Doing More with Slurm Advanced Capabilities

Shawn Hoopes, Director – Training Services
shawn@schedmd.com

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What is Slurm…

- **Policy-driven, open source, fault-tolerant, and highly scalable workload management and job scheduling system**
- **Some Key Functions**
    - Allocates exclusive and/or non-exclusive access to resources to users for some duration of time for a workload
    - Provides a framework for starting, executing, and monitoring work on the set of allocated nodes
    - Arbitrates contention for resources by managing a queue of pending work
    - Enforces customized workload policies to grant and/or restrict access to compute resources

What is Slurm…

- **Features Details**
  - Straight-forward batch and serial job submission methods
  - Easy to administer
  - Plug-in infrastructure
  - Very highly scalable
  - Secure and fault-tolerant
  - Flexible priority and fairshare policies
  - Powerful database integration for job detail tracking, reporting, and policy enforcement, as well as job script storage and QOS definitions
  - Policy-driven preemption methods

What is Slurm…

- **Some Advanced Features**
    - NSS Slurm, pam_slurm_adopt, scrontab
    - Configless Slurm
    - Job dependencies
    - Heterogenous job submission
    - MPI Support via srun
    - Cgroup v1 and v2 support
    - Detailed cpu-binding options
    - Job Profiling
    - Node Sets and Dynamic Node provisioning

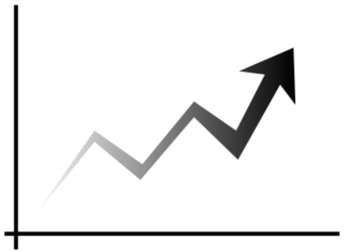
Rank	System	Cores	Rpeak
1	**Frontier** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE	8,730,112	1,685.65 PFlop/s
2	**Supercomputer Fugaku** - Supercomputer Fugaku, A64FX 48C 2.2GHz, Tofu interconnect D, Fujitsu	7,630,848	537.21 PFlop/s
3	**LUMI** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE	1,110,144	214.35 PFlop/s
4	**Summit** - IBM Power System AC922, IBM POWER9 22C 3.07GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband, IBM	2,414,592	200.79 PFlop/s
5	**Sierra** - IBM Power System AC922, IBM POWER9 22C 3.1GHz, NVIDIA Volta GV100, Dual-rail Mellanox EDR Infiniband, IBM / NVIDIA / Mellanox	1,572,480	125.71 PFlop/s
6	**Sunway TaihuLight** - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway, NRCPC	10,649,600	125.44 PFlop/s
7	**Perlmutter** - HPE Cray EX235n, AMD EPYC 7763 64C 2.45GHz, NVIDIA A100 SXM4 40 GB, Slingshot-10, HPE	761,856	93.75 PFlop/s
8	**Selene** - NVIDIA DGX A100, AMD EPYC 7742 64C 2.25GHz, NVIDIA A100, Mellanox HDR Infiniband, Nvidia	555,520	79.22 PFlop/s
9	**Tianhe-2A** - TH-IVB-FEP Cluster, Intel Xeon E5-2692v2 12C 2.2GHz, TH Express-2, Matrix-2000, NUDT	4,981,760	100.68 PFlop/s
10	**Adastra** - HPE Cray EX235a, AMD Optimized 3rd Generation EPYC 64C 2GHz, AMD Instinct MI250X, Slingshot-11, HPE	319,072	61.61 PFlop/s

But what is SchedMD?

- **Maintainers and Supporters of Slurm**
    - Only organization providing level-3 support
    - Training
    - Consultation
    - Custom Development

Industry Trends

- GPUs - AI Workloads
- Hybrid Cloud
- AI Tooling Integration



- Manufacturing & EDA
- Healthcare & Lifesciences
- Financial Services & Insurance
- Energy
- Government
- Academic

GPU Scheduling for AI Workloads

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Fine-Grained GPU Control

All options apply to salloc, sbatch and srun commands

- --cpus-per-gpu= CPUs required per allocated GPU
- -G/--gpus= GPU count across entire job allocation
- --gpu-bind= Task/GPU binding option
- --gpu-freq= Specify GPU and memory frequency
- --gpus-per-node= Works like "--gres=gpu:#" option today
- --gpus-per-socket= GPUs per allocated socket
- --gpus-per-task= GPUs per spawned task
- --mem-per-gpu= Memory per allocated GPU

Examples of Use

```
$ sbatch --ntasks=16 --gpus-per-task=2 my.bash
```

```
$ sbatch --ntasks=8 --ntasks-per-socket=2 --gpus-per-socket=k80:1 my.bash
```

```
$ sbatch --gpus=16 --gpu-bind=closest --nodes=2 my.bash
```

```
$ sbatch --gpus=k80:8,a100:2 --nodes=1 my.bash
```

Configuring GPUs

- GPUs fall under the Generic Resource (GRES) plugin
  - Node-specific resources
- Requires definition in slurm.conf and gres.conf on node
- GRES can be associated with specific device files (e.g. specific GPUs)
- GPUs can be autodetected with NVML or RSMI libraries
- Sets CUDA_VISIBLE_DEVICES environment variable for the job

Restricting Devices with Cgroups

- Uses the *devices* subsystem
  - *devices.allow* and *devices.deny* control access to devices
  - All devices in gres.conf that the job does not request are added to devices.deny so the job can't use them
- Must be a Unix device file. Cgroups restrict devices based on major/minor number, not file path (/dev/nvidia0)
- GPUs are the most common use case, but any Unix device file can be restricted with cgroups

NVIDIA MIG Support

- Configured like regular GPUs in Slurm
- Fully supported by task/cgroup and --gpu-bind
- AutoDetect support
- Make it work with CUDA_VISIBLE_DEVICES
- MIGs must be manually partitioned outside of Slurm beforehand via nvidia-smi

Hybrid Cloud Autoscaling

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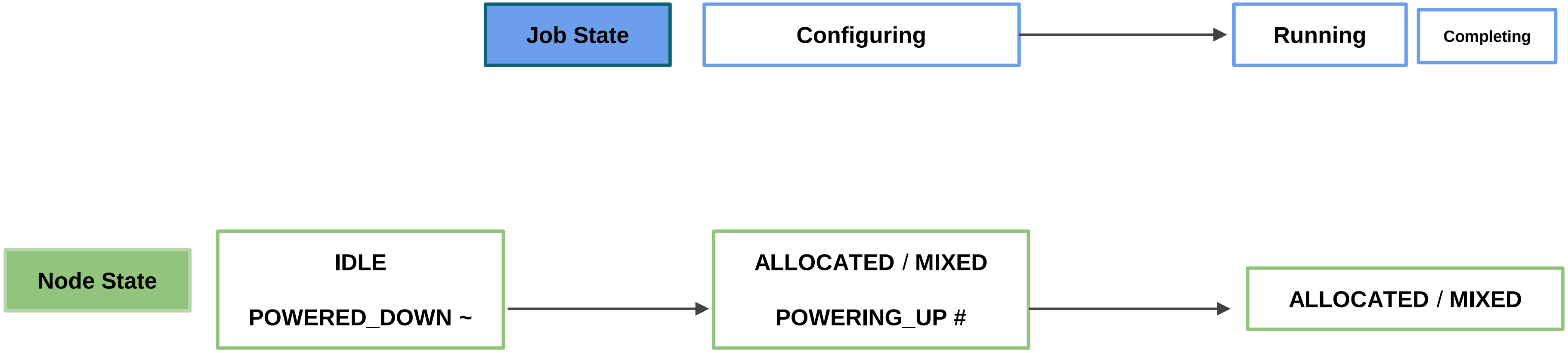
Hybrid Cloud

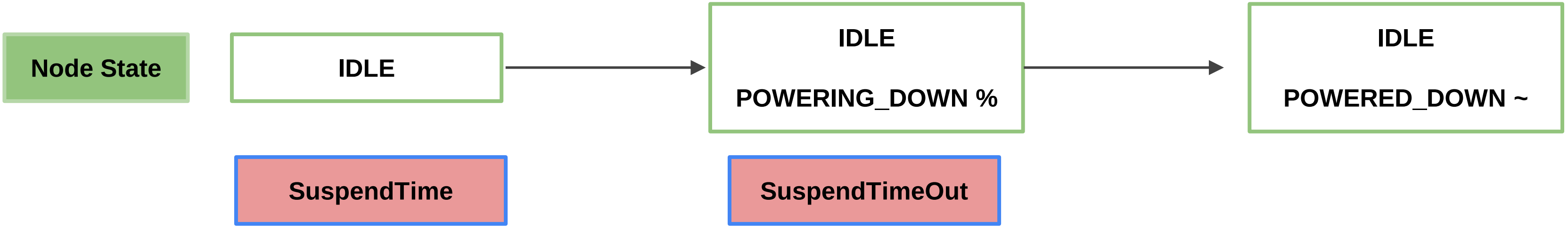
Cloud Enablement

- Power Saving module
  - Requires 3 parameters to enable
    - ResumeProgram
    - SuspendProgram
    - SuspendTime (Either global or Partition)
  - Other important parameters
    - ResumeTimeout
    - SuspendTimeout

Power State Transition - Resume



Power State Transition - Suspend



What about the Data?

- Most common question - How do we get my data from onprem to cloud?
- Previous best option - mini-workflow w/ job dependency

Stage-in job > Application job > Stage-out job

- Benefit: easy to increase the number of nodes involved in moving the data

New Option: Lua Burst Buffer plugin

- Originally developed for Cray Datawarp
  - Intermediate storage - in between slow long-term storage and the fast memory on compute nodes
- Asynchronously calls an external script to not interfere with the scheduler
- Generalized this function so you don't need Cray Datawarp or actual hardware "burst buffers" or Cray's API
- Good for Data movement or provisioning cloud nodes
  - Anything you think you want to do while the job is pending (or at other job states)

Asynchronous “stages”

- Stage in - called before the job is scheduled, job state == pending
  - Best time for Cloud data staging
- Pre run - called after the job is scheduled, job state == running + configuring
  - Job not actually running yet
- Stage out - called after the job completes, job state == stage out
  - Job cannot be purged until this is done
- Teardown - called after stage out, job state == complete

AI Tooling Integration:
Enter the REST API

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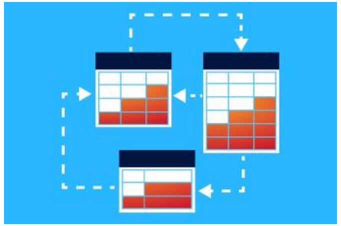
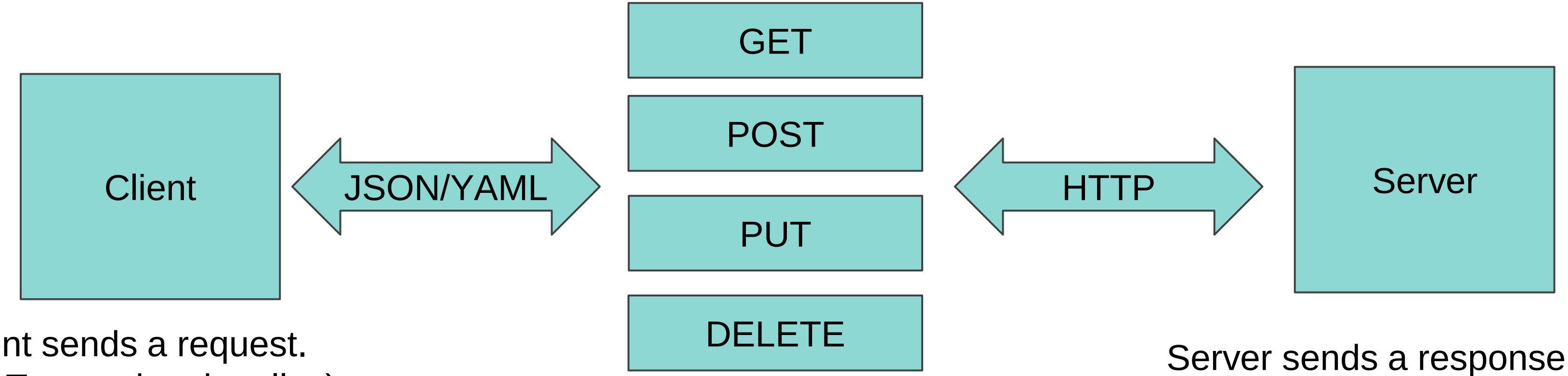
New Integration Requirements



What is Slurm REST API



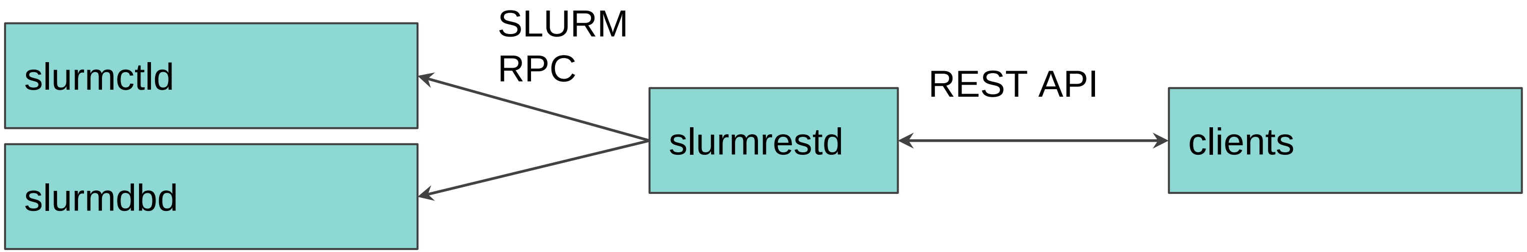
Client sends a request.
(NOT srun,sbatch,salloc)

HTTP Method

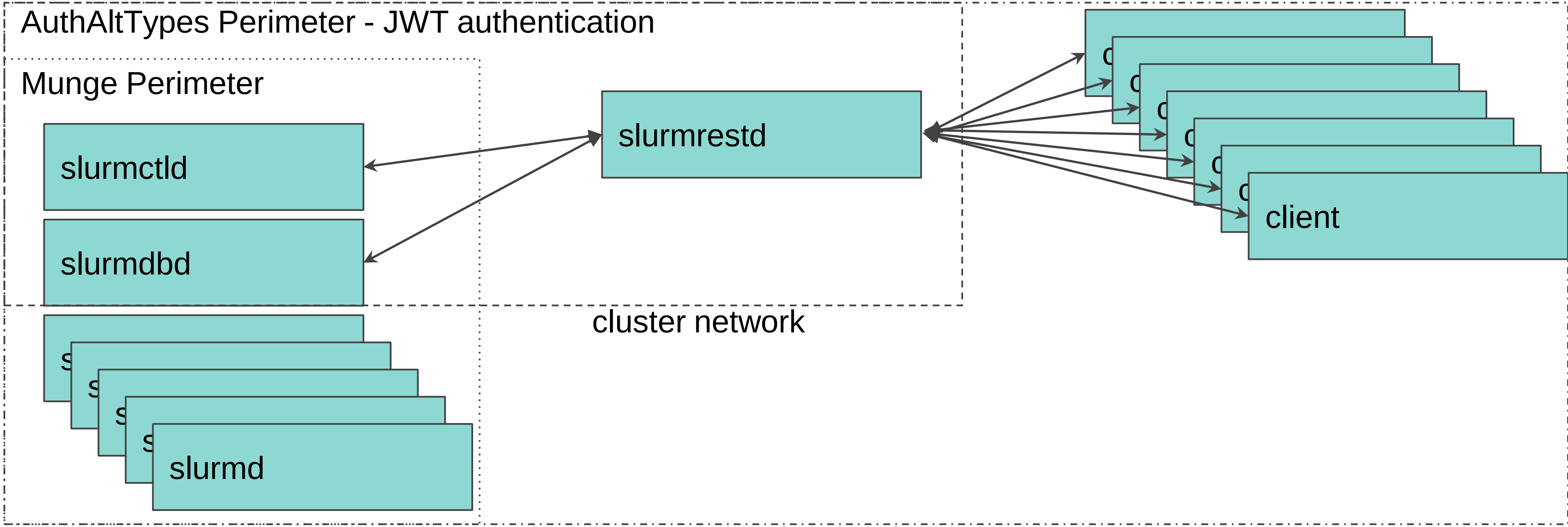
Server sends a response.

slurmrestd

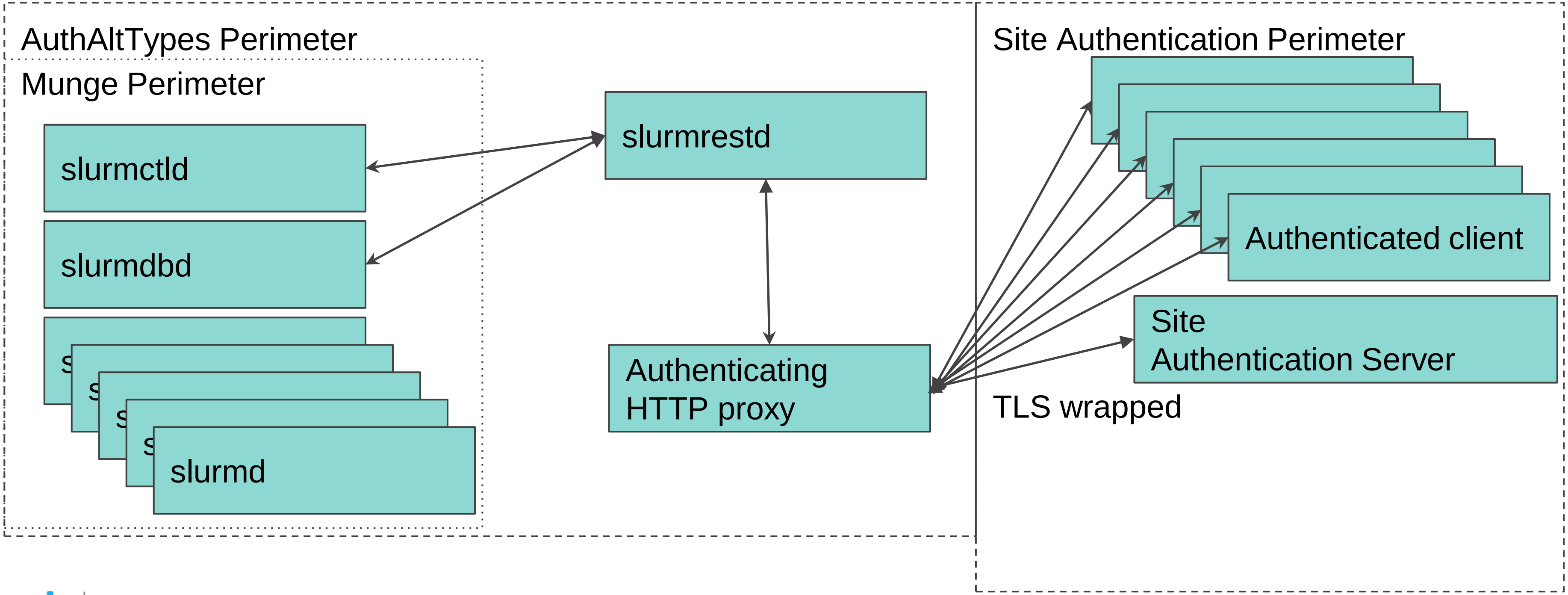
A tool that runs inside of the Slurm perimeter that will translate JSON/YAML requests into Slurm RPC requests



Slurm REST API Architecture (rest_auth/jwt)



Slurm REST API Architecture (rest_auth/jwt + Proxy)



JSON/YAML output

- Slurmrestd uses content (a.k.a. openapi) plugins. These plugins have been made global to allow other parts of Slurm to be able to dump JSON/YAML output.
- New output formatting (limited to these binaries only):
  - *sacct --json* or *sacct --yaml*
  - *sinfo --json* or *squeue --yaml*
  - *squeue --json* or *squeue --yaml*
- Output is always same format of latest version of slurmrestd output.
  - Formatting arguments are ignored for JSON or YAML output as it is expected that clients can easily pick and choose what they want.

```
$ sinfo --json
{
   "meta": {
     "plugin": {
       "type": "openapi\/v0.0.37",
       "name": "Slurm OpenAPI v0.0.37"
     },
     "Slurm": {
       "version": {
         "major": 22,
         "micro": 0,
         "minor": 5
       },
       "release": "21.08.6"
     }
   },
   "errors": [
   ],
   "nodes": [
     {
       "architecture": "x86_64",
       "burstbuffer_network_address": "",
       "boards": 1,
       "boot_time": 1646380817,
       "comment": "",
       "cores": 6,
       "cpu_binding": 0,
       "cpu_load": 64,
       "extra": "",
       "free_memory": 3208,
       "cpus": 12,
       "last_busy": 1646430364,
       "features": "",
       "active_features": "",
…
```

```
…
"gres": "",
       "gres_drained": "N\/A",
       "gres_used": "scratch:0",
       "mcs_label": "",
       "name": "node00",
       "next_state_after_reboot":
"invalid",
       "address": "node00",
       "hostname": "node00",
       "state": "idle",
       "state_flags": [
       ],
       "next_state_after_reboot_flags": [
       ],
       "operating_system": "Linux 5.4.0-
100-generic #113-Ubuntu SMP Thu Feb 3
18:43:29 UTC 2022",
       "owner": null,
       "partitions": [
         "debug"
       ],
       "port": 6818,
       "real_memory": 31856,
       "reason": "",
       "reason_changed_at": 0,
       "reason_set_by_user": null,
       "slurmd_start_time": 1646430151,
       "sockets": 1,
       "threads": 2,
       "temporary_disk": 0,
       "weight": 1,
       "tres":
       "cpu=12,mem=31856M,billing=12",
…
```

```
…
       "operating_system": "Linux 5.4.0-
100-generic #113-Ubuntu SMP Thu Feb 3
18:43:29 UTC 2022",
       "owner": null,
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       "reason_changed_at": 0,
       "reason_set_by_user": null,
       "slurmd_start_time": 1646430151,
       "sockets": 1,
       "threads": 2,
       "temporary_disk": 0,
       "weight": 1,
       "tres":
       "cpu=12,mem=31856M,billing=12",
       "slurmd_version": "22.05.0-0pre1",
       "alloc_memory": 0,
       "alloc_cpus": 0,
       "idle_cpus": 12,
       "tres_used": null,
       "tres_weighted": 0.0
}
   ]
 }
```

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How To Get There with Slurm

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Large Energy Company

- **Using their scheduler for many years**
  - Can’t just flip a switch and go to production
- **Massive scale -** multiple international sites, nodes and workloads
- **Many integrations required**

3-4 Months to Production

Three Migration Steps

- **Admin/User education**
  - Training - Help admins identify the commonalities and learn the Slurm way
  - Wrappers - a bridge to migration not a crutch
    - LSF, Grid Engine - command and submission
    - PBS - command, submission, environment variables, #PBS scripts
- **Policy replication**
  - Reevaluate policies
    - Are we continuing to produce technical debt due to “doing things how we’ve always done them?”
  - Optimizing for scale and throughput - 1 million jobs/day
    - Some Financial sites doing up to 15 million/day
- **Tooling integration**
  - Most time consuming of the journey

Questions?

Thank You

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http://slurm.schedmd.com

shawn@schedmd.com

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