Design and Implementation of a Real-Time Cloud Analytics Platform

OSCON Data 2011

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Agenda

The Problem

Cloud Analytics

Demo

Experiences

Cloud Performance

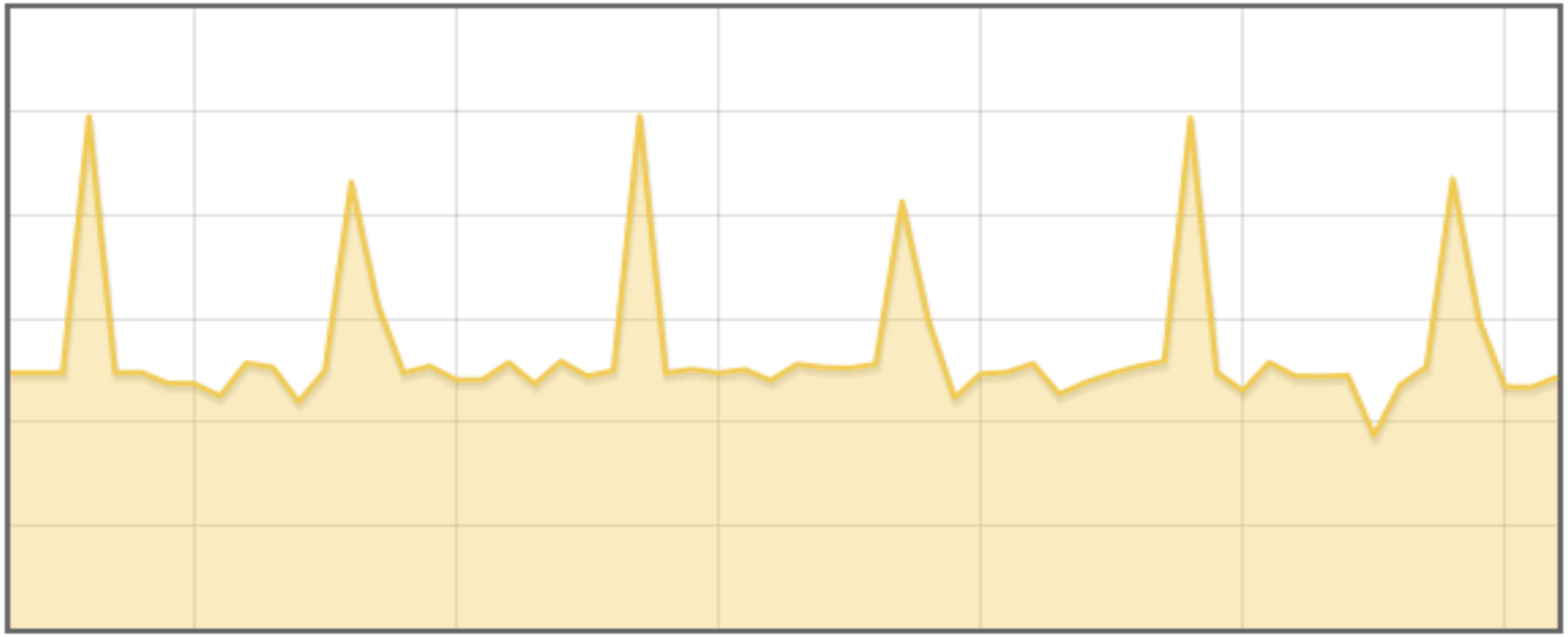
- The problem: we've deployed our software, and now performance sucks.
  - How do we figure out why?
- Focus on source of the pain: **latency**
  - How long a synchronous operation takes
  - ... while a client is waiting for data
  - ... while a user is waiting for a page to load
- How do you **summarize** the latency of thousands of operations?
  - ...without losing important details?
- How do you summarize that **across a distributed system**?
- How do you do this **in real time**?

Latency: event-by-event

```
# ./iosnoop –Dots
STIME        TIME         DELTA  DTIME    UID   PID D    BLOCK   SIZE     COMM PATHNAME
949417936651 949417948636 11984  11999    104 29008 R 99310470  16384   mysqld <none>
949418267667 949418275701 8033   8052     104 29008 R  1947809  16384   mysqld <none>
949418843669 949418843808 139    156        0     3 W    29024   2048  fsflush /var/log/…
949418873385 949418873488 103    121        0     3 W  6695855   2048  fsflush <none>
949418873564 949418873617 52     57         0     3 W  1829584    512  fsflush <none>
949418921970 949418932931 10960  10976    104 29008 R 95362430  16384   mysqld <none>
949419684613 949419692319 7706   7723     104 29952 R 81475146  16384   mysqld <none>
949419693574 949419699461 5886   5906     104 29952 R 60593276  16384   mysqld <none>
949422857833 949422857981 148    168        0     3 W    26720   4096  fsflush /var/adm/…
949423846191 949423846355 163    181        0     3 W  1990648   4096  fsflush /var/log/…
949426420134 949426420265 130    151        0     0 R      400   8192    sched <none>
949426420346 949426420423 77     85         0     0 W       65    512    sched <none>
949426420367 949426420459 92     35         0     0 W      129    512    sched <none>
949426420386 949426420490 103    30         0     0 W      146    512    sched <none>
949426420404 949426420566 161    76         0     0 W      193    512    sched <none>
949426420530 949426420604 73     37         0     0 W      206    512    sched <none>
949426420547 949426420679 131    75         0     0 W      210    512    sched <none>
[...thousands of lines...]
```

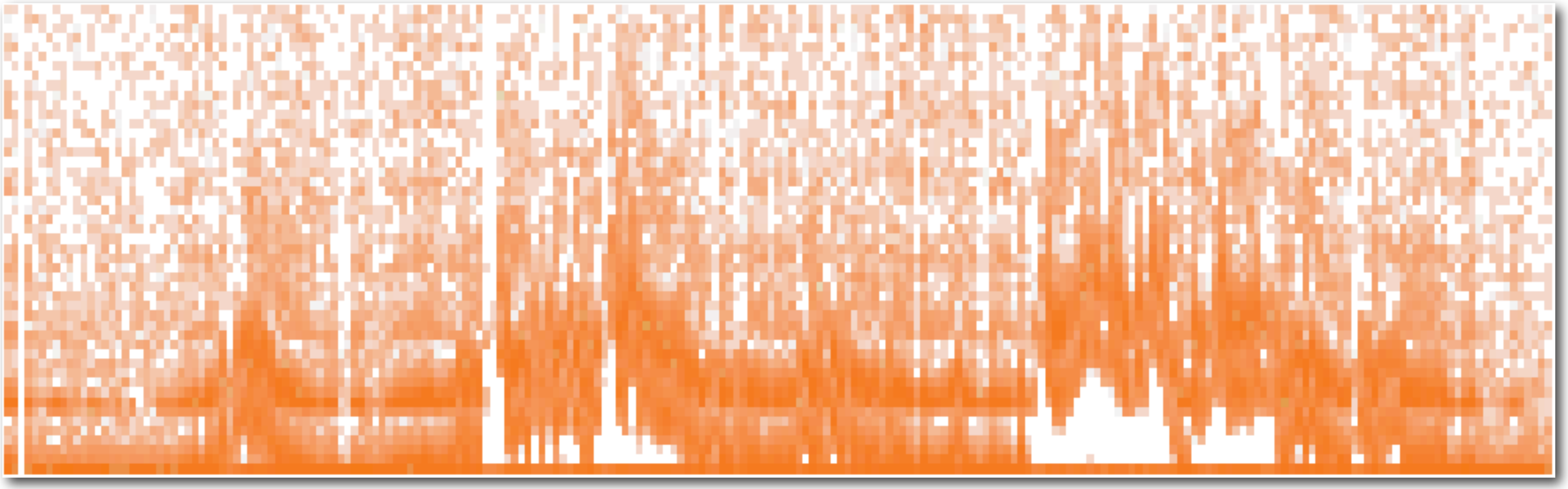
- Lots of of data to sift through; effective as a last resort

Latency: average



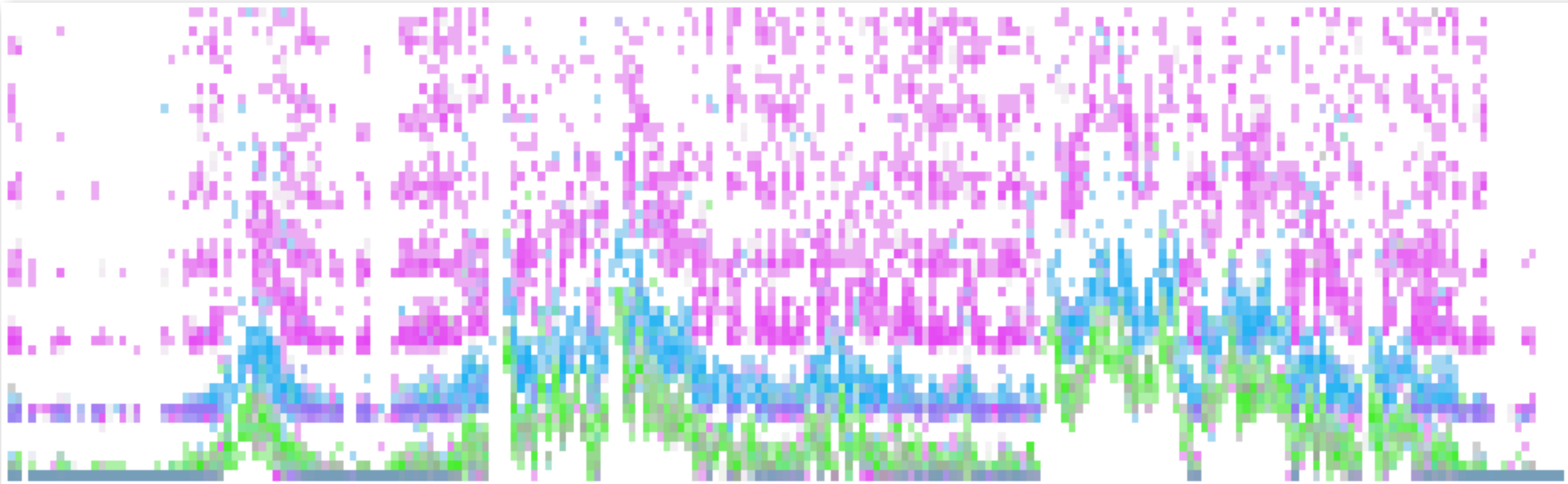
- Some patterns more visible; outlier hidden
- x-axis = time, y-axis = average latency

Latency: heatmap



- Great! This example is MySQL query latency
- x-axis = time, y-axis = latency, **z-axis (color saturation) = count of queries**

Latency: heatmap, sliced and diced



- Even better! 4th dimension (color hue) represents different database tables
- x-axis = time, y-axis = latency, **color hue = table**, color saturation = count

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- Key building blocks
  - DTrace
  - OS-level virtualization
  - Node.js

Building blocks: DTrace

- Facility for dynamic instrumentation of production systems
  - Originally developed circa 2003 for Solaris 10, then open-sourced in 2005
  - Available on Solaris-derived OSes (SmartOS, Illumos, etc.)
  - Available on Mac OSX 10.5+, FreeBSD 7.1+, Linux? (http://crtags.blogspot.com)
- Supports arbitrary actions and predicates, in situ data aggregation, dynamic and static tracing of both **userland** and **kernel**.
- Designed for safe, ad hoc use in production: concise answers to arbitrary questions

DTrace example: MySQL query latency

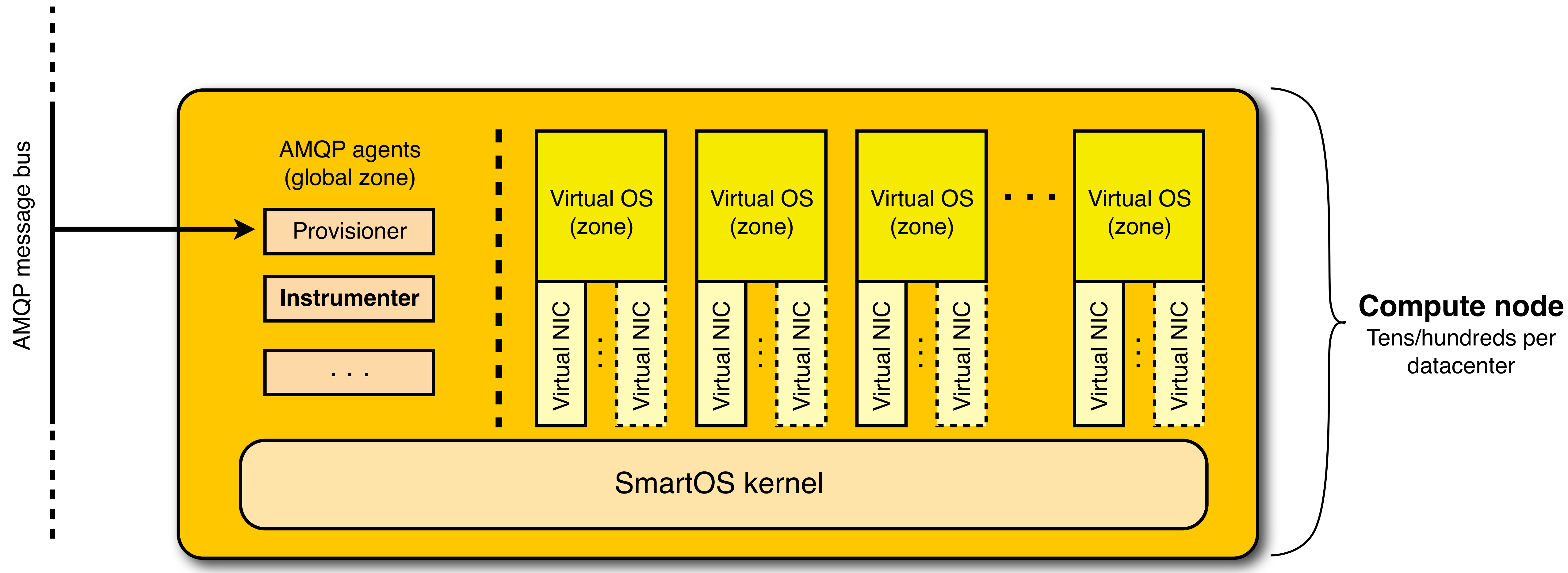
- MySQL query latency can be measured with a (long) one-liner:

```
# dtrace –n ‘
mysql*:::query-start { self->start = timestamp; } mysql*:::query-done /self->start/ {
 @[“nanoseconds”] = quantize(timestamp – self->start);
 self->start = 0;
}’
```

```
nanoseconds
           value  ------------- Distribution ------------- count
            1024 |                                         0
            2048 |                                         16
            4096 |@                                        93
            8192 |                                         19
           16384 |@@@                                      232
           32768 |@@                                       172
           65536 |@@@@@@                                   532
          131072 |@@@@@@@@@@@@@@@@@                        1513
          262144 |@@@@@                                    428
          524288 |@@@                                      258
         1048576 |@                                        127
         2097152 |@                                        47
         4194304 |                                         20
         8388608 |                                         33
        16777216 |                                         9
        33554432 |                                         0
```

Building blocks: OS-level Virtualization

- The Joyent cloud uses OS-level virtualization to achieve high levels of tenancy on a single kernel without sacrificing performance:



- Allows for transparent instrumentation of *all* virtual OS instances using DTrace

Building blocks: Node.js

- node.js is a JavaScript-based framework for building event-oriented servers:

```
var http = require('http');

http.createServer(function (req, res) {
        res.writeHead(200, {'Content-Type': 'text/plain'});
        res.end('Hello World\n');
}).listen(8124, "127.0.0.1");

console.log('Server running at http://127.0.0.1:8124!');
```

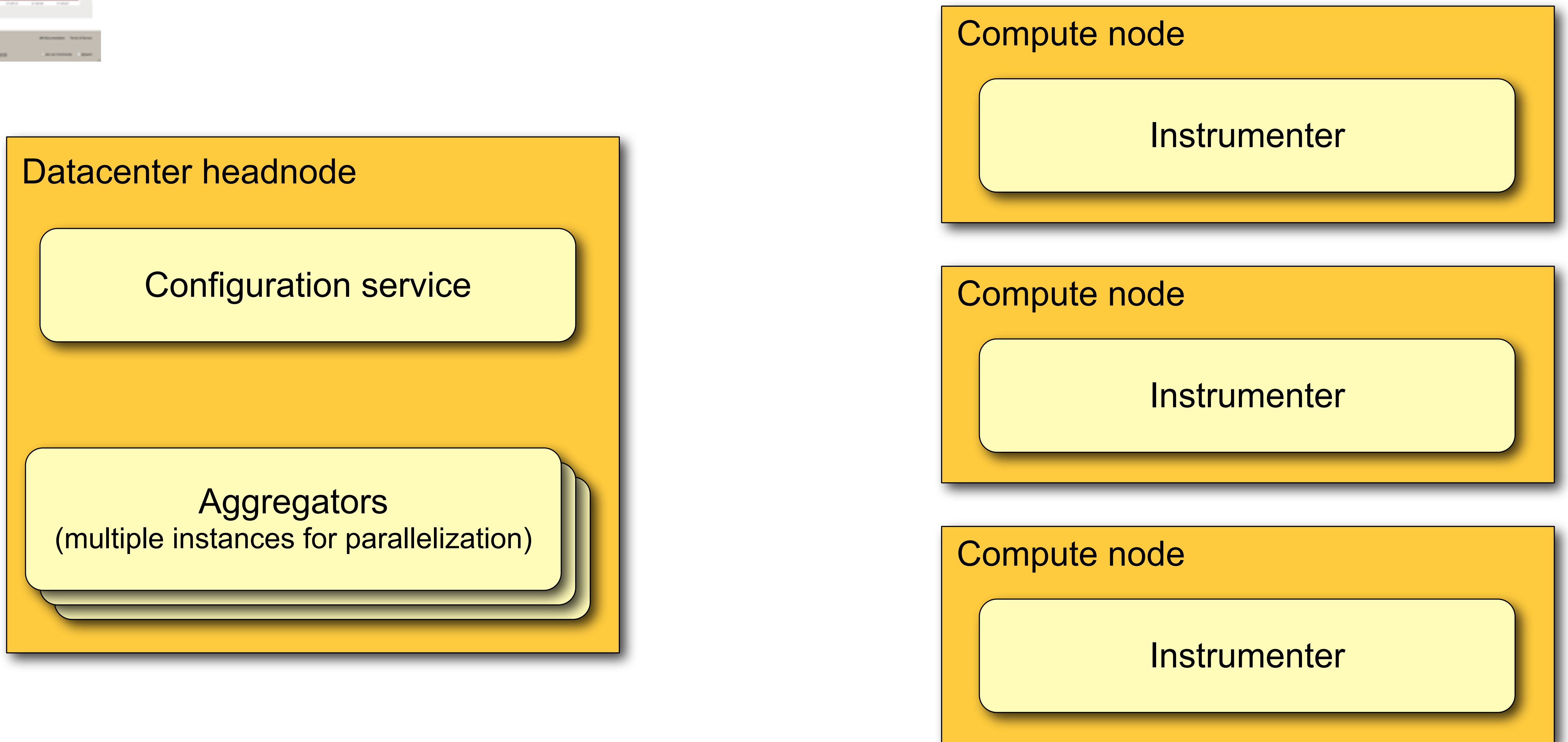
The energy behind Node.js

Joyent

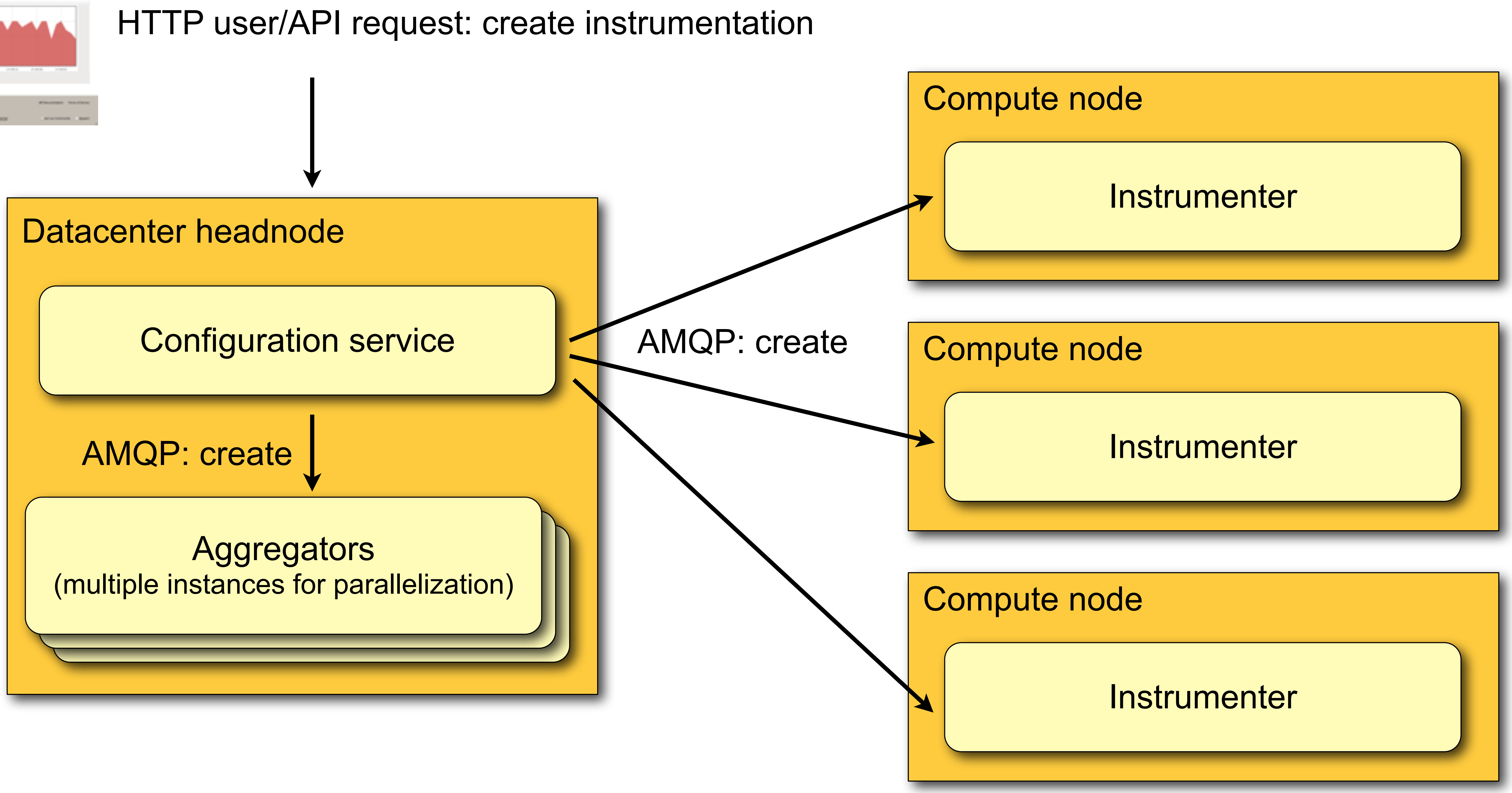
- node.js is a confluence of three ideas:
  - JavaScript's rich support for asynchrony (i.e. closures)
  - High-performance JavaScript VMs (e.g. V8)
  - Solid system abstractions (i.e. UNIX)
- Because everything is asynchronous, node.js is ideal for delivering scale in the presence of long-latency events

- **configuration service**: manages which metrics are gathered
- **instrumenter**: uses DTrace to gather metric data
  - one per compute node, not per OS instance
  - reports data at 1Hz, summarized in-kernel
- **aggregators**: combine metric data from instrumenters
- **client**: presents metric data retrieved from aggregators

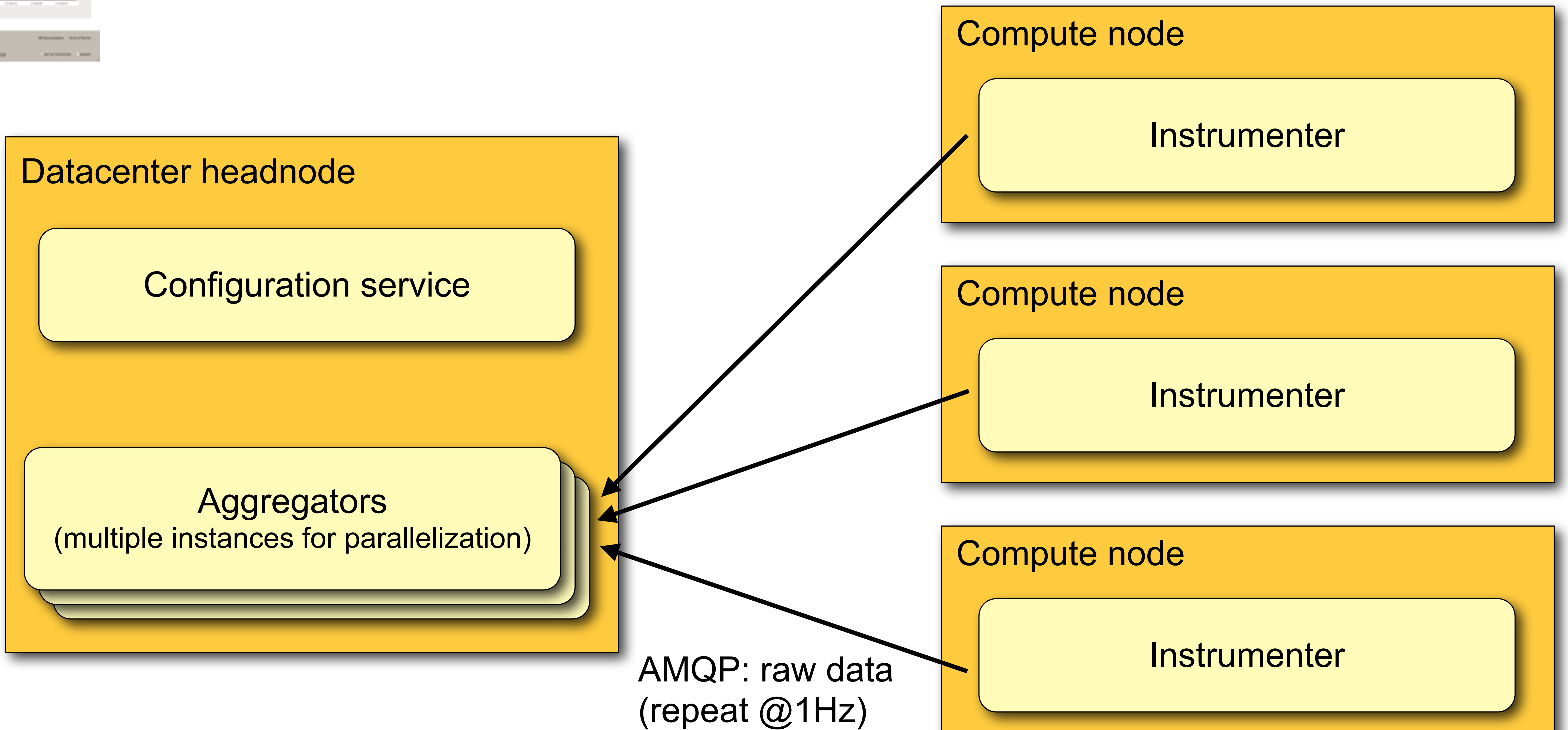
Distributed service



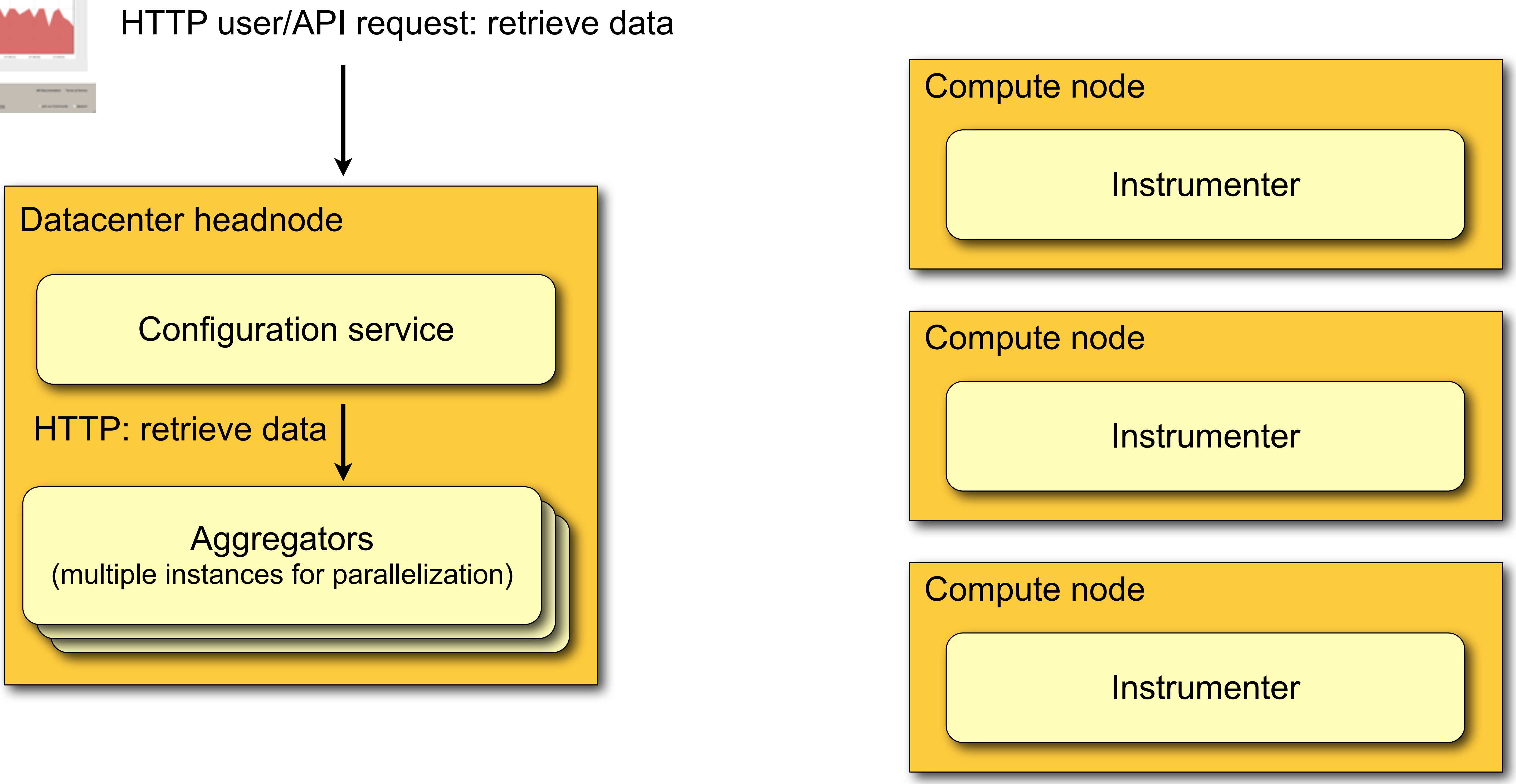
Step 1: User creates an instrumentation



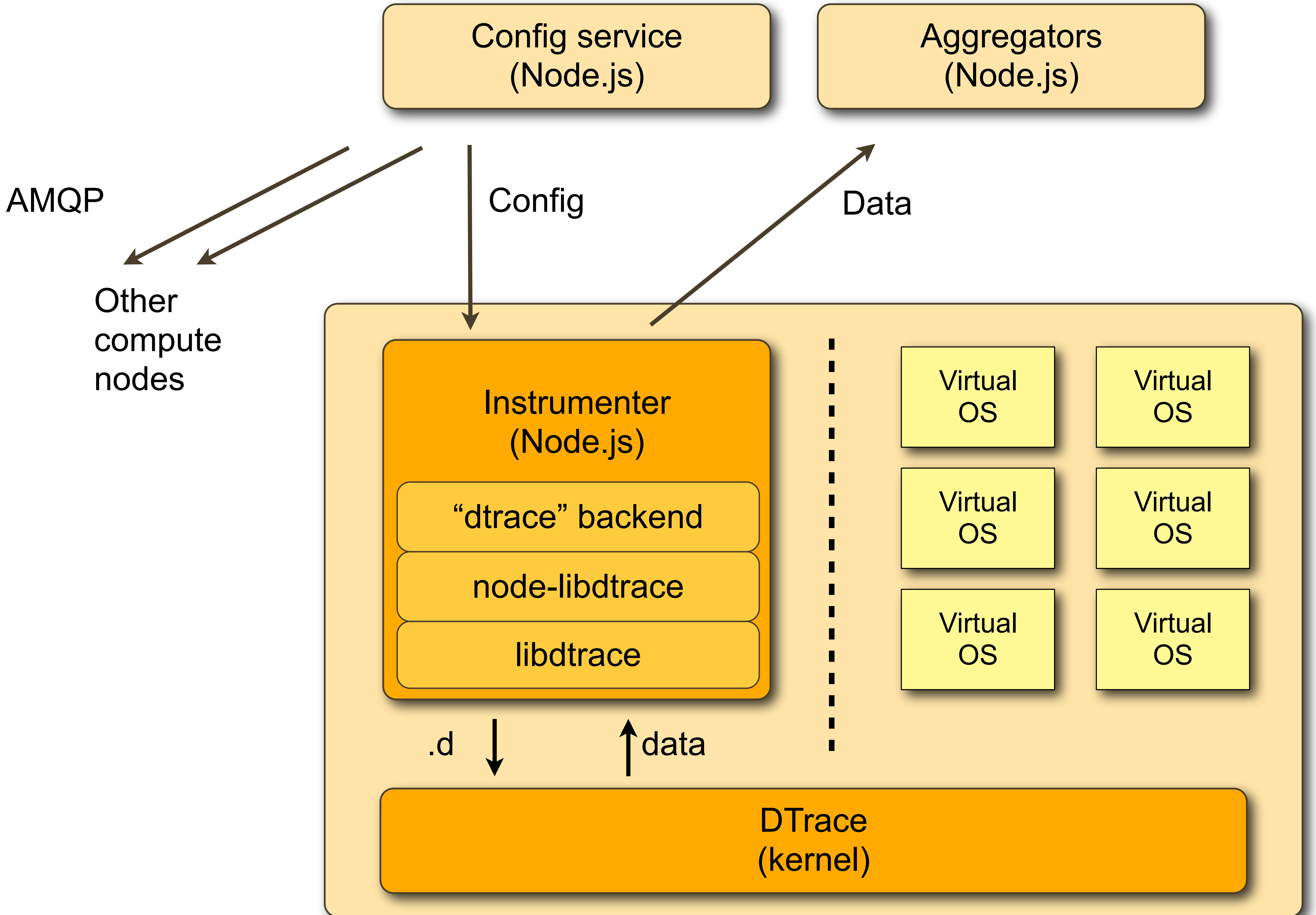
Step 2: Instrumenters report data



Step 3: Users retrieve data



Inside the instrumenter



Instrumenter: pluggable backends

- AMQP daemon, pluggable backends (DTrace, kstat, ZFS, ...)
- Predefined metrics; each plugin registers implementations for each metric
- Backend interface:

`registerMetric(metric, constructor)`	(Invoked by plugin)
`constructor(metric_info)`	Initialize object based on metric, decomposition, predicate, etc.
`obj.instrument(callback)`	Start collecting data (e.g., start DTrace).
`obj.deinstrument(callback)`	Stop collecting data (e.g., stop DTrace).
`obj.value(callback)`	Retrieve current data point (**invoked @ 1Hz**)

DTrace backend

- Assemble a D script, compile it, and enable DTrace:

```
this.cad_prog = mdGenerateDScript(metric, ...)

this.cad_dtr = new mod_dtrace.Consumer();

this.cad_dtr.strcompile(this.cad_prog);

this.cad_dtr.go();
```

- But how do you dynamically generate a D script to support predicates and decompositions?

DTrace backend: simple case

- System calls

```
syscall:::return
{
        @ = count();
}
```

DTrace backend: with decompositions

- System calls decomposed by application name and latency

```
syscall:::entry
{
        self->latency0 = timestamp;
}

syscall:::return
/self->latency0 != NULL/
{
        @[execname] =
            llquantize(timestamp - self->latency0, 10, 3, 11, 100);
}

syscall:::return
{
        self->latency0 = 0;
}
```

Generating D scripts

- Number of possible D scripts: exponential with number of possible decompositions
- Need way to automatically generate them

Meta-D

- Meta-D uses JSON to describe a family of D scripts differing in predicate and decomposition

```
{
    module: 'syscall', stat: 'syscalls', fields: [ 'hostname', 'zonename', 'execname', 'latency' ... ],
    metad: {
        probedesc: [ {
                probes: [ 'syscall:::entry' ],
                gather: { latency: { gather: 'timestamp', store: 'thread' } }
            }, {
                probes: [ 'syscall:::return' ],
                aggregate: {
                        default: 'count()',
                        zonename: 'count()',
                        hostname: 'count()',
                        execname: 'count()',
                        latency: 'llquantize($0, 10, 3, 11, 100)'
                },
                transforms: {
                        hostname: '"' + caHostname + '"',
                        zonename: 'zonename',
                        execname: 'execname',
                        latency: 'timestamp - $0',
                }
```

DTracing system calls

- Enable: hot-patches system call table entries (redirect into DTrace)
- Disable: revert system call table entries
- Advantages of dynamic tracing:
  - Instruments syscalls in all processes on the system at once
  - **The thread is never stopped**
  - Zero disabled probe effect

More complex: instrumenting MySQL

- Want to instrument MySQL commands by command name and latency:

```
mysql*:::command-start
{
        self->command0 = lltostr(arg1);
        self->latency0 = timestamp;
}

mysql*:::command-done
/(((((self->command0 != NULL)))) && ((((self->latency0 != NULL)))))/
{
        @[self->command0] =
                llquantize(timestamp - self->latency0, 10, 3, 11, 100);
}

mysql*:::command-done
{
        self->command0 = 0;
        self->latency0 = 0;
}
```

DTracing userland applications

- Userland Statically-Defined Tracing (USDT): developer-defined static probes
  - e.g., mysql*:::command-start
  - maintained as functions and arguments evolve
- How it works:
  - In source, macro expands to DTrace function call
  - During link phase: function calls are replaced with nops and their locations recorded
  - On enable, DTrace replaces nops with trap
  - On disable, revert trap back to nop
- Thread is never actually stopped, but does take a round-trip to the kernel.
- **Zero disabled probe effect.**
- See also: pid provider
  - extremely powerful, but interface is unstable and requires instrumenting each process

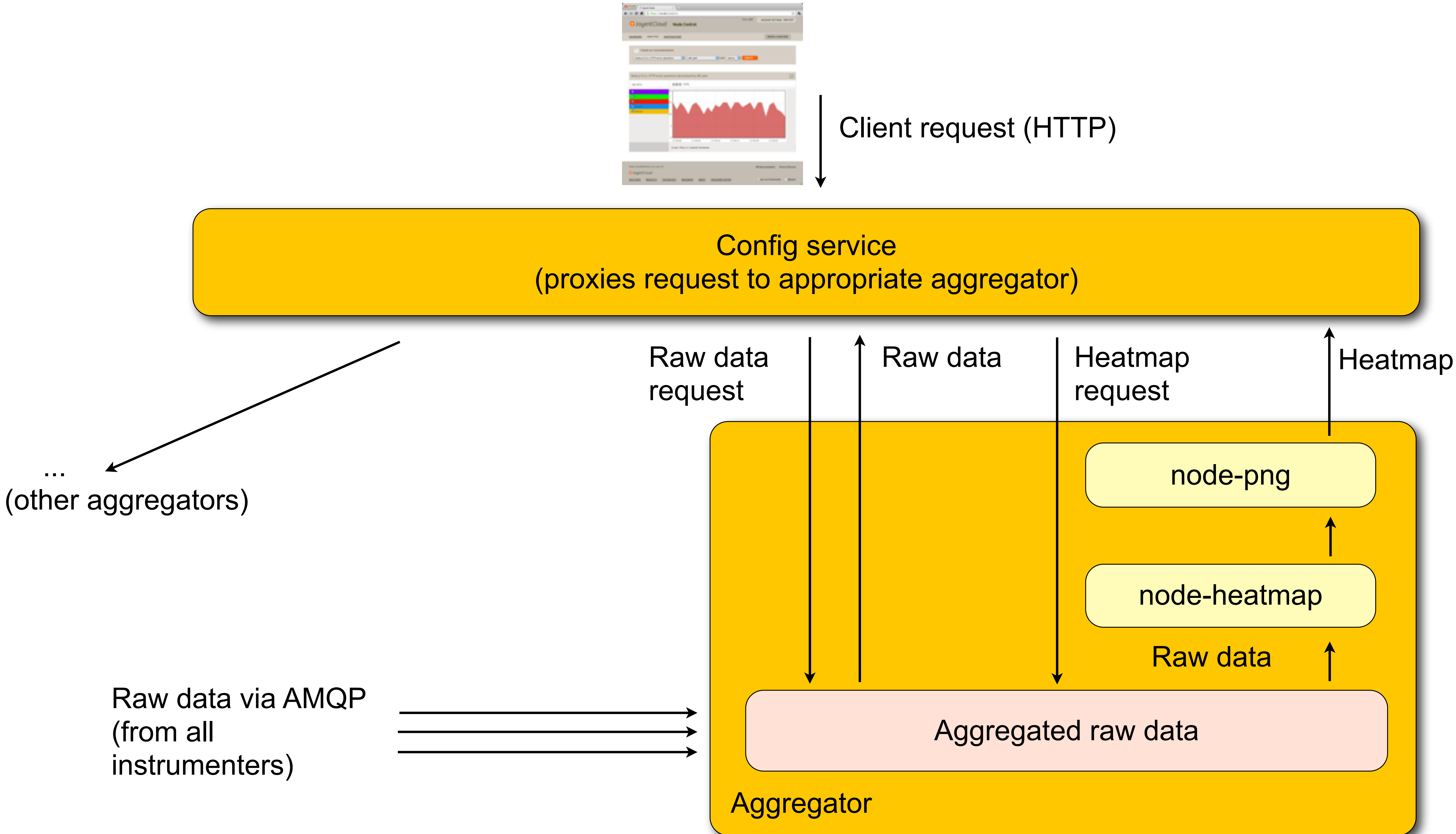
Advantages of DTrace-based analytics

- Combine userland and kernel tracing:
  - heatmap of total time spent in CPU dispatcher queue *per HTTP request*
  - heatmap of total time spent waiting for filesystem I/O *per MySQL query*
- Examine activity in all applications at once:
  - heatmap of filesystem latency *for all applications on a system*, *by application name*
  - *...and for all systems in a data center*
- Zero performance impact when not enabled, small impact when enabled
- No need to restart applications
- Can answer arbitrary performance questions **safely in production**.

Visualizations

- Bar charts: easy
  - Clients request raw data, render a chart
  - e.g., Total number of MySQL queries
- Stacked bar charts: easy
  - Clients request raw data for multiple separate data series, render a stacked chart.
  - e.g., Total number of MySQL queries *decomposed by zone name*
    (each virtual OS instance gets its own set of bars)
- Heatmaps: hard(er)
  - Heatmap contains a **lot** of raw data -- transferring it doesn't scale.
  - Render the heatmaps server-side
  - Rendering is compute-bound, but generally <40ms per heatmap (often more like 10ms).
    - We use multiple aggregators to parallelize the work.

Visualizations



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- http://rm.no.de:8001

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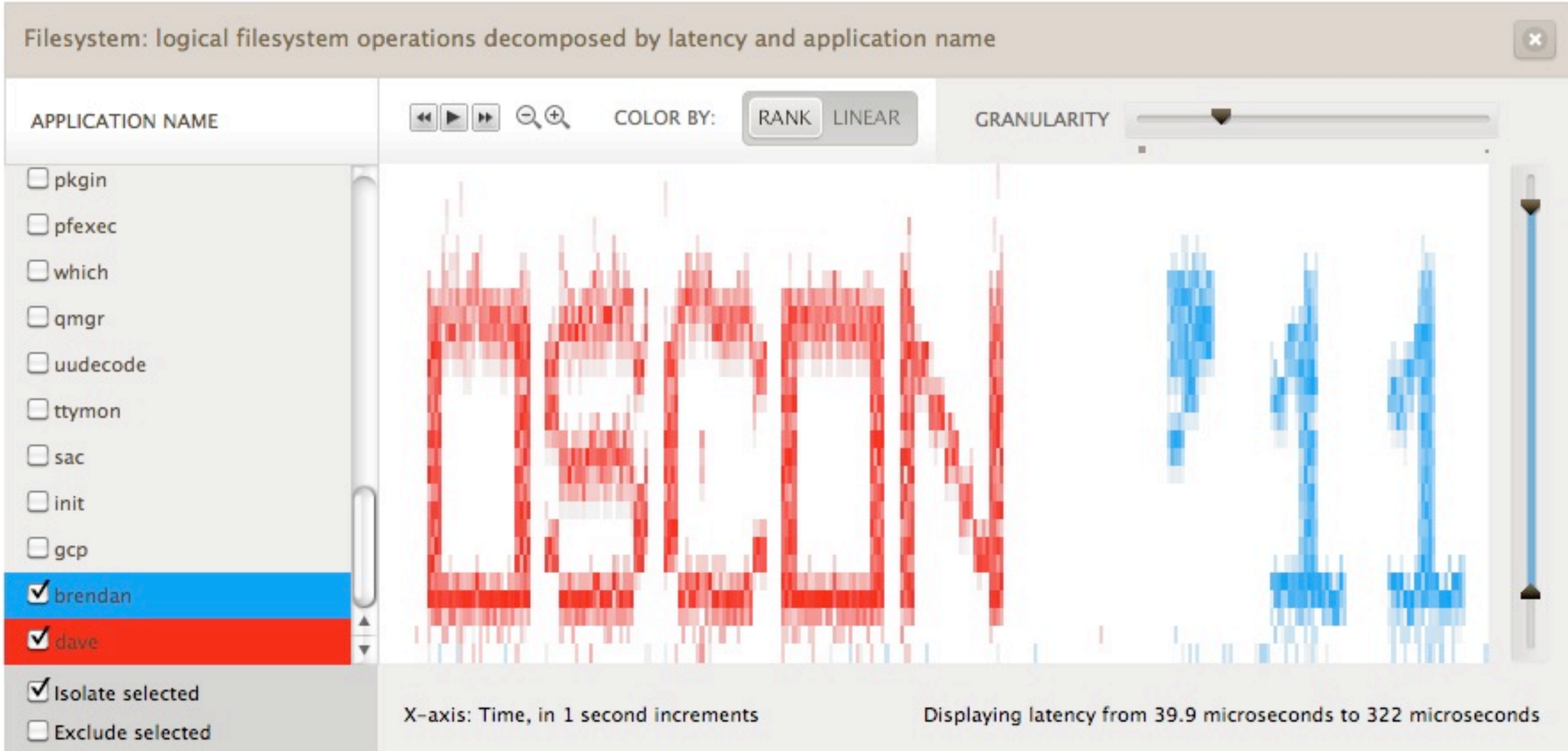
- Node is solid:
  - All CA components are 100% Node.js (about 85% JavaScript, 15% C++)
  - Although aggregator is compute-bound, scaling it with multiple Node processes was easy
- Weak points:
  - C++ add-ons (no stable ABI and the failure modes are *not* crisp)
  - Diagnosing failures from the field (no post-mortem debugging)
- Building robust AMQP services is non-trivial (exclusive queue problem)



Filesystem: logical filesystem operations decomposed by latency and application name
APPLICATION NAME
COLOR BY:
RANK
LINEAR
GRANULARITY
pkgin
pfexec
which
qmgr
uudecode
ttymon
sac
init
gcp
brendan
dave
Isolate selected
Exclude selected
X-axis: Time, in 1 second increments
Displaying latency from 39.9 microseconds to 322 microseconds

About us

- Thanks!
  - Cloud Analytics: @dapsays, @brendangregg, @bcantrill, @rmustacc
  - Portal and API: @rob_ellis, @notmatt, @kevinykchan, @mcavage
  - OS, Node teams at Joyent
- Check out our blogs at http://dtrace.org/

Resources

- “Instrumenting the real-time web: Node.js, DTrace, and the Robinson Projection” (Bryan Cantrill, http://velocityconf.com/velocity2011/public/schedule/detail/18293)
- “Breaking Down MySQL/Percona Query Latency with DTrace” (Brendan Gregg, http://www.percona.com/live/nyc-2011/schedule/sessions/)
- “Visualizing System Latency” (Brendan Gregg, http://queue.acm.org/detail.cfm?id=1809426)
- “Visualizations for Performance Analysis” (Brendan Gregg, http://www.usenix.org/event/lisa10/tech/tech.html#gregg)
- DTrace Book: http://www.dtracebook.com/
- Our blogs: http://dtrace.org/