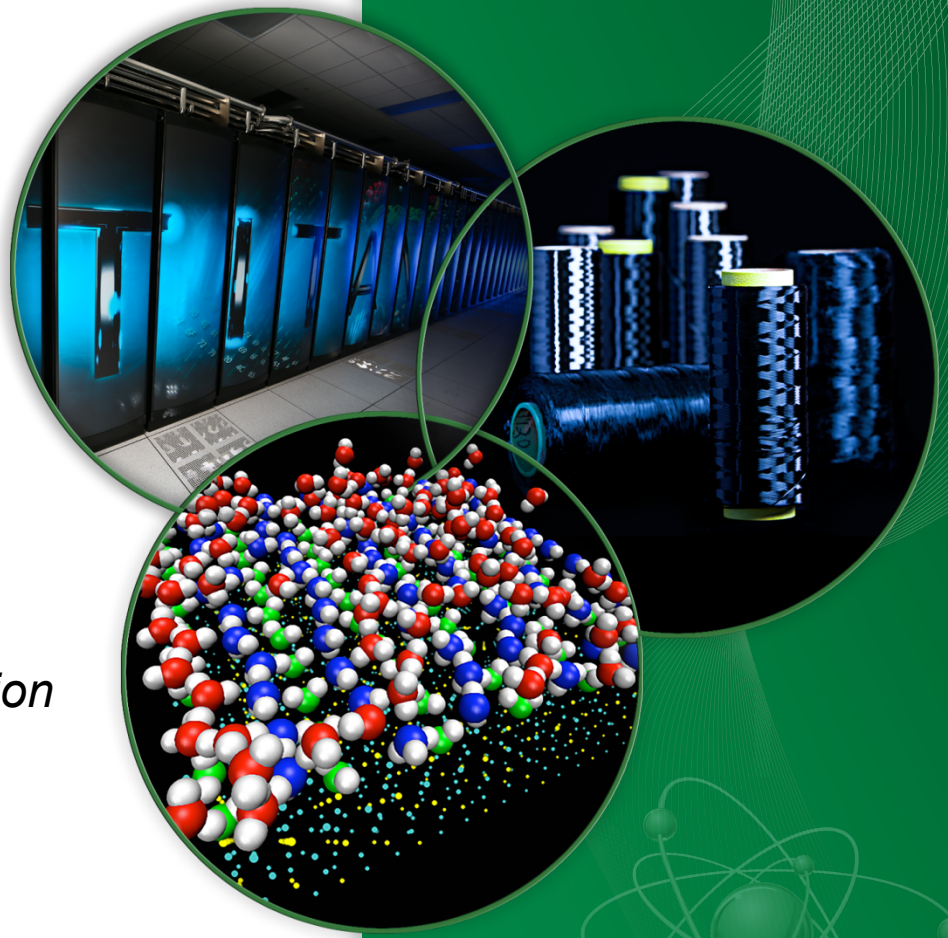
Monitoring Extreme-scale Lustre Toolkit



Michael J. Brim

Joshua K. Lothian

Computer Science Research Group
Computer Science & Mathematics Division
Oak Ridge National Laboratory

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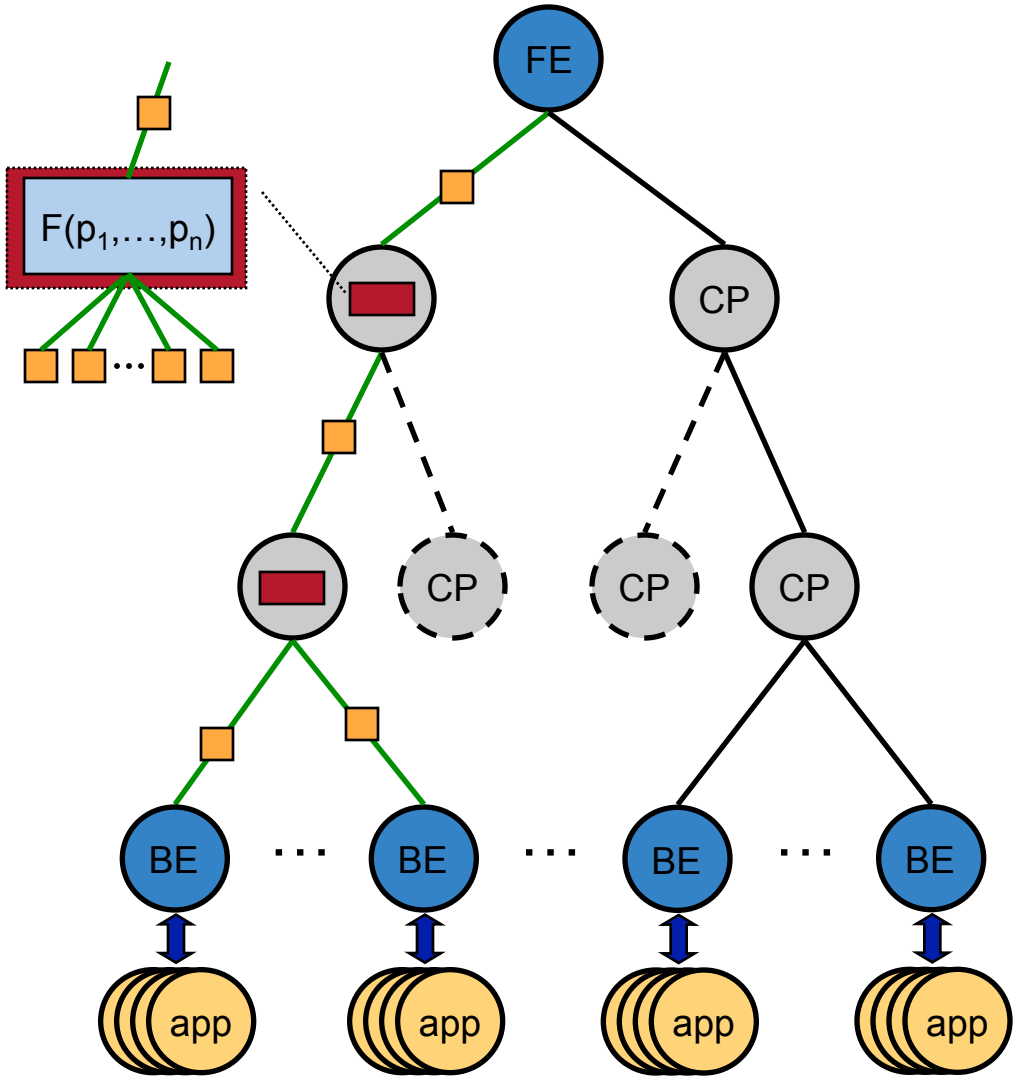
Tree-Based Overlay Networks (TBONs)

- Designed to address scalability problems in master-worker tool/application architectures
- Overlay network structured as a tree graph
  - provides logarithmic scaling for multicast/gather communication
  - provides distributed data processing (e.g., filtering, reductions)
- Distributed Data Processing
  - distribute processing across subtrees to reduce master load
  - for streaming data, pipeline parallelism on paths from leaves to root
- Tree topology can be optimized based on communication and data processing needs
  - Balanced: equal fan-out from all vertices at a given tree depth
    - good for load-balanced distributed aggregation
  - Binomial: good for streaming throughput

MRNet (since 2003)

- General-purpose TBŌN API (C++)
  - Network: user-defined topology
  - Stream: logical data channel
    - to a set of back-ends
    - multicast, gather, and custom filter reduction
  - Packet: collection of data
  - Filter: stream data operator
    - synchronization
    - transformation
- Tool developer writes front-end (FE), back-end (BE), and Stream Filter code using library API
- MRNet provides communication process (CP) executable



The Birth of an Idea

@Brad Settlemyer - Hey Mike, do you think it would be possible to build an MRNet-based tool to diagnose Lustre locking issues?

@Mike - Sure, assuming the problem can be tackled using hierarchical data aggregation.

… a couple months pass …

@Brad - Could you use the same infrastructure to continuously monitor Lustre performance and detect problems?

@Mike - That sounds a bit like my parallel top tool, only more Lustre oriented.

@Mike - But in its current state, you can't use MRNet across separate network domains.

Current Lustre Performance Monitoring

- General-purpose host monitoring
  - Collectl
  - Ganglia
  - NAGIOS
- Lustre-specific performance monitoring
  - LLNL LMT
    - server-side monitoring (OSS, MDS, LNET)
    - realtime monitoring via top-like display
    - uses a real database to store historical data!!
    - dependent on LLNL Cerebro, multicast can be hard to deploy
  - TACC lltop/xltop
    - server-side monitoring (OSS, MDS)
    - integrates with batch job system to display per-job information
    - direct ssh/socket connections between master and server daemons => limits scalability
  - Collectl plugin for Lustre
    - single host information for clients, OSS, and MDS
    - detailed info available on clients and OSS

Limitations of Current Lustre Monitoring

- Limitations of current toolkits include one or more of:
  - problem analysis is generally post-mortem
  - hard to correlate measurements:
    - across clients within a job or application
    - across servers used by a job or application
    - across servers used by a given client
    - ...
  - lack of insight into MDS, LNET, etc.
  - scalability (# of monitored nodes)
  - center-wide monitoring

Lustre Monitoring Grand Vision

- Full visibility
  - clients, MDS, OSS, OST, LNET
  - storage devices (if possible)
- Support for center-wide deployments
  - multiple compute systems sharing one or more Lustre filesystems
- Two usage modes
  1. always on, low-overhead monitoring
     - with active problem detection and alerting
  2. on demand, in-depth problem inspection and diagnosis
     - aka “Right Now Queries”

Monitoring Extreme-scale Lustre Toolkit (MELT)

- Collects Lustre performance metrics
  - on clients, OSS, MDS, LNET
- Uses SNOflake overlay network to:
  - aggregate metric data into performance summaries
    - for clients and LNET routers of each compute cluster
    - for OSS and MDS servers of each storage cluster
  - correlate data within and across compute/storage domains
    - within compute domain: e.g., app-level or job-level aggregation
    - across compute/storage domains: identify server or filesystem contention

MELT Command-line Interface

`melt [options] target mode classes [mode-opts]`

- Targets - specifies information source
  - `fs`: filesystem-level information
  - `job`: information for a given job
  - `oss`: information for a given OSS server
  - `mds`: information for a given MDS server or all MDS
  - `clnt`: information for a given client

MELT Command-line Interface

`melt [options] target mode classes [mode-opts]`

- Modes - controls how information aggregated
  - `status`: min/max/sum/avg (default is sum)
  - `top`: show top-k entries for a given metric and k-value
- Metric Classes - which metrics to gather
  - `io, lock, meta, rpc, client, op, path`
  - each class has a set of associated metrics
    - e.g., `IO_RD_BW`, `META_OP_RATE`, `RPC_PENDING`

MELT CLI Example – Filesystems Status

```
% melt fs status io,meta -delay=1m \
    -metrics=IO_RD_BW,IO_WR_BW,META_OP_RATE
  TIME    FILESYS    RD_BW     WR_BW    MD_RATE
-------- -------- -------- -------- --------
08:30:32 knot1     217 MB/s 133 MB/s    7 op/s
08:30:33 knot2      49 MB/s 7.6 GB/s   43 op/s

08:31:33 knot1     183 MB/s  94 MB/s    0 op/s
08:31:35 knot2      53 MB/s 7.8 GB/s   61 op/s
...
```

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MELT CLI Example – Job Status

```
% melt job=tait.1234 status io,meta -delay=5m \
    -metrics=IO_RD_BW,IO_WR_BW,META_OP_RATE
  TIME     RD_BW     WR_BW    MD_RATE
-------- -------- -------- --------
08:40:32 692 MB/s     0 B/s   75 op/s
08:45:33 117 MB/s  13 MB/s   33 op/s
08:50:32     0 B/s   9 MB/s   13 op/s
08:55:32     0 B/s   8 MB/s   14 op/s
09:00:33 153 MB/s   2 MB/s   47 op/s
...
```

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MELT CLI Example - Filesystem Status

```
% melt fs=knot2 status io,rpc -delay=10s \
    -metrics=IO_RD_BW,IO_CLNT_DIRTY,RPC_PENDING
  TIME     WR_BW    CL_DIRTY RPC_PEND
-------- -------- -------- --------
08:34:16 7.7 GB/s  1.32 TB    32345
08:34:26 7.8 GB/s  1.30 TB    30178
08:34:35 7.4 GB/s  1.29 TB    29006
...
08:36:45 7.9 GB/s  91.7 GB     2456
08:36:56 3.3 GB/s  7.85 GB      913
08:37:06 127 MB/s   372 MB      123
```

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MELT CLI Example - Filesystem Top Jobs

```
% melt -group=job fs=knot2 top io \
    -topk=5 -topmetric=IO_RD_BW \
    -metrics=IO_RD_BW,IO_CLNT_AVG_RD_SZ,\
IO_CLNT_AVG_RD_TIME
```

JOB	RD_BW	RD_SZ	RD_TIME
conway.2789	12 GB/s	127 MB	63.9 ms
tait.4321	7.8 GB/s	156 MB	72.3 ms
euler.22397	7.2 GB/s	112 MB	64.5 ms
tait.4334	3.4 GB/s	354 MB	283 ms
euler.22388	780 MB/s	31.9 MB	54.7 ms

MELT CLI Example - Job Performance Log

```
% melt -group=job -format=log fs status io \
    -delay=5m
```

```
Jan 15 11:22:33 skein melt[123]: job=tait.1111 IO_RD_BW=20M/s
IO_WR_BW=476M/s IO_CLNT_NUM=256 IO_CLNT_DIRTY=4.3G
IO_CLNT_AVG_RD_SZ=776K IO_CLNT_AVG_WR_SZ=1M ...

Jan 15 11:22:33 skein melt[123]: job=tait.1113 IO_RD_BW=89M/s
IO_WR_BW=21M/s IO_CLNT_NUM=64 IO_CLNT_DIRTY=1.2G
IO_CLNT_AVG_RD_SZ=507K IO_CLNT_AVG_WR_SZ=123K ...

Jan 15 11:22:33 skein melt[123]: job=tait.1114 IO_RD_BW=364M/s
IO_WR_BW=28M/s IO_CLNT_NUM=32 IO_CLNT_DIRTY=86M
IO_CLNT_AVG_RD_SZ=1.4M IO_CLNT_AVG_WR_SZ=67K ...

...

Jan 15 11:27:37 skein melt[123]: job=tait.1113 IO_RD_BW=52M/s
IO_WR_BW=156M/s  IO_CLNT_NUM=64 IO_CLNT_DIRTY=5.5G
IO_CLNT_AVG_RD_SZ=27K IO_CLNT_AVG_WR_SZ=509M ...

Jan 15 11:27:37 skein melt[123]: job=tait.1114 IO_RD_BW=364M/s
IO_WR_BW=28M/s IO_CLNT_NUM=32 IO_CLNT_DIRTY=86M
IO_CLNT_AVG_RD_SZ=1.4M IO_CLNT_AVG_WR_SZ=67K …
```

SNOflake - Scalable Network Overlay

- General-purpose overlay network infrastructure for constructing distributed services, tools, and apps
  - bootstrapping and distributed launching
    - system-level and user-level
    - deployments spanning intra-network domains
  - peer and group communication
    - leverage advanced network capabilities (e.g., RDMA or collectives)
  - integrated, customizable data analysis and aggregation

- Real Scalability: no changes to core design/architecture required for use on future “extreme scale” systems
- Real Resilience: overlay network should persist as long as any of the constituent distributed systems are operational

SNOflake Design Characteristics

- Support for cross-domain overlay deployments

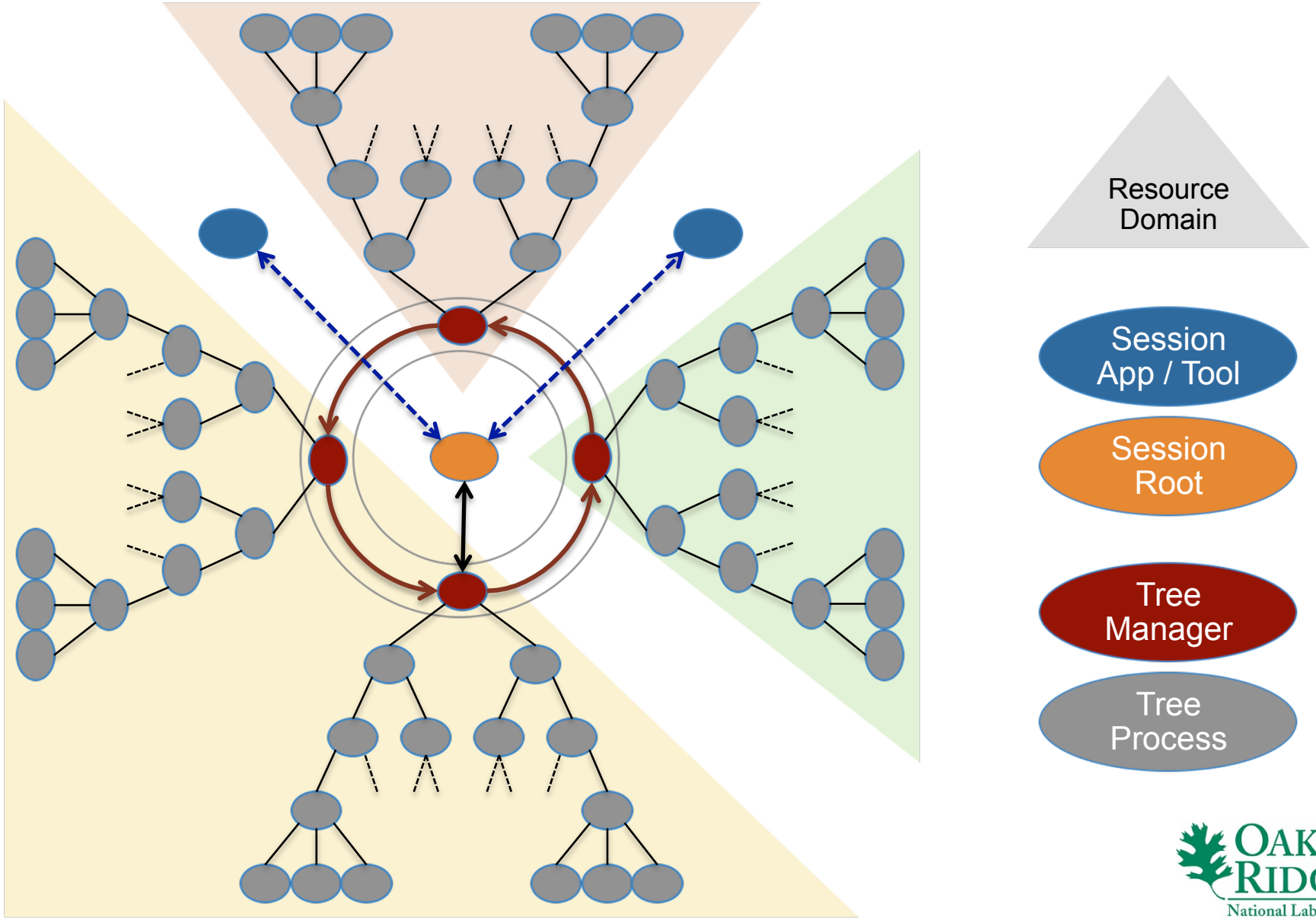
- Simple yet flexible API in C
  - *Session* represents an overlay shared among clients
  - each *Session* supports many logical *Services*
  - each *Service* supports many data *Streams*
  - *Streams* used to transfer/process opaque *Data Buffers*, rather than formatted Packets
  - *Filter Graph* instead of single filter per Stream

- Ability to leverage advanced networking capabilities
  - incorporate layers such as the Common Communication Interface (CCI) or the Universal Common Communication Substrate (UCCS)

SNOflake Architecture Overview

- Deploy TBŌNs on separate resource domains
  - place *Tree Managers* (i.e., TBŌN roots) on hosts with inter-domain communication capability
  - use separate trees for distinct resource classes within same distributed system (e.g., compute, management, storage)
- Ring of Tree Managers
  - data routing between TBŌNs
  - state replication within ring for fault tolerance
- “SNOflake as a Service”
  - at-boot SNOflake provides bootstrap/launch service for scalable deployment of additional SNOflake-based services, tools, and apps

SNOflake Architecture



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MELT Architecture Overview

- Uses SNOflake overlay network for:
  - aggregating metric data into performance summaries for each domain
  - correlating data within and across domains
- Deploys monitoring services and associated backend agents on clients, servers, and LNET routers
  - intended as an on-boot infrastructure

MELT Continuous Monitoring

- meltmon frontend
  - controls default aggregations and sampling rates for all the metrics
  - periodically polls the job scheduling system(s) to associate compute nodes with jobs
    - multicasts the job=>{node,…} mappings to client agents
  - dumps aggregated metrics to logs

MELT On-Demand Investigation

- CLI tool attaches to MELT session as additional frontend
- Tool may:
  - subscribe to existing service data streams
    - no additional transmission of performance data vs. meltmon
  - create new streams that use different metric aggregations (e.g., to filter on a specific job)
    - performance data from backends will be sent on multiple streams
- Backends sample at the highest requested rate for a given metric

MELT – backend data collection

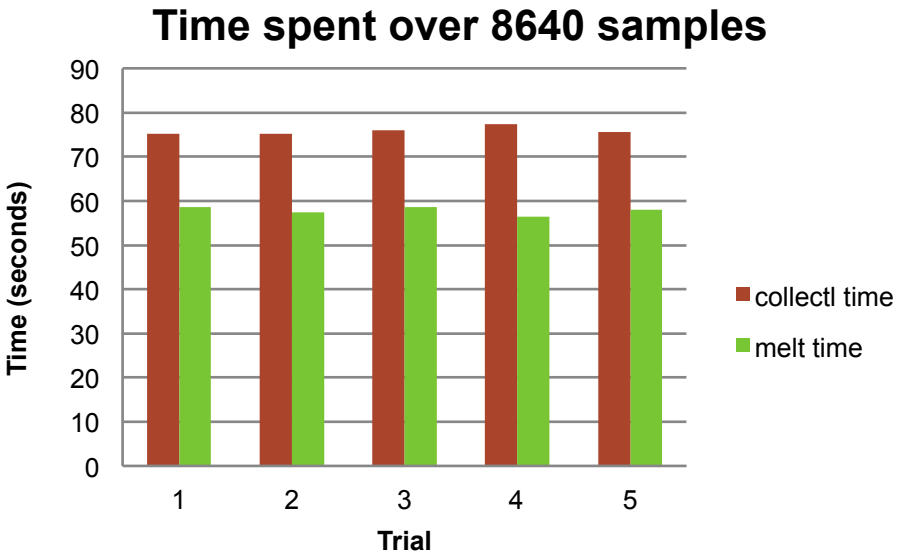
- Considered methods
  1. read directly from Lustre /proc files
     - first-party, likely most efficient method
     - high development/maintenance cost (e.g., procfs to sysfs) ✖
  2. leverage Collectl Lustre plugin
     - already used at a number of sites, integrates well with other monitoring (e.g., Ganglia)
     - ongoing support a concern
     - overhead of Perl a concern
  3. use persistent lctl and periodic queries
     - @Andreas Dilger – lctl is “the path forward” for reading metrics
     - improvements/fixes will be integrated into ongoing releases
     - overhead of third-party collection a concern

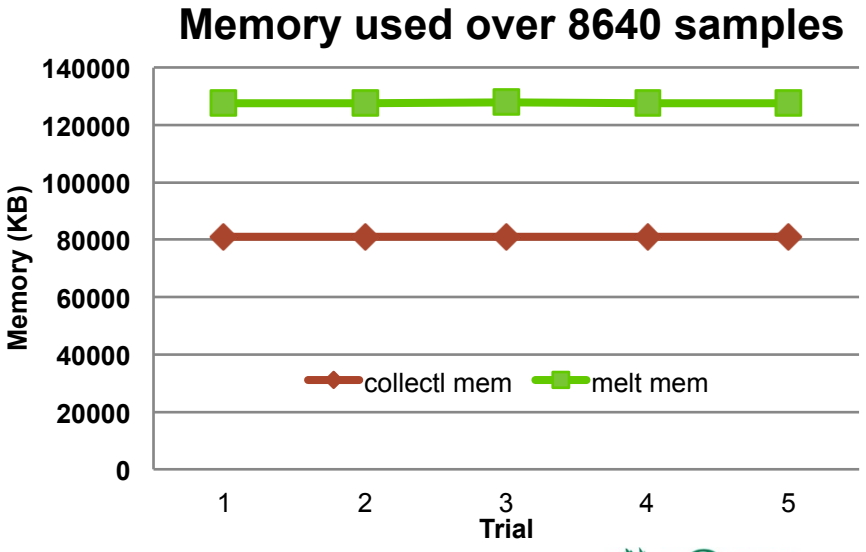
MELT – backend data collection

- Choice between collectl and lctl
- Experiment to monitor overheads on a single host
  - sample client per-OST statistics
    - polling 56 separate entries in /proc (one per OST)
  - Collectl default sampling rate is every 10 seconds
  - simulate whole-day collection (8640 total samples) by decreasing inter-sample delay to 0
  - measure walltime, CPU & memory usage
    - via /usr/bin/time, which uses wait4() to get rusage data

MELT - collectl vs. lctl overhead

- Collectl
  - average time per sample ~ 8.8ms
  - average CPU load 99%
    - ~ .087% scaled to normal sampling
  - maximum resident memory ~ 79MB
- MELT querying lctl
  - average time per sample ~ 6.7ms
  - average CPU load 27.2%
    - ~ .018% scaled to normal sampling
  - maximum resident memory ~ 124MB





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MELT – lctl bugs and improvements

- Using a persistent lctl and periodically querying it has revealed a few usability issues
  - no clear marker to indicate end of query response
    - have a quick fix, still need to submit patch
  - initial request determines query buffer size, so subsequent longer requests are truncated
    - already fixed (by others) in git head
  - query command options ignored in subsequent requests

SNOflake Implementation Status

- Complete
  - bootstrapping over multiple domains
  - core communication (for base TCP sockets)
  - basic data filtering
- Under Construction
  - frontend/backend client API and request servicing
  - service-launching service
- Future Work
  - ring-state replication
  - TBON recover after overlay process failure
  - integration of advanced network abstraction layers

MELT Implementation Status

- Backend agents
  - collecting an initial set of relevant metrics
  - on clients, OSS, MDS, and LNET routers
- Metric data aggregations
  - implementing metric-specific performance summaries (min,max,sum,avg) as data filter aggregations
  - considering other aggregations such as histograms
- Under construction
  - meltmon frontend
  - CLI frontend

You're the experts - Please advise

- Still a work-in-progress
  - you can influence delivered capabilities
- What metrics are you most interested in?
  - are there new metrics you would like added to Lustre?
- Besides instantaneous performance summaries and a historical record of such summaries, what else?

Future Directions: Performance Alerts

- With continuous monitoring, opportunity to detect anomalous performance and notify
- Challenges
  - what's anomalous: need a baseline
    - for any metric that you wish to alert on
  - performance is dependent on offered load
  - changing workloads could move the baseline

Future Directions: Oracle Mode

- Assuming MELT command-line tools allow experienced admins to find root causes of performance problems, can we embed that expertise in the tools
- Add a new “oracle” mode that searches for common problems on a filesystem or server level
- Challenges
  - copying the brains of expert admins
  - what level of overhead is acceptable for oracle mode?
  - is this something you could give to users for job-level problem diagnosis?