The SLURM Scheduler Design

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Agenda

- Purpose of the talk
- Scope of the talk
- What the scheduler must do
- Job submission options
- How it does it

Purpose of the Talk

- To provide a conceptual framework to serve as a reference as you:
  - Read through the documentation
  - Diagnose problems
  - Particularly when trying to discover why a job is not being scheduled.
  - Modify the code

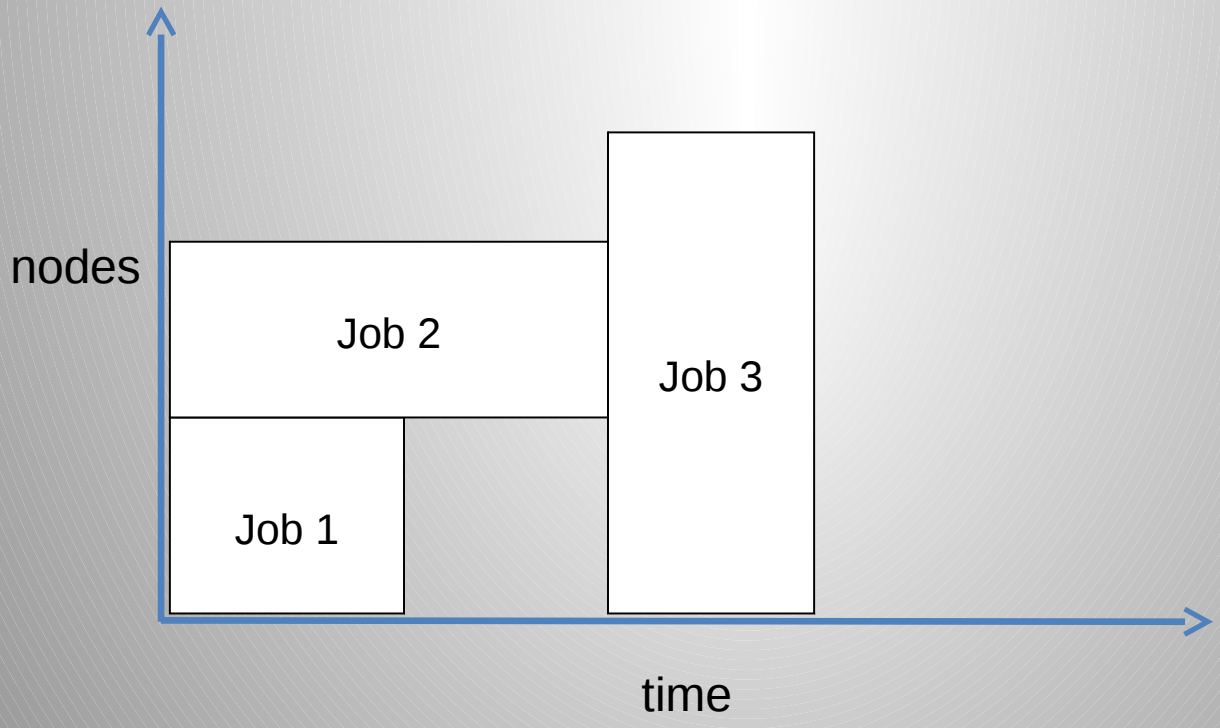
Scope of the Talk

- Explain how SLURM selects the resources needed to run the top priority job
- Explore the code design, SLURM v2.4
- Illuminate the scheduling loop
- Include a discussion of the supporting plugins
- Omit Blue Gene and Cray ports
- Omit the multi-factor priority plugin
- Less important details omitted in the interest of time
- Focus on scheduling activities, not all of the functionality of the SLURM control daemon

Scheduling

- The process of determining what job to run next and on which resources.
- Based on the job request, resources available, and policy limits imposed.
- Starts with job priority.
- Results in a resource allocation over a period of time.
- The slurmctld loops through a set of jobs and finds resources to schedule to those jobs.

Scheduling Jobs



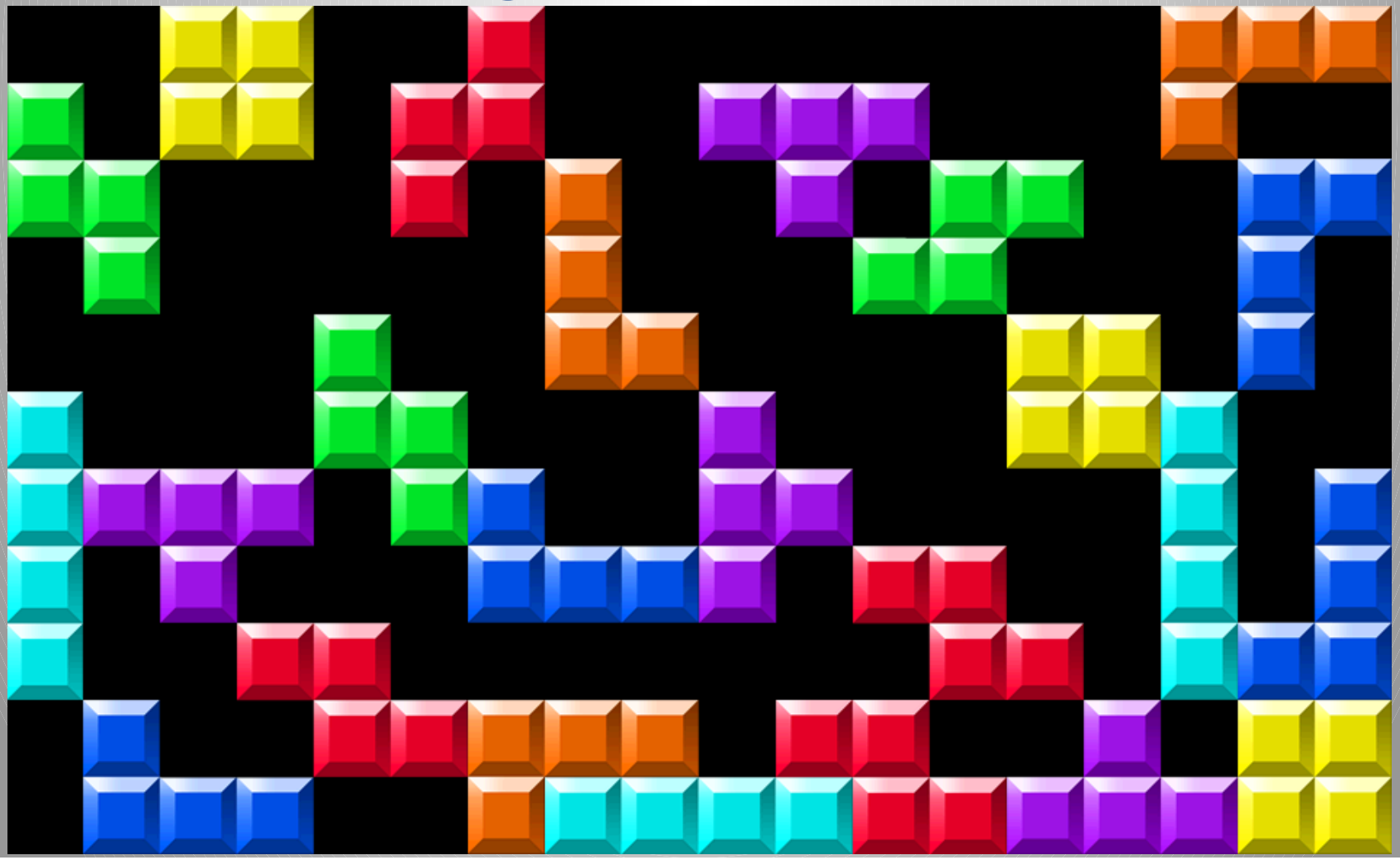
Allocation vs. Task Placement

- Allocation is the selection of the resources needed for the job
- Each job includes zero or more job steps (**`srun`**)
- Each job step is comprised of one to multiple tasks
- Task placement is the process of assigning a subset of the job's allocated resources (cpus) to each task

What the Scheduler Must Schedule

- Nodes
- Sockets
- Cores
- Hardware Threads (cpus)
- Memory
- Generic resources (e.g., gpus, file systems)
- Licenses

Effectively amounts to an n-dimensional game of Tetris



Scheduling-related Plugins - 1

- sched
  - backfill
  - builtin
  - hold
  - wiki
  - wiki2
- select
  - bluegene
  - cons_res
  - cray
  - linear
  - serial (in v2.5)

Scheduling-related Plugins - 2

- gres
  - gpu
  - nic
- preempt
  - none
  - partition_prio
  - qos
- priority
  - basic
  - multifactor
- topology
  - 3d_torus
  - node_rank
  - none
  - tree

Scheduling Modes

- Node scheduled
  - linear, bluegene, and cray select plugins
- CPU scheduled
  - cons_res (consumable resources) plugin

Job Submit Options

- **`sbatch`**
  - Submits a job command script for batch scheduling
  - **`sbatch`** returns immediately with the job ID
- **`salloc`**
  - Requests an interactive shell
  - **`salloc`** blocks until the job is scheduled, at which point a shell prompt appears
- **`srun`**
  - Run an executable as a single job and job step
  - **`srun`** blocks until the job is scheduled

sbatch/salloc/srun
Resource Allocation Specifications - 1

- Cluster -M, --clusters (one or many)
- Partition -p, --partition (one or many)
- Node count-N, --nodes (accepts range)
- Node restrictions
  - --exclusive
  - --share
  - --contiguous
  - --geometry
  - -F, --nodefile
  - -w, --nodelist
  - -x, --exclude
  - --switches

sbatch/salloc/srun Resource Allocation Specifications - 2

- Task count -n, --ntasks
- Task specifications
  - --ntasks-per-node
  - --ntasks-per-socket
  - --ntasks-per-core
  - --cpus-per-task
  - -O, --overcommit
- Memory (node) --mem
- Memory (cpu) --mem-per-cpu
- Generic resources --gres
- Licenses --licenses

sbatch/salloc/srun Filters Eliminate Nodes from Consideration

-C, --constraint

--sockets-per-node=<sockets>

--cores-per-socket=<cores>

--threads-per-core=<threads>

--mem

--mem-per-cpu

--mincpus

--tmp=<min disk space>

Further Constraints

- Job dependency -d, --dependency
- Node reservation --reservation

Time Dimension

- Duration -t, --time
- Min duration --time-min
- Start after --begin

Task Placement Directives

- --cpus-per-task
- -m, --distribution
- --ntasks-per-node
- --ntasks-per-socket
- --ntasks-per-core
- -O, --overcommit
- --hint

Task Binding

- For info on task binding, see the 2011 SLURM User Group Meeting presentation:

  Resource Management for Multi-Core/Multi-Threaded Usage by Martin Perry

  http://www.schedmd.com/slurmdocs/slurm_ug_2011/cons_res.pdf

Configuration Options Affecting Scheduling

- DefMemPerCPU
  MaxMemPerCPU
- DefMemPerNode
  MaxMemPerNode
- FastSchedule
- GresTypes
- Licenses
- MaxTasksPerNode
- ResvOverRun
- SchedulerTimeSlice
- SchedulerType
  SchedulerParameters
- SelectType
  SelectTypeParameters
- TopologyPlugin
- Node and Partition settings

slurmctld standard threads

- _slurmctld_background

  actually, the main thread

- _slurmctld_rpc_mgr

  responds to remote procedure calls

- _slurmctld_signal_hand

  responds to signals to transition the system to a different state

- slurmctld_state_save

  repeatedly runs to save system state

Examples of Other Threads

- Multifactor Priority Plugin Threads

  _decay_thread

  _cleanup_thread

- Sched Plugin Threads

  builtin_agent

  backfill_agent

- Accounting Storage slurmdbd Plugin Thread

  _set_db_inx_thread

Agents

- Responsible for transmitting a common RPC in parallel across a set of nodes
- agent_queue_request() is the standard call to initiate an agent
- Allows services that send messages to continue without waiting for the delivery of a message.
- These threads live just long enough to deliver (and perhaps confirm delivery of) the message.

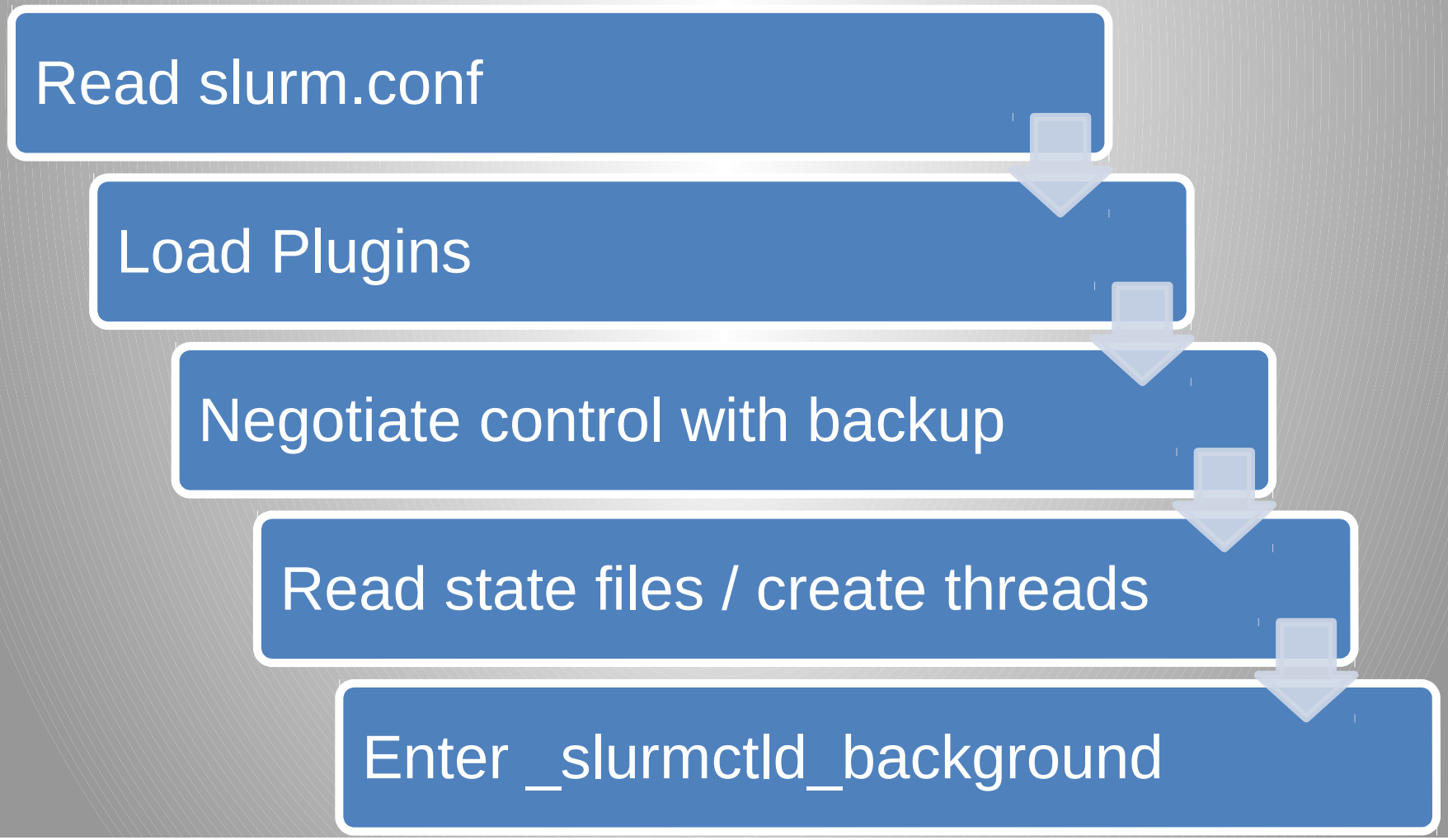
Global objects of interest

- node_record_table_ptr - table of node_record structures
- node_record_count - number of entries
- node_hash_table - used to quickly search the node_record_table
- avail_node_bitmap
- job_list - unsorted List of job_record structures
- part_list - List of part_record structures
- Protected by read/write locks defined at the start of _slurmctld_background()

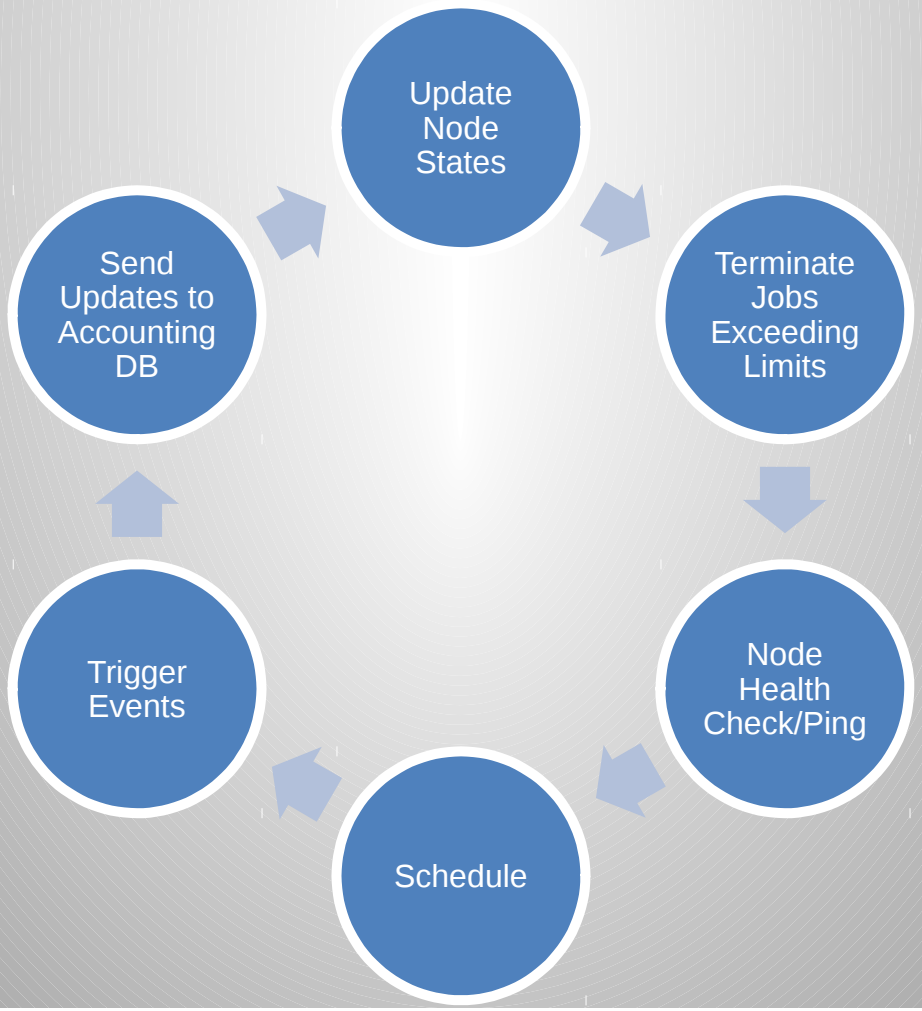
Node Bitmaps

- One bit per node
- Node bitmaps always include all nodes in the cluster
- Part of the secret sauce contributing to the scheduler's performance
  - bitwise and operations are faster than **`if`** clauses

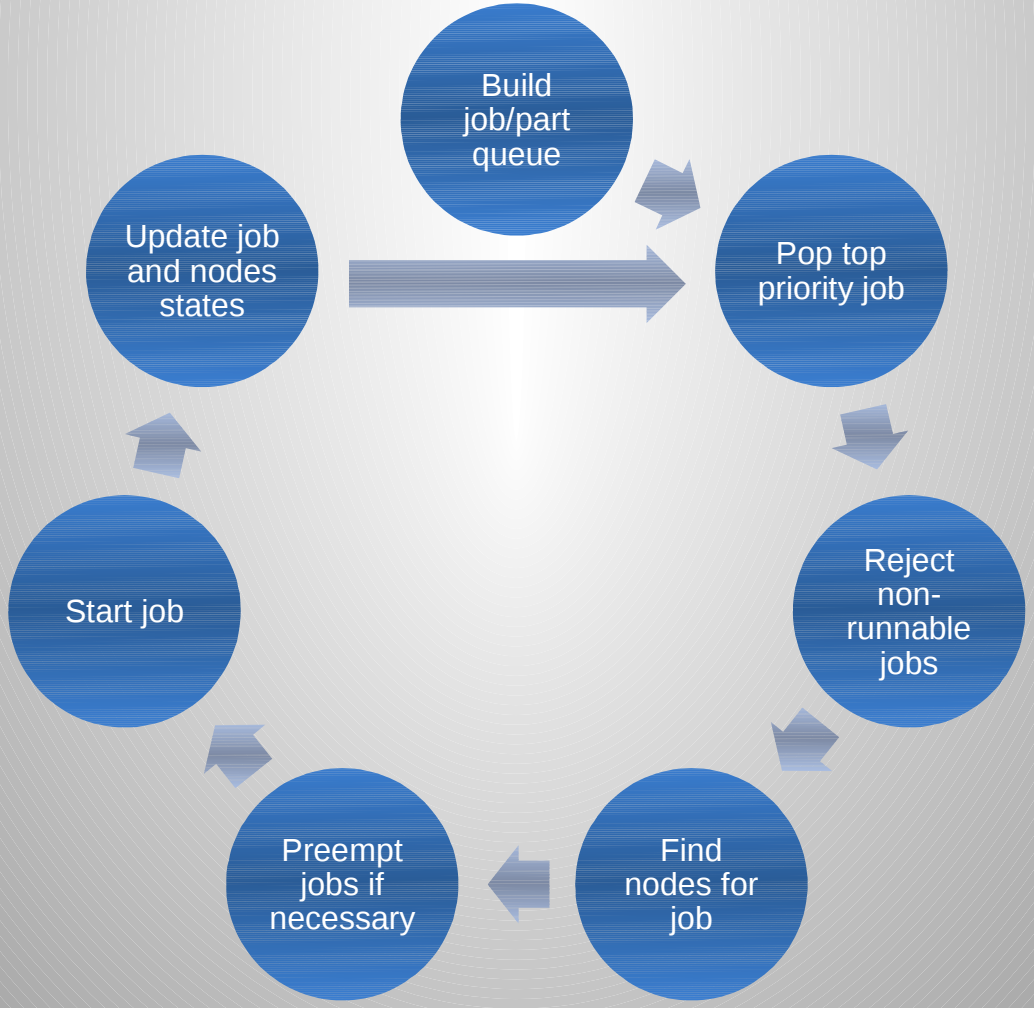
Slurmctld's main()



_slurmctld_background



Generic Scheduling Loop



Scheduling Call Stack

schedule()

schedule()
- Build job queue
- Pop top priority, least preemptable job

select_nodes()
- Build node candidate list

_get_req_features()
- Omit reserved nodes
- Build preemptable jobs list

_pick_best_nodes()
- Cycles through each feature
- Consider where nodes can be shared

select_g_job_test()
- Selects “best” nodes
- Returns preemptee list

select_g_job_test()

- Selects the “best” nodes for the job
- Depending on mode, decides whether the job:
  - Can ever run (SELECT_MODE_TEST_ONLY)
  - Can run now (SELECT_MODE_RUN_NOW)
  - Can run later (SELECT_MODE_WILL_RUN) - used to provide start time estimates
- Considers switch_record_table entries when present
- Inputs a list of running jobs that are candidates for preemption
- RUN_NOW and WILL_RUN return
  - Where job can run
  - A list of jobs to preempt

Scheduling-Related Plugins

select Plugin-Specific Behavior

- linear
  - schedules whole nodes and memory
- con_res
  - schedules sockets/cores/threads and memory
- bluegene
- cray
- serial

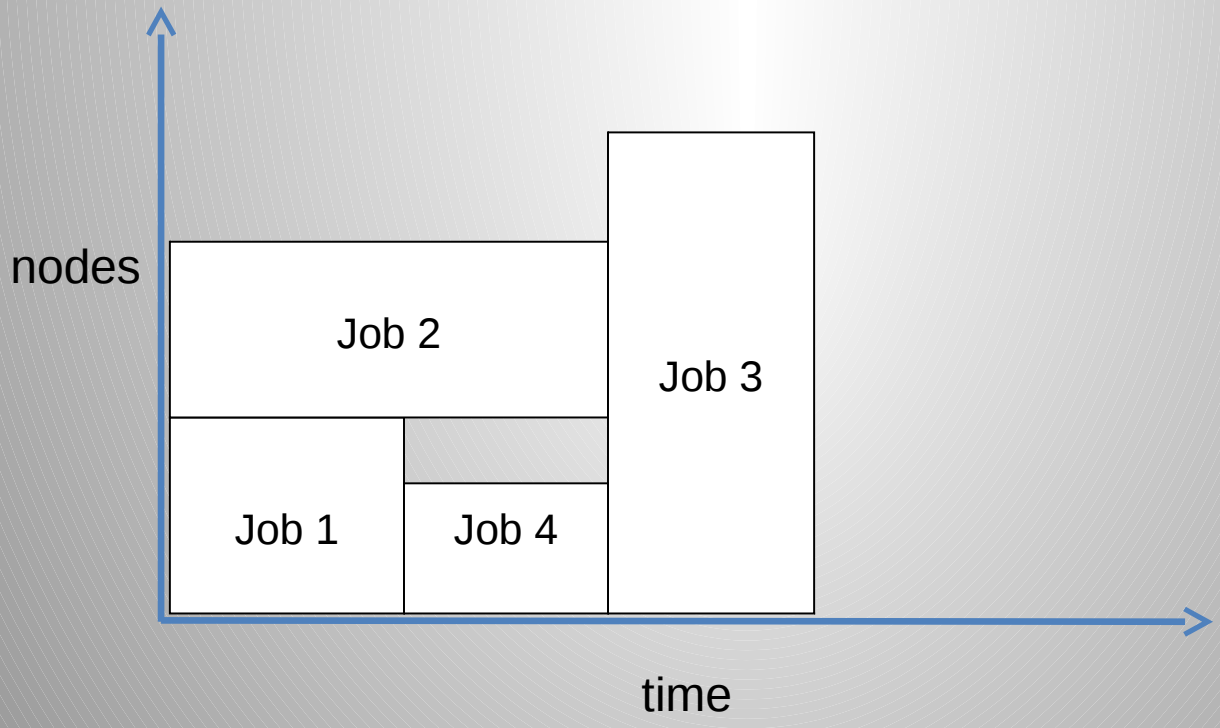
sched plugin

- backfill
  - Separate thread schedules lower priority jobs when they will not delay the start of the top priority job.
- builtin
  - Implements FIFO scheduling when paired with priority/basic plugin
  - Creates a new thread to calculate the projected start times of pending jobs
- hold
  - Assigns a zero priority to every job submitted
- wiki, wiki2
  - Contains the code necessary to dialog with an external scheduler (Maui / Moab)

sched/builtin plugin

- A separate thread that periodically cycles through each pending job
- First calculation:
  - select_g_job_test(SELECT_MODE_WILL_RUN) to determine the job's start time
- Second calculation:
  - Delays the start time of a subsequent job using the same nodes as a previous job to start after the time limit of the previous job.

Bacfill Scheduling Jobs



sched/backfill plugin

- SchedulerType=sched/backfill
- SchedulerParameters
  - bf_interval - minimum backfill cycle period (30 sec default)
  - bf_max_job_user - limits number of backfilled jobs per user per cycle
  - bf_resolution - job start / end time accuracy (60 sec default)
  - bf_window - how many minutes into the future to look (1 day default)
  - max_job_bf - limits number of backfilled jobs per cycle
- An additional thread, separate from the _slurmctld_background thread
- Uses lock_slurmctld() to keep from clobbering the slurmctld's objects
- Descends the job queue running every job that will complete before the expected start time of the top priority job
- Follows logic similar to the schedule() function

Generic Scheduling Loop (again)

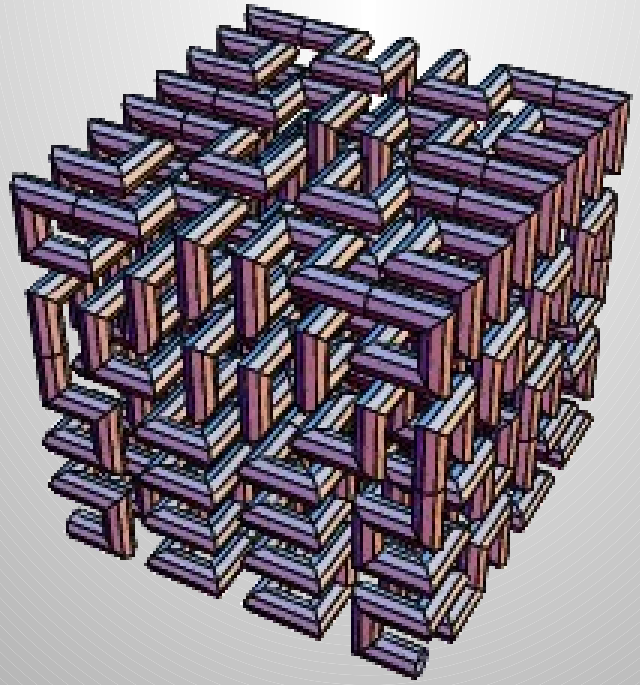
- Build queue of runnable job/parts
- Remove top priority job from queue
- Reject jobs that cannot or should not run
- Find nodes for job
- Create preemption list and preempt jobs if necessary
- Start job
- Update job and node states

topology plugin

- 3d_torus
  - modifies the node_rank member of each node_record which is used by the slurmctld to order the node_record_table and thereby influence the order of the nodes that are allocated
- tree
  - populates the switch_record_table which is used by the linear and cons_res select plugins to select the nodes for each job
- node_rank, none
  - stub functions

topology/3d_torus plugin Implements Hilbert Curve

- Maps 3D coordinates into 1D such that contiguous coordinates in 1D map to 3D coordinates with the shortest communication path between them.



gres plugin

- GresTypes can specify multiple gres plugins
- Gres can be defined for nodes in slurm.conf and does not require a plugin to be created.
- Each node reads its own, optional gres.conf
  - name, count, device file, associated cpus
  - slurmd sends this info to slurmctld at registration
- A job can request gres(s)
- Generic resources are searched and allocated in select plugin's select_p_job_test() by invoking gres plugin's gres_plugin_job_test()

preempt plugin

- partition_prio, qos, or none
- Provides functions to assist scheduling
  - job_preempt_check() used in job queue sorting
  - preemption_enabled() used by _pick_best_nodes() to build the bitmap of candidate nodes
  - find_jobs() used by _get_req_features() and backfill scheduler to generate list of candidates for job preemption
  - job_preempt_mode() determines the mode of preemption select_nodes() uses to preempt jobs

Gang Scheduling

- gs_job_start() adds jobs to be gang scheduled to a list
- The _timeslicer_thread cycles through jobs in this list, resuming or suspending each job.
- Gang scheduling can work in concert with the preempt plugin

Possible PreemptMode Values

PreemptType= preempt/none	PreemptType= preempt/partition_prio	PreemptType= preempt/qos
OFF		
OFF,GANG		
	CANCEL	CANCEL
	CANCEL,GANG	CANCEL,GANG
	CHECKPOINT	CHECKPOINT
	CHECKPOINT,GANG	CHECKPOINT,GANG
	REQUEUE	REQUEUE
	REQUEUE,GANG	REQUEUE,GANG
	SUSPEND,GANG	

Reservations

- Reserves nodes, and CPUs in the future
- Slurmctld maintains a list of reservations
- The req_node_bitmap of jobs with a reservation is populated with the nodes from that reservation [_build_node_list()]
- Jobs without a reservation are can only select nodes from an avail_node_bitmap that is missing the reserved nodes [_get_req_features()]

Job Reduction and Expansion

- Both operations use update_job() to do the work
- Job reduction done by excise_node_from_job()
- Job expansion requires the submission of a new job with the “expand” dependency, requesting *additional* nodes.
- Once the expand job is scheduled, select_p_job_expand() does the work of transferring the original job’s resources to the expanded job.

Checkpoint / restart

- "**`scontrol checkpoint vacate`**" releases nodes to the scheduling pool, making them available to other jobs.
- Restart relies on a new job being scheduled.

job_allocate

- In response to an sbatch invocation (as well as other scenarios)
- Provides will-run data if requested and returns
  - Example: **`srun --test-only`**
- Creates the job and adds it to the job list
- Provides a path for a submitted job to be immediately scheduled - calls select_nodes()

Immediate Scheduling Path

job_allocate

- job_allocate()
  - Confirm job is independent
  - Confirm job is top priority
- select_nodes()
  - Build node candidate list
- _get_req_features()
  - Omit reserved nodes
  - Build preemptable jobs list
- _pick_best_nodes()
  - Cycles through each feature
  - Consider where nodes can be shared
- select_g_job_test()
  - Selects “best” nodes
  - Returns preemptee list

(Most Common) Reasons for Job Pending State

Reason	Enum	When it gets set
BeginTime	WAIT_TIME	build_job_queue()
Dependency	WAIT_DEPENDENCY	build_job_queue()
JobHeldAdmin	WAIT_HELD	Job create / update
JobHeldUser	WAIT_HELD_USER	Job create / update
Licenses	WAIT_LICENSES	schedule() while loop
PartitionTimeLimit	WAIT_PART_TIME_LIMIT	build_job_queue() and select_nodes()
PartitionNodeLimit	WAIT_PART_NODE_LIMIT	build_job_queue()
Priority	WAIT_PRIORITY	schedule() while loop
ReqNodeNotAvail	WAIT_NODE_NOT_AVAIL	select_nodes()
Reservation	WAIT_RESERVATION	select_nodes()
Resources	WAIT_RESOURCES	schedule() while loop and select_nodes()

References

- Documentation

  http://www.schedmd.com/slurmdocs/documentation.html

- Publications

  http://www.schedmd.com/slurmdocs/publications.html

- Man Pages

  http://www.schedmd.com/slurmdocs/man_index.html

- Job scheduling with the SLURM resource manager by Michal Novotný

  https://is.muni.cz/th/173052/fi_b_b1/thesis.pdf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