Using Condor
An Introduction

Condor Week 2010

Condor Project
Computer Sciences Department
University of Wisconsin-Madison

The Condor Project (Established '85)

- Research and Development in the Distributed High Throughput Computing field
- 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
- GCB & CCB
- MW
- NeST / LotMan
- And others… all as open source

High-Throughput Computing

- High-Throughput Computing:
  - Allows for many computational tasks to be done over a long period of time

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 w/ a wide array of Grid Middleware

Full featured system

- Workflow management (inter-dependencies)
- Support for many job types – serial, parallel, etc.
- Fault-tolerant: can survive crashes, network outages, no single point of failure.
- Development APIs: via SOAP / web services, DRMAA (C), Perl package, GAHP, flexible command-line tools, MW
- Platforms:
  - Linux i386 / IA64 / X86-64 / PPC
  - Windows XP / Vista / 7
  - MacOS X
  - Solaris
  - HP-UX
  - AIX

DRMAA: Distributed Resource Management Application API

GAHP: Grid ASCII Helper Protocol

Example of application: simulation of cosmos

Varying values for parameters:

- 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 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

FCT won't fund the Blue Gene that I requested.

Condor and 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

Definitions

- Job
  - The Condor representation of your work (next slide)
- Machine
  - The Condor representation of computers and that can perform the work
- ClassAd
  - Condor's internal data representation
- Match Making
  - Matching a job with a machine "Resource"
- Central Manager
  - Central repository for the whole pool
  - Performs job / machine matching, etc.

Job

- Condor's quanta of work
  - Like a UNIX process
  - Can be an element of a workflow

Jobs Have Wants & Needs

- Jobs state their requirements and preferencs:
  - Requirements:
    - I **require** a Linux/x86 platform
  - Preferences ("Rank"):
    - 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
  - Preferences ("Rank"):
    - 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
  - 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 Ad" represents your job to Condor
  - A "Machine Ad" represents the various compute resources in your Condor pool
  - Others represent other pieces of your Condor pool

ClassAd Structure

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

The Pet Exchange

Pet Ad

```
Type   = "Dog"
Color = "Brown"
Price = 75
Sex = "Male"
AgeWeeks = 8
Breed = "Saint Bernard"
Size = "Very Large"
Weight = 27
```

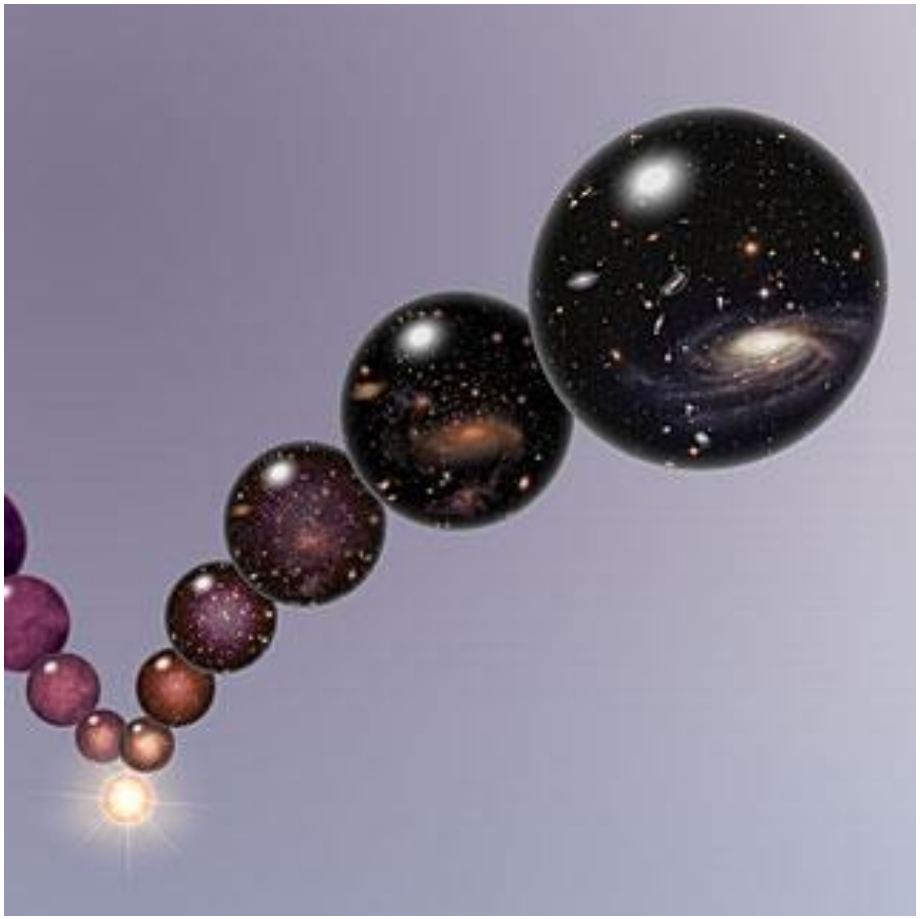
Buyer Ad

```
. . .
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
  - 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 our Simulation..



Getting Started: Submitting Jobs to Condor

- Get access to submit host
- Choose a "Universe" for your job
- Make your job "batch-ready"
  - Includes making your data available to your job
- Create a *submit description* file
- Run *condor_submit* to put your job(s) in the queue
- Relax while Condor manages and watches over your job(s)

2. Choose the "Universe"

- Controls how Condor handles jobs
- Condors 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

3. Make your job batch-ready

Must be able to run in the background

- No interactive input
- No GUI/window clicks

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

4. Create a Submit Description File

- A plain ASCII text file
- Condor does ***not*** care about file extensions
  - Most people use ".sub" or ".submit", though
- Tells Condor about your job:
  - Which executable, universe, input, output and error files to use, command-line arguments, environment variables, any special requirements or preferences (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 submit file settings
- You can define the job's standard input, standard output and standard error:
  - Read job's standard input from "input_file":
    - `Input = input_file`
    - Shell equivalent: `$ program <input_file`
  - Write job's standard ouput to "output_file":
    - `Output = output_file`
    - Shell equivalent: `$ program >output_file`
  - Write job's standard error to "error_file":
    - `Error = error_file`
    - Shell equivalent: `$ program 2>error_file`

Simple Submit File

```
# Simple condor_submit input file
# (Lines beginning with # are comments)
# NOTE: the words on the left side are not
#       case sensitive, but filenames are!
Universe   = vanilla
Executable = cosmos
Output     = cosmos.out
Input      = cosmos.in
Log        = cosmos.log
Queue
```

- Job's executable
- Job's STDOUT
- Job's STDIN
- Log the job's activities
- Put the job in the queue!

Logging your Job's Activities

- Create a log of job events
- Add to 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 Condor User 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)
...
```

5. Submit the Job to Condor

- Run *condor_submit*:
  - Provide the name of the submit file you have created on the command line:

```
$ condor_submit cosmos.submit
```

  - *condor_submit*:
    - Parses the submit file, checks for errors
    - Creates one or more job ad(s) that describes your job(s)
    - Hands the job ad(s) off to the schedd

The Job Ad

Example:

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

String

Number

Boolean

Boolean Expression

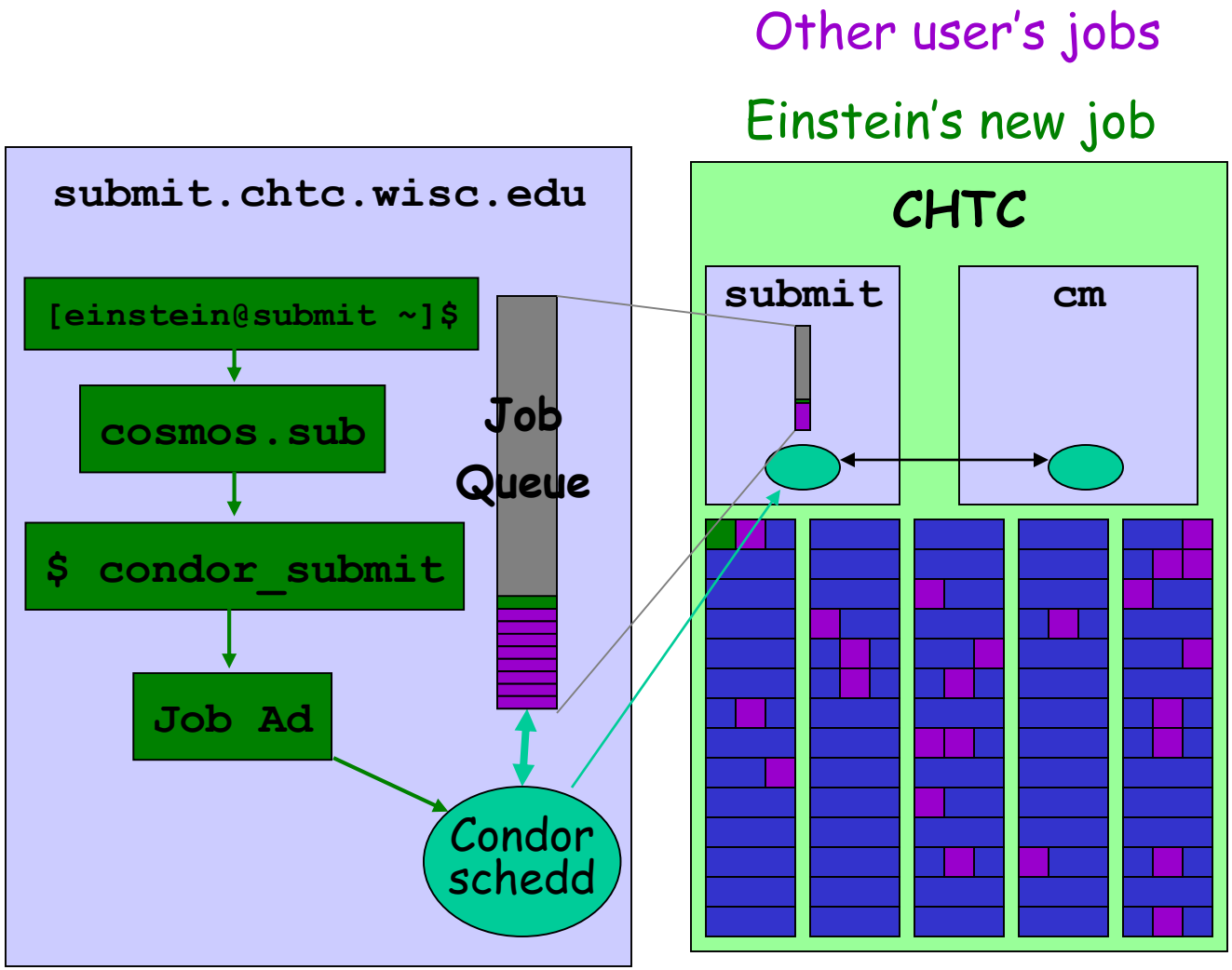
Submitting The Job

```
[einstein@submit ~]$ condor_submit cosmos.submit-file
Submitting job(s).
2 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
[einstein@submit ~]$
```

The Job Queue

- condor_submit sends your job's ClassAd(s) to the schedd
- 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*

CHTC Condor Pool



Condor File Transfer Lists

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

Condor File Transfer Controls

- **ShouldTransferFiles**
  - **YES:** Always transfer files to execution site
  - **NO:** Always rely on a shared filesystem
  - **IF_NEEDED:** Condor will automatically transfer the files if the submit and execute machine are not in the same **FileSystemDomain** (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

Simple File Transfer Example

```
# Example submit file 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
```

Need Command Line Args?

- You can specify command line arguments to pass to your program with the **arguments** directive:

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

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

InitialDir

- With `InitialDir`, you can give jobs a directory with respect to file input and output.
- Also provides a directory (on the **submit** machine) for the user log, when a full path is not specified.
- Executable is **not** relative to `InitialDir`

```
# Example submit input file with InitialDir
Universe   = vanilla
InitialDir = /home/einstein/cosmos/run
Executable = cosmos                    · NOT Relative to InitialDir
Log        = cosmos.log                · Is Relative to InitialDir
Input      = cosmos.in                 · Is Relative to InitialDir
Output     = cosmos.out                · Is Relative to InitialDir
Error      = cosmos.err                · Is Relative to InitialDir
TransferInputFiles=cosmos.dat          · Is Relative to InitialDir
Arguments  = -f cosmos.dat
Queue
```

Need More Feedback?

- Condor sends email about job events to the submitting user
- Specify "notification" in your submit file to control which events:

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

Jobs, Clusters, and Processes

- If your submit file describes multiple jobs, we call this a "cluster"
- Each cluster has a "cluster number"
  - The cluster number is unique to the schedd
- Each individual job in a cluster is called a "process"
  - 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 The Job

```
[einstein@submit ~]$ condor_submit cosmos.submit-file
Submitting job(s).
2 job(s) submitted to cluster 101.
[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 ~]$
```

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 file: 6,000,000+ lines, ~128M
  - Difficult (at best) to sort through
- Better: Create a subdirectory for each run
  - Take advantage of `InitialDir` directive

Organize your files and directories 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 your job's output

More Data Files

- Move the values of G, c & $\mathcal{R}_{\mu\nu}$ for each run to a data file
  - Let's call it `cosmos.in`
  - Each run directory would contain a unique `cosmos.in` file
- The common `cosmos.dat` file could be shared by all jobs
  - Can be symlinks to a common file

cosmos.in files

- These `cosmos.in` files can be automatically generated

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

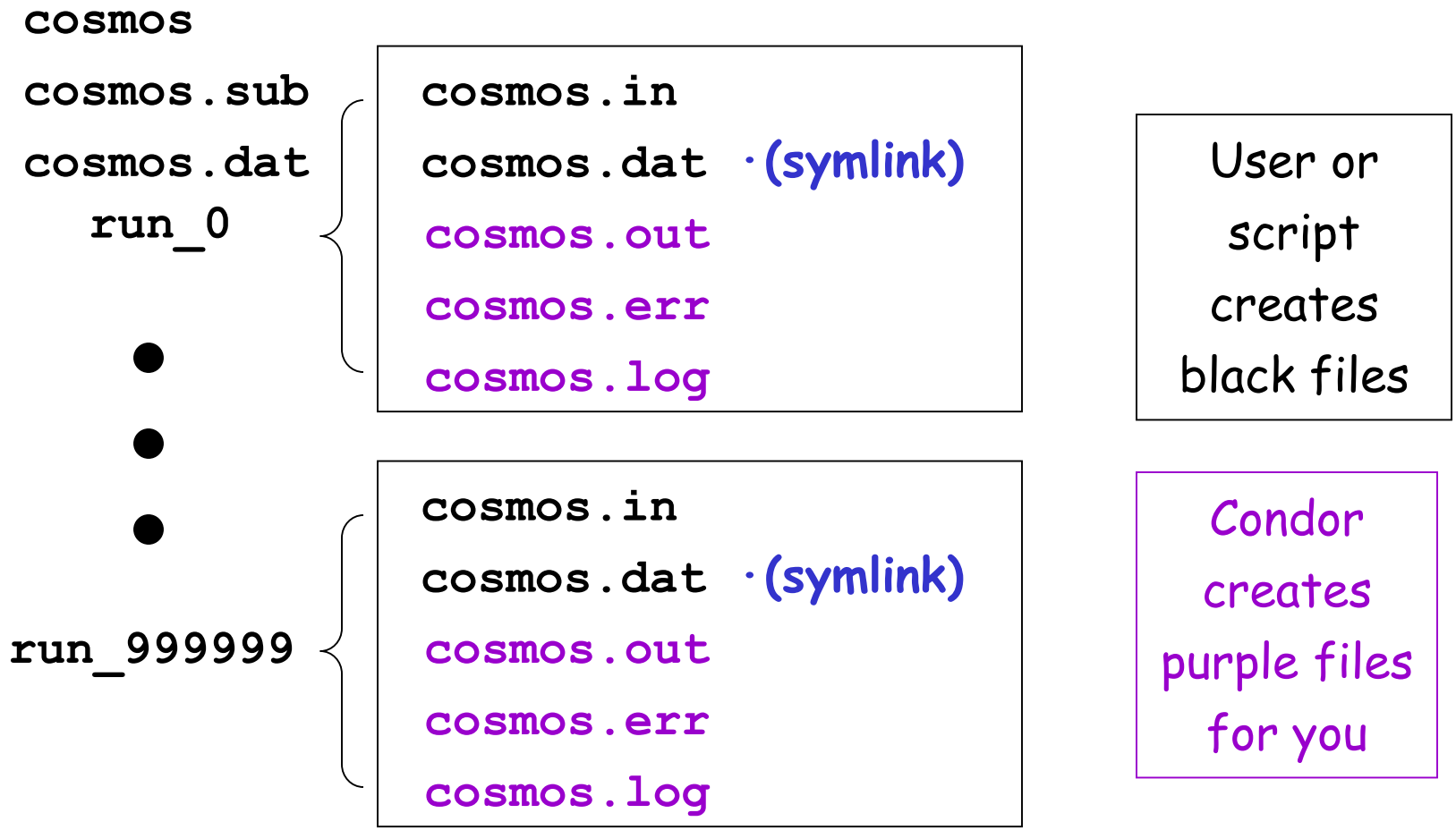
```
run_1/cosmos.in
c = 299792409
G = 6.67300e-112
R = 10.00e-29
```

...

```
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 Description File for 1,000,000 Jobs

```
# 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
TransferInputFiles    = cosmos.dat
...

InitialDir = run_0
Queue

InitialDir = run_1
Queue
```

- Log, input, output & error files -> run_0
- Job 103.0 (Cluster 103, Process 0)
- Log, input, output & error files -> run_1
- Job 103.1 (Cluster 103, Process 1)

- Do this 999,998 more times……

Submit File for a Big Cluster of Jobs

- We just submitted 1 cluster with 1,000,000 processes
- All the input/output files will be in different directories
- The submit file still is pretty unwieldy
  - 2,000,000+ lines, ~32M
- Isn't there a better way?

The Better Way

- We can queue all 1,000,000 in 1 "Queue" directive
  - `Queue 1000000`
- Condor provides `$(Process)` and `$(Cluster)`
  - `$(Process)` will be expanded to the process number for each job in the cluster
    - 0, 1, … 999999
  - `$(Cluster)` will be expanded to the cluster number
    - Will be the same for all jobs in the cluster
    - 104 in our example

Using $(Process)

- The initial directory for each job can be specified using `$(Process)`
  - `InitialDir = run_$(Process)`
  - Condor will expand these to:
    - "`run_0`", "`run_1`", … "`run_999999`" directories
- Similarly, arguments can be variable
  - `Arguments = -n $(Process)`
  - Condor will expand these to:
    - "`-n 0`", "`-n 1`", … "`-n 999999`"

Better Submit File for 1,000,000 Jobs

```
# Example condor_submit input file that defines
# a cluster of 100000 jobs with different directories
Universe   = vanilla
Executable = cosmos
Log        = cosmos.log
Input      = cosmos.in
Output     = cosmos.out
Error      = cosmos.err
Arguments  = -f cosmos.dat
InitialDir = run_$(Process)
Queue 1000000
```

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

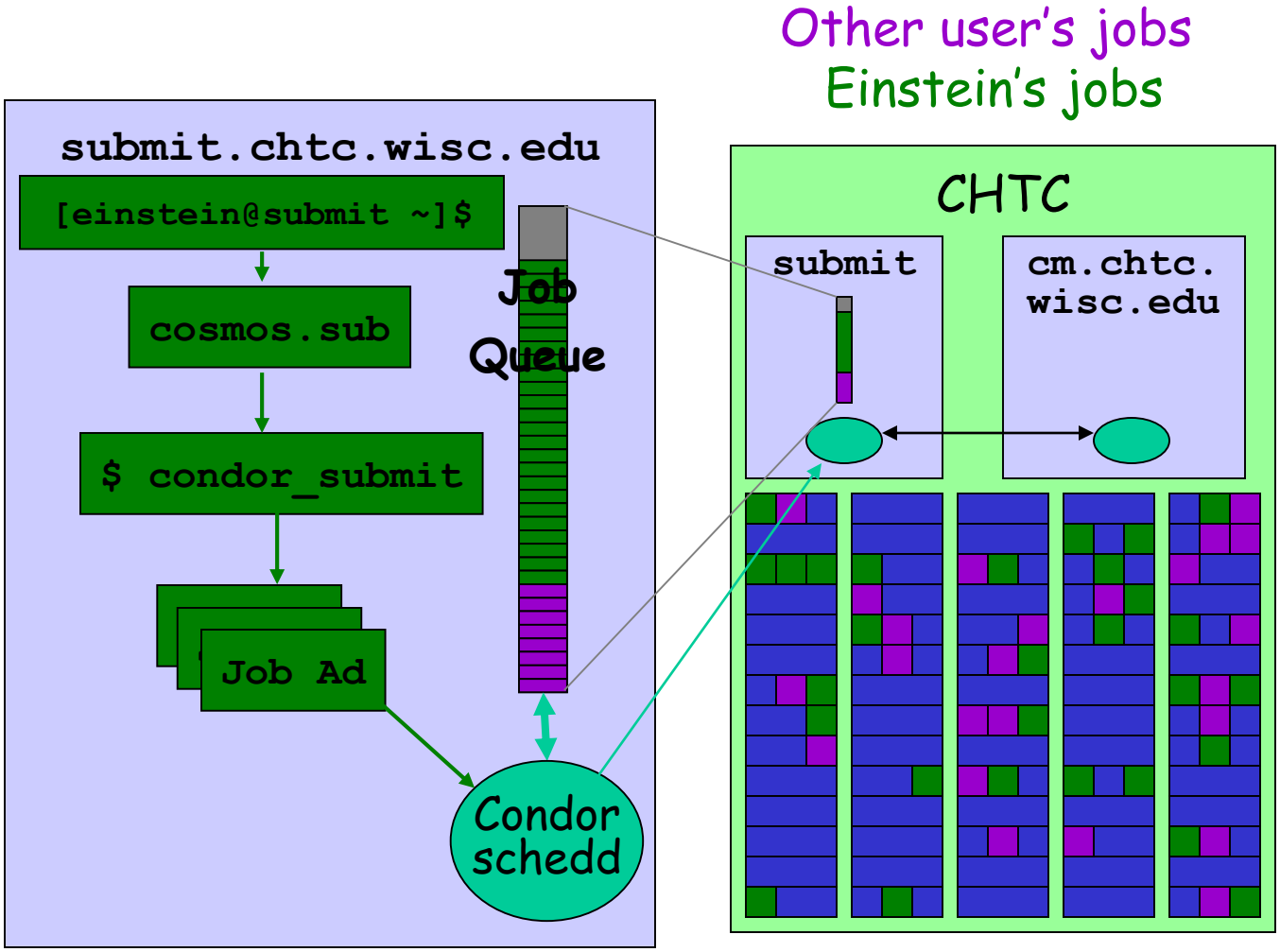
Now, we submit it…

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

Check the Job Queue

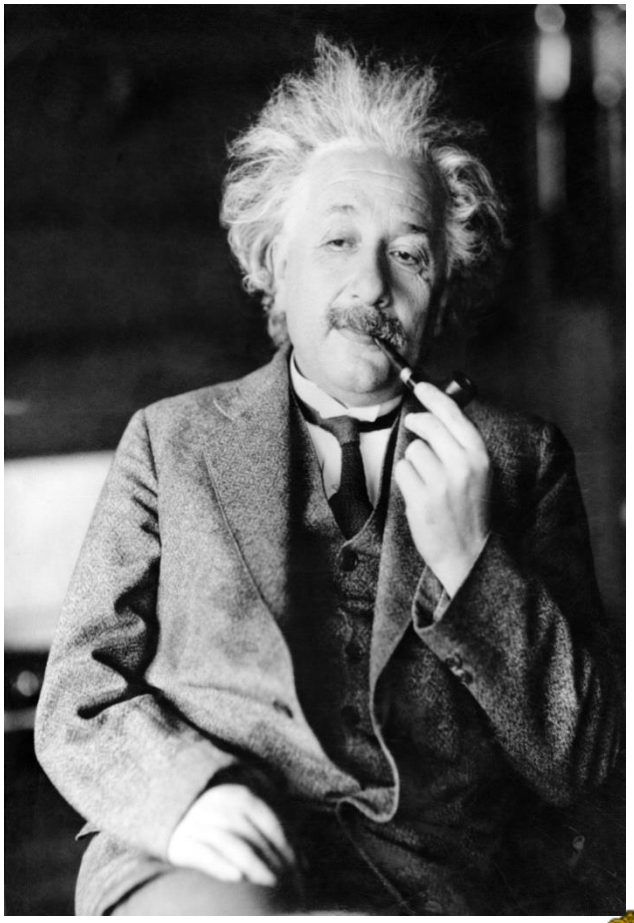
```
[einstein@submit ~]$ condor_q
-- Submitter: submit.chtc.wisc.edu : <128.104.55.9:51883> :
   submit.chtc.wisc.edu
ID        OWNER   SUBMITTED   RUN_TIME  ST PRI SIZE CMD
104.0       einstein 4/20 12:08 0+00:00:05 R 0 9.8 cosmos -f cosmos.dat
104.1       einstein 4/20 12:08 0+00:00:03 I 0 9.8 cosmos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



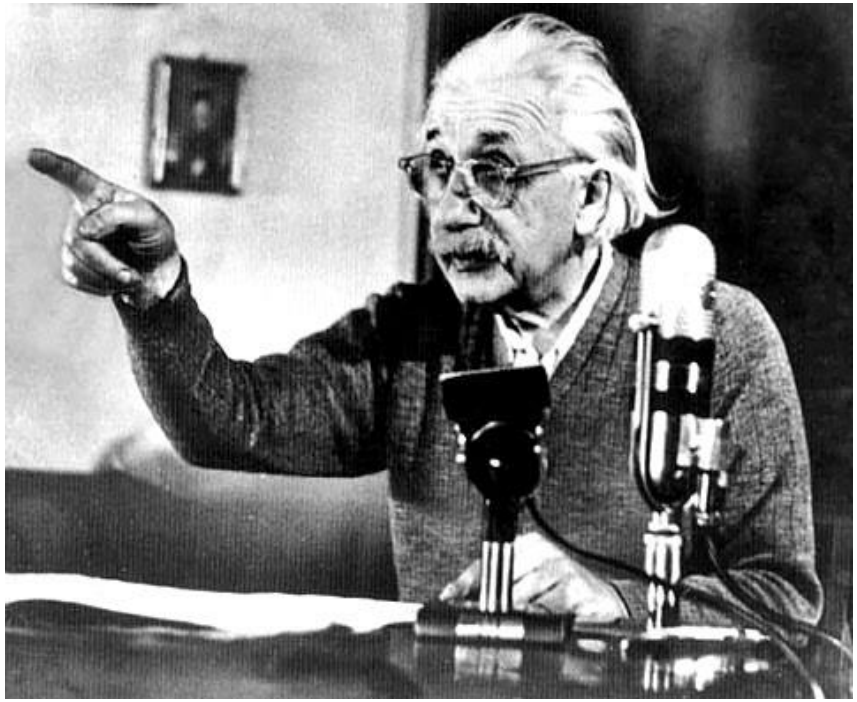
6. Relax

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



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
  - "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*"
  - `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"
```

- 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 "Administering Condor" tutorial 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)
- 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" 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?**
- Introducing ClassAd Meta Operators:
  - Allow you to test if an 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

- Rank:
  - Numerical expression
  - All matches which meet the requirements can be sorted by preference with a Rank expression..
  - Higher values match first

```
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
```

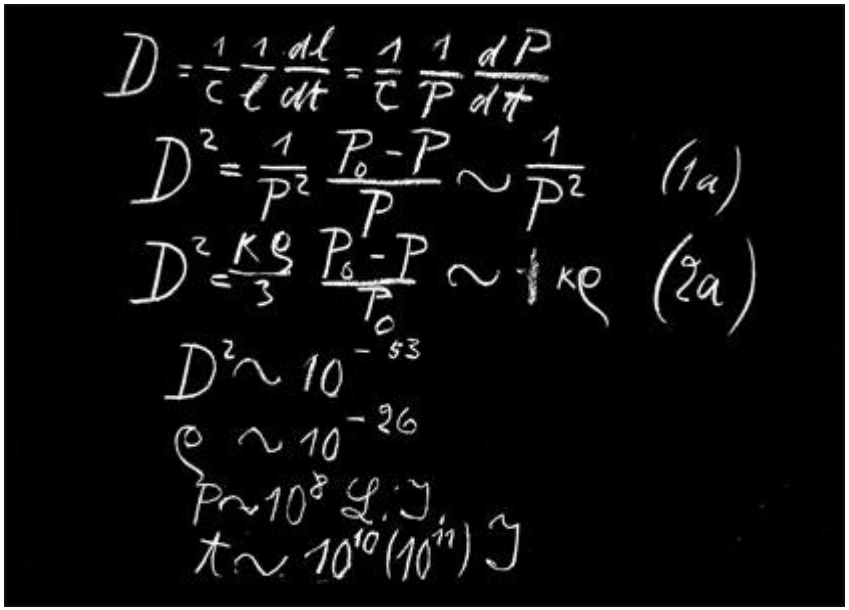
- Place on hold if exits with nonzero status or ran for less than an hour:

```
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
  - Can be encrypted over the wire
- 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 without 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 Jobs

- Condor is a High Throughput system, designed for long running jobs
- Starting a job in Condor is somewhat expensive
- There are some configuration parameters that may be able to help
  - Contact a Condor staff person for more

What else can I do to run my Short Jobs with Condor?

- 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

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

```
# Example condor_submit input file that for MPI
# jobs
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`

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 cannot yet be used for sensitive data

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

Using Condor

An Introduction

Part II

Condor Week 2010

More 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
  - 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 / 2003 / Vista
- 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: 7.4
    - Examples: 7.2.5, 7.4.2
      - 7.4.2 just released
  - If minor is odd (a.b.c): Developer series
    - New features, may have some bugs
    - Current: 7.5
    - Examples: 7.3.2, 7.5.1
      - 7.5.1 just released

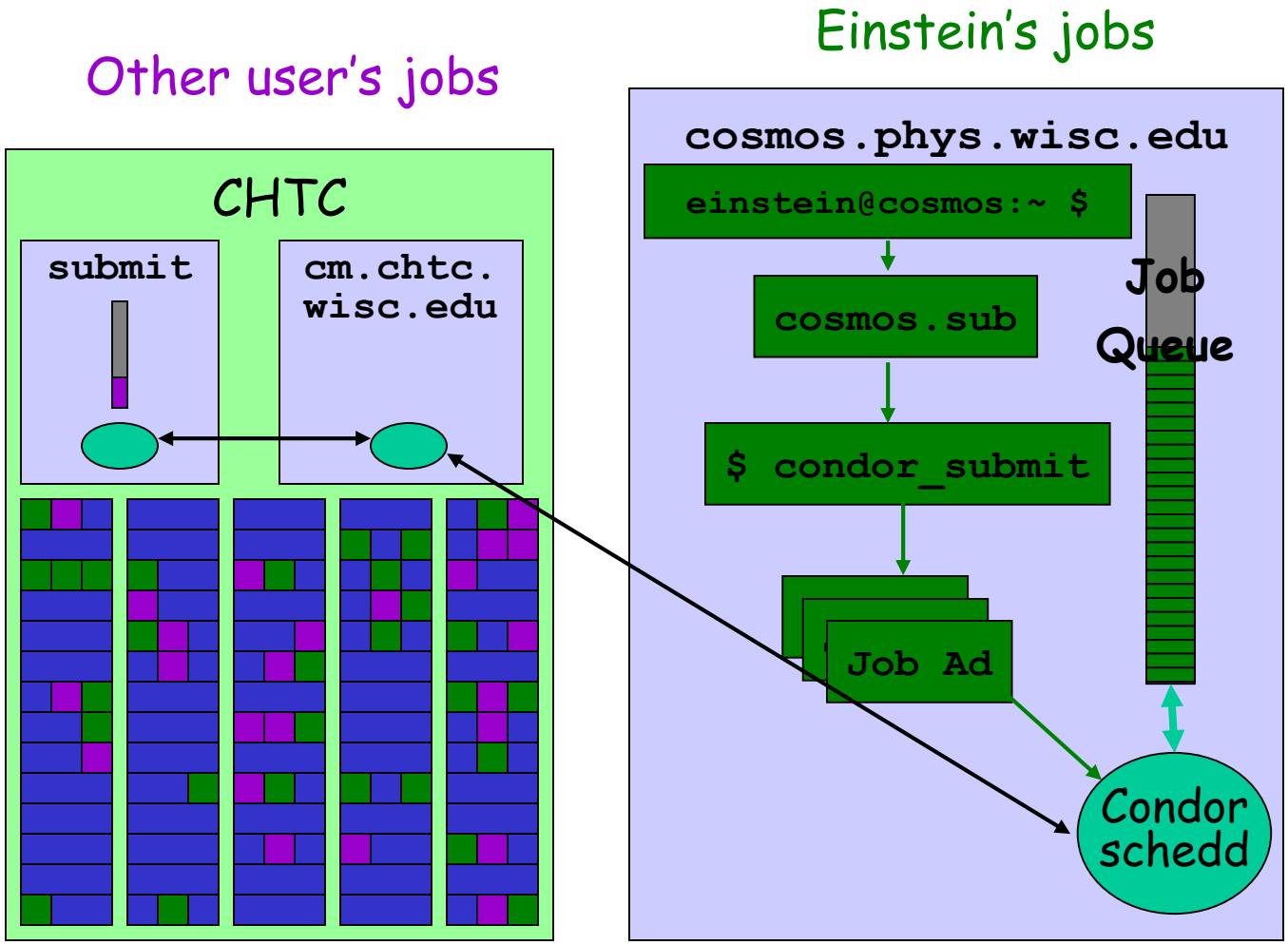
Condor Installation

- 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?

- Flocking is a Condor-specific technology
- Allows Condor jobs to run in other friendly Condor pools
- Needs to be setup on both ends
- Can be bi-directional

Flocking to CHTC

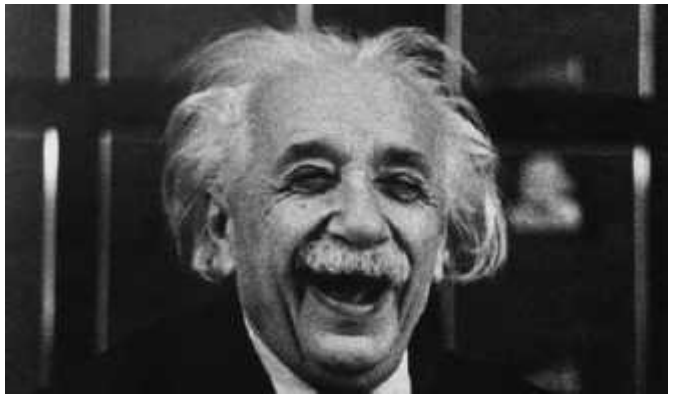


We *STILL* Need More

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!

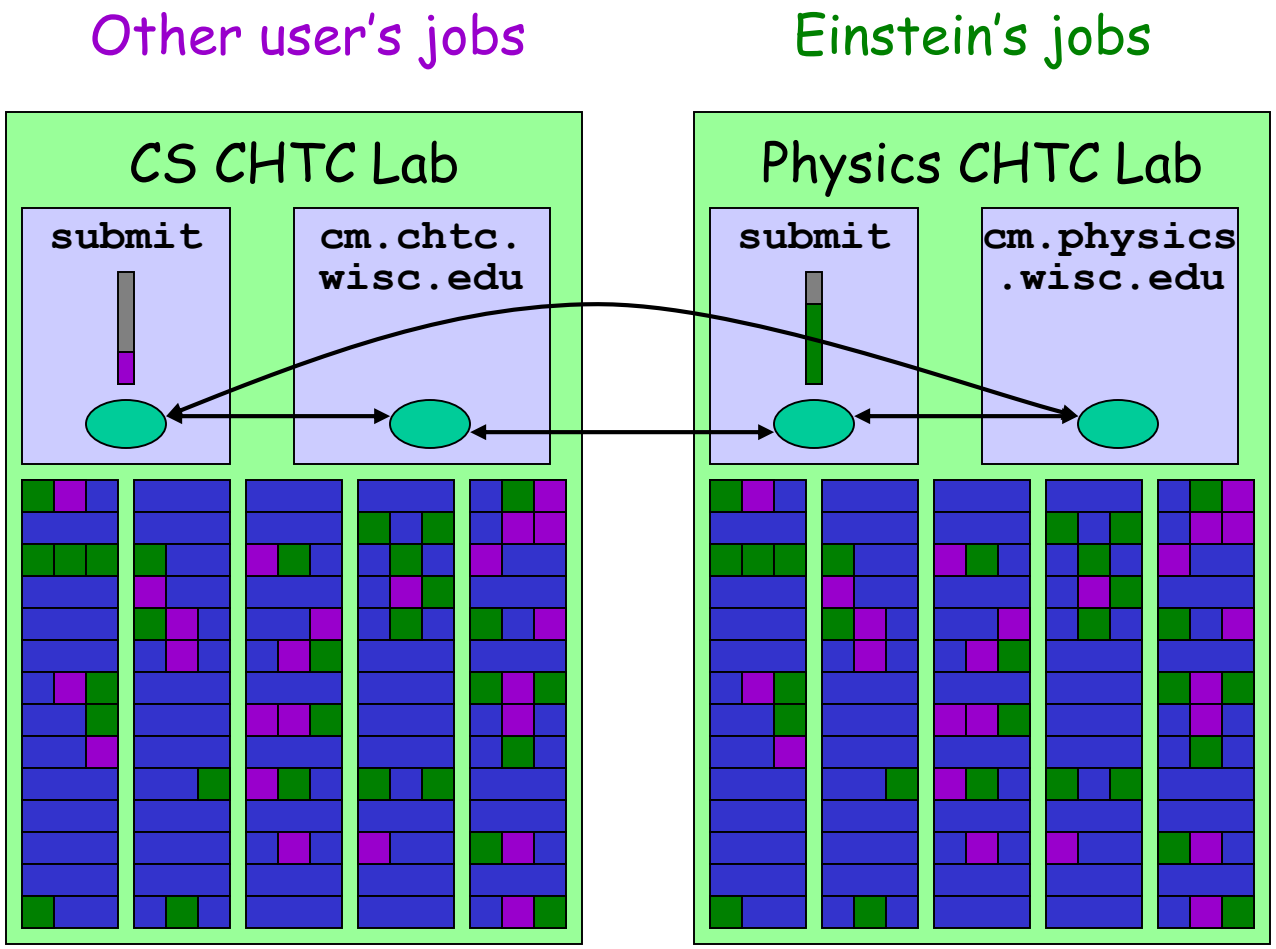


- The administrator installs Condor on all these new dedicated cluster nodes

Adding dedicated nodes

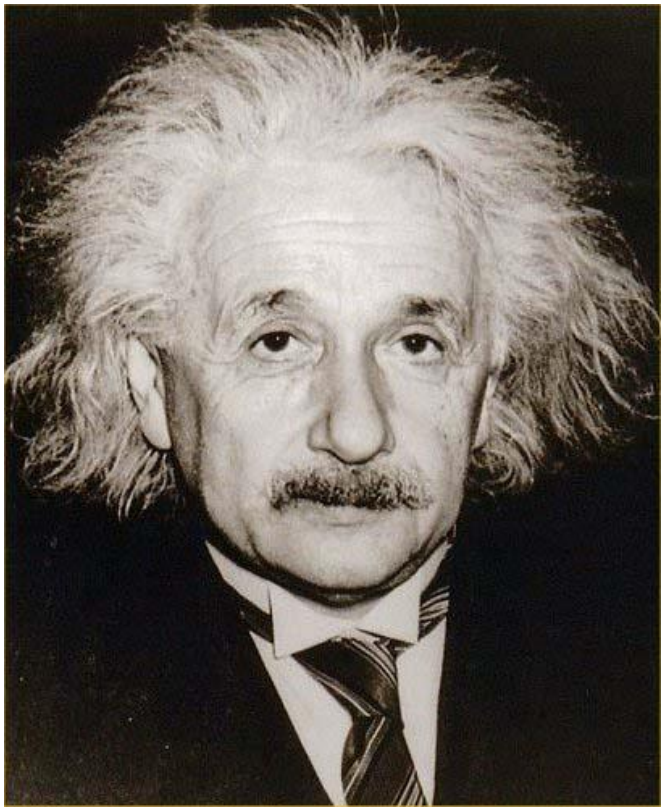
- The administrator installs Condor on these new machines, and configures them with his machine as the central manager
  - The central manager:
    - Central repository for the whole pool
    - Performs job / machine matching, etc.
- These are dedicated nodes, meaning that they're always able run Condor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

Flocking to CHTC

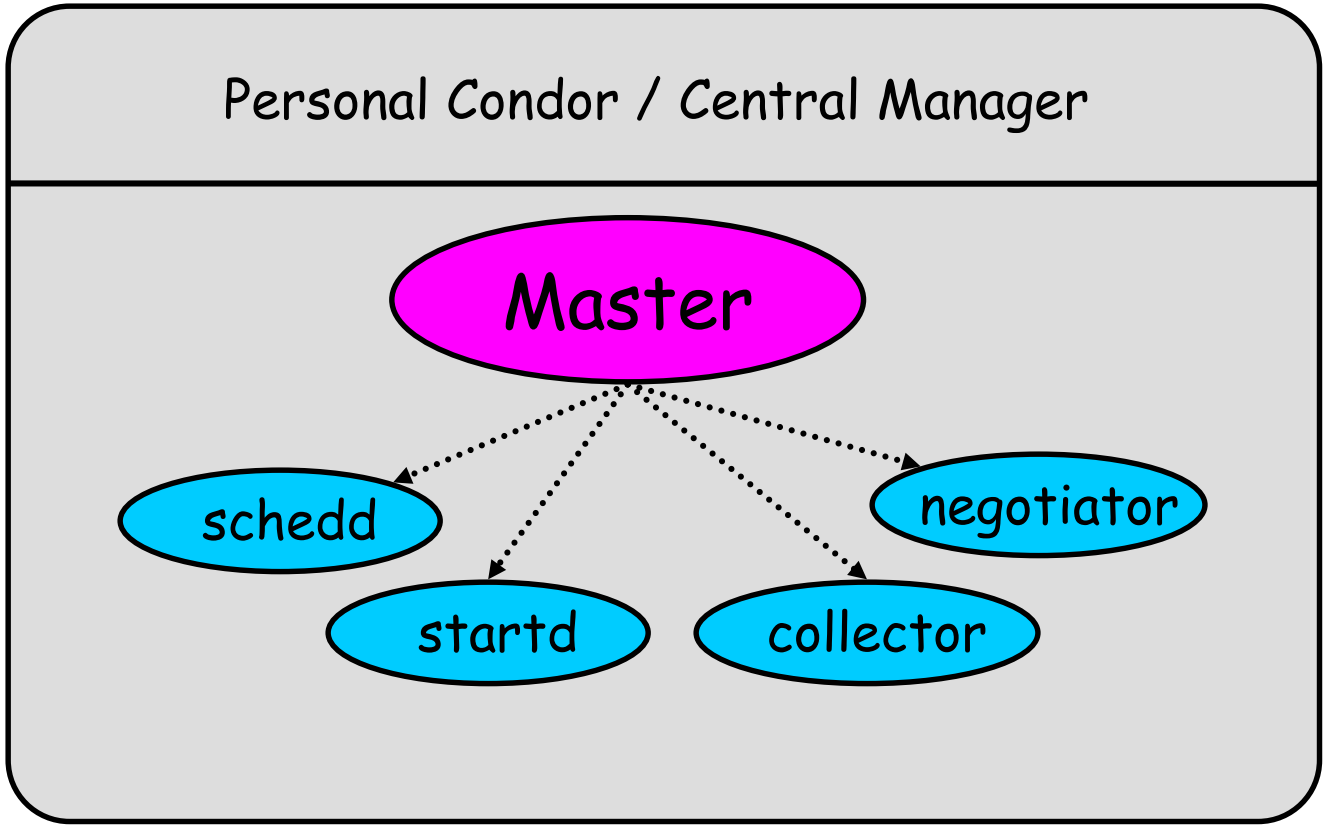


Some Good Questions…

- What are all of these Condor Daemons running on my machine?
- What do they do?



Condor Daemon Layout



⋯⋯▸ = Process Spawned

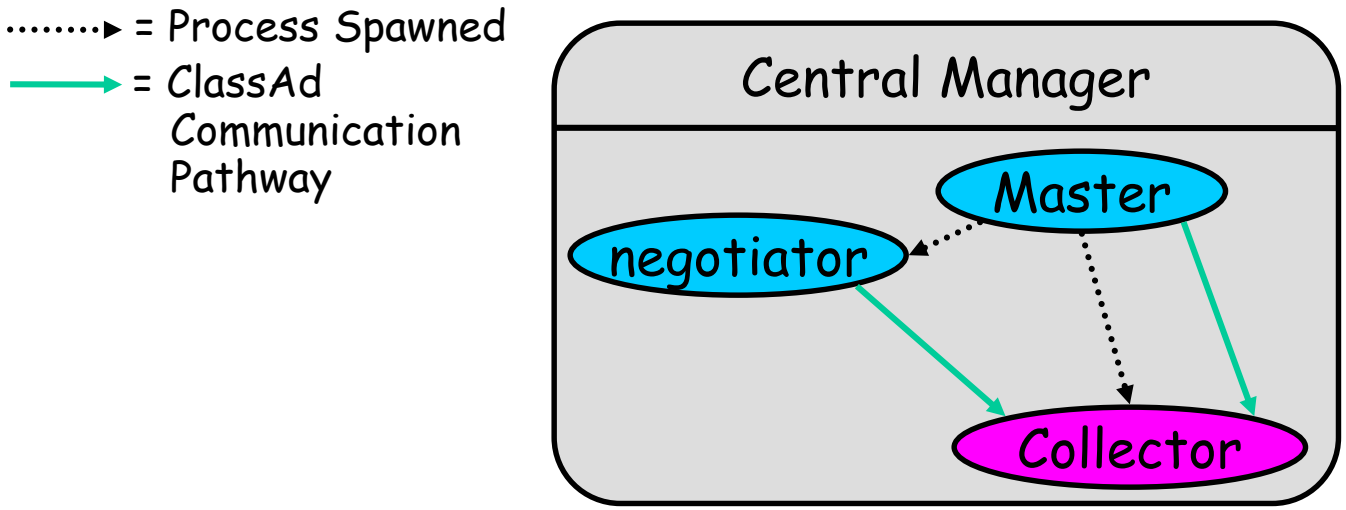
condor_master

- 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

- Central manager: central repository and match maker for whole pool
- 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

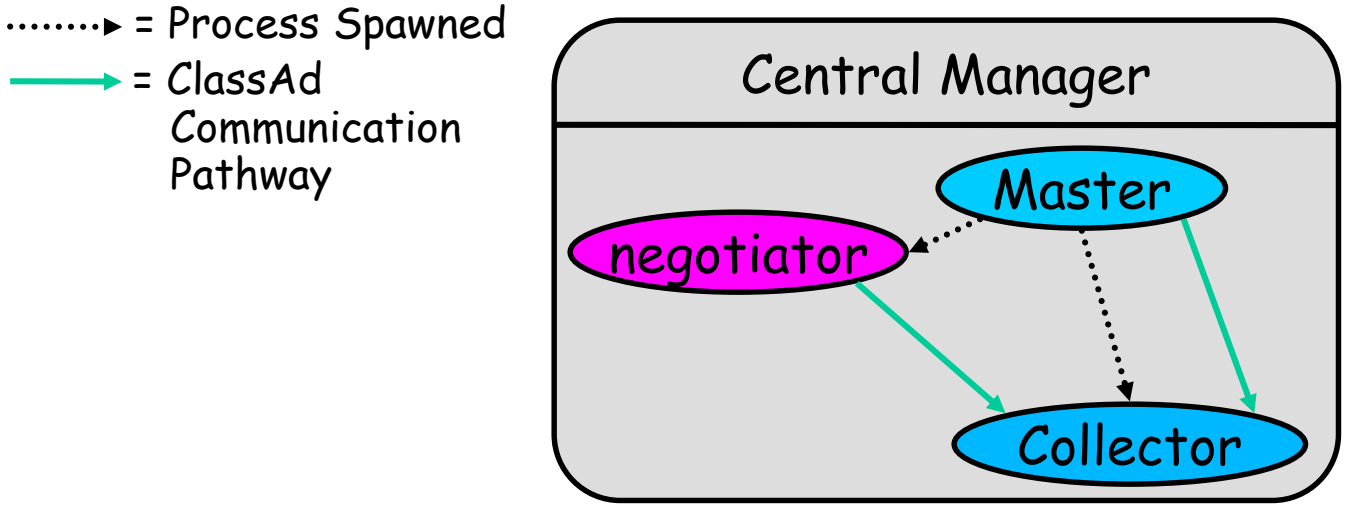
Condor Pool Layout: Collector



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
- Only on the Central Manager(s)

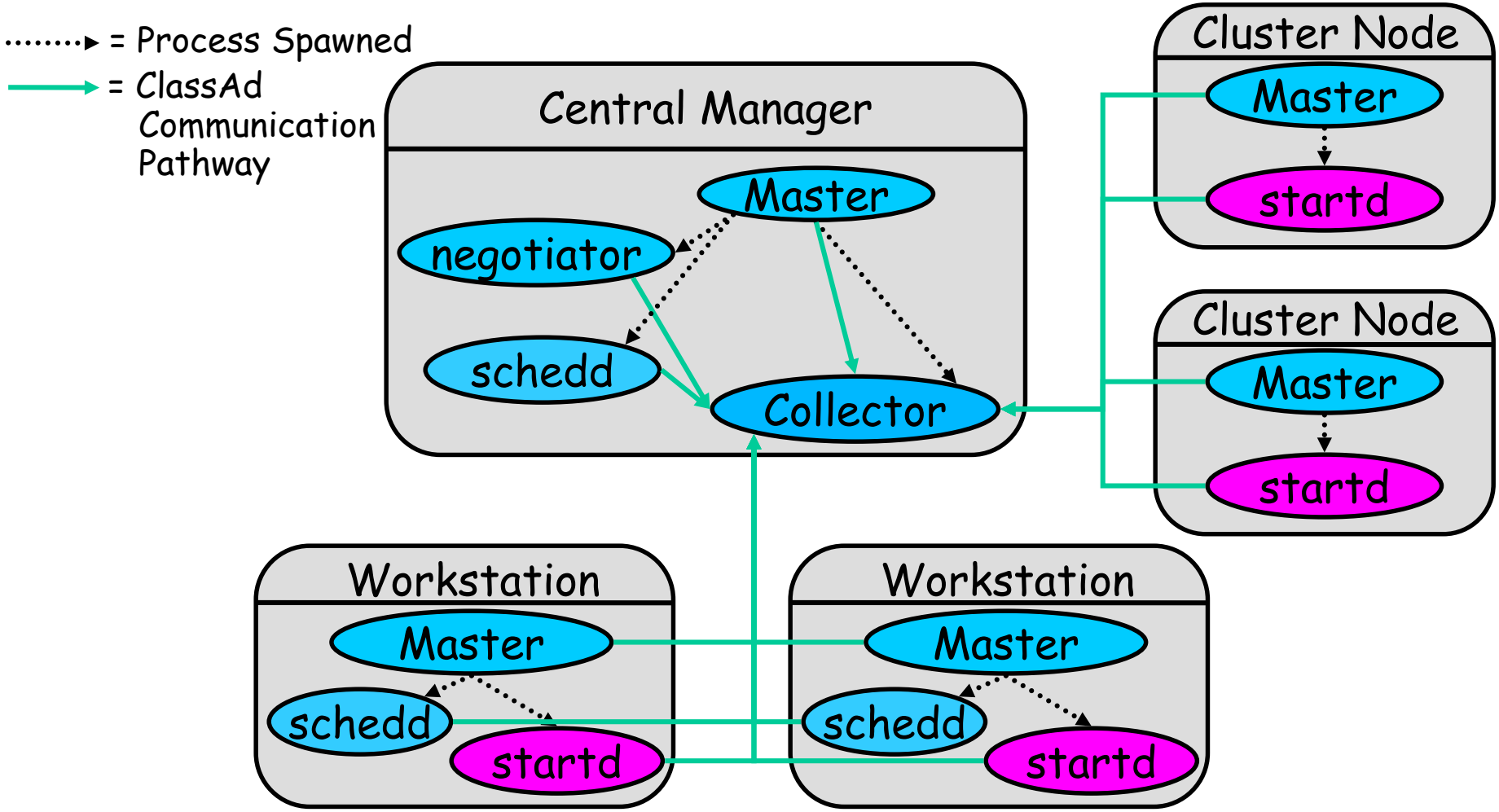
Condor Pool Layout: Negotiator



Execute Hosts: condor_startd

- Execute host: machines that run user jobs
- 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

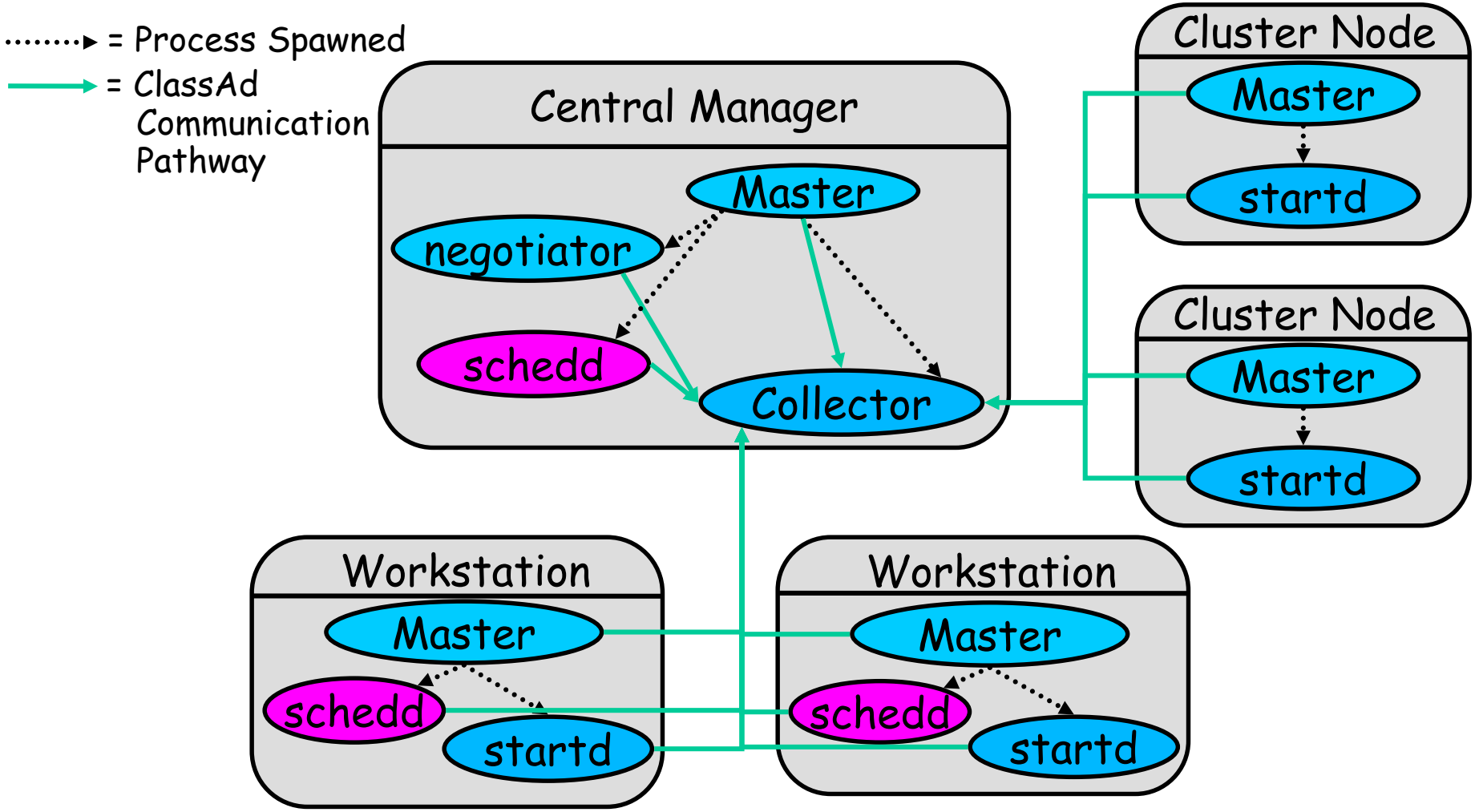
Condor Pool Layout: startd



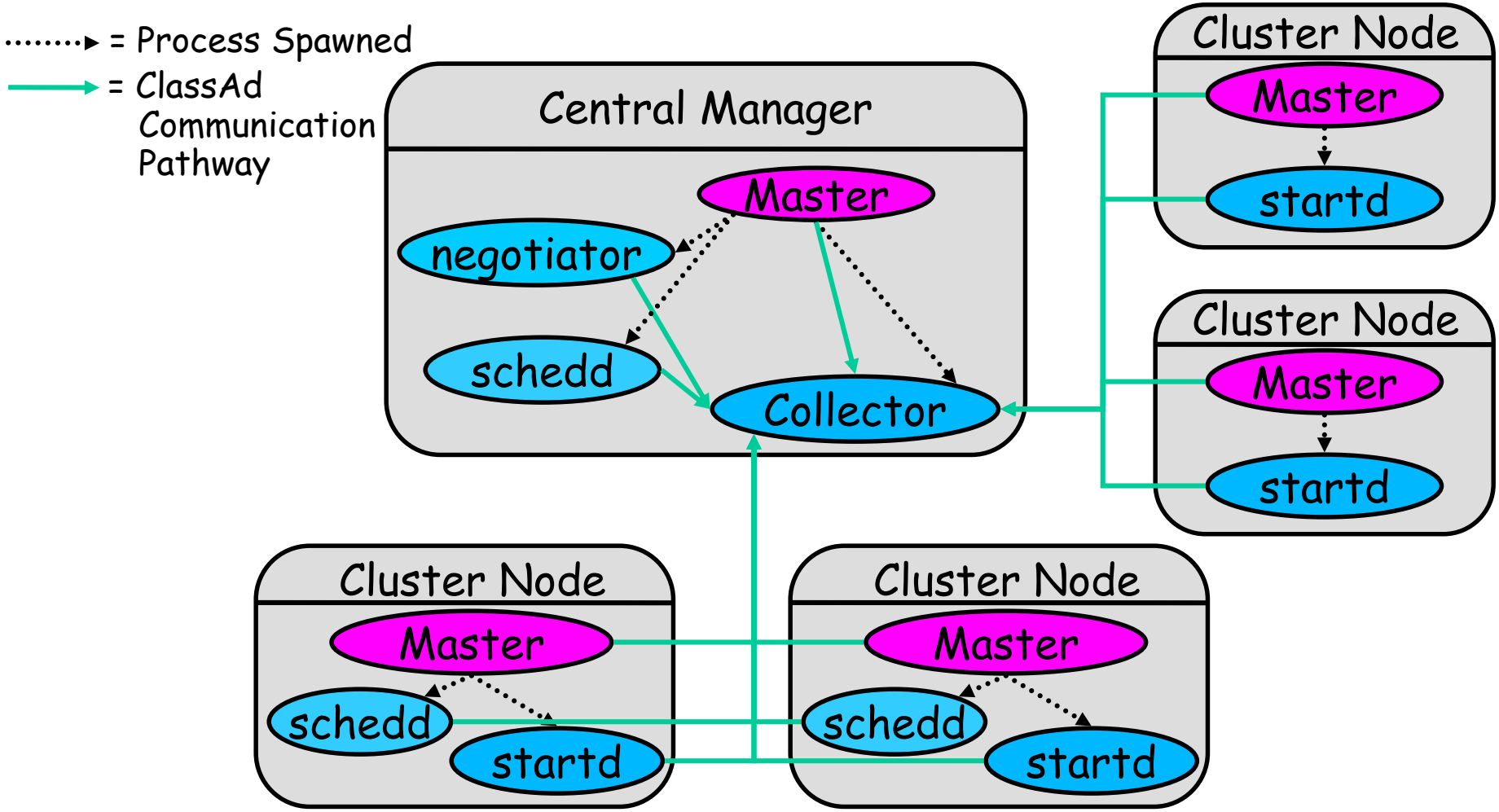
Submit Hosts: condor_schedd

- Submit hosts: machines that users can submit jobs on
- 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
- One schedd runs on each submit host

Condor Pool Layout: schedd



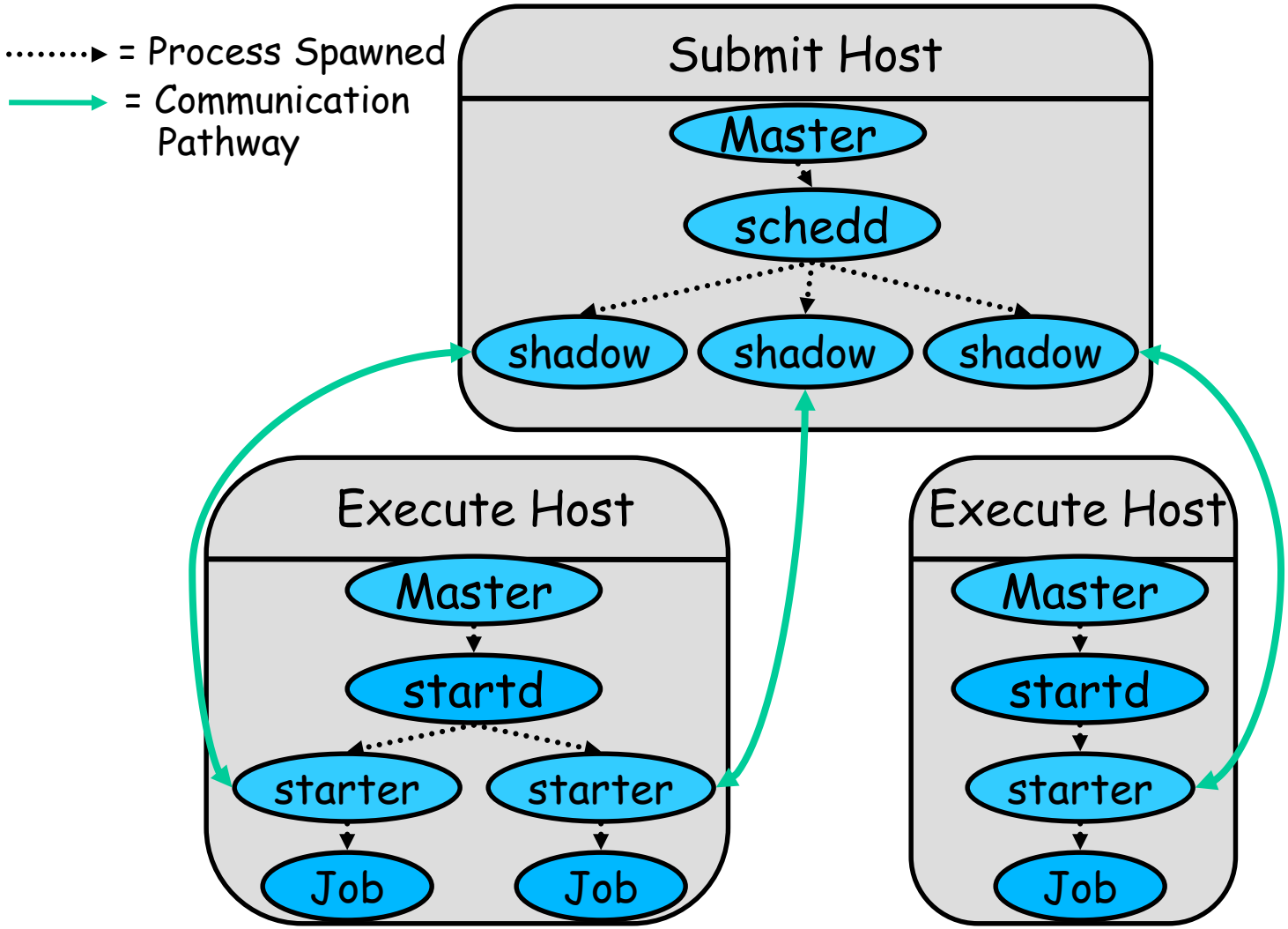
Condor Pool Layout: master



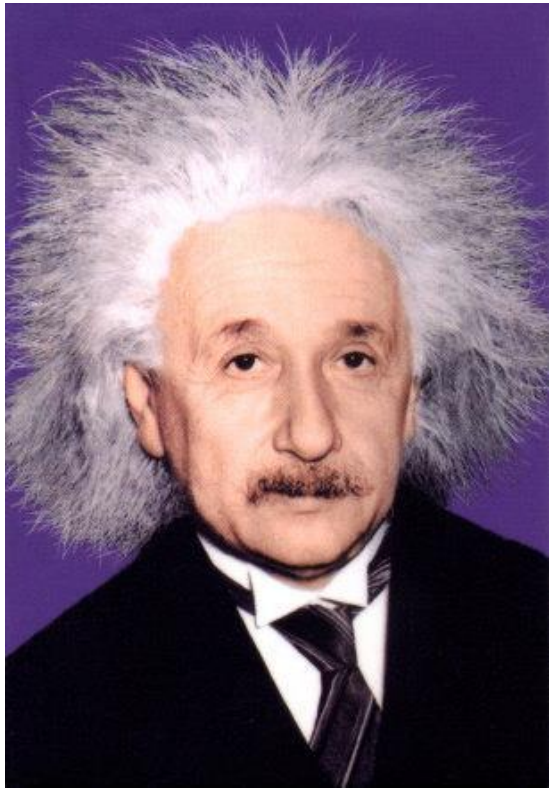
What about these "condor_shadow" processes?

- 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 jobs aren't running!!



Check the queue

- Check the queue with condor_q:

```
[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
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
6.0 einstein  4/20 13:22  0+00:00:00 H 0    9.8  cosmos -arg1 -arg2
8 jobs; 8 idle, 0 running, 1 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
```

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
```

Look in the Job Log

- Look in your job log for 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
...
```

Still not running? 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)

Let Condor help: 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
```

It's Still not Working

- Verify that the submitted job runs stand alone
  - We've had many cases in which users blame Condor, but haven't tried running it outside of Condor

Interact With Your Job

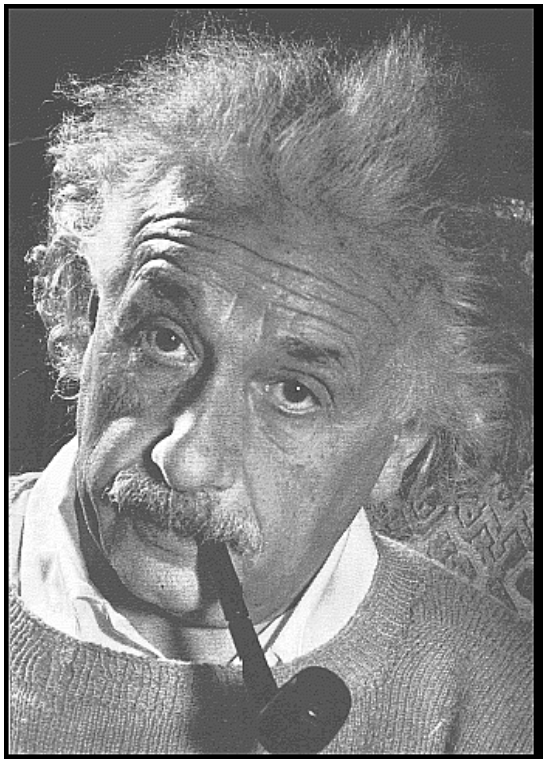
- Why is my job still running?
  Is it stuck accessing a file?
  Is it in an infinite loop?
- Try this: **`$ condor_ssh_to_job`**
  - Interactive debugging in UNIX
  - Use ps, top, gdb, strace, lsof, …
  - Forward ports, X, transfer files, etc.

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
  …
```

My new jobs can run for 20 days…

- What happens when a job is forced off it's 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!

- Support for transparent process checkpoint and restart
- Remote system calls (remote I/O)
  - Your job can read / write files as if they were local

Remote System Calls in the Standard Universe

- I/O system calls are trapped and sent back to the submit machine
  Examples: open a file, write to a file
- No source code changes typically required
- Programming language independent

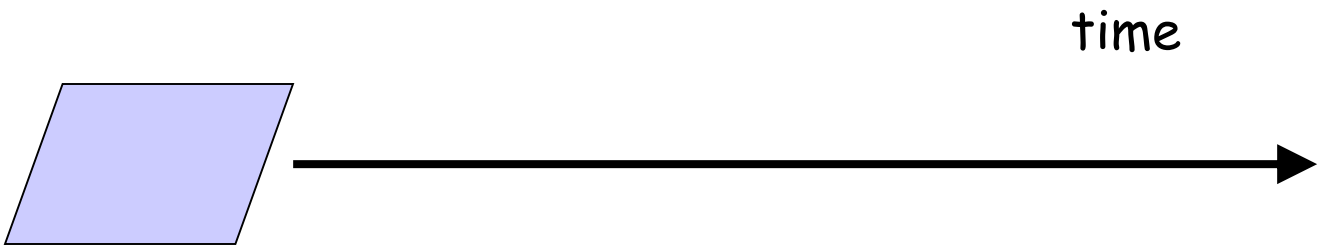
Process Checkpointing in the Standard Universe

- 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.

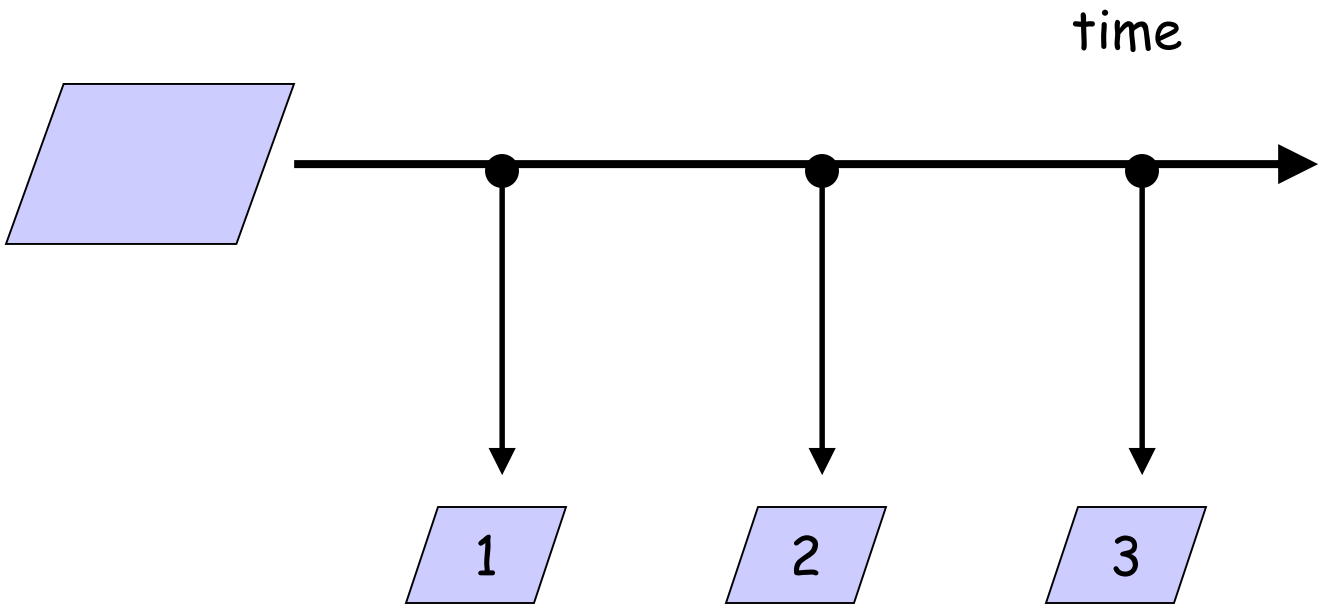
Checkpointing: Process Starts

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

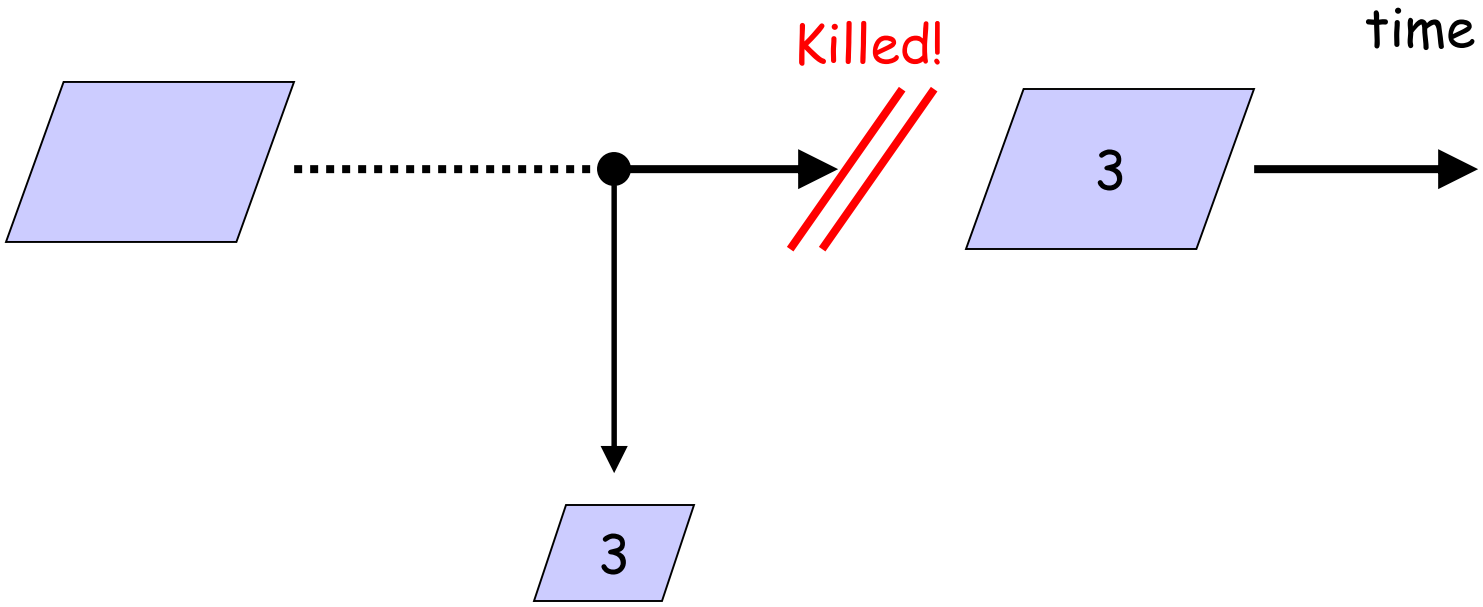
- CPU registers, memory image, I/O



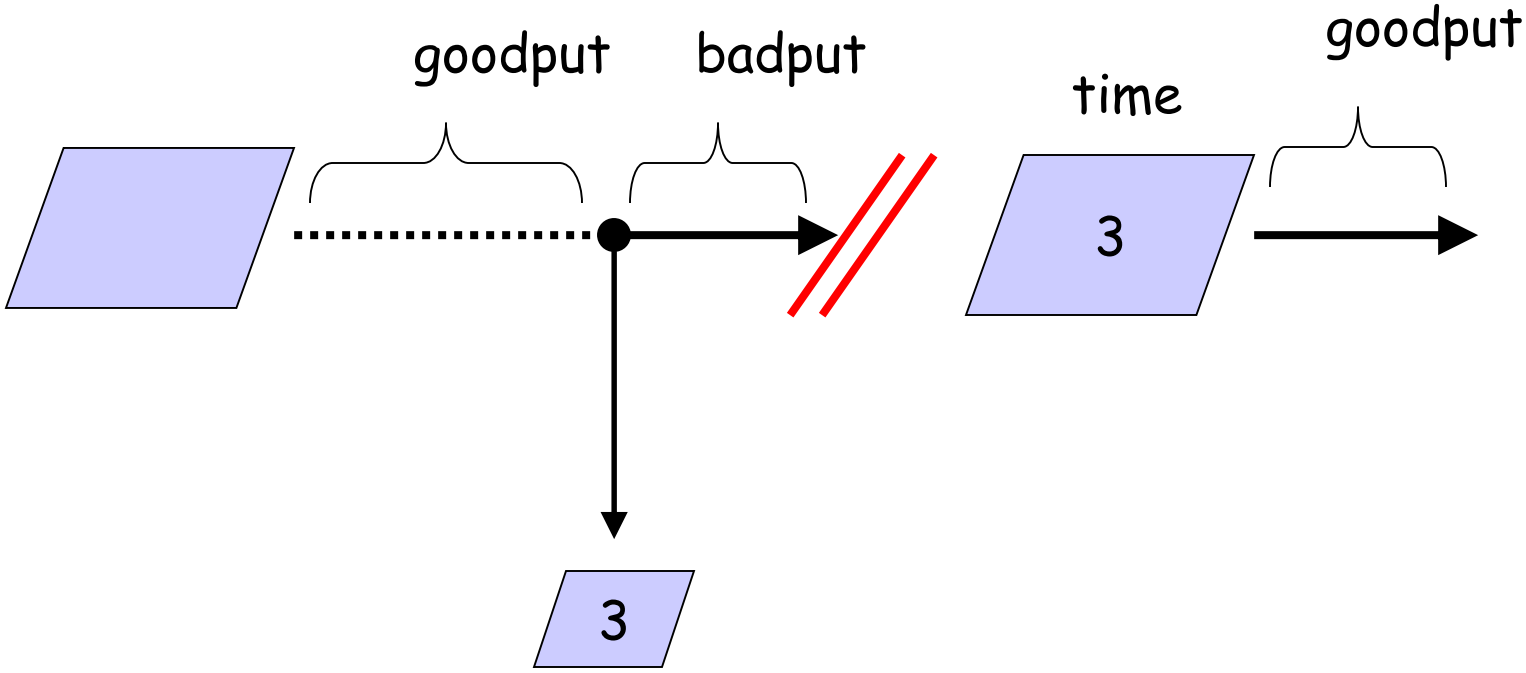
Checkpointing: Process Checkpointed



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

DMTCP & Parrot

- DMTCP (Checkpointing)
  - "Distributed MultiThreaded Checkpointing"
  - Developed at Northeastern University
  - http://dmtcp.sourceforge.net/
  - See Gene Cooperman's (Northeastern University) talk tomorrow @ 2:20
- 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

More on VM Universe

- Supports VMware, Xen, KVM
- Input files can be imported as CD-ROM image
- When VM shuts down, modified disk image is returned as job output

Example VMware Job

- This example uses the **vmware_dir** command to identify the location of the disk image to be executed as a Condor job.
- The contents of this directory are transferred to the machine assigned to execute the Condor job.

```
universe                        = vm
executable                      = vmware_sample_job
log                             = simple.vm.log.txt
vm_type                         = vmware
vm_memory                       = 64
vmware_dir                      = C:\condor-test
vmware_should_transfer_files = True
queue
```

- See Jaime's talk at 4:30 today for lots more!

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 a number of "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
```

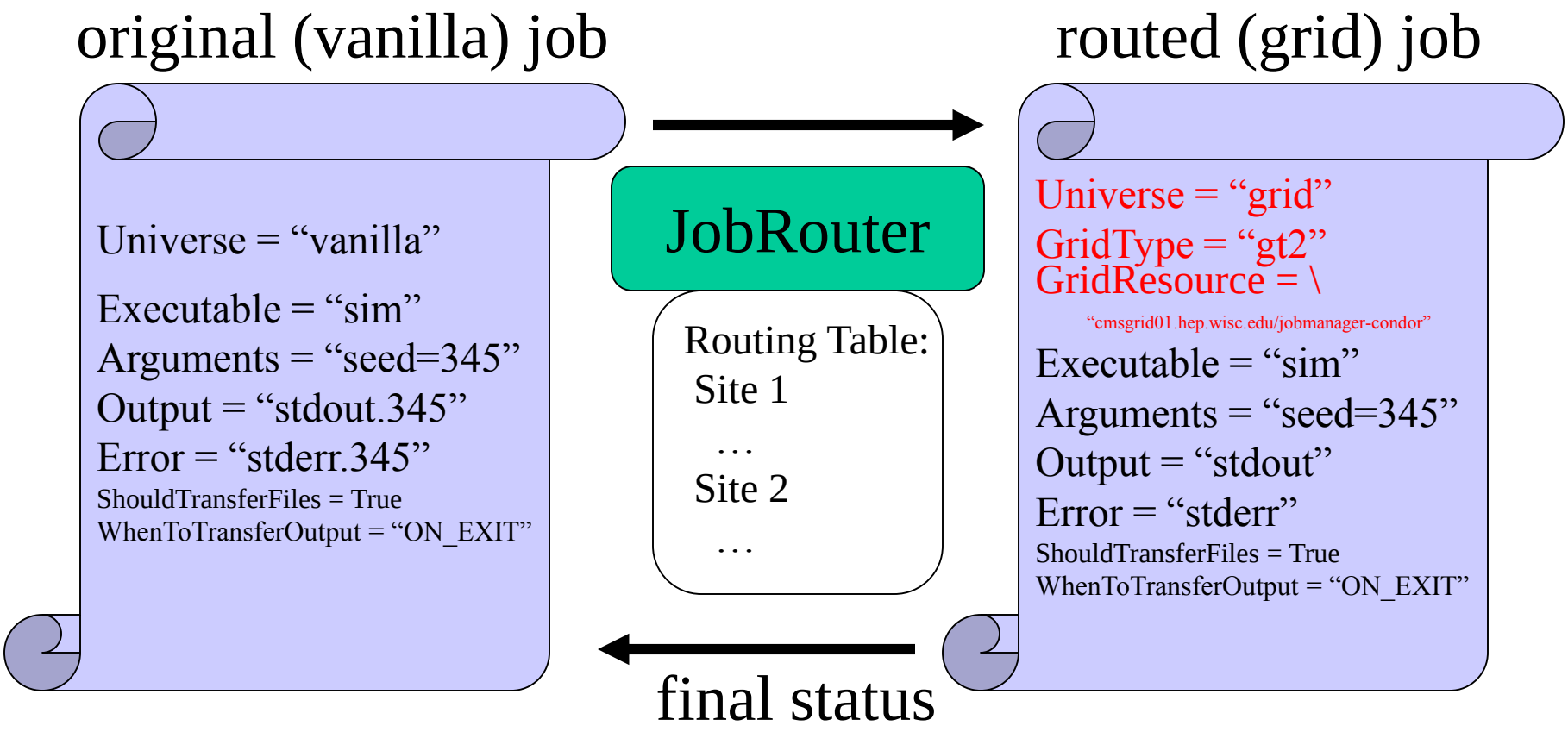
Credential Management

- 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

JobRouter
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
  - 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

Condor Universes: Scheduler and Local

- Scheduler Universe
  - Plug in a meta-scheduler
  - Similar to Globus's fork job manager
  - Developed for DAGMan (next slides)
- Local
  - Very similar to vanilla, but jobs run on the local host
  - Has more control over jobs than scheduler universe

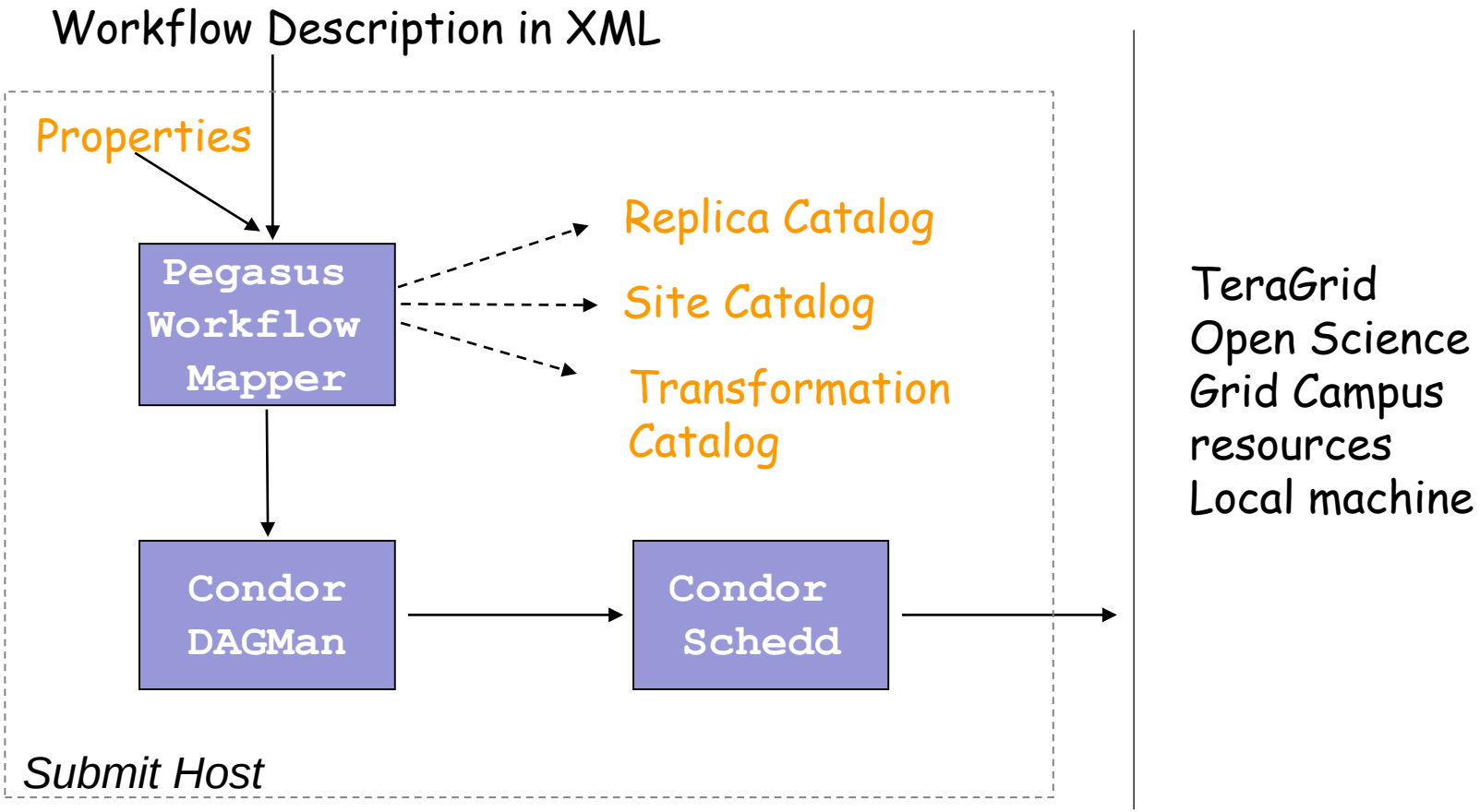
My jobs have have dependencies…

Can Condor help solve my dependency problems?

Workflows – Launch and Forget

- A single workflow can take days, weeks or even months
- Automates tasks user *could* perform manually…
  - But WMS takes care of automatically
- Includes features such as retries in the case of failures – avoids the need for user intervention
- The workflow itself can include error checking
- The result: one user action can utilize many resources while maintaining complex job inter-dependencies and data flows
- Maximizes compute resources / human time

Pegasus WMS



Pegasus WMS restructures and optimizes the workflow, provides reliability

DAGMan Configuration

- Condor configuration files
- Environment variables:
  - `_CONDOR_<macroname>`
- DAGMan configuration file
- `condor_submit_dag` command line

Submit the DAG

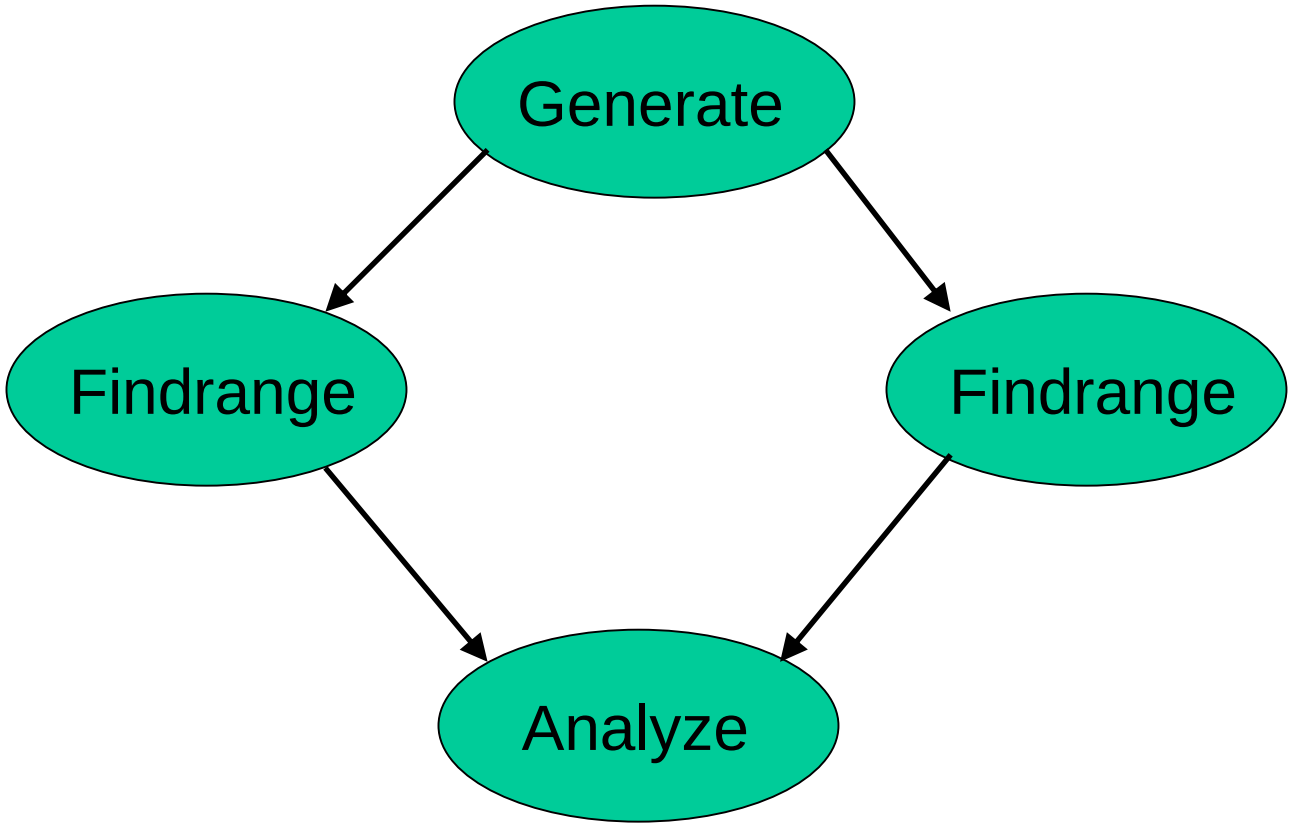
- Run:
  - `condor_submit_dag <file>`
- Creates a Condor submit file for DAGMan
- Also submits it to Condor
  - Unless `-no_submit` option is given
- `-f` option forces overwriting of existing files

Condor Monitoring

- Monitoring your DAG
  - condor_q [–dag] [*name*]
  - dagman.out file

```
[einstein@submit ~]$ condor_q -dag train15

-- Submitter: einstein@cosmos.phys.wisc.edu : <128.9.72.178:43684>
 ID     OWNER/NODENAME SUBMITTED   RUN_TIME ST PRI SIZE CMD
1860.0 train15        5/31 10:59 0+00:00:26 R 0   9.8  condor_dagman -f -
1861.0 |-Setup        5/31 10:59 0+00:00:12 R 0   9.8  nodejob Setup node

2 jobs; 0 idle, 2 running, 0 held
```

Exercise 2.6 - A simple DAG

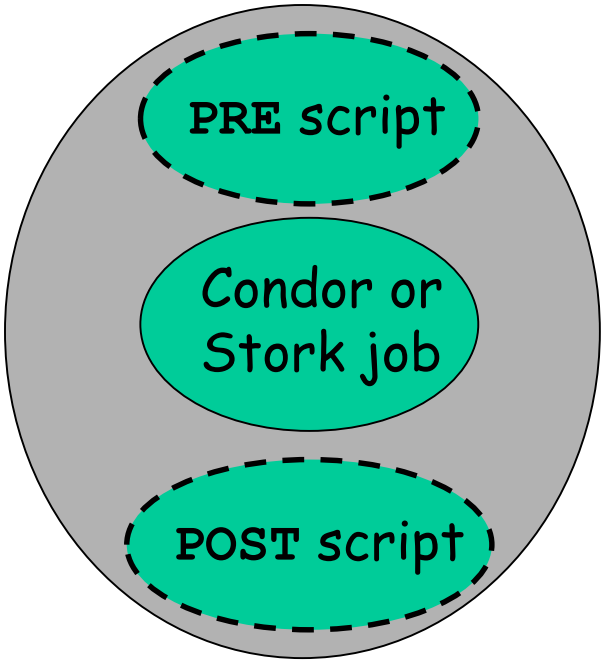


DAG file

- Defines the DAG shown previously
- Node names *are* case-sensitive
- Keywords are not case-sensitive

```
# Simple DAG file.

JOB Generate generate.submit
JOB Findrange1 findrange1.submit
JOB Findrange2 findrange2.submit
JOB Analyze analyze.submit
PARENT Generate CHILD Findrange1 Findrange2
PARENT Findrange1 Findrange2 CHILD Analyze
```

DAG node

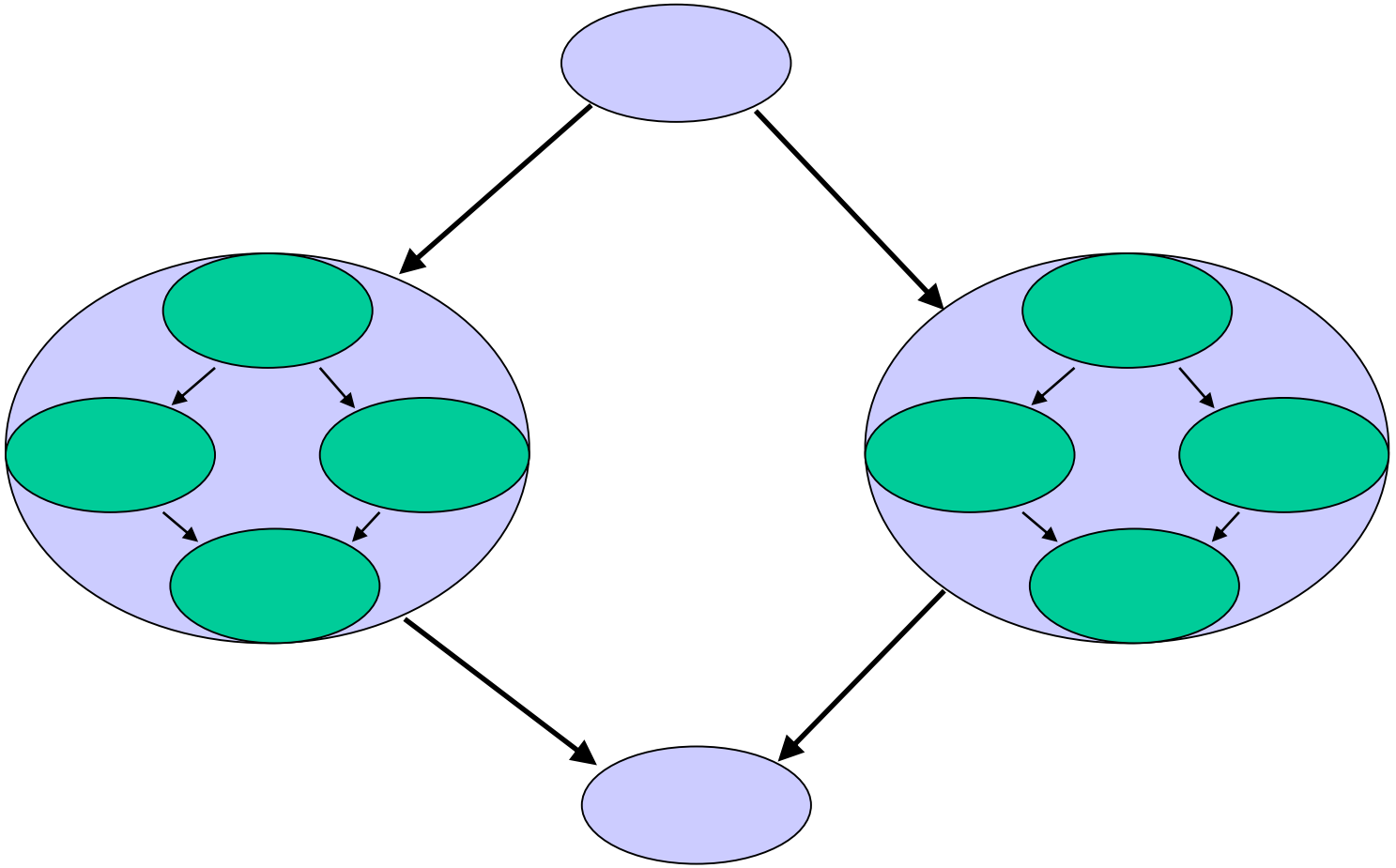


- Treated as a unit
- Job or POST script determines node success or failure

PRE/POST in DAGMan scripts

- **SCRIPT PRE|POST** ***node script*** **[*arguments*]**
- All scripts run on submit machine
- If **PRE** script fails, node fails w/o running job or **POST** script (for now…)
- If job succeeds or fails, **POST** script is run
- If **POST** script fails, node fails
- Special macros:
  - **$JOB**
  - **$RETRY**
  - **$JOBID** (POST only)
  - **$RETURN** (POST only)

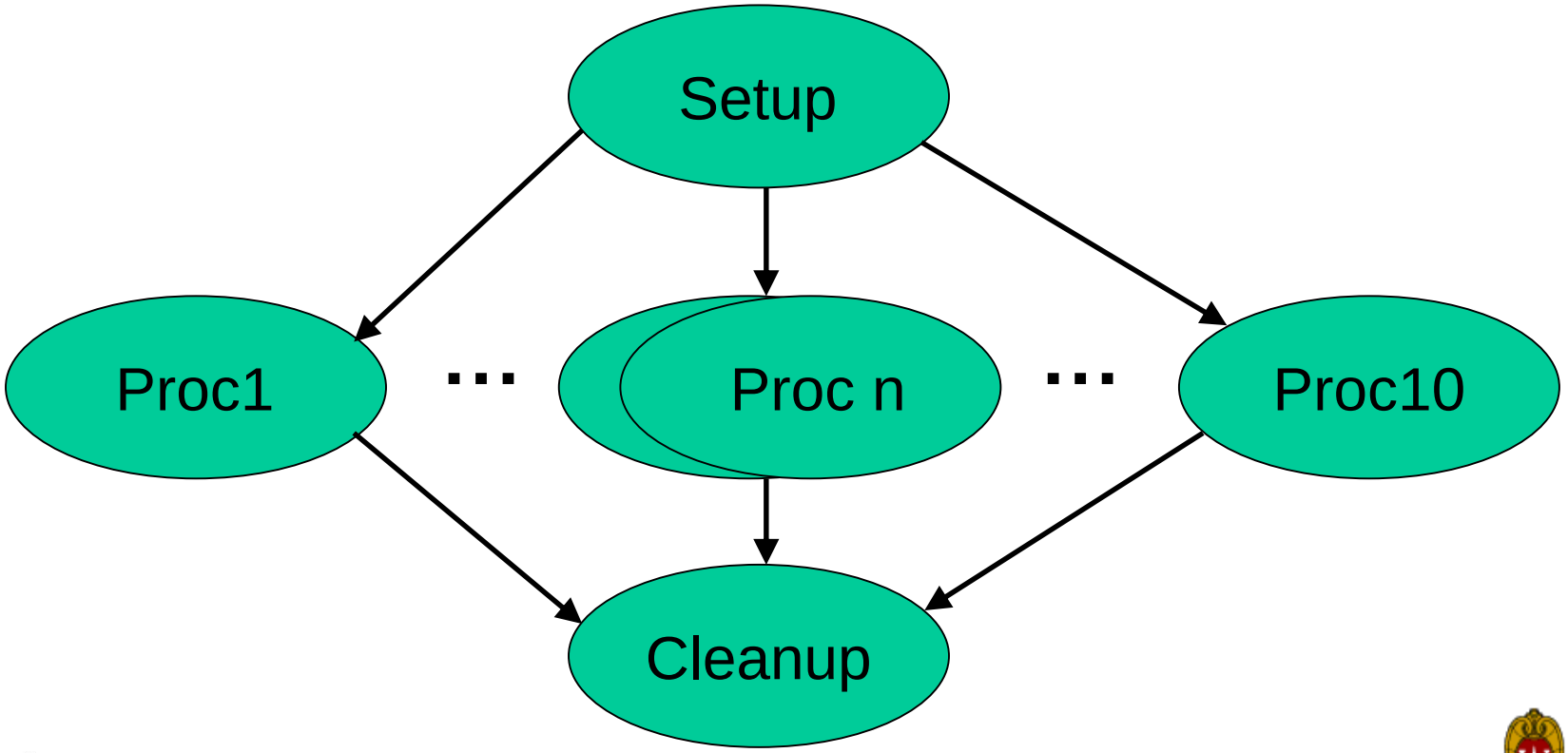
Nested DAGs



VARS (per-node variables)

- **VARS** ***JobName macroname="string"*** **[*macroname="string"*...]**
- Macroname can only contain alphanumeric characters and underscore
- Value can't contain single quotes; double quotes must be escaped
- Macronames cannot begin with "**queue**"
- Macronames are not case-sensitive

Exercise 3.4 – VARS and CONFIG



Exercise 3.4, continued

```
[einstein@submit ~]$ cat dagman/vars/vars.dag
# DAG to illustrate VARS and CONFIG.

CONFIG vars.config

JOB Setup setup.submit
SCRIPT PRE Setup setup.pre

JOB Proc1 pijob.submit
VARS Proc1 ARGS = "-sleep 60 -trials 10000 -seed 1234567"
PARENT Setup CHILD Proc1

JOB Proc2 pijob.submit
VARS Proc2 ARGS = "-sleep 80 -trials 20000 -seed 7654321"
PARENT Setup CHILD Proc2

JOB Proc3 pijob.submit
PARENT Setup CHILD Proc3
VARS Proc3 ARGS = "YOUR ARGS HERE"
[....]
```

Exercise 3.4, continued

```
[einstein@submit ~]$  cat dagman/vars/vars.config
# DAGMan configuration file for vars.dag.

DAGMAN_MAX_JOBS_SUBMITTED = 3
DAGMAN_STARTUP_CYCLE_DETECT = true
DAGMAN_SUBMIT_DEPTH_FIRST = true

[einstein@submit ~]$  cat dagman/vars/pijob.submit
# Simple Condor submit file.

Executable      = ../pi/pi
Universe        = scheduler
#Error          = pi.err.$(cluster)
Output          = output/pi.out.$(cluster)
Getenv          = true
Log             = pi.log

Arguments       = $(ARGS)
Notification    = never
Queue
```

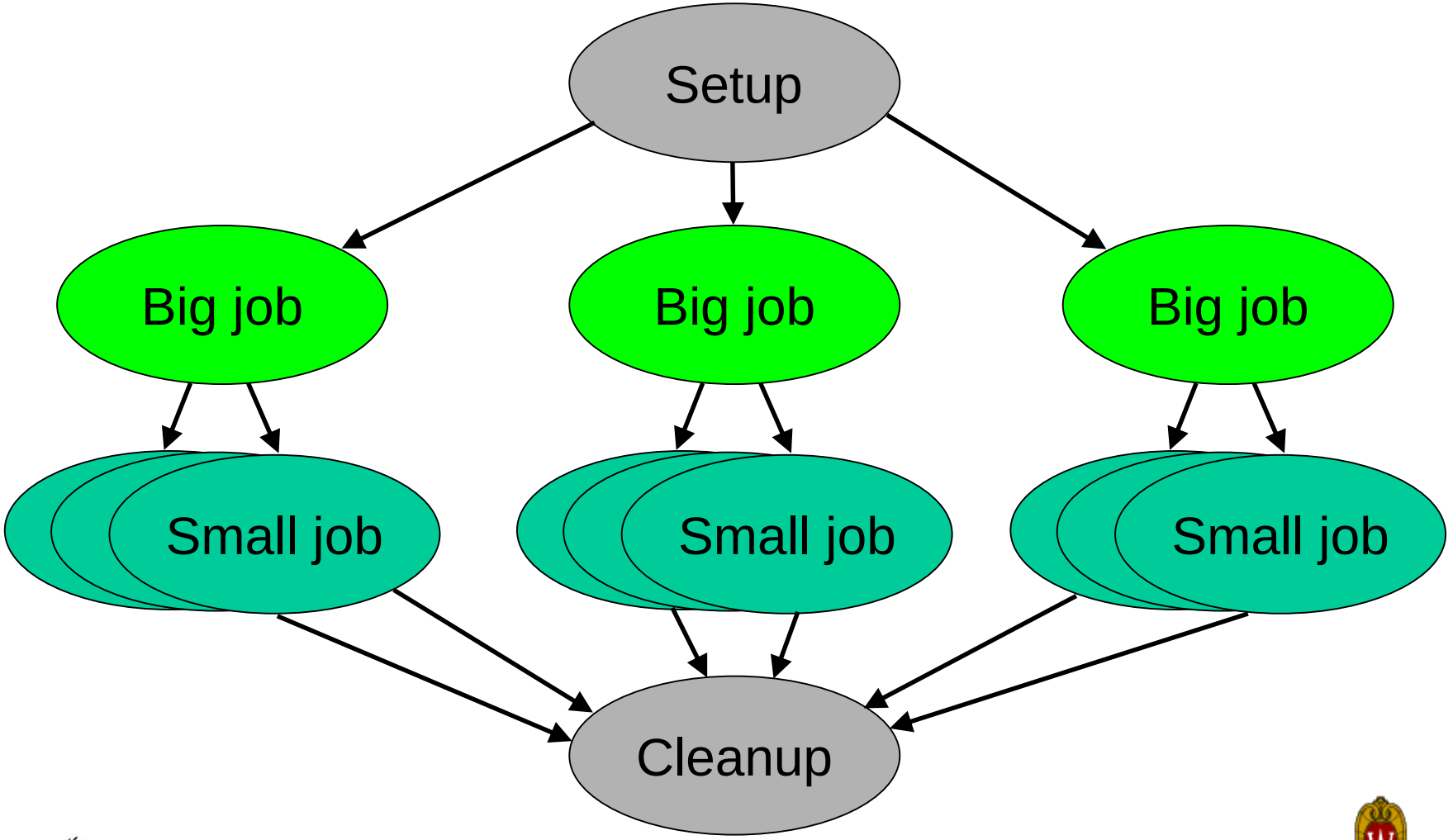
Throttling in DAGMan

- **`Maxjobs`** (limits jobs in queue/running)
- **`Maxidle`** (limits idle jobs)
- **`Maxpre`** (limits PRE scripts)
- **`Maxpost`** (limits POST scripts)
- All limits are *per* ***`DAGMan`***, not global for the pool
- Limits can be specified as arguments to **`condor_submit_dag`** or in configuration

Throttling by category

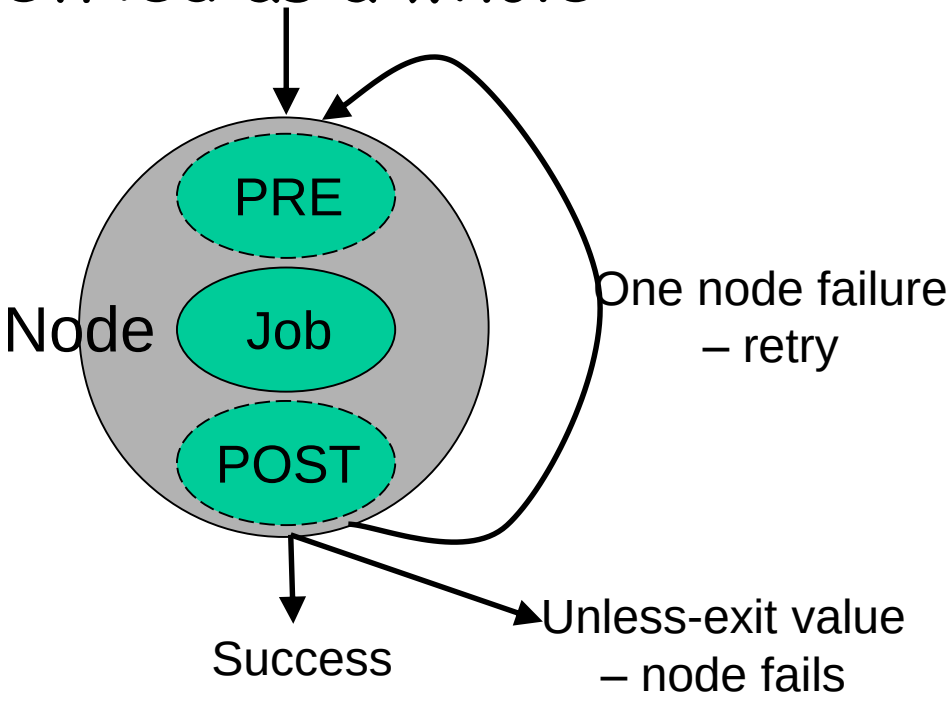
- **`CATEGORY`** ***`JobName CategoryName`***
- **`MAXJOBS`** ***`CategoryName MaxJobsValue`***
- Applies the **`maxjobs`** setting to only jobs assigned to the given category
- Global throttles still apply
- Useful with different types of jobs that cause different loads

Node categories



Node retries

- **RETRY *JobName NumberOfRetries* [UNLESS-EXIT *value*]**
- Node is retried as a whole



Node Categories and Retries

```
[einstein@submit ~]$ more montage.dag
# DAG to illustrate node categories/category throttles.

MAXJOBS projection 2

CATEGORY mProjectPP_ID000002 projection
JOB mProjectPP_ID000002 mProjectPP_ID000002.sub
SCRIPT POST mProjectPP_ID000002
   /nfs/software/pegasus/default/bin/exitpost  …..
RETRY mProjectPP_ID000002 2
...
```

Rescue DAG

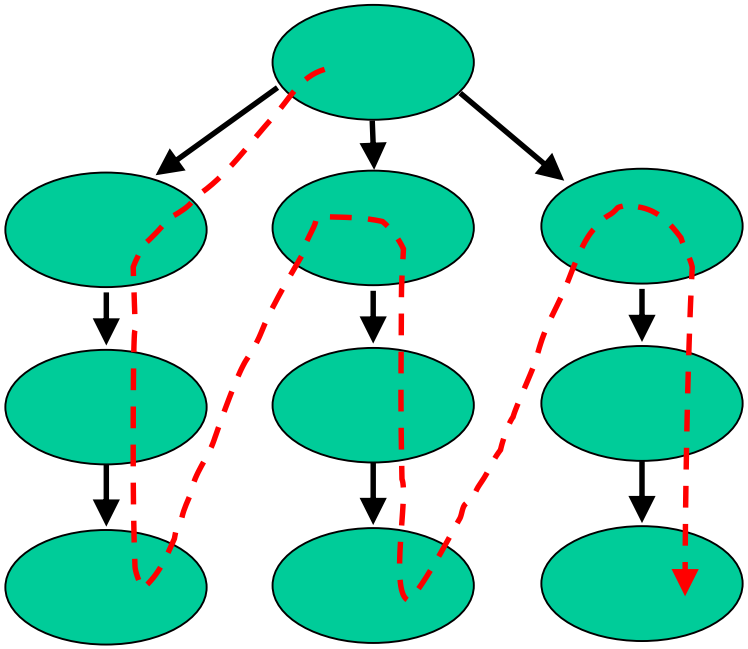
- Generated when a node fails or DAGMan is condor_rm'ed
- Saves state of DAG
- Run the rescue DAG to restart from where you left off

Recovery/bootstrap mode

- Most commonly, after condor_hold/condor_release of DAGMan
- Also after DAGMan crash/restart
- Restores DAG state by reading node job logs

Depth-first DAG traversal

- Get results more quickly
- Possibly clean up intermediate files more quickly
  - **`DAGMAN_SUBMIT_DEPTH_FIRST=True`**



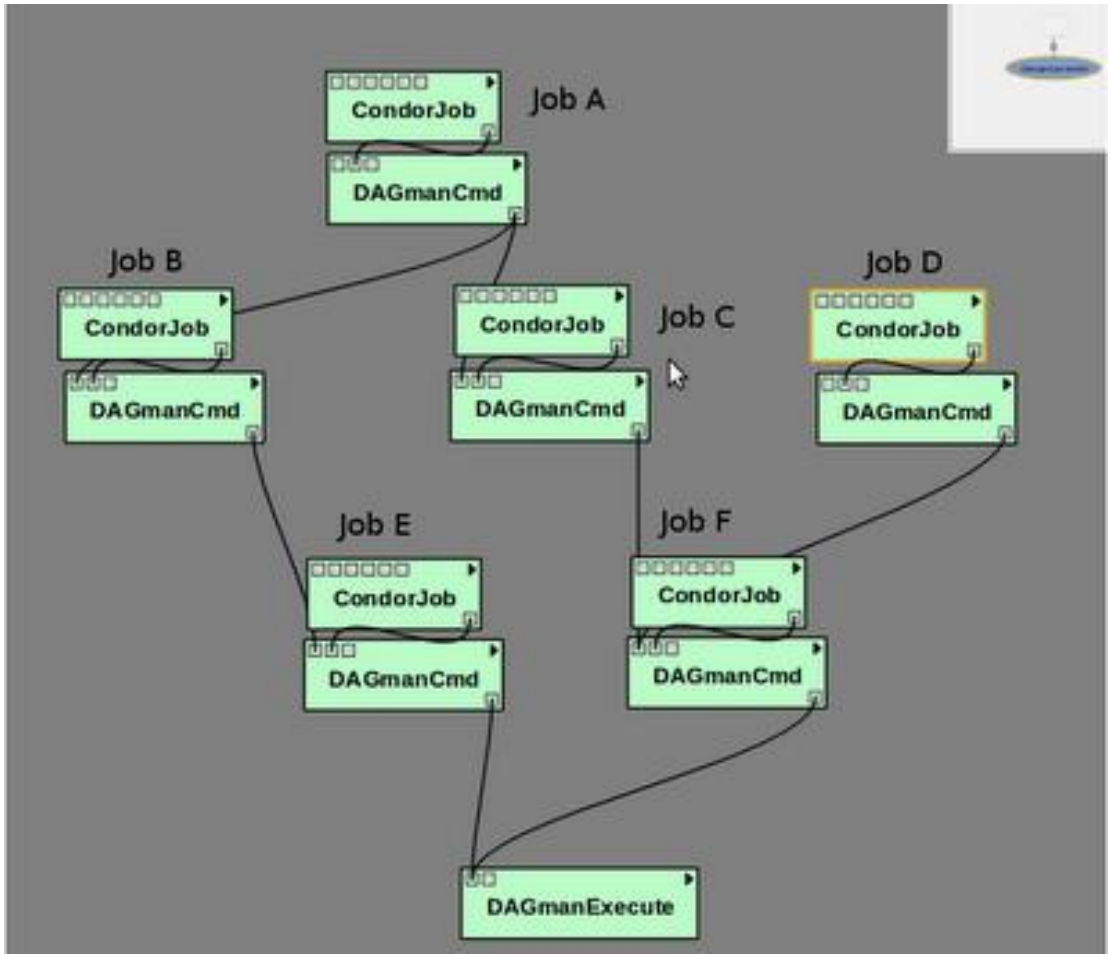
DAG node priorities

- **PRIORITY** ***JobName PriorityValue***
- Determines order of submission of ready nodes
- Does *not* violate/change DAG semantics
- Mostly useful when DAG is throttled
- Higher Numerical value equals higher priority

VisTrails

- An open-source scientific workflow and provenance management system developed at the University of Utah
- We are working with the VisTrails group to add DAGMan support to VisTrails
- See www.vistrails.org

VisTrails, continued



Relevant Links

- DAGMan:
  www.cs.wisc.edu/condor/dagman

- For more questions:
  condor_admin@cs.wisc.edu

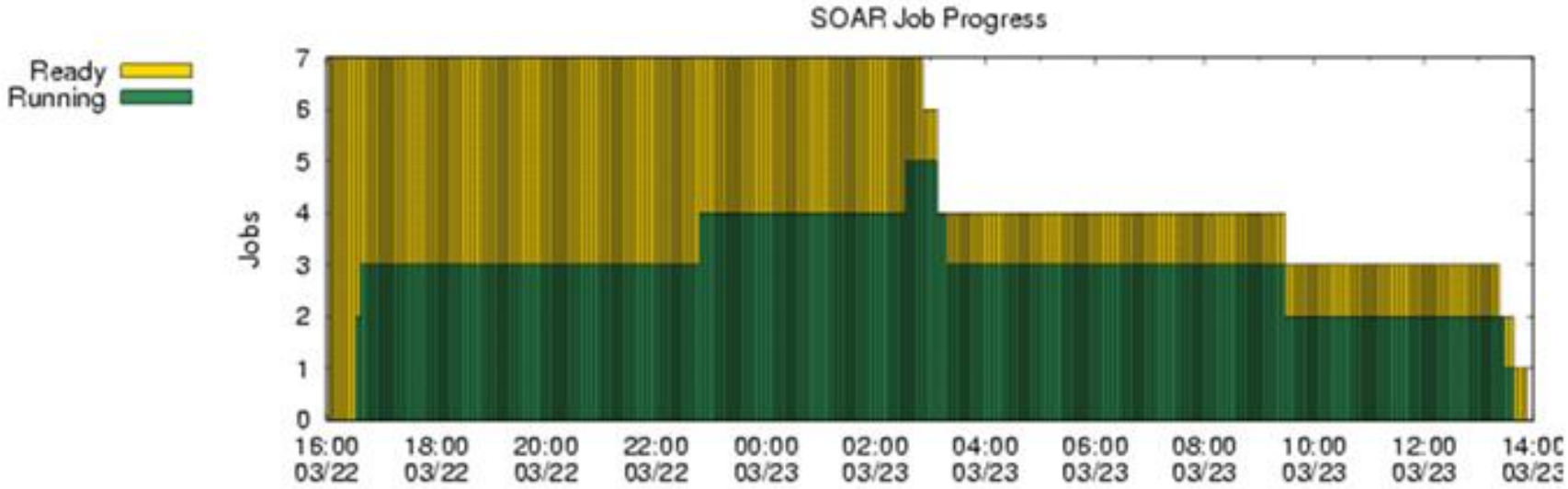
SOAR

- 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.

Universe Java Job

```
# 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.

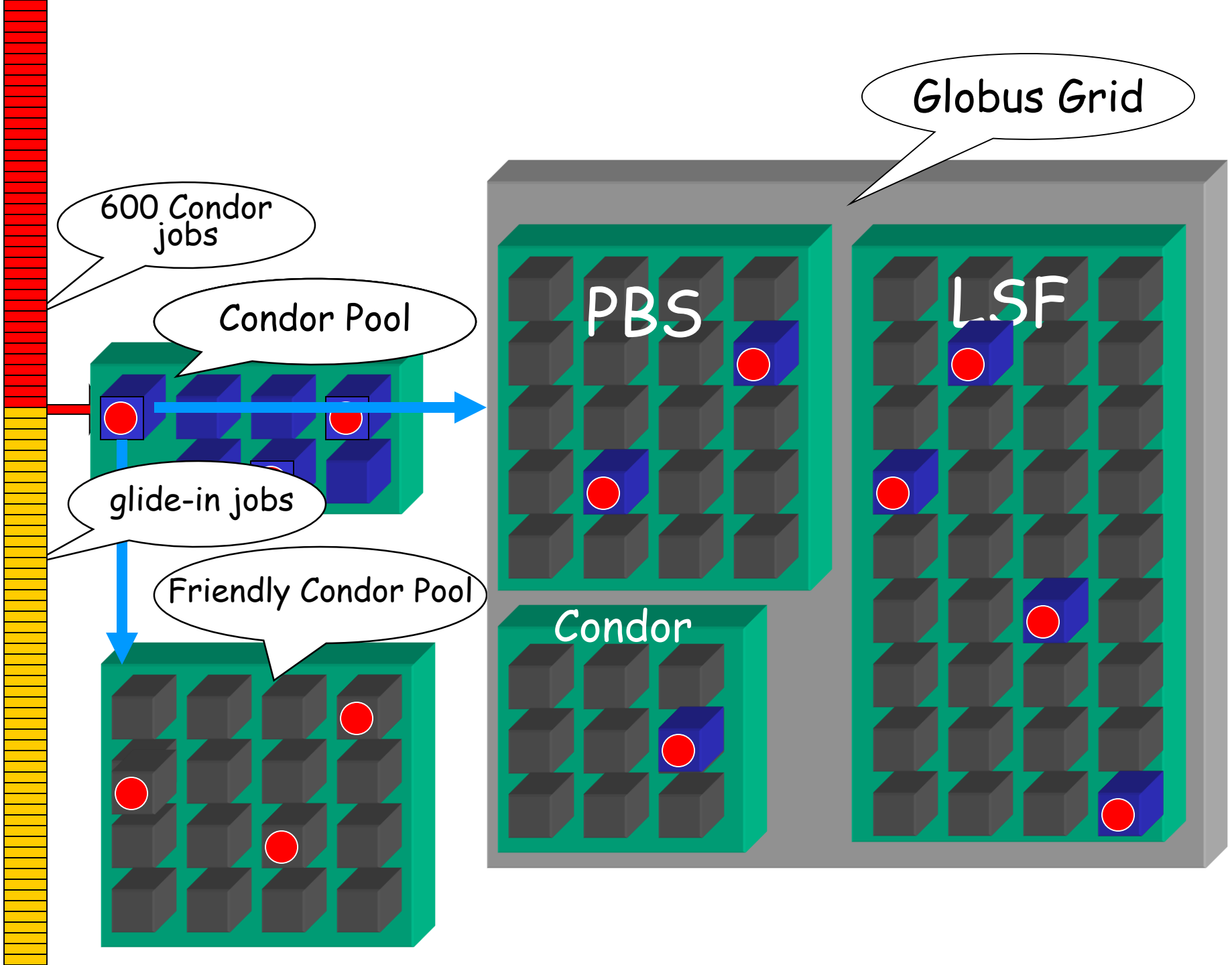
```
bash-2.05a$ condor_status -java
 Name          JavaVendor  Ver     State     Actv LoadAv Mem
abulafia.cs Sun Microsy 1.5.0_ Claimed   Busy 0.180   503
acme.cs.wis Sun Microsy 1.5.0_ Unclaimed Idle 0.000   503
adelie01.cs Sun Microsy 1.5.0_ Claimed   Busy 0.000  1002
adelie02.cs Sun Microsy 1.5.0_ 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
```

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, PVM, 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

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

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

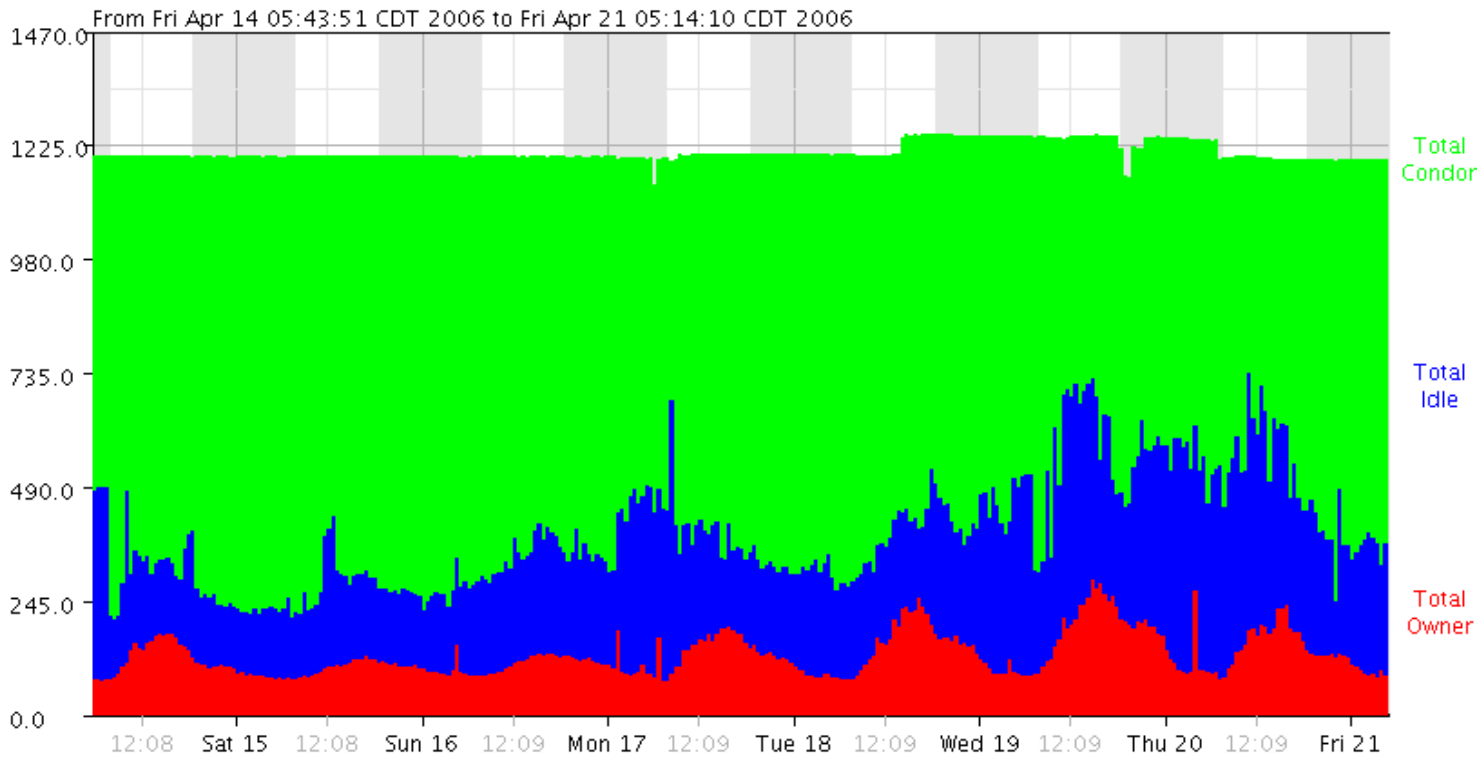
condor_vacate	Leave a machine now
condor_on	Start Condor
condor_off	Stop Condor
condor_reconfig	Reconfig on-the-fly
condor_config_val	View/set config
condor_userprio	User Priorities
condor_stats	View detailed usage accounting stats

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



More…

- GCB: Living with firewalls & private networks
- Federated Grids/Clusters
- APIs and Portals
- MW
- Database Support (Quill)
- High Availability Fail-over
- Compute On-Demand (COD)
- Dynamic Pool Creation ("Glide-in")
- Role-based prioritization and accounting
- Strong security, incl 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