Linux Performance Analysis and Tools

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SCaLE11x
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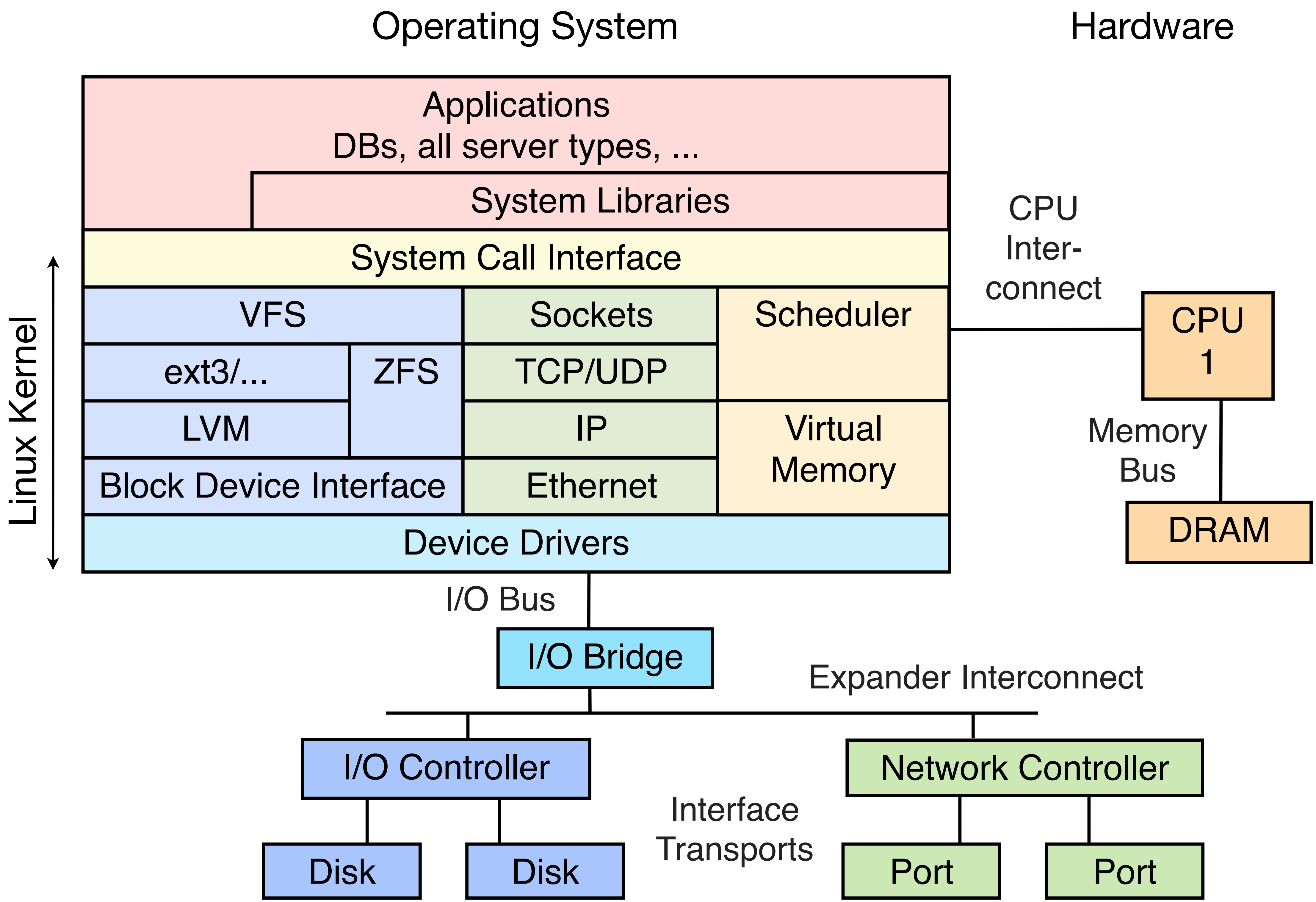
Find the Bottleneck



whoami

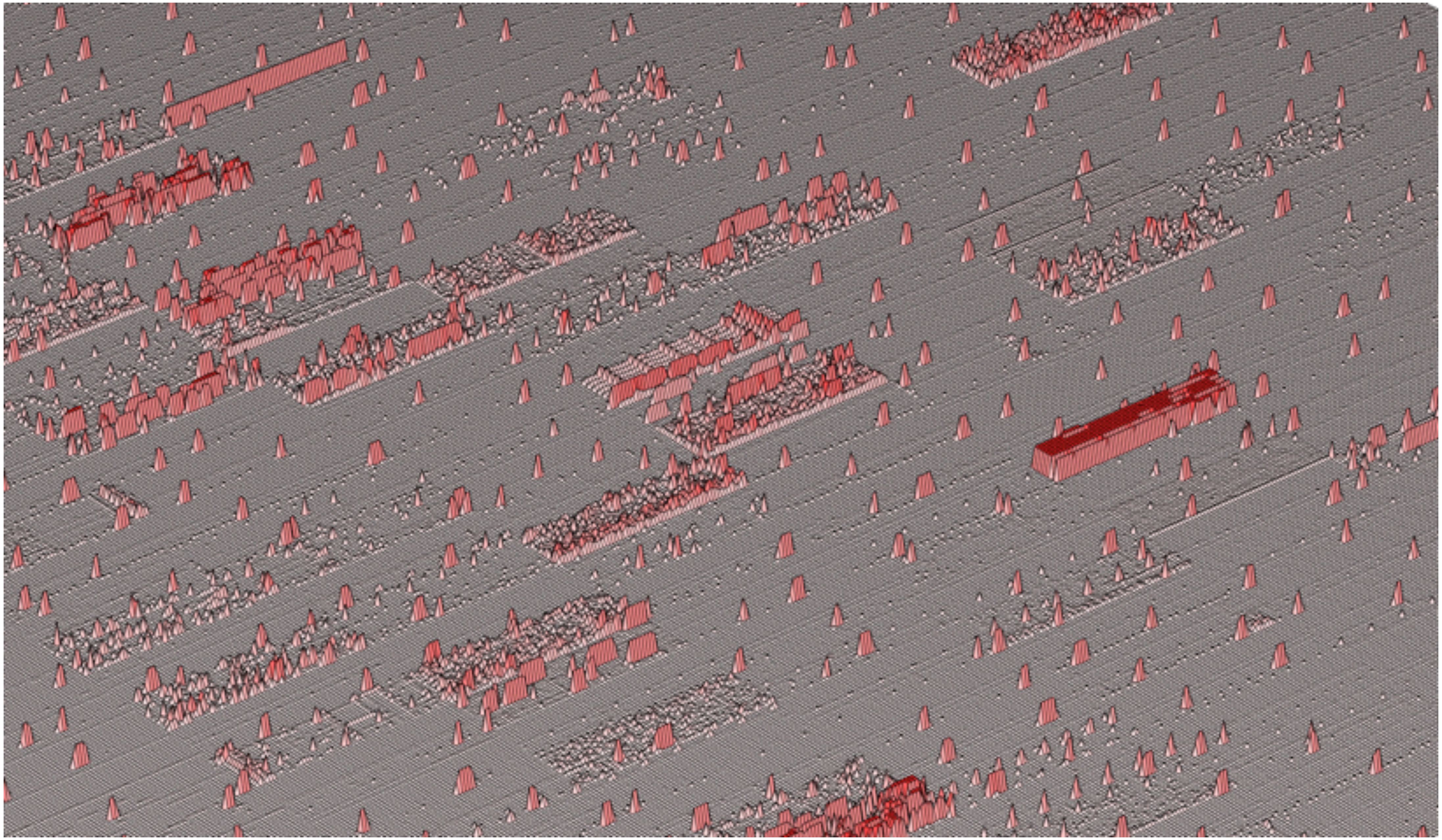
- Lead Performance Engineer
- Work/Research: tools, visualizations, methodologies
- Was Brendan@Sun Microsystems, Oracle, now Joyent

Joyent

- High-Performance Cloud Infrastructure
  - Compete on cloud instance/OS performance
- Public/private cloud provider
- OS-Virtualization for bare metal performance (Zones)
- Core developers of SmartOS and node.js
- KVM for Linux guests

SCaLE10x: Cloud Performance Analysis

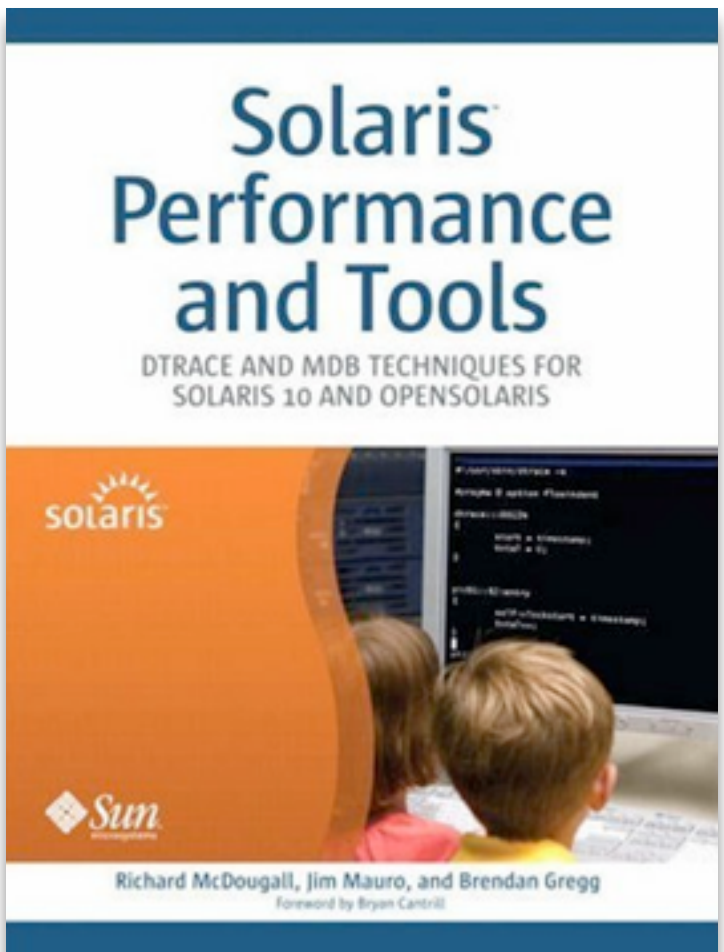
- Example perf issues, including new tools and visualizations:

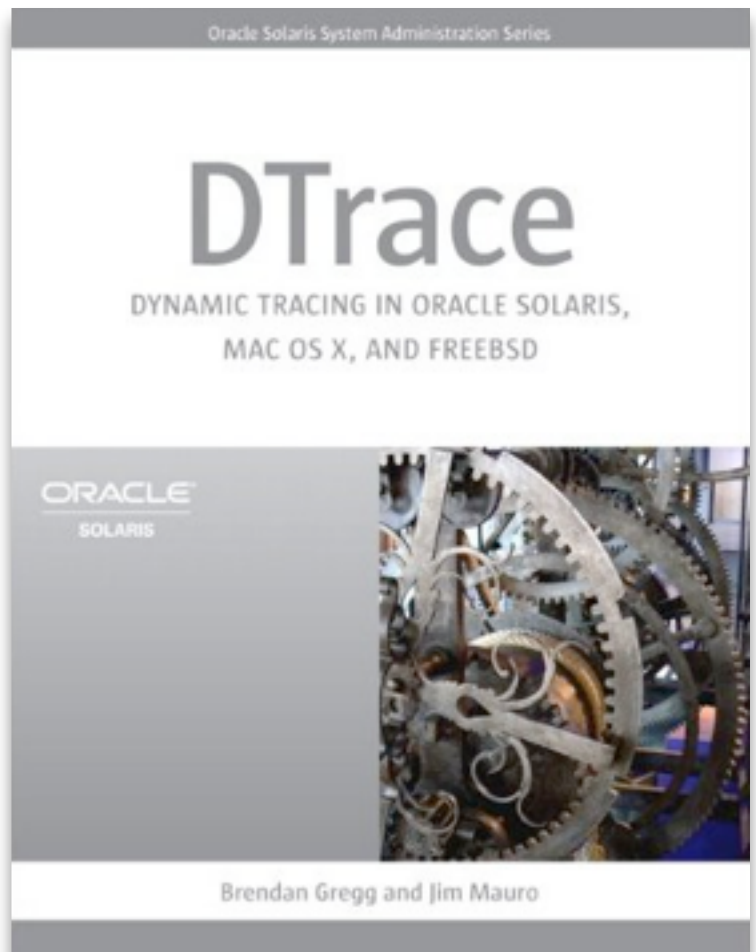


http://dtrace.org/blogs/brendan/2012/01/30/performance-analysis-talk-at-scale10x/

SCaLE11x: Linux Performance Analysis

- The primary operating system for my next book:
  (secondary is the OpenSolaris-illumos-based SmartOS)





Systems Performance

ENTERPRISE AND THE CLOUD

Brendan Gregg

Prentice Hall, 2013

Agenda

- Background
- Linux Analysis and Tools
    - Basic
    - Intermediate
    - Advanced
- Methodologies
- Challenges

Performance

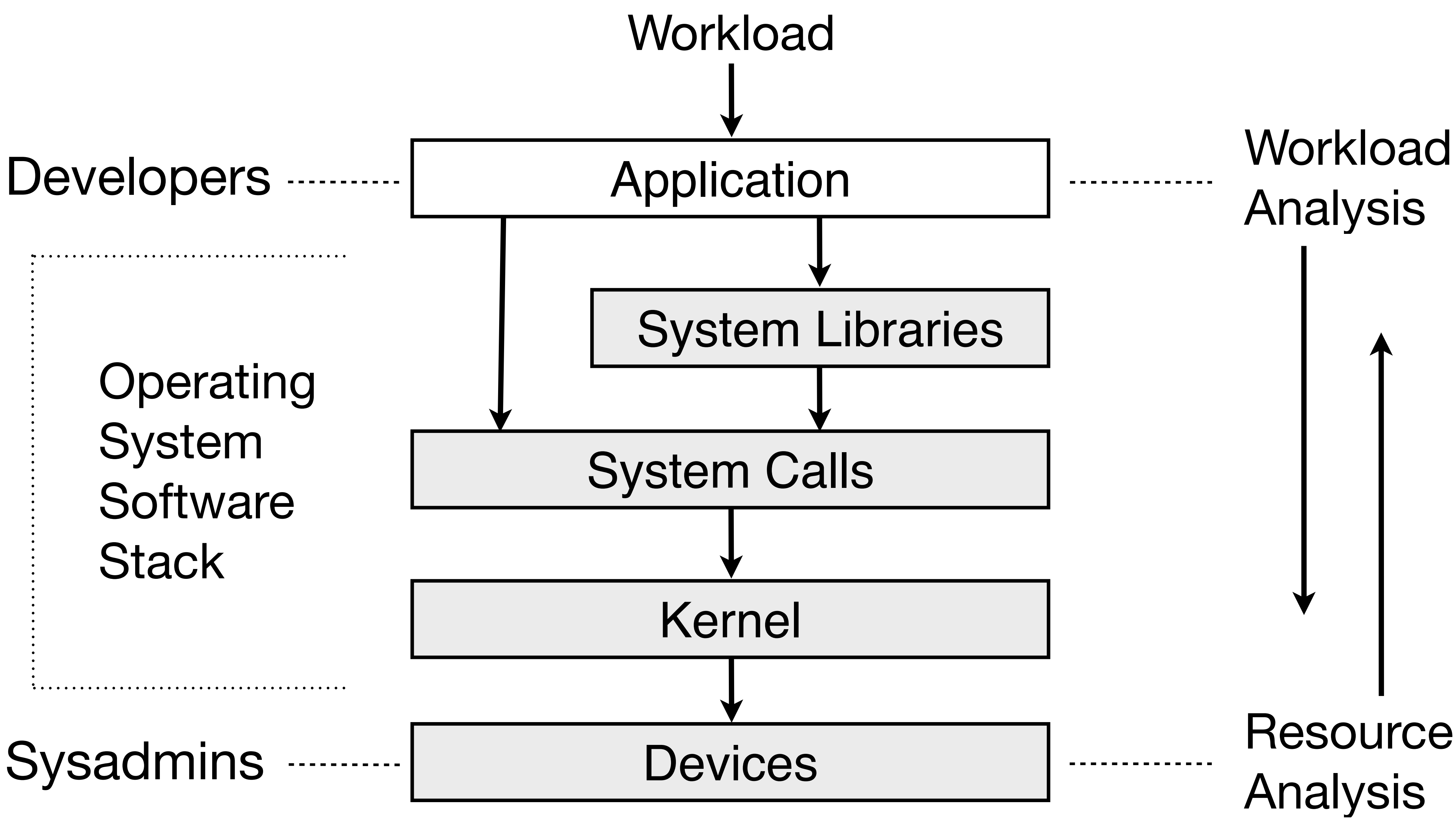
- Why do performance analysis?
  - **Reduce IT spend** – find and eliminate waste, find areas to tune, and do more with less
  - **Build scalable architectures** – understand system limits and develop around them
  - **Solve issues** – locate bottlenecks and latency outliers

Systems Performance

- Why study the operating system?
  - Find and fix **kernel**-based perf issues
    - 2-20% wins: I/O or buffer size tuning, NUMA config, etc
    - 2-200x wins: bugs, disabled features, perturbations causing latency outliers
    - Kernels change, new devices are added, workloads scale, and new perf issues are encountered.
  - Analyze **application** perf from kernel/system context
    - 2-2000x wins: identifying and eliminating unnecessary work

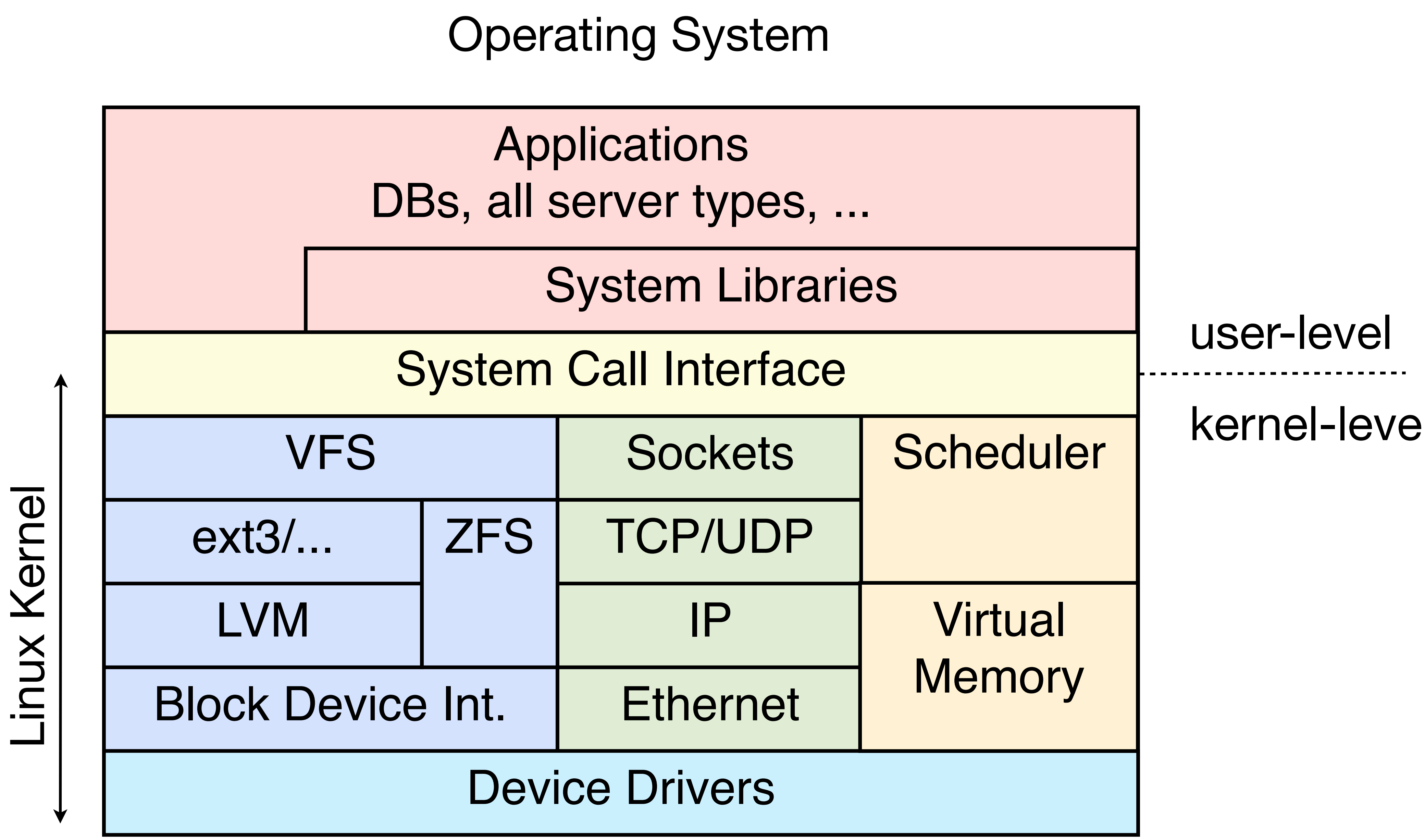
Perspectives

- System analysis can be top-down, or bottom-up:



Kernel Internals

- Eventually you'll need to know some kernel internals



Common System Metrics

```
$ iostat
Linux 3.2.6-3.fc16.x86_64 (node104)     02/20/2013    _x86_64_ (1 CPU)

avg-cpu:  %user   %nice %system %iowait  %steal   %idle
           0.02    0.00    0.10    0.04    0.00   99.84

Device:            tps    kB_read/s    kB_wrtn/s    kB_read    kB_wrtn
vda               0.24         7.37         2.15   80735422   23571828
vdb               0.06         5.51         7.79   60333940   85320072
```

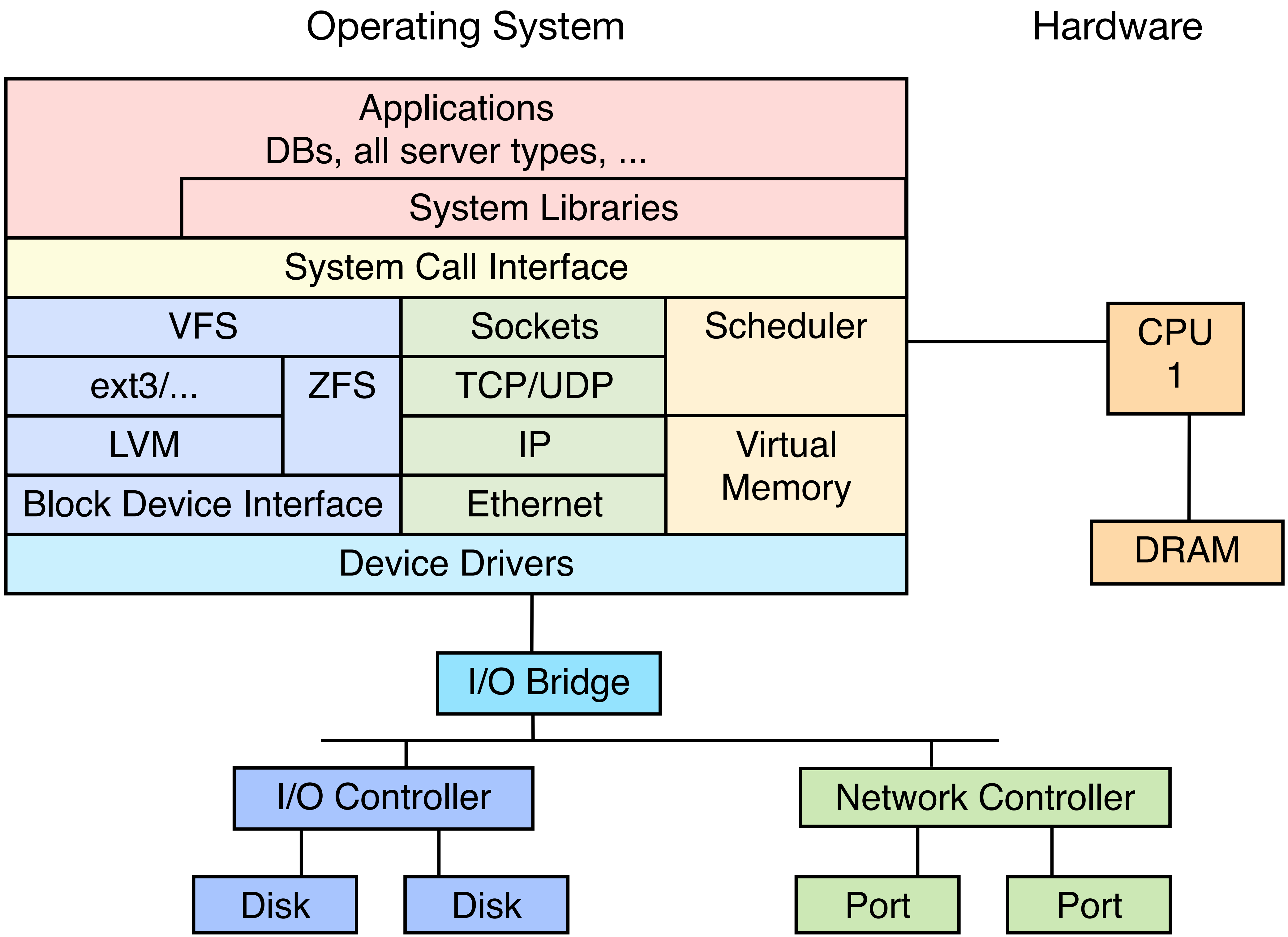
- It's also worth studying common system metrics (iostat, ...), even if you intend to use a monitoring product. Monitoring products often use the same metrics, read from /proc.

Analysis and Tools

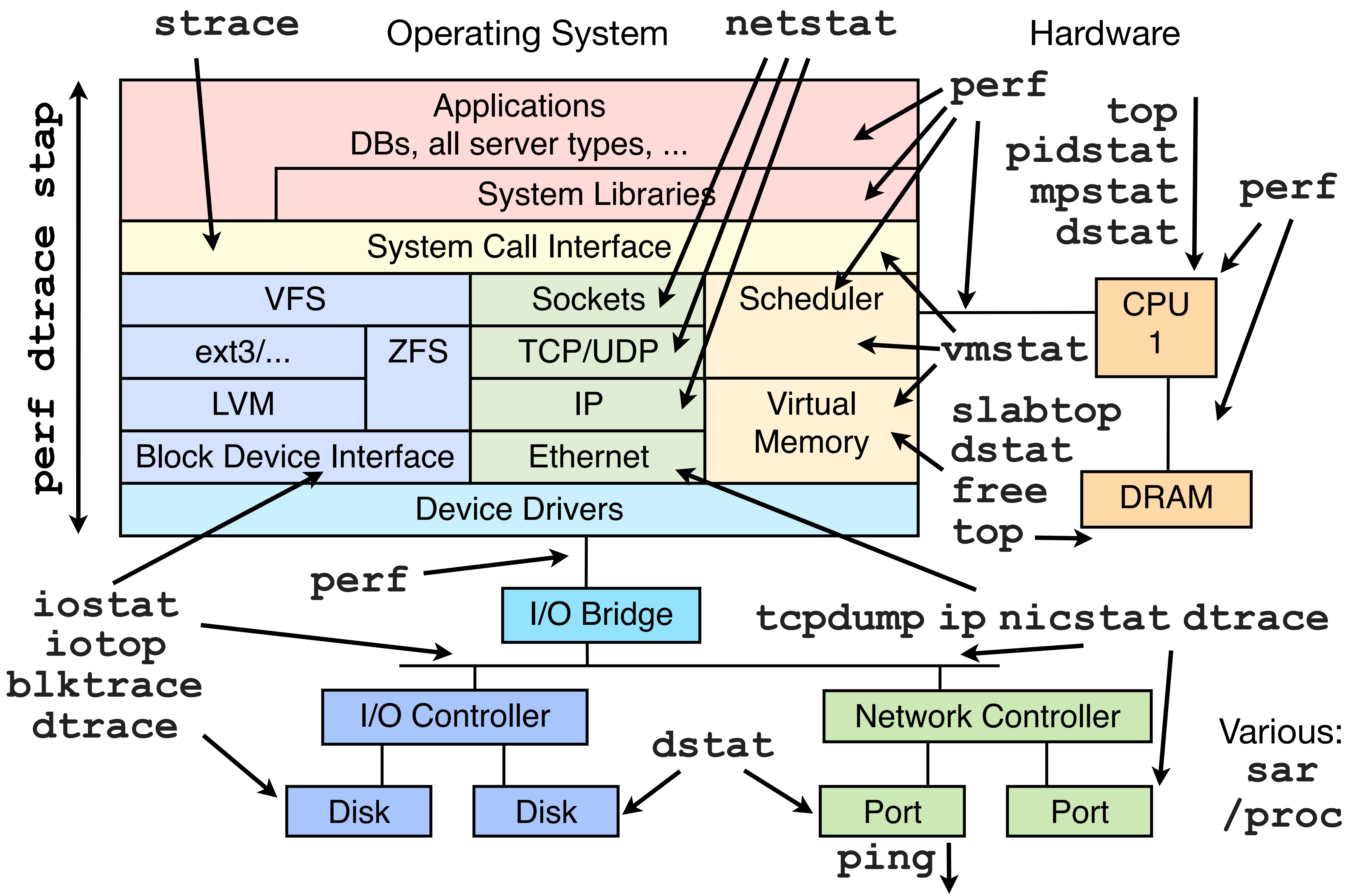
Analysis and Tools

- A quick tour of tools, to show what can be done
- Then, some methodologies for applying them

Analysis and Tools



Analysis and Tools



Tools: Basic

- uptime
- top or htop
- mpstat
- iostat
- vmstat
- free
- ping
- nicstat
- dstat

uptime

- Shows *load averages*, which are also shown by other tools:

```
$ uptime
 16:23:34 up 126 days,  1:03,  1 user,  load average: 5.09, 2.12, 1.82
```

- This counts runnable threads (tasks), on-CPU, or, runnable and waiting. Linux includes tasks blocked on disk I/O.
- These are exponentially-damped moving averages, with time constants of 1, 5 and 15 minutes. With three values you can see if load is increasing, steady, or decreasing.
- If the load is greater than the CPU count, it might mean the CPUs are saturated (100% utilized), and threads are suffering scheduler latency. Might. There's that disk I/O factor too.
- This is only useful as a clue. Use other tools to investigate!

top

- System-wide and per-process summaries:

```
$ top
top - 01:38:11 up 63 days,  1:17,  2 users,  load average: 1.57, 1.81, 1.77
Tasks: 256 total,   2 running, 254 sleeping,   0 stopped,   0 zombie
Cpu(s):  2.0%us,  3.6%sy,  0.0%ni, 94.2%id,  0.0%wa,  0.0%hi,  0.2%si,  0.0%st
Mem:  49548744k total, 16746572k used, 32802172k free,   182900k buffers
Swap: 100663292k total,        0k used, 100663292k free, 14925240k cached

  PID USER      PR  NI  VIRT  RES  SHR S %CPU %MEM    TIME+  COMMAND
11721 web       20   0  623m  50m 4984 R   93  0.1   0:59.50 node
11715 web       20   0  619m  20m 4916 S   25  0.0   0:07.52 node
   10 root      20   0     0    0    0 S    1  0.0 248:52.56 ksoftirqd/2
   51 root      20   0     0    0    0 S    0  0.0   0:35.66 events/0
11724 admin     20   0 19412 1444  960 R    0  0.0   0:00.07 top
    1 root      20   0 23772 1948 1296 S    0  0.0   0:04.35 init
[...]
```

- %CPU = interval sum for all CPUs (varies on other OSes)
- top can consume CPU (syscalls to read /proc)
- Straight-forward. Or is it?

top, cont.

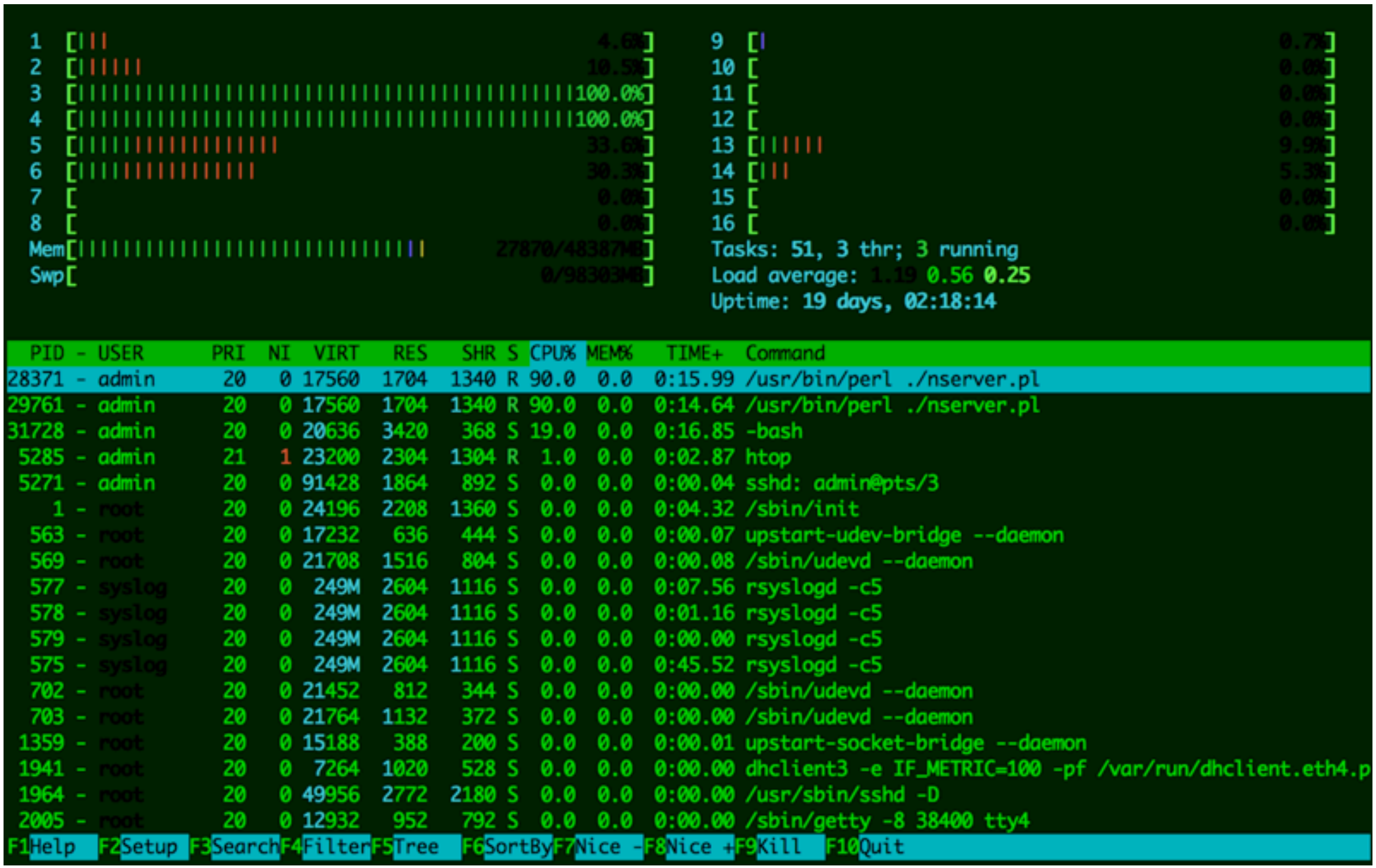
- Interview questions:
  - 1. Does it show all CPU consumers?
  - 2. A process has high %CPU – next steps for analysis?

top, cont.

- 1. top can miss:
  - short-lived processes
  - kernel threads (tasks), unless included (see top options)
- 2. analyzing high CPU processes:
  - identify why – profile code path
  - identify what – execution or stall cycles
- High %CPU time may be stall cycles on memory I/O – upgrading to faster CPUs doesn't help!

htop

- Super top. Super configurable. Eg, basic CPU visualization:



mpstat

- Check for hot threads, unbalanced workloads:

```
$ mpstat -P ALL 1
02:47:49    CPU    %usr  %nice    %sys %iowait    %irq   %soft  %steal  %guest   %idle
02:47:50    all   54.37   0.00   33.12    0.00    0.00    0.00    0.00    0.00   12.50
02:47:50      0   22.00   0.00   57.00    0.00    0.00    0.00    0.00    0.00   21.00
02:47:50      1   19.00   0.00   65.00    0.00    0.00    0.00    0.00    0.00   16.00
02:47:50      2   24.00   0.00   52.00    0.00    0.00    0.00    0.00    0.00   24.00
02:47:50      3  100.00   0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
02:47:50      4  100.00   0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
02:47:50      5  100.00   0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
02:47:50      6  100.00   0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
02:47:50      7   16.00   0.00   63.00    0.00    0.00    0.00    0.00    0.00   21.00
02:47:50      8  100.00   0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00
[...]
```

- Columns are summarized system-wide in top(1)'s header

iostat

- Disk I/O statistics. 1st output is summary since boot.

```
$ iostat -xkdz 1

Linux 2.6.35-32-server (prod21)      02/20/13     _x86_64_    (16 CPU)

Device:          rrqm/s   wrqm/s     r/s     w/s    rkB/s    wkB/s \ ...
sda                0.00     0.00    0.00    0.00     0.00     0.00 / ...
sdb                0.00     0.35    0.00    0.05     0.10     1.58 \ ...
                                                                   / ...
Device:          rrqm/s   wrqm/s     r/s     w/s    rkB/s    wkB/s \ ...
sdb                0.00     0.00  591.00    0.00  2364.00     0.00 / ...
```

workload input →

```
... \   avgqu-sz   await r_await w_await  svctm  %util
... /       0.00    0.84    0.84    0.00   0.84   0.00
... \       0.00    3.82    3.47    3.86   0.30   0.00
... /       0.00    2.31    2.31    0.00   2.31   0.00
... \
... /   avgqu-sz   await r_await w_await  svctm  %util
... \       0.95    1.61    1.61    0.00   1.61  95.00
```

resulting performance →

iostat, cont.

- %util: usefulness depends on target – virtual devices backed by multiple disks may accept more work a 100% utilization
- Also calculate I/O controller stats by summing their devices
- One nit: would like to see disk errors too. Add a “-e”?

vmstat

- Virtual-Memory statistics, and other high-level summaries:

```
$ vmstat 1
procs -----------memory---------- ---swap-- -----io---- -system-- ----cpu----
 r  b   swpd   free   buff  cache   si   so    bi    bo   in    cs us sy id wa
15  0   2852 46686812 279456 1401196    0    0     0     0    0     0  0  0 100  0
16  0   2852 46685192 279456 1401196    0    0     0     0 2136 36607 56 33 11  0
15  0   2852 46685952 279456 1401196    0    0     0    56 2150 36905 54 35 11  0
15  0   2852 46685960 279456 1401196    0    0     0     0 2173 36645 54 33 13  0
[...]
```

- First line of output includes *some* summary-since-boot values
- “r” = total number of runnable threads, *including* those running
- Swapping (aka paging) allows over-subscription of main memory by swapping pages to disk, but costs performance

free

- Memory usage summary (Kbytes default):

```
$ free
                 total       used       free     shared    buffers     cached
Mem:          49548744   32787912   16760832          0      61588     342696
-/+ buffers/cache:       32383628   17165116
Swap:        100663292          0  100663292
```

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

ping

- Simple network test (ICMP):

```
$ ping www.hilton.com
PING a831.b.akamai.net (63.234.226.9): 56 data bytes
64 bytes from 63.234.226.9: icmp_seq=0 ttl=56 time=737.737 ms
Request timeout for icmp_seq 1
64 bytes from 63.234.226.9: icmp_seq=2 ttl=56 time=819.457 ms
64 bytes from 63.234.226.9: icmp_seq=3 ttl=56 time=897.835 ms
64 bytes from 63.234.226.9: icmp_seq=4 ttl=56 time=669.052 ms
64 bytes from 63.234.226.9: icmp_seq=5 ttl=56 time=799.932 ms
^C
--- a831.b.akamai.net ping statistics ---
6 packets transmitted, 5 packets received, 16.7% packet loss
round-trip min/avg/max/stddev = 669.052/784.803/897.835/77.226 ms
```

- Used to measure network latency. Actually kernel <-> kernel IP stack latency, including how the network handles ICMP.
- Tells us some, but not a lot (above is an exception).
  Lots of other/better tools for this (eg, hping). Try using TCP.

nicstat

- Network statistics tool, ver 1.92 on Linux:

```
# nicstat -z 1
    Time      Int   rKB/s   wKB/s   rPk/s   wPk/s    rAvs    wAvs %Util    Sat
01:20:58     eth0    0.07    0.00    0.95    0.02   79.43   64.81  0.00   0.00
01:20:58     eth4    0.28    0.01    0.20    0.10  1451.3   80.11  0.00   0.00
01:20:58  vlan123    0.00    0.00    0.00    0.02   42.00   64.81  0.00   0.00
01:20:58      br0    0.00    0.00    0.00    0.00   42.00   42.07  0.00   0.00
    Time      Int   rKB/s   wKB/s   rPk/s   wPk/s    rAvs    wAvs %Util    Sat
01:20:59     eth4 42376.0   974.5 28589.4 14002.1  1517.8   71.27  35.5   0.00
    Time      Int   rKB/s   wKB/s   rPk/s   wPk/s    rAvs    wAvs %Util    Sat
01:21:00     eth0    0.05    0.00    1.00    0.00   56.00    0.00  0.00   0.00
01:21:00     eth4 41834.7   977.9 28221.5 14058.3  1517.9   71.23  35.1   0.00
    Time      Int   rKB/s   wKB/s   rPk/s   wPk/s    rAvs    wAvs %Util    Sat
01:21:01     eth4 42017.9   979.0 28345.0 14073.0  1517.9   71.24  35.2   0.00
[...]
```

- This was the tool I wanted, and finally wrote it out of frustration (Tim Cook ported and enhanced it on Linux)
- Calculate network controller stats by summing interfaces

dstat

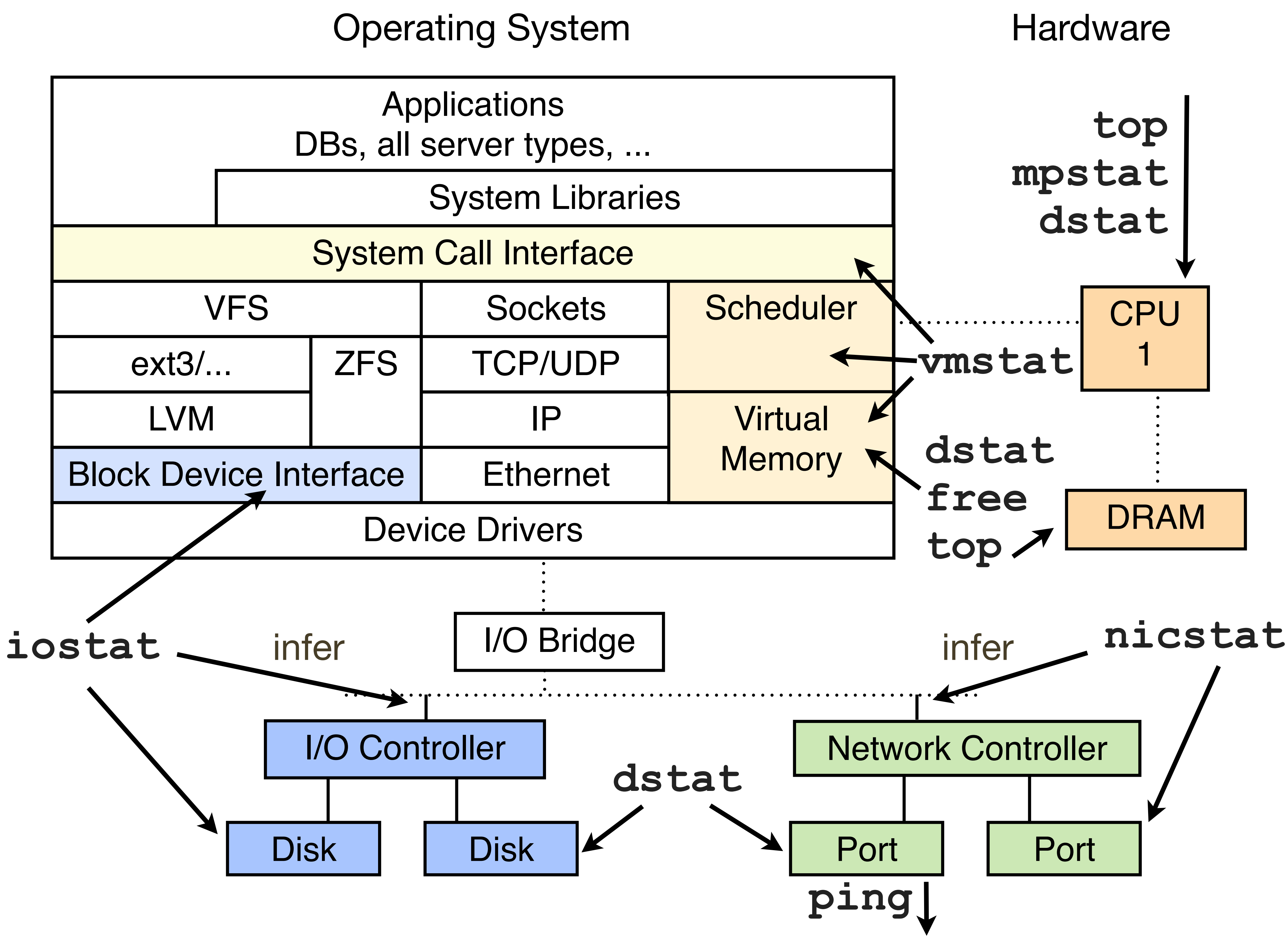
- A better vmstat-like tool. Does coloring (FWIW).

```
# dstat 1
You did not select any stats, using -cdngy by default.
----total-cpu-usage---- -dsk/total- -net/total- ---paging-- ---system--
usr sys idl wai hiq siq| read  writ| recv  send|  in   out | int   csw 
  0   0 100   0   0   0|  13k   10k|   0     0 |  15B   96B|   7    14 
 25  27   0   0  11  37|   0     0 |  22M  122k|   0     0 |2333  1426 
 22  23   9   0  13  32|   0    53M|  19M  143k|   0   508k|2037  1377 
 22  26   1   0  12  38|   0   208k|  23M  174k|   0     0 |2425  1649 
 14  12  40   1  13  19|   0    36k|  13M  127k|   0     0 |1164  1045 
 18  16  16   0  24  25|4096B   16M|  18M  265k|   0     0 |1584  1822 
 13  14  47   0   6  21|   0    39M|  13M  105k|   0     0 |1253   857 
 23  27   0   0  12  37|   0     0 |  23M  113k|   0     0 |2248  1432 
 23  30   0   0  10  37|   0    20k|  23M  113k|   0     0 |2305  1424 
 12  11  48   0   9  19|   0    16M|  11M  128k|   0     0 |1133   959 
 19  19  17   0  15  31|   0    56M|  18M  189k|   0     0 |1717  1388 
  3   1  92   2   1   1| 428k    0 | 787k 5576B|  24k    0 | 136   216 
  0   1  99   0   0   0|   0     0 | 108B   66B|   0     0 |   8     9 
```

Tools: Basic, recap

- uptime
- top or htop
- mpstat
- iostat
- vmstat
- free
- ping
- nicstat
- dstat

Tools: Basic, recap



Tools: Intermediate

- sar
- netstat
- pidstat
- strace
- tcpdump
- blktrace
- iotop
- slabtop
- sysctl
- /proc

sar

- System Activity Reporter. Eg, paging statistics -B:

```
$ sar -B 1
Linux 3.2.6-3.fc16.x86_64 (node104)     02/20/2013 _x86_64_    (1 CPU)

05:24:34 PM  pgpgin/s pgpgout/s   fault/s  majflt/s  pgfree/s pgscank/s pgscand/s pgsteal/s    %vmeff
05:24:35 PM      0.00      0.00    267.68      0.00     29.29      0.00      0.00      0.00      0.00
05:24:36 PM     19.80      0.00    265.35      0.99     28.71      0.00      0.00      0.00      0.00
05:24:37 PM     12.12      0.00   1339.39      1.01   2763.64      0.00   1035.35   1035.35    100.00
05:24:38 PM      0.00      0.00    534.00      0.00     28.00      0.00      0.00      0.00      0.00
05:24:39 PM    220.00      0.00    644.00      3.00     74.00      0.00      0.00      0.00      0.00
05:24:40 PM   2206.06      0.00   6188.89     17.17   5222.22   2919.19      0.00   2919.19    100.00
[...]
```

- Configure to archive statistics from cron
- Many, many statistics available:
  - -d: block device statistics, -q: run queue statistics, ...
- Same statistics as shown by other tools (vmstat, iostat, ...)

netstat

- Various network protocol statistics using -s:

```
$ netstat -s
[...]
Tcp:
    127116 active connections openings
    165223 passive connection openings
    12904 failed connection attempts
    19873 connection resets received
    20 connections established
    662889209 segments received
    354923419 segments send out
    405146 segments retransmited
    6 bad segments received.
    26379 resets sent
[...]
TcpExt:
    2142 invalid SYN cookies received
    3350 resets received for embryonic SYN_RECV sockets
    7460 packets pruned from receive queue because of socket buffer overrun
    2932 ICMP packets dropped because they were out-of-window
    96670 TCP sockets finished time wait in fast timer
    86 time wait sockets recycled by time stamp
    1007 packets rejects in established connections because of timestamp
[...many...]
```

pidstat

- Very useful process breakdowns:

```
# pidstat 1
Linux 3.2.6-3.fc16.x86_64 (node107)     02/20/2013    _x86_64_ (1 CPU)

05:55:18 PM       PID    %usr %system  %guest    %CPU   CPU  Command
05:55:19 PM     12642    0.00    1.01    0.00    1.01     0  pidstat
05:55:19 PM     12643    5.05   11.11    0.00   16.16     0  cksum

05:55:19 PM       PID    %usr %system  %guest    %CPU   CPU  Command
05:55:20 PM     12643    6.93    6.93    0.00   13.86     0  cksum
[...]
```

```
# pidstat -d 1
Linux 3.2.6-3.fc16.x86_64 (node107)     02/20/2013    _x86_64_ (1 CPU)

05:55:22 PM       PID   kB_rd/s    kB_wr/s kB_ccwr/s  Command
05:55:23 PM       279      0.00      61.90      0.00  jbd2/vda2-8
05:55:23 PM     12643 151985.71       0.00      0.00  cksum

05:55:23 PM       PID   kB_rd/s    kB_wr/s kB_ccwr/s  Command
05:55:24 PM     12643  96616.67       0.00      0.00  cksum
[...]
```

disk I/O (yay!)

strace

- System call tracer:

```
$ strace -tttT -p 12670
1361424797.229550 read(3, "REQUEST 1888 CID 2"..., 65536) = 959 <0.009214>
1361424797.239053 read(3, "", 61440)     = 0 <0.000017>
1361424797.239406 close(3)               = 0 <0.000016>
1361424797.239738 munmap(0x7f8b22684000, 4096) = 0 <0.000023>
1361424797.240145 fstat(1, {st_mode=S_IFCHR|0620, st_rdev=makedev(136, 0), ...}) = 0
<0.000017>
[...]
```

- -ttt: microsecond timestamp since epoch (left column)
- -T: time spent in syscall (<seconds>)
- -p: PID to trace (or provide a command)
- Useful – high application latency often caused by resource I/O, and *most* resource I/O is performed by syscalls

strace, cont.

- -c: print summary:

```
# strace -c dd if=/dev/zero of=/dev/null bs=512 count=1024k
[...]
% time     seconds  usecs/call     calls    errors syscall
------ ----------- ----------- --------- --------- ----------------
 51.32    0.028376           0   1048581           read
 48.68    0.026911           0   1048579           write
  0.00    0.000000           0         7           open
[...]
```

- This is also a (worst case) demo of the strace *overhead*:

```
# time dd if=/dev/zero of=/dev/null bs=512 count=1024k
[...]
536870912 bytes (537 MB) copied, 0.35226 s, 1.5 GB/s
real 0m0.355s
user 0m0.021s
sys  0m0.022s
# time strace -c dd if=/dev/zero of=/dev/null bs=512 count=1024k
[...]
536870912 bytes (537 MB) copied, 71.9565 s, 7.5 MB/s
real 1m11.969s
user 0m3.179s
sys  1m6.346s
```

200x slower

tcpdump

- Sniff network packets, dump to output files for post analysis:

```
# tcpdump -i eth4 -w /tmp/out.tcpdump
tcpdump: listening on eth4, link-type EN10MB (Ethernet), capture size 65535
bytes
^C33651 packets captured
34160 packets received by filter
508 packets dropped by kernel

# tcpdump -nr /tmp/out.tcpdump
reading from file /tmp/out.tcpdump, link-type EN10MB (Ethernet)
06:24:43.908732 IP 10.2.0.2.55502 > 10.2.203.2.22: Flags [.], ack ...
06:24:43.908922 IP 10.2.0.2.55502 > 10.2.203.2.22: Flags [.], ack ...
06:24:43.908943 IP 10.2.203.2.22 > 10.2.0.2.55502: Flags [.], seq ...
06:24:43.909061 IP 10.2.0.2.55502 > 10.2.203.2.22: Flags [.], ack ...
```

- Output has timestamps with microsecond resolution
- Study odd network latency packet-by-packet
- Import file into other tools (wireshark)

tcpdump, cont.

- Does have overhead in terms of CPU and storage; previous example dropped packets
  - Should be using socket ring buffers to reduce overhead
  - Can use filter expressions to also reduce overhead
  - Could still be problematic for busy interfaces

blktrace

- Block device I/O event tracing. Launch using btrace, eg:

```
# btrace /dev/sdb
  8,16    3     1      0.429604145 20442  A   R 184773879 + 8 <- (8,17) 184773816
  8,16    3     2      0.429604569 20442  Q   R 184773879 + 8 [cksum]
  8,16    3     3      0.429606014 20442  G   R 184773879 + 8 [cksum]
  8,16    3     4      0.429607624 20442  P   N [cksum]
  8,16    3     5      0.429608804 20442  I   R 184773879 + 8 [cksum]
  8,16    3     6      0.429610501 20442  U   N [cksum] 1
  8,16    3     7      0.429611912 20442  D   R 184773879 + 8 [cksum]
  8,16    1     1      0.440227144     0  C   R 184773879 + 8 [0]
[...]
```

- Above output shows a single disk I/O event. Action time is highlighted (seconds).
- Use for investigating I/O latency outliers

iotop

- Disk I/O by process:

```
# iotop -bod5
Total DISK READ:       35.38 M/s | Total DISK WRITE:      39.50 K/s
  TID  PRIO  USER     DISK READ  DISK WRITE  SWAPIN      IO    COMMAND
12824 be/4 root      35.35 M/s    0.00 B/s  0.00 % 80.59 % cksum ...
  279 be/3 root       0.00 B/s   27.65 K/s  0.00 %  2.21 % [jbd2/vda2-8]
12716 be/4 root      28.44 K/s    0.00 B/s  2.35 %  0.00 % sshd: root@pts/0
12816 be/4 root       6.32 K/s    0.00 B/s  0.89 %  0.00 % python /usr/bin/
iotop -bod5
[...]
```

- IO: time thread was waiting on I/O (this is even more useful than pidstat's Kbytes)

- Needs CONFIG_TASK_IO_ACCOUNTING or something similar enabled to work.

slabtop

- Kernel slab allocator usage top:

```
# slabtop -sc
Active / Total Objects (% used)     : 900356 / 1072416 (84.0%)
 Active / Total Slabs (% used)      : 29085 / 29085 (100.0%)
 Active / Total Caches (% used)     : 68 / 91 (74.7%)
 Active / Total Size (% used)       : 237067.98K / 260697.24K (90.9%)
 Minimum / Average / Maximum Object : 0.01K / 0.24K / 10.09K

  OBJS ACTIVE  USE OBJ SIZE  SLABS OBJ/SLAB CACHE SIZE NAME
112035 110974  99%    0.91K   3201       35    102432K ext4_inode_cache
726660 579946  79%    0.11K  20185       36     80740K buffer_head
  4608   4463  96%    4.00K    576        8     18432K kmalloc-4096
 83496  76878  92%    0.19K   1988       42     15904K dentry
 23809  23693  99%    0.55K    821       29     13136K radix_tree_node
 11016   9559  86%    0.62K    216       51      6912K proc_inode_cache
  3488   2702  77%    1.00K    109       32      3488K kmalloc-1024
   510    431  84%    5.73K    102        5      3264K task_struct
 10948   9054  82%    0.17K    238       46      1904K vm_area_struct
  2585   1930  74%    0.58K     47       55      1504K inode_cache
[...]
```

- Shows where kernel memory is consumed

sysctl

- System settings:

```
# sysctl -a
[...]
net.ipv4.tcp_fack = 1
net.ipv4.tcp_reordering = 3
net.ipv4.tcp_ecn = 2
net.ipv4.tcp_dsack = 1
net.ipv4.tcp_mem = 24180   32240    48360
net.ipv4.tcp_wmem = 4096   16384    1031680
net.ipv4.tcp_rmem = 4096   87380    1031680
[...]
```

- Static performance tuning: check the config of the sysetm

/proc

- Read statistic sources directly:

```
$ cat /proc/meminfo
MemTotal:         8181740 kB
MemFree:            71632 kB
Buffers:           163288 kB
Cached:           4518600 kB
SwapCached:          7036 kB
Active:           4765476 kB
Inactive:         2866016 kB
Active(anon):     2480336 kB
Inactive(anon):    478580 kB
Active(file):     2285140 kB
Inactive(file):   2387436 kB
Unevictable:            0 kB
Mlocked:                0 kB
SwapTotal:        2932728 kB
SwapFree:         2799568 kB
Dirty:                 76 kB
Writeback:              0 kB
[...]
```

- Also see /proc/vmstat

Tools: Intermediate, recap.

- sar
- netstat
- pidstat
- strace
- tcpdump
- blktrace
- iotop
- slabtop
- sysctl
- /proc

Tools: Advanced

- perf
- DTrace
- SystemTap
- and more ...

perf

- Originally Performance Counters for Linux (PCL), focusing on CPU performance counters (programmable registers)
- Now a collection of profiling and tracing tools, with numerous subcommands, including:

kmem	Trace/measure kernel memory (slab) properties
kvm	Trace/measure KVM guest OS
list	List available events (targets of instrumentation)
lock	Analyze lock events
probe	Create dynamic probe points (dynamic tracing!)
record	Run a command and record profile data (as perf.data)
report	Read perf.data and summarize, has an interactive mode
sched	Trace/measure kernel scheduler statistics
stat	Run a command, gather, and report perf counter stats

perf: Performance Counters

- Key performance counter summary:

```
$ perf stat gzip file1

 Performance counter stats for 'gzip file1':

       2294.924314  task-clock-msecs         #      0.901 CPUs
                62  context-switches         #      0.000 M/sec
                 0  CPU-migrations           #      0.000 M/sec
               265  page-faults              #      0.000 M/sec
        5496871381  cycles                   #   2395.230 M/sec
       12210601948  instructions             #      2.221 IPC
        1263678628  branches                 #    550.641 M/sec
          13037608  branch-misses            #      1.032 %
           4725467  cache-references         #      2.059 M/sec
           2779597  cache-misses             #      1.211 M/sec

       2.546444859  seconds time elapsed
```

yay

- Low IPC (<0.2) means stall cycles (likely memory); look for ways to reduce memory I/O, and improve locality (NUMA)

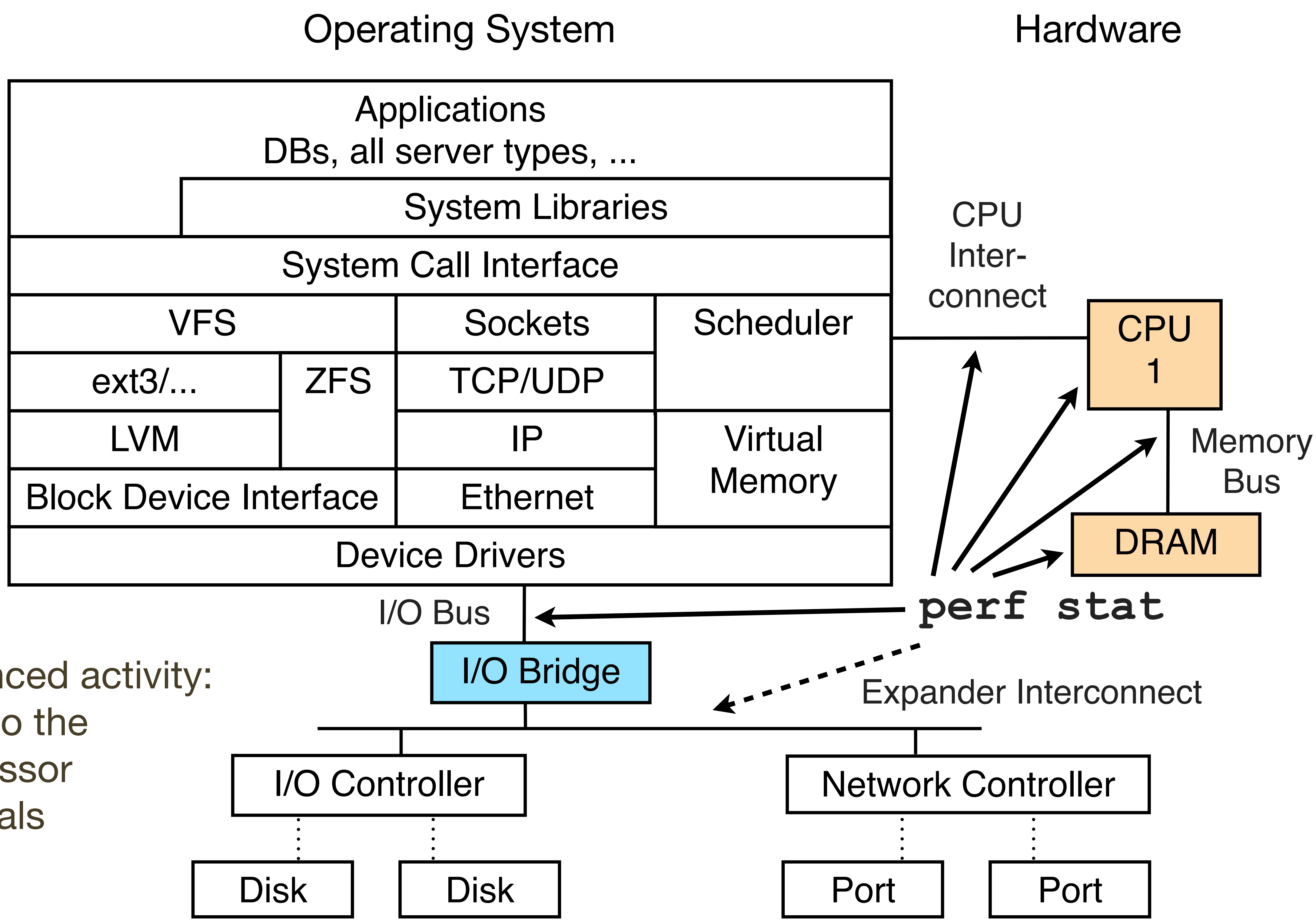
perf: Performance Counters, cont.

- Can choose different counters:

```
$ perf list | grep 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]
  cache-references                                       [Hardware event]
[...]
$ perf stat -e instructions,cycles,L1-dcache-load-misses,LLC-load-
misses,dTLB-load-misses gzip file1

 Performance counter stats for 'gzip file1':

       12278136571  instructions              #      2.199 IPC
        5582247352  cycles
          90367344  L1-dcache-load-misses
           1227085  LLC-load-misses
            685149  dTLB-load-misses

       2.332492555  seconds time elapsed
```

- Supports additional custom counters (in hex or a desc) for whatever the processor supports. Examine bus events.

perf: Performance Counters, cont.



advanced activity: refer to the processor manuals

perf: Profiling

- Profiling (sampling) CPU activity:

```
# perf record -a -g -F 997 sleep 10
[ perf record: Woken up 44 times to write data ]
```

- -a: all CPUs
- -g: call stacks
- -F: Hertz
- sleep 10: duration to sample (dummy command)
- Generates a perf.data file
- Can profile other hardware events too, with call stacks

perf: Profiling, cont.

- Reading perf.data, forcing non-interactive mode (--stdio):

```
# perf report --stdio
[...]
# Overhead      Command      Shared Object                              Symbol
# ........  ...........  .................  ..............................
#
    72.98%      swapper  [kernel.kallsyms]  [k] native_safe_halt
                |
                --- native_safe_halt
                    default_idle
                    cpu_idle
                    rest_init
                    start_kernel
                    x86_64_start_reservations
                    x86_64_start_kernel

     9.43%           dd  [kernel.kallsyms]  [k] acpi_pm_read
                     |
                     --- acpi_pm_read
                         ktime_get_ts
                        |
                        |--87.75%-- __delayacct_blkio_start
                        |          io_schedule_timeout
                        |          balance_dirty_pages_ratelimited_nr
                        |          generic_file_buffered_write
[...]
```

perf: Profiling, cont.

- Flame Graphs support perf profiling data:

- Interactive SVG. Navigate to quantify and compare code paths

perf: Static Tracing

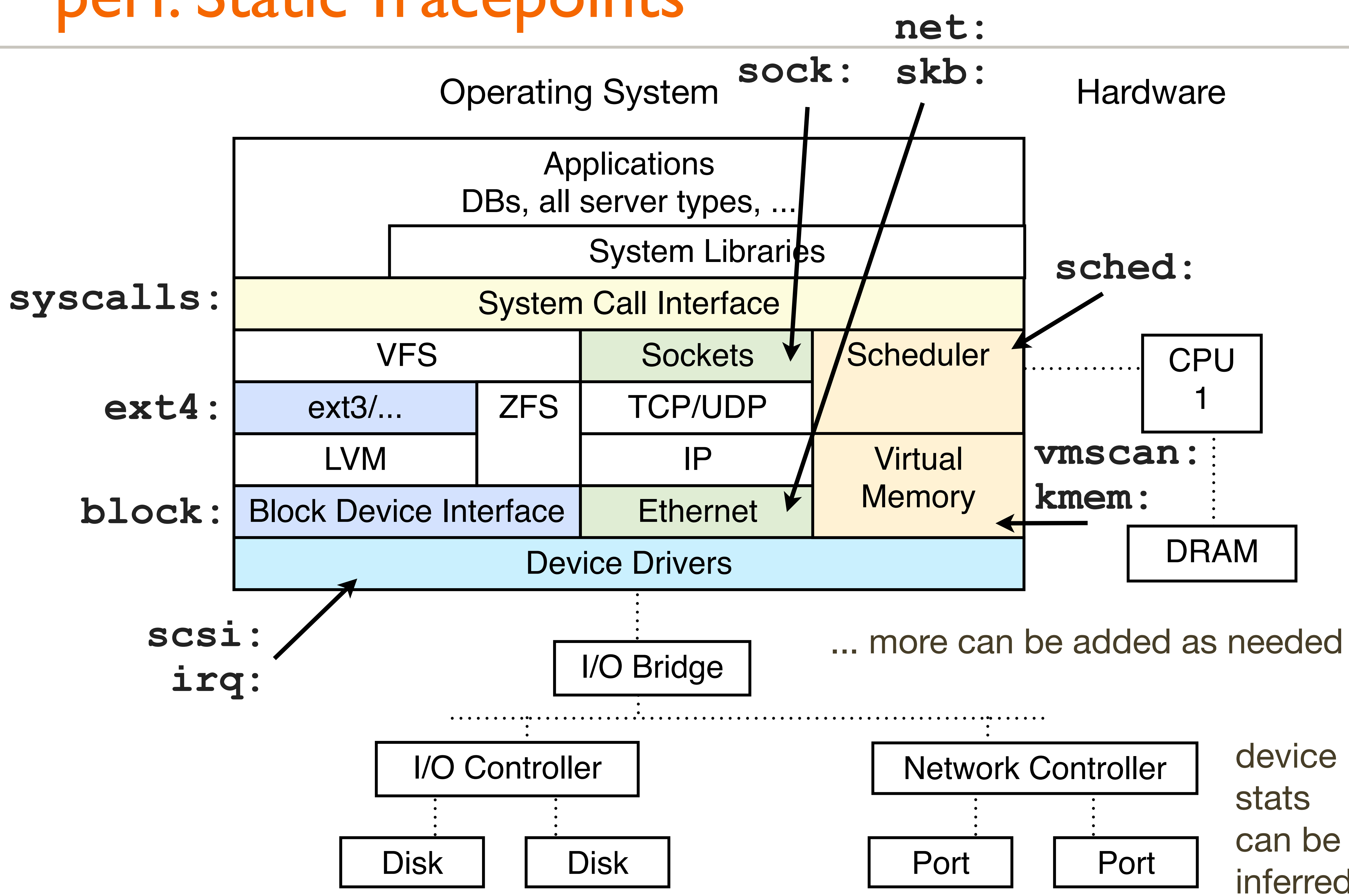
- Listing static tracepoints for block I/O:

```
$ perf list | grep block:
  block:block_rq_abort                                     [Tracepoint event]
  block:block_rq_requeue                                   [Tracepoint event]
  block:block_rq_complete                                  [Tracepoint event]
  block:block_rq_insert                                    [Tracepoint event]
  block:block_rq_issue                                     [Tracepoint event]
  block:block_bio_bounce                                   [Tracepoint event]
  block:block_bio_complete                                 [Tracepoint event]
  block:block_bio_backmerge                                [Tracepoint event]
  block:block_bio_frontmerge                               [Tracepoint event]
  block:block_bio_queue                                    [Tracepoint event]
  block:block_getrq                                        [Tracepoint event]
  block:block_sleeprq                                      [Tracepoint event]
  block:block_plug                                         [Tracepoint event]
  block:block_unplug                                       [Tracepoint event]
  block:block_split                                        [Tracepoint event]
  block:block_bio_remap                                    [Tracepoint event]
  block:block_rq_remap                                     [Tracepoint event]
```

- Many useful probes already provided for kernel tracing:

```
$ perf list | grep Tracepoint | wc -l
    840
```

perf: Static Tracepoints



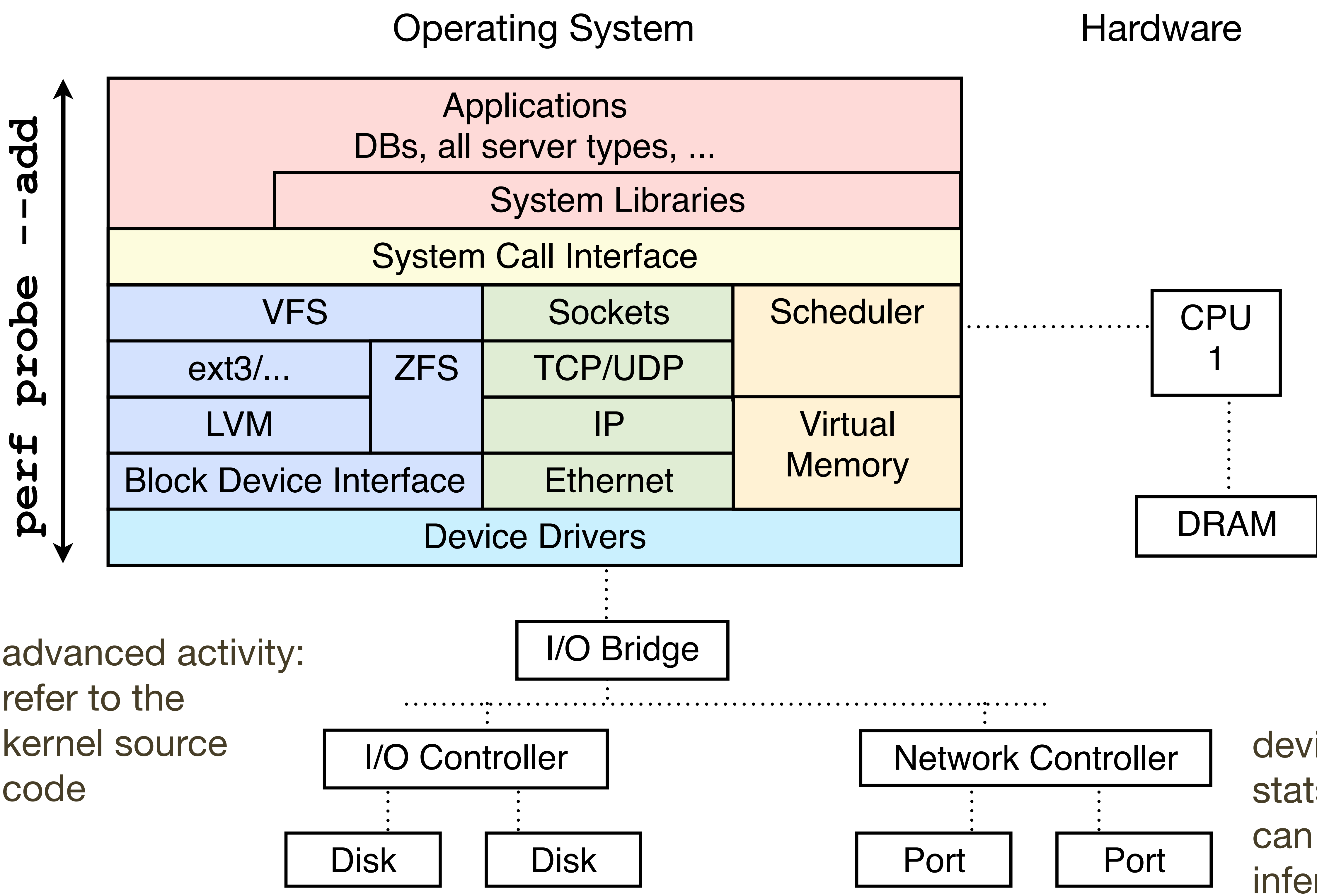
perf: Dynamic Tracing

- Define custom probes from kernel code; eg, tcp_sendmsg():

```
# perf probe --add='tcp_sendmsg'
Add new event:
  probe:tcp_sendmsg    (on tcp_sendmsg)
[...]

# perf record -e probe:tcp_sendmsg -aR -g sleep 5
[ perf record: Woken up 1 times to write data ]
[ perf record: Captured and wrote 0.091 MB perf.data (~3972 samples) ]

# perf report --stdio
[...]
# Overhead  Command      Shared Object       Symbol
# ........  .......  .................  ...........
#
   100.00%     sshd  [kernel.kallsyms]  [k] tcp_sendmsg
                |
                --- tcp_sendmsg
                    sock_aio_write
                    do_sync_write
                    vfs_write
                    sys_write
                    system_call
                    __GI___libc_write
```

active traced call stacks from arbitrary kernel locations!

perf: Dynamic Tracing, cont.



advanced activity: refer to the kernel source code

device stats can be inferred

perf: Dynamic Tracing, cont.

- Fills in kernel observability gaps
- Awesome capability
    - Takes some effort to use (waiting for the trace-dump-analyze cycle, and using post-processors to rework the output, or the post-scripting capability)
- Would be the awesomest tool ever, if it wasn't for ...

DTrace

DTrace

- *Programmable, real-time,* dynamic and static tracing
- Perf analysis and troubleshooting, without restarting anything
- Used on Solaris, illumos/SmartOS, Mac OS X, FreeBSD, ...
- Two ports in development for **Linux** (that we know of):
- 1. dtrace4linux
    - Mostly by Paul Fox
- 2. Oracle Enterprise Linux DTrace
    - Steady progress

There are a couple of awesome books about DTrace too

DTrace: Installation

- dtrace4linux version:

    1. https://github.com/dtrace4linux/dtrace
    2. README:

```
tools/get-deps.pl            # if using Ubuntu
tools/get-deps-fedora.sh     # RedHat/Fedora
make all
make install
make load             (need to be root or have sudo access)
```

```
# make load
tools/load.pl
13:40:14 Syncing...
13:40:14 Loading: build-3.2.6-3.fc16.x86_64/driver/dtracedrv.ko
13:40:15 Preparing symbols...
13:40:15 Probes available: 281887
13:40:18 Time: 4s
```

- WARNING: still a prototype, can panic/freeze kernels.
  I'm using it the lab to solve replicated production perf issues

DTrace: Programming

- Programming capabilities allow for powerful, efficient, one-liners and scripts. In-kernel custom filtering and aggregation.

```
# dtrace -n 'fbt::tcp_sendmsg:entry /execname == "sshd"/ {
    @["bytes"] = quantize(arg3); }'
dtrace: description 'fbt::tcp_sendmsg:entry ' matched 1 probe
^C

  bytes
           value  ------------- Distribution ------------- count
              16 |                                         0
              32 |@@@@@@@@@@@@@@@@                         1869
              64 |@@@@@@@@@@@@@                            1490
             128 |@@@                                      355
             256 |@@@@                                     461
             512 |@@@                                      373
            1024 |@                                        95
            2048 |                                         4
            4096 |                                         1
            8192 |                                         0
```

- Example shows tcp_sendmsg() size dist for “sshd” PIDs

DTrace: Programming

- Programming capabilities allow for powerful, efficient, one-liners and scripts. In-kernel custom filtering and aggregation.

```
# dtrace -n 'fbt::tcp_sendmsg:entry /execname == "sshd"/ {
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  bytes
           value  ------------- Distribution ------------- count
              16 |                                         0
              32 |@@@@@@@@@@@@@@@@                         1869
              64 |@@@@@@@@@@@@@                            1490
             128 |@@@                                      355
             256 |@@@@                                     461
             512 |@@@                                      373
            1024 |@                                        95
            2048 |                                         4
            4096 |                                         1
            8192 |                                         0
```

filter

aggregation (summarizes)

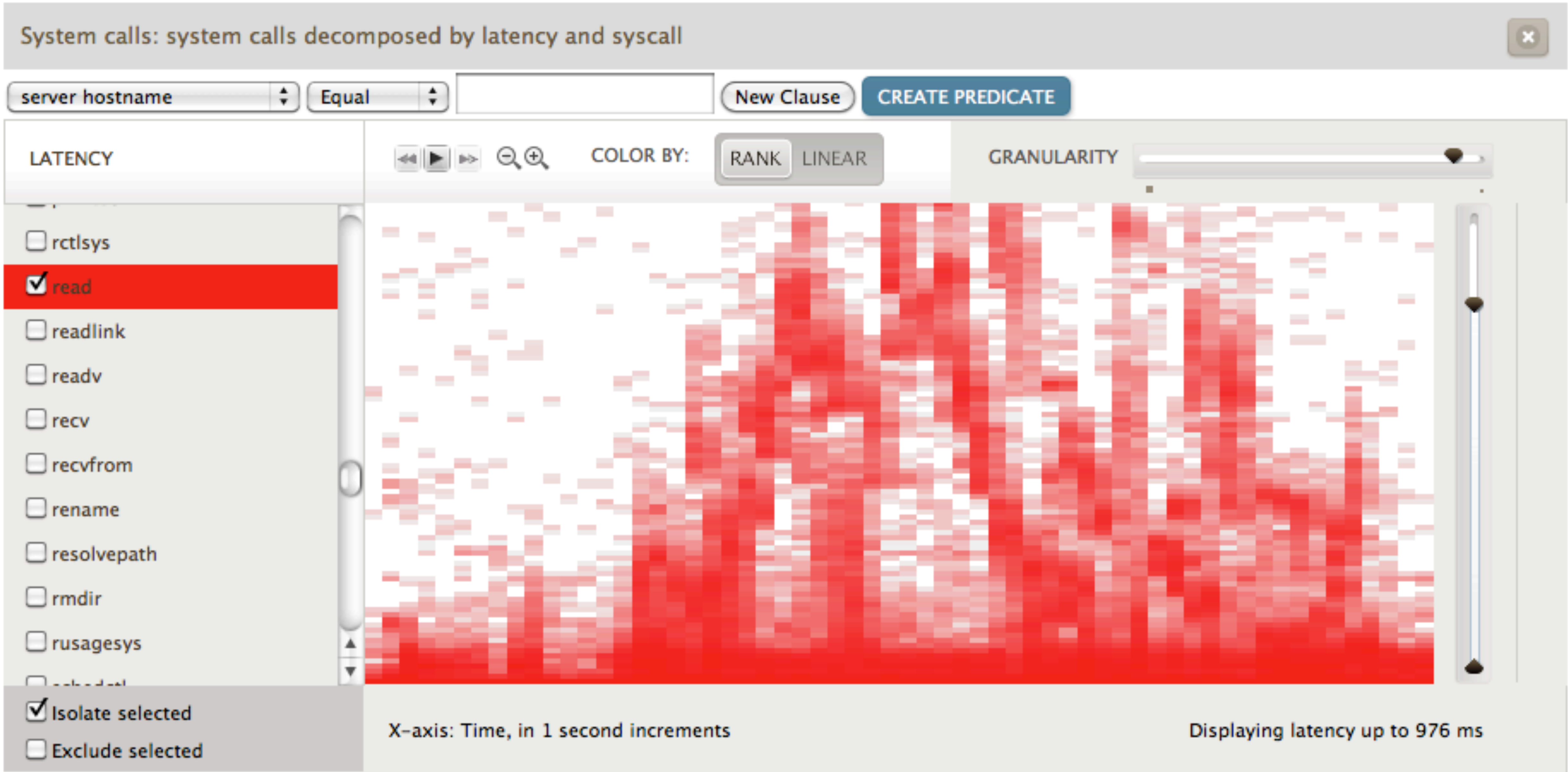
kernel -> user transfers these these numbers only (pre-summarized)

- Example shows tcp_sendmsg() size dist for “sshd” PIDs

these examples use dtrace4linux

DTrace: Real-Time

- Multiple GUIs use DTrace for real-time statistics. Eg, Joyent Cloud Analytics, showing real-time cloud-wide syscall latency:



DTrace, cont.

- Has advanced capabilities, but not necessarily difficult;
  You may just:
    - use one-liners (google “DTrace one-liners”)
    - use scripts (DTraceToolkit; DTrace book; google)
    - tweak one-liners or scripts a little
    - ask someone else to write the scripts you need
- Ideally, you learn DTrace and write your own

DTrace: Scripts

```
#!/usr/sbin/dtrace -s

fbt::vfs_read:entry
{
        self->start = timestamp;
}

fbt::vfs_read:return
/self->start/
{
        @[execname, "ns"] = quantize(timestamp - self->start);
        self->start = 0;
}
```

13 line script to time VFS reads by process name

```
# ./vfsread.d
dtrace: script './vfsread.d' matched 2 probes
  cksum                                                       ns
           value  ------------- Distribution ------------- count
[...]
          262144 |                                         0
          524288 |@@@@@@@@@@                               834
         1048576 |                                         8
         2097152 |                                         30
         4194304 |                                         40
         8388608 |@                                        66
        16777216 |                                         28
        33554432 |                                         1
```

read latency distribution, 0.5ms -> 33ms (disks)

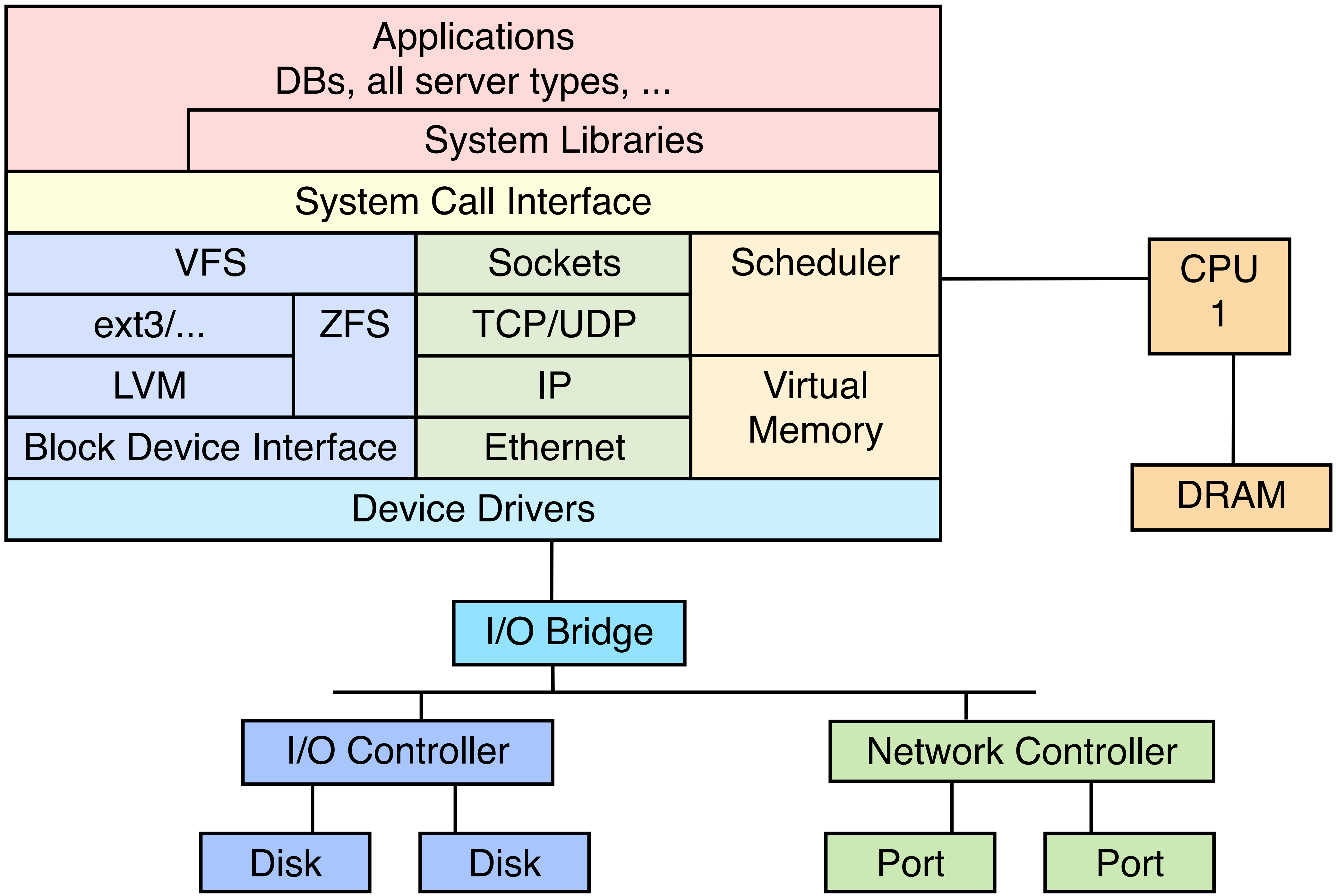
DTrace: Basics

- CLI syntax:

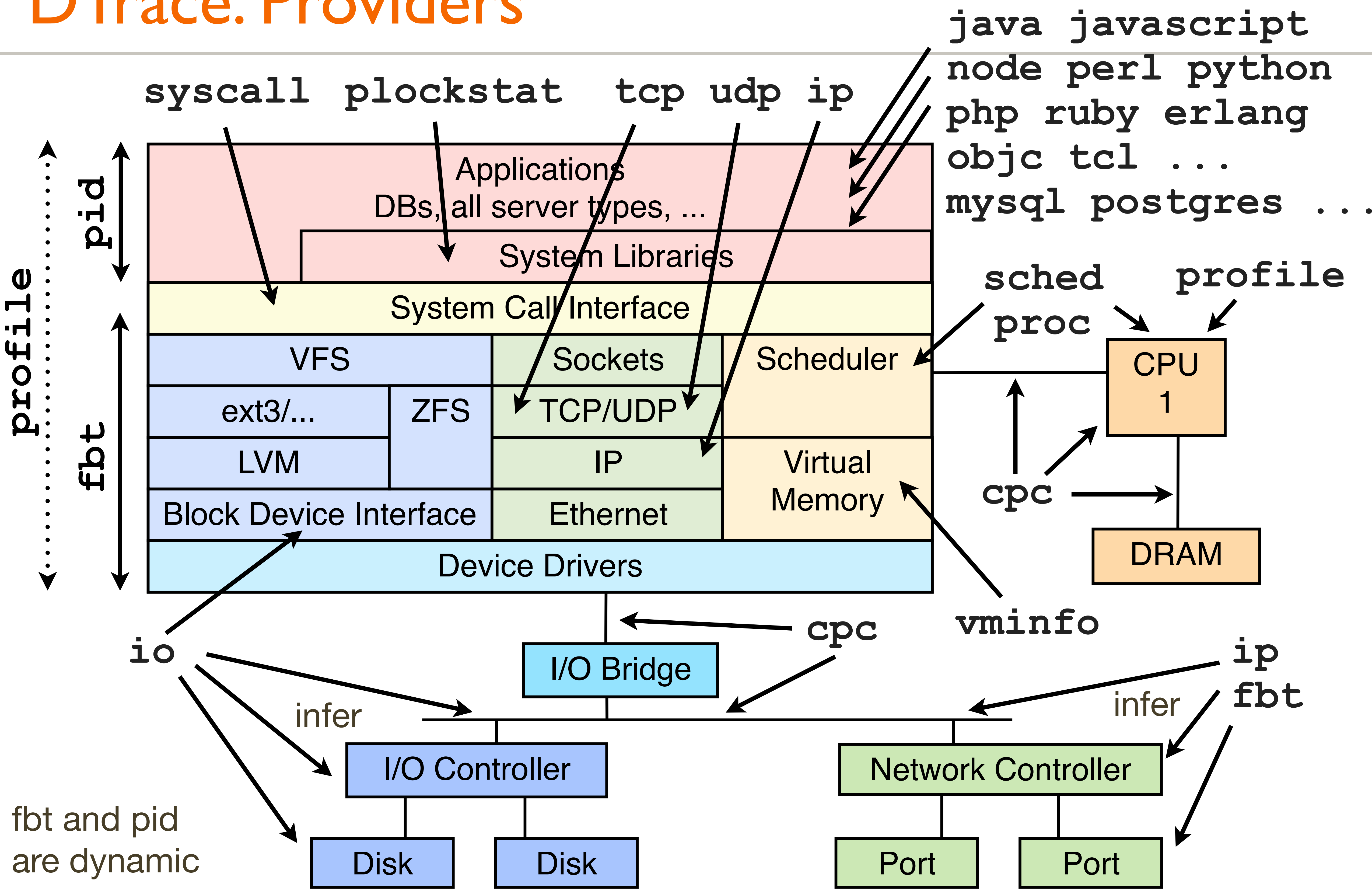
dtrace -n ‘provider:module:function:name /predicate/ { action }’

- provider – library of related probes
- module:function – shows where probe is located (for debug)
- name – name of probe
- Online reference and tutorial: http://dtrace.org/guide

DTrace: Providers



DTrace: Providers



fbt and pid
are dynamic

DTrace: Linux Examples

- Following examples use fbt – kernel dynamic tracing

DTrace: ext4slower.d

- Show me:
  - ext4 reads and writes
  - slower than a specified latency (milliseconds)
  - with time, process, direction, size, latency, and file name

```
# ./ext4slower.d 10
Tracing ext4 read/write slower than 10 ms
TIME                     PROCESS                D    KB      ms  FILE
2013 Feb 22 17:17:02 cksum                  R    64      35  100m
2013 Feb 22 17:17:02 cksum                  R    64      16  1m
2013 Feb 22 17:17:03 cksum                  R    64      18  data1
2013 Feb 22 17:17:03 cksum                  R    64      23  data1
```

- I wrote this to answer: is ext4 to blame for latency outliers?
- Argument is latency you are looking for: here, 10+ ms

DTrace: ext4slower.d, cont.

- Extending vfs_read() example:

```
#!/usr/sbin/dtrace -s

#pragma D option quiet
#pragma D option defaultargs
#pragma D option switchrate=5

dtrace:::BEGIN
{
        min_ns = $1 * 1000000;
        printf("Tracing ext4 read/write slower than %d ms\n", $1);
        printf("%-20s %-16s %1s %4s %6s %s\n", "TIME", "PROCESS",
            "D", "KB", "ms", "FILE");
}

fbt::vfs_read:entry, fbt::vfs_write:entry
{
        this->file = (struct file *)arg0;
        this->fs = this->file->f_path.dentry->d_inode->i_sb->s_type->name;
}
```

- ... continued:

DTrace: ext4slower.d, cont.

```
fbt::vfs_read:entry, fbt::vfs_write:entry
/stringof(this->fs) == "ext4"/
{
        self->start = timestamp;
        self->name = this->file->f_path.dentry->d_name.name;
}

fbt::vfs_read:return, fbt::vfs_write:return
/self->start && (this->delta = timestamp - self->start) > min_ns/
{
        this->dir = probefunc == "vfs_read" ? "R" : "W";
        printf("%-20Y %-16s %1s %4d %6d %s\n", walltimestamp,
            execname, this->dir, arg1 / 1024, this->delta / 1000000,
            stringof(self->name));
}

fbt::vfs_read:return, fbt::vfs_write:return
{
        self->start = 0;
        self->name = 0;
}
```

- Immediately exonerate or blame ext4.

... should add more vfs_*() calls; or trace ext4 funcs directly

DTrace: tcpretransmit.d

- Show me:
  - TCP retransmits
  - destination IP address
  - kernel stack (shows why)
  - in real-time
- Don’t sniff all packets – *only* trace retransmits, to minimize overhead

DTrace: tcpretransmit.d, cont.

```
# ./tcpretransmit.d
Tracing TCP retransmits... Ctrl-C to end.
2013 Feb 23 18:24:11: retransmit to 10.2.124.2, by:
              kernel`tcp_retransmit_timer+0x1bd
              kernel`tcp_write_timer+0x188
              kernel`run_timer_softirq+0x12b
              kernel`tcp_write_timer
              kernel`__do_softirq+0xb8
              kernel`read_tsc+0x9
              kernel`sched_clock+0x9
              kernel`sched_clock_local+0x25
              kernel`call_softirq+0x1c
              kernel`do_softirq+0x65
              kernel`irq_exit+0x9e
              kernel`smp_apic_timer_interrupt+0x6e
              kernel`apic_timer_interrupt+0x6e
[...]
```

... can trace those stack functions directly for more detail

DTrace: tcpretransmit.d, cont.

- Source:

```
#!/usr/sbin/dtrace -s

#pragma D option quiet

dtrace:::BEGIN { trace("Tracing TCP retransmits... Ctrl-C to end.\n"); }

fbt::tcp_retransmit_skb:entry {
      this->so = (struct sock *)arg0;
      this->d = (unsigned char *)&this->so->__sk_common.skc_daddr;
      printf("%Y: retransmit to %d.%d.%d.%d, by:", walltimestamp,
          this->d[0], this->d[1], this->d[2], this->d[3]);
      stack(99);
}
```

DTrace: Current State

- This was demoed on a prototype DTrace for Linux
  - Right now (Feb 2013) not stable – will panic/freeze
  - Needs other handholding to work around nits/bugs
  - AFAIK, both DTrace ports welcome help (that means you!)
- Those examples were also fbt-based:
  - Will probably need tweaks to match different kernels, since the API is dynamically built from the kernel code
  - DTrace stable providers solve that problem – but many aren't there on Linux yet

DTrace: Trying it out

- All providers are available to try on illumos/SmartOS
    - illumos is the on-going fork of the OpenSolaris kernel
    - SmartOS is Joyent's illumos-based cloud OS (distro)
    - Rough translation guide:

      kernel: linux == illumos

      distros: {ubuntu|CentOS|Fedora} == {SmartOS|OmniOS|OpenIndiana}
    - DTrace implementation mature
- Joyent uses SmartOS as a hypervisor for running KVM Linux on ZFS

DTrace: Other Capabilities

- Trace short lived processes
- Profile CPU usage
- Time any thread blocking event
- Investigate disk I/O latency
- Investigate network I/O latency
- Examine cache activity
- Investigate memory allocation: growth or leaks
- Investigate swapping (paging) in detail
- Follow network packets through the stack
- Examine lock contention
- ...

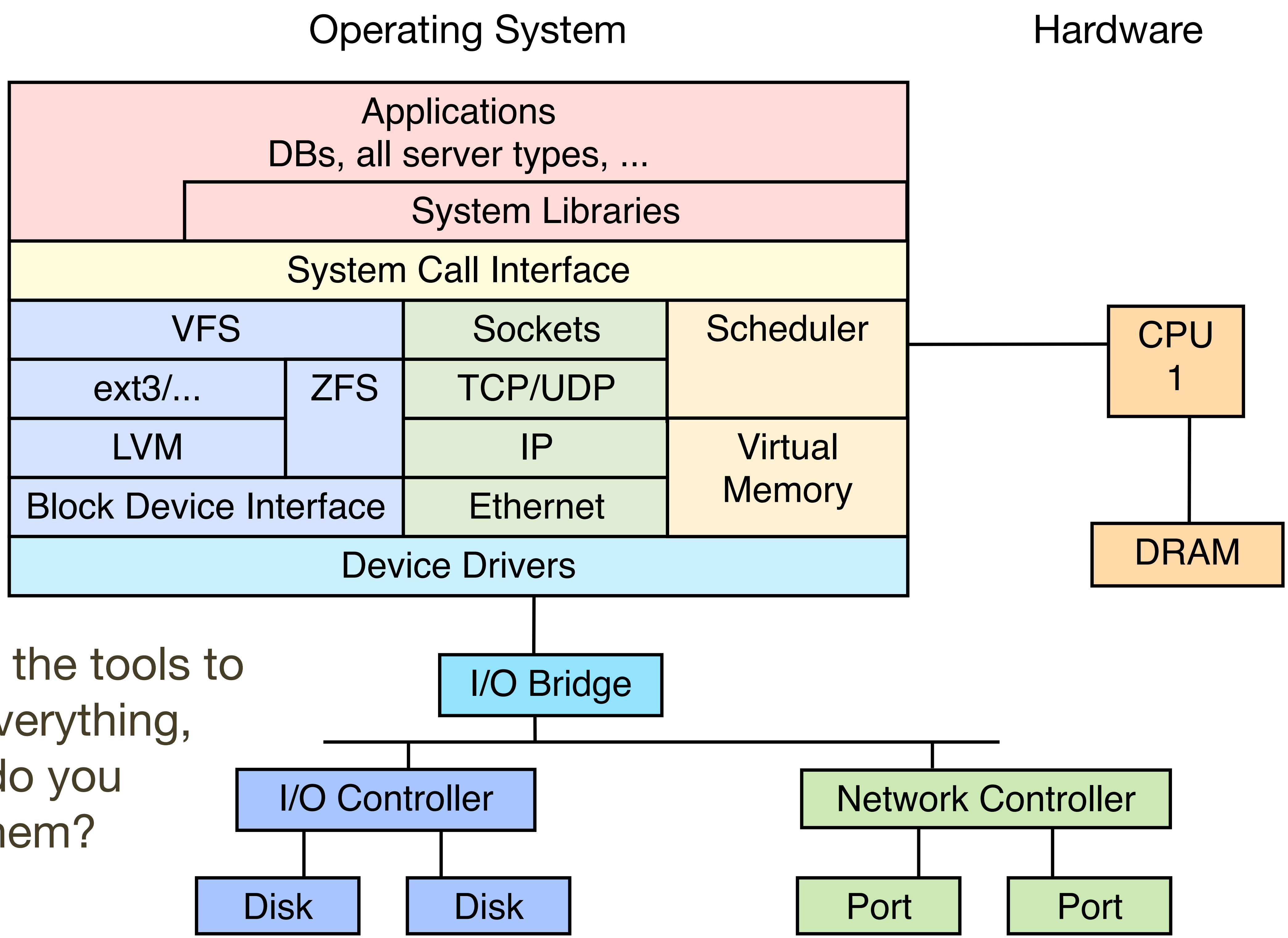
System Tap

systemtap

SystemTap

- Created when there wasn't DTrace for Linux ports
- Static and dynamic tracing, probes, tapsets, scripts, ...
- I've used it a lot:
    - panics/freezes
    - slow startups
    - for Linux only
    - incompatible with D

Tools: Advanced, recap.



Given the tools to see everything, how do you use them?

And More ...

- Other observability tools at all levels include:
  - ps, pmap, traceroute, ntop, ss, lsof, oprofile, gprof, kcachegrind, valgrind, google profiler, nfsiostat, cifsiostat, latencytop, powertop, LLTng, ktap, ...
- And many experimental tools: micro-benchmarks
- So many tools it gets confusing – where do you start?

Methodologies

- Selected four:
  - Streetlight Anti-Method
  - Workload Characterization Method
  - Drill-Down Analysis Method
  - USE Method
- Methodologies give beginners a starting point, casual users a checklist, and experts a reminder

Streetlight Anti-Method

Streetlight Anti-Method

- 1. Pick observability tools that are
  - familiar
  - found on the Internet
  - found at random
- 2. Run tools
- 3. Look for obvious issues

- Included for comparison (don’t use this methodology)

Streetlight Anti-Method, cont.

- Named after an observational bias called the *streetlight effect*

A policeman sees a drunk looking under a streetlight,
and asks what he is looking for.
The drunk says he has lost his keys.
The policeman can't find them either,
and asks if he lost them under the streetlight.
The drunk replies:
“No, but this is where the light is best.”

Streetlight Anti-Method, cont.

```
top - 15:09:38 up 255 days, 16:54, 10 users,  load average: 0.00, 0.03, 0.00
Tasks: 274 total,   1 running, 273 sleeping,   0 stopped,   0 zombie
Cpu(s):  0.7%us,  0.0%sy,  0.0%ni, 99.1%id,  0.1%wa,  0.0%hi, 0.0%si, 0.0%st
Mem:   8181740k total,  7654228k used,   527512k free,   405616k buffers
Swap:  2932728k total,   125064k used,  2807664k free,  3826244k cached

  PID USER      PR  NI  VIRT  RES  SHR S %CPU %MEM    TIME+  COMMAND
16876 root      20   0 57596  17m 1972 S    4  0.2   3:00.60 python
 3947 brendan   20   0 19352 1552 1060 R    0  0.0   0:00.06 top
15841 joshw     20   0 67144  23m  908 S    0  0.3 218:21.70 mosh-server
16922 joshw     20   0 54924  11m  920 S    0  0.1 121:34.20 mosh-server
    1 root      20   0 23788 1432  736 S    0  0.0   0:18.15 init
    2 root      20   0     0    0    0 S    0  0.0   0:00.61 kthreadd
    3 root      RT   0     0    0    0 S    0  0.0   0:00.11 migration/0
    4 root      20   0     0    0    0 S    0  0.0  18:43.09 ksoftirqd/0
    5 root      RT   0     0    0    0 S    0  0.0   0:00.00 watchdog/0
[...]
```

- Why are you *still* running top?

Streetlight Anti-Method, cont.

- Tools-based approach
- Inefficient:
  - can take time before the right tool is found
  - can be wasteful when investigating false positives
- Incomplete:
  - don't find the right tool, or,
  - the right tool doesn't exist

Workload Characterization Method

Workload Characterization Method

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

Workload Characterization Method

- 1. Who is causing the load? PID, UID, IP addr, ...
- 2. Why is the load called? code path
- 3. What is the load? IOPS, tput, direction, type
- 4. How is the load changing over time?

Workload Characterization Method, cont.

- Identifies issues of load
- Best performance wins are from *eliminating unnecessary work*
- Don’t assume you know what the workload is – characterize
- Many of the previous analysis tools included workload statistics

Workload Characterization Method, cont.

- Pros:
  - Potentially largest wins
- Cons:
  - Only solves a class of issues – load
  - Time consuming, and can be discouraging – most attributes examined will not be a problem

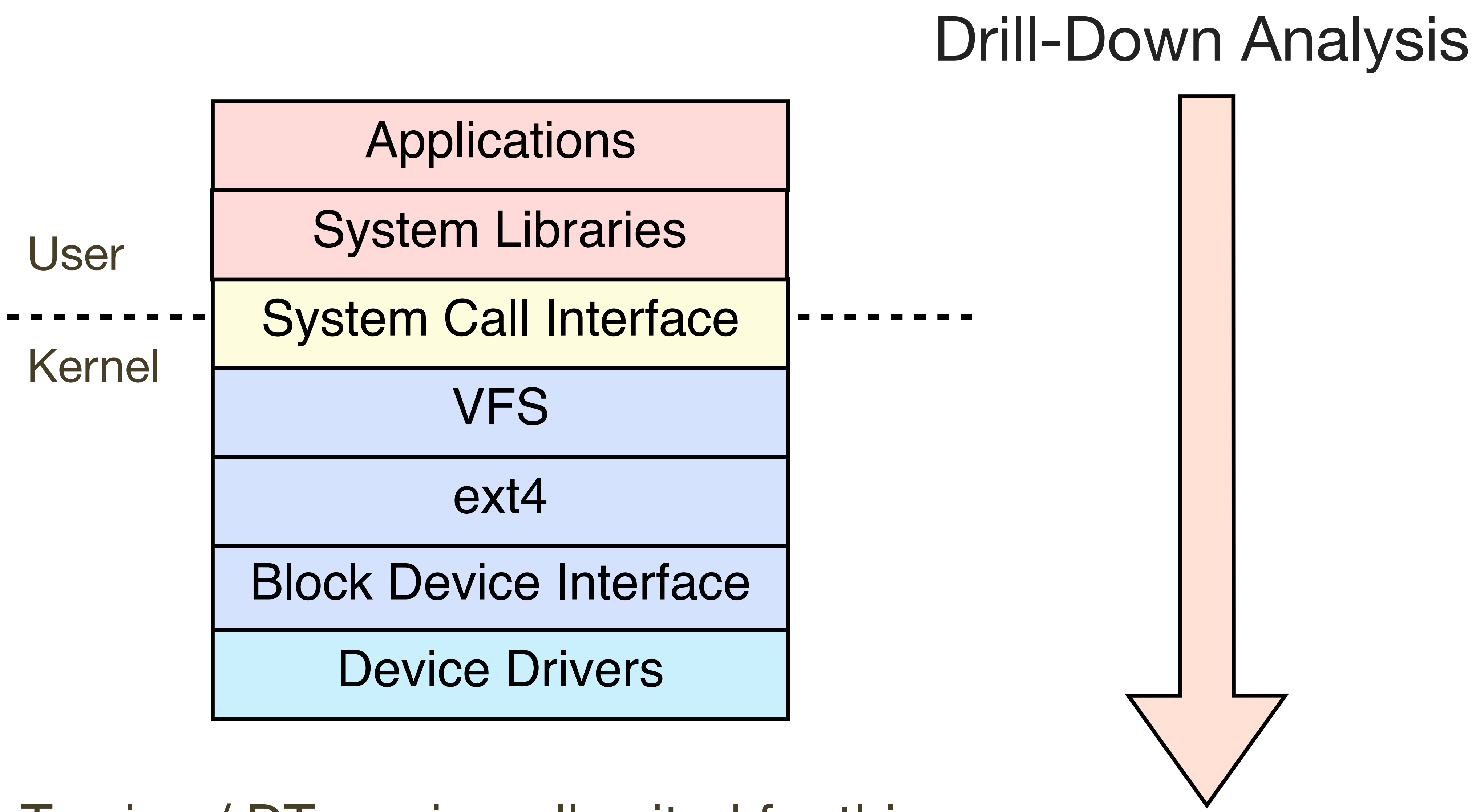
Drill-Down Analysis Method

Drill-Down Analysis Method

- 1. Start at highest level
- 2. Examine next-level details
- 3. Pick most interesting breakdown
- 4. If problem unsolved, go to 2

Drill-Down Analysis Method, cont.: Example

- For example, ext4 – identify latency origin top-down:



Dynamic Tracing / DTrace is well suited for this,
as it can dig through all layers with custom detail

Drill-Down Analysis: ext4

- eg, ext4_readpages() latency distribution (microseconds):

```
# dtrace -n 'fbt::ext4_readpages:entry { self->ts = timestamp; }
    fbt::ext4_readpages:return /self->ts/ {
    @["us"] = lquantize((timestamp - self->ts) / 1000, 0, 10000, 250);
    self->ts = 0;
}'
dtrace: description 'fbt::ext4_readpages:entry ' matched 2 probes
^C

  us
           value  ------------- Distribution ------------- count
             < 0 |                                         0
               0 |@@@@@@@@@@@@                             303
             250 |                                         0
             500 |                                         0
             750 |@@@@                                     88
            1000 |@@@@@@@@@@@@@@                           335
            1250 |                                         0
            1500 |                                         0
            1750 |@@@@                                     107
            2000 |@@@@@@                                   144
            2250 |                                         0
            2500 |                                         0
[...]
```

cache hits (arrow to the 0 row)

disk I/O (arrows to the 1000 and 1750 rows)

Drill-Down Analysis: ext4

- ... can dig out more details as needed: file name, code path:

```
# dtrace -n 'fbt::ext4_readpages:entry {
    this->file = (struct file *)arg0;
    this->name = this->file->f_path.dentry->d_name.name;
    @[stringof(this->name), stack()] = count();
}'
dtrace: description 'fbt::ext4_readpages:entry ' matched 1 probe
^C[...]
  foo8
              kernel`__do_page_cache_readahead+0x1c7
              kernel`ra_submit+0x21
              kernel`ondemand_readahead+0x115
              kernel`page_cache_async_readahead+0x80
              kernel`radix_tree_lookup_slot+0xe
              kernel`find_get_page+0x1e
              kernel`generic_file_aio_read+0x48b
              kernel`vma_merge+0x121
              kernel`do_sync_read+0xd2
              kernel`__switch_to+0x132
              kernel`security_file_permission+0x93
              kernel`rw_verify_area+0x61
              kernel`vfs_read+0xb0
              kernel`sys_read+0x4a
              kernel`system_call_fastpath+0x16
              122
```

# of occurrences →

Drill-Down Analysis Method, cont.

- Moves from higher- to lower-level details based on findings: environment-wide down to metal
- Pros:
  - Will identify root cause(s)
- Cons:
  - Time consuming – especially when drilling in the wrong direction

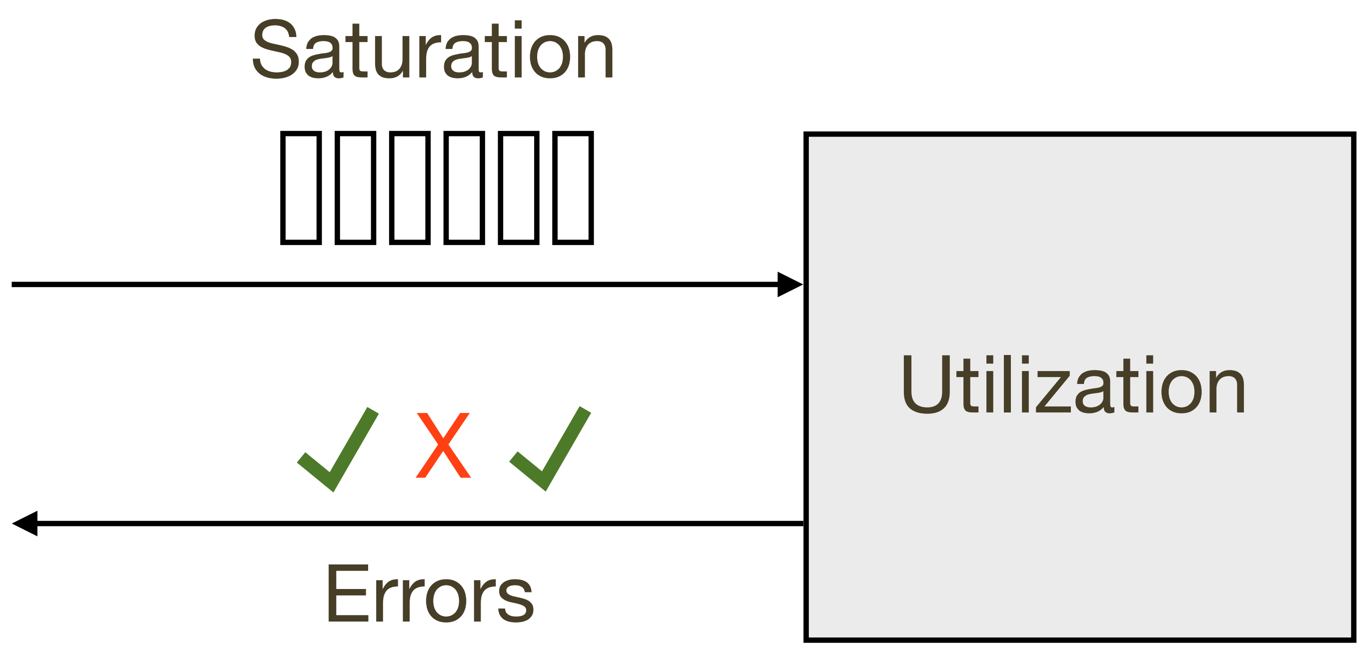
USE Method

USE Method

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

USE Method, cont.

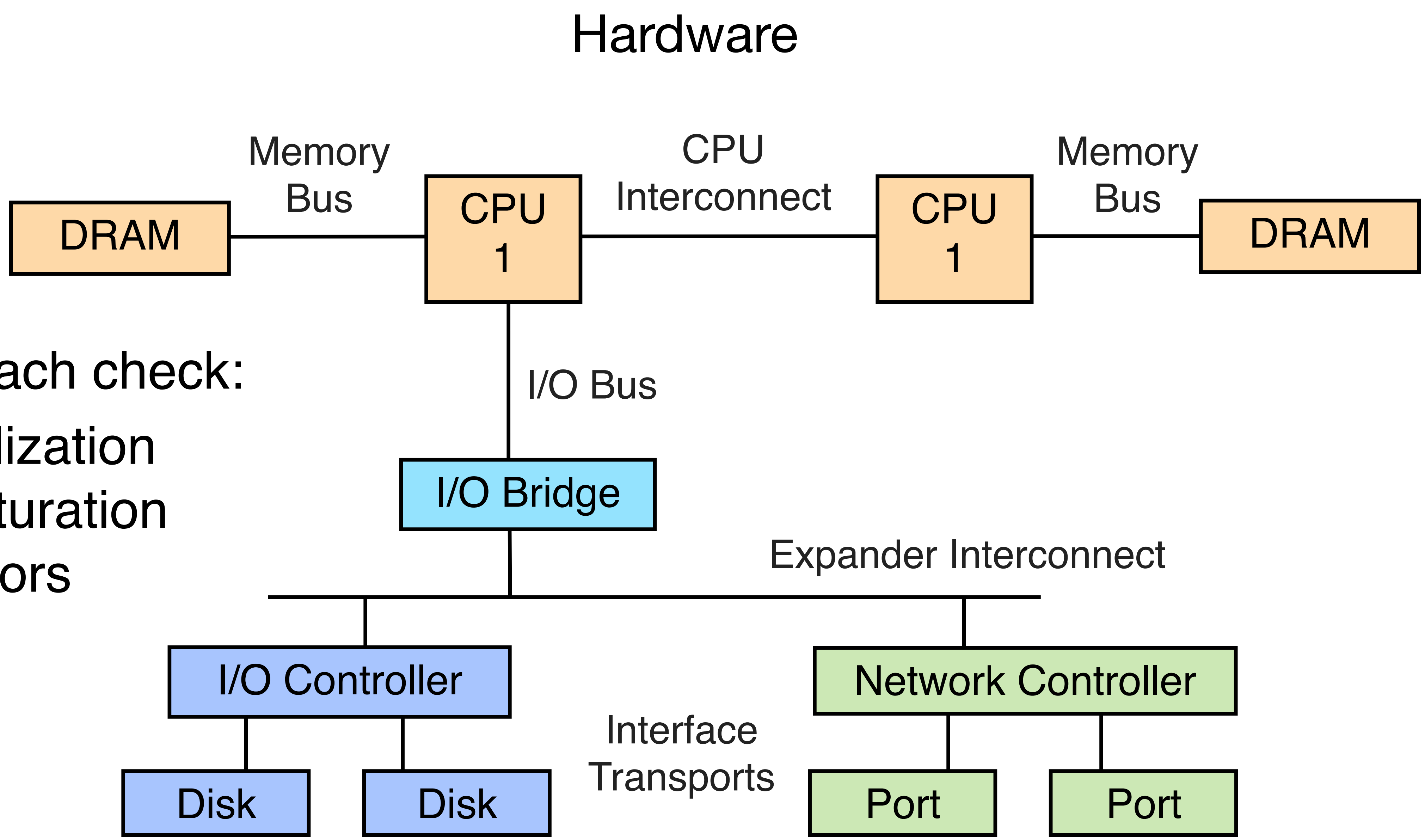
- For every resource, check:
- 1. Utilization: time resource was busy, or degree used
- 2. Saturation: degree of queued extra work
- 3. Errors: any errors



USE Method, cont.

- Hardware Resources:
  - CPUs
  - Main Memory
  - Network Interfaces
  - Storage Devices
  - Controllers
  - Interconnects
- Find the *functional diagram* and examine every item in the *data path...*

USE Method, cont.: Functional Diagram



For each check:

1. Utilization
2. Saturation
3. Errors

USE Method, cont.: Example Linux Checklist

http://dtrace.org/blogs/brendan/2012/03/07/the-use-method-linux-performance-checklist

Resource	Type	Metric
CPU	Utilization	per-cpu: `mpstat -P ALL 1`, "%idle"; `sar -P ALL`, "%idle"; system-wide: `vmstat 1`, "id"; `sar -u`, "%idle"; `dstat -c`, "idl"; per-process:`top`, "%CPU"; `htop`, "CPU %"; `ps -o pcpu`; `pidstat 1`, "%CPU"; per-kernel-thread: `top/htop` ("K" to toggle), where VIRT == 0
CPU	Saturation	system-wide: `vmstat 1`, "r" > CPU count [2]; `sar -q`, "runq-sz" > CPU count; `dstat -p`, "run" > CPU count; per-process: /proc/PID/schedstat 2nd field (sched_info.run_delay); `perf sched latency` (shows "Average" and "Maximum" delay per-schedule); dynamic tracing, eg, SystemTap schedtimes.stp "queued(us)" [3]
CPU	Errors	`perf` (LPE) if processor specific error events (CPC) are available; eg, AMD64's "04Ah Single-bit ECC Errors Recorded by Scrubber" [4]

... etc for all combinations (would fill a dozen slides)

USE Method, cont.

- Some software resources can also be studied:
  - Mutex Locks
  - Thread Pools
  - Process/Thread Capacity
  - File Descriptor Capacity
- Consider possible USE metrics for each

USE Method, cont.

- This process may reveal *missing metrics* – those not provided by your current toolset
  - They are your *known unknowns*
  - Much better than *unknown unknowns*
- More tools can be installed and developed to help
  - So many top(1)s, but where is the *interconnect*-top?
- Full USE Method checklist may, practically, only be used for critical issues

USE Method, cont.

- Resource-based approach
- Quick system health check, early in an investigation
- Pros:
  - Complete: all resource bottlenecks and errors
  - Not limited in scope by your current toolset
  - No unknown unknowns – at least known unknowns
  - Efficient: picks three metrics for each resource – from what may be dozens available
- Cons:
  - Limited to a class of issues

Other Methodologies

- Include:
  - Blame-Someone-Else Anti-Method
  - Tools Method
  - Ad-Hoc Checklist Method
  - Problem Statement Method
  - Scientific Method
  - Latency Analysis
  - Stack Profile Method

- http://dtrace.org/blogs/brendan/2012/12/13/usenix-lisa-2012-performance-analysis-methodology/

Challenges

- Performance counter analysis (eg, bus or interconnect port analysis) is time consuming – would like tools for convenience
    - How about a “bustop” subcommand for perf?
- DTrace for Linux ports still in progress – will be awesome when complete

Cloud Computing

- Performance may be limited by cloud resource controls, rather than physical limits
- Hardware Virtualization complicates things – as a guest you can't analyze down to metal directly
    - Hopefully the cloud provider provides an API for accessing physical statistics, or does the analysis on your behalf
- We do analysis at Joyent (and our hypervisors have DTrace!)
    - Free trial for new customers: good for $125 of usage value (~ one Small 1GB SmartMachine for 60 days). All prices subject to change. Limited time only. Sign up at joyent.com

References

- Linux man pages, source, /Documentation
- USE Method: http://queue.acm.org/detail.cfm?id=2413037
- http://dtrace.org/blogs/brendan/2012/03/07/the-use-method-linux-performance-checklist/
- http://dtrace.org/blogs/brendan/2012/12/13/usenix-lisa-2012-performance-analysis-methodology/
- https://github.com/dtrace4linux, http://www.dtracebook.com, http://illumos.org, http://smartos.org
- Upcoming: “Systems Performance” (Prentice Hall)

Thank you!

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- blog: http://dtrace.org/blogs/brendan
- blog resources:
    - http://dtrace.org/blogs/brendan/tag/linux-2/
    - http://dtrace.org/blogs/brendan/2012/02/29/the-use-method/
    - http://dtrace.org/blogs/brendan/2012/03/07/the-use-method-linux-performance-checklist/
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