Enabling and Scaling Diverse Work Loads Efficiently With Slurm

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MIT Lincoln Laboratory

SLURM User Group Meeting, September 17-18, 2019

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Outline

- Introduction
- LLSC Environment
- Slurm at LLSC
  - Lua job_submit script
  - SPANK plug-in module
  - Resource limit enforcement
  - Throughput tuning
- Summary

Who We Are – a Little History


MIT Building 20

Mission: ***Development of radar systems and technology***

Main projects: Surveillance radar
Fire control radar
Navigation systems

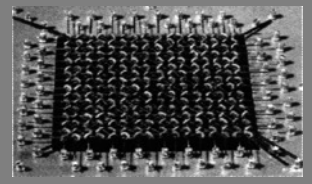
4000 employees
Designed half of all US WWII radars

Est. 1951: ***Air defense and technology development***

Main projects: Semi-Automatic Ground Environment (SAGE)

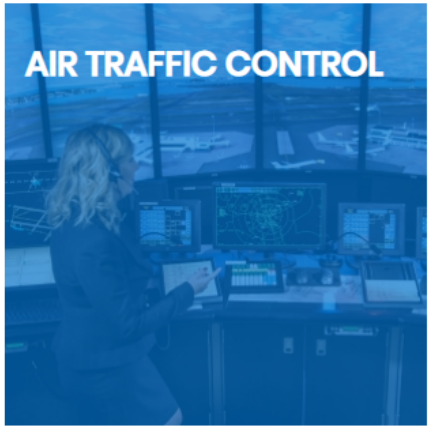
Major Innovations:

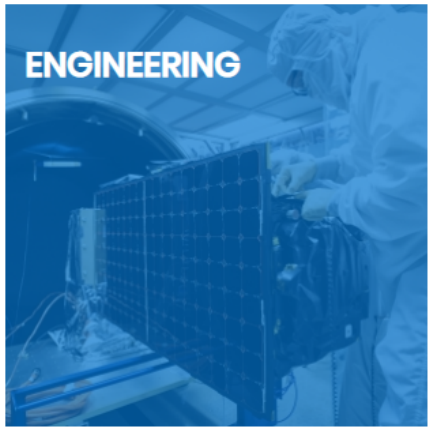
Real-Time Computing


Magnetic-core Memory


Light-pen CRT Interface

Research And Development





History of Supercomputing at Lincoln Laboratory

1951 Whirlwind

1963 Sketchpad

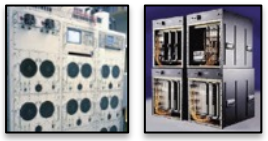
1956 TX-0

1970 Fast Digital Processor (FDP)

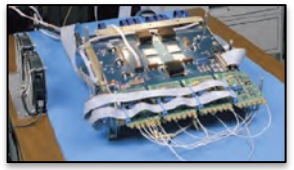
Late 1970s High-speed FFT pipelined processor

1977 : Lincoln Digital Signal Processor (LDSP)

1982 Compact LPC Vocoder



Early 1990s
- APT processor
- RAPTOR processor
- Space-Time Adaptive Processing Library (STAPL)



2002
- ISR Processing and Array Technology (IPAT) processor
- MatlabMPI

2004 Knowledge-Aided Sensor Signal Processing and expert Reasoning (KASSPER) processor

2016 Lincoln Laboratory Supercomputing Center (LLSC)

1950 | 1960 | 1970 | 1980 | 1990 | 2000 | 2010

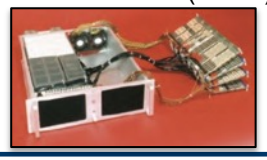
1953 Magnetic-Core Memory Array

1958
- AN/FSQ-7 (Whirlwind II)
- Average Response Computer (ARC)
- CG-24
- TX-2

1962 Lincoln Instrument Computer (LINC)

1970 GENESYS

1974 Lincoln Digital Voice Terminal (LDVT)



1978 Micro-Processor Based LPC Vocoder (LPCM)

1992 Radar Surveillance Technology Experimental Radar (RSTER) processor

1999 Parallel Vector Library (PVL)

2003 pMatlab

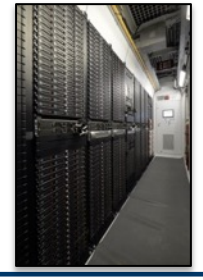
2004
- pMapper gridMatlab
- LLGrid TX-2500

2007
- Parallel Vector Tile Optimizing Library (PVTOL)
- Real-Time Communication Layer (RTCL)

2012 D4M

2015 BigDAWG

2014 LLGrid TX-Green



LLSC Approach

Approach

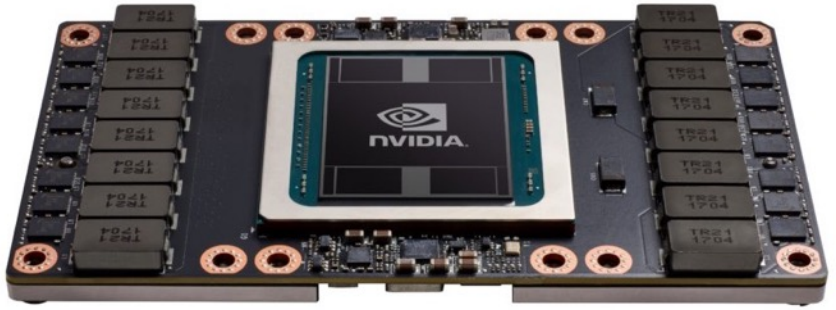
- LLSC develops and deploys unique, energy-efficient high performance computing that provides
  - Integrated HPC and Big Data capabilities
  - Data centers, hardware, software, and user support
  - 100X more productivity than standard HPC
  - 100X better performance than standard Cloud providers

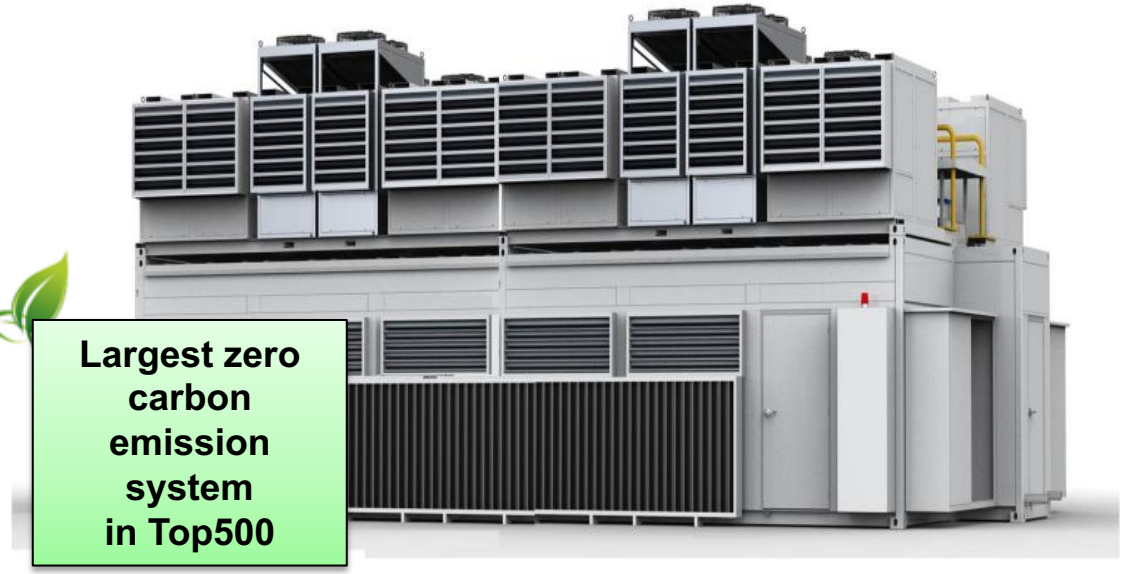
Carbon-free power

Diverse Locations

Supercomputer Upgrade & EcoPOD II

	Capability
Processor	Intel Xeon & Nvidia Volta
Total Cores	737,000
Peak	7.4 Petaflops
Top500	4.7 Petaflops (#32 in World*)
Memory	172 Terabytes
Peak AI Flops	100+ Petaflops (#6 in World*)
Network Link	Intel OmniPath 25 GB/s





Largest zero carbon emission system in Top500

- Significant increase in computing power for simulation, data analysis, and machine learning
- Leverages power of 900 Nvidia Volta GPUs
- <u>Largest AI System at any University in the World</u>

*Based on 2018 Top500.org

AI Flops = 4x4 matrix multiply half precision in, single precision out (mixed precision training)

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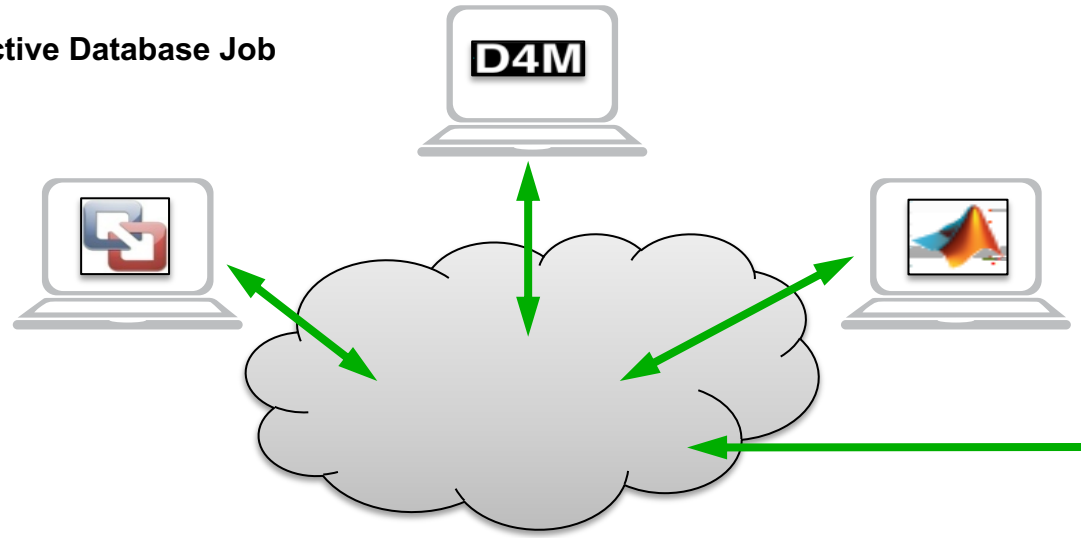
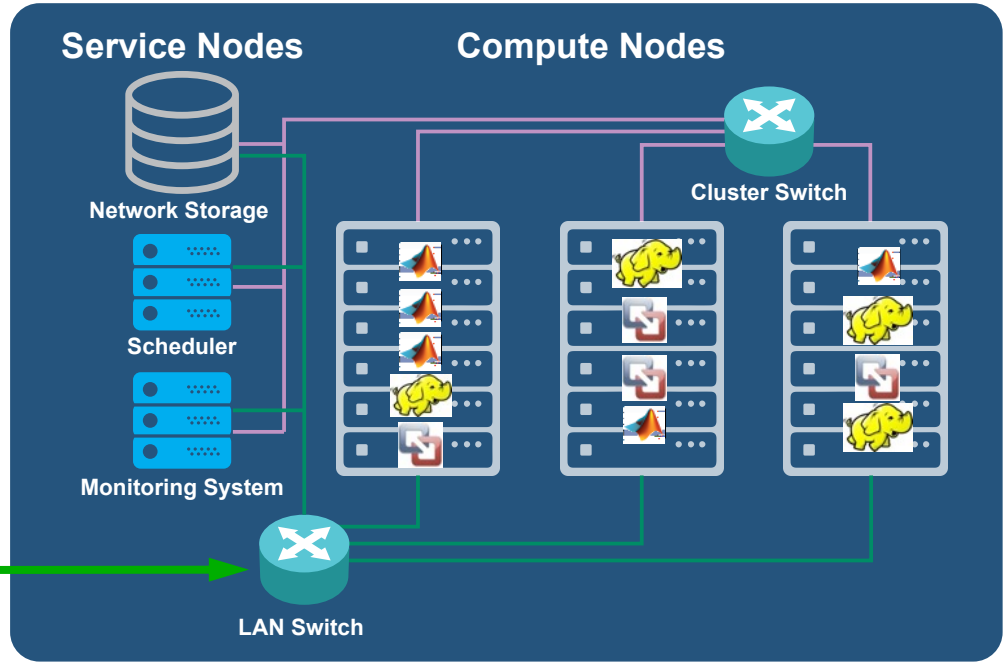
LLSC Advantage: Interactive Supercomputing

Interactive Compute Job

Interactive VM Job

Interactive Database Job

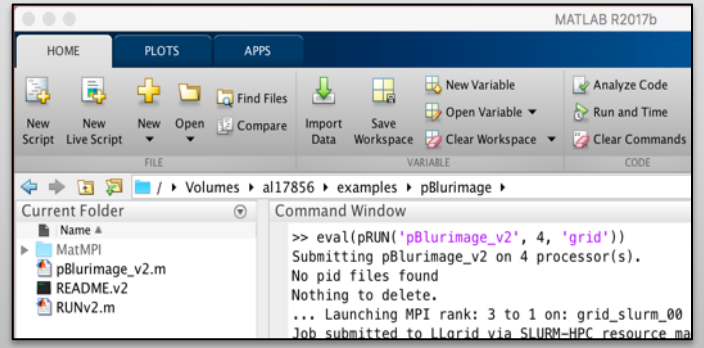




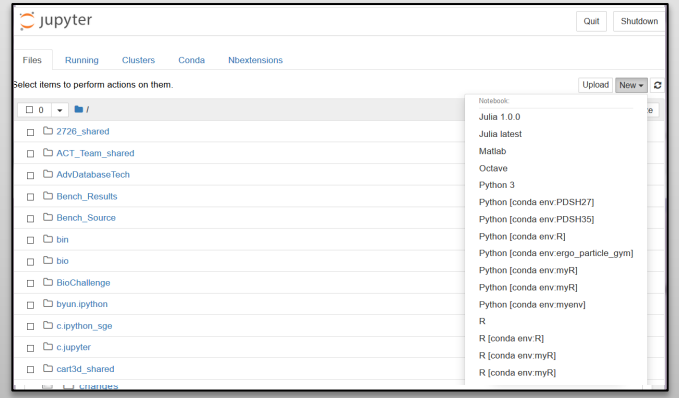
- LLSC provides a software platform that allows users to
  - Launch interactive compute jobs from their desktop
  - Share large volumes of project data
- The LLSC experience provides
  - Reference datasets pre-positioned in databases
  - Software modules and training to reduce user ramp up up time

Unique Interactive Supercomputing Capabilities

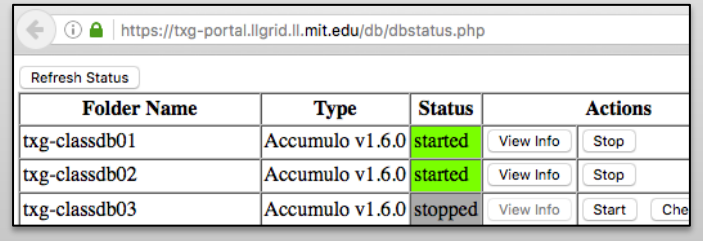
Parallel MATLAB: world's most productive parallel computing environment



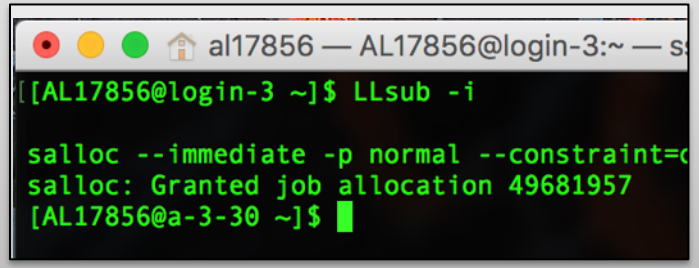
Jupyter Notebook: web-based IDE & more



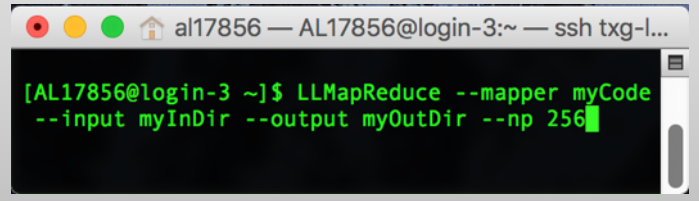
Dynamic Databases: manage world's most powerful databases from a GUI



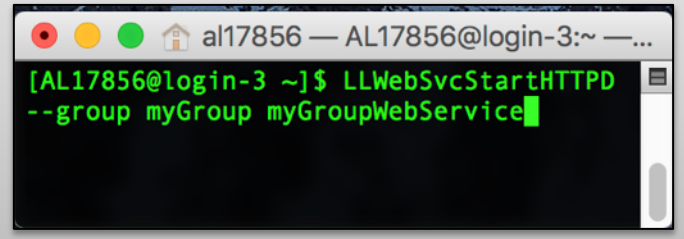
Interactive Hardware: get a processor core or a whole node



LLMapReduce: parallel data analysis in any language with one line of code



Dynamic Web Services: start an authenticated web-service



MIT SuperCloud Portal

George
Passw0rd

User-Based Firewall Rules

Connector		*Listener*
UID: 501	User is the same	UID: 500
GID: 501	Primary group is the same	GID: 702
SGIDs: • 501 • 702	Listener primary group matches one of the connector's supplemental groups	

- System services exempt
- Users configured to be exempt

gridsan/
db/
vm/
jupyter/

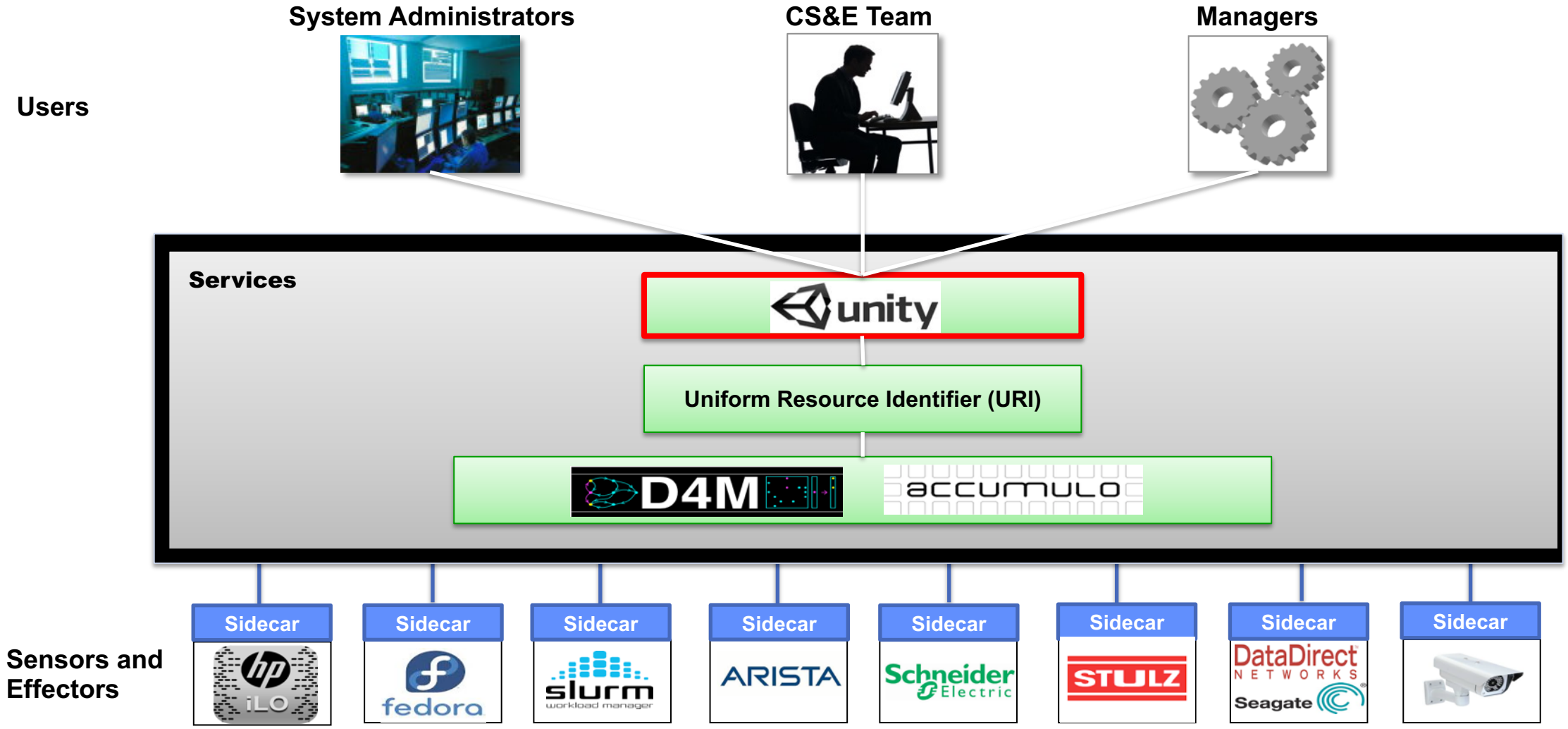
mod_dav_fs

George

Files

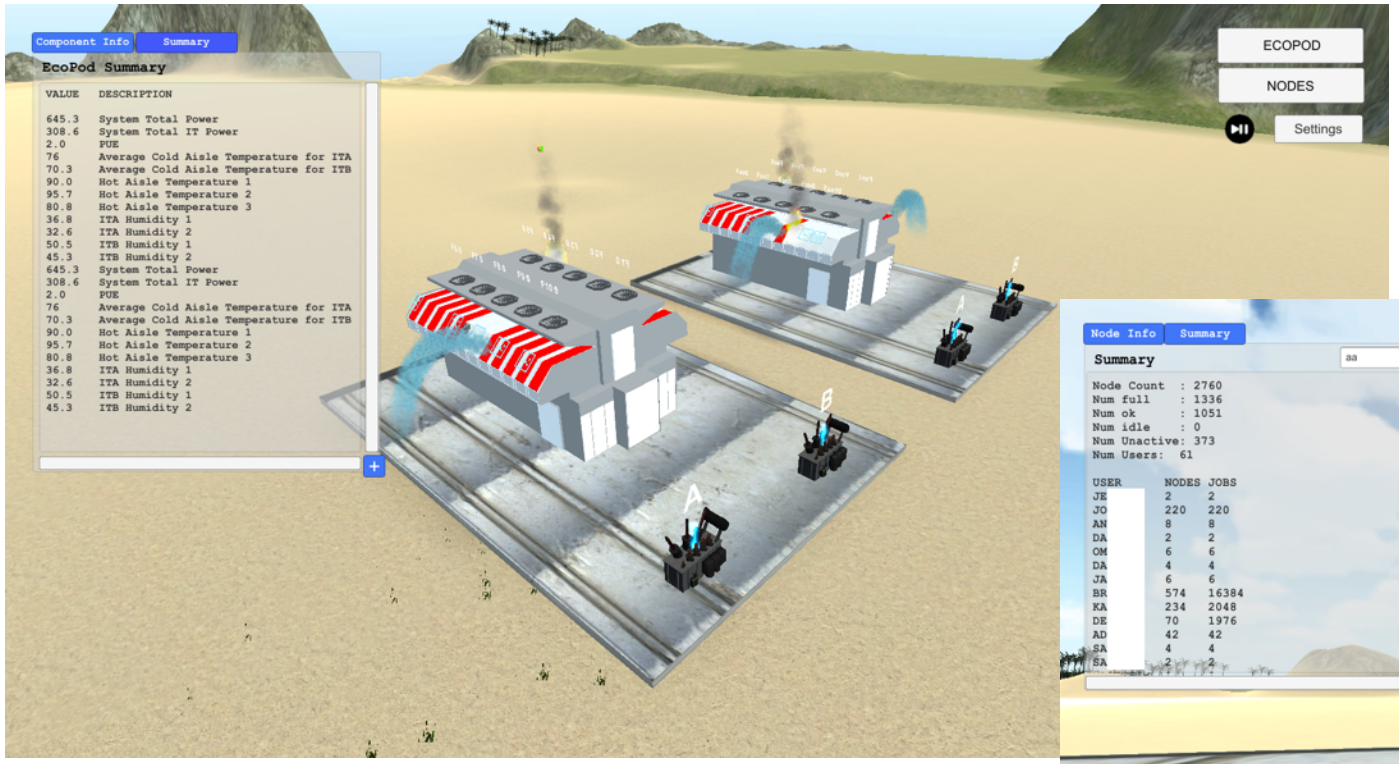
User's Desktop | Portal Node | HPC Compute Nodes and Central Storage

LLSC System Monitoring Framework



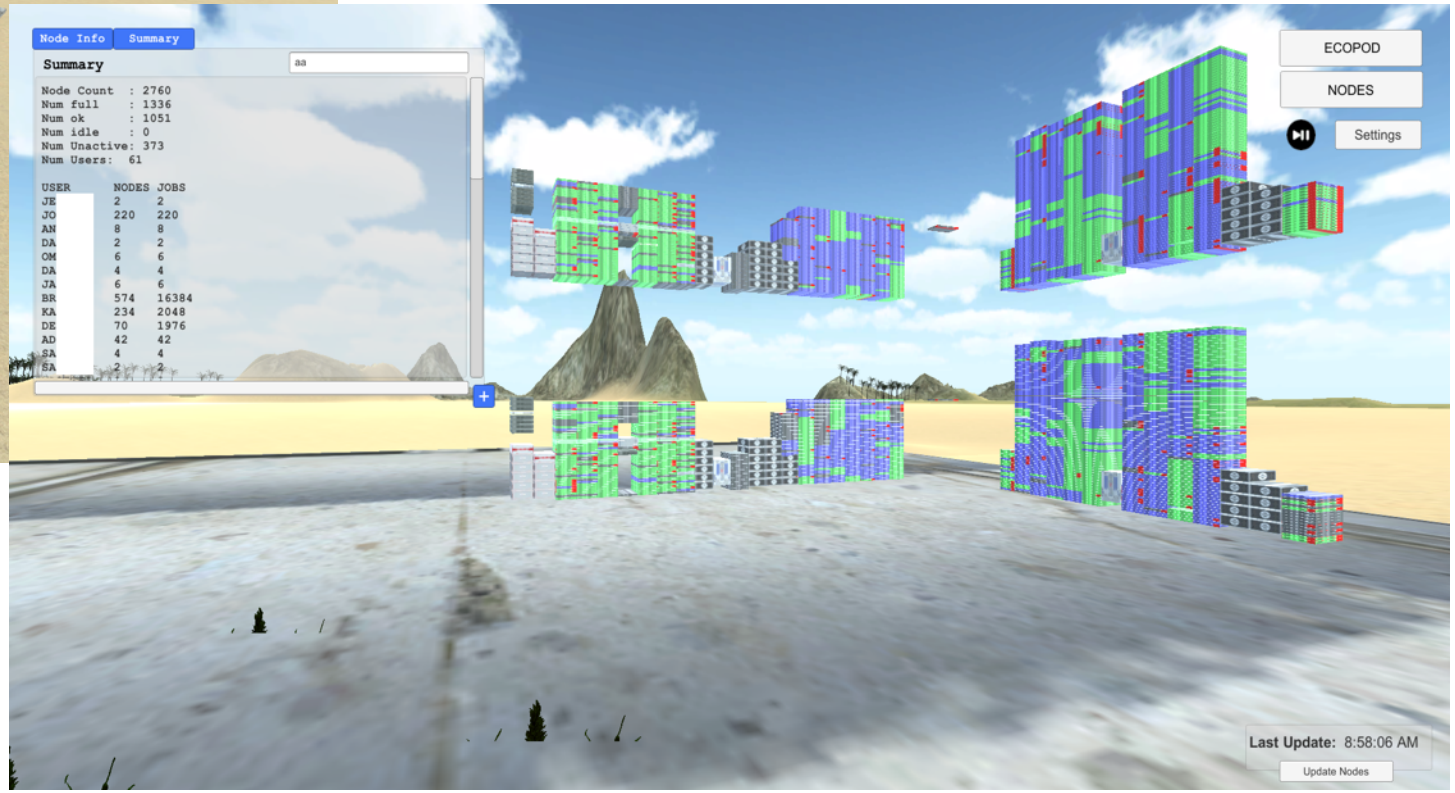
CS&E: Computational Science and Engineering

Data Center Monitoring System Screen Shots



- Data center screen shows status of all EcoPOD systems and subsystems including
  - Power distribution
  - Temperatures and humidity
  - Fans and air conditioners

- Nodes screen shows status of all login and compute nodes, storage nodes, and network switches
- Nodes are shown in rack positions



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Slurm Experience at LLSC

- Slurm 15.08.8
  - Several QoS: normal, pmatlab, high, db, and gpu
  - LUA job_submit plugin
    - To enforce various requirements for jobs
  - Multi-factor priority scheduling
  - SPANK Plugin - X11 forwarding & TMPDIR
- Slurm 15.08.8 -> Slurm 16.05.10
  - Job array task dependency, “aftercorr”
- Slurm 16.05.10 -> Slurm 17.11.7
  - Native X11 forwarding support
- Slurm 17.11.7 -> Slurm 19.05.x (in progress)
  - Better support for GPU resources

Implementation Considerations

- Three separate partitions for different node types/work loads
  - Normal: General compute jobs (including DB services)
  - Manycore: Large simulations
  - GPU: Machine-Learning/AI jobs

- Support for resource management enforcement at partition level
  - User limit on resources
    - CPU: able to set different core/job slot limits within each partition
    - GPU: number based on availability and user demand
    - Memory: supports Linux OS CGROUPS kernel feature

LUA job_submit Plug-in

- Enforce the default feature (used for CPU type) request if not specified
- Set the highest QoS for interactive jobs
  - With the highest QoS and multi-factor priority scheduling, interactive jobs are immediately scheduled

```
$ salloc --immediate --constraint=opteron srun --pty bash -i
```

salloc: error: Unable to allocate resources: Immediate execution impossible, insufficient priority

```
$ salloc --immediate --constraint=opteron --qos=high \
        srun --pty bash -i
```

salloc: Granted job allocation 4109683

- Enforces GPU resource count to be 2 or 4 (Slurm recognizes one K80 as two K40s)
- GPU memory cleanup
  - GPU memory is not cleared at the end of job
  - Epilog script clears the entire K80 memory

SPANK Plug-in Module

- X11 forwarding
  - Used for applications requires a graphical user interface
  - Limited to interactive jobs only

    https://github.com/hautreux/slurm-spank-x11
  - Switched to the native X11 forwarding support with Slurm

- Redirecting TMP/TMPDIR
  - A per-job temporary directory plugin creates a directory on a local filesystem and exports it in the TMPDIR environment variable
  - This provides similar behavior of the previous scheduler
  - Useful for applications requiring a local filesystem
    - At LLSC, Lustre parallel filesystem disabled file locking for performance
  - Used for file-based message communication in gridMatlab for large scale parallel Matlab/Octave jobs[1]

[1] *Large Scale Parallelization Using File-Based Communications*, Byun et. al, IEEE HPEC 2019

LLSC Resource Limit Enforcement

- Partition specific user association limits enforced
  - normal partition: GrpTRES=cpu=512
  - manycore partition: GrpTRES=cpu=8192
  - gpu partition: GrpTRES=cpu=56,gres/gpu:tesla=16
- Allows us to adjust the per-user limit if needed
  - Users can request increased core limits for specified time periods
  - For some cases, we need to enforce the memory limit as well
- Caveat
  - User account for each partition needs to be created to enforce the partition-specific user association limit
- Desired to handle a single user account to enforce the partition-specific user association limit

Immediate Job Support

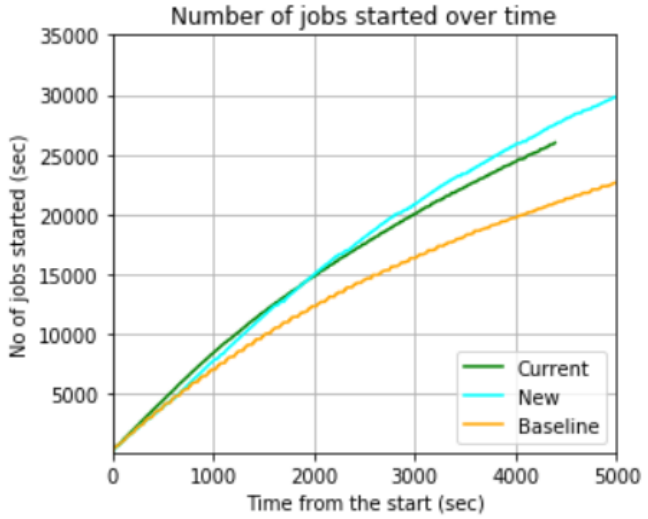
- The immediate jobs (--immediate flag) are important to LLSC users
  - Interactive, on-demand supercomputing resources for interactive jobs
  - Database jobs
  - Jupyter notebook jobs
- Multi-factor priority scheduling with a high-priority QoS
  - Configure slurm.conf for multi-factor priority scheduling
  - Attach the high QoS to all immediate jobs
- Changes with low priority jobs to harvest idle resources
  - When the cluster is full with low priority jobs, any immediate job submission is rejected
  - Add a time delay with the --immediate flag for interactive jobs
    - Time delay allows Slurm to pre-empt the low priority jobs before scheduling the immediate jobs
  - sbatch command does not support time delay with the immediate flag
    - Implemented own logic to support SPOT (low-priority preemptable) jobs

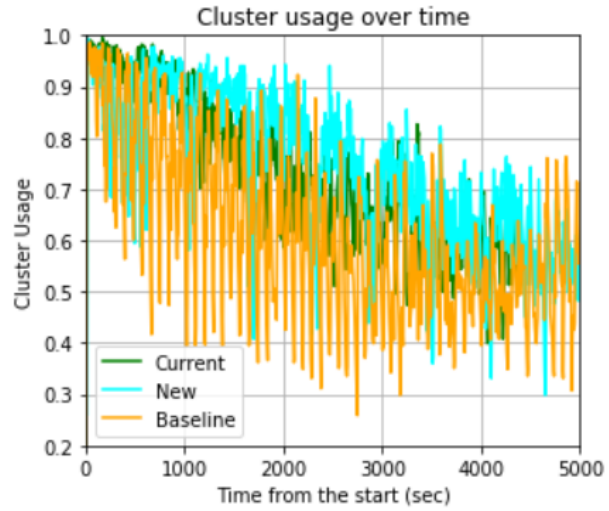
Tuning For Throughput Jobs

- **Job Characteristics**
  - **Majority of jobs are throughput jobs (array jobs)**
  - **Small number of MPI jobs**
  - **Tuning the scheduler for maximum throughput performance**
- **Tuned Parameters**
  - **Started with the baseline high-throughput configuration**

    https://slurm.schedmd.com/high_throughput.html
  - **Compared the throughput performance with the current and new parameters**

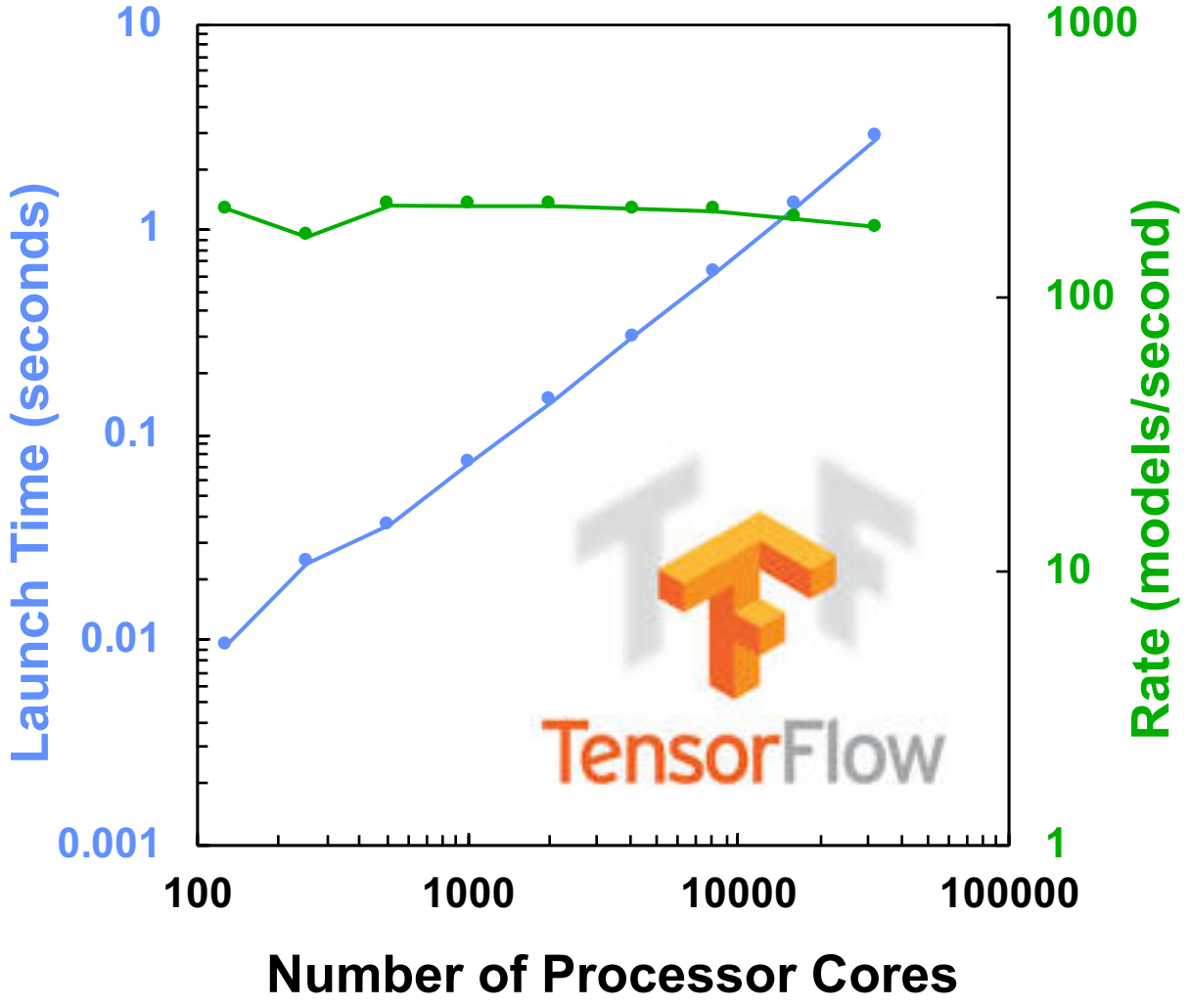
    SchedulerParameters=bf_interval=30,preempt_youngest_first,pack_serial_at_end,bf_busy_nodes,batch_sched_delay=10,bf_min_age_reserve=600,bf_resolution=600,bf_continue,bf_yield_interval=1000000,sched_min_interval=2000000,max_rpc_cnt=200





Interactive High Performance Machine Learning (HPML)
- Interactive Launch on 32,000+ Cores -

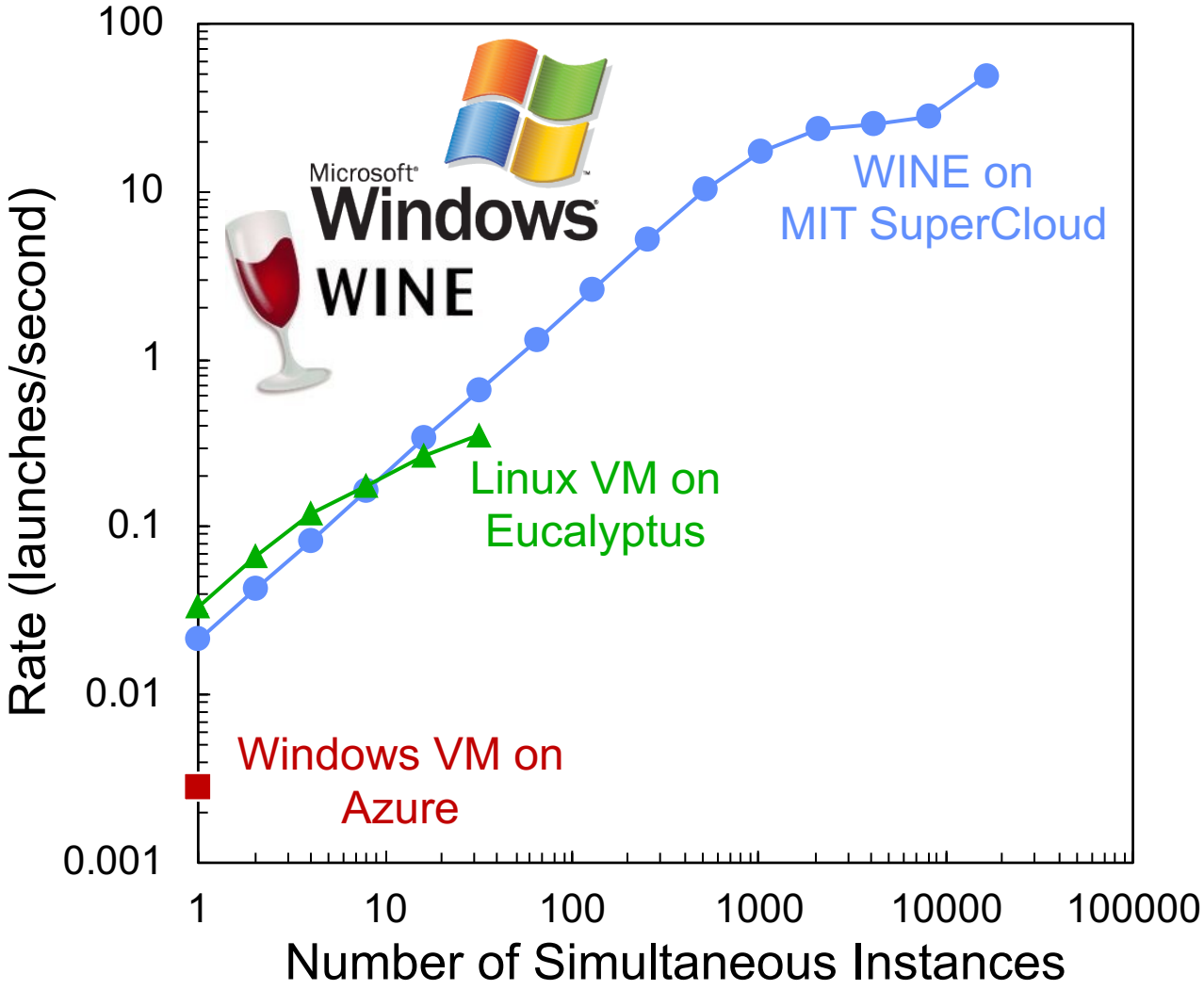
- **Machine Learning models require**
  - **High level programming environments for building models**
  - **Rapid interaction with analyst**
- **Standard approaches take minutes to hours to launch on thousands of cores**
- **MIT SuperCloud optimizes every aspect of HPML system to enable**
  - **Launching hundreds of machine learning models in seconds**
  - **32,000+ cores (512 64-core Xeon nodes)**
  - **Truly interactive machine learning**



Scalable System Scheduling for HPC and Big Data, Reuther et al, Journal of Parallel and Distributed Computing, 2017

Launching 16,000+ Microsoft Windows Environments

- **Some analytic applications are written uniquely for Microsoft Windows**
- **Standard approaches take hours to launch on thousands of cores**
  - **VMs, Windows HPC, …**
- **MIT SuperCloud optimizes every aspect of launch system to enable**
  - **16,000+ Microsoft Windows environments (running WINE)**
  - **16,000+ cores (256 x 64-core Xeon nodes)**
  - **Launched in 5 minutes**
  - **50+ launches/second**
  - **100x faster than standard approaches[1]**
  - **Truly interactive supercomputing**



[1] *Interactive Launch of 16,000 Microsoft Windows Instances on a Supercomputer*, Jones et al, IEEE HPEC 2018

Summary

- LLSC has been using Slurm for 3+ years
- LLSC has learned and exploited a number of features available to Slurm
  - LUA job_submit plug-in
  - SPANK plug-in module
  - Association limit enforcement
  - Multi-factor priority scheduling
  - QoS
  - Prolog/Epilog
  - Advance reservation
- LLSC software stack with Slurm enables scaling up users' applications
  - Interactive High Performance Machine Learning
  - Microsoft Windows Environment via Wine