Monitorama

Jun 2015

Netflix Instance Performance Analysis Requirements

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NETFLIX

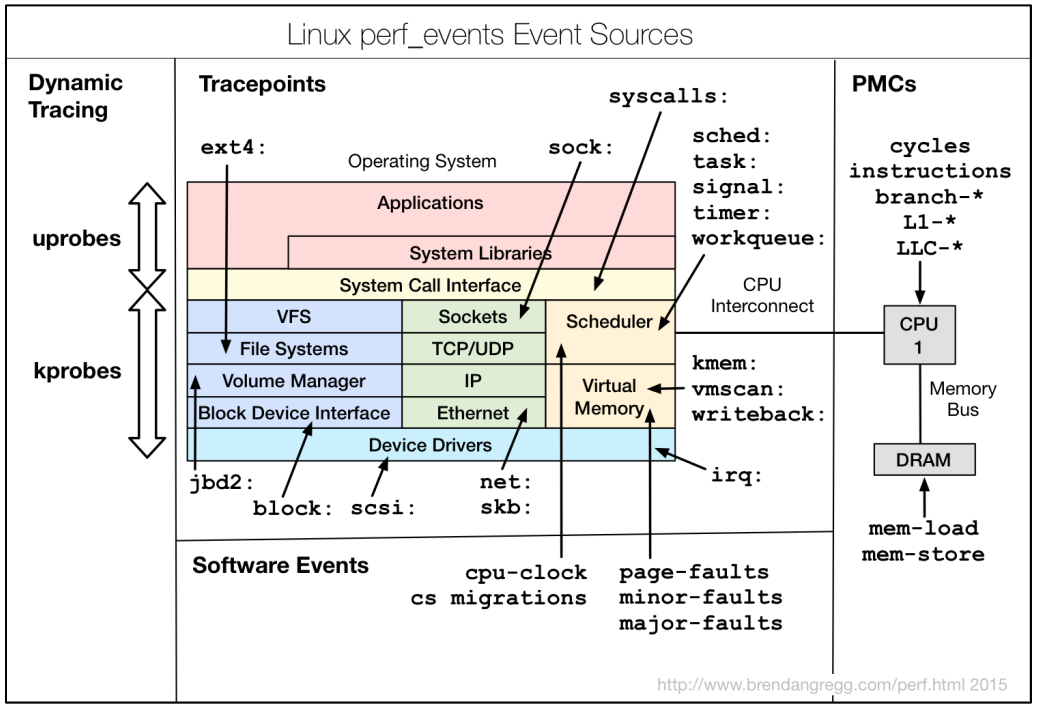
Monitoring companies are selling faster horses

I want to buy a car

Server/Instance Analysis Potential

In the last 10 years…

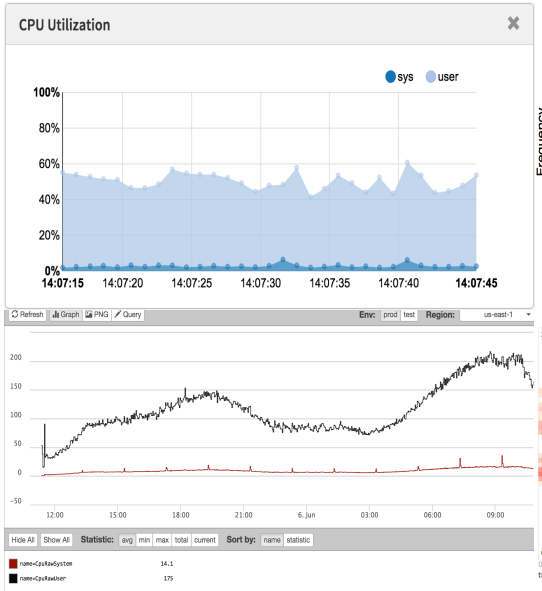
- More Linux
- More Linux metrics
- Better visualizations
- Containers

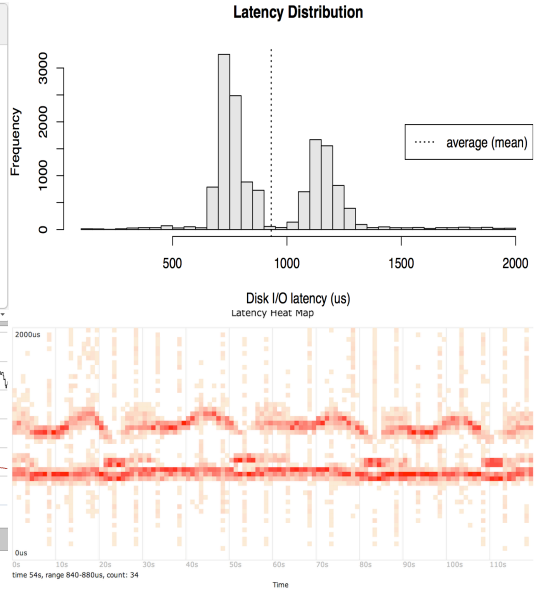


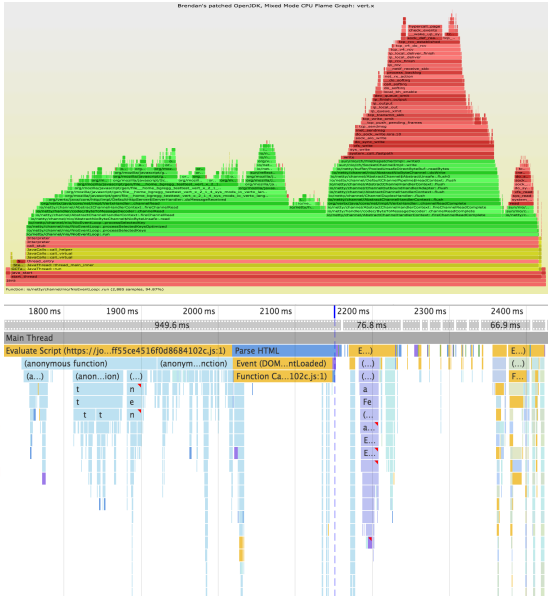
Conditions ripe for innovation: where is our Henry Ford?

This Talk

- **Instance analysis**: system resources, kernel, processes
  - For customers: what you can ask for
  - For vendors: our desirables & requirements
  - What we are building (and open sourcing) at Netflix to modernize instance performance analysis (Vector, …)







NETFLIX

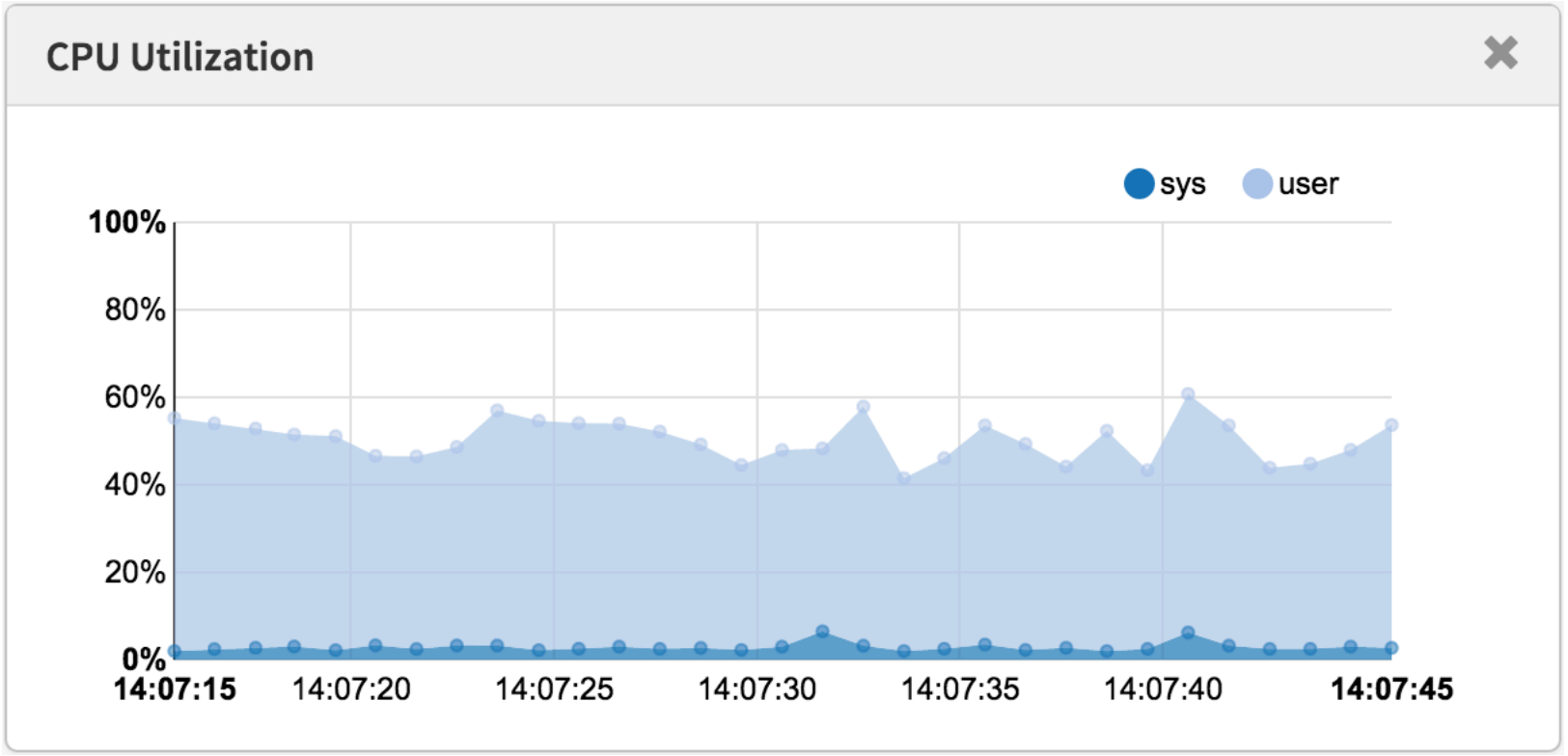
- Over 60M subscribers
- FreeBSD CDN for content delivery
- Massive AWS EC2 Linux cloud
- Many monitoring/analysis tools
- Awesome place to work

Agenda

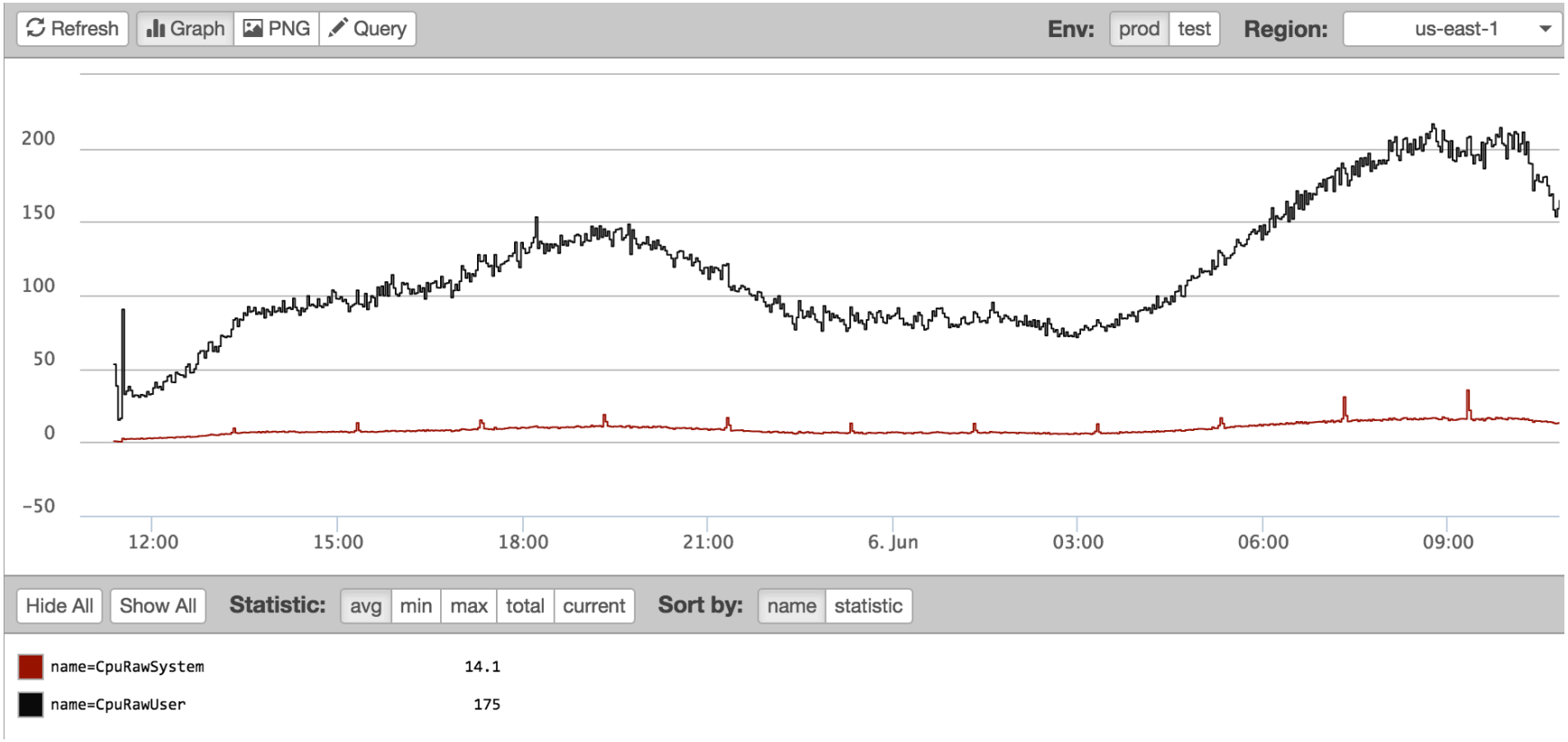
1. Desirables
2. Undesirables
3. Requirements
4. Methodologies
5. Our Tools

1. Desirables

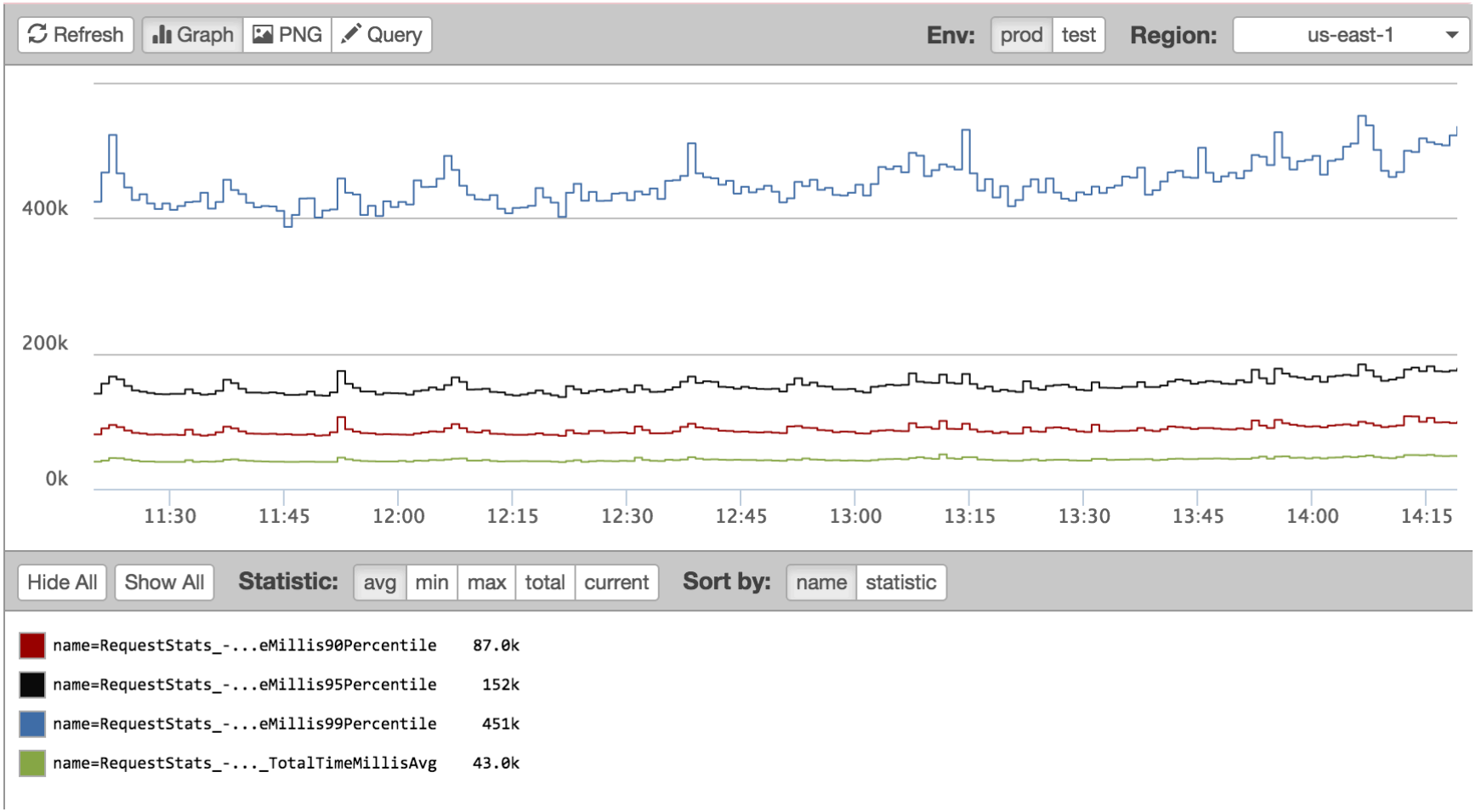
Line Graphs


CPU Utilization
sys
user
100%
80%
60%
40%
20%
0%
14:07:15
14:07:20
14:07:25
14:07:30
14:07:35
14:07:40
14:07:45

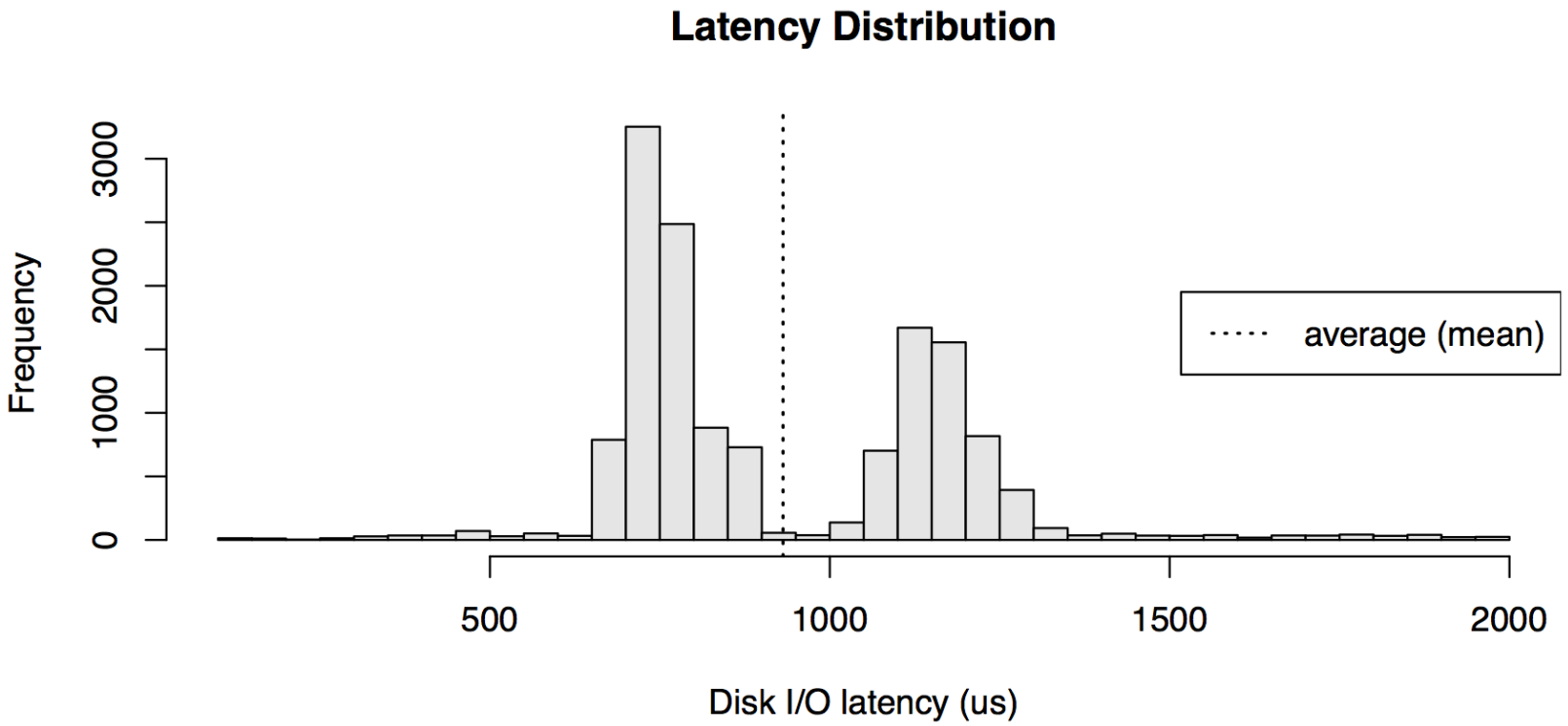
Historical Data



Summary Statistics

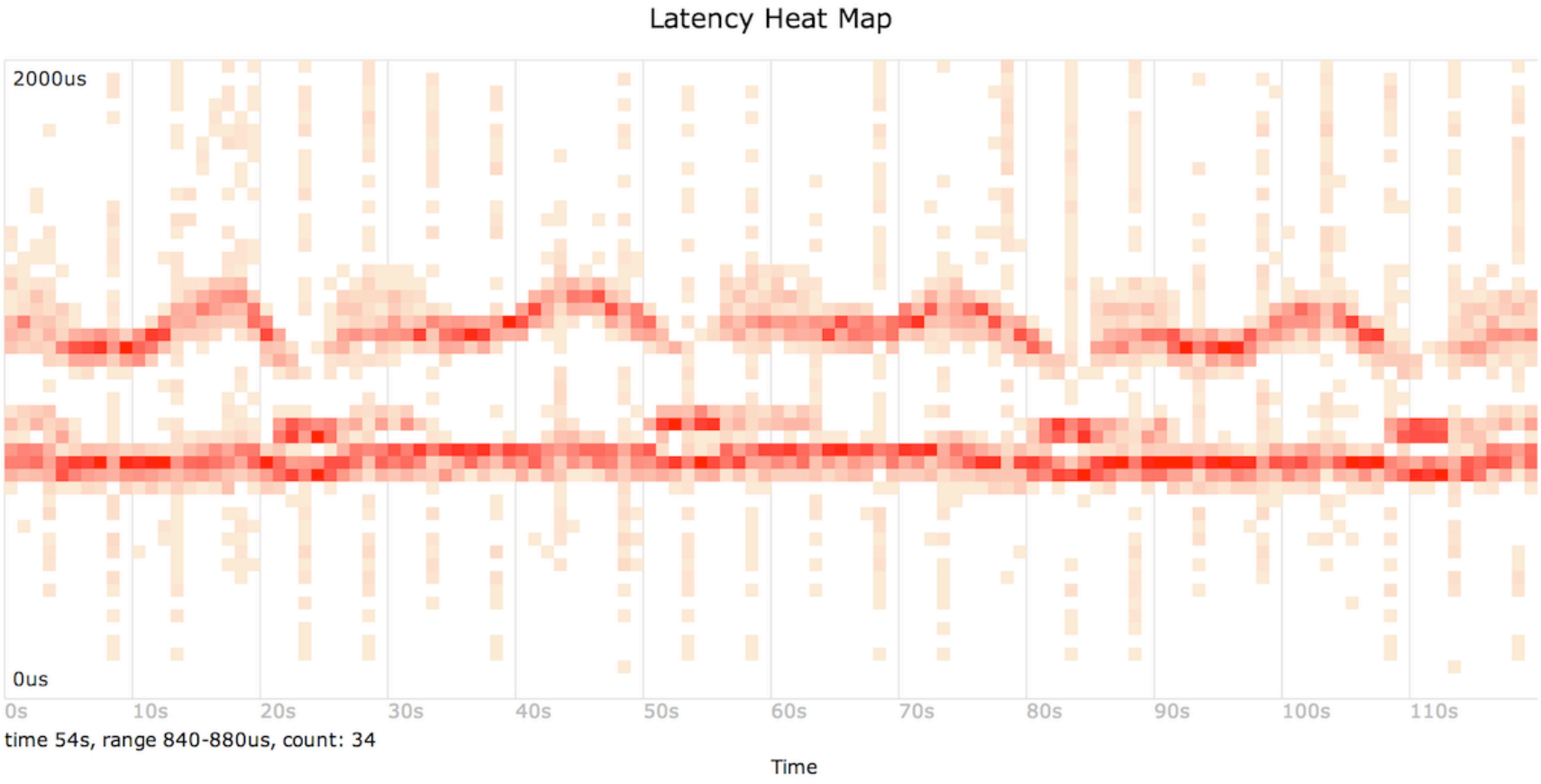


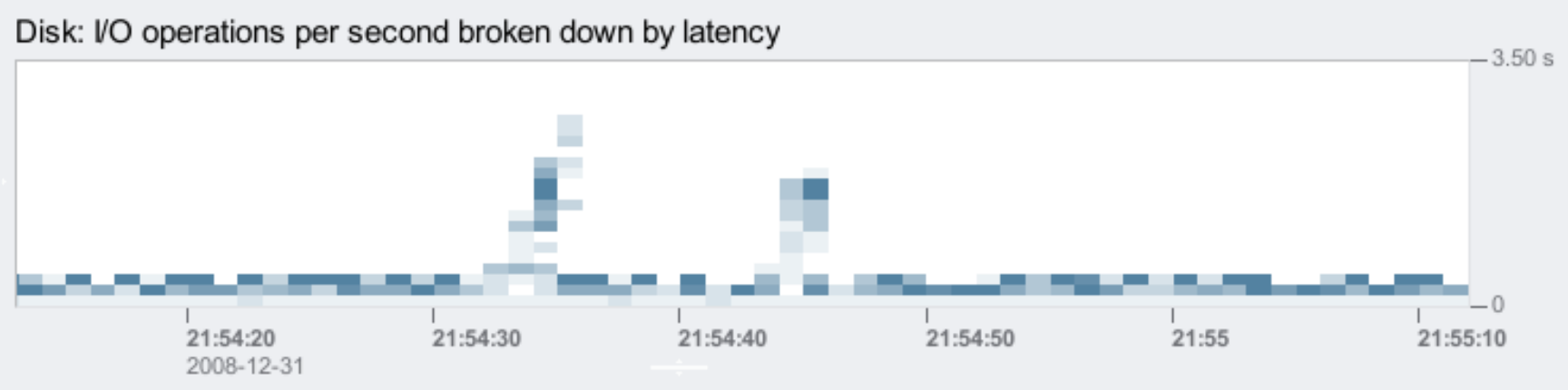
Histograms

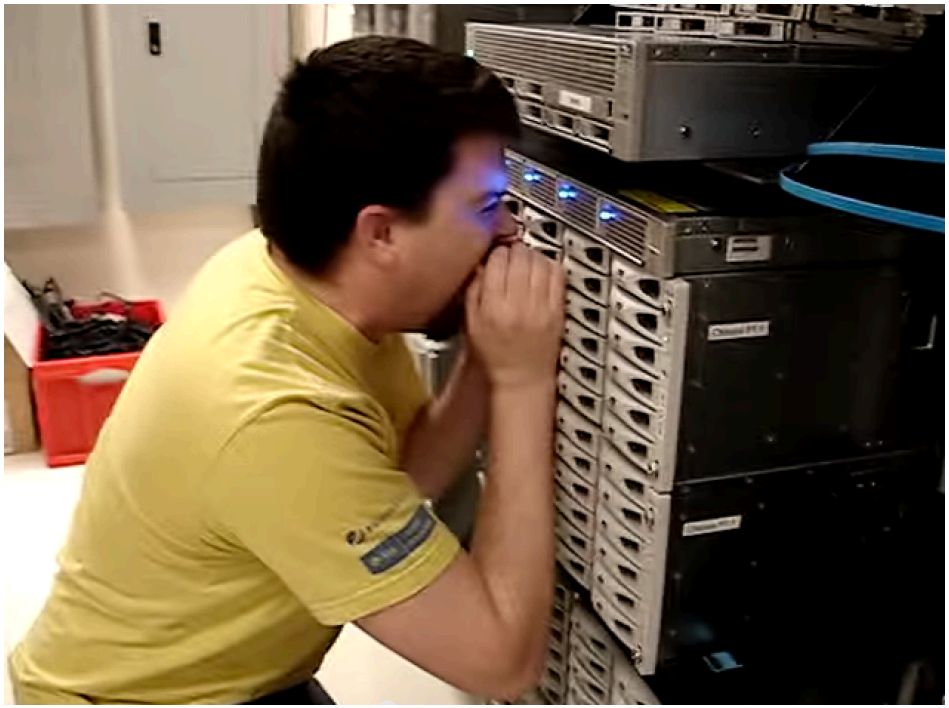


… or a density plot

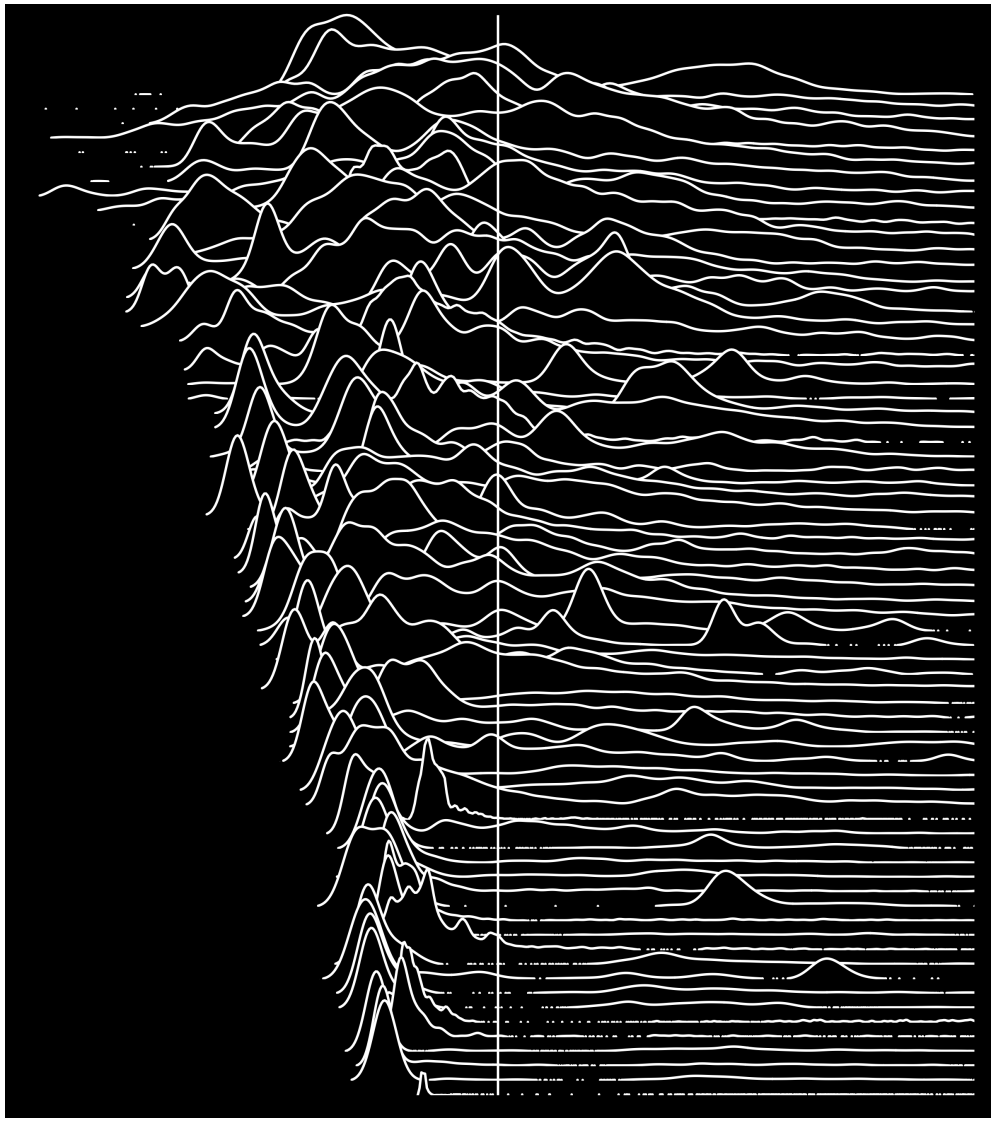
Heat Maps


Latency Heat Map
2000us
0us
0s
10s
20s
30s
40s
50s
60s
70s
80s
90s
100s
110s
time 54s, range 840-880us, count: 34
Time


Disk: I/O operations per second broken down by latency
3.50 s
0
21:54:20
2008-12-31
21:54:30
21:54:40
21:54:50
21:55
21:55:10

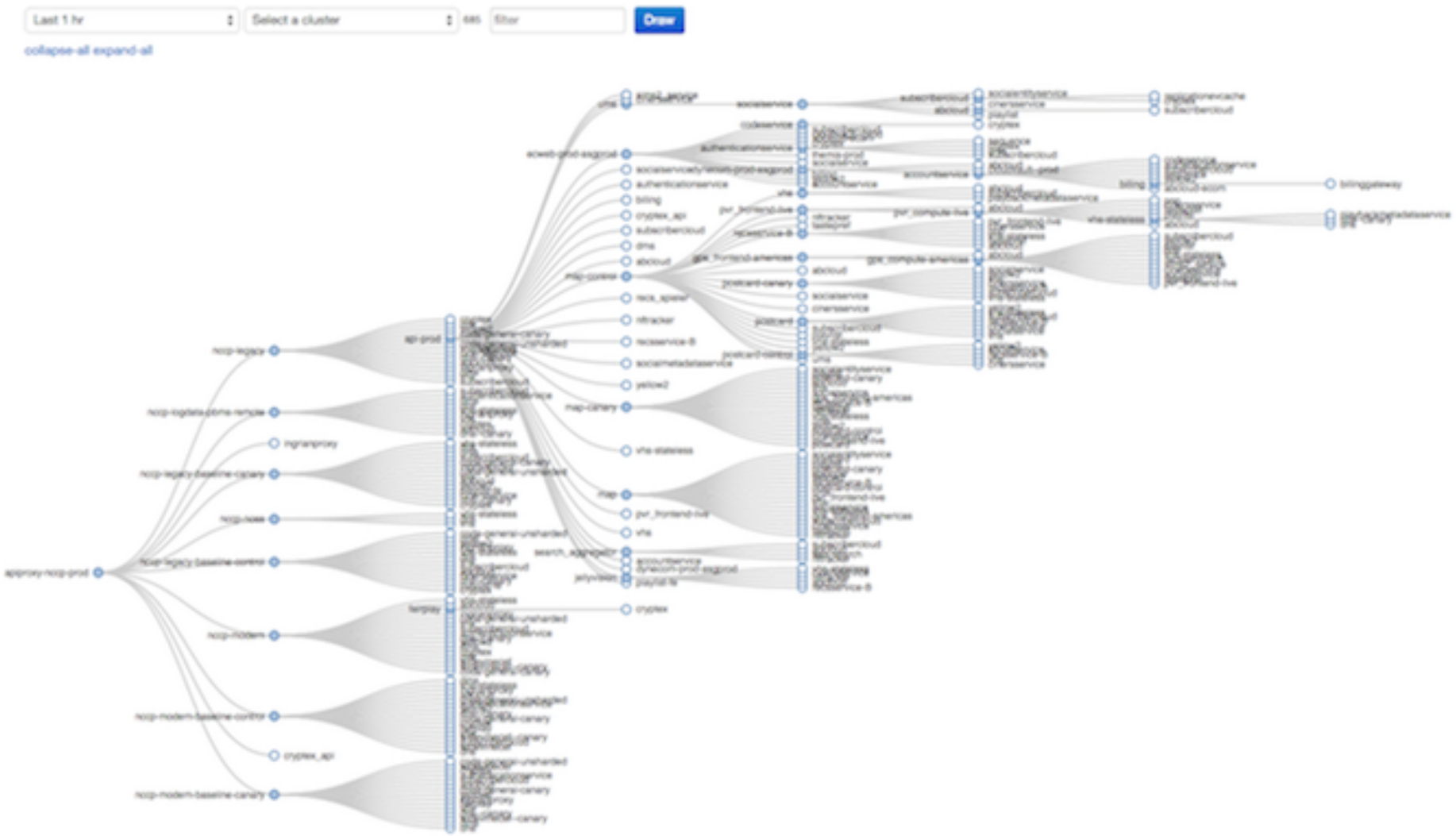


Frequency Trails

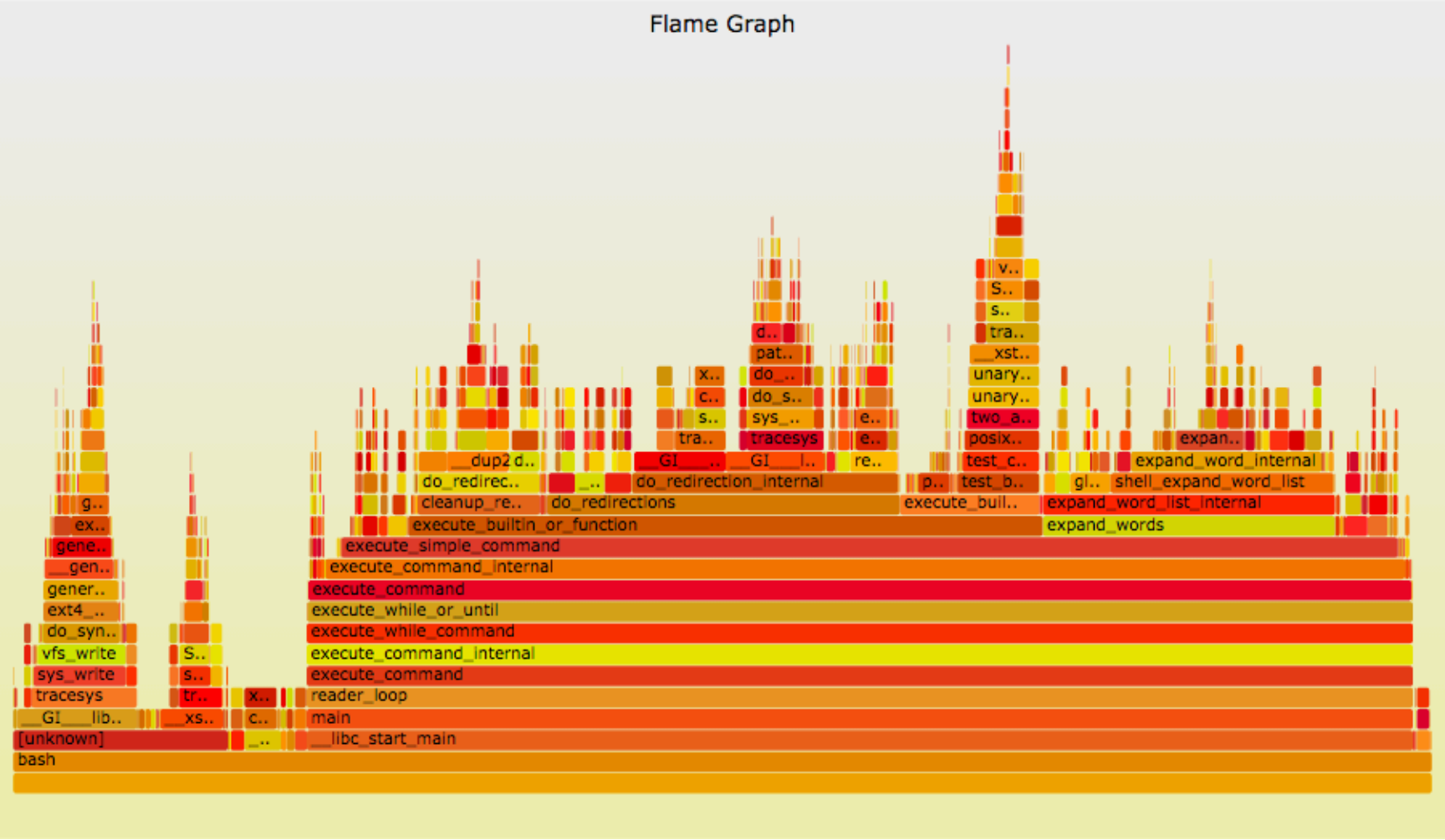


Waterfall Charts

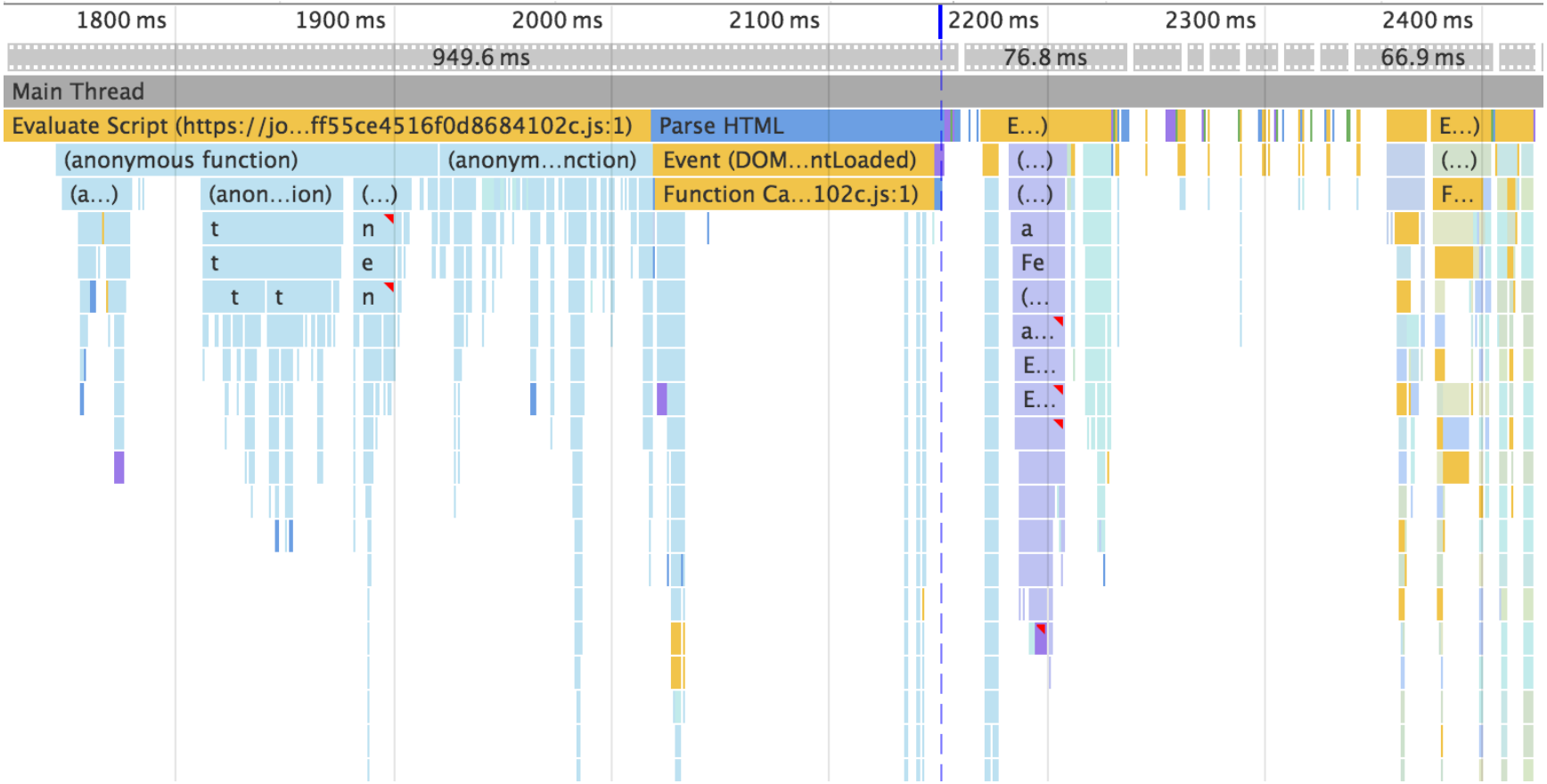
Directed Graphs



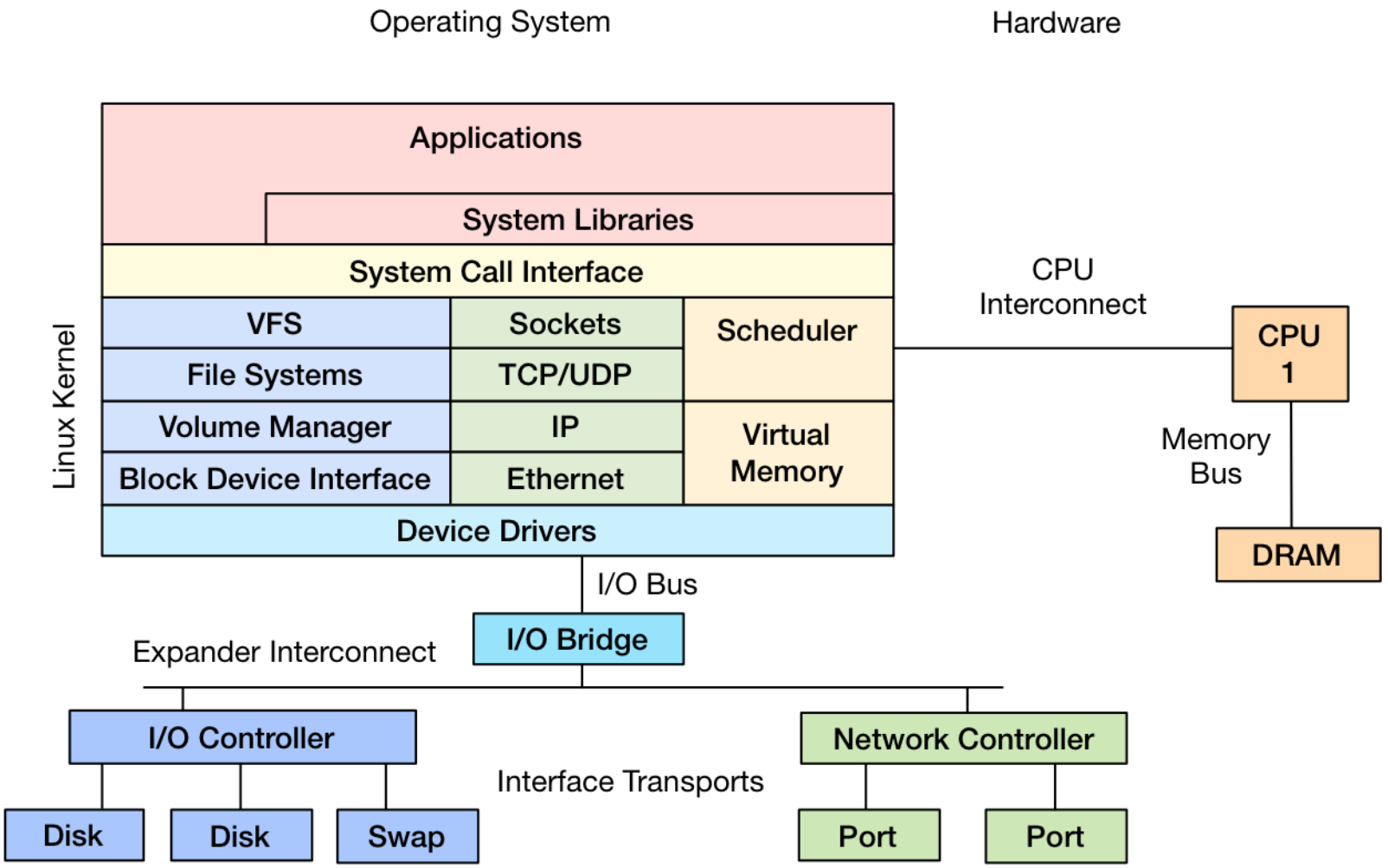
Flame Graphs



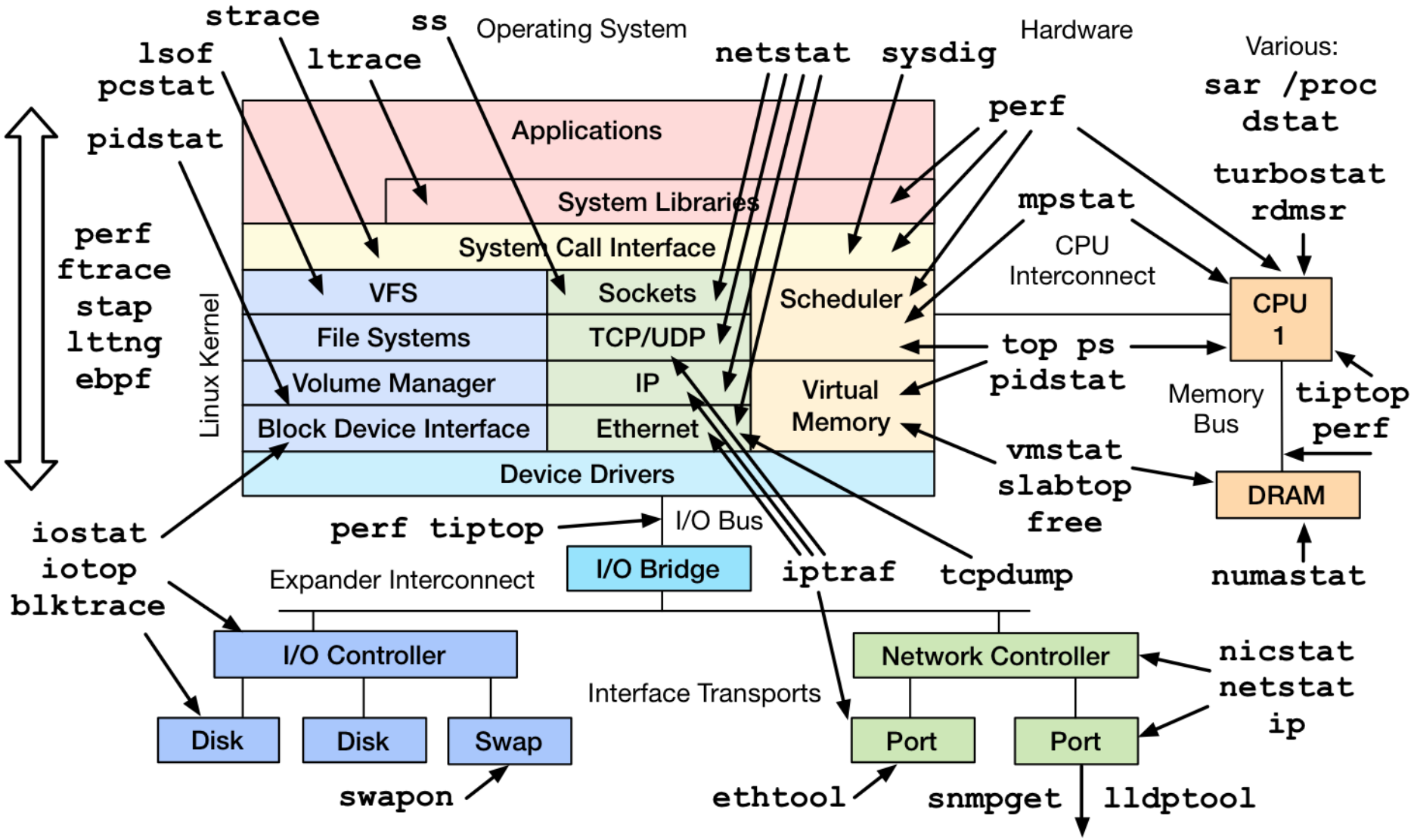
Flame Charts



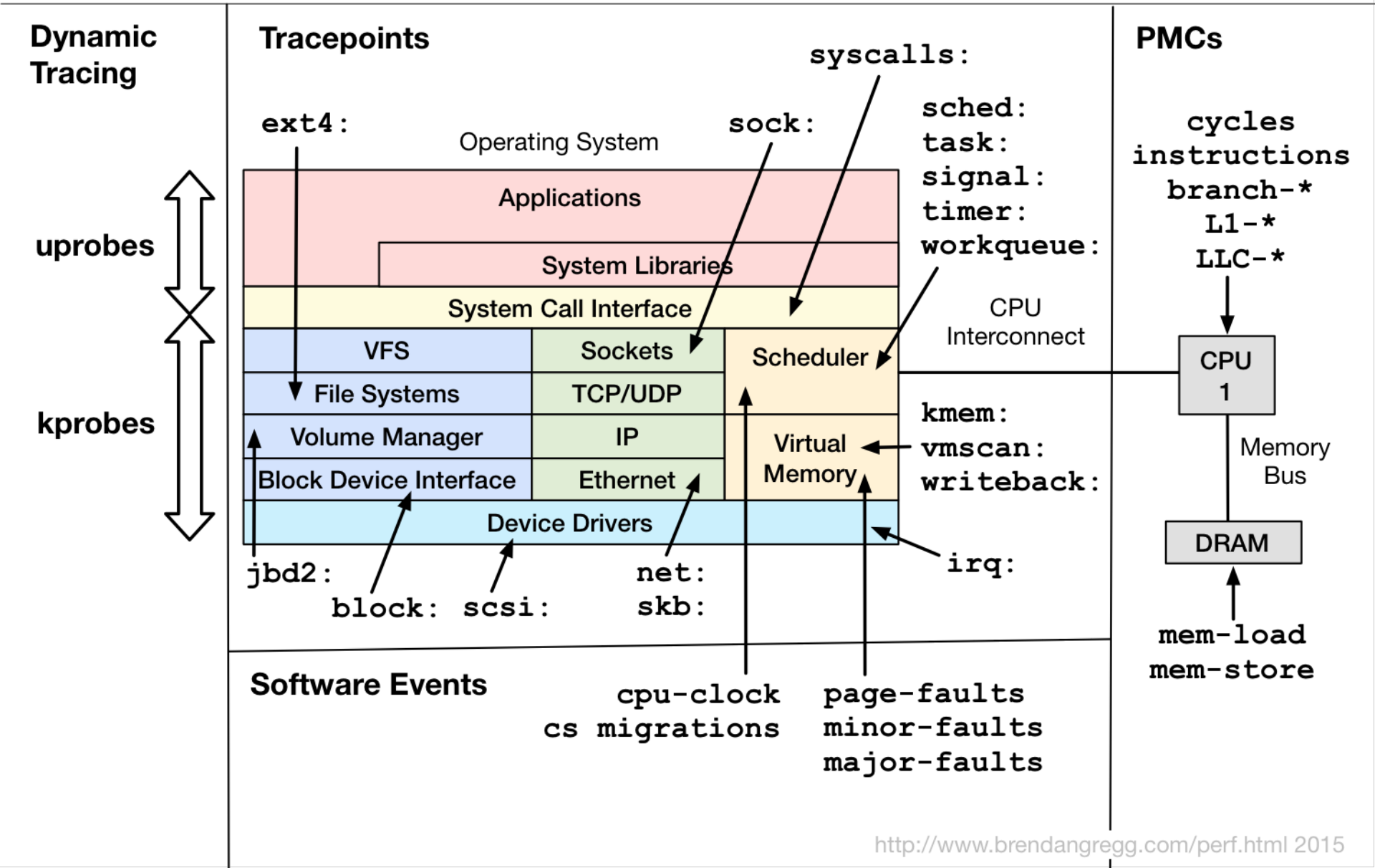
Full System Coverage



… Without Running All These



Deep System Coverage

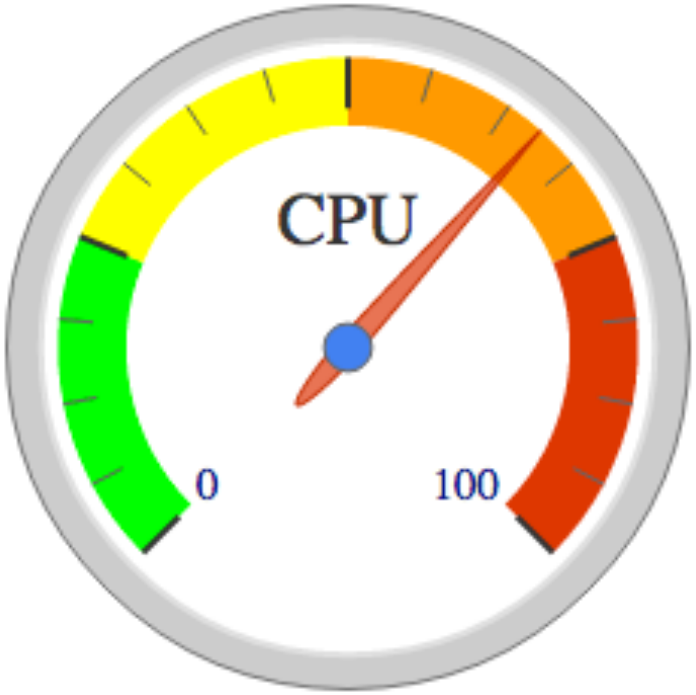


Other Desirables

- Safe for production use
- Easy to use: self service
- [Near] Real Time
- Ad hoc / custom instrumentation
- Complete documentation
- Graph labels and units
- Open source
- Community

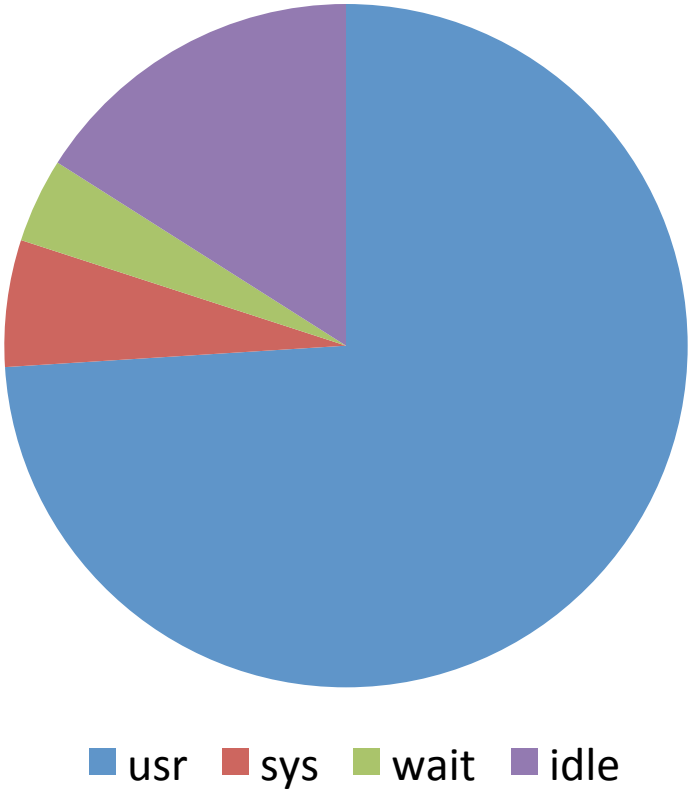
2. Undesirables

Tachometers



…especially with arbitrary color highlighting

Pie Charts

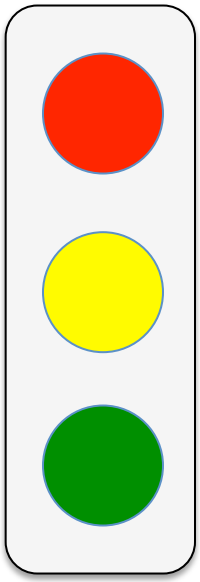


…for real-time metrics

Doughnuts

…like pie charts but worse

Traffic Lights



RED == BAD (usually)

GREEN == GOOD (hopefully)

…when used for *subjective* metrics

These can be used for *objective* metrics

For subjective metrics (eg, IOPS/latency) try weather icons instead

3. Requirements

Acceptable T&Cs

- Probably acceptable:

> XXX, Inc. shall have a royalty-free, worldwide, transferable, and perpetual license to use or incorporate into the Service any suggestions, ideas, enhancement requests, feedback, or other information provided by you or any Authorized User relating to the Service.

- Probably **not** acceptable:

> By submitting any Ideas, Customer and Authorized Users agree that: ... (iii) all right, title and interest in and to the Ideas, including all associated IP Rights, shall be, and hereby are, **assigned** to [us]

- Check with your legal team

Acceptable Technical Debt

- It must be worth the …
  - Extra complexity when debugging
  - Time to explain to others
  - Production reliability risk
  - Security risk
- There is no such thing as a free trial

Known Overhead

- Overhead must be known to be managed
  - T&Cs should not prohibit its measurement or publication
- Sources of overhead:
  - CPU cycles
  - File system I/O
  - Network I/O
  - Installed software size
- We will measure it

Low Overhead

- Overhead should also be the lowest possible
  - 1% CPU overhead means 1% more instances, and $$$
- Things we try to avoid
  - Tracing every function/method call
  - Needless kernel/user data transfers
  - strace (ptrace), tcpdump, libpcap, …
- Event logging doesn't scale

Scalable

- Can the product scale to (say) 100,000 instances?
  - Atlas, our cloud-wide analysis tool, can
  - We tend to kill other monitoring tools that attempt this
- Real-time dashboards showing all instances:
  - How does that work? Can it scale to 1k? … 100k?
  - Adrian Cockcroft's spigo can simulate protocols at scale
- High overhead might be worth it: on-demand only

Useful

An instance analysis solution must provide

actionable information

that helps us improve performance

4. Methodologies

Methodologies

Methodologies pose the questions
for metrics to answer

Good monitoring/analysis tools should support
performance analysis methodologies

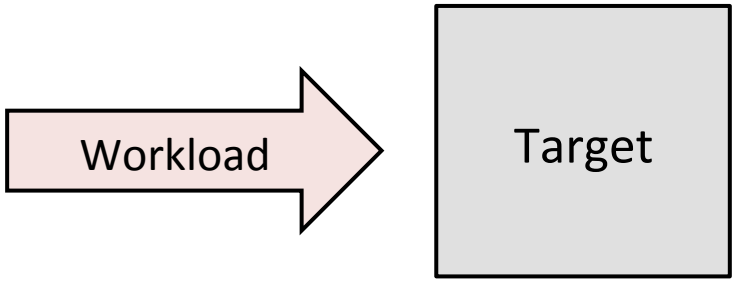
Drunk Man *Anti*-Method

- Tune things at random until the problem goes away

Workload Characterization

Study the workload applied:

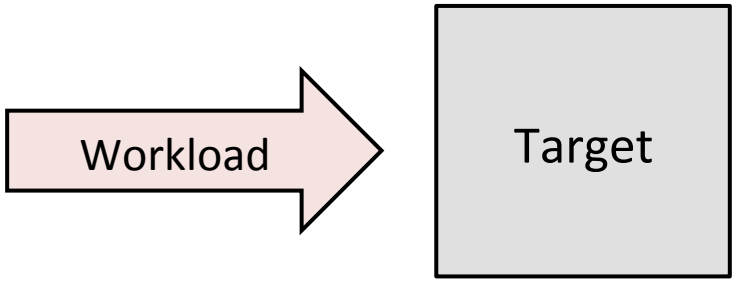
1. **Who**
2. **Why**
3. **What**
4. **How**



Workload Characterization

Eg, for CPUs:

1. **Who**: which PIDs, programs, users
2. **Why**: code paths, context
3. **What**: CPU instructions, cycles
4. **How**: changing over time

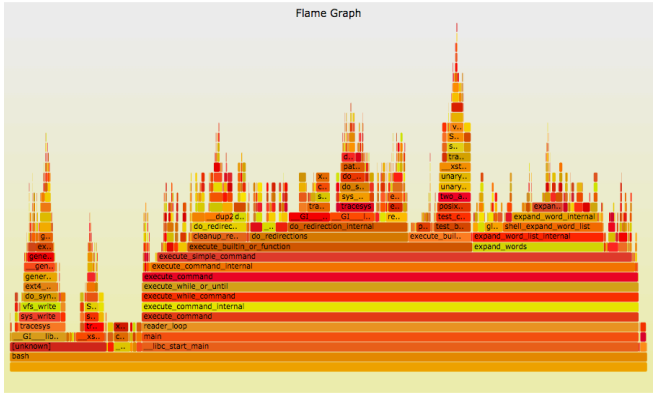


CPUs

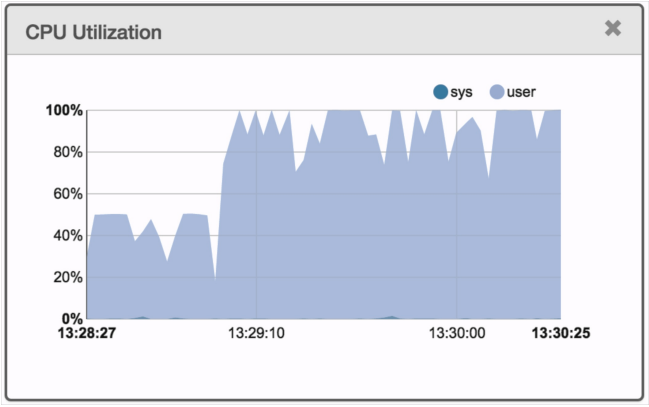
Who

```
  PID USER      VIRT   RES CPU% MEM%   TIME+  Command
27983 root      3233M  204M 147.  2.7  2:10.50 /usr/lib/jvm/java-
28004 root      3233M  204M 144.  2.7  2:02.60 /usr/lib/jvm/java-
28173 root     63488  4992 95.0  0.1  0:02.68 ab -k -c 100 -n 1
28170 root     24660  2176  3.0  0.0  0:00.62 htop
 2730 bgregg-te  202M 58668  0.0  0.8 2h31:25 /apps/epic/perl/b
 2752 bgregg-te  151M 10308  0.0  0.1 1h48:36 postgres: bgregg-
28000 root      3233M  204M  0.0  2.7  0:00.26 /usr/lib/jvm/java-
    1 root     24320  2256  0.0  0.0  0:01.29 /sbin/init
  341 root     17236   632  0.0  0.0  0:00.04 upstart-udev-brid
  346 root     21600  1304  0.0  0.0  0:00.06 /sbin/udevd --dae
  357 messagebu 23944  1164  0.0  0.0  0:00.21 dbus-daemon --sys
  408 root     21464   792  0.0  0.0  0:00.00 /sbin/udevd --dae
  549 root     15192   392  0.0  0.0  0:00.00 upstart-socket-br
  612 root      7268  1028  0.0  0.0  0:00.24 dhclient3 -e IF_M
  644 root     50036  2920  0.0  0.0  0:00.06 /usr/sbin/sshd -D
  772 root     14508   956  0.0  0.0  0:00.00 /sbin/getty -8 38
  777 root     14508   952  0.0  0.0  0:00.00 /sbin/getty -8 38
  785 root     14508   952  0.0  0.0  0:00.00 /sbin/getty -8 38
```

Why



How

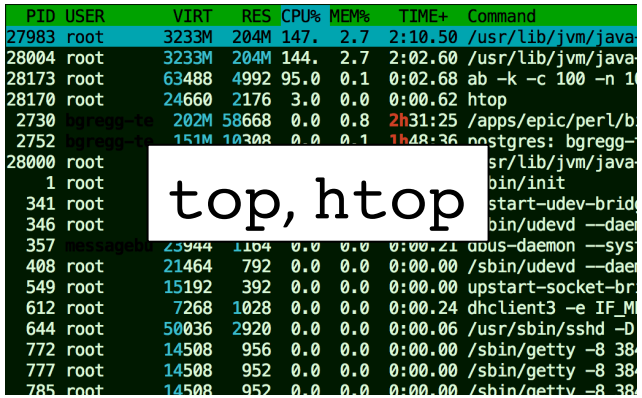


What

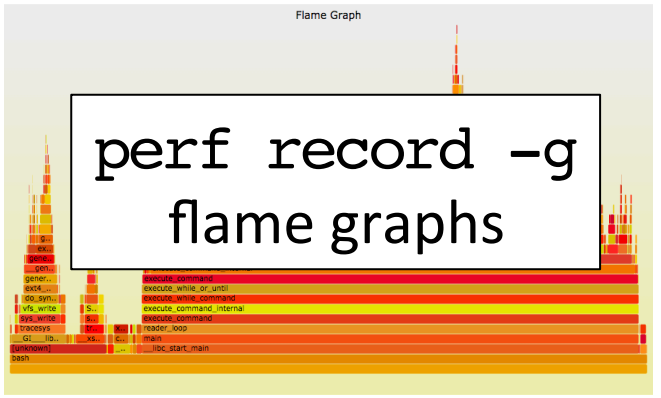
```
root@lgud-bgregg:~# perf stat -a -d sleep 10

 Performance counter stats for 'system wide':

     39996.388668 task-clock (msec)         #    3.999 CPUs ut
        1,026,540 context-switches          #    0.026 M/sec
          193,563 cpu-migrations            #    0.005 M/sec
            4,835 page-faults               #    0.121 K/sec
   83,859,543,001 cycles                    #    2.097 GHz
   61,028,919,136 stalled-cycles-frontend   #   72.78% fronten
   50,812,852,642 stalled-cycles-backend    #   60.59% backend
   52,969,864,055 instructions              #    0.63  insns p
                                            #    1.15  stalled
   10,223,584,755 branches                  #  255.613 M/sec
      376,529,869 branch-misses             #    3.68% of all
                0 L1-dcache-loads           #    0.000 K/sec
    1,339,950,792 L1-dcache-load-misses     #    0.00% of all
      762,761,193 LLC-loads                 #   19.071 M/sec
```

CPUs

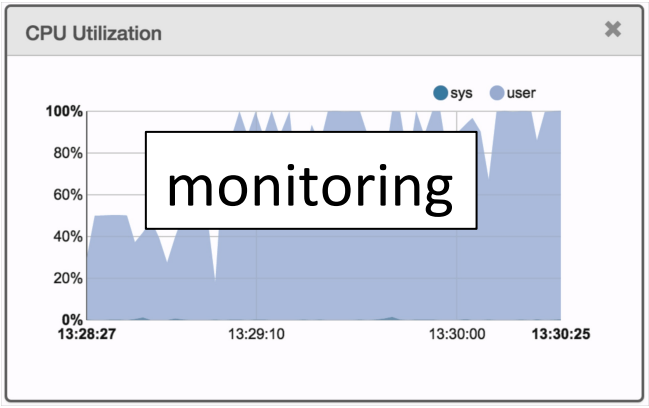
Who



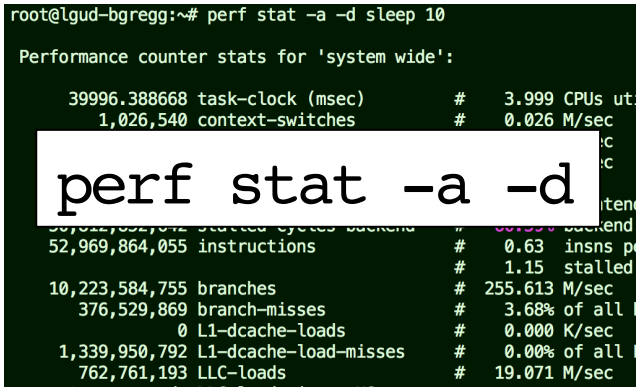
Why



How

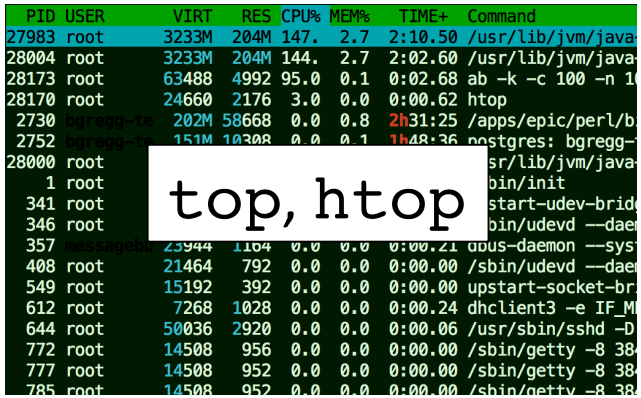


What

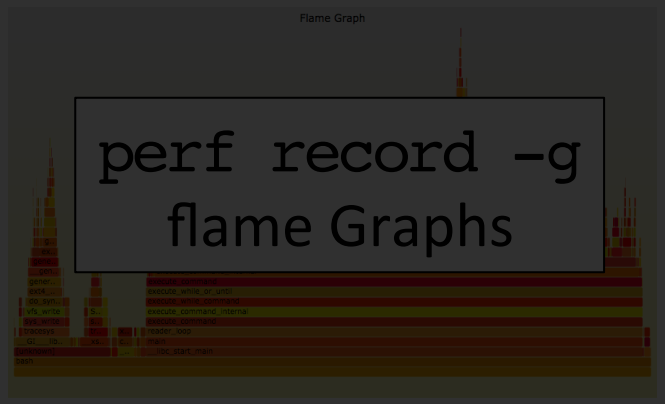


Most Monitoring Products Today

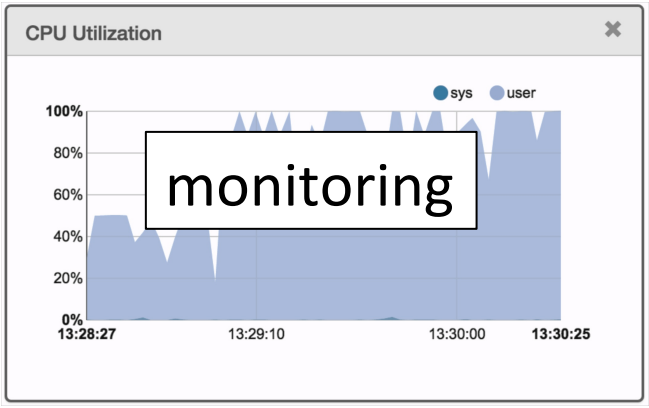
Who



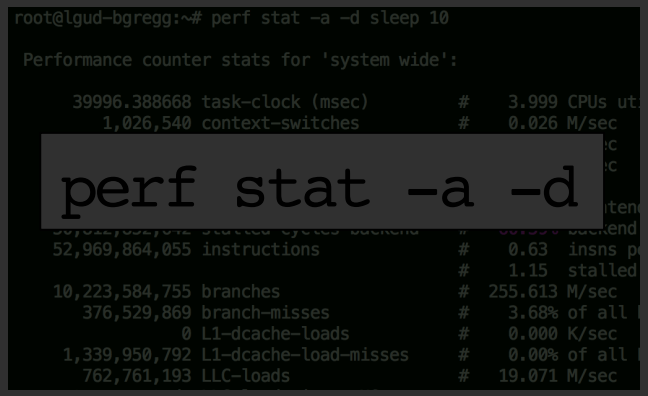
Why



How

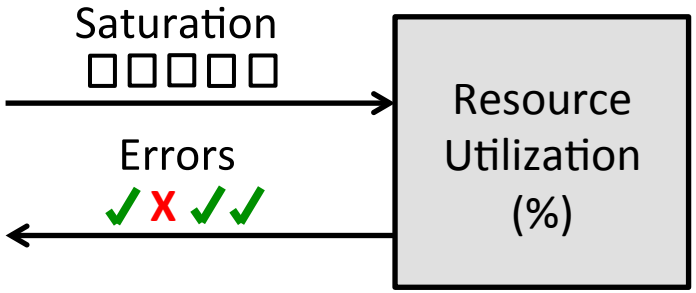


What



The USE Method

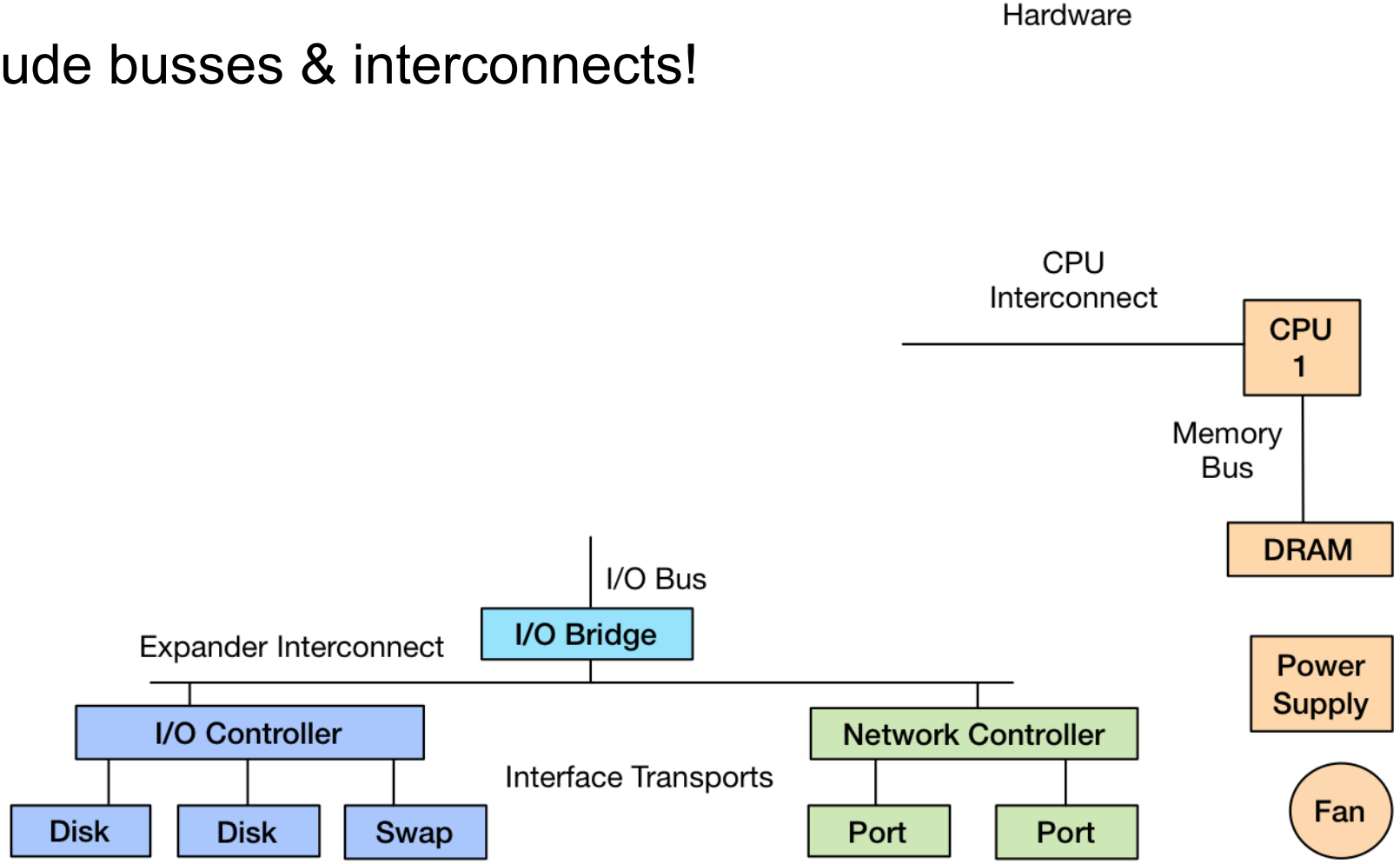
- For every resource, check:
  1. **Utilization**
  2. **Saturation**
  3. **Errors**



- Saturation is queue length or queued time
- Start by drawing a functional (block) diagram of your system / software / environment

USE Method for Hardware

Include busses & interconnects!



USE Method: Linux Performance Checklist

The USE Method provides a strategy for performing a complete check of system health, identifying common bottlenecks and errors. For each system resource, metrics for utilization, saturation and errors are identified and checked. Any issues discovered are then investigated using further strategies.

This is an example USE-based metric list for Linux operating systems (eg, Ubuntu, CentOS, Fedora). This is primarily intended for system administrators of the physical systems, who are using command line tools. Some of these metrics can be found in remote monitoring tools.

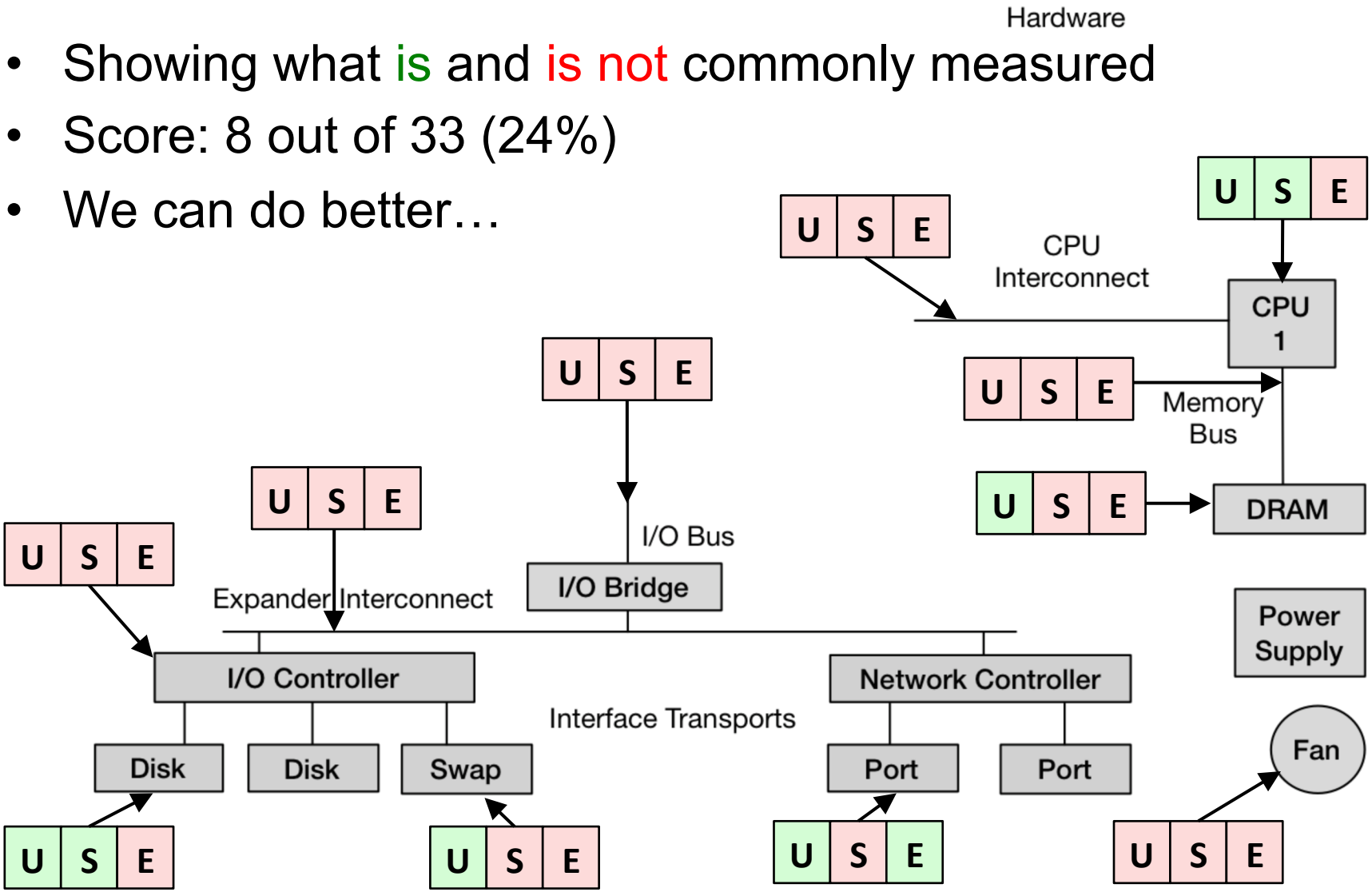
Physical Resources

http://www.brendangregg.com/USEmethod/use-linux.html

component	type	metric
CPU	utilization	system-wide: `vmstat 1`, "us" + "sy" + "st"; `sar -u`, sum fields except "%idle" and "%iowait"; `dstat -c`, sum fields except "idl" and "wai"; per-cpu: `mpstat -P ALL 1`, sum fields except "%idle" and "%iowait"; `sar -P ALL`, same as `mpstat`; per-process: `top`, "%CPU"; `htop`, "CPU%"; `ps -o pcpu`; `pidstat 1`, "%CPU"; per-kernel-thread: `top`/`htop` ("K" to toggle), where VIRT == 0 (heuristic). [1]
CPU	saturation	system-wide: `vmstat 1`, "r" > CPU count [2]; `sar -q`, "runq-sz" > CPU count; `dstat -p`, "run" > CPU count; per-process: /proc/PID/schedstat 2nd field (sched_info.run_delay); `perf sched latency` (shows "Average" and "Maximum" delay per-schedule); dynamic tracing, eg, SystemTap schedtimes.stp "queued(us)" [3]
CPU	errors	`perf` (LPE) if processor specific error events (CPC) are available; eg, AMD64's "04Ah Single-bit ECC Errors Recorded by Scrubber" [4]
Memory capacity	utilization	system-wide: `free -m`, "Mem:" (main memory), "Swap:" (virtual memory); `vmstat 1`, "free" (main memory), "swap" (virtual memory); `sar -r`, "%memused"; `dstat -m`, "free"; `slabtop -s c` for kmem slab usage; per-process: `top`/`htop`, "RES" (resident main memory), "VIRT" (virtual memory), "Mem" for system-wide summary
Memory capacity	saturation	system-wide: `vmstat 1`, "si"/"so" (swapping); `sar -B`, "pgscank" + "pgscand" (scanning); `sar -W`; per-process: 10th field (min_flt) from /proc/PID/stat for minor-fault rate, or dynamic tracing [5]; OOM killer: `dmesg | grep killed`
Memory capacity	errors	`dmesg` for physical failures; dynamic tracing, eg, SystemTap uprobes for failed malloc()s
Network Interfaces	utilization	`sar -n DEV 1`, "rxKB/s"/max "txKB/s"/max; `ip -s link`, RX/TX tput / max bandwidth; /proc/net/dev, "bytes" RX/TX tput/max; nicstat "%Util" [6]
Network Interfaces	saturation	`ifconfig`, "overruns", "dropped"; `netstat -s`, "segments retransmited"; `sar -n EDEV`, *drop and *fifo metrics; /proc/net/dev, RX/TX "drop"; nicstat "Sat" [6]; dynamic tracing for other TCP/IP stack queueing [7]
Network Interfaces	errors	`ifconfig`, "errors", "dropped"; `netstat -i`, "RX-ERR"/"TX-ERR"; `ip -s link`, "errors"; `sar -n EDEV`, "rxerr/s" "txerr/s"; /proc/net/dev, "errs", "drop"; extra counters may be under /sys/class/net/...; dynamic tracing of driver function returns 76]

Most Monitoring Products Today

- Showing what is and is not commonly measured
- Score: 8 out of 33 (24%)
- We can do better…



Other Methodologies

- There are many more:
  - Drill-Down Analysis Method
  - Time Division Method
  - Stack Profile Method
  - Off-CPU Analysis
  - …
  - I've covered these in previous talks & books

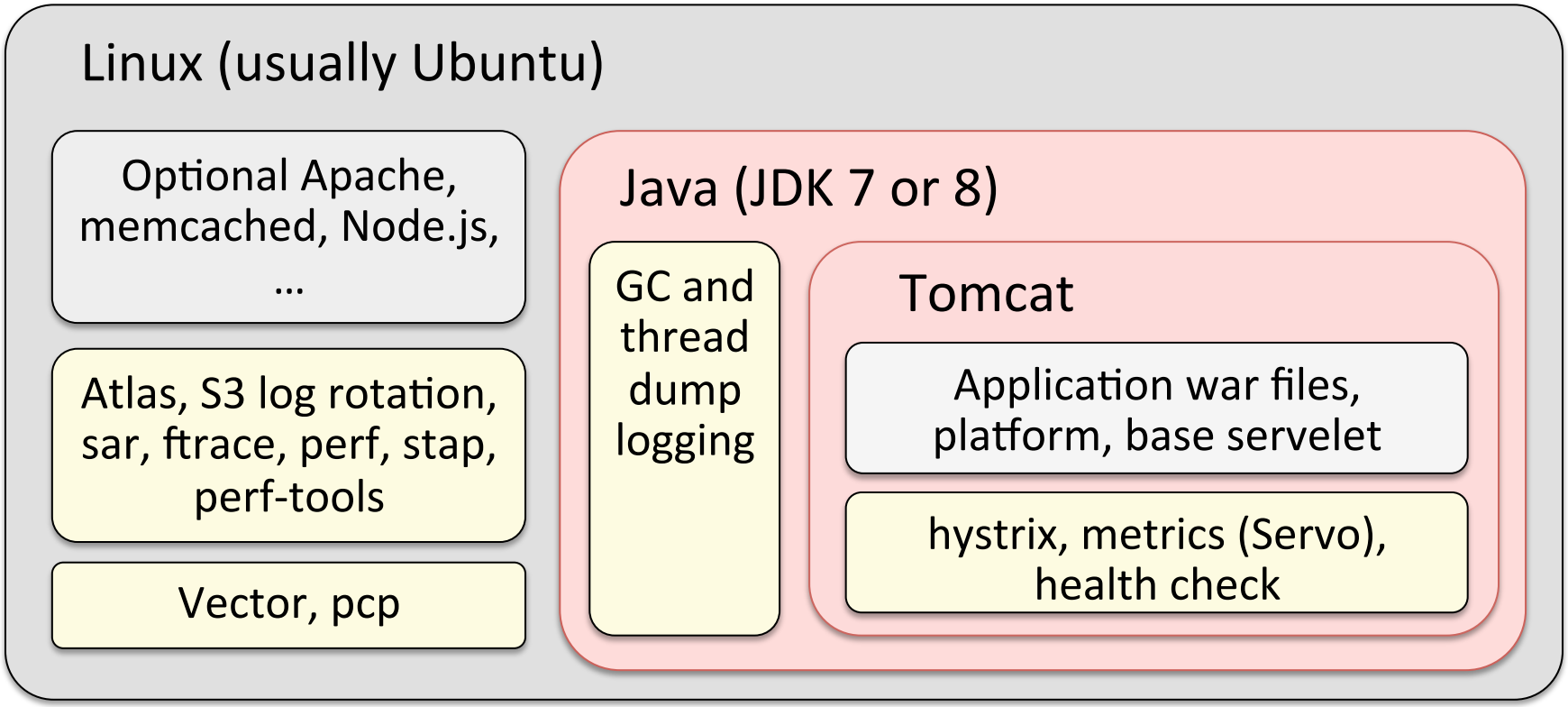
5. Our Tools

Atlas

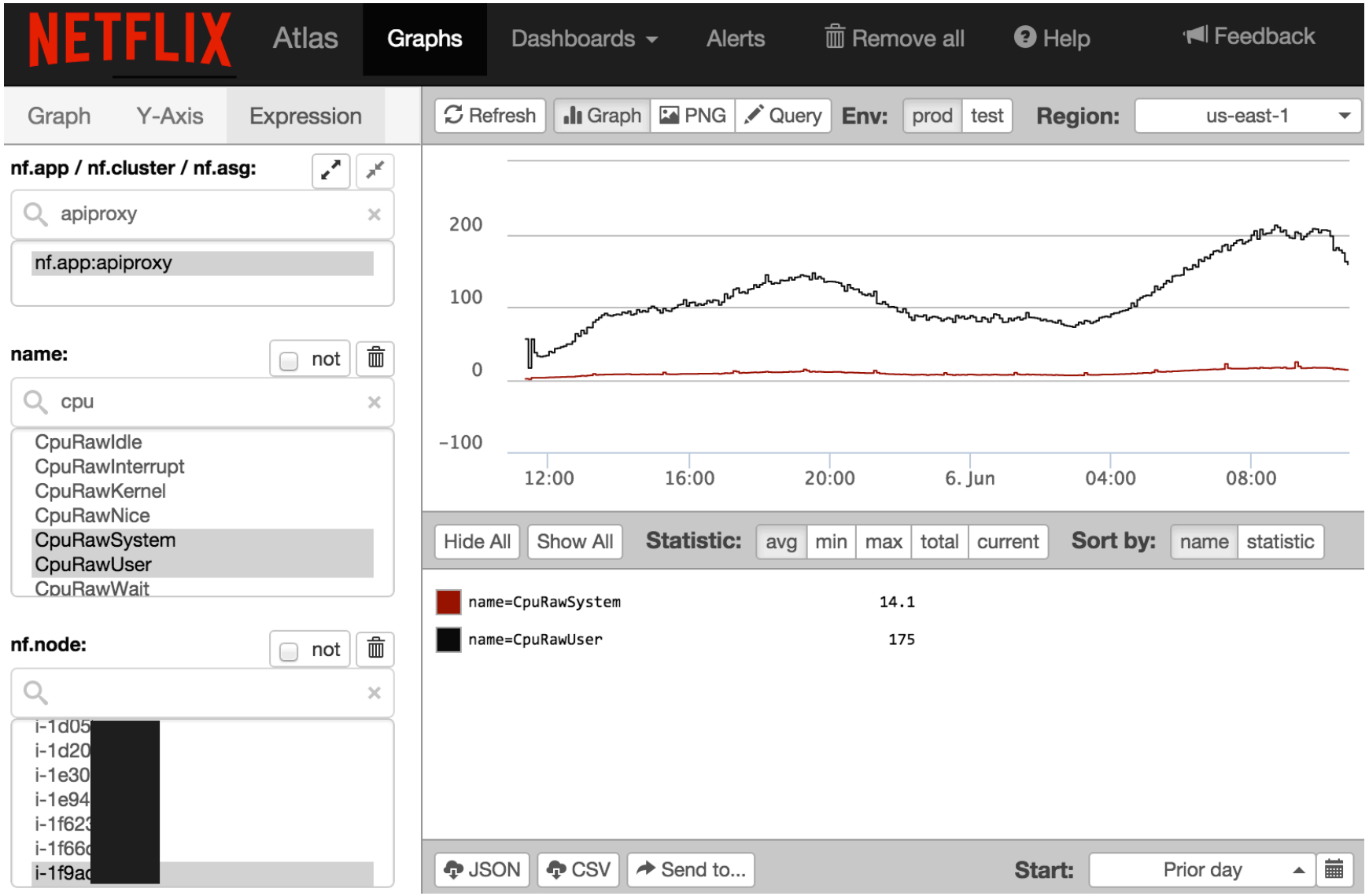
NETFLIX | OSS Netflix Open Source Software

BaseAMI

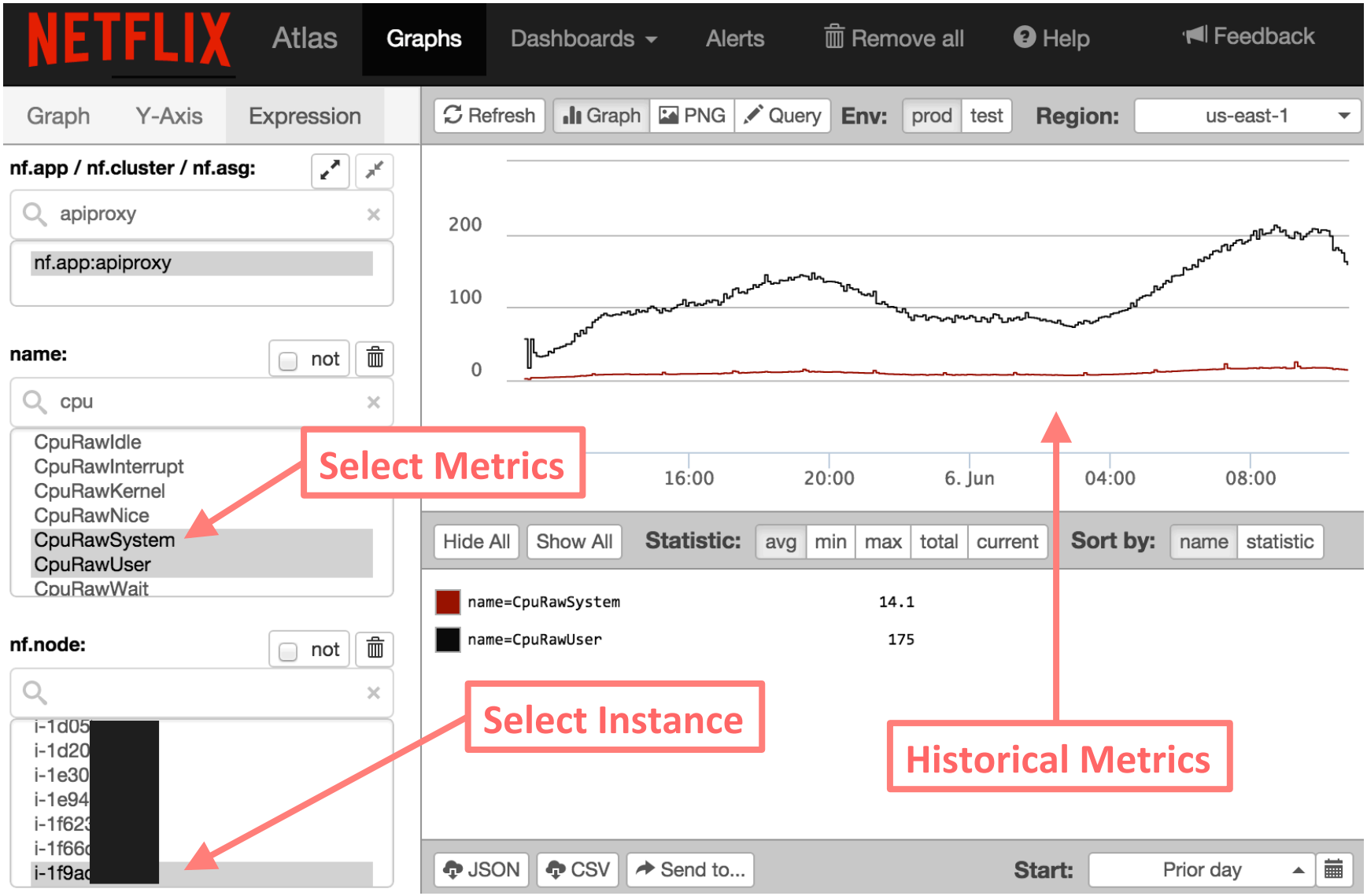
- Many sources for instance metrics & analysis
  - Atlas, Vector, sar, perf-tools (ftrace, perf_events), …
- Currently not using 3rd party monitoring vendor tools



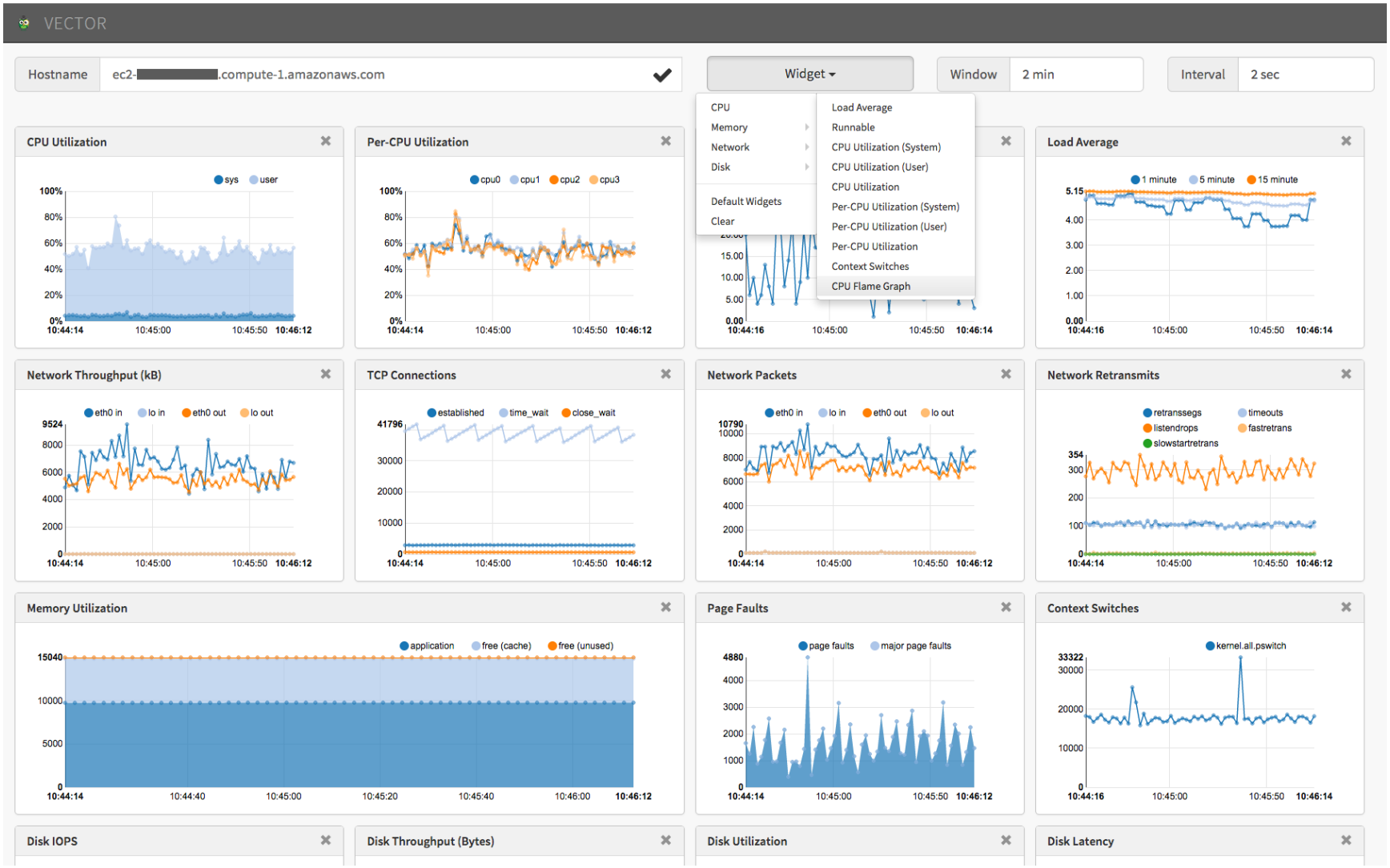
Netflix Atlas



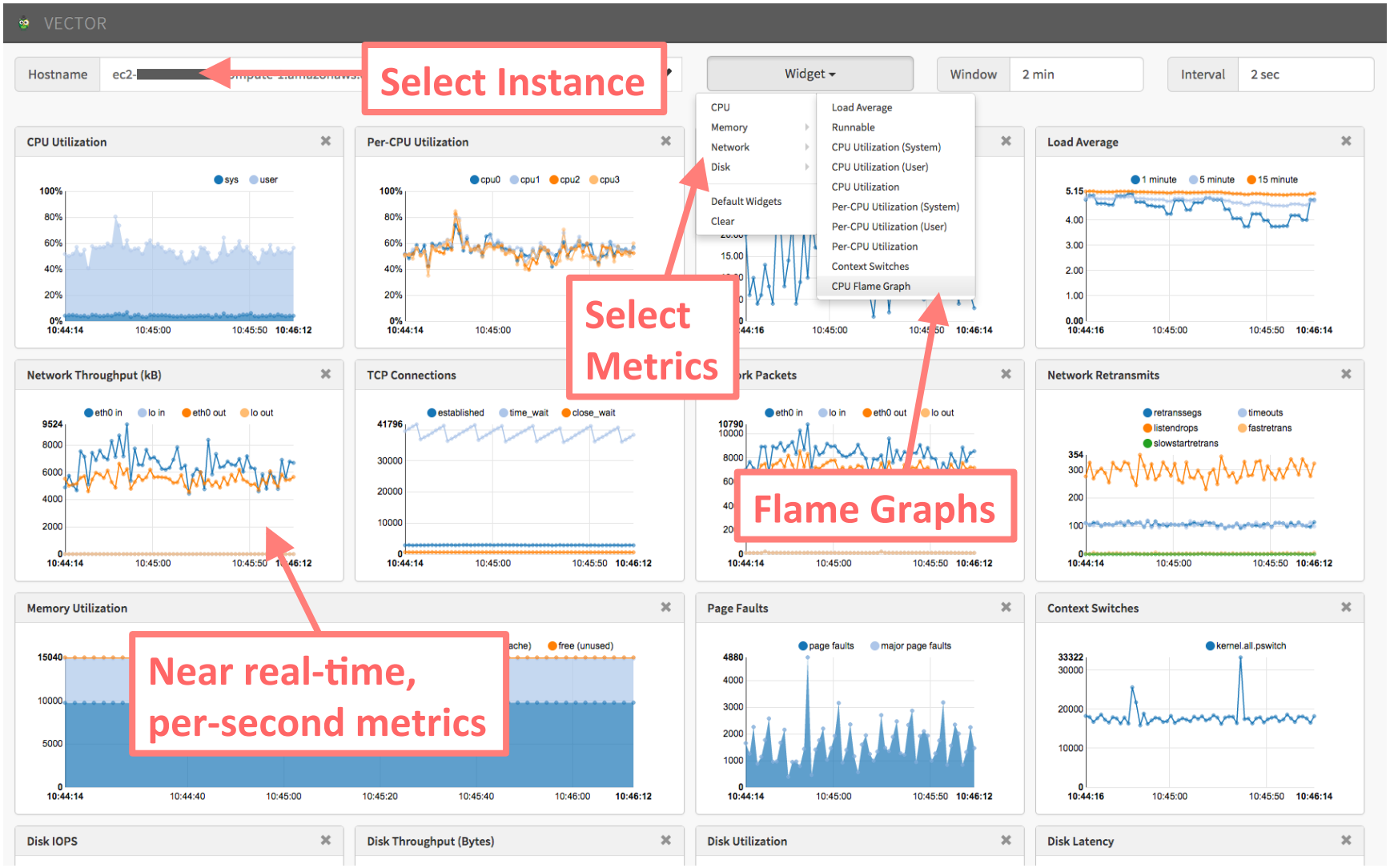
Netflix Atlas



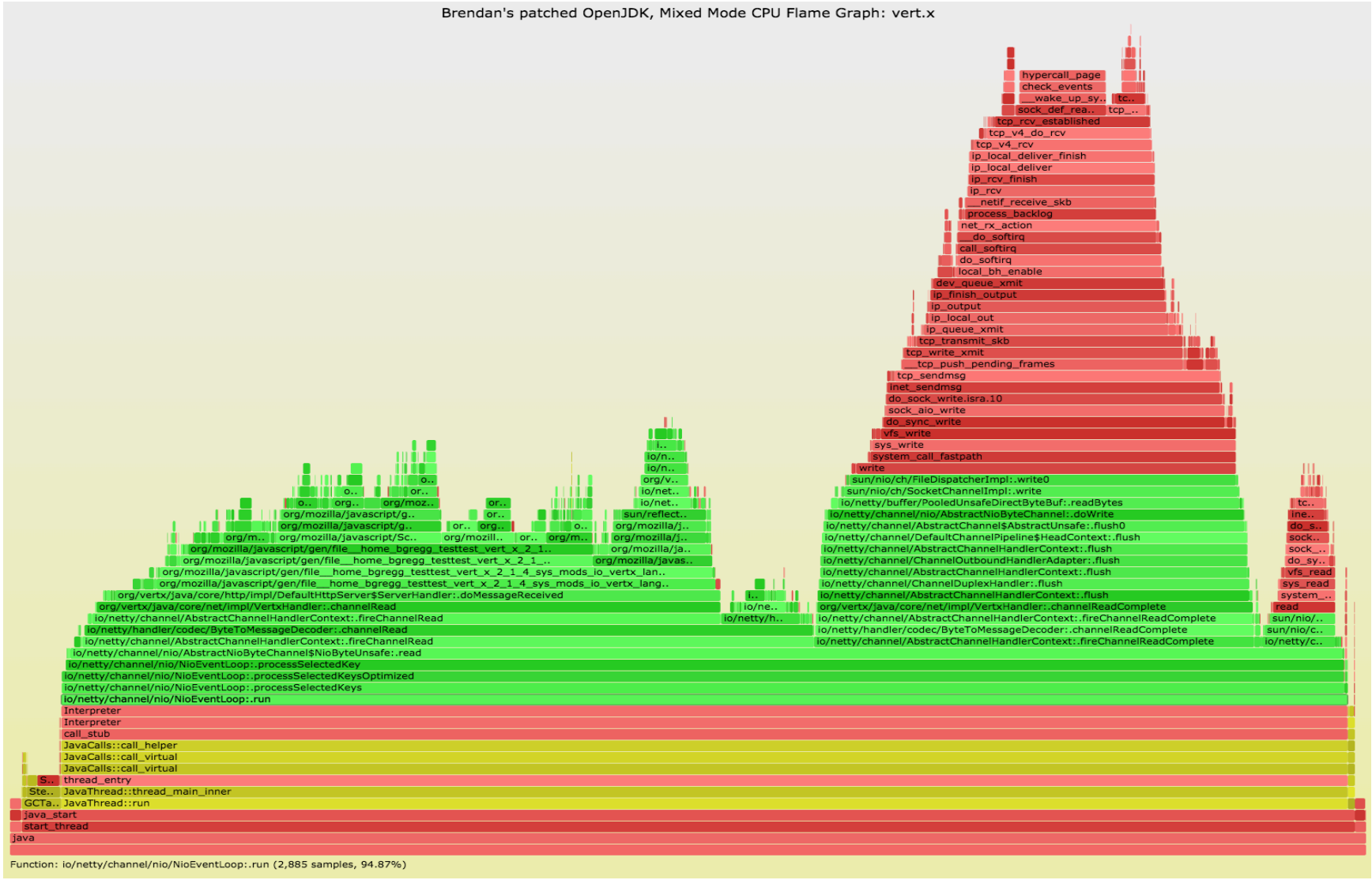
Netflix Vector



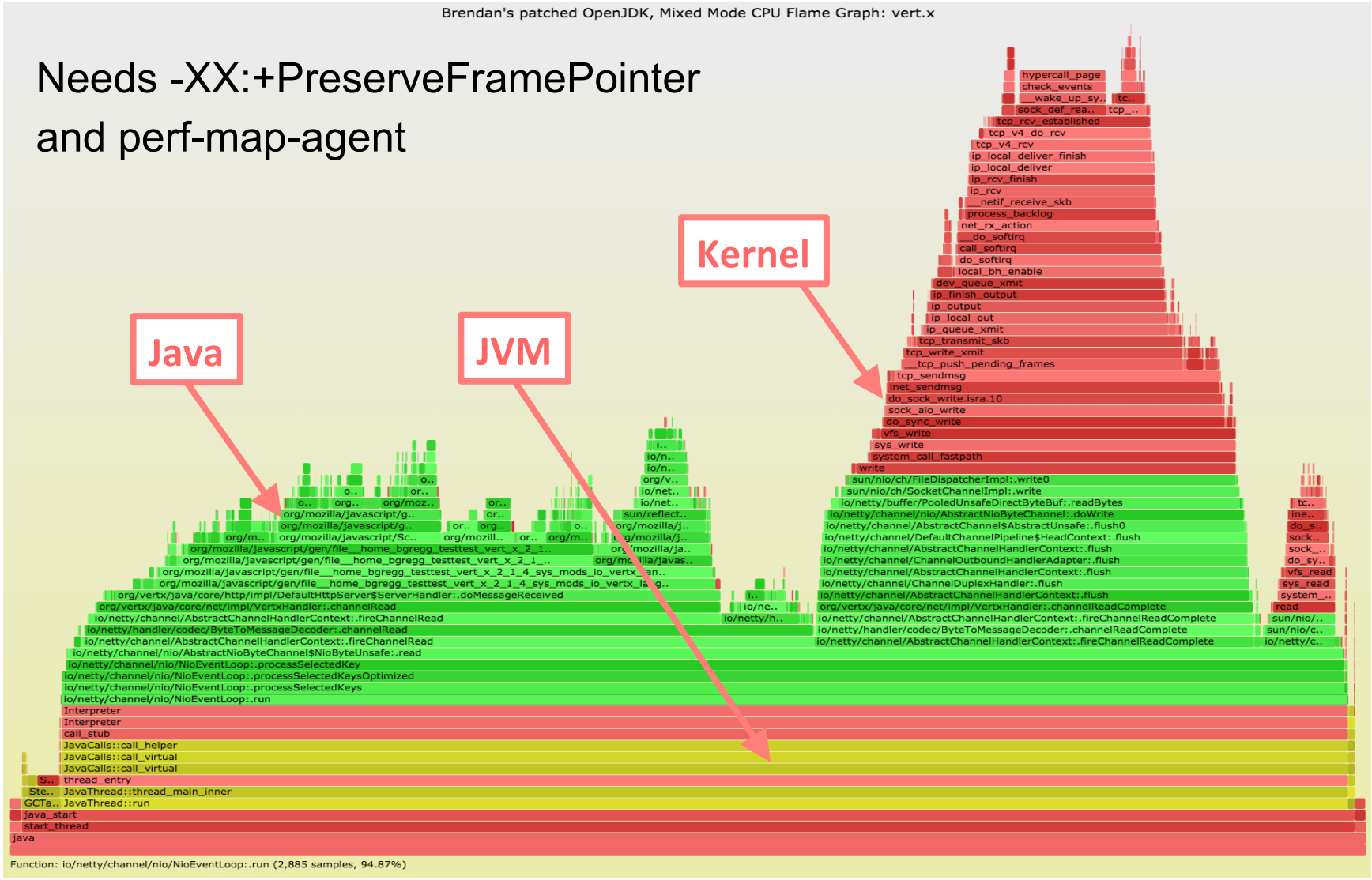
Netflix Vector



Java CPU Flame Graphs



Java CPU Flame Graphs



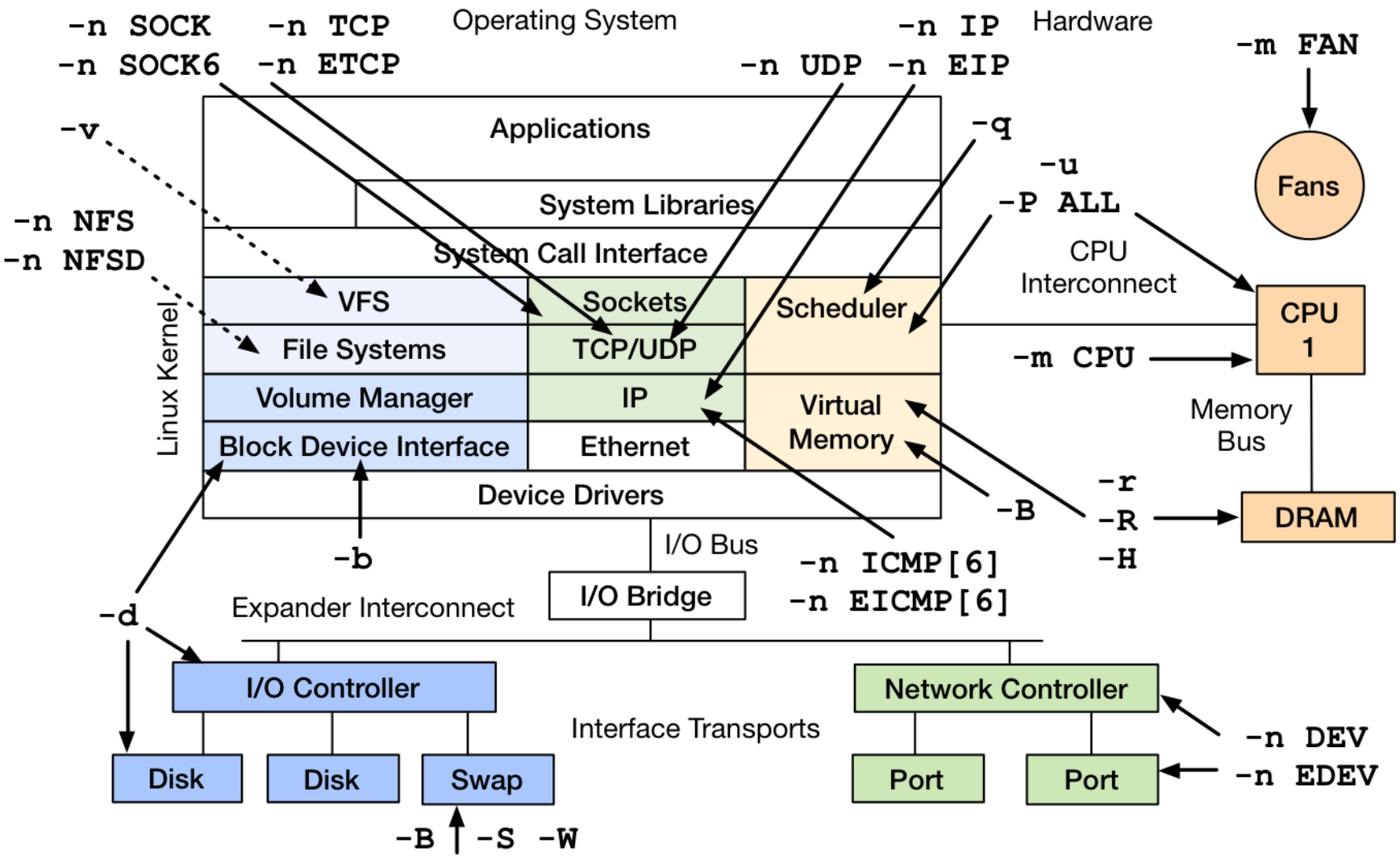
sar

- System Activity Reporter. Archive of metrics, eg:

```
$ sar -n DEV
Linux 3.13.0-49-generic (prod0141)     06/06/2015 _x86_64_    (16 CPU)

12:00:01 AM     IFACE   rxpck/s   txpck/s    rxkB/s    txkB/s  rxcmp/s  txcmp/s  rxmcst/s  %ifutil
12:05:01 AM      eth0   4824.26   3941.37    919.57  15706.14     0.00     0.00      0.00     0.00
12:05:01 AM        lo  23913.29  23913.29  17677.23  17677.23     0.00     0.00      0.00     0.00
12:15:01 AM      eth0   4507.22   3749.46    909.03  12481.74     0.00     0.00      0.00     0.00
12:15:01 AM        lo  23456.94  23456.94  14424.28  14424.28     0.00     0.00      0.00     0.00
12:25:01 AM      eth0  10372.37   9990.59   1219.22  27788.19     0.00     0.00      0.00     0.00
12:25:01 AM        lo  25725.15  25725.15  29372.20  29372.20     0.00     0.00      0.00     0.00
12:35:01 AM      eth0   4729.53   3899.14    914.74  12773.97     0.00     0.00      0.00     0.00
12:35:01 AM        lo  23943.61  23943.61  14740.62  14740.62     0.00     0.00      0.00     0.00
[…]
```

- Metrics are also in Atlas and Vector
- Linux sar is well designed: units, groups

sar Observability



perf-tools

- Some front-ends to Linux ftrace & perf_events
  - Advanced, custom kernel observability when needed (rare)
  - https://github.com/brendangregg/perf-tools
  - Unsupported hacks: see WARNINGs
- ftrace
  - First added to Linux 2.6.27
  - A collection of capabilities, used via /sys/kernel/debug/tracing/
- perf_events
  - First added to Linux 2.6.31
  - Tracer/profiler multi-tool, used via "perf" command

perf-tools: funccount

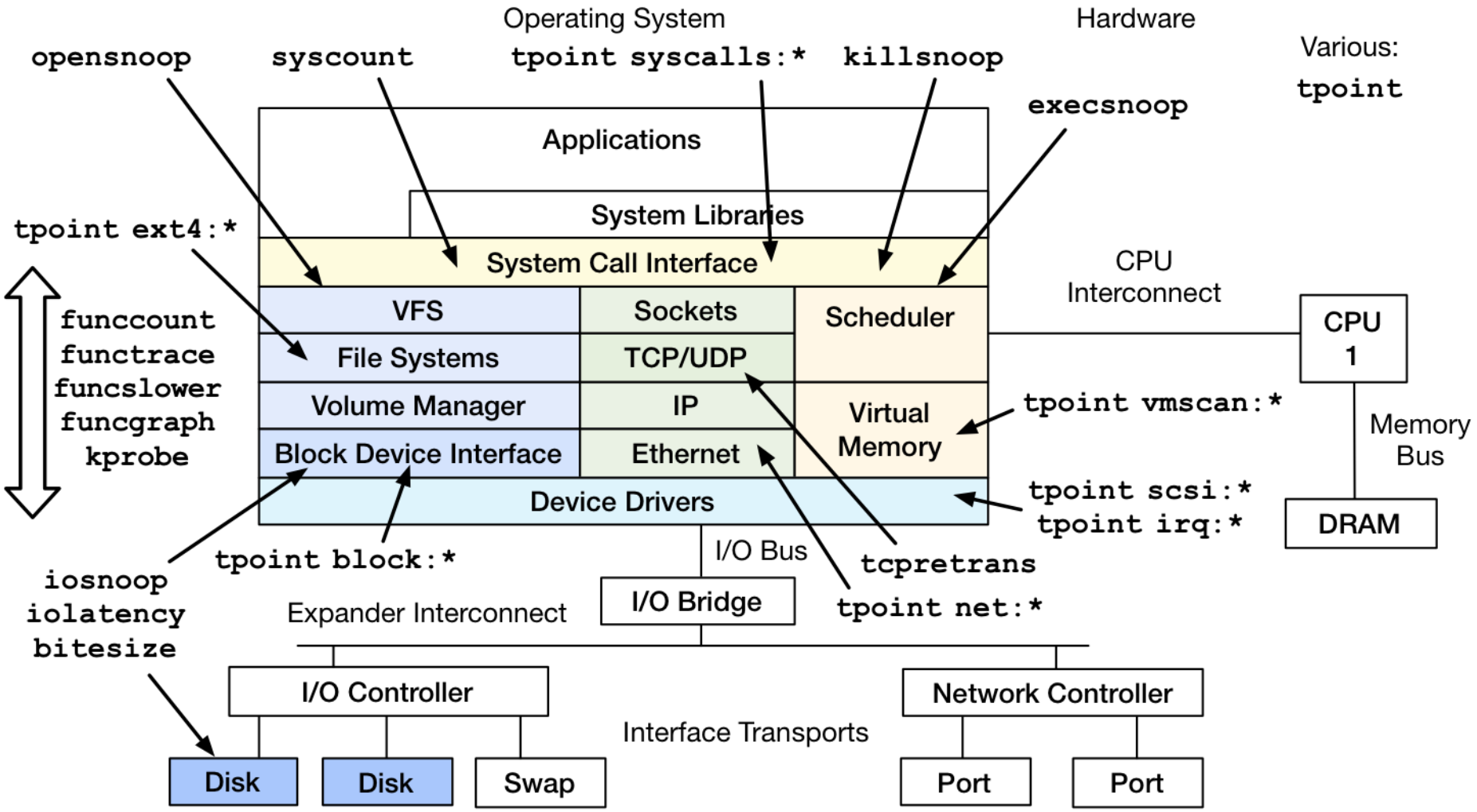
- Eg, count a kernel function call rate:

```
# ./funccount -i 1 'bio_*'
Tracing "bio_*"... Ctrl-C to end.

FUNC                                    COUNT
bio_attempt_back_merge                     26
bio_get_nr_vecs                           361
bio_alloc                                 536
bio_alloc_bioset                          536
bio_endio                                 536
bio_free                                  536
bio_fs_destructor                         536
bio_init                                  536
bio_integrity_enabled                     536
bio_put                                   729
bio_add_page                             1004

[...]
```

Counts are in-kernel, for low overhead

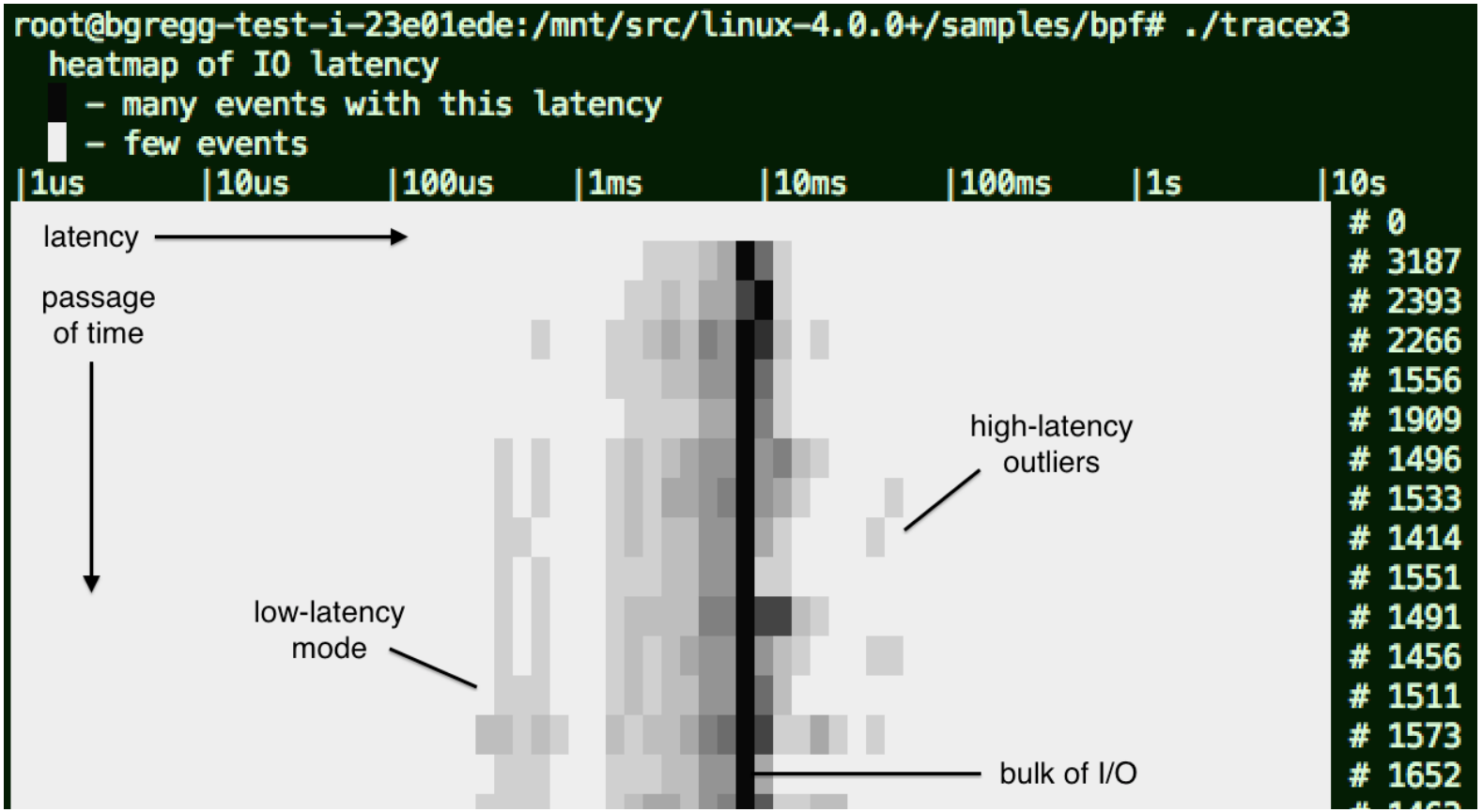
- Other perf-tools can then instrument these in more detail

perf-tools (so far…)



eBPF

- Currently being integrated. Efficient (JIT) in-kernel maps.
- Measure latency, heat maps, …



eBPF

eBPF will make a profound difference to monitoring on Linux systems

There will be an arms race to support it, post Linux 4.1+

If it's not on your roadmap, it should be

Summary

Requirements

- Acceptable T&Cs
- Acceptable technical debt
- Known overhead
- Low overhead
- Scalable
- Useful

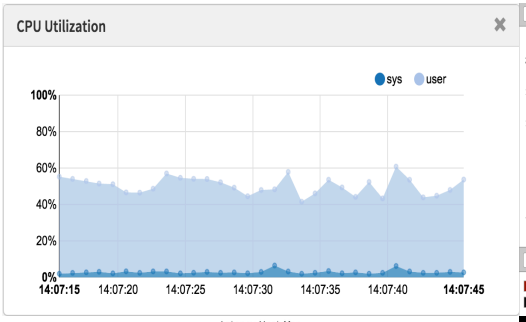
Methodologies

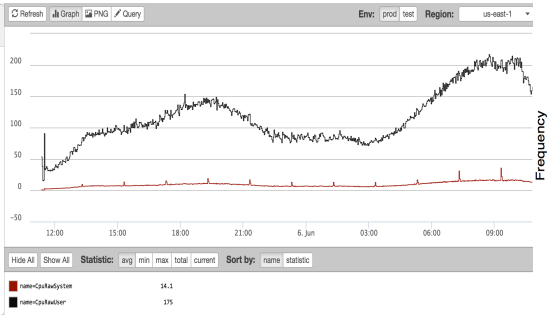
Support for:

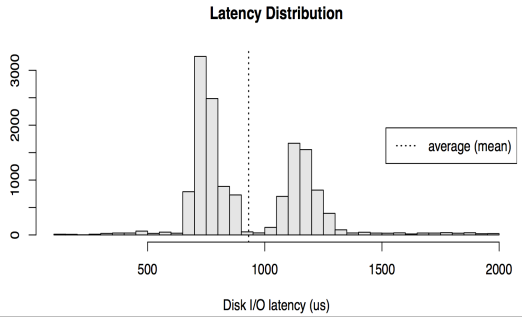
- Workload Characterization
- The USE Method
- …

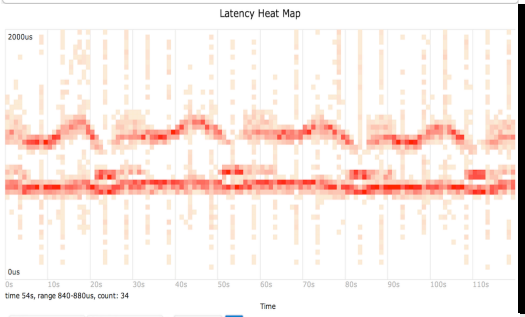
Not starting with metrics in search of uses

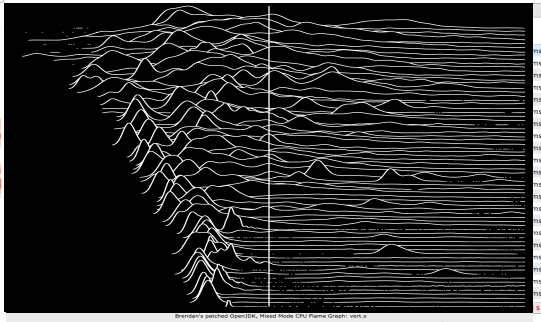
Desirables

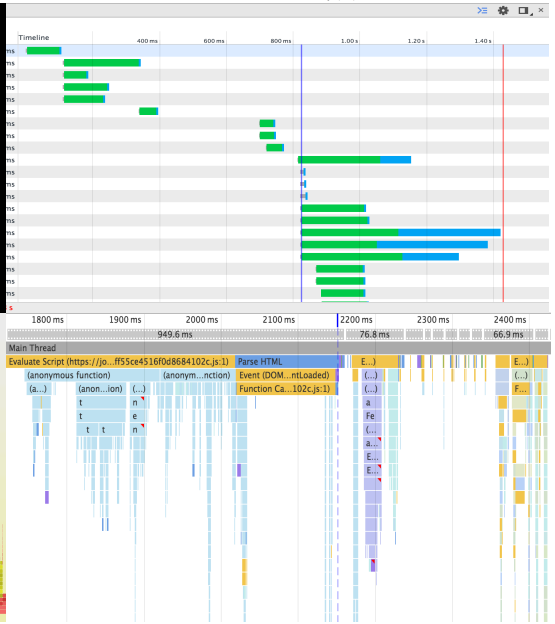

CPU Utilization
sys
user
100%
80%
60%
40%
20%
0%
14:07:15
14:07:20
14:07:25
14:07:30
14:07:35
14:07:40
14:07:45

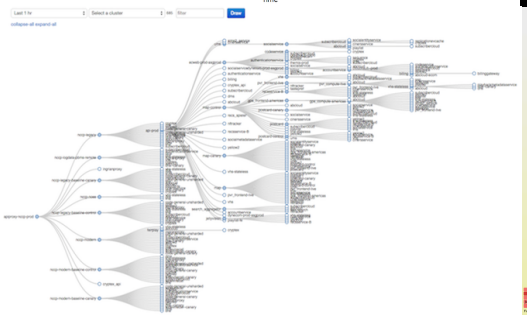

Refresh
Graph
PNG
Query
Env:
prod
test
Region:
us-east-1
Hide All
Show All
Statistic:
avg
min
max
total
current
Sort by:
name
statistic

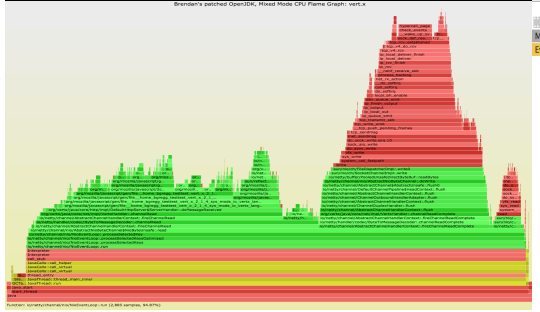

Latency Distribution
Frequency
average (mean)
Disk I/O latency (us)


Latency Heat Map
time 54s, range 840-880us, count: 34
Time

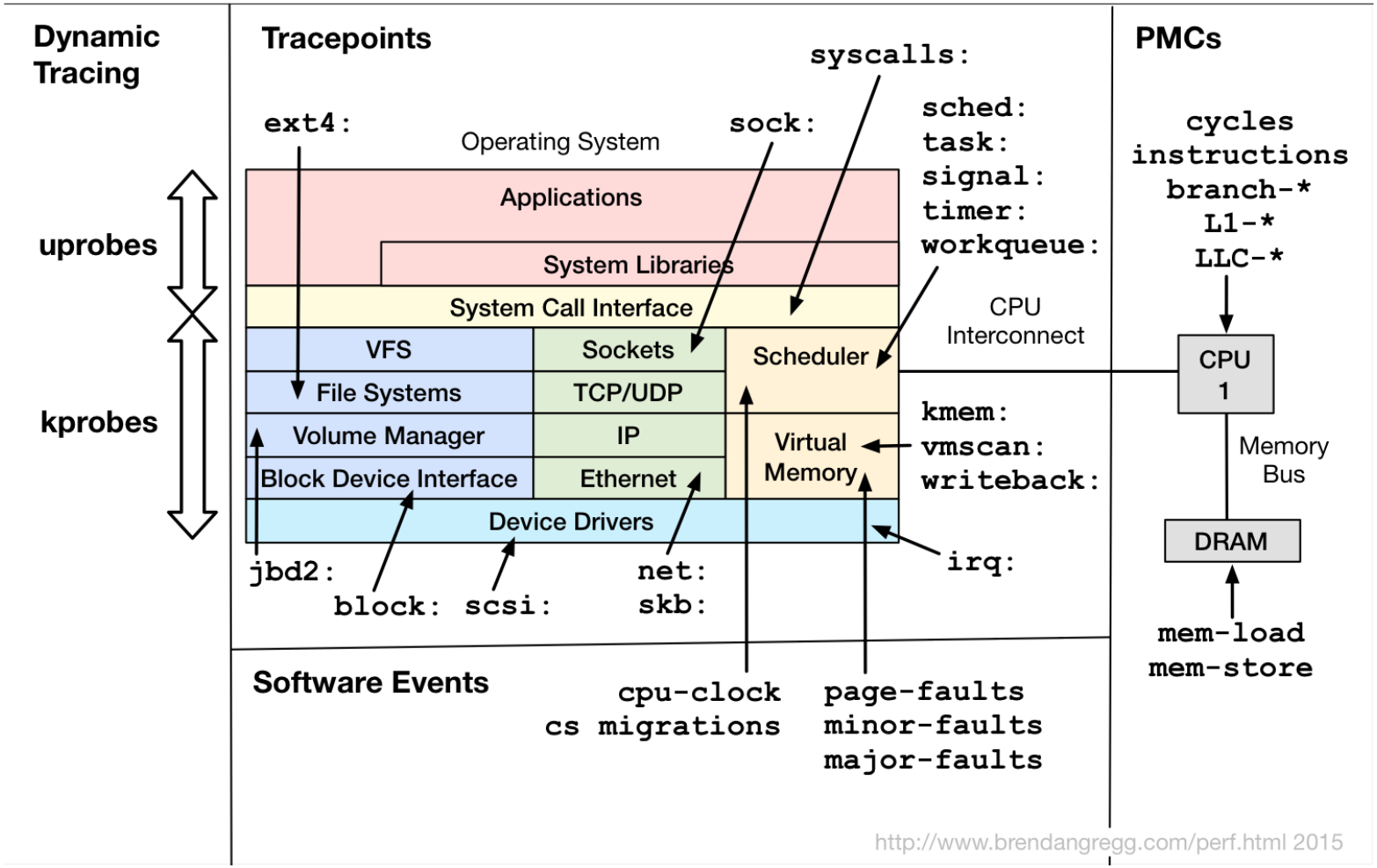



Timeline
Main Thread





Instrument These



With full eBPF support

Linux has awesome instrumentation: use it!

Links & References

- Netflix Vector
  - https://github.com/netflix/vector
  - http://techblog.netflix.com/2015/04/introducing-vector-netflixs-on-host.html
- Netflix Atlas
  - http://techblog.netflix.com/2014/12/introducing-atlas-netflixs-primary.html
- Heat Maps
  - http://www.brendangregg.com/heatmaps.html
  - http://www.brendangregg.com/HeatMaps/latency.html
- Flame Graphs
  - http://www.brendangregg.com/flamegraphs.html
  - http://techblog.netflix.com/2014/11/nodejs-in-flames.html
- Frequency Trails: http://www.brendangregg.com/frequencytrails.html
- Methodology
  - http://www.brendangregg.com/methodology.html
  - http://www.brendangregg.com/USEmethod/use-linux.html
- perf-tools: https://github.com/brendangregg/perf-tools
- eBPF: http://www.brendangregg.com/blog/2015-05-15/ebpf-one-small-step.html
- Images:
  - horse: Microsoft Powerpoint clip art
  - gauge: https://github.com/thlorenz/d3-gauge
  - eBPF ponycorn: Deirdré Straughan & General Zoi's Pony Creator

Thanks

- Questions?
- http://techblog.netflix.com
- http://slideshare.net/brendangregg
- http://www.brendangregg.com
- bgregg@netflix.com
- @brendangregg

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