Distributed Common API for Measuring Performance

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Outline

Building Distributed Systems

Due to the **plateauing speed** of individual processing units and encouraged by the **interconnectedness** of the internet at large, there exists a natural trend of distributing large, complex systems across multiple components locally and throughout the world.

Building Distributed Systems

In order to effectively build these systems, software practitioners must be able to test their system for **performance defects** as well as bottlenecks, all while the distributed system itself is responding to changes in availability and work load on its individual nodes.

Distributed Performance Frameworks (DPF)

Distributed **Performance Testing** Frameworks:

- tools to evaluate performance of system
- both black box and white box
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Distributed **Performance Monitoring** Frameworks:

- considered part of the testing framework
- black box interface
- monitoring a distributed system or application
- mechanisms for triggering actions based on performance events

Distributed Performance Frameworks (DPF)

Three types of metric gathering techniques:

1. hardware counters and sensors use specialized hardware to gather highly accurate metrics and are highly dependent on the underlying hardware architecture,
2. software sensors use modern operating system interfaces to acquire moderately accurate performance metrics in an architecture-independent interface, and
3. hybrid approaches use a combination of hardware and software sensors to attain a balance between the two.

Criterion for Evaluating Distributed Performance Frameworks

In order for practitioners and researchers alike to **effectively choose** a distributed performance framework, it is necessary to have a set criteria for evaluation. Presented here is an extended criterion of the general requirements presented by Zanikolas et al. for grid systems [3].

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7. Validity (new)
8. Portability (alternate)

Distributed Common API for Measuring Performance

dCAMP is a distributed performance framework built on top of Mark Gabel and Michael Haungs' 2007 research on *CAMP: a common API for measuring performance*[1]. *CAMP* provides an **accurate** and "**consistent** method for retrieving system performance data from **multiple platforms**."

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dCAMP builds on this functionality and the authors' work validating *CAMP*'s accuracy by adding these core feature sets:

- stateful performance API
- distributed performance data aggregation
- performance filters and triggers
- simplistic fault tolerance

System Architecture

dCAMP is designed as a **semi-centralized, hierarchical peer-to-peer system** utilizing the UNIX **Pipes and Filter** architectural pattern in which leaf nodes of the hierarchy collect data, filter out extraneous data, and send it up the pipe to a parent node which subsequently filters out more data and sends it up to another parent node.

dCAMP Roles and Services

The *dCAMP* distributed system is comprised of one or more nodes, each executing a **role**—a named grouping of a specific, known set of **services**. Each *dCAMP* service implements a specific function.

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- **Management**–end-user control of *dCAMP*
- **Configuration**–configuration replication; topology and configuration distribution

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A service's scope can vary depending on the node's level in the *dCAMP* topology.

- *Root*: master copy of the configuration, publishing new values as needed
- *Collector*: stores (and forwards) every update from the *Root*
- *Metric*: only stores updates relevant to the node

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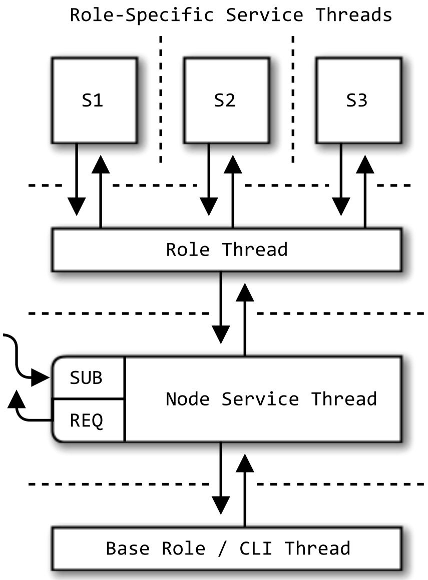
Role	Service(s)
Root	Management, Aggregation, Filter, Configuration (Full)
Collector	Aggregation, Filter, Configuration (Full)
Metric	Sensor, Filter, Configuration (Partial)
Base	Node



The *Base* role must be running on each node for it to be part of the *dCAMP* distributed system. All other roles are launched from within the *Base* role.

Sequence of *dCAMP* Operation

1. User promotes a *Root* node via the *dCAMP* CLI, specifying a configuration file and a *Base* node's address.

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7. *Collector* and *Metric* nodes exit the topology and revert to *Base* nodes.
8. *Root* node exits, reverting to *Base* node.

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1. Performance counters are sampled, filtered, reported, and logged by the Metric nodes at regular intervals according to the *dCAMP* Configuration.

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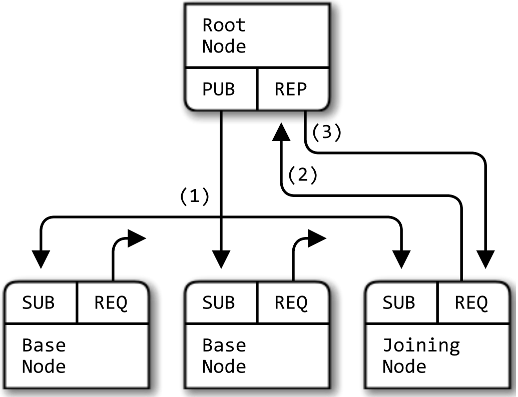
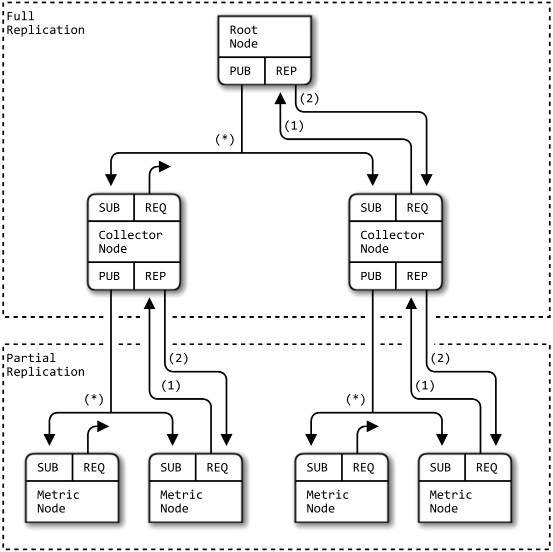
3. Performance counters received from child nodes are aggregated and logged by *Root* node for later processing (e.g. graphing metrics during a test scenario or correlating statistics with a distributed event log).

Topology Protocol

The *dCAMP* distributed topology is dynamically established as the *Root* node sends out its discovery message and receives join messages from *Base* nodes. When a *Base* node responds to the *Root*, the *Base* node is given its assignment.



Configuration Protocol



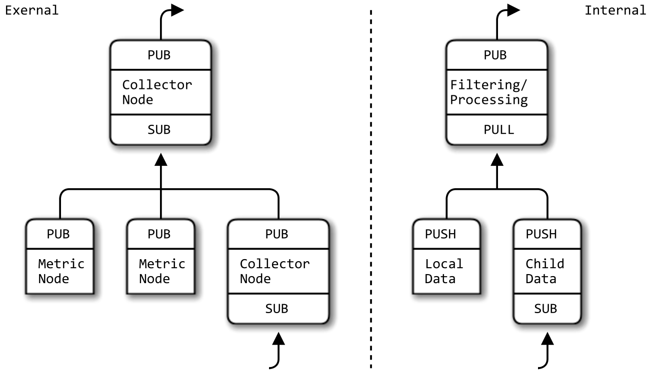
Configuration Protocol

The *dCAMP* configuration replication algorithm generally adheres to the Clustered Hashmap Protocol[2].

```
config-replication = *update / snap-sync
update             = P-KVPUB / P-HUGZ
snap-sync          = C-ICANHAZ ( *P-KVSYNC P-KTHXBAI )
```

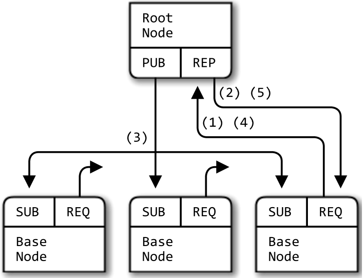
Data Protocol

There are two data flow protocols in the *dCAMP* system: the **external protocol** for data flowing between nodes and the **internal protocol** for data flowing between components within a single node.



Recovery Protocols: Promotion

The *dCAMP* Recovery Protocols are used for the Promotion and Election algorithms and use the same base messages as the Topology Protocol.



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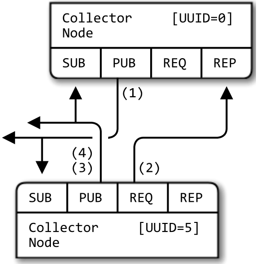


Strategy

To measure the impact of *dCAMP* on a monitored process, a workload is defined and measured with and without *dCAMP* active. The measured difference in performance of the monitored process is defined to be *dCAMP*'s monitoring overhead.

Workload

Client: Apache JMeter (v2.11) on a MacBook Pro (2.7GHz Core i7, 8GB 1333MHz DDR3, SSD) running OSX 10.9.
Server: default-configured Apache instance on a Lenovo Thinkpad (dual 2.16GHz Centrino Duo T2600, 2GB 667MHz DDR2, SATA) running Ubuntu 13.10.

Each test run includes 18 different load points, scaling the number of client threads from 2 to 2048. For every load point, the threads continuously (in this order):

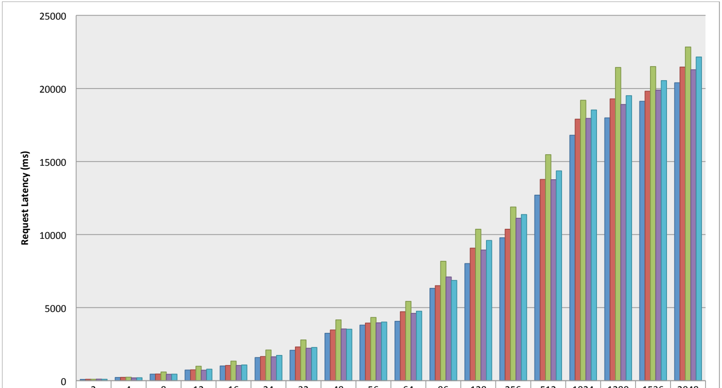
1. load a static home page,
2. load a PHP page which calculates the 25th Fibonacci number, and
3. download a 5MB file of random binary data.

Configuration

Each *dCAMP* configuration level monitors **four global metrics** and **three process-specific metrics** on the Apache process(es). The global metrics are CPU usage (`proc`), memory usage (`mem`), disk throughput (`disk`), and network throughput (`net`); the Apache metrics are CPU usage (`apache_cpu`), memory usage (`apache_mem`), and combined disk/network throughput (`apache_io`).

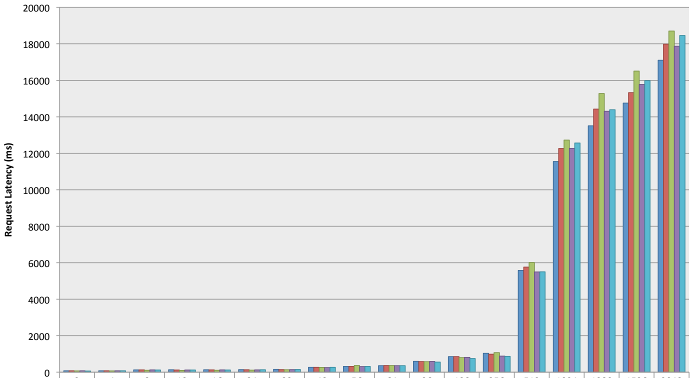
- **baseline** – *dCAMP* off
- **5m** – all metrics every 300 seconds, heartbeats every 60 seconds
- **1m** – all metrics every 60 seconds, heartbeats every 60 seconds
- **10s** – global metrics every 300 seconds, Apache metrics every 10 seconds, heartbeats every 300 seconds
- **1s** – global metrics every 300 seconds, Apache metrics every 1 second, heartbeats every 300 seconds

CPU-Bound Results



	2	4	8	12	16	24	32	48	56	64	96	128	256	512	1024	1280	1536	2048
baseline	94	224	450	727	1013	1586	2082	3241	3802	4068	6320	8017	9777	12697	16797	17989	19119	20388
5m	99	228	454	744	1043	1651	2314	3472	3943	4722	6506	9072	10370	13770	17895	19290	19812	21465
1m	103	243	594	989	1338	2096	2795	4166	4331	5431	8174	10364	11890	15466	19194	21436	21495	22838
10s	104	200	436	717	1042	1640	2221	3541	3963	4608	7095	8944	11116	13754	17954	18906	19894	21284
1s	98	206	447	786	1077	1736	2279	3523	4018	4760	6863	9600	11370	14357	18527	19508	20535	22152

Disk-Bound Results



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5m	81	79	125	123	128	138	144	268	314	368	584	857	991	5766	12267	14421	15327	17981
1m	76	76	106	103	109	118	132	261	364	365	575	801	1073	6016	12726	15276	16506	18704
10s	80	81	128	125	128	132	146	254	312	356	588	813	883	5500	12268	14308	15770	17868
1s	68	78	125	124	125	138	153	267	315	359	554	751	870	5507	12566	14390	15984	18459

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5. Possibly using *dCAMP*'s reporting threshold, system impact can be minimized while still maintaining fine sample granularity.

Strategy

One of the primary measures of scalability for a distributed system is its network traffic.[3] By simulating successively larger *dCAMP* systems (with respect to node count), one can extrapolate *dCAMP*'s effectiveness at monitoring large distributed systems and how to best configure its metric collections.

Workload

dCAMP is setup to monitor a machine's global metrics, scaling the number of **simulated nodes in the dCAMP system from 3 nodes up to 200 nodes**. The metric configuration is kept constant for each test run. As *dCAMP* starts, monitors in steady state, and shuts down, the machine's network traffic is monitored and recorded every five seconds.

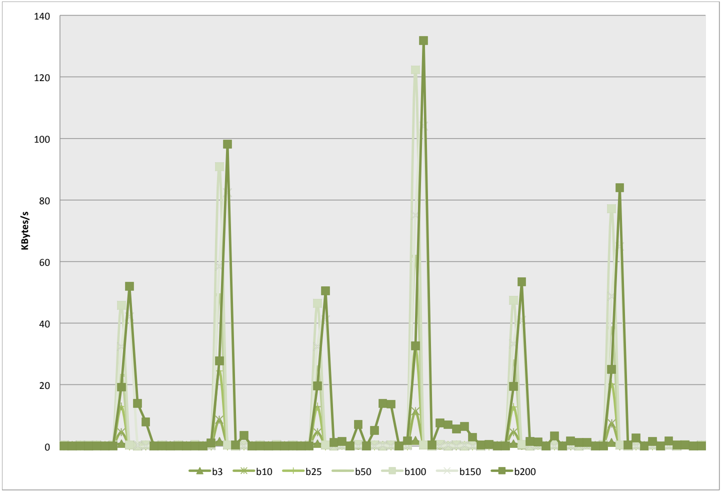
The test machine is a MacBook Pro (2.7GHz Core i7, 8GB 1333MHz DDR3, SSD) running OSX 10.9. All simulated *dCAMP* nodes use endpoints on the machine's loopback interface, and only the loopback interface traffic is monitored. The machine is otherwise entirely idle during the test runs.

Configuration

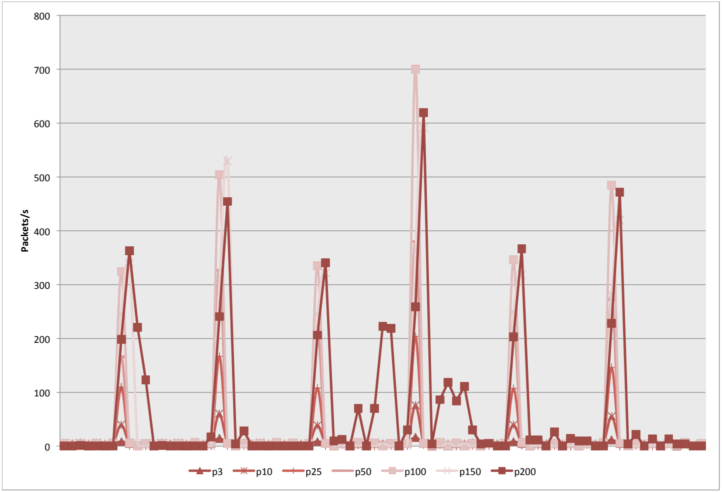
dCAMP is configured to monitor and report the below **global metrics**, using a heartbeat of 60 seconds.

- CPU usage every 60 seconds
- total disk throughput every 120 seconds
- total network throughput every 120 seconds
- memory usage every 60 seconds

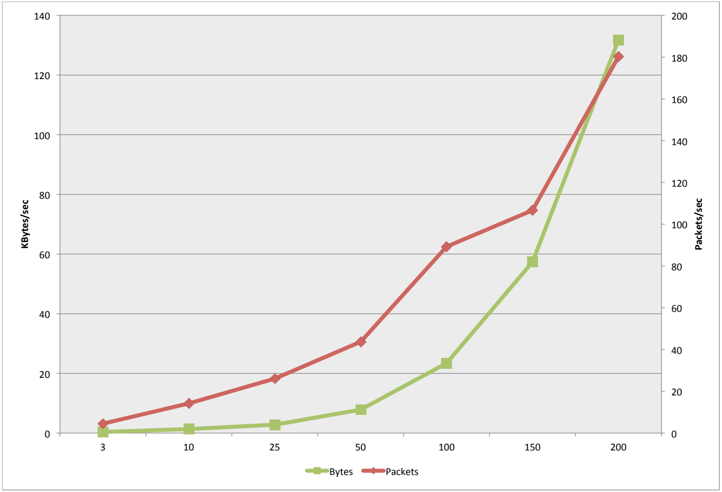
Steady State Network Bytes



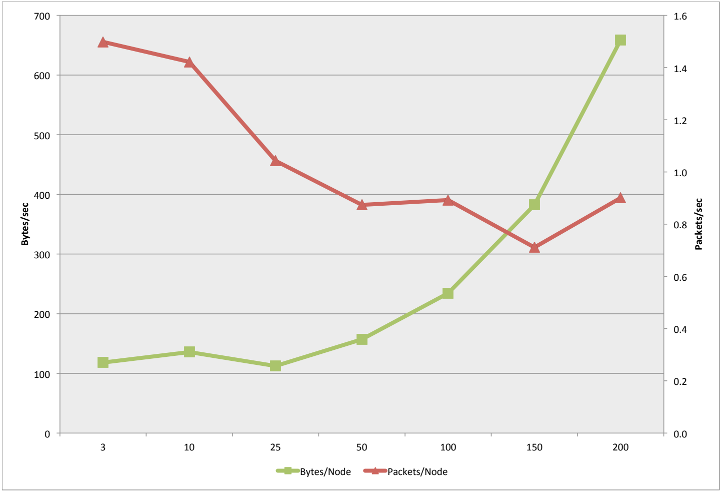
Steady State Network Packets



Average Network Utilization



Average Network Utilization Per Node



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4. The number of messages being sent per node actually goes down and levels off just under 1 packet per node per second.
5. As the ratio of Sensor to Collector increases, the number of messages per node is expected to decrease. Therefore, a higher number of child nodes per parent should result in lower network utilization and better *dCAMP* scalability.

Evaluation

The previous section presents an empirical evaluation of *dCAMP*'s **transparency** and **scalability**, showing *dCAMP* to be both transparent and scalable when properly configured.

Validity and **portability** are inherited from *CAMP* as well as the use of portable Python libraries. *dCAMP*'s **data delivery models** and **completeness** are apparent in the system's design and configuration capabilities, and these will be easily achieved with a full implementation of *dCAMP*.

Likewise, updating *dCAMP* to meet the **security** criterion is unfinished work, but the *dCAMP* design and use of ZeroMQ makes this work straightforward.

Contributions

In this work I presented the **Distributed Common API for Measuring Performance**, a distributed performance framework built on top of *CAMP* [1]. I described the design and implementation of *dCAMP*, using roles and services on top of ZeroMQ to build a simple, reliable distributed system.

I also presented a set of **criterion for evaluating distributed performance frameworks** by extending and updating the criterion presented by Zanikolas [3]. I used this criterion to evaluate *dCAMP* along with several other level 2 distributed performance frameworks and related works.

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6 Appendix

- Terminology
- Evaluation Criterion Details
- Related Work
- ZeroMQ: Sockets and Patterns
- dCAMP Metrics

Terminology

dCAMP **Service:** Services are a way of logically grouping functions within the *dCAMP* system. Each service is implemented in *dCAMP* as an independent thread.

dCAMP **Role:** Roles in the *dCAMP* system are groupings of one or more *dCAMP* services. There does not exist a one-to-one relationship between roles and services.

ZeroMQ: ZeroMQ is a message queuing framework which allows a developer to build distributed systems by focusing on the data and implementing simple design patterns.

ZeroMQ Address: A ØMQ address is the combination of network host identifier (i.e. an IP Address or resolvable name) and Internet socket port number.

ZeroMQ Endpoint: An endpoint is the combination of any ZeroMQ transport (`pgm`, `inproc`, `ipc`, or `tcp`) and a ØMQ address.

Terminology

Performance Metric: Performance metrics are any data about a given node relating to its throughput, capacity, utilization, or latency.

Metric Sampling: Metric collection or sampling is the process of measuring metrics on a given node.

Metric Reporting: Metric reporting is the process of sending sampled metrics to a parent node.

Metric Aggregation: Metric aggregation is the process of combining metrics from multiple nodes into a single metric, providing a coarser granularity for the performance metrics. Metrics are combined by calculating a sum, average, percent, or any other mathematically relevant operation.

Metric Calculation: Metric calculation is the process of combining identical metrics from multiple timestamps into a single metric.

Data Delivery Models

Monitoring information includes fairly static (e.g., software and hardware configuration of a given node) and dynamic events (e.g., current processor load, memory), which suggests the use of different measurement policies (e.g., periodic or on demand). In addition, consumer patterns may vary from sparse interactions to long lived subscriptions for receiving a constant stream of events. In this regard, the monitoring system must support both pull and push data delivery models.

Security

Certain scenarios may require a monitoring service to support security services such as access control, single or mutual authentication of parties, and secure transport of monitoring information.

Scalability

Monitoring systems have to cope efficiently with a growing number of resources, events and users. This scalability can be achieved as a result of good performance which guarantees that a monitoring system will achieve the needed throughput within an acceptable response time in a variety of load scenarios.

Transparency

Transparency refers to the lack of impact a distributed performance framework makes on the system being monitored. As [3] states, it is "typically measured as a function of host (processor, memory, I/O) and network load (bandwidth) generated by the collection, processing and distribution of events." If a framework lacks transparency it will fail to allow the underlying distributed system to perform well and will produce inaccurate performance measurements, thereby reducing its Scalability and destroying its Validity.

Completeness

The Completeness of a distributed performance framework refers to the exhaustiveness to which it gathers performance metrics. At a minimum, a framework must provide interfaces for measuring and aggregating performance data about a system's processor, memory, disk, and network usage. Several distributed performance frameworks provide further detailed performance metrics about the given distributed system being monitored, but this is usually at the cost of Portability.

Validity

A distributed performance framework is only as good as the data is produces; if the sensors or gathering techniques are inaccurate, then the data is useless at best, misleading at worst. Validity of a framework is achieved when the authors of a framework provide formal verification of its accuracy.

Portability

A framework's ability to run on a completely heterogeneous distributed system without special considerations by the practitioner is what this work defines as Portability. More specifically, a portable framework has a unified API regardless of the system architecture, does not restrict itself to applications written in specific programming languages, and does not require practitioners to manually instrument their application code. This black box characteristic is vital for a viable distributed performance framework's effectiveness as it allows practitioners to focus on the performance data and not on a myriad of APIs for various architectures or languages.

NetLogger

Their research has shown NetLogger to be highly scalable, complete, and transparent as well as valid. The activation service provides a push data delivery and can utilize the security mechanisms part of current web services in order to authenticate requests for performance data. NetLogger is currently implemented for C, C++, Java, Perl, and Python applications. Because the framework lacks black box characteristics, its **portability is greatly reduced**.

JAMM

JAMM, being heavily based off of NetLogger, inherits the validity, completeness, security, and transparency of NetLogger along with its lack of **portability**. JAMM does, however, prove itself in terms of scalability with it's own architecture.

Hawkeye

While no experiments have been run, the generally centralized manager reduces the Hawkeye framework's scalability, and its transparency is unknown. The frameworks module based producer architecture gives it an infinite completeness, but being only available on Linux and Solaris makes the framework less **portable**. Lastly, the ability to run jobs **securely** on target machines has been left as future work by the authors.

SCALEA-G

The framework makes use of secure sockets to achieve secure communications and achieves high completeness via code instrumentation. Unfortunately, the authors do not provide any report on SCALEA-G's **validity** or **transparency**.

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Host sFlow

In supporting host and application performance metric analysis alongside network metrics in one common system, sFlow has an advantage over more traditional host-only distributed performance frameworks. While sFlow's claims to scalable and accurate network level monitoring have been validated, less work has been to show the same for Host sFlow.

Ganglia

The analysis presented shows the design scales and maintains transparency for systems of several hundred nodes. Still, **scalability** is a concern of the authors since the multicast protocol exhibits a quadratic trendline as the number of nodes within a cluster increases. Memory usage and inter-cluster bandwidth also increase as the number of nodes increases, albeit much more linearly. In comparison, *dCAMP* memory usage is nearly constant since performance data is not persisted in memory to the same extent.

ZeroMQ in 100 Words

ØMQ (also known as ZeroMQ, 0MQ, or zmq) looks like an embeddable networking library but acts like a concurrency framework. It gives you sockets that carry atomic messages across various transports like in-process, inter-process, TCP, and multicast. You can connect sockets N-to-N with patterns like fan-out, pub-sub, task distribution, and request-reply. It's fast enough to be the fabric for clustered products. Its asynchronous I/O model gives you scalable multicore applications, built as asynchronous message-processing tasks. It has a score of language APIs and runs on most operating systems. ØMQ is from iMatix [http://www.imatix.com] and is LGPLv3 open source.

ZeroMQ Sockets

ØMQ sockets mimic standard TCP sockets, exposing interfaces for creating and destroying instances, binding and connecting to network endpoints, and sending and receiving data. However, they have two key differences from their TCP counterparts.

- asynchronous—the actual sending and receiving of data on a ZeroMQ socket is handled by a background thread.
- built-in support for one-to-many connections; a single socket can send and receive data from multiple endpoints.

ZeroMQ Messages

ZeroMQ messages are the building blocks of all data sent across ZeroMQ sockets. A message is comprised of one or more frames (or parts), and a single frame can be any size (including zero) that fits in memory. ZeroMQ guarantees messages are delivered atomically, meaning either all frames of the message are sent/received or none of the frames. Lastly, because sockets are asynchronous and messages are atomic, the entire message must fit in memory.

ZeroMQ Messaging Patterns

Publish-Subscribe: "The publish-subscribe pattern is used for one-to-many distribution of data from a single publisher to multiple subscribers in a fan out fashion."

Request-Reply: "The request-reply pattern is used for sending requests from a [...] client to one or more [...] services, and receiving subsequent replies to each request sent."

Pipeline: "The pipeline pattern is used for distributing data to nodes arranged in a pipeline. Data always flows down the pipeline, and each stage of the pipeline is connected to at least one node. When a pipeline stage is connected to multiple nodes data is round-robined among all connected nodes."

Exclusive Pair: "The exclusive pair pattern is used to connect a peer to precisely one other peer. This pattern is used for inter-thread communication across the inproc transport."

Metric Groups

In *dCAMP*, metrics are grouped into four different sets of performance metrics—global, network, disk, and per-process—and a fifth set of inquiry metrics.

Metric Details

Type	Single Sample	Calculation
basic	raw value at specified timestamp	$C = V_{t_2}$
delta	raw value at specified timestamp	$C = V_{t_2} - V_{t_1}$
rate	raw value at timestamp	$C = \frac{V_{t_2} - V_{t_1}}{t_2 - t_1}$
average	raw value and base value at timestamp	$C = \frac{V_{t_2} - V_{t_1}}{B_{t_2} - B_{t_1}}$
percent	raw value and base value at timestamp	$C = 100 \frac{V_{t_2} - V_{t_1}}{B_{t_2} - B_{t_1}}$