LINUXCON
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Linux Performance Tools

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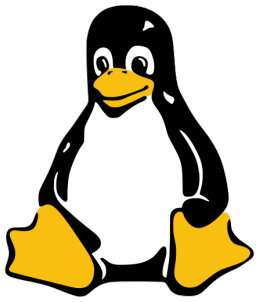
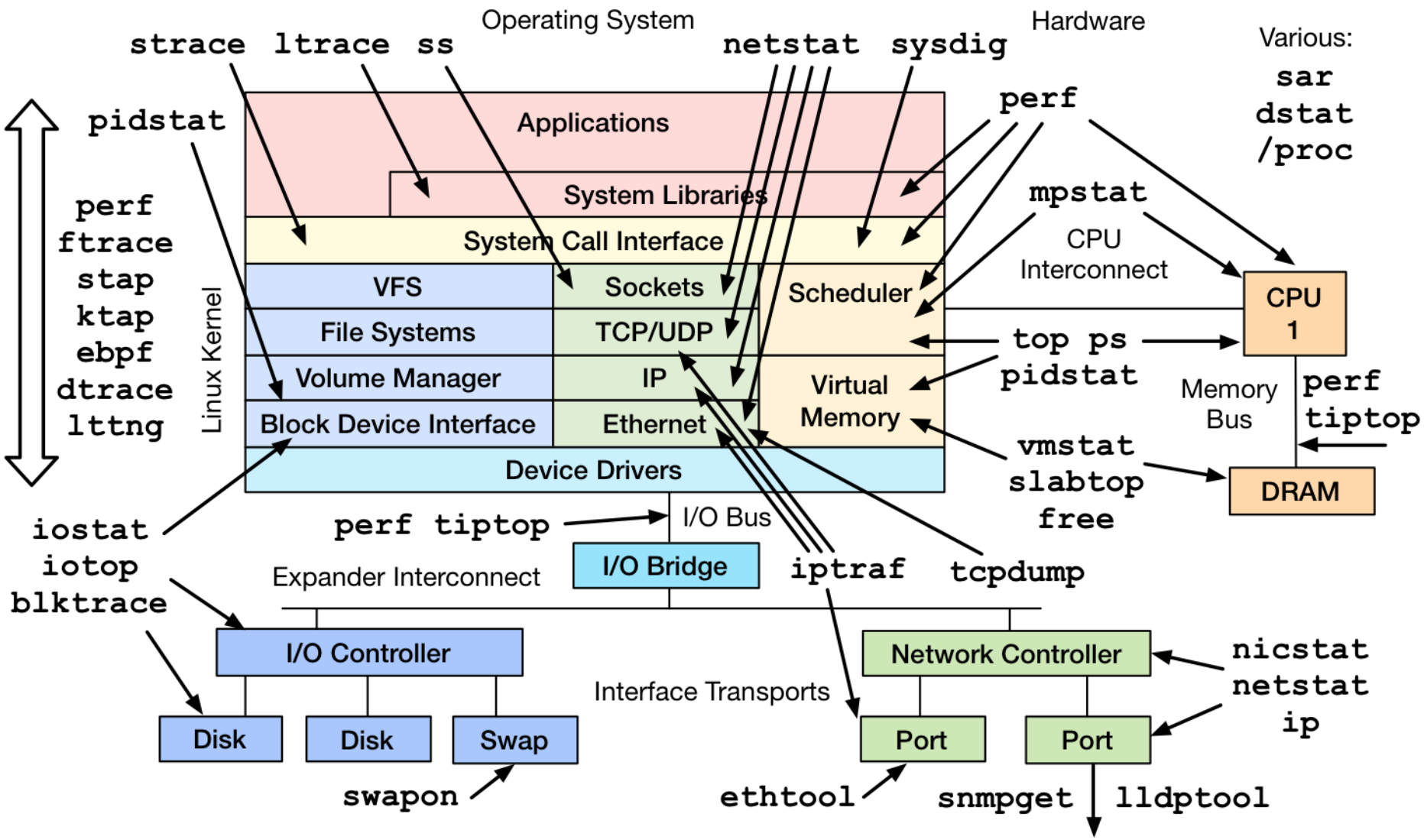


NETFLIX

A quick tour of many tools…

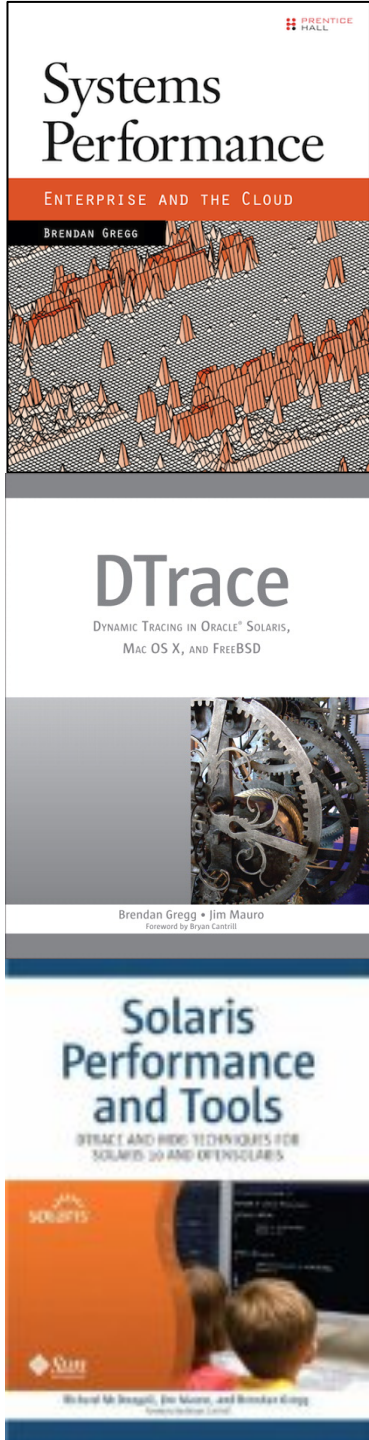


NETFLIX

- Massive AWS EC2 Linux cloud
  - Tens of thousands of instances
  - Autoscale by ~3k each day
  - CentOS and Ubuntu
- FreeBSD for content delivery
  - Approx 33% of US Internet traffic at night
- Performance is critical
  - Customer satisfaction: >50M subscribers
  - $$$ price/performance
  - Develop tools for cloud-wide analysis; use server tools as needed

Brendan Gregg

- Senior Performance Architect, Netflix
  - Linux and FreeBSD performance
  - Performance Engineering team (@coburnw)
- Recent work:
  - Linux perf-tools, using ftrace & perf_events
  - Systems Performance, Prentice Hall, 2014
- Previous work includes:
  - USE Method, flame graphs, latency & utilization heat maps, DTraceToolkit, iosnoop and others on OS X, ZFS L2ARC
- Twitter @brendangregg (these slides)



Agenda

- Methodologies & Tools
- Tool Types:
  - Observability
  - Benchmarking
  - Tuning
- Tracing

Methodologies & Tools

Methodologies & Tools

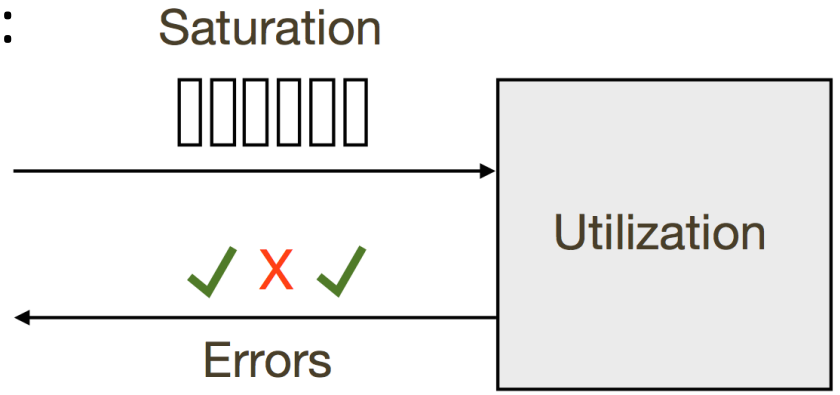
- There are dozens of performance tools for Linux
  - Packages: sysstat, procps, coreutils, …
  - Commercial products
- Methodologies can provide guidance for choosing and using tools effectively

Anti-Methodologies

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

Methodologies

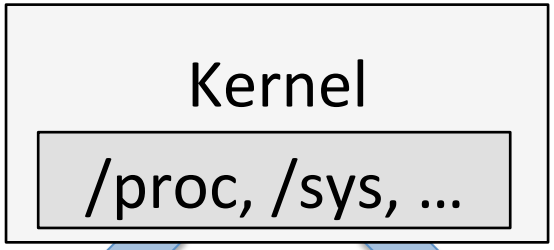
- For example, the USE Method:
  - For every resource, check:
    - Utilization
    - Saturation
    - Errors



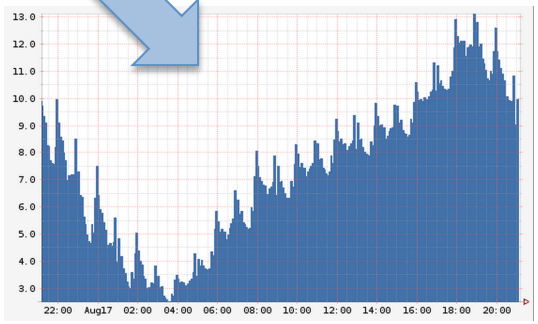
- Other methods include:
  - Workload characterization, drill-down analysis, event tracing, baseline stats, static performance tuning, …
- Start with the questions, then find the tools

Command Line Tools

- Useful to study even if you never use them: GUIs and commercial products often use the same interfaces




```
$ vmstat 1
procs -----------memory---------- ---swap-- …
 r  b   swpd   free   buff  cache   si   so …
 9  0      0 29549320  29252 9299060    0    …
 2  0      0 29547876  29252 9299332    0    …
 4  0      0 29548124  29252 9299460    0    …
 5  0      0 29548840  29252 9299592    0    …
```

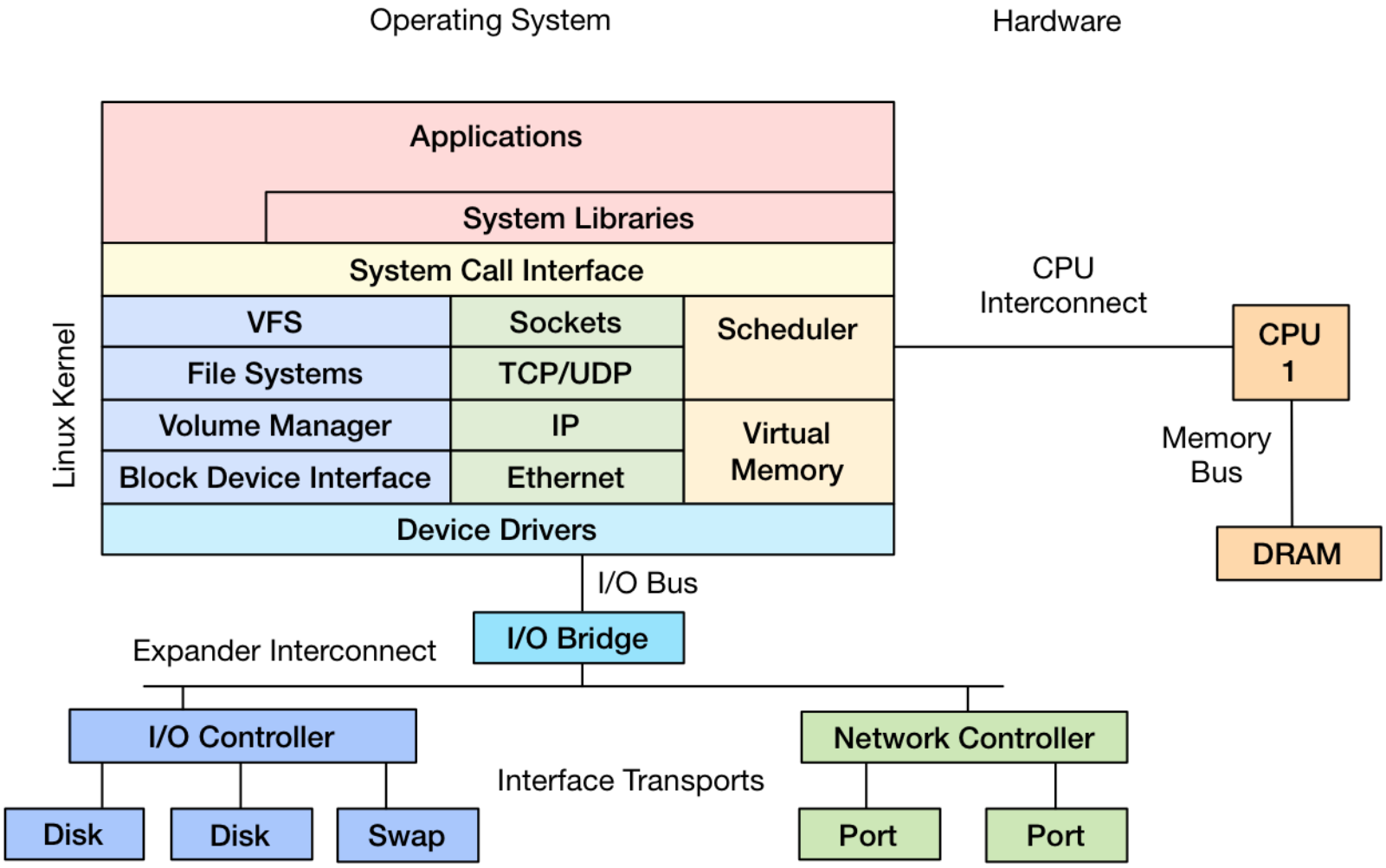


Tool Types

Type	Characteristic
Observability	Watch. Safe, usually, depending on resource overhead.
Benchmarking	Load test. Caution: production tests can cause issues due to contention.
Tuning	Change. Danger: changes could hurt performance, now or later with load.

Observability Tools

How do you measure these?



Observability Tools: Basic

- uptime
- top (or htop)
- ps
- vmstat
- iostat
- mpstat
- free

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 with 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

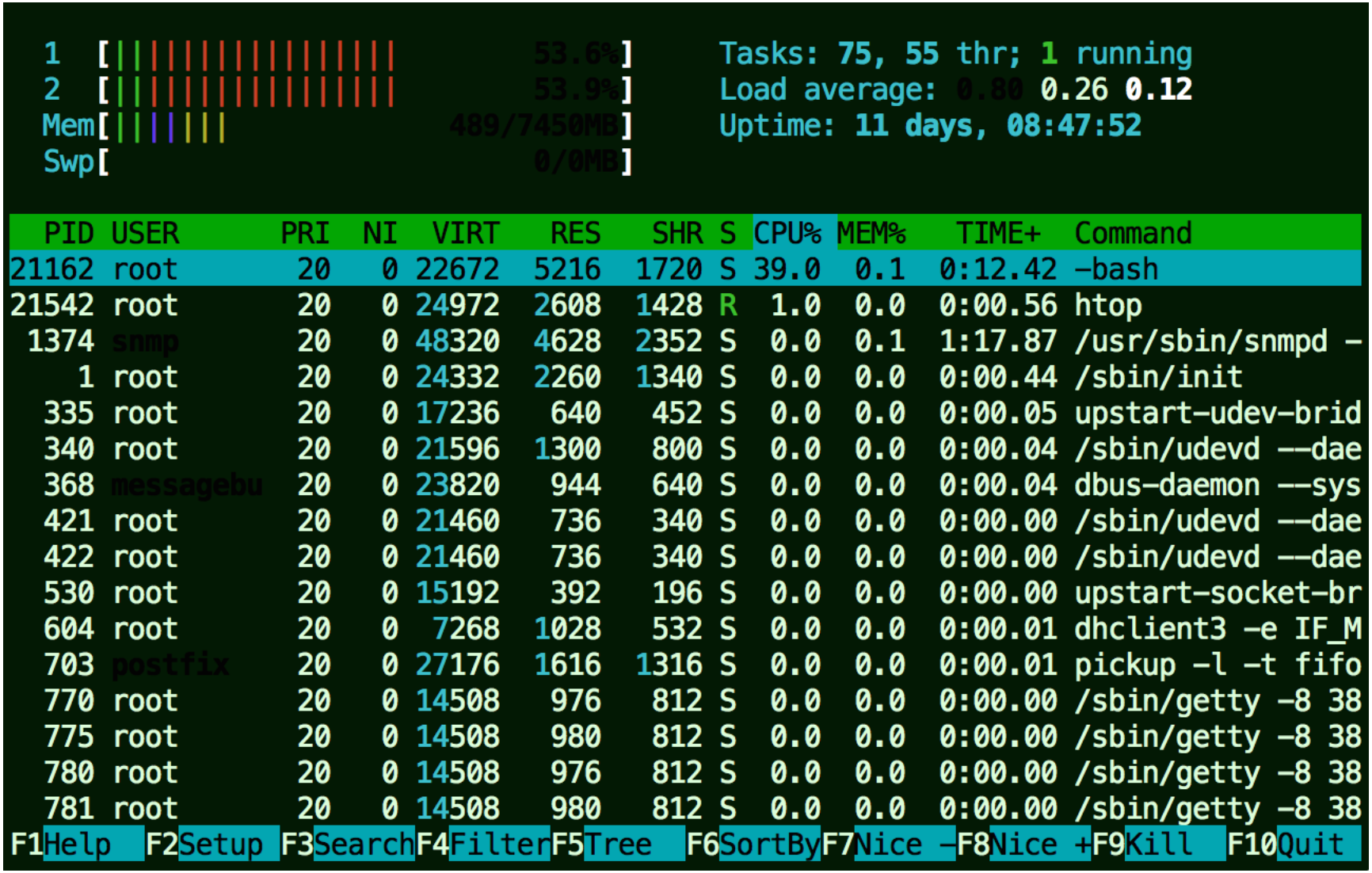
top (or htop)

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

ps

- Process status listing (eg, “ASCII art forest”):

```
$ ps -ef f
UID          PID  PPID  C STIME TTY      STAT   TIME CMD
[…]
root        4546     1  0 11:08 ?        Ss     0:00 /usr/sbin/sshd -D
root       28261  4546  0 17:24 ?        Ss     0:00  \_ sshd: prod [priv]
prod       28287 28261  0 17:24 ?        S      0:00      \_ sshd: prod@pts/0
prod       28288 28287  0 17:24 pts/0    Ss     0:00          \_ -bash
prod        3156 28288  0 19:15 pts/0    R+     0:00              \_ ps -ef f
root        4965     1  0 11:08 ?        Ss     0:00 /bin/sh /usr/bin/svscanboot
root        4969  4965  0 11:08 ?        S      0:00  \_ svscan /etc/service
[…]
```

- Custom fields:

```
$ ps -eo user,sz,rss,minflt,majflt,pcpu,args
USER         SZ   RSS MINFLT MAJFLT %CPU COMMAND
root       6085  2272  11928     24  0.0 /sbin/init
[…]
```

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 →

mpstat

- Multi-processor statistics, per-CPU:

```
$ mpstat –P ALL 1
[…]
08:06:43 PM  CPU   %usr  %nice   %sys %iowait   %irq  %soft %steal %guest  %idle
08:06:44 PM  all  53.45   0.00   3.77    0.00   0.00   0.39   0.13   0.00  42.26
08:06:44 PM    0  49.49   0.00   3.03    0.00   0.00   1.01   1.01   0.00  45.45
08:06:44 PM    1  51.61   0.00   4.30    0.00   0.00   2.15   0.00   0.00  41.94
08:06:44 PM    2  58.16   0.00   7.14    0.00   0.00   0.00   1.02   0.00  33.67
08:06:44 PM    3  54.55   0.00   5.05    0.00   0.00   0.00   0.00   0.00  40.40
08:06:44 PM    4  47.42   0.00   3.09    0.00   0.00   0.00   0.00   0.00  49.48
08:06:44 PM    5  65.66   0.00   3.03    0.00   0.00   0.00   0.00   0.00  31.31
08:06:44 PM    6  50.00   0.00   2.08    0.00   0.00   0.00   0.00   0.00  47.92
[…]
```

- Look for unbalanced workloads, hot CPUs.

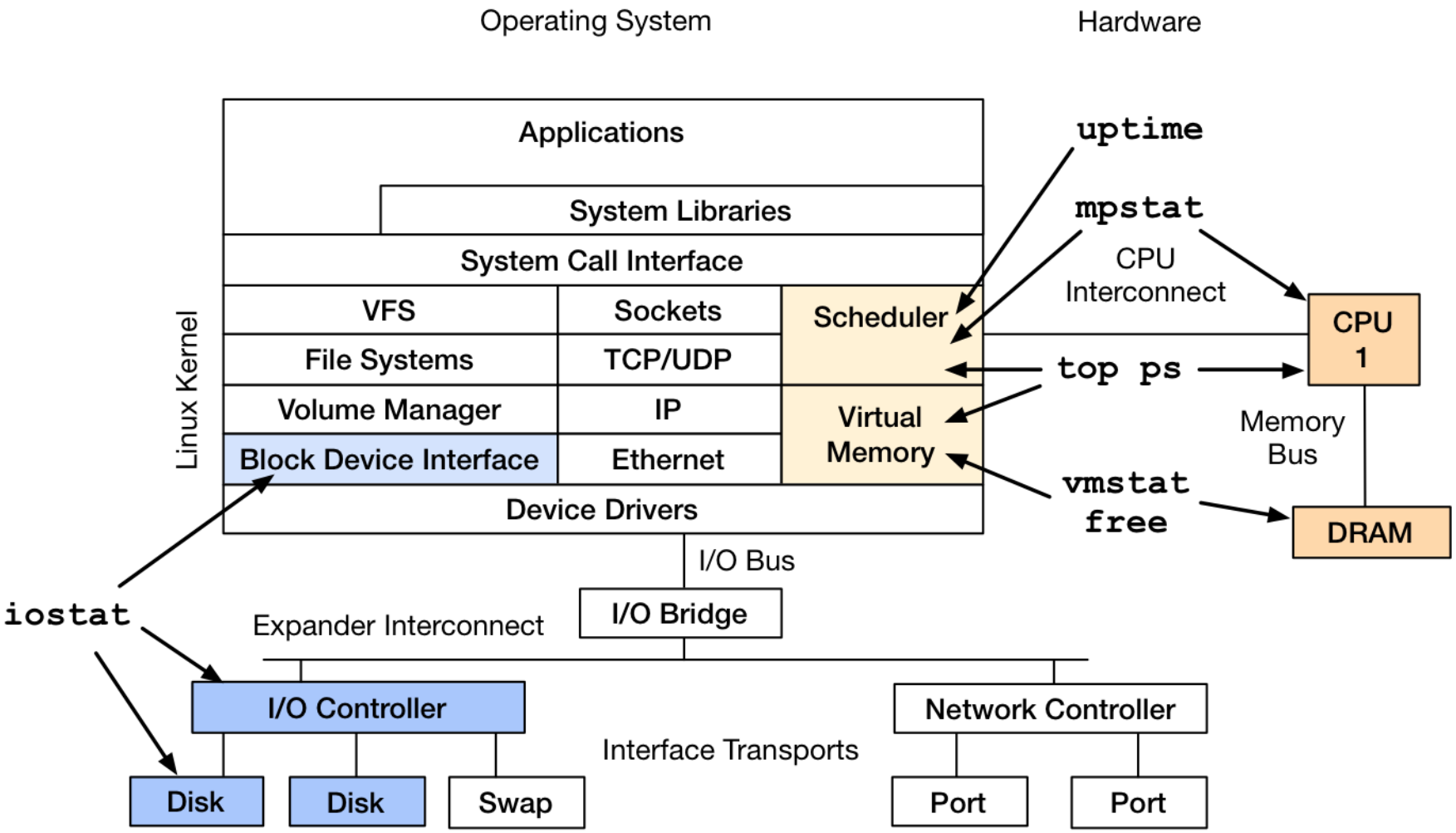
free

- 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

Observability Tools: Basic



Observability Tools: Intermediate

- strace
- tcpdump
- netstat
- nicstat
- pidstat
- swapon
- sar (and collectl, dstat, etc.)

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
[…]
```

nicstat

- Network interface stats, iostat-like output:

```
$ ./nicstat 1
    Time      Int   rKB/s   wKB/s   rPk/s   wPk/s    rAvs    wAvs %Util    Sat
21:21:43       lo   823.0   823.0   171.5   171.5  4915.4  4915.4  0.00   0.00
21:21:43     eth0    5.53    1.74   15.11   12.72   374.5   139.8  0.00   0.00
    Time      Int   rKB/s   wKB/s   rPk/s   wPk/s    rAvs    wAvs %Util    Sat
21:21:44       lo    0.00    0.00    0.00    0.00    0.00    0.00  0.00   0.00
21:21:44     eth0   20.42  3394.1   355.8   85.94   58.76 40441.3  0.00   0.00
    Time      Int   rKB/s   wKB/s   rPk/s   wPk/s    rAvs    wAvs %Util    Sat
21:21:45       lo  1409.1  1409.1   327.9   327.9  4400.8  4400.8  0.00   0.00
21:21:45     eth0   75.12  4402.3  1398.9  1513.2   54.99  2979.1  0.00   0.00
[…]
```

- Check network throughput and interface %util
- I wrote this years ago; Tim Cook ported to Linux

pidstat

- Very useful process stats. eg, by-thread, disk I/O:

```
$ pidstat -t 1
Linux 3.2.0-54 (db002-91befe03)  08/18/2014    _x86_64_  (8 CPU)

08:57:52 PM      TGID       TID    %usr %system  %guest    %CPU   CPU  Command
08:57:54 PM      5738         -  484.75   39.83    0.00  524.58     1  java
08:57:54 PM         -      5817    0.85    0.00    0.00    0.85     2  |__java
08:57:54 PM         -      5931    1.69    1.69    0.00    3.39     4  |__java
08:57:54 PM         -      5981    0.85    0.00    0.00    0.85     7  |__java
08:57:54 PM         -      5990    0.85    0.00    0.00    0.85     4  |__java
[…]
$ pidstat -d 1
[…]
08:58:27 PM       PID   kB_rd/s   kB_wr/s kB_ccwr/s  Command
08:58:28 PM      5738      0.00    815.69      0.00  java
[…]
```

- I usually prefer this over top(1)

swapon

- Show swap device usage:

```
$ swapon -s
Filename                        Type            Size    Used    Priority
/dev/sda3                       partition       5245212 284     -1
```

- If you have swap enabled…

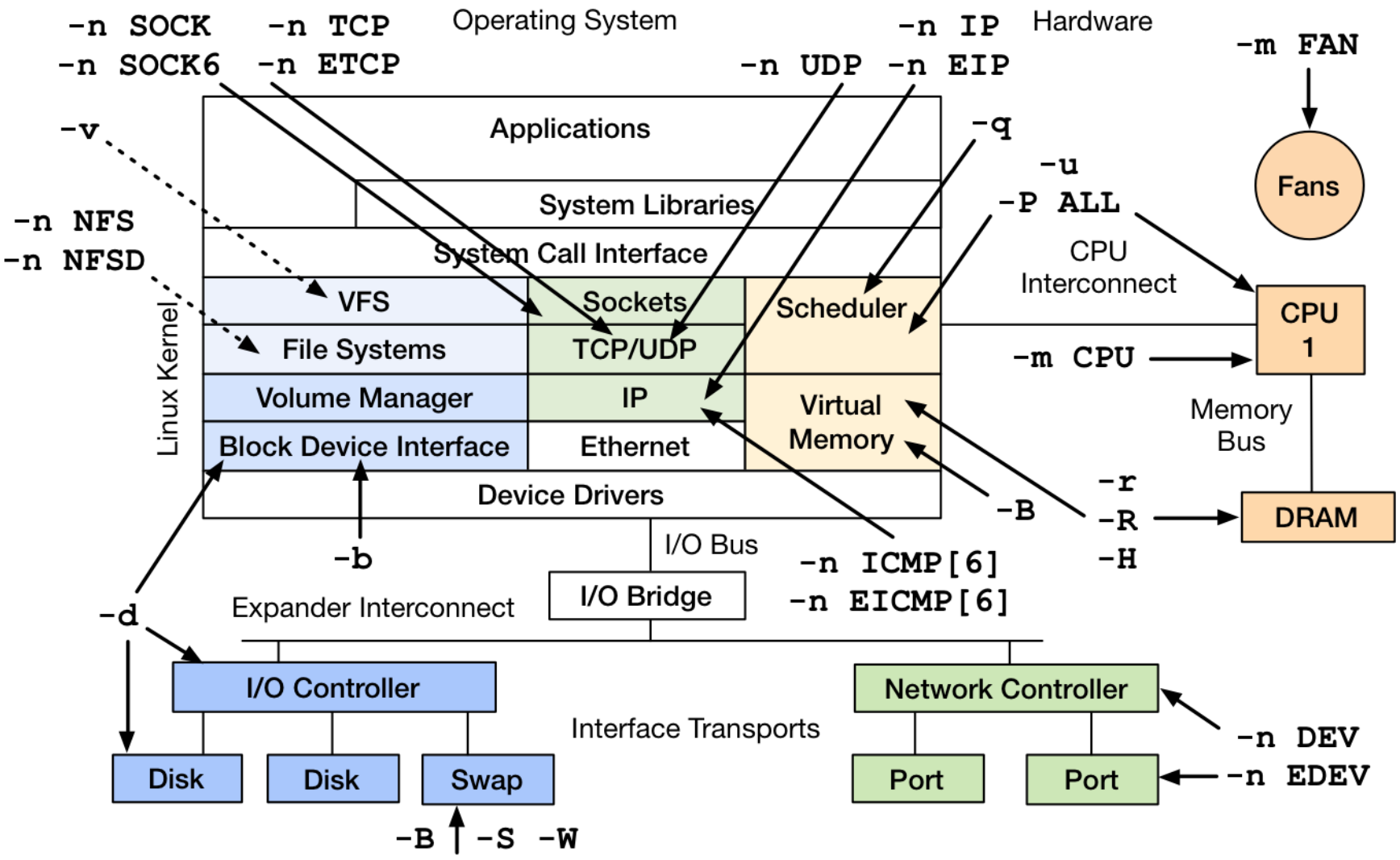
sar

- System Activity Reporter. Many stats, eg:

```
$ sar -n TCP,ETCP,DEV 1
Linux 3.2.55 (test-e4f1a80b)    08/18/2014    _x86_64_ (8 CPU)

09:10:43 PM  IFACE  rxpck/s  txpck/s   rxkB/s   txkB/s rxcmp/s txcmp/s  rxmcst/s
09:10:44 PM     lo    14.00    14.00     1.34     1.34    0.00    0.00      0.00
09:10:44 PM   eth0  4114.00  4186.00  4537.46 28513.24    0.00    0.00      0.00

09:10:43 PM  active/s passive/s    iseg/s    oseg/s
09:10:44 PM     21.00      4.00   4107.00  22511.00

09:10:43 PM  atmptf/s  estres/s retrans/s isegerr/s   orsts/s
09:10:44 PM      0.00      0.00     36.00      0.00      1.00
[…]
```

- Archive or live mode: (interval [count])
- Well designed. Header naming convention, logical groups: TCP, ETCP, DEV, EDEV, …

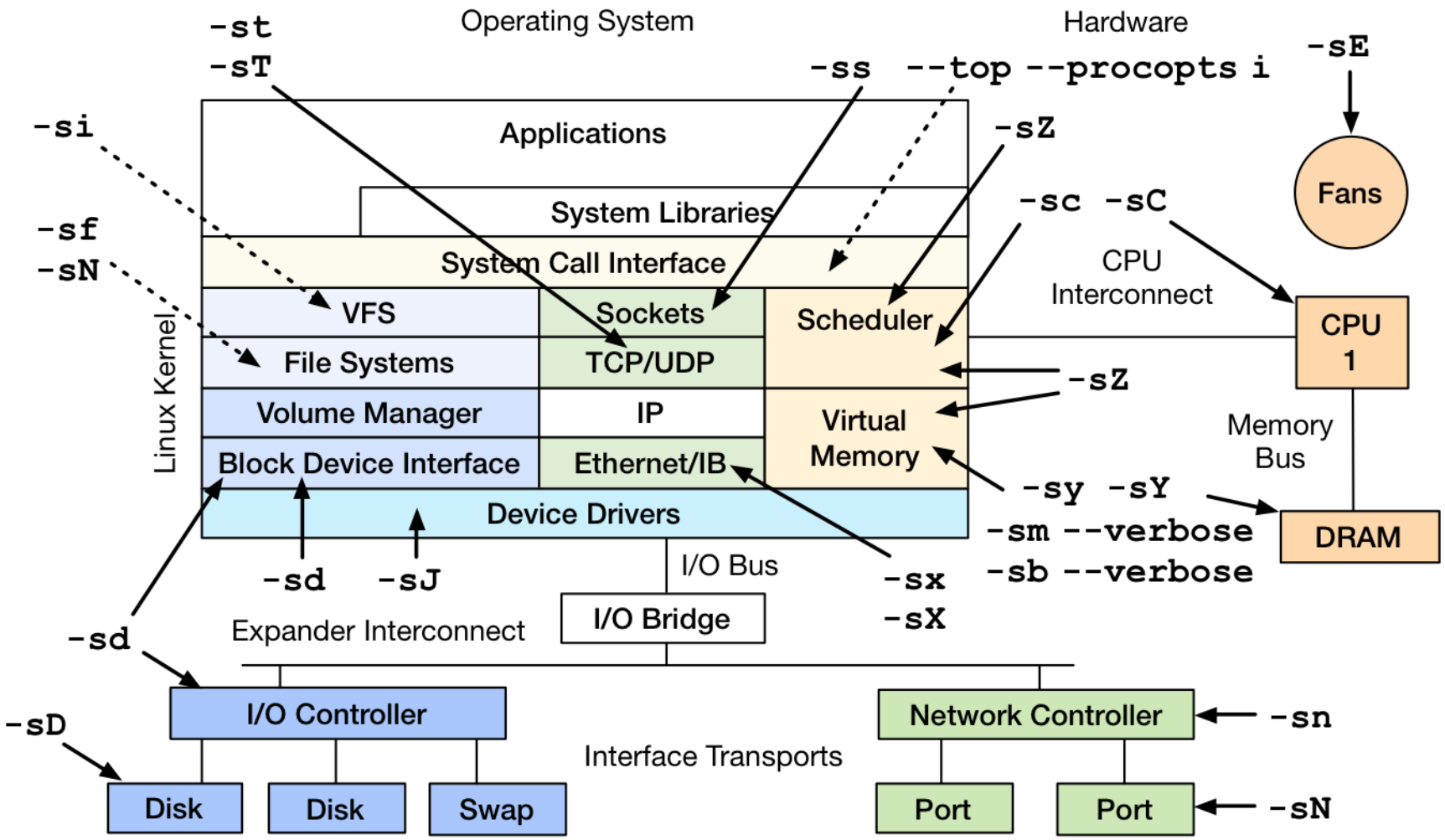
Observability: sar



collectl

- sar-like multitool
- Supports distributed environments
  - designed for HPC
- One ~6k line Perl program (hackable)
- Exposes /proc/PID/io syscr & syscw stats, so gets a dotted line to syscalls…

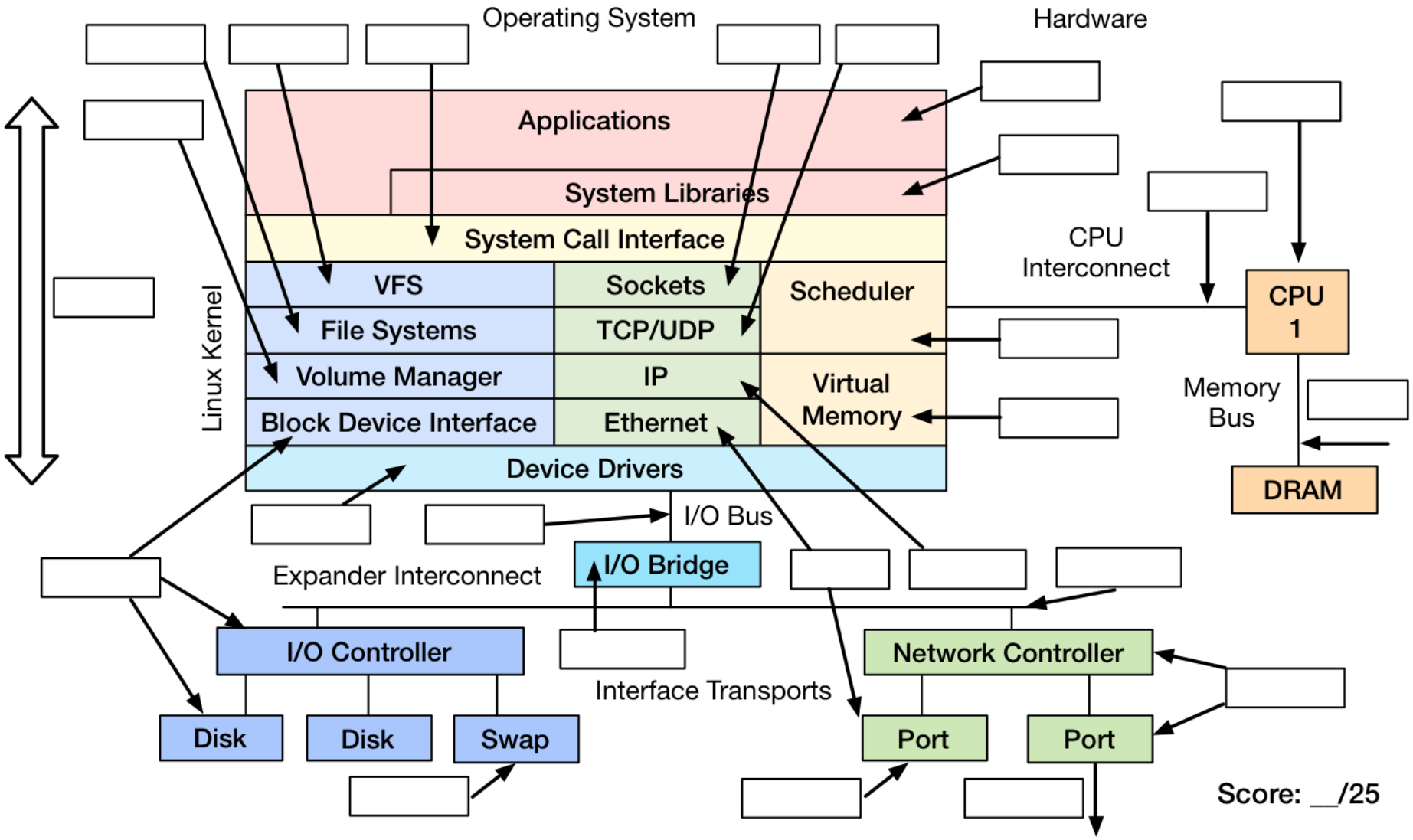
Observability: collectl



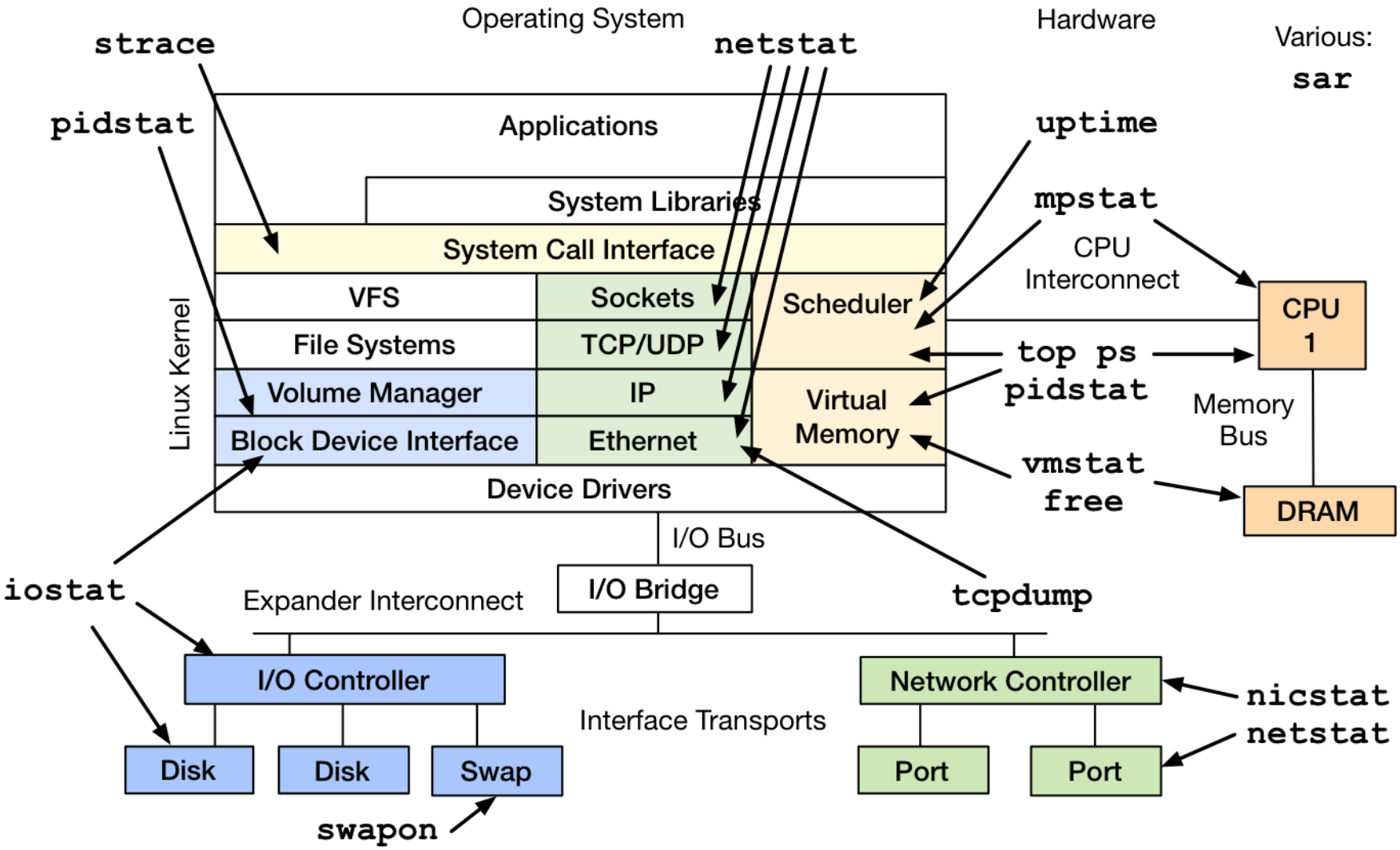
Other Tools

- With these measure-all-tools, the point isn't to use sar or collectl (or dstat or whatever); it's to have *a* way to measure everything you want
- In cloud environments, you are probably using a monitoring product, developed in-house or commercial. Same method applies…

How does your monitoring tool measure these?



Observability Tools: Intermediate



Advanced Observability Tools

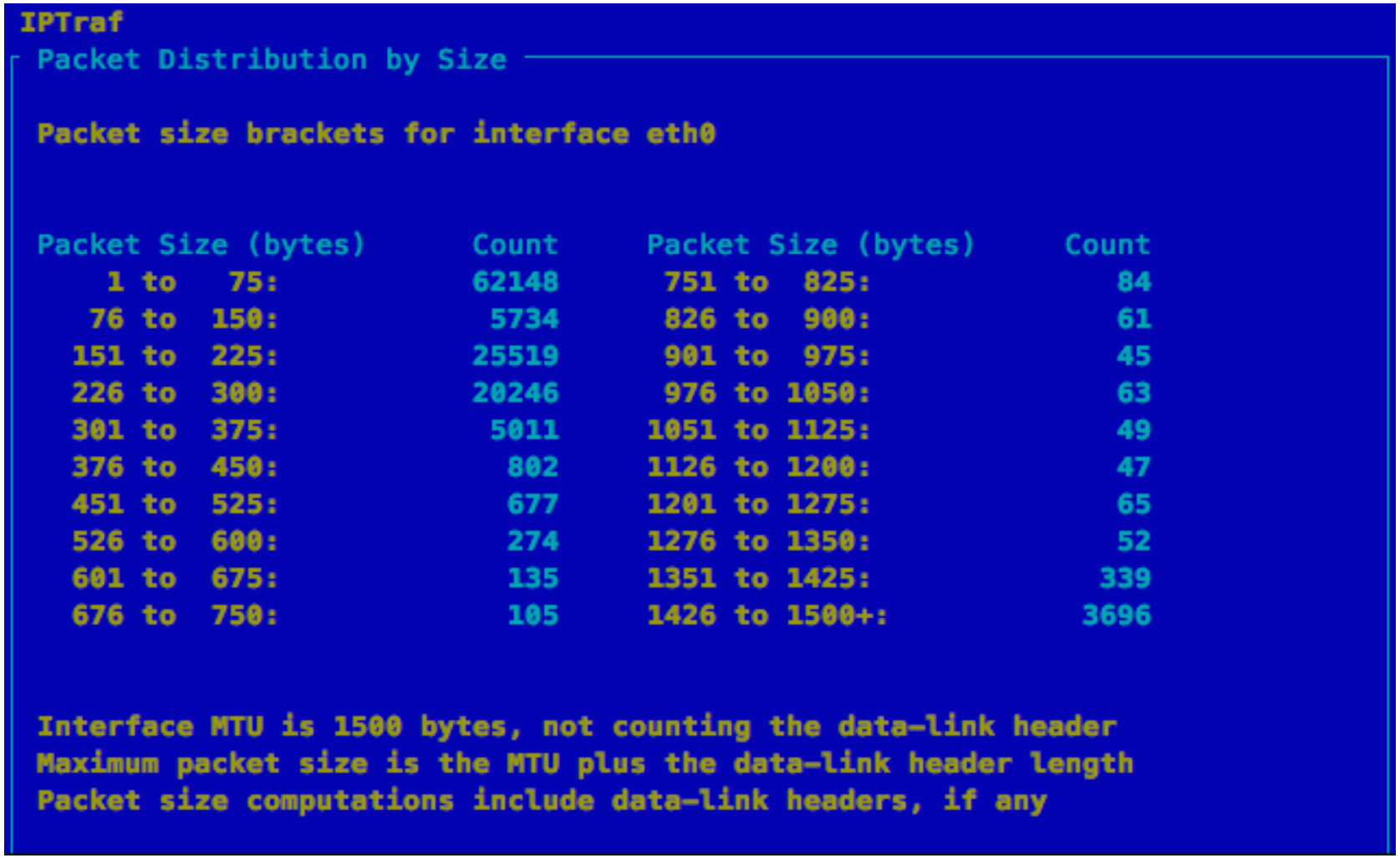
- Misc:
  - ltrace, ss, iptraf, ethtool, snmpget, lldptool, iotop, blktrace, slabtop, /proc
- CPU Performance Counters:
  - perf_events, tiptop
- Advanced Tracers:
  - perf_events, ftrace, eBPF, SystemTap, ktap, LTTng, dtrace4linux, sysdig
- Some selected demos…

ss

- More socket statistics:

```
$ ss -mop
State      Recv-Q Send-Q      Local Address:Port          Peer Address:Port
CLOSE-WAIT 1      0               127.0.0.1:42295            127.0.0.1:28527
users:(("apacheLogParser",2702,3))
     mem:(r1280,w0,f2816,t0)
ESTAB      0      0               127.0.0.1:5433             127.0.0.1:41312
timer:(keepalive,36min,0) users:(("postgres",2333,7))
     mem:(r0,w0,f0,t0)
[…]
$ ss –i
State      Recv-Q Send-Q      Local Address:Port          Peer Address:Port
CLOSE-WAIT 1      0               127.0.0.1:42295            127.0.0.1:28527
 cubic wscale:6,6 rto:208 rtt:9/6 ato:40 cwnd:10 send 145.6Mbps rcv_space:32792
ESTAB      0      0          10.144.107.101:ssh            10.53.237.72:4532
 cubic wscale:4,6 rto:268 rtt:71.5/3 ato:40 cwnd:10 send 1.5Mbps rcv_rtt:72
rcv_space:14480
[…]
```

iptraf


IPTraf
Packet Distribution by Size
Packet size brackets for interface eth0
Packet Size (bytes) Count Packet Size (bytes) Count
1 to 75: 62148 751 to 825: 84
76 to 150: 5734 826 to 900: 61
151 to 225: 25519 901 to 975: 45
226 to 300: 20246 976 to 1050: 63
301 to 375: 5011 1051 to 1125: 49
376 to 450: 802 1126 to 1200: 47
451 to 525: 677 1201 to 1275: 65
526 to 600: 274 1276 to 1350: 52
601 to 675: 135 1351 to 1425: 339
676 to 750: 105 1426 to 1500+: 3696
Interface MTU is 1500 bytes, not counting the data-link header
Maximum packet size is the MTU plus the data-link header length
Packet size computations include data-link headers, if any

iotop

- Block device I/O (disk) by process:

```
$ iotop
 Total DISK READ:      50.47 M/s | Total DISK WRITE:      59.21 M/s
  TID  PRIO  USER     DISK READ  DISK WRITE  SWAPIN      IO>    COMMAND
  959 be/4 root        0.00 B/s    0.00 B/s  0.00 % 99.99 % [flush-202:1]
 6641 be/4 root       50.47 M/s   82.60 M/s  0.00 % 32.51 % java –Dnop –X
    1 be/4 root        0.00 B/s    0.00 B/s  0.00 %  0.00 % init
    2 be/4 root        0.00 B/s    0.00 B/s  0.00 %  0.00 % [kthreadd]
    3 be/4 root        0.00 B/s    0.00 B/s  0.00 %  0.00 % [ksoftirqd/0]
    4 be/4 root        0.00 B/s    0.00 B/s  0.00 %  0.00 % [kworker/0:0]
    5 be/4 root        0.00 B/s    0.00 B/s  0.00 %  0.00 % [kworker/u:0]
    6 rt/4 root        0.00 B/s    0.00 B/s  0.00 %  0.00 % [migration/0]
[…]
```

- Needs kernel support enabled
  - CONFIG_TASK_IO_ACCOUNTING

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
[…]
```

perf_events (counters)

- "perf" command. CPU perf counters (listing):

```
$ 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
- Sadly, can't access these in most clouds (yet)
- Can be time-consuming to use (CPU manuals)

tiptop

```
tiptop -
Tasks: 378 total,  15 displayed                                screen  0: default

  PID [ %CPU] %SYS    P    Mcycle    Minstr   IPC   %MISS   %BMIS   %BUS COMMAND
 5910+  13.4   0.5    0    603.72    461.80  0.76    0.29    0.67      ? plugin-con
 3249+  11.4   3.5    1    394.35    551.39  1.40    0.10    0.19      ? gnome-term
17838    9.4   0.0    0    472.37    547.62  1.16    0.24    0.52      ? python
24782    8.4   7.9    0     47.99     39.76  0.83    0.09    1.02      ? find
 2889+   4.0   0.5    5    114.78     30.42  0.27    2.38    1.81      ? enlightenm
 3311+   4.0   0.5    3    186.75     96.11  0.51    0.71    0.85      ? firefox
 3534+   4.0   1.0    1    157.75     69.34  0.44    1.23    0.74      ? chromium-b
 3518+   1.5   0.0    7         ?         ?     ?       ?       ?      ? chromium-b
 3307+   1.0   0.0    0     15.31      3.30  0.22    1.86    1.98      ? chromium-b
24717    1.0   1.0    3     13.29     13.60  1.02    0.05    0.65      ? tiptop
 3635+   0.5   0.0    0         ?         ?     ?       ?       ?      ? chromium-b
```

- IPC by process? %MISS? %BUS? Awesome!
- Needs some love. Still can’t use it yet (cloud)

More Advanced Tools…

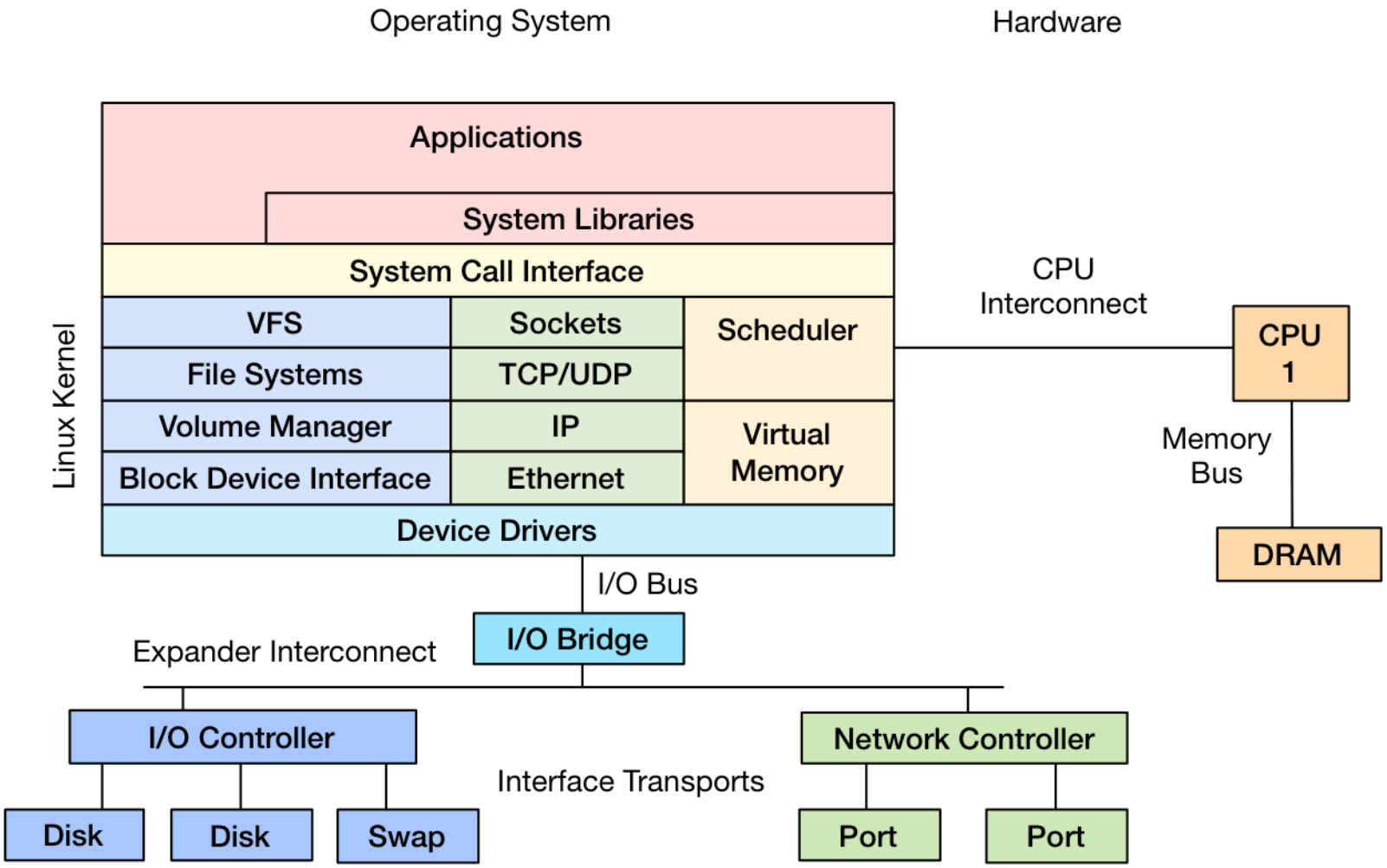
- Some others worth mentioning:

Tool	Description
ltrace	Library call tracer
ethtool	Mostly interface tuning; some stats
snmpget	SNMP network host statistics
lldptool	Can get LLDP broadcast stats
blktrace	Block I/O event tracer
/proc	Many raw kernel counters

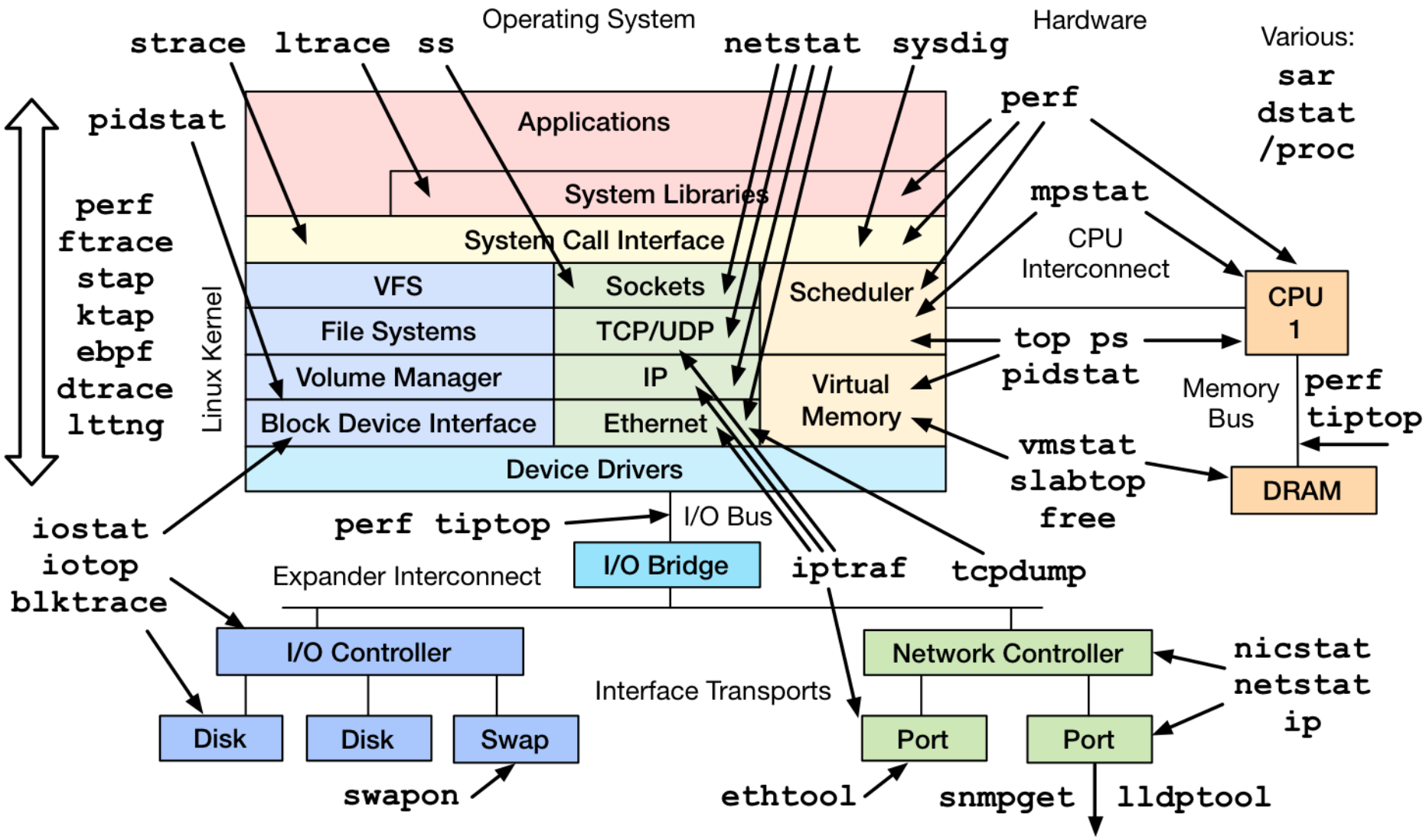
Advanced Tracers

- Many options on Linux:
  - perf_events, ftrace, eBPF, SystemTap, ktap, LTTng, dtrace4linux, sysdig
- Most can do static and dynamic tracing
  - Static: pre-defined events (tracepoints)
  - Dynamic: instrument any software (kprobes, uprobes). Custom metrics on-demand. *Catch all*.
- Many are in-development.
  - I'll summarize their state later…

Linux Observability Tools



Linux Observability Tools



Benchmarking Tools

Benchmarking Tools

- Multi:
  - UnixBench, lmbench, sysbench, perf bench
- FS/disk:
  - dd, hdparm, fio
- App/lib:
  - ab, wrk, jmeter, openssl
- Networking:
  - ping, hping3, iperf, ttcp, traceroute, mtr, pchar

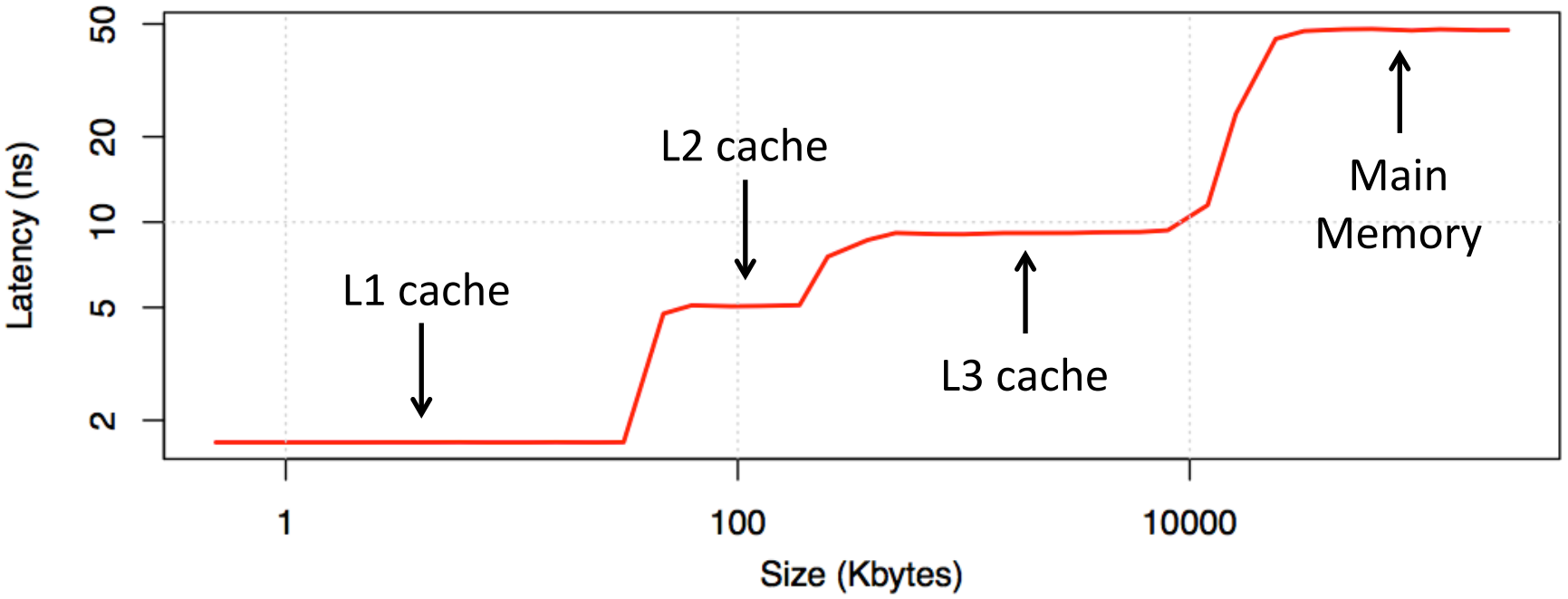
Active Benchmarking

- Most benchmarks are misleading or wrong
  - You benchmark A, but actually measure B, and conclude that you measured C
- Active Benchmarking
  1. Run the benchmark for hours
  2. While running, analyze and confirm the performance limiter using *observability tools*
- We just covered those tools – use them!

lmbench

- CPU, memory, and kernel micro-benchmarks
- Eg, memory latency by stride size:

```
$ lat_mem_rd 100m 128 > out.latencies
some R processing…
```



fio

- FS or disk I/O micro-benchmarks

```
$ fio --name=seqwrite --rw=write --bs=128k --size=122374m
[…]
seqwrite: (groupid=0, jobs=1): err= 0: pid=22321
  write: io=122374MB, bw=840951KB/s, iops=6569 , runt=149011msec
    clat (usec): min=41 , max=133186 , avg=148.26, stdev=1287.17
     lat (usec): min=44 , max=133188 , avg=151.11, stdev=1287.21
    bw (KB/s) : min=10746, max=1983488, per=100.18%, avg=842503.94,
stdev=262774.35
  cpu          : usr=2.67%, sys=43.46%, ctx=14284, majf=1, minf=24
  IO depths    : 1=100.0%, 2=0.0%, 4=0.0%, 8=0.0%, 16=0.0%, 32=0.0%, >=64=0.0%
     submit    : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >=64=0.0%
     complete  : 0=0.0%, 4=100.0%, 8=0.0%, 16=0.0%, 32=0.0%, 64=0.0%, >=64=0.0%
     issued r/w/d: total=0/978992/0, short=0/0/0
     lat (usec): 50=0.02%, 100=98.30%, 250=1.06%, 500=0.01%, 750=0.01%
     lat (usec): 1000=0.01%
     lat (msec): 2=0.01%, 4=0.01%, 10=0.25%, 20=0.29%, 50=0.06%
     lat (msec): 100=0.01%, 250=0.01%
```

- Results include basic latency distribution

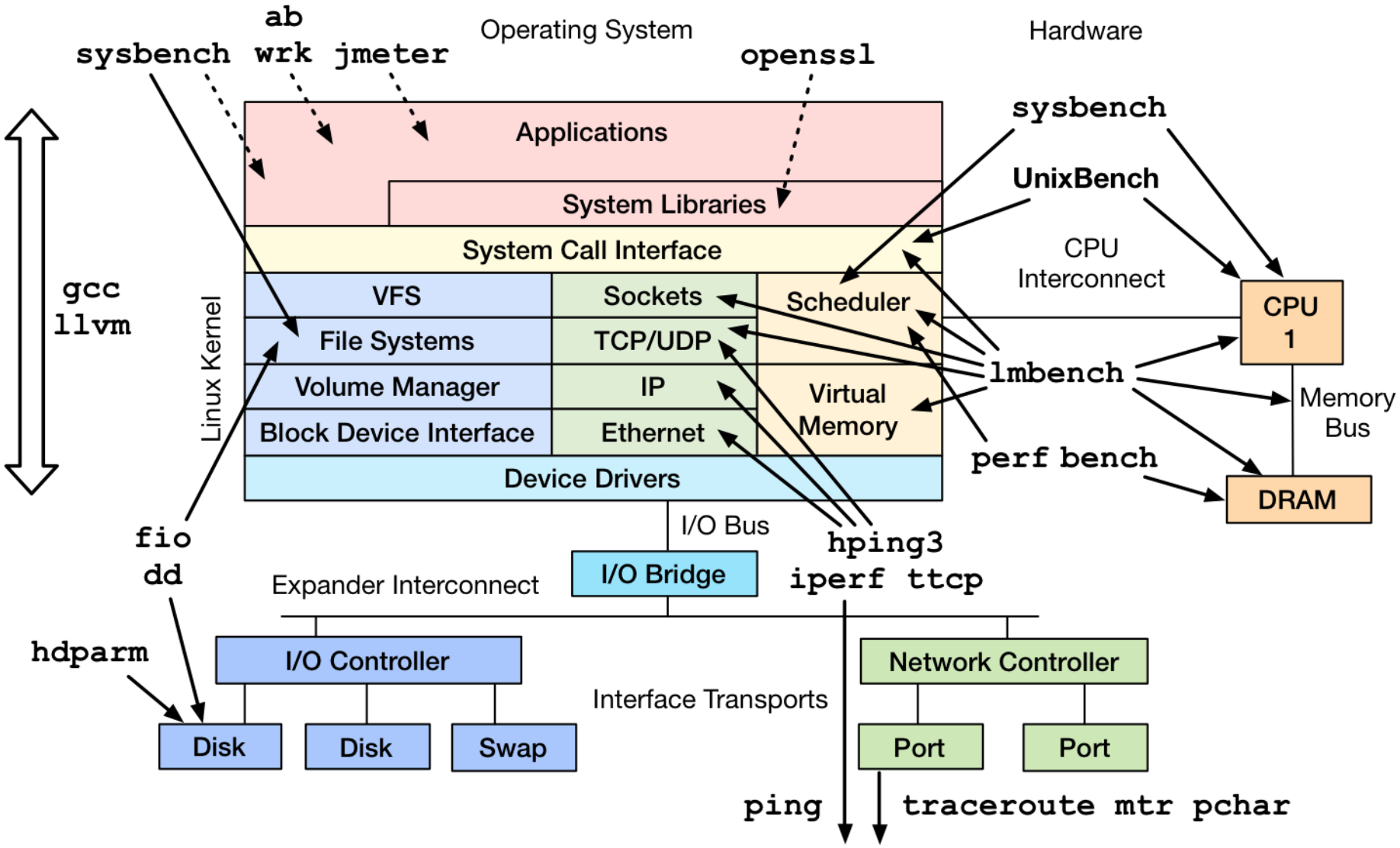
pchar

- Traceroute with bandwidth per hop!

```
$ pchar 10.71.83.1
[…]
 4: 10.110.80.1 (10.110.80.1)
    Partial loss:      0 / 5 (0%)
    Partial char:      rtt = 9.351109 ms, (b = 0.004961 ms/B), r2 = 0.184105
                       stddev rtt = 4.967992, stddev b = 0.006029
    Partial queueing:  avg = 0.000000 ms (0 bytes)
    Hop char:          rtt = --.--- ms, bw = 1268.975773 Kbps
    Hop queueing:      avg = 0.000000 ms (0 bytes)
 5: 10.193.43.181 (10.193.43.181)
    Partial loss:      0 / 5 (0%)
    Partial char:      rtt = 25.461597 ms, (b = 0.011934 ms/B), r2 = 0.228707
                       stddev rtt = 10.426112, stddev b = 0.012653
    Partial queueing:  avg = 0.000000 ms (0 bytes)
    Hop char:          rtt = 16.110487 ms, bw = 1147.210397 Kbps
    Hop queueing:      avg = 0.000000 ms (0 bytes)
[…]
```

- Needs love. Based on pathchar (Linux 2.0.30).

Benchmarking Tools



Tuning Tools

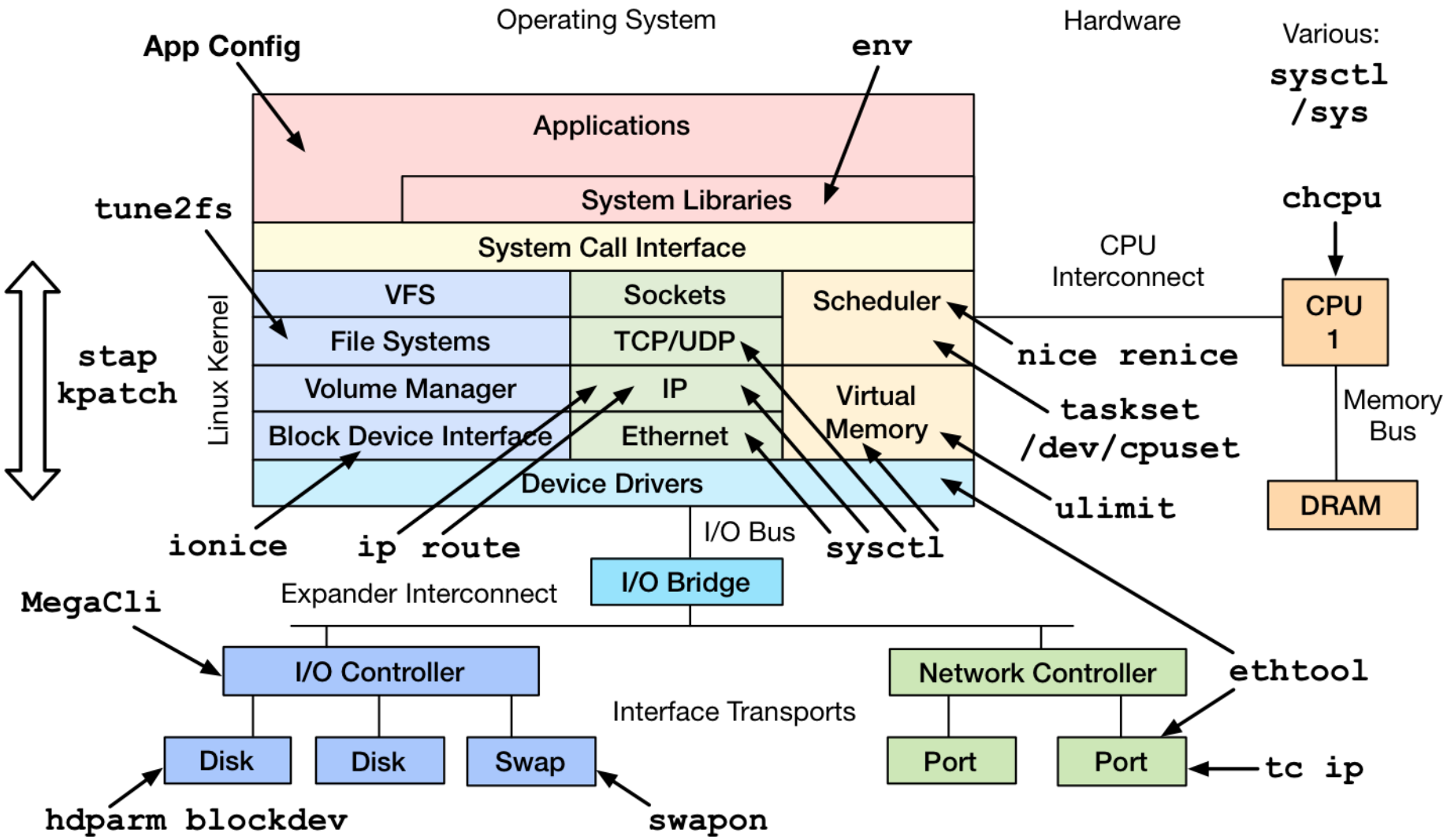
Tuning Tools

- Generic interfaces:
  - sysctl, /sys
- Many areas have custom tuning tools:
  - Applications: their own config
  - CPU/scheduler: nice, renice, taskset, ulimit, chcpu
  - Storage I/O: tune2fs, ionice, hdparm, blockdev, …
  - Network: ethtool, tc, ip, route
  - Dynamic patching: stap, kpatch

Tuning Methods

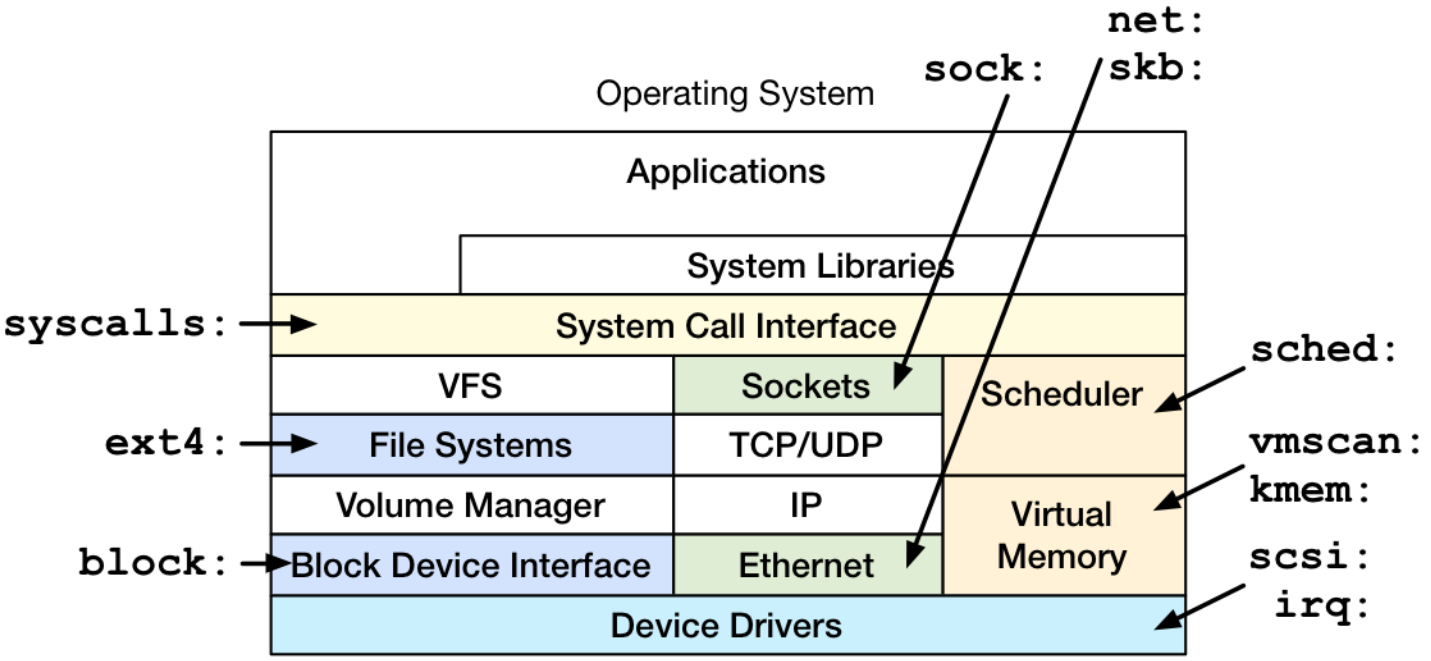
- Scientific Method:
  1. Question
  2. Hypothesis
  3. Prediction
  4. Test
  5. Analysis
- Any *observational* or *benchmarking* tests you can try before tuning?
- Consider risks, and see previous tools

Tuning Tools



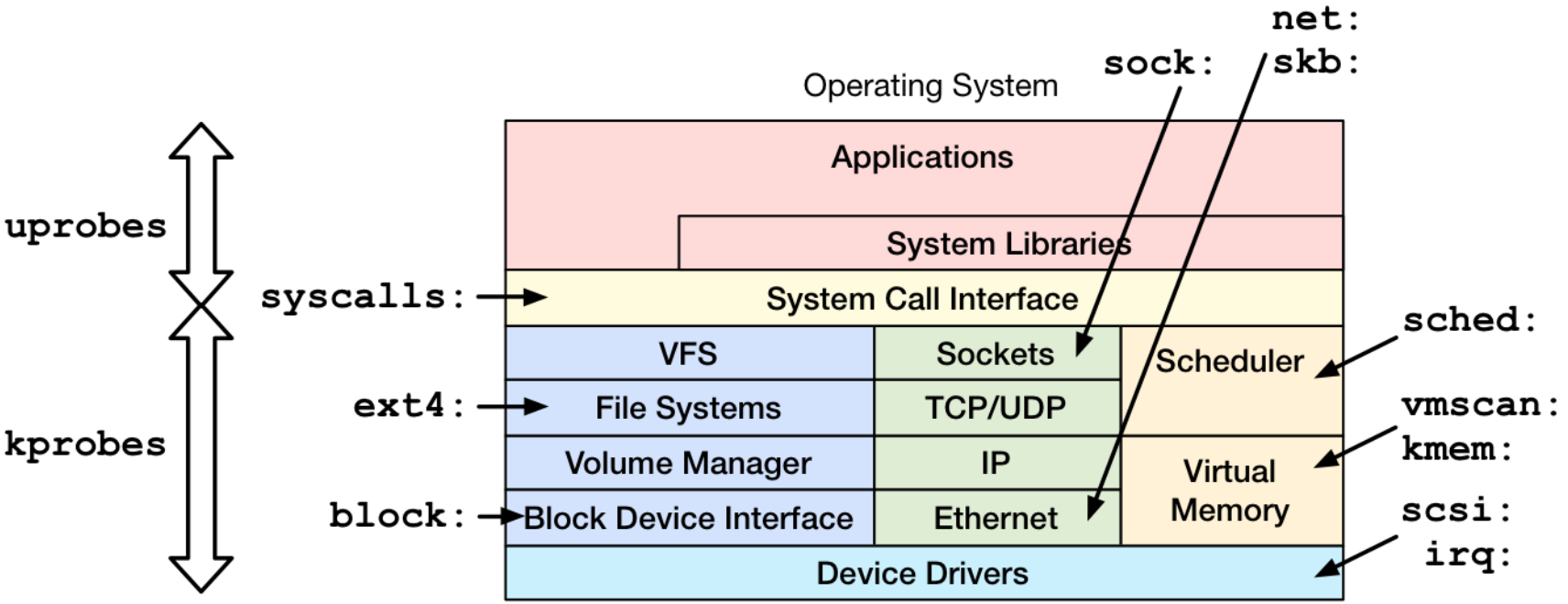
Tracing

Tracing Frameworks: Tracepoints



- Statically placed at logical places in the kernel
- Provides key event details as a “format” string

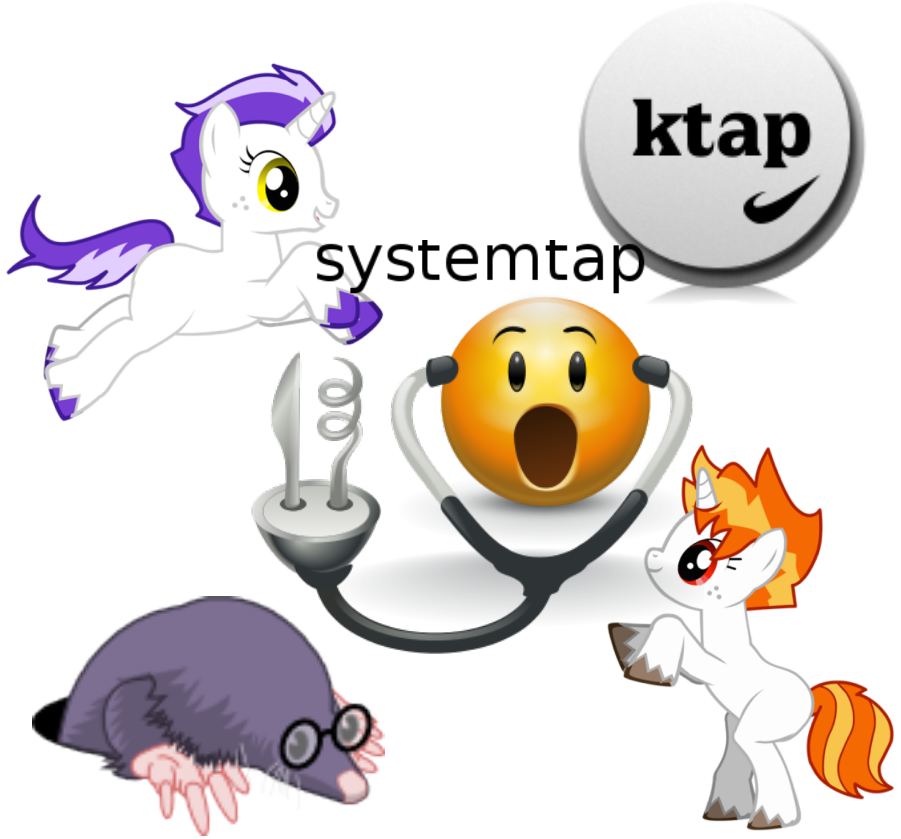
Tracing Frameworks: + probes



- kprobes: dynamic kernel tracing
  - function calls, returns, line numbers
- uprobes: dynamic user-level tracing

Tracing Tools

- Options:
  - ftrace
  - perf_events
  - eBPF
  - SystemTap
  - ktap
  - LTTng
  - dtrace4linux
  - sysdig



- Too many choices, and many still in-development

Imagine Linux with Tracing

- With a programmable tracer, high level tools can be written, such as:
  - iosnoop
  - iolatency
  - opensnoop
  - …

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
[…]
```

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      |####                                  |
[…]
```

opensnoop

- Trace open() syscalls showing filenames:

```
# ./opensnoop -t
Tracing open()s. Ctrl-C to end.
TIMEs             COMM          PID      FD FILE
4345768.332626    postgres      23886    0x8 /proc/self/oom_adj
4345768.333923    postgres      23886    0x5 global/pg_filenode.map
4345768.333971    postgres      23886    0x5 global/pg_internal.init
4345768.334813    postgres      23886    0x5 base/16384/PG_VERSION
4345768.334877    postgres      23886    0x5 base/16384/pg_filenode.map
4345768.334891    postgres      23886    0x5 base/16384/pg_internal.init
4345768.335821    postgres      23886    0x5 base/16384/11725
4345768.347911    svstat        24649    0x4 supervise/ok
4345768.347921    svstat        24649    0x4 supervise/status
4345768.350340    stat          24651    0x3 /etc/ld.so.cache
4345768.350372    stat          24651    0x3 /lib/x86_64-linux-gnu/libselinux…
4345768.350460    stat          24651    0x3 /lib/x86_64-linux-gnu/libc.so.6
4345768.350526    stat          24651    0x3 /lib/x86_64-linux-gnu/libdl.so.2
4345768.350981    stat          24651    0x3 /proc/filesystems
4345768.351182    stat          24651    0x3 /etc/nsswitch.conf
[…]
```

funcgraph

- Trace a graph of kernel code flow:

```
# ./funcgraph -Htp 5363 vfs_read
Tracing "vfs_read" for PID 5363... Ctrl-C to end.
# tracer: function_graph
#
#     TIME        CPU  DURATION                  FUNCTION CALLS
#      |          |     |   |                     |   |   |   |
4346366.073832 |   0)               |  vfs_read() {
4346366.073834 |   0)               |    rw_verify_area() {
4346366.073834 |   0)               |      security_file_permission() {
4346366.073834 |   0)               |        apparmor_file_permission() {
4346366.073835 |   0)   0.153 us    |          common_file_perm();
4346366.073836 |   0)   0.947 us    |        }
4346366.073836 |   0)   0.066 us    |        __fsnotify_parent();
4346366.073836 |   0)   0.080 us    |        fsnotify();
4346366.073837 |   0)   2.174 us    |      }
4346366.073837 |   0)   2.656 us    |    }
4346366.073837 |   0)               |    tty_read() {
4346366.073837 |   0)   0.060 us    |      tty_paranoia_check();
[…]
```

kprobe

- Dynamically trace a kernel function call or return, with variables, and in-kernel filtering:

```
# ./kprobe 'p:open do_sys_open filename=+0(%si):string' 'filename ~ "*stat"'
Tracing kprobe myopen. Ctrl-C to end.
        postgres-1172  [000] d... 6594028.787166: open: (do_sys_open
+0x0/0x220) filename="pg_stat_tmp/pgstat.stat"
        postgres-1172  [001] d... 6594028.797410: open: (do_sys_open
+0x0/0x220) filename="pg_stat_tmp/pgstat.stat"
        postgres-1172  [001] d... 6594028.797467: open: (do_sys_open
+0x0/0x220) filename="pg_stat_tmp/pgstat.stat”
^C
Ending tracing...
```

- Add -s for stack traces; -p for PID filter in-kernel.
- Quickly confirm kernel behavior; eg: did a tunable take effect?

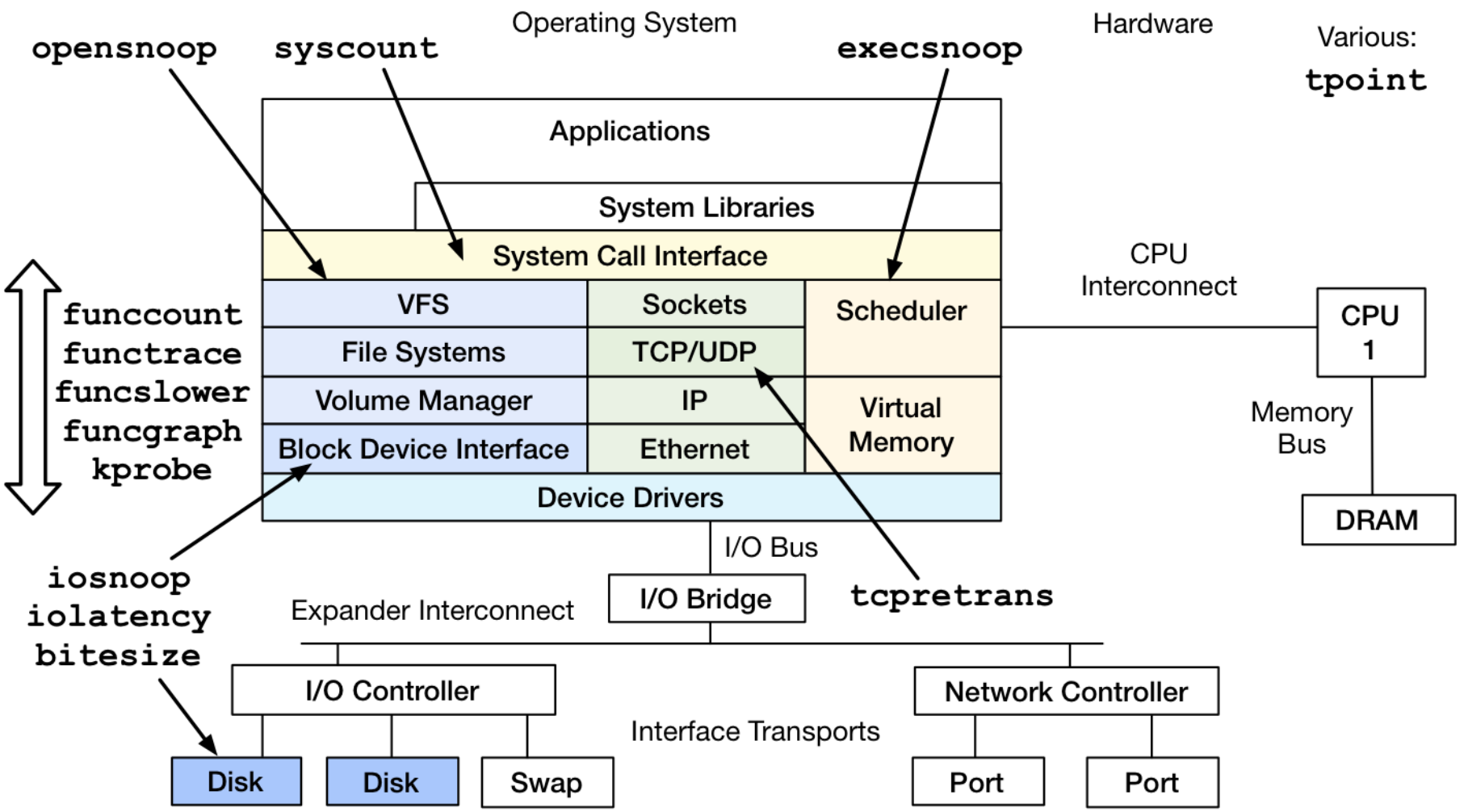
~~Imagine~~ Linux with Tracing

- These tools aren't using dtrace4linux, SystemTap, ktap, or any other add-on tracer
- These tools use **existing Linux capabilities**
  - No extra kernel bits, not even kernel debuginfo
  - Just Linux's built-in **ftrace** profiler
  - Demoed on **Linux 3.2**
- Solving real issues *now*

ftrace

- Added by Steven Rostedt and others since 2.6.27
- Already enabled on our servers (3.2+)
  - CONFIG_FTRACE, CONFIG_FUNCTION_PROFILER, …
  - Use directly via /sys/kernel/debug/tracing
- My front-end tools to aid usage
  - https://github.com/brendangregg/perf-tools
  - Unsupported hacks: see WARNINGs
- Also see the trace-cmd front-end, as well as perf
- lwn.net today: “Ftrace: The Hidden Light Switch”

My perf-tools (so far…)



Tracing Summary

- ftrace
- perf_events
- eBPF
- SystemTap
- ktap
- LTTng
- dtrace4linux
- sysdig

perf_events

- aka “perf” command
- **In Linux**. Add from linux-tools-common.
- Powerful multi-tool and profiler
  - interval sampling, CPU performance counter events
  - user and kernel dynamic tracing
  - kernel line tracing and local variables (debuginfo)
  - kernel filtering, and in-kernel counts (perf stat)
- Not very programmable, yet
  - limited kernel summaries. May improve with eBPF.

perf_events Example

```
# perf record –e skb:consume_skb -ag
^C[ perf record: Woken up 1 times to write data ]
[ perf record: Captured and wrote 0.065 MB perf.data (~2851 samples) ]
# perf report
[...]
    74.42%  swapper  [kernel.kallsyms]  [k] consume_skb
            |
            --- consume_skb
                arp_process
                arp_rcv
                __netif_receive_skb_core
                __netif_receive_skb
                netif_receive_skb
                virtnet_poll
                net_rx_action
                __do_softirq
                irq_exit
                do_IRQ
                ret_from_intr
                default_idle
                cpu_idle
                start_secondary
[…]
```

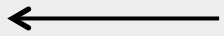
← Summarizing stack traces for a tracepoint

perf_events can do many things – hard to pick just one example

eBPF

- Extended BPF: programs on tracepoints
  - High performance filtering: JIT
  - In-kernel summaries: maps
- Linux in 3.18? Enhance perf_events/ftrace/…?

```
# ./bitesize 1
writing bpf-5 -> /sys/kernel/debug/tracing/events/block/block_rq_complete/filter

I/O sizes:
       Kbytes              : Count
       4 -> 7              : 131
       8 -> 15             : 32
      16 -> 31             : 1
      32 -> 63             : 46
      64 -> 127            : 0
     128 -> 255            : 15
[…]
```



in-kernel summary

SystemTap

- Fully programmable, fully featured
- Compiles tracing programs into kernel modules
  - Needs a compiler, and takes time
- "Works great on Red Hat"
  - I keep trying on other distros and have hit trouble in the past; make sure you are on the latest version.
  - I'm liking it a bit more after finding ways to use it without kernel debuginfo (a difficult requirement in our environment). Work in progress.
- Ever be mainline?

ktap

- Sampling, static & dynamic tracing
- Lightweight, simple. Uses bytecode.
- Suited for embedded devices
- Development appears suspended after suggestions to integrate with eBPF (which itself is in development)
- ktap + eBPF would be awesome: easy, lightweight, fast. Likely?

sysdig

- sysdig: Innovative new tracer. Simple expressions:

```
sysdig fd.type=file and evt.failed=true
sysdig evt.type=open and fd.name contains /etc
sysdig -p"%proc.name %fd.name" "evt.type=accept and proc.name!=httpd"
```

- Replacement for strace? (or "perf trace" will)
- Programmable "chisels". Eg, one of mine:

```
# sysdig -c fileslower 1
TIME                     PROCESS      TYPE      LAT(ms) FILE
2014-04-13 20:40:43.973 cksum        read            2 /mnt/partial.0.0
2014-04-13 20:40:44.187 cksum        read            1 /mnt/partial.0.0
2014-04-13 20:40:44.689 cksum        read            2 /mnt/partial.0.0
[…]
```

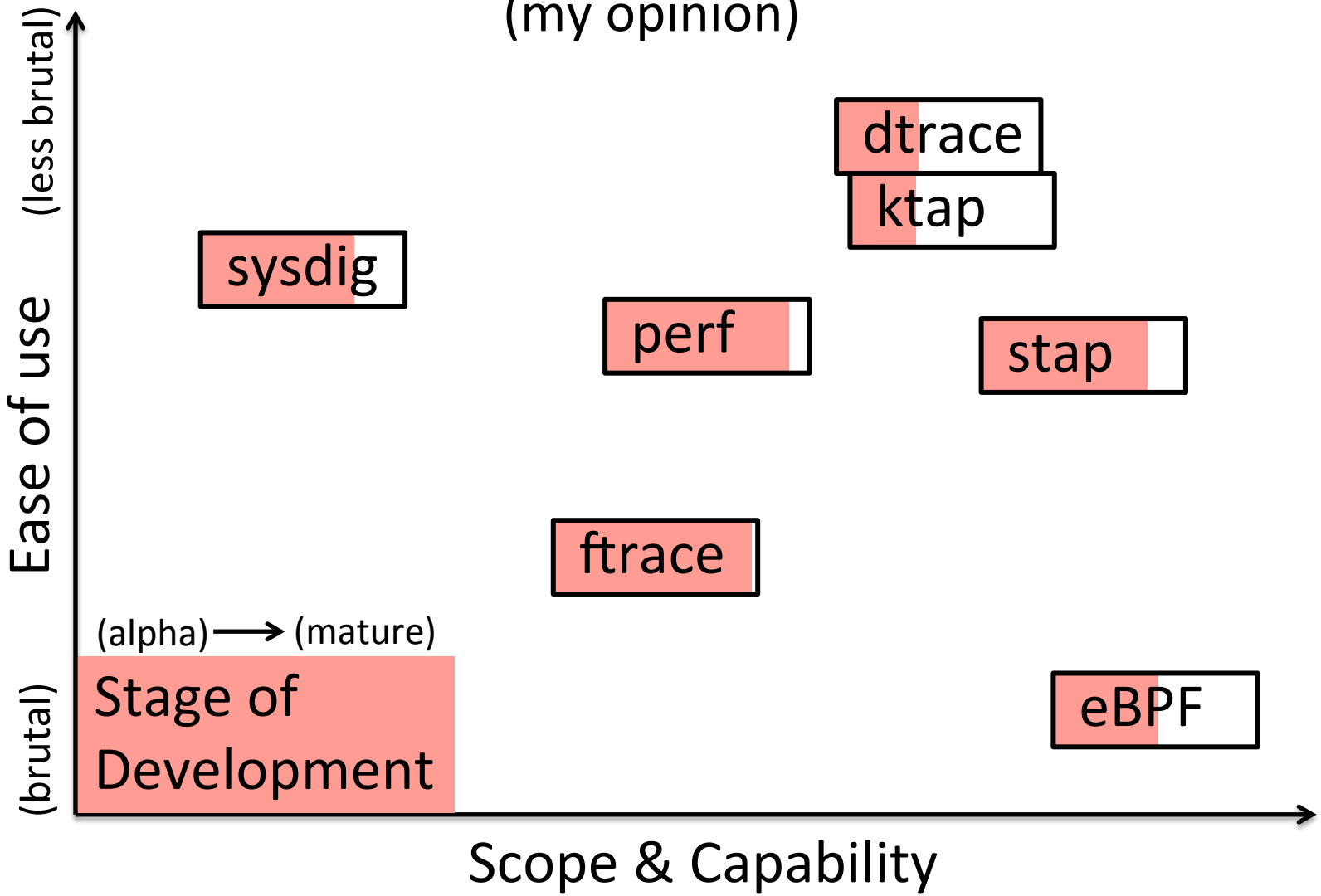
- Currently syscalls and user-level processing only. It is optimized, but I'm not sure it can be enough for kernel tracing

Present & Future

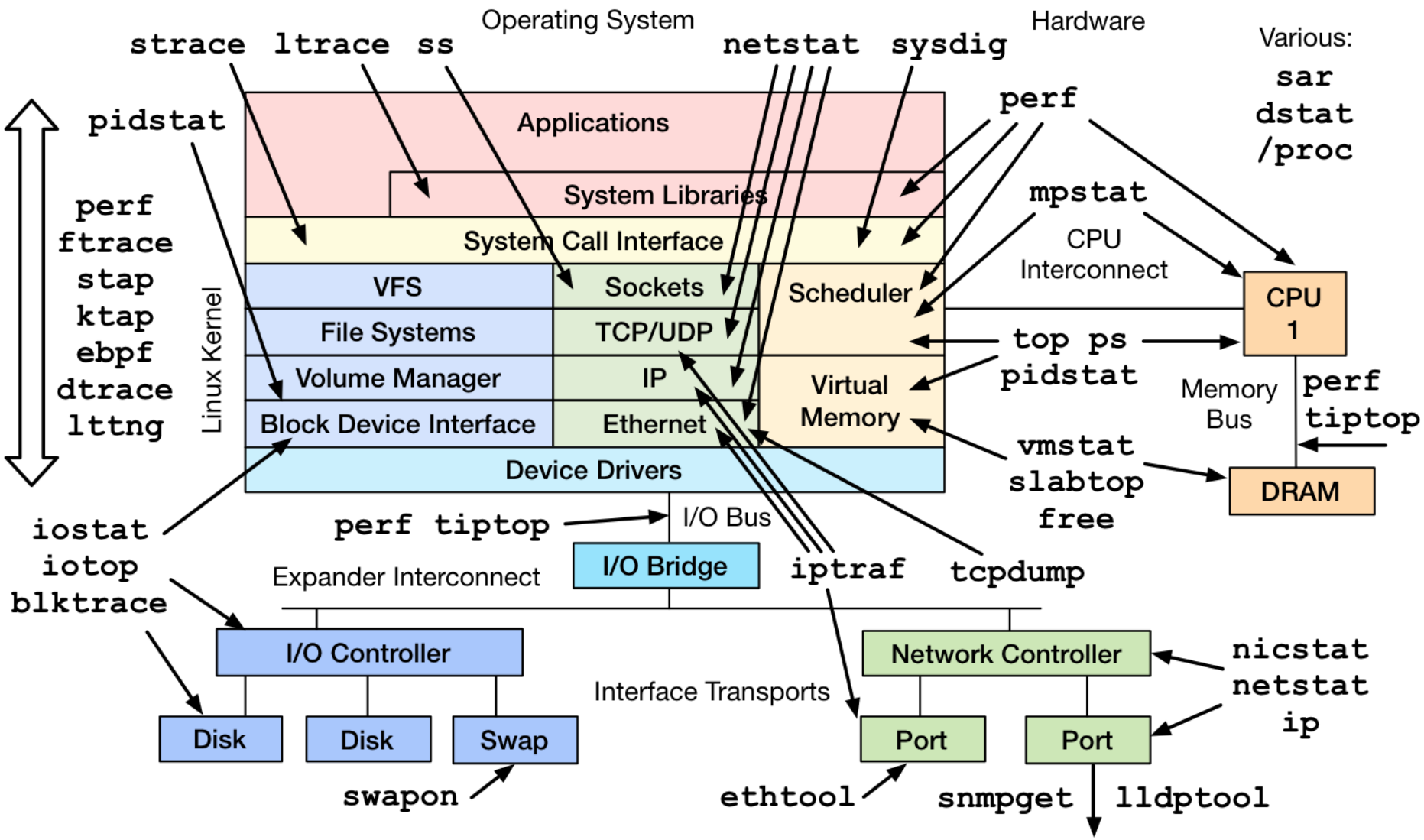
- Present:
  - ftrace can serve many needs today
  - perf_events some more, esp. with debuginfo
  - ah hoc SystemTap, ktap, … as needed
- Future:
  - ftrace/perf_events/ktap with eBPF, for a fully featured and mainline tracer?
  - One of the other tracers going mainline?

The Tracing Landscape, Aug 2014

(my opinion)



In Summary



In Summary…

- Plus diagrams for benchmarking, tuning, tracing
- Try to start with the questions (methodology), to help guide your use of the tools
- I hopefully turned some unknown unknowns into known unknowns

References & Links

- Systems Performance: Enterprise and the Cloud, Prentice Hall, 2014
- http://www.brendangregg.com/linuxperf.html
- nicstat: http://sourceforge.net/projects/nicstat/
- tiptop: http://tiptop.gforge.inria.fr/
  - Tiptop: Hardware Performance Counters for the Masses, Erven Rohou, Inria Research Report 7789, Nov 2011.
- ftrace & perf-tools
  - https://github.com/brendangregg/perf-tools
  - http://lwn.net/Articles/608497/
- eBPF: http://lwn.net/Articles/603983/
- ktap: http://www.ktap.org/
- SystemTap: https://sourceware.org/systemtap/
- sysdig: http://www.sysdig.org/
- http://www.slideshare.net/brendangregg/linux-performance-analysis-and-tools
- Tux by Larry Ewing; Linux® is the registered trademark of Linus Torvalds in the U.S. and other countries.

Thanks

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