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Linux Systems Performance

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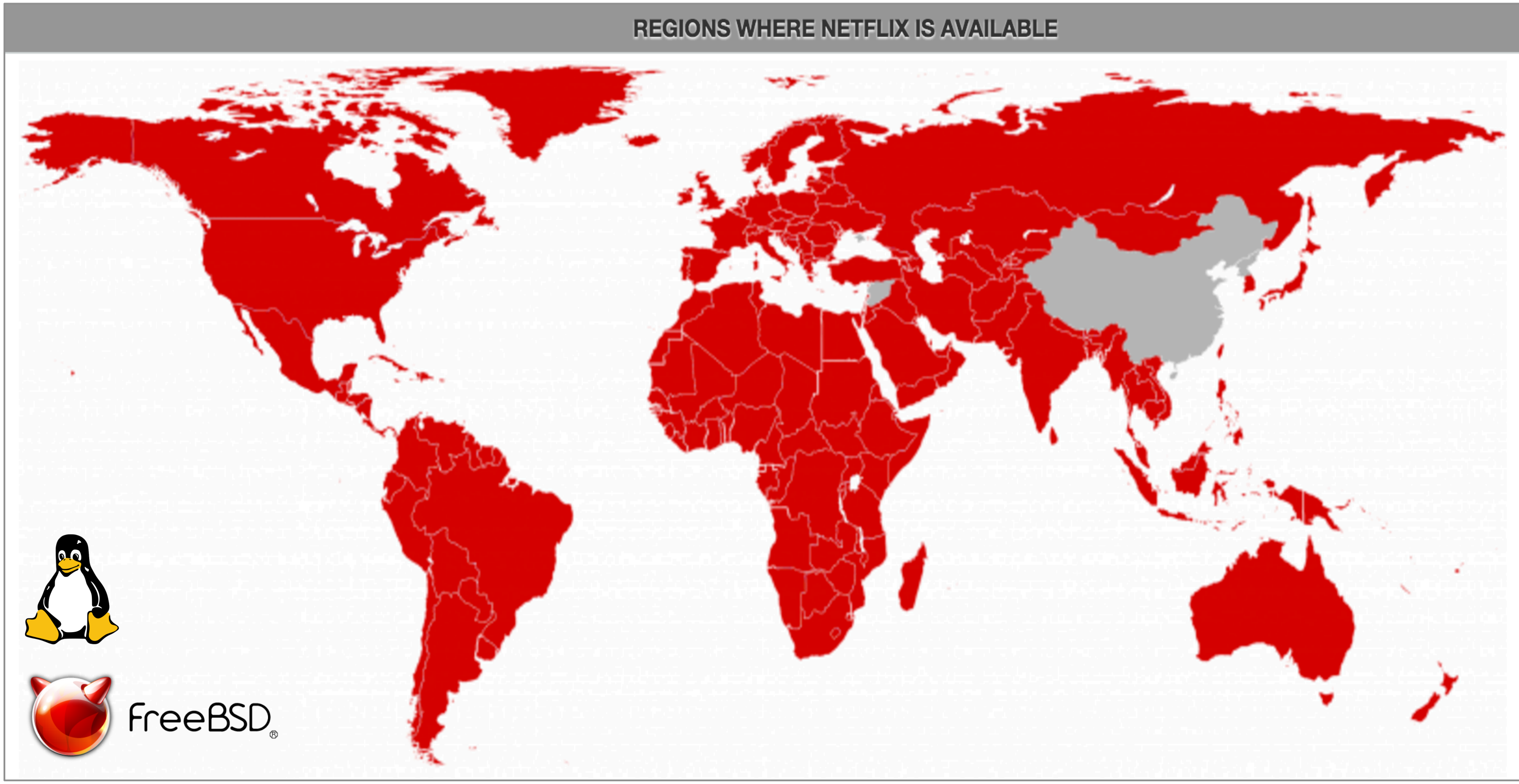
NETFLIX

Systems Performance in 50 mins

NETFLIX



Agenda

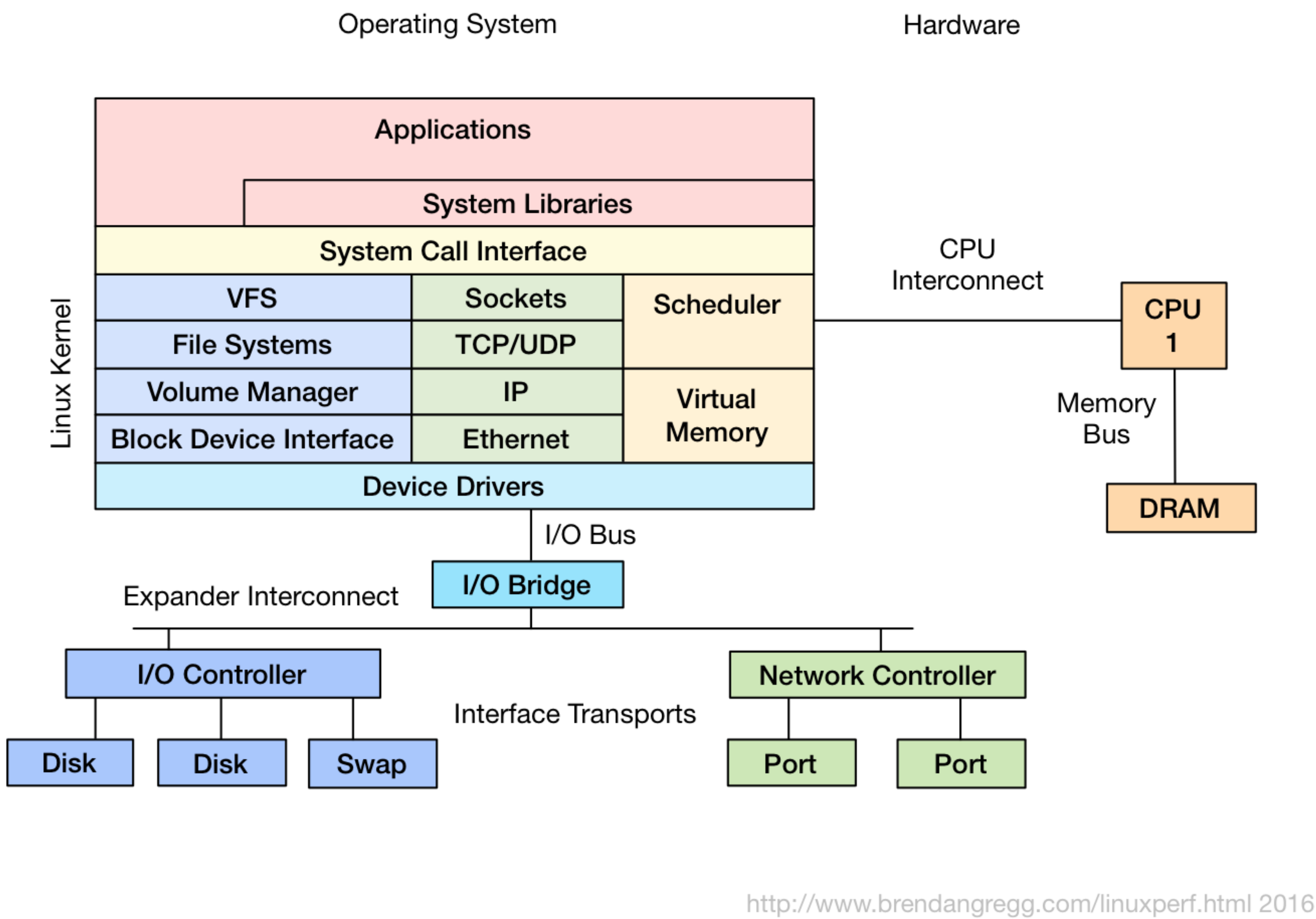
A brief discussion of 6 facets of Linux performance:

1. Observability
2. Methodologies
3. Benchmarking
4. Profiling
5. Tracing
6. Tuning

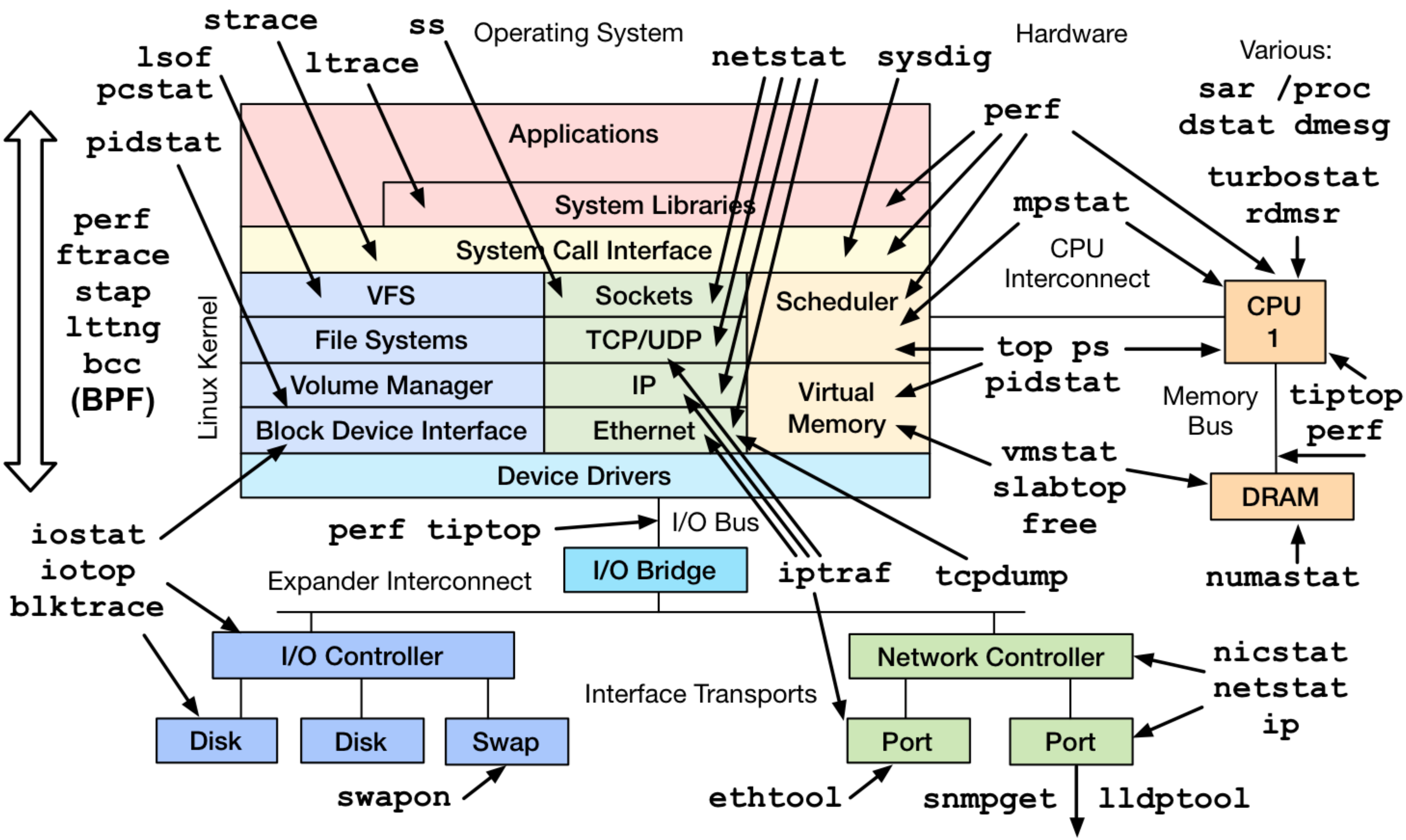
Audience: Everyone (DBAs, developers, operations, …)

1. Observability

How do you measure these?



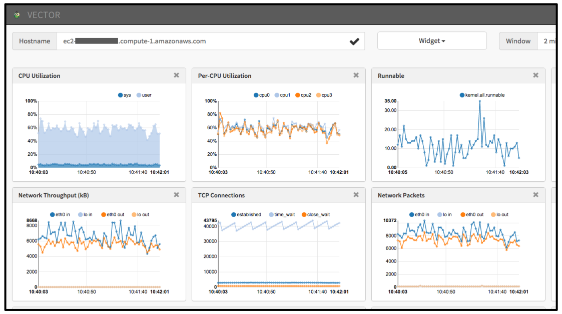
Linux Observability Tools



http://www.brendangregg.com/linuxperf.html 2016

Observability Tools

- Tools showcase common metrics
  – Learning Linux tools is useful even if you never use them: the same metrics are in GUIs
- We usually use these metrics via:
  – Netflix Atlas: cloud-wide monitoring
  – Netflix Vector: instance analysis



- Linux has many tools
  – Plus many extra kernel sources of data that lack tools, are harder to use, and are practically undocumented
- Some tool examples…

uptime

- One way to print *load averages*:

```
$ uptime
 07:42:06 up  8:16,  1 user,  load average: 2.27, 2.84, 2.91
```

- A measure of resource demand: CPUs + disks
  - Other OSes only show CPUs: easier to interpret
- Exponentially-damped moving averages
- Time constants of 1, 5, and 15 minutes
  - Historic trend without the line graph
- Load > # of CPUs, may mean CPU saturation
  - Don't spend more than 5 seconds studying these

top (or htop)

- System and per-process interval summary:

```
$ top - 18:50:26 up  7:43,  1 user,  load average: 4.11, 4.91, 5.22
Tasks: 209 total,   1 running, 206 sleeping,   0 stopped,   2 zombie
Cpu(s): 47.1%us, 4.0%sy, 0.0%ni, 48.4%id, 0.0%wa, 0.0%hi, 0.3%si, 0.2%st
Mem:  70197156k total, 44831072k used, 25366084k free,    36360k buffers
Swap:        0k total,        0k used,        0k free, 11873356k cached

  PID USER      PR  NI  VIRT  RES  SHR S %CPU %MEM    TIME+  COMMAND
 5738 apiprod   20   0 62.6g  29g 352m S  417 44.2   2144:15 java
 1386 apiprod   20   0 17452 1388  964 R    0  0.0   0:00.02 top
    1 root      20   0 24340 2272 1340 S    0  0.0   0:01.51 init
    2 root      20   0     0    0    0 S    0  0.0   0:00.00 kthreadd
[…]
```

- %CPU is summed across all CPUs
- Can miss short-lived processes (atop won't)
- Can consume noticeable CPU to read /proc

htop

```
  1  [||||||||||||||||||        53.6%]     Tasks: 75, 55 thr; 1 running
  2  [||||||||||||||||||        53.9%]     Load average: 0.80 0.26 0.12
  Mem[|||||||             489/7450MB]     Uptime: 11 days, 08:47:52
  Swp[                         0/0MB]

  PID USER      PRI  NI  VIRT   RES   SHR S CPU% MEM%   TIME+  Command
21162 root       20   0 22672  5216  1720 S 39.0  0.1  0:12.42 -bash
21542 root       20   0 24972  2608  1428 R  1.0  0.0  0:00.56 htop
 1374 snmp       20   0 48320  4628  2352 S  0.0  0.1  1:17.87 /usr/sbin/snmpd -
    1 root       20   0 24332  2260  1340 S  0.0  0.0  0:00.44 /sbin/init
  335 root       20   0 17236   640   452 S  0.0  0.0  0:00.05 upstart-udev-brid
  340 root       20   0 21596  1300   800 S  0.0  0.0  0:00.04 /sbin/udevd --dae
  368 messagebu  20   0 23820   944   640 S  0.0  0.0  0:00.04 dbus-daemon --sys
  421 root       20   0 21460   736   340 S  0.0  0.0  0:00.00 /sbin/udevd --dae
  422 root       20   0 21460   736   340 S  0.0  0.0  0:00.00 /sbin/udevd --dae
  530 root       20   0 15192   392   196 S  0.0  0.0  0:00.00 upstart-socket-br
  604 root       20   0  7268  1028   532 S  0.0  0.0  0:00.01 dhclient3 -e IF_M
  703 postfix    20   0 27176  1616  1316 S  0.0  0.0  0:00.01 pickup -l -t fifo
  770 root       20   0 14508   976   812 S  0.0  0.0  0:00.00 /sbin/getty -8 38
  775 root       20   0 14508   980   812 S  0.0  0.0  0:00.00 /sbin/getty -8 38
  780 root       20   0 14508   976   812 S  0.0  0.0  0:00.00 /sbin/getty -8 38
  781 root       20   0 14508   980   812 S  0.0  0.0  0:00.00 /sbin/getty -8 38
F1Help  F2Setup F3SearchF4FilterF5Tree  F6SortByF7Nice -F8Nice +F9Kill  F10Quit
```

vmstat

- Virtual memory statistics and more:

```
$ vmstat –Sm 1
procs -----------memory---------- ---swap-- -----io---- -system-- ----cpu----
 r  b   swpd   free   buff  cache   si   so    bi    bo   in    cs us sy id wa
 8  0      0   1620    149    552    0    0     1   179   77    12 25 34  0  0
 7  0      0   1598    149    552    0    0     0     0  205   186 46 13  0  0
 8  0      0   1617    149    552    0    0     0     8  210   435 39 21  0  0
 8  0      0   1589    149    552    0    0     0     0  218   219 42 17  0  0
[…]
```

- USAGE: vmstat [interval [count]]
- First output line has *some* summary since boot values
  - Should be all; partial is confusing
- High level CPU summary
  - “r” is runnable tasks

iostat

- Block I/O (disk) stats. 1st output is since boot.

```
$ iostat -xmdz 1

Linux 3.13.0-29 (db001-eb883efa)   08/18/2014   _x86_64_   (16 CPU)

Device:          rrqm/s   wrqm/s      r/s      w/s     rMB/s     wMB/s \ ...
xvda               0.00     0.00     0.00     0.00      0.00      0.00 / ...
xvdb             213.00     0.00 15299.00     0.00    338.17      0.00 \ ...
xvdc             129.00     0.00 15271.00     3.00    336.65      0.01 / ...
md0                0.00     0.00 31082.00     3.00    678.45      0.01 \ ...
```

Workload →

- Very useful set of stats

```
... \ avgqu-sz     await r_await w_await  svctm  %util
... /     0.00      0.00    0.00    0.00   0.00   0.00
... \   126.09      8.22    8.22    0.00   0.06  86.40
... /    99.31      6.47    6.47    0.00   0.06  86.00
... \     0.00      0.00    0.00    0.00   0.00   0.00
```

Resulting Performance →

free

- Main memory usage:

```
$ free -m
             total       used       free     shared    buffers     cached
Mem:          3750       1111       2639          0        147        527
-/+ buffers/cache:        436       3313
Swap:            0          0          0
```

- buffers: block device I/O cache
- cached: virtual page cache

strace

- System call tracer:

```
$ strace –tttT –p 313
1408393285.779746 getgroups(0, NULL)    = 1 <0.000016>
1408393285.779873 getgroups(1, [0])     = 1 <0.000015>
1408393285.780797 close(3)              = 0 <0.000016>
1408393285.781338 write(1, "LinuxCon 2014!\n", 15LinuxCon 2014!
) = 15 <0.000048>
```

- Eg, -ttt: time (us) since epoch; -T: syscall time (s)
- Translates syscall args
  – Very helpful for solving system usage issues
- Currently has massive overhead (ptrace based)
  – Can slow the target by > 100x. Use extreme caution.

tcpdump

- Sniff network packets for post analysis:

```
$ tcpdump -i eth0 -w /tmp/out.tcpdump
tcpdump: listening on eth0, link-type EN10MB (Ethernet), capture size 65535 bytes
^C7985 packets captured
8996 packets received by filter
1010 packets dropped by kernel
# tcpdump -nr /tmp/out.tcpdump | head
reading from file /tmp/out.tcpdump, link-type EN10MB (Ethernet)
20:41:05.038437 IP 10.44.107.151.22 > 10.53.237.72.46425: Flags [P.], seq 18...
20:41:05.038533 IP 10.44.107.151.22 > 10.53.237.72.46425: Flags [P.], seq 48...
20:41:05.038584 IP 10.44.107.151.22 > 10.53.237.72.46425: Flags [P.], seq 96...
[…]
```

- Study packet sequences with timestamps (us)
- CPU overhead optimized (socket ring buffers), but can still be significant. Use caution.

netstat

- Various network protocol statistics using -s:
- A multi-tool:

  -i: interface stats

  -r: route table

  default: list conns
- netstat -p: shows process details!
- Per-second interval with -c

```
$ netstat –s
[…]
Tcp:
    736455 active connections openings
    176887 passive connection openings
    33 failed connection attempts
    1466 connection resets received
    3311 connections established
    91975192 segments received
    180415763 segments send out
    223685 segments retransmited
    2 bad segments received.
    39481 resets sent
[…]
TcpExt:
    12377 invalid SYN cookies received
    2982 delayed acks sent
[…]
```

slabtop

- Kernel slab allocator memory usage:

```
$ slabtop
 Active / Total Objects (% used)    : 4692768 / 4751161 (98.8%)
 Active / Total Slabs (% used)      : 129083 / 129083 (100.0%)
 Active / Total Caches (% used)     : 71 / 109 (65.1%)
 Active / Total Size (% used)       : 729966.22K / 738277.47K (98.9%)
 Minimum / Average / Maximum Object : 0.01K / 0.16K / 8.00K

  OBJS ACTIVE  USE OBJ SIZE  SLABS OBJ/SLAB CACHE SIZE NAME
3565575 3565575 100%    0.10K  91425       39    365700K buffer_head
314916 314066  99%    0.19K  14996       21     59984K dentry
184192 183751  99%    0.06K   2878       64     11512K kmalloc-64
138618 138618 100%    0.94K   4077       34    130464K xfs_inode
138602 138602 100%    0.21K   3746       37     29968K xfs_ili
102116  99012  96%    0.55K   3647       28     58352K radix_tree_node
 97482  49093  50%    0.09K   2321       42      9284K kmalloc-96
 22695  20777  91%    0.05K    267       85      1068K shared_policy_node
 21312  21312 100%    0.86K    576       37     18432K ext4_inode_cache
 16288  14601  89%    0.25K    509       32      4072K kmalloc-256
[…]
```

pcstat

- Show page cache residency by file:

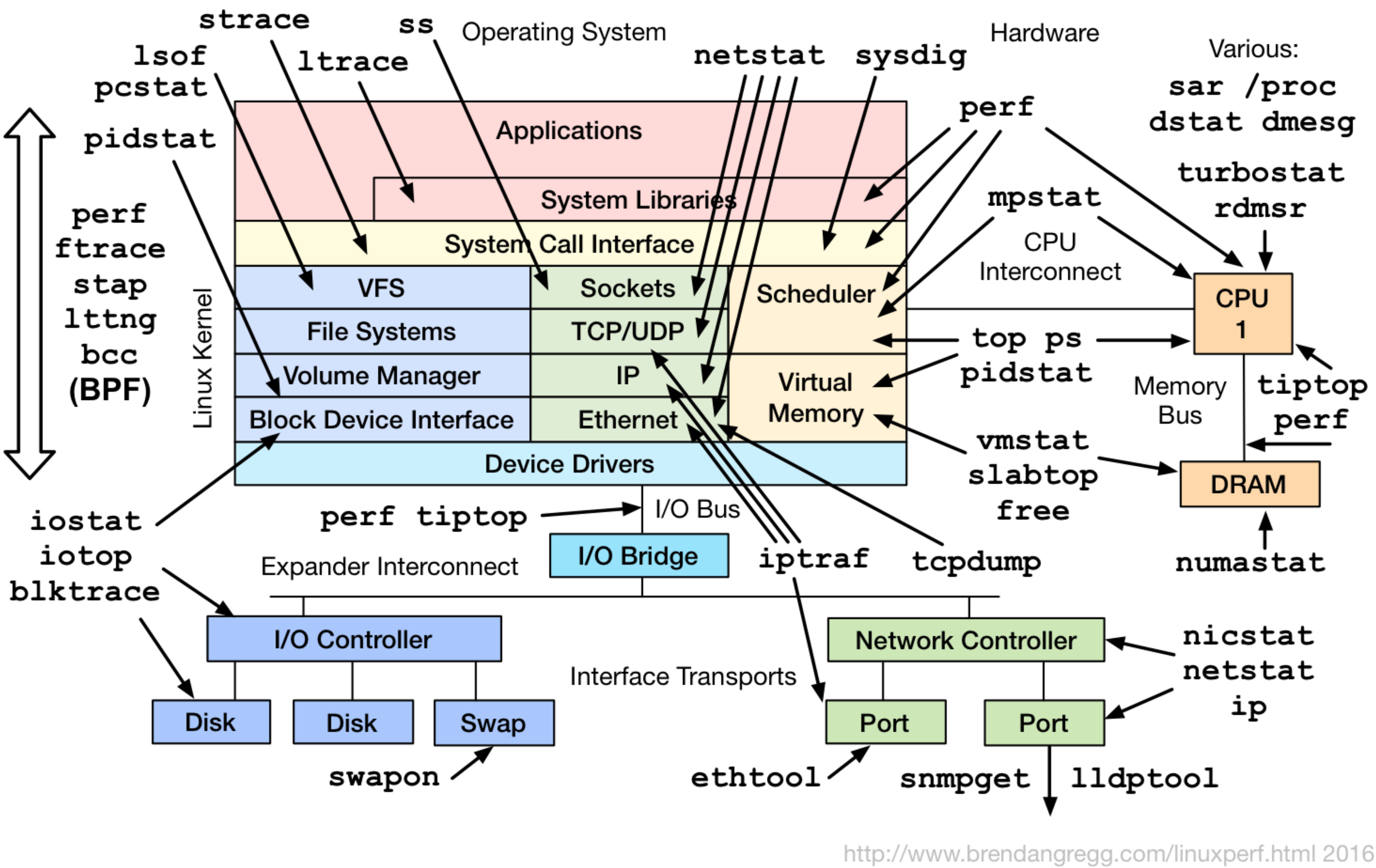
```
# ./pcstat data0*
|----------+----------------+------------+-----------+---------|
| Name     | Size           | Pages      | Cached    | Percent |
|----------+----------------+------------+-----------+---------|
| data00   | 104857600      | 25600      | 25600     | 100.000 |
| data01   | 104857600      | 25600      | 25600     | 100.000 |
| data02   | 104857600      | 25600      | 4080      | 015.938 |
| data03   | 104857600      | 25600      | 25600     | 100.000 |
| data04   | 104857600      | 25600      | 16010     | 062.539 |
| data05   | 104857600      | 25600      | 0         | 000.000 |
|----------+----------------+------------+-----------+---------|
```

- Uses the mincore(2) syscall. Useful for database performance analysis.

perf_events

- Provides the "perf" command
- In Linux source code: tools/perf
  - Usually pkg added by linux-tools-common, etc.
- **Multi-tool** with many capabilities
  - CPU profiling
  - PMC profiling
  - Static & dynamic tracing
- *Covered later in Profiling & Tracing*

Where do you start?...and stop?



2. Methodologies

Anti-Methodologies

- The lack of a deliberate methodology…
- Street Light Anti-Method:
  - 1. Pick observability tools that are
    - Familiar
    - Found on the Internet
    - Found at random
  - 2. Run tools
  - 3. Look for obvious issues
- Drunk Man Anti-Method:
  - Tune things at random until the problem goes away

Methodologies

- Linux Performance Analysis in 60 seconds
- The USE method
- CPU Profile Method
- Resource Analysis
- Workload Analysis
- Others include:
  - Workload characterization
  - Drill-down analysis
  - Off-CPU analysis
  - Static performance tuning
  - 5 whys
  - …

Linux Perf Analysis in 60s

1. `uptime`
2. `dmesg | tail`
3. `vmstat 1`
4. `mpstat -P ALL 1`
5. `pidstat 1`
6. `iostat -xz 1`
7. `free -m`
8. `sar -n DEV 1`
9. `sar -n TCP,ETCP 1`
10. `top`

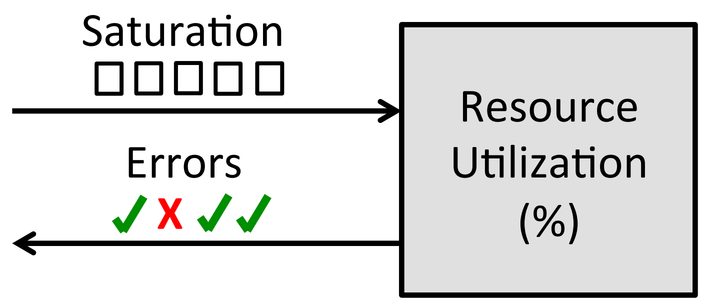
Linux Perf Analysis in 60s

1. `uptime` ----------------------------► load averages
2. `dmesg | tail` ---------------------► kernel errors
3. `vmstat 1` -------------------------► overall stats by time
4. `mpstat -P ALL 1` ------------------► CPU balance
5. `pidstat 1` ------------------------► process usage
6. `iostat -xz 1` ---------------------► disk I/O
7. `free -m` --------------------------► memory usage
8. `sar -n DEV 1` ---------------------► network I/O
9. `sar -n TCP,ETCP 1` ----------------► TCP stats
10. `top` -----------------------------► check overview

http://techblog.netflix.com/2015/11/linux-performance-analysis-in-60s.html

The USE Method

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

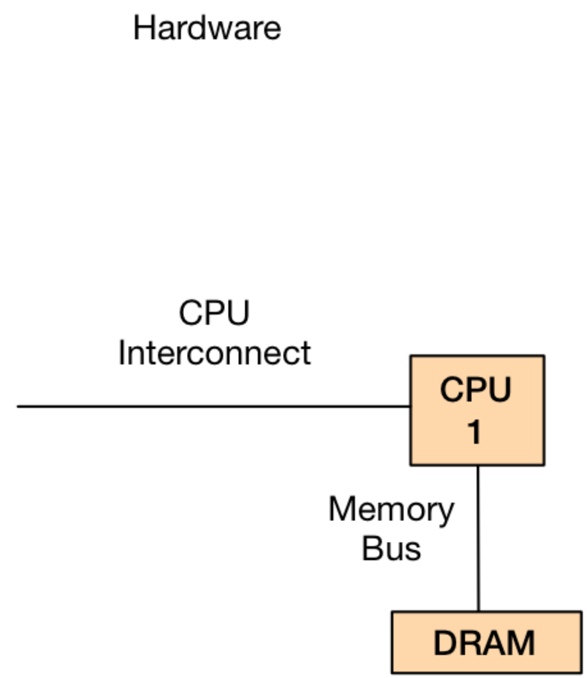
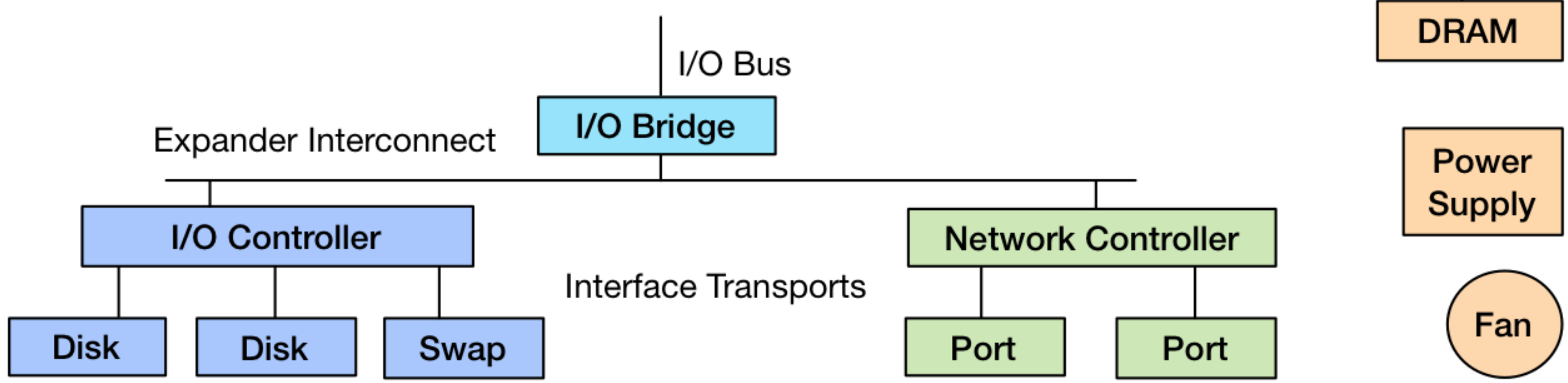


- Definitions:
    - Utilization: busy time
    - Saturation: queue length or queued time
    - Errors: easy to interpret (objective)
- Helps if you have a functional (block) diagram of your system / software / environment, showing all resources

Start with the questions, then find the tools

USE Method for Hardware

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

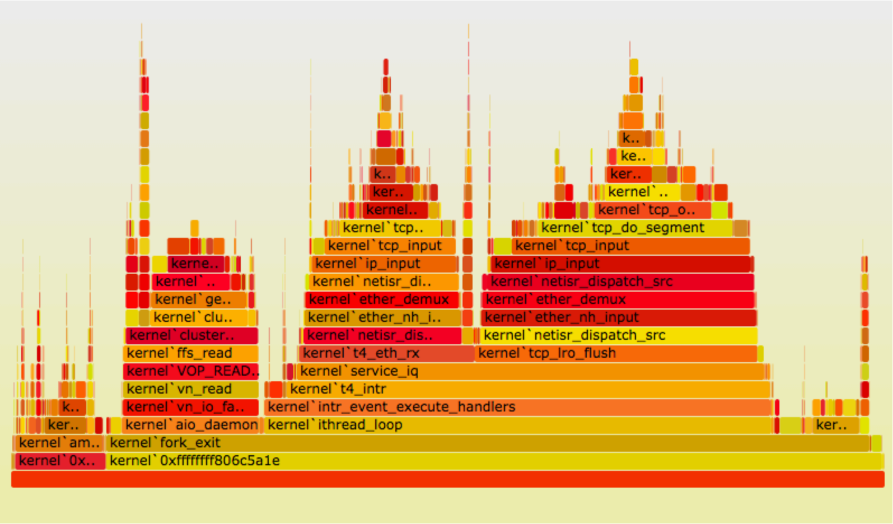
component	type	metric
CPU	utilization	system-wide: `vmstat 1`, "us" + "sy" + "st"; `sar -u`, sum fields except "%idle" and "%iowait"; `dstat -c`, sum fields except "idl" and "wai"; per-cpu: `mpstat -P ALL 1`, sum fields except "%idle" and "%iowait"; `sar -P ALL`, same as `mpstat`; per-process: `top`, "%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]

CPU Profile Method

1. Take a CPU profile
2. Understand all software in profile > 1%

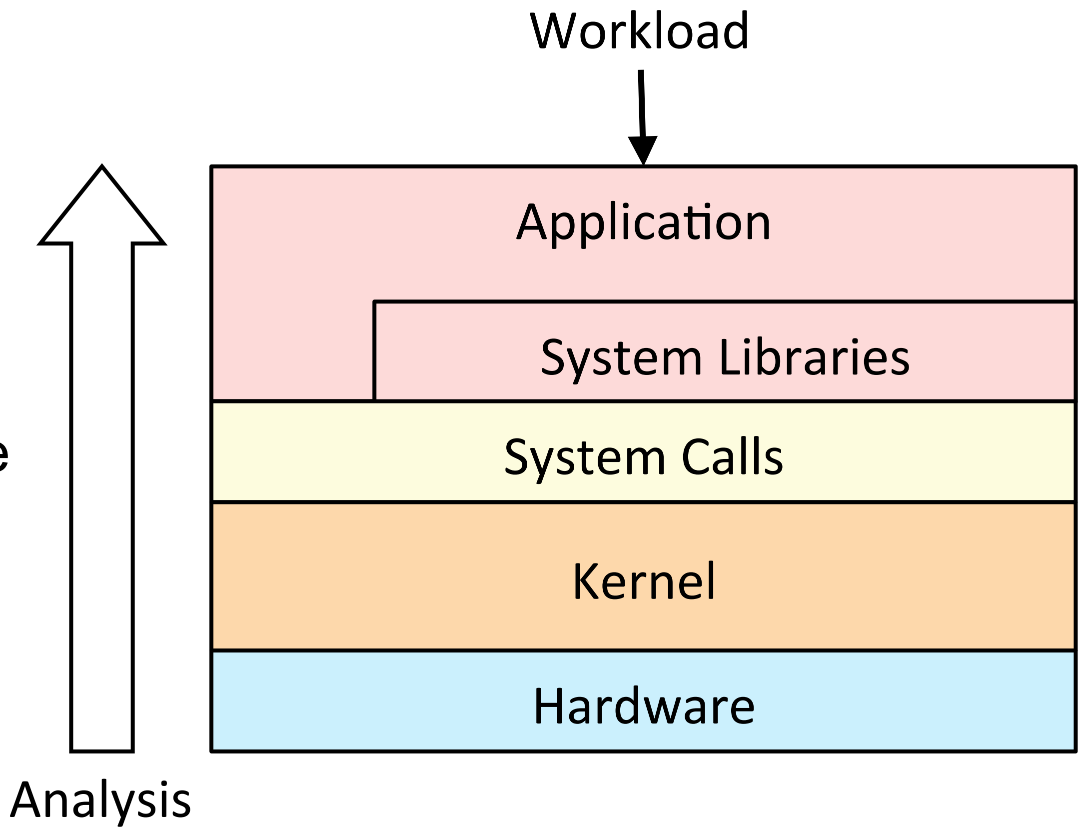
- Discovers a wide range of issues by their CPU usage
  - Directly: CPU consumers
  - Indirectly: initialization of I/O, locks, times, ...
- Narrows target of study to only its running components

Flame Graph



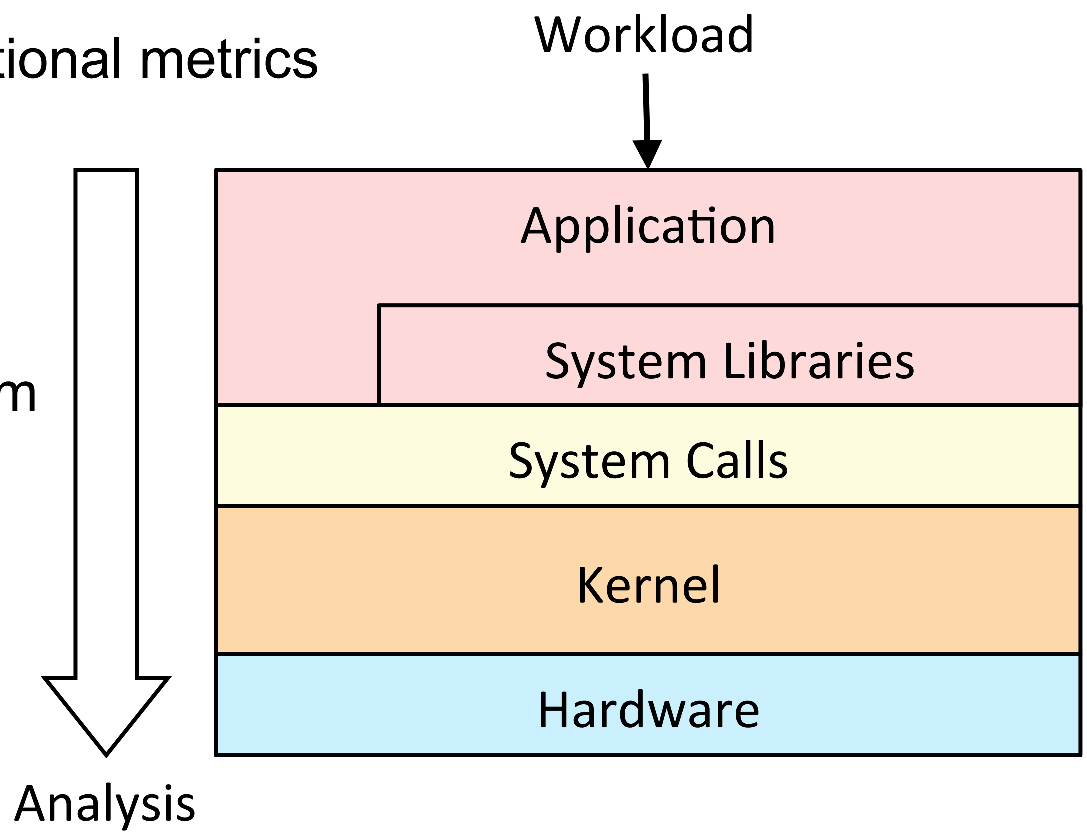
Resource Analysis

- Typical approach for system performance analysis: begin with system tools & metrics
- Pros:
  - Generic
  - Aids resource perf tuning
- Cons:
  - Uneven coverage
  - False positives



Workload Analysis

- Begin with application metrics & context
- Pros:
  - Accurate, proportional metrics
  - App context
- Cons:
  - App specific
  - Difficult to dig from app to resource



3. Benchmarking

~100% of benchmarks are wrong

Benchmarking

- Apart from observational analysis, benchmarking is a useful form of experimental analysis
  - Try observational first; benchmarks can perturb
- However, benchmarking is error prone:
  - Testing the wrong target: eg, FS cache instead of disk
  - Choosing the wrong target: eg, disk instead of FS cache … doesn't resemble real world usage
  - Invalid results: eg, bugs
  - Misleading results: you benchmark A, but actually measure B, and conclude you measured C
- The energy needed to refute benchmarks is multiple orders of magnitude bigger than to run them

Benchmark Examples

- Micro benchmarks:
  - File system maximum cached read operations/sec
  - Network maximum throughput
- Macro (application) benchmarks:
  - Simulated application maximum request rate
- Bad benchmarks:
  - gitpid() in a tight loop
  - Context switch timing

The Benchmark Paradox

- Benchmarking is used for product evaluations
  - Eg, evaluating cloud vendors
- The Benchmark Paradox:
  - If your product's chances of winning a benchmark are 50/50, you'll usually lose
  - http://www.brendangregg.com/blog/2014-05-03/the-benchmark-paradox.html
- Solving this seeming paradox (and benchmarking in general)…

For any given benchmark result,
ask:
why isn’t it 10x?

Active Benchmarking

- Root cause performance analysis while the benchmark is still running
  - Use the earlier observability tools
  - Identify the limiter (or suspected limiter) and include it with the benchmark results
  - Answer: why not 10x?
- This takes time, but uncovers most mistakes

4. Profiling

Profiling

- Can you do this?

“As an experiment to investigate the performance of the resulting TCP/IP implementation ... the is CPU saturated, but the has about 30% idle time. The time spent in the system processing the data is spread out among handling for the Ethernet (20%), IP packet processing (10%), TCP processing (30%), checksumming (25%), and user system call handling (15%), with no single part of the handling dominating the time in the system.”

Profiling

- Can you do this?

“As an experiment to investigate the performance of the resulting TCP/IP implementation ... the 11/750 is CPU saturated, but the 11/780 has about 30% idle time. The time spent in the system processing the data is spread out among handling for the Ethernet (20%), IP packet processing (10%), TCP processing (30%), checksumming (25%), and user system call handling (15%), with no single part of the handling dominating the time in the system.”

– Bill Joy, **1981**, TCP-IP Digest, Vol 1 #6

https://www.rfc-editor.org/rfc/museum/tcp-ip-digest/tcp-ip-digest.v1n6.1

perf_events

- Introduced earlier: multi-tool, profiler. Provides "perf".

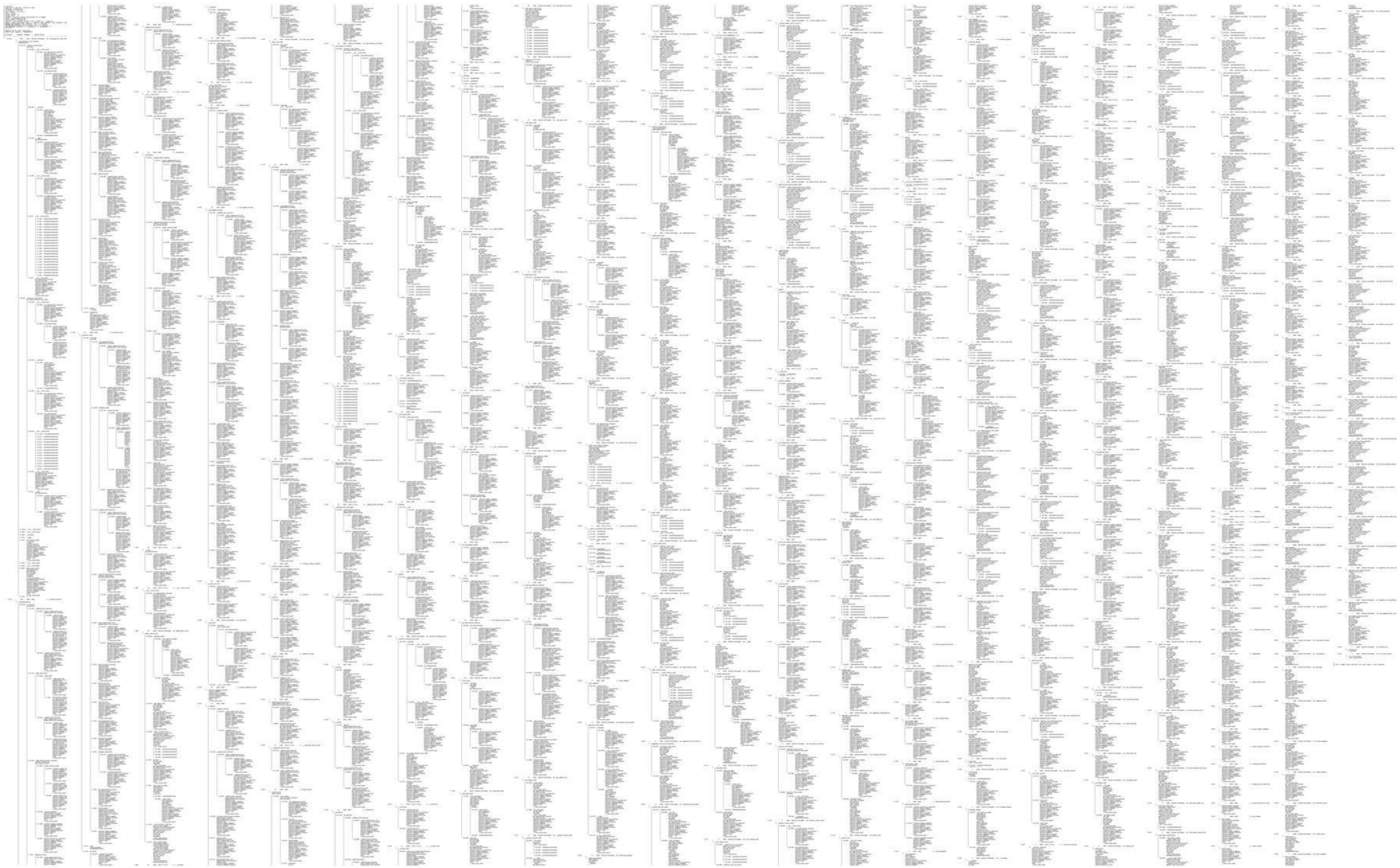
```
usage: perf [--version] [--help] [OPTIONS] COMMAND [ARGS]

The most commonly used perf commands are:
  annotate        Read perf.data (created by perf record) and display annotated code
  archive         Create archive with object files with build-ids found in perf.data file
  bench           General framework for benchmark suites
  buildid-cache   Manage build-id cache.
  buildid-list    List the buildids in a perf.data file
  data            Data file related processing
  diff            Read perf.data files and display the differential profile
  evlist          List the event names in a perf.data file
  inject          Filter to augment the events stream with additional information
  kmem            Tool to trace/measure kernel memory(slab) properties
  kvm             Tool to trace/measure kvm guest os
  list            List all symbolic event types
  lock            Analyze lock events
  mem             Profile memory accesses
  record          Run a command and record its profile into perf.data
  report          Read perf.data (created by perf record) and display the profile
  sched           Tool to trace/measure scheduler properties (latencies)
  script          Read perf.data (created by perf record) and display trace output
  stat            Run a command and gather performance counter statistics
  test            Runs sanity tests.
  timechart       Tool to visualize total system behavior during a workload
  top             System profiling tool.
  trace           strace inspired tool
  probe           Define new dynamic tracepoints

See 'perf help COMMAND' for more information on a specific command.
```

perf_events: CPU profiling

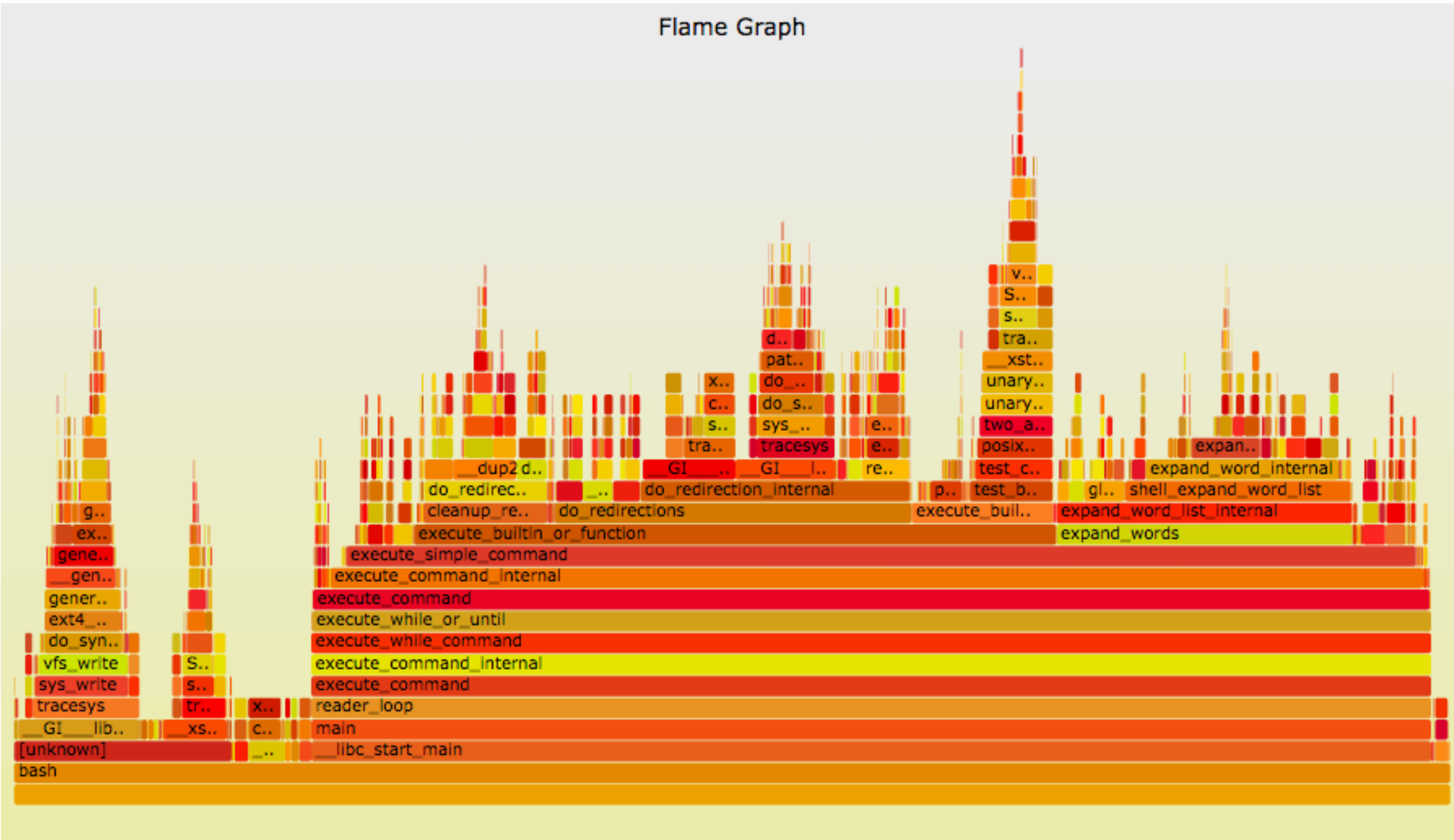
- Sampling full stack traces at 99 Hertz, for 30 secs:

```
# perf record -F 99 -ag -- sleep 30
[ perf record: Woken up 9 times to write data ]
[ perf record: Captured and wrote 2.745 MB perf.data (~119930 samples) ]
# perf report -n --stdio
1.40%   162              java  [kernel.kallsyms]       [k] _raw_spin_lock
          |
          --- _raw_spin_lock
             |
             |--63.21%-- try_to_wake_up
             |          |
             |          |--63.91%-- default_wake_function
             |          |          |
             |          |          |--56.11%-- __wake_up_common
             |          |          |          __wake_up_locked
             |          |          |          ep_poll_callback
             |          |          |          __wake_up_common
             |          |          |          __wake_up_sync_key
             |          |          |          |
             |          |          |          |--59.19%-- sock_def_readable
[…78,000 lines truncated…]
```

perf_events: Full "report" Output



… as a Flame Graph



perf_events: Flame Graphs

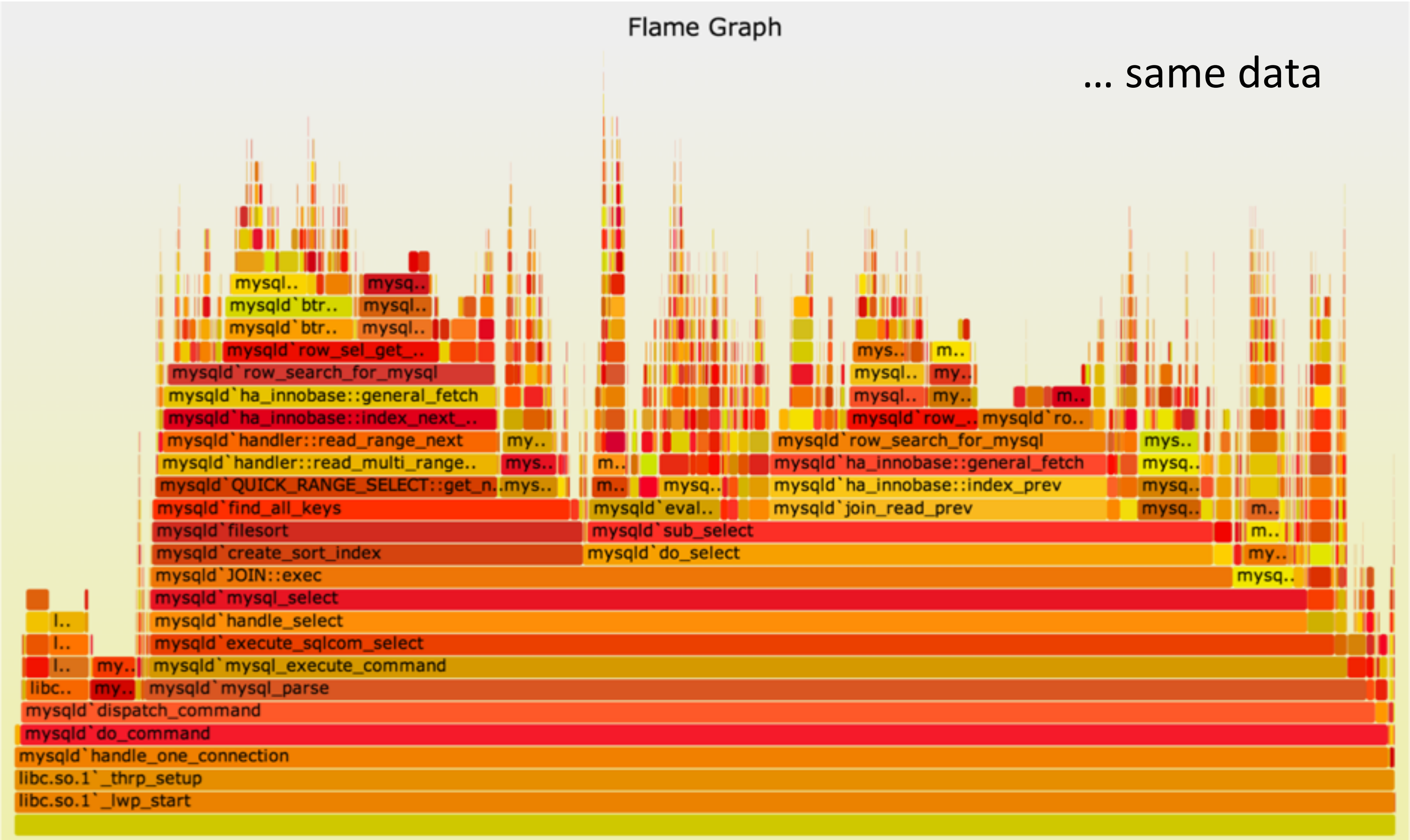
```
git clone --depth 1 https://github.com/brendangregg/FlameGraph
cd FlameGraph
perf record -F 99 -a –g -- sleep 30
perf script | ./stackcollapse-perf.pl |./flamegraph.pl > perf.svg
```

- Flame Graphs:
  - **x-axis**: alphabetical stack sort, to maximize merging
  - **y-axis**: stack depth
  - **color**: random, or hue can be a dimension (eg, diff)
- Interpretation:
  - top edge is on-CPU, beneath it is ancestry
- Easy to get working
  - http://www.brendangregg.com/FlameGraphs/cpuflamegraphs.html
- Also in Mar/Apr issue of ACMQ

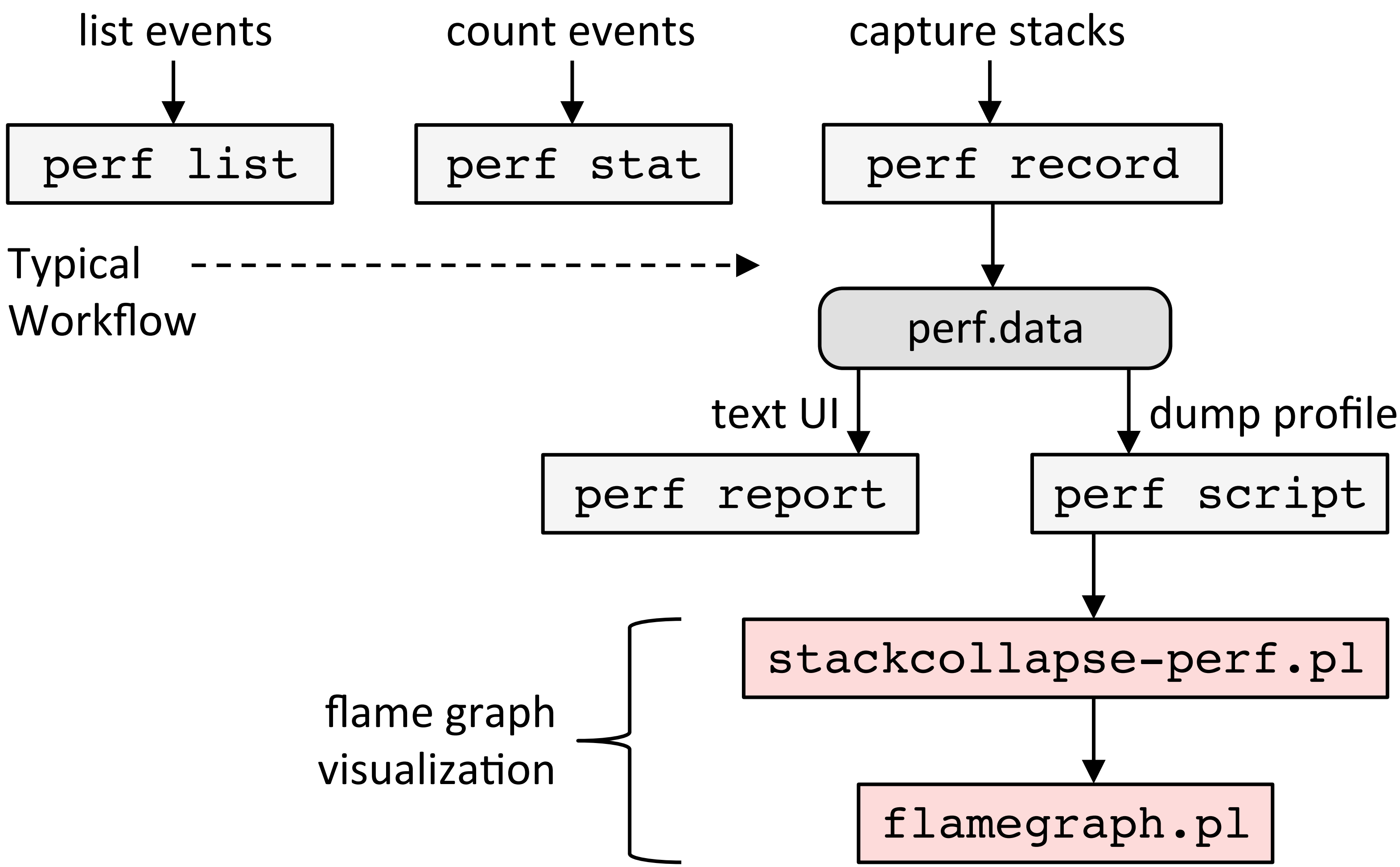
- The first ever flame graph was generated for MySQL
- This background is the output of a DTrace CPU profile, which only printed unique stacks with counts

Size of
one stack

1st Flame Graph: MySQL



perf_events: Workflow



perf_events: Counters

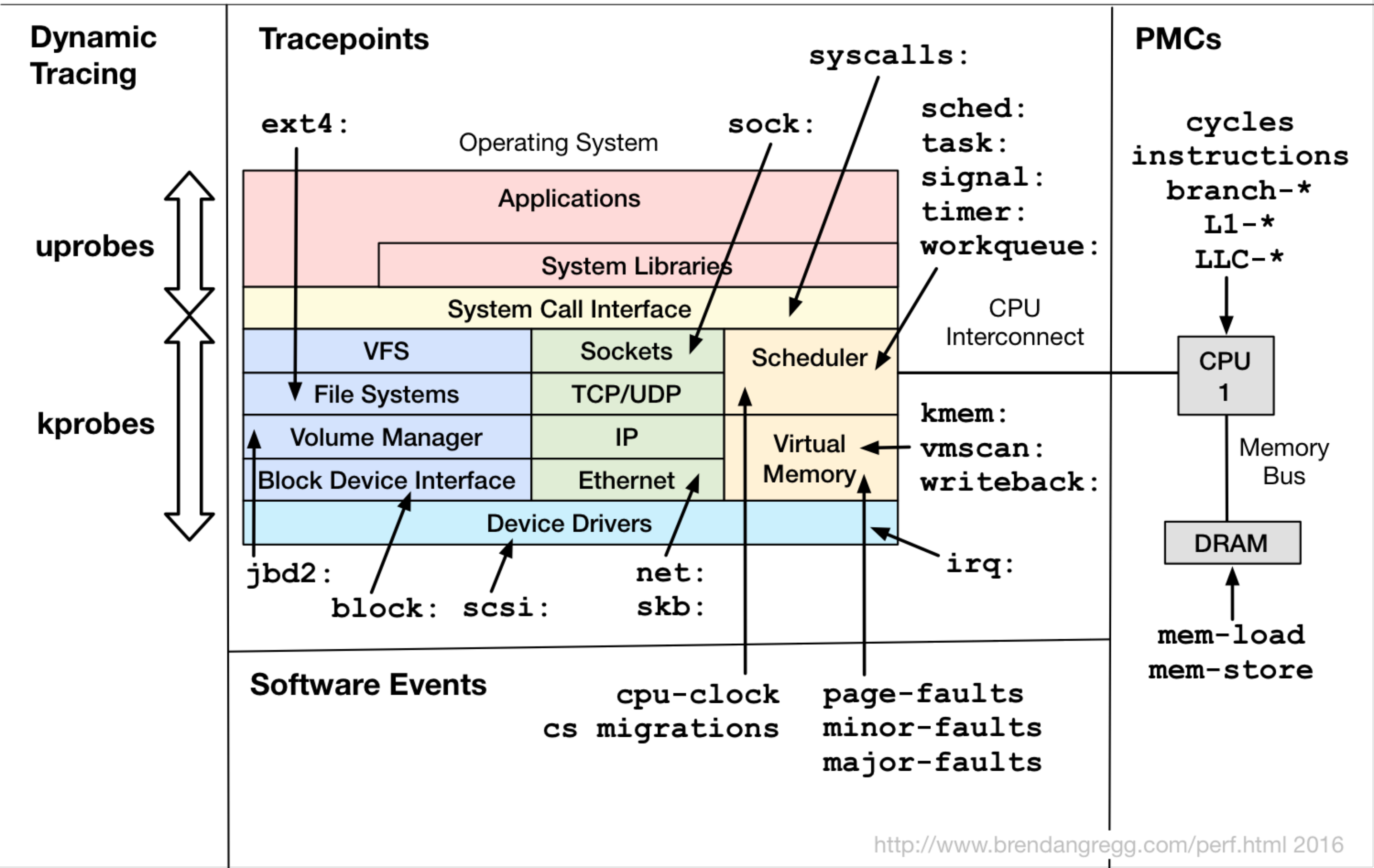
- Performance Monitoring Counters (PMCs):

```
$ perf list | grep –i hardware
  cpu-cycles OR cycles                                  [Hardware event]
  stalled-cycles-frontend OR idle-cycles-frontend       [Hardware event]
  stalled-cycles-backend OR idle-cycles-backend         [Hardware event]
  instructions                                          [Hardware event]
[…]
  branch-misses                                         [Hardware event]
  bus-cycles                                            [Hardware event]
  L1-dcache-loads                                       [Hardware cache event]
  L1-dcache-load-misses                                 [Hardware cache event]
[…]
  rNNN (see 'perf list --help' on how to encode it)    [Raw hardware event …
  mem:<addr>[:access]                                   [Hardware breakpoint]
```

- Identify CPU cycle breakdowns, esp. stall types
- PMCs not enabled by-default in clouds (yet)
- Can be time-consuming to use (CPU manuals)

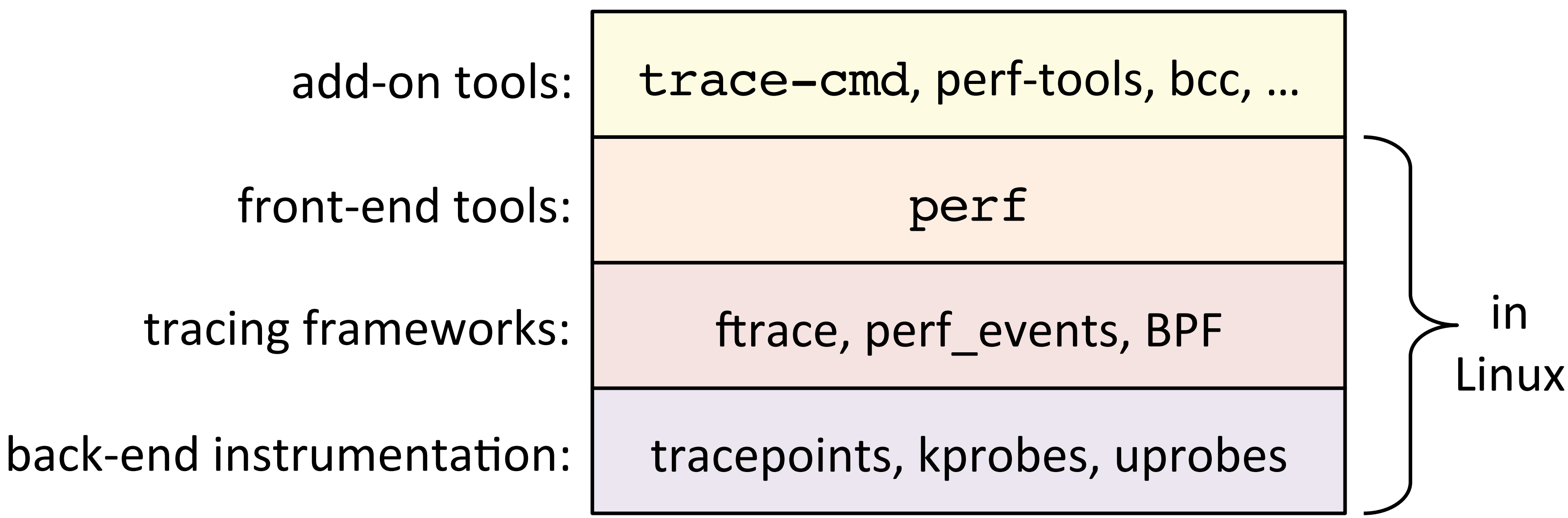
5. Tracing

Linux Event Sources



http://www.brendangregg.com/perf.html 2016

Tracing Stack



ftrace

- Added by Steven Rostedt and others since 2.6.27
  - CONFIG_FTRACE, CONFIG_FUNCTION_PROFILER, …
  - See Linux source: Documentation/trace/ftrace.txt
  - A collection of powerful features, good for hacking
- Use directly via /sys/kernel/debug/tracing (not easy):

```
linux-4.0.0+# ls /sys/kernel/debug/tracing/
available_events             max_graph_depth      stack_max_size
available_filter_functions   options              stack_trace
available_tracers            per_cpu              stack_trace_filter
buffer_size_kb               printk_formats       trace
[…]
```

- Or via front-ends:
  - Steven's trace-cmd
  - my perf-tools: iosnoop, iolatency, funccount, kprobe, …

ftrace: perf-tools iosnoop

- Block I/O (disk) events with latency:

```
# ./iosnoop –ts
Tracing block I/O. Ctrl-C to end.
STARTs          ENDs            COMM         PID    TYPE DEV      BLOCK        BYTES LATms
5982800.302061 5982800.302679 supervise  1809   W    202,1    17039600     4096   0.62
5982800.302423 5982800.302842 supervise  1809   W    202,1    17039608     4096   0.42
5982800.304962 5982800.305446 supervise  1801   W    202,1    17039616     4096   0.48
5982800.305250 5982800.305676 supervise  1801   W    202,1    17039624     4096   0.43
[…]
```

```
# ./iosnoop –h
USAGE: iosnoop [-hQst] [-d device] [-i iotype] [-p PID] [-n name] [duration]
                 -d device       # device string (eg, "202,1)
                 -i iotype       # match type (eg, '*R*' for all reads)
                 -n name         # process name to match on I/O issue
                 -p PID          # PID to match on I/O issue
                 -Q              # include queueing time in LATms
                 -s              # include start time of I/O (s)
                 -t              # include completion time of I/O (s)
                 -h              # this usage message
                 duration        # duration seconds, and use buffers
[…]
```

ftrace: perf-tools iolatency

- Block I/O (disk) latency distributions:

```
# ./iolatency
Tracing block I/O. Output every 1 seconds. Ctrl-C to end.

  >=(ms) .. <(ms)   : I/O      |Distribution                          |
       0 -> 1       : 2104     |######################################|
       1 -> 2       : 280      |######                                |
       2 -> 4       : 2        |#                                     |
       4 -> 8       : 0        |                                      |
       8 -> 16      : 202      |####                                  |

  >=(ms) .. <(ms)   : I/O      |Distribution                          |
       0 -> 1       : 1144     |######################################|
       1 -> 2       : 267      |#########                             |
       2 -> 4       : 10       |#                                     |
       4 -> 8       : 5        |#                                     |
       8 -> 16      : 248      |#########                             |
      16 -> 32      : 601      |####################                  |
      32 -> 64      : 117      |####                                  |
[…]
```

ftrace: perf-tools funccount

- 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

  - -i: set an output interval (seconds), otherwise until Ctrl-C

ftrace: perf-tools uprobe

- Dynamically trace user-level functions; eg, MySQL:

```
# ./uprobe 'p:dispatch_command /opt/mysql/bin/mysqld:_Z16dispatch_command19enum_server_commandP3THDPcj
+0(%dx):string'
Tracing uprobe dispatch_command (p:dispatch_command /opt/mysql/bin/mysqld:0x2dbd40 +0(%dx):string).
Ctrl-C to end.
          mysqld-2855  [001] d... 19956674.509085: dispatch_command: (0x6dbd40) arg1="show tables"
          mysqld-2855  [001] d... 19956675.541155: dispatch_command: (0x6dbd40) arg1="SELECT * FROM
numbers where number > 32000"
```

  – Filter on string match; eg, "SELECT":

```
# ./uprobe 'p:dispatch_command /opt/mysql/bin/mysqld:_Z16dispatch_command19enum_server_commandP3THDPcj
cmd=+0(%dx):string' 'cmd ~ "SELECT*"'
Tracing uprobe dispatch_command (p:dispatch_command /opt/mysql/bin/mysqld:0x2dbd40 cmd=
+0(%dx):string). Ctrl-C to end.
          mysqld-2855  [001] d... 19956754.619958: dispatch_command: (0x6dbd40) cmd="SELECT * FROM
numbers where number > 32000"
          mysqld-2855  [001] d... 19956755.060125: dispatch_command: (0x6dbd40) cmd="SELECT * FROM
numbers where number > 32000"
```

- Ok for hacking, but not friendly; need perf_events/BPF

perf_events

- Powerful profiler (covered earlier) and tracer:
  - User-level and kernel dynamic tracing
  - Kernel line tracing and local variables (debuginfo)
  - Kernel filtering expressions
  - Efficient in-kernel counts (perf stat)
- Intended as the official Linux tracer/profiler
- Becoming more programmable with BPF support (2016)
  - Search lkml for "perf" and "BPF"

perf_events: Listing Events

```
# perf list
 cpu-cycles OR cycles                                   [Hardware event]
 instructions                                           [Hardware event]
 cache-references                                       [Hardware event]
 cache-misses                                           [Hardware event]
 branch-instructions OR branches                        [Hardware event]
[…]
  skb:kfree_skb                                         [Tracepoint event]
  skb:consume_skb                                       [Tracepoint event]
  skb:skb_copy_datagram_iovec                           [Tracepoint event]
  net:net_dev_xmit                                      [Tracepoint event]
  net:net_dev_queue                                     [Tracepoint event]
  net:netif_receive_skb                                 [Tracepoint event]
  net:netif_rx                                          [Tracepoint event]
[…]
  block:block_rq_abort                                  [Tracepoint event]
  block:block_rq_requeue                                [Tracepoint event]
  block:block_rq_complete                               [Tracepoint event]
  block:block_rq_insert                                 [Tracepoint event]
  block:block_rq_issue                                  [Tracepoint event]
  block:block_bio_bounce                                [Tracepoint event]
  block:block_bio_complete                              [Tracepoint event]
[…]
```

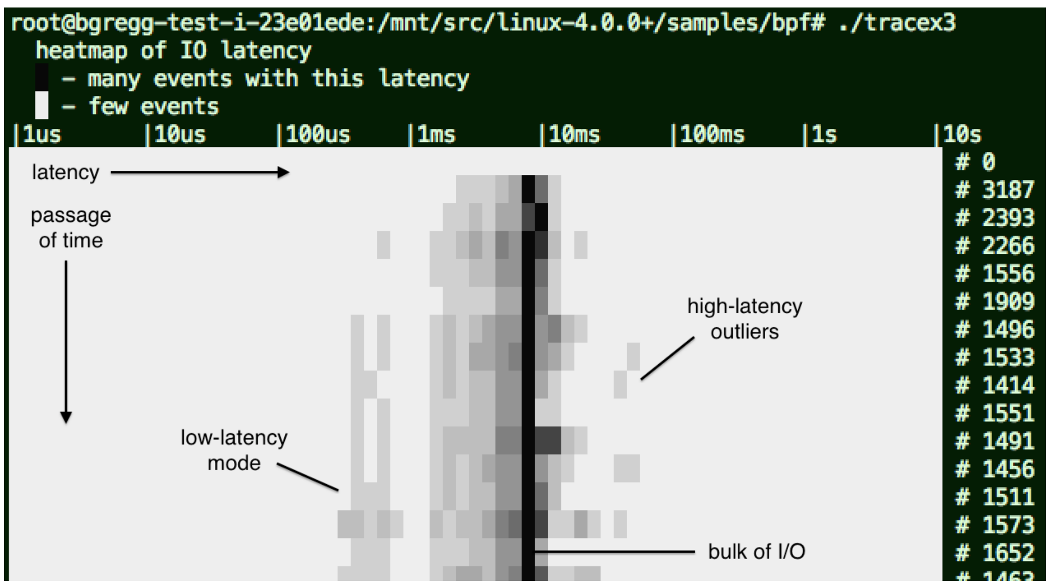
perf_events: Tracing Tracepoints

```
# perf record -e block:block_rq_complete -a sleep 10
[ perf record: Woken up 1 times to write data ]
[ perf record: Captured and wrote 0.428 MB perf.data (~18687 samples) ]
# perf script
        run 30339 [000] 2083345.722767: block:block_rq_complete: 202,1 W () 12984648 + 8 [0]
        run 30339 [000] 2083345.722857: block:block_rq_complete: 202,1 W () 12986336 + 8 [0]
        run 30339 [000] 2083345.723180: block:block_rq_complete: 202,1 W () 12986528 + 8 [0]
    swapper     0 [000] 2083345.723489: block:block_rq_complete: 202,1 W () 12986496 + 8 [0]
    swapper     0 [000] 2083346.745840: block:block_rq_complete: 202,1 WS () 1052984 + 144 [0]
  supervise 30342 [000] 2083346.746571: block:block_rq_complete: 202,1 WS () 1053128 + 8 [0]
  supervise 30342 [000] 2083346.746663: block:block_rq_complete: 202,1 W () 12986608 + 8 [0]
        run 30342 [000] 2083346.747003: block:block_rq_complete: 202,1 W () 12986832 + 8 [0]
[...]
```

- If -g is used in "perf record", stack traces are included
- If "perf script" output is too verbose, try "perf report", or making a flame graph

BPF

- Enhanced Berkeley Packet Filter, now just "BPF"
  - Enhancements added in Linux 3.15, 3.19, 4.1, 4.5, …
- Provides programmatic tracing
  - measure latency, custom histograms, …



System dashboards of 2017+ should look very different

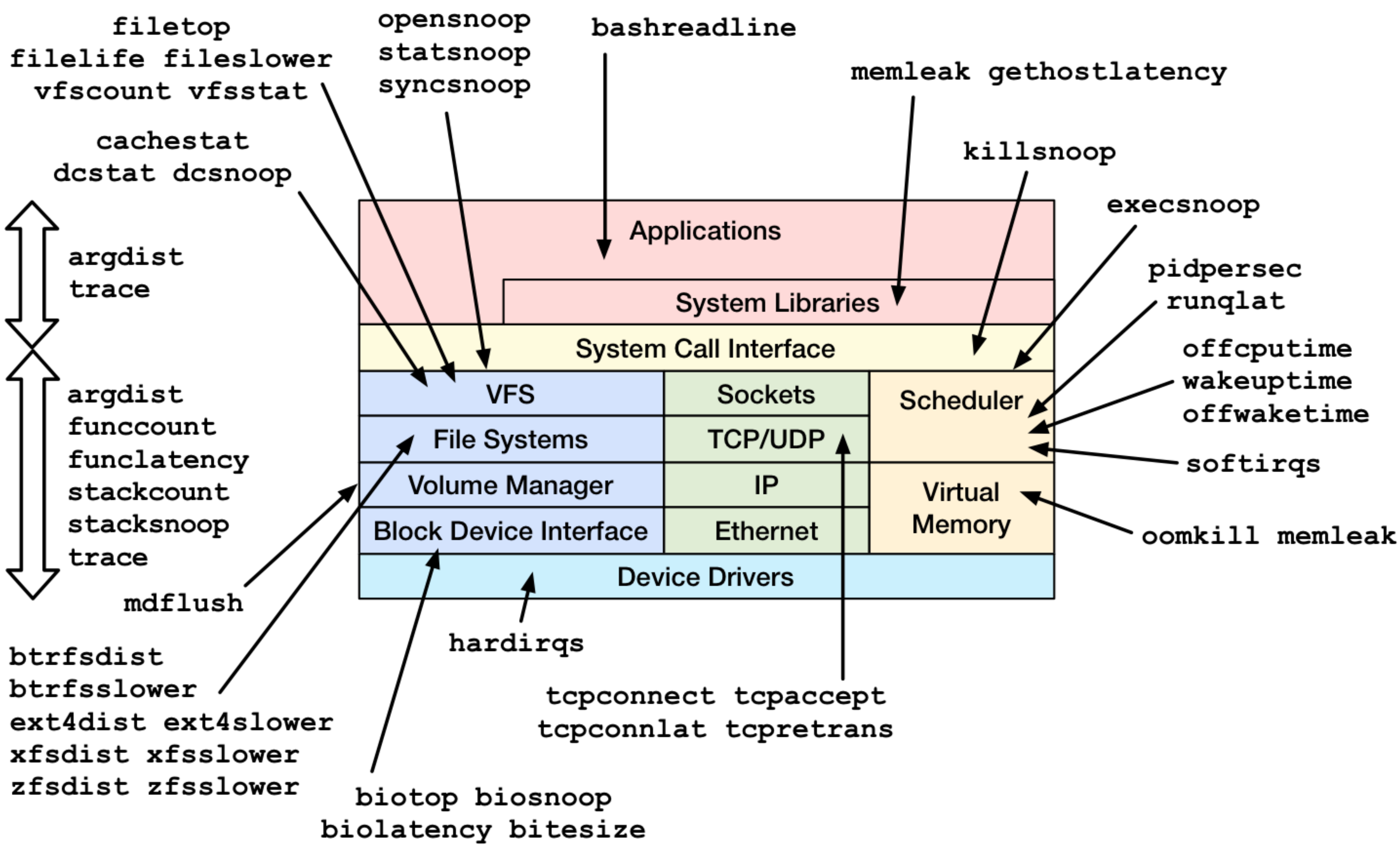
BPF: bcc ext4slower

- ext4 operations slower than the threshold:

```
# ./ext4slower 1
Tracing ext4 operations slower than 1 ms
TIME     COMM           PID    T BYTES   OFF_KB   LAT(ms) FILENAME
06:49:17 bash           3616   R 128     0           7.75 cksum
06:49:17 cksum          3616   R 39552   0           1.34 [
06:49:17 cksum          3616   R 96      0           5.36 2to3-2.7
06:49:17 cksum          3616   R 96      0          14.94 2to3-3.4
06:49:17 cksum          3616   R 10320   0           6.82 411toppm
06:49:17 cksum          3616   R 65536   0           4.01 a2p
06:49:17 cksum          3616   R 55400   0           8.77 ab
06:49:17 cksum          3616   R 36792   0          16.34 aclocal-1.14
06:49:17 cksum          3616   R 15008   0          19.31 acpi_listen
[…]
```

- Better indicator of application pain than disk I/O
- Measures & filters in-kernel for efficiency using BPF
  - https://github.com/iovisor/bcc

BPF: bcc tools (early 2016)



https://github.com/iovisor/bcc#tracing 2016

6. Tuning

Ubuntu Trusty Tuning: Early 2016 (1/2)

- CPU

  schedtool –B PID
  disable Ubuntu apport (crash reporter)
  also upgrade to Xenial (better HT scheduling)
- Virtual Memory

  ```
  vm.swappiness = 0            # from 60
  kernel.numa_balancing = 0  # temp workaround
  ```
- Huge Pages

  ```
  echo never > /sys/kernel/mm/transparent_hugepage/enabled
  ```
- File System

  ```
  vm.dirty_ratio = 80                          # from 40
  vm.dirty_background_ratio = 5                # from 10
  vm.dirty_expire_centisecs = 12000            # from 3000
  mount -o defaults,noatime,discard,nobarrier …
  ```
- Storage I/O

  ```
  /sys/block/*/queue/rq_affinity    2
  /sys/block/*/queue/scheduler      noop
  /sys/block/*/queue/nr_requests    256
  ```

Ubuntu Trusty Tuning: Early 2016 (2/2)

- Storage (continued)

```
/sys/block/*/queue/read_ahead_kb  256
mdadm –chunk=64 …
```

- Networking

```
net.core.somaxconn = 1000
net.core.netdev_max_backlog = 5000
net.core.rmem_max = 16777216
net.core.wmem_max = 16777216
net.ipv4.tcp_wmem = 4096 12582912 16777216
net.ipv4.tcp_rmem = 4096 12582912 16777216
net.ipv4.tcp_max_syn_backlog = 8096
net.ipv4.tcp_slow_start_after_idle = 0
net.ipv4.tcp_tw_reuse = 1
net.ipv4.ip_local_port_range = 10240 65535
net.ipv4.tcp_abort_on_overflow = 1    # maybe
```

- Hypervisor (Xen)

```
echo tsc > /sys/devices/…/current_clocksource
```

Plus PVHVM (HVM), SR-IOV, …

Summary

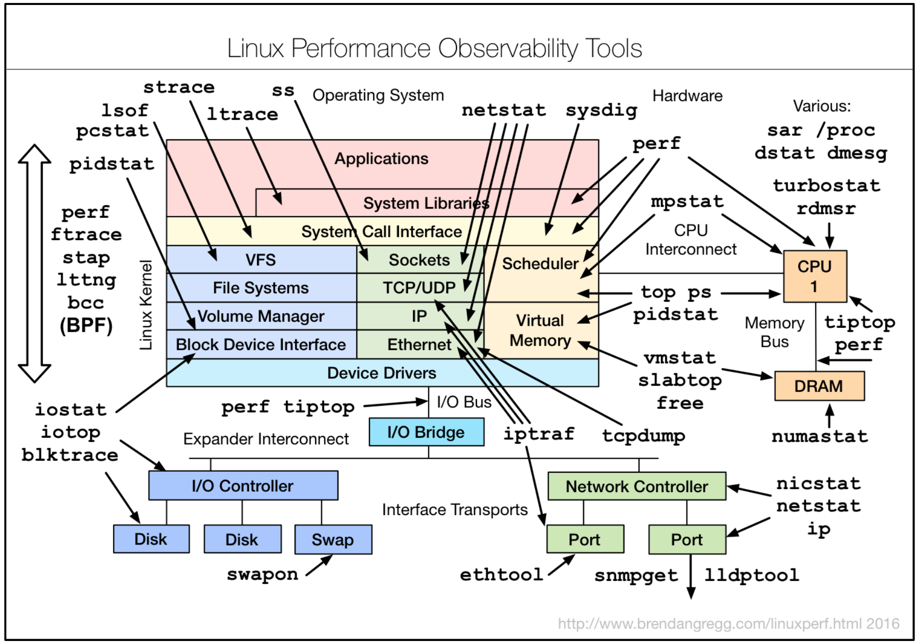
A brief discussion of 6 facets of Linux performance:

1. Observability
2. Methodologies
3. Benchmarking
4. Profiling
5. Tracing
6. Tuning

Takeaways

Some things to print out for your office wall:

1. `uptime`
2. `dmesg -T | tail`
3. `vmstat 1`
4. `mpstat -P ALL 1`
5. `pidstat 1`
6. `iostat -xz 1`
7. `free -m`
8. `sar -n DEV 1`
9. `sar -n TCP,ETCP 1`
10. `top`



More Links

- Netflix Tech Blog on Linux:
  - http://techblog.netflix.com/2015/11/linux-performance-analysis-in-60s.html
  - http://techblog.netflix.com/2015/08/netflix-at-velocity-2015-linux.html
- Linux Performance:
  - http://www.brendangregg.com/linuxperf.html
- Linux perf_events:
  - https://perf.wiki.kernel.org/index.php/Main_Page
  - http://www.brendangregg.com/perf.html
- Linux ftrace:
  - https://www.kernel.org/doc/Documentation/trace/ftrace.txt
  - https://github.com/brendangregg/perf-tools
- USE Method Linux:
  - http://www.brendangregg.com/USEmethod/use-linux.html
- Flame Graphs:
  - http://www.brendangregg.com/FlameGraphs/cpuflamegraphs.html
  - http://queue.acm.org/detail.cfm?id=2927301

Thanks

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