Open Science Grid

Workflows with HTCondor's DAGMan

Tuesday, Aug 10

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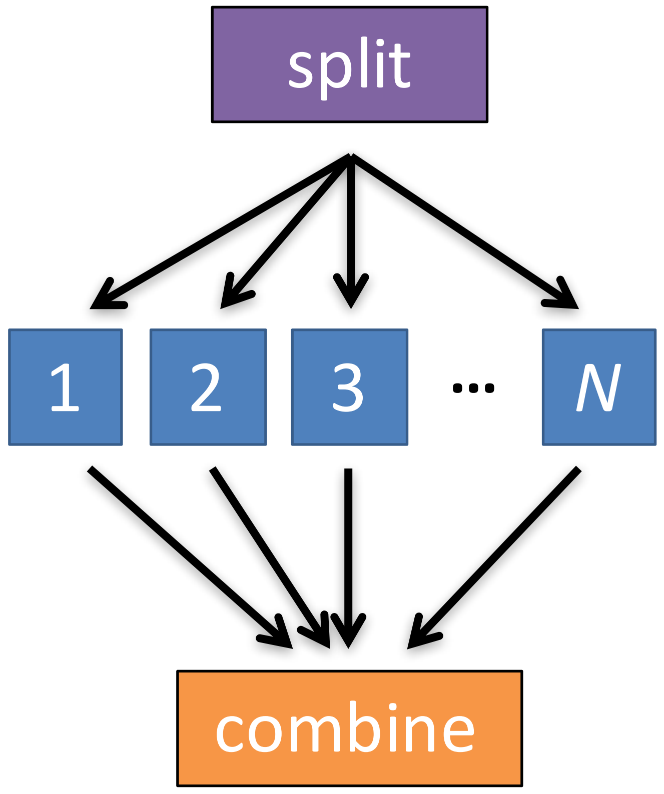
Goals for this Session

- Why create a workflow?
- Describe workflows as *directed acyclic graphs* (DAGs)
- Workflow execution via DAGMan (DAG Manager)
- Node-level options in a DAG
- Modular organization of DAG components
- Additional DAGMan Features

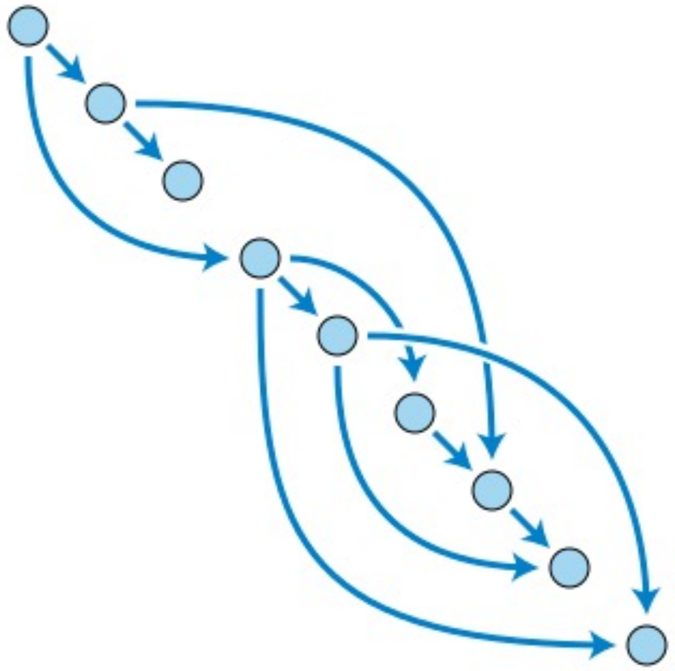
Automation!

- Objective: Submit jobs **in a particular order**, *automatically*.
- Especially if: Need to replicate the same workflow multiple times in the future.



DAG = ”directed acyclic graph”

- topological ordering of vertices (“**nodes**”) is established by directional connections (“**edges**”)
- “acyclic” aspect requires a start and end, with no looped repetition
  - can contain cyclic subcomponents, covered in later slides for DAG workflows



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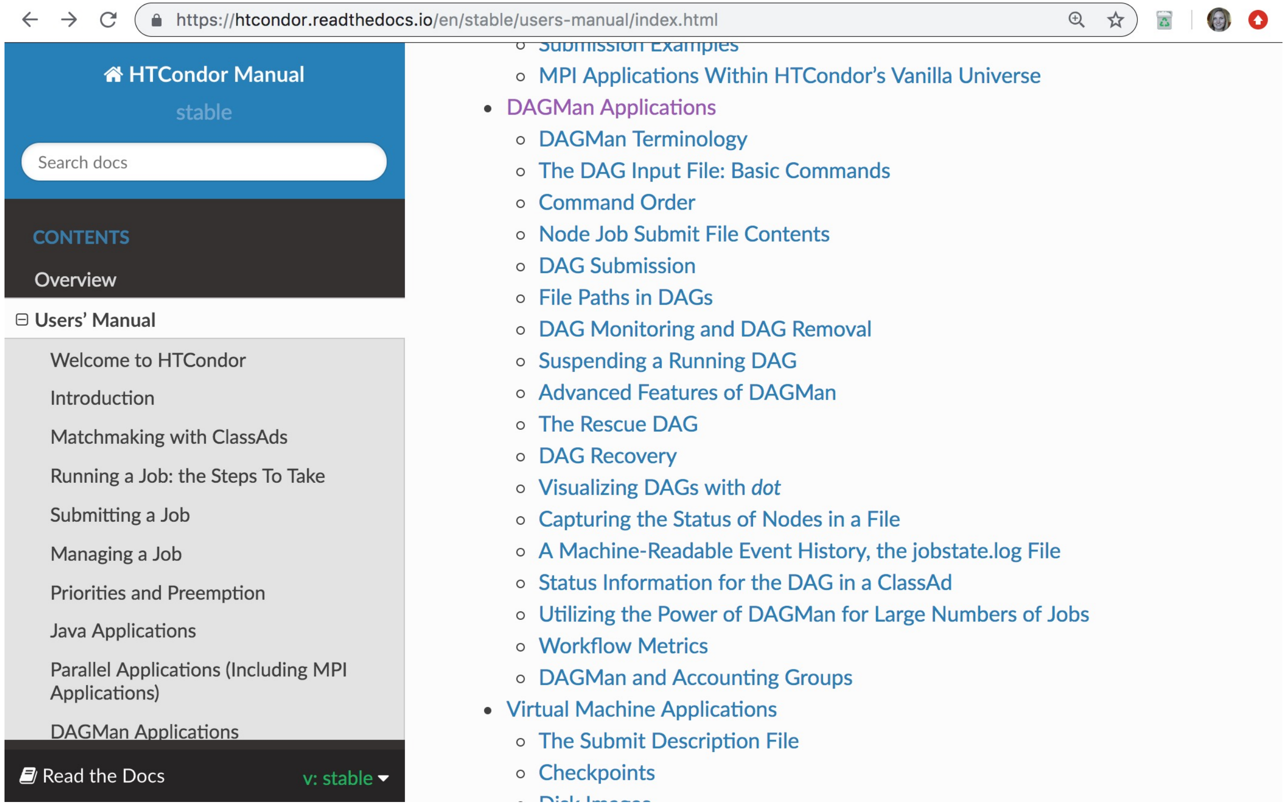
wikipedia.org/wiki/Directed_acyclic_graph

DESCRIBING WORKFLOWS WITH DAGMAN

DAGMan in the HTCondor Manual

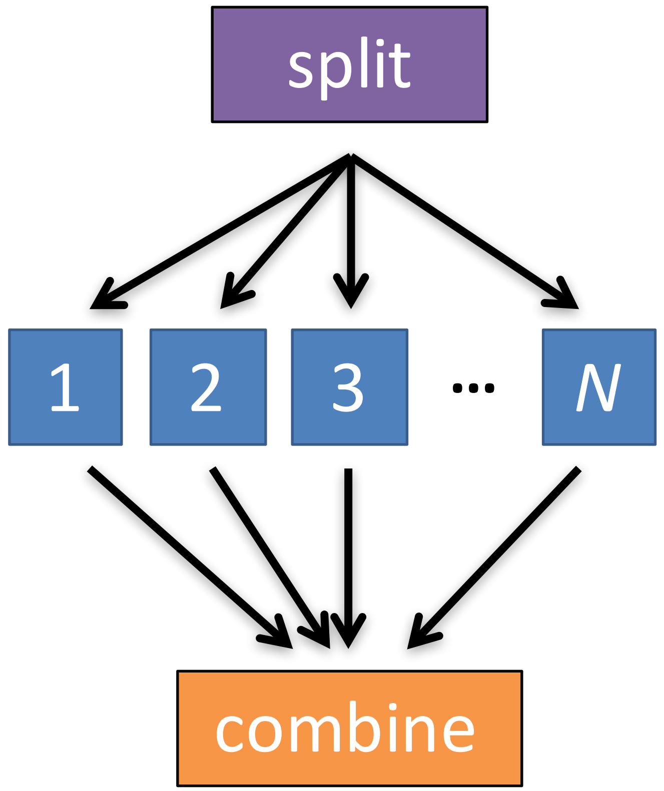


https://htcondor.readthedocs.io/en/stable/users-manual/index.html

https://htcondor.readthedocs.io/en/latest/users-manual/dagman-workflows.html

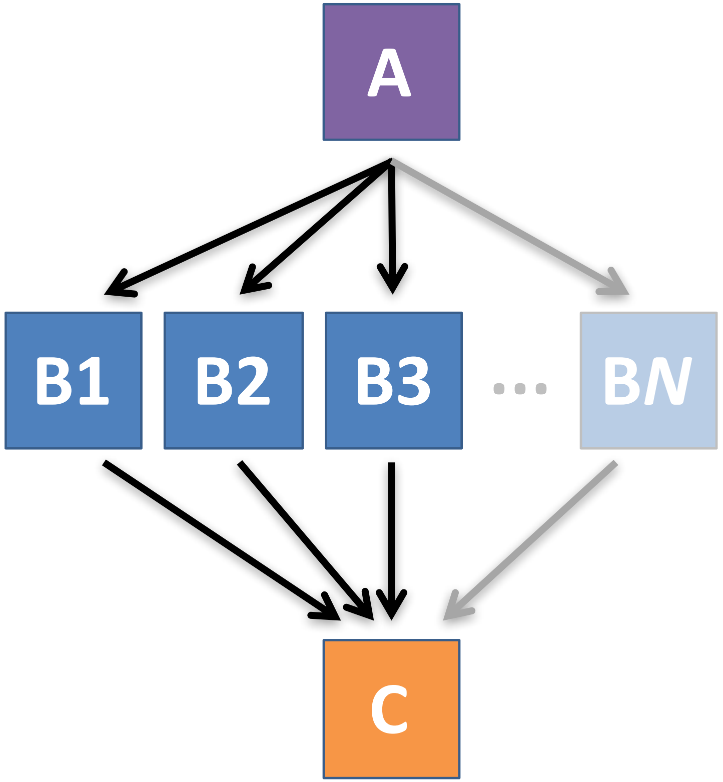
An Example HTC Workflow

- User must communicate the "nodes" and directional "edges" of the DAG



Simple Example for this Tutorial

- **The DAG input file will** communicate the "nodes" and directional "edges" of the DAG



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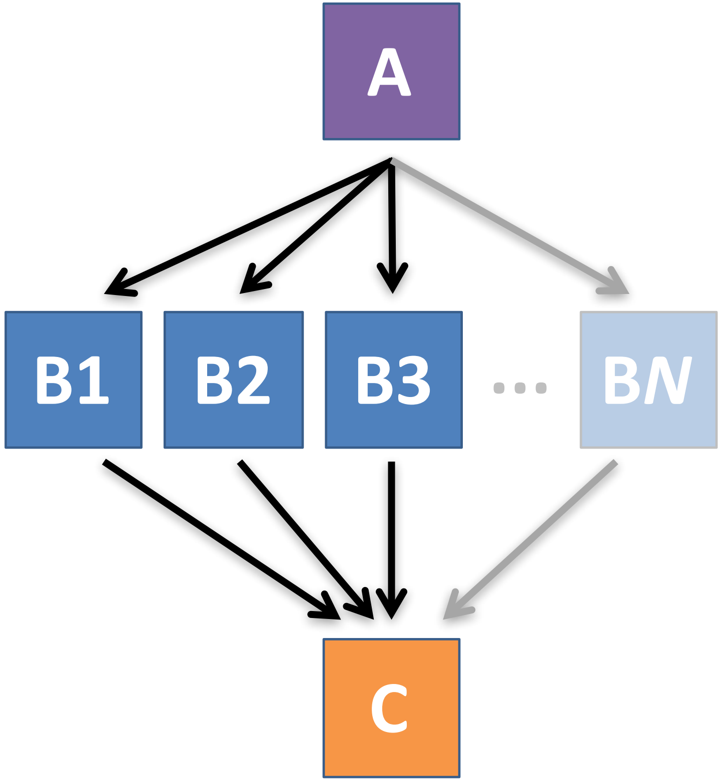
Basic DAG input file: *JOB* nodes, *PARENT-CHILD* edges

my.dag

```
JOB A A.sub
JOB B1 B1.sub
JOB B2 B2.sub
JOB B3 B3.sub
JOB C C.sub
PARENT A CHILD B1 B2 B3
PARENT B1 B2 B3 CHILD C
```

- Node names will be used by various DAG features to modify their execution by DAGMan.



Basic DAG input file: *JOB* nodes, *PARENT-CHILD* edges

my.dag

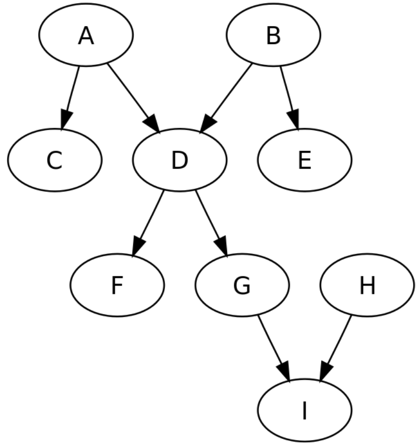
```
JOB A A.sub
JOB B1 B1.sub
JOB B2 B2.sub
JOB B3 B3.sub
JOB C C.sub
PARENT A CHILD B1 B2 B3
PARENT B1 B2 B3 CHILD C
```

(dag_dir)/

```
A.sub        B1.sub
B2.sub       B3.sub
C.sub        my.dag
(other job files)
```

- Node names and filenames are your choice.
- Node name and submit filename do not have to match.

Endless Workflow Possibilities



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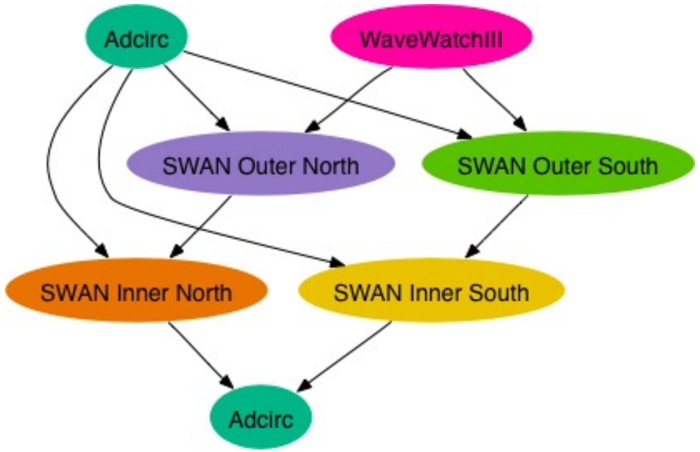
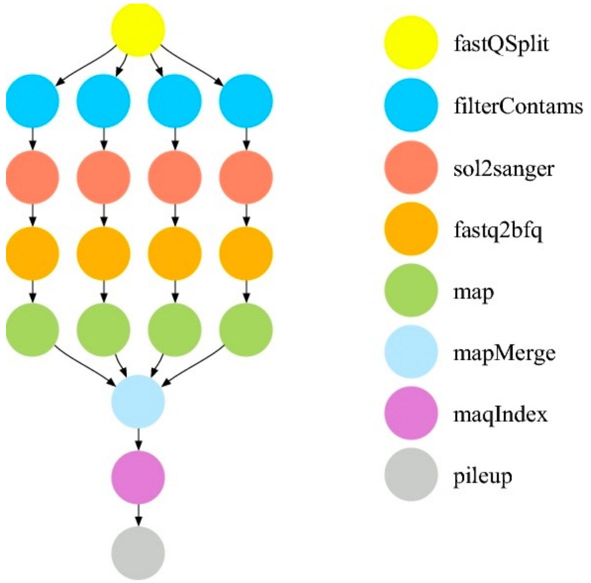
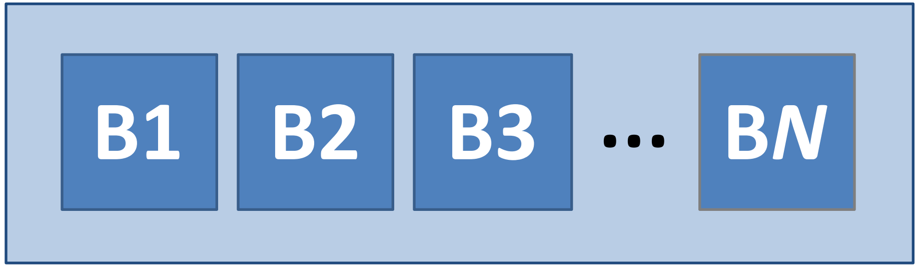




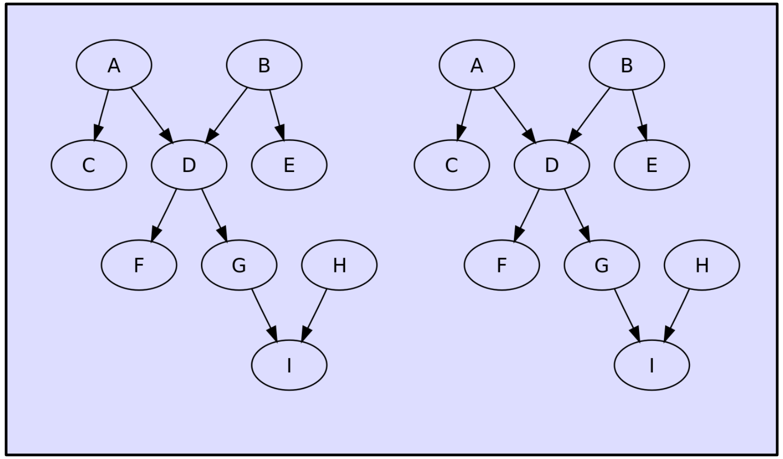
https://confluence.pegasus.isi.edu/display/pegasus/WorkflowGenerator

DAGs are also useful for non-sequential work

'bag' of HTC jobs



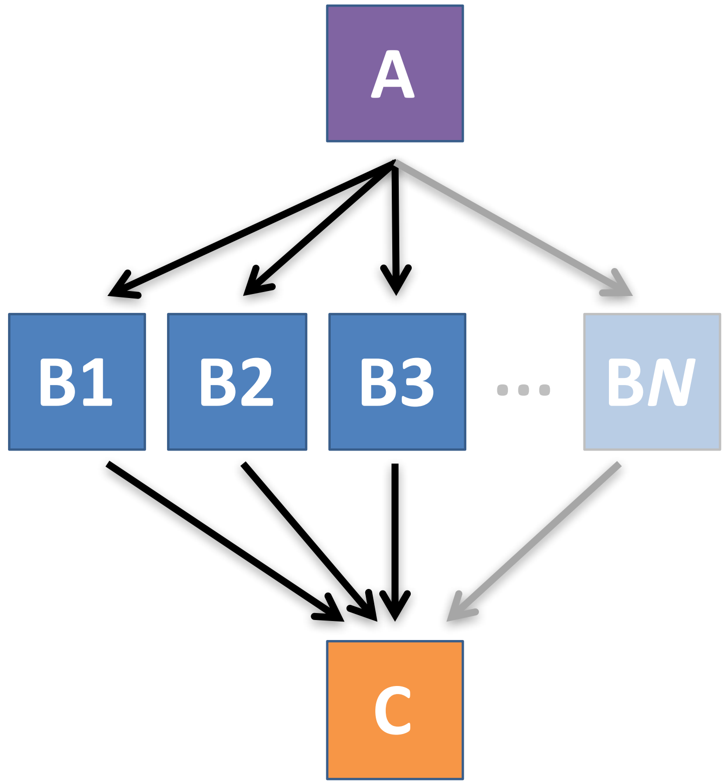
disjointed workflows



Basic DAG input file: *JOB* nodes, *PARENT-CHILD* edges

my.dag

```
JOB A A.sub
JOB B1 B1.sub
JOB B2 B2.sub
JOB B3 B3.sub
JOB C C.sub
PARENT A CHILD B1 B2 B3
PARENT B1 B2 B3 CHILD C
```



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SUBMITTING AND MONITORING A DAGMAN WORKFLOW

Submitting a DAG to the queue

- Submission command:

condor_submit_dag *dag_file*

```
$ condor_submit_dag my.dag

-----------------------------------------------------------------------
File for submitting this DAG to HTCondor     : mydag.dag.condor.sub
Log of DAGMan debugging messages             : mydag.dag.dagman.out
Log of HTCondor library output               : mydag.dag.lib.out
Log of HTCondor library error messages       : mydag.dag.lib.err
Log of the life of condor_dagman itself      : mydag.dag.dagman.log

Submitting job(s).
1 job(s) submitted to cluster 128.
-----------------------------------------------------------------------
```

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A submitted DAG creates a *DAGMan job* in the queue

- DAGMan runs on the access point, as a job in the queue
- At first:

```
$ condor_q
-- Schedd: submit-3.chtc.wisc.edu : <128.104.100.44:9618?...
OWNER    BATCH_NAME     SUBMITTED    DONE    RUN    IDLE   TOTAL  JOB_IDS
alice    my.dag+128    4/30 18:08      _       _       _       _  0.0
1 jobs; 0 completed, 0 removed, 0 idle, 1 running, 0 held, 0 suspended

$ condor_q -nobatch
-- Schedd: submit-3.chtc.wisc.edu : <128.104.100.44:9618?...
 ID      OWNER     SUBMITTED     RUN_TIME ST PRI SIZE CMD
128.0    alice    4/30 18:08   0+00:00:06 R  0    0.3 condor_dagman
1 jobs; 0 completed, 0 removed, 0 idle, 1 running, 0 held, 0 suspended
```

Jobs are automatically submitted by the DAGMan job

- Seconds later, node **A** is submitted:

```
$ condor_q
-- Schedd: submit-3.chtc.wisc.edu : <128.104.100.44:9618?...
OWNER    BATCH_NAME    SUBMITTED   DONE   RUN   IDLE  TOTAL  JOB_IDS
alice    my.dag+128   4/30 18:08     _     _      1      5  129.0
2 jobs; 0 completed, 0 removed, 1 idle, 1 running, 0 held, 0 suspended

$ condor_q -nobatch
-- Schedd: submit-3.chtc.wisc.edu : <128.104.100.44:9618?...
 ID      OWNER     SUBMITTED     RUN_TIME ST PRI SIZE CMD
128.0    alice    4/30 18:08   0+00:00:36 R  0    0.3 condor_dagman
129.0    alice    4/30 18:08   0+00:00:00 I  0    0.3 A_split.sh
2 jobs; 0 completed, 0 removed, 1 idle, 1 running, 0 held, 0 suspended
```

Jobs are automatically submitted by the DAGMan job

- After **A** completes, **B1-3** are submitted

```
$ condor_q
-- Schedd: submit-3.chtc.wisc.edu : <128.104.100.44:9618?...
OWNER    BATCH_NAME    SUBMITTED   DONE   RUN   IDLE   TOTAL  JOB_IDS
alice    my.dag+128   4/30 18:08      1     _      3       5  130.0...132.0
4 jobs; 0 completed, 0 removed, 3 idle, 1 running, 0 held, 0 suspended

$ condor_q -nobatch
-- Schedd: submit-3.chtc.wisc.edu : <128.104.100.44:9618?...
 ID      OWNER     SUBMITTED     RUN_TIME ST PRI SIZE CMD
128.0    alice    4/30 18:08   0+00:20:36 R  0    0.3 condor_dagman
130.0    alice    4/30 18:18   0+00:00:00 I  0    0.3 B_run.sh
131.0    alice    4/30 18:18   0+00:00:00 I  0    0.3 B_run.sh
132.0    alice    4/30 18:18   0+00:00:00 I  0    0.3 B_run.sh
4 jobs; 0 completed, 0 removed, 3 idle, 1 running, 0 held, 0 suspended
```

Jobs are automatically submitted by the DAGMan job

- After **B1-3** complete, node **C** is submitted

```
$ condor_q
-- Schedd: submit-3.chtc.wisc.edu : <128.104.100.44:9618?...
OWNER   BATCH_NAME   SUBMITTED  DONE  RUN  IDLE   TOTAL  JOB_IDS
alice   my.dag+128  4/30 18:08     4    _     1      5  133.0
2 jobs; 0 completed, 0 removed, 1 idle, 1 running, 0 held, 0 suspended

$ condor_q -nobatch
-- Schedd: submit-3.chtc.wisc.edu : <128.104.100.44:9618?...
 ID     OWNER    SUBMITTED     RUN_TIME ST PRI SIZE CMD
128.0   alice   4/30 18:08   0+00:46:36 R  0    0.3 condor_dagman
133.0   alice   4/30 18:54   0+00:00:00 I  0    0.3 C_combine.sh
2 jobs; 0 completed, 0 removed, 1 idle, 1 running, 0 held, 0 suspended
```

Status files are created at the time of DAG submission

```
(dag_dir)/
```

```
A.sub                B1.sub               B2.sub
B3.sub               C.sub                (other job files)
my.dag               my.dag.condor.sub    my.dag.dagman.log
my.dag.dagman.out    my.dag.lib.err       my.dag.lib.out
my.dag.nodes.log
```

- **`*.condor.sub`** and **`*.dagman.log`** describe the queued DAGMan job process, as for any other jobs
- **`*.dagman.out`** has DAGMan-specific logging (look to first for errors)
- **`*.lib.err/out`** contain std err/out for the DAGMan job process
- **`*.nodes.log`** is a combined log of all jobs within the DAG

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DAG Completion

(dag_dir)/

```
A.sub                B1.sub               B2.sub
B3.sub               C.sub                (other job files)
my.dag               my.dag.condor.sub    my.dag.dagman.log
my.dag.dagman.out    my.dag.lib.err       my.dag.lib.out
my.dag.nodes.log     my.dag.dagman.metrics
```

`*.dagman.metrics` is a summary of events and outcomes

`*.dagman.log` will note the completion of the DAGMan job

`*.dagman.out` has detailed logging (look to first for errors)

STOPPING, RESTARTING, AND TROUBLESHOOTING

Removing a DAG from the queue

- Remove the DAGMan job in order to stop and remove the entire DAG:

  `condor_rm` ***`dagman_jobID`***

- Creates a **rescue file** so that only incomplete or unsuccessful NODES are repeated upon resubmission

```
$ condor_q
-- Schedd: submit-3.chtc.wisc.edu : <128.104.100.44:9618?...
OWNER   BATCH_NAME   SUBMITTED  DONE  RUN  IDLE  TOTAL  JOB_IDS
alice   my.dag+128  4/30 8:08      4    _     1      6  129.0...133.0
2 jobs; 0 completed, 0 removed, 1 idle, 1 running, 0 held, 0 suspended
$ condor_rm 128
All jobs in cluster 128 have been marked for removal
```

Removal of a DAG creates a *rescue file*

```
(dag_dir)/
A.sub   B1.sub   B2.sub   B3.sub   C.sub  (other job files)
my.dag              my.dag.condor.sub   my.dag.dagman.log
my.dag.dagman.out   my.dag.lib.err      my.dag.lib.out
my.dag.metrics      my.dag.nodes.log    my.dag.rescue001
```

- Named ***dag_file*.rescue001**
  - increments if more rescue DAG files are created
- Records which NODES have completed successfully
  - does not contain the actual DAG structure

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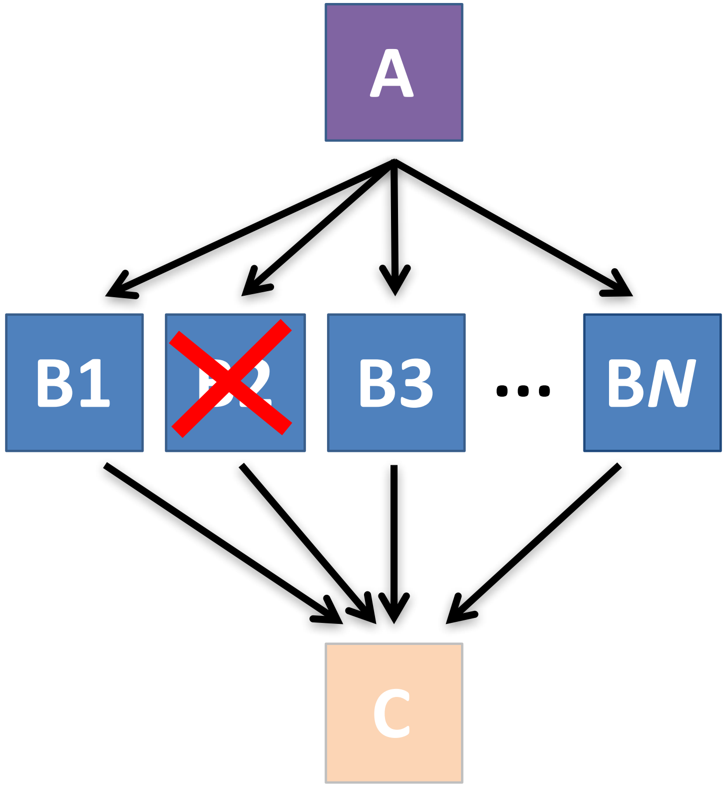
Rescue Files
For Resuming a Failed DAG

- A rescue file is created when:
  - a node fails, and after DAGMan advances through any other possible nodes
  - the DAG is removed from the queue (or **aborted**, see manual)
  - the DAG is **halted** and not unhalted (see manual)
- Resubmission uses the rescue file (if it exists) when the original DAG file is resubmitted
  - override: `condor_submit_dag` ***`dag_file -f`***

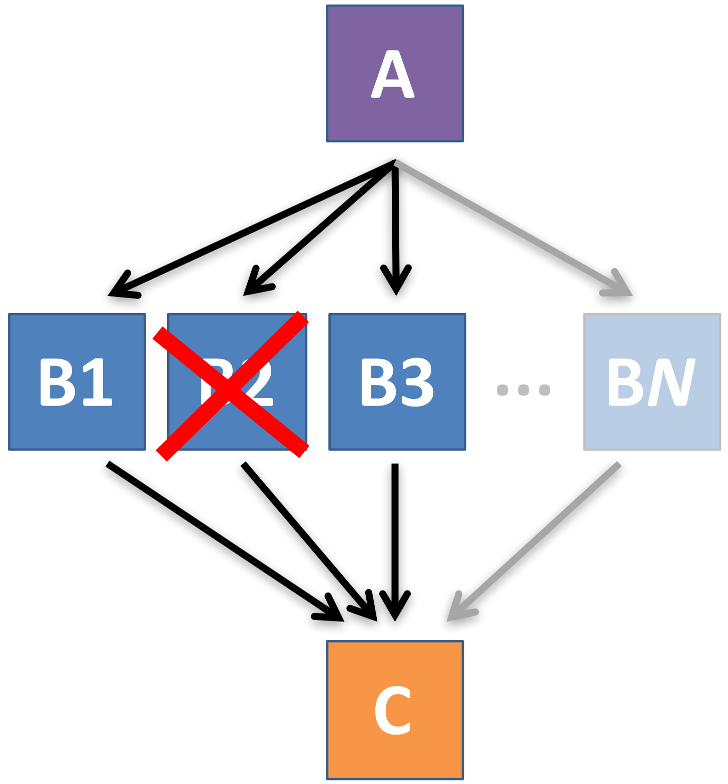
Node Failures Result in DAG Failure

- If a node JOB fails (non-zero exit code)
  - DAGMan continues to run other JOB nodes until it can no longer make progress
- Example at right:
  - **B2** fails
  - Other **B*** jobs continue
  - DAG fails and exits after **B*** and before node **C**



Best Control Achieved with One Process per JOB Node

- While submit files can '`queue`' many processes, a ***single process per submit file*** is usually best for DAG JOBs
  - Failure of any queued *process* in a JOB node results in failure of the *entire node* and immediate removal of all other processes in the node.
  - RETRY of a JOB node retries the entire submit file.



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Resolving held node jobs

```
$ condor_q -nobatch
-- Schedd: submit-3.chtc.wisc.edu : <128.104.100.44:9618?...
 ID      OWNER     SUBMITTED      RUN_TIME ST PRI SIZE CMD
128.0    alice    4/30 18:08    0+00:20:36 R  0     0.3 condor_dagman
130.0    alice    4/30 18:18    0+00:00:00 H  0     0.3 B_run.sh
131.0    alice    4/30 18:18    0+00:00:00 H  0     0.3 B_run.sh
132.0    alice    4/30 18:18    0+00:00:00 H  0     0.3 B_run.sh
4 jobs; 0 completed, 0 removed, 0 idle, 1 running, 3 held, 0 suspended
```

- Look at the hold reason (in the job log, or with '`condor_q -hold`')
- Fix the issue and release the jobs (`condor_release`) -OR- remove the entire DAG, resolve, then resubmit the DAG (remember the automatic rescue DAG file!)

HTCondor Manual: DAGMan > DAG Submission

BEYOND THE BASIC DAG: NODE-LEVEL MODIFIERS

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Default File Organization

my.dag

```
JOB A A.sub
JOB B1 B1.sub
JOB B2 B2.sub
JOB B3 B3.sub
JOB C C.sub
PARENT A CHILD B1 B2 B3
PARENT B1 B2 B3 CHILD C
```

(dag_dir)/

```
A.sub          B1.sub
B2.sub         B3.sub
C.sub          my.dag
(other job files)
```

- What if you want to organize files into other directories?

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Node-specific File Organization with *DIR*

- **DIR** sets the submission directory of the node

my.dag

```
JOB A A.sub DIR A
JOB B1 B1.sub DIR B
JOB B2 B2.sub DIR B
JOB B3 B3.sub DIR B
JOB C C.sub DIR C
PARENT A CHILD B1 B2 B3
PARENT B1 B2 B3 CHILD C
```

(dag_dir)/

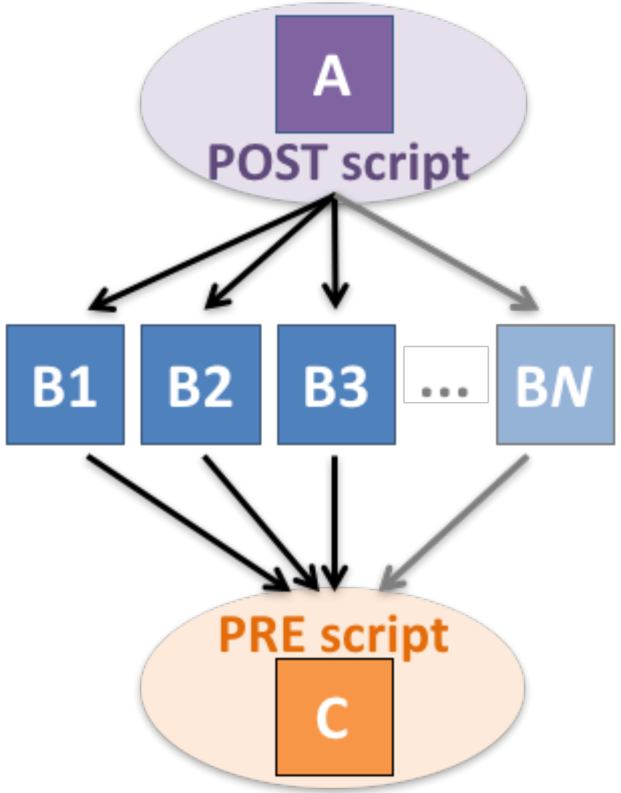
```
my.dag
A/     A.sub    (A job files)
B/     B1.sub  B2.sub
       B3.sub  (B job files)
C/     C.sub    (C job files)
```

PRE and *POST* scripts run on the access point, as part of the node

my.dag

```
JOB A A.sub
SCRIPT POST A sort.sh
JOB B1 B1.sub
JOB B2 B2.sub
JOB B3 B3.sub
JOB C C.sub
SCRIPT PRE C tar_it.sh
PARENT A CHILD B1 B2 B3
PARENT B1 B2 B3 CHILD C
```

- **Use sparingly for lightweight work; otherwise include work in node jobs**



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RETRY failed nodes to overcome transient errors

- Retry a node up to *N* times if the exit code is non-zero:

RETRY *node_name N*

Example:

```
JOB A A.sub
RETRY A 5
JOB B B.sub
PARENT A CHILD B
```

- **Note:** Unnecessary for nodes (jobs) that can use `max_retries` in the submit file
- See also: retry except for a particular exit code (`UNLESS-EXIT`), or retry scripts (`DEFER`)

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RETRY applies to whole node, including *PRE/POST* scripts

- PRE and POST scripts are included in retries
- RETRY of a node with a POST script uses the exit code from the POST script (not from the job)
  - POST script can do more to determine node success, perhaps by examining JOB output

Example:

```
SCRIPT PRE A download.sh
JOB A A.sub
SCRIPT POST A checkA.sh
RETRY A 5
```

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MODULAR ORGANIZATION OF DAG COMPONENTS

Submit File Templates via *VARS*

- **VARS** line defines node-specific values that are passed into submit file variables

```
VARS node_name var1="value" [var2="value"]
```

- Allows a single submit file shared by all B jobs, rather than one submit file for each JOB.

my.dag

```
JOB B1 B.sub
VARS B1 data="B1" opt="10"
JOB B2 B.sub
VARS B2 data="B2" opt="12"
JOB B3 B.sub
VARS B3 data="B3" opt="14"
```

B.sub

```
…
InitialDir = $(data)
arguments = $(data).csv $(opt)
…
queue
```

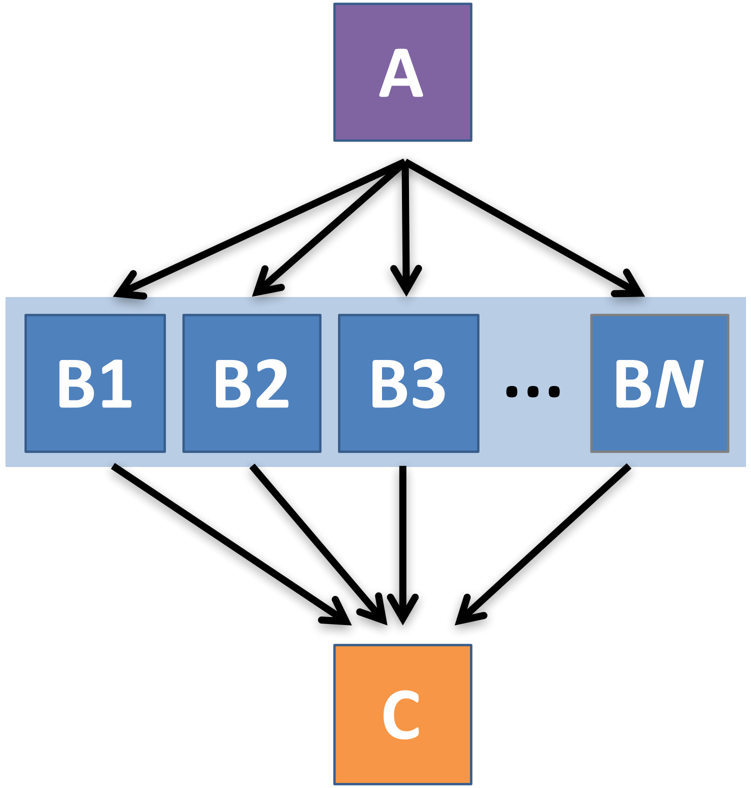
SPLICE subsets of a DAG to simplify lengthy DAG files

my.dag

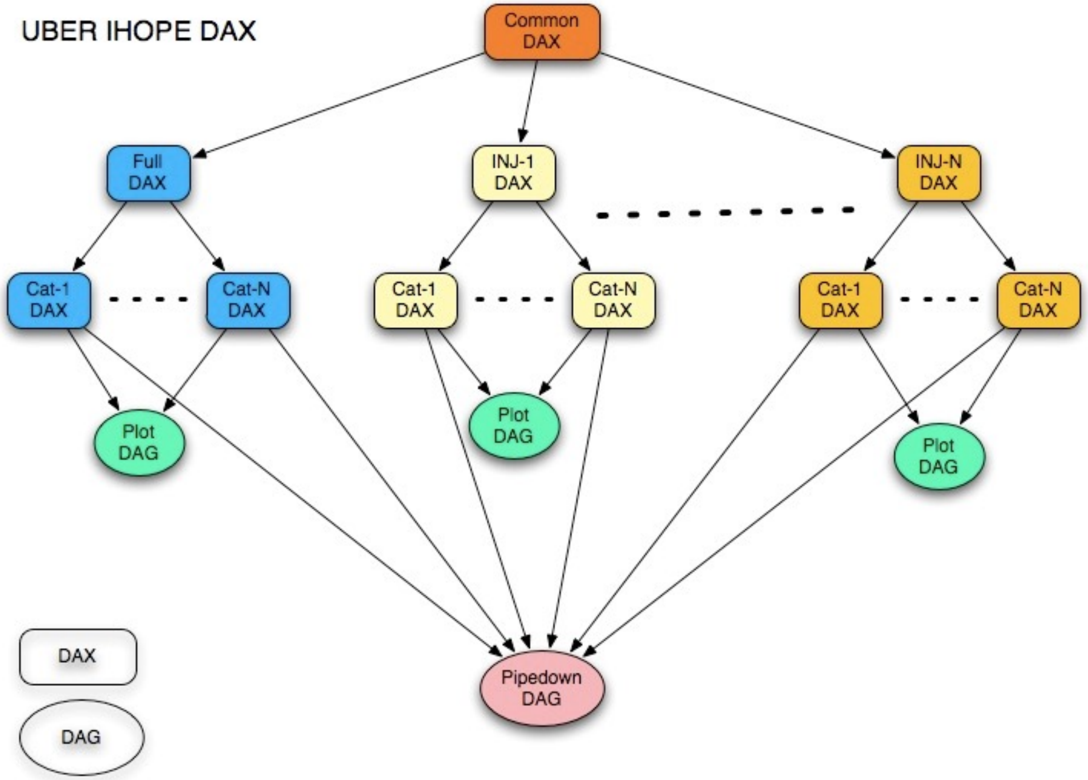
```
JOB A A.sub
SPLICE B B.spl
JOB C C.sub
PARENT A CHILD B
PARENT B CHILD C
```

B.spl

```
JOB B1 B1.sub
JOB B2 B2.sub
…
JOB BN BN.sub
```

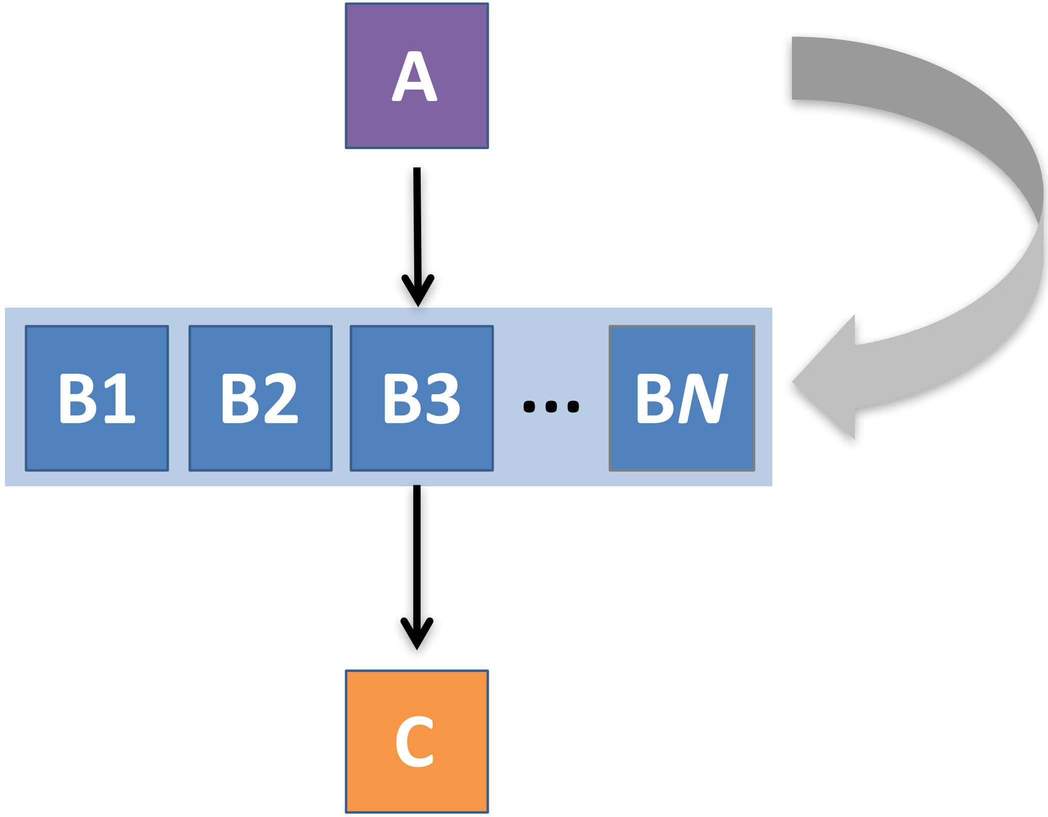


Repeating DAG Components!!



https://confluence.pegasus.isi.edu/display/pegasus/LIGO+IHOPE

What if some DAG components can't be known at submit time?



If *N* can only be determined as part of the work of **A** …

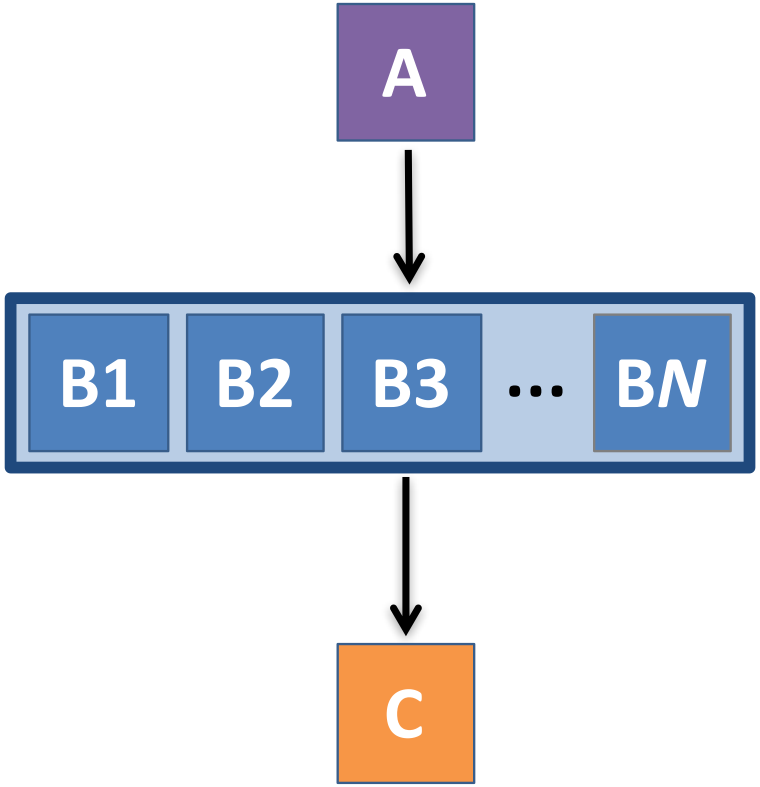
A *SUBDAG* within a DAG

my.dag

```
JOB A A.sub
SUBDAG EXTERNAL B B.dag
JOB C C.sub
PARENT A CHILD B
PARENT B CHILD C
```

B.dag (written by A)

```
JOB B1 B1.sub
JOB B2 B2.sub
…
JOB BN BN.sub
```

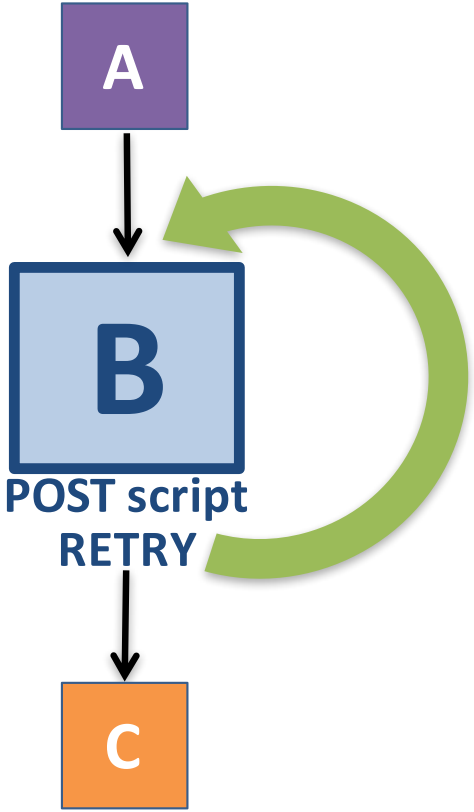


Use a *SUBDAG* to achieve a Cyclic Component within a DAG

- POST script determines whether another iteration is necessary; if so, exits non-zero
- RETRY applies to entire SUBDAG, which may include multiple, sequential nodes

my.dag

```
JOB A A.sub
SUBDAG EXTERNAL B B.dag
SCRIPT POST B iterateB.sh
RETRY B 1000
JOB C C.sub
PARENT A CHILD B
PARENT B CHILD C
```



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More in the HTCondor Manual and the HTCondor Week DAGMan Tutorial!!!

YOUR TURN!

DAGMan Exercises!

- Essential: Exercises 1-4
- Ask questions! ‘See you in Slack!