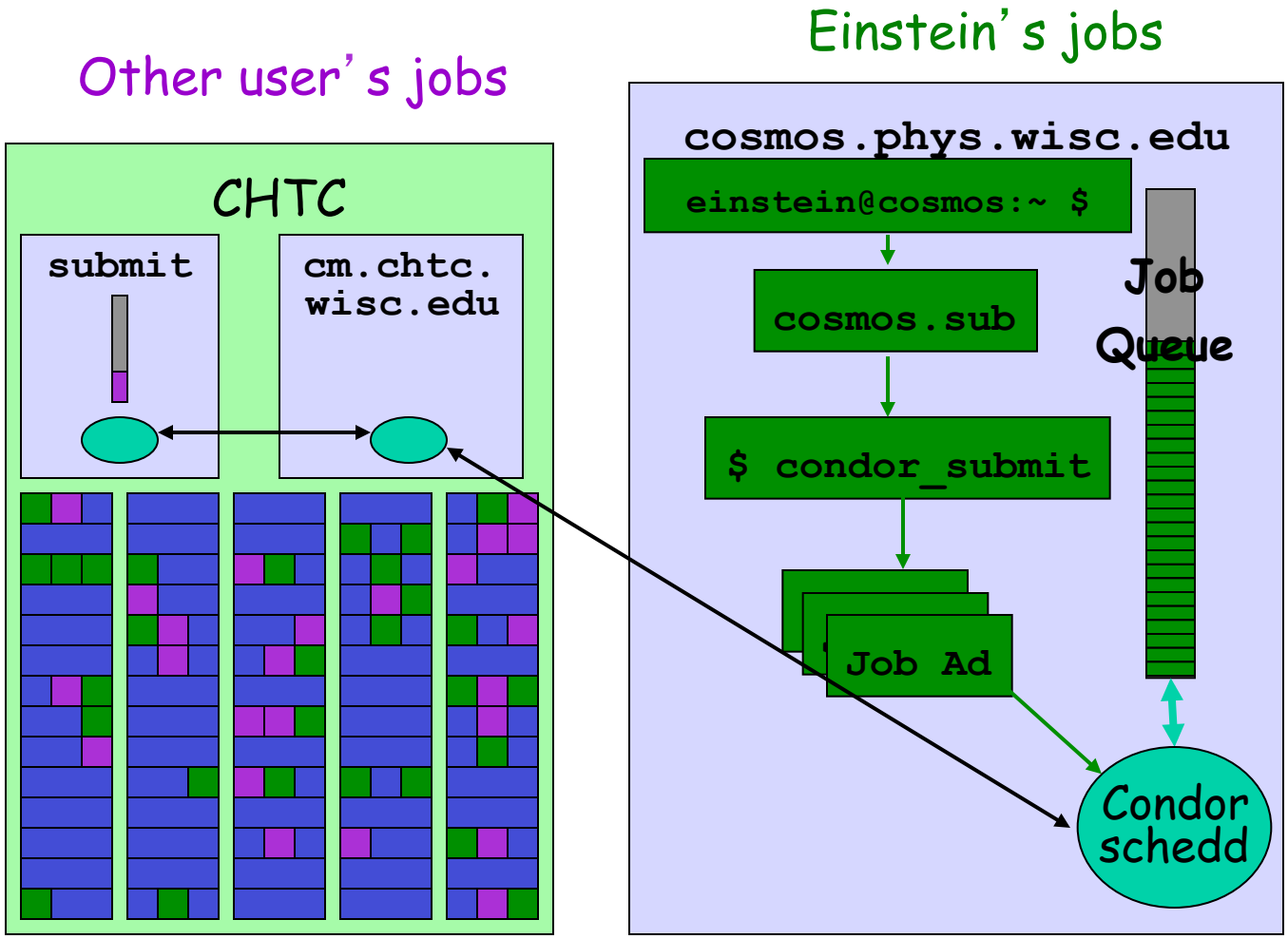
- Albert's sysadmin installs Condor
  - This new submit / manager machine
  - On department desktop machines
    - Submission points
    - Non-dedicated excution machines
      - Configured to only run jobs when the machine is idle
  - Enables flocking to CHTC and other campus pools

Flocking

A Condor-specific technology which:

- Allows Condor jobs to run in other friendly Condor pools
- Needs to be set up on both ends
- Can be bi-directional

Flocking to CHTC

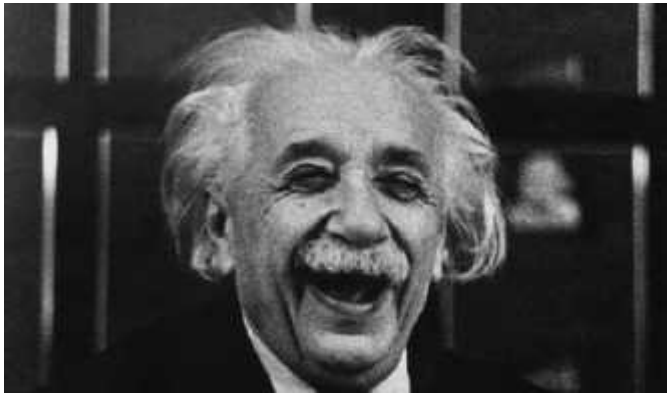


We *STILL* Need More

Condor is managing and running our jobs, but:

- Our CPU requirements are greater than our resources
- Jobs are preempted more often than we like

Happy Day! The Physics Department is adding a cluster!

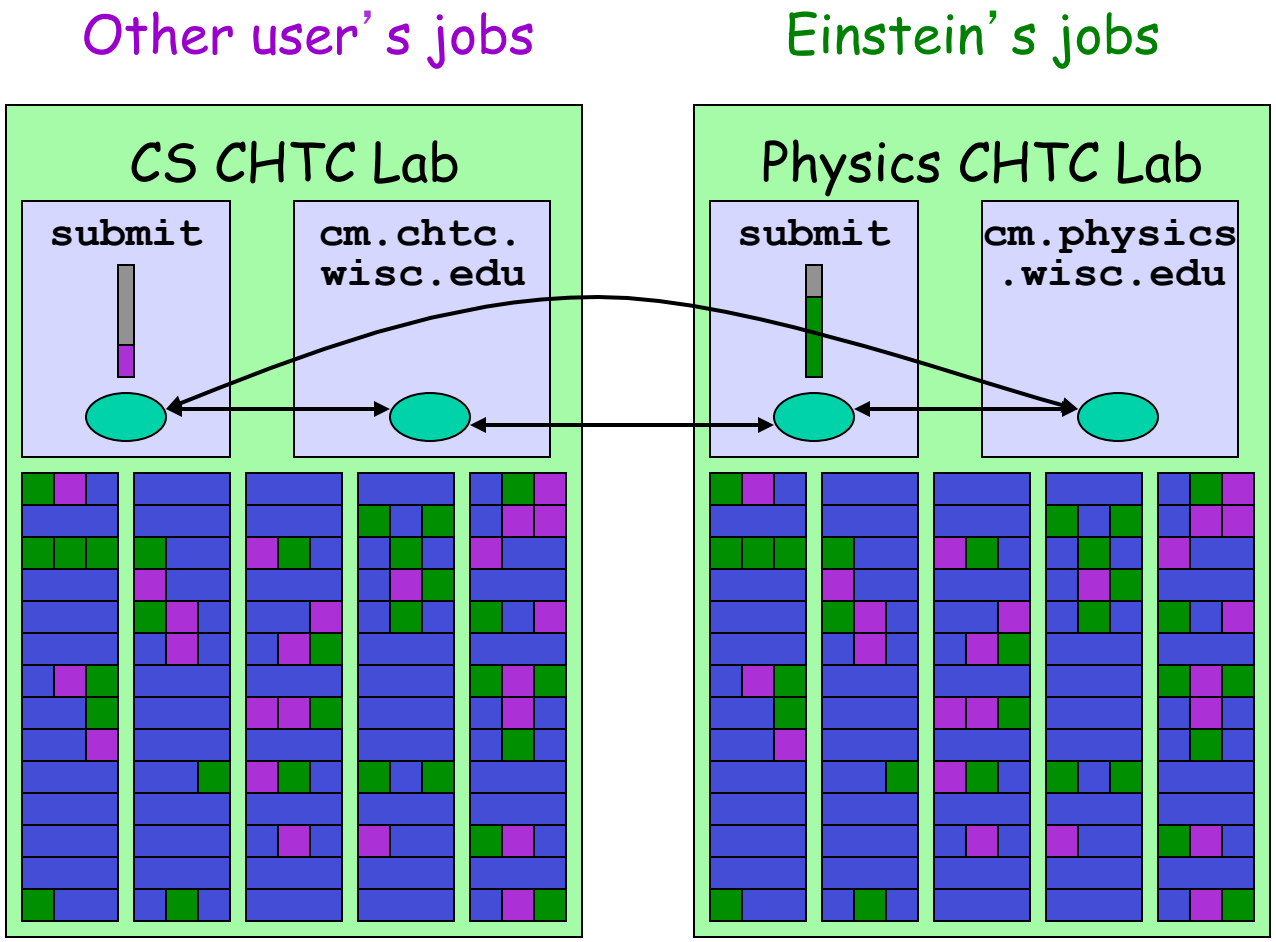


- The administrator installs Condor on all these new dedicated cluster nodes

Adding dedicated nodes

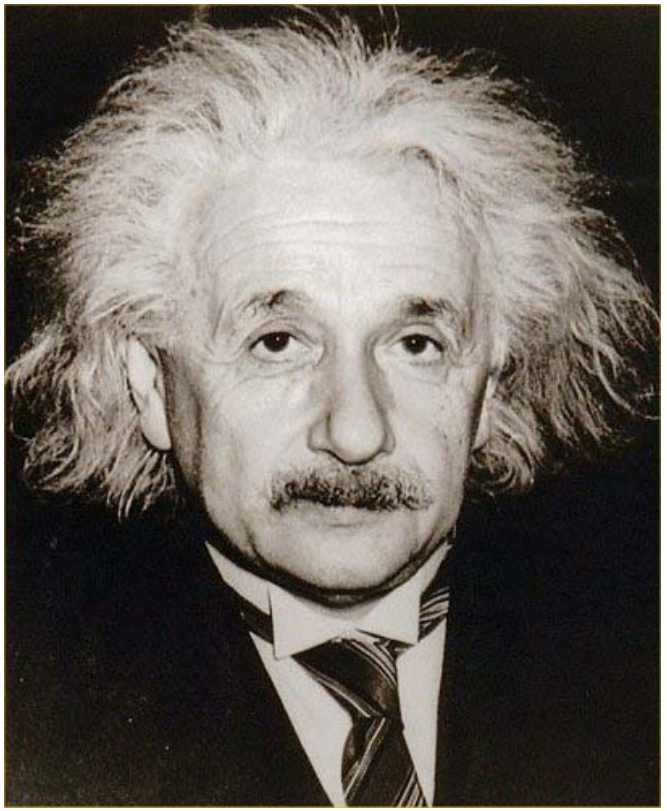
- The administrator installs Condor on these new machines, and configures them with his machine as the central manager
  - The central manager:
    - Central repository for the whole pool
    - Performs job / machine matching, etc.
- These are dedicated nodes, meaning that they are always able run Condor jobs

Flocking to CHTC

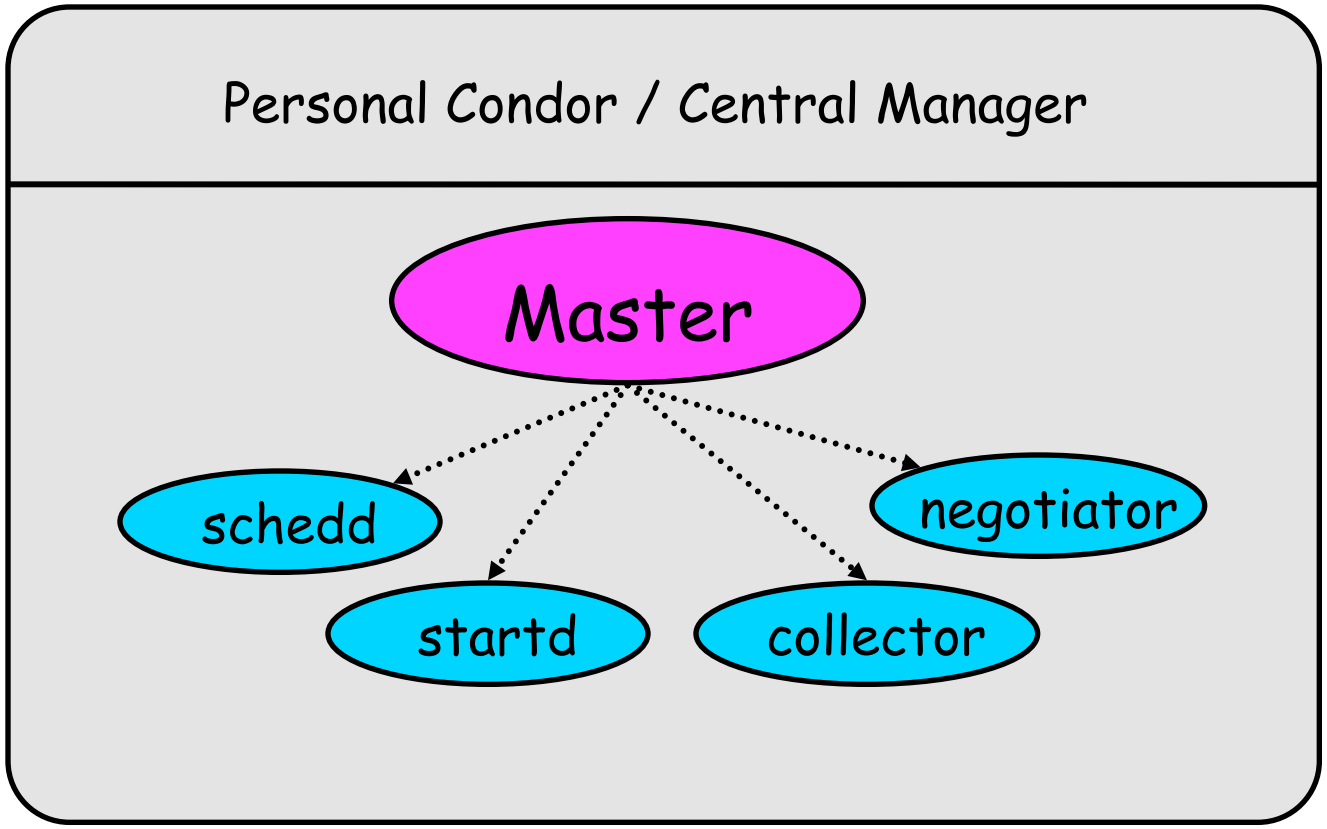


Some Good Questions…

What are all of these Condor Daemons running on my machine, and what do they do?



Condor Daemon Layout



= Process Spawned

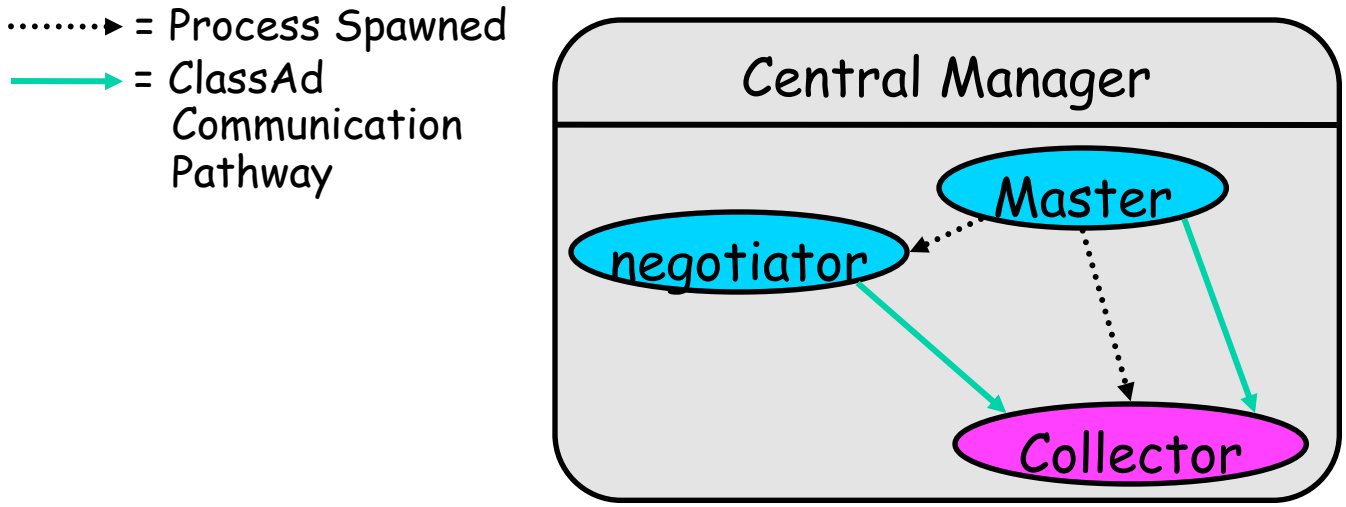
condor_master

- Starts up all other Condor daemons
- Runs on **all** Condor hosts
- If there are any problems and a daemon exits, it restarts the daemon and sends email to the administrator
- Acts as the server for many Condor remote administration commands:
  - *condor_reconfig, condor_restart*
  - *condor_off, condor_on*
  - *condor_config_val*
  - etc.

Central Manager: condor_collector

- Collects information from all other Condor daemons in the pool
  - "Directory Service" / Database for a Condor pool
  - Each daemon sends a periodic update ClassAd to the collector
- Services queries for information:
  - Queries from other Condor daemons
  - Queries from users (*condor_status*)
- Only on the Central Manager(s)
- At least one collector per pool

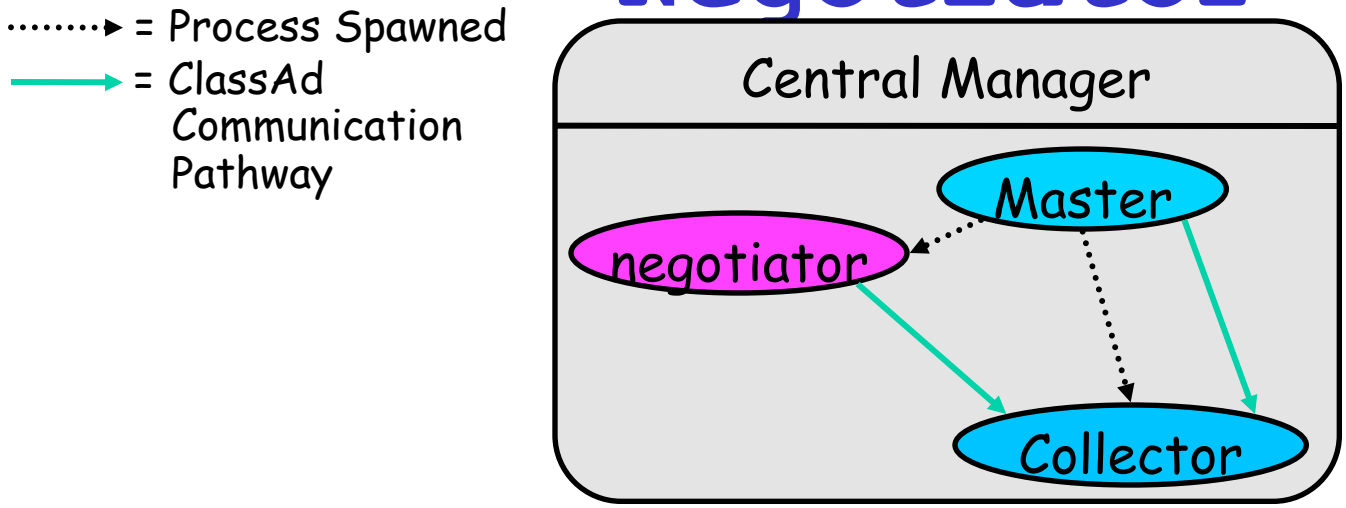
Condor Pool Layout: Collector



Central Manager: condor_negotiator

- Performs "matchmaking" in Condor
- Each "Negotiation Cycle" (typically 5 minutes):
  - Gets information from the collector about all available machines and all idle jobs
  - Tries to match jobs with machines that will serve them
  - Both the job and the machine must satisfy each other's requirements
- Only one Negotiator per pool
  - Ignoring HAD
- Only on the Central Manager(s)

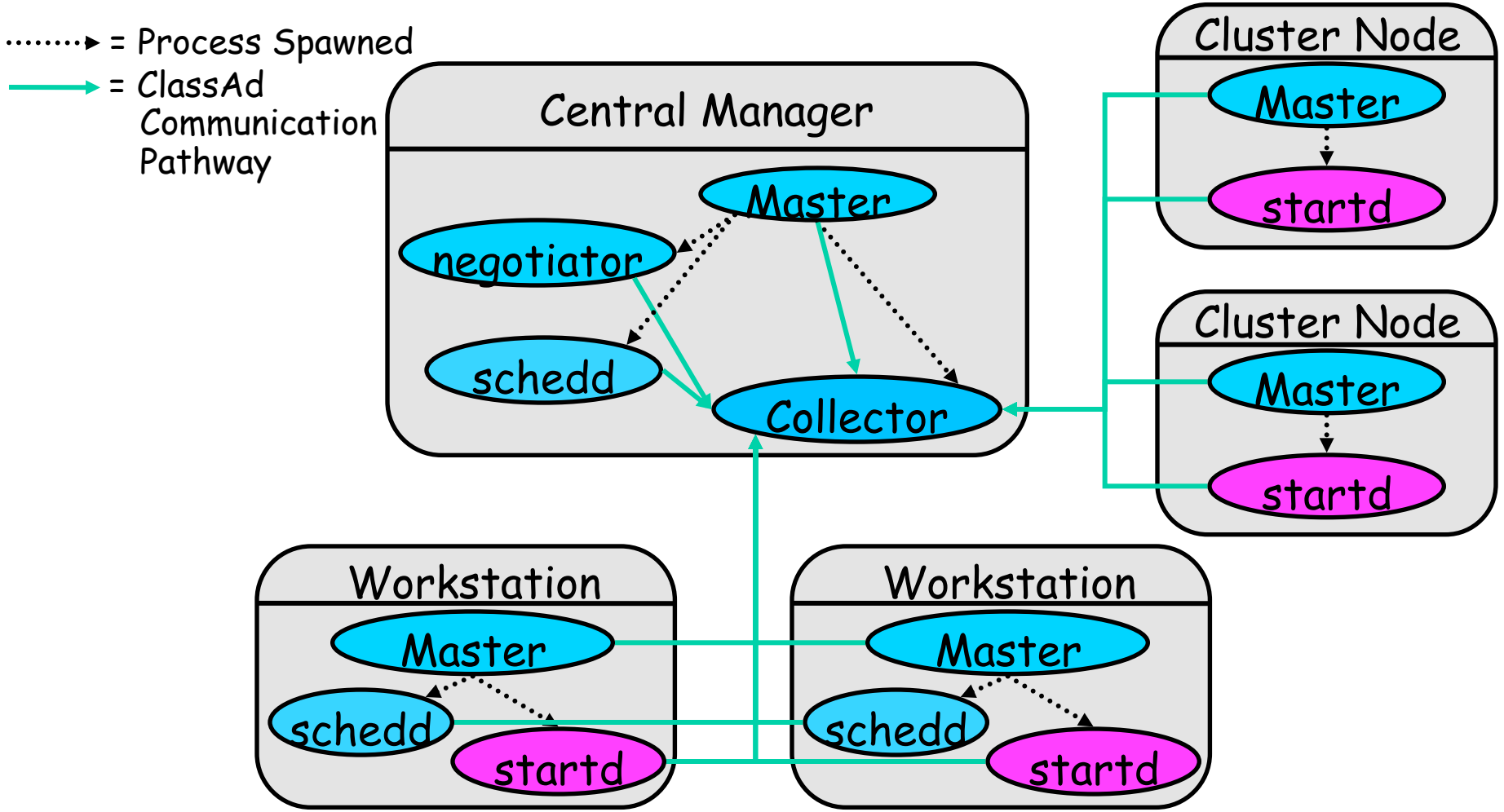
Condor Pool Layout: Negotiator



Execute Hosts: condor_startd

- Represents a machine to the Condor system
- Responsible for starting, suspending, and stopping jobs
- Enforces the wishes of the machine owner (the owner's "policy"… more on this in the administrator's tutorial)
- Creates a "starter" for each running job
- One startd runs on each execute node

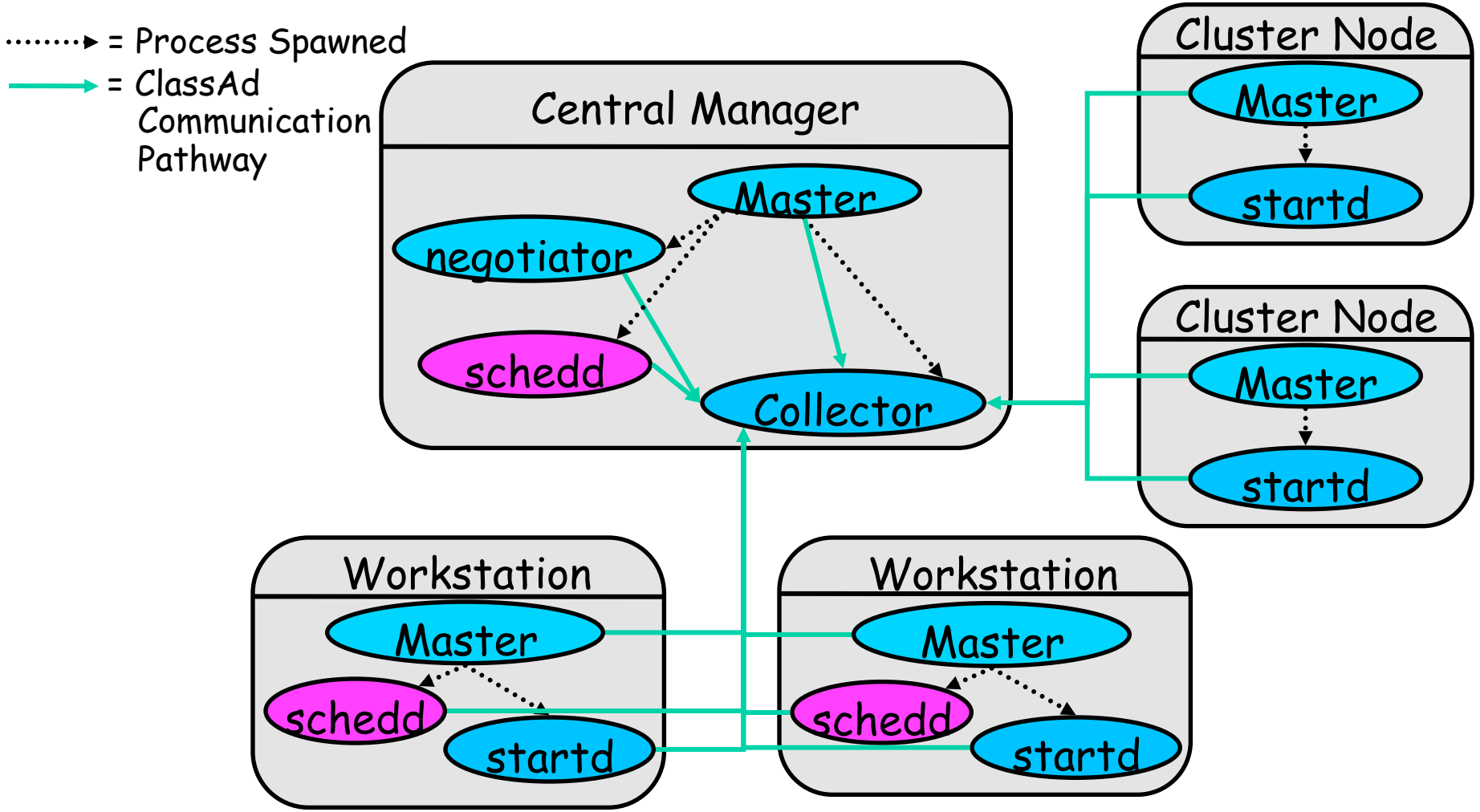
Condor Pool Layout: startd



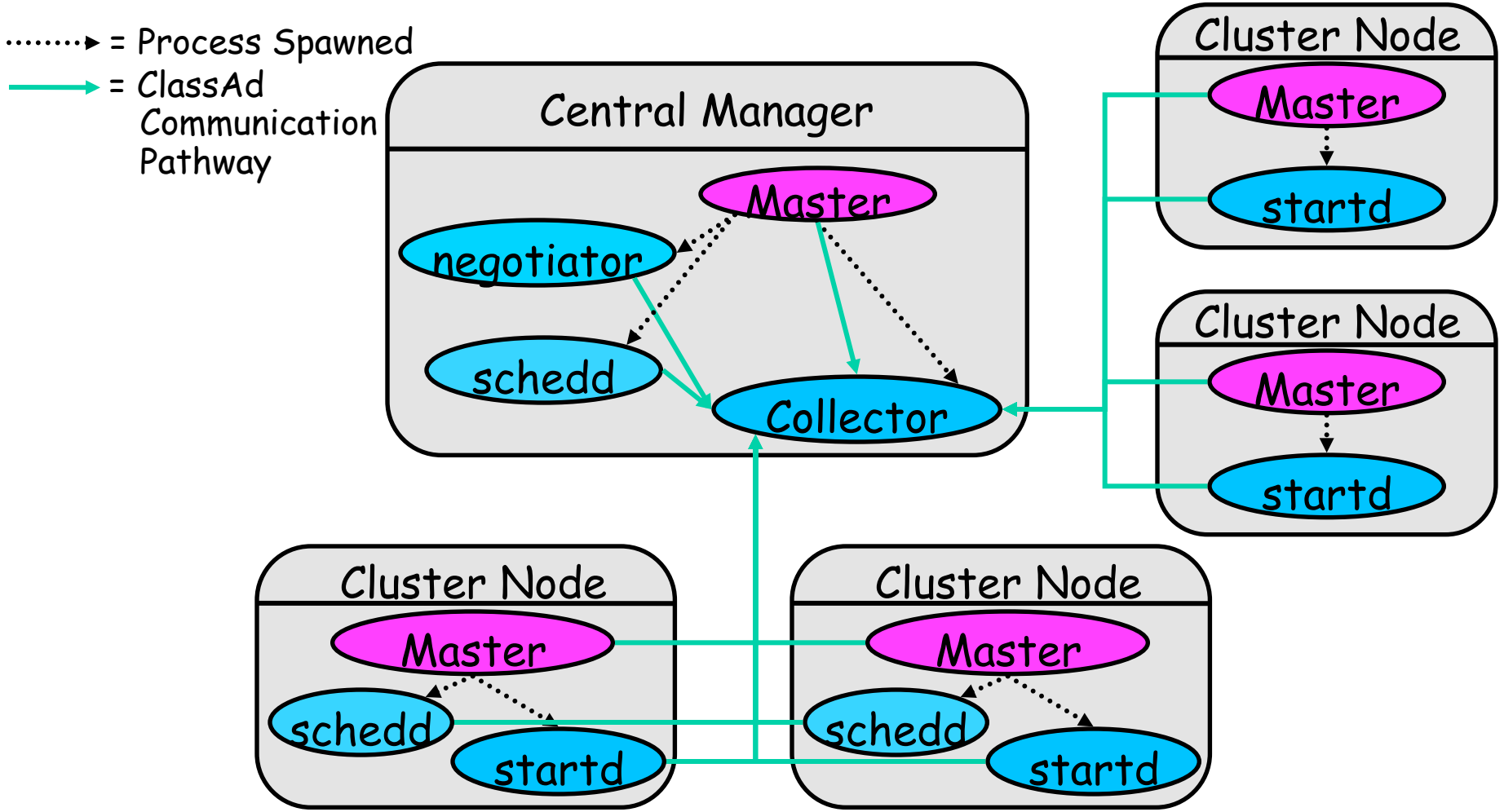
Submit Hosts: condor_schedd

- Condor's Scheduler Daemon
- One **schedd** runs on each submit host
- Maintains the persistent queue of jobs
- Responsible for contacting available machines and sending them jobs
- Services user commands which manipulate the job queue:
  - *condor_submit, condor_rm, condor_q, condor_hold, condor_release, condor_prio, …*
- Creates a "shadow" for each running job

Condor Pool Layout: schedd



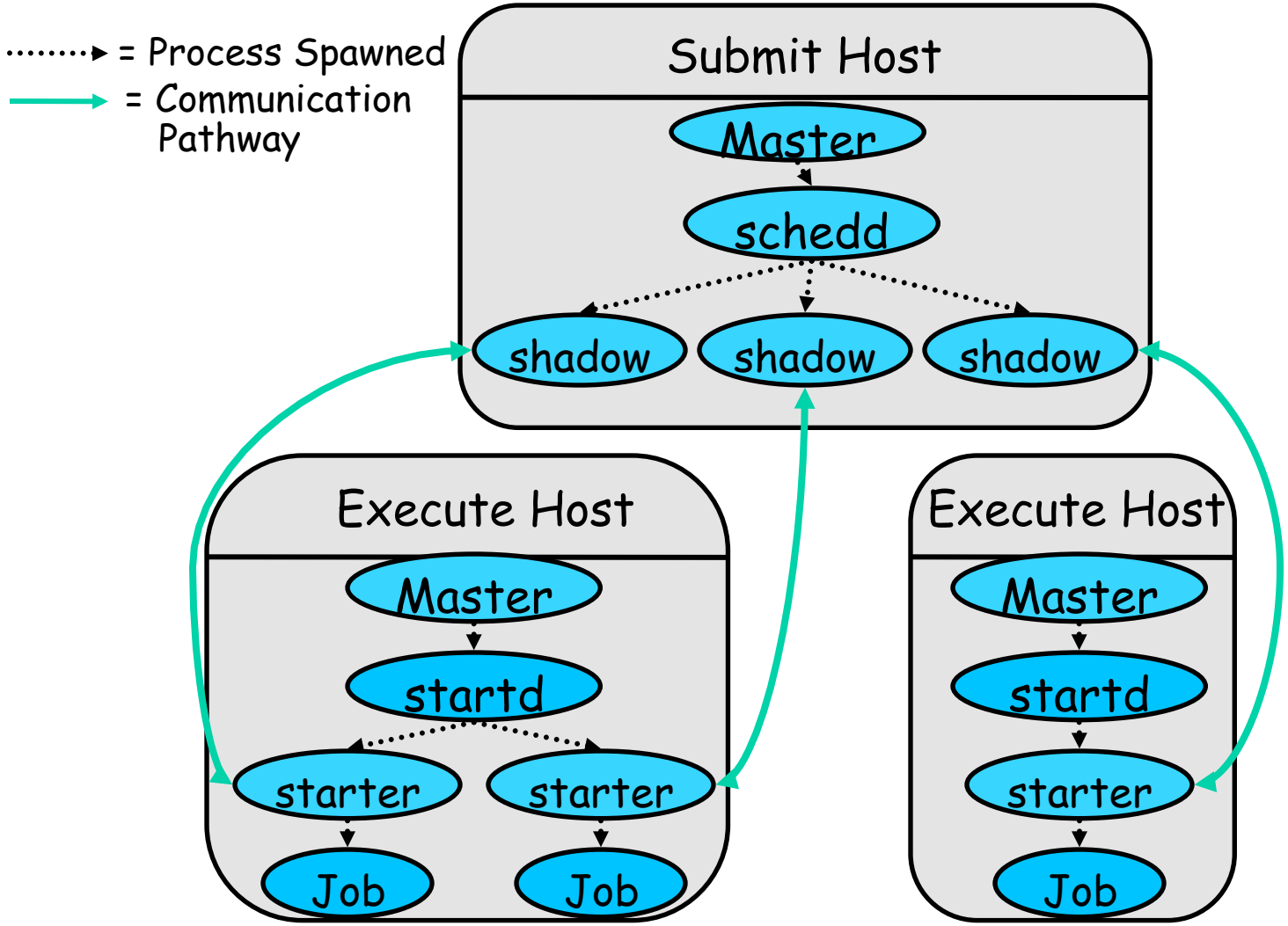
Condor Pool Layout: master



What's the "condor_shadow"

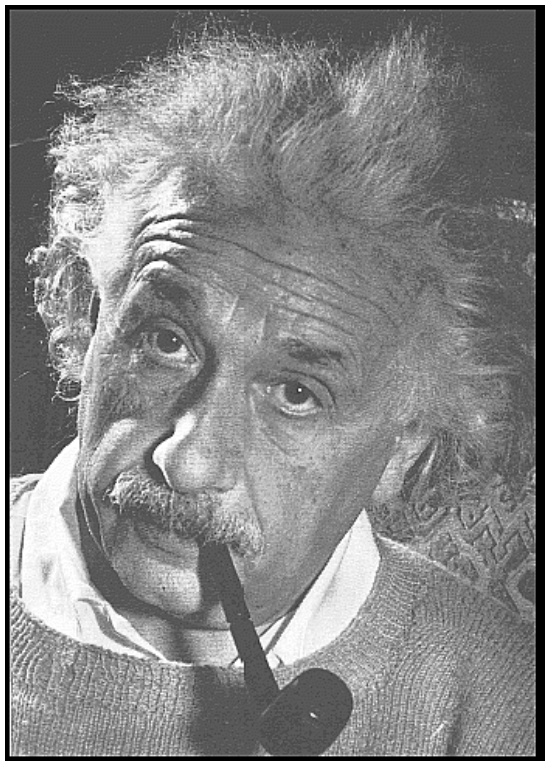
- The Shadow processes are Condor's local representation of your running job
  - One is started for each job
- Similarly, on the "execute" machine, a `condor_starter` is run for each job

Condor Pool Layout: running a job



My new jobs can run for 20 days…

- What happens when a job is forced off its CPU?
  - Preempted by higher priority user or job
  - Vacated because of user activity
- How can I add fault tolerance to my jobs?



Condor's Standard Universe to the rescue!

- Condor's process checkpointing provides a mechanism to automatically save the state of a job
- The process can then be restarted *from right where it was checkpointed*
  - After preemption, crash, etc.

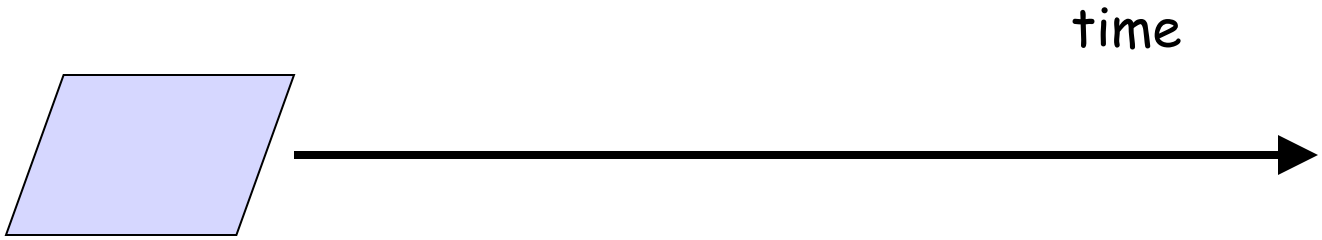
Other Standard Universe Features

- Remote system calls (remote I/O)
  - Your job can read / write files as if they were local
- No source code changes typically required
- Programming language independent
- Relinking of your execute is required

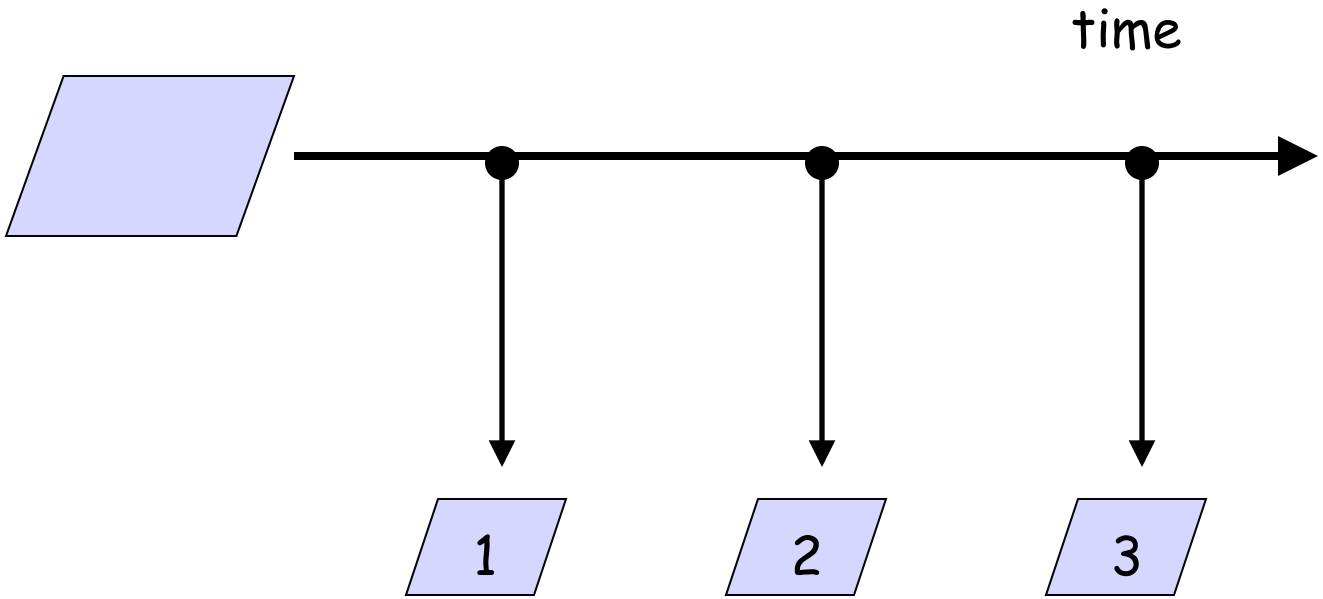
Checkpointing: Process Starts

checkpoint: the entire state of a program, saved in a file

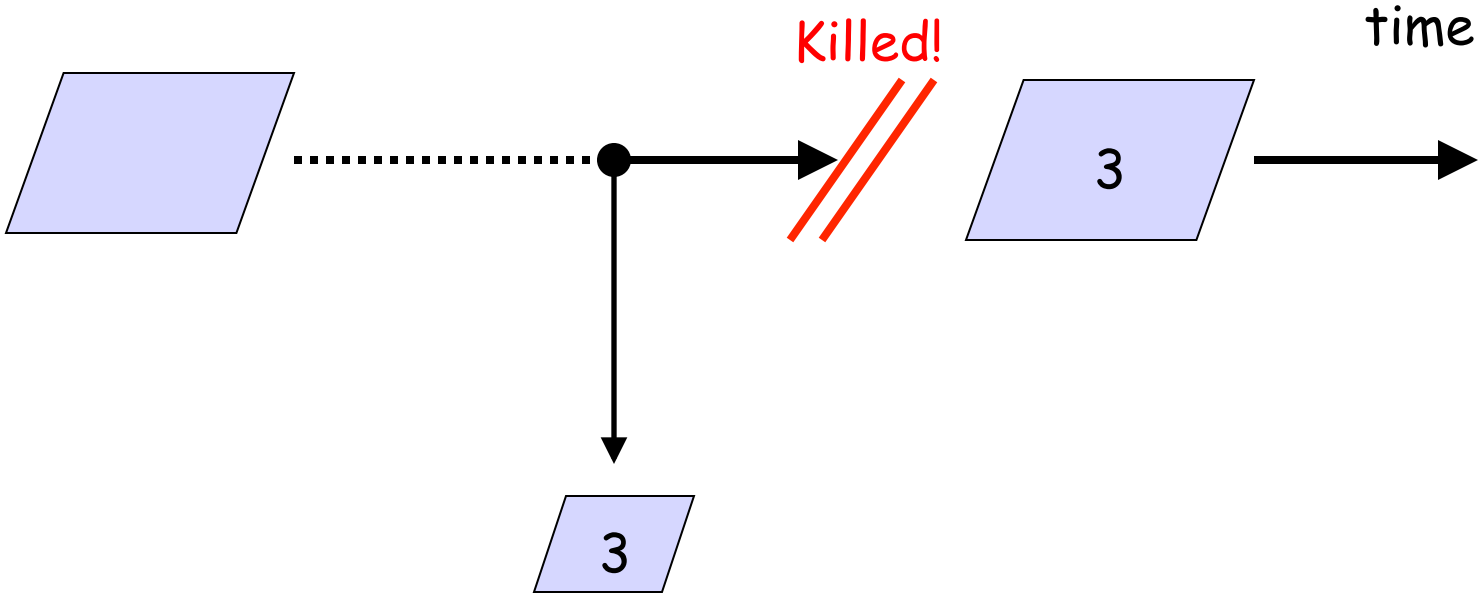
- CPU registers, memory image, I/O



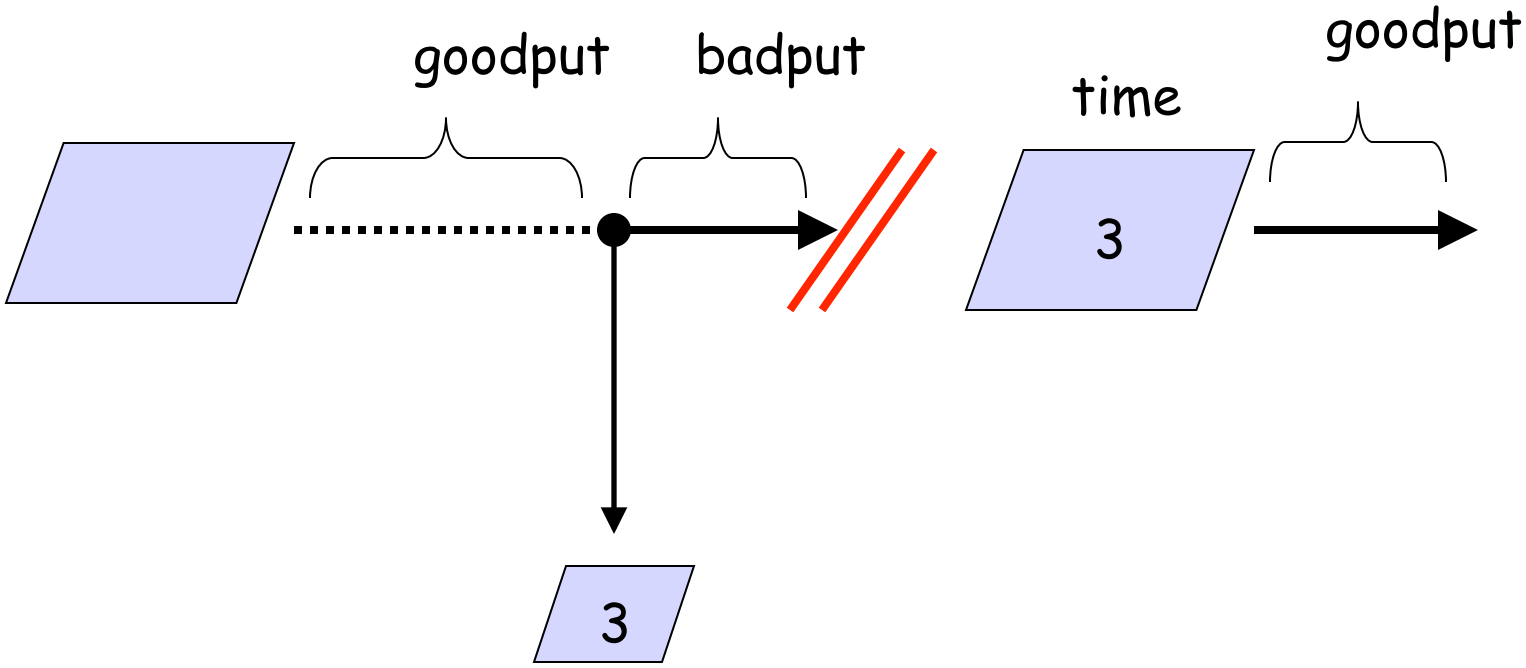
Checkpointing: Process Checkpointed



Checkpointing: Process Killed



Checkpointing: Process Resumed



When will Condor checkpoint your job?

- Periodically, if desired
  - For fault tolerance
- When your job is preempted by a higher priority job
- When your job is vacated because the execution machine becomes busy
- When you explicitly run *condor_checkpoint*, *condor_vacate*, *condor_off* or *condor_restart* command

Making the Standard Universe Work

- The job **must be relinked** with Condor's standard universe support library
- To relink, place **condor_compile** in front of the command used to link the job:

```
% condor_compile gcc -o myjob myjob.c
```

- OR -

```
% condor_compile f77 -o myjob filea.f fileb.f
```

- OR -

```
% condor_compile make -f MyMakefile
```

Limitations of the Standard Universe

- Condor's checkpointing is not at the kernel level.
- Standard Universe the job may not:
  - Fork()
  - Use kernel threads
  - Use some forms of IPC, such as pipes and shared memory
- Must have access to source code to relink
- Many typical scientific jobs are OK
- Only available on Linux platforms

Death of the Standard Universe*

*It's only MOSTLY dead

DMTCP & Parrot

- DMTCP (Checkpointing)
  - "Distributed MultiThreaded Checkpointing"
  - Developed at Northeastern University
  - **http://dmtcp.sourceforge.net/**
  - See Gene Cooperman's (Northeastern University) talk tomorrow (Wednesday) @ 4:05
- Parrot (Remote I/O)
  - Parrot is a tool for attaching existing programs to remote I/O system
  - Developed by Doug Thain (now at Notre Dame)
  - **http://www.cse.nd.edu/~ccl/software/parrot/**
  - dthain@nd.edu

VM Universe

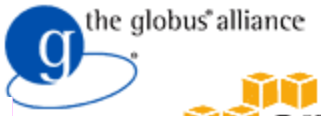
- Runs a virtual machine instance as a job
- VM Universe:
  - Job sandboxing
  - Checkpoint and migration
  - Safe elevation of privileges
  - Cross-platform
- Supports VMware, Xen, KVM
- Input files can be imported as CD-ROM image
- When the VM shuts down, the modified disk image is returned as job output

Albert meets The Grid

- Albert also has access to grid resources he wants to use
  - He has certificates and access to Globus or other resources at remote institutions
- But Albert wants Condor's queue management features for his jobs!
- He installs Condor so he can submit "Grid Universe" jobs to Condor

Grid Universe

- All handled in your submit file
- Supports many "back end" types:
  - Globus: GT2, GT4
  - NorduGrid
  - UNICORE
  - Condor
  - PBS
  - LSF
  - EC2
  - NQS



Grid Universe & Globus 2

- Used for a Globus GT2 back-end
  - "Condor-G"
- Format:

```
Grid_Resource = gt2 Head-Node
Globus_rsl = <RSL-String>
```

- Example:

```
Universe = grid
Grid_Resource = gt2 beak.cs.wisc.edu/jobmanager
Globus_rsl = (queue=long)(project=atom-smasher)
```

Grid Universe & Globus 4

- Used for a Globus GT4 back-end
- Format:

```
Grid_Resource = gt4 <Head-Node> <Scheduler-Type>
Globus_XML = <XML-String>
```

- Example:

```
Universe = grid
Grid_Resource = gt4 beak.cs.wisc.edu Condor
Globus_xml = <queue>long</queue><project>atom-
   smasher</project>
```

Grid Universe & Condor

- Used for a Condor back-end
  - "Condor-C"
- Format:

```
Grid_Resource = condor <Schedd-Name> <Collector-Name>
Remote_<param> = <value>
```

  - "Remote_" part is stripped off
- Example:

```
Universe = grid
Grid_Resource = condor beak condor.cs.wisc.edu
Remote_Universe = standard
```

Grid Universe & NorduGrid

- Used for a NorduGrid back-end

```
Grid_Resource = nordugrid <Host-Name>
```

- Example:

```
Universe = grid
Grid_Resource = nordugrid ngrid.cs.wisc.edu
```

Grid Universe & UNICORE

- Used for a UNICORE back-end
- Format:

```
Grid_Resource = unicore <USite> <VSite>
```

- Example:

```
Universe = grid
Grid_Resource = unicore uhost.cs.wisc.edu vhost
```

Grid Universe & PBS

- Used for a PBS back-end
- Format:

```
Grid_Resource = pbs
```

- Example:

```
Universe = grid
Grid_Resource = pbs
```

Grid Universe & LSF

- Used for a LSF back-end
- Format:

```
Grid_Resource = lsf
```

- Example:

```
Universe = grid
Grid_Resource = lsf
```

Credential Management

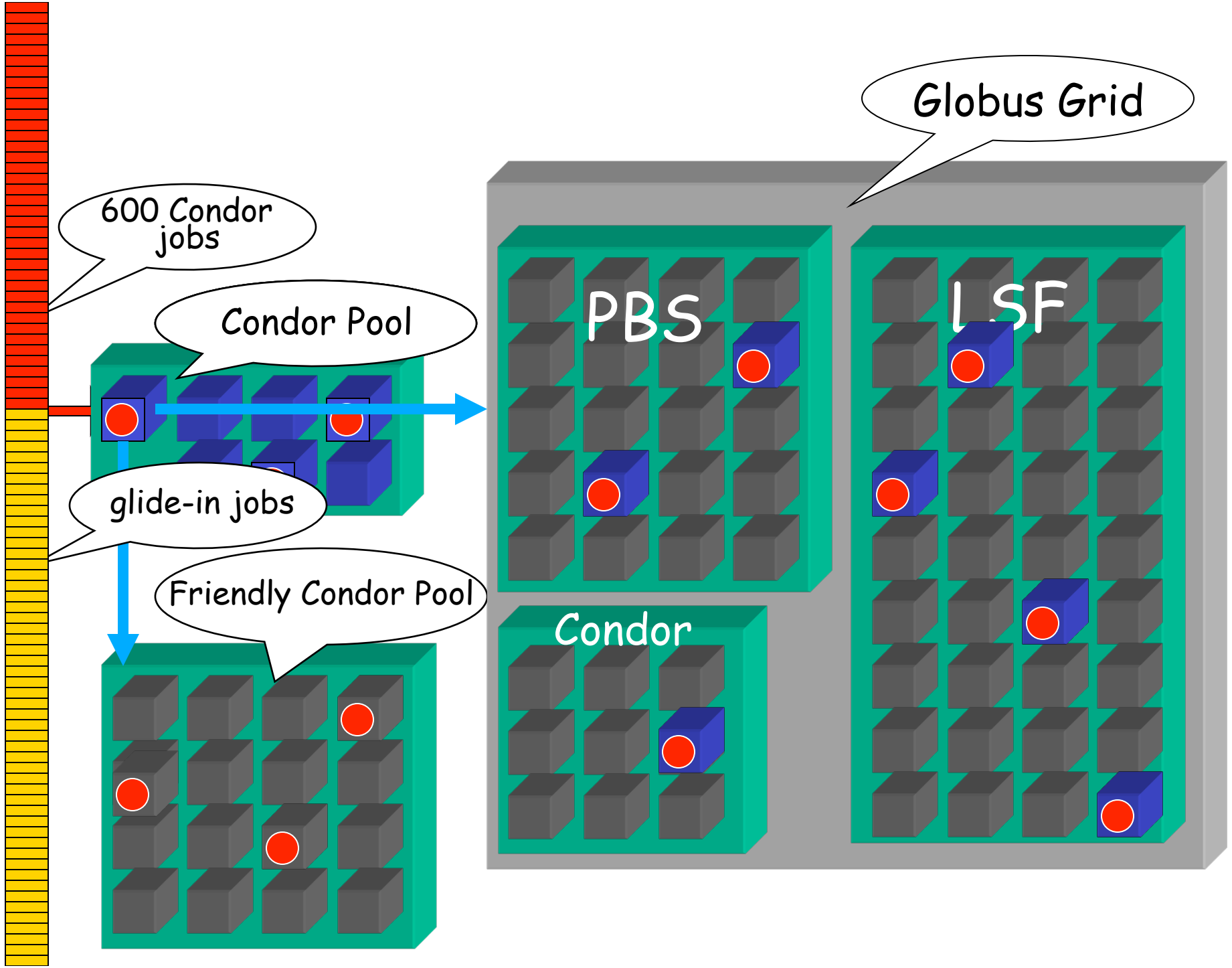
- Condor will do The Right Thing™ with your X509 certificate and proxy
- Override default proxy:
  - `X509UserProxy = /home/einstein/other/proxy`
- Proxy may expire before jobs finish executing
  - Condor can use MyProxy to renew your proxy
  - When a new proxy is available, Condor will forward the renewed proxy to the job
  - This works for non-grid jobs, too

Albert wants Condor features on remote resources

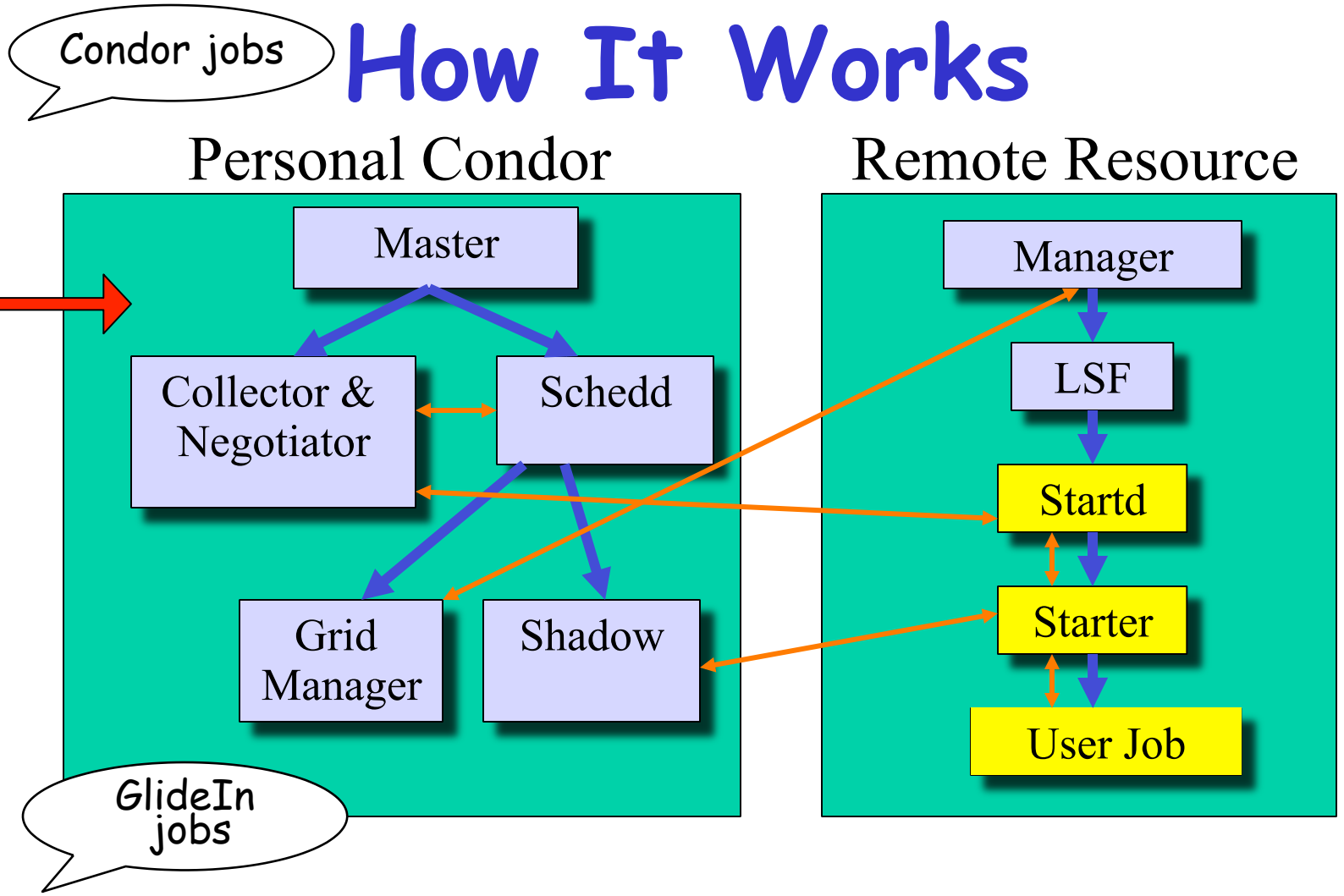
- He wants to run standard universe jobs on Grid-managed resources
  - For matchmaking and dynamic scheduling of jobs
  - For job checkpointing and migration
  - For remote system calls

Condor GlideIn

- Albert can use the Grid Universe to run Condor daemons on Grid resources
- When the resources run these GlideIn jobs, they will temporarily join his Condor Pool
- He can then submit Standard, Vanilla, or MPI Universe jobs and they will be matched and run on the remote resources
- Currently only supports Globus GT2
  - We hope to fix this limitation


Globus Grid
600 Condor jobs
Condor Pool
PBS
LSF
glide-in jobs
Friendly Condor Pool
Condor

How It Works


Condor jobs
Personal Condor
Remote Resource
Master
Collector & Negotiator
Schedd
Grid Manager
Shadow
Manager
LSF
Startd
Starter
User Job
GlideIn jobs

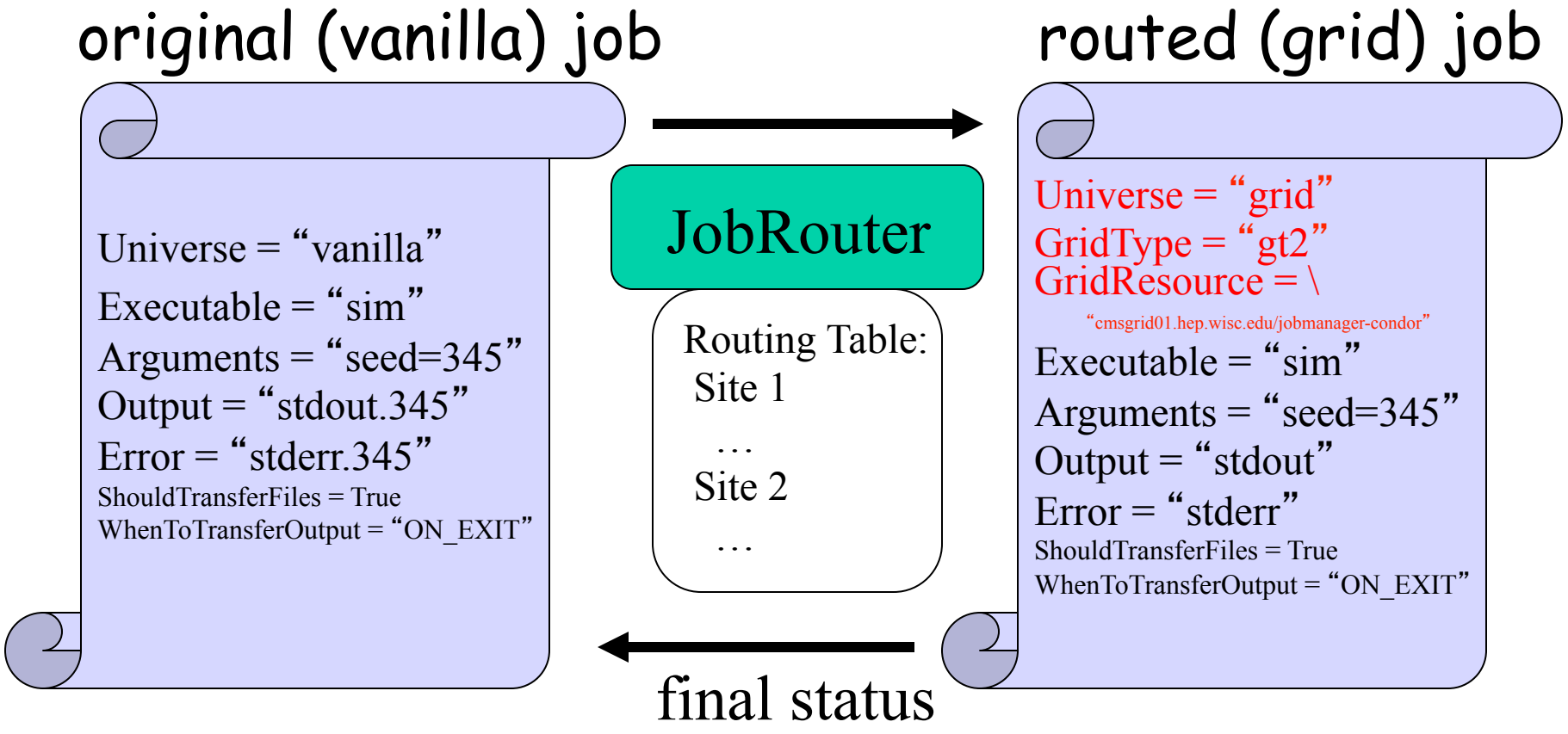
GlideIn Concerns

- What if the remote resource kills my GlideIn job?
  - That resource will disappear from your pool and your jobs will be rescheduled on other machines
  - Standard universe jobs will resume from their last checkpoint like usual
- What if all my jobs are completed before a GlideIn job runs?
  - If a GlideIn Condor daemon is not matched with a job in 10 minutes, it terminates, freeing the resource

The Job Router
A Flexible Job Transformer

- Acts upon jobs in queue
- Policy controls when:
  - (jobs currently routed to site X) < max
  - (*idle* jobs routed to site X) < max
  - (rate of recent failure at site X) < max
- And how to:
  - Change attribute values (e.g. Universe)
  - Insert new attributes (e.g. GridResource)
  - Other arbitrary actions in hooks

Example: sending excess vanilla jobs to a grid site



JobRouter vs. Glidein

- Glidein - Condor overlays the grid
  - Job never waits in remote queue
  - Full job management (e.g. `condor_ssh_to_job`)
  - Private networks doable, but add to complexity
  - Need something to submit glideins on demand
- JobRouter
  - Some jobs wait in remote queue (`MaxIdleJobs`)
  - Job must be compatible with target grid semantics
  - Job managed by remote batch system
  - Simple to set up, fully automatic to run

My jobs have have dependencies…

- Can Condor help solve my dependency problems?
- DAGMan to the rescue
- See Kent's tutorial @ 11:30 today
  - Immediately following this tutorial

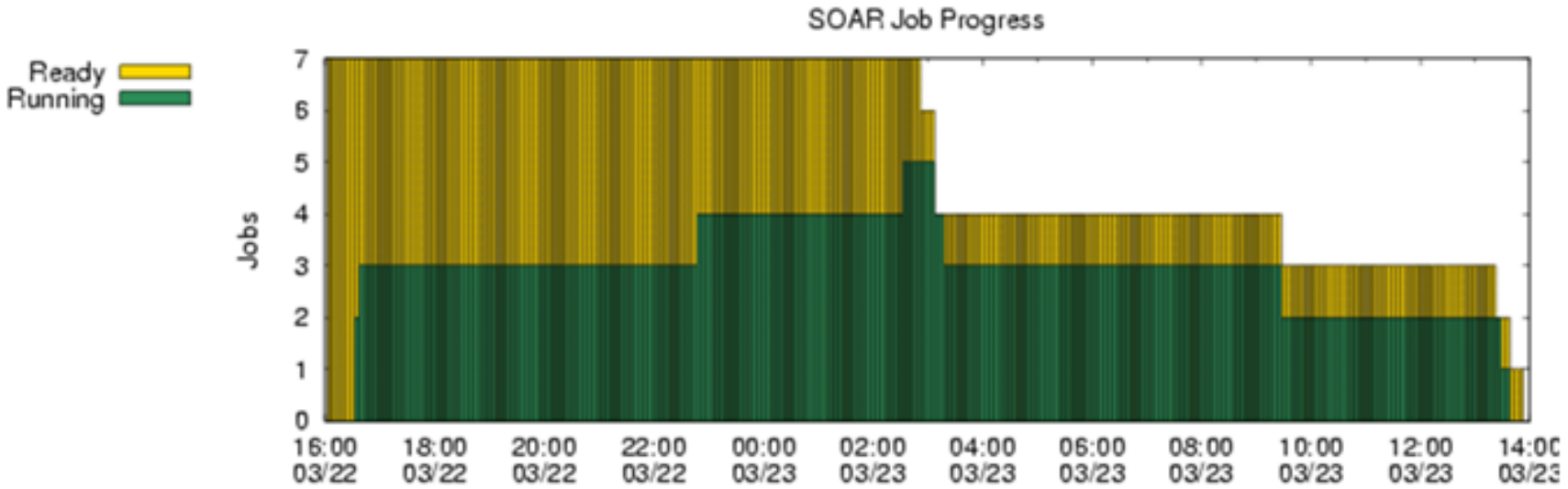
SOAR

- What is SOAR?
  - A System Of Automatic Runs
  - A framework for collecting N jobs into a DAG, submitting them to Condor and tracking the run
  - A tool that lets one make these jobs complex workflows
  - An environment to control production of large sets of data
  - A simple web interface for tracking runs and downloading results.

How does SOAR work?

- SOAR:
  - Sweeps drop box for new job data
  - Creates the run
  - Periodically creates plot and reports showing progress of run
  - After the DAG completes, SOAR makes your results available through the web interface

View SOAR Job Progress



SOAR

- When is it best used?
  - When a production environment is desired.
  - When a researcher is Linux challenged
  - When each job is a complex DAG in itself.
- Web peak: www.submit.chtc.wisc.edu/SOAR/
- Info: Bill Taylor bt@cs.wisc.edu CHTC Staff

General User Commands

condor_status	View Pool Status
condor_q	View Job Queue
condor_submit	Submit new Jobs
condor_rm	Remove Jobs
condor_prio	Intra-User Prios
condor_history	Completed Job Info
condor_submit_dag	Submit new DAG
condor_checkpoint	Force a checkpoint
condor_compile	Link Condor library

Condor Job Universes

- Vanilla Universe
- Standard Universe
- Grid Universe
- Scheduler Universe
- Local Universe
- Virtual Machine Universe
- Java Universe
- Parallel Universe
  - MPICH-1
  - MPICH-2
  - LAM
  - …

Why have a special Universe for Java jobs?

- Java Universe provides more than just inserting "java" at the start of the execute line of a vanilla job:
  - Knows which machines have a JVM installed
  - Knows the location, version, and performance of JVM on each machine
  - Knows about jar files, etc.
  - Provides more information about Java job completion than just JVM exit code
    - Program runs in a Java wrapper, allowing Condor to report Java exceptions, etc.

Java Universe Example

```
# Example Java Universe Submit file
Universe   = java
Executable = Main.class
jar_files  = MyLibrary.jar
Input      = infile
Output     = outfile
Arguments  = Main 1 2 3
Queue
```

Java support, cont.

```
bash-2.05a$ condor_status -java
 Name          JavaVendor  Ver    State     Actv LoadAv Mem
abulafia.cs Sun Microsy 1.5.0_ Claimed   Busy 0.180   503
acme.cs.wis Sun Microsy 1.5.0_ Unclaimed Idle 0.000   503
adelie01.cs Sun Microsy 1.5.0_ Claimed   Busy 0.000  1002
adelie02.cs Sun Microsy 1.5.0_ Claimed   Busy 0.000  1002
...
                     Total Owner Claimed Unclaimed Matched Preempting
        INTEL/LINUX    965   179     516       250      20          0
      INTEL/WINNT50    102     6      65        31       0          0
    SUN4u/SOLARIS28      1     0       0         1       0          0
       X86_64/LINUX    128     2     106        20       0          0

              Total   1196   187     687       302      20          0
```

In Review

With Condor's help, Albert can:

- Manage his compute job workload
- Access local machines
- Access remote Condor Pools via flocking
- Access remote compute resources on the Grid via "Grid Universe" jobs
- Carve out his own personal Condor Pool from the Grid with GlideIn technology

Administrator Commands

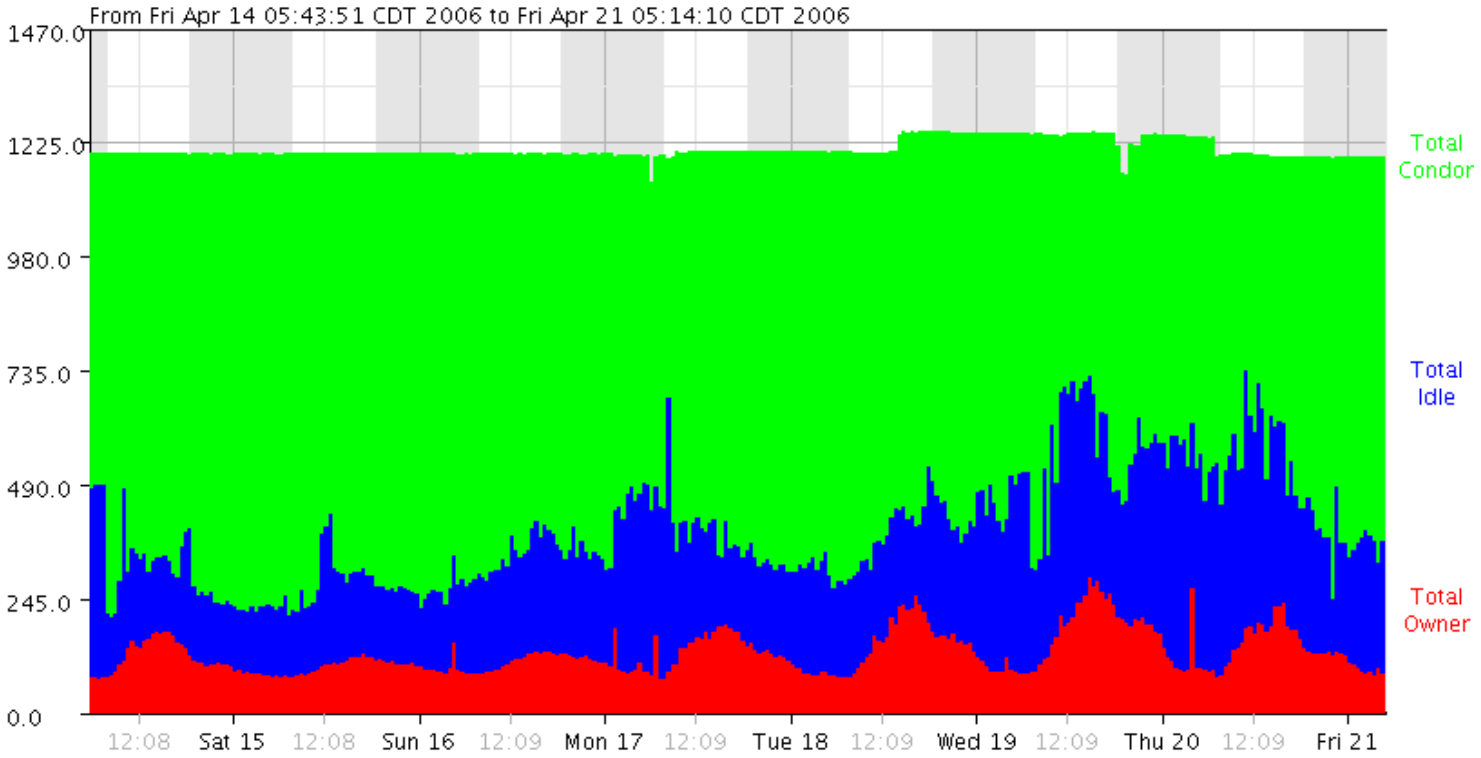
condor_vacate	Leave a machine now
condor_on	Start Condor
condor_off	Stop Condor
condor_reconfig	Reconfig on-the-fly
condor_config_val	View/set config
condor_userprio	User Priorities
condor_stats	View detailed usage accounting stats

My boss wants to watch what Condor is doing

Use CondorView!

- Provides visual graphs of current and past utilization
- Data is derived from Condor's own accounting statistics
- Interactive Java applet
- Quickly and easily view:
  - How much Condor is being used
  - How many cycles are being delivered
  - Who is using them
  - Utilization by machine platform or by user

CondorView Usage Graph



I could also talk lots about…

- CCB: Living with firewalls & private networks
- Federated Grids/Clusters
- APIs and Portals
- MW
- High Availability Fail-over
- Compute On-Demand (COD)
- Role-based prioritization and accounting
- Strong security, including privilege separation
- Data movement scheduling in workflows
- …

Thank you!

Check us out on the Web:
http://www.condorproject.org

Email:
condor-admin@cs.wisc.edu