LINUXCON EUROPE

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Linux Performance Tools

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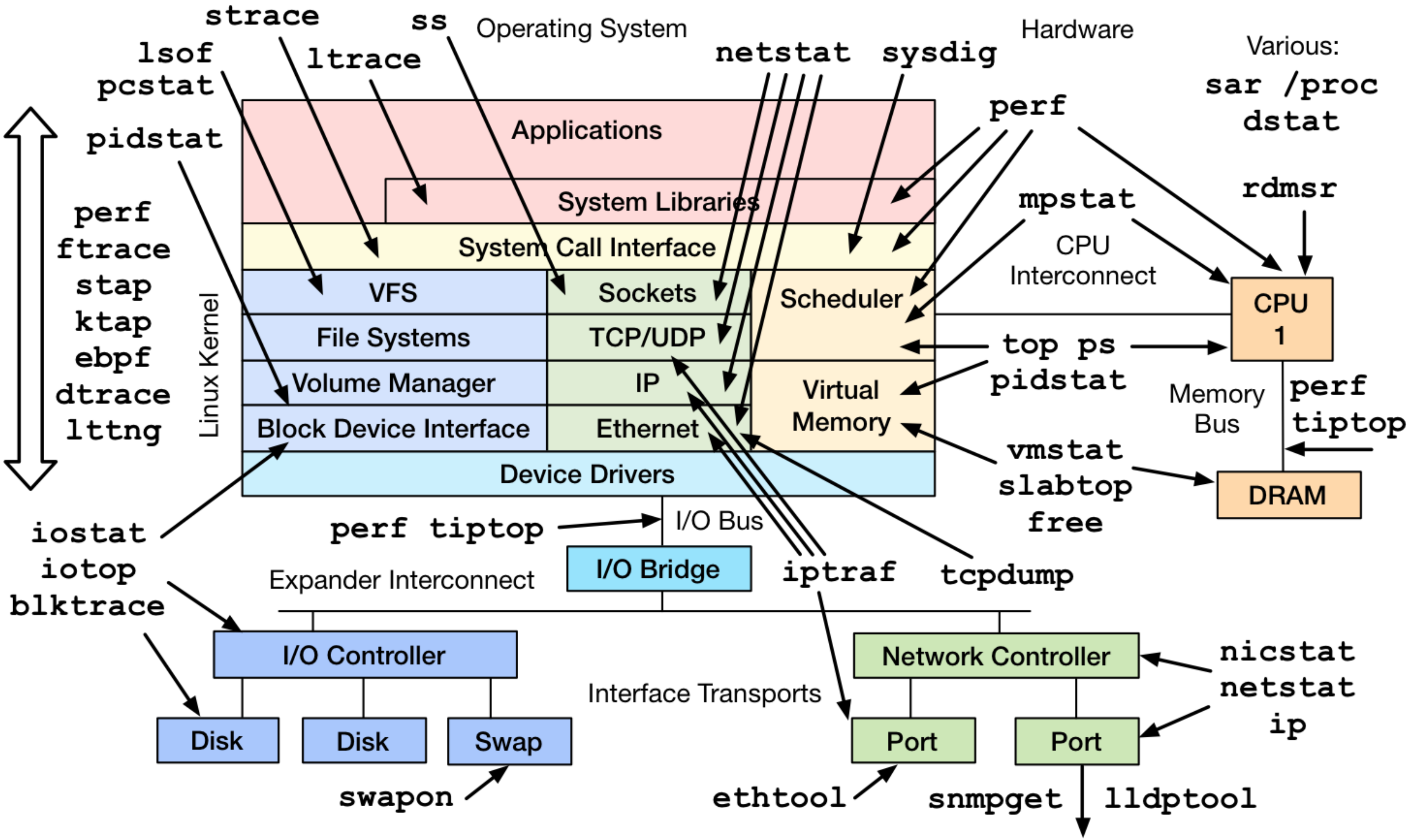
NETFLIX

A quick tour of many tools…



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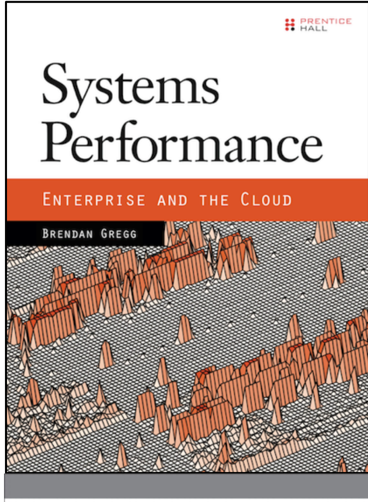
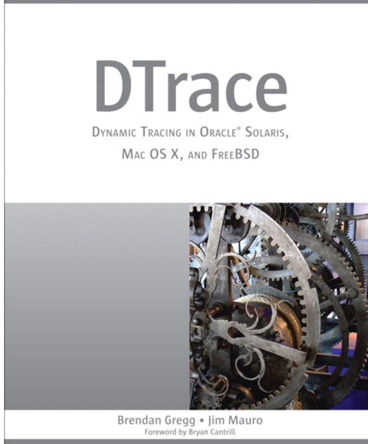
NETFLIX

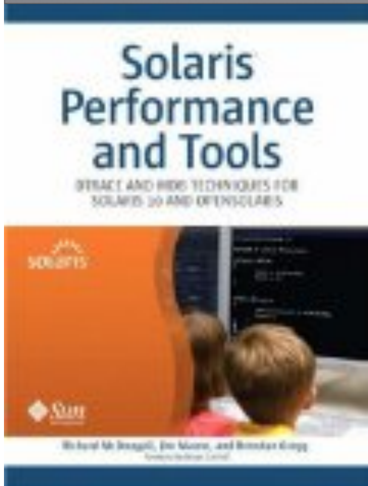
- Massive AWS EC2 Linux cloud
  - Tens of thousands of instances
  - Autoscale by ~3k each day
  - CentOS and Ubuntu
- FreeBSD for content delivery
  - Approx 33% of US Internet traffic at night
- Performance is critical
  - Customer satisfaction: >50M subscribers
  - $$$ price/performance
  - Develop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

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
- Previous work includes:
  - USE Method, flame graphs, utilization & latency heat maps, DTrace tools, ZFS L2ARC
- Twitter @brendangregg (these slides)




DTrace
DYNAMIC TRACING IN ORACLE® SOLARIS, MAC OS X, AND FREEBSD
Brendan Gregg • Jim Mauro
Foreword by Bryan Cantrill



Agenda

- Methodologies & Tools
- Tool Types:
  - Observability
    - Basic
    - Intermediate
    - Advanced
  - Benchmarking
  - Tuning
  - Static
- Tracing

Aim: to show what can be done

> Knowing that something can be done is more important than knowing how to do it.

Methodologies & Tools

Methodologies & Tools

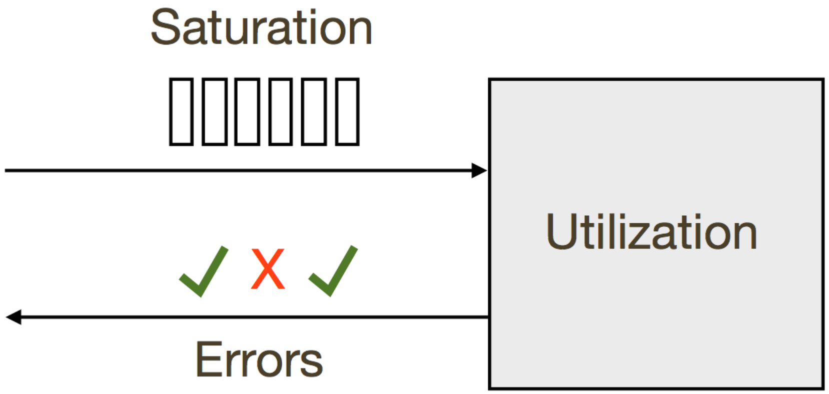
- There are dozens of performance tools for Linux
  - Packages: sysstat, procps, coreutils, …
  - Commercial products
- Methodologies can provide guidance for choosing and using tools effectively

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

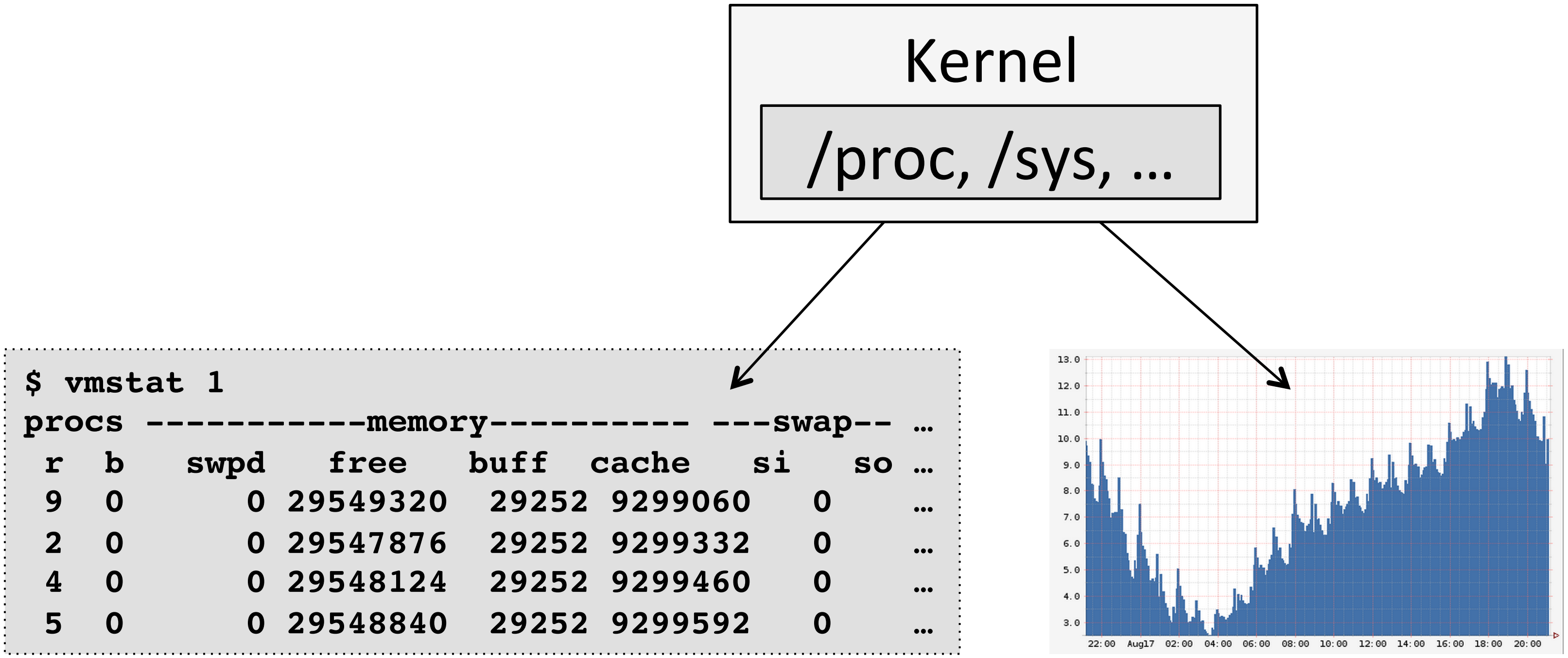
Methodologies

- For example, the USE Method:
  - For every resource, check:
    - Utilization
    - Saturation
    - Errors
- 5 Whys:
  - Ask “why?” 5 times
- 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



Kernel

/proc, /sys, …

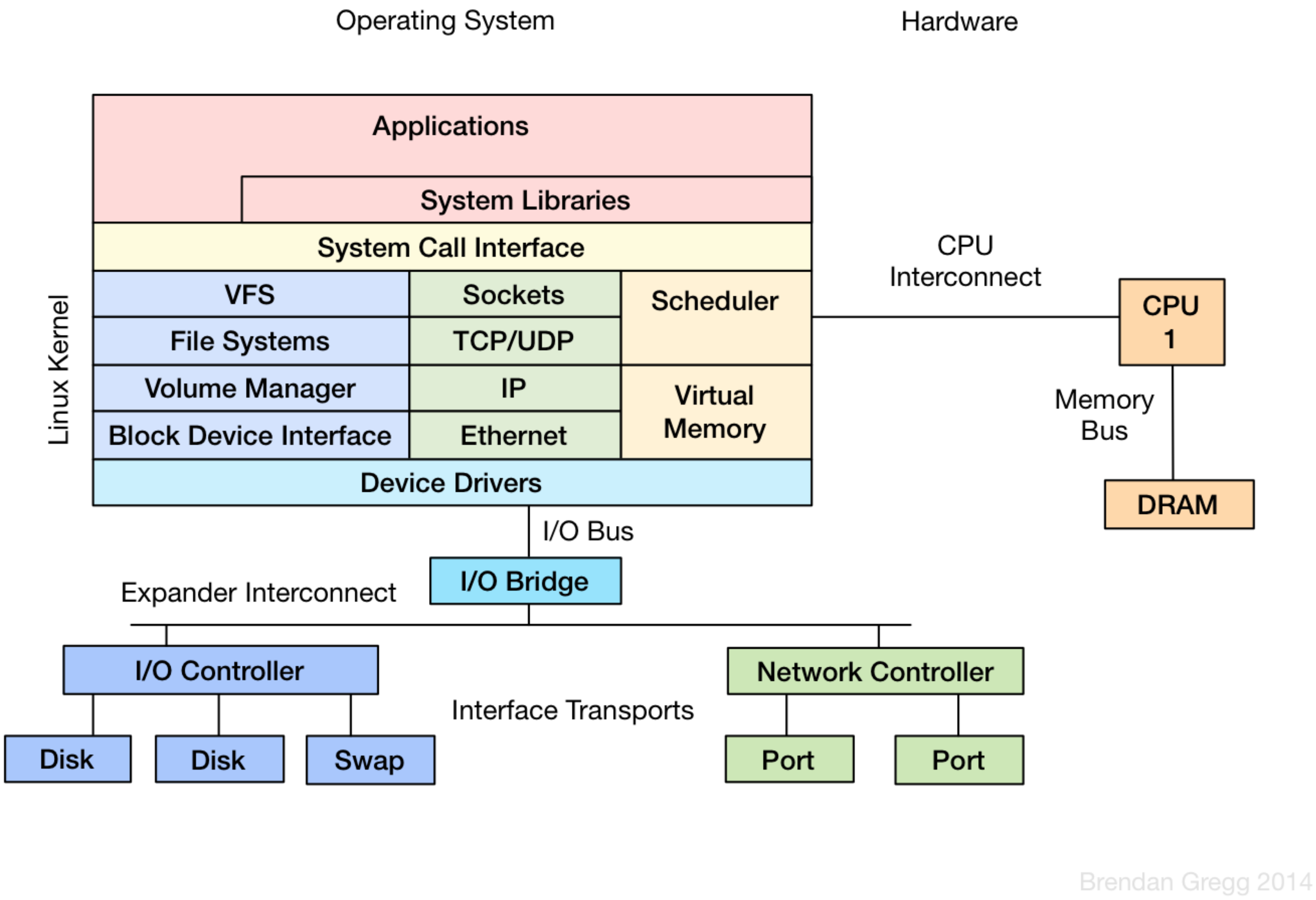
```
$ vmstat 1
procs -----------memory---------- ---swap-- …
 r  b   swpd   free   buff  cache   si   so …
 9  0      0 29549320  29252 9299060    0    …
 2  0      0 29547876  29252 9299332    0    …
 4  0      0 29548124  29252 9299460    0    …
 5  0      0 29548840  29252 9299592    0    …
```

Tool Types

Type	**Characteristic**
Observability	Watch activity. 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.
Static	Check configuration. Should be safe.

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)

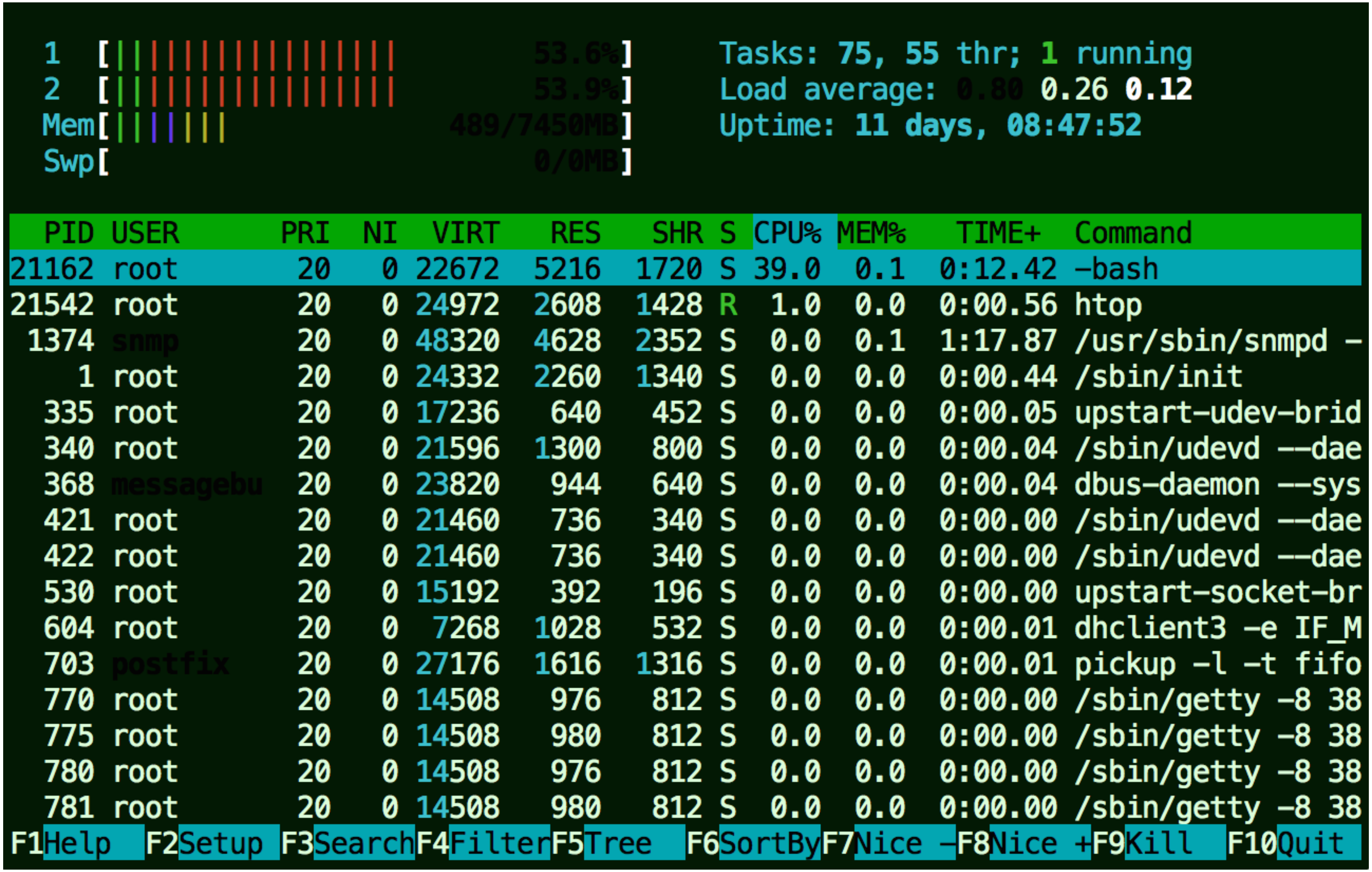
- System and per-process interval summary:

```
$ 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
[…]
```

- 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
```

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.

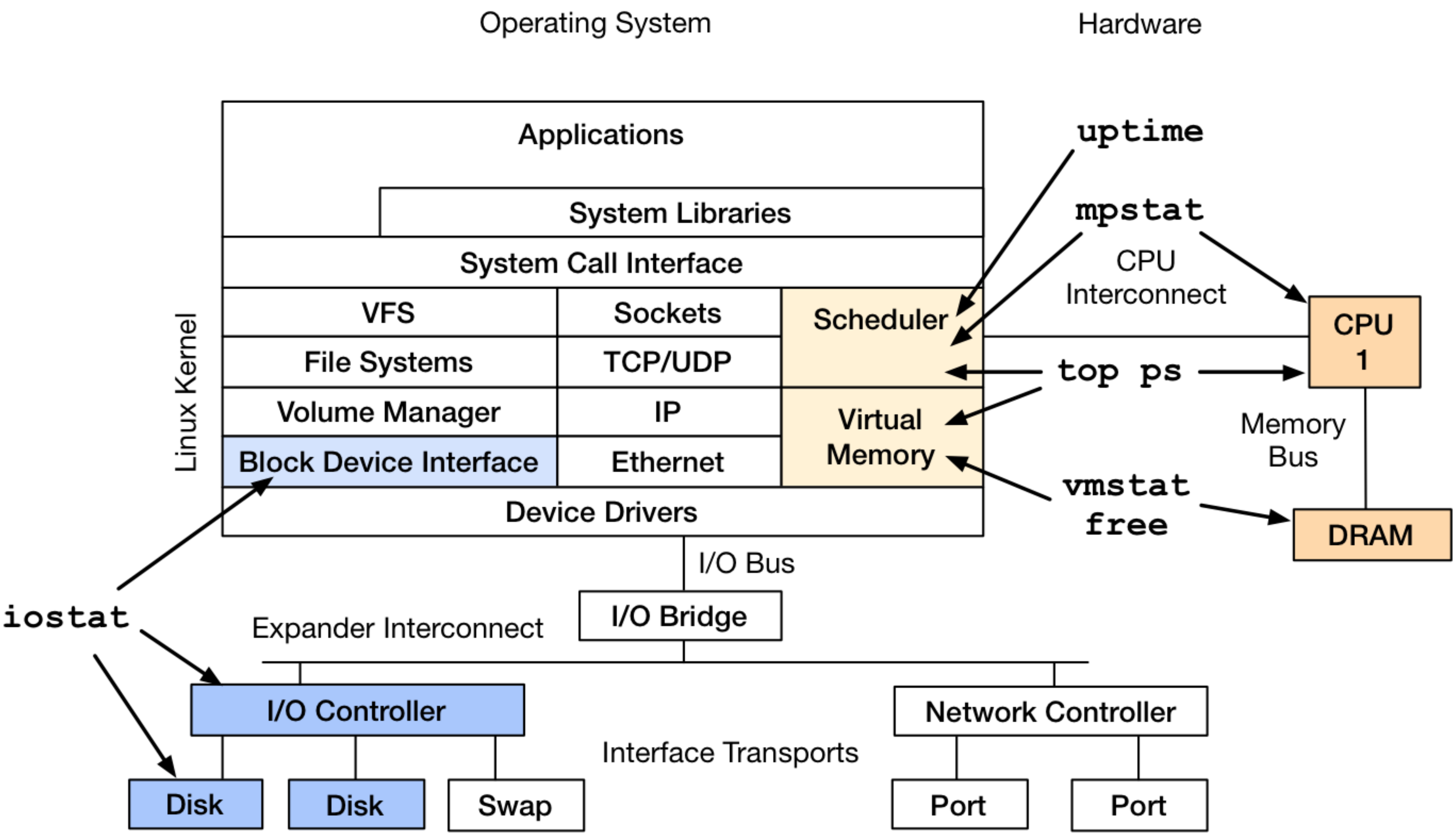
free

- 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



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Observability Tools: Intermediate

- strace
- tcpdump
- netstat
- nicstat
- pidstat
- swapon
- lsof
- 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…

lsof

- More a debug tool, lsof(8) shows file descriptor usage, which for some apps, equals current active network connections:

```
# lsof -iTCP -sTCP:ESTABLISHED
COMMAND    PID  USER   FD   TYPE   DEVICE SIZE/OFF NODE NAME
sshd       755  root   3r  IPv4 13576887      0t0  TCP bgregg-test-i-f106:ssh->prod100.netflix.com:
15241 (ESTABLISHED)
platforms 2614  app1   8u  IPv4    14618      0t0  TCP localhost:33868->localhost:5433 (ESTABLISHED)
postgres  2648  app1   7u  IPv4    14619      0t0  TCP localhost:5433->localhost:33868 (ESTABLISHED)
epic_plug 2857  app1   7u  IPv4    15678      0t0  TCP localhost:33885->localhost:5433 (ESTABLISHED)
postgres  2892  app1   7u  IPv4    15679      0t0  TCP localhost:5433->localhost:33885 (ESTABLISHED)
[…]
```

- I'd prefer to: `echo /proc/`*`PID`*`/fd | wc -l`

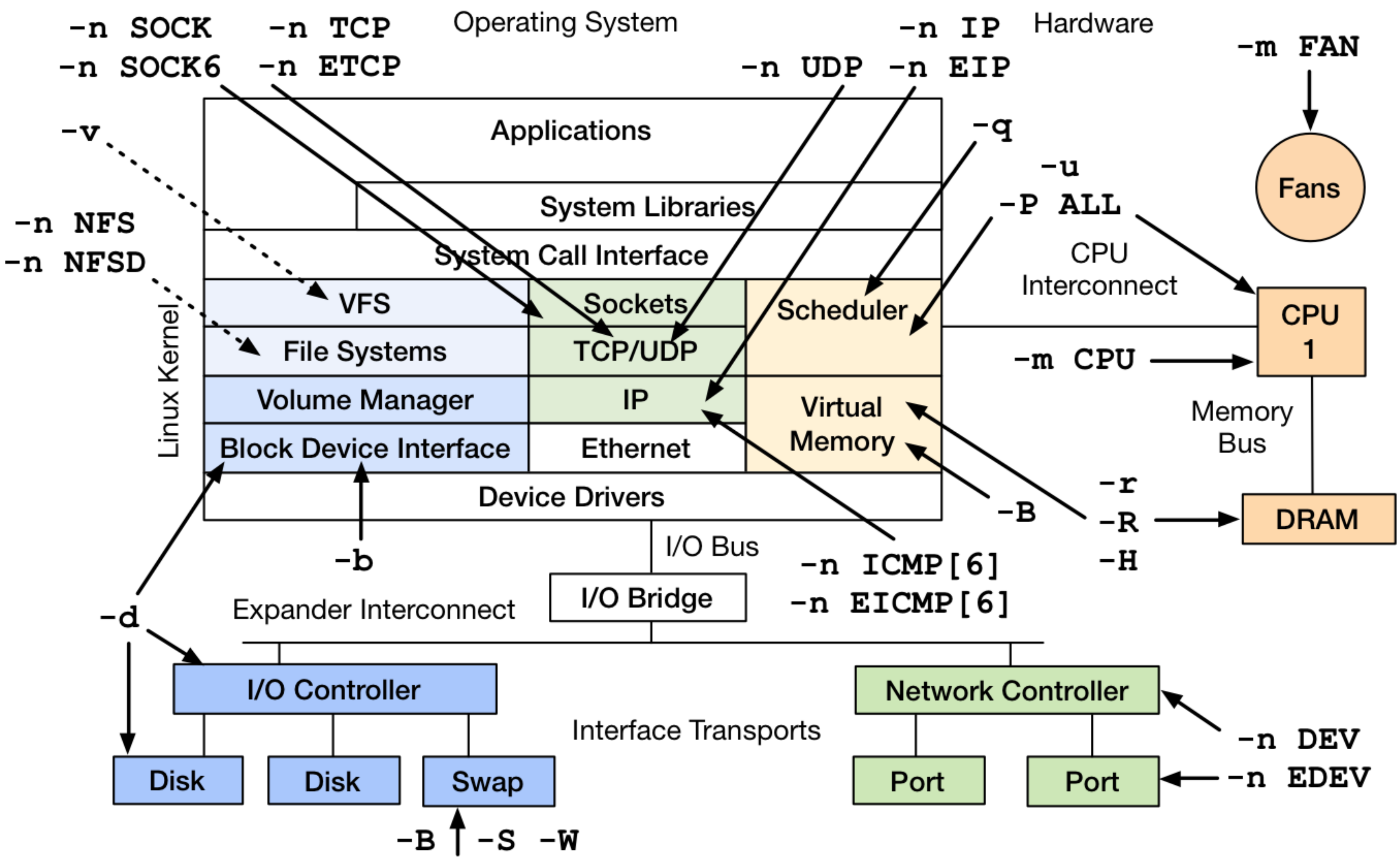
sar

- 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



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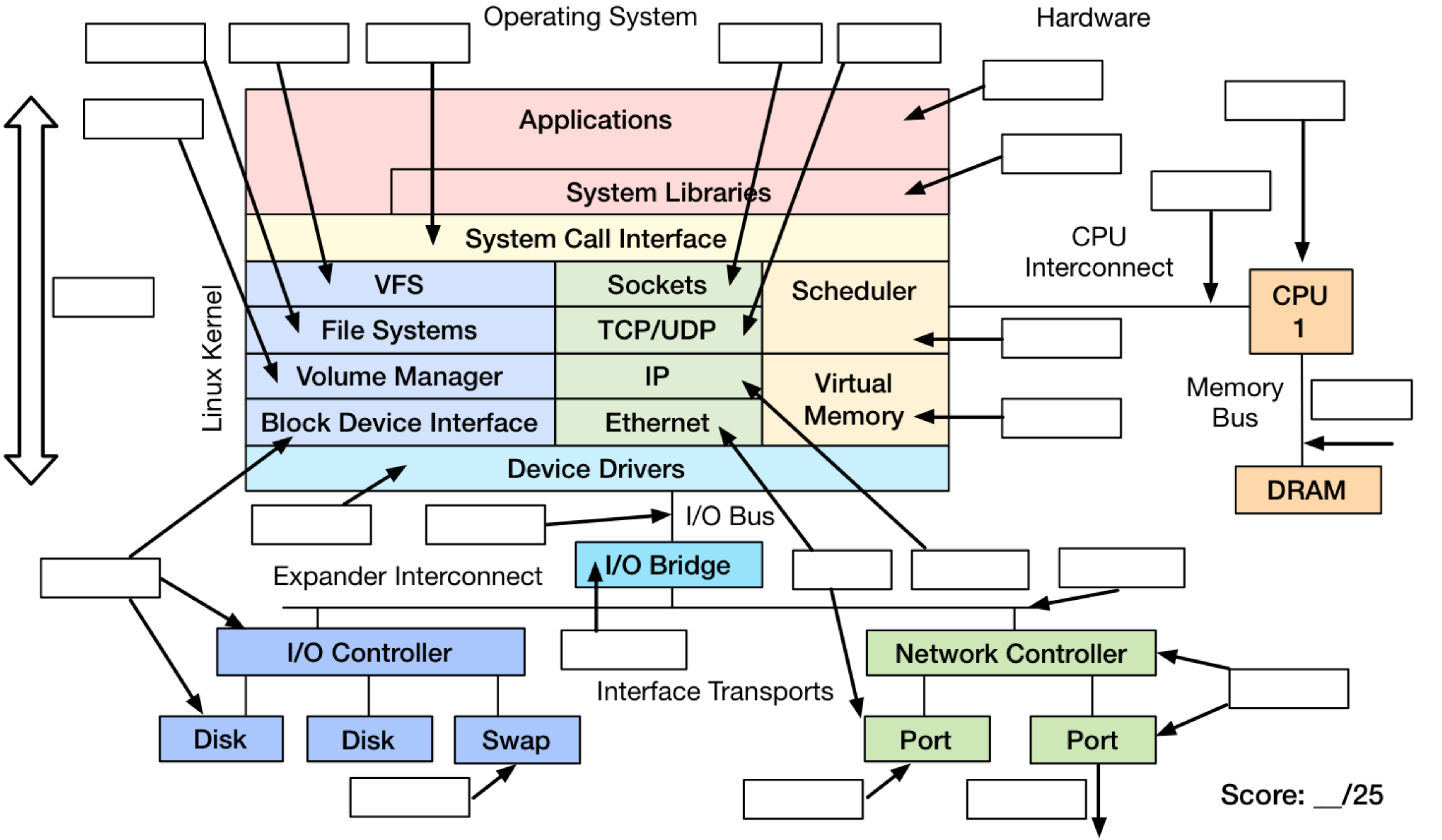
Other Tools

- You may also use collectl, atop, dstat, or another measure-all tool
- The tool isn’t important
- It’s important 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?



Score: __/25

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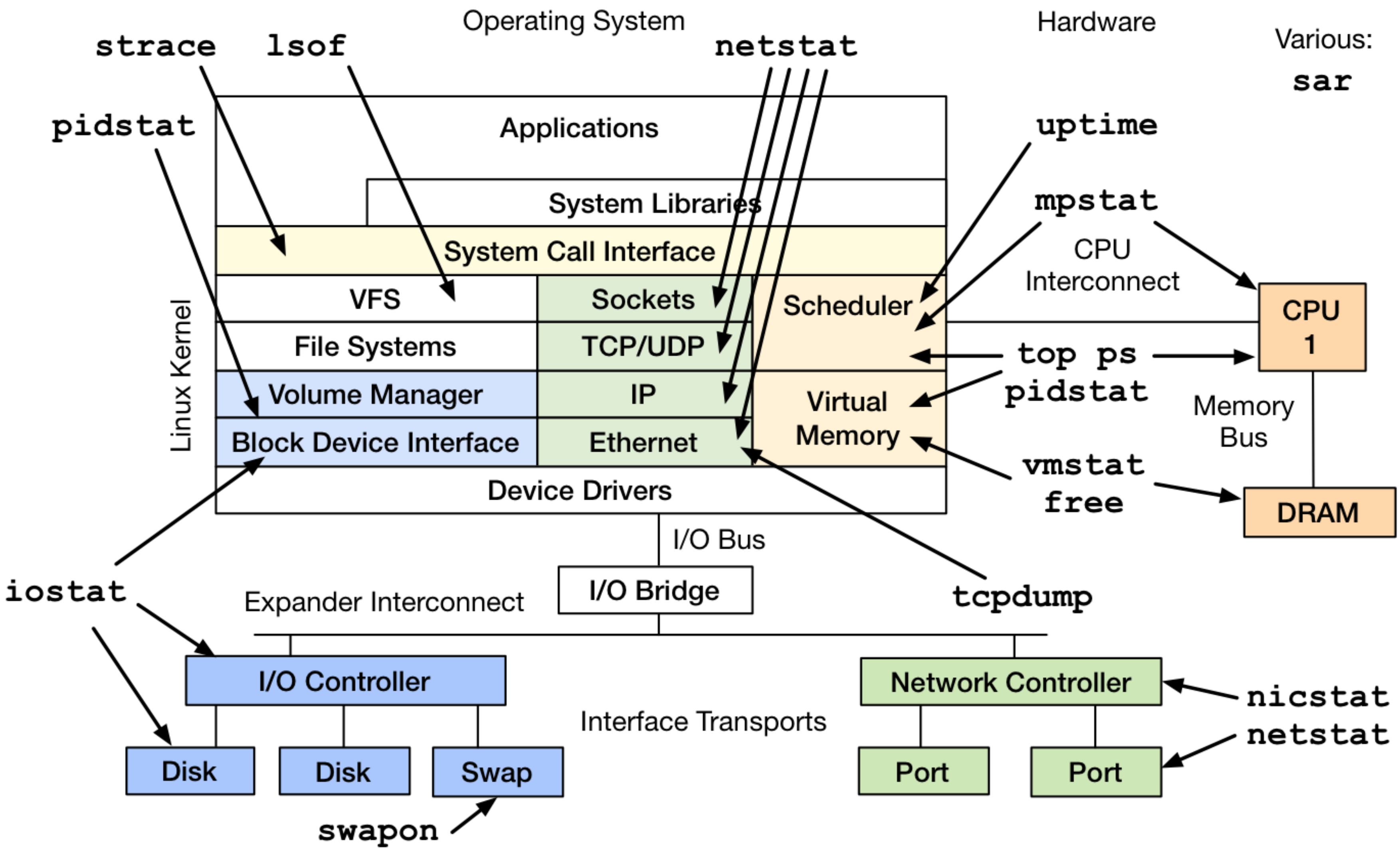
Observability Tools: Intermediate



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Advanced Observability Tools

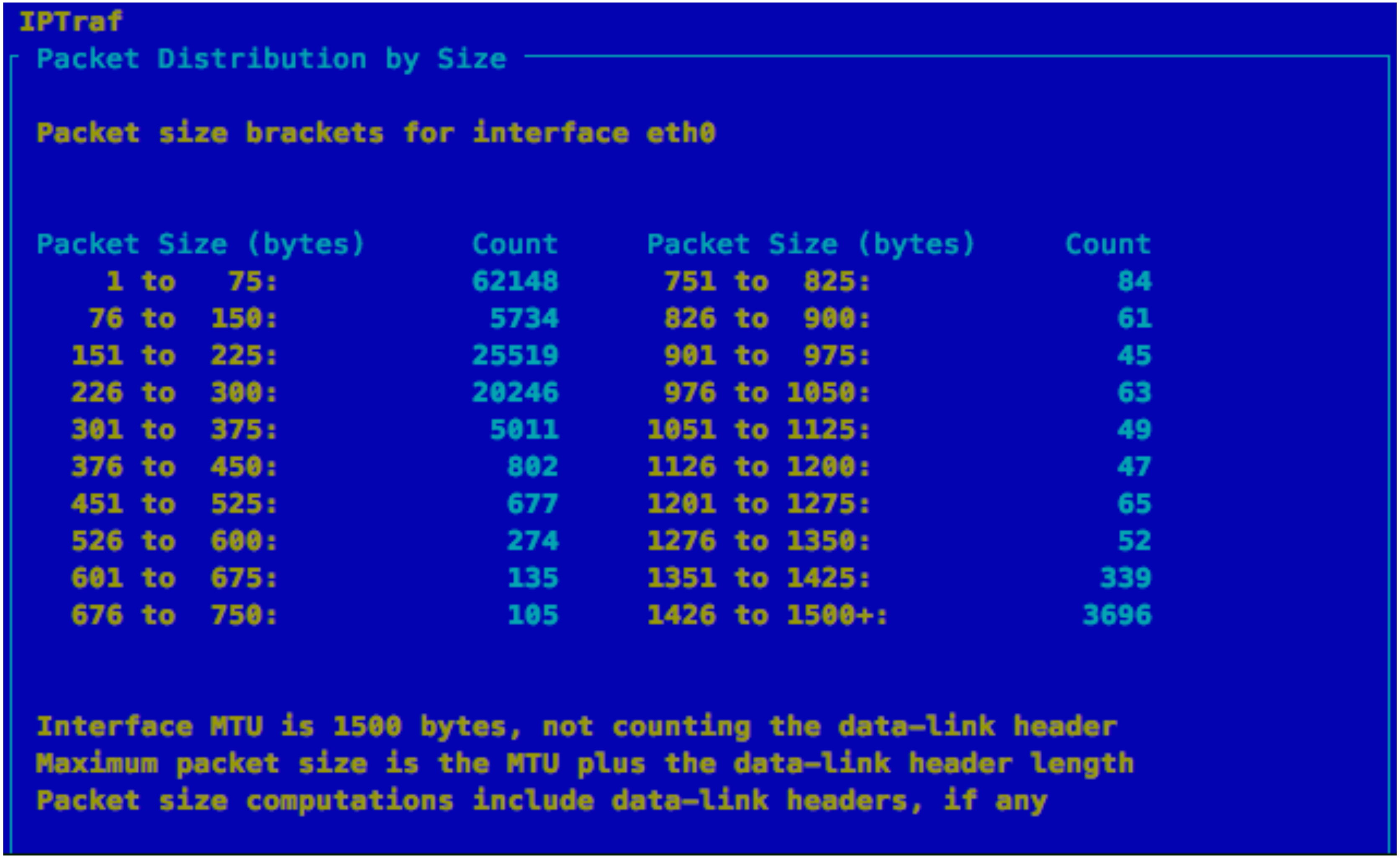
- Misc:
  - ltrace, ss, iptraf, ethtool, snmpget, lldptool, iotop, blktrace, slabtop, /proc, pcstat
- CPU Performance Counters:
  - perf_events, tiptop, rdmsr
- Advanced Tracers:
  - perf_events, ftrace, eBPF, SystemTap, ktap, LTTng, dtrace4linux, sysdig
- Some selected demos…

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
[…]
```

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.

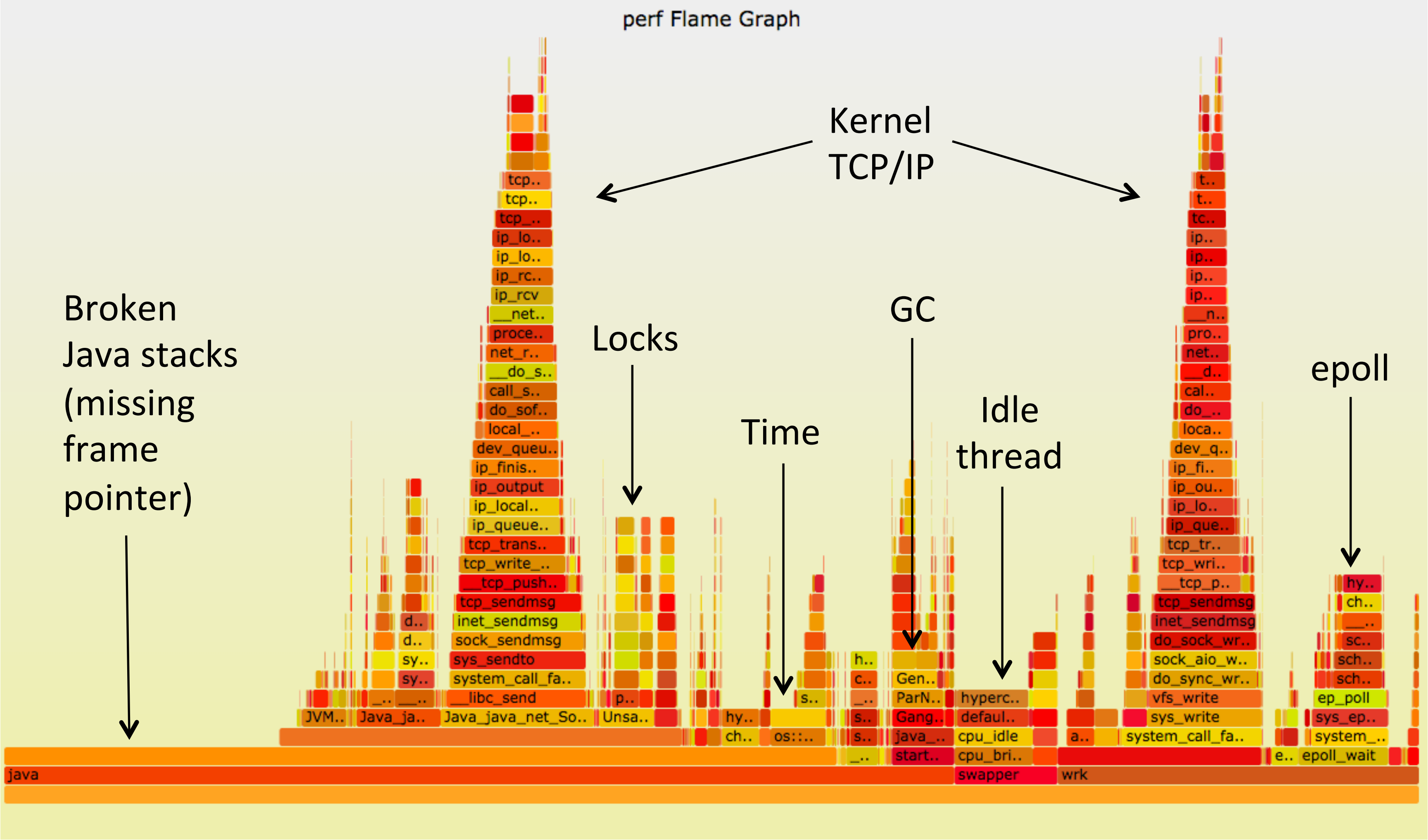
perf_events (counters)

- 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)
- Use flame graphs to visualize sampled stack traces

perf_events CPU Flame Graph



Kernel TCP/IP

Broken Java stacks (missing frame pointer)

Locks

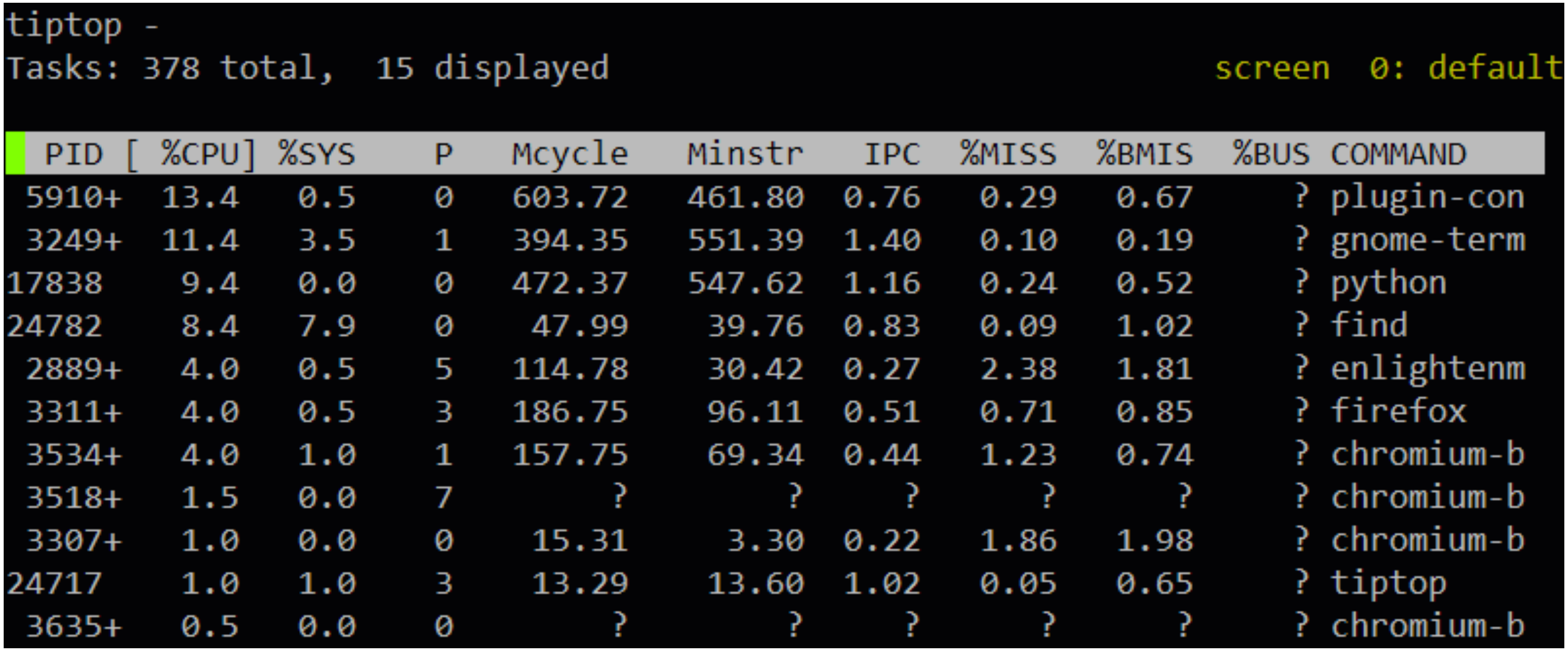
Time

GC

Idle thread

epoll

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
- Needs some love. perfmon2 library integration?
- Still can't use it in clouds yet (needs PMCs enabled)

rdmsr

- Model Specific Registers (MSRs), unlike PMCs, can be read by default in Xen guests
  - Timestamp clock, temp, power, …
  - Use rdmsr(1) from the msr-tools package to read them
  - Uses include (https://github.com/brendangregg/msr-cloud-tools):

```
ec2-guest# ./showboost
[...]
TIME         C0_MCYC        C0_ACYC         UTIL  RATIO    MHz
06:11:35   6428553166   7457384521        51%    116%   2900
06:11:40   6349881107   7365764152        50%    115%   2899
06:11:45   6240610655   7239046277        49%    115%   2899
[...]
ec2-guest# ./cputemp 1
CPU1 CPU2 CPU3 CPU4
61 61 60 59
60 61 60 60
[...]
```

Real CPU MHz

CPU Temperature

More Advanced Tools…

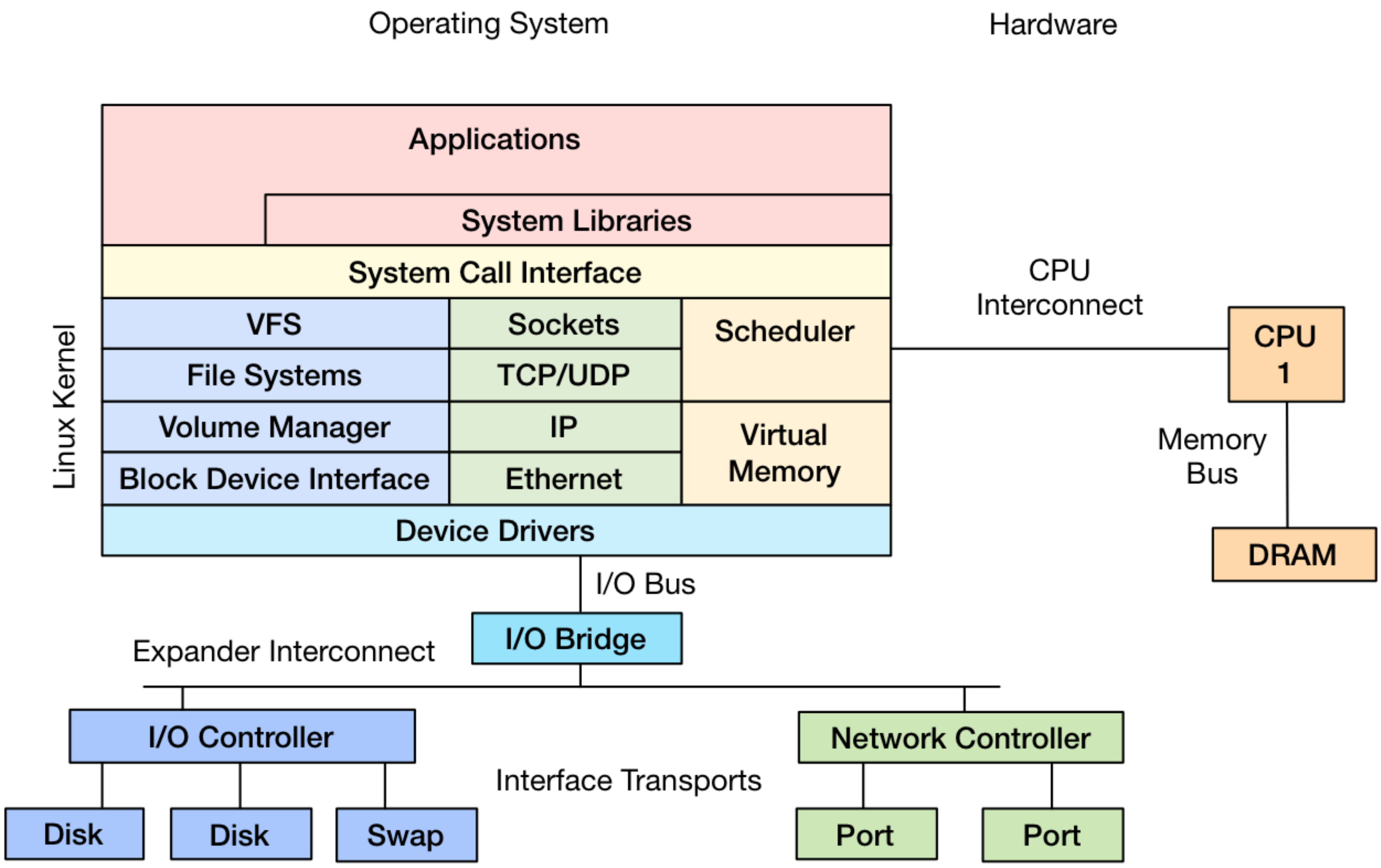
- Some others worth mentioning:

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
pmu-tools	On- and off-core CPU counter tools

Advanced Tracers

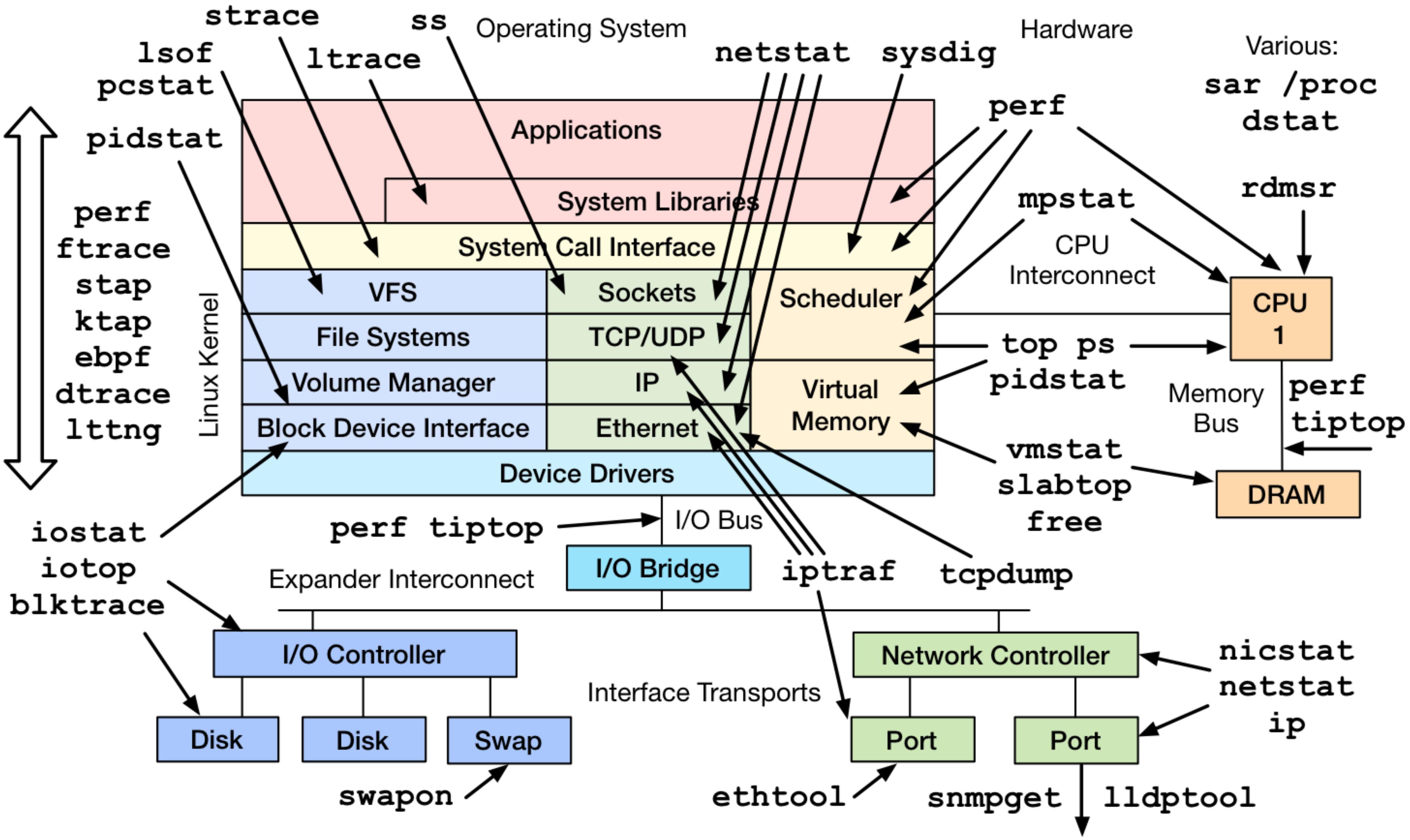
- Many options on Linux:
  - perf_events, ftrace, eBPF, SystemTap, ktap, LTTng, dtrace4linux, sysdig
- Most can do static and dynamic tracing
  - Static: pre-defined events (tracepoints)
  - Dynamic: instrument any software (kprobes, uprobes). Custom metrics on-demand. *Catch all*.
- Many are in-development.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

Linux Observability Tools



Brendan Gregg 2014

Linux Observability Tools



http://www.brendangregg.com/linuxperf.html 2014

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

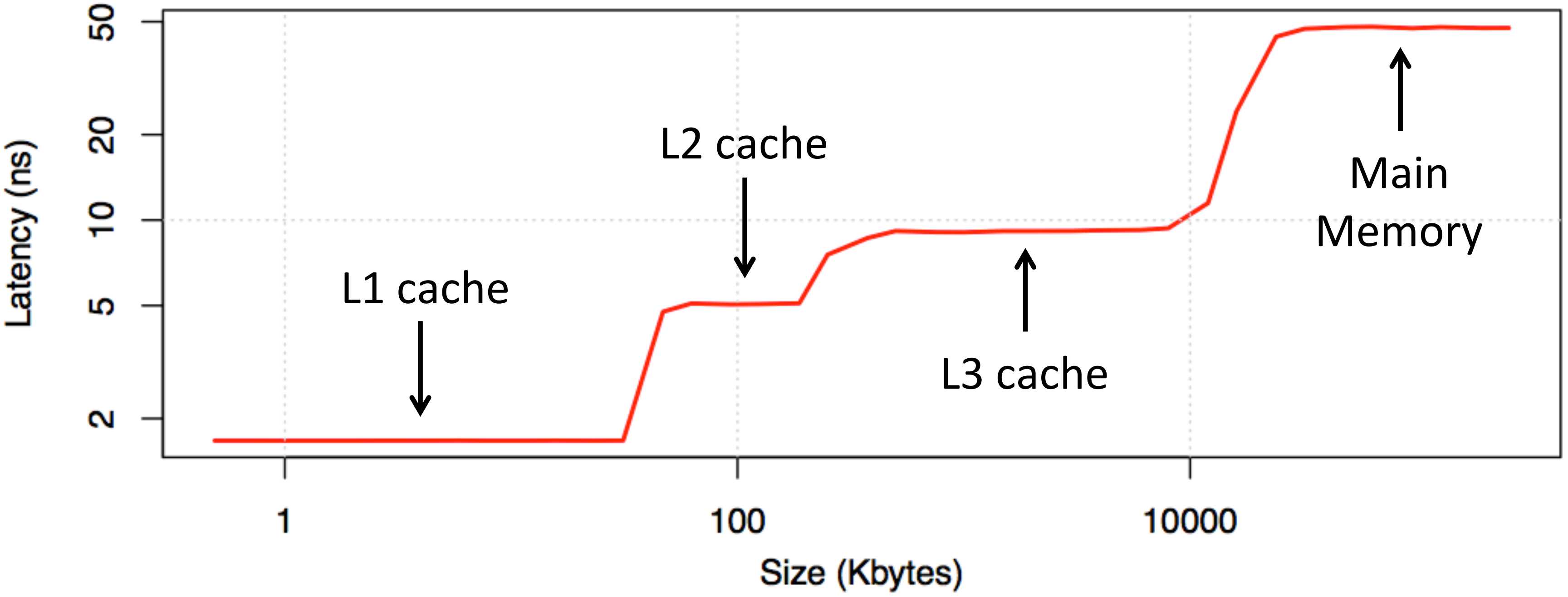
Active Benchmarking

- 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

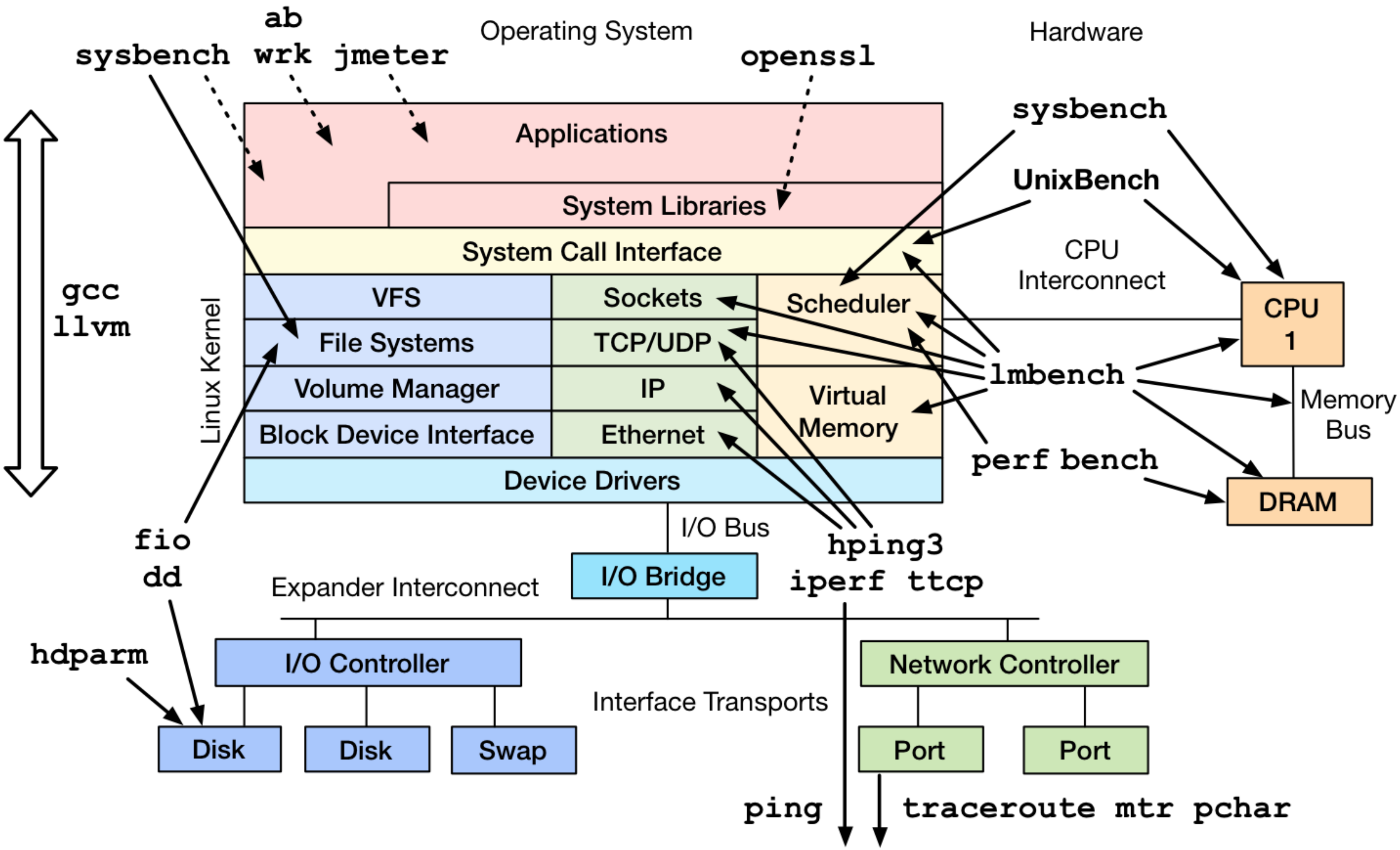
pchar

- 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

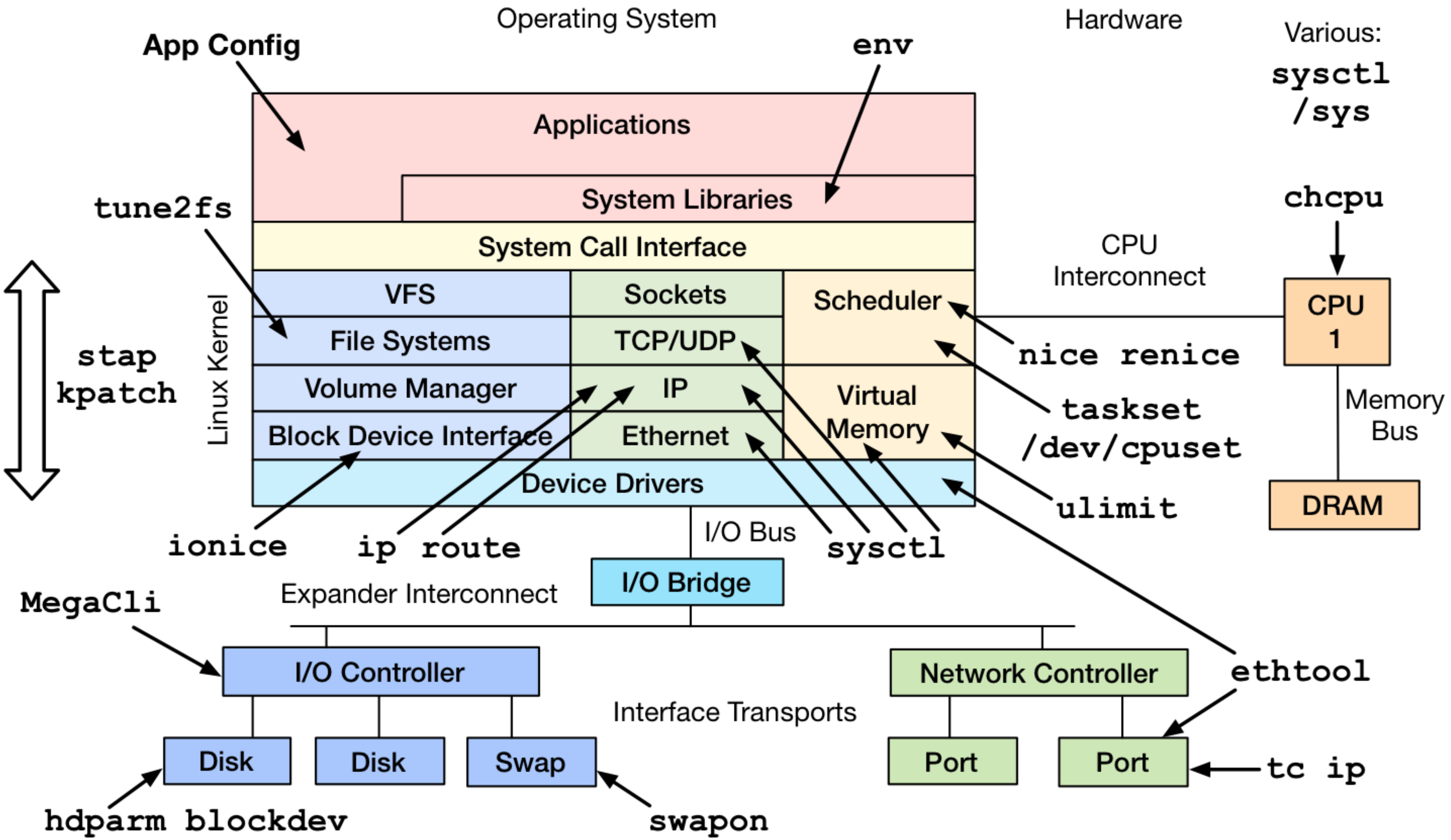
Tuning Tools

- 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

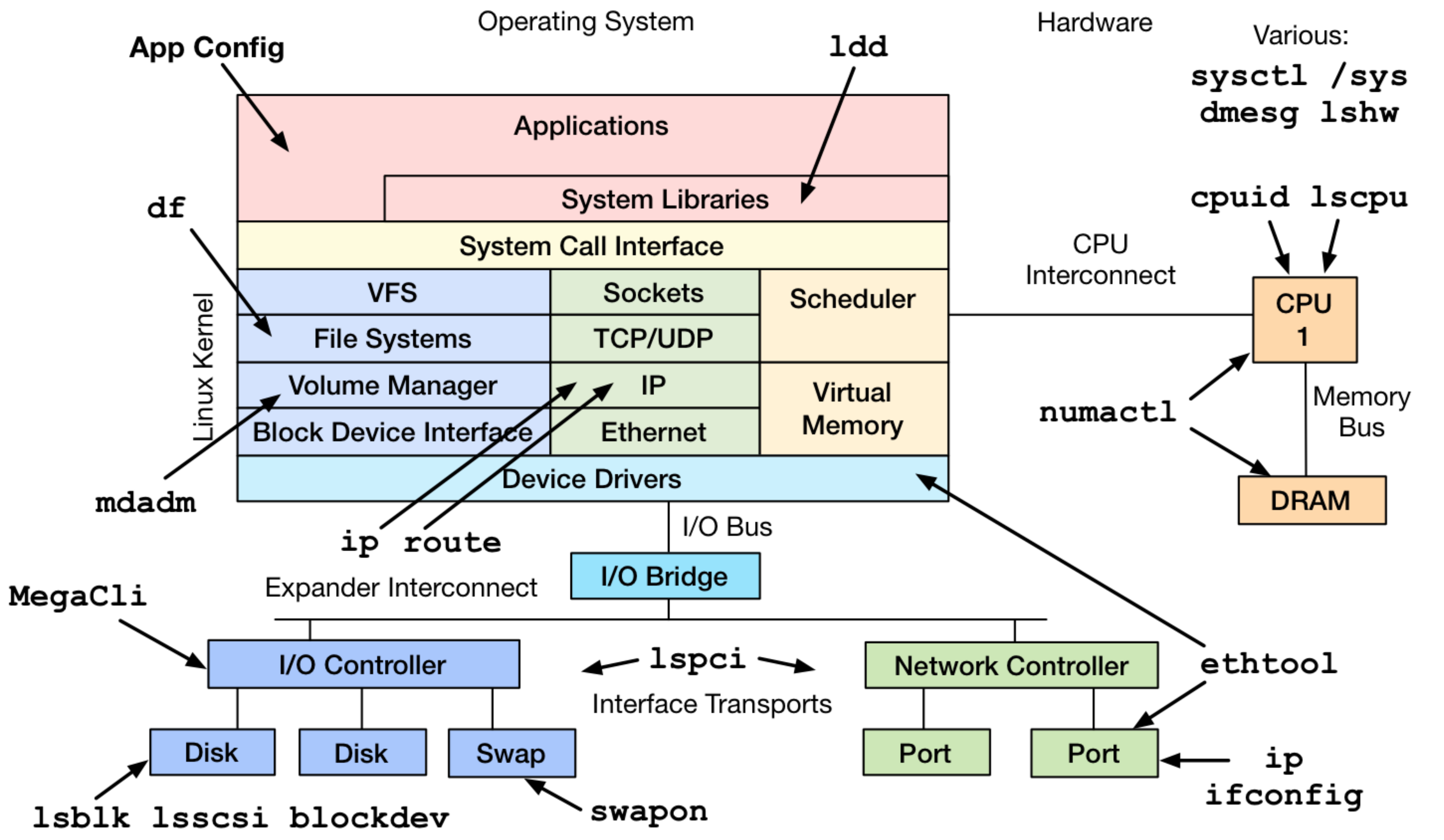


Static Tools

Static Tools

- Static Performance Tuning: check the static state and configuration of the system
  - CPU types
  - Storage devices
  - File system capacity
  - File system and volume configuration
  - Route table
  - State of hardware
- What can be checked on a system without load

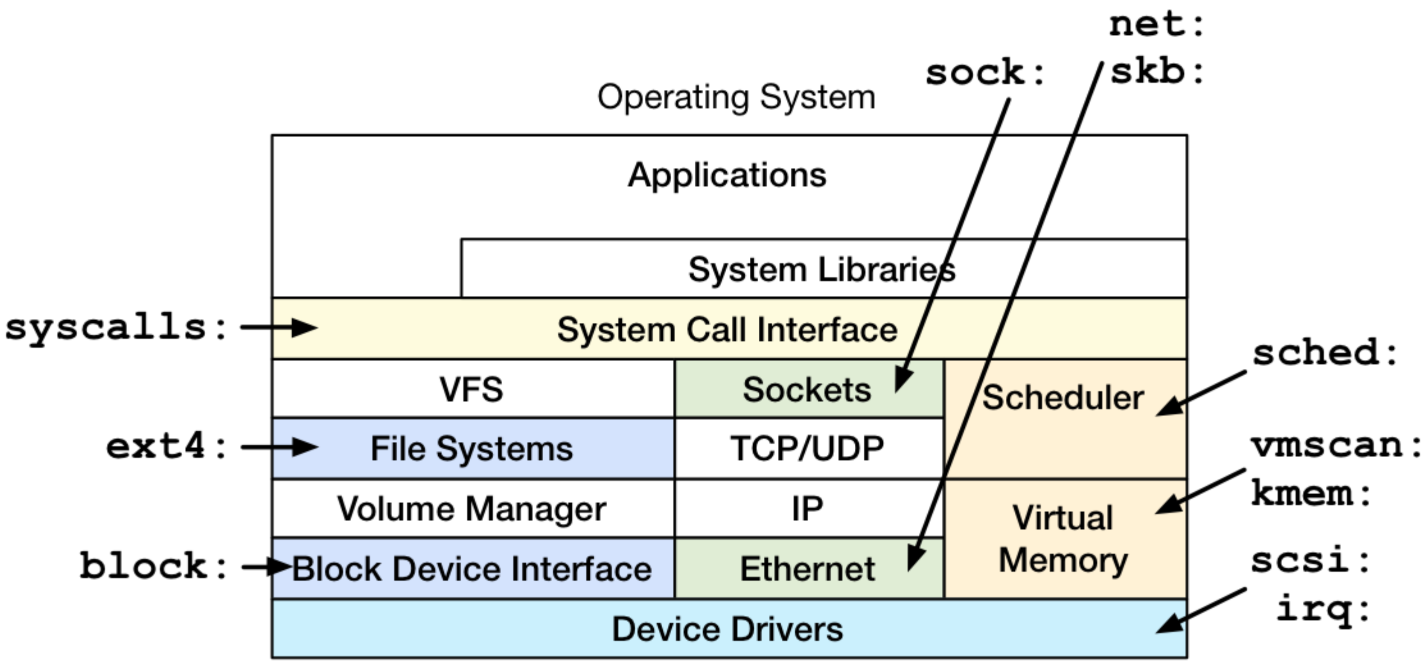
Static Tools



http://www.brendangregg.com/linuxperf.html 2014

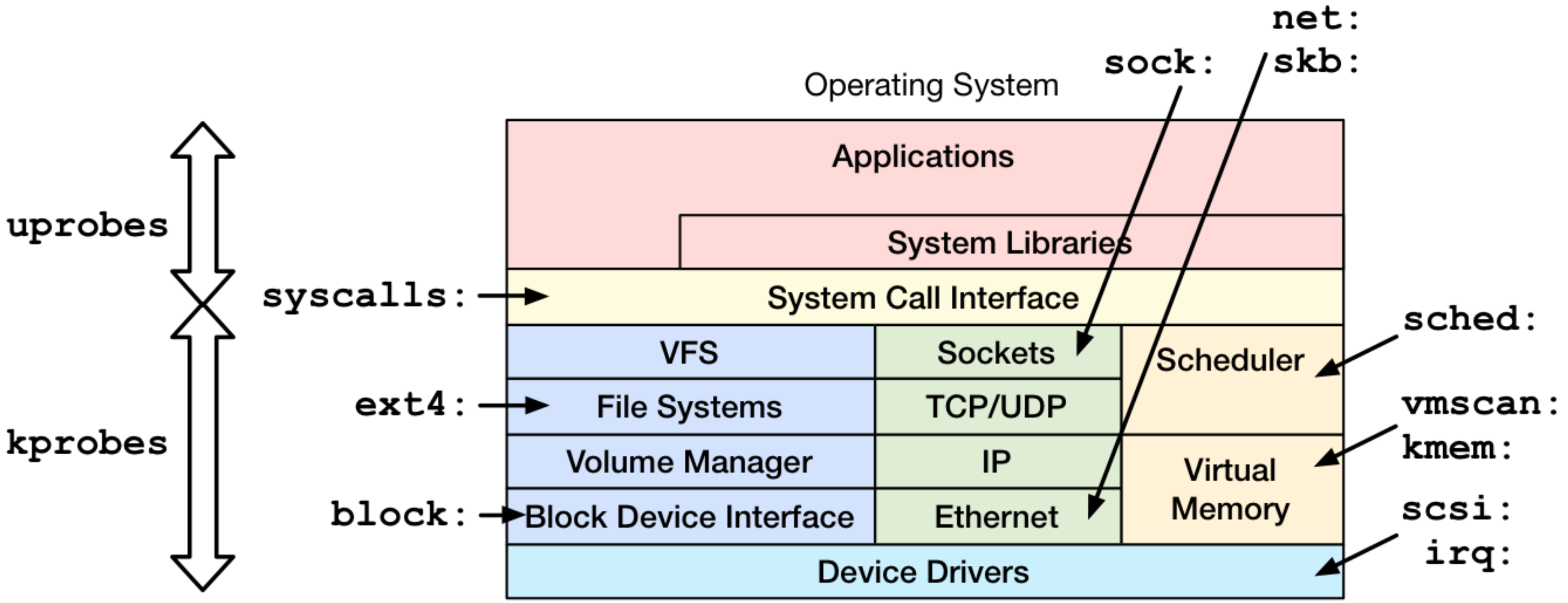
Tracing

Tracing Frameworks: Tracepoints



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

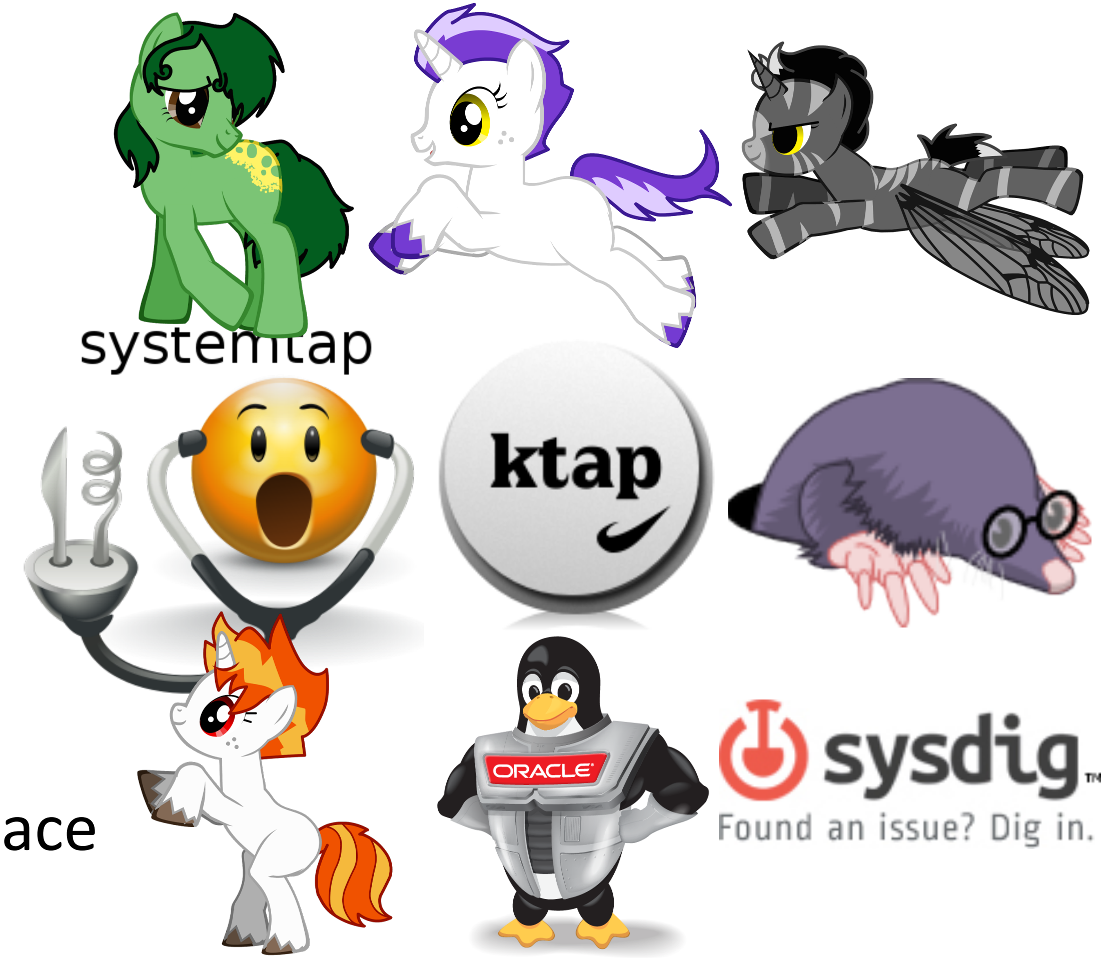
Tracing Frameworks: + probes



- 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
  - Oracle Linux DTrace
  - 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?

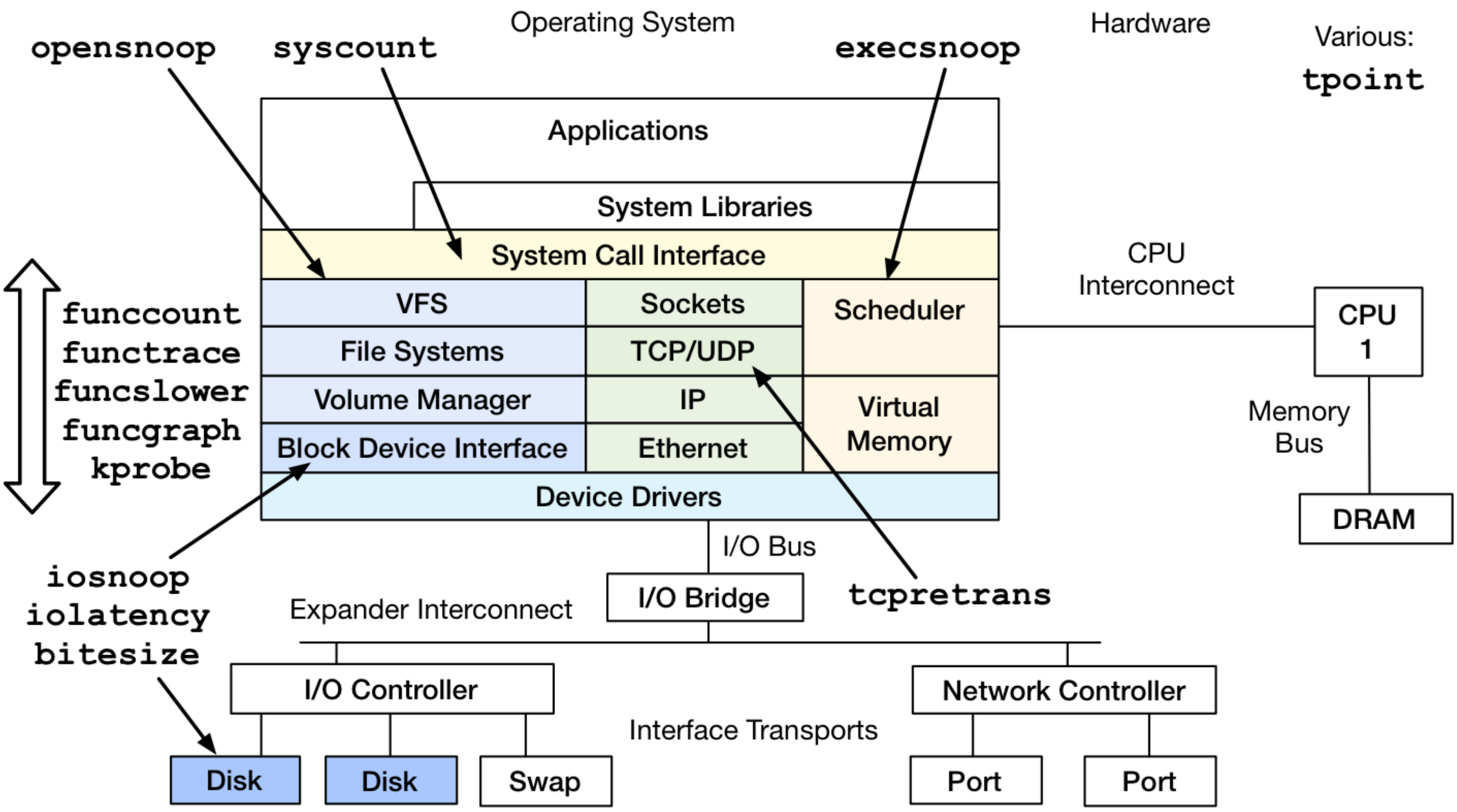
~~Imagine~~ Linux with Tracing

- 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: "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

Found an issue? Dig in.

- 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:

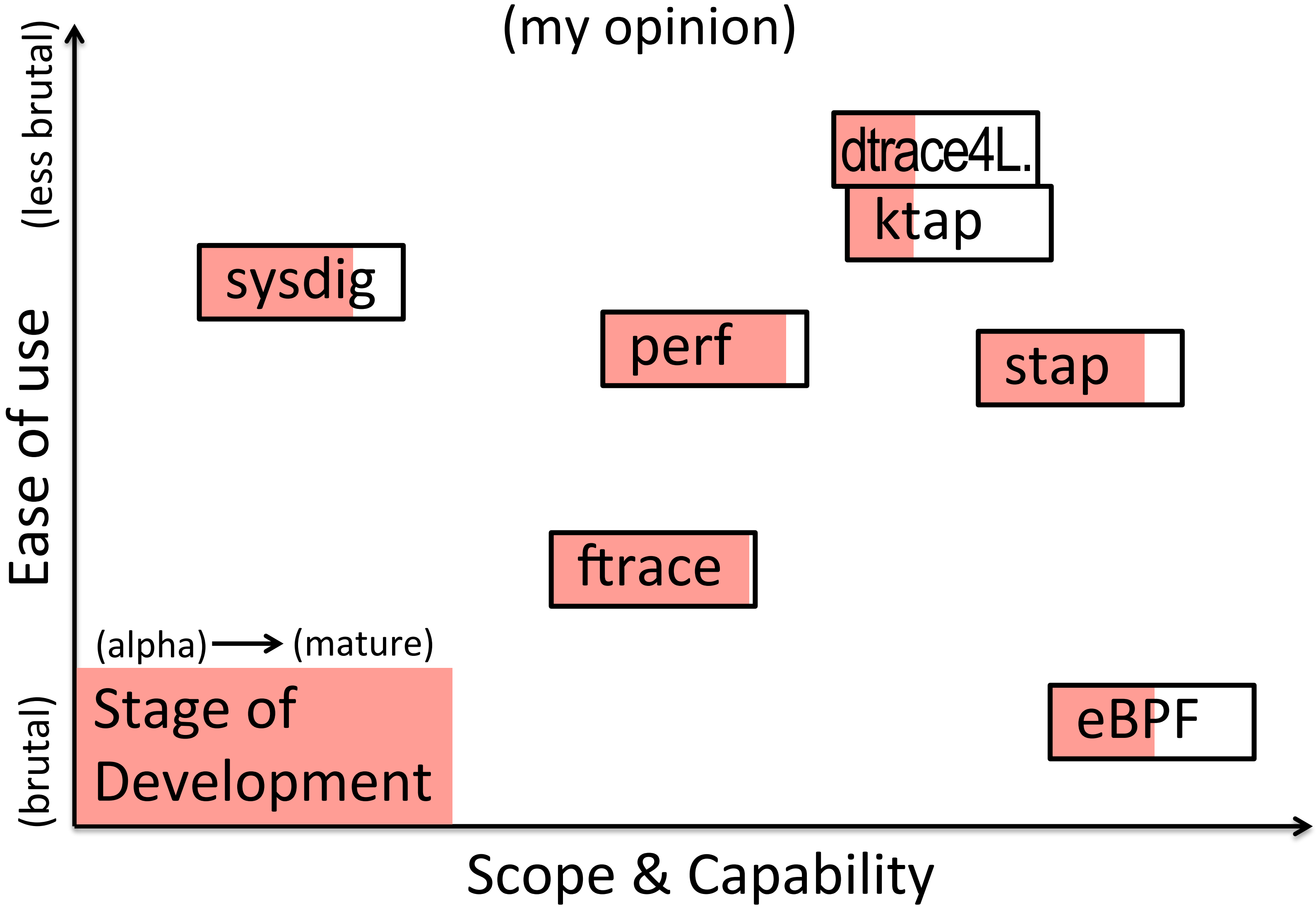
```
# sysdig -c fileslower 1
TIME                    PROCESS      TYPE     LAT(ms) FILE
2014-04-13 20:40:43.973 cksum        read           2 /mnt/partial.0.0
2014-04-13 20:40:44.187 cksum        read           1 /mnt/partial.0.0
2014-04-13 20:40:44.689 cksum        read           2 /mnt/partial.0.0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

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

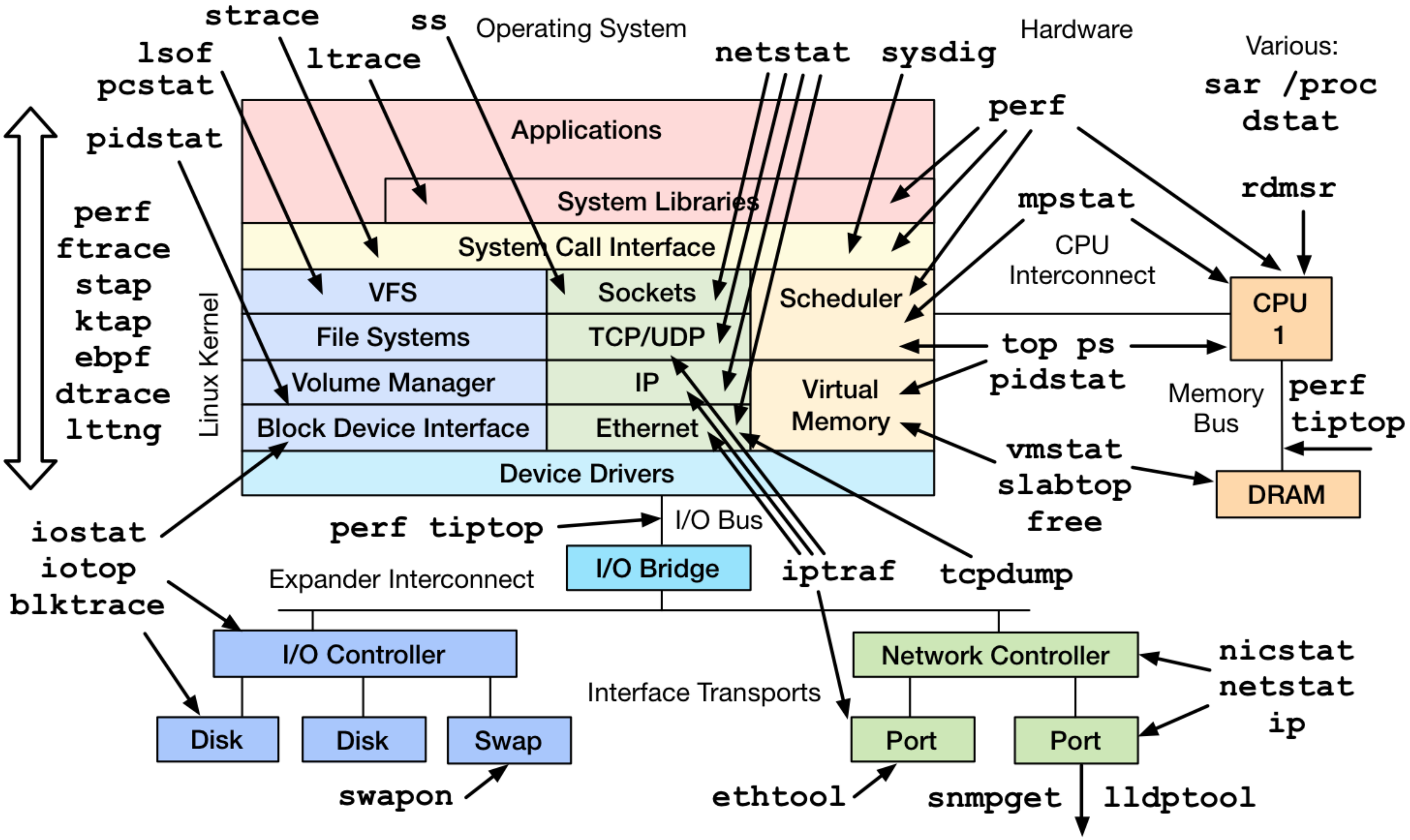
Present & Future

- Present:
  - ftrace can serve many needs today
  - perf_events some more, esp. with debuginfo
  - ad 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, Oct 2014



In Summary



http://www.brendangregg.com/linuxperf.html 2014

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
- http://www.brendangregg.com/perf.html#FlameGraphs
- 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/
- MSR tools: https://github.com/brendangregg/msr-cloud-tools
- pcstat: https://github.com/tobert/pcstat
- 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?
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