SAND2014-3299P

Large Scale HPC Monitoring

NMSU Las Cruses New Mexico

April 23, 2014

Overview

- Technology Description
- Project Goals
- Deployment configuration and architecture of data collection component
- Use cases including data visualizations
  - Sandia
  - National Center for Supercomputing Applications
- Overview of current analysis and visualization status
- Conclusions
- Future Work

Description of Technology

- What is it?
  - Highly scalable platform independent system for HPC resource monitoring and understanding
- What does it do?
  - Collects, transports, and stores both numeric and log run-time information
  - Provides plugin capabilities for analysis, visualization and decision support including direct application/system feedback
  - Admin collection for troubleshooting, root cause analysis, and understanding of application/system interaction
  - User driven collection for understanding system/application interaction
- Addresses Large scale HPC system understanding and troubleshooting
  - System snapshots
  - Correlation of events and behaviors to degraded performance/failure

OVIS Framework

Sample

Bundle

Sample

Bundle

Aggregate

- Notification
- Feedback

Original Set

Bloom Filter

Filtered Set

Filter

Raw

- Analyze
- Visualize
- Model

$$\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2}$$

Store

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Significance of Technology

- Technological advantage
  - Enable whole system state snapshots that can:
    - Pinpoint issues driving run-to-run application performance variability
    - Help system administrators troubleshoot problems
    - Relatively fine grained information can help users discover performance issues and solutions without having to re-compile or re-link their programs
  - Scalable auto-discovery of problems
  - Decision support for problem identification and resolution

Competitiveness

- How does this technology compare with its competition?
  - Complete solution (others tackle a piece of the problem)
  - Low overhead (small CPU and memory footprints)
  - Easy to build, configure, and use
  - Modular for plug-n-play functionality
- Crucial factors
  - Support for RDMA transport across a variety of interconnects
  - Sampler plug-ins (both kernel and user) that support run-time modification of sampling frequency
  - Large fan-in ratios (> 10,000:1)
- Intellectual property position
  - The software is open sourced and publically available
  - SNL and OGC hold joint copyright

Wow! Factor

- What is compelling about this technology?
  - First comprehensive **platform independent** HPC monitoring, transport, storage, analysis, visualization, and feedback **system**
  - Low overhead (both CPU and memory)
  - Simple to build, configure, and use
  - Extensible
  - Modular (Plug-n-play)
  - Highly scalable (no known limitations due to parallel everything)
  - Large fan-in ratio (> 10,000:1)

Project Goals

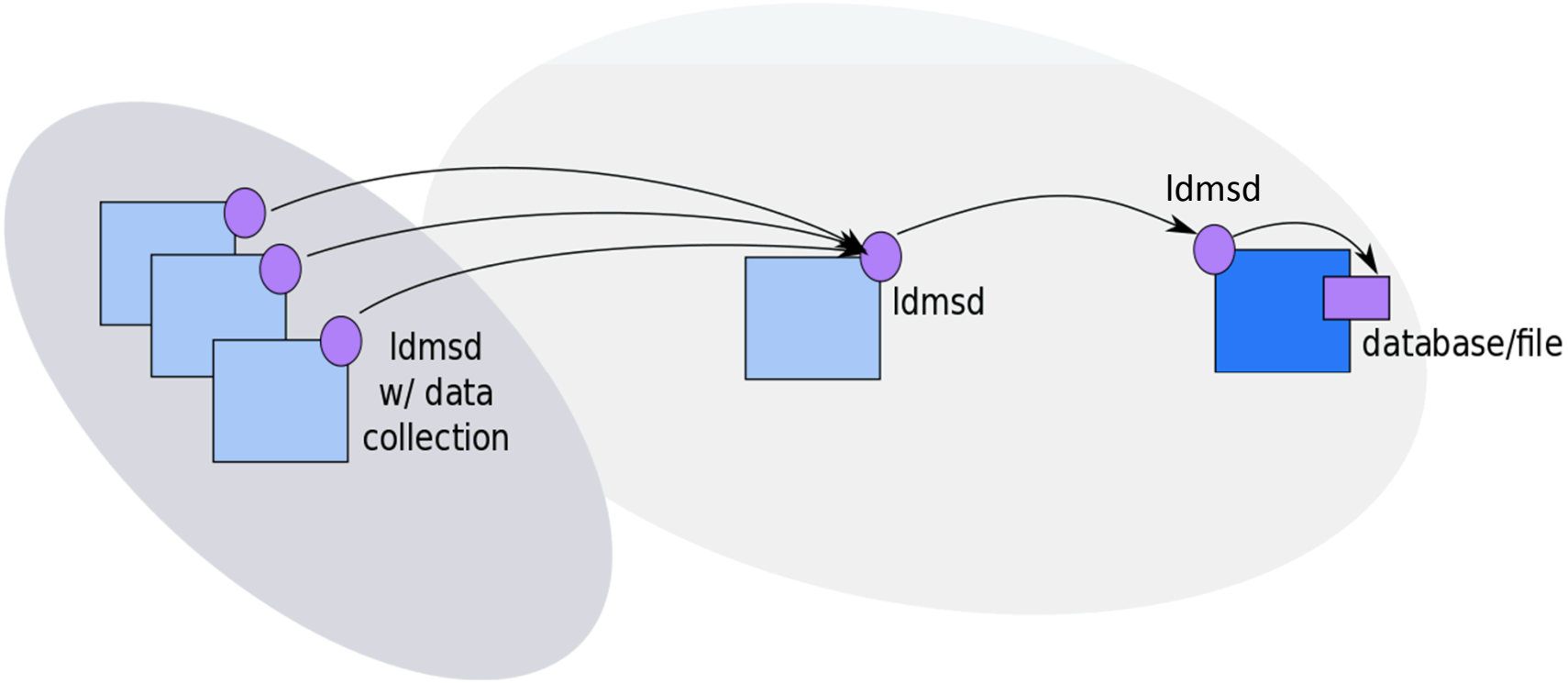
Monitor system resource state and utilization as a system service, running asynchronous to applications, for both administrators and users of High Performance Computing (HPC) systems

- Provide:
  - Run-time collection of metrics of interest on time scales of interest
  - Per-node resource utilization understanding
  - Application profiles
- Lightweight (negligible application impact)
  - ~1.5MB memory footprint
  - CPU overhead is dependent on number of metrics, frequency of collection, and communication technology
- High fidelity (~< 100Hz)
  - Typically run at intervals of seconds
- Platform independent (i.e. portable across Linux OSs)
  - Fedora, RHEL, SUSE, CentOS, Mint, Ubuntu
- Support for Socket and RDMA on major network technologies
  - Ethernet, Infiniband, Cray Gemini/Aries
- Simple configuration

Data Collection

Lightweight Distributed Metric Service (LDMS)

Deployment Configuration: Data Collection, Transport, and Storage



LDMS Metric Set Examples

cn1/meminfo

- U64 160032 MemFree
- U64 181728 Buffers
- U64 3443332 Cached
- U64 33076 SwapCached
- U64 2987544 Active

cn1/procstatutil

- U64 1826564 cpu0_user_raw
- U64 699631 cpu0_sys_raw
- U64 663843760 cpu0_idle_raw
- U64 201018 cpu0_iowait_raw

cn1/vmstat

- U64 40008 nr_free_pages
- U64 122286 nr_interactive_anon
- U64 321902 nr_active_anon
- U64 465532 nr_inactive_file
- U64 424986 nr_active_file

Metric sets:

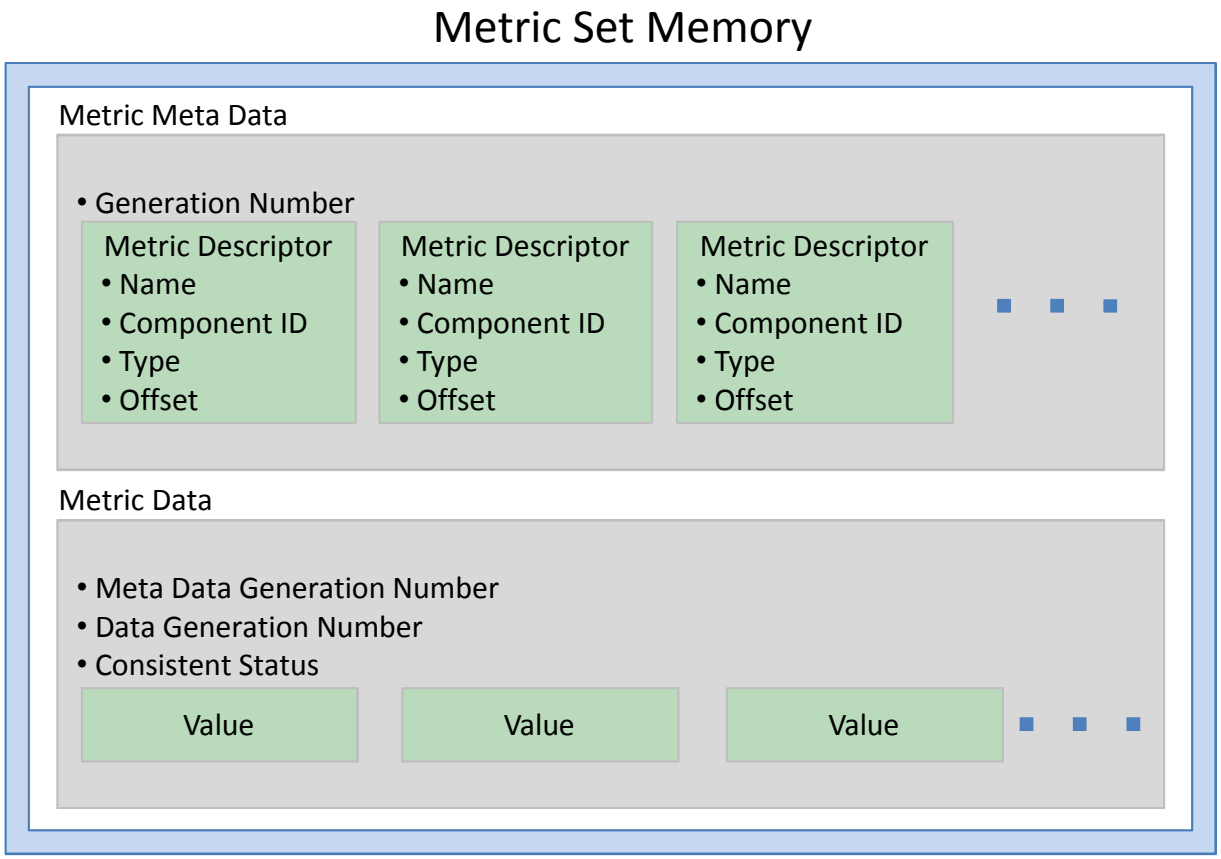
- (datatype, value, metricname) tuples
- optional per metric user metadata e.g., component id

API:

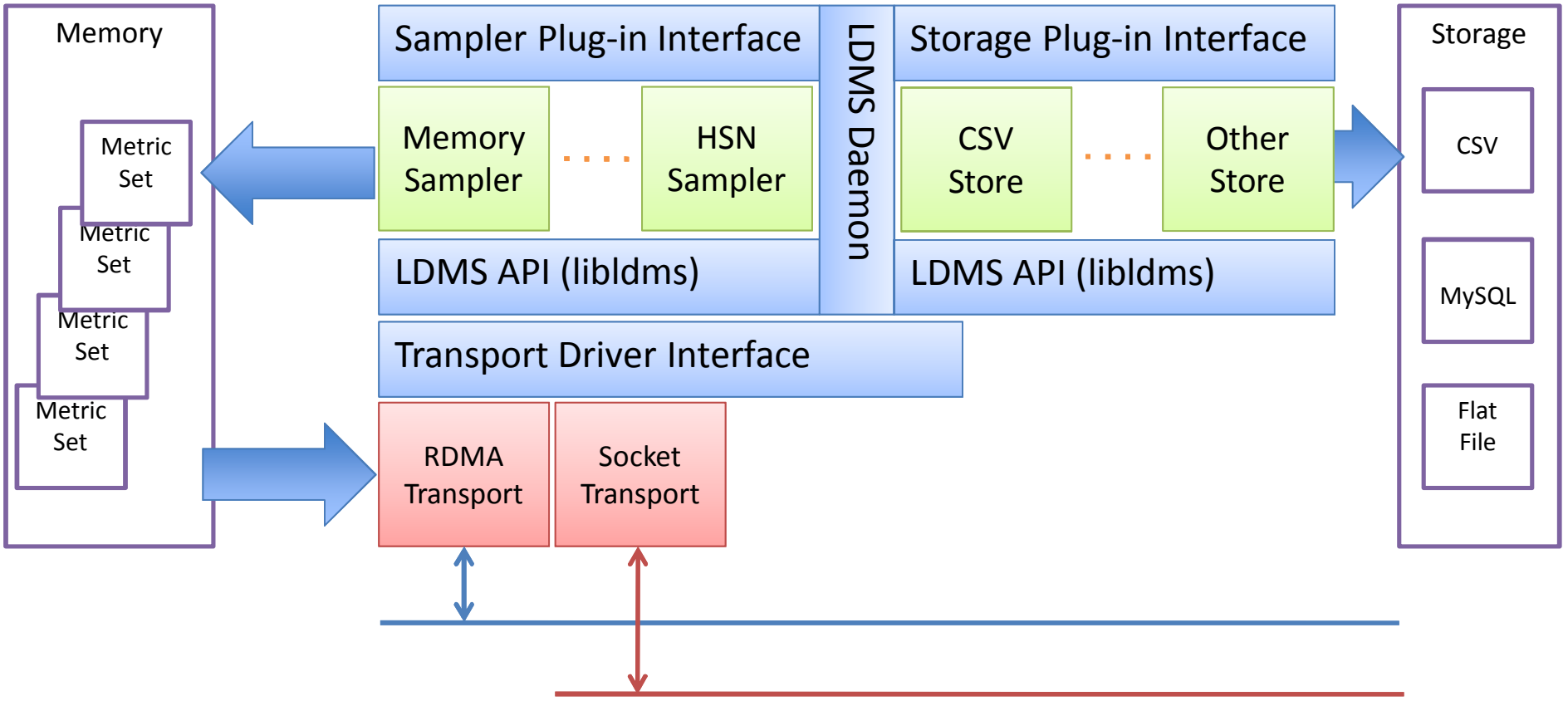
- *ldms_get_set*
- *ldms_get_metric*
- *ldms_get_u64*

- Same API for on-node and off-node transport

Metric Set Format



LDMS Architecture



Major Functional Components and Features

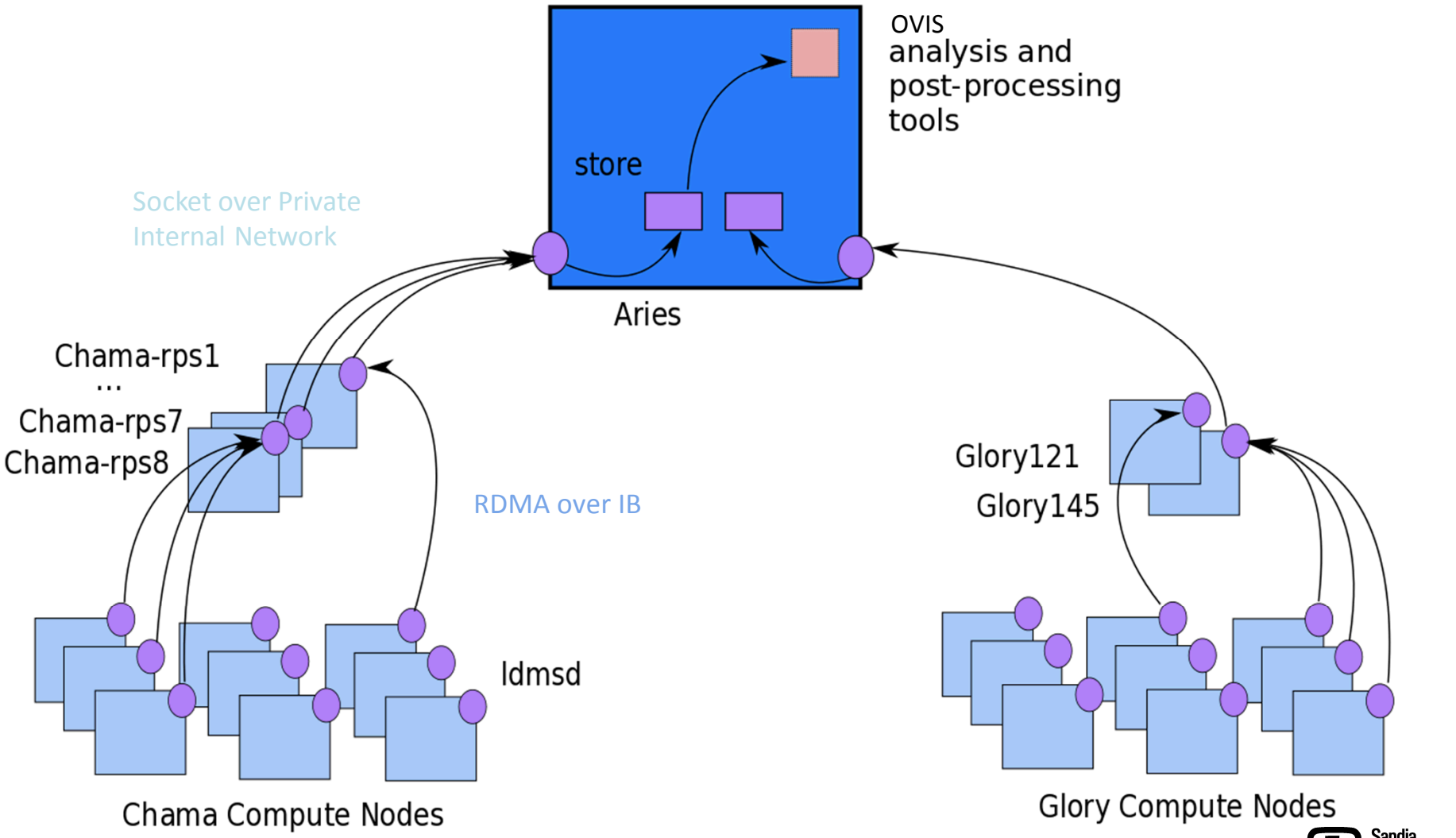
- Collection
  - Run-time loadable monitor plugins (collect data into a “metric set”)
  - Run-time configurable sampling period from ~100Hz to days
  - Variety of collectors draw from /proc, /sys, lm-sensors, perf-event
  - Control is at the granularity of a “metric set”
  - Synchronous option enables “system view” to within clock skew
- Aggregation
  - Fan-in of thousands to 1
  - Support for failover configuration
  - Supports daisy-chaining
    - Aggregate from collectors and/or aggregators
- Storage
  - Support for: CSV, flatfile, MySQL, custom

Current Monitor Plugins

- /proc
  - meminfo, vmstat, net/dev/stat, interrupts, nfs
  - kgnilnd (Cray specific)
  - Lustre
- cray_system_sampler (Cray specific)
  - Gemini Tile and NIC counters w/ link aggregation
  - Lustre llite counters
  - A variety of metrics from other sources
- perf_event
  - Generic interface for acquisition of hardware counters e.g., data cache misses, instruction cache misses, hyper-transport bandwidth
- rsyslog (Cray specific)
  - SEDC (RAS) and ALPSdata
- lmsensors (`/sys`)
  - Temperatures, fan speeds, voltages
- IB traffic counters (`/sys`)

USE CASES: PROFILING SYSTEM AND APPLICATION RESOURCE UTILIZATION

Chama: 1232 node TLCC2 cluster (SNL)
Glory: 288 node TLCC1 cluster (SNL)



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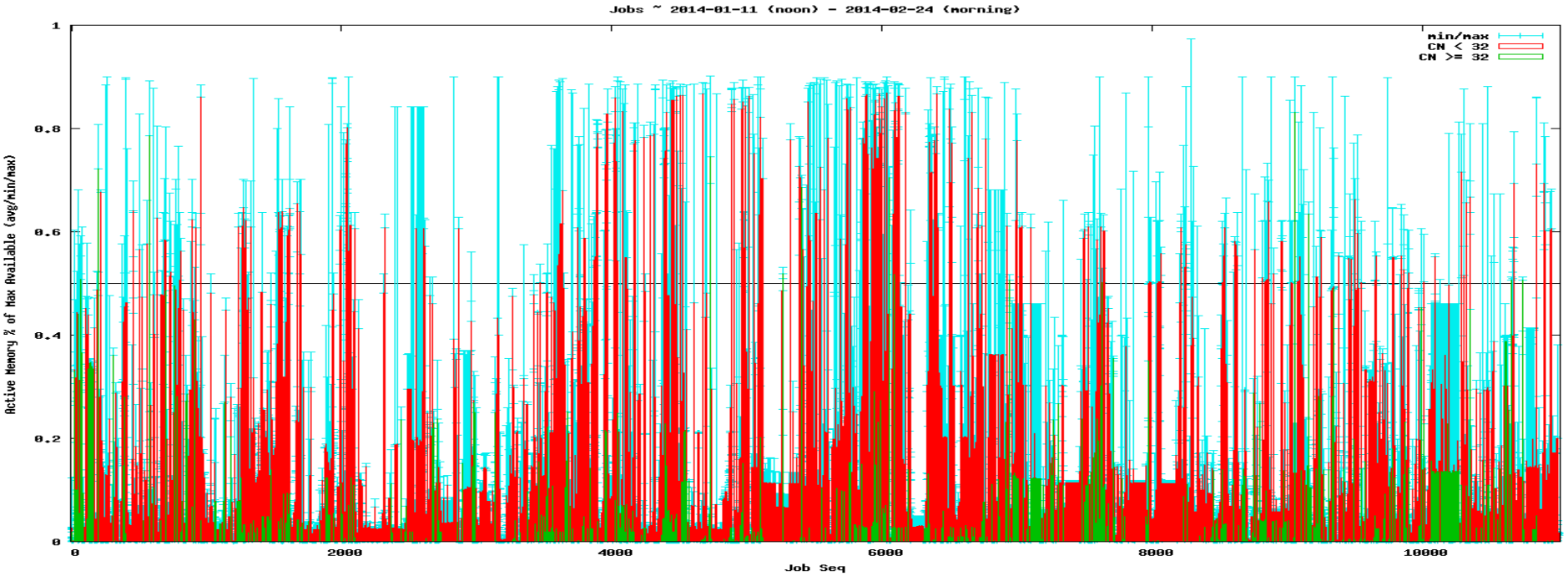
Memory Use Across All Jobs
(Chama)



- Green represents jobs with greater than or equal to 32 nodes
- Blue (error bars) shows high water mark while green and red are average over job

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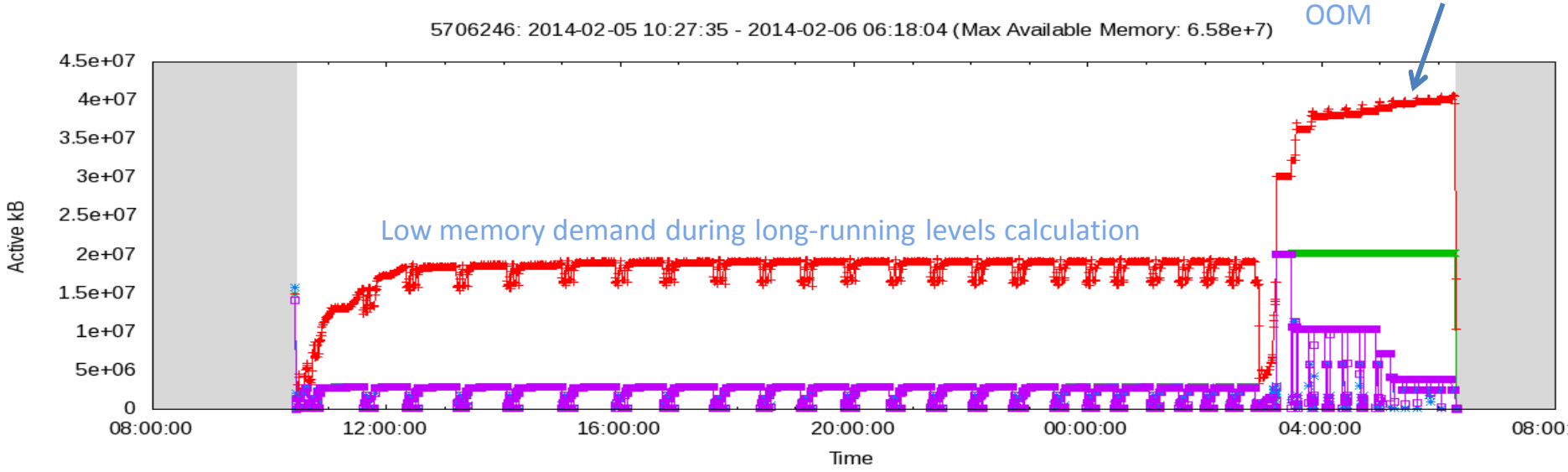
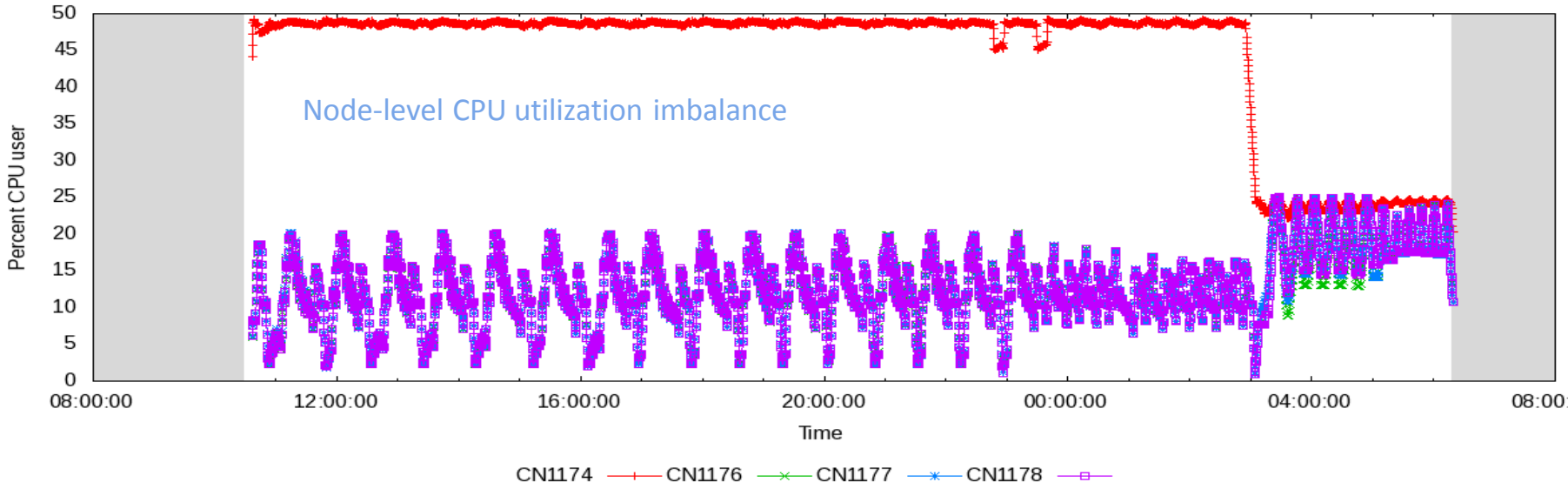
Application Profile: Gaussian

High memory demand during DFT may result in OOM

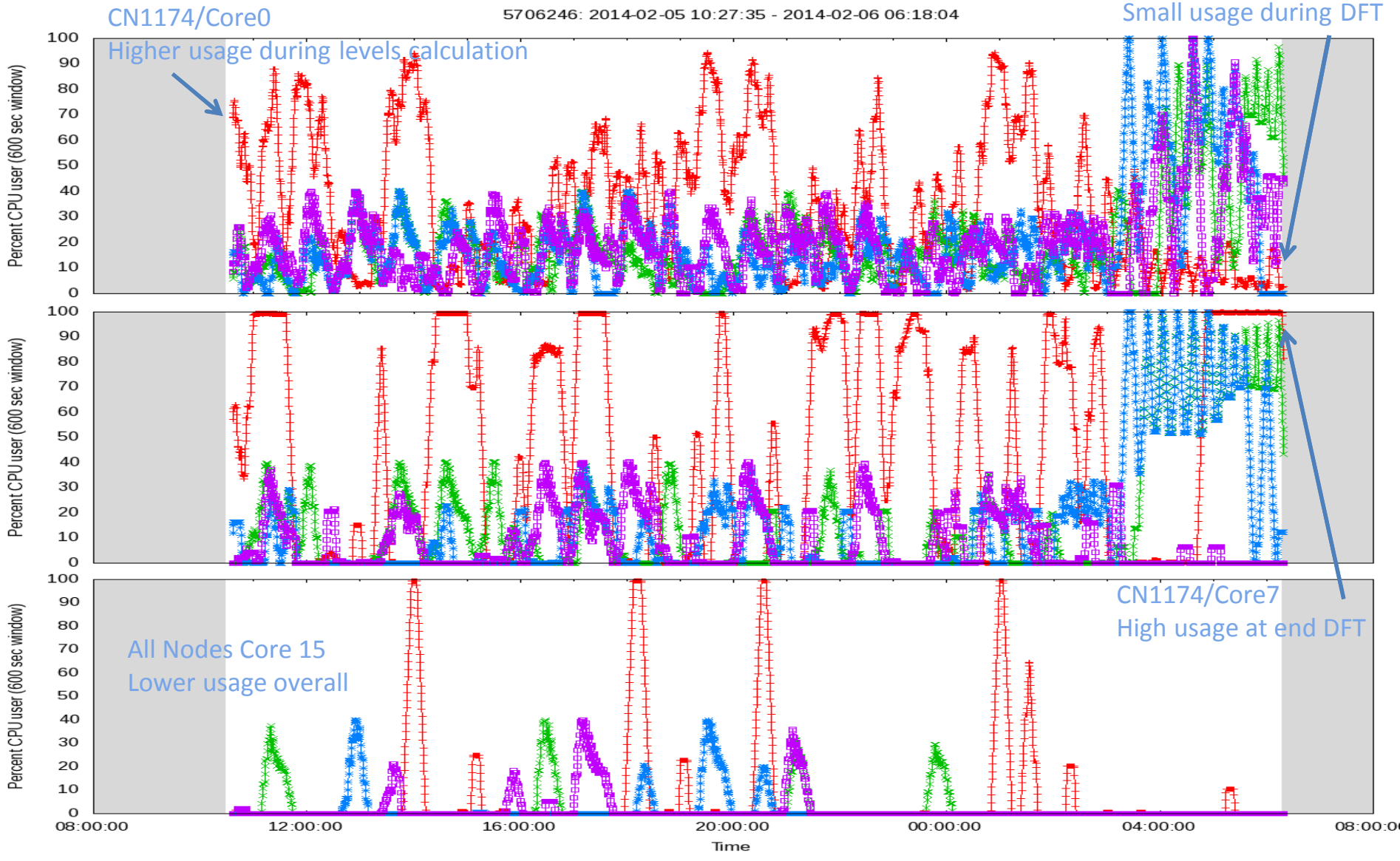


Two-execution phases are potentially separable enabling better application-to-resource mapping

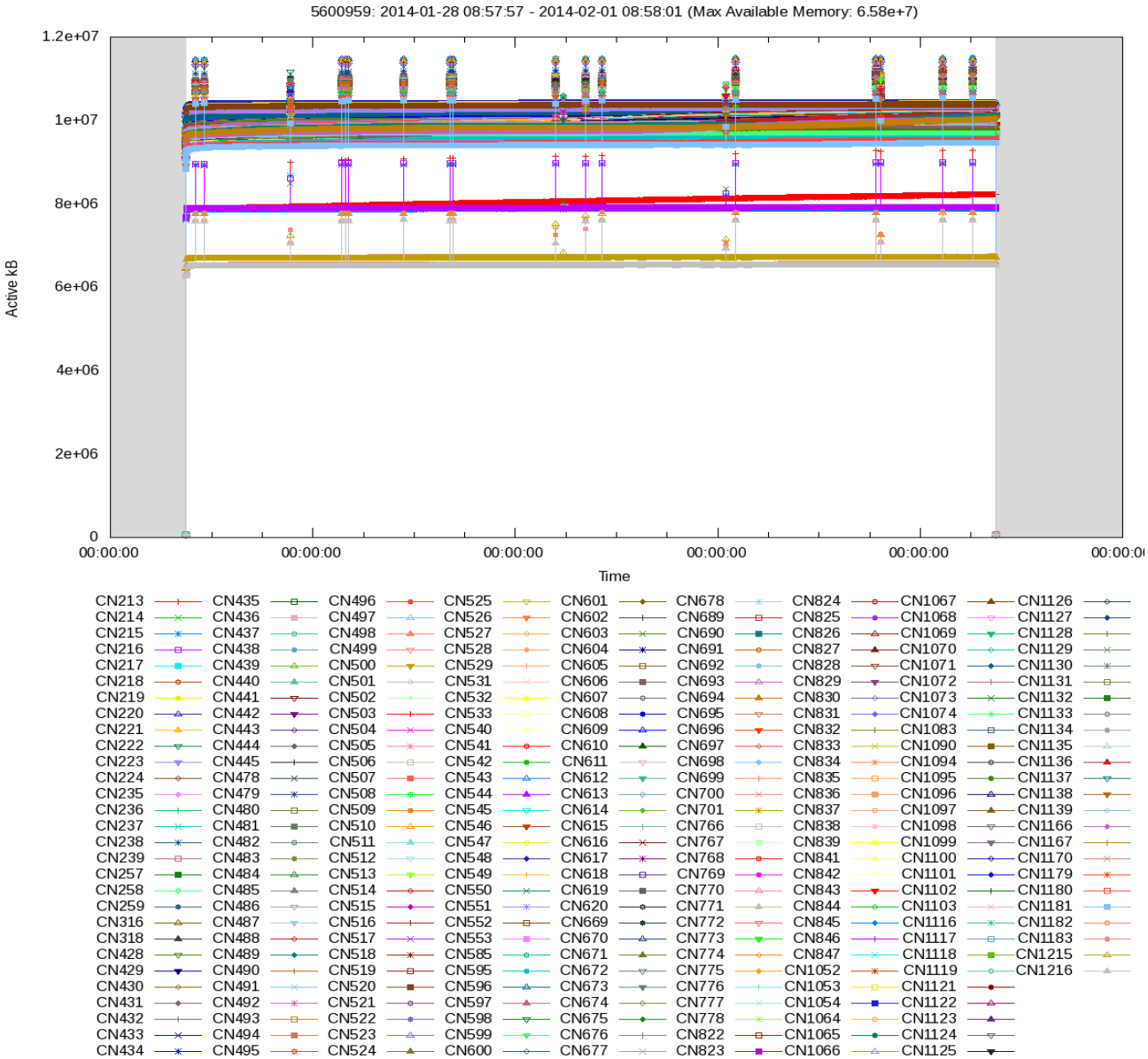


Gaussian: Per core CPU Load

(Cores 0/7/15)

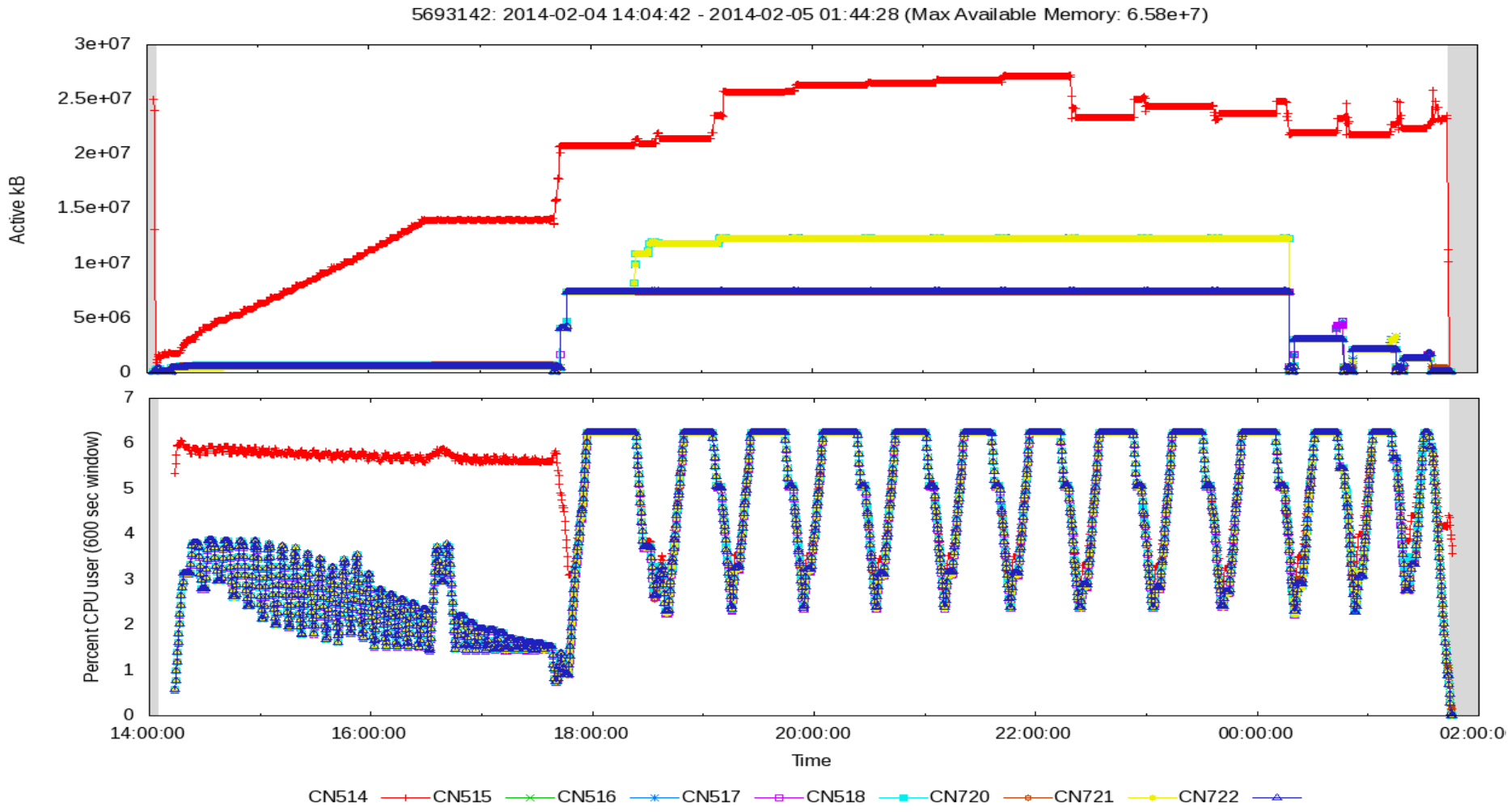


Application Profile: LAMMPS



- Generally well balanced in memory usage
- Running on fewer nodes can increase memory usage (17%->25%)
- However application is CPU bound, running nearly 100% user time on all cores.

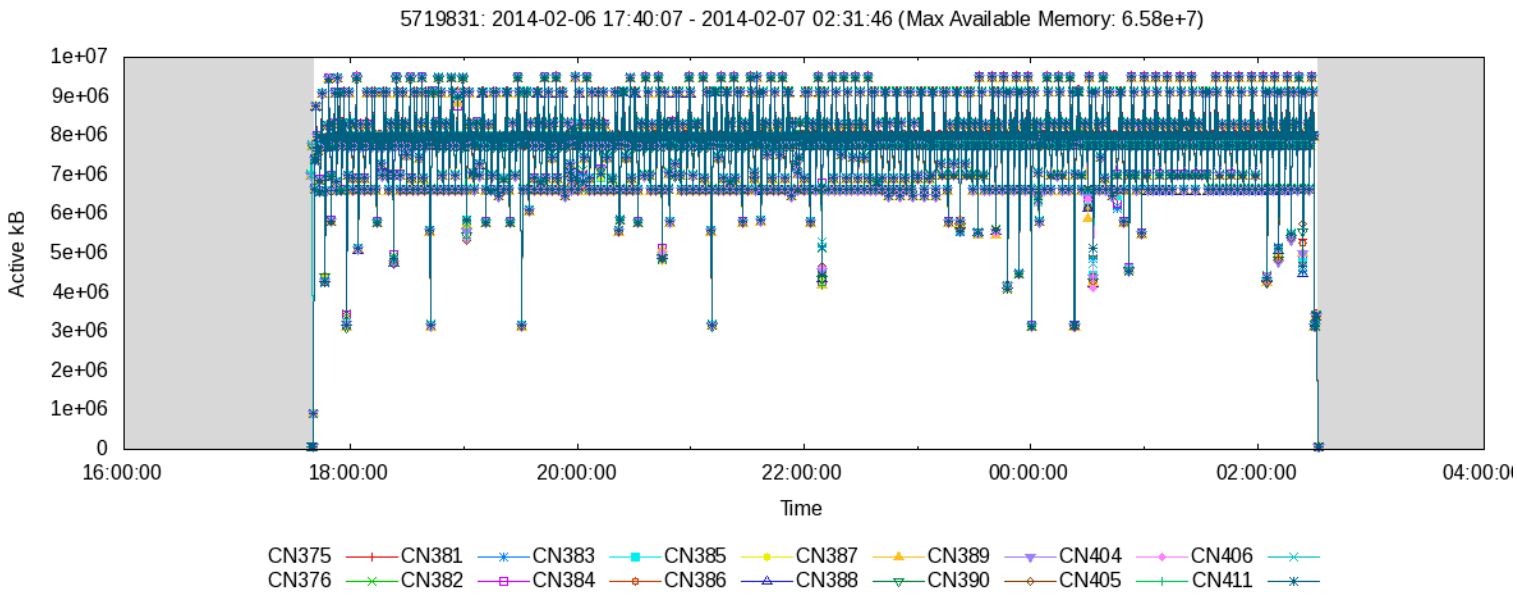
Application Profile: Unknown



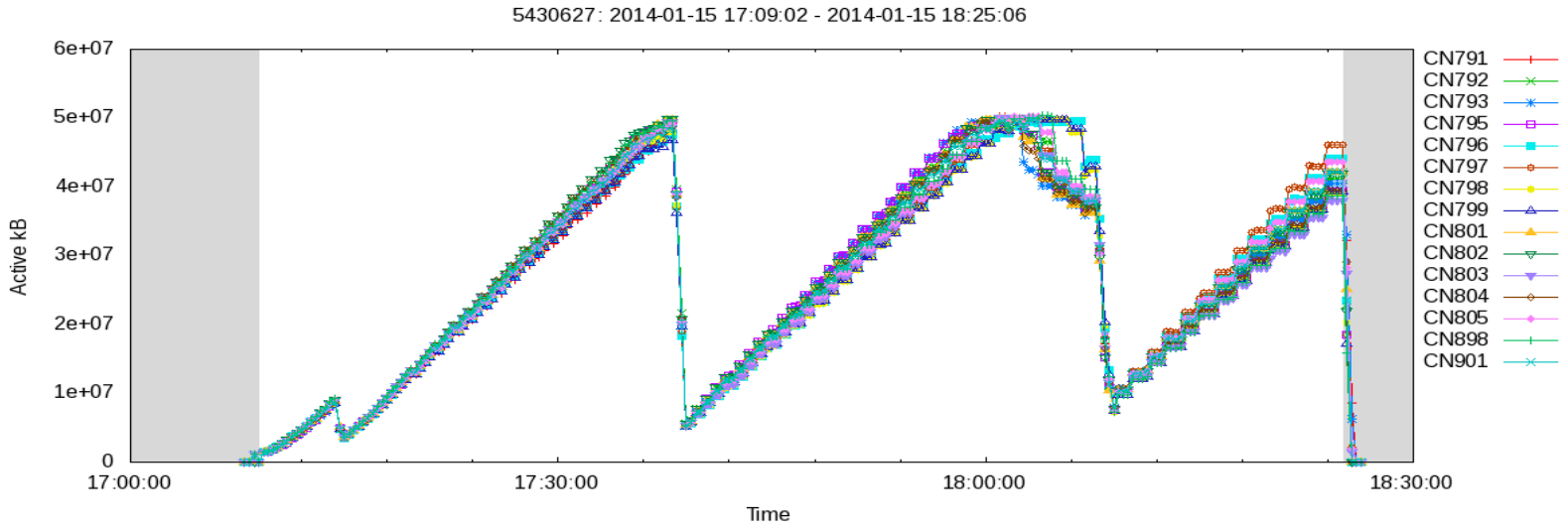
- Neither CPU nor memory bound. Investigating other quantities

Application Memory Usage Patterns

(Chama)



Soccoro



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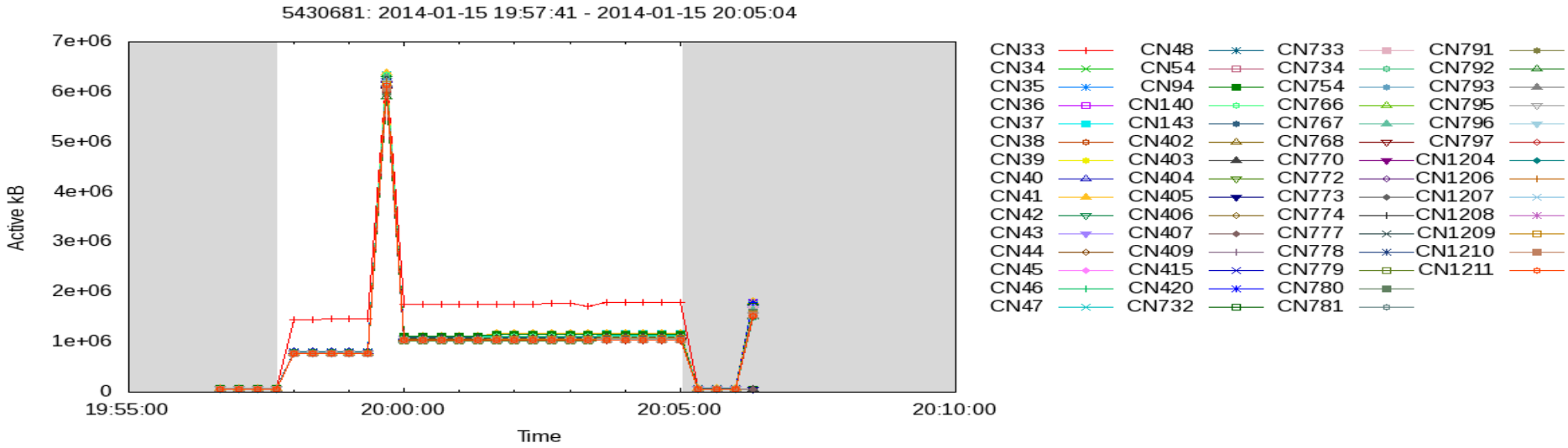
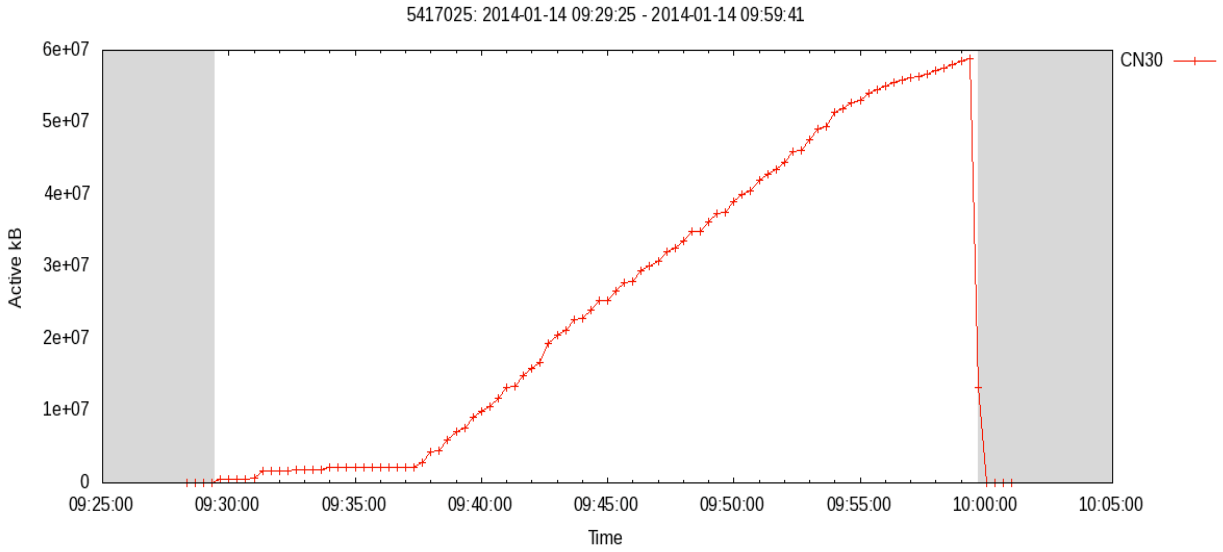
Application Memory Usage Patterns

(Chama)





- Memory usage results in OOM

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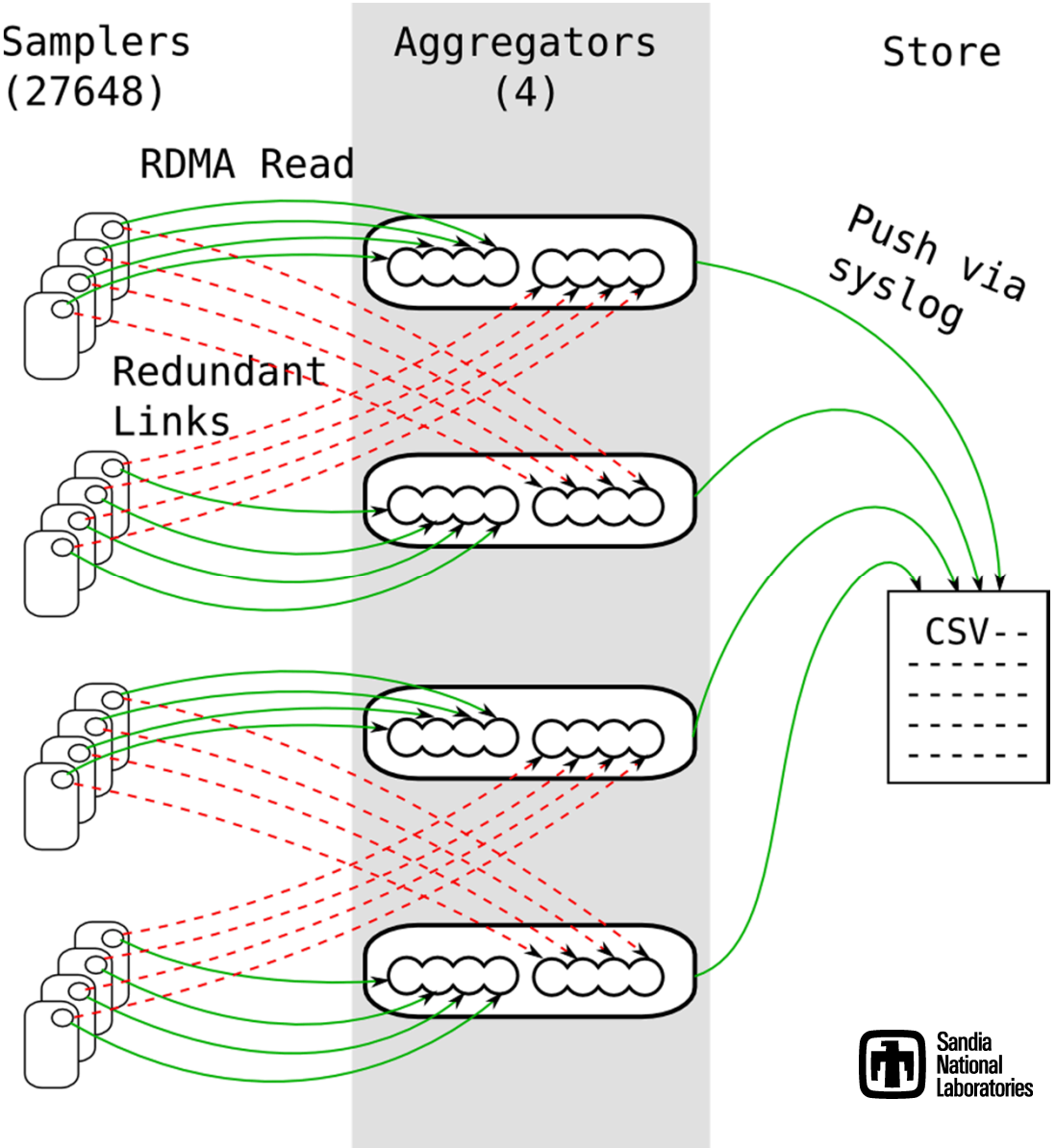
NCSA's Blue Waters: 27648 node Cray XE6/XK7

- All metric sets identical independent of node
  - 194 metrics
- Sample period
  - 60 seconds (normal)
  - 1 second (high)
- Each aggregator primary for 6912 nodes
  - Pull model using RDMA read
- Each aggregator secondary for 6912 nodes
  - RDMA connection established
- In event of failover aggregator collects from 13824 nodes
- Data is pushed to store (MySQL database) using syslog-ng
- One day data set for 60 second collection period contains ~35 million data points per metric and 6.8 billion data points overall



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Cray System Sampler Metric Set

- Gemini Mesh coordinates
- HSN network utilization and status:
  - Directional Gemini network counters:
    - +/- XYZ traffic, packets, inq stall, credit stall, send link status, recv link status
  - Derived directional Gemini network status:
    - link BW, Used Link BW,aved packet size, % stalls
  - NIC counters
- OS traffic
  - Enables attribution of user vs OS traffic
- Lustre stats
- Scheduling pages to disk
  - nr_dirty nr_writeback
- Memory util
- Load averages

LDMS metric set Example (data)

```
# ldms_ls -h nid00044 -x ugni -p 412 -l
nid00044/cray_system_sampler_r: consistent, last update: Wed Apr 09 08:52:40 2014 [726us]
 U64 1              nettopo_mesh_coord_X
 U64 1              nettopo_mesh_coord_Y
 U64 6              nettopo_mesh_coord_Z
 U64 3265901109447   X-_traffic (B)
 U64 21509840670687  Y-_traffic (B)
 U64 53884897461291  Z+_traffic (B)
 U64 89887627257     X-_packets (1)
 U64 475674895649    Y-_packets (1)
 U64 1333216704813   Z+_packets (1)
 U64 40775903446     X-_inq_stall (ns)
 U64 711117651410    Y-_inq_stall (ns)
 U64 544039347642    Z+_inq_stall (ns)
 U64 48             X-_sendlinkstatus (1)
 U64 24             Y-_sendlinkstatus (1)
 U64 24             Z+_sendlinkstatus (1)
 U64 191            X-_SAMPLE_GEMINI_LINK_BW (B/s)
 U64 306            Y-_SAMPLE_GEMINI_LINK_BW (B/s)
 U64 344            Z+_SAMPLE_GEMINI_LINK_BW (B/s)
 U64 1              X-_SAMPLE_GEMINI_LINK_USED_BW (% x10e6)
 U64 2              Y-_SAMPLE_GEMINI_LINK_USED_BW (% x10e6)
 U64 2              Z+_SAMPLE_GEMINI_LINK_USED_BW (% x10e6)
 U64 19             X-_SAMPLE_GEMINI_LINK_PACKETSIZE_AVE (B)
 U64 19             Y-_SAMPLE_GEMINI_LINK_PACKETSIZE_AVE (B)
 U64 19             Z+_SAMPLE_GEMINI_LINK_PACKETSIZE_AVE (B)
 U64 0              X-_SAMPLE_GEMINI_LINK_INQ_STALL (% x10e6)
 U64 0              Y-_SAMPLE_GEMINI_LINK_INQ_STALL (% x10e6)
 U64 0              Z+_SAMPLE_GEMINI_LINK_INQ_STALL (% x10e6)
 U64 13071017859520  totaloutput_optA
 U64 1551040415605   read_bytes#stats.snx11024
 U64 111681033094    write_bytes#stats.snx11024
 U64 33185713        open#stats.snx11024
 U64 33459578        close#stats.snx11024
 U64 200             loadavg_latest(x100)
 U64 203             loadavg_5min(x100)
 U64 2               loadavg_running_processes
 U64 217             loadavg_total_processes
 U64 32069868        current_freemem
 U64 180128670       SMSG_ntx
 U64 84138092941     SMSG_tx_bytes
 U64 179201767       SMSG_nrx
 U64 62591572089     SMSG_rx_bytes
 U64 2463841         RDMA_ntx
 U64 166910425701    RDMA_tx_bytes
 U64 5995457         RDMA_nrx
 U64 265128956892    RDMA_rx_bytes
 U64 207633071910    ipogif0_rx_bytes
 U64 116299863623    ipogif0_tx_bytes
```

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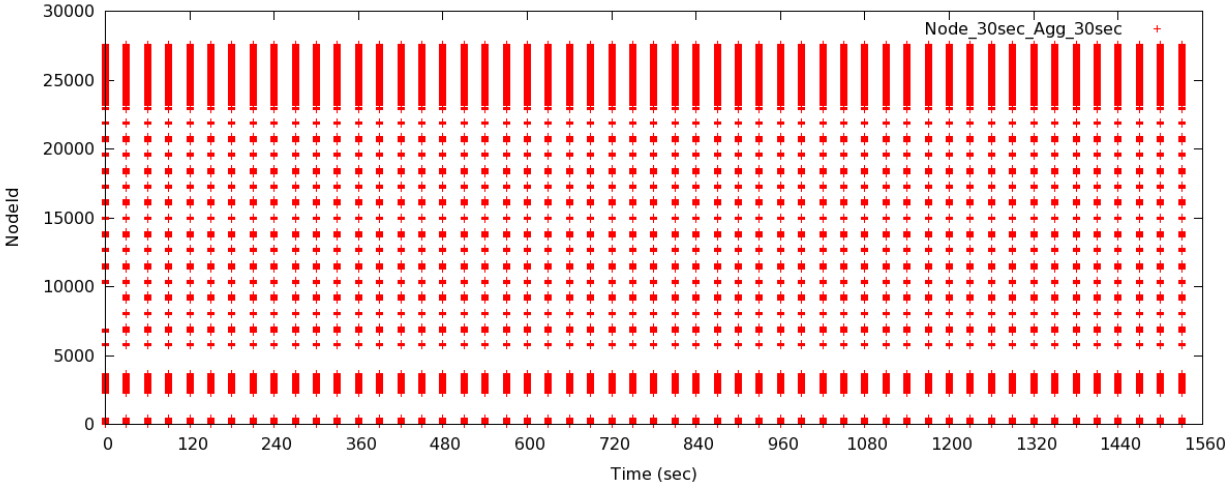
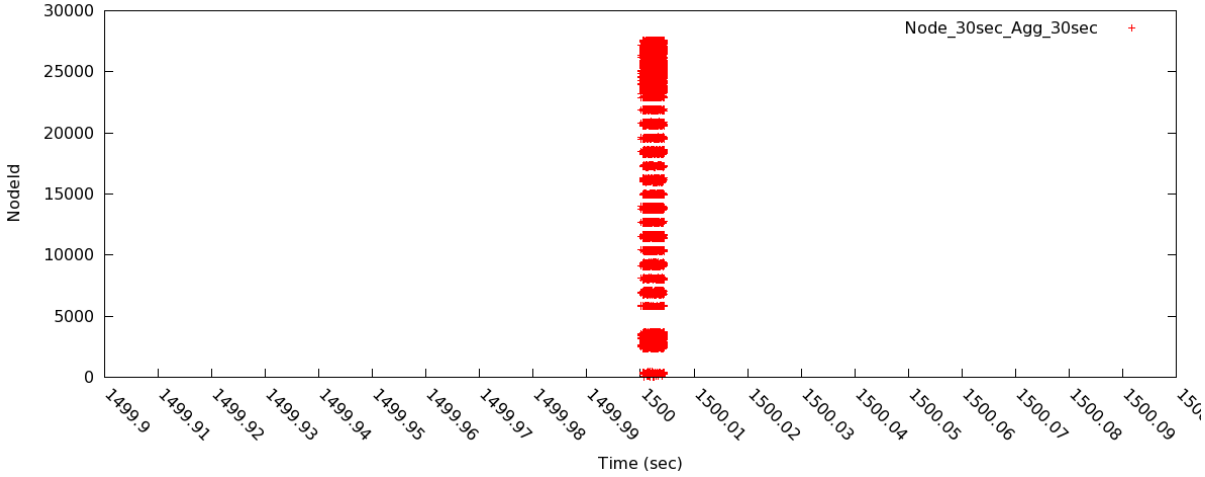
Blue Waters Related Enhancements

- Synchronization
- Minimize Image Footprint
- Node type independent metric set
- Single Metric Set
  - Single Time Attribution
- Storage
  - CSV
  - Split sec and fraction with comma

Synchronous Collection





Synchronized collection across all nodes:

- Enables a coherent system snapshot

Asynchronous option spreads network load

Synchronous:

- Variance in collection timestamps ~ 4ms

Note: Clock skew not accounted for

Collection occurrences over 10000 nodes on Blue Waters

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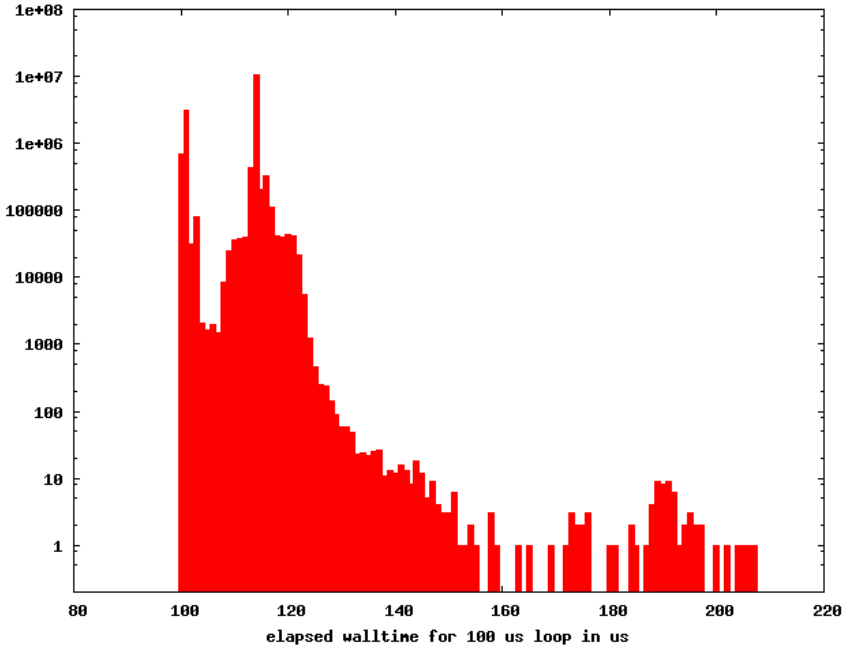
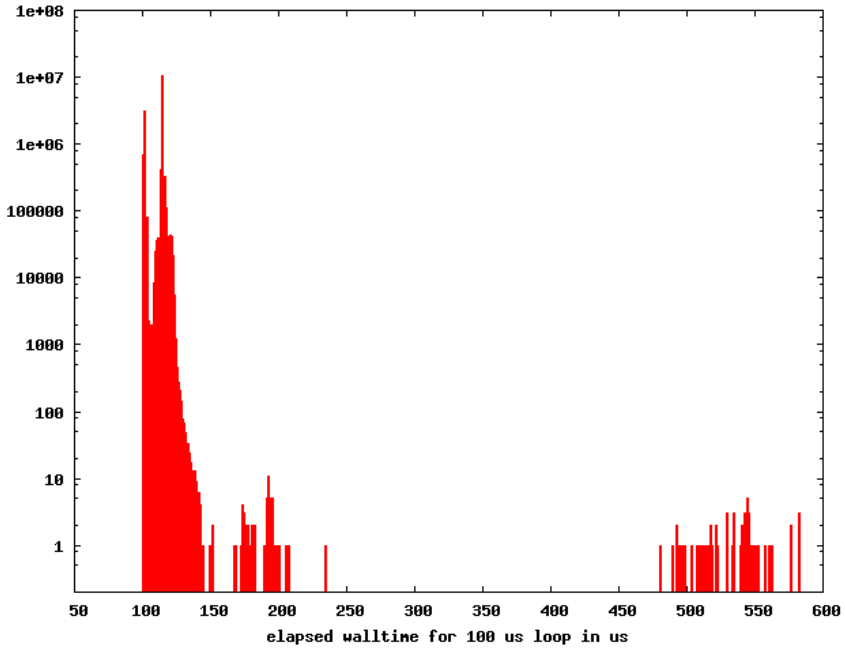
Low-Impact: System Noise



PSNAP No LDMSD 32 cores 5.5 sec total run. Target loop time is 100 usec. Offset from 100 usec is due to system noise.



PSNAP w/ LDMSD (1s) 32 cores 5.5 sec. Same profile except for the occasions when LDMS runs -- once per sec. Adds ~ 400us to those times. 60 (6 instances per node) points of the entire run.

No statistically significant difference in system noise w/LDMS (PSNAP)
No statistically significant impact on MILC, IMB AllReduce, minighost

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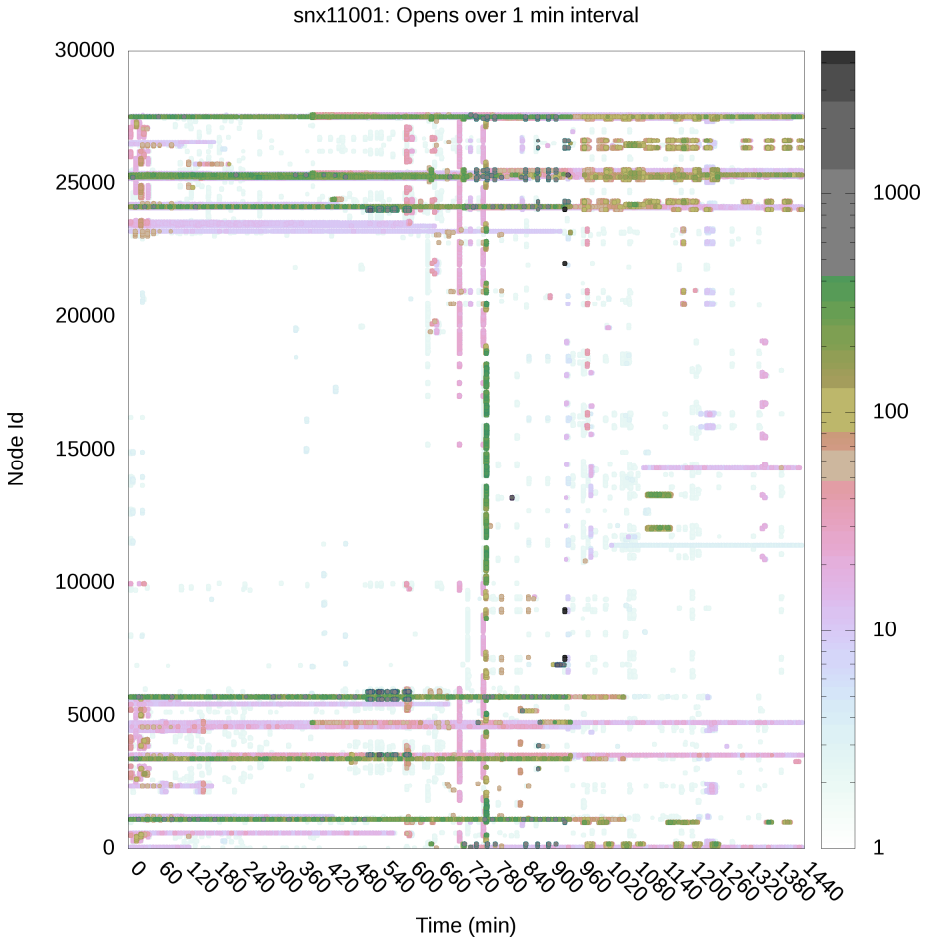
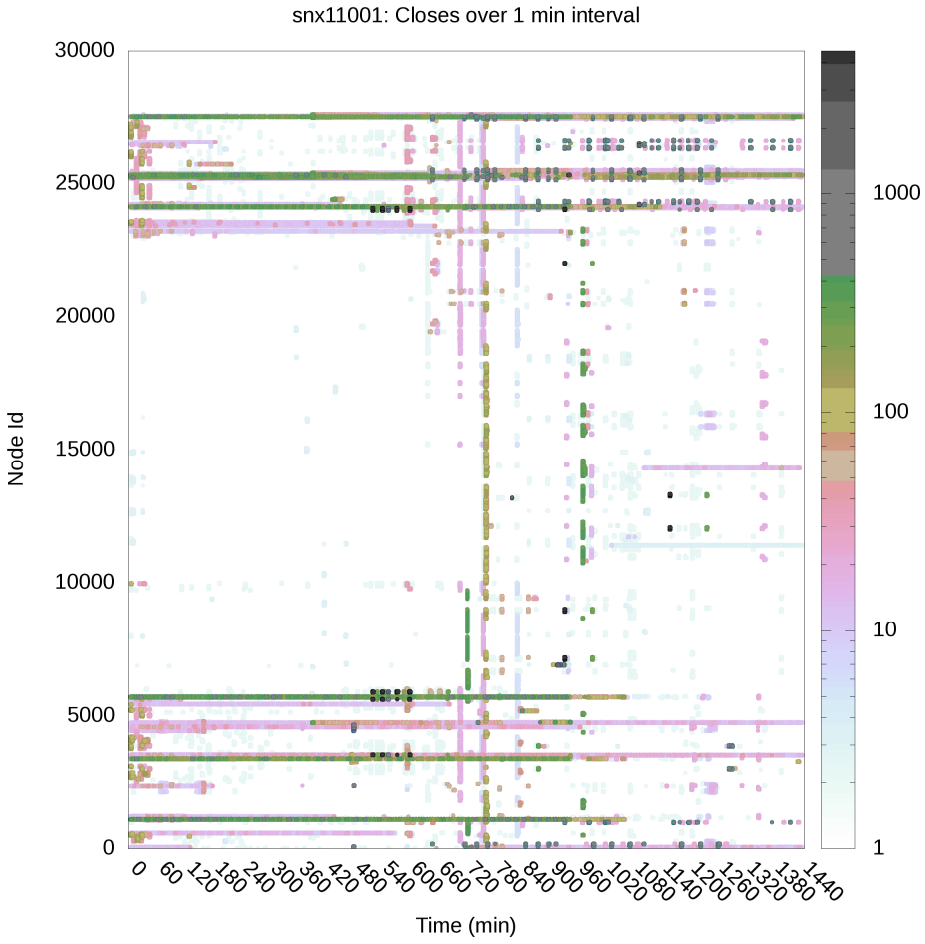
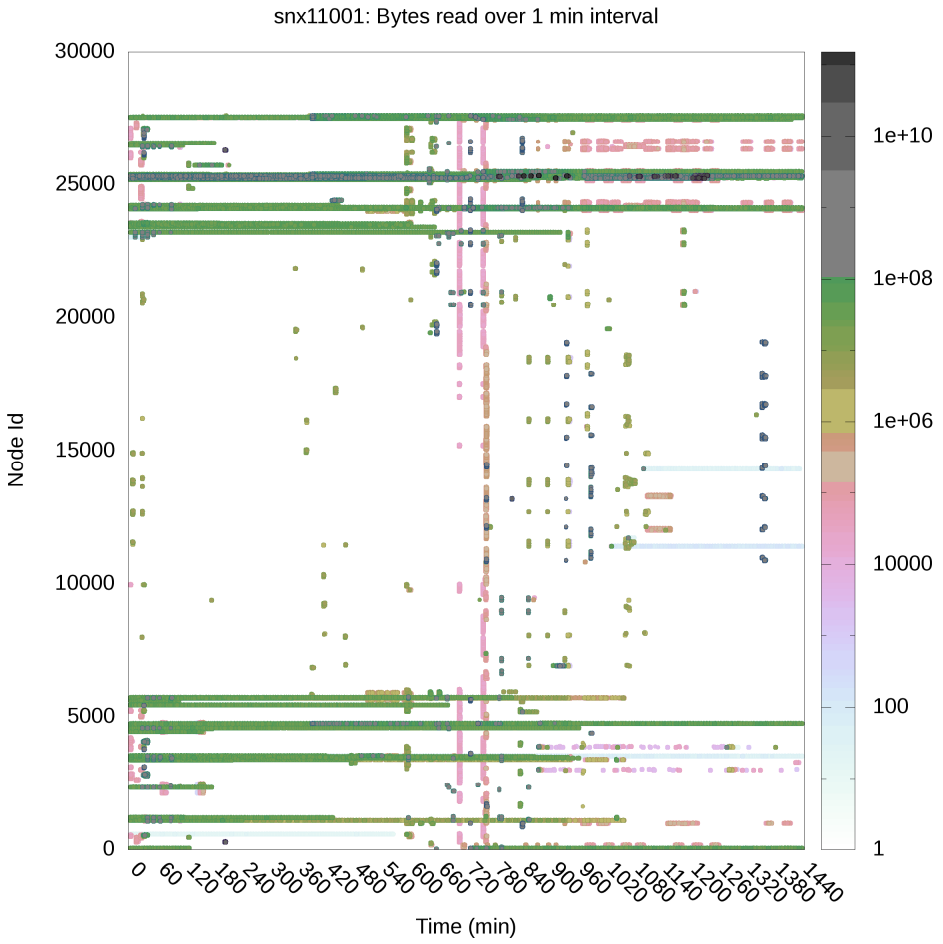
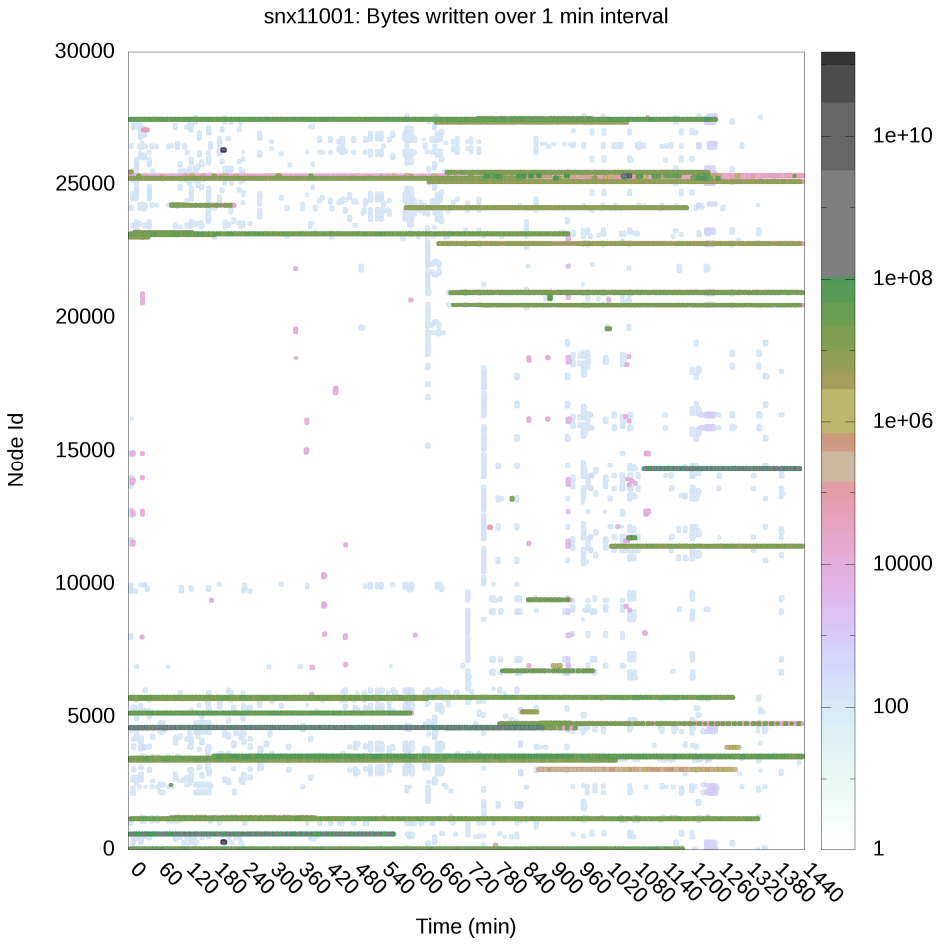
Lustre Opens/Closes





Lustre Reads/Writes





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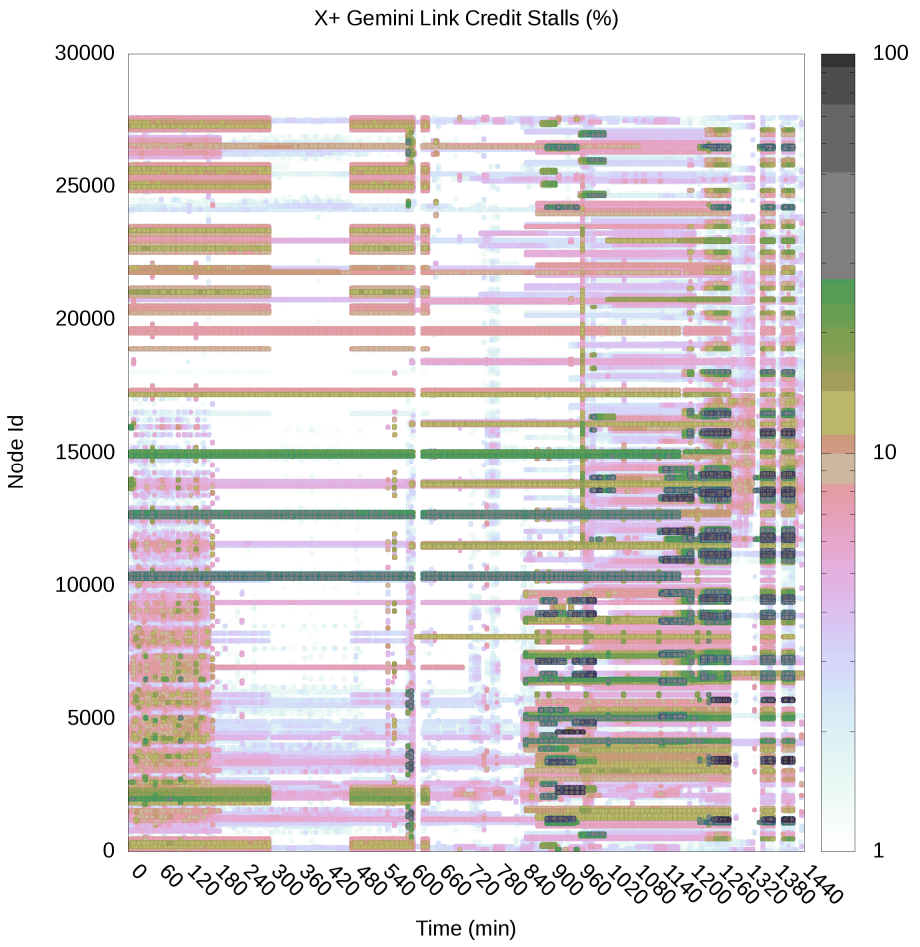
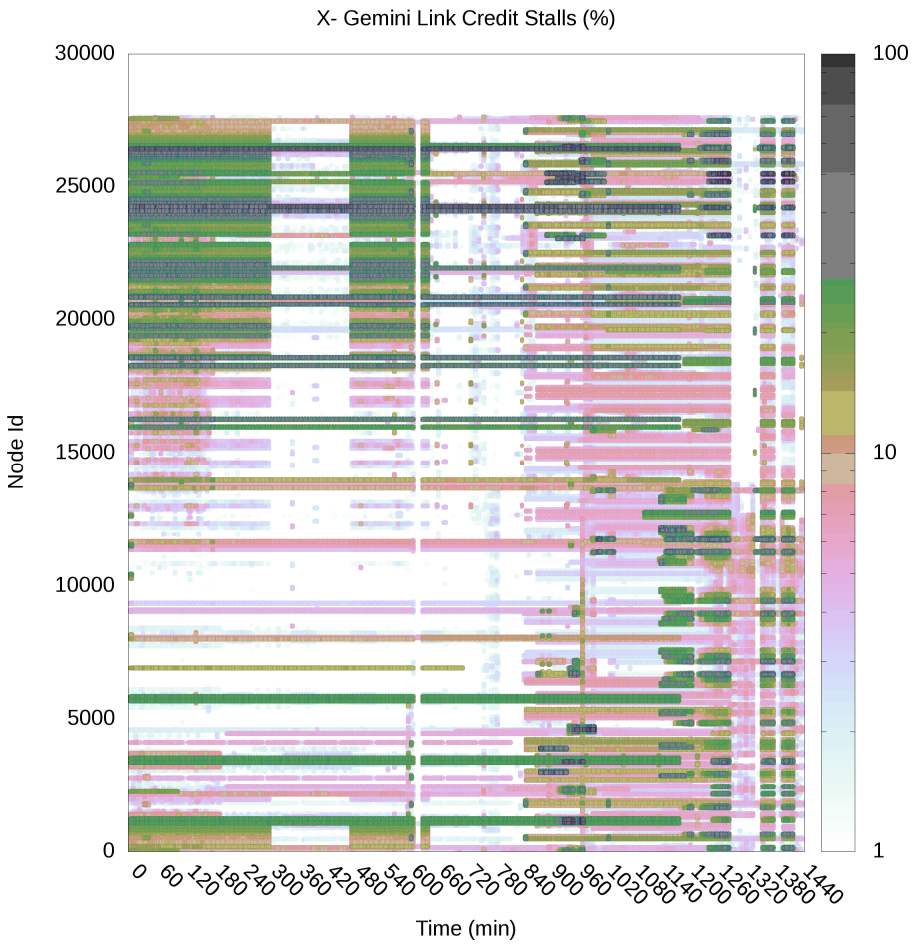
HSN Output Stalls (X)





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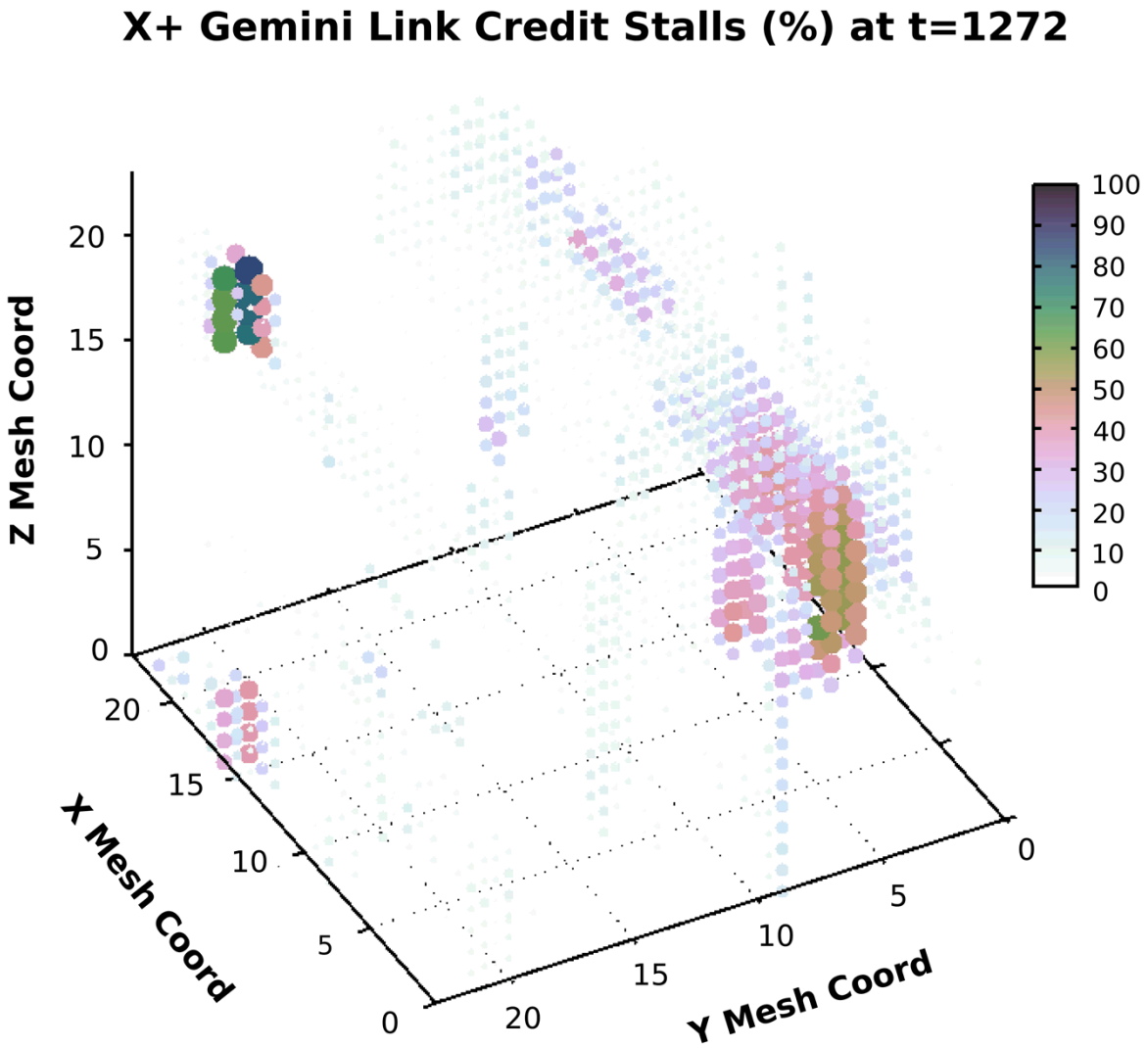
HSN Output Stalls (X) Time Slice



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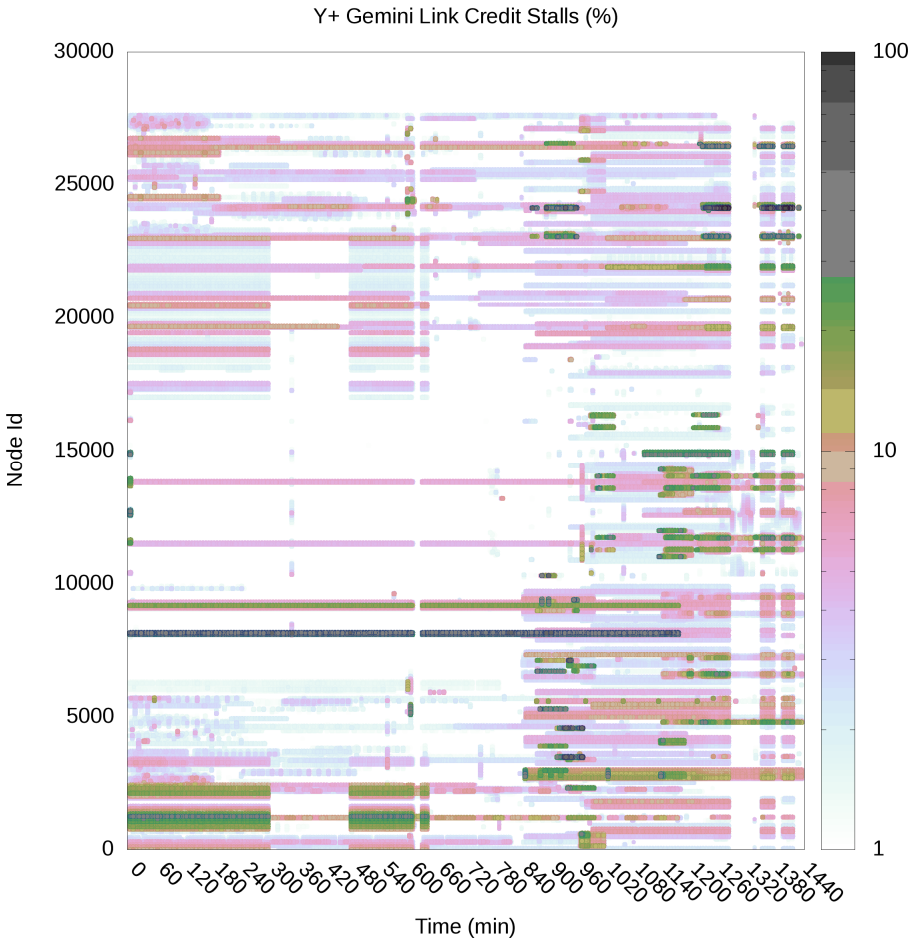
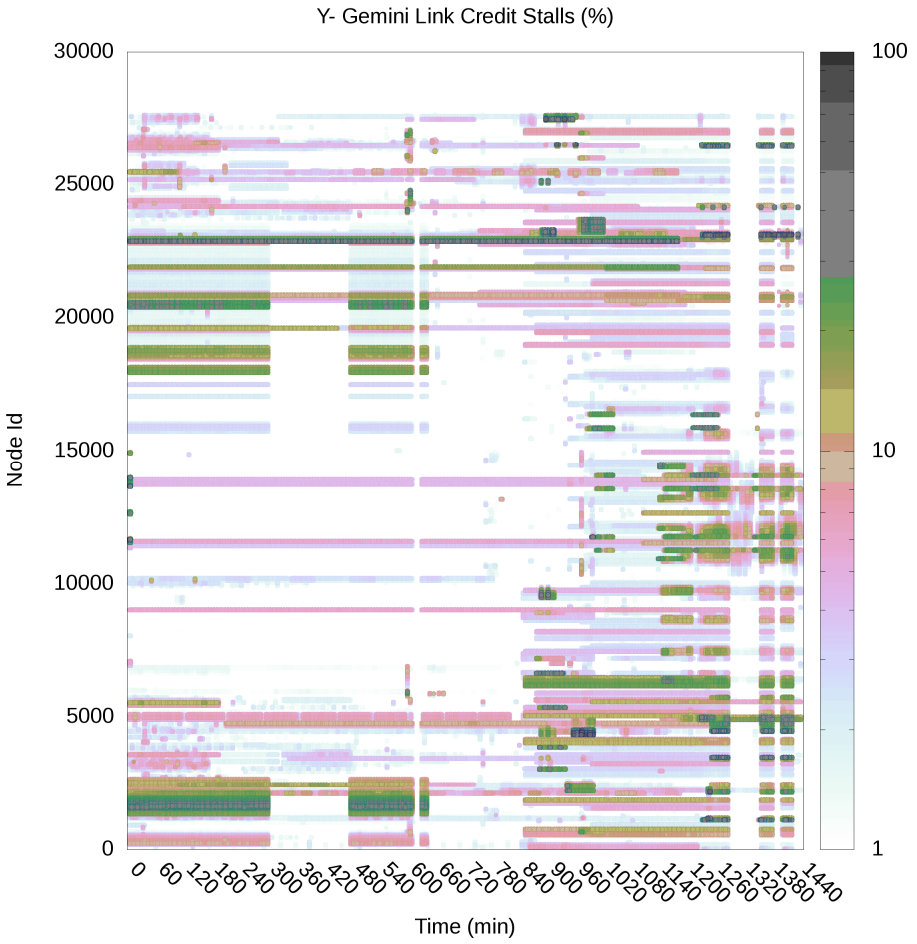
HSN Output Stalls (Y)





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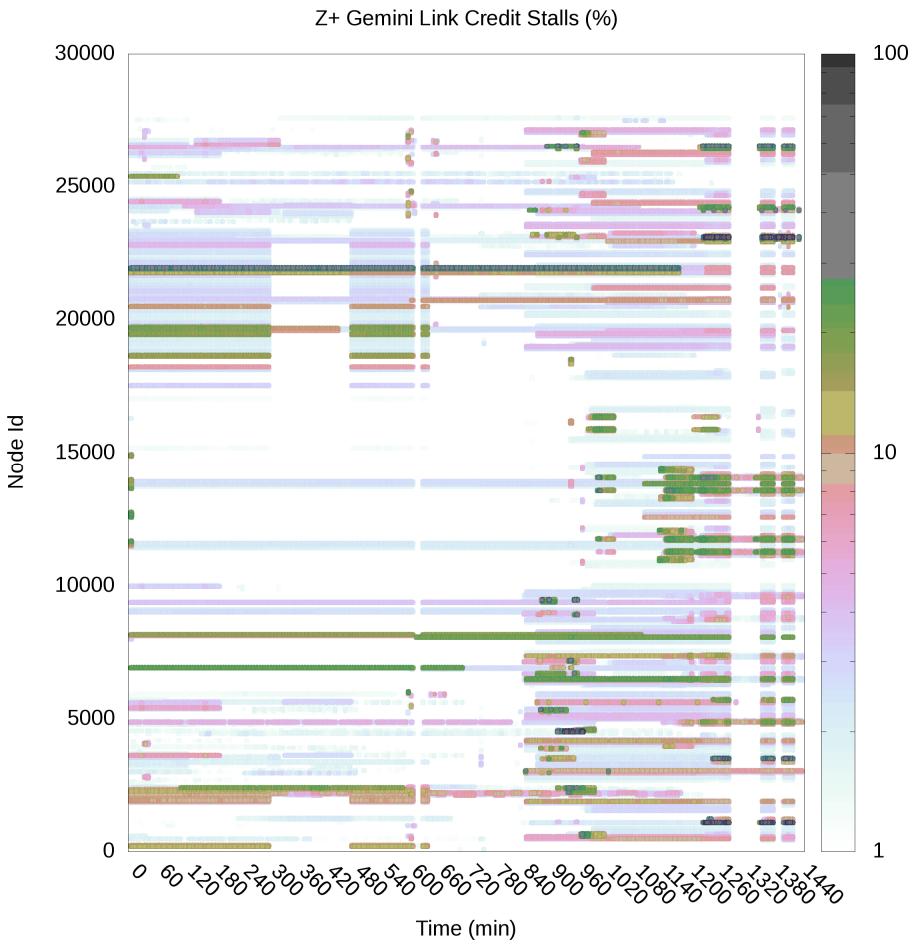
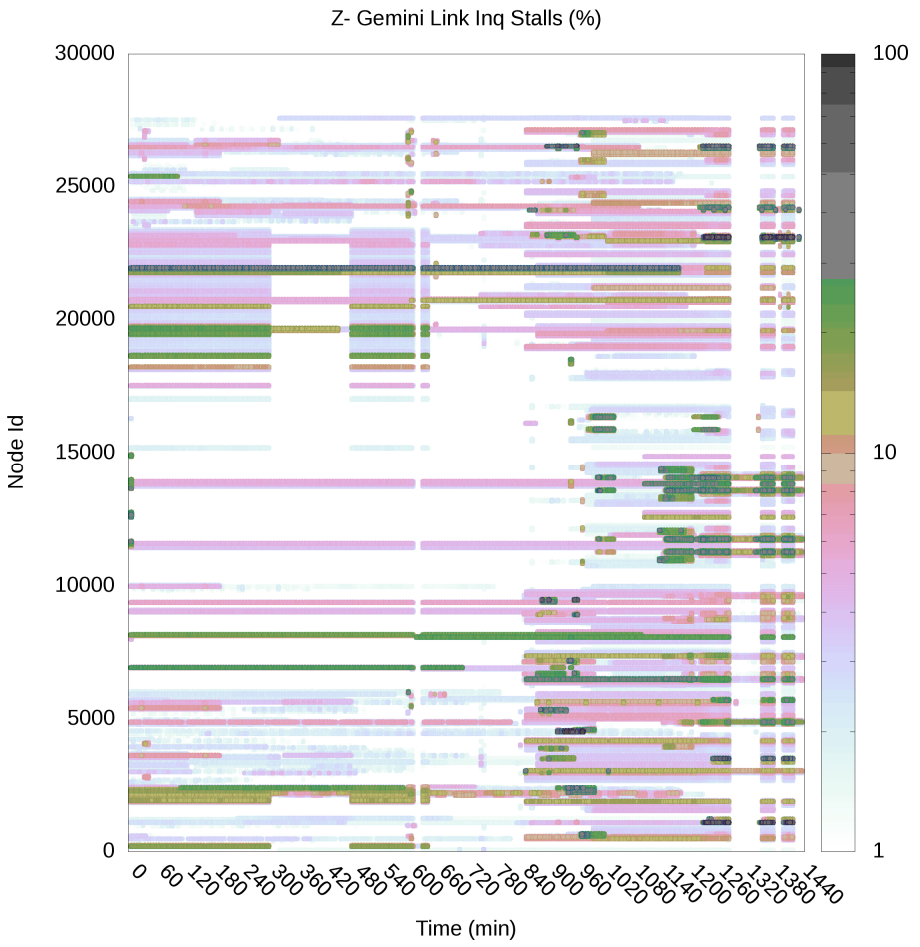
HSN Output Stalls (Z)





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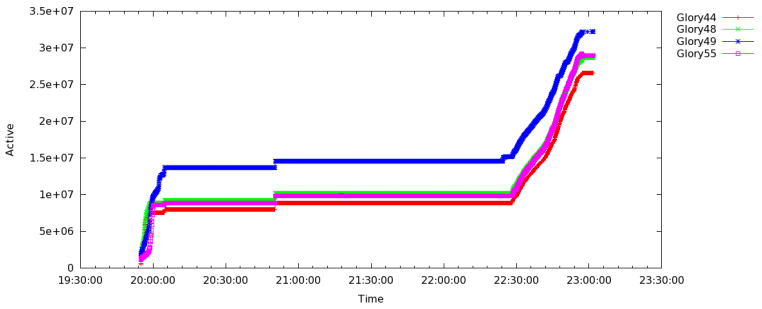
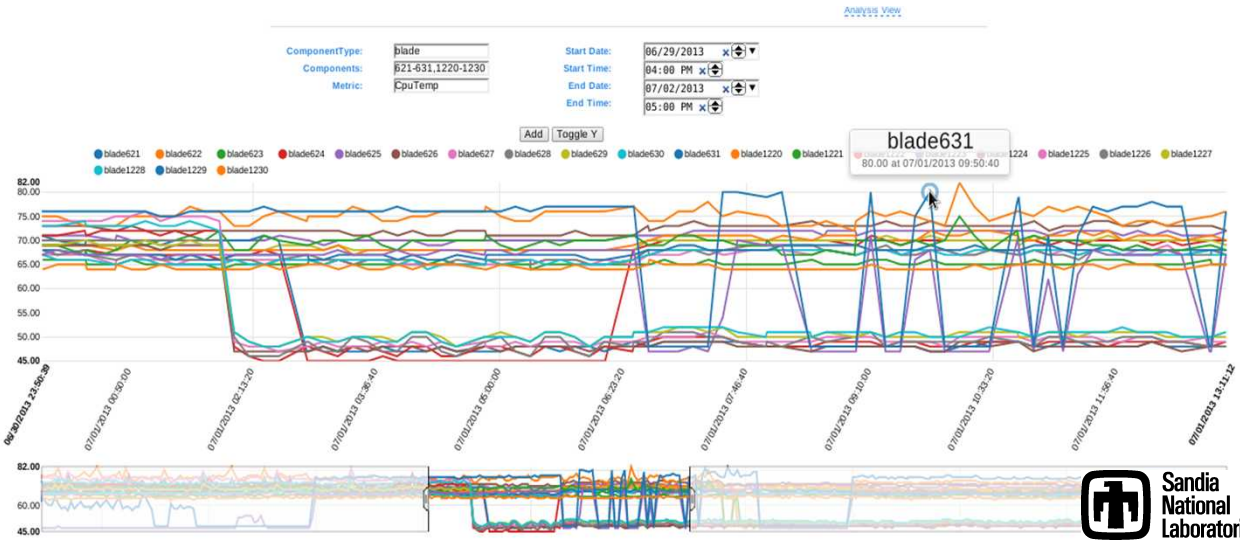
Current Analysis and Post Processing




```
================================================================================
COMP_TYPE: node METRIC_NAME: Active
================================================================================
 CompId   NPts     Ave      Std          Min              MinTime              Max              MaxTime
------- ------- -------- --------- ---------- ------------------- ---------- -------------------
     45    2242 1.023e+07 4.537e+06     525824 12/14/12 19:54:52 2.65823e+07 12/14/12 23:01:15
     49    2242 1.161e+07 4.805e+06 1.61549e+06 12/14/12 19:54:52 2.87072e+07 12/14/12 23:01:20
     50    2195 1.545e+07 4.362e+06  1.7361e+06 12/14/12 19:54:52 3.22476e+07 12/14/12 23:01:35
     56    2242 1.124e+07 5.072e+06 1.19422e+06 12/14/12 19:54:52 2.91891e+07 12/14/12 22:56:55
------- ------- -------- --------- ---------- ------------------- ---------- -------------------
------- ------- -------- --------- ---------- ------------------- ---------- -------------------
 Group    NPts     Ave                  Min          MinCompId              Max          MaxCompId
------- ------- -------- --------- ---------- ------------------- ---------- -------------------
         8921 1.211e+07                525824                 45 3.22476e+07                 50
```

Post-Job Stats and Plots

Interactive Web Interface: System Layout and Time Series



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Conclusions

- The OVIS data collection, transport, and storage framework (LDMS) provides scalable whole system data access with no statistically significant adverse impact to applications
- Whole system snapshots of shared system resource utilization can provide valuable insights to system and application performance
- We need to develop new analysis and visualization tools to fully utilize the new wealth of data we are collecting

Future Work

- More Tools – both run-time and post processing
  - Analysis
  - Visualization
- Log collection without store for diagnostics
- More LDMS plugins to support derived data, high frequency metrics (e.g. power, memory access info.), runtime configuration, etc.

Miscellaneous

- Collaborative Interactions Welcome
- Monitoring and Analysis Workshop held in conjunction with IEEE Cluster 2014 in Madrid Spain
  - See call www.cluster2014.org
  - Submissions due May 23, 2013
    - Full papers
    - Mini-talks

Questions?