SCALABLE COMPUTING LABORATORY

VANDERBILT UNIVERSITY

SC3260 / SC5260

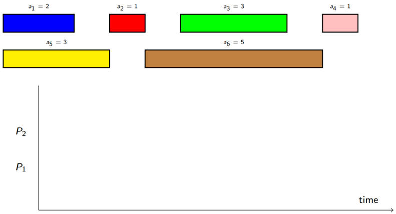
Batch Scheduler - part 2 -

Lecture by: Ana Gainaru

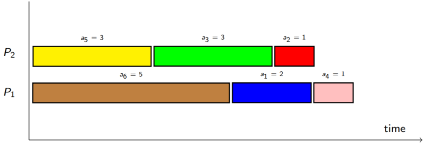
Why do we need batch schedulers?

The scheduler can be used to balance all the metrics

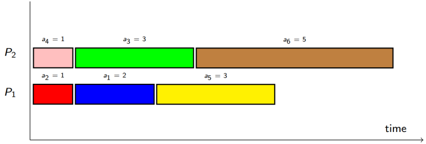
- User fairness
- System utilization
- Application response time



Longest job first



Shortest job first



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Recap

Currently used: FCFS scheduling policy with backfilling

Let's look at some examples to better understand the difference
Examples from: `https://github.com/vanderbiltscl/SC3260_HPC/schedule_simulations`

ScheduleFlow

- Scheduler simulator developed by our group
- `https://github.com/anagainaru/ScheduleFlow`

Today

Where did we left off?

1. SLURM and how to use it

2. A few promising directions for the future
   - Gang scheduling
   - Task based scheduler (work stealing)

SLURM

Simple Linux Utility for Resource Management

- Development started in 2002 @ Lawrence Livermore National Lab as a resource manager for Linux clusters
  - Sophisticated scheduling plugins added in 2008
- About 550,000 lines of C code today
- Supports Linux and limited support for other Unix variants
- Used on many of the world's largest computers
- Active global user community

SLURM design

- Highly scalable
  - Managing 3.1 million core Tianhe-2
  - Tested to much larger systems using emulation
- Open source GPLv2, available on Github: `https://github.com/SchedMD/`
- Fault-tolerant (no single point of failure)

- Dynamically linked objects loaded at run time based upon configuration file and/or user options
- Multiple plugins in 30 classes currently available
  - Network topology: 3D-torus, tree, etc
  - MPI: OpenMPI, PMI2, PMIx
  - Process tracking: cgroup, linuxproc, pgid, ipmi, etc.

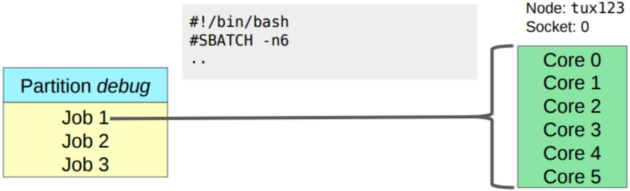
SLURM Usage

- Users submit jobs to partitions (queue)

Priority ordered queue of jobs

Partition *debug*
Job 1
Job 2
Job 3

- Jobs are allocated resources



```
#!/bin/bash
#SBATCH -n6
..
```

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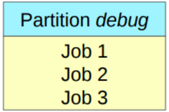
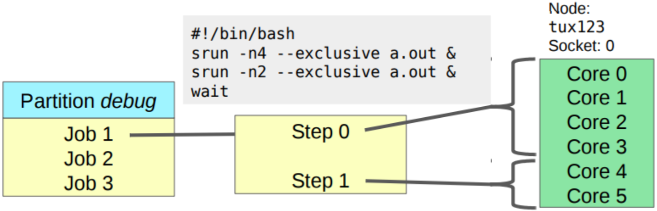
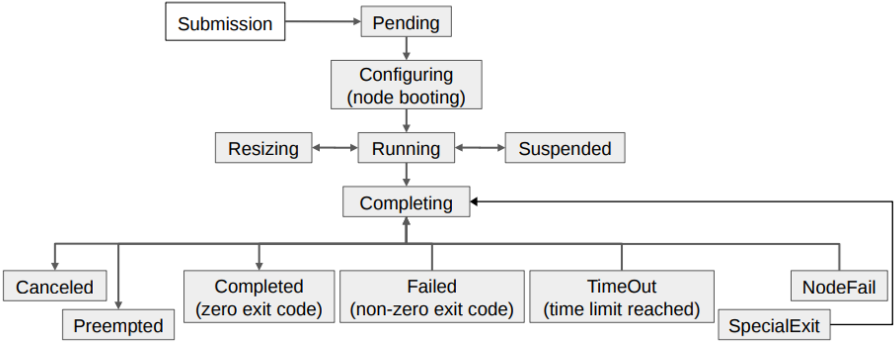


- Jobs spawn steps, which are allocated resources from within the job's allocation



```
#!/bin/bash
srun -n4 --exclusive a.out &
srun -n2 --exclusive a.out &
wait
```

Job States



Submission

Pending

Configuring (node booting)

Resizing

Running

Suspended

Completing

Canceled

Preempted

Completed (zero exit code)

Failed (non-zero exit code)

TimeOut (time limit reached)

NodeFail

SpecialExit

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SLURM implementation

SLURM can be configured by system administrators in different formats

Frequently using a reservation-based configuration that assigns reservations on job arrival, job finish and at priority change.

- Can use one or multiple priority queues
- FCFS policy of ordering the queue
- Job priority is increased when waiting long time in the queue
- EASY Backfilling
- Node hours are required, job is killed in case of under-estimation
- Supports interactive sessions (`salloc`)
- Supports non-interactive sessions (`srun`, `sbatch`)

Summary

Documentation for SLURM available at `https://slurm.schedmd.com`

What you used for the homeworks should be enough for most projects

`https://hpc-carpentry.github.io/hpc-intro/13-scheduler/index.html`

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Next

- Gang scheduling
- Task based scheduler (work stealing)

Gang Scheduling: Basis

- All processes belonging to a job run at the same time (the term gang denotes all processors within a job).
- Each process runs alone on each processor.
- BUT: there is rapid coordinated context switching.
- It is possible to suspend/preempt jobs arbitrarily

May allow more flexibility to improve some metrics

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- If processing times are not known in advance (or grossly erroneous), preemption can help short jobs that would be "stuck" behind a long job.
- Should improve machine utilization

Gang Scheduling: Example

- A 128 node cluster.
- A running 64-node job.
- A 32-node job and a 128-node job are queued.

Should the 32-node job be started?

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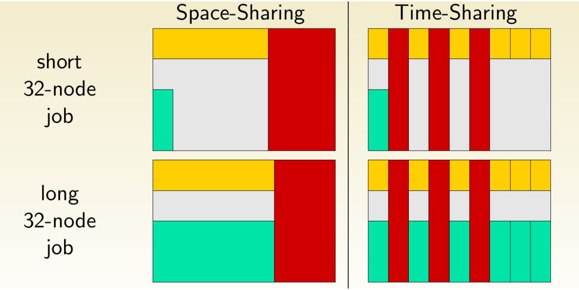

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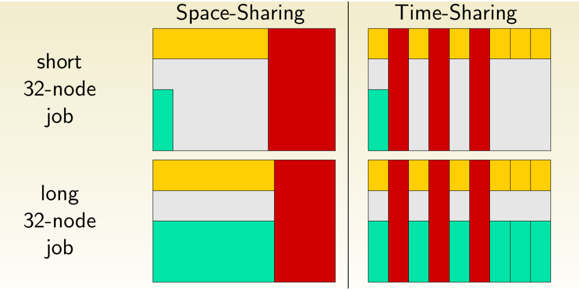

More uniform slowdown, better resource usage.

Drawbacks

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- RAM Pressure (more jobs must fit in memory, swapping to disk causes unacceptable overhead)

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Typically not used in production HPC systems (batch scheduling is preferred)

Some implementations (MOSIX, Kerighed)

Gang Scheduling conclusion

- Nice idea, might work in the future.

For now it is not implemented in any of the major HPC systems

Work stealing

- A task-graph G needs to be executed on p processors.
- Non-clairvoyant setting : the structure of G and/or the execution times of its constitutive tasks are discovered online

Sharing vs Stealing

Batch scheduling

- Centralized scheduling
- A single list stores all ready tasks
- All processors retrieve work from that list
- Advantage(s)
  - Global view and knownledge
- Drawback(s)
  - Does not scale (contentions, etc.)

Work stealing

- Distributed scheduling
- Each processor owns a list of 'its' ready tasks
- Advantage(s)
  - No contention problem
  - Scalable solution
- Drawback(s)
  - Processors with empty lists do not know where to retrieve work from

Policies

Global round-robin

- A global variable holds the identity of the next processor to steal from
- Variable incremented after each steal (successful or not)
- Advantage : eventual progress
- Drawback : centralized solution...

Local round-robin

- Each processor has its own variable indicating the next processor it should try to steal from
- Variable incremented after each steal (successful or not)
- Advantage : eventual progress ; solution is scalable
- Drawback : all stealing processors may attempt to steal from the same processor; arbitrary notion of "distance" between processors

For now we're stuck with batch scheduling

Why don't we like Batch Scheduling?

For now we're stuck with batch scheduling

Why don't we like Batch Scheduling? Because queue waiting times are difficult to predict

- depends on the status of the queue
- depends on the scheduling algorithm used
- depends on all sorts of configuration parameters set by system administrator
- depends on future job completions!
- etc.

There is more and more demand for reservation support

Conclusion

Batch schedulers are complex pieces of software that are used in practice

- A lot of experience on how they work and how to use them
- But ultimately everybody knows they are an imperfect solution
- Many view the lack of theoretical foundations as a big problem

You need to know about them since every cluster uses them

Further Reading

Book on the theory of scheduling

D.B. Shmoys, J. Wein, and D.P. Williamson. *Scheduling parallel machines on-line* Symposium on Foundations of Computer Science, 0:131-140, 1991.

SLURM slides from

https://slurm.schedmd.com/SLUG18/slurm_overview.pdf

List of SLURM commands

https://hpc-carpentry.github.io/hpc-intro/13-scheduler/index.html

Figures from today's slides courtesy of Arnaud Legrand and Guillaume Pallez
http://people.bordeaux.inria.fr/gaupy/ressources/teachings/2019/algo_hpc/