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Linux Systems Performance

Brendan Gregg

Senior Performance Engineer

NETFLIX

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Experience: A 3x Perf Difference

mpstat

load averages: serverA 90, serverB 17

```
serverA# mpstat 10
Linux 4.4.0-130-generic (serverA) 07/18/2019 _x86_64_ (48 CPU)

10:07:55 PM  CPU    %usr   %nice    %sys %iowait    %irq   %soft  %steal  %guest  %gnice   %idle
10:08:05 PM  all   89.72    0.00    7.84    0.00    0.00    0.04    0.00    0.00    0.00    2.40
10:08:15 PM  all   88.60    0.00    9.18    0.00    0.00    0.05    0.00    0.00    0.00    2.17
10:08:25 PM  all   89.71    0.00    9.01    0.00    0.00    0.05    0.00    0.00    0.00    1.23
[...]
Average:     all   89.49    0.00    8.47    0.00    0.00    0.05    0.00    0.00    0.00    1.99

serverB# mpstat 10
Linux 4.19.26-nflx (serverB) 07/18/2019 _x86_64_ (64 CPU)

09:56:11 PM  CPU    %usr   %nice    %sys %iowait    %irq   %soft  %steal  %guest  %gnice   %idle
09:56:21 PM  all   23.21    0.01    0.32    0.00    0.00    0.10    0.00    0.00    0.00   76.37
09:56:31 PM  all   20.21    0.00    0.38    0.00    0.00    0.08    0.00    0.00    0.00   79.33
09:56:41 PM  all   21.58    0.00    0.39    0.00    0.00    0.10    0.00    0.00    0.00   77.92
[...]
Average:     all   21.50    0.00    0.36    0.00    0.00    0.09    0.00    0.00    0.00   78.04
```

pmcarch

```
serverA# ./pmcarch -p 4093 10
K_CYCLES   K_INSTR      IPC BR_RETIRED   BR_MISPRED  BMR% LLCREF      LLCMISS     LLC%
982412660  575706336   0.59 126424862460 2416880487  1.91 15724006692 10872315070 30.86
999621309  555043627   0.56 120449284756 2317302514  1.92 15378257714 11121882510 27.68
991146940  558145849   0.56 126350181501 2530383860  2.00 15965082710 11464682655 28.19
996314688  562276830   0.56 122215605985 2348638980  1.92 15558286345 10835594199 30.35
979890037  560268707   0.57 125609807909 2386085660  1.90 15828820588 11038597030 30.26
^C

serverB# ./pmcarch -p 1928219 10
K_CYCLES   K_INSTR      IPC BR_RETIRED   BR_MISPRED  BMR% LLCREF      LLCMISS     LLC%
147523816  222396364   1.51 46053921119  641813770   1.39 8880477235  968809014  89.09
156634810  229801807   1.47 48236123575  653064504   1.35 9186609260  1183858023 87.11
152783226  237001219   1.55 49344315621  692819230   1.40 9314992450  879494418  90.56
140787179  213570329   1.52 44518363978  631588112   1.42 8675999448  712318917  91.79
136822760  219706637   1.61 45129020910  651436401   1.44 8689831639  617678747  92.89
```

perf

```
serverA# perf stat -e cs -a -I 1000
#            time             counts unit events
     1.000411740          2,063,105      cs
     2.000977435          2,065,354      cs
     3.001537756          1,527,297      cs
     4.002028407            515,509      cs
     5.002538455          2,447,126      cs
[...]

serverB# perf stat -e cs -p 1928219 -I 1000
#            time             counts unit events
     1.001931945              1,172      cs
     2.002664012              1,370      cs
     3.003441563              1,034      cs
     4.004140394              1,207      cs
     5.004947675              1,053      cs
[...]
```

bcc/BPF

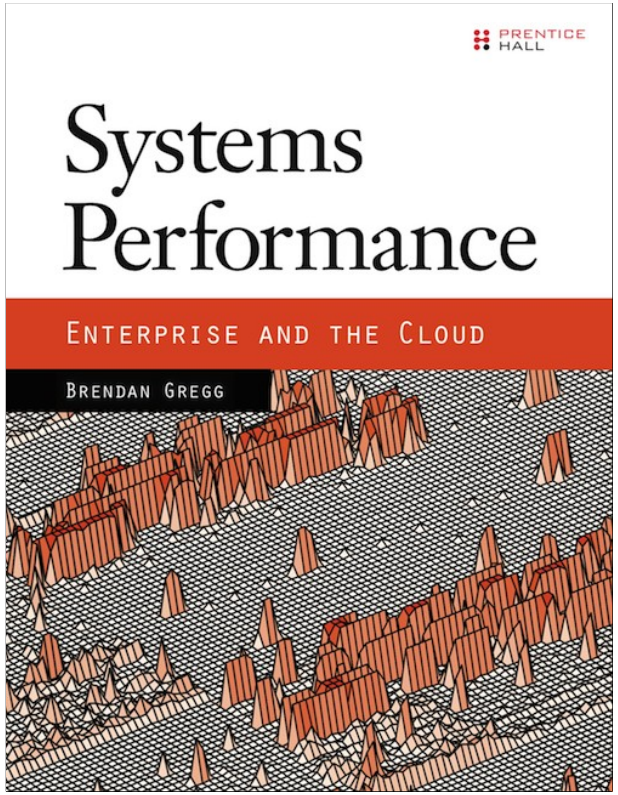
```
serverA# /usr/share/bcc/tools/cpudist -p 4093 10 1
Tracing on-CPU time... Hit Ctrl-C to end.

     usecs               : count     distribution
         0 -> 1          : 3618650  |****************************************|
         2 -> 3          : 2704935  |*****************************           |
         4 -> 7          : 421179   |****                                    |
         8 -> 15         : 99416    |*                                       |
        16 -> 31         : 16951    |                                        |
        32 -> 63         : 6355     |                                        |
[...]
serverB# /usr/share/bcc/tools/cpudist -p 1928219 10 1
Tracing on-CPU time... Hit Ctrl-C to end.

     usecs               : count     distribution
       256 -> 511        : 44       |                                        |
       512 -> 1023       : 156      |*                                       |
      1024 -> 2047       : 238      |**                                      |
      2048 -> 4095       : 4511     |****************************************|
      4096 -> 8191       : 277      |**                                      |
      8192 -> 16383      : 286      |**                                      |
     16384 -> 32767      : 77       |                                        |
[...]
```

Systems Performance in 45 mins

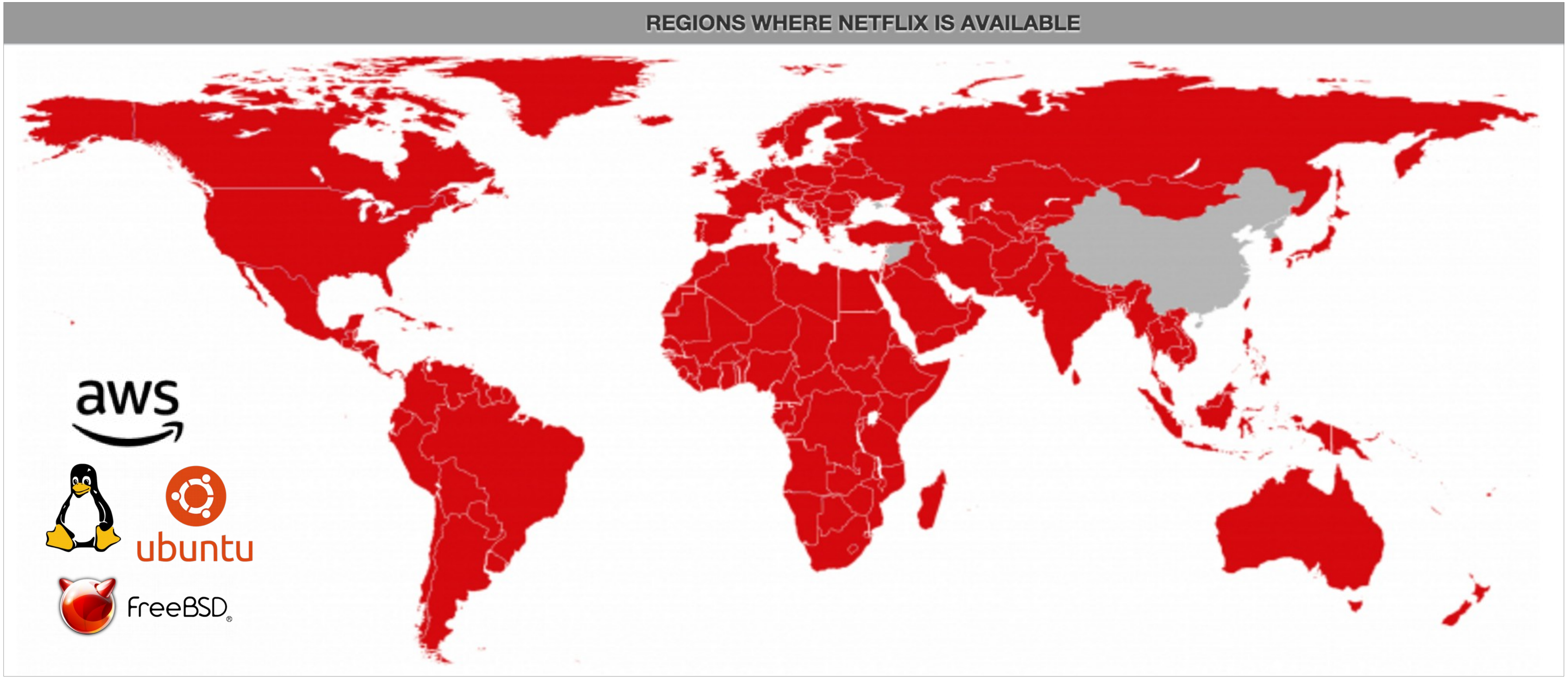
- This is slides + discussion
- For more detail and stand-alone texts:



Agenda

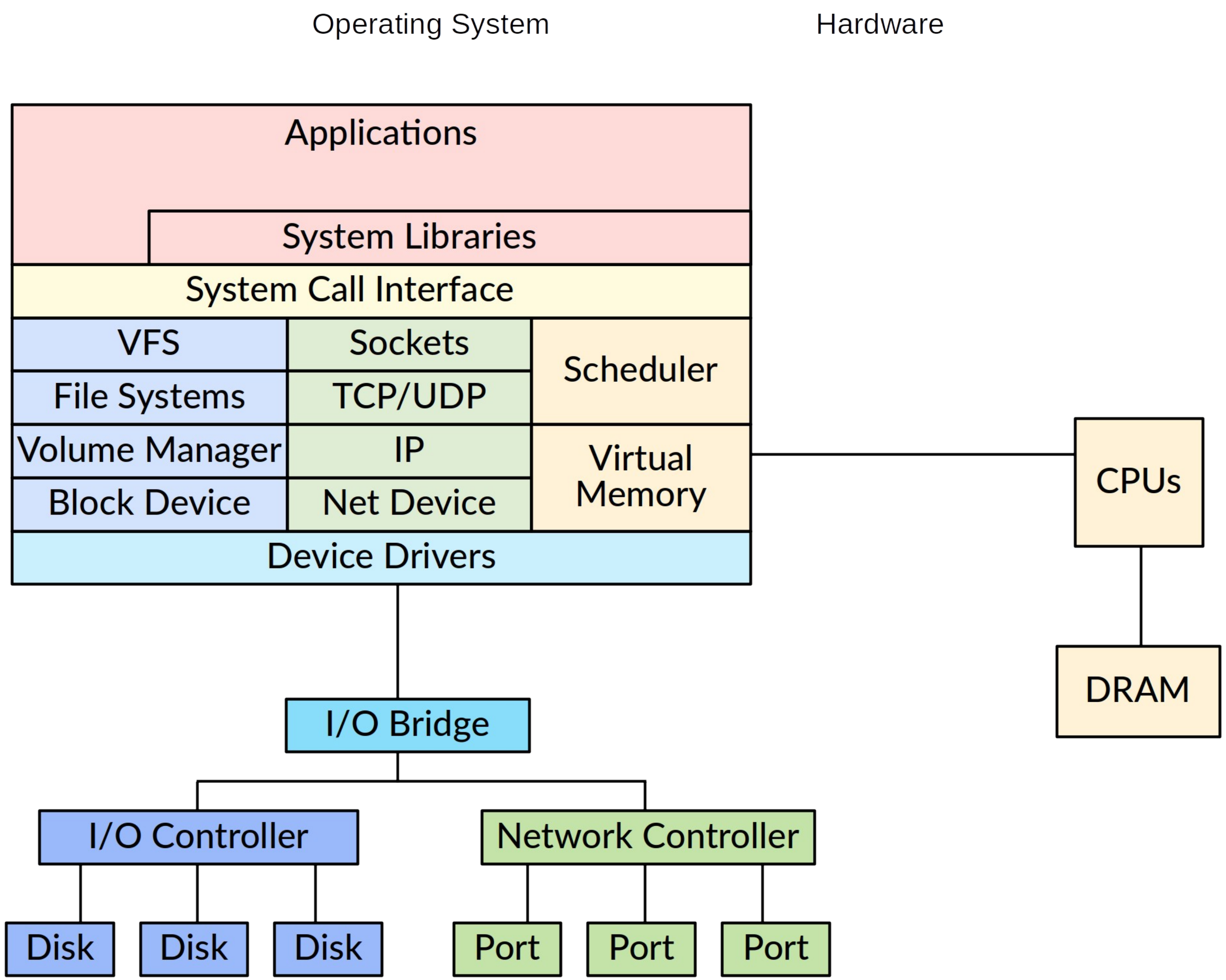
1. Observability
2. Methodologies
3. Benchmarking
4. Profiling
5. Tracing
6. Tuning

NETFLIX



1. Observability

How do you measure these?



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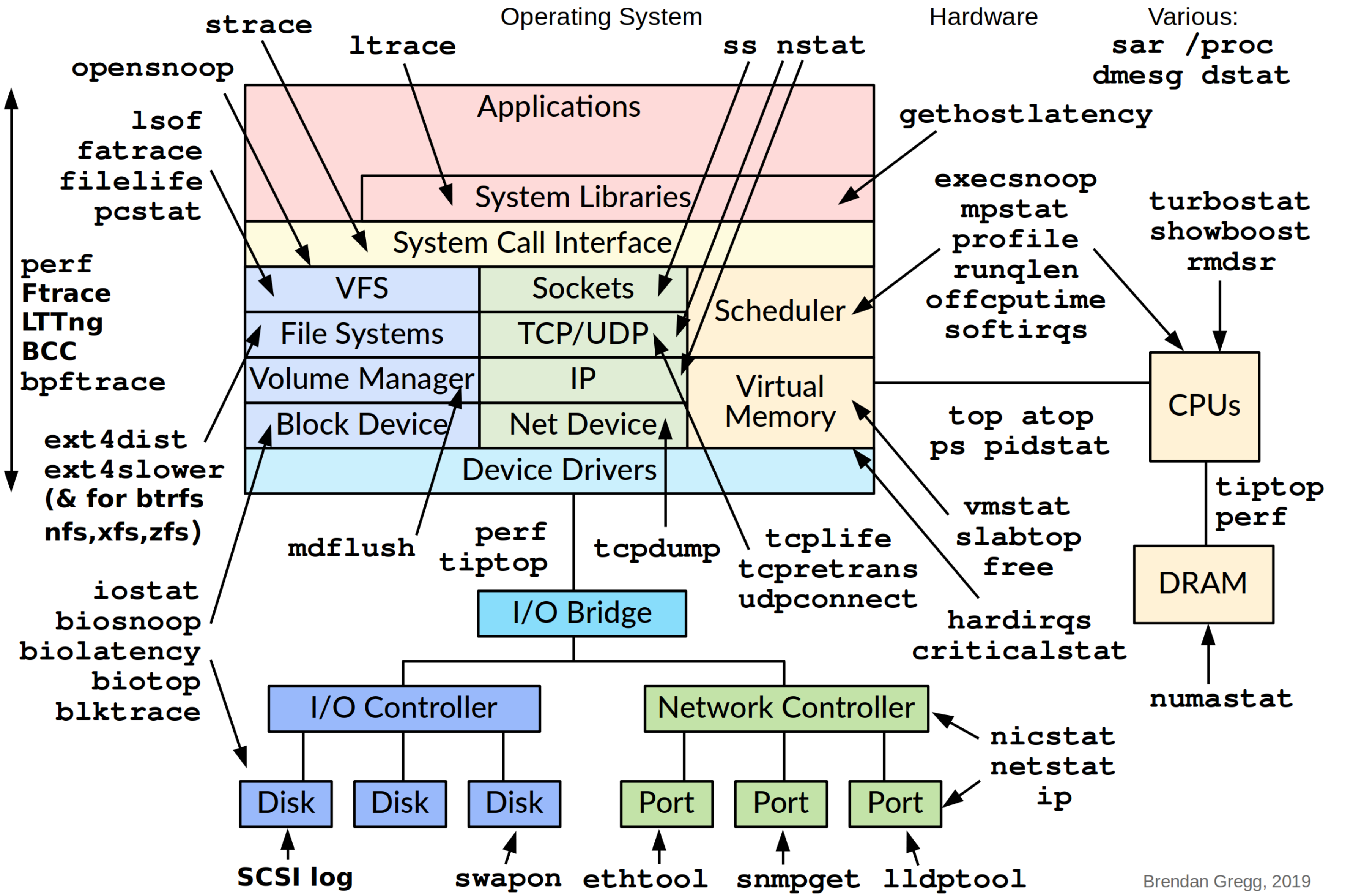
Linux Observability Tools



Why Learn Tools?

- Most analysis at Netflix is via GUIs
- Benefits of command-line tools:
  - Helps you understand GUIs: they show the same metrics
  - Often documented, unlike GUI metrics
  - Often have useful options not exposed in GUIs
- Installing essential tools (something like):

```
$ sudo apt-get install sysstat bcc-tools bpftrace linux-tools-common \
    linux-tools-$(uname -r) iproute2 msr-tools
$ git clone https://github.com/brendangregg/msr-cloud-tools
$ git clone https://github.com/brendangregg/bpf-perf-tools-book
```

These are crisis tools and should be installed by default

In a performance meltdown you may be unable to install them

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
  - Includes TASK_UNINTERRUPTIBLE state to show all demand types
  - You can use BPF & off-CPU flame graphs to explain this state: http://www.brendangregg.com/blog/2017-08-08/linux-load-averages.html
  - PSI in Linux 4.20 shows CPU, I/O, and memory loads
- Exponentially-damped moving averages
  - With time constants of 1, 5, and 15 minutes. See historic trend.
- Load > # of CPUs, may mean CPU saturation

Don't spend more than 5 seconds studying these

top

- 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)

htop

```
$ htop
  1  [||||||||||70.0%]    13 [||||||||||70.6%]   25 [||||||||||69.7%]    37 [||||||||||66.6%]
  2  [||||||||||68.7%]    14 [||||||||||69.4%]   26 [||||||||||67.7%]    38 [||||||||||66.0%]
  3  [||||||||||68.2%]    15 [||||||||||68.5%]   27 [||||||||||68.8%]    39 [||||||||||73.3%]
  4  [||||||||||69.3%]    16 [||||||||||69.2%]   28 [||||||||||67.6%]    40 [||||||||||67.0%]
  5  [||||||||||68.0%]    17 [||||||||||67.6%]   29 [||||||||||70.1%]    41 [||||||||||66.5%]
[…]
  Mem[||||||||||||||||||||||||||||||176G/187G]   Tasks: 80, 3206 thr; 43 running
  Swp[                                0K/0K]   Load average: 36.95 37.19 38.29
                                               Uptime: 01:39:36

  PID USER      PRI  NI  VIRT   RES   SHR S CPU% MEM%   TIME+  Command
 4067 www-data   20   0  202G  173G 55392 S 3359 93.0 48h51:30 /apps/java/bin/java -Dnop -Djdk.map
 6817 www-data   20   0  202G  173G 55392 R 56.9 93.0 48:37.89 /apps/java/bin/java -Dnop -Djdk.map
 6826 www-data   20   0  202G  173G 55392 R 25.7 93.0 22:26.90 /apps/java/bin/java -Dnop -Djdk.map
 6721 www-data   20   0  202G  173G 55392 S 25.0 93.0 22:05.51 /apps/java/bin/java -Dnop -Djdk.map
 6616 www-data   20   0  202G  173G 55392 S 13.6 93.0 11:15.51 /apps/java/bin/java -Dnop -Djdk.map
[…]
F1Help  F2Setup F3SearchF4FilterF5Tree  F6SortByF7Nice -F8Nice +F9Kill  F10Quit
```

- Pros: configurable. Cons: misleading colors.
- dstat is similar, and now dead (May 2019); see pcp-dstat

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
- High level CPU summary
  - “r” is runnable tasks

iostat

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

```
$ iostat -xz 1
Linux 5.0.21 (c099.xxxx)     06/24/19    _x86_64_    (32 CPU)
[...]
Device             r/s     w/s     rkB/s     wkB/s   rrqm/s   wrqm/s  %rrqm  %wrqm \...
sda               0.01    0.00      0.16      0.00     0.00     0.00   0.00   0.00 /...
nvme3n1       19528.04   20.39 293152.56  14758.05     0.00     4.72   0.00  18.81 \...
nvme1n1       18513.51   17.83 286402.15  13089.56     0.00     4.05   0.00  18.52 /...
nvme0n1       16560.88   19.70 258184.52  14218.55     0.00     4.78   0.00  19.51 \...
```

Workload →

```
...\ r_await w_await aqu-sz rareq-sz wareq-sz  svctm  %util
.../    1.90    0.00   0.00    17.01     0.00   1.13   0.00
...\    0.13   53.56   1.05    15.01   723.80   0.02  47.29
.../    0.13   49.26   0.85    15.47   734.21   0.03  48.09
...\    0.13   50.46   0.96    15.59   721.65   0.03  46.64
```

Very useful set of stats

Resulting Performance →

free

- Main memory usage:

```
$ free -m
              total        used        free      shared  buff/cache   available
Mem:          23850       18248         592        3776        5008        1432
Swap:         31699        2021       29678
```

- Recently added “available” column
  - buff/cache: block device I/O cache + virtual page cache
  - available: memory likely available to apps
  - free: completely unused memory

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, "wow much syscall\n", 17wow much syscall
) = 17 <0.000048>
```

- Translates syscall arguments
- Not all kernel requests (e.g., page faults)
- Currently has massive overhead (ptrace based)
  - Can slow the target by > 100x. Skews measured time (-ttt, -T).
  - http://www.brendangregg.com/blog/2014-05-11/strace-wow-much-syscall.html
- `perf trace` will replace it: uses a ring buffer & BPF

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 BPF in-kernel summaries instead.**

nstat

- Replacement for netstat from iproute2
- Various network protocol statistics:
  - -s won’t reset counters, otherwise intervals can be examined
  - -d for daemon mode
- Linux keeps adding more counters

```
$ nstat -s
#kernel
IpInReceives                    31109659           0.0
IpInDelivers                    31109371           0.0
IpOutRequests                   33209552           0.0
[...]
TcpActiveOpens                  508924             0.0
TcpPassiveOpens                 388584             0.0
TcpAttemptFails                 933                0.0
TcpEstabResets                  1545               0.0
TcpInSegs                       31099176           0.0
TcpOutSegs                      56254112           0.0
TcpRetransSegs                  3762               0.0
TcpOutRsts                      3183               0.0
[...]
```

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 mincore(2) syscall. Used for database perf analysis.

docker stats

- Soft limits (cgroups) by container:

```
# docker stats
CONTAINER     CPU %     MEM USAGE / LIMIT     MEM %    NET I/O     BLOCK I/O         PIDS
353426a09db1  526.81%   4.061 GiB / 8.5 GiB   47.78%   0 B / 0 B   2.818 MB / 0 B    247
6bf166a66e08  303.82%   3.448 GiB / 8.5 GiB   40.57%   0 B / 0 B   2.032 MB / 0 B    267
58dcf8aed0a7  41.01%    1.322 GiB / 2.5 GiB   52.89%   0 B / 0 B   0 B / 0 B         229
61061566ffe5  85.92%    220.9 MiB / 3.023 GiB 7.14%    0 B / 0 B   43.4 MB / 0 B     61
bdc721460293  2.69%     1.204 GiB / 3.906 GiB 30.82%   0 B / 0 B   4.35 MB / 0 B     66
6c80ed61ae63  477.45%   557.7 MiB / 8 GiB     6.81%    0 B / 0 B   9.257 MB / 0 B    19
337292fb5b64  89.05%    766.2 MiB / 8 GiB     9.35%    0 B / 0 B   5.493 MB / 0 B    19
b652ede9a605  173.50%   689.2 MiB / 8 GiB     8.41%    0 B / 0 B   6.48 MB / 0 B     19
d7cd2599291f  504.28%   673.2 MiB / 8 GiB     8.22%    0 B / 0 B   12.58 MB / 0 B    19
05bf9f3e0d13  314.46%   711.6 MiB / 8 GiB     8.69%    0 B / 0 B   7.942 MB / 0 B    19
09082f005755  142.04%   693.9 MiB / 8 GiB     8.47%    0 B / 0 B   8.081 MB / 0 B    19
[...]
```

- Stats are in /sys/fs/cgroups
- CPU shares and bursting breaks monitoring assumptions

showboost

- Determine current CPU clock rate

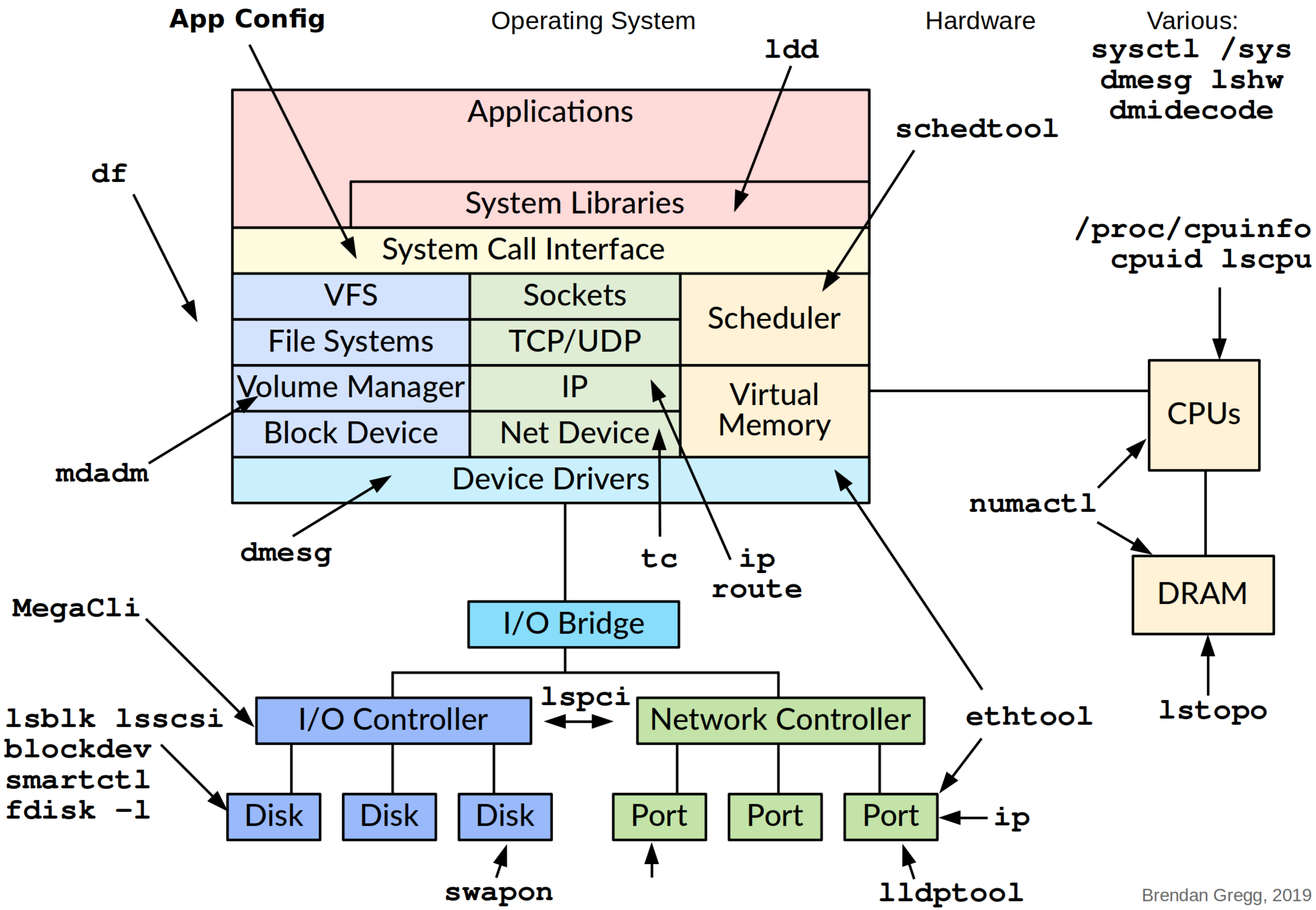
```
# showboost
Base CPU MHz : 2500
Set CPU MHz  : 2500
Turbo MHz(s) : 3100 3200 3300 3500
Turbo Ratios : 124% 128% 132% 140%
CPU 0 summary every 1 seconds...

TIME       C0_MCYC      C0_ACYC        UTIL  RATIO    MHz
23:39:07   1618910294   89419923        64%     5%    138
23:39:08   1774059258   97132588        70%     5%    136
23:39:09   2476365498   130869241       99%     5%    132
^C
```

- Uses MSRs. Can also use PMCs for this.
- Also see turbostat.

https://github.com/brendangregg/msr-cloud-tools

Also: Static Performance Tuning Tools



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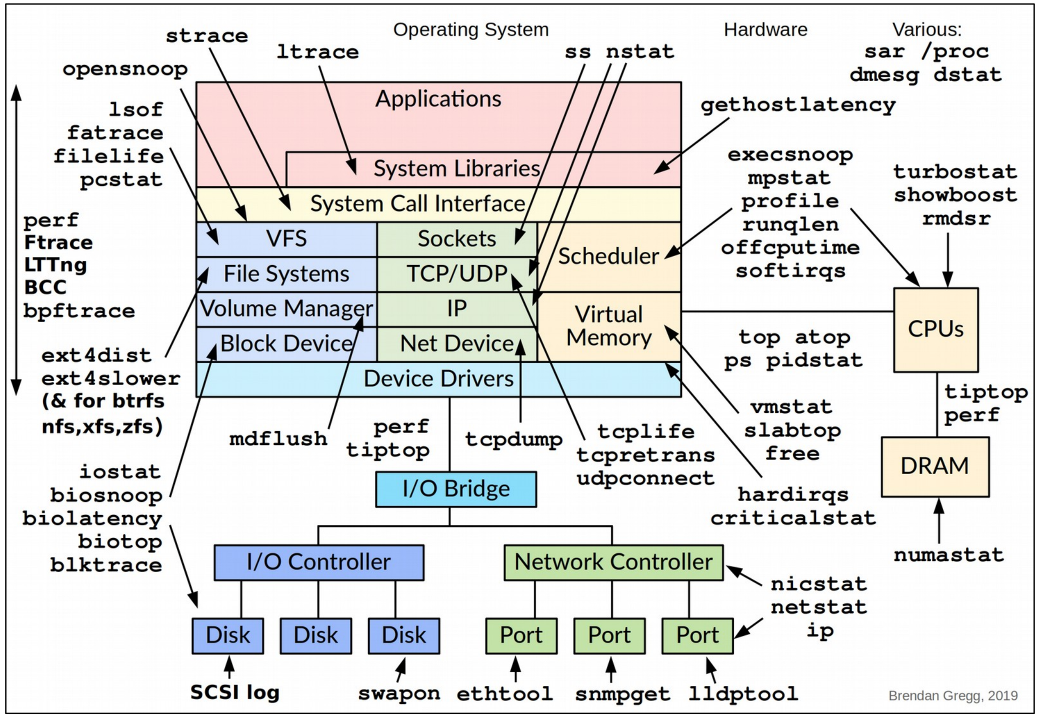
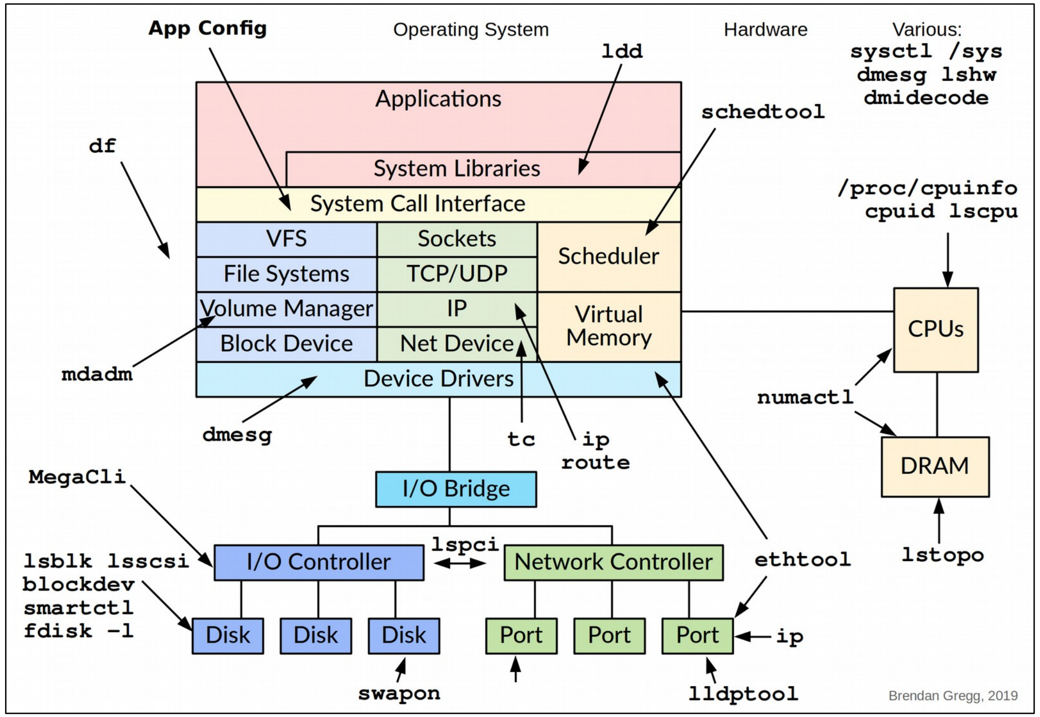
Where do you start...and stop?



Workload Observability



Static Configuration

2. Methodologies

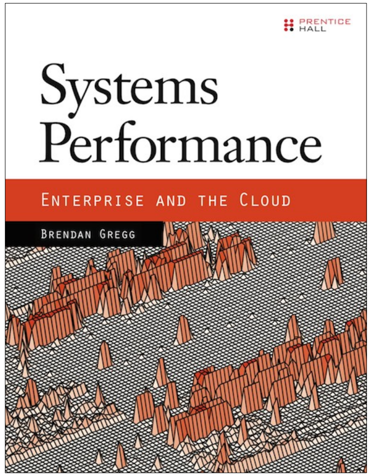
Anti-Methodologies

- 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
- Workload characterization
- Many others:
  - Resource analysis
  - Workload analysis
  - Drill-down analysis
  - CPU profile method
  - Off-CPU analysis
  - Static performance tuning
  - 5 whys

  …



Linux Perf Analysis in 60s

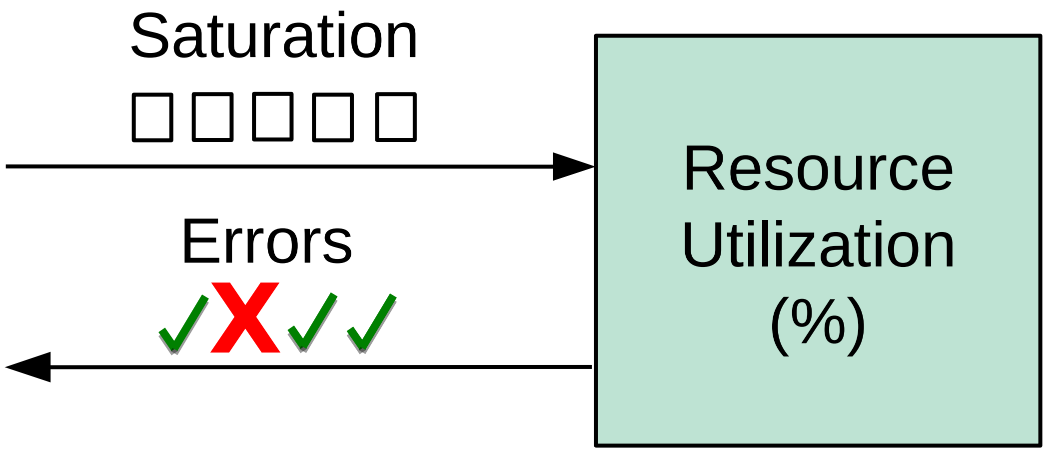
1. `uptime` → load averages
2. `dmesg -T | tail` → kernel errors
3. `vmstat 1` → overall stats by time
4. `mpstat -P ALL 1` → CPU balance
5. `pidstat 1` → process usage
6. `iostat -xz 1` → disk I/O
7. `free -m` → memory usage
8. `sar -n DEV 1` → network I/O
9. `sar -n TCP,ETCP 1` → TCP stats
10. `top`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

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

USE Method

For every resource, check:

1. **Utilization**
2. **Saturation**
3. **Errors**



For example, CPUs:

- Utilization: time busy
- Saturation: run queue length or latency
- Errors: ECC errors, etc.

Start with the questions, then find the tools

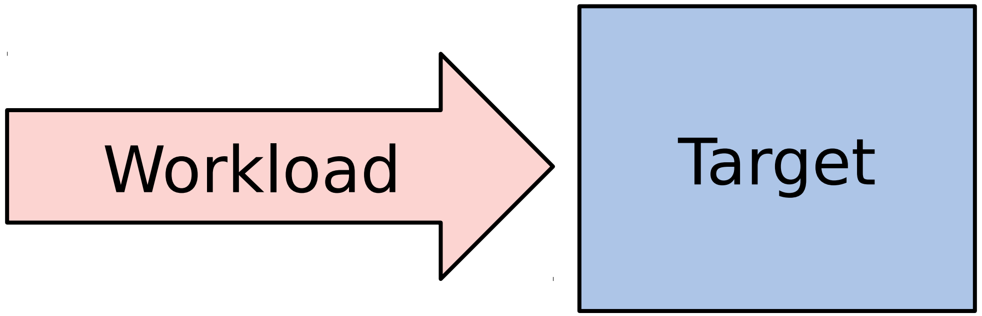
Can be applied to hardware and software (cgroups)

Workload Characterization

Analyze workload characteristics, not resulting performance

For example, CPUs:

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



3. Benchmarking

~100% of benchmarks are wrong

The energy needed to refute benchmarks
is orders of magnitude bigger than
to run them (so, no one does)

Benchmarking

- An experimental analysis activity
  - Try observational analysis first; benchmarks can perturb
- Benchmarking is error prone:
  - Testing the wrong target
    - eg, FS cache I/O instead of disk I/O
  - Choosing the wrong target
    - eg, disk I/O instead of FS cache I/O
  - Invalid results
    - eg, bugs
  - Misleading results:
    - you benchmark A,
      but actually measure B,
      and conclude you measured C

caution: benchmarking

Benchmark Examples

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

kitchen sink benchmarks

If your product's chances of winning a benchmark are 50/50, you'll usually lose

Benchmark paradox

caution: despair

http://www.brendangregg.com/blog/2014-05-03/the-benchmark-paradox.html

Solution: Active Benchmarking

- Root cause analysis while the benchmark runs
  - Use the earlier observability tools
  - Identify the limiter (or suspect) and include it with the results
- For any given benchmark, ask: 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 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

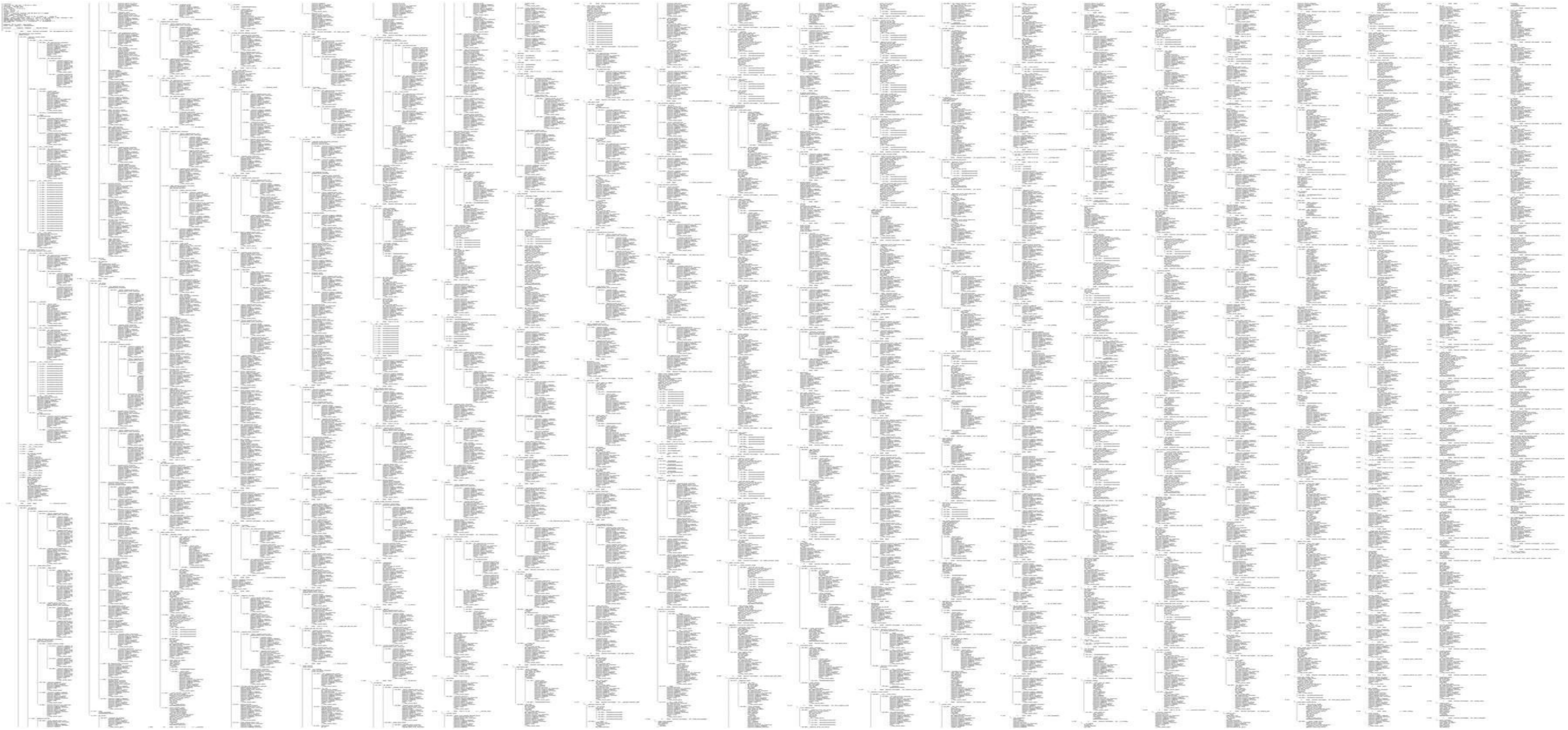
perf: CPU profiling

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

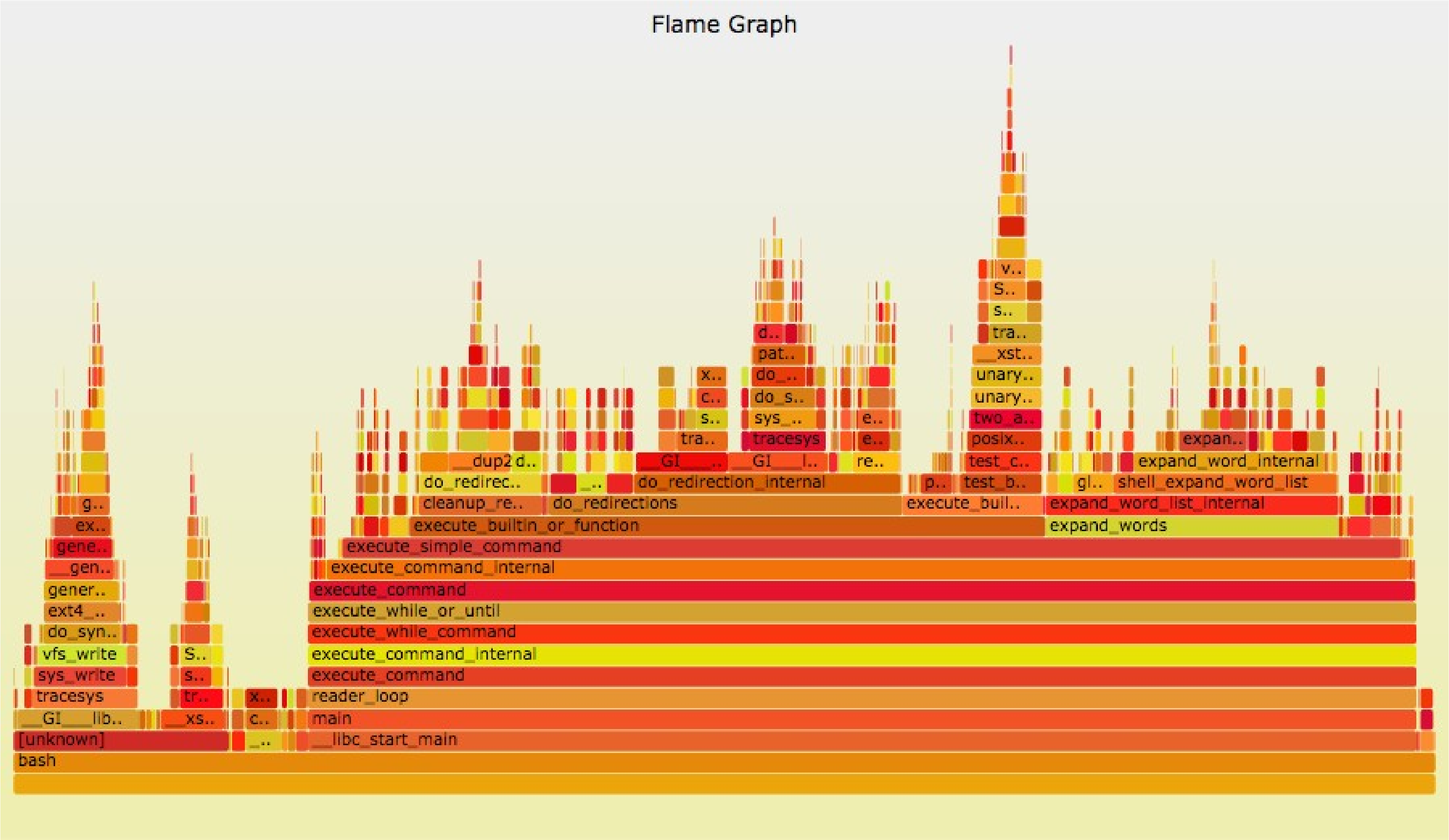
```
# perf record -F 99 -ag -- sleep 30
[ perf record: Woken up 9 times to write data ]
[ perf record: Captured and wrote 2.745 MB perf.data (~119930 samples) ]
# perf report -n --stdio
1.40%   162             java  [kernel.kallsyms]       [k] _raw_spin_lock

          |
          --- _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…]
```

Full "perf report" Output

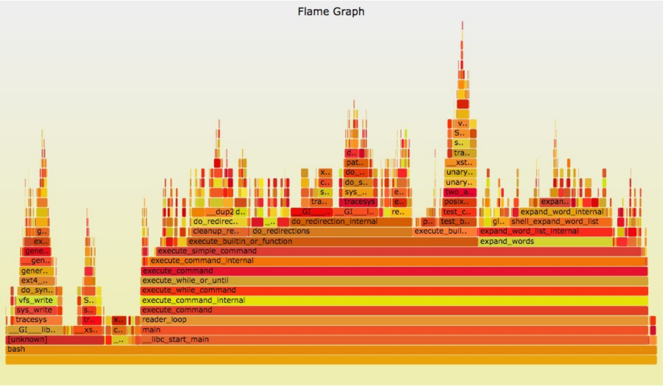


… as a Flame Graph



Flame Graphs

- Visualizes a collection of stack traces
  - **x-axis**: alphabetical stack sort, to maximize merging
  - **y-axis**: stack depth
  - **color**: random (default), or a dimension
- Perl + SVG + JavaScript
  - https://github.com/brendangregg/FlameGraph
  - Takes input from many different profilers
  - Multiple d3 versions are being developed
- References:
  - http://www.brendangregg.com/FlameGraphs/cpuflamegraphs.html
  - http://queue.acm.org/detail.cfm?id=2927301
  - "The Flame Graph" CACM, June 2016



Linux CPU Flame Graphs

Linux 2.6+, via perf:

```
git clone --depth 1 https://github.com/brendangregg/FlameGraph
cd FlameGraph
perf record -F 99 -a –g -- sleep 30
perf script --header > out.perf01
./stackcollapse-perf.pl < out.perf01 |./flamegraph.pl > perf.svg
```

These files can be read using FlameScope

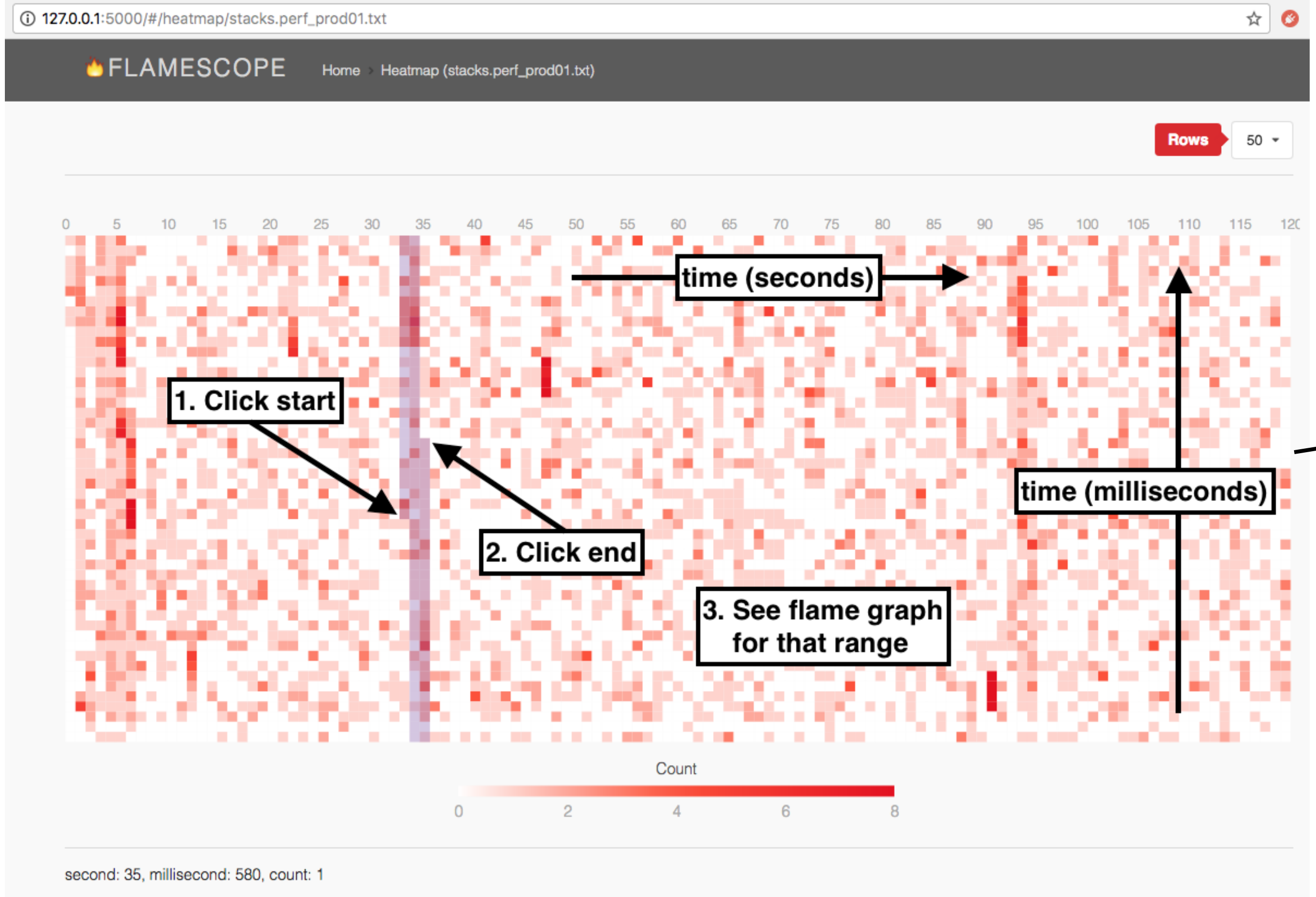
Linux 4.9+, via BPF:

```
git clone --depth 1 https://github.com/brendangregg/FlameGraph
git clone --depth 1 https://github.com/iovisor/bcc
./bcc/tools/profile.py -dF 99 30 | ./FlameGraph/flamegraph.pl > perf.svg
```

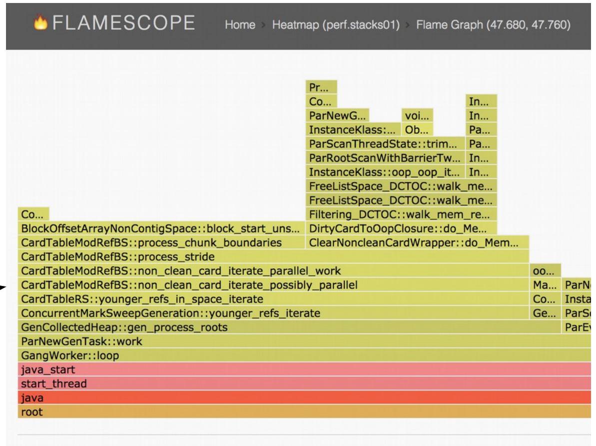
– Most efficient: no perf.data file, summarizes in-kernel

FlameScope

- Analyze variance, perturbations



Subsecond-offset heat map



Flame graph

https://github.com/Netflix/flamescope

perf: Counters

- Performance Monitoring Counters (PMCs):

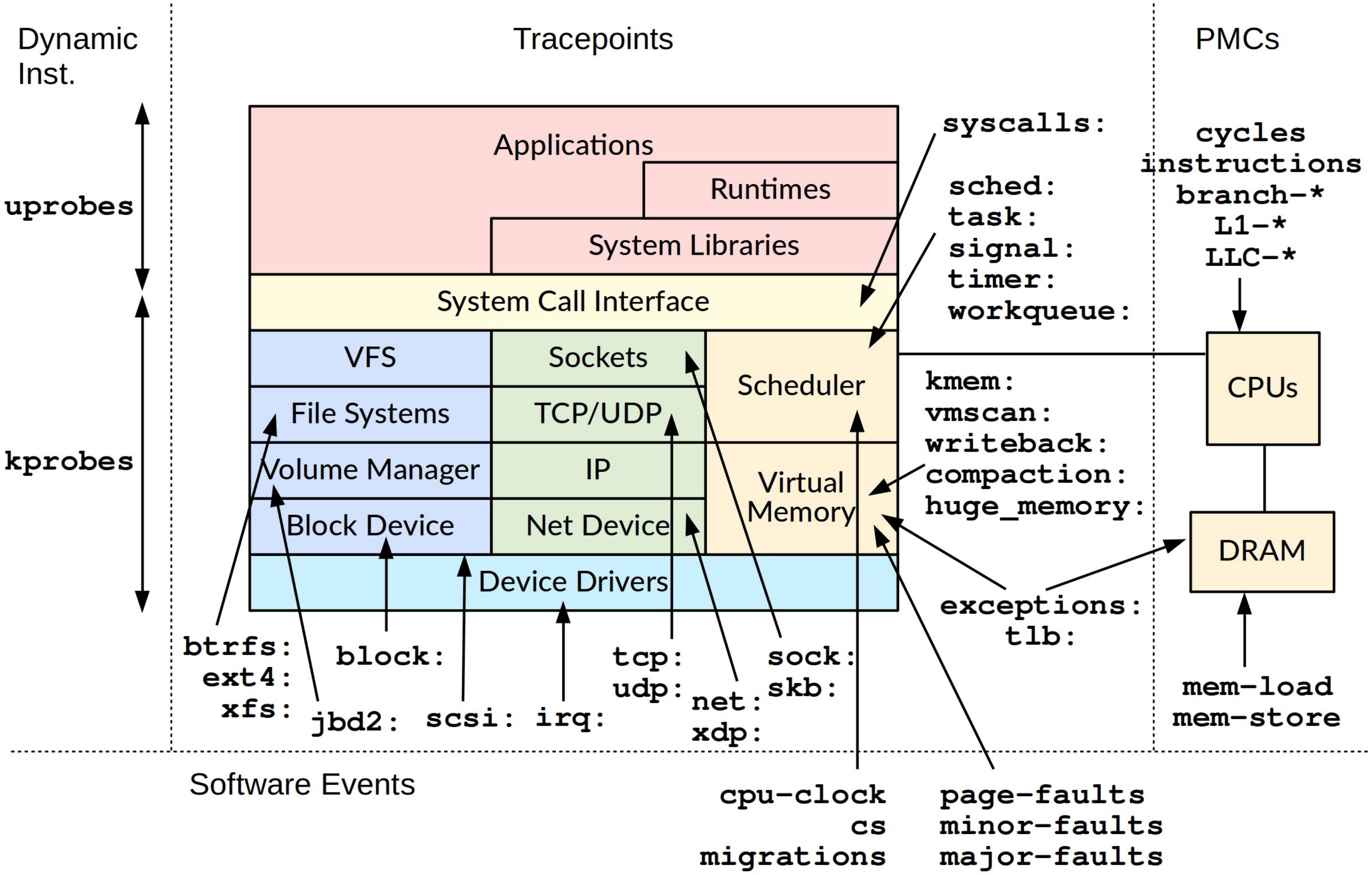
```
$ perf list | grep –i hardware
  cpu-cycles OR cycles                                [Hardware event]
  stalled-cycles-frontend OR idle-cycles-frontend     [Hardware event]
  stalled-cycles-backend OR idle-cycles-backend       [Hardware event]
  instructions                                        [Hardware event]
[…]
  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]
```

- Measure instructions-per-cycle (IPC) and CPU stall types
- PMCs only enabled for some cloud instance types

My front-ends, incl. pmcarch:
https://github.com/brendangregg/pmc-cloud-tools

5. Tracing

Linux Tracing Events



Source: http://www.brendangregg.com/bpf-performance-tools-book.html, Brendan Gregg, 2019

Tracing Stack

add-on tools:	`trace-cmd`, perf-tools, bcc, bpftrace
front-end tools:	`perf`
tracing frameworks:	Ftrace, perf_events, BPF
back-end instrumentation:	tracepoints, kprobes, uprobes

in Linux

BPF enables a new class of
custom, **efficient**, and **production safe**
performance analysis tools

Ftrace: perf-tools funccount

- Built-in kernel tracing capabilities, added by Steven Rostedt and others since Linux 2.6.27

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

FUNC                                              COUNT
[...]
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
```

- Also see trace-cmd

perf: Tracing Tracepoints

- perf was introduced earlier; it is also a powerful tracer

In-kernel counts (efficient)

```
# perf stat -e block:block_rq_complete -a sleep 10
 Performance counter stats for 'system wide':

                91      block:block_rq_complete
```

Dump & post-process

```
# 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] 2083345.722857: 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]
[...]
```

http://www.brendangregg.com/perf.html
https://perf.wiki.kernel.org/index.php/Main_Page

BCC/BPF: 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
[…]
```

- Better indicator of application pain than disk I/O
- Measures & filters in-kernel for efficiency using BPF

https://github.com/iovisor/bcc

bpftrace: one-liners

- Block I/O (disk) events by type; by size & comm:

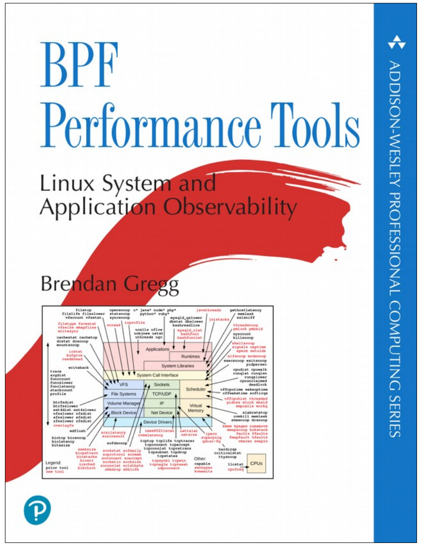
```
# bpftrace -e 't:block:block_rq_issue { @[args->rwbs] = count(); }'
Attaching 1 probe...
^C
@[WS]: 2
@[RM]: 12
@[RA]: 1609
@[R]: 86421
```

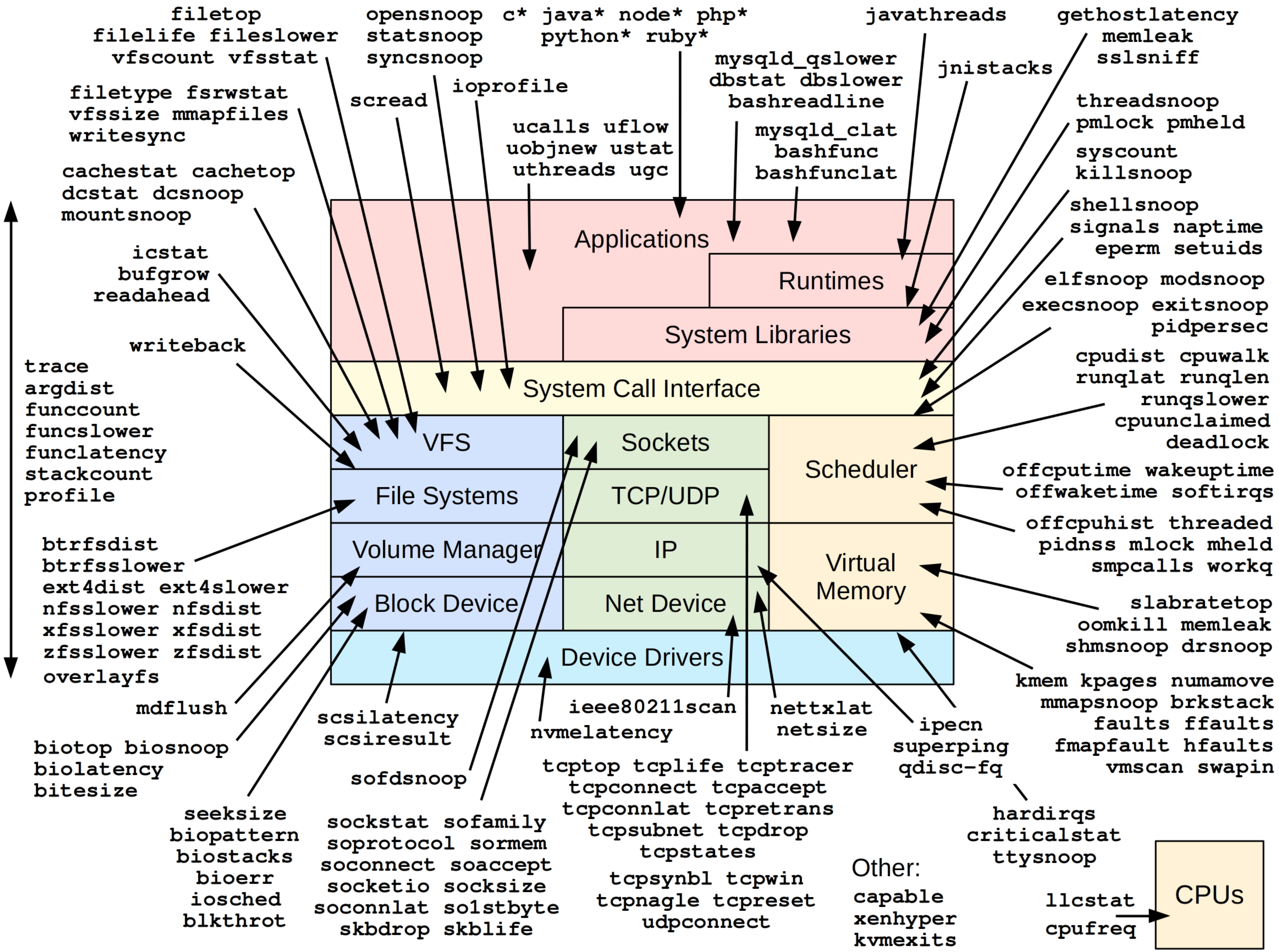
```
# bpftrace -e 't:block:block_rq_issue { @bytes[comm] = hist(args->bytes); }'
Attaching 1 probe...
^C
@bytes[dmcrypt_write]:
[4K, 8K)              68 |@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@|
[8K, 16K)             35 |@@@@@@@@@@@@@@@@@@@@@@@@@@                          |
[16K, 32K)             4 |@@@                                                 |
[32K, 64K)             1 |                                                    |
[64K, 128K)            2 |@                                                   |
[...]
```

https://github.com/iovisor/bpftrace

BPF Perf Tools (2019)

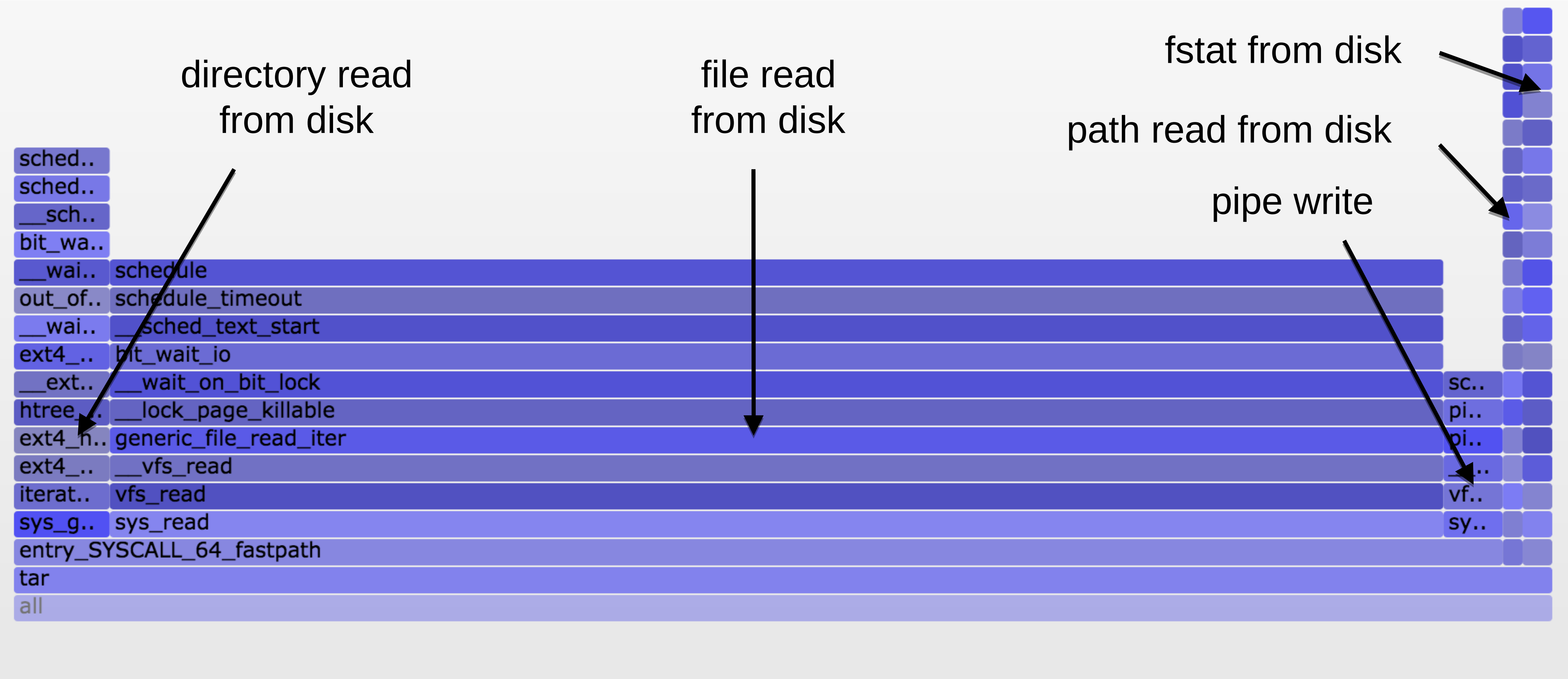
BCC & bpftrace repos contain many of these. The book has them all.





Off-CPU Analysis

- Explain all blocking events. High-overhead: needs BPF.



6. Tuning

Ubuntu Bionic Tuning: Late 2019 (1/2)

- CPU
  schedtool –B PID
  disable Ubuntu apport (crash reporter)
  upgrade to Bionic (scheduling improvements)
- Virtual Memory
  vm.swappiness = 0 # from 60
- Memory
  echo madvise > /sys/kernel/mm/transparent_hugepage/enabled
  kernel.numa_balancing = 0
- 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 1 # or 2
  /sys/block/*/queue/scheduler kyber
  /sys/block/*/queue/nr_requests 256
  /sys/block/*/queue/read_ahead_kb 128
  mdadm –chunk=64 …

Ubuntu Bionic Tuning: Late 2019 (2/2)

- Networking

```
net.core.default_qdisc = fq
net.core.netdev_max_backlog = 5000
net.core.rmem_max = 16777216
net.core.somaxconn = 1024
net.core.wmem_max = 16777216
net.ipv4.ip_local_port_range = 10240 65535
net.ipv4.tcp_abort_on_overflow = 1    # maybe
net.ipv4.tcp_congestion_control = bbr
net.ipv4.tcp_max_syn_backlog = 8192
net.ipv4.tcp_rmem = 4096 12582912 16777216   # or 8388608 ...
net.ipv4.tcp_slow_start_after_idle = 0
net.ipv4.tcp_syn_retries = 2
net.ipv4.tcp_tw_reuse = 1
net.ipv4.tcp_wmem = 4096 12582912 16777216   # or 8388608 ...
```

- Hypervisor

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

  Plus use AWS Nitro

- Other

```
net.core.bpf_jit_enable = 1
sysctl -w kernel.perf_event_max_stack=1000
```

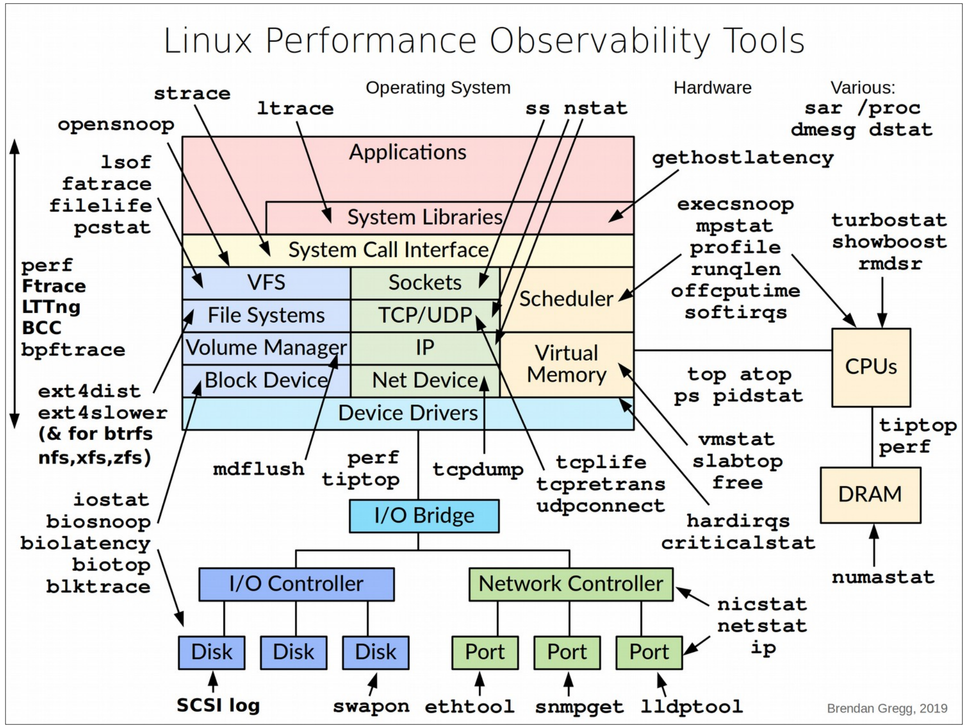
Takeaways

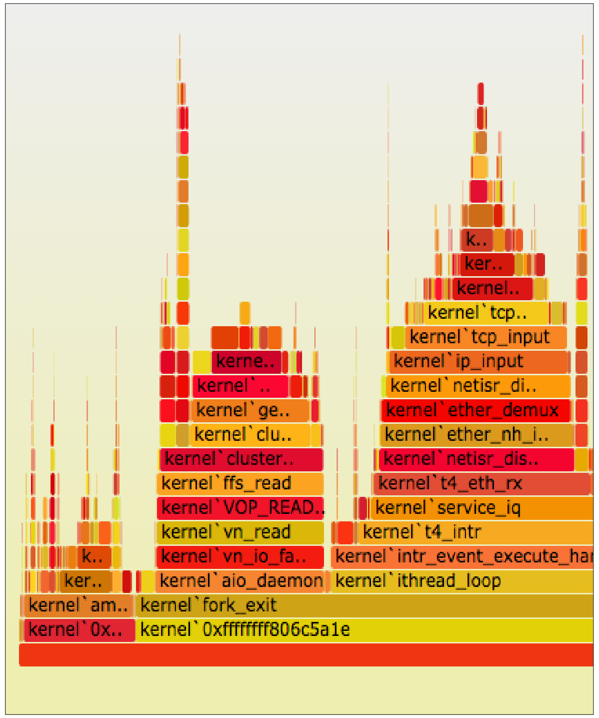
Systems Performance is:

Observability, Methodologies, Benchmarking, Profiling, Tracing, Tuning

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





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:
- https://perf.wiki.kernel.org/index.php/Main_Page
- http://www.brendangregg.com/perf.html

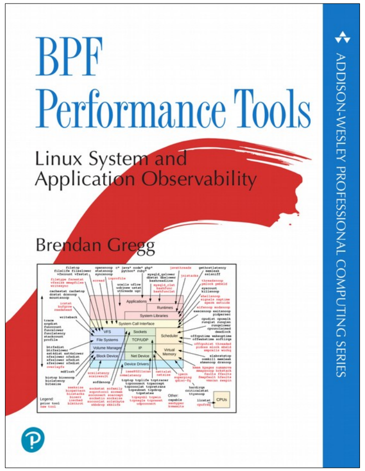
Linux ftrace:
- https://www.kernel.org/doc/Documentation/trace/ftrace.txt
- https://github.com/brendangregg/perf-tools

Linux BPF:
- http://www.brendangregg.com/ebpf.html
- http://www.brendangregg.com/bpf-performance-tools-book.html
- https://github.com/iovisor/bcc
- https://github.com/iovisor/bpftrace

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

Flame Graphs & FlameScope:
- http://www.brendangregg.com/FlameGraphs/cpuflamegraphs.html
- http://queue.acm.org/detail.cfm?id=2927301
- https://github.com/Netflix/flamescope

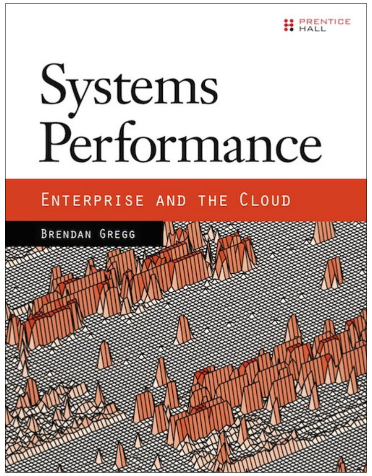
MSRs and PMCs
- https://github.com/brendangregg/msr-cloud-tools
- https://github.com/brendangregg/pmc-cloud-tools



BPF Performance Tools

Thanks

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



Look out for 2nd Ed.