

# An Exascale Slurm Testing and Evaluation Environment Utilising Generated DAG Workloads

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# Motivation

## Current state of Slurm simulators

- ▶ Mostly focus on scheduling performance
- ▶ Very fragile and broken due to large changes to Slurm codebase
- ▶ DAG workloads not supported, but more and more common due to workflow managers/meta-schedulers

## Exascale challenges

- ▶ Some previously trivial things become very difficult (e.g. GPU testing/monitoring)
- ▶ Monitoring/data analysis tools require more testing
- ▶ No public access representative workload data

## Reproducibility

- ▶ Many MODA innovations are unpublished, especially for exascale systems
- ▶ Reproduction/Documentation is often difficult due to tight integration

# Goals

## Extend the scope of Slurm simulators

- ▶ Job prologs, epilogs, inter-job profiling, etc.
- ▶ Observe plugin interactions, facilitate software integration/testing
- ▶ Exascale testing and evaluation environment on a single node

## Provide a robust and flexible solution

- ▶ Minimal code changes
- ▶ Wide range of applications (monitoring, analytics, etc.)

## Improve reproducibility

- ▶ Clearly document environment setup
- ▶ Provide environment for testing and evaluation of exascale tooling on test machines

# DAG Workload Generation (1/2)

## Algorithm

- ▶ No data available, need to generate DAGs
- ▶ Proposed algorithm

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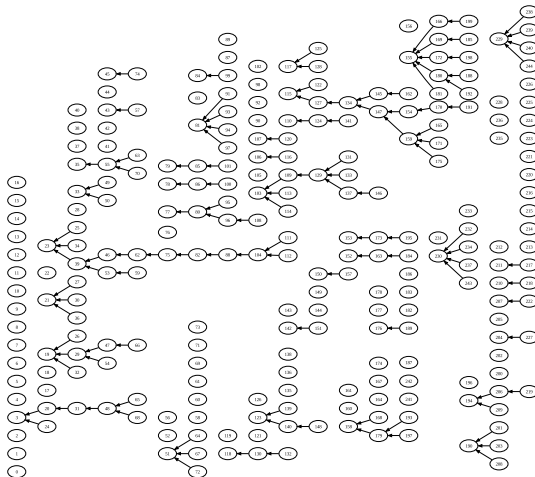
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```
input :  $r \in \mathbb{N}_0$ : number of ranks  
          $\underline{n} \leq \bar{n} \in \mathbb{N}_1$ : min./max. nodes per rank  
          $\underline{d} \leq \bar{d} \in \mathbb{N}_0$ : min./max. deps. per node  
output:  $G := (V, E)$ : directed acyclic graph  
          $R_1, \dots, R_r$ : sets of nodes of each rank  
  
 $G = (V, E) \leftarrow (\emptyset, \emptyset)$   
for  $i \leftarrow 1$  to  $r$  do  
     $n_i \leftarrow \text{DiscreteUniformRandom}(\underline{n}, \bar{n})$   
     $R_i \leftarrow \text{GenerateNodes}(n_i)$   
     $V \leftarrow V \cup R_i$   
    if  $i > 1$  then  
        for  $j \leftarrow 1$  to  $n_i$  do  
             $d \leftarrow \text{Min}(n_{i-1}, \text{DiscreteUniformRandom}(\underline{d}, \bar{d}))$   
             $D \leftarrow \text{DrawDistinctRandomFrom}(R_{i-1}, d)$   
            for  $k \leftarrow 1$  to  $d$  do  
                 $E \leftarrow E \cup (R_i[j], D[k])$   
            end  
        end  
    end  
end
```

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# DAG Workload Generation (2/2)

## Example and Parameter Choice



**Parameter choice:** High sparsity, low node degree

**Job parameters:** Randomly generated separately as 'node weights'

# Exascale Slurm Setup (1/3)

## Reference and first steps

Reference system: Frontier, Oak Ridge National Labs (1.194 EFLOPS)

- ▶ 74 rack cabinets, 64 blades per cabinet, 2 nodes per blade
- ▶ 9,472  $\approx$  10,000 nodes, 64 cores per node

What stop us from running Slurm with 10,000 nodes on a single machine?

## Basic configuration

- ▶ Compile Slurm from source with special flag  
`./configure ... --enable-multiple-slurmd`
- ▶ Modify `slurm.conf`: Include %n (node name) in `SlurmdSpoolDir`, `SlurmdLogFile`, `SlurmdPidFile`
- ▶ Add node definitions

```
NodeName=atom[00000-09999] NodeHostname=HOSTNAME
Port=[10000-19999] Sockets=1 CPUs=1 CoresPerSocket=64
ThreadsPerCore=128 State=UNKNOWN PartitionName=part1
Nodes=ALL Default=YES MaxTime=INFINITE State=Up
```

Does it work? No, hits hard cgroup limits after 1,500 nodes

# Exascale Slurm Setup (2/3)

## Trimming overhead

- ▶ Disable cgroup process tracking (Set ProctrackType to proctrack/pgid)
- ▶ Disable task plugin

Does it work? No, nodes launch but are lobotomised

It turns out (after many hours)

- ▶ Systemd insists on being a 'cgroup broker' via dbus
- ▶ Chokes after around 2,500 nodes, no direct error
- ▶ Nodes start but can't communicate with control daemon
- ▶ **Solution** (found in Slurm source, but also buried in the manual):  
Create a file `/etc/cgroup.conf` containing `IgnoreSystemd=yes`



# Exascale Slurm Setup (3/3)

## System integration and helper scripts

- ▶ Give Slurmd a higher scheduling priority (add `Nice=-20` to `slurmd.service`)
- ▶ Create node template service (Rename `slurmd.service` to `slurmd@.service` and add `-N %i` to `slurmd` call in `ExecStart`), each node is a service (e.g. `slurmd@atom00001`, etc.)
- ▶ Start/stop scripts (complete reset, database wipe)

```
#!/bin/sh

systemctl stop slurmd
systemctl stop slurmdbd
rm -rf /var/spool/slurm/* /var/log/
    slurm/* /run/slurm/*

systemctl start slurmdbd
sleep 2
systemctl start slurmd
printf "started slurmdbd, slurmd\n"
for i in $(seq -f "%05g" 0 9999); do
    systemctl start slurmd@atom$i;
    printf "\rstarted atom $i/09999";
done
printf "\n"
```

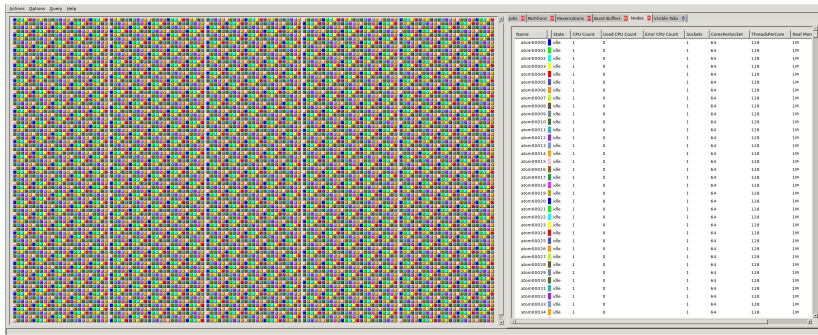
```
#!/bin/sh

for i in $(seq -f "%05g" 0 9999); do
    systemctl kill --signal=SIGKILL
        slurmd@atom$i;
    printf "\rstopped atom $i/09999";
done
printf "\n"
systemctl stop slurmd
printf "stopped slurmd\n"
systemctl stop slurmdbd
printf "stopped slurmdbd\n"
rm -rf /var/spool/slurm/* /var/log/
    slurm/* /run/slurm/*
printf "DROP DATABASE slurm_acct_db;\n"
| mysql
```



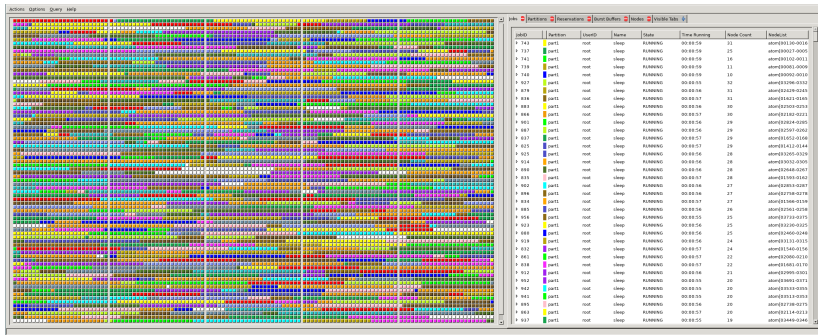
# sview(1)

## Node Overview



# sview(1)

## Job Overview



# WOG (Workload Generator and Evaluator)

## Overview

### Core Functions

- ▶ Randomly generate DAG workloads
- ▶ Submit workload to Slurm
- ▶ Supervise execution and collect data

### Implementation Notes

- ▶ C99 using POSIX interfaces
- ▶ Separate DAG from job parameters
- ▶ Parse job completion log for data

# WOG (Workload Generator and Evaluator)

## Model Job

- ▶ Jobs are sleepers
- ▶ Target runtime is randomly jittered
- ▶ Batch script

```
#!/bin/sh

#SBATCH --job-name=sleep

sleep $EXECUTION_TIME
```

- ▶ Dummy job is extensible (telemetry, prolog/epilog, etc.)
- ▶ Control via environment variables

# WOG (Workload Generator and Evaluator)

## Workload Generation and Slurm Interface

### Workload generation and processing

- ▶ `struct dag_parameters`: Number of ranks, range of node count per rank, range of number of dependencies per node
- ▶ `dag_generate()`: Generate DAG from parameters
- ▶ `struct experiment`: DAG parameters, job parameters
- ▶ `experiment_run()`

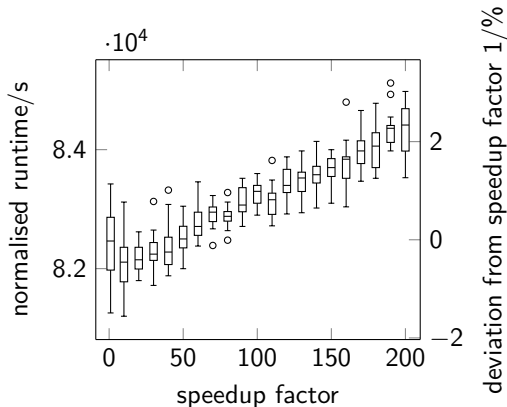
### Slurm Interface

- ▶ Use Slurm CLI with `execve(2)` (high stability)
- ▶ `slurm_clear_job_queue()`
- ▶ `slurm_submit_sleeper_job()`: Job is submitted in a held state
- ▶ `slurm_release_sleeper_jobs()`: Single call to `scontrol(1)`, no loop

# WOG (Workload Generator and Evaluator)

## Benchmark

- ▶ Machine: Intel Xeon E5-2637 v2, 4c8t, 192 GiB RAM
- ▶ Memory consumption: 16 MiB per virtual node, 160 GiB total
- ▶ Evaluation function: Time taken
- ▶ Workload: 1 day, speedup  $\{1, 10, 20, \dots, 200\}$ , 20 repetitions each



Only around 2-3% deviation despite speedup factor 200

# Conclusion

- ▶ Fully reproducible Slurm virtual exascale cluster setup, all steps laid out (e.g. student reference)
- ▶ WOGÉ for submitting and evaluating artificial workloads
- ▶ Outlook: More intricate random distributions, graph generators (more data needed)
- ▶ Long-term: Characterise workloads with a set of parameters and reproduce it artificially this way