Job-tree

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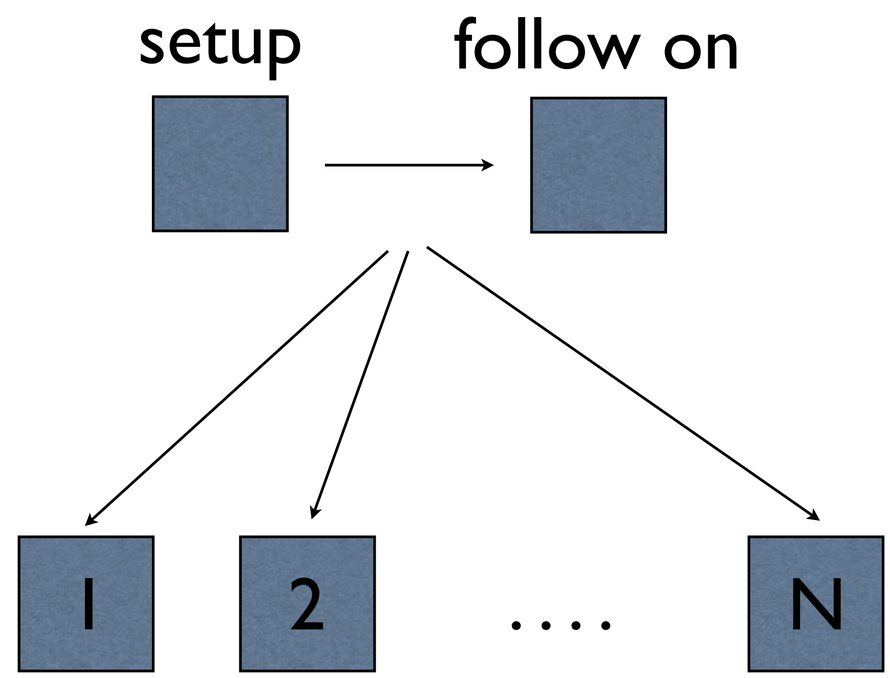
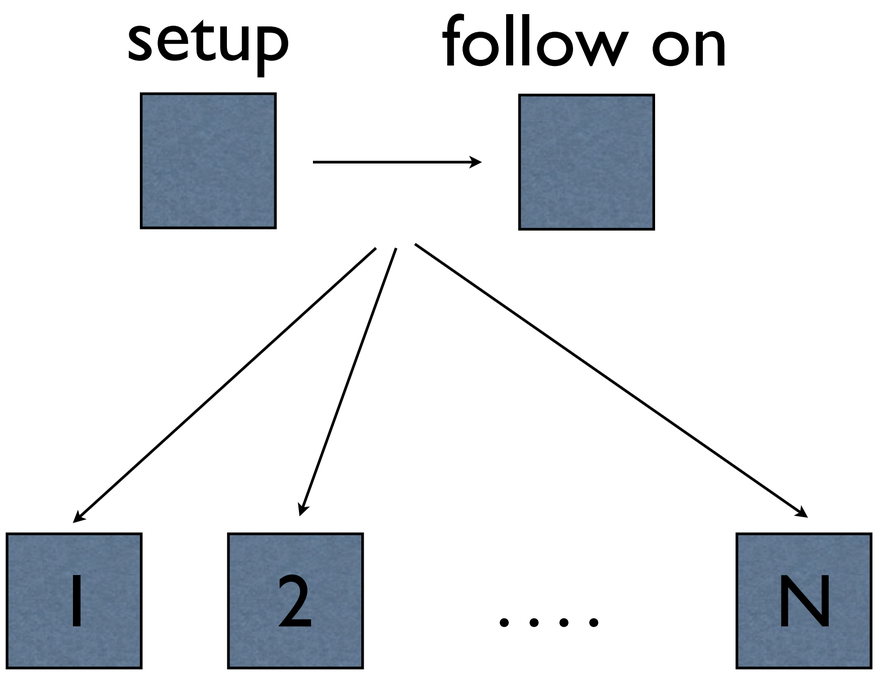
Traditional Batch System

- Composed of a series of 'jobs'
- Single 'setup' job
- Parallel 'child' job
- Single 'follow on' job



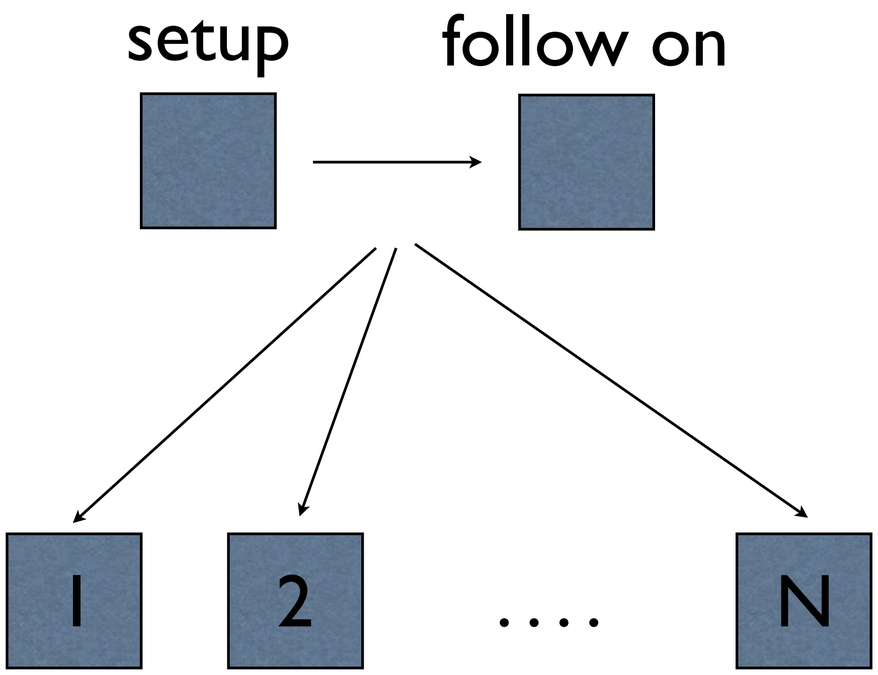
Traditional Batch System

- Setup creates inputs for children
- Children create output
- Follow on aggregates output



Traditional Batch System

- Jobs can get lost at any point during their runtime.
- To maintain 'atomicity' jobs must always be restartable, therefore:
  - No job must alter its own input.
  - The follow on 'cleans up' the setup job



Traditional Batch System Summary

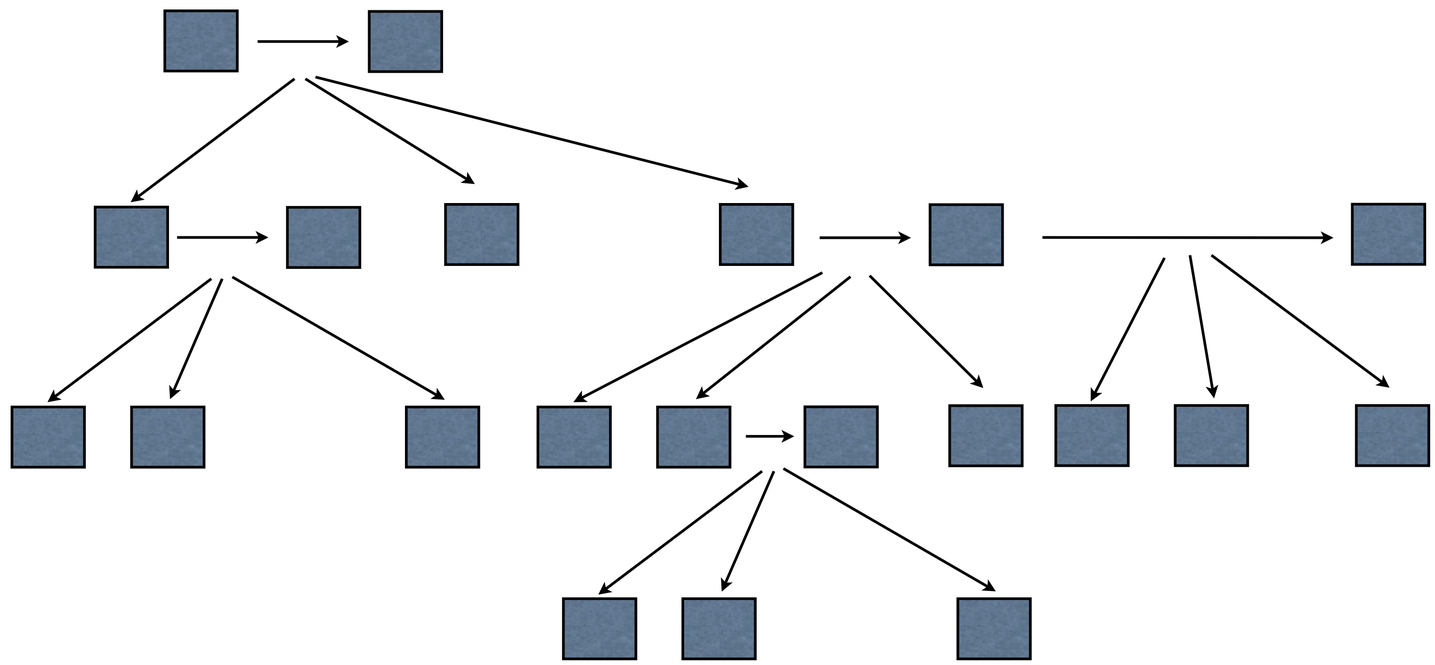
- Traditional batch system can be described, from the users point of view, as a parallel 'for' loop.
- Robust pipelines must maintain atomicity

Job-tree

- For loops are useful, but what if..
  - I want to further parallelise a ‘child’ job?
  - I want to do this selectively?
  - I want to do this dynamically and recursively?

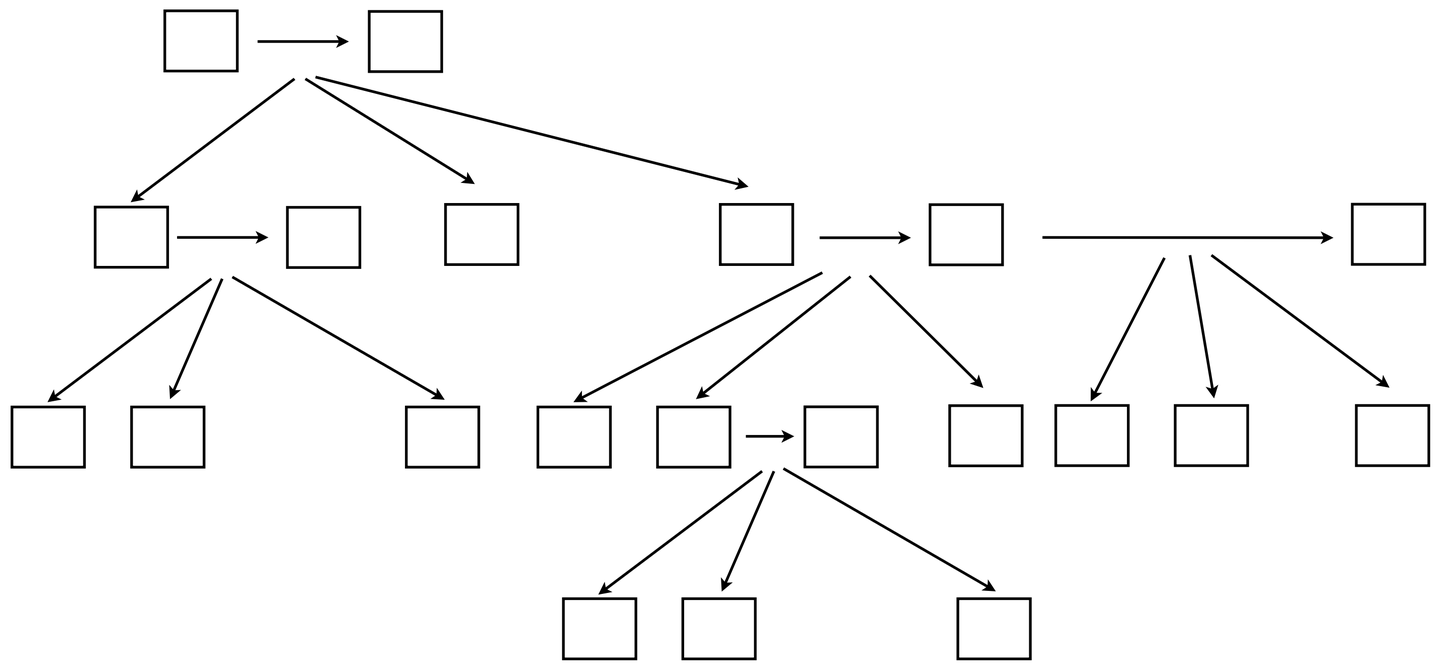
Job-tree

- Job-tree allows you to create arbitrary ‘job-trees’



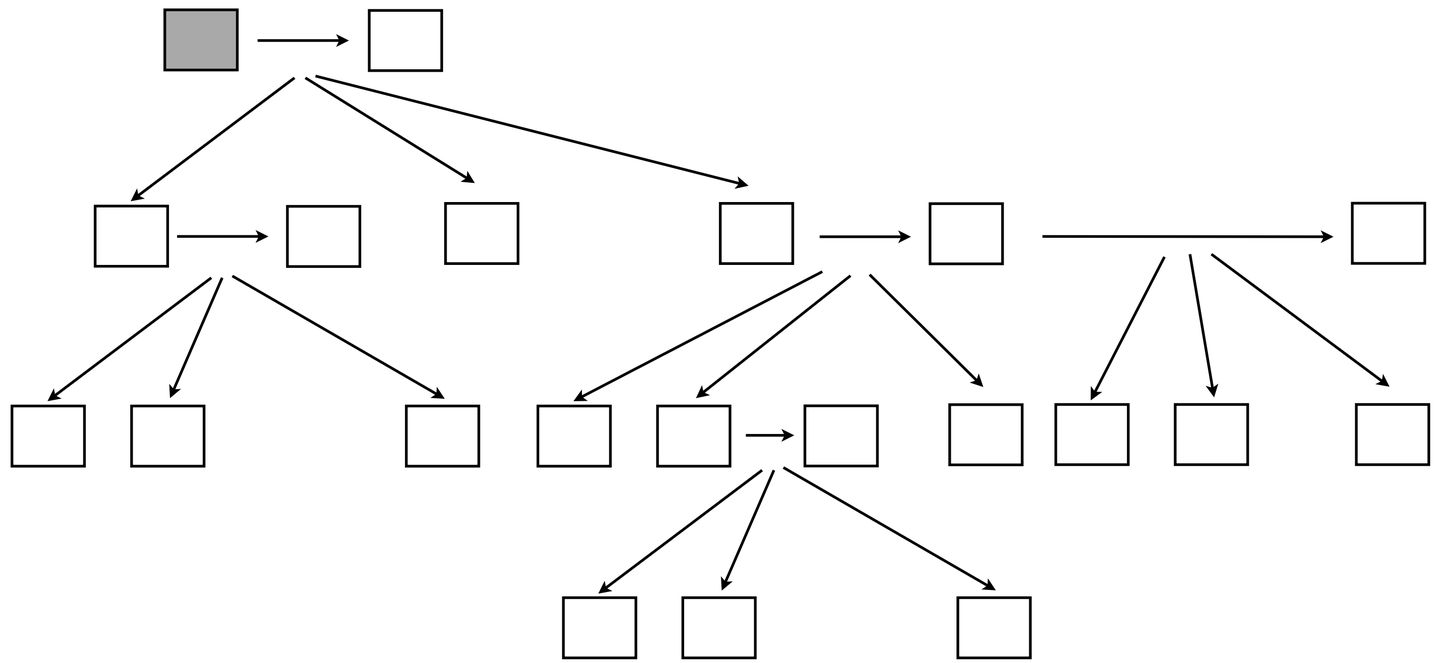
Job-tree

- Let's walk through an example.



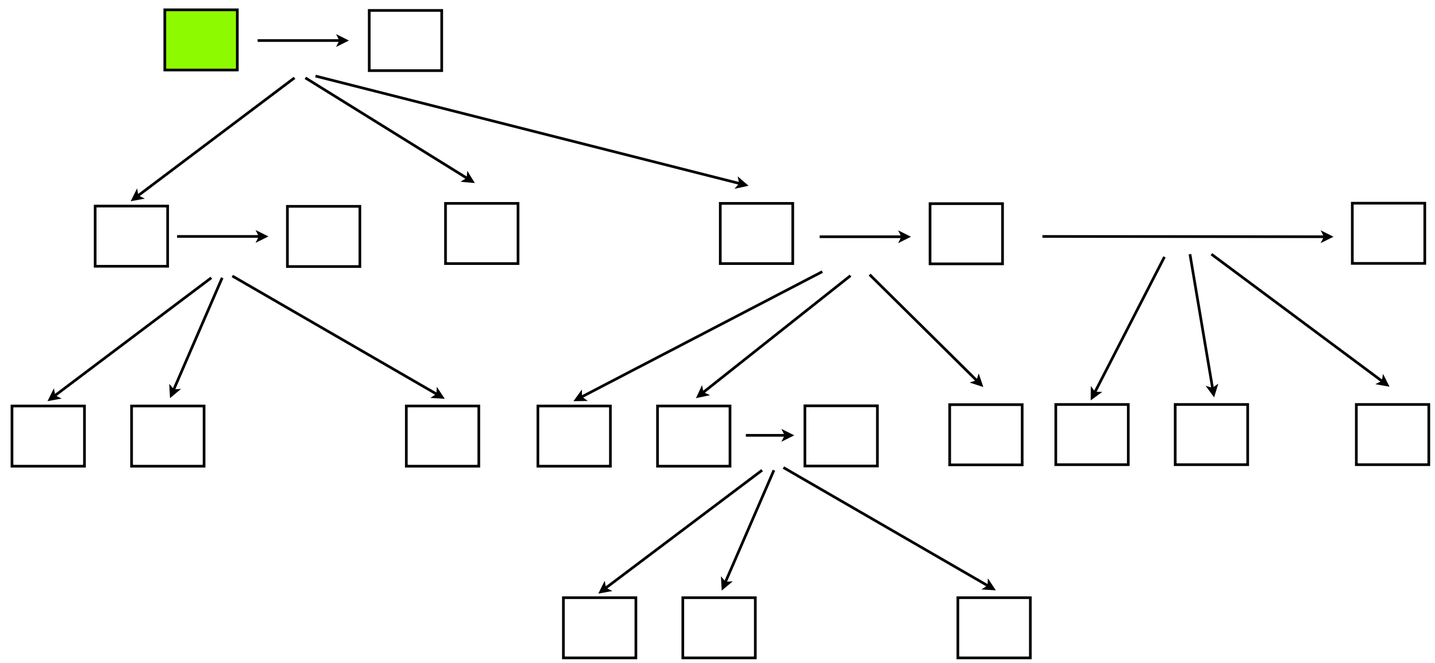
Job-tree

- The first job is issued to the system (grey)
- White boxes are jobs not yet created.



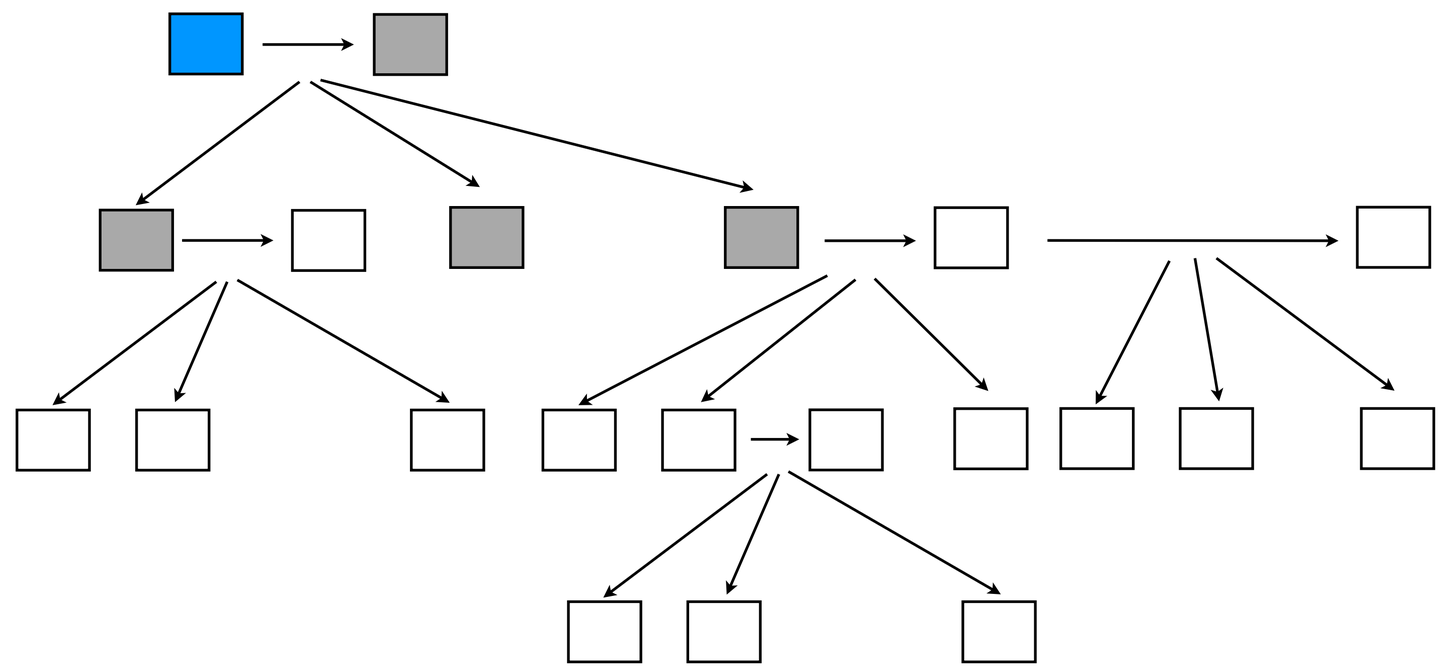
Job-tree

- The first job is run (green)



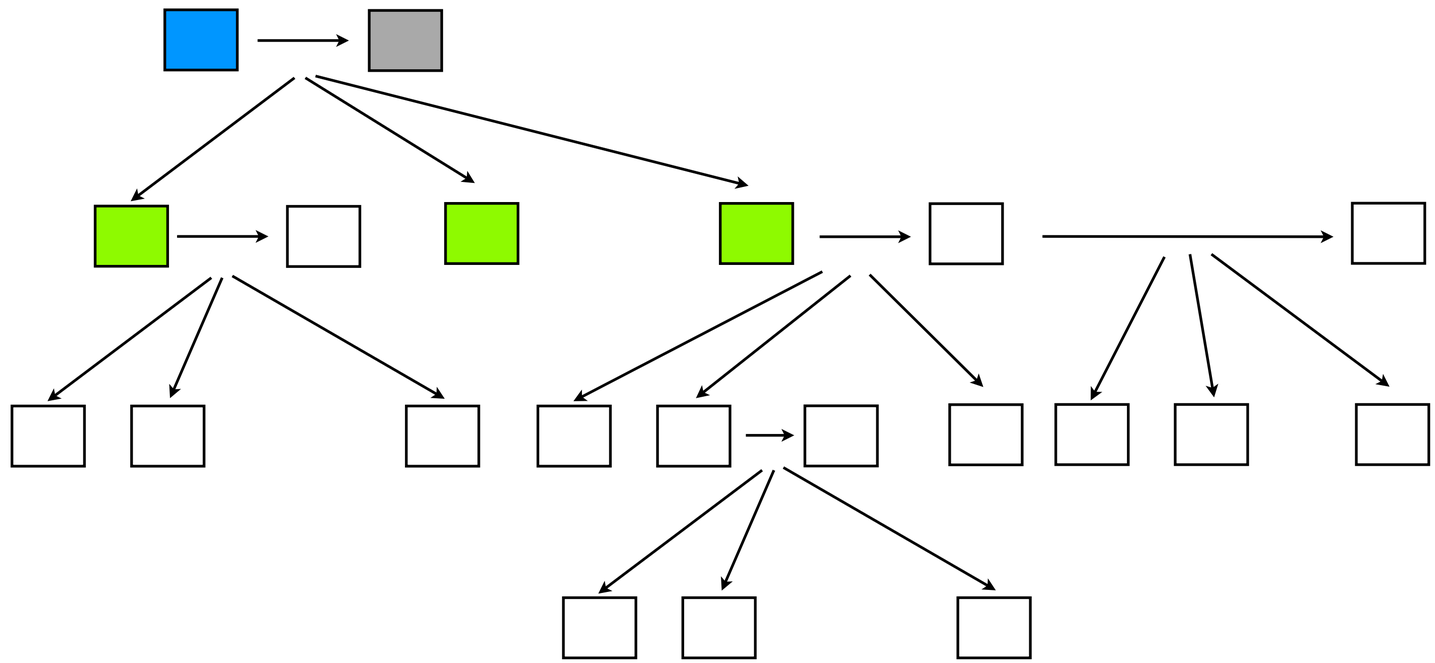
Job-tree

- It completes successively and creates some children and a follow on.
- It is blue, indicating it has children/follow ons not yet complete.



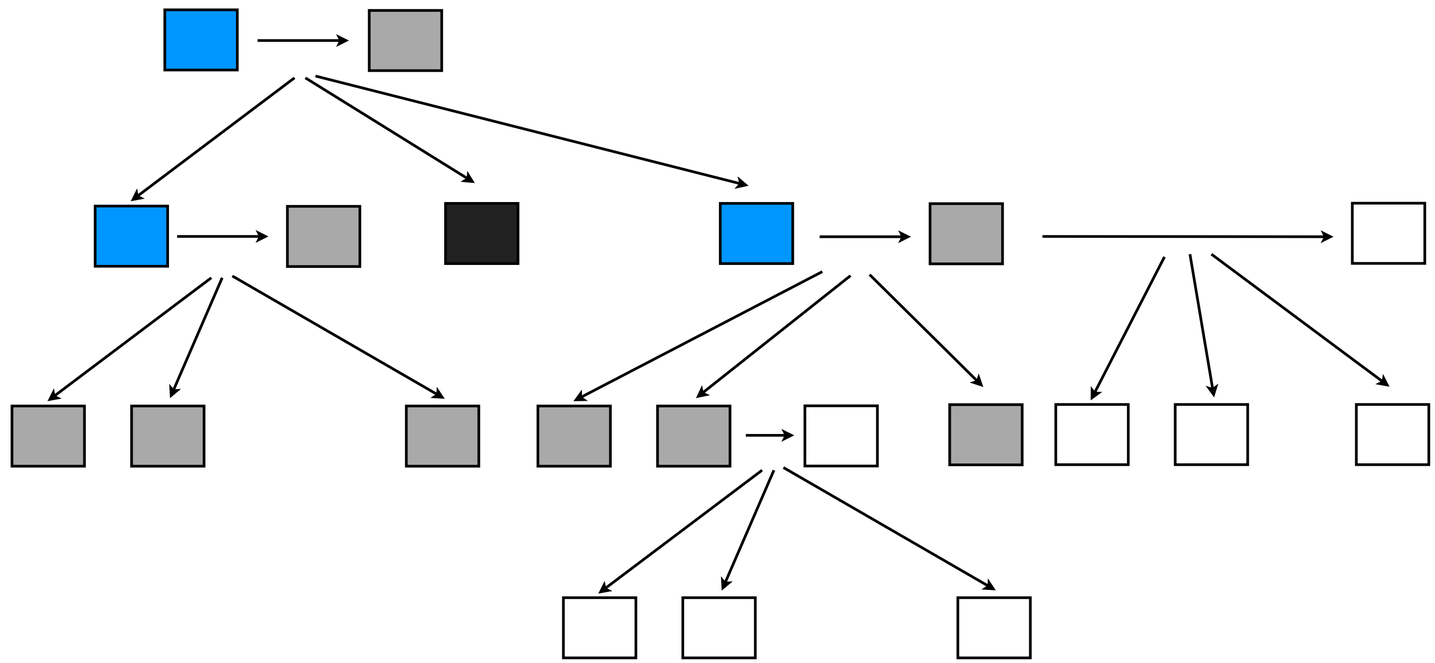
Job-tree

- The children are run



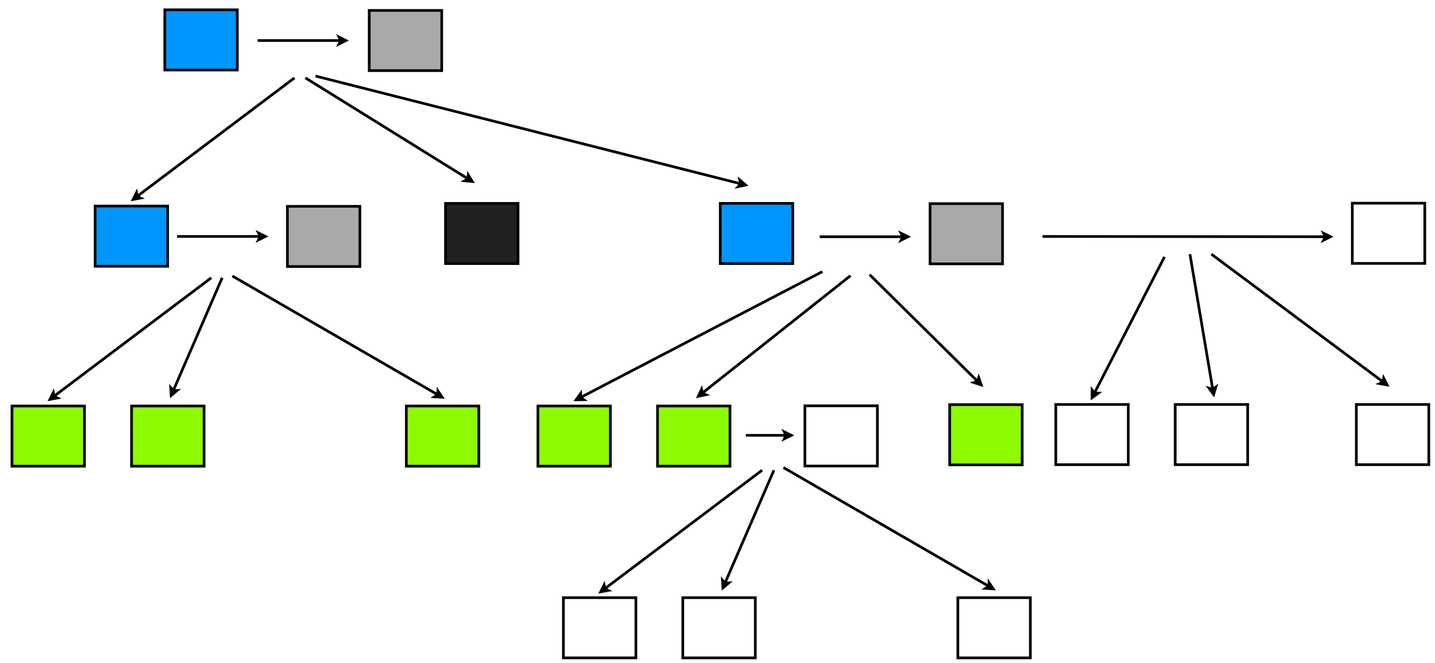
Job-tree

- Some create children and follow ons.
- Some do not, they are now complete (coloured black)



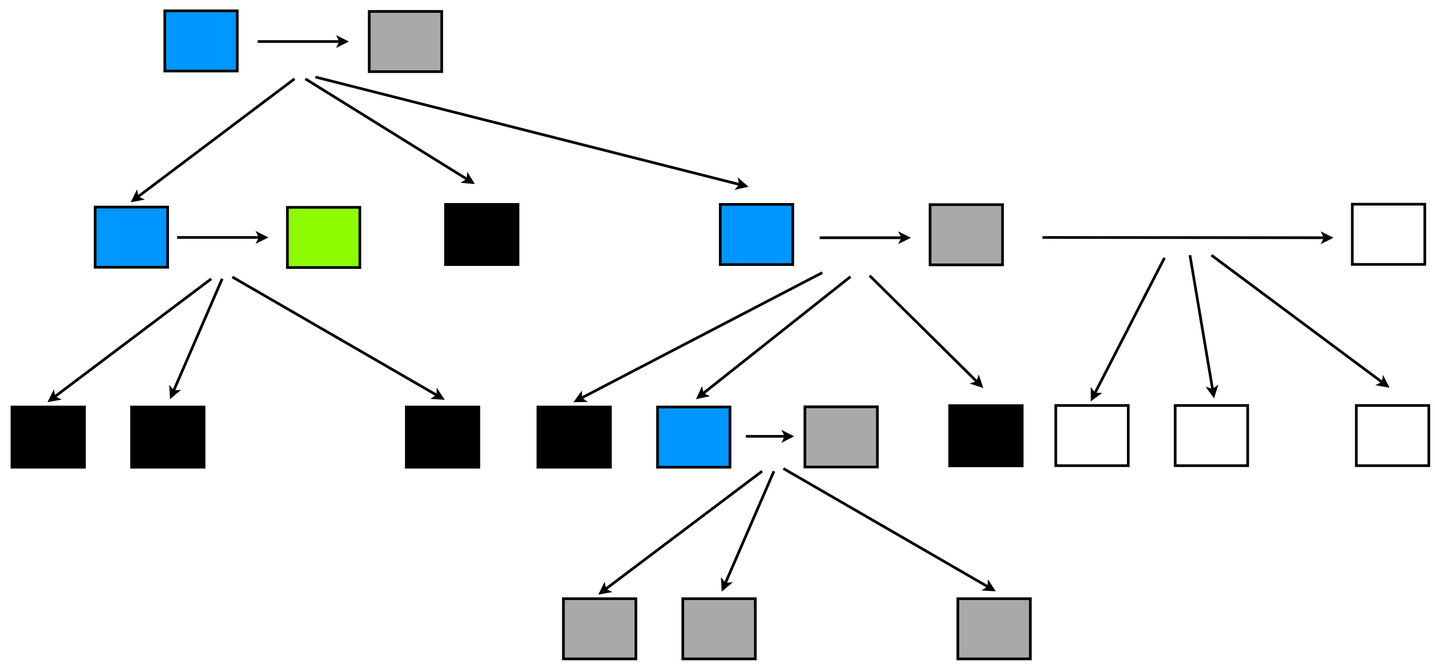
Job-tree

- More children are run

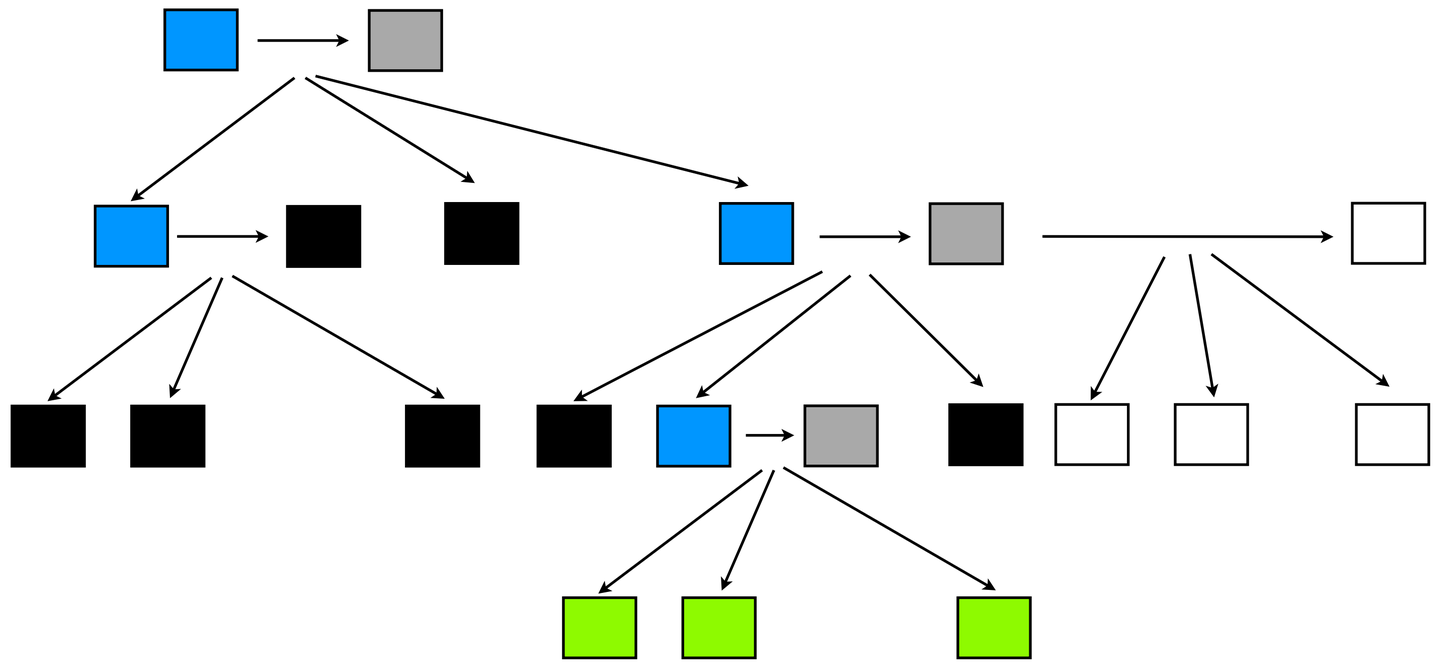


Job-tree

- Most are finished, one creates more children, and one follow can be run

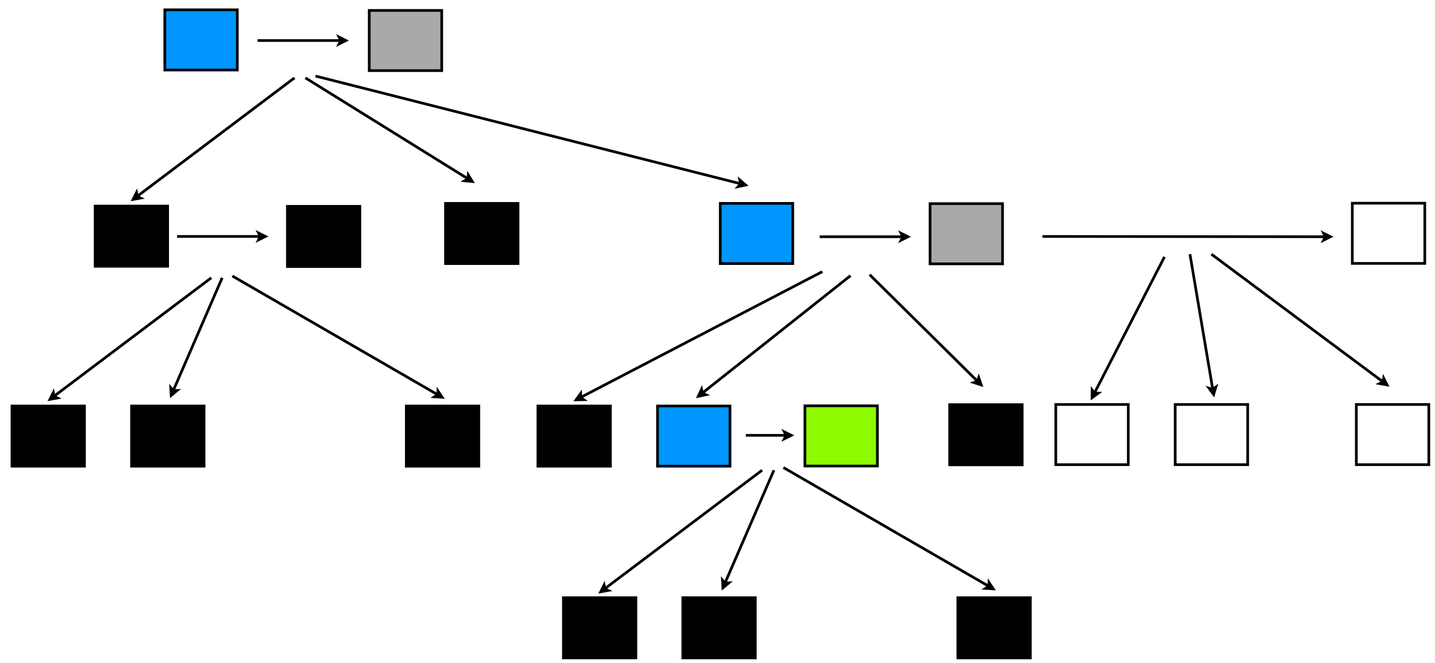


Job-tree



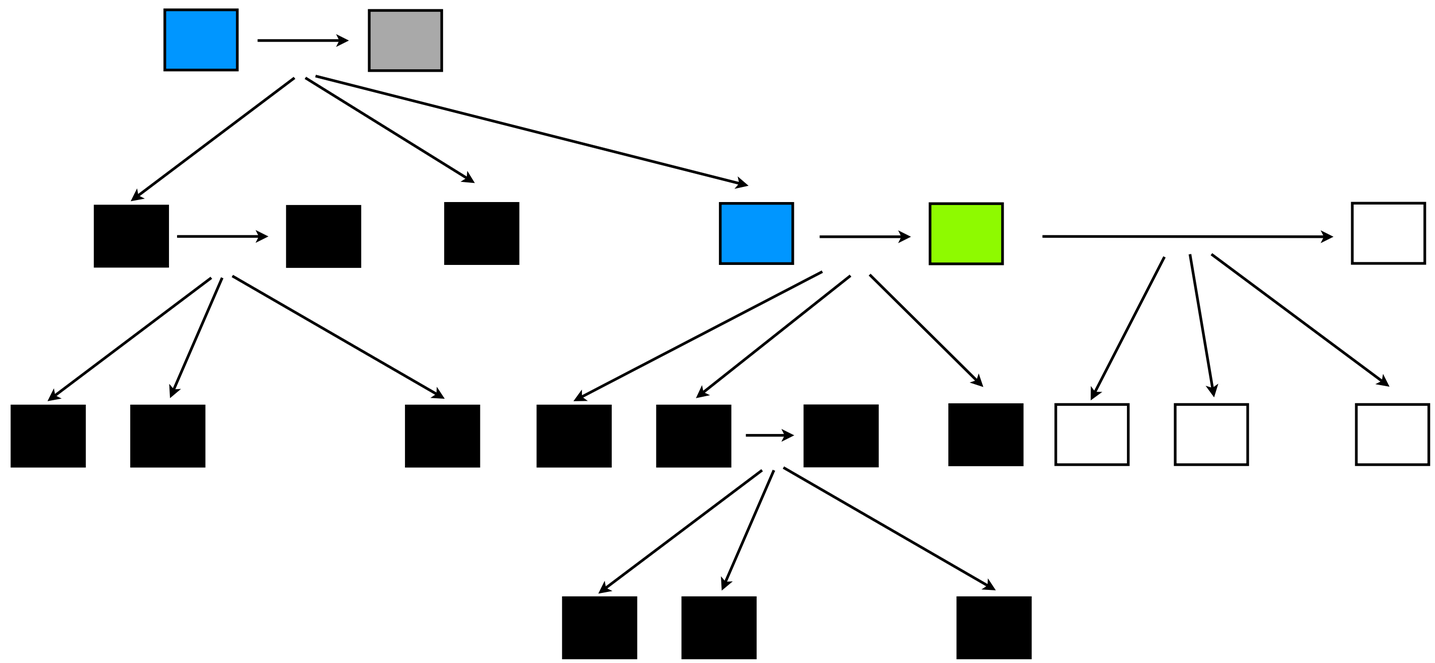
- etc, etc..

Job-tree



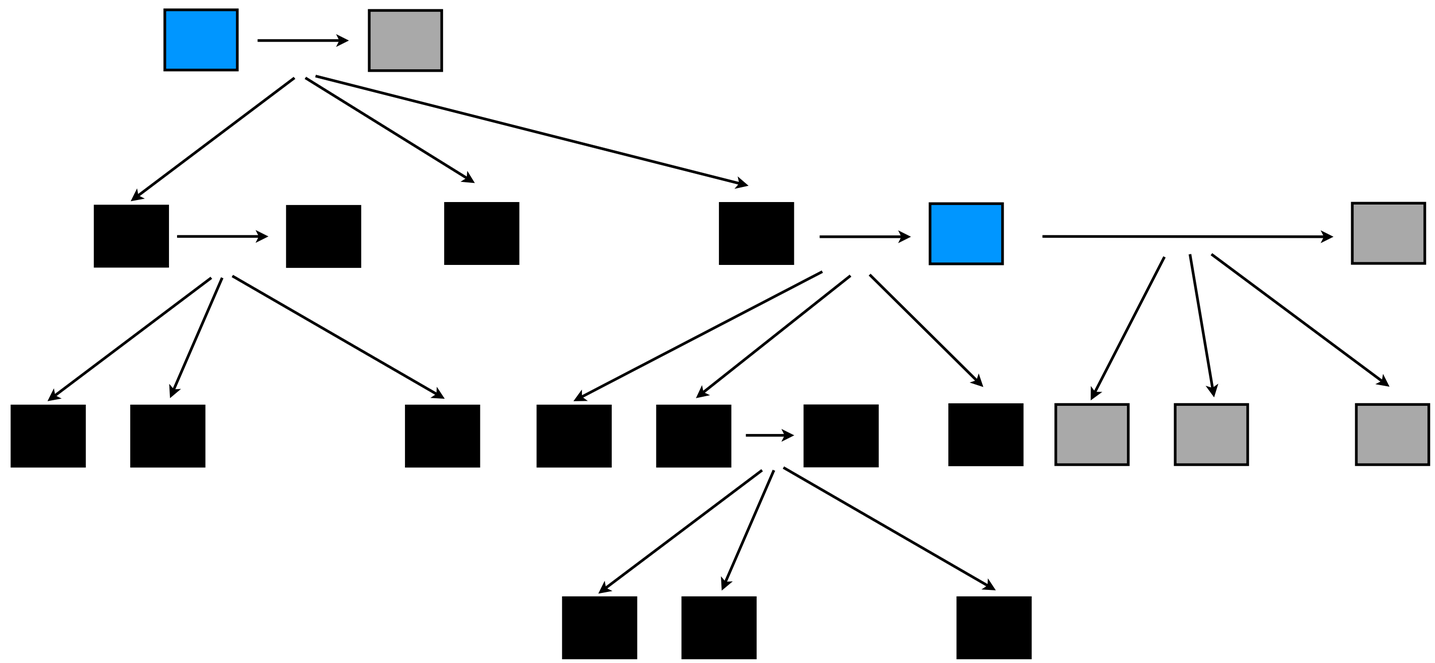
- etc, etc..

Job-tree



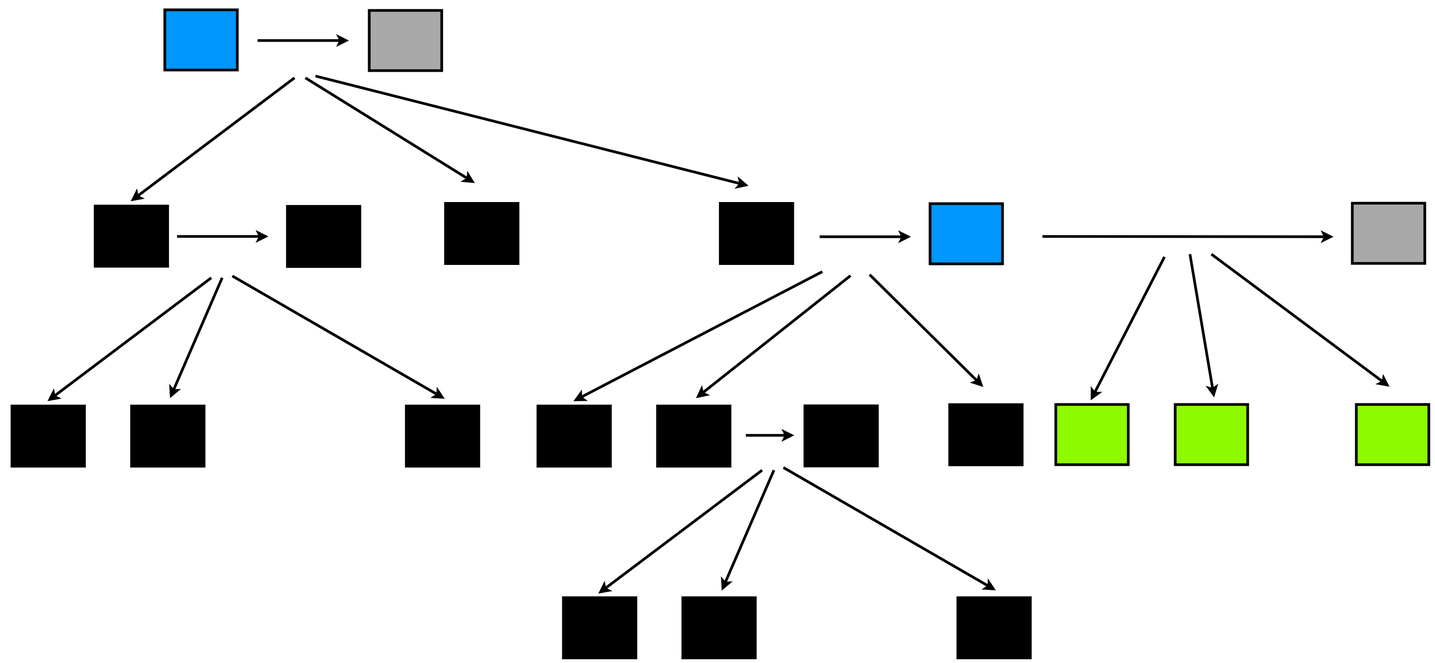
- etc, etc..

Job-tree



- etc, etc..

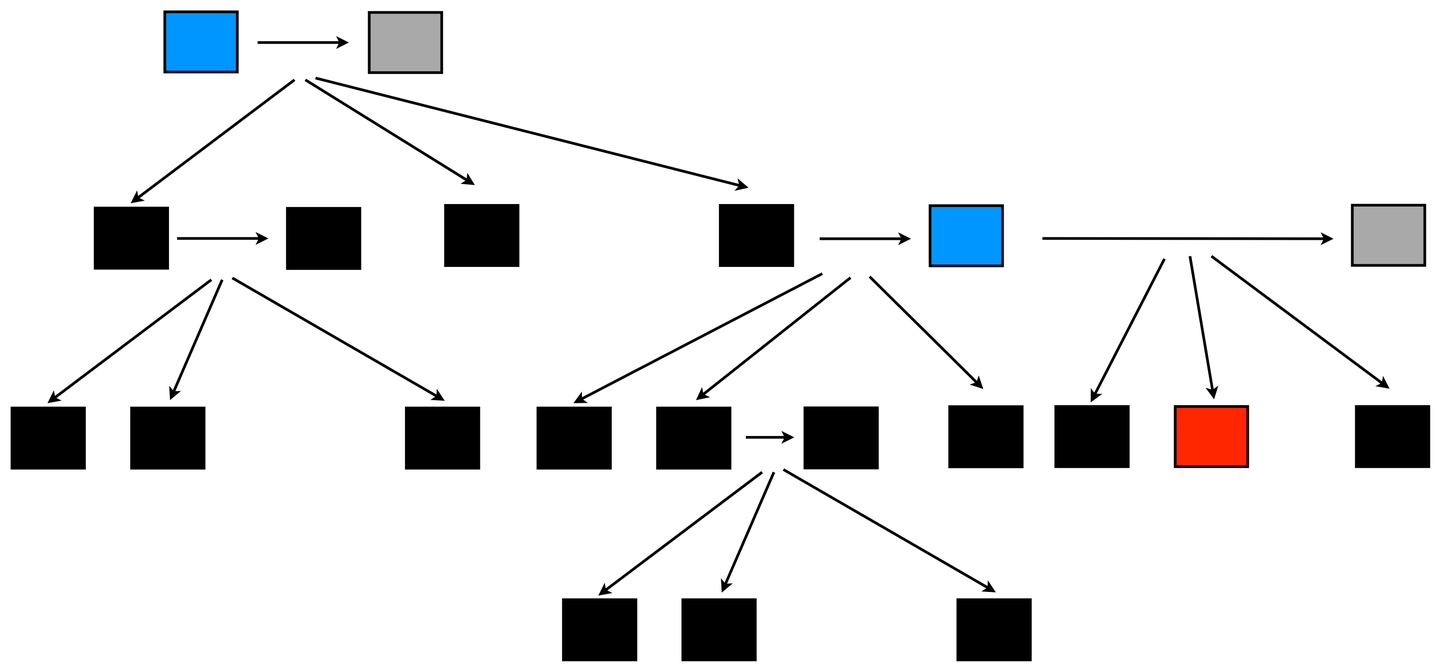
Job-tree



- etc, etc..

Job-tree

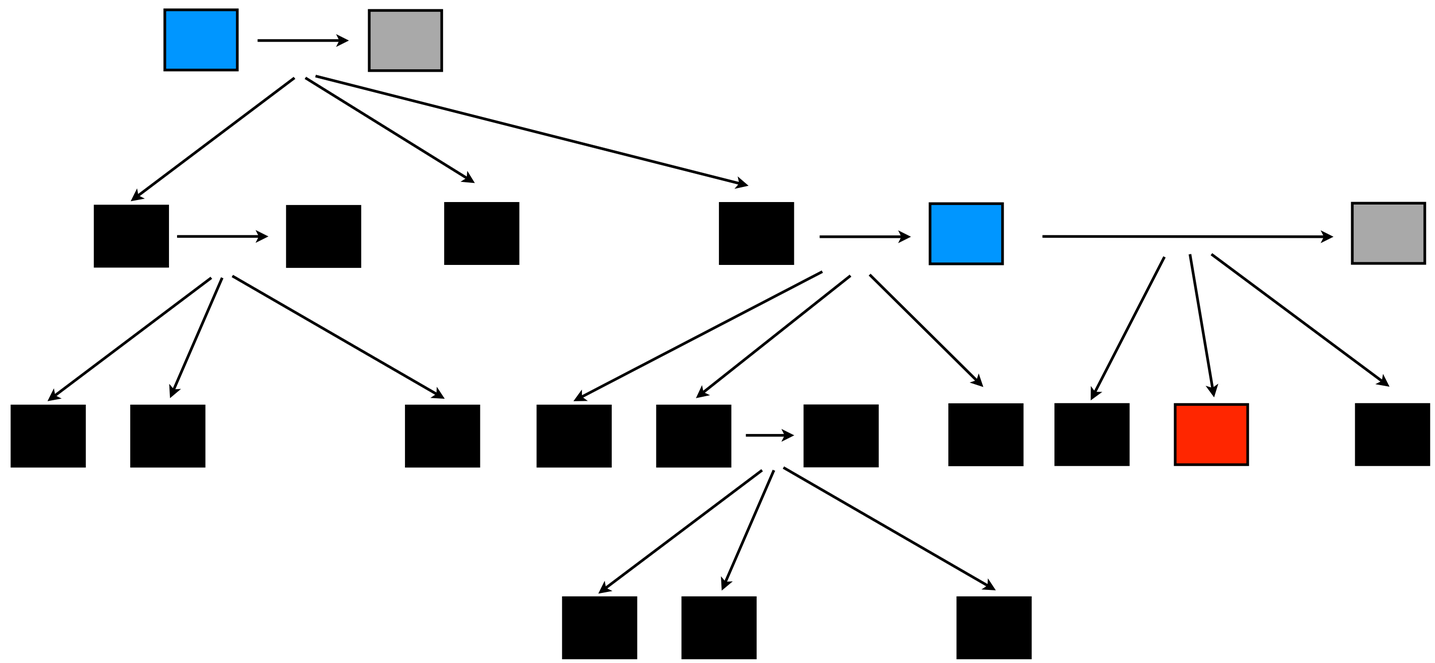
- Oh no! A job failed (coloured red)
  - It will be restarted a preset number of times.



Job-tree

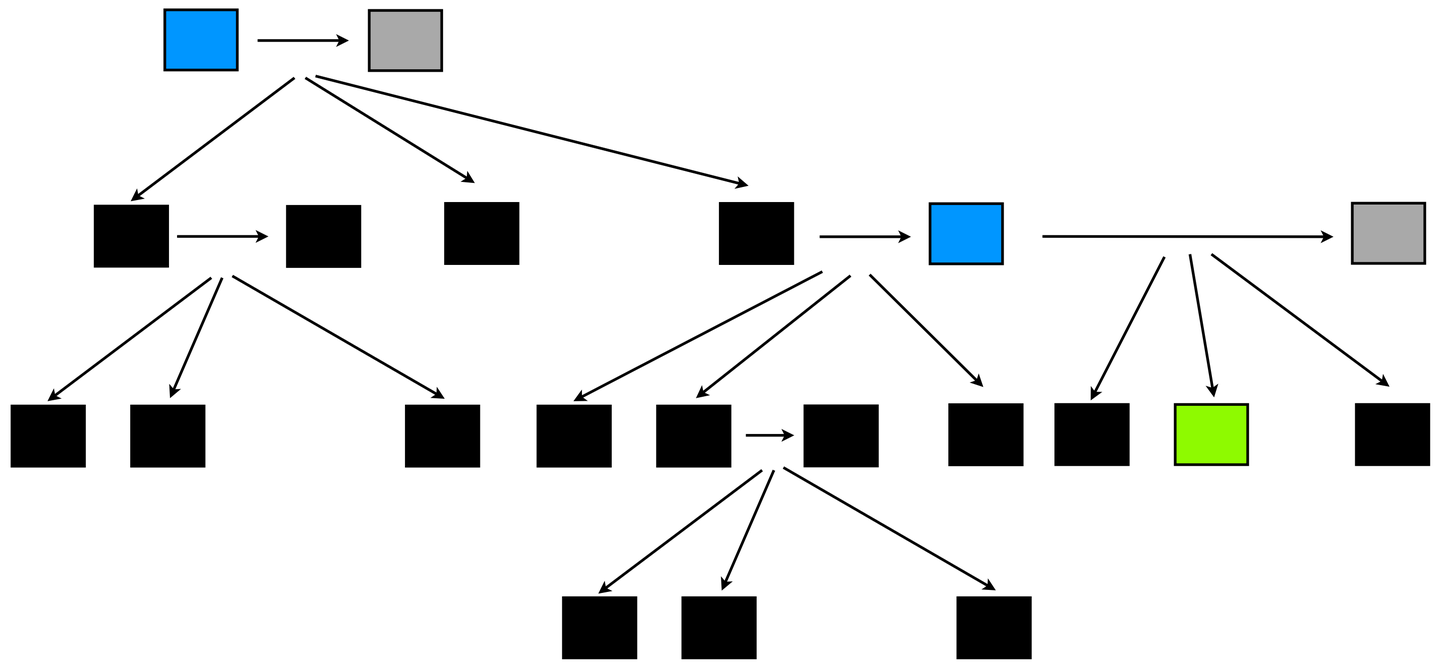
- If it still fails Job-tree will continue as far as it can, then return, so you can fix the job.

- Job-tree will then re-start from that point.

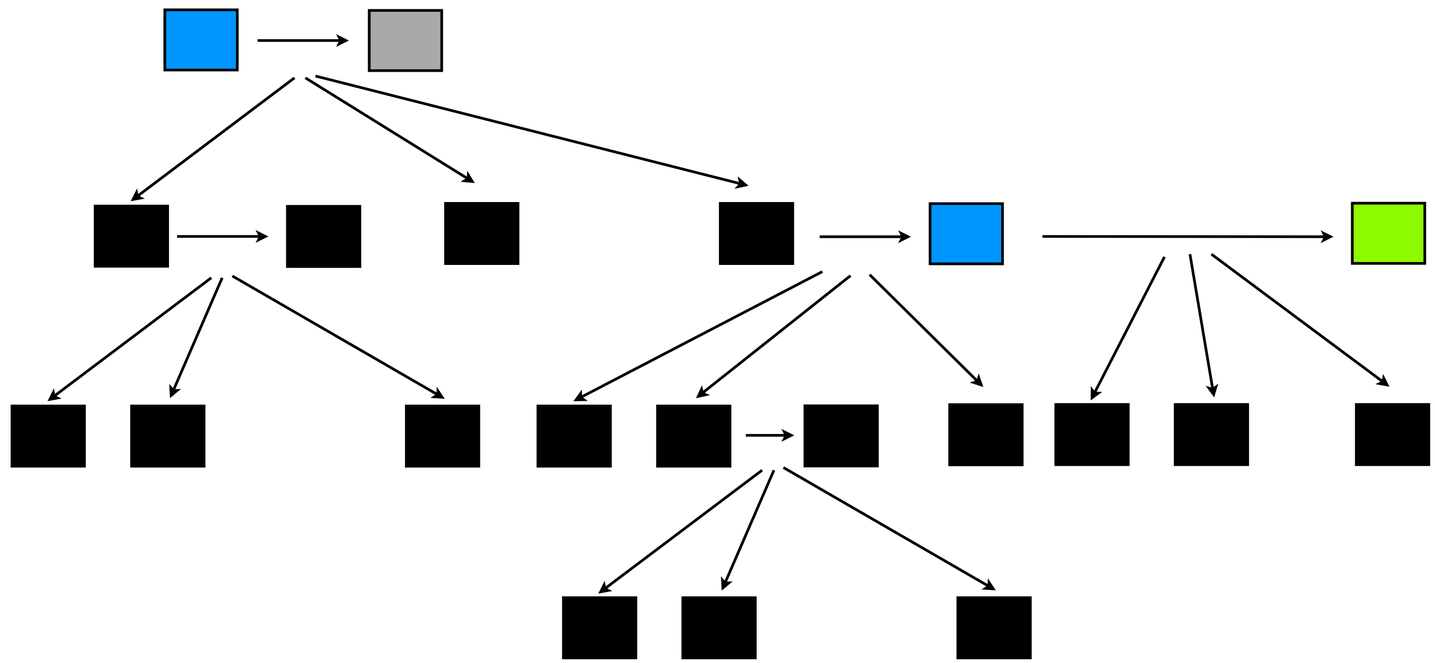


Job-tree

- So now we're running again..



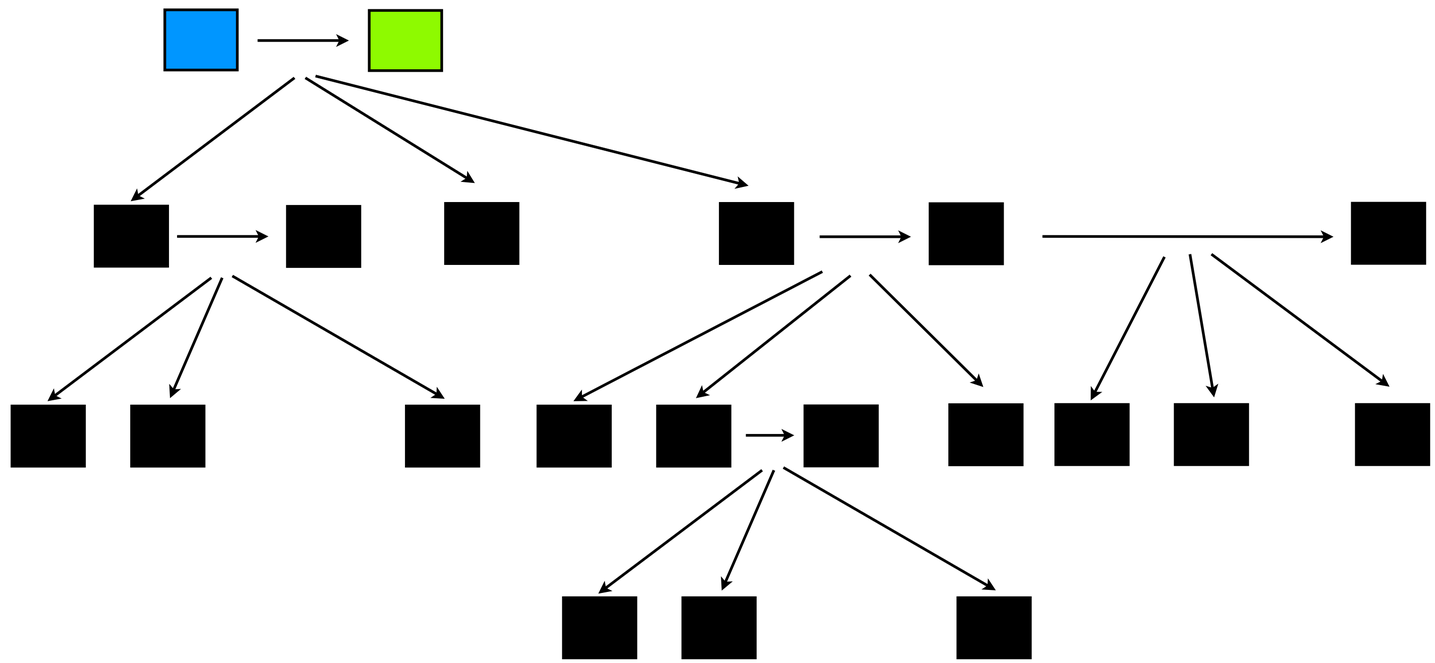
Job-tree



- etc, etc..

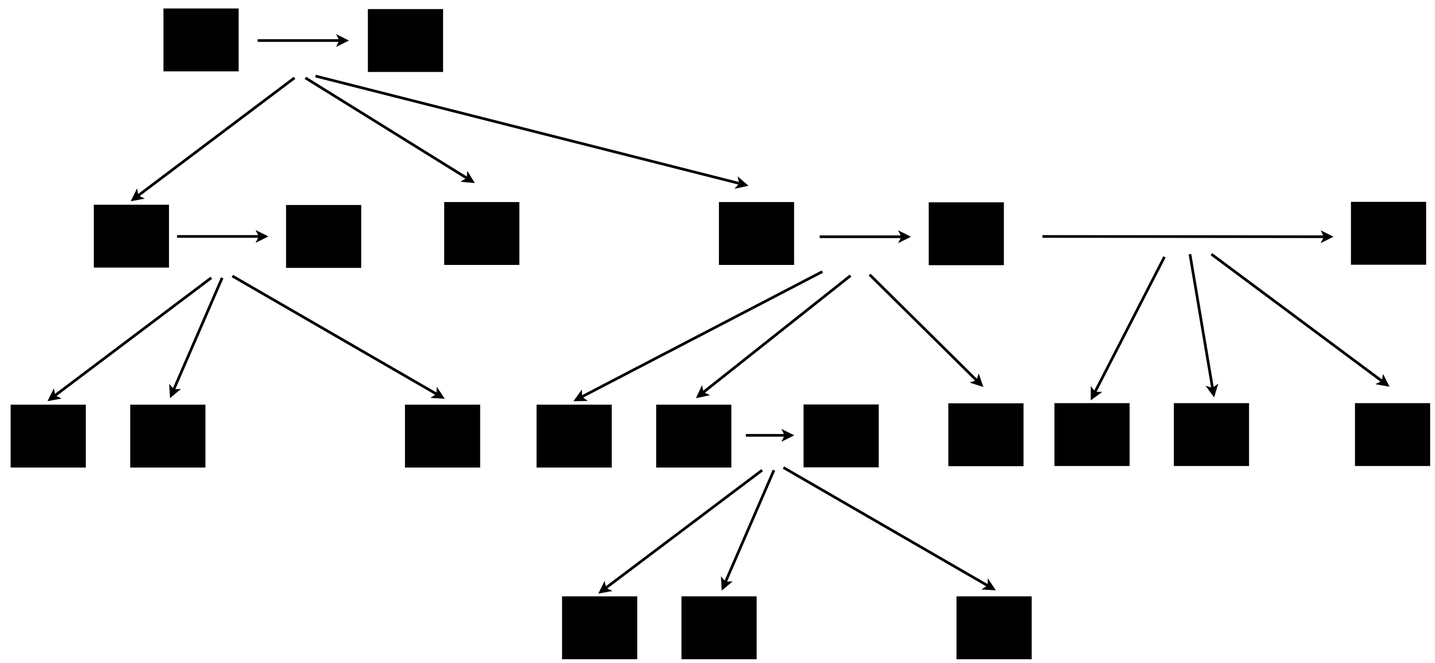
Job-tree

- etc, etc..



Job-tree

- And we're done.



Job-tree/Script-tree

- jobTree.py communicates by clunky XML files. Each job is passed a an xml file, which it edits and when the job is complete this file is processed.
- scriptTree.py removes this pain, you just inherit a 'Target' python class, as follows (we'll look at example for doing parallel merge sort).

Job-tree/Script-tree

```
import os
from workflow.jobTree.scriptTree.target import Target

class Setup(Target):
    """Sets up the sort.
    """
    def __init__(self, inputFile, N):
        Target.__init__(self, time=1, memory=1000000, cpu=1)
        self.inputFile = inputFile
        self.N = N

    def run(self):
        tempOutputFile = getTempFile(rootDir=self.getGlobalTempDir())
        self.addChildTarget(Down(self.inputFile, 0, os.path.getsize(self.inputFile),
self.N, tempOutputFile))
        self.setFollowOnTarget(Cleanup(tempOutputFile, self.inputFile))
```

Job-tree/Script-tree

```
import os
from workflow.jobTree.scriptTree.target import Target

class Setup(Target):
    """Sets up the sort.
    """
    def __init__(self, inputFile, N):
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self.N, tempOutputFile))
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```

Estimated runtime lets the meta-scheduler be more efficient

Job-tree/Script-tree

Memory (bytes) and cpu requirements can be specified

```
import os
from workflow.jobTree.scriptTree.target import Target

class Setup(Target):
    """Sets up the sort.
    """
    def __init__(self, inputFile, N):
        Target.__init__(self, time=1, memory=1000000, cpu=1)
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```

Job-tree/Script-tree

```
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    def run(self):
        tempOutputFile = getTempFile(rootDir=self.getGlobalTempDir())
        self.addChildTarget(Down(self.inputFile, 0, os.path.getsize(self.inputFile),
self.N, tempOutputFile))
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```

Run, where you create children, a follow on and do work

Job-tree/Script-tree

```
import os
from workflow.jobTree.scriptTree.target import Target

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        self.inputFile = inputFile
        self.N = N

    def run(self):
        tempOutputFile = getTempFile(rootDir=self.getGlobalTempDir())
        self.addChildTarget(Down(self.inputFile, 0, os.path.getsize(self.inputFile),
self.N, tempOutputFile))
        self.setFollowOnTarget(Cleanup(tempOutputFile, self.inputFile))
```

Creating a child

Job-tree/Script-tree

```
import os
from workflow.jobTree.scriptTree.target import Target

class Setup(Target):
    """Sets up the sort.
    """
    def __init__(self, inputFile, N):
        Target.__init__(self, time=1, memory=1000000, cpu=1)
        self.inputFile = inputFile
        self.N = N

    def run(self):
        tempOutputFile = getTempFile(rootDir=self.getGlobalTempDir())
        self.addChildTarget(Down(self.inputFile, 0, os.path.getsize(self.inputFile),
self.N, tempOutputFile))
        self.setFollowOnTarget(Cleanup(tempOutputFile, self.inputFile))
```

Creating the follow on

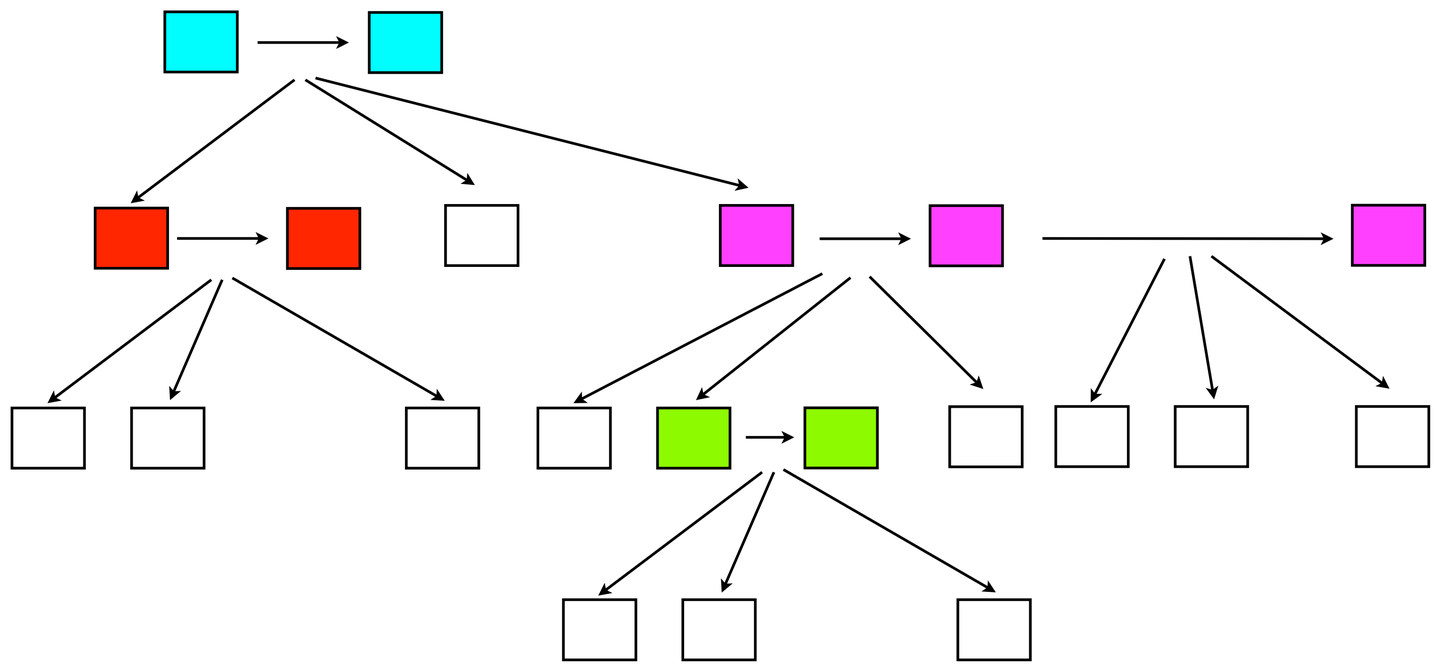
Job-tree/Script-tree

```
import os
from workflow.jobTree.scriptTree.target import Target

class Setup(Target):
    """Sets up the sort.
    """
    def __init__(self, inputFile, N):
        Target.__init__(self, time=1, memory=1000000, cpu=1)
        self.inputFile = inputFile
        self.N = N

    def run(self):
        tempOutputFile = getTempFile(rootDir=self.getGlobalTempDir())
        self.addChildTarget(Down(self.inputFile, 0, os.path.getsize(self.inputFile),
self.N, tempOutputFile))
        self.setFollowOnTarget(Cleanup(tempOutputFile, self.inputFile))
```

A global (visible to all machines on the cluster) temporary directory that exists for the life of the job, its setup jobs and its follow ons.

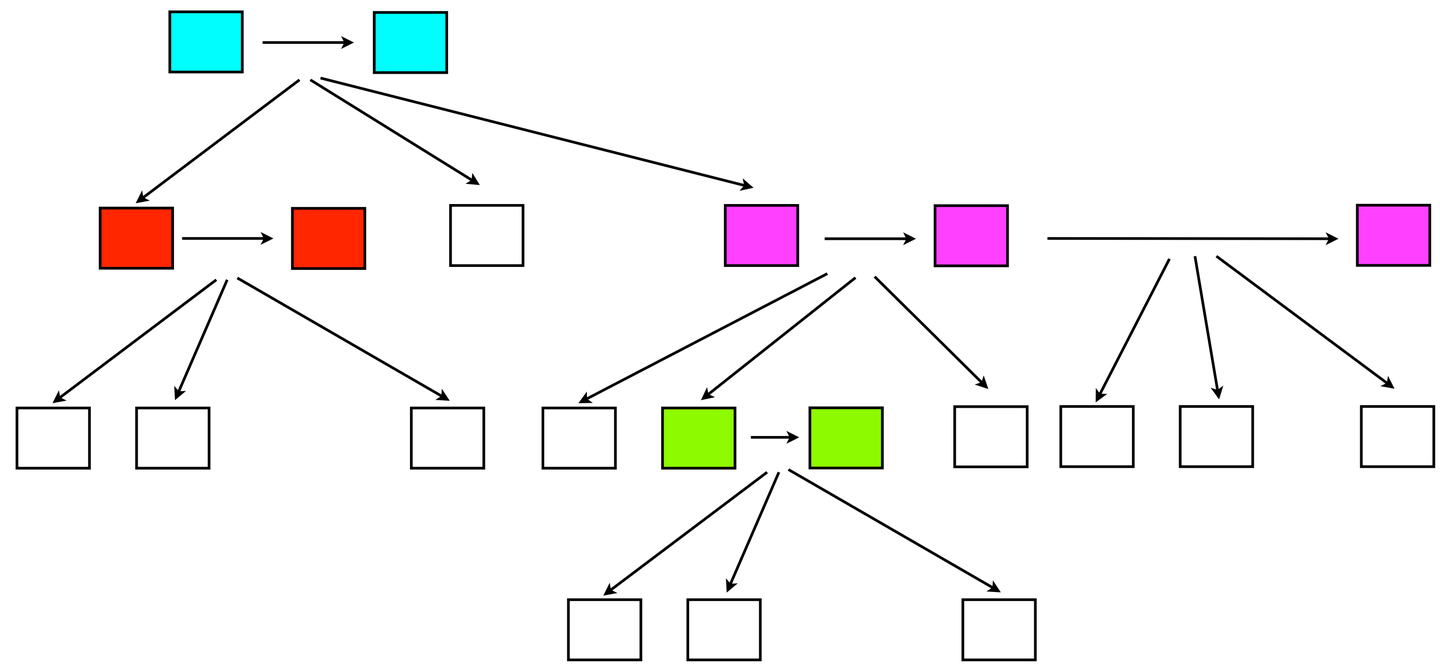
GlobalTempDir

- A chain consists of a founder, a sequence of successive follow ons and a closer.
- Non-trivial chains are coloured in example



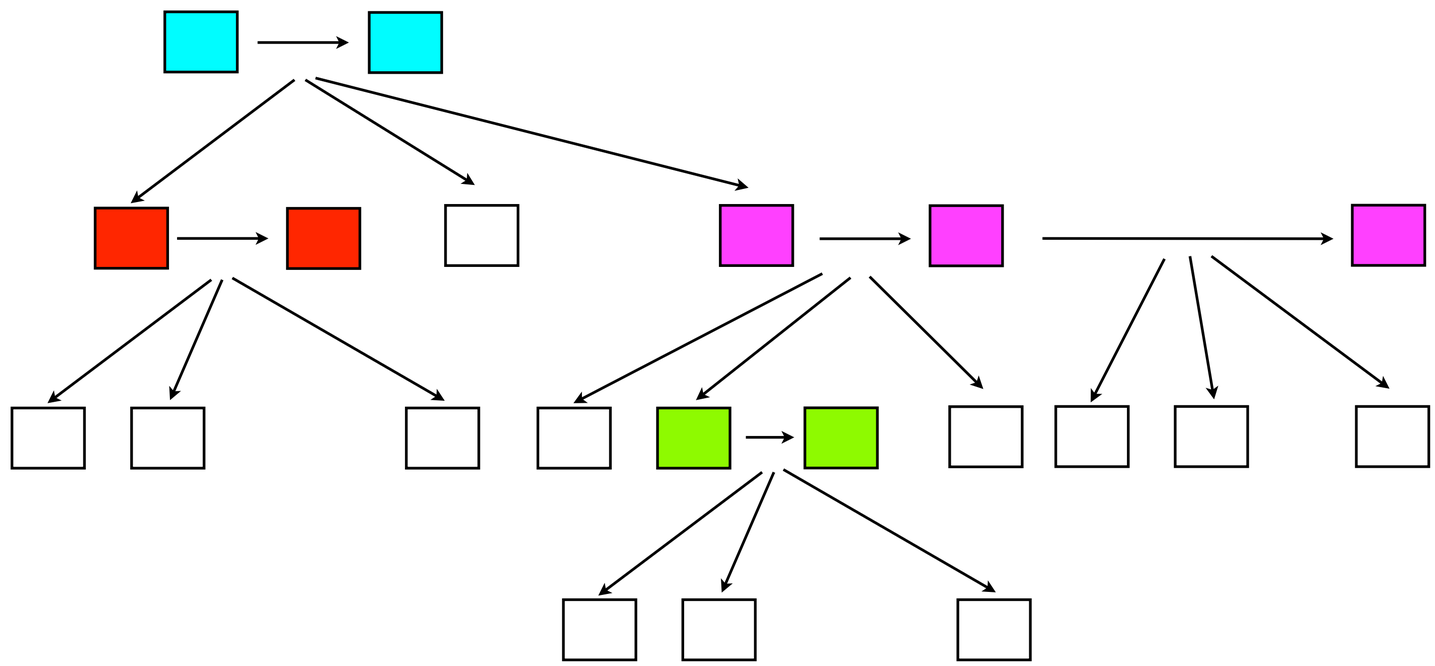
GlobalTempDir

- A ‘globalTempDir’ temporary directory is created for each chain.



GlobalTempDir

- It is created just before the founder and deleted just after the closer.
- It allows files to be passed around between follow ons and their children.



Job-tree/Script-tree

```python
#!/usr/bin/env python

"""A demonstration of jobTree. Sorts the lines of a file into ascending order by doing a parallel merge
sort.
"""
from optparse import OptionParser
import os
import shutil
from sonLib.bioio import getTempFile
from workflow.jobTree.scriptTree.target import Target
from workflow.jobTree.scriptTree.stack import Stack
from workflow.jobTree.test.sort.lib import merge, sort, copySubRangeOfFile, getMidPoint

class Setup(Target):
    """Sets up the sort.
    """
    def __init__(self, inputFile, N):
        Target.__init__(self, time=1, memory=1000000, cpu=1)
        self.inputFile = inputFile
        self.N = N

    def run(self):
        tempOutputFile = getTempFile(rootDir=self.getGlobalTempDir())
        self.addChildTarget(Down(self.inputFile, 0, os.path.getsize(self.inputFile), self.N,
tempOutputFile))
        self.setFollowOnTarget(Cleanup(tempOutputFile, self.inputFile))

class Cleanup(Target):
    """Copies back the temporary file to input once we've successfully sorted the temporary file.
    """
    def __init__(self, tempOutputFile, outputFile):
        Target.__init__(self)
        self.tempOutputFile = tempOutputFile
        self.outputFile = outputFile

    def run(self):
        shutil.copyfile(self.tempOutputFile, self.outputFile)
```

```python
class Down(Target):
    """Input is a file and a range into that file to sort and an output location in which
    to write the sorted file.
    If the range is larger than a threshold N the range is divided recursively and
    a follow on job is then created which merges back the results else
    the file is sorted and placed in the output.
    """
    def __init__(self, inputFile, fileStart, fileEnd, N, outputFile):
        assert fileStart >= 0
        assert fileStart <= fileEnd
        Target.__init__(self, time=0.05)
        self.inputFile = inputFile
        self.fileStart = fileStart
        self.fileEnd = fileEnd
        self.N = N
        self.outputFile = outputFile

    def run(self):
        length = self.fileEnd - self.fileStart
        assert length >= 0
        if length > self.N:
            midPoint = getMidPoint(self.inputFile, self.fileStart, self.fileEnd)
            assert midPoint >= self.fileStart
            assert midPoint+1 < self.fileEnd
            #We will subdivide the file
            tempFile1 = getTempFile(rootDir=self.getGlobalTempDir())
            tempFile2 = getTempFile(rootDir=self.getGlobalTempDir())
            self.addChildTarget(Down(self.inputFile, self.fileStart, midPoint+1, self.N, tempFile1))
            self.addChildTarget(Down(self.inputFile, midPoint+1, self.fileEnd, self.N, tempFile2)) #Add
one to avoid the newline
            self.setFollowOnTarget(Up(tempFile1, tempFile2, self.outputFile))
        else:
            #We can sort this bit of the file
            copySubRangeOfFile(self.inputFile, self.fileStart, self.fileEnd, self.outputFile)
            sort(self.outputFile)

class Up(Target):
    """Merges the two files and places them in the output.
    """
    def __init__(self, inputFile1, inputFile2, outputFile):
        Target.__init__(self, time=0.05)
        self.inputFile1 = inputFile1
        self.inputFile2 = inputFile2
        self.outputFile = outputFile

    def run(self):
        merge(self.inputFile1, self.inputFile2, self.outputFile)
```

Running Job-tree/Script-tree

```
def main():
    parser = OptionParser()
    Stack.addJobTreeOptions(parser)

    parser.add_option("--fileToSort", dest="fileToSort",
                      help="The file you wish to sort")

    options, args = parser.parse_args()

    if options.fileToSort == None:
        raise RuntimeError("No file to sort given")

    #Now we are ready to run
    i = Stack(Setup(options.fileToSort, int(options.N))).startJobTree(options)

    if i:
        raise RuntimeError("The jobtree contained %i failed jobs" % i)

if __name__ == '__main__':
    from workflow.jobTree.test.sort.Script-treeTest_Sort import *
    main()
```

benedict$ Script-treeTest_Sort.py --jobTree foo/Job-tree --logDebug --fileToSort bar.txt

Running Job-tree/Script-tree

```
def main():
    parser = OptionParser()
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if __name__ == '__main__':
    from workflow.jobTree.test.sort.Script-treeTest_Sort import *
    main()
```

Create a parser for the script and add the Job-tree options to it.

benedict$ Script-treeTest_Sort.py --jobTree foo/Job-tree --logDebug --fileToSort bar.txt

Running Job-tree/Script-tree

```
def main():
    parser = OptionParser()
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if __name__ == '__main__':
    from workflow.jobTree.test.sort.Script-treeTest_Sort import *
    main()
```

Parse the options and args

benedict$ Script-treeTest_Sort.py --jobTree foo/Job-tree --logDebug --fileToSort bar.txt

Running Job-tree/Script-tree

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def main():
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if __name__ == '__main__':
    from workflow.jobTree.test.sort.Script-treeTest_Sort import *
    main()
```

Run Job-tree (alternatively you can pass in the options to jobtre manually and use your own options/args parser)

benedict$ Script-treeTest_Sort.py --jobTree foo/Job-tree --logDebug --fileToSort bar.txt

Running Job-tree/Script-tree

```
def main():
    parser = OptionParser()
    Stack.addJobTreeOptions(parser)

    parser.add_option("--fileToSort", dest="fileToSort",
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    options, args = parser.parse_args()

    if options.fileToSort == None:
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    #Now we are ready to run
    i = Stack(Setup(options.fileToSort, int(options.N))).startJobTree(options)

    if i:
        raise RuntimeError("The jobtree contained %i failed jobs" % i)

if __name__ == '__main__':
    from workflow.jobTree.test.sort.Script-treeTest_Sort import *
    main()
```

The command line

benedict$ Script-treeTest_Sort.py --jobTree foo/Job-tree --logDebug --fileToSort bar.txt

Running Job-tree/Script-tree

```
def main():
    parser = OptionParser()
    Stack.addJobTreeOptions(parser)

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    #Now we are ready to run
    i = Stack(Setup(options.fileToSort, int(options.N))).startJobTree(options)

    if i:
        raise RuntimeError("The jobtree contained %i failed jobs" % i)

if __name__ == '__main__':
    from workflow.jobTree.test.sort.Script-treeTest_Sort import *
    main()
```

Oh, and a little voodoo required by the pickler

benedict$ Script-treeTest_Sort.py --jobTree foo/Job-tree --logDebug --fileToSort bar.txt

Job-tree/Script-tree Misc.

- You can put as many targets as you like in a file, allowing complex pipelines to be created in a single physical file.
  - The Haussler group reconstruction pipeline consists of more than a dozen high level targets in a file, with subparts of the pipeline logically divided in other files.
- Your environment variables are inherited from the executing shell, so you can use relative path names and program names without stressing.
- Can run on a parasol cluster, or in single machine mode (using multiple threads!), so you can test on a workstation before you push your pipeline to the cluster.
- Is (theoretically) easily extended to work on another batch system - just inherit the abstract batch system class.

Job-tree Summary

- Allows you to dynamically create arbitrarily parallelised batches of jobs.
- Provides other nice features.
- Is stable and used by me, Dent, Krish, Charlie, Daniel, Ngan and run by others, including Wendy, Ted, Bernard, etc.
- Unfortunately, the code is pretty dense and prototype-y, and there are some clunky edges.

Utilities

- These next slides detail the utilities for job-tree

jobTreeStats: Balancing job-trees

- Your jobs on the cluster should run for some 'ideal' time in order to efficient.
- Job-tree will attempt to agglomerate your short running jobs to avoid paying scheduling costs (which may be a few seconds of latency per job!)
- Running job-tree with --stats option allows you to run jobTreeStats

```
benedict$ Script-treeTest_Sort.py --jobTree foo/Job-tree --logDebug --fileToSort bar.txt --stats
benedict$ jobTreeStats --jobTree foo/Job-tree
```

jobTreeStats: Balancing job-trees


```
<collated_stats batch_system="single_machine" default_cpu="1" default_memory="2147483648" job_time="0.5" max_jobs="922337203
6854775807" max_threads="1" total_run_time="8.50252699852">
  <slave average_time="0.55012343824" max_time="1.75700092316" median_time="0.429350137711" min_time="0.0157799720764" total
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  <job average_number_per_slave="2.5625" average_time="0.19536111413" max_number_per_slave="10" max_time="0.69593000412" med
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  <target average_number_per_job="199.829268293" average_time="0.000488620646544" max_number_per_job="1112" max_time="0.0799
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tal_number="8193" total_time="4.00326895714"/>
  <target_types>
    <Down average_time="0.00047725673919" estimated_time="0.00045" max_time="0.0799999237061" median_time="0.000394821166992
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    <Setup average_time="0.00031590461731" estimated_time="0.00025" max_time="0.00031590461731" median_time="0.0003159046173
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    <ParallelFollowOnTarget average_time="0.000471115112305" estimated_time="0.0" max_time="0.000471115112305" median_time="
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    <Up average_time="0.000521550483685" estimated_time="0.0007" max_time="0.0595879554749" median_time="0.000261068344116"
min_time="0.000193119049072" total_number="2047" total_time="1.0676138401"/>
  </target_types>
</collated_stats>
```


Example from script-treeTest_Sort.py

jobTreeStats: Balancing job-trees


```
<collated_stats batch_system="single_machine" default_cpu="1" default_memory="2147483648" job_time="0.5" max_jobs="922337203
6854775807" max_threads="1" total_run_time="8.50252659852">
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    <Setup average_time="0.00031590461731" estimated_time="0.00025" max_time="0.00031590461731" median_time="0.0003159046173
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    <Cleanup average_time="0.00308609008789" estimated_time="0.0031" max_time="0.00308609008789" median_time="0.003086090087
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    <ParallelFollowOnTarget average_time="0.000471115112305" estimated_time="0.0" max_time="0.000471115112305" median_time="
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    <Up average_time="0.000521550483685" estimated_time="0.0007" max_time="0.0595879554749" median_time="0.000261068344116"
min_time="0.000193119049072" total_number="2047" total_time="1.0676138401"/>
  </target_types>
</collated_stats>
```


Total runtime and stats about job tree.

jobTreeStats: Balancing job-trees


```
<collated_stats batch_system="single_machine" default_cpu="1" default_memory="2147483648" job_time="0.5" max_jobs="922337203
6854775807" max_threads="1" total_run_time="8.50252699852">
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min_time="0.000193119049072" total_number="2047" total_time="1.0676138401"/>
  </target_types>
</collated_stats>
```


Times on targets, which are agglomerated into jobs

jobTreeStats: Balancing job-trees


```
<collated_stats batch_system="single_machine" default_cpu="1" default_memory="2147483648" job_time="0.5" max_jobs="922337203
6854775807" max_threads="1" total_run_time="8.50252699852">
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min_time="0.000193119049072" total_number="2047" total_time="1.0676138401"/>
  </target_types>
</collated_stats>
```


Times on individual targets, showing how close your estimated jobs came to the actual run-times

jobTreeStats: Balancing job-trees


```
<collated_stats batch_system="single_machine" default_cpu="1" default_memory="2147483648" job_time="0.5" max_jobs="922337203
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min_time="0.000193119049072" total_number="2047" total_time="1.0676138401"/>
  </target_types>
</collated_stats>
```


This example ran 8193 targets, in a single thread in 8.5 seconds!

jobTreeStats: Balancing job-trees


```
<collated_stats batch_system="single_machine" default_cpu="1" default_memory="2147483648" job_time="0.5" max_jobs="922337203
6854775807" max_threads="1" total_run_time="8.50252699852">
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_number="16" total_time="8.80197501183"/>
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ian_number_per_slave="1" median_time="0.134316921234" min_number_per_slave="1" min_time="0.0079870223999" total_number="41"
total_time="8.00980567932"/>
  <target average_number_per_job="199.829268293" average_time="0.000488620646544" max_number_per_job="1112" max_time="0.0799
999237061" median_number_per_job="32" median_time="0.000387191772461" min_number_per_job="0" min_time="0.000193119049072" to
tal_number="8193" total_time="4.00326895714"/>
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" min_time="0.000314950942993" total_number="6142" total_time="2.93131089211"/>
    <Setup average_time="0.00031590461731" estimated_time="0.00025" max_time="0.00031590461731" median_time="0.0003159046173
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    <Cleanup average_time="0.00308609008789" estimated_time="0.0031" max_time="0.00308609008789" median_time="0.003086090087
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    <ParallelFollowOnTarget average_time="0.000471115112305" estimated_time="0.0" max_time="0.000471115112305" median_time="
0.000471115112305" min_time="0.000471115112305" total_number="2" total_time="0.00094223022461"/>
    <Up average_time="0.000521550483685" estimated_time="0.0007" max_time="0.0595879554749" median_time="0.000261068344116"
min_time="0.000193119049072" total_number="2047" total_time="1.0676138401"/>
  </target_types>
</collated_stats>
```


Times that the slaves ran 'jobs', in this case we've asked for a job-runtime of 0.5 seconds, the actual average was 0.55 seconds