Lawrence Livermore National Laboratory

SLURM Grid Ideas

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Don Lipari

Livermore Computing

Lawrence Livermore National Laboratory, P. O. Box 808, Livermore, CA 94551

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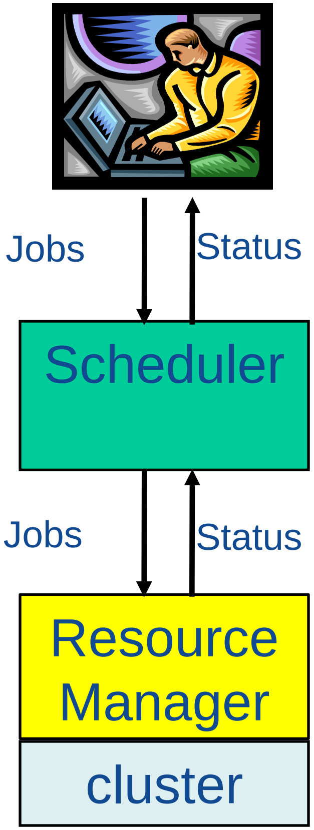
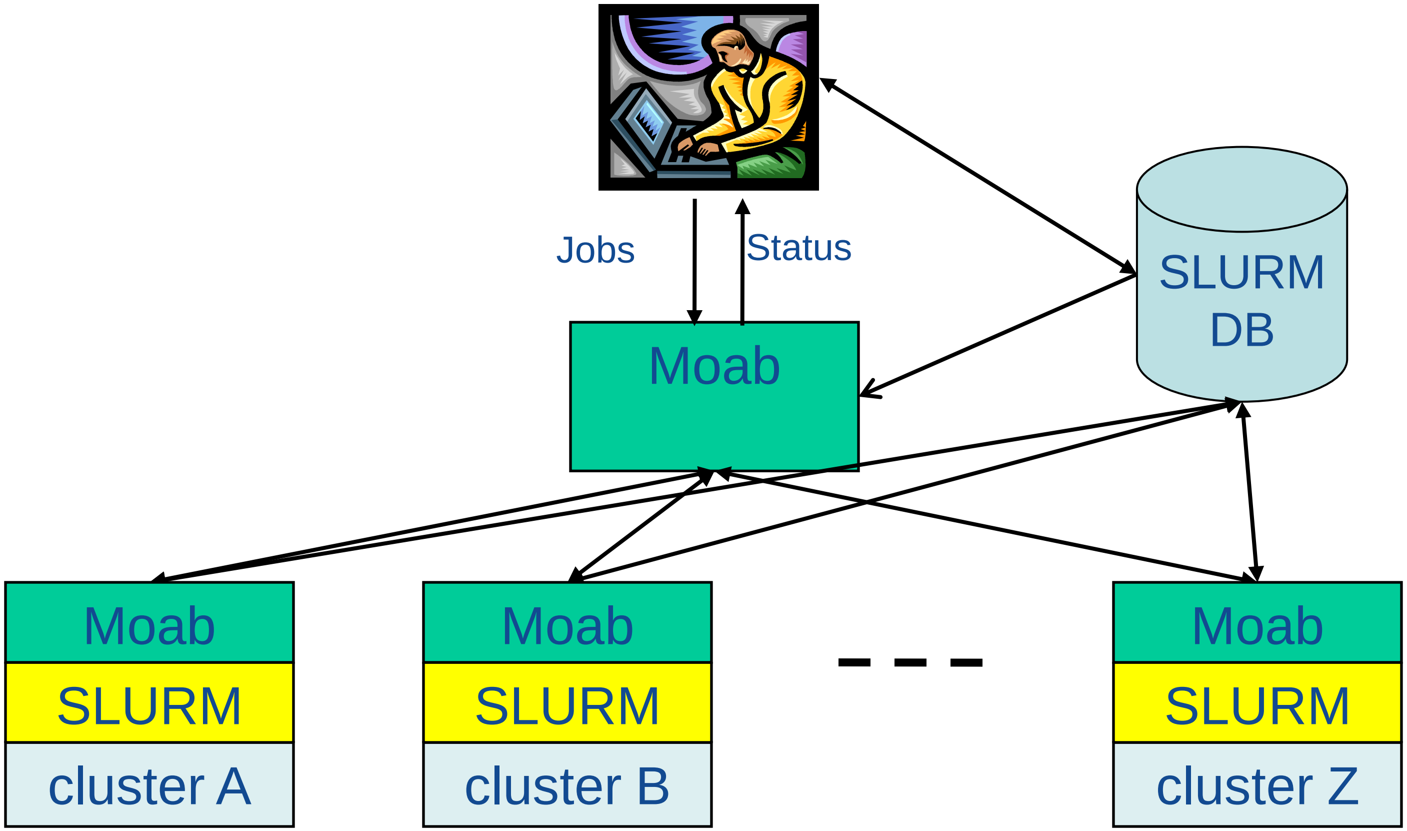
Scheduler and Resource Manager

- Determines job priorities
- Implements scheduling policy
- Enforces limits
- Workload management



- Manages the computing resources of a single cluster
- Launches job across node(s)
- Provides job status and reports resource usage

Moab Grid Scheduling



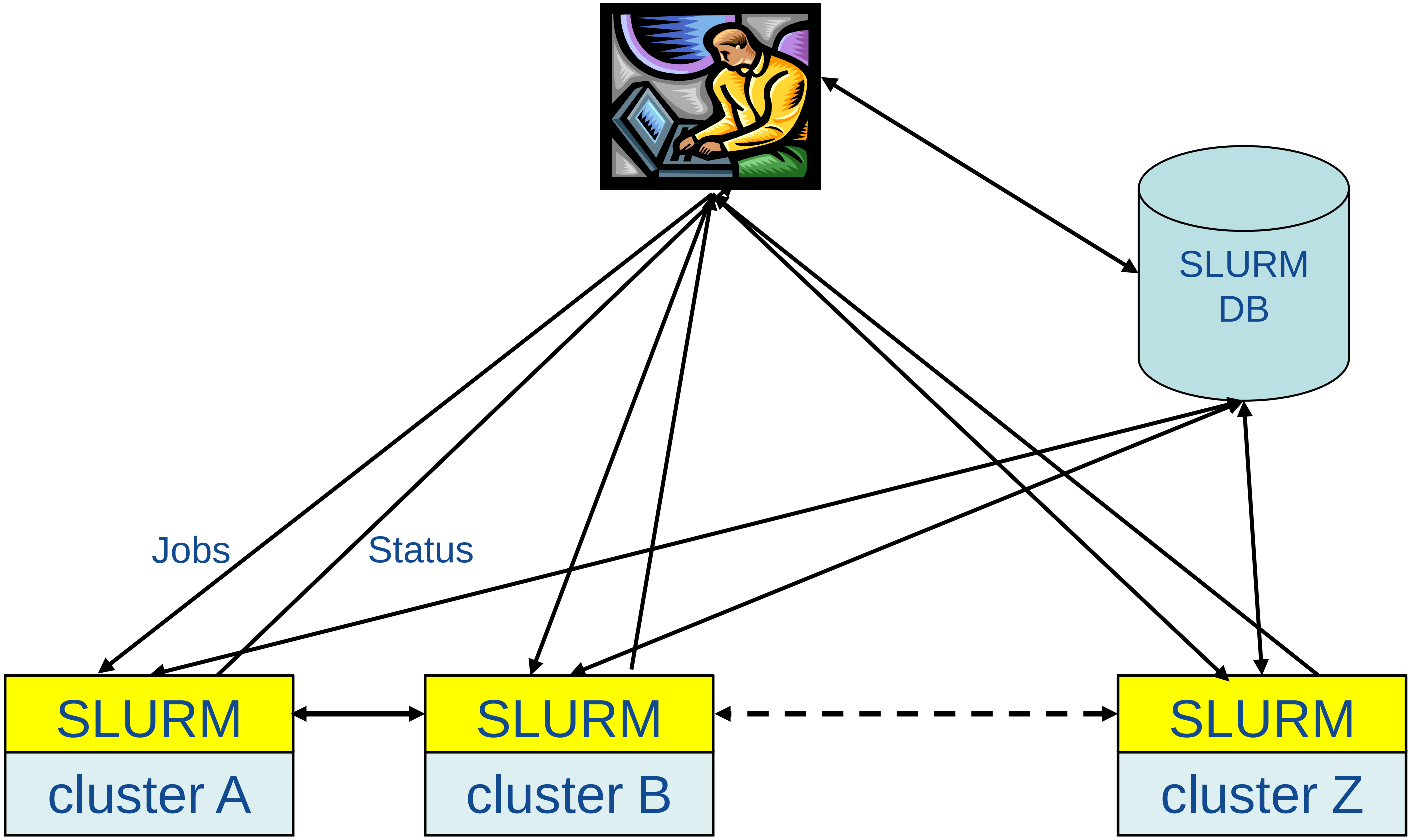
Grid Advantages

- Users can submit jobs to, and obtain status from, any cluster in the grid.
- Users can target their jobs to multiple clusters, and run on the soonest available cluster.
- Users can submit jobs that can depend on any job(s) on any cluster within the grid.
  - Includes existing support for: after, afterany, afterok, afternotok, singleton
- Job IDs are unique across the grid.
  - Users reference their job by ID.
  - They do not have to remember which machine it is on.

Grid vs. Cloud

- There are a fixed number of clusters within a grid.
- The OS and environment of the grid's clusters remains fixed over time.

SLURM Grid Scheduling



Show-Stoppers to Deploying the SLURM Grid

- There are three main deficiencies in SLURM’s v2.3 grid implementation:
  - Target clusters are selected at job submission time and cannot be changed with a dynamic workload (newly submitted jobs and jobs finishing early)
  - Does not support job dependencies off-cluster
  - Job IDs are not unique across the grid. Users are unable to status a job without knowing which cluster it is on.

Detailed Requirements

- Administrators can configure multiple clusters into a single grid.
  - By default, this includes all the clusters defined in the Accounting Storage db.
- Users can submit jobs to, and obtain status from, any cluster in the grid.
- Users can target their jobs to multiple clusters, and run on the soonest available cluster.
- If a partition is specified, only clusters containing that partition will be candidates.
- If AccountingStorageEnforce=associations is enabled, only clusters containing the requested account/user association will be candidates.
- The “soonest available” decision must be periodically re-computed to accommodate:
  - Changing workload as clusters’ queues change unpredictably (e.g., jobs finish prematurely or high priority jobs are submitted).
  - Loss of communication to other clusters.
  - Resources fail or are removed from service.

More Detailed Requirements

- Users can submit jobs that can depend on any job(s) on any cluster within the grid.
  - Includes existing support for: after, afterany, afterok, afternotok, singleton
- Job IDs targeted to multiple clusters must be unique across the grid.
  - This avoids the need for job IDs of the form cluster.jobID.
  - We need to give the user a way to status jobs by job ID and not have to hunt for a job cluster-by-cluster.
- Users must have the ability to add and remove target machines and job dependencies.
- Multi-factor job priority determination must remain cluster-specific.
- Design must avoid a single point-of-failure.
- Design must be resilient and tolerant of system or communication failures.

Enterprise Scheduling Design Option 1
Peer-to-Peer

- The slurmdbd is enhanced to dispense multi-cluster job IDs for all clusters in the grid.
  - Jobs that users submit to multiple clusters will request the next job ID from the slurmdbd.
  - Jobs that users submit to a single cluster will not request a job ID from the slurmdbd. Instead, it will receive the next job ID in that cluster’s sequence (as it does now).
  - If the slurmdbd is down, or fails to respond within a reasonable time, the job will be submitted to just the soonest target candidate (as it does now).
  - Admins will be expected to configure each cluster’s, and the slurmdbd’s, FirstJobId and MaxJobId into mutually exclusive ranges.

Peer-to-Peer (page 2)

- Jobs that users submit to multiple clusters are sent, including the script, to each cluster using the same job ID received from the slurmdbd.
- The cluster that is predicted, at the time of submission, to run the job the soonest is tagged the “leading” candidate. Job submissions to the remaining clusters are tagged, “fall-back” candidates.
  - The job on the leading candidate cluster has a list of all the fall-back candidate clusters for that job.
  - Jobs on fall-back candidate clusters have only the name of the leading candidate cluster.
  - (No resources are ever reserved for fall-back candidate jobs ?)
- If a job on the leading candidate cluster reaches the top of its queue, messages are sent to all the fall-back candidate clusters to cancel the fall-back jobs.

Peer-to-Peer (page 3)

- If a fall-back candidate job reaches the top of its queue, and the leading candidate has not run the job yet and has a predicted start time later than the fall-back candidate cluster, it can make the request to take over the leadership, (including the candidate list) and then run the job.
  - The new leading candidate cluster would then issue a message to all the other fall-backs (including the former leader) to cancel their fall-back jobs.
  - If the request for leadership is denied or goes unanswered, the fall-back candidate job is cancelled (after some configurable period).
  - If the leading candidate cluster is removed from service or becomes unresponsive, all of the fall-back candidate clusters will eventually cancel their fall-back jobs.
- Admins would be given the ability to manually transfer leading status to a fall-back cluster. This could be done in preparation for taking the leading cluster out-of-service.
- Users will have the option to delete a target cluster from their job.
  - A message would be sent to cancel the job from the removed machine, while updating the fall-back list that the leader maintains.
  - Giving users the ability to add a target cluster to their job is conceivable. The script would have to be copied over to the new target.

Enterprise Scheduling Design Option 2
Meta-Scheduling Elf

- Elf is a non-critical, independent service
- Jobs that users submit to multiple clusters will request the next job ID from the elf.
- Multi-cluster jobs are sent to the elf and the soonest candidate cluster at submit time.
- Elf periodically invokes will-run on candidate clusters to look for a cluster that can run the job sooner.
    - Must include the submit time so candidate can compute job priority as if job were submitted in the past and not now.
- If a sooner candidate is found, the elf moves the job from the original target to the sooner candidate.

Enterprise Scheduling Design Option 3
Full Blown Meta-Scheduler

- FBMS is resembles the Moab grid master
- Jobs that are submitted for multiple clusters are relayed to the FBMS where they are assigned a multi-cluster Job ID.
- FBMS maintains its own copy of the job queues of all the clusters in the enterprise.
- FBMS dispatches jobs just-in-time to target clusters.
- The FBMS takes on the scheduling of all clusters.
- The slurmctld's scheduling capability is deactivated.
- Job status now reported through the FBMS.
  - squeue reports local cluster.
  - fbms_queue reports all jobs in grid.

Job Dependencies Across Clusters

- Option A - Parent job knows dependent jobs and the condition for dependence and alerts clusters with pending dependent jobs when its condition is met.
- Option B - Dependent job periodically polls for condition of parent job
- Peer-to-peer and elf design could implement option B utilizing the Accounting Storage db or by direct communication
- FBMS would know the status of all jobs and release job dependencies when conditions were met.

Grid Options Compared

	Peer-to-Peer	Elf	FBMS
Reliability	Excellent	Excellent	Good (w/ backup design)
Complexity	slurmctld	elf + slurmctld	FBMS only
Scalability	good	better	best
Slurmctld performance penalty	fair	good	best
Scheduling	slurmctld	slurmctld	FBMS
Job Migration	All clusters have a copy of job	Elf moves jobs when needed	Dispatched to cluster at run time
Workload change	complicated	complicated	easy
User modifies candidate clusters	easy as long as a cluster is dropped	easy	easy
Job dependency	complicated	complicated	easy
Job dependency change	complicated	complicated	easy
Job ID generator	slurmdbd	Elf	FBMS

Yet Another Design Option
Ubiquitous Meta Schedulers

- A meta-scheduler daemon (umsd) to accompany every slurmctld.
- The umsd has three primary functions:
  - Selecting local, multi-cluster jobs to run once they reach to the top of the local queue.
  - Determine when job dependencies are met and release dependent jobs on the local cluster.
  - Return job information for all jobs within the grid to ms-squeue client commands.
- Requires no changes to the slurmctld's or SLURM client commands.

Ubiquitous Meta Scheduler

- All job reports (submit/run/cancel/complete) that the slurmctld sends the slurmdbd are reflected by the slurmdbd to all umsd’s.
- Multi-cluster jobs are submitted to all candidates like the peer-to-peer model.
- slurmdbd dispenses the multi-cluster job IDs.
- The local umsd detects when a multi-cluster job reaches (or nears) the top of its local queue.
- That umsd permits (and commits) the job to run on its local cluster and issues an scancel of the same job ID to all of the other clusters.
- The slurmdbd receives notice of the started job as well as the job cancellations from all the other clusters.

Ubiquitous Meta-Scheduler (cont.)

- squeue is unchanged - reports jobs from local cluster
- ms-squeue interrogates the local umsd for job reports from all clusters
- Jobs with the same ID that are candidates for multiple clusters appear as separate records in the slurmdb.
- Using its global view of all jobs running across the grid, the meta-scheduler decides when dependencies are met for jobs from local cluster and releases dependency.

umsd Option Compared

	Peer-to-Peer	Elf	FBMS	umsd
Reliability	Excellent	Excellent	Good	Excellent
Complexity	slurmctld	elf + slurmctld	FBMS only	umsd only
Scalability	good	better	best	better?
Slurmctld performance penalty	fair	good	best	best
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Job Migration	All clusters have a copy of job	Elf moves jobs when needed	Dispatched to cluster at run time	All clusters have a copy of job
Workload change	complicated	complicated	easy	easy
User modifies candidate clusters	easy as long as a cluster is dropped	easy	easy	easy as long as a cluster is dropped
Job dependency	complicated	complicated	FBMS	umsd
Job dependency change	complicated	complicated	FBMS	umsd
Job ID generator	slurmdbd	Elf	FBMS	slurmdbd