An Introduction To Condor

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First…

These slides are available from:

http://www.cs.wisc.edu/~roy/italy-condor/

This Morning's Condor Topics

- Matchmaking: Finding machines for jobs
- Running a job
- Running a parameter sweep
- Managing sets of dependent jobs
- Master-Worker applications

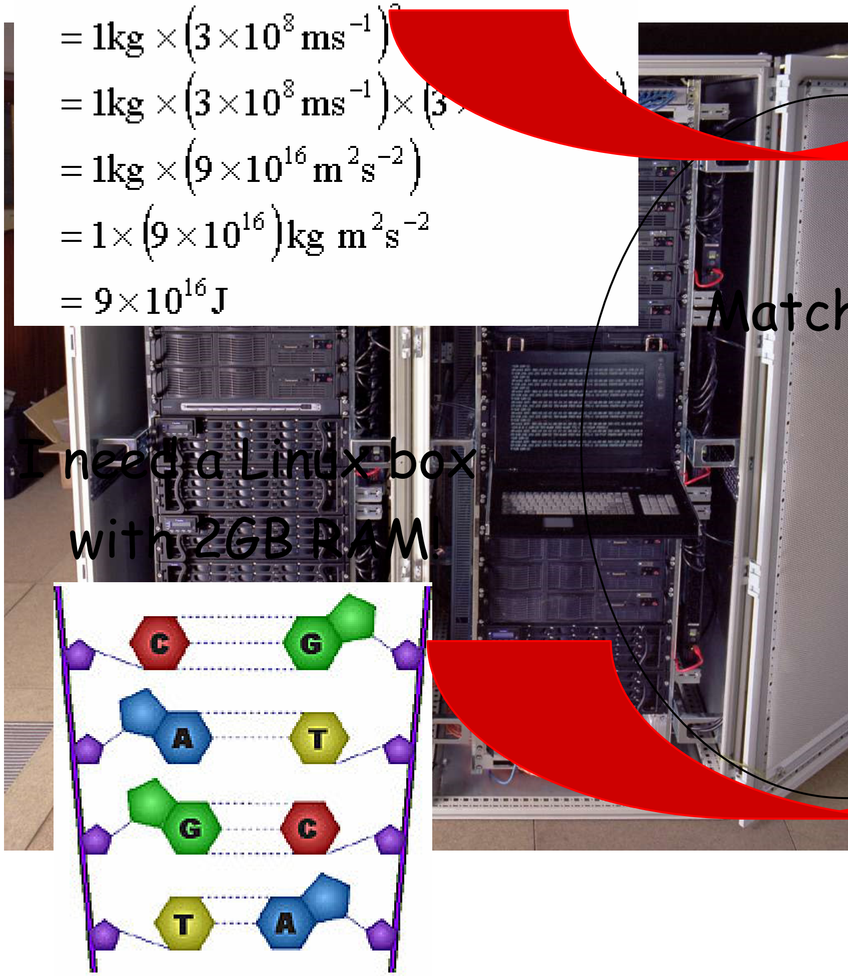
Part One

Matchmaking:
Finding Machines For Jobs
Finding Jobs for Machines

Condor Takes Computers…
…And matches them

I need a Mac!

$$
\begin{aligned}
E &= mc^2 \\
&= 1\text{kg} \times \left(3\times10^{8}\,\text{ms}^{-1}\right)^2 \\
&= 1\text{kg} \times \left(3\times10^{8}\,\text{ms}^{-1}\right)\times\left(3 \right. \\
&= 1\text{kg} \times \left(9\times10^{16}\,\text{m}^2\text{s}^{-2}\right) \\
&= 1\times\left(9\times10^{16}\right)\text{kg m}^2\text{s}^{-2} \\
&= 9\times10^{16}\,\text{J}
\end{aligned}
$$



I need a Linux box with 2GB RAM!

Matchm

Desktop Computers

Quick Terminology

- Cluster: A dedicated set of computers not for interactive use
- Pool: A collection of computers used by Condor
  - May be dedicated
  - May be interactive

Matchmaking

- Matchmaking is fundamental to Condor
- Matchmaking is two-way
  - Job describes what it requires:

    I need Linux && 2 GB of RAM
  - Machine describes what it requires:

    I need a Mac
- Matchmaking allows preferences
  - I need Linux, and I prefer machines with more memory but will run on any machine you provide me

Why Two-way Matching?

- Condor conceptually divides people into three groups:
  - Job submitters
  - Machine owners
  - Pool (cluster) administrator

  } May or may not be the same people
- All three of these groups have preferences

Machine owner preferences

- I prefer jobs from the physics group
- I will only run jobs between 8pm and 4am
- I will only run certain types of jobs
- Jobs can be preempted if something better comes along (or not)

System Admin Prefs

- When can jobs preempt other jobs?
- Which users have higher priority?

ClassAds

- ClassAds state facts
  - My job's executable is analysis.exe
  - My machine's load average is 5.6
- ClassAds state preferences
  - I require a computer with Linux

ClassAds

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

Example:

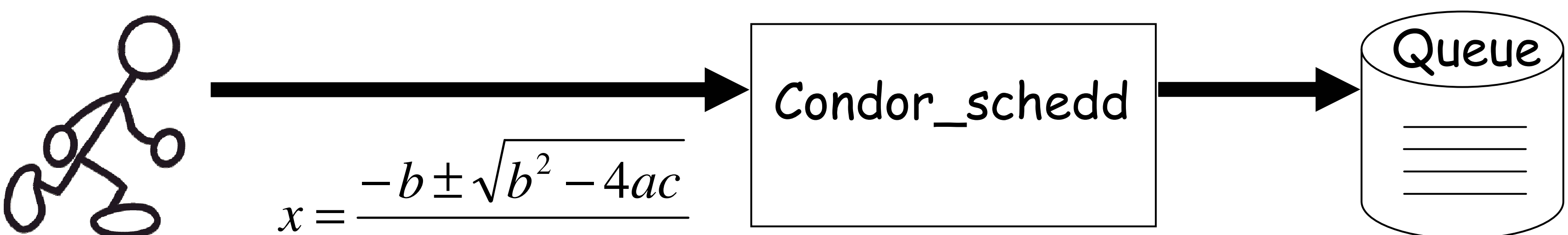
```
MyType        = "Job"          String
TargetType    = "Machine"
ClusterId     = 1377           Number
Owner         = "roy"
Cmd           = "analysis.exe"
Requirements  =
   (Arch == "INTEL")           Boolean
&& (OpSys == "LINUX")
&& (Disk >= DiskUsage)
&& ((Memory * 1024)>=ImageSize)
…
```

Schema-free ClassAds

- Condor imposes some schema
  - Owner is a string, ClusterID is a number…
- But users can extend it however they like, for jobs or machines
  - `AnalysisJobType = “simulation”`
  - `HasJava_1_4 = TRUE`
  - `ShoeLength = 7`
- Matchmaking can use these attributes
  - ```
    Requirements = OpSys == "LINUX"
             && HasJava_1_4 == TRUE
    ```
    ```

Submitting jobs

- Users submit jobs from a computer
  - Jobs described as a ClassAd
  - Each submission computer has a queue
  - Queues are not centralized
  - Submission computer watches over queue
  - Can have multiple submission computers
  - Submission handled by condor_schedd



$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Advertising computers

- Machine owners describe computers
  - Configuration file extends ClassAd
  - ClassAd has dynamic features
    - Load Average
    - Free Memory
    - …
  - ClassAds are sent to Matchmaker

ClassAd

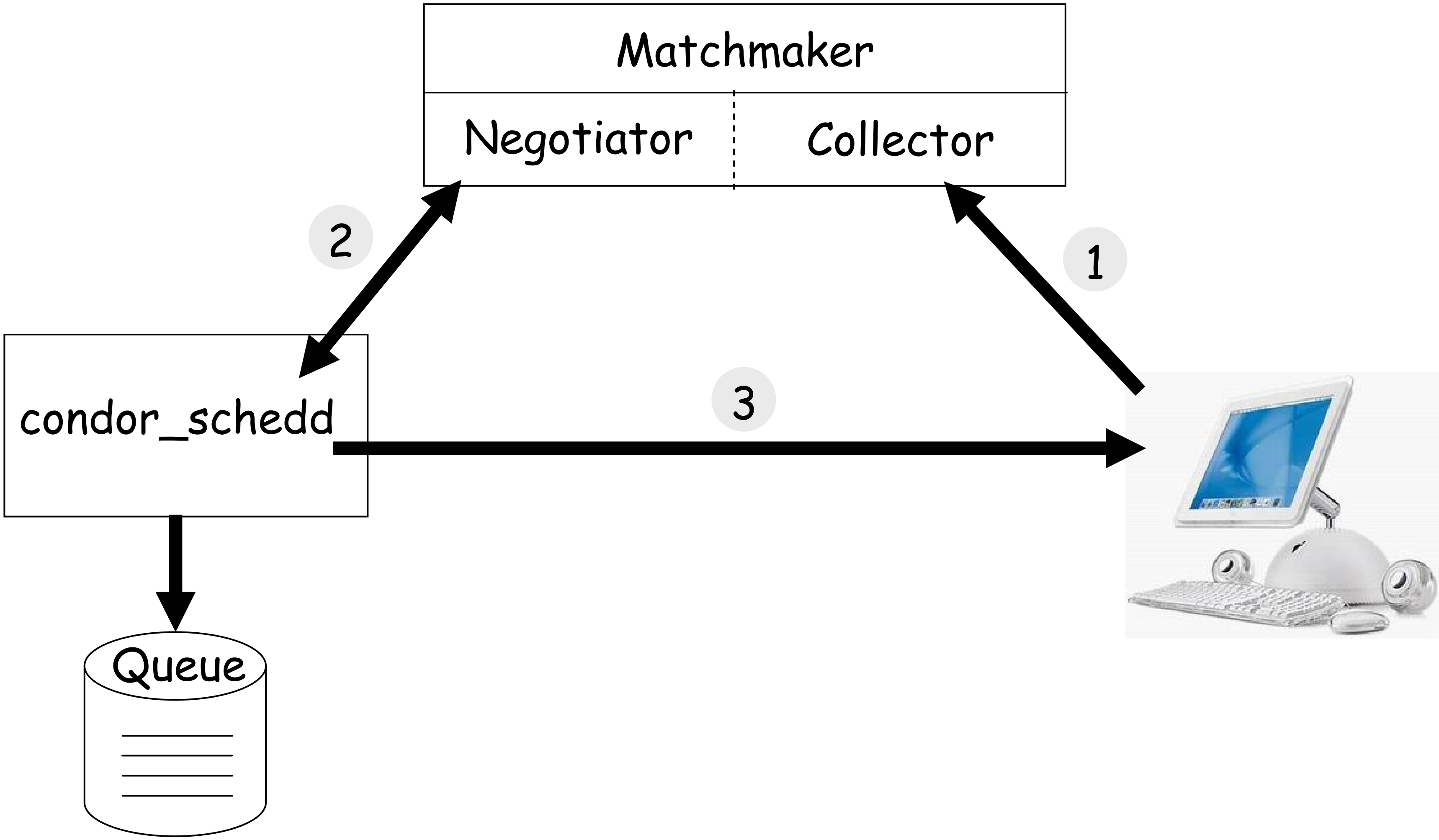
```
Type = "Machine"
Requirements = "…"
```

Matchmaker (Collector)

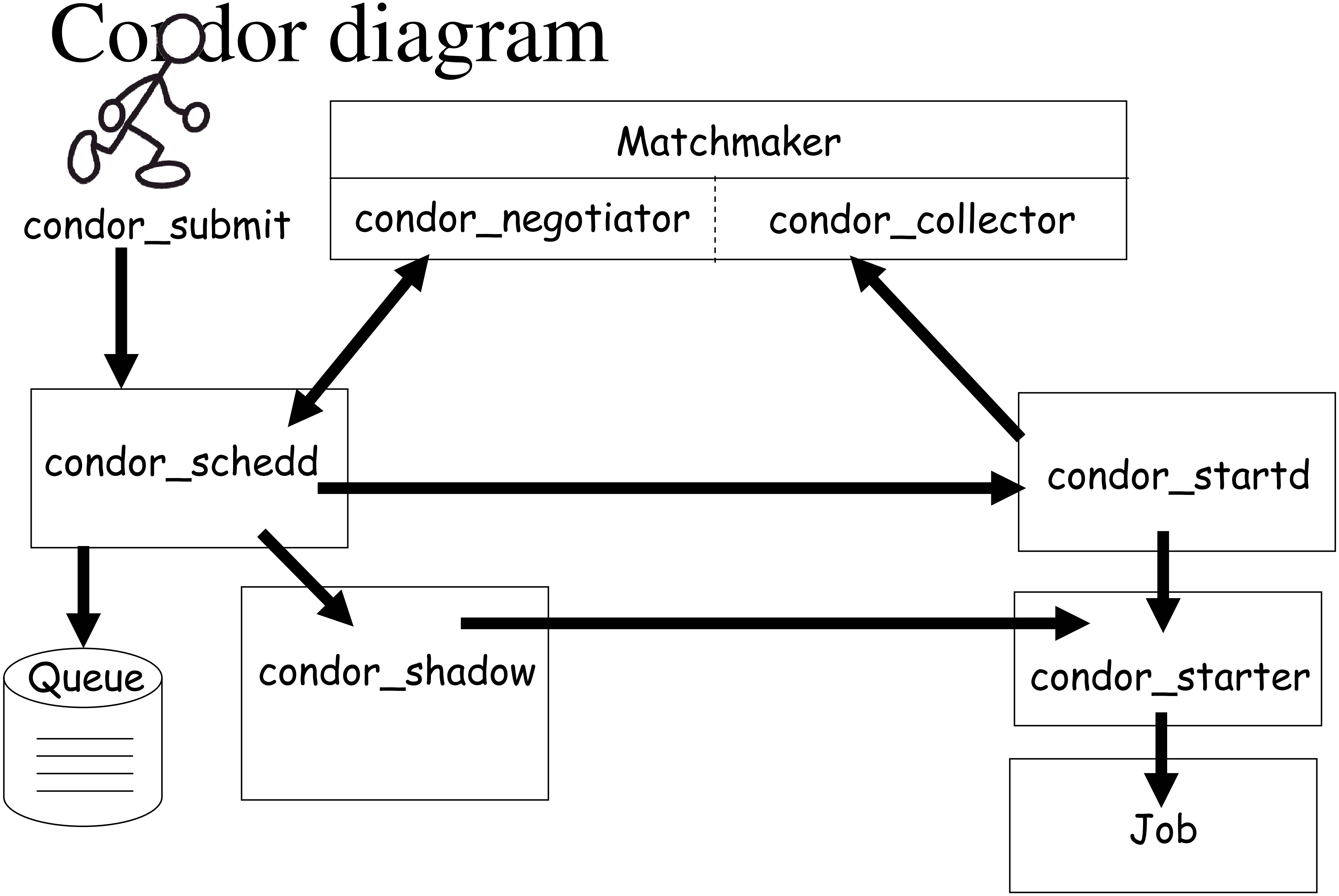
Matchmaking

- Negotiator collects list of computers
- Negotiator contacts each schedd
  - What jobs do you have to run?
- Negotiator compares each job to each computer
  - Evaluate requirements of job & machine
  - Evaluate in context of both ClassAds
  - If both evaluate to true, there is a match
- Upon match, schedd contacts execution computer

Matchmaking diagram



Condor diagram



Condor processes

- Master: Takes care of other processes
- Collector: Stores ClassAds
- Negotiator: Performs matchmaking
- Schedd: Manages job queue
- Shadow: Manages job (submit side)
- Startd: Manages computer
- Starter: Manages job (execution side)

Some notes

- Exactly one negotiator/collector per pool
- Can have many schedds (submitters)
- Can have many startds (computers)
- A machine can have any combination
    - Dedicated cluster: maybe just startds
    - Shared workstations: schedd + startd
    - Personal Condor: everything

Our Condor Pool

- Each student machine has
  - Schedd (queue)
  - Startd (with two virtual machines)
- Several servers
  - Most: Only a startd
  - One: Startd + collector/negotiator
- At your leisure:
  - condor_status

Our Condor Pool

```
Name             OpSys        Arch    State        Activity    LoadAv Mem    ActvtyTime

vm1@server4.g LINUX        INTEL   Unclaimed   Idle        0.000    501   0+03:45:08
vm2@server4.g LINUX        INTEL   Unclaimed   Idle        0.000    501   0+03:45:05
vm1@server5.g LINUX        INTEL   Unclaimed   Idle        0.000    501   0+03:40:08
vm2@server5.g LINUX        INTEL   Unclaimed   Idle        0.000    501   0+03:40:05
vm1@ws-01.gs. LINUX        INTEL   Unclaimed   Idle        0.000    501   0+00:02:45
vm2@ws-01.gs. LINUX        INTEL   Unclaimed   Idle        0.000    501   0+00:02:46
vm1@ws-03.gs. LINUX        INTEL   Unclaimed   Idle        0.000    501   0+02:30:24
vm2@ws-03.gs. LINUX        INTEL   Unclaimed   Idle        0.000    501   0+02:30:20
vm1@ws-04.gs. LINUX        INTEL   Unclaimed   Idle        0.080    501   0+03:30:09
vm2@ws-04.gs. LINUX        INTEL   Unclaimed   Idle        0.000    501   0+03:30:05
...

                     Machines Owner Claimed Unclaimed Matched Preempting

         INTEL/LINUX       66     0       0        66       0          0

               Total       66     0       0        66       0          0
```

Evolution of ClassAds

- ClassAds are very powerful
  - Schema-free, user-extensible, …
- ClassAds could be fancier
  - No lists
  - No nested ClassAds
  - No functions
  - Ad-hoc evaluation semantics

New ClassAds

- Future versions of Condor will have new ClassAds to solve these problems

```
[ Type = "Machine";
  Friends = {"alain", "miron", "peter"};
  LoadAverages = [ OneMinute = 3; FiveMinute=2.0];
  Requirements = member(other.name, Friends);
  …
]
```

list

Nested classad

Built-in function

Summary

- Condor uses ClassAd to represent state of jobs and machines
- Matchmaking operates on ClassAds to find matches
- Users and machine owners can specify their preferences

Let’s take a break!

Part Two

Running a Condor Job

Getting Condor

- Available as a free download from
  http://www.cs.wisc.edu/condor
- Download Condor for your operating system
  - Available for many UNIX platforms:
    - Linux, Solaris, HPUX, IRIX, Tru64...
  - Also for Windows

Condor Releases

- Naming scheme similar to the Linux Kernel…
- Major.minor.release
  - Stable: Minor is even (a.b.c)
    - Examples: 6.4.3, 6.6.8, 6.6.9
    - Very stable, mostly bug fixes
  - Developer: Minor is odd (a.b.c)
    - New features, may have some bugs
    - Examples: 6.5.5, 6.7.5, 6.7.6
- Today's releases:
  - Stable: 6.6.10
  - Development: 6.7.9

Try out Condor: Use a Personal Condor

- Condor:
  - on your own workstation
  - no root access required
  - no system administrator intervention needed
- We'll try this during the exercises

Personal Condor?!

What’s the benefit of a Condor Pool with just one user and one machine?

Your Personal 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
- ... keep a log of your job activities
- ... add fault tolerance to your jobs
- ... implement your policy on when the jobs can run on your workstation

After Personal Condor…

- When a Personal Condor pool works for you…
  - Convince your co-workers to add their computers to the pool
  - Add dedicated hardware to the pool

Four Steps to Run a Job

1. Choose a Universe for your job
2. Make your job batch-ready
3. Create a *submit description* file
4. Run *condor_submit*

1. Choose a Universe

- There are many choices
  - Vanilla: any old job
  - Standard: checkpointing & remote I/O
  - Java: better for Java jobs
  - MPI: Run parallel MPI jobs
  - …
- For now, we'll just consider vanilla

2. Make your job batch-ready

- Must be able to run in the background: no interactive input, windows, GUI, etc.
- Can still use `STDIN`, `STDOUT`, and `STDERR` (the keyboard and the screen), but files are used for these instead of the actual devices
- Organize data files

3. Create a Submit Description File

- A plain ASCII text file
  - Not a ClassAd
  - But condor_submit will make a ClassAd from it
- Condor does **not** care about file extensions
- 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

Simple Submit Description 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 = analysis
Log        = my_job.log
Queue
```

4. Run condor_submit

- You give *condor_submit* the name of the submit file you have created:

```
condor_submit my_job.submit
```

- *condor_submit* parses the submit file, checks for it errors, and creates a ClassAd that describes your job.

The Job Queue

- condor_submit sends your job's ClassAd to the schedd
  - Manages the local job queue
  - Stores the job in the job queue
    - Atomic operation, two-phase commit
    - "Like money in the bank"
- View the queue with `condor_q`

An example submission

```
% condor_submit my_job.submit
Submitting job(s).
1 job(s) submitted to cluster 1.

% condor_q

-- Submitter: perdita.cs.wisc.edu : <128.105.165.34:1027> :
 ID      OWNER           SUBMITTED     RUN_TIME ST PRI SIZE CMD
  1.0    roy             7/6 06:52   0+00:00:00 I  0   0.0  analysis

1 jobs; 1 idle, 0 running, 0 held

%
```

Some details

- Condor sends you email about events
  - Turn it off: **`Notification = Never`**
  - Only on errors: **`Notification = Error`**
- Condor creates a log file (user log)
  - "The Life Story of a Job"
  - Shows all events in the life of a job
  - Always have a log file
  - Specified with: **`Log = filename`**

Sample Condor User Log

```
000 (0001.000.000) 05/25 19:10:03 Job submitted from host: <128.105.146.14:1816>
...
001 (0001.000.000) 05/25 19:12:17 Job executing on host: <128.105.146.14:1026>
...
005 (0001.000.000) 05/25 19:13:06 Job terminated.
     (1) Normal termination (return value 0)
          Usr 0 00:00:37, Sys 0 00:00:00  -  Run Remote Usage
          Usr 0 00:00:00, Sys 0 00:00:05  -  Run Local Usage
          Usr 0 00:00:37, Sys 0 00:00:00  -  Total Remote Usage
          Usr 0 00:00:00, Sys 0 00:00:05  -  Total Local Usage
     9624  -  Run Bytes Sent By Job
     7146159  -  Run Bytes Received By Job
     9624  -  Total Bytes Sent By Job
     7146159  -  Total Bytes Received By Job
...
```

More Submit Features

```
# Example condor_submit input file

Universe   = vanilla
Executable = /home/roy/condor/my_job.condor
Log        = my_job.log
Input      = my_job.stdin
Output     = my_job.stdout
Error      = my_job.stderr
Arguments  = -arg1 -arg2
InitialDir = /home/roy/condor/run_1
Queue
```

Using condor_rm

- If you want to remove a job from the Condor queue, you use `condor_rm`
- You can only remove jobs that you own (you can't run `condor_rm` on someone else's jobs unless you are root)
- You can give specific job ID's (cluster or cluster.proc), or you can remove all of your jobs with the "*-a*" option.
  - **`condor_rm 21.1`** · Removes a single job
  - **`condor_rm 21`** · Removes a whole cluster

condor_status

```
% condor_status

Name           OpSys       Arch   State     Activity   LoadAv Mem   ActvtyTime

haha.cs.wisc.  IRIX65      SGI    Unclaimed Idle       0.198  192   0+00:00:04
antipholus.cs  LINUX       INTEL  Unclaimed Idle       0.020  511   0+02:28:42
coral.cs.wisc  LINUX       INTEL  Claimed   Busy       0.990  511   0+01:27:21
doc.cs.wisc.e  LINUX       INTEL  Unclaimed Idle       0.260  511   0+00:20:04
dsonokwa.cs.w  LINUX       INTEL  Claimed   Busy       0.810  511   0+00:01:45
ferdinand.cs.  LINUX       INTEL  Claimed   Suspended  1.130  511   0+00:00:55
vm1@pinguino.  LINUX       INTEL  Unclaimed Idle       0.000  255   0+01:03:28
vm2@pinguino.  LINUX       INTEL  Unclaimed Idle       0.190  255   0+01:03:29
```

How can my jobs access their data files?

Access to Data in Condor

- Use shared filesystem if available
- No shared filesystem?
  - Condor can transfer files
    - Can automatically send back changed files
    - Atomic transfer of multiple files
    - Can be encrypted over the wire
  - Remote I/O Socket
  - Standard Universe can use remote system calls (more on this later)

Condor File Transfer

- `ShouldTransferFiles = YES`
  - Always transfer files to execution site
- `ShouldTransferFiles = NO`
  - Rely on a shared filesystem
- `ShouldTransferFiles = IF_NEEDED`
  - Will automatically transfer the files if the submit and execute machine are not in the same FileSystemDomain

```
Universe    = vanilla
Executable = my_job
Log         = my_job.log
ShouldTransferFiles    = IF_NEEDED
Transfer_input_files   = dataset$(Process), common.data
Transfer_output_files = TheAnswer.dat
Queue 600
```

Some of the machines in the Pool do not have enough memory or scratch disk space to run my job!

Specify Requirements!

- An expression (syntax similar to C or Java)
- Must evaluate to True for a match to be made

```
Universe     = vanilla
Executable = my_job
Log          = my_job.log
InitialDir = run_$(Process)
Requirements = Memory >= 256 && Disk > 10000
Queue 600
```

Specify Rank!

- All matches which meet the requirements can be sorted by preference with a Rank expression.
- Higher the Rank, the better the match

```
Universe   = vanilla
Executable = my_job
Log        = my_job.log
Arguments  = -arg1 -arg2
InitialDir = run_$(Process)
Requirements = Memory >= 256 && Disk > 10000
Rank = (KFLOPS*10000) + Memory
Queue 600
```

We’ve seen how Condor can:

… keeps an eye on your jobs and will keep you posted on their progress

… implements your policy on the execution order of the jobs

… keeps a log of your job activities

My jobs run for 20 days…

- What happens when they get pre-empted?
- How can I add fault tolerance to my jobs?

Condor’s Standard Universe to the rescue!

- Condor can support various combinations of features/environments in different “Universes”
- Different Universes provide different functionality for your job:
  - Vanilla – Run any Serial Job
  - Scheduler – Plug in a scheduler
  - Standard – Support for transparent process checkpoint and restart

Process Checkpointing

- Condor's Process Checkpointing mechanism saves the entire state of a process into a checkpoint file
  - Memory, CPU, I/O, etc.
- The process can then be restarted *from right where it left off*
- Typically no changes to your job's source code needed – however, your job must be *relinked* with Condor's Standard Universe support library

Relinking Your Job for Standard Universe

To do this, just place "***condor_compile***" in front of the command you normally use to link your 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. Thus in the Standard Universe the job may not:
  - Fork()
  - Use kernel threads
  - Use some forms of IPC, such as pipes and shared memory
- Many typical scientific jobs are OK

When will Condor checkpoint your job?

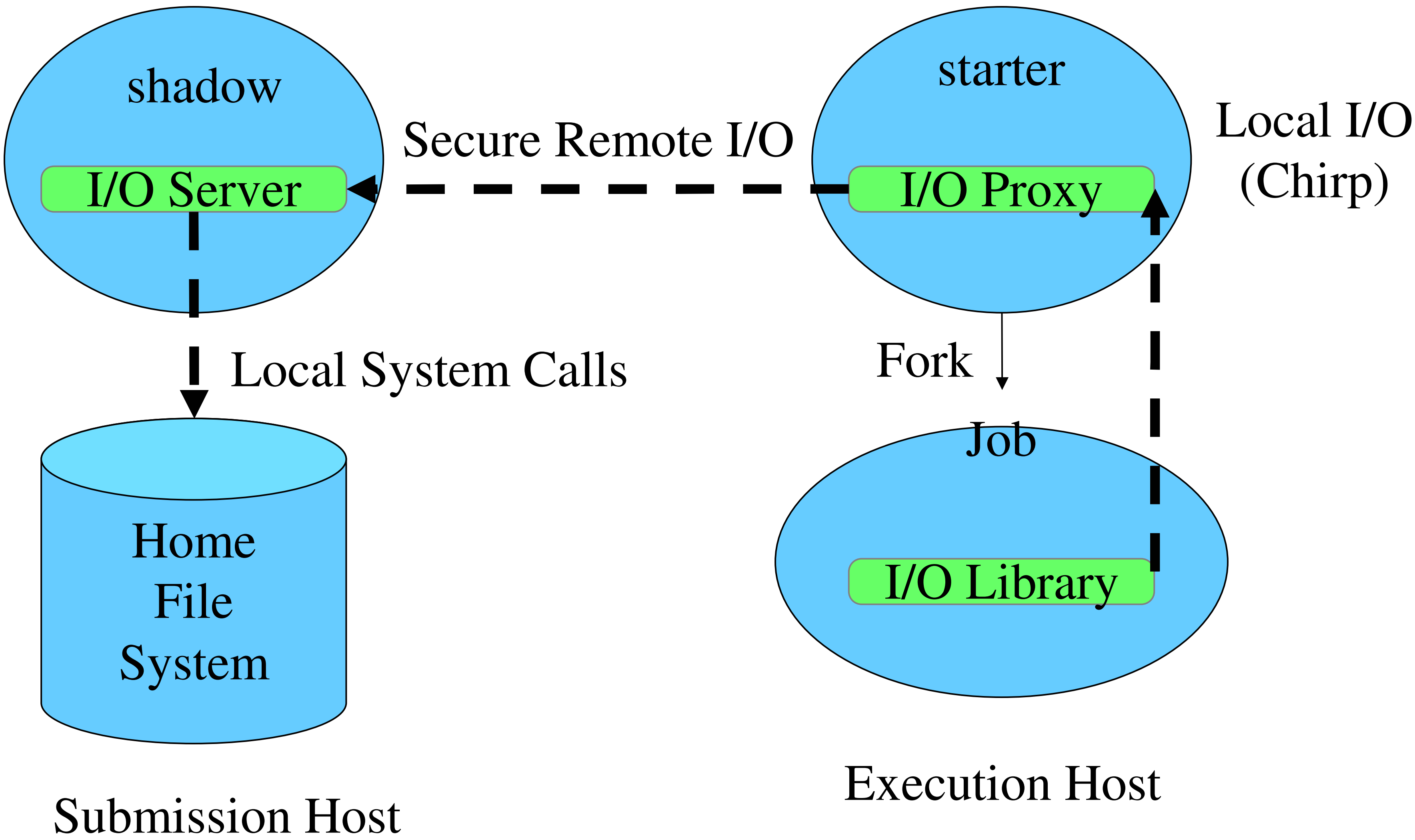
- Periodically, if desired
  - For fault tolerance
- When your job is preempted by a higher priority job
- When your job is vacated because the execution machine becomes busy
- When you explicitly run *condor_checkpoint*, *condor_vacate*, *condor_off* or *condor_restart* command

Remote I/O Socket

- Job can request that the condor_starter process on the execute machine create a *Remote I/O Socket*
- Used for online access of file on submit machine – *without Standard Universe.*
  - Use in Vanilla, Java, …
- Libraries provided for Java and for C, e.g. :

  Java: FileInputStream -> ChirpInputStream

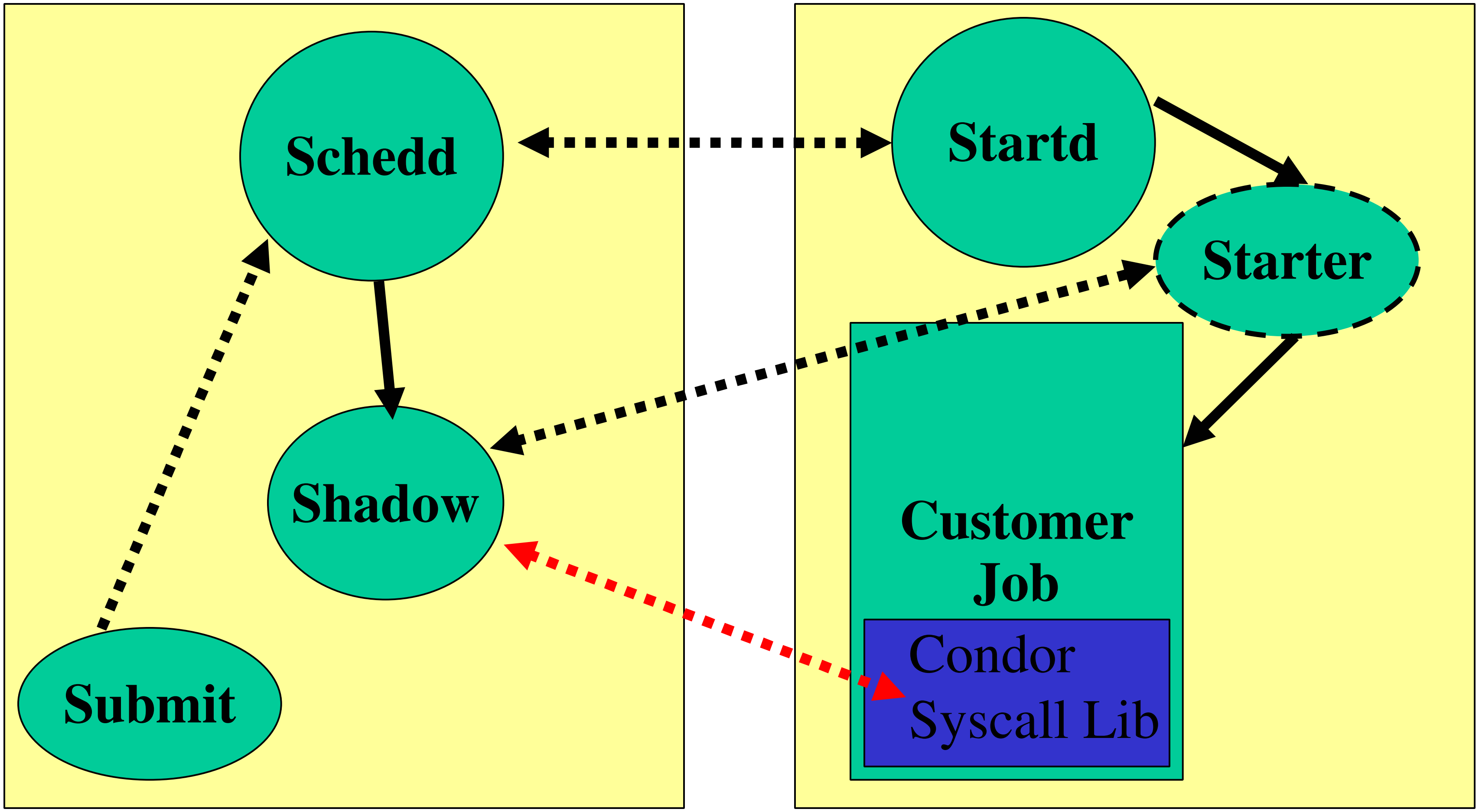
  C : open() -> chirp_open()


shadow
I/O Server
Secure Remote I/O
starter
I/O Proxy
Local I/O
(Chirp)
Local System Calls
Fork
Job
Home
File
System
I/O Library
Submission Host
Execution Host

Remote System Calls

- I/O System calls are trapped and sent back to submit machine
- Allows Transparent Migration Across Administrative Domains
  - Checkpoint on machine A, restart on B
- No Source Code changes required
- Language Independent
- Opportunities for Application Steering
  - Example: Condor tells customer process "how" to open files

Job Startup



Schedd
Startd
Starter
Shadow
Customer Job
Condor Syscall Lib
Submit

condor_q -io

```
c01(69)% condor_q -io


-- Submitter: c01.cs.wisc.edu : <128.105.146.101:2996> : c01.cs.wisc.edu
ID        OWNER          READ    WRITE     SEEK       XPUT  BUFSIZE  BLKSIZE
  72.3    edayton           [ no i/o data collected yet ]
  72.5    edayton    6.8 MB   0.0 B         0 104.0 KB/s 512.0 KB  32.0 KB
  73.0    edayton    6.4 MB   0.0 B         0 140.3 KB/s 512.0 KB  32.0 KB
  73.2    edayton    6.8 MB   0.0 B         0 112.4 KB/s 512.0 KB  32.0 KB
  73.4    edayton    6.8 MB   0.0 B         0 139.3 KB/s 512.0 KB  32.0 KB
  73.5    edayton    6.8 MB   0.0 B         0 139.3 KB/s 512.0 KB  32.0 KB
  73.7    edayton           [ no i/o data collected yet ]

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

Condor Job Universes

- Serial Jobs
  - Vanilla Universe
  - Standard Universe
- Scheduler Universe
- Parallel Jobs
  - MPI Universe (soon the Parallel Universe)
  - PVM Universe
- Java Universe

Java Universe Job

condor_submit →

```
universe      = java
executable    = Main.class
jar_files     = MyLibrary.jar
input         = infile
output        = outfile
arguments     = Main 1 2 3
queue
```

Why not use Vanilla Universe for Java jobs?

- Java Universe provides more than just inserting "java" at the start of the execute line
  - Knows which machines have a JVM installed
  - Knows the location, version, and performance of JVM on each machine
  - 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 support, cont.

```
condor_status -java

Name             JavaVendor   Ver     State       Activity LoadAv Mem

aish.cs.wisc. Sun Microsy 1.2.2   Owner       Idle     0.000   249
anfrom.cs.wis Sun Microsy 1.2.2   Owner       Idle     0.030   249
babe.cs.wisc. Sun Microsy 1.2.2   Claimed     Busy     1.120   123
...
```

Summary

- Use:
  - condor_submit
  - condor_q
  - condor_status
- Condor can run
  - Any old program (vanilla)
  - Some jobs with checkpointing & remote I/O (standard)
  - Java jobs with better understanding
- Files can be accessed via
  - Shared filesystem
  - File transfer
  - Remote I/O

Part Three

Running a parameter sweep




Clusters and Processes

- If your submit file describes multiple jobs, we call this a "cluster"
- Each cluster has a unique "cluster number"
- Each 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 ("20.1")
- A cluster is allowed to have one or more processes.
  - There is always a cluster for every job

Example Submit Description File for a Cluster

```
# Example submit description file that defines a
# cluster of 2 jobs with separate working directories
Universe   = vanilla
Executable = my_job
log        = my_job.log
Arguments  = -arg1 -arg2
Input      = my_job.stdin
Output     = my_job.stdout
Error      = my_job.stderr
InitialDir = run_0
Queue                 ·Becomes job 2.0
InitialDir = run_1
Queue                 ·Becomes job 2.1
```

Submitting The Job

```
% condor_submit my_job.submit-file
Submitting job(s).
2 job(s) submitted to cluster 2.

% condor_q
-- Submitter: perdita.cs.wisc.edu : <128.105.165.34:1027> :
 ID      OWNER            SUBMITTED     RUN_TIME ST PRI SIZE CMD
  1.0    frieda          4/15 06:52  0+00:02:11 R  0   0.0  my_job
  2.0    frieda          4/15 06:56  0+00:00:00 I  0   0.0  my_job
  2.1    frieda          4/15 06:56  0+00:00:00 I  0   0.0  my_job
3 jobs; 2 idle, 1 running, 0 held
```

Submit Description File for a *BIG* Cluster of Jobs

- The initial directory for each job can be specified as run_$(Process), and instead of submitting a single job, we use "Queue 600" to submit 600 jobs at once
- The $(Process) macro will be expanded to the process number for each job in the cluster (0 - 599), so we'll have "run_0", "run_1", … "run_599" directories
- All the input/output files will be in different directories!

Submit Description File for a *BIG* Cluster of Jobs

```
# Example condor_submit input file that defines
# a cluster of 600 jobs with different directories
Universe   = vanilla
Executable = my_job
Log        = my_job.log
Arguments  = -arg1 -arg2
Input      = my_job.stdin
Output     = my_job.stdout
Error      = my_job.stderr
InitialDir = run_$(Process)
Queue 600
```

- run_0 … run_599
- Becomes job 3.0 … 3.599

More $(Process)

- You can use $(Process) anywhere.

```
Universe    = vanilla
Executable  = my_job
Log         = my_job.$(Process).log
Arguments   = -randomseed $(Process)
Input       = my_job.stdin
Output      = my_job.stdout
Error       = my_job.stderr
InitialDir  = run_$(Process)
Queue 600
```

- run_0 … run_599
- Becomes job 3.0 … 3.599

Sharing a directory

- You don't have to use separate directories.
- $(Cluster) will help distinguish runs

```
Universe   = vanilla
Executable = my_job
Log        = my_job.$(Cluster).$(Process).log
Arguments  = -randomseed $(Process)
Input      = my_job.input.$(Process)
Output     = my_job.stdout.$(Cluster).$(Process)
Error      = my_job.stderr.$(Cluster).$(Process)
Queue 600
```

Difficulties with $(Process)

- Some people want to pass their program $(Process) + 10 (or another number)
- You can't do this. ☹
- You can do things like:

```
Universe    = vanilla
Executable = my_job
Arguments   = -randomseed 10$(Process)
…
Queue 600
```

- 10 is pre-pended to each $(Process) Argument

Job Priorities

- Are some of the jobs in your sweep more interesting than others?
- `condor_prio` lets you set the job priority
  - Priority relative to your jobs, not other peoples
  - Condor 6.6: priority can be -20 to +20
  - Condor 6.7: priority can be any integer
- Can be set in submit file:
  - `Priority = 14`

What if you have LOTS of jobs?

- System resources
  - Each job requires a shadow process
  - Each shadow requires file descriptors and sockets
  - Each shadow requires ports/sockets
  - Set system limits for these to be large
- Each condor_schedd limits max number of jobs running
  - Default is 200
  - Configurable
- Consider multiple submit hosts
  - You can submit jobs from multiple computers
  - Immediate increase in scalability & complexity

Advanced Trickery

- You submit 10 parameter sweeps
- You have five classes of parameters sweeps
  - Call them A, B, C, D, E
- How can you look at the status of jobs that are part of Type B parameter sweeps?

Advanced Trickery cont.

- In your job file:
  - +SweepType = "B"
- You can see this in your job ClassAd
  - `condor_q -l`
- You can show jobs of a certain type:
  - `condor_q -constraint 'SweepType == "B"'`
- Very useful when you have a complex variety of jobs
- Try this during the exercises!
- Be careful with the quoting…

Part Four

Managing Job Dependencies

DAGMan

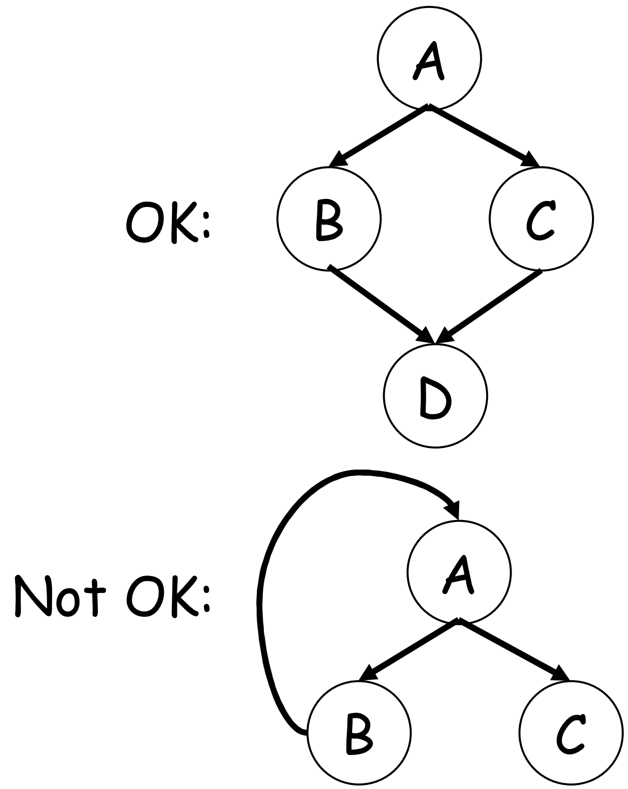
Directed Acyclic Graph

Manager

- DAGMan allows you to specify the dependencies between your Condor jobs, so it can manage them automatically for you.
- Example: "Don't run job B until job A has completed successfully."

What is a DAG?

- A DAG is the data structure used by DAGMan to represent these dependencies.
- Each job is a node in the DAG.
- Each node can have any number of "parent" or "children" nodes – as long as there are no loops!

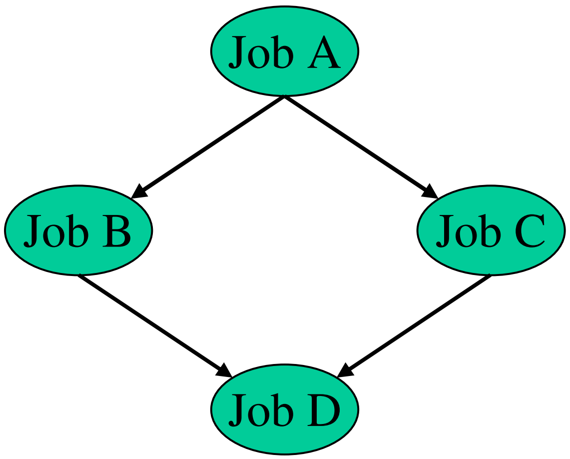


Defining a DAG

- A DAG is defined by a *.dag file*, listing each of its nodes and their dependencies:

```
Job A a.sub
Job B b.sub
Job C c.sub
Job D d.sub

Parent A Child B C
Parent B C Child D
```



DAG Files….

- The complete DAG is five files

One DAG File:

```
Job A a.sub
Job B b.sub
Job C c.sub
Job D d.sub

Parent A Child B C
Parent B C Child D
```

Four Submit Files:

```
Universe = Vanilla
Executable = analysis…
```

Submitting a DAG

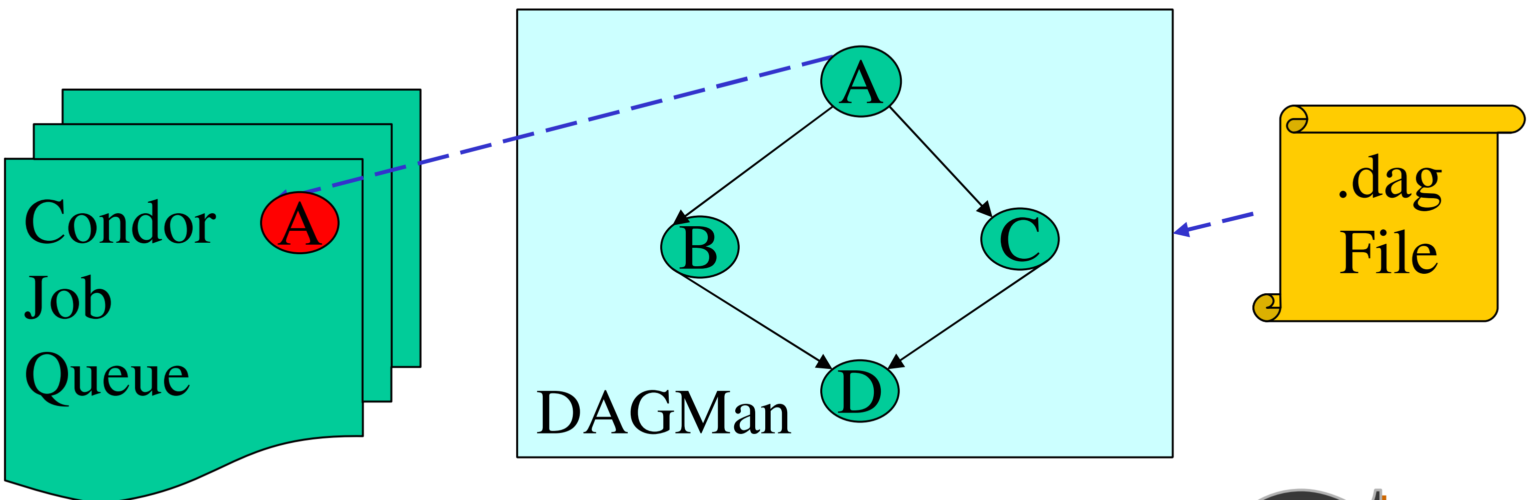
- To start your DAG, just run **`condor_submit_dag`** with your .dag file, and Condor will start a personal DAGMan process which to begin running your jobs:

```
% condor_submit_dag diamond.dag
```

- condor_submit_dag submits a Scheduler Universe job with DAGMan as the executable.
- Thus the DAGMan daemon itself runs as a Condor job, so you don't have to baby-sit it.

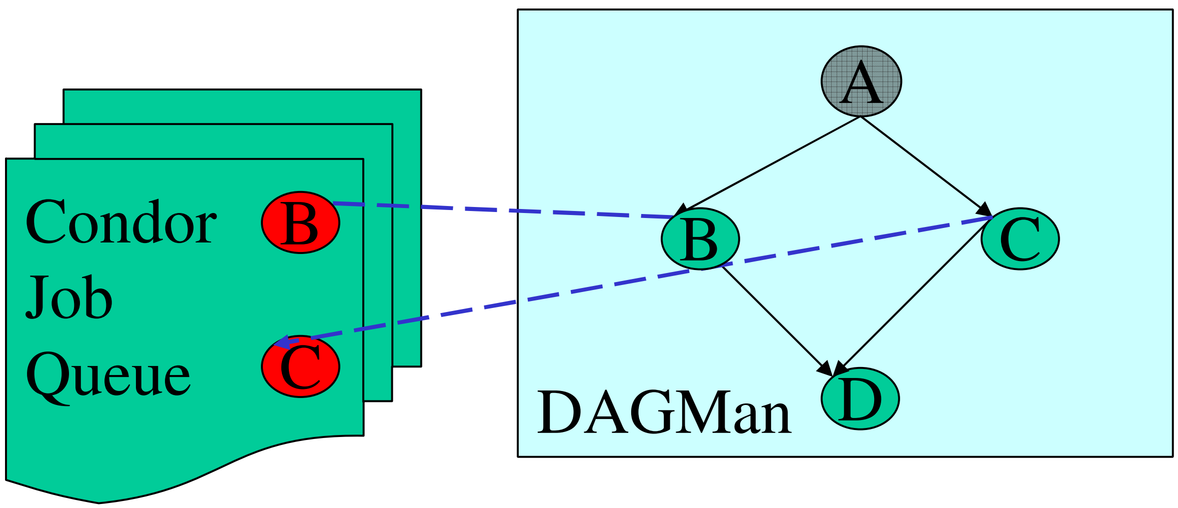
Running a DAG

- DAGMan acts as a scheduler, managing the submission of your jobs to Condor based on the DAG dependencies.



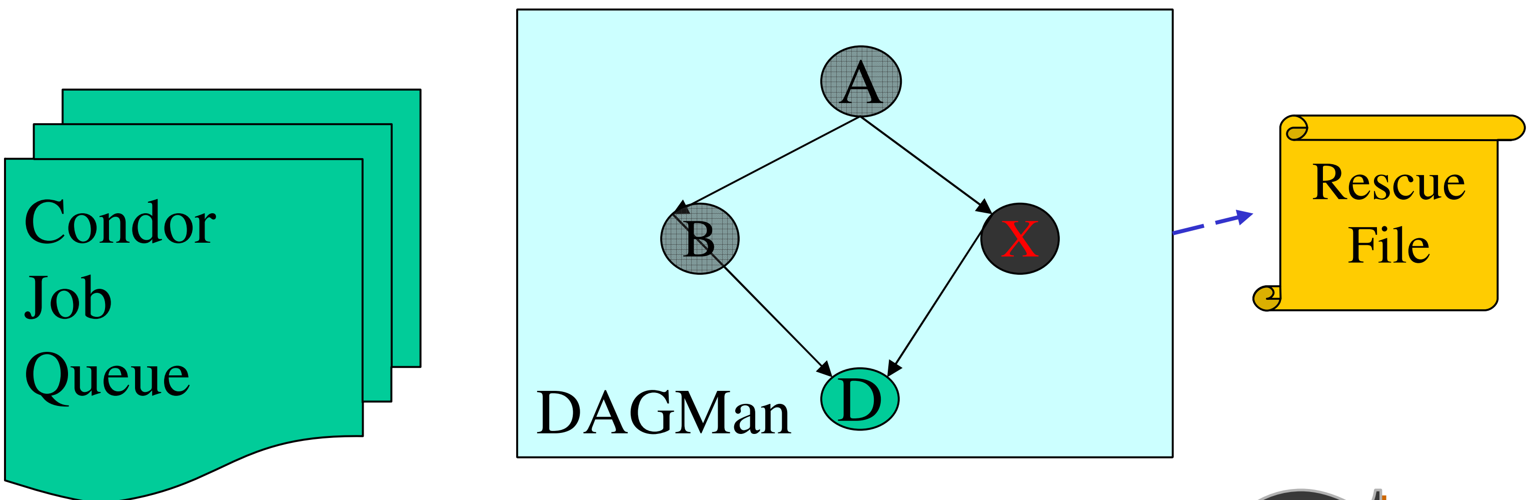
Running a DAG (cont'd)

- DAGMan holds & submits jobs to the Condor queue at the appropriate times.



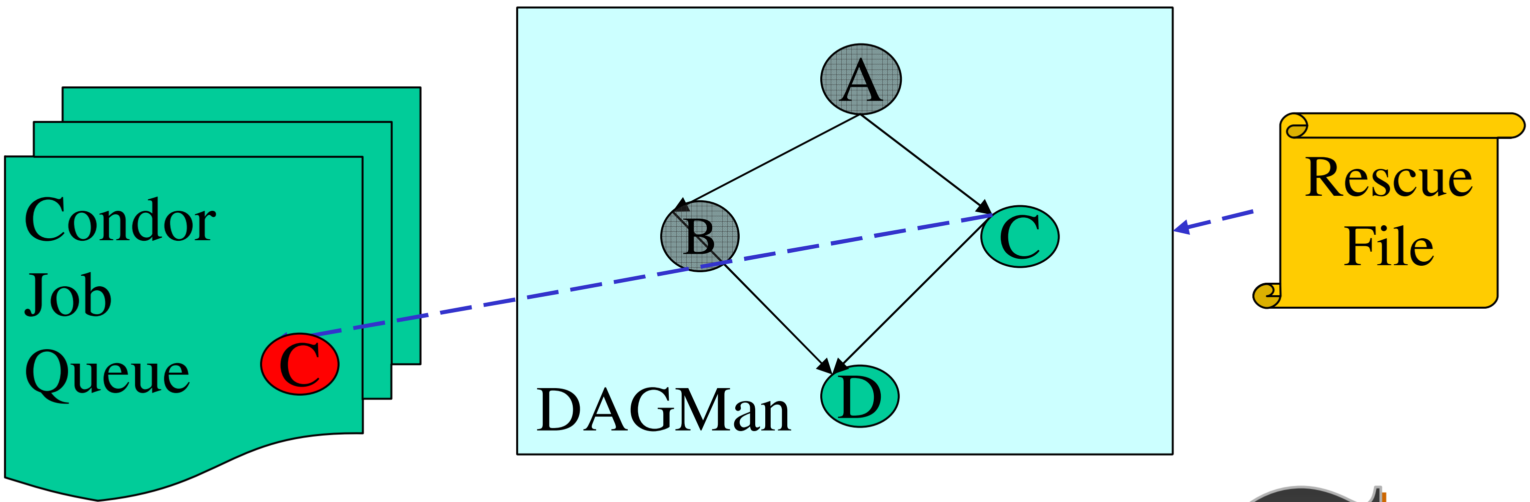
Running a DAG (cont'd)

- In case of a job failure, DAGMan continues until it can no longer make progress, and then creates a *"rescue" file* with the current state of the DAG.



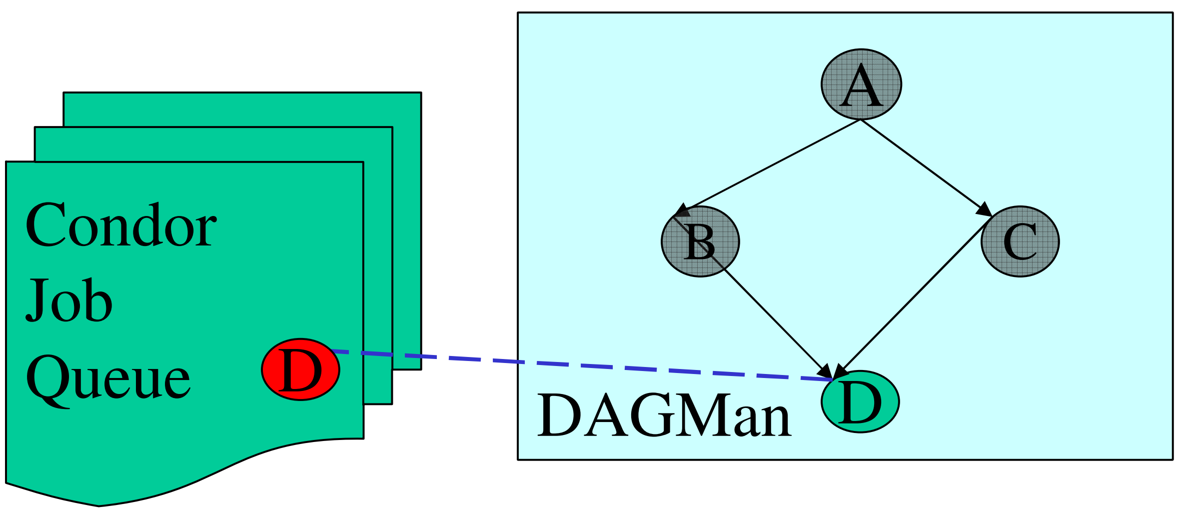
Recovering a DAG

- Once the failed job is ready to be re-run, the rescue file can be used to restore the prior state of the DAG.



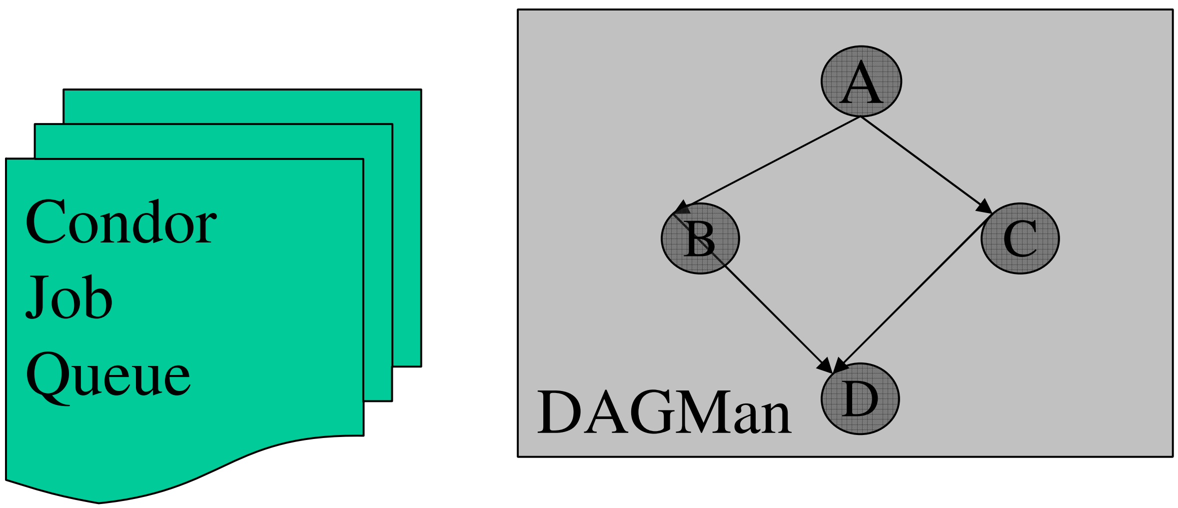
Recovering a DAG (cont'd)

- Once that job completes, DAGMan will continue the DAG as if the failure never happened.



Finishing a DAG

- Once the DAG is complete, the DAGMan job itself is finished, and exits.



DAGMan & Log Files

- For each job, Condor generates a log file
- DAGMan reads this log to see what has happened
- If DAGMan dies (crash, power failure, etc...)
  - Condor will restart DAGMan
  - DAGMan re-reads log file
  - DAGMan knows everything it needs to know

Advanced DAGMan Tricks

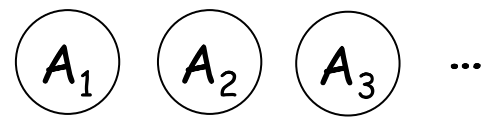
- Throttles and degenerative DAGs
- Recursive DAGs: Loops and more
- Pre and Post scripts: editing your DAG

Throttles

- Failed nodes can be automatically re-tried a configurable number of times
  - Can retry N times
  - Can retry N times, unless a node returns specific exit code
- Throttles to control job submissions
  - Max jobs submitted
  - Max scripts running

Degenerative DAG

- Submit DAG with:
  - 200,000 nodes
  - No dependencies

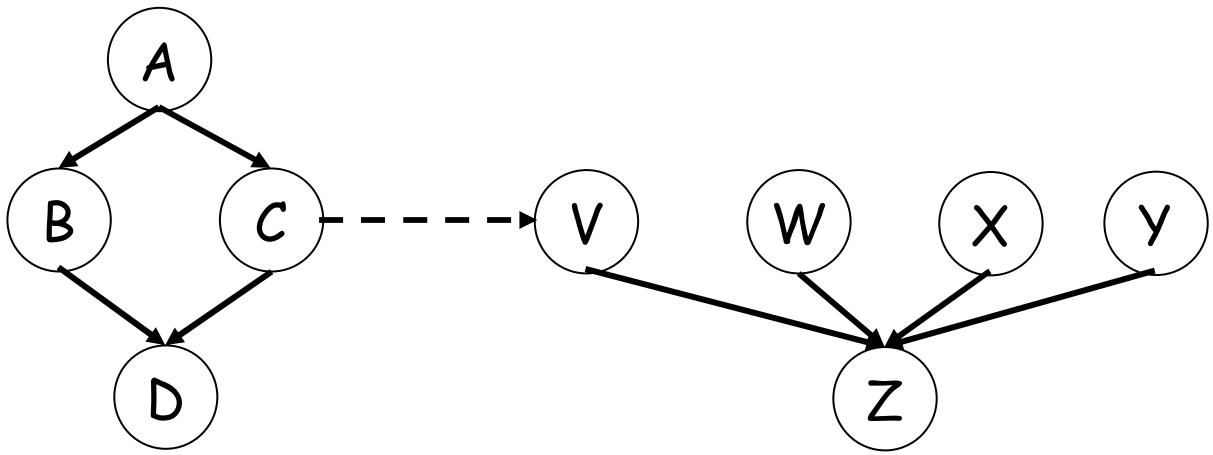


- Use DAGMan to throttle the jobs
  - Condor is scalable, but it will have problems if you submit 200,000 jobs simultaneously
  - DAGMan can help you get scalability even if you don't have dependencies

Recursive DAGs

- Idea: any given DAG node can be a script that does:
  1. Make decision
  2. Create DAG file
  3. Call condor_submit_dag
  4. Wait for DAG to exit
- DAG node will not complete until recursive DAG finishes,
- Why?
  - Implement a fixed-length loop
  - Modify behavior on the fly

Recursive DAG



DAGMan scripts

- DAGMan allows pre & post scripts
  - Don't have to be scripts: any executable
  - Run before (pre) or after (post) job
  - Run on the same computer you submitted from
- Syntax:

```
JOB A a.sub
SCRIPT PRE A before-script $JOB
SCRIPT POST A after-script $JOB $RETURN
```

So What?

- Pre script can make decisions
  - Where should my job run? (Particularly useful to make job run in same place as last job.)
  - Should I pass different arguments to the job?
  - Lazy decision making
- Post script can change return value
  - DAGMan decides job failed in non-zero return value
  - Post-script can look at {error code, output files, etc} and return zero or non-zero based on deeper knowledge.

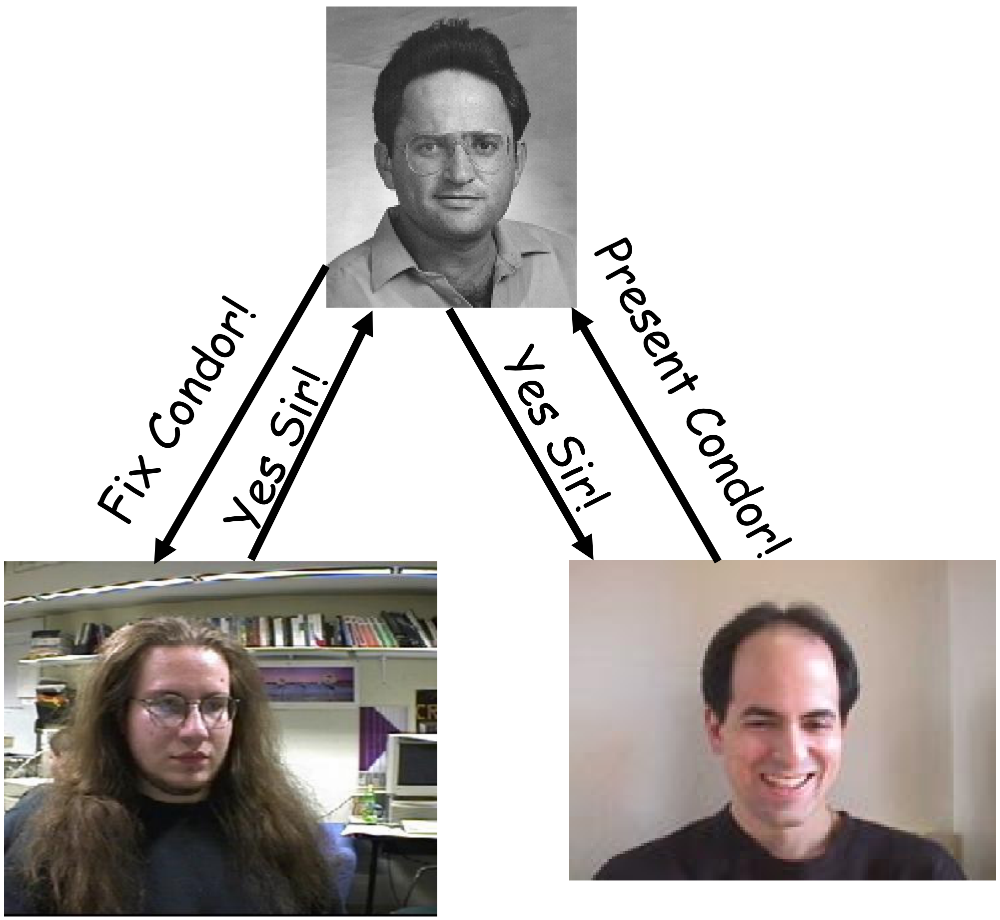
Part Five
Master Worker Applications

(Slides adapted from Condor Week 2005 presentation by Jeff Linderoth)

Why Master Worker?

- An alternative to DAGMan
- DAGMan
  - Create a bunch of Condor jobs
  - Run them in parallel
- Master Worker (MW)
  - Write a bunch of tasks in C++
  - MW uses Condor to run your tasks
  - Don't worry about the jobs
  - But rewrite your application to fit MW

Master Worker Basics



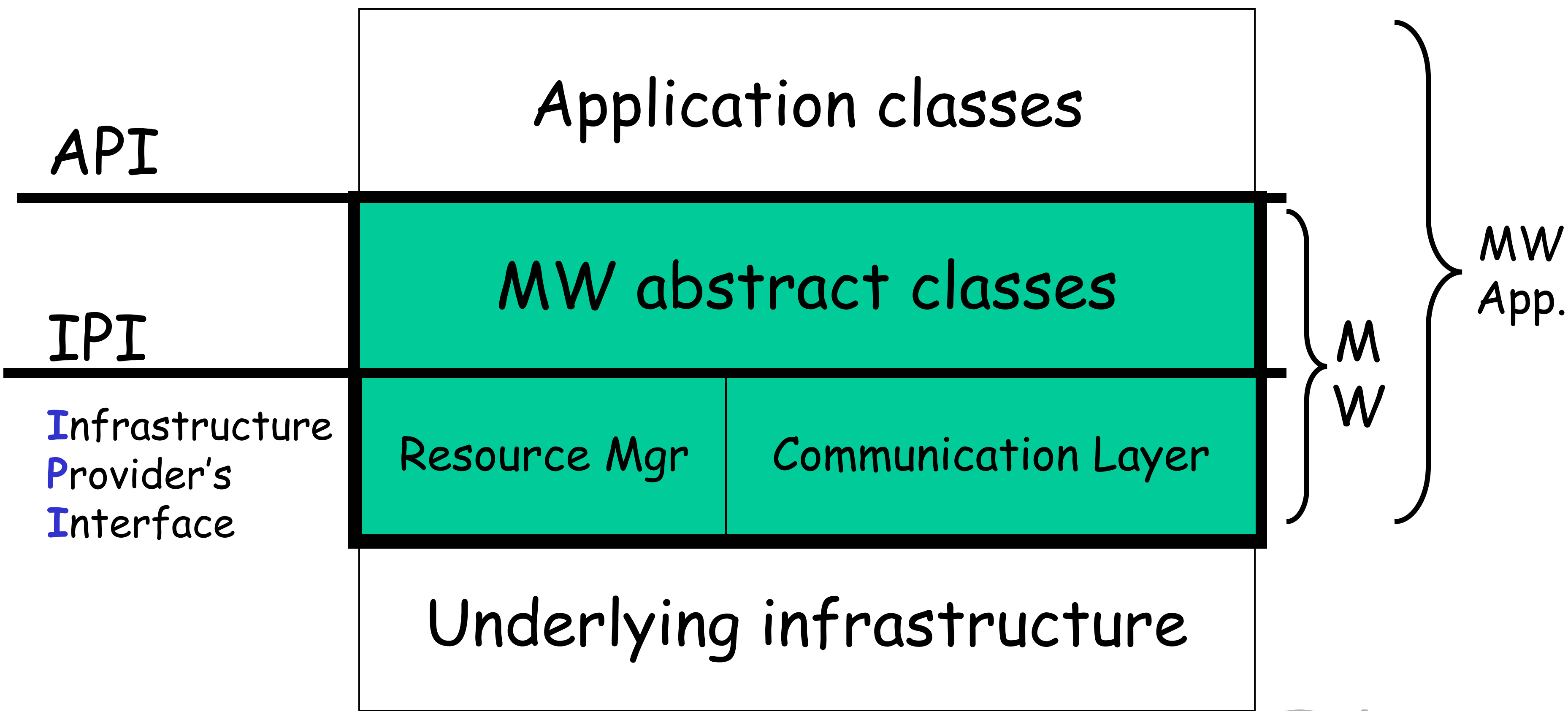
- Master assigns tasks to workers
- Workers perform tasks and report results
- Workers do not communicate (except via master)

- Simple
- Fault Tolerant
- Dynamic

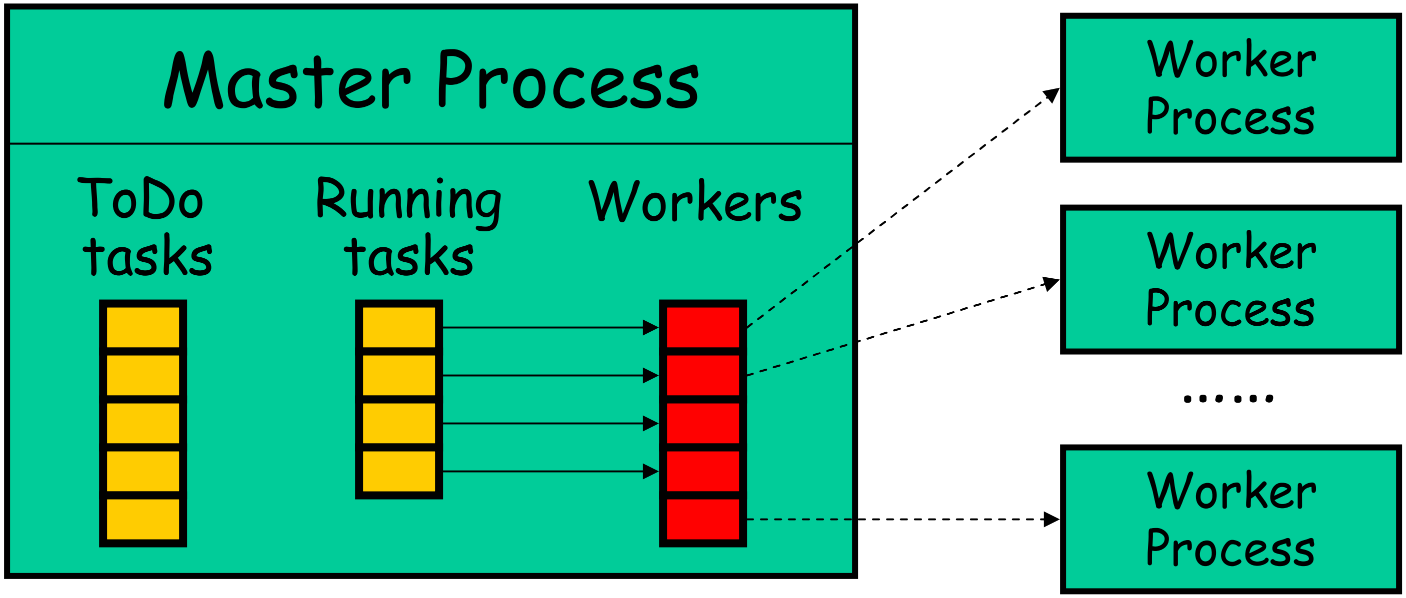
Master Worker Toolkit

- There are three abstraction in the master-worker paradigm: Master, Worker, and Task.
- MW is a software package that encapsulates these abstractions
  - API : C++ abstract classes
  - User writes 10 methods
  - The MWized code will transparently adapt to the dynamic and heterogeneous computing environment
- MW also has abstract layer to resource management and communications packages (an Infrastructure Programming Interface).
  - Condor/{PVM, Sockets, Files}
  - Single processor

MW's Layered Architecture



MW's Runtime Structure



1. User code adds tasks to the master's Todo list;
2. Each task is sent to a worker (Todo -> Running);
3. The task is executed by the worker;
4. The result is sent back to the master;
5. User code processes the result (can add/remove tasks).

MW API

- MWMaster
  - get_userinfo()
  - setup_intial_tasks()
  - pack_worker_init_data()
  - act_on_completed_task()
- MWTask
  - pack_work(), unpack_work()
  - pack_result, unpack_result()
- MWWorker
  - unpack_worker_init_data()
  - execute_task()

Setup

Encode/decode communication

Main loops

Other MW Utilities

- MWprintf

  to print progress, result, debug info, etc;

- MWDriver

  to get information, set control policies, etc;

- RMC:

  to specify resource requirements, prepare for communication, etc.

Real MW Applications

- MWFATCOP (Chen, Ferris, Linderoth)
  - A branch and cut code for linear integer programming
- MWMINLP (Goux, Leyffer, Nocedal)
  - A branch and bound code for nonlinear integer programming
- MWQPBB (Linderoth)
  - A (simplicial) branch and bound code for solving quadratically constrained quadratic programs
- MWAND (Linderoth, Shen)
  - A nested decomposition based solver for multistage stochastic linear programming
- MWATR (Linderoth, Shapiro, Wright)
  - A trust-region-enhanced cutting plane code for linear stochastic programming and statistical verification of solution quality.
- MWQAP (Anstreicher, Brixius, Goux, Linderoth)
  - A branch and bound code for solving the quadratic assignment problem

Example: Nug30

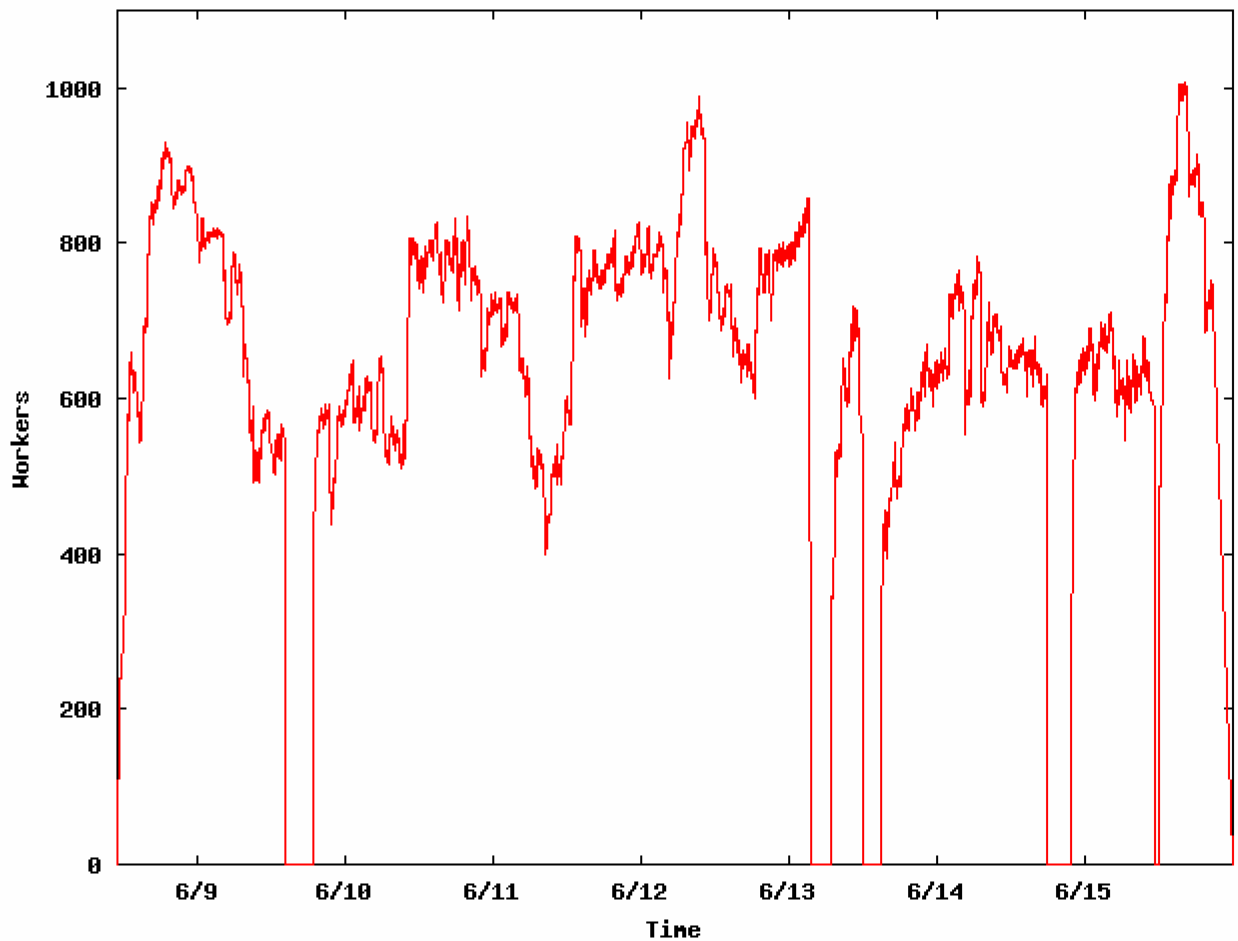
- nug30 (a Quadratic Assignment Problem instance of size 30) had been the "holy grail" of computational QAP research for > 30 years
- In 2000, Anstreicher, Brixius, Goux, & Linderoth set out tosolve this problem
- Using a mathematically sophisticated and well-engineered algorithm, they still estimated that we would require 11 CPU years to solve the problem.

Nug 30 Computational Grid

Number	Arch/OS	Location
414	Intel/Linux	Argonne
96	SGI/Irix	Argonne
1024	SGI/Irix	NCSA
16	Intel/Linux	NCSA
45	SGI/Irix	NCSA
246	Intel/Linux	Wisconsin
146	Intel/Solaris	Wisconsin
133	Sun/Solaris	Wisconsin
190	Intel/Linux	Georgia Tech
94	Intel/Solaris	Georgia Tech
54	Intel/Linux	Italy (INFN)
25	Intel/Linux	New Mexico
12	Sun/Solaris	Northwestern
5	Intel/Linux	Columbia U.
10	Sun/Solaris	Columbia U.

- Used tricks to make it look like one Condor pool
  - Flocking
  - Glide-in
- 2510 CPUs total

Workers Over Time



Nug30 solved

Wall Clock Time	6 days 22:04:31 hours
Avg # Machines	653
CPU Time	11 years
Parallel Efficiency	93%

More on MW

- http://www.cs.wisc.edu/condor/mw
- Version 0.2 is the latest
  - It's more stable than the version number suggests!
- Mailing list available for discussion
- Active development by the Condor team

I could also tell you about…

- Condor-G: Condor's ability to talk to other Grid systems
  - Globus 2, 3, 4
  - NorduGrid
  - Oracle
  - Condor…
- Stork: Treating data placement like computational jobs
- Nest: File server with space allocations
- GCB: Living with firewalls & private networks

But I won't

- After lunch: Exercises
- Please ask me questions, now or later