Condor and Workflows: An Introduction

Condor Week 2012

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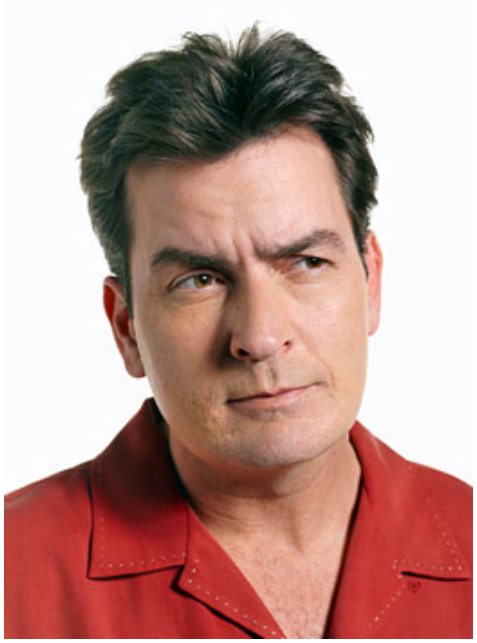
Outline

- Introduction/motivation
- Basic DAG concepts
- Running and monitoring a DAG
- Configuration
- Rescue DAGs and recovery
- Advanced DAGMan features

My jobs have dependencies…

Can Condor help solve my dependency problems?

Yes!

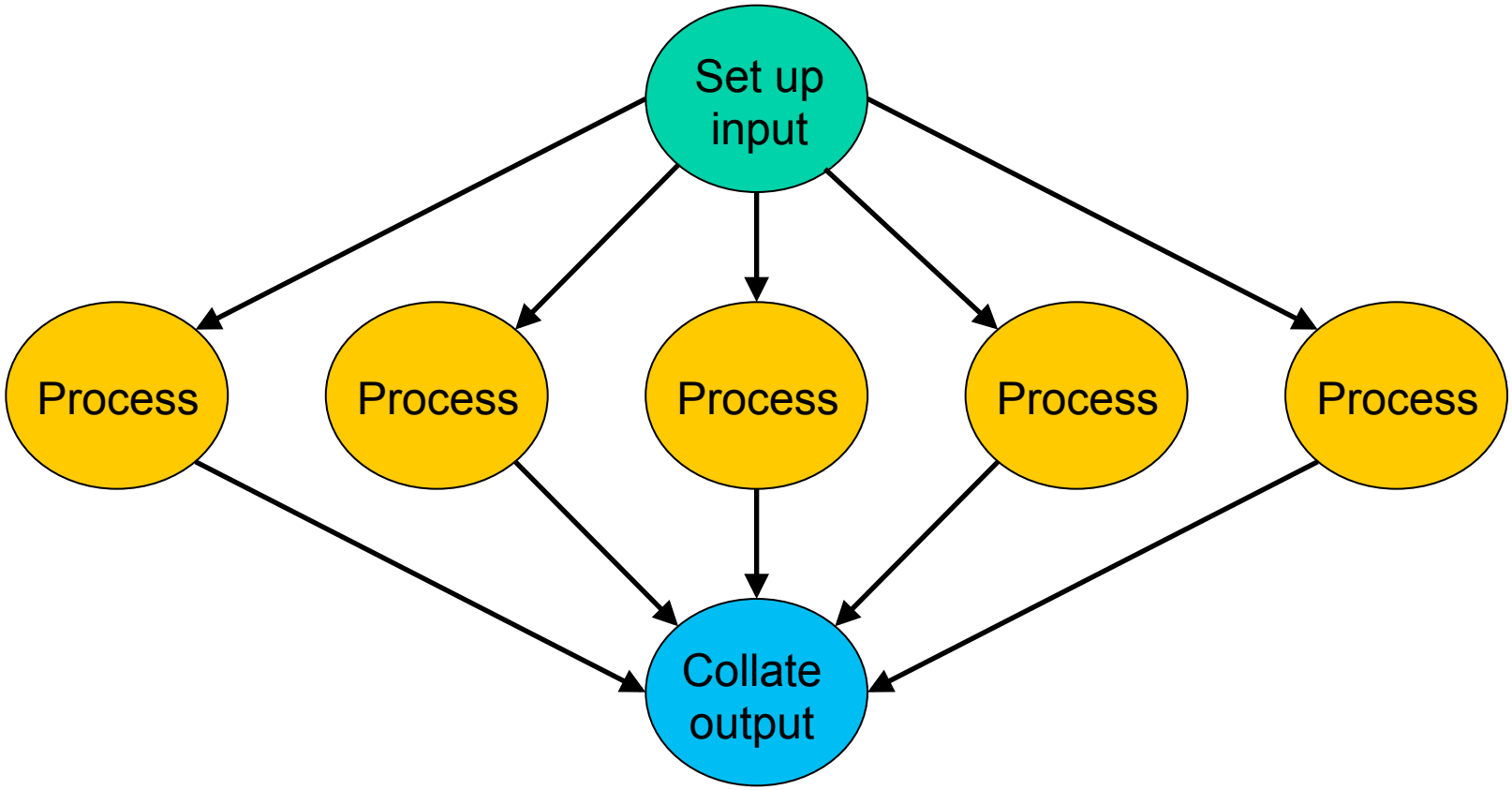


Workflows are the answer

What are workflows?

- General: a sequence of connected steps
- Our case
  - Steps are Condor jobs
  - Sequence defined at higher level
  - Controlled by a Workflow Management System (WMS), *not just a script*

Workflow example



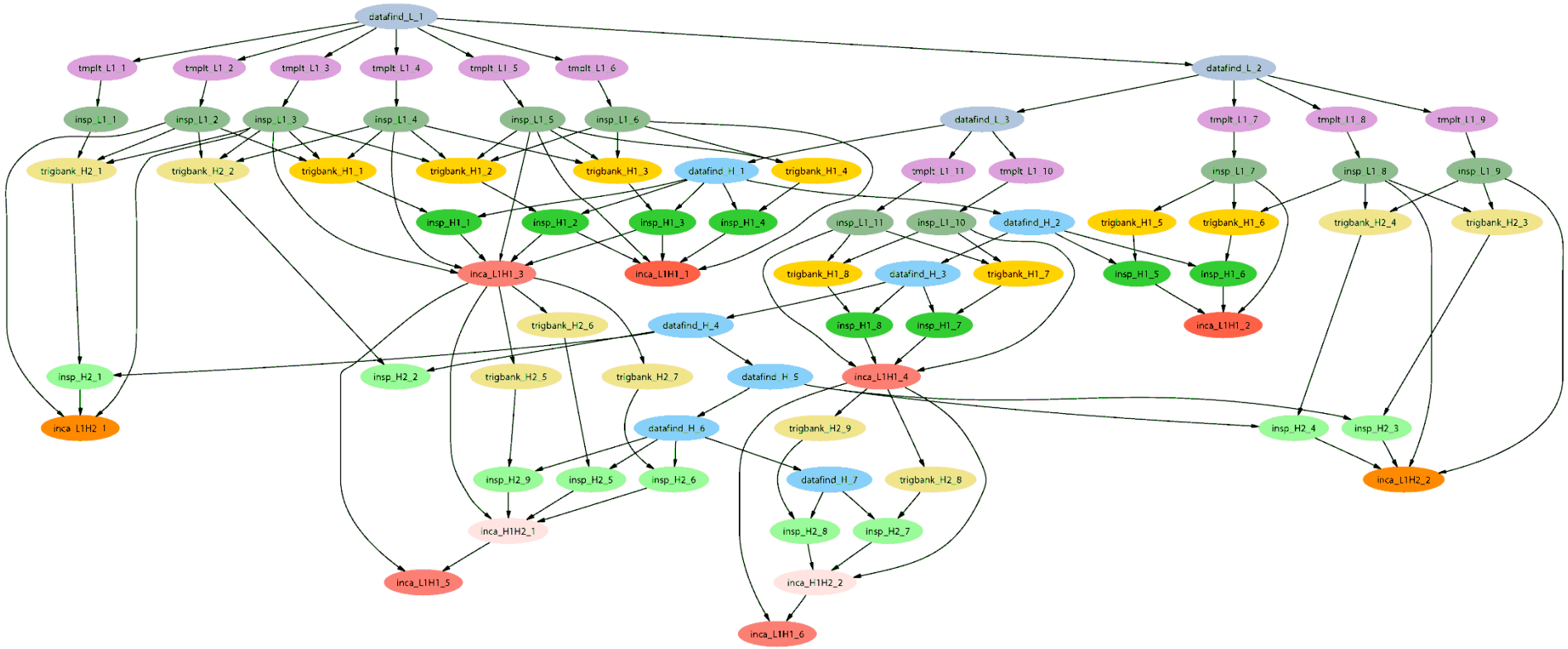
Workflows – launch and forget

- A workflow can take days, weeks or even months
- Automates tasks user *could* perform manually…
  - But WMS takes care of automatically
- Enforces inter-job dependencies
- 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

Workflow tools

- DAGMan: Condor's workflow tool
- Pegasus: a layer on top of DAGMan that is grid-aware and data-aware
- Makeflow: not covered in this talk
- Others…
- This talk will focus mainly on DAGMan

LIGO inspiral search application



Inspiral workflow application is the work of Duncan Brown, Caltech, Scott Koranda, UW Milwaukee, and the LSC Inspiral group

How big?

- We have users running 500k-job workflows in production
- Depends on resources on submit machine (memory, max. open files)
- "Tricks" can decrease resource requirements

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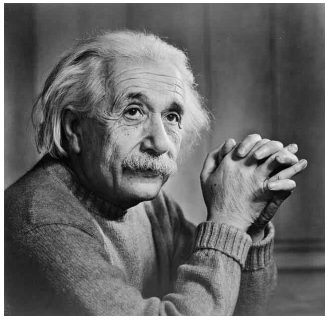
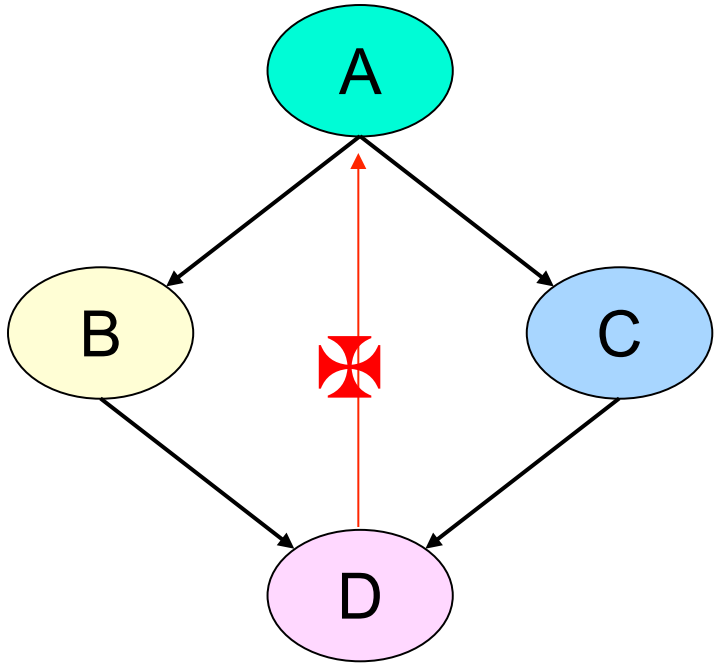


Albert learns DAGMan

- **Directed Acyclic Graph Manager**
- DAGMan allows Albert to specify the dependencies between his Condor jobs, so DAGMan manages the jobs automatically
- Dependency example: do not run job B until job A has completed successfully

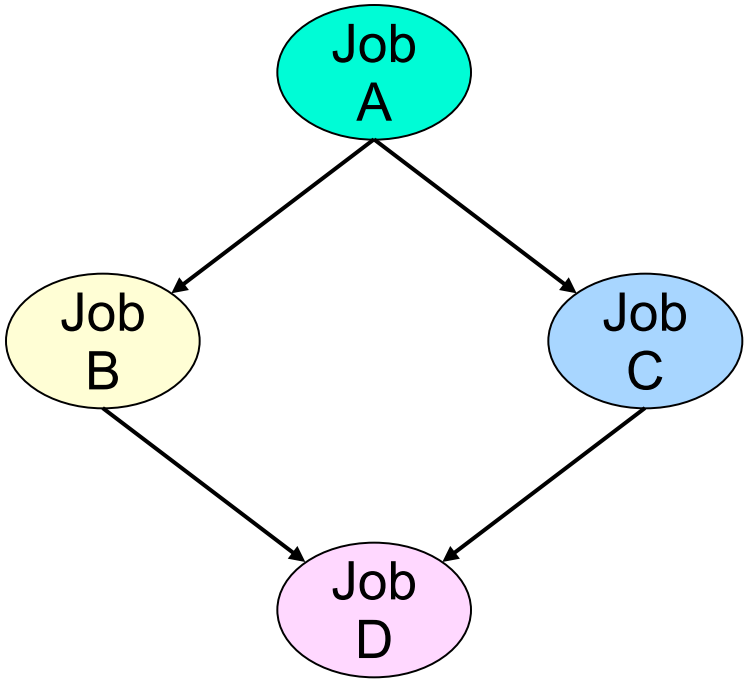
DAG definitions

- DAGs have one or more nodes (or vertices)
- Dependencies are represented by arcs (or edges). These are arrows that go from parent to child)
- No cycles!



Condor and DAGs

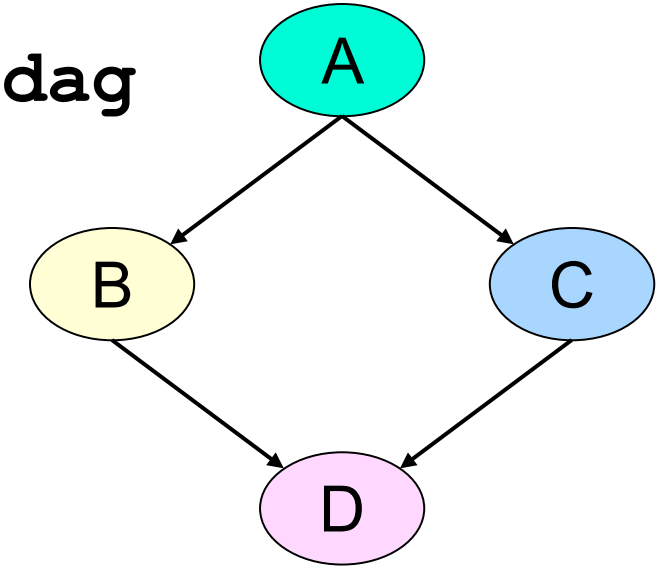
- Each node represents a Condor job (or cluster)
- Dependencies define the possible order of job execution



Defining a DAG to Condor

A DAG input file defines a DAG:

```
# file name: diamond.dag
Job A a.submit
Job B b.submit
Job C c.submit
Job D d.submit
Parent A Child B C
Parent B C Child D
```



Submit description files

For node B:

```
# file name:
#    b.submit
universe   = vanilla
executable = B
input      = B.in
output     = B.out
error      = B.err
log        = B.log
queue
```

For node C:

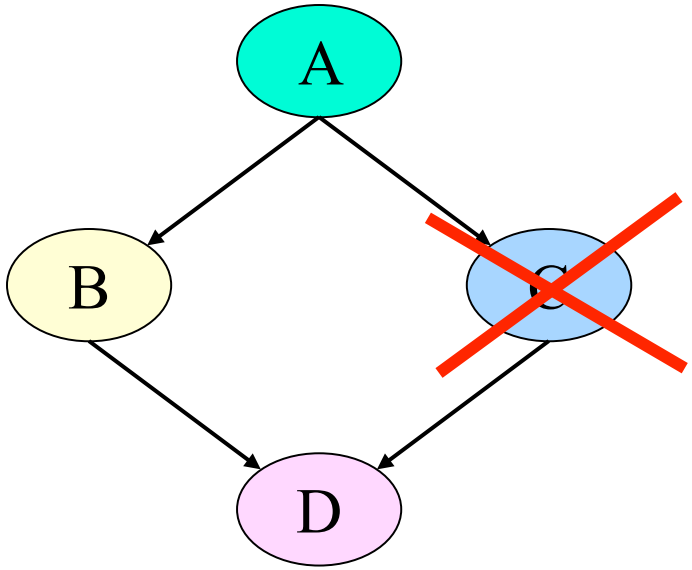
```
# file name:
#    c.submit
universe   = standard
executable = C
input      = C.in
output     = C.out
error      = C.err
log        = C.log
queue
```

Jobs/clusters

- Submit description files used in a DAG can create multiple jobs, but they must all be in a single cluster
- The failure of any job means the entire cluster fails. Other jobs are removed.
- No macros in "log" submit entries (for now)

Node success or failure

- A node either succeeds or fails
- Based on the return value of the job(s)
  - 0 ⇨ success
  - not 0 ⇨ failure
- This example: C fails
- Failed nodes block execution; DAG fails



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Submitting the DAG to Condor

- To submit the entire DAG, run

  `condor_submit_dag` *`DagFile`*

- condor_submit_dag creates a submit description file for DAGMan, and DAGMan itself is submitted as a Condor job (in the scheduler universe)
- **`-f(orce)`** option forces overwriting of existing files

Vocabulary

- Rescue DAGs save the state of a partially-completed DAG, and are created when a node fails or the **condor_dagman** job is removed with **condor_rm**
- PRE And POST scripts are code associated with a job that run on the submit host.
- Nested DAGs are jobs that are themselves DAGs.

Controlling running DAGs

- `condor_rm`
  - Removes all queued node jobs, kills PRE/POST scripts (removes *entire* workflow)
  - Kills PRE/POST scripts
  - Removes entire workflow
  - Creates rescue DAG

Controlling running DAGs (cont)

- `condor_hold` and `condor_release`
  - Node jobs continue when DAG is held
  - No new node jobs submitted
  - DAGMan "catches up" when released

Controlling running DAGS: the halt file

- New in Condor version 7.7.5.
- Create a file named DAGfile.halt in the same directory as your DAG file.
- Jobs that are running will continue to run.
- No new jobs will be submitted and no PRE scripts will be run.

The halt file (cont)

- When all submitted jobs complete, DAGman creates a rescue dag and
- When jobs finish, POST scripts will be run.
- When all submitted jobs complete, DAGman creates a rescue dag and exits.

The halt file (cont)

- If the halt file is removed, DAGman returns to normal operation.

condor_q -dag

- The **-dag** option associates DAG node jobs with the parent DAGMan job.
- New in 7.7.5: Shows nested DAGs properly.
- Shows current workflow state

condor_q -dag example

```
-- Submitter: nwp@llunet.cs.wisc.edu : <128.105.14.28:51264> : llunet.cs.wisc.edu ID
    OWNER/NODENAME   SUBMITTED     RUN_TIME ST PRI SIZE CMD
    392.0   nwp             4/25 13:27   0+00:00:50 R  0   1.7  condor_dagman -f -
    393.0    |-1            4/25 13:27   0+00:00:23 R  0   0.0  1281.sh 393
    395.0    |-0            4/25 13:27   0+00:00:30 R  0   1.7  condor_dagman -f -
    399.0     |-A           4/25 13:28   0+00:00:03 R  0   0.0  1281.sh 399
4 jobs; 0 completed, 0 removed, 0 idle, 4 running, 0 held, 0 suspended
```

dagman.out file

- *DagFile*.dagman.out
- Verbosity controlled by the **DAGMAN_VERBOSITY** configuration macro (new in 7.5.6) and **-debug** on the **condor_submit_dag** command line
- Directory specified by **-outfile_dir** *directory*
- Mostly for debugging
- Logs detailed workflow history

dagman.out contents

```
...
04/17/11 13:11:26 Submitting Condor Node A job(s)...
04/17/11 13:11:26 submitting: condor_submit -a dag_node_name' '=' 'A -a +DAGManJobId' '='
    '180223 -a DAGManJobId' '=' '180223 -a submit_event_notes' '=' 'DAG' 'Node:' 'A -a
    +DAGParentNodeNames' '=' '"" dag_files/A2.submit
04/17/11 13:11:27 From submit: Submitting job(s).
04/17/11 13:11:27 From submit: 1 job(s) submitted to cluster 180224.
04/17/11 13:11:27       assigned Condor ID (180224.0.0)
04/17/11 13:11:27 Just submitted 1 job this cycle...
04/17/11 13:11:27 Currently monitoring 1 Condor log file(s)
04/17/11 13:11:27 Event: ULOG_SUBMIT for Condor Node A (180224.0.0)
04/17/11 13:11:27 Number of idle job procs: 1
04/17/11 13:11:27 Of 4 nodes total:
04/17/11 13:11:27  Done     Pre   Queued    Post   Ready   Un-Ready   Failed
04/17/11 13:11:27   ===     ===      ===     ===     ===        ===      ===
04/17/11 13:11:27     0       0        1       0       0          3        0
04/17/11 13:11:27 0 job proc(s) currently held
...
```

This is a small excerpt of the dagman.out file.

Node status file

- In the DAG input file:
  NODE_STATUS_FILE ***statusFileName*** **[*minimumUpdateTime*]**
- Not enabled by default
- Shows a snapshot of workflow state
  - Overwritten as the workflow runs

Node status file contents

```
BEGIN 1302885255 (Fri Apr 15 11:34:15 2011)
Status of nodes of DAG(s): job_dagman_node_status.dag

JOB A STATUS_DONE       ()
JOB B1 STATUS_SUBMITTED (not_idle)
JOB B2 STATUS_SUBMITTED (idle)
...
DAG status: STATUS_SUBMITTED ()
Next scheduled update: 1302885258 (Fri Apr 15 11:34:18
   2011)
END 1302885255 (Fri Apr 15 11:34:15 2011)
```

jobstate.log file

- In the DAG input file:
  JOBSTATE_LOG ***JobstateLogFileName***
- Not enabled by default
- Meant to be machine-readable (for Pegasus)
- Shows workflow history
- Basically a subset of the **dagman.out** file

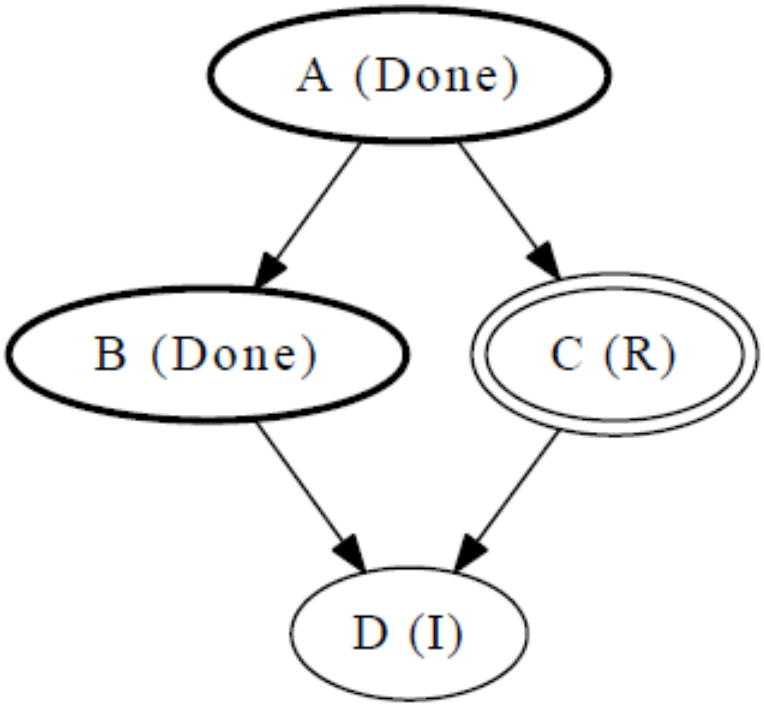
jobstate.log contents

```
1302884424 INTERNAL *** DAGMAN_STARTED 48.0 ***
1302884436 NodeA PRE_SCRIPT_STARTED - local - 1
1302884436 NodeA PRE_SCRIPT_SUCCESS - local - 1
1302884438 NodeA SUBMIT 49.0 local - 1
1302884438 NodeA SUBMIT 49.1 local - 1
1302884438 NodeA EXECUTE 49.0 local - 1
1302884438 NodeA EXECUTE 49.1 local - 1
...
```

Dot file

- In the DAG input file:
  `DOT DotFile [UPDATE] [DONT-OVERWRITE]`
- To create an image
  `dot -Tps DotFile -o PostScriptFile`
- Shows a snapshot of workflow state

Dot file example



DAGMan Job status at Mon Apr 18 16:57:33 2011

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DAGMan configuration

- A few dozen DAGMan-specific configuration macros (see the manual…)
- From lowest to highest precedence
  - Condor configuration files
  - User's environment variables:
    - `_CONDOR_`*`macroname`*
  - DAG-specific configuration file (preferable)
  - `condor_submit_dag` command line

Per-DAG configuration

- In DAG input file:
  CONFIG *ConfigFileName*
  or
  condor_submit_dag -config *ConfigFileName ...*
- Generally prefer **CONFIG** in DAG file over **condor_submit_dag -config** or individual arguments
- Specifying more than one configuration is an error.

Per-DAG configuration (cont)

- Configuration entries not related to DAGman are ignored by DAGman
- Syntax like any other Condor config file

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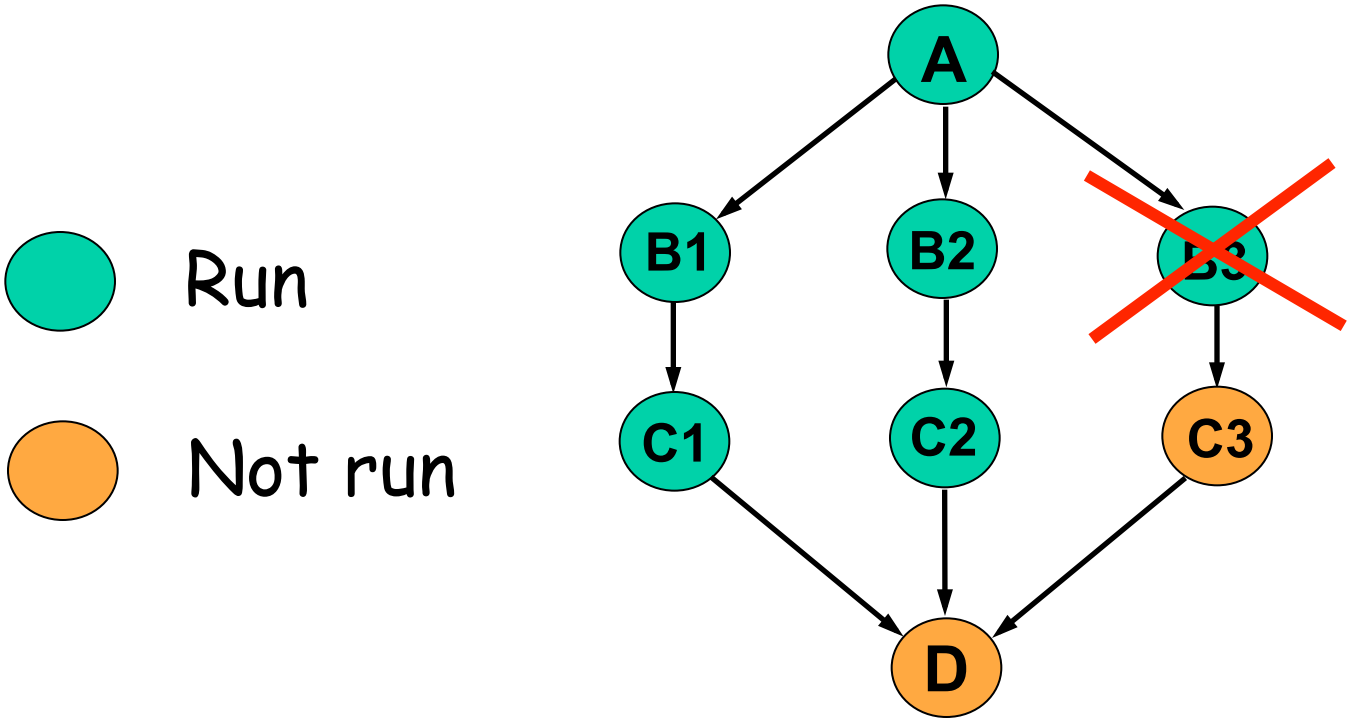
Rescue DAGs



Rescue DAGs (cont)

- Save the state of a partially-completed DAG
- Created when a node fails or the **`condor_dagman`** job is removed with **`condor_rm`**
  - DAGMan makes as much progress as possible in the face of failed nodes

Rescue DAGs (cont)

- Automatically run when you re-run the original DAG (unless -f) (since 7.1.0)
- DAGman immediately exits after writing a rescue DAG file

Rescue DAGs (cont)

- New in condor version 7.7.2, the Rescue DAG file, by default, is only a partial DAG file
- **`DAGMAN_WRITE_PARTIAL_RESCUE = False`** turns this off.

Rescue DAGs (cont)

- A partial Rescue DAG file contains only information about which nodes are done, and the number of retries remaining for nodes with retries.
- Does not contain information such as the actual DAG structure and the specification of the submit file for each node job.

Rescue DAGs (cont)

- Partial Rescue DAGs are automatically parsed in combination with the original DAG file, which contains information such as the DAG structure.

Rescue DAGs (cont)

- If you change something in the original DAG file, such as changing the submit file for a node job, that change will take effect when running a partial Rescue DAG.

Rescue DAG naming

- ***DagFile.rescue001***, ***DagFile.rescue002***, etc.
- Up to 100 by default (last is overwritten once you hit the limit)
- Newest is run automatically when you re-submit the original ***DagFile***
- **condor_submit_dag -dorescuefrom *number*** to run specific rescue DAG

Recovery mode

- Happens automatically when DAGMan is held/released, or if DAGMan crashes and restarts
- Node jobs continue
- DAGMan recovers node job state
- DAGMan is robust in the face of failures

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PRE and POST scripts

- DAGMan allows PRE and/or POST scripts
  - Not necessarily a script: any executable
  - Run before (PRE) or after (POST) job
- In the DAG input file:

```
Job A a.submit
Script PRE A before-script arguments
Script POST A after-script arguments
```

- No spaces in script name or arguments

Why PRE/POST scripts?

- Set up input
- Check output
- Create submit file (dynamically)
- Force jobs to run on same machine

Script argument variables

- **$JOB**: node name
- **$JOBID**: Condor ID (cluster.proc)
- **$RETRY**: current retry
- **$MAX_RETRIES**: max # of retries
- **$RETURN**: exit code of Condor/Stork job (POST only)

Script argument variables (cont)

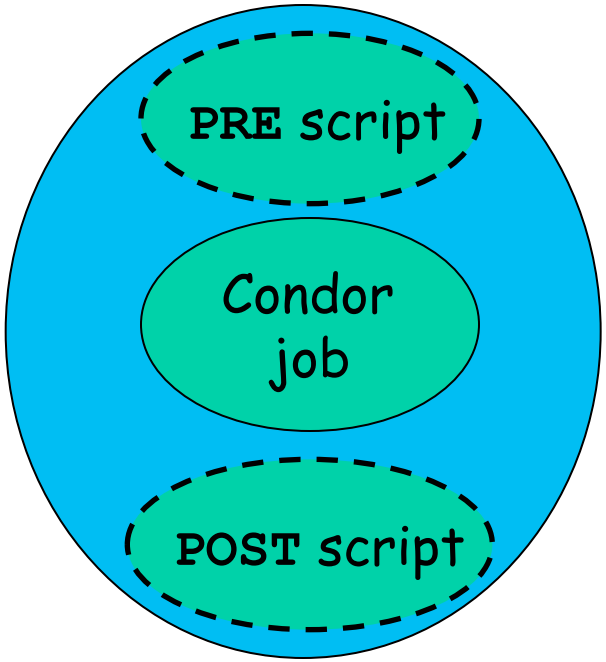
- **$PRE_SCRIPT_RETURN**: More on this below (POST only)
- **$DAG_STATUS**: A number indicating the state of DAGman. See the manual for details.
- **$FAILED_COUNT**: is simply the number of nodes that have failed in the DAG

NOOP nodes

- It is useful to have the ability to check your work.
- Appending the keyword **NOOP** causes a job to not be run, without affecting the DAG structure.
- The pre- and post- scripts of NOOP nodes will be run. If this is not desired, comment them out.

DAG node with scripts

- PRE script, Job, or POST script determines node success or failure (table in manual gives details)



DAG node with scripts (cont)

- If PRE script fails, job is not run. The POST script is run (new in 7.7.2). Set `DAGMAN_ALWAYS_RUN_POST = False` to get old behavior

DAG node with scripts: PRE_SKIP

- New feature in Condor version 7.7.2.
- Here is the syntax:

```
JOB A A.cmd
SCRIPT PRE A A.pre
PRE SKIP A non-zero integer
```

- Here, the PRE script of *A* will run. If the script exits with the indicated value, this is normally a failure.

DAG node with scripts: PRE_SKIP (cont)

- DAGman instead recognizes this as an indication to succeed this node immediately, and skip the node job and POST script.
- If the PRE script fails with a different value, the node job is skipped, and the postscript runs.

DAG node with scripts: PRE_SKIP (cont)

- When the postscript runs, the **$PRE_SCRIPT_RETURN** variable contains the return value from the prescript. (See manual for specific cases)

NOOP nodes

- It is useful to have the ability to check your work.
- Appending the keyword **NOOP** causes a job to not be run, without affecting the DAG structure.
- The pre- and post- scripts of NOOP nodes will be run. If this is not desired, comment them out.

NOOP nodes (ex)

- Here is an example:

```
# file name: diamond.dag
Job A a.submit NOOP
Job B b.submit NOOP
Job C c.submit NOOP
Job D d.submit NOOP
Parent A Child B C
Parent B C Child D
```

- Submitting this to DAGman will cause DAGman to exercise the DAG, without actually running anything.

Node retries

- In case of transient errors
- Before a node is marked as failed. . .
  - Retry N times. In the DAG file:

```
Retry C 4
```

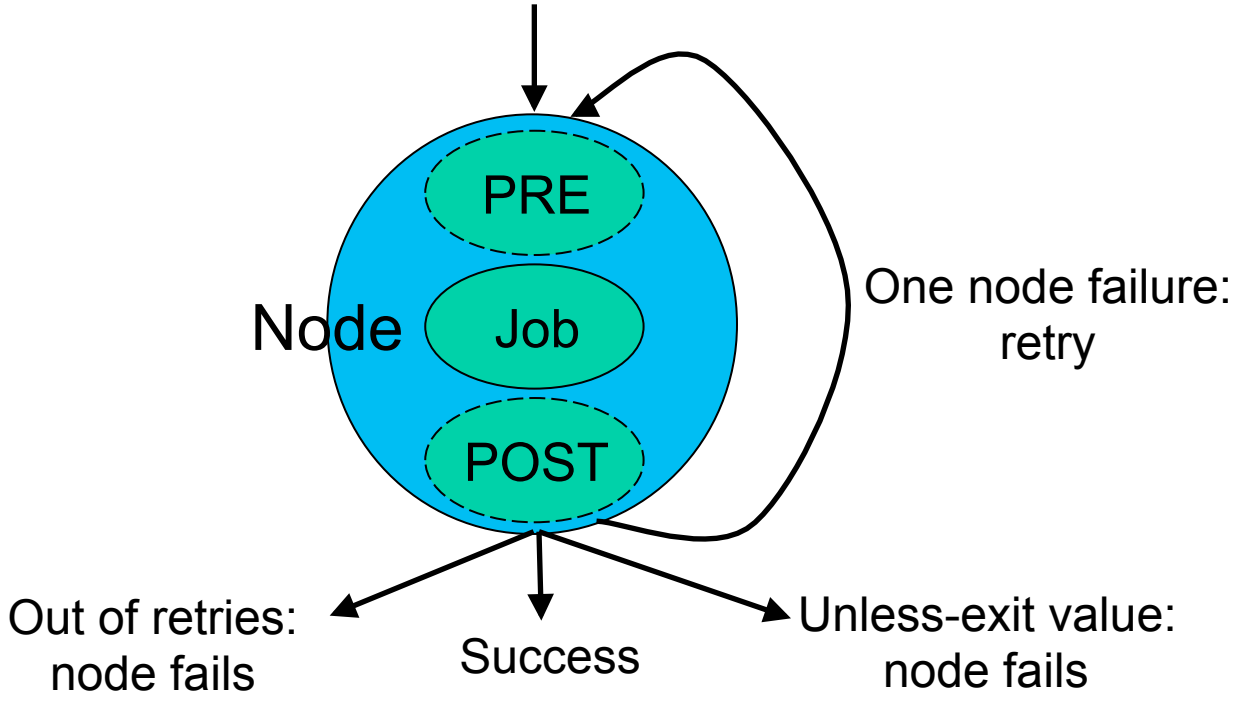
(to retry node C four times before calling the node failed)

  - Retry N times, unless a node returns specific exit code. In the DAG file:

```
Retry C 4 UNLESS-EXIT 2
```

Node retries, continued

- Node is retried as a whole



Node variables

- To re-use submit files
- In DAG input file

```
VARS JobName
varname="string" [varname="string"... ]
```

- In submit description file

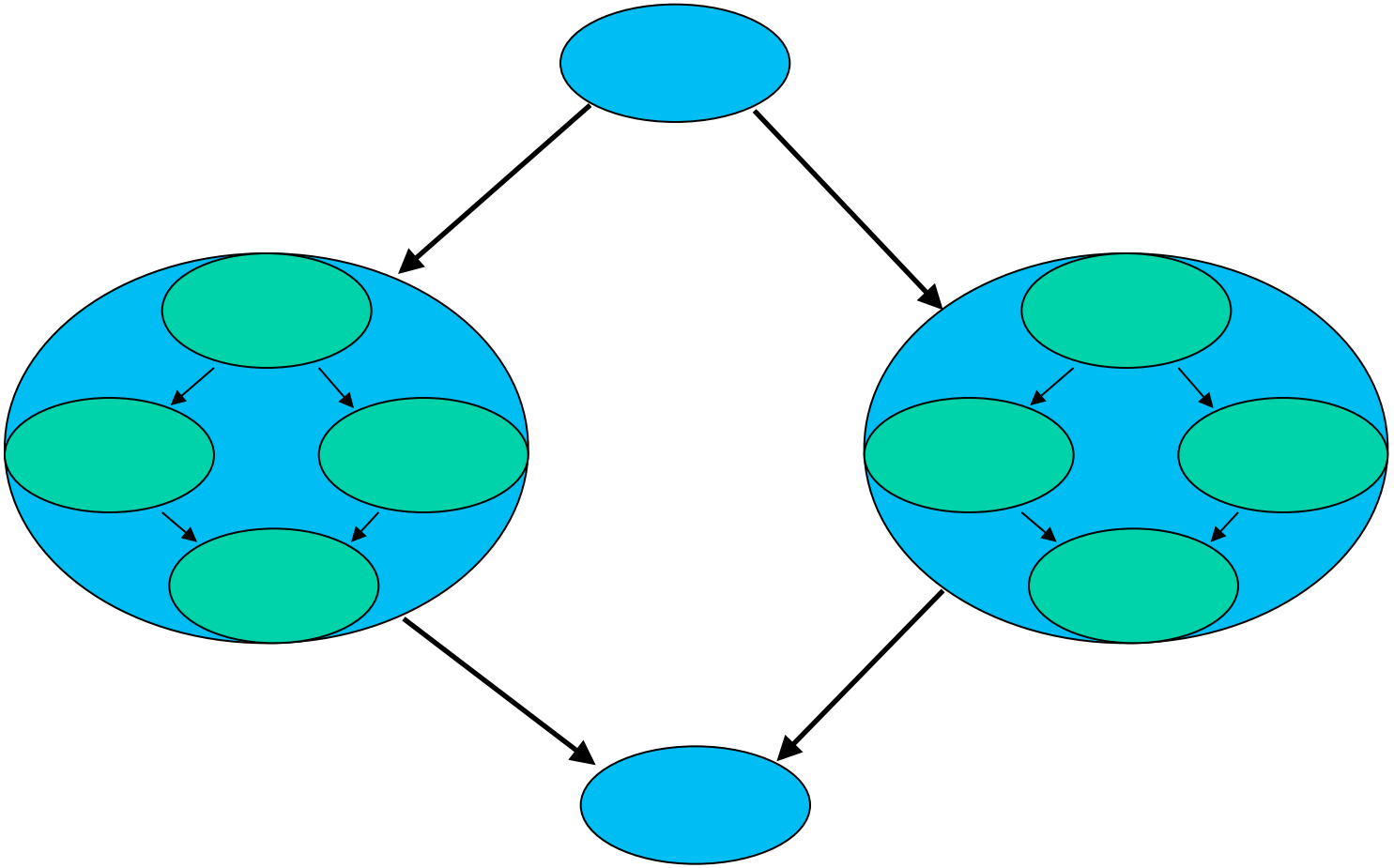
```
$(varname)
```

- **varname** can only contain alphanumeric characters and underscore
- **varname** cannot begin with "**queue**"
- **varname** is not case-sensitive
- Cannot use variables in a log file name (for now)

Node variables (cont)

- Value cannot contain single quotes; double quotes must be escaped
- The variable `$(JOB)` contains the DAG node name of the job.
- More than one VARS line per job.
- DAGman warns if a VAR is defined more than once for a job.

Nested DAGs



Nested DAGs (cont)

- Runs the sub-DAG as a job within the top-level DAG
- In the DAG input file:

  SUBDAG EXTERNAL *JobName DagFileName*
- Any number of levels
- Sub-DAG nodes are like any other
- Each sub-DAG has its own DAGMan
  - Separate throttles for each sub-DAG

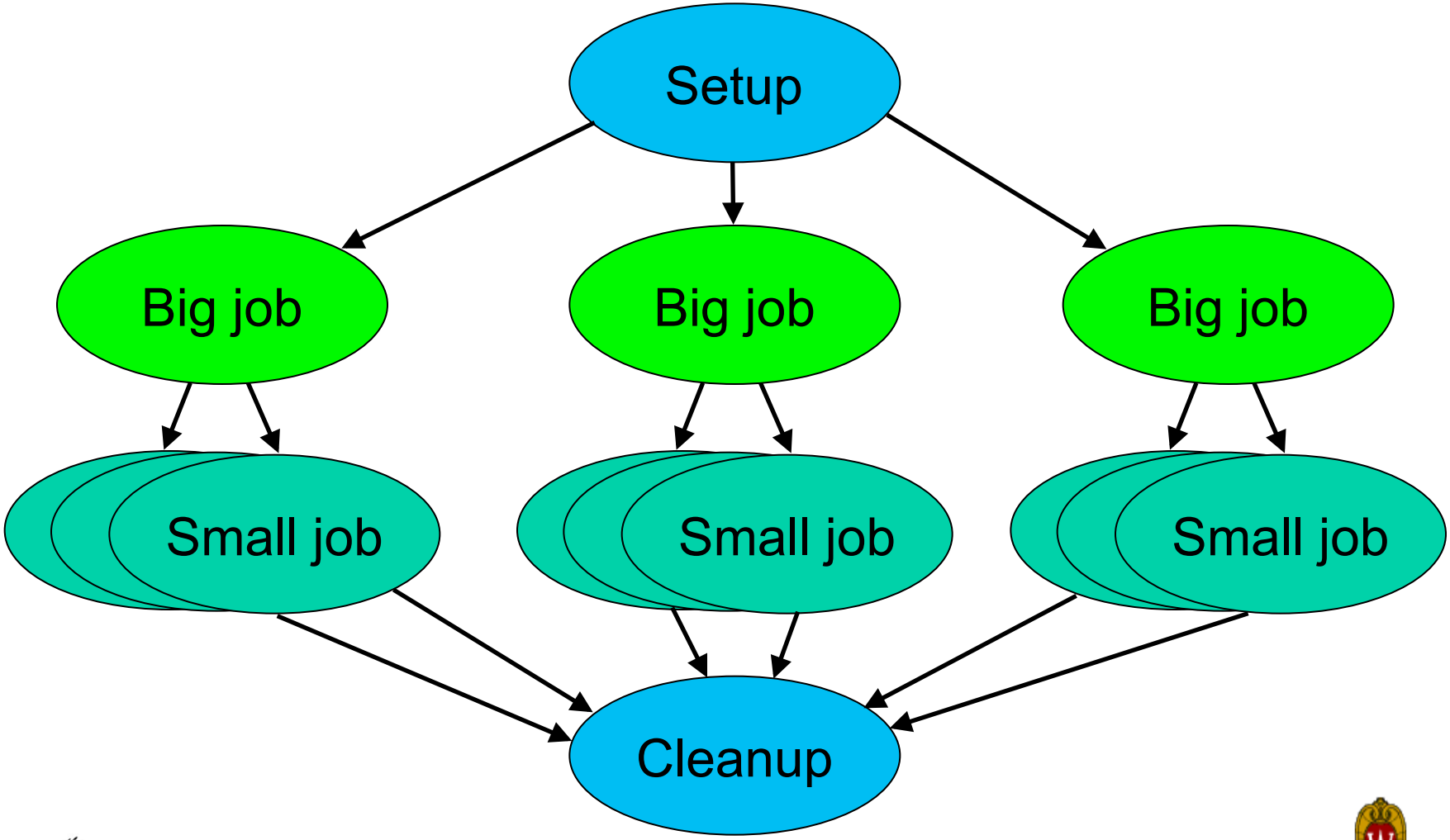
Why nested DAGs?

- Scalability
- Re-try more than one node
- Dynamic workflow modification
- DAG re-use

Throttling

- Limit load on submit machine and pool
  - **Maxjobs** limits jobs in queue/running
  - **Maxidle** submit jobs until idle limit is hit
  - **Maxpre** limits PRE scripts
  - **Maxpost** limits POST scripts
- All limits are *per* ***DAGMan***, not global for the pool or submit machine
- Limits can be specified as arguments to **condor_submit_dag** or in configuration

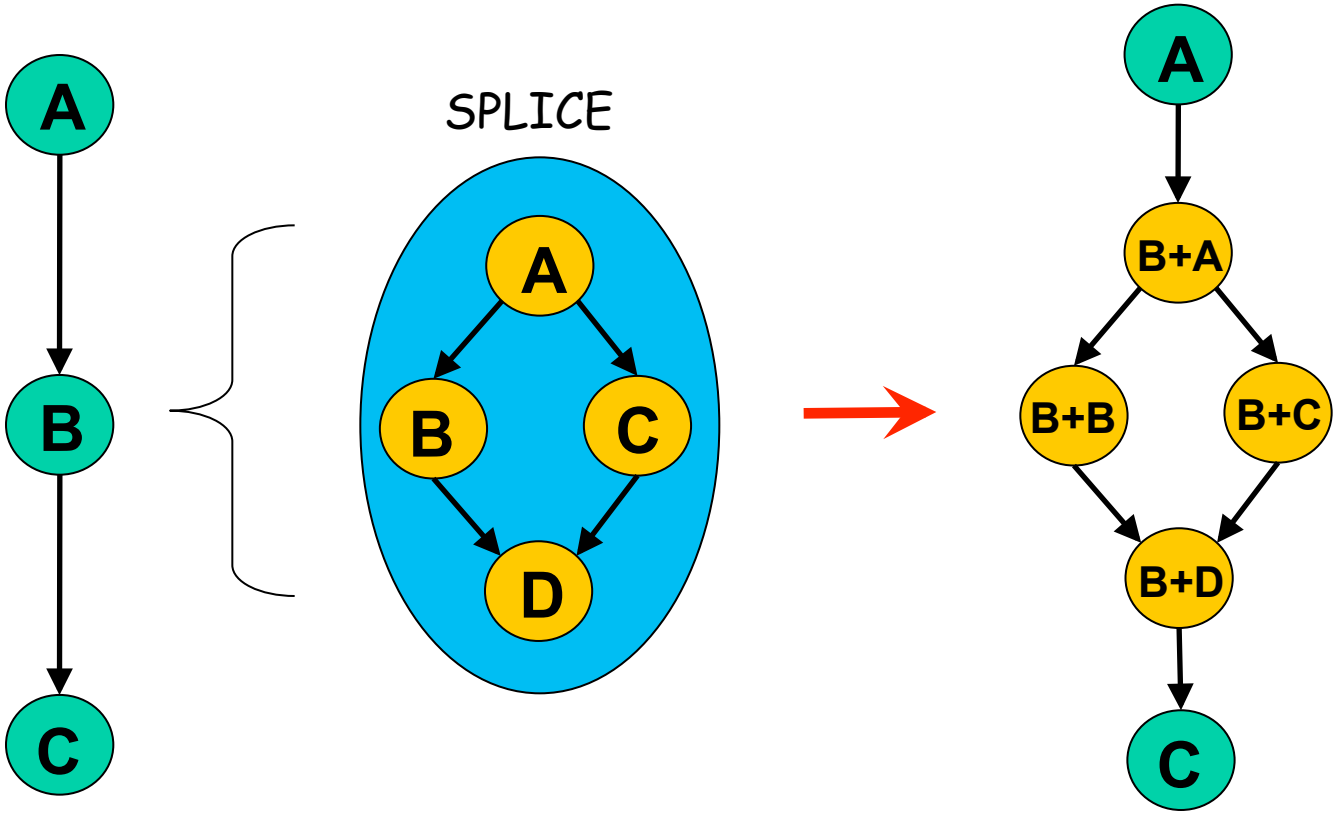
Node categories



Node category throttles

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

Splices



Splices (cont)

- Directly includes splice's nodes within the top-level DAG
- In the DAG input file:
  SPLICE *JobName DagFileName*
- Splices cannot have PRE and POST scripts (for now)
- No retries
- Splice DAGs must exist at submit time

Why splices?

- Advantages of splices over sub-DAGs
  - Reduced overhead (single DAGMan instance)
  - Simplicity (e.g., single rescue DAG)
  - Throttles apply across entire workflow
  - DAG re-use

DAG input files for splice diagram

Top level

```
# splice1.dag
Job A A.submit
Splice B splice2.dag
Job C C.submit
Parent A Child B
Parent B Child C
```

Splice

```
# splice2.dag
Job A A.submit
Job B B.submit
Job C C.submit
Job D D.submit
Parent A Child B C
Parent B C Child D
```

DAG abort

- In DAG input file:
  ABORT-DAG-ON ***JobName AbortExitValue***
  [RETURN ***DagReturnValue*****]**
- If node value is ***AbortExitValue***, the entire DAG is aborted, implying that jobs are removed, and a rescue DAG is created.
- Can be used for conditionally skipping nodes (especially with sub-DAGs)

FINAL Nodes

- Introduced in Condor version 7.7.5
- Use **FINAL** in place of **JOB** in DAG file.
- At most one FINAL node per DAGman.
- FINAL nodes cannot have parents or children.

FINAL Nodes (cont)

- The FINAL node is submitted after DAGman has made as much progress as possible.
- In case of a DAG failure, the FINAL node is run; some nodes may not be run, but the FINAL node will be run.

FINAL Nodes (cont)

- Success or failure of the FINAL node determines the success of the DAG run.
- It is envisioned that PRE and POST scripts of FINAL nodes will use **$DAG_STATUS** and **$FAILED_COUNT**

Node priorities

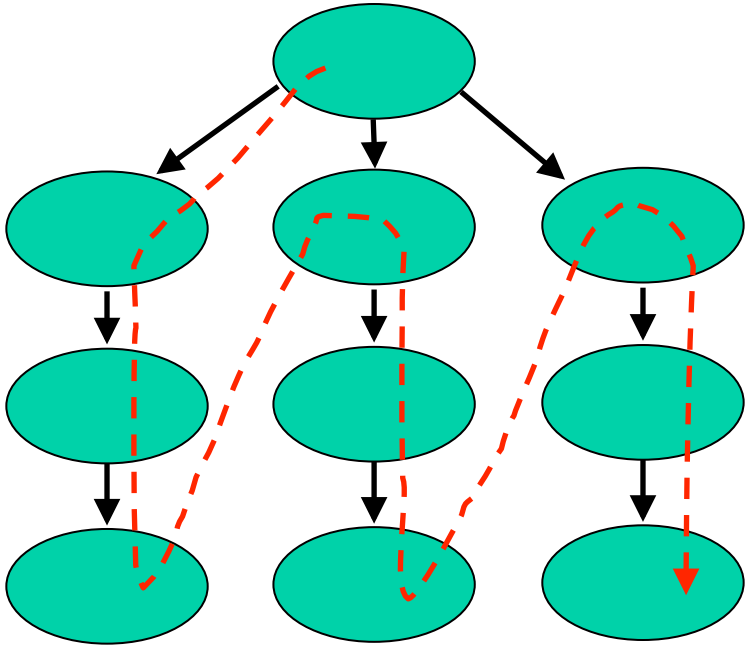
- In the DAG input file:
  PRIORITY *JobName PriorityValue*
- Determines order of submission of ready nodes
- Does *not* violate or change DAG semantics
- Higher numerical value equals "better" priority

Node priorities (cont)

- Child nodes get the largest priority of parents. This may or may not be useful. Let us know if you want a different policy
- For subdags, pretend that the subdag is spliced in.
- DAGman priorities are copied to job priorities

Depth-first DAG traversal

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



Multiple DAGs

- On the command line:
  `condor_submit_dag dag1 dag2 ...`
- Runs multiple, independent DAGs
- Node names modified (by DAGMan) to avoid collisions
- Useful: throttles apply across DAGs
- Failure produces a single rescue DAG

Cross-splice node categories

- Prefix category name with "+"

```
MaxJobs +init 2

Category A +init
```

- See the Splice section in the manual for details

DAGMAN_HOLD_CLAIM_TIME

- An optimization introduced in Condor version 7.7.5 as a configuration option
- If a DAGman job has child nodes, it will instruct the condor schedd to hold the machine claim for the integer number of seconds that is the value of this option, which defaults to 20.

DAGMAN_HOLD_CLAIM_TIME

- Thus, upon completion, the schedd will not go through a negotiation cycle
- before starting the job; it will simply start a new job with the old claim on the startd we have just finished using.

DAGMAN_USE_STRICT

- New configuration option introduced in Condor version 7.7.0
- Think of it as `-Werror` for DAGman.
- If set to 0, no warnings become errors.
- If set to 3, all warnings become errors.

DAGMAN_USE_STRICT (ex)

- One place where we check for warnings is the log file code: if we see strangeness, we print out a warning. If you are paranoid, you might want DAGman to write a rescue DAG and exit immediately, and set option = 3.

More information

- There's much more detail, as well as examples, in the DAGMan section of the online Condor manual.

Outline

- Introduction/motivation
- Basic DAG concepts
- Running and monitoring a DAG
- Configuration
- Rescue DAGs and recovery
- Advanced DAGMan features

Relevant Links

- DAGMan: www.cs.wisc.edu/condor/dagman
- Pegasus: http://pegasus.isi.edu/
- Makeflow: http://nd.edu/~ccl/software/makeflow/
- For more questions: condor-admin@cs.wisc.edu