LINUX.CONF.AU
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THE FUTURE OF OPEN SOURCE

BPF: Tracing and More

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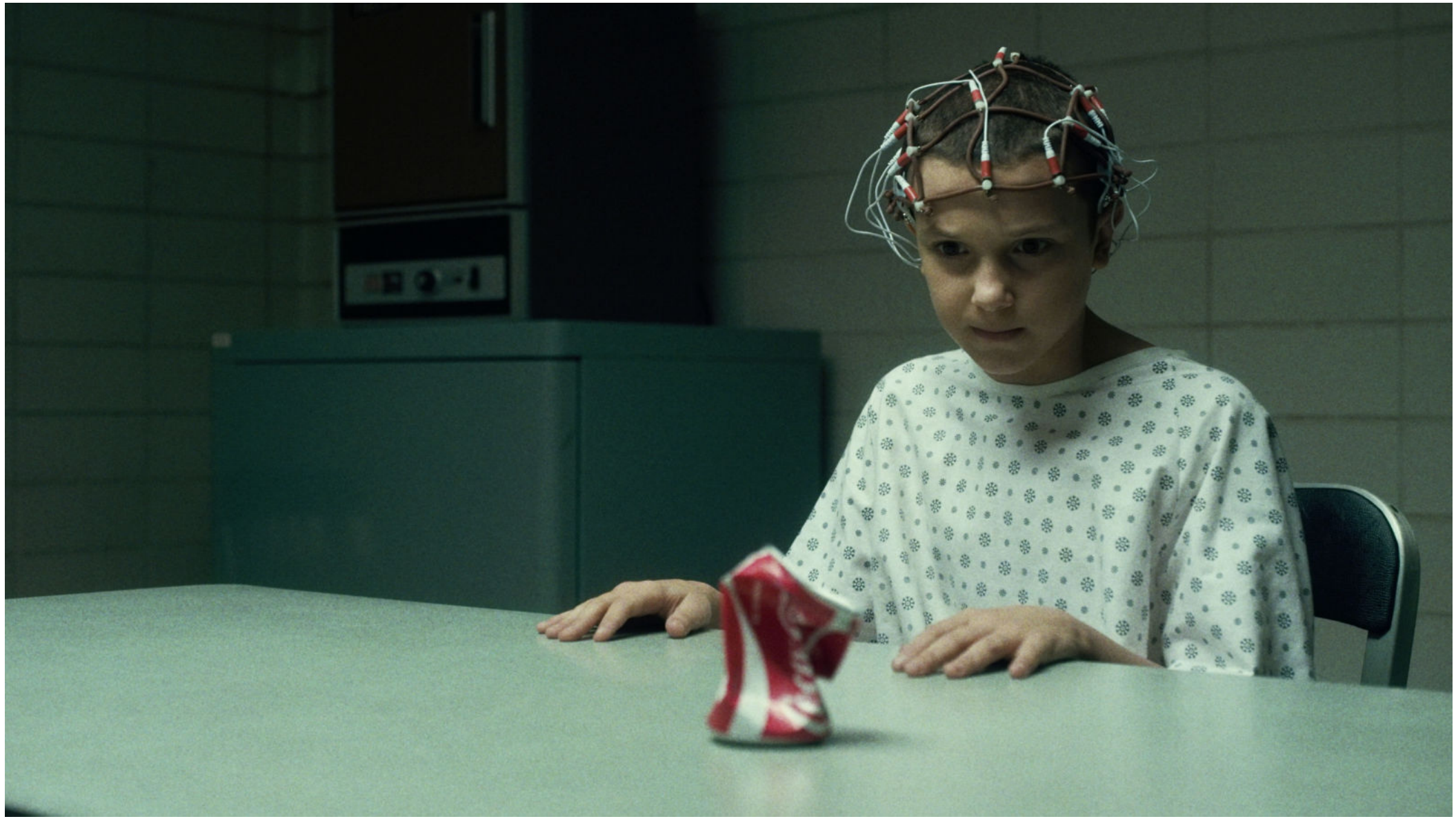
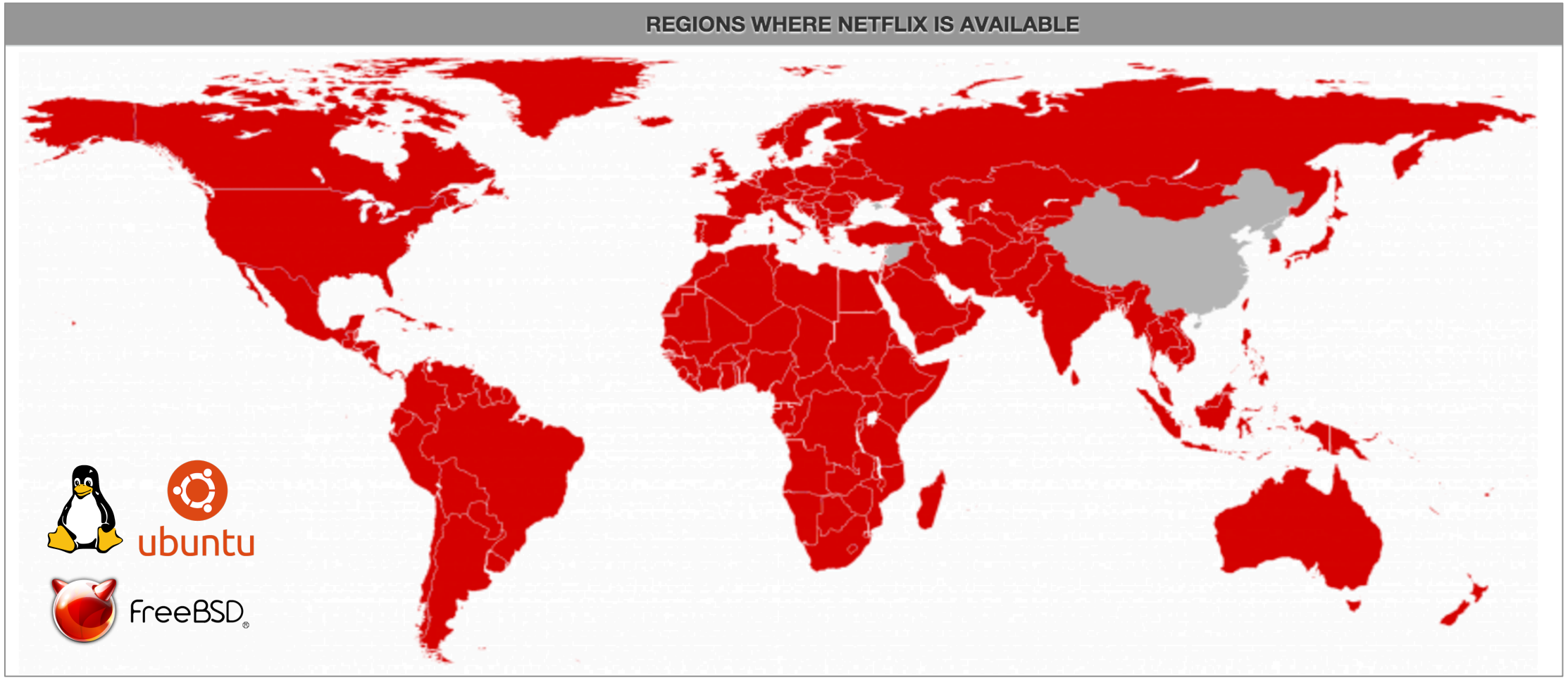
Senior Performance Architect

NETFLIX



NETFLIX



Ye Olde BPF

Berkeley Packet Filter

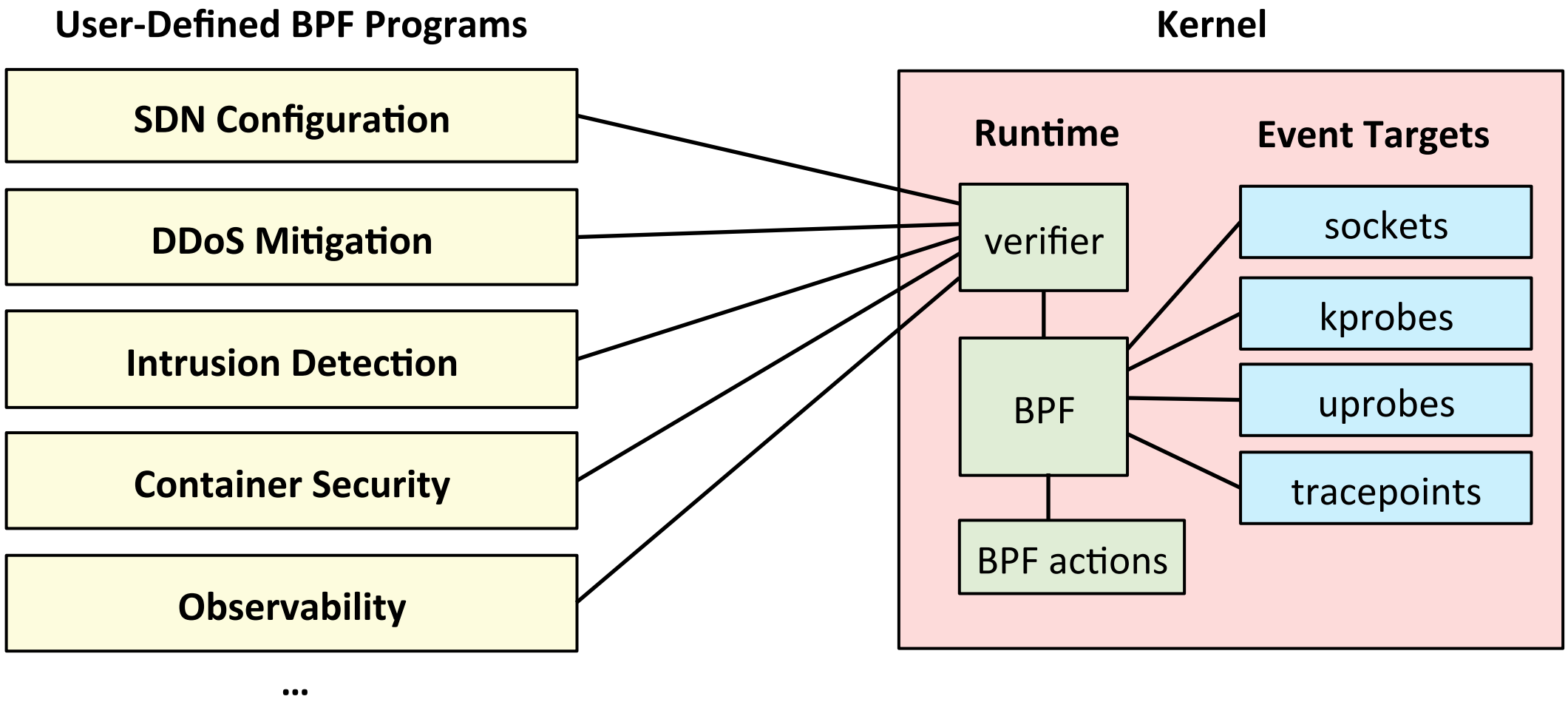
```
# tcpdump host 127.0.0.1 and port 22 -d
(000) ldh      [12]
(001) jeq      #0x800           jt 2    jf 18
(002) ld       [26]
(003) jeq      #0x7f000001      jt 6    jf 4
(004) ld       [30]
(005) jeq      #0x7f000001      jt 6    jf 18
(006) ldb      [23]
(007) jeq      #0x84            jt 10   jf 8
(008) jeq      #0x6             jt 10   jf 9
(009) jeq      #0x11            jt 10   jf 18
(010) ldh      [20]
(011) jset     #0x1fff          jt 18   jf 12
(012) ldxb     4*([14]&0xf)
[...]
```

Optimizes tcpdump filter performance

An in-kernel sandboxed virtual machine

Enhanced BPF

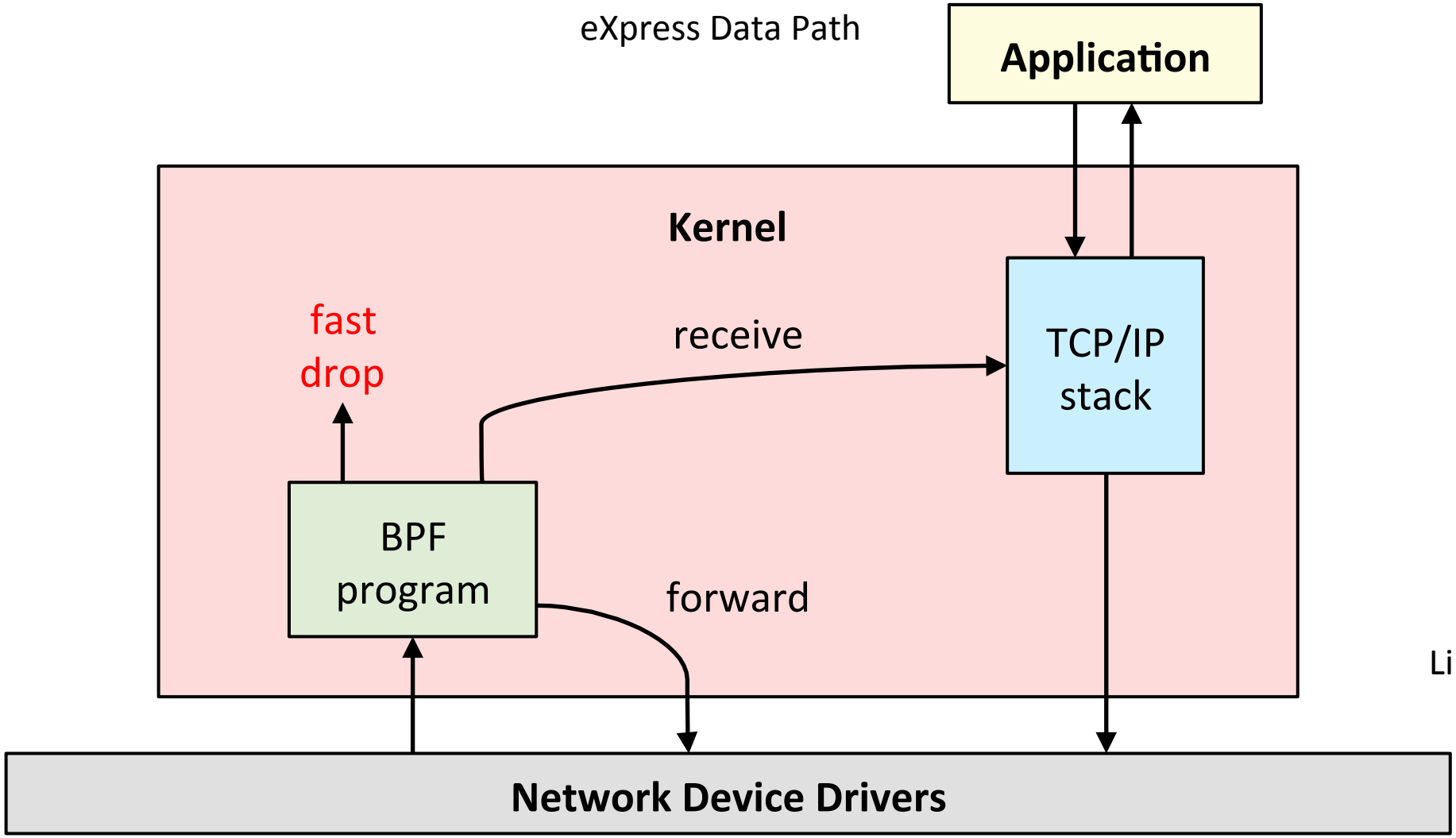
also known as just "BPF"



Demo

XDP

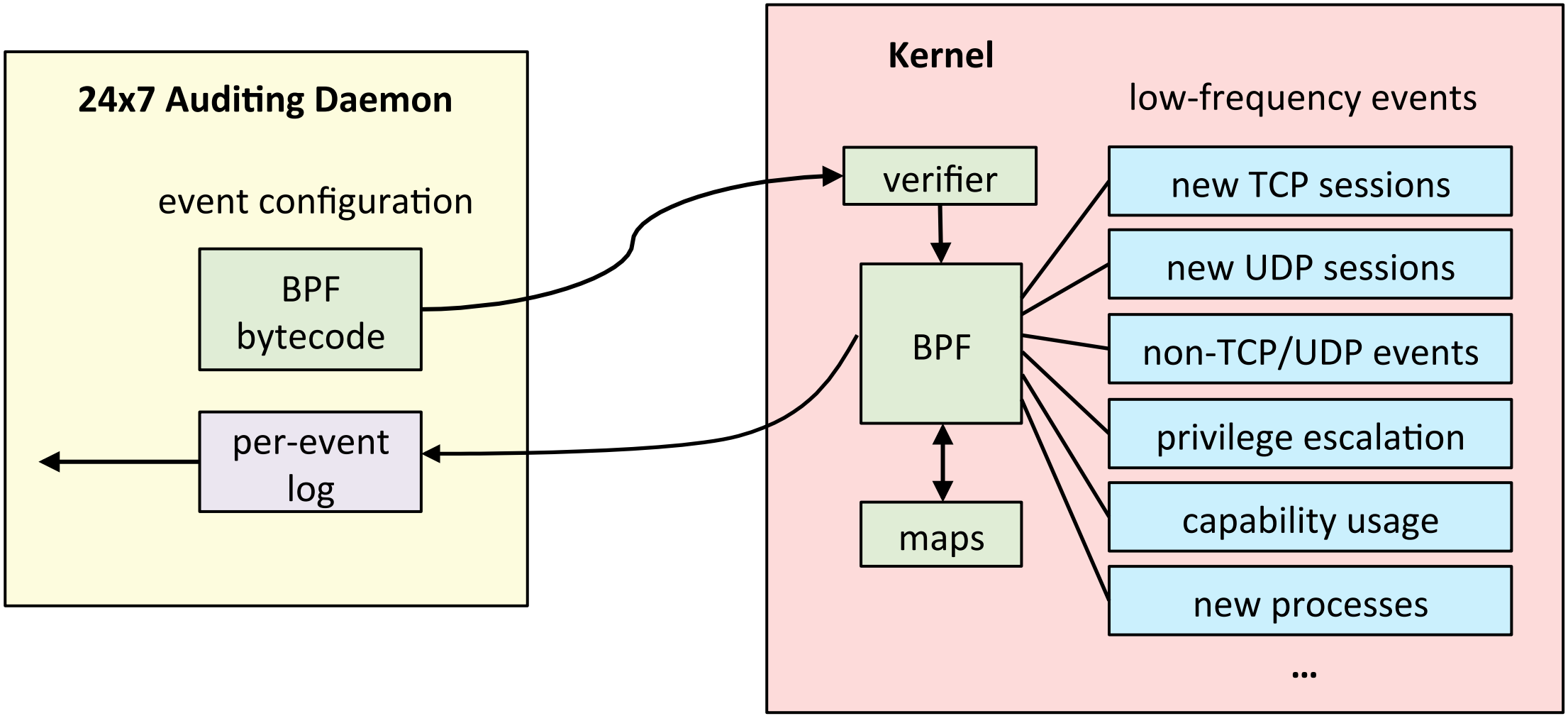
eXpress Data Path



Linux 4.8+

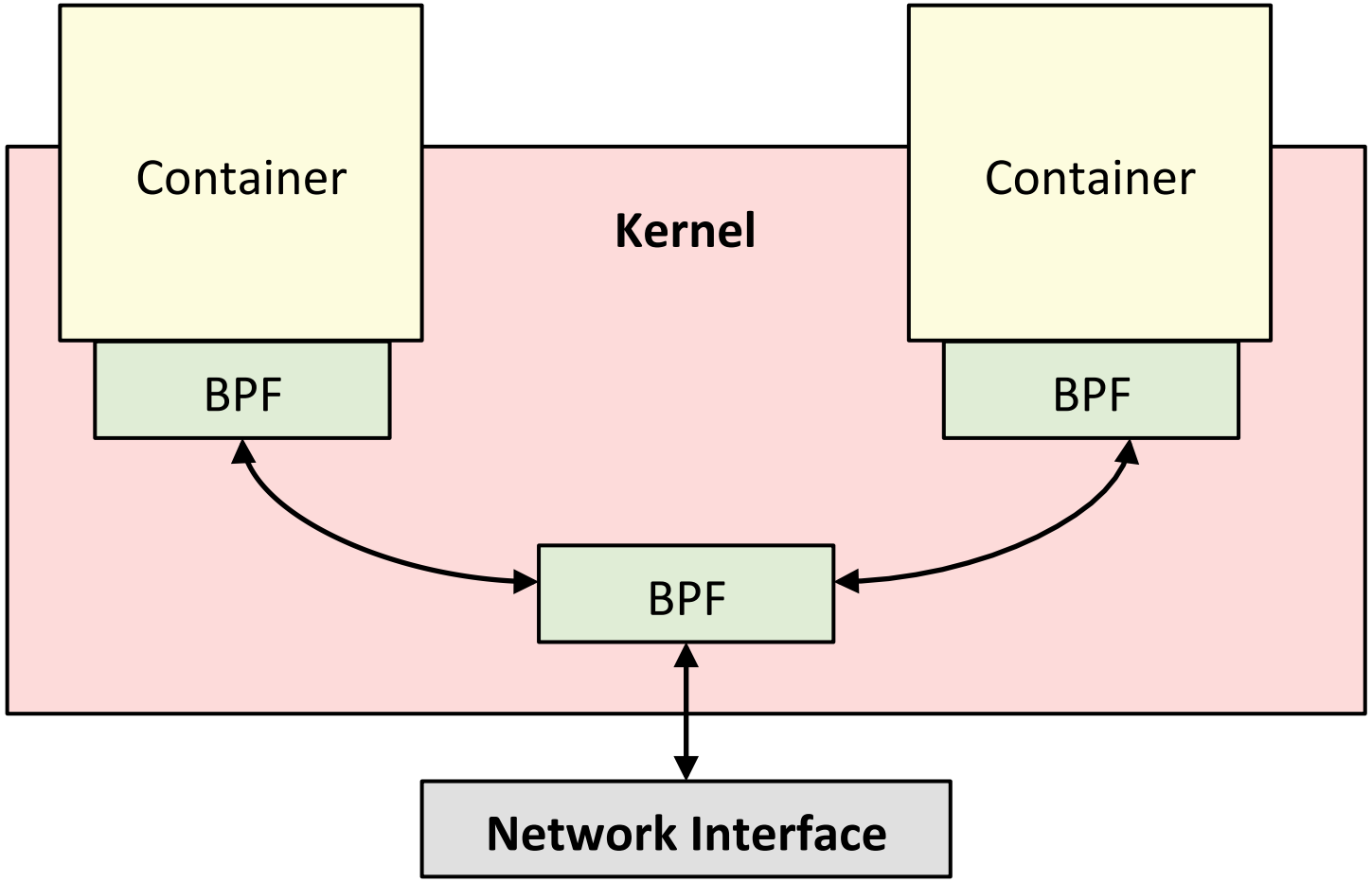
Intrusion Detection

BPF Security Module



Container Security

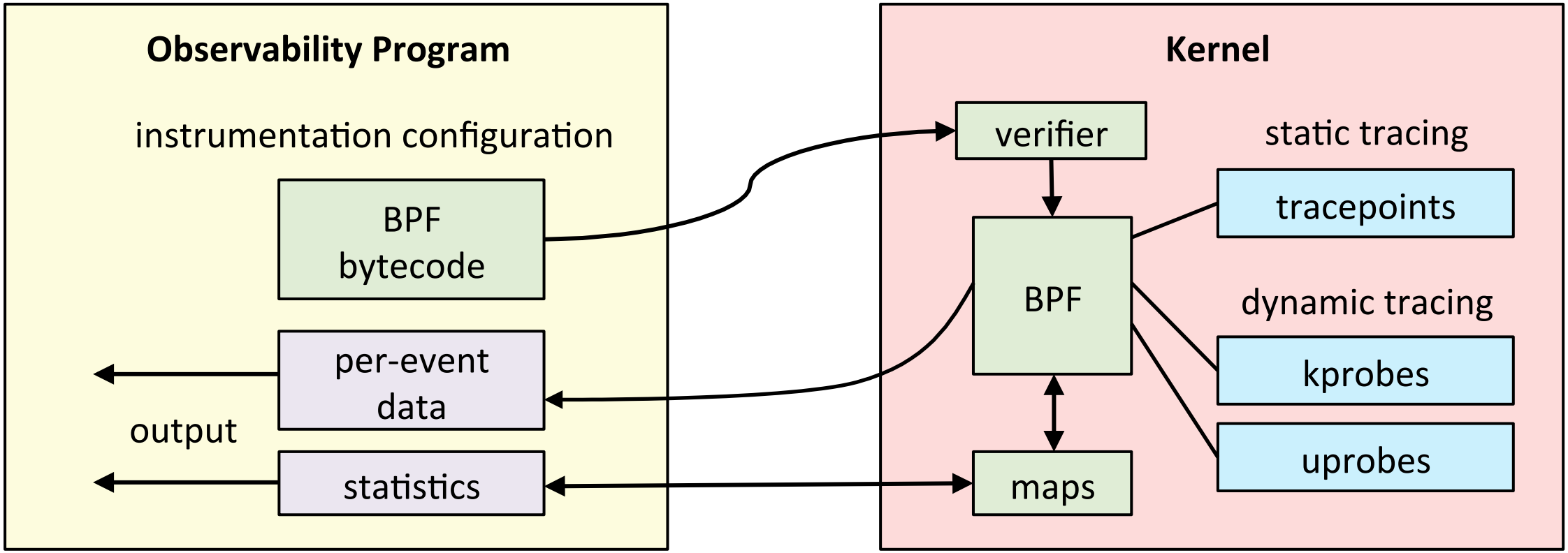
Networking & security policy enforcement



https://github.com/cilium/cilium

Observability

Performance Analysis & Debugging



https://github.com/iovisor/bcc

Wielding Superpowers

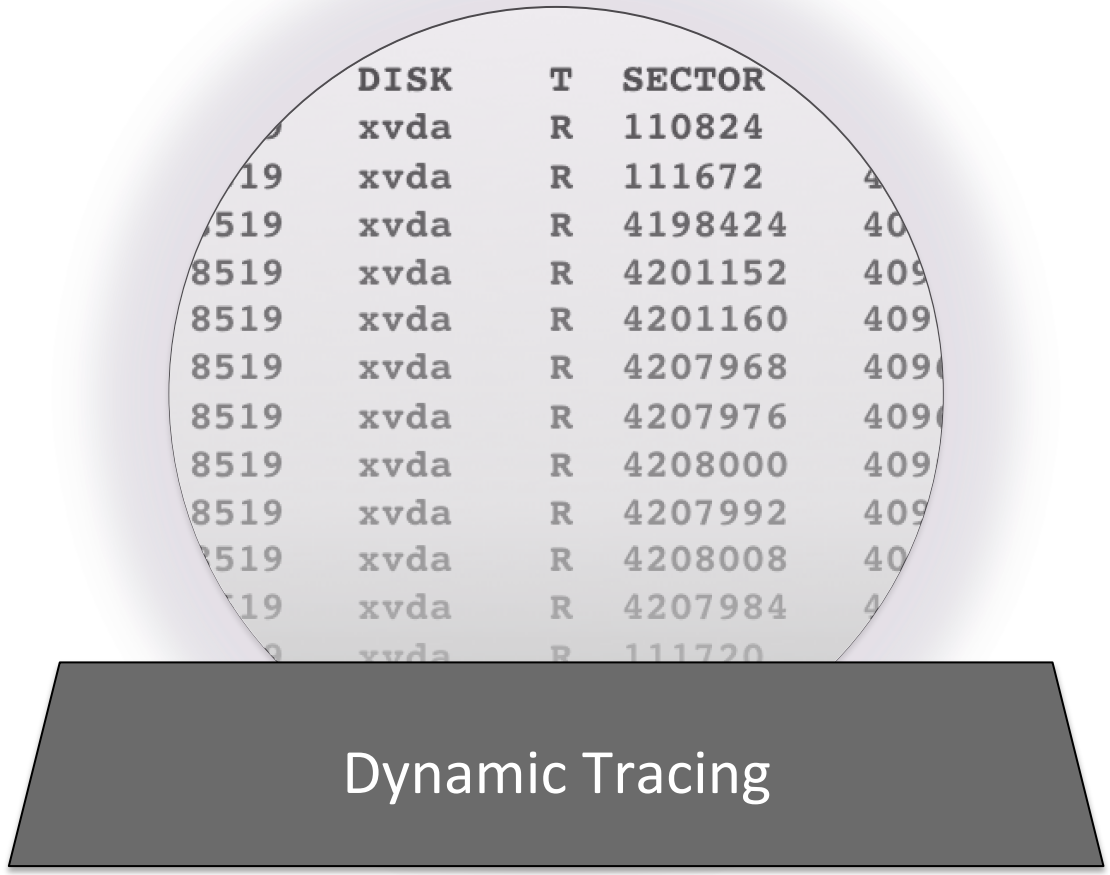
WHAT DYNAMIC TRACING CAN DO

Previously

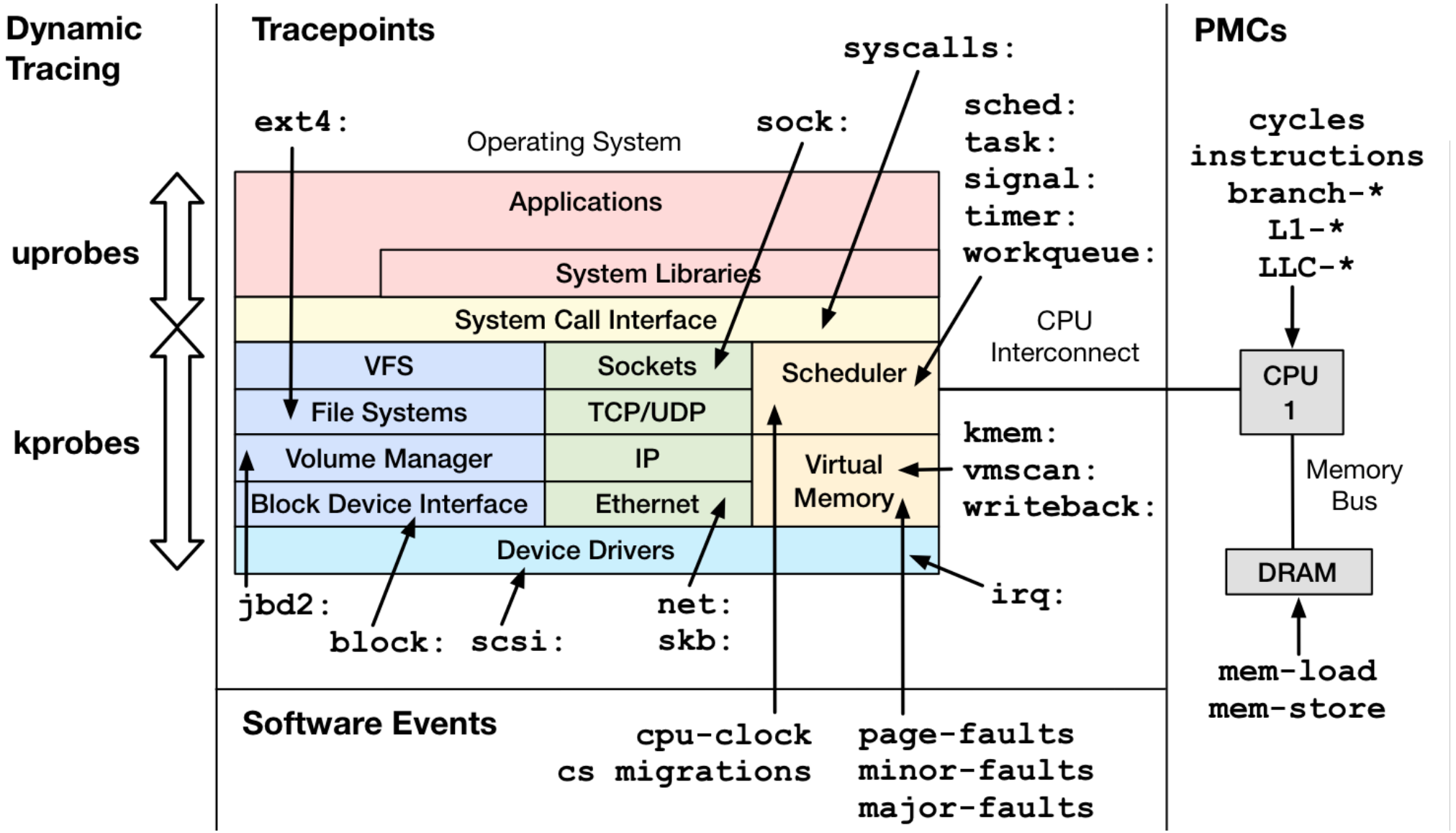
- Metrics were vendor chosen, closed source, and incomplete
- The art of inference & making do

```
# ps alx
 F S UID   PID  PPID CPU PRI NICE  ADDR  SZ  WCHAN TTY TIME CMD
 3 S   0     0     0   0   0   20  2253   2   4412 ?  186:14 swapper
 1 S   0     1     0   0  30   20  2423   8  46520 ?   0:00 /etc/init
 1 S   0    16     1   0  30   20  2273  11  46554 co  0:00 –sh
[…]
```

Crystal Ball Observability

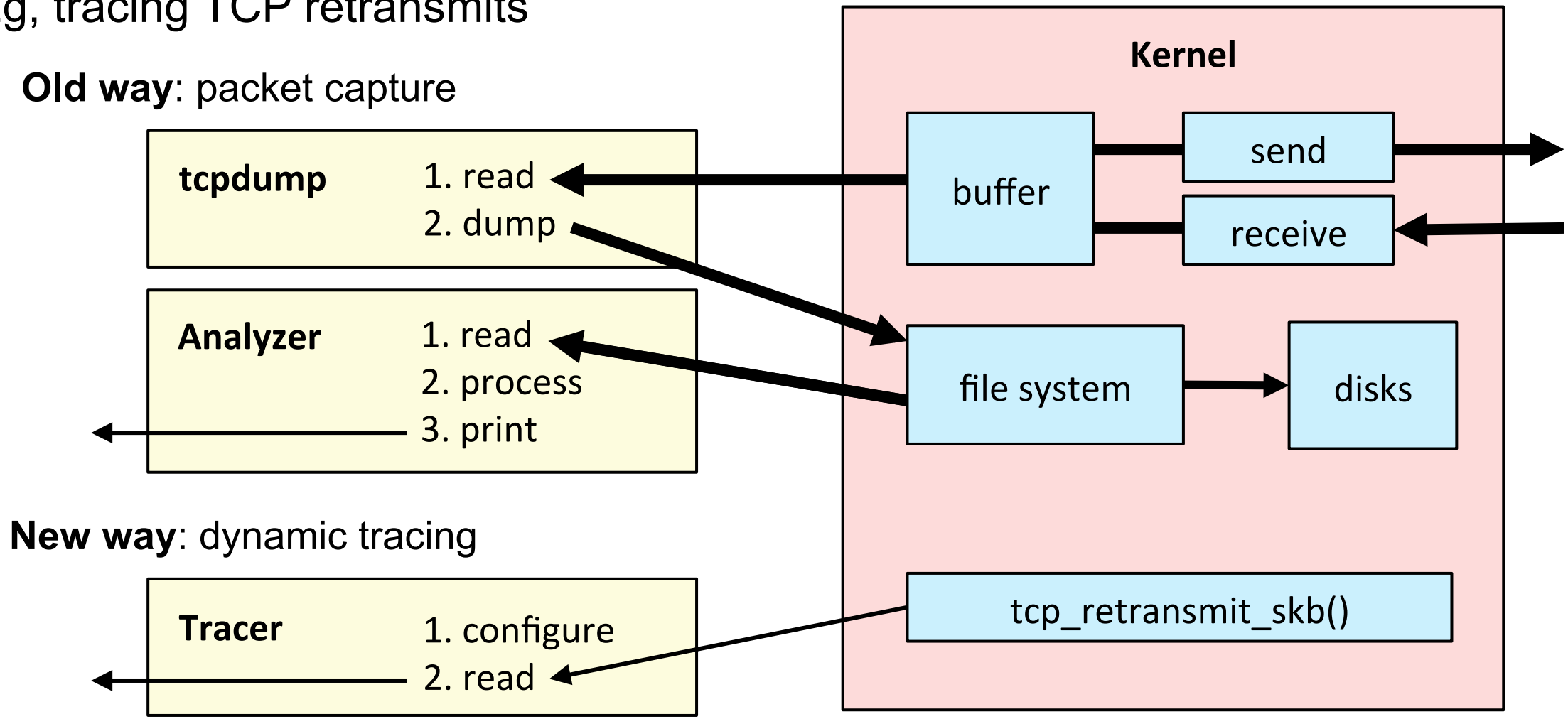


Linux Event Sources



Event Tracing Efficiency

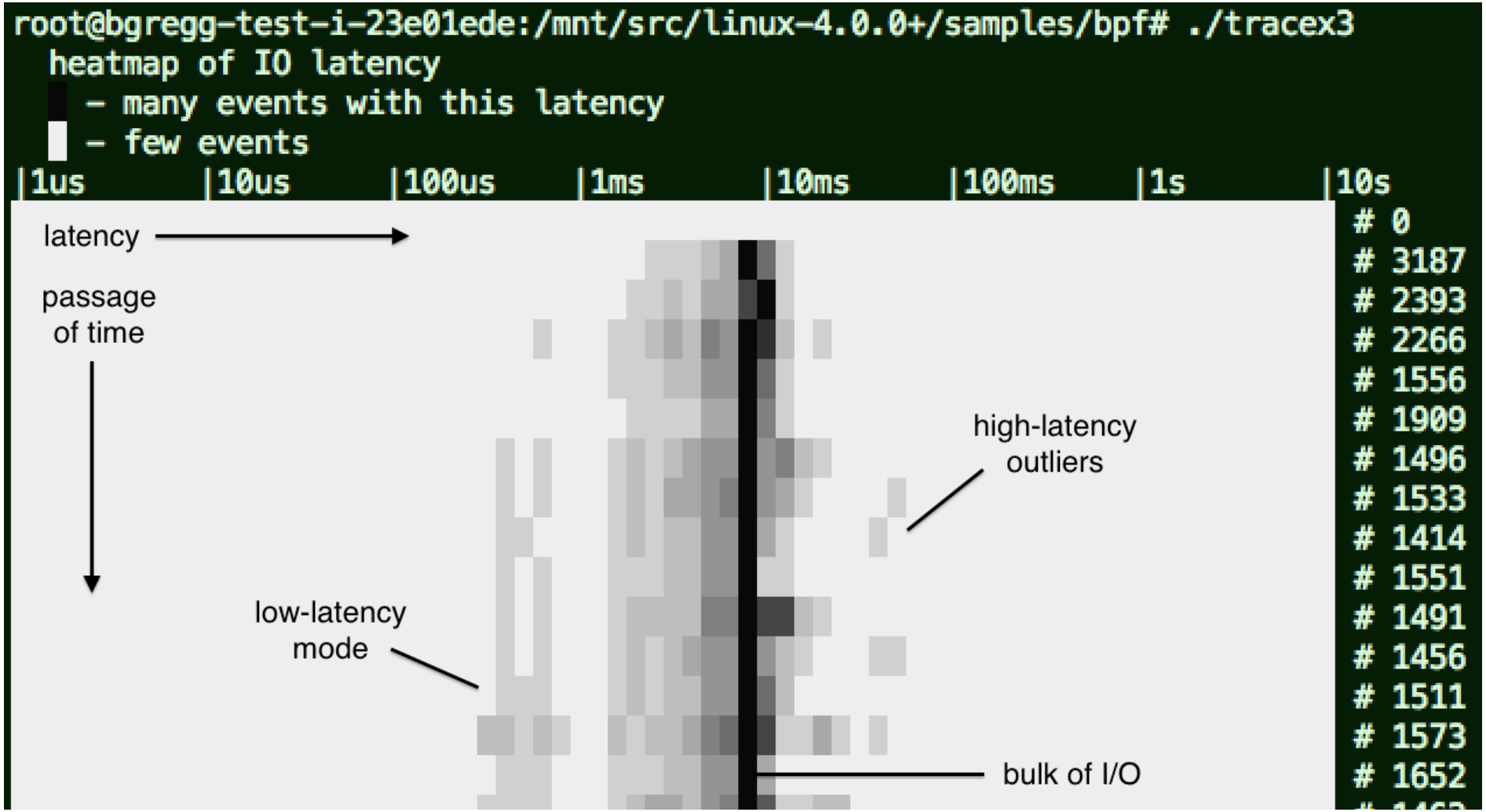
Eg, tracing TCP retransmits



New CLI Tools

```
# biolatency
Tracing block device I/O... Hit Ctrl-C to end.
^C
     usecs               : count     distribution
       4 -> 7            : 0        |                                        |
       8 -> 15           : 0        |                                        |
      16 -> 31           : 0        |                                        |
      32 -> 63           : 0        |                                        |
      64 -> 127          : 1        |                                        |
     128 -> 255          : 12       |********                                |
     256 -> 511          : 15       |**********                              |
     512 -> 1023         : 43       |******************************          |
    1024 -> 2047         : 52       |************************************    |
    2048 -> 4095         : 47       |********************************        |
    4096 -> 8191         : 52       |************************************    |
    8192 -> 16383        : 36       |*************************               |
   16384 -> 32767        : 15       |**********                              |
   32768 -> 65535        : 2        |*                                       |
   65536 -> 131071       : 2        |*                                       |
```

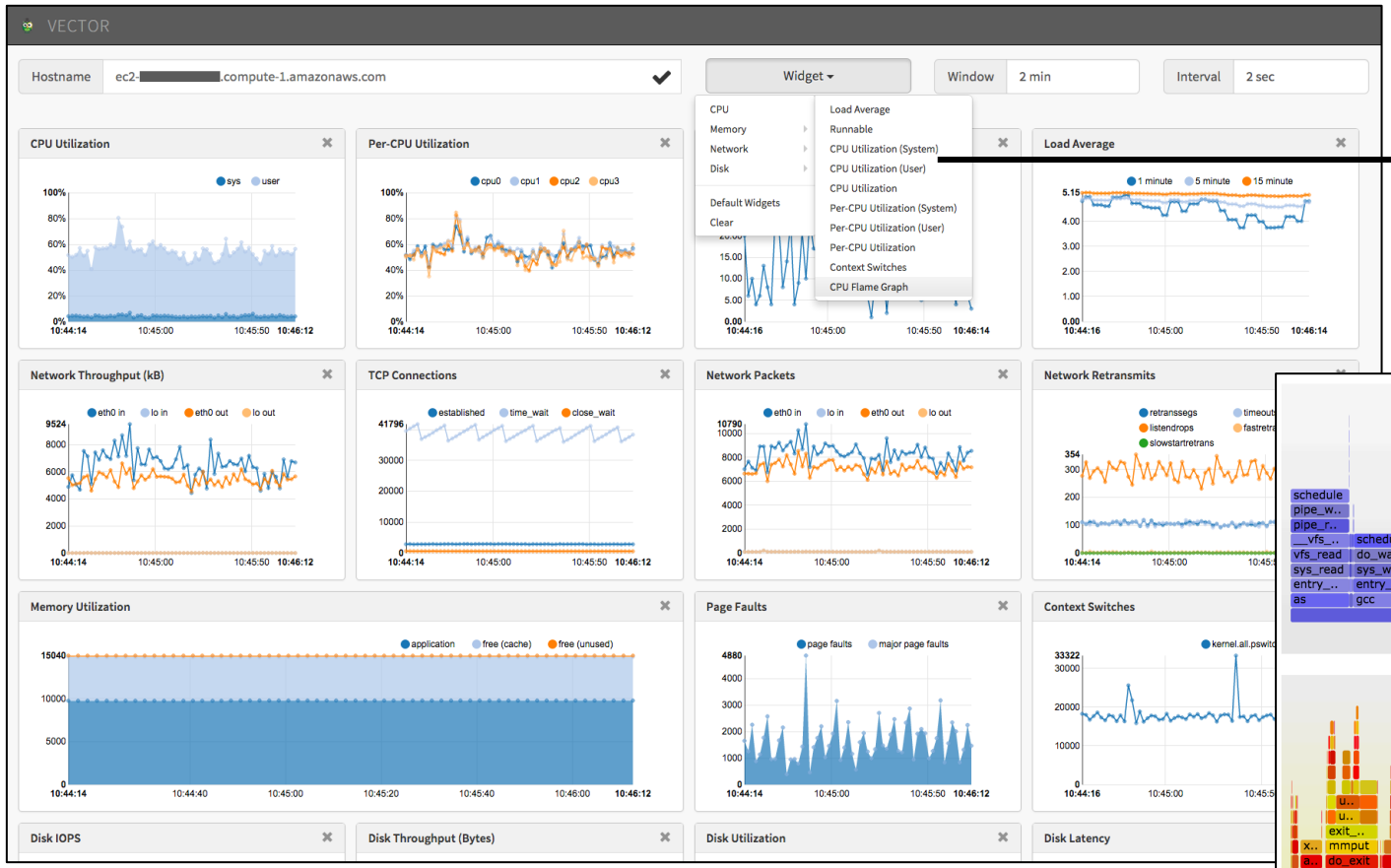
New Visualizations and GUIs



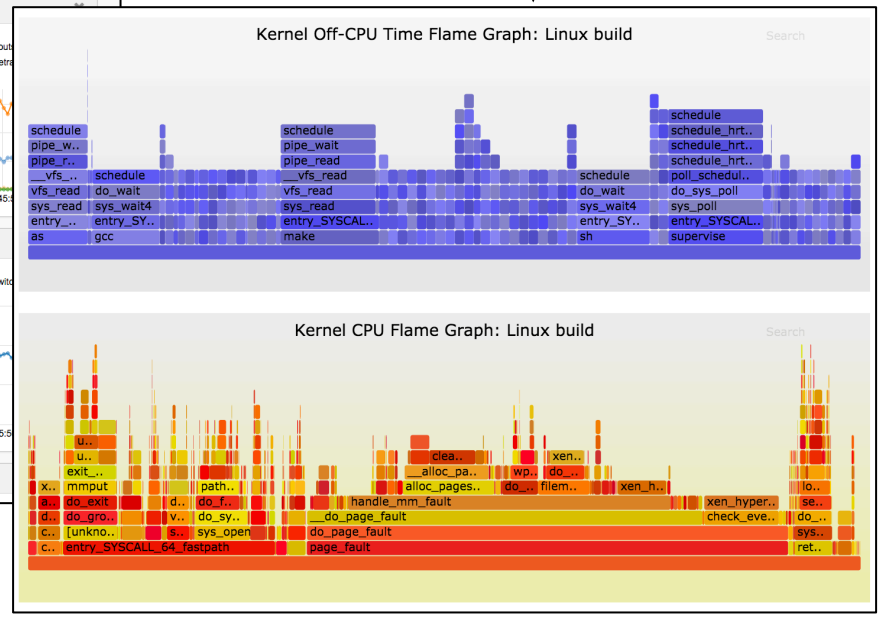
Netflix Intended Usage

Vector

Self-service UI:

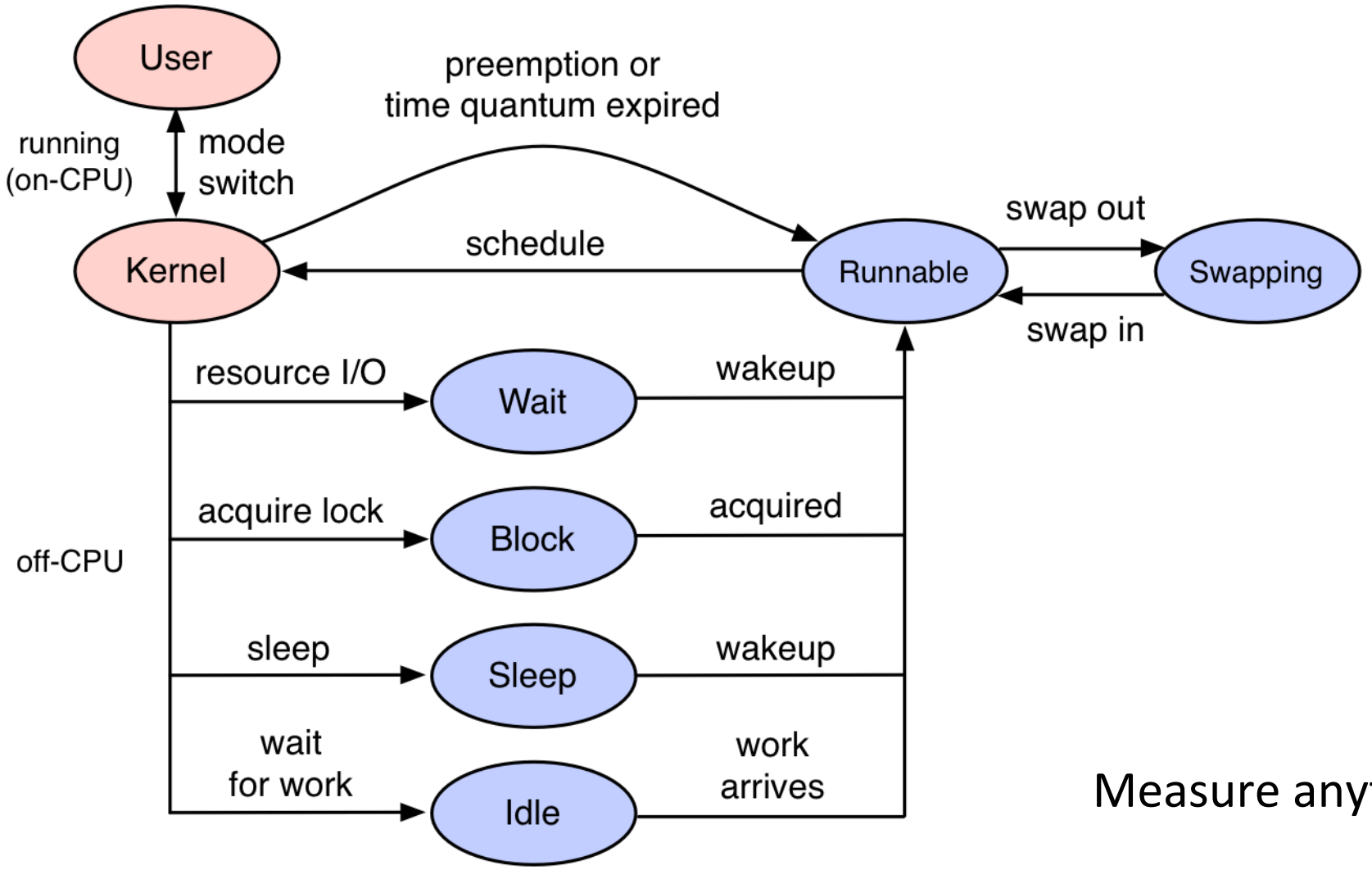


Flame Graphs
Tracing Reports
…



should be open sourced; you may also build/buy your own

Conquer Performance



Measure anything

Introducing enhanced BPF

BPF TRACING

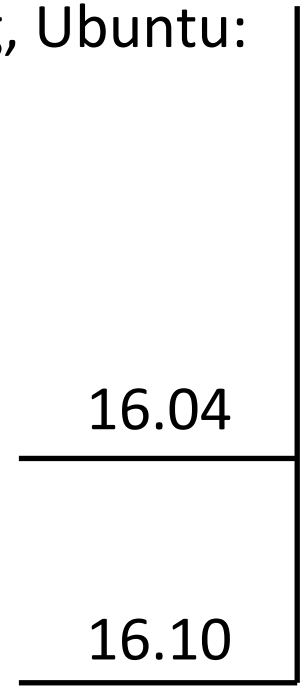
A Linux Tracing Timeline

- 1990's: Static tracers, prototype dynamic tracers
- 2000: LTT + DProbes (dynamic tracing; not integrated)
- 2004: kprobes (2.6.9)
- 2005: DTrace (not Linux), SystemTap (out-of-tree)
- 2008: ftrace (2.6.27)
- 2009: perf (2.6.31)
- 2009: tracepoints (2.6.32)
- 2010-2016: ftrace & perf_events enhancements
- 2014-2016: BPF patches

also: LTTng, ktap, sysdig, ...

BPF Enhancements by Linux Version

- 3.18: bpf syscall
- 3.19: sockets
- 4.1: kprobes
- 4.4: bpf_perf_event_output
- 4.6: stack traces
- 4.7: tracepoints
- 4.9: profiling



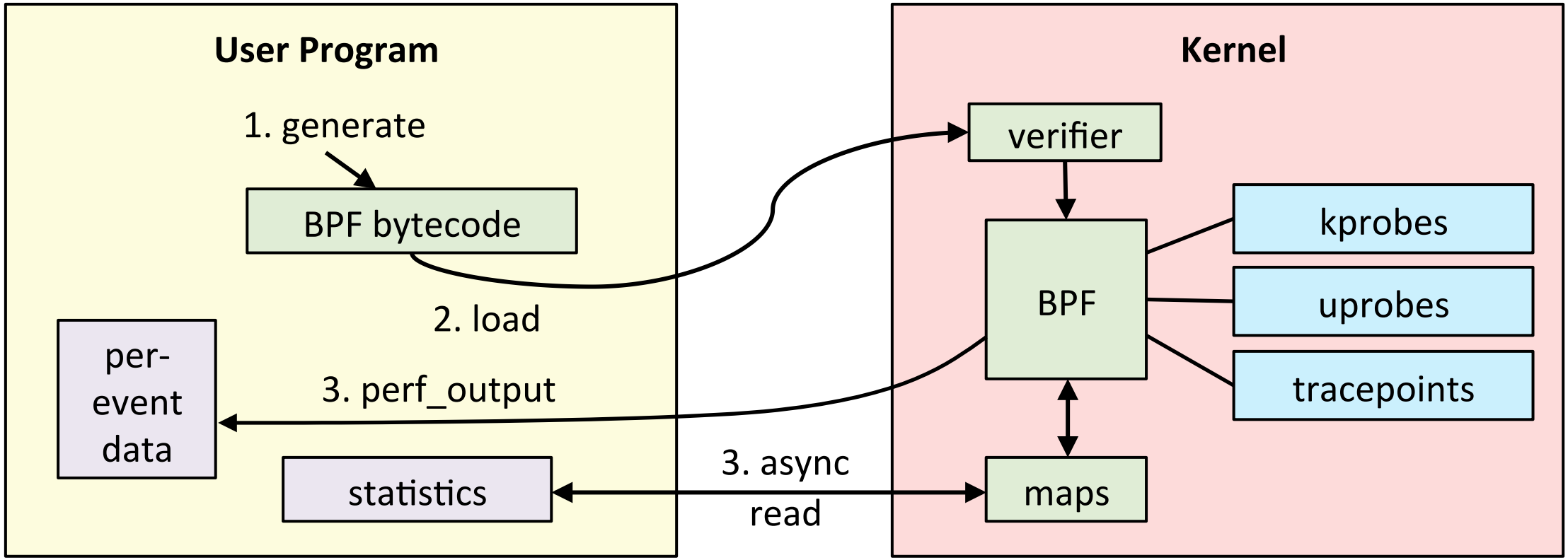
Enhanced BPF is in Linux

BPF

- aka eBPF == enhanced Berkeley Packet Filter
  - Lead developer: Alexei Starovoitov (Facebook)
- Many uses
  - Virtual networking
  - Security
  - Programmatic tracing
- Different front-ends
  - C, perf, bcc, ply, …

BPF mascot

BPF for Tracing



Raw BPF

```
struct bpf_insn prog[] = {
        BPF_MOV64_REG(BPF_REG_6, BPF_REG_1),
        BPF_LD_ABS(BPF_B, ETH_HLEN + offsetof(struct iphdr, protocol) /* R0 = ip->proto */),
        BPF_STX_MEM(BPF_W, BPF_REG_10, BPF_REG_0, -4), /* *(u32 *)(fp - 4) = r0 */
        BPF_MOV64_REG(BPF_REG_2, BPF_REG_10),
        BPF_ALU64_IMM(BPF_ADD, BPF_REG_2, -4), /* r2 = fp - 4 */
        BPF_LD_MAP_FD(BPF_REG_1, map_fd),
        BPF_RAW_INSN(BPF_JMP | BPF_CALL, 0, 0, 0, BPF_FUNC_map_lookup_elem),
        BPF_JMP_IMM(BPF_JEQ, BPF_REG_0, 0, 2),
        BPF_MOV64_IMM(BPF_REG_1, 1), /* r1 = 1 */
        BPF_RAW_INSN(BPF_STX | BPF_XADD | BPF_DW, BPF_REG_0, BPF_REG_1, 0, 0), /* xadd r0 += r1 */
        BPF_MOV64_IMM(BPF_REG_0, 0), /* r0 = 0 */
        BPF_EXIT_INSN(),
};
```

samples/bpf/sock_example.c

87 lines truncated

C/BPF

```c
SEC("kprobe/__netif_receive_skb_core")
int bpf_prog1(struct pt_regs *ctx)
{
        /* attaches to kprobe netif_receive_skb,
         * looks for packets on loobpack device and prints them
         */
        char devname[IFNAMSIZ];
        struct net_device *dev;
        struct sk_buff *skb;
        int len;

        /* non-portable! works for the given kernel only */
        skb = (struct sk_buff *) PT_REGS_PARM1(ctx);
        dev = _(skb->dev);
```

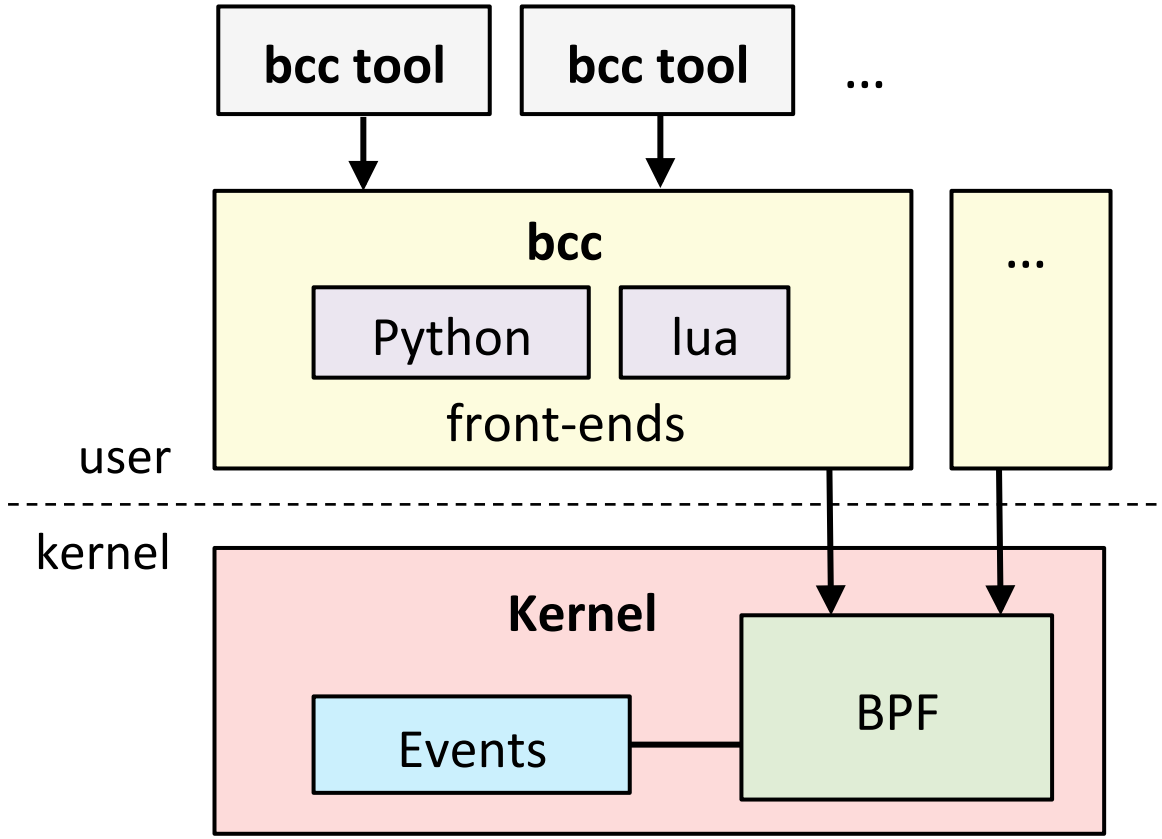
samples/bpf/tracex1_kern.c

58 lines truncated

bcc

- BPF Compiler Collection
  - https://github.com/iovisor/bcc
  - Lead developer: Brenden Blanco
- Includes tracing tools
- Front-ends:
  - Python
  - Lua
  - C++
  - C helper libraries
  - golang (gobpf)

Tracing layers:



bcc/BPF

```
# load BPF program
b = BPF(text="""
#include <uapi/linux/ptrace.h>
#include <linux/blkdev.h>
BPF_HISTOGRAM(dist);
int kprobe__blk_account_io_completion(struct pt_regs *ctx,
    struct request *req)
{
    dist.increment(bpf_log2l(req->__data_len / 1024));
    return 0;
}
""")
```

```
# header
print("Tracing... Hit Ctrl-C to end.")


# trace until Ctrl-C
try:
    sleep(99999999)
except KeyboardInterrupt:
    print


# output
b["dist"].print_log2_hist("kbytes")
```

bcc examples/tracing/bitehist.py
entire program

ply/BPF

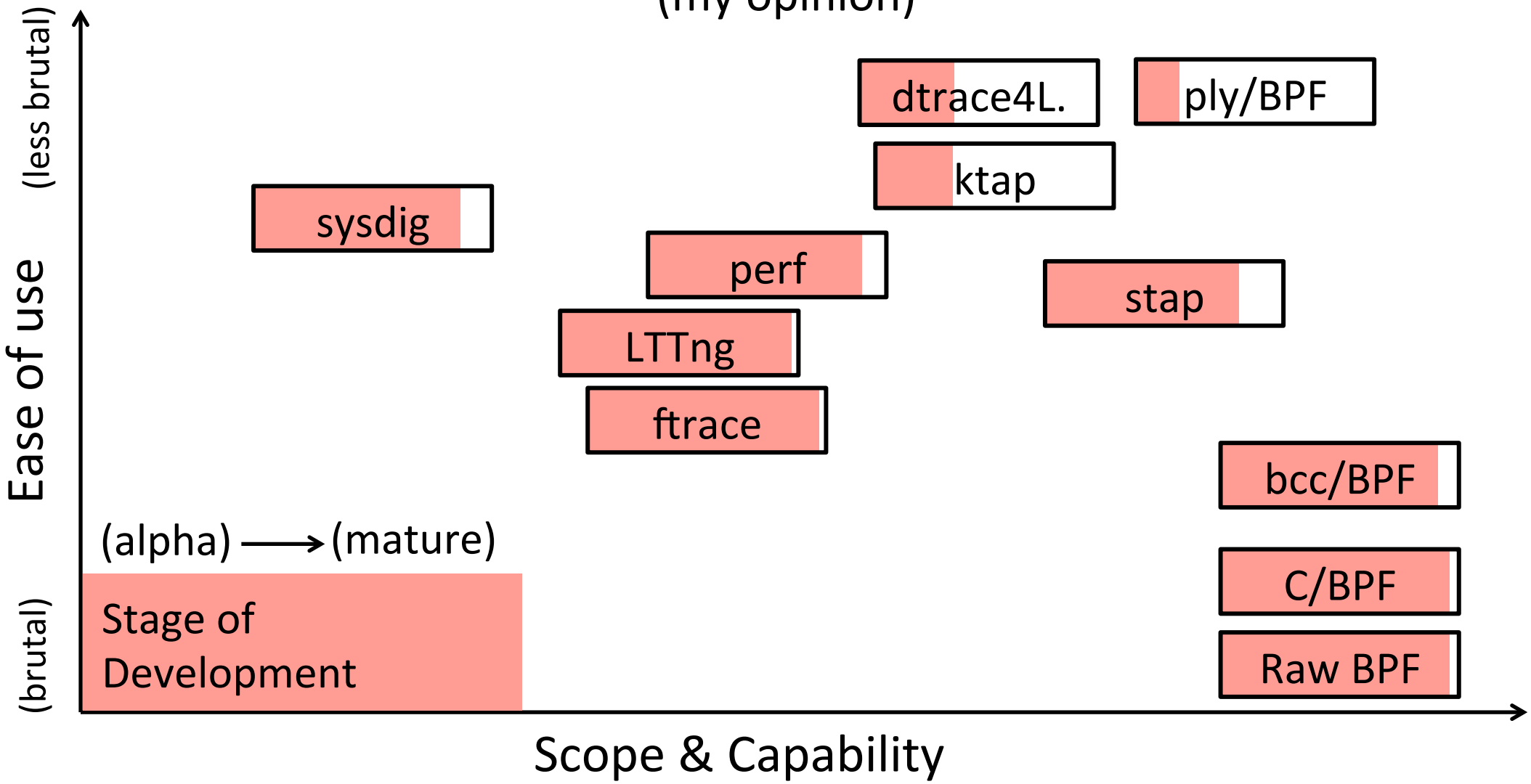
```
#!/usr/bin/env ply

kprobe:SyS_read
{
    $sizes.quantize(arg(2))
}
```

https://github.com/wkz/ply/blob/master/README.md

entire program

The Tracing Landscape, Jan 2017

(my opinion)



State of BPF, Jan 2017

1. Dynamic tracing, kernel-level (BPF support for kprobes)
2. Dynamic tracing, user-level (BPF support for uprobes)
3. Static tracing, kernel-level (BPF support for tracepoints)
4. Timed sampling events (BPF with perf_event_open)
5. PMC events (BPF with perf_event_open)
6. Filtering (via BPF programs)
7. Debug output (bpf_trace_printk())
8. Per-event output (bpf_perf_event_output())
9. Basic variables (global & per-thread variables, via BPF maps)
10. Associative arrays (via BPF maps)
11. Frequency counting (via BPF maps)
12. Histograms (power-of-2, linear, and custom, via BPF maps)
13. Timestamps and time deltas (bpf_ktime_get_() and BPF)
14. Stack traces, kernel (BPF stackmap)
15. Stack traces, user (BPF stackmap)
16. Overwrite ring buffers
17. String factory (stringmap)
18. Optional: bounded loops, < and <=, …

done

not yet

State of bcc, Jan 2017

1. Static tracing, user-level (USDT probes via uprobes)
2. Static tracing, dynamic USDT (needs library support)
3. Debug output (Python with BPF.trace_pipe() and BPF.trace_fields())
4. Per-event output (BPF_PERF_OUTPUT macro and BPF.open_perf_buffer())
5. Interval output (BPF.get_table() and table.clear())
6. Histogram printing (table.print_log2_hist())
7. C struct navigation, kernel-level (maps to bpf_probe_read())
8. Symbol resolution, kernel-level (ksym(), ksymaddr())
9. Symbol resolution, user-level (usymaddr())
10. BPF tracepoint support (via TRACEPOINT_PROBE)
11. BPF stack trace support (incl. walk method for stack frames)
12. Examples (under /examples)
13. Many tools (/tools)
14. Tutorials (/docs/tutorial*.md)
15. Reference guide (/docs/reference_guide.md)
16. Open issues: (https://github.com/iovisor/bcc/issues)

For end-users

HOW TO USE BCC/BPF

Installation

https://github.com/iovisor/bcc/blob/master/INSTALL.md

- eg, Ubuntu Xenial:

```
# echo "deb [trusted=yes] https://repo.iovisor.org/apt/xenial xenial-nightly main" | \
    sudo tee /etc/apt/sources.list.d/iovisor.list
# sudo apt-get update
# sudo apt-get install bcc-tools
```

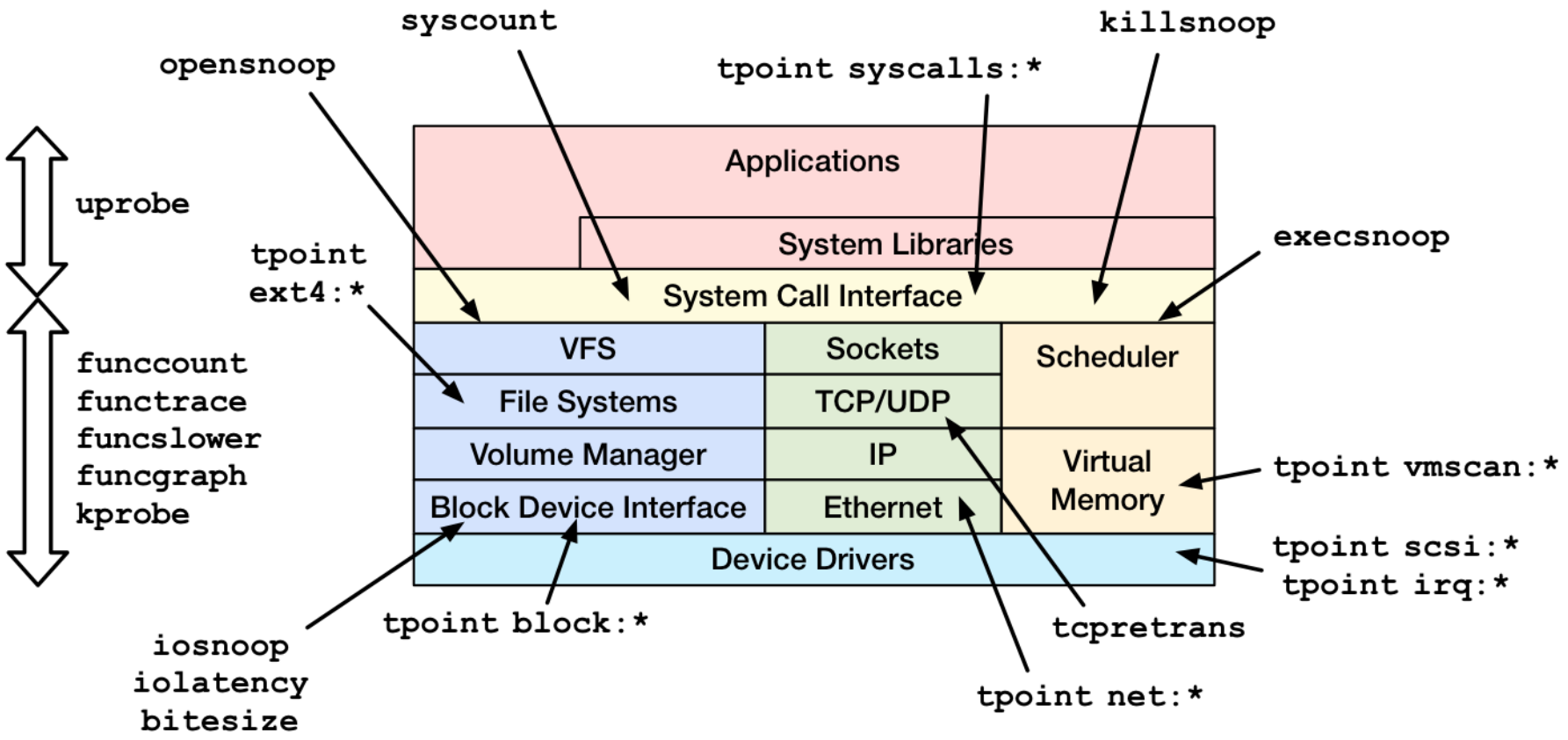
  - puts tools in /usr/share/bcc/tools, and tools/old for older kernels
  - 16.04 is good, 16.10 better: more tools work
  - bcc should also arrive as an official Ubuntu snap

Linux Perf Analysis in 60s

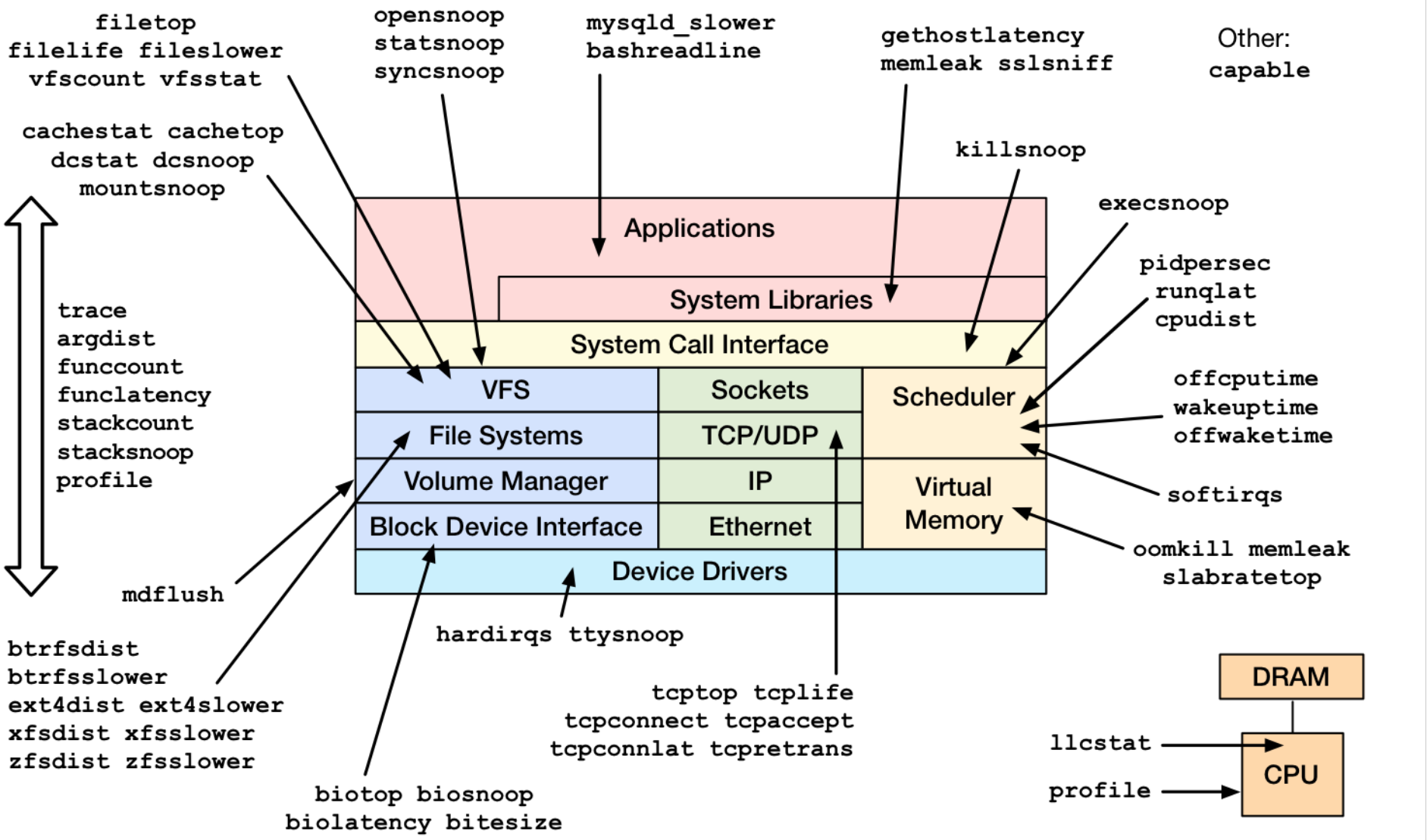
1. `uptime`
2. `dmesg | tail`
3. `vmstat 1`
4. `mpstat -P ALL 1`
5. `pidstat 1`
6. `iostat -xz 1`
7. `free -m`
8. `sar -n DEV 1`
9. `sar -n TCP,ETCP 1`
10. `top`

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

perf-tools (ftrace)



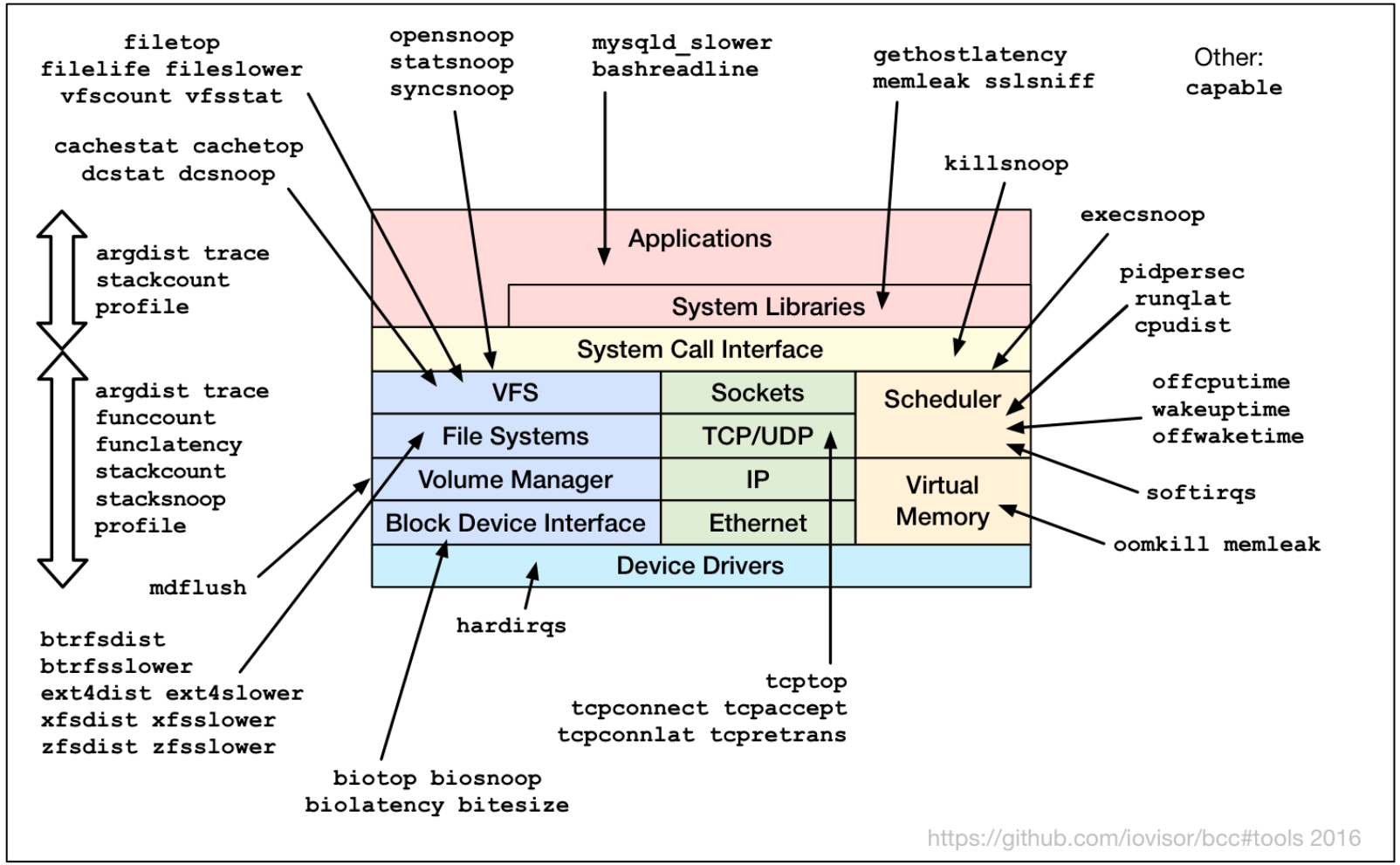
bcc Tracing Tools



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

bcc General Performance Checklist

1. execsnoop
2. opensnoop
3. ext4slower(...)
4. biolatency
5. biosnoop
6. cachestat
7. tcpconnect
8. tcpaccept
9. tcpretrans
10. gethostlatency
11. runqlat
12. profile



1. execsnoop

```
# execsnoop
PCOMM            PID    RET ARGS
bash             15887    0 /usr/bin/man ls
preconv          15894    0 /usr/bin/preconv -e UTF-8
man              15896    0 /usr/bin/tbl
man              15897    0 /usr/bin/nroff -mandoc -rLL=169n -rLT=169n -Tutf8
man              15898    0 /usr/bin/pager -s
nroff            15900    0 /usr/bin/locale charmap
nroff            15901    0 /usr/bin/groff -mtty-char -Tutf8 -mandoc -rLL=169n -rLT=169n
groff            15902    0 /usr/bin/troff -mtty-char -mandoc -rLL=169n -rLT=169n -Tutf8
groff            15903    0 /usr/bin/grotty
[…]
```

2. opensnoop

```
# opensnoop
PID    COMM               FD ERR PATH
27159  catalina.sh         3   0 /apps/tomcat8/bin/setclasspath.sh
4057   redis-server        5   0 /proc/4057/stat
2360   redis-server        5   0 /proc/2360/stat
30668  sshd                4   0 /proc/sys/kernel/ngroups_max
30668  sshd                4   0 /etc/group
30668  sshd                4   0 /root/.ssh/authorized_keys
30668  sshd                4   0 /root/.ssh/authorized_keys
30668  sshd               -1   2 /var/run/nologin
30668  sshd               -1   2 /etc/nologin
30668  sshd                4   0 /etc/login.defs
30668  sshd                4   0 /etc/passwd
30668  sshd                4   0 /etc/shadow
30668  sshd                4   0 /etc/localtime
4510   snmp-pass           4   0 /proc/cpuinfo
[…]
```

3. ext4slower

```
# ext4slower 1
Tracing ext4 operations slower than 1 ms
TIME     COMM            PID    T BYTES   OFF_KB   LAT(ms) FILENAME
06:49:17 bash            3616   R 128     0          7.75 cksum
06:49:17 cksum           3616   R 39552   0          1.34 [
06:49:17 cksum           3616   R 96      0          5.36 2to3-2.7
06:49:17 cksum           3616   R 96      0         14.94 2to3-3.4
06:49:17 cksum           3616   R 10320   0          6.82 411toppm
06:49:17 cksum           3616   R 65536   0          4.01 a2p
06:49:17 cksum           3616   R 55400   0          8.77 ab
06:49:17 cksum           3616   R 36792   0         16.34 aclocal-1.14
06:49:17 cksum           3616   R 15008   0         19.31 acpi_listen
06:49:17 cksum           3616   R 6123    0         17.23 add-apt-repository
06:49:17 cksum           3616   R 6280    0         18.40 addpart
06:49:17 cksum           3616   R 27696   0          2.16 addr2line
06:49:17 cksum           3616   R 58080   0         10.11 ag
[…]
```

also: btrfsslower, xfsslower, zfslower

4. biolatency

```
# biolatency -mT 1
Tracing block device I/O... Hit Ctrl-C to end.

06:20:16
     msecs               : count     distribution
       0 -> 1            : 36       |****************************************|
       2 -> 3            : 1        |*                                       |
       4 -> 7            : 3        |***                                     |
       8 -> 15           : 17       |*****************                       |
      16 -> 31           : 33       |********************************        |
      32 -> 63           : 7        |*******                                 |
      64 -> 127          : 6        |******                                  |

[…]
```

5. biosnoop

```
# biosnoop
TIME(s)        COMM           PID    DISK    T  SECTOR    BYTES   LAT(ms)
0.000004001    supervise      1950   xvda1   W  13092560  4096       0.74
0.000178002    supervise      1950   xvda1   W  13092432  4096       0.61
0.001469001    supervise      1956   xvda1   W  13092440  4096       1.24
0.001588002    supervise      1956   xvda1   W  13115128  4096       1.09
1.022346001    supervise      1950   xvda1   W  13115272  4096       0.98
1.022568002    supervise      1950   xvda1   W  13188496  4096       0.93
1.023534000    supervise      1956   xvda1   W  13188520  4096       0.79
1.023585003    supervise      1956   xvda1   W  13189512  4096       0.60
2.003920000    xfsaild/md0    456    xvdc    W  62901512  8192       0.23
2.003931001    xfsaild/md0    456    xvdb    W  62901513  512        0.25
2.004034001    xfsaild/md0    456    xvdb    W  62901520  8192       0.35
2.004042000    xfsaild/md0    456    xvdb    W  63542016  4096       0.36
2.004204001    kworker/0:3    26040  xvdb    W  41950344  65536      0.34
2.044352002    supervise      1950   xvda1   W  13192672  4096       0.65
[…]
```

6. cachestat

```
# cachestat
    HITS   MISSES  DIRTIES  READ_HIT% WRITE_HIT%   BUFFERS_MB  CACHED_MB
  170610    41607       33      80.4%      19.6%           11        288
  157693     6149       33      96.2%       3.7%           11        311
  174483    20166       26      89.6%      10.4%           12        389
  434778       35       40     100.0%       0.0%           12        389
  435723       28       36     100.0%       0.0%           12        389
  846183    83800   332534      55.2%       4.5%           13        553
   96387       21       24     100.0%       0.0%           13        553
  120258       29       44      99.9%       0.0%           13        553
  255861       24       33     100.0%       0.0%           13        553
  191388       22       32     100.0%       0.0%           13        553
[…]
```

7. tcpconnect

```
# tcpconnect
PID    COMM         IP SADDR            DADDR            DPORT
25333  recordProgra 4  127.0.0.1        127.0.0.1        28527
25338  curl         4  100.66.3.172     52.22.109.254    80
25340  curl         4  100.66.3.172     31.13.73.36      80
25342  curl         4  100.66.3.172     104.20.25.153    80
25344  curl         4  100.66.3.172     50.56.53.173     80
25365  recordProgra 4  127.0.0.1        127.0.0.1        28527
26119  ssh          6  ::1              ::1              22
25388  recordProgra 4  127.0.0.1        127.0.0.1        28527
25220  ssh          6  fe80::8a3:9dff:fed5:6b19 fe80::8a3:9dff:fed5:6b19 22
[…]
```

8. tcpaccept

```
# tcpaccept
PID    COMM         IP RADDR           LADDR           LPORT
2287   sshd         4  11.16.213.254   100.66.3.172    22
4057   redis-server 4  127.0.0.1       127.0.0.1       28527
4057   redis-server 4  127.0.0.1       127.0.0.1       28527
4057   redis-server 4  127.0.0.1       127.0.0.1       28527
4057   redis-server 4  127.0.0.1       127.0.0.1       28527
2287   sshd         6  ::1             ::1             22
4057   redis-server 4  127.0.0.1       127.0.0.1       28527
4057   redis-server 4  127.0.0.1       127.0.0.1       28527
2287   sshd         6  fe80::8a3:9dff:fed5:6b19 fe80::8a3:9dff:fed5:6b19 22
4057   redis-server 4  127.0.0.1       127.0.0.1       28527
[…]
```

9. tcpretrans

```
# tcpretrans
TIME     PID    IP LADDR:LPORT          T> RADDR:RPORT          STATE
01:55:05 0      4  10.153.223.157:22    R> 69.53.245.40:34619   ESTABLISHED
01:55:05 0      4  10.153.223.157:22    R> 69.53.245.40:34619   ESTABLISHED
01:55:17 0      4  10.153.223.157:22    R> 69.53.245.40:22957   ESTABLISHED
[…]
```

10. gethostlatency

```
# gethostlatency
TIME      PID    COMM           LATms HOST
06:10:24  28011  wget           90.00 www.iovisor.org
06:10:28  28127  wget            0.00 www.iovisor.org
06:10:41  28404  wget            9.00 www.netflix.com
06:10:48  28544  curl           35.00 www.netflix.com.au
06:11:10  29054  curl           31.00 www.plumgrid.com
06:11:16  29195  curl            3.00 www.facebook.com
06:11:24  25313  wget            3.00 www.usenix.org
06:11:25  29404  curl           72.00 foo
06:11:28  29475  curl            1.00 foo
[…]
```

11. runqlat

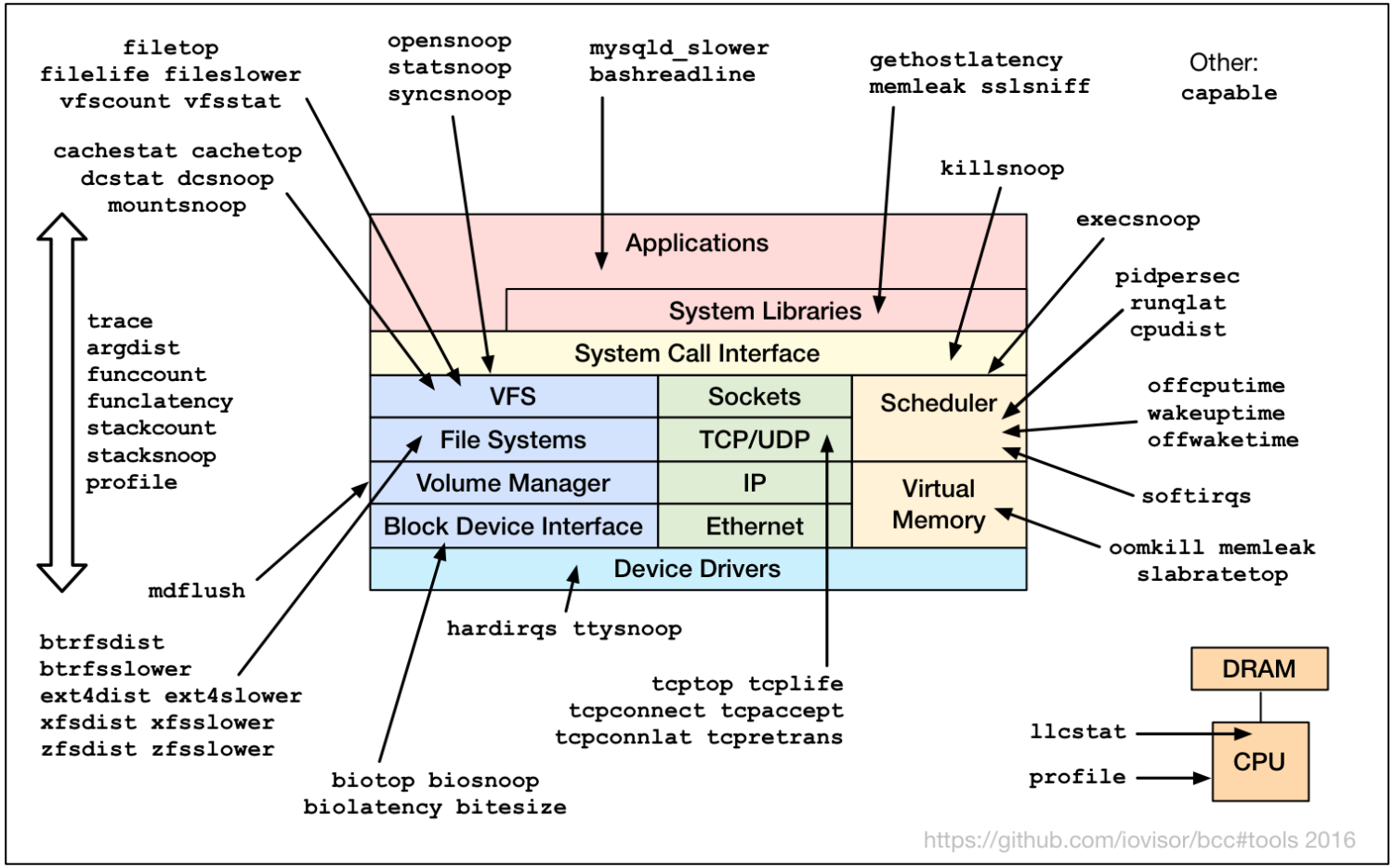
```
# runqlat -m 5
Tracing run queue latency... Hit Ctrl-C to end.

     msecs               : count     distribution
         0 -> 1          : 3818     |****************************************|
         2 -> 3          : 39       |                                        |
         4 -> 7          : 39       |                                        |
         8 -> 15         : 62       |                                        |
        16 -> 31         : 2214     |***********************                 |
        32 -> 63         : 226      |**                                      |

[…]
```

12. profile

```
# profile
Sampling at 49 Hertz of all threads by user + kernel stack... Hit Ctrl-C to end.
^C
[…]

    ffffffff813d0af8 __clear_user
    ffffffff813d5277 iov_iter_zero
    ffffffff814ec5f2 read_iter_zero
    ffffffff8120be9d __vfs_read
    ffffffff8120c385 vfs_read
    ffffffff8120d786 sys_read
    ffffffff817cc076 entry_SYSCALL_64_fastpath
    00007fc5652ad9b0 read
    -                dd (25036)
        7

[…]
```

Other bcc Tracing Tools

- Single-purpose
  - bitesize
  - capabile
  - memleak
  - ext4dist (btrfs, …)
- Multi tools
  - funccount
  - argdist
  - trace
  - stackcount



https://github.com/iovisor/bcc#tools

trace

- Trace custom events. Ad hoc analysis:

```
# trace 'sys_read (arg3 > 20000) "read %d bytes", arg3'
TIME     PID    COMM         FUNC             -
05:18:23 4490   dd           sys_read         read 1048576 bytes
05:18:23 4490   dd           sys_read         read 1048576 bytes
05:18:23 4490   dd           sys_read         read 1048576 bytes
05:18:23 4490   dd           sys_read         read 1048576 bytes
^C
```

by Sasha Goldshtein

trace One-Liners

```
trace –K blk_account_io_start
       Trace this kernel function, and print info with a kernel stack trace
trace 'do_sys_open "%s", arg2'
       Trace the open syscall and print the filename being opened
trace 'sys_read (arg3 > 20000) "read %d bytes", arg3'
       Trace the read syscall and print a message for reads >20000 bytes
trace r::do_sys_return
       Trace the return from the open syscall
trace 'c:open (arg2 == 42) "%s %d", arg1, arg2'
       Trace the open() call from libc only if the flags (arg2) argument is 42
trace 'p:c:write (arg1 == 1) "writing %d bytes to STDOUT", arg3'
       Trace the write() call from libc to monitor writes to STDOUT
trace 'r:c:malloc (retval) "allocated = %p", retval
       Trace returns from malloc and print non-NULL allocated buffers
trace 't:block:block_rq_complete "sectors=%d", args->nr_sector'
       Trace the block_rq_complete kernel tracepoint and print # of tx sectors
trace 'u:pthread:pthread_create (arg4 != 0)'
       Trace the USDT probe pthread_create when its 4th argument is non-zero
```

from: trace -h

argdist

```
# argdist -H 'p::tcp_cleanup_rbuf(struct sock *sk, int copied):int:copied'
[15:34:45]
     copied              : count     distribution
         0 -> 1          : 15088     |************************************    |
         2 -> 3          : 0         |                                        |
         4 -> 7          : 0         |                                        |
         8 -> 15         : 0         |                                        |
        16 -> 31         : 0         |                                        |
        32 -> 63         : 0         |                                        |
        64 -> 127        : 4786      |***********                             |
       128 -> 255        : 1         |                                        |
       256 -> 511        : 1         |                                        |
       512 -> 1023       : 4         |                                        |
      1024 -> 2047       : 11        |                                        |
      2048 -> 4095       : 5         |                                        |
      4096 -> 8191       : 27        |                                        |
      8192 -> 16383      : 105       |                                        |
     16384 -> 32767      : 0         |                                        |
     32768 -> 65535      : 10086     |************************                |
     65536 -> 131071     : 60        |                                        |
    131072 -> 262143     : 17285     |****************************************|
[...]
```

by Sasha Goldshtein

argdist One-Liners

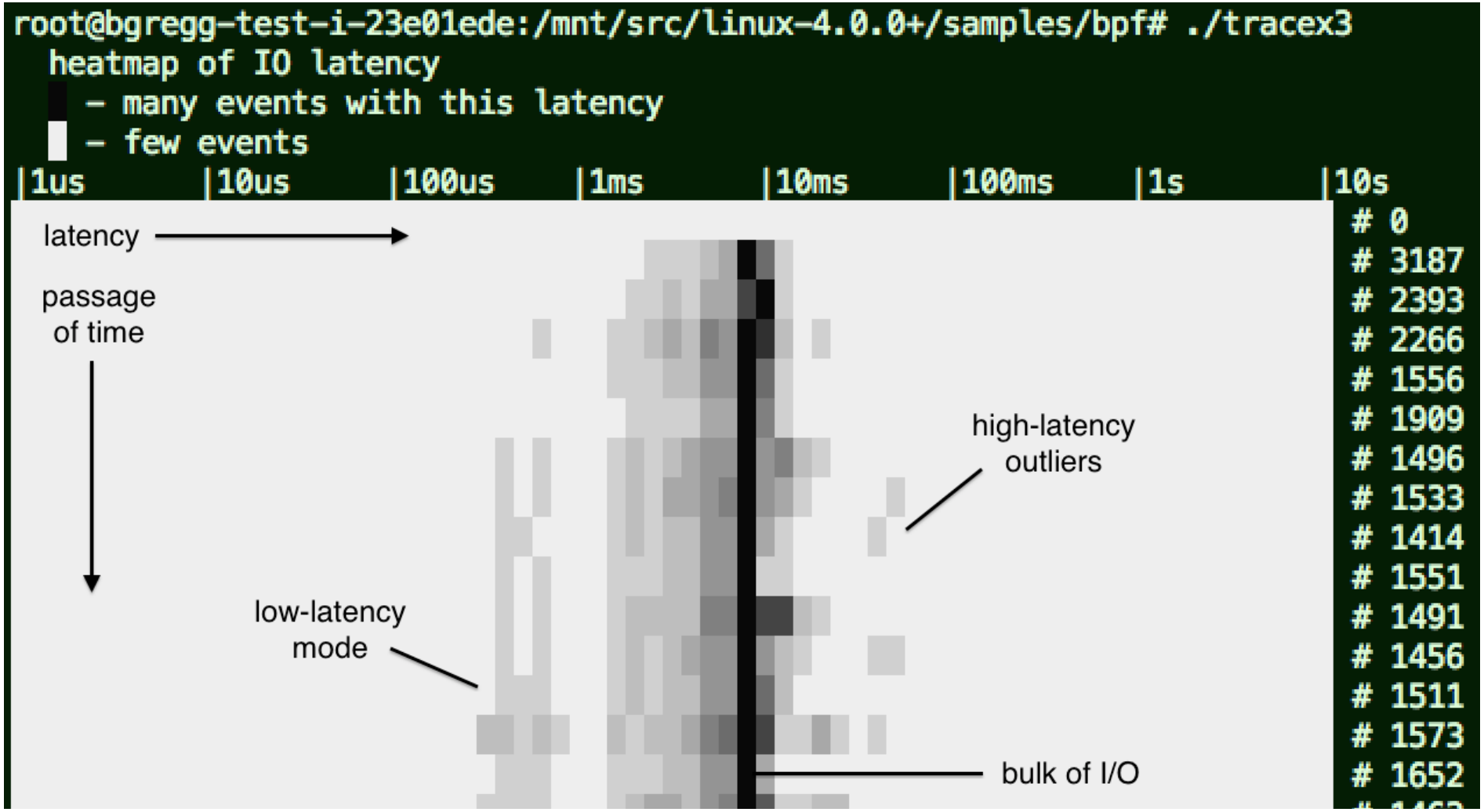
```
argdist -H 'p::__kmalloc(u64 size):u64:size'
        Print a histogram of allocation sizes passed to kmalloc

argdist -p 1005 -C 'p:c:malloc(size_t size):size_t:size:size==16'
        Print a frequency count of how many times process 1005 called malloc for 16 bytes

argdist -C 'r:c:gets():char*:$retval#snooped strings'
        Snoop on all strings returned by gets()

argdist -H 'r::__kmalloc(size_t size):u64:$latency/$entry(size)#ns per byte'
        Print a histogram of nanoseconds per byte from kmalloc allocations

argdist -C 'p::__kmalloc(size_t size, gfp_t flags):size_t:size:flags&GFP_ATOMIC'
        Print frequency count of kmalloc allocation sizes that have GFP_ATOMIC

argdist -p 1005 -C 'p:c:write(int fd):int:fd' -T 5
        Print frequency counts of how many times writes were issued to a particular file descriptor
        number, in process 1005, but only show the top 5 busiest fds

argdist -p 1005 -H 'r:c:read()'
        Print a histogram of error codes returned by read() in process 1005

argdist -C 'r::__vfs_read():u32:$PID:$latency > 100000'
        Print frequency of reads by process where the latency was >0.1ms
```

from: argdist -h

Coming to a GUI near you

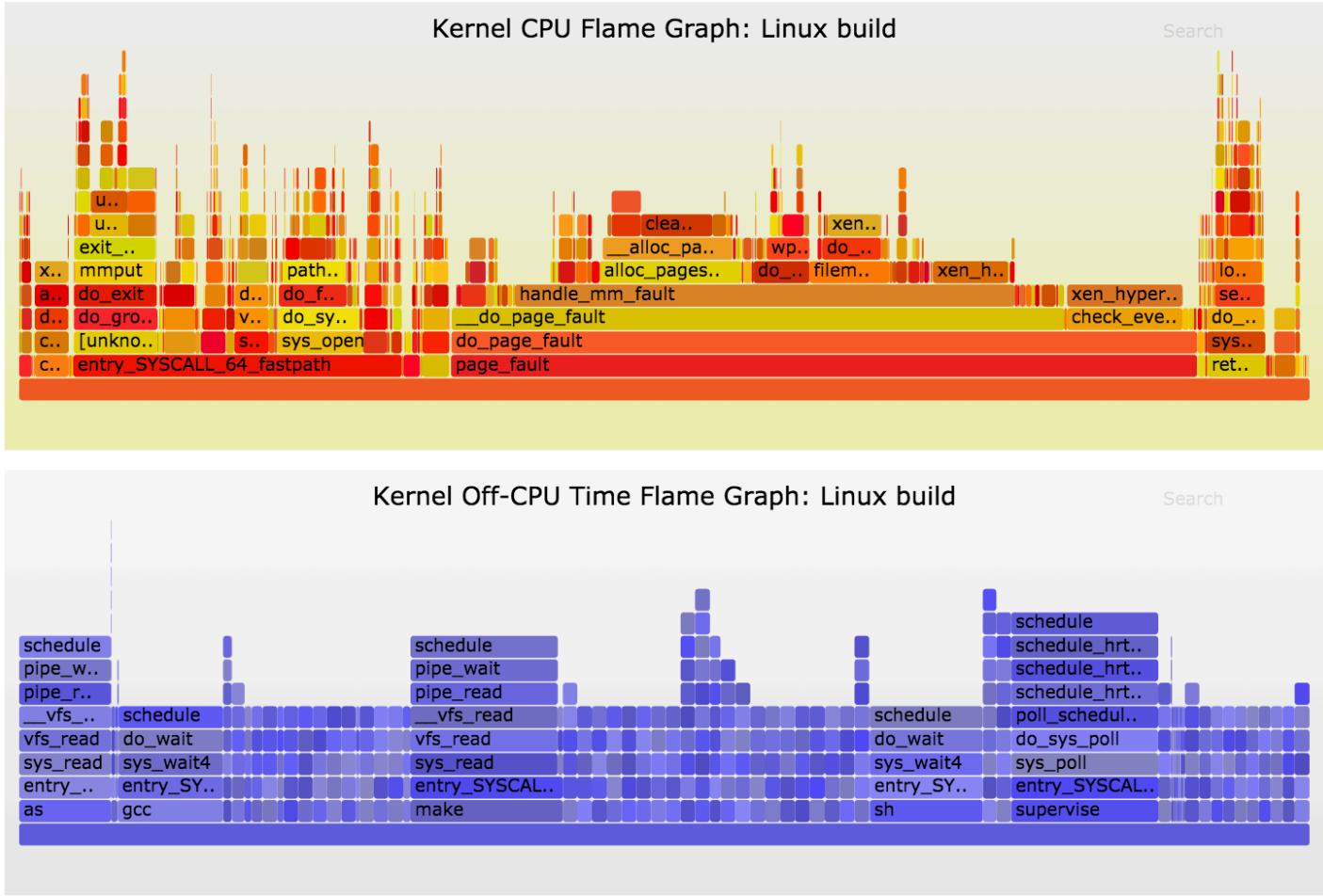
BCC/BPF VISUALIZATIONS

Latency Heatmaps



CPU + Off-CPU Flame Graphs

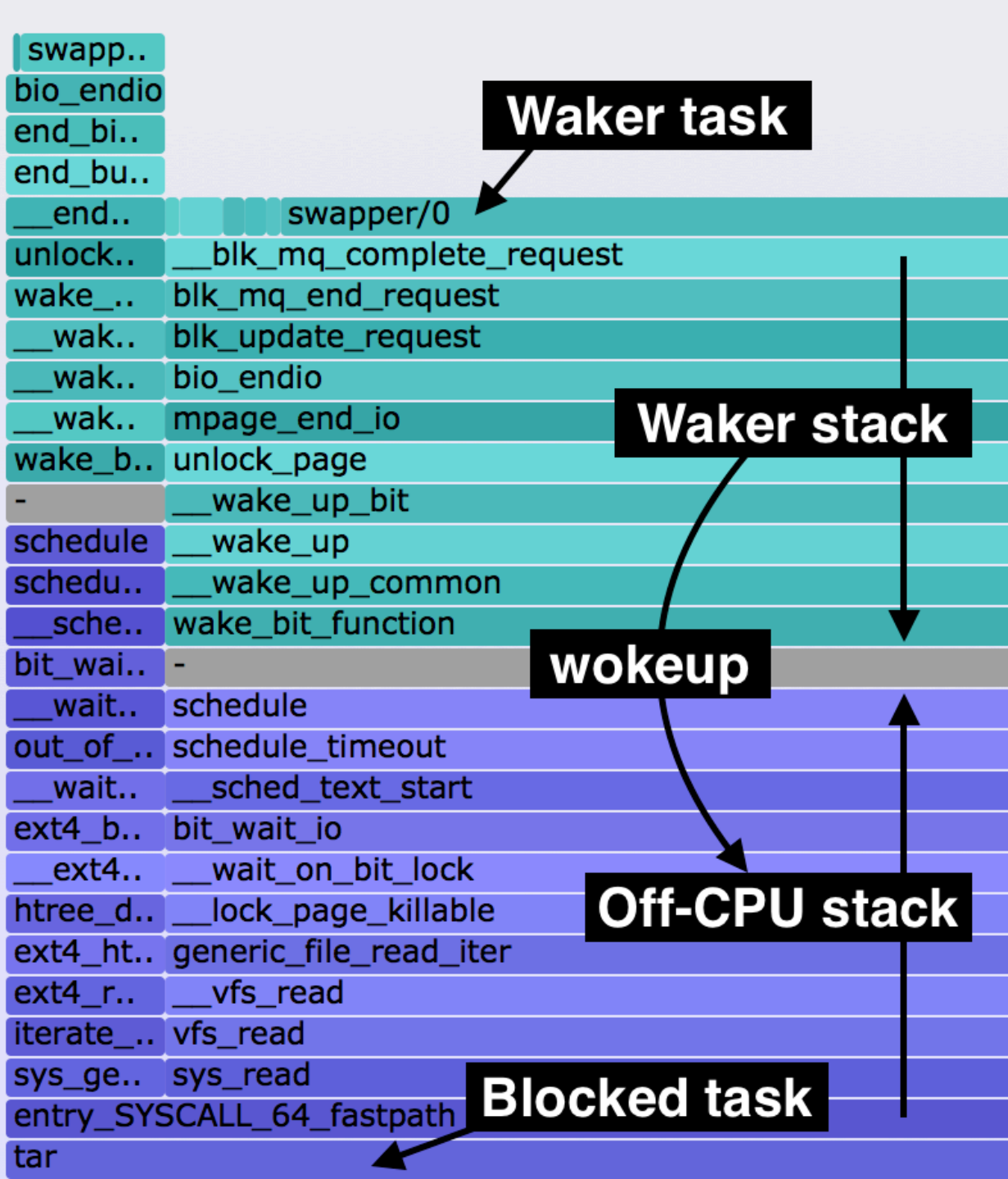
- Can now be BPF optimized



http://www.brendangregg.com/flamegraphs.html

Off-Wake Flame Graphs

- Shows blocking stack with waker stack
  - Better understand why blocked
  - Merged in-kernel using BPF
  - Include multiple waker stacks == chain graphs
- We couldn't do this before



Overview for tool developers

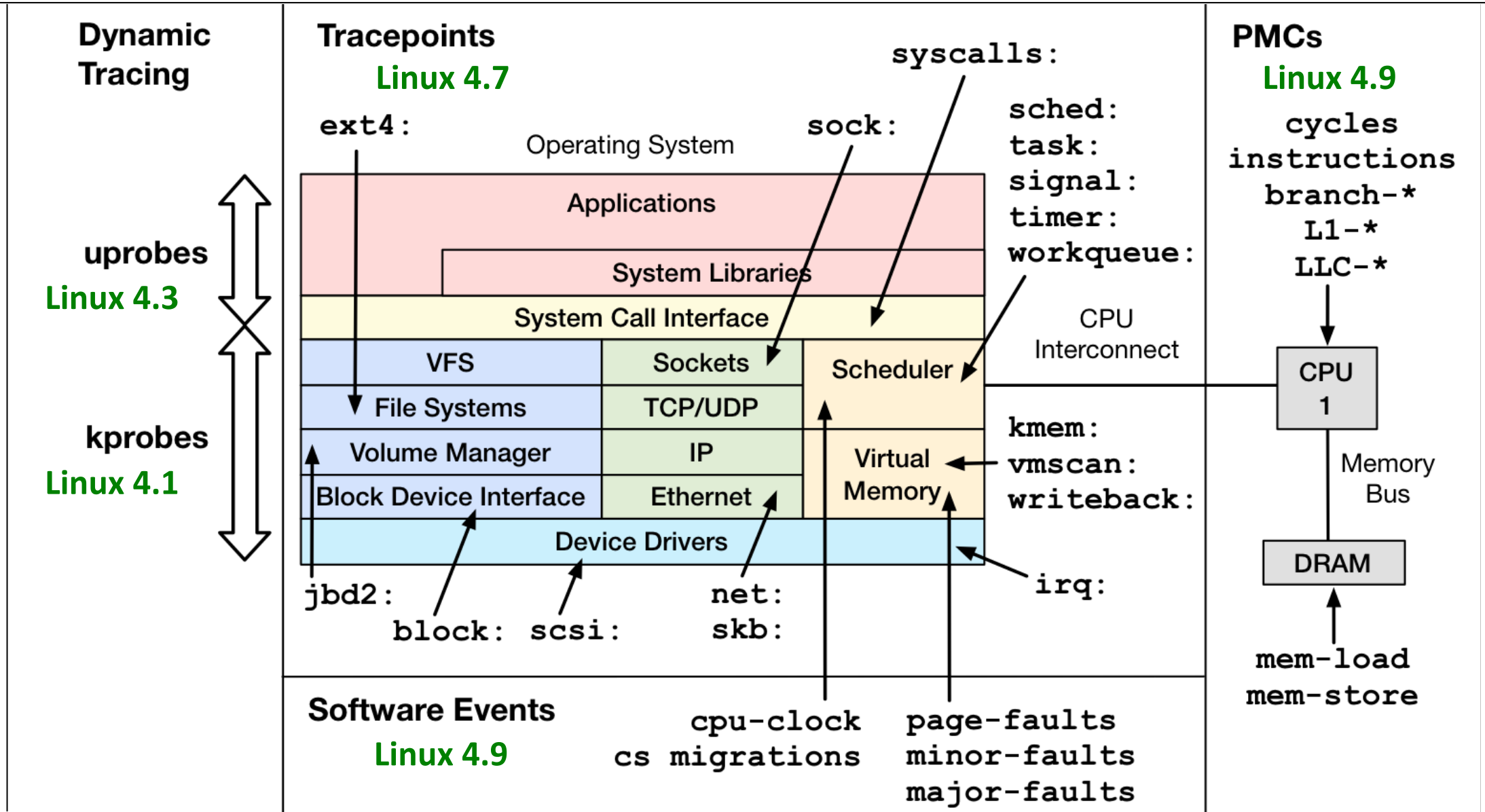
HOW TO PROGRAM BCC/BPF

Linux Event Sources

BPF output
Linux 4.4

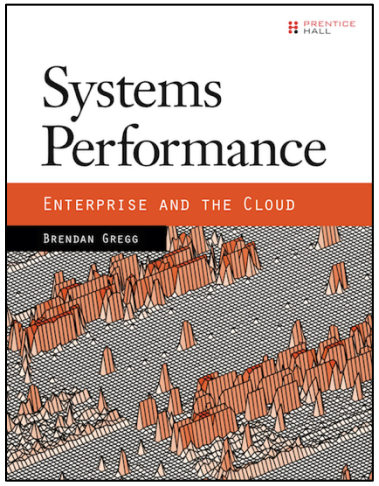
BPF stacks
Linux 4.6

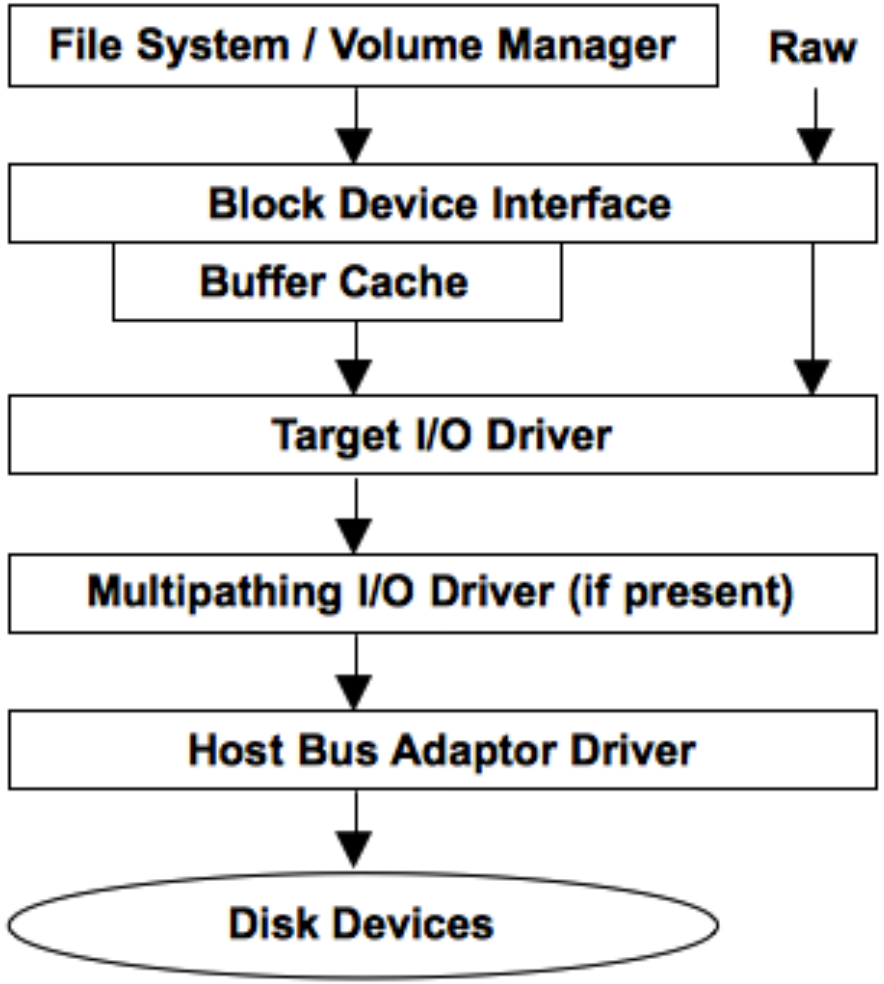
(version feature arrived)



Methodology

- Find/draw a functional diagram
  - Eg, storage I/O subsystem:
- Apply performance methods
  http://www.brendangregg.com/methodology.html
  1. Workload Characterization
  2. Latency Analysis
  3. USE Method
- Start with the Q's, then find the A's





bitehist.py Output

```
# ./bitehist.py
Tracing... Hit Ctrl-C to end.
^C
     kbytes              : count     distribution
       0 -> 1            : 3        |                                        |
       2 -> 3            : 0        |                                        |
       4 -> 7            : 211      |**********                              |
       8 -> 15           : 0        |                                        |
      16 -> 31           : 0        |                                        |
      32 -> 63           : 0        |                                        |
      64 -> 127          : 1        |                                        |
     128 -> 255          : 800      |****************************************|
```

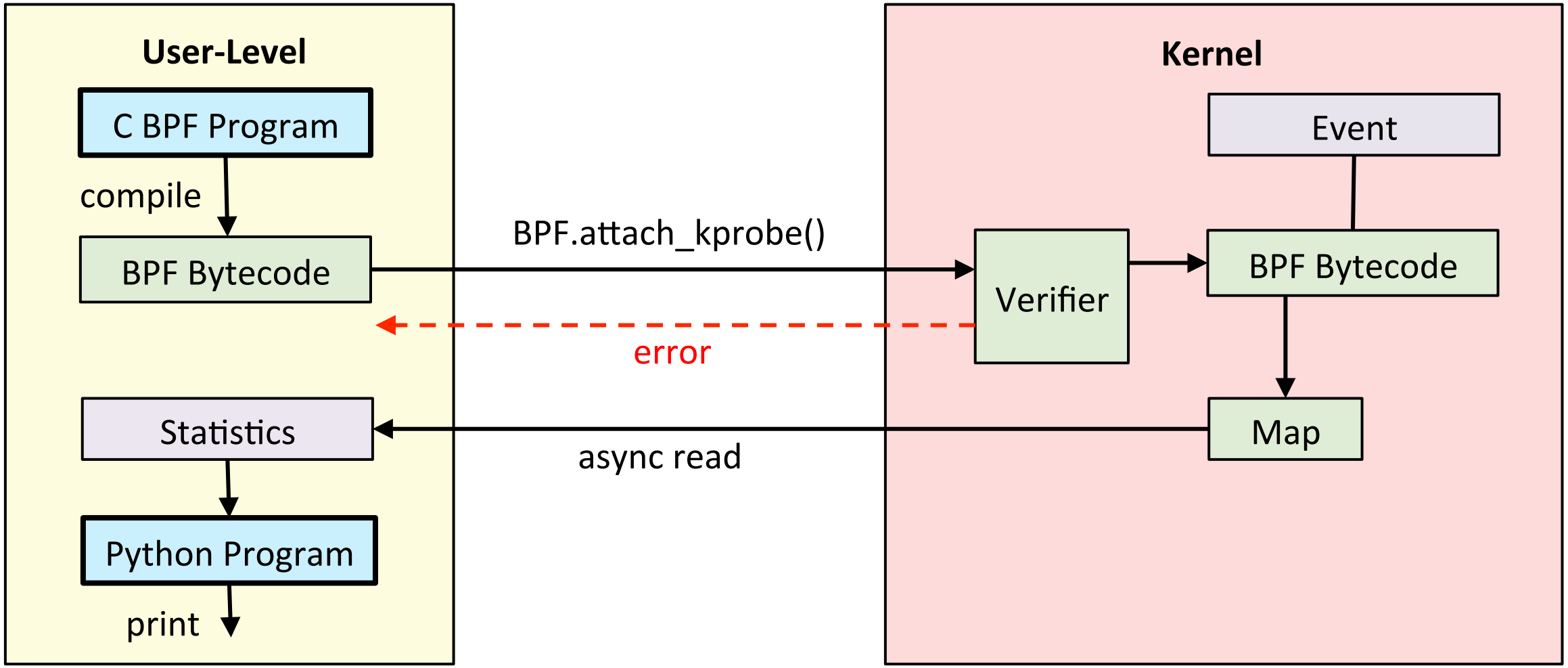
bitehist.py Code

```
# load BPF program
b = BPF(text="""
#include <uapi/linux/ptrace.h>
#include <linux/blkdev.h>
BPF_HISTOGRAM(dist);
int kprobe__blk_account_io_completion(struct pt_regs *ctx,
    struct request *req)
{
    dist.increment(bpf_log2l(req->__data_len / 1024));
    return 0;
}
""")
```

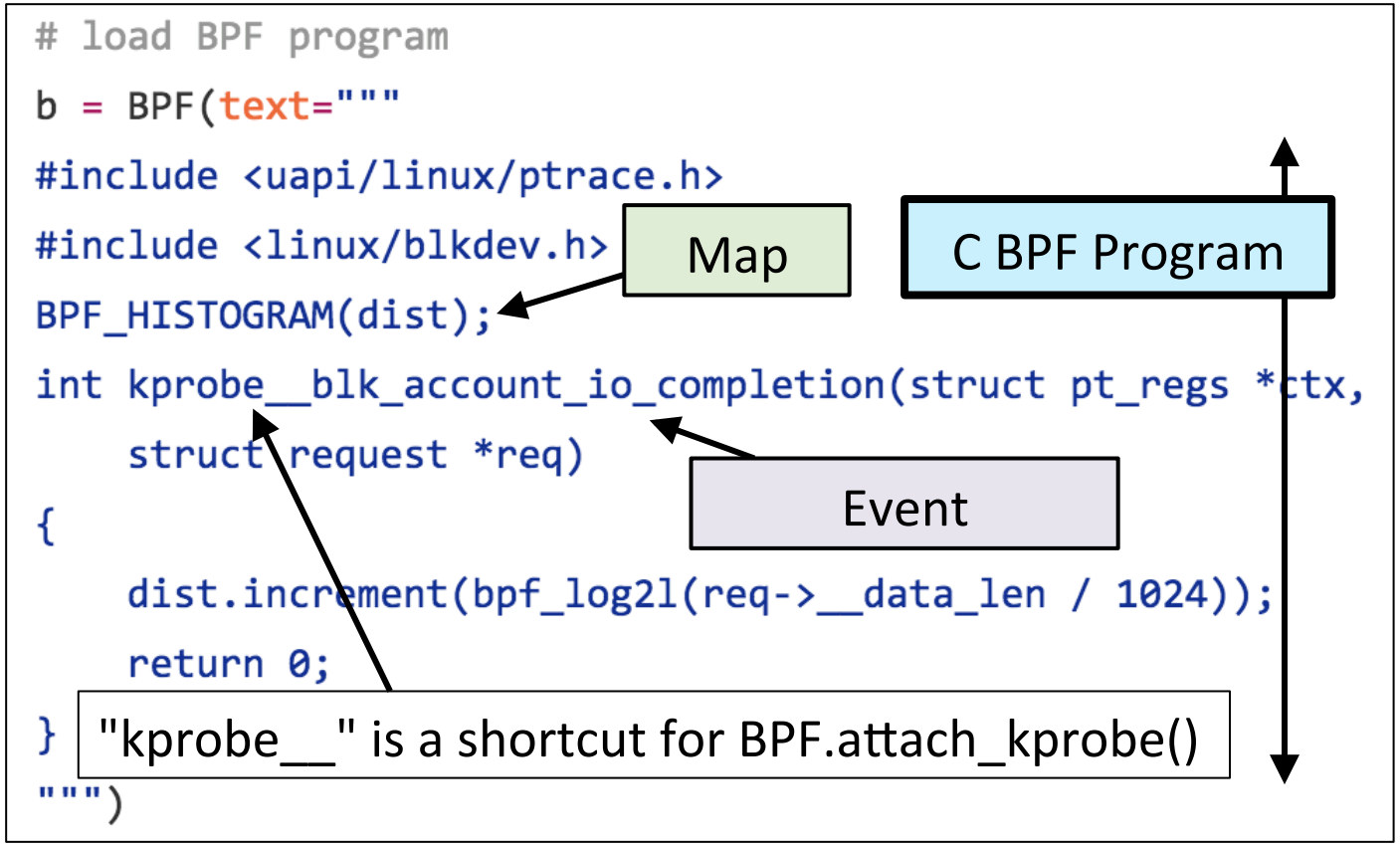
```
# header
print("Tracing... Hit Ctrl-C to end.")


# trace until Ctrl-C
try:
    sleep(99999999)
except KeyboardInterrupt:
    print


# output
b["dist"].print_log2_hist("kbytes")
```

bcc examples/tracing/bitehist.py

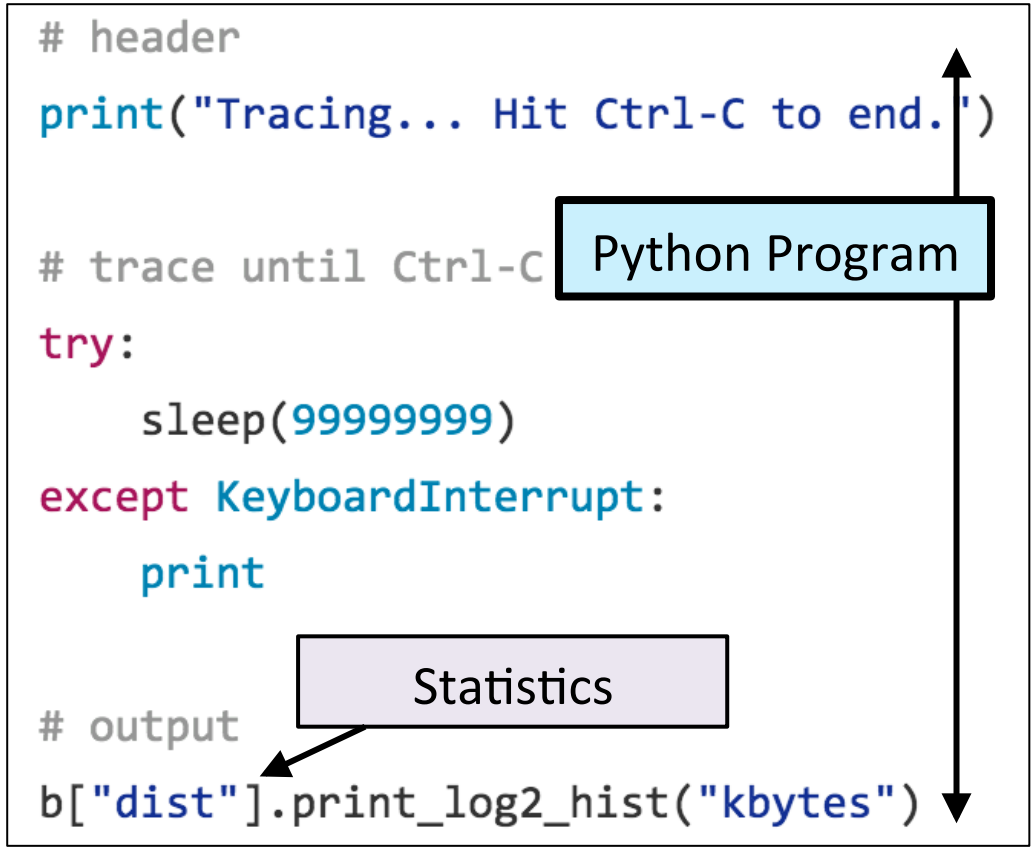
bytehist.py Internals



bytehist.py Annotated




```
# load BPF program
b = BPF(text="""
#include <uapi/linux/ptrace.h>
#include <linux/blkdev.h>
BPF_HISTOGRAM(dist);
int kprobe__blk_account_io_completion(struct pt_regs *ctx,
    struct request *req)
{
    dist.increment(bpf_log2l(req->__data_len / 1024));
    return 0;
}
""")
```




```
# header
print("Tracing... Hit Ctrl-C to end.")

# trace until Ctrl-C
try:
    sleep(99999999)
except KeyboardInterrupt:
    print

# output
b["dist"].print_log2_hist("kbytes")
```

bcc examples/tracing/bitehist.py

Current Complications

- Initialize all variables
- Extra bpf_probe_read()s
- BPF_PERF_OUTPUT()
- Verifier errors

```
struct sock *skp = NULL;
bpf_probe_read(&skp, sizeof(skp), &sk);

// pull in details
u16 family = 0, lport = 0, dport = 0;
char state = 0;
bpf_probe_read(&family, sizeof(family), &skp->__sk_common
bpf_probe_read(&lport, sizeof(lport), &skp->__sk_common.s
bpf_probe_read(&dport, sizeof(dport), &skp->__sk_common.s
bpf_probe_read(&state, sizeof(state), (void *)&skp->__sk_

if (family == AF_INET) {
    struct ipv4_data_t data4 = {.pid = pid, .ip = 4, .typ
    bpf_probe_read(&data4.saddr, sizeof(u32),
        &skp->__sk_common.skc_rcv_saddr);
    bpf_probe_read(&data4.daddr, sizeof(u32),
        &skp->__sk_common.skc_daddr);
    // lport is host order
    data4.lport = lport;
    data4.dport = ntohs(dport);
    data4.state = state;
    ipv4_events.perf_submit(ctx, &data4, sizeof(data4));
```

bcc Tutorials

1. https://github.com/iovisor/bcc/blob/master/INSTALL.md
2. .../docs/tutorial.md
3. .../docs/tutorial_bcc_python_developer.md
4. .../docs/reference_guide.md
5. .../CONTRIBUTING-SCRIPTS.md

bcc lua

```
local program = string.gsub([[
#include <uapi/linux/ptrace.h>
int printarg(struct pt_regs *ctx) {
  if (!PT_REGS_PARM1(ctx))
    return 0;
  u32 pid = bpf_get_current_pid_tgid();
  if (pid != PID)
    return 0;
  char str[128] = {};
  bpf_probe_read(&str, sizeof(str), (void *)PT_REGS_PARM1(ctx));
  bpf_trace_printk("strlen(\"%s\")\n", &str);
  return 0;
};
]], "PID", arg[1])
```

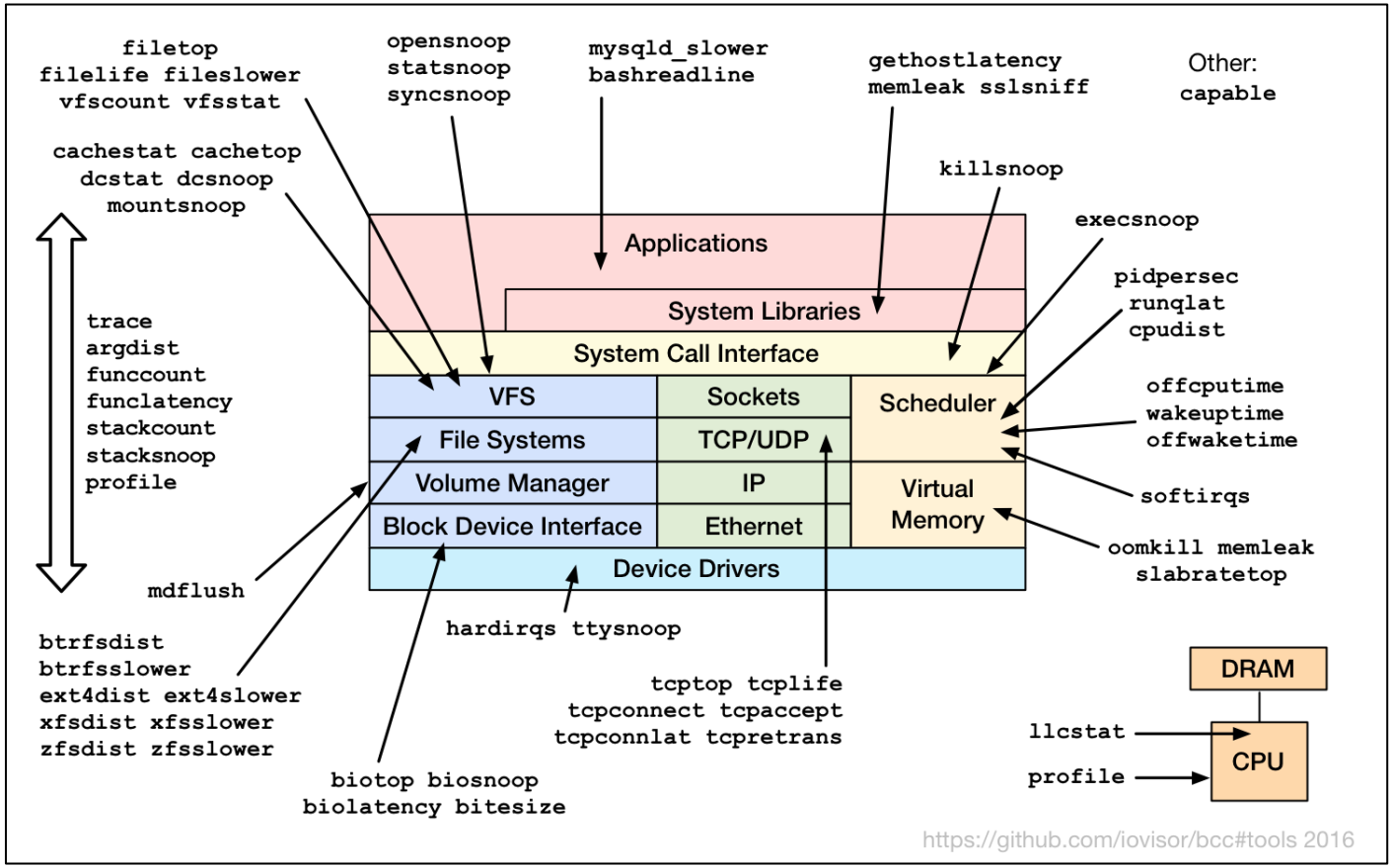
```
return function(BPF)
  local b = BPF:new{text=program, debug=0}
  b:attach_uprobe{name="c", sym="strlen", fn_name="printarg"}

  local pipe = b:pipe()
  while true do
    local task, pid, cpu, flags, ts, msg = pipe:trace_fields()
    print("%-18.9f %-16s %-6d %s" % {ts, task, pid, msg})
  end
end
```

bcc examples/lua/strlen_count.lua

Summary

BPF Tracing in Linux

- 3.19: sockets
- 3.19: maps
- 4.1: kprobes
- 4.3: uprobes
- 4.4: BPF output
- 4.6: stacks
- 4.7: tracepoints
- 4.9: profiling
- 4.9: PMCs



Future Work

- More tooling
- Bug fixes
- Better errors
- Visualizations
- GUIs
- High-level language

https://github.com/iovisor/bcc#tools

Links & References

- iovisor bcc:
  - https://github.com/iovisor/bcc https://github.com/iovisor/bcc/tree/master/docs
  - http://www.brendangregg.com/blog/ (search for "bcc")
  - http://blogs.microsoft.co.il/sasha/2016/02/14/two-new-ebpf-tools-memleak-and-argdist/
  - I'll change your view of Linux tracing: https://www.youtube.com/watch?v=GsMs3n8CB6g
  - On designing tracing tools: https://www.youtube.com/watch?v=uibLwoVKjec
- BPF:
  - https://www.kernel.org/doc/Documentation/networking/filter.txt
  - https://github.com/iovisor/bpf-docs
  - https://suchakra.wordpress.com/tag/bpf/
- Flame Graphs:
  - http://www.brendangregg.com/flamegraphs.html
  - http://www.brendangregg.com/blog/2016-01-20/ebpf-offcpu-flame-graph.html
  - http://www.brendangregg.com/blog/2016-02-01/linux-wakeup-offwake-profiling.html
- Dynamic Instrumentation:
  - http://ftp.cs.wisc.edu/par-distr-sys/papers/Hollingsworth94Dynamic.pdf
  - https://en.wikipedia.org/wiki/DTrace
  - DTrace: Dynamic Tracing in Oracle Solaris, Mac OS X and FreeBSD, Brendan Gregg, Jim Mauro; Prentice Hall 2011
- Netflix Tech Blog on Vector:
  - http://techblog.netflix.com/2015/04/introducing-vector-netflixs-on-host.html
- Linux Performance: http://www.brendangregg.com/linuxperf.html

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Thanks

- Questions?
- iovisor bcc: https://github.com/iovisor/bcc
- http://www.brendangregg.com
- http://slideshare.net/brendangregg
- bgregg@netflix.com
- @brendangregg

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