# Linux 4.x Tracing: Performance Analysis with bcc/BPF


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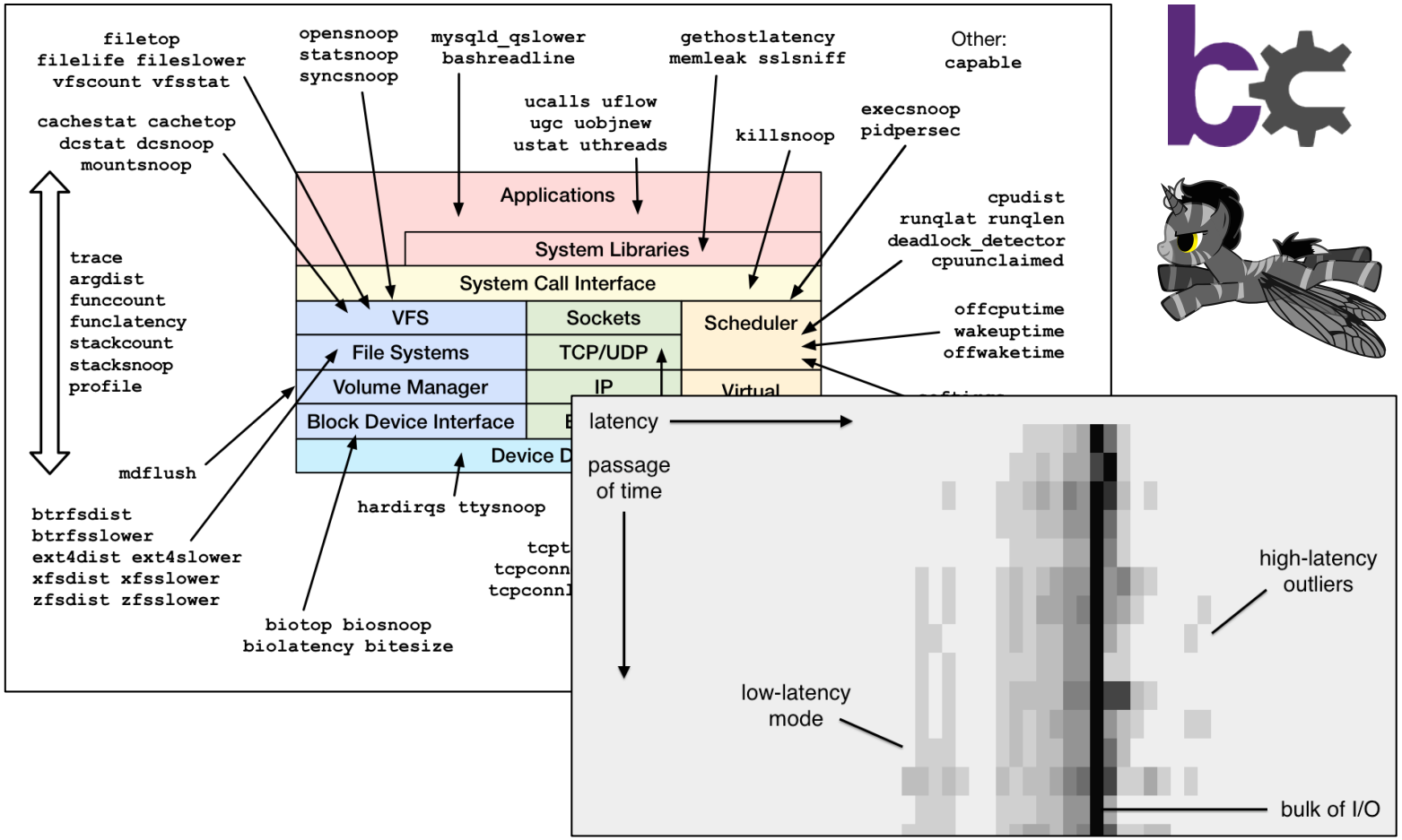
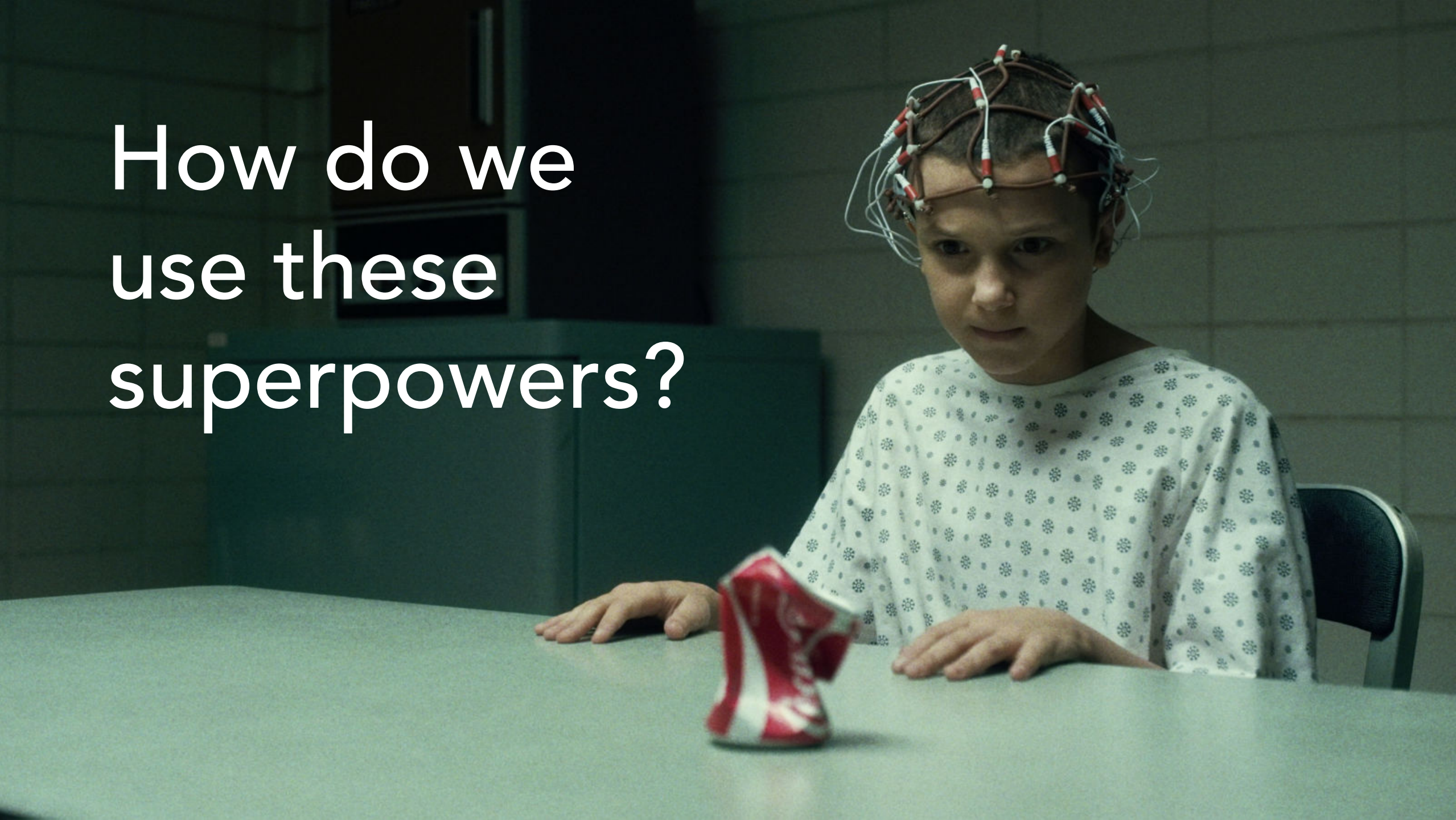
*Senior Performance Architect*

Mar 2017

NETFLIX



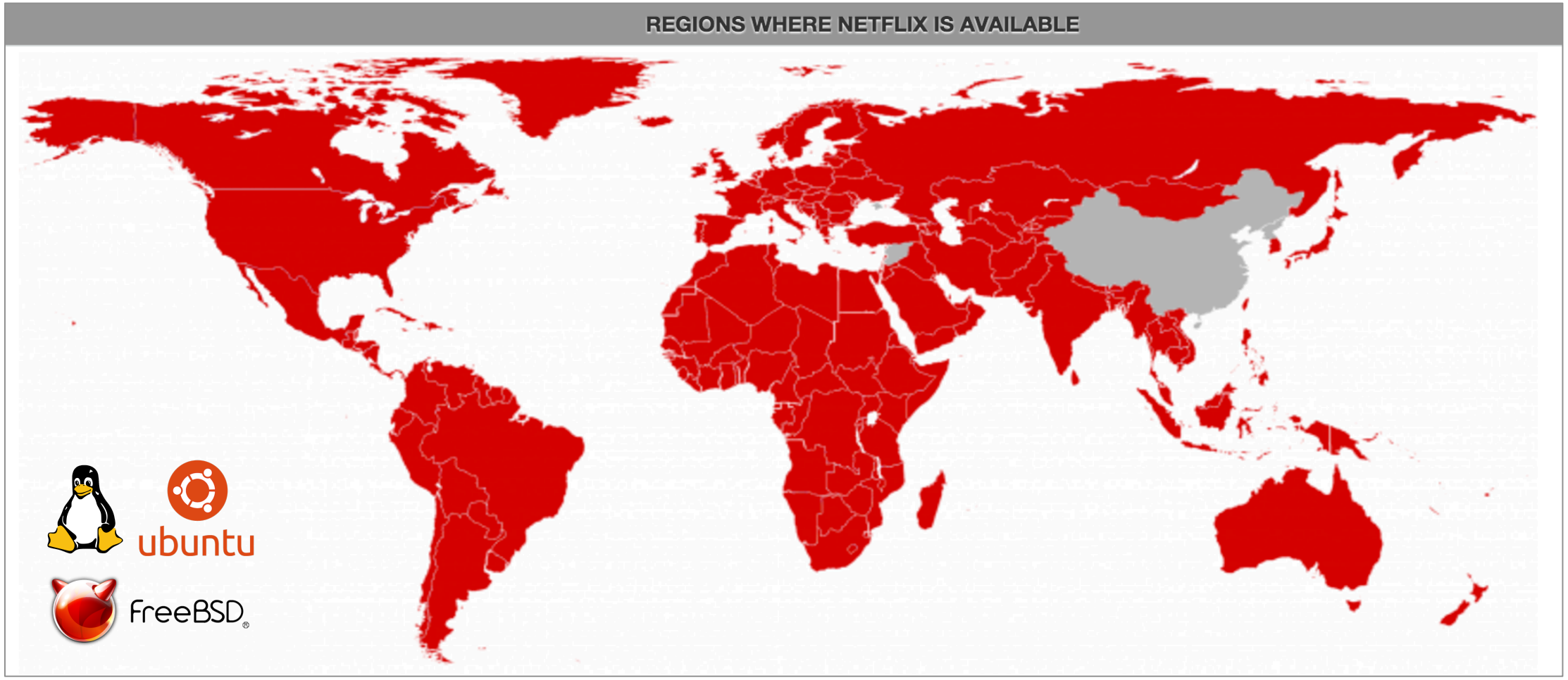
# Linux tracing
# in the last 3 years…


How do we
use these
superpowers?

# Take aways

1. Understanding the value of Linux tracing superpowers
2. Upgrade to Linux 4.4+ (4.9 is better)
3. Ask for eBPF support in your perf analysis/monitoring tools

# 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)
(013) ldh      [x + 14]
[...]
```

Optimizes packet filter performance

**2 x 32-bit registers & scratch memory**

User-defined bytecode executed by an in-kernel sandboxed virtual machine

Steven McCanne and Van Jacobson, 1993

# Enhanced BPF

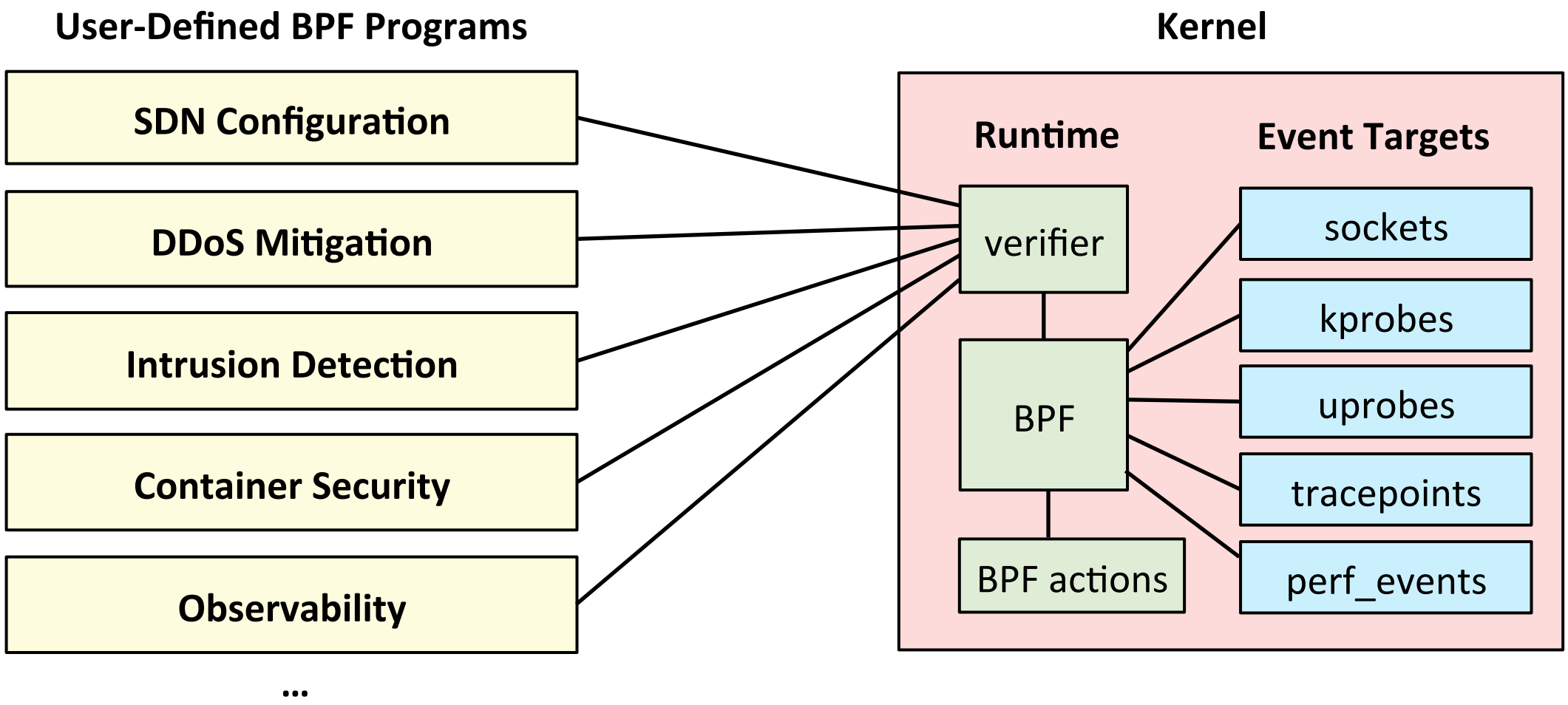
aka eBPF or just "BPF"

```
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(),
};
```

**10 x 64-bit registers**
**maps (hashes)**
**actions**

Alexei Starovoitov, 2014+

# Enhanced BPF Use Cases



# Enhanced BPF is in Linux

# Demo

# New Observability Tools

- Efficient, production safe, useful metrics:

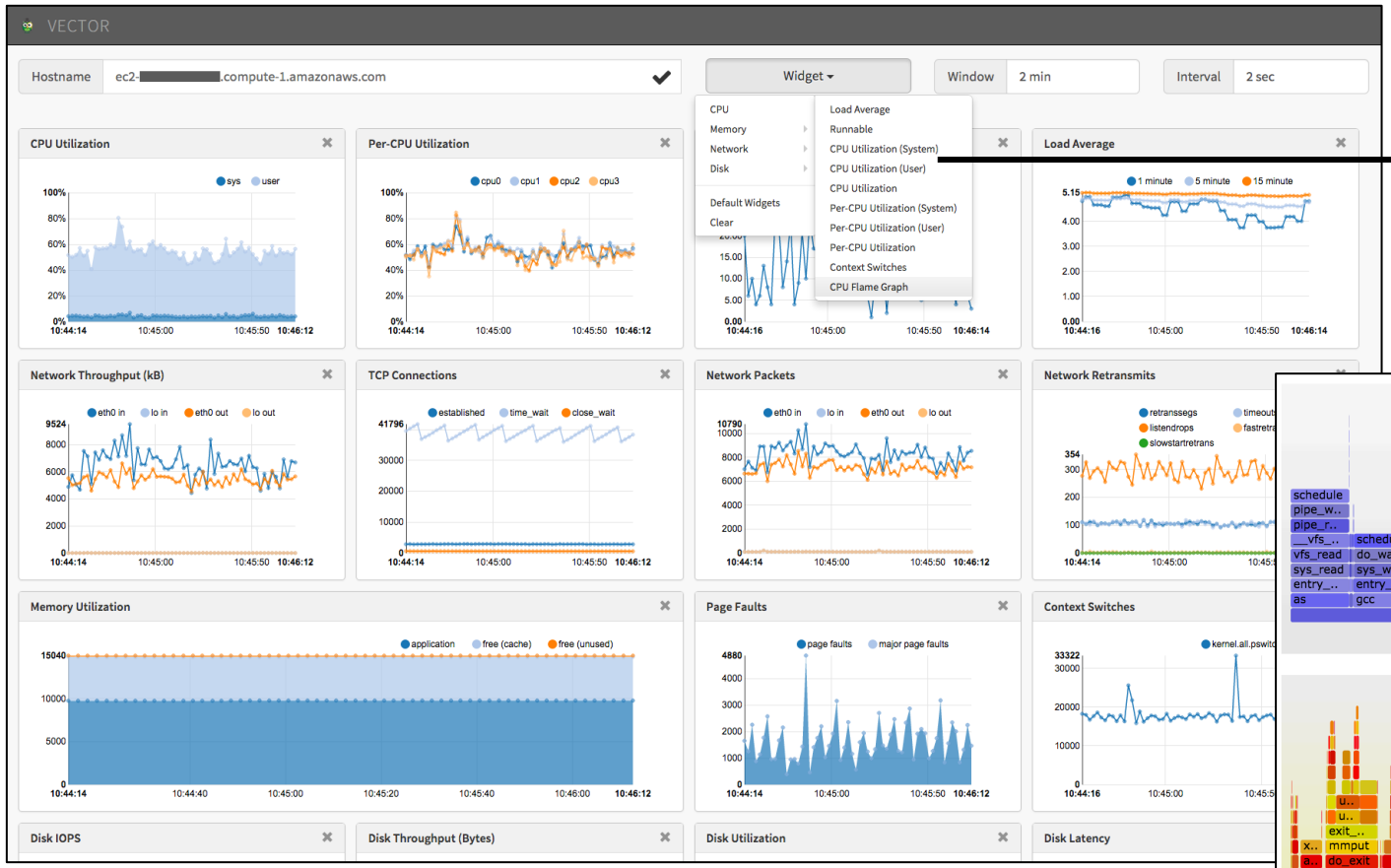
```
# biolatency -mT 1
Tracing block device I/O... Hit Ctrl-C to end.

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        |******                                  |
[…]
```

These CLI tools may be useful even if you never use them, as examples of what to implement in GUIs

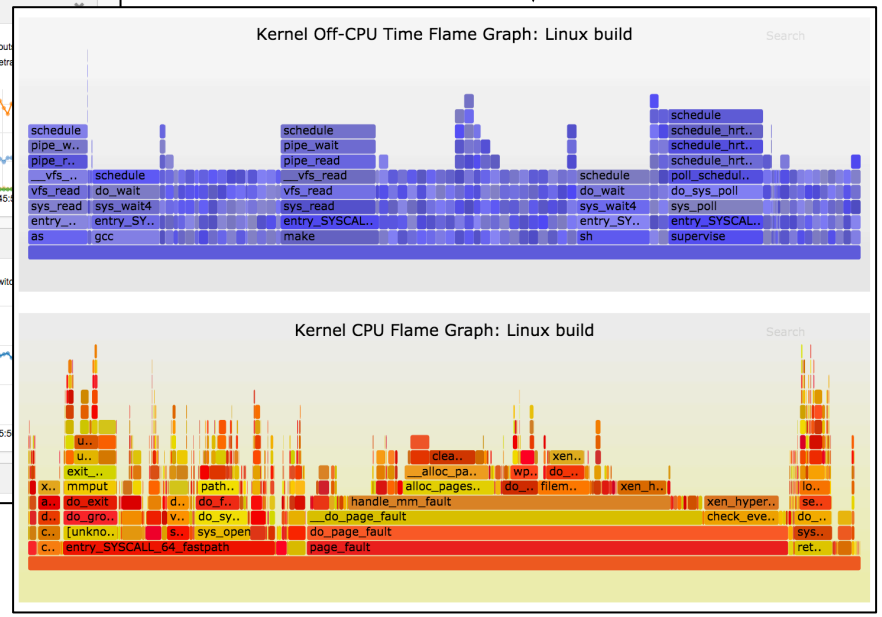
# New Visualizations and GUIs

Vector

Eg, Netflix self-service UI:




Flame Graphs
Tracing Reports
…




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

Introducing enhanced BPF

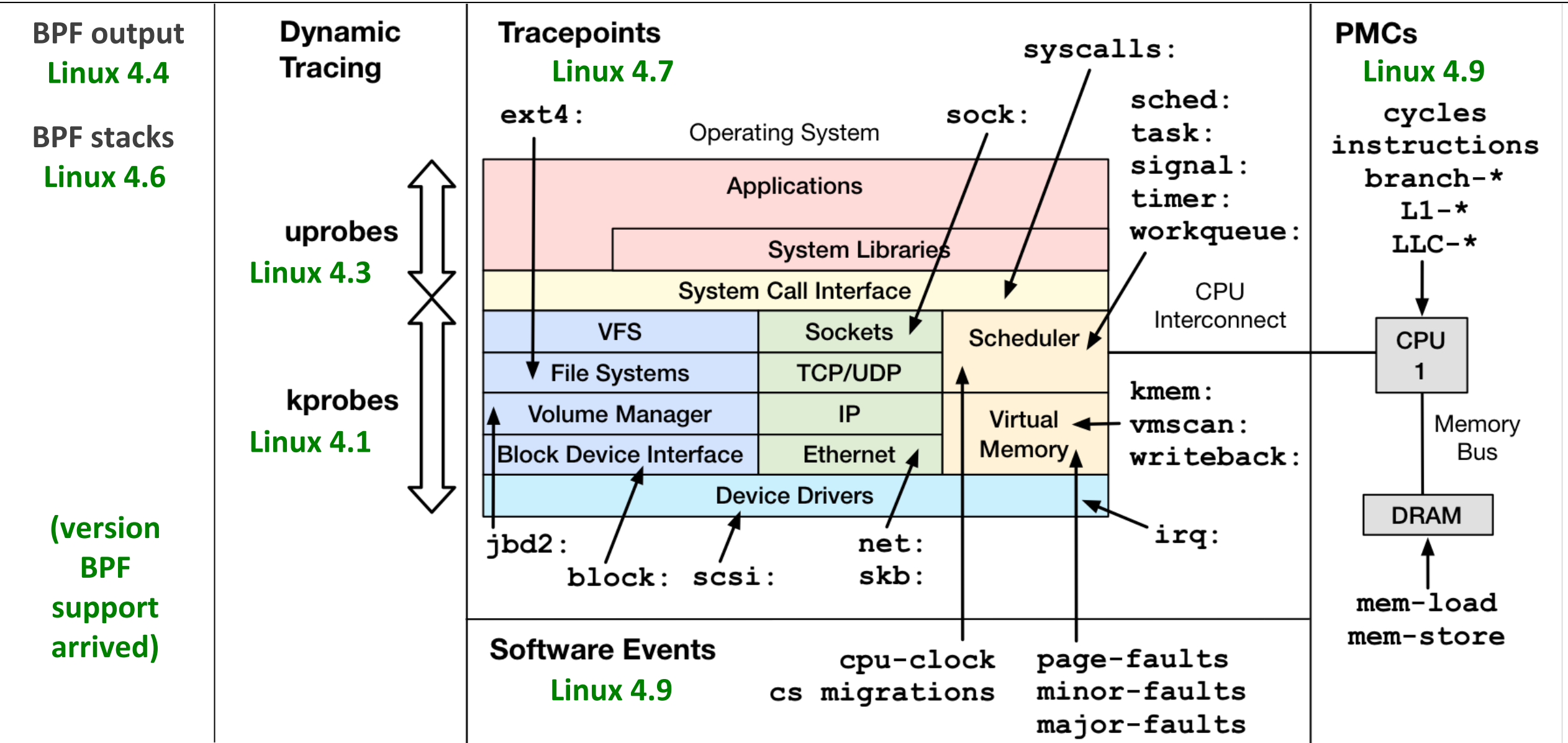
# BPF TRACING

# 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_events (2.6.31)
- 2009: tracepoints (2.6.32)
- 2010-2016: ftrace & perf_events enhancements
- 2012: uprobes (3.5)
- **2014-2017: enhanced BPF patches: supporting tracing events**
- 2016-2017: ftrace hist triggers

also: LTTng, ktap, sysdig, ...

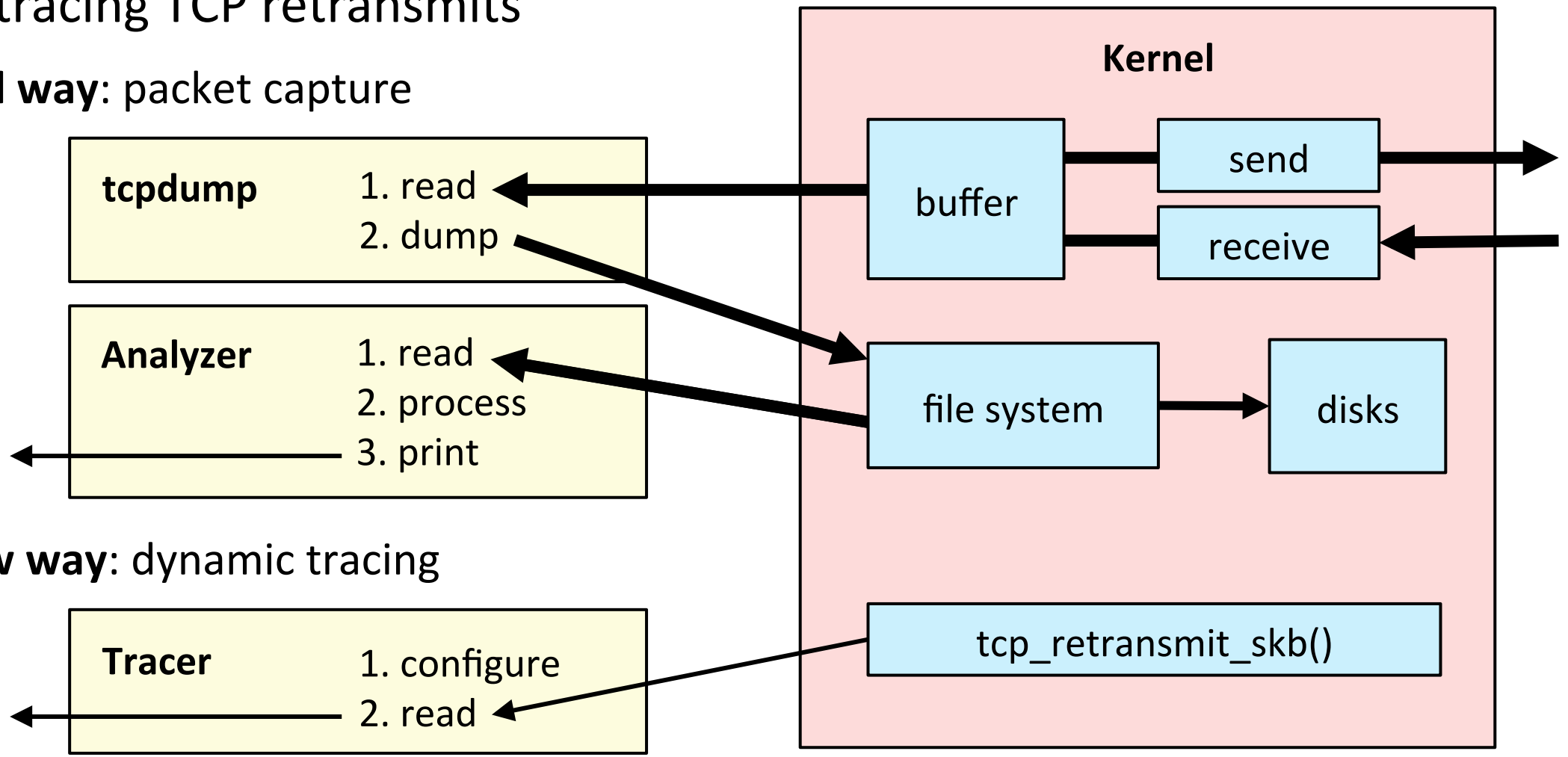
# Linux Events & BPF Support



# Event Tracing Efficiency

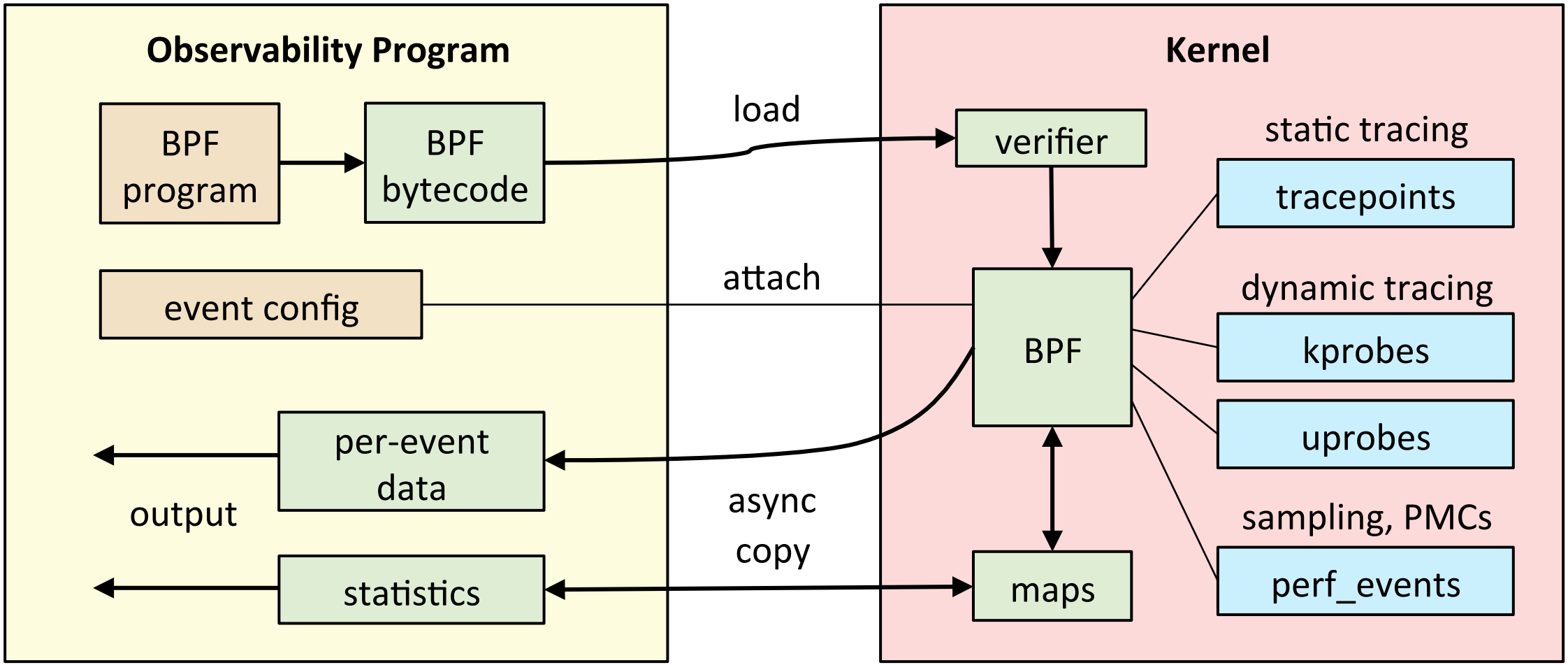
E.g., tracing TCP retransmits

**Old way**: packet capture




**New way**: dynamic tracing

# BPF Tracing Internals



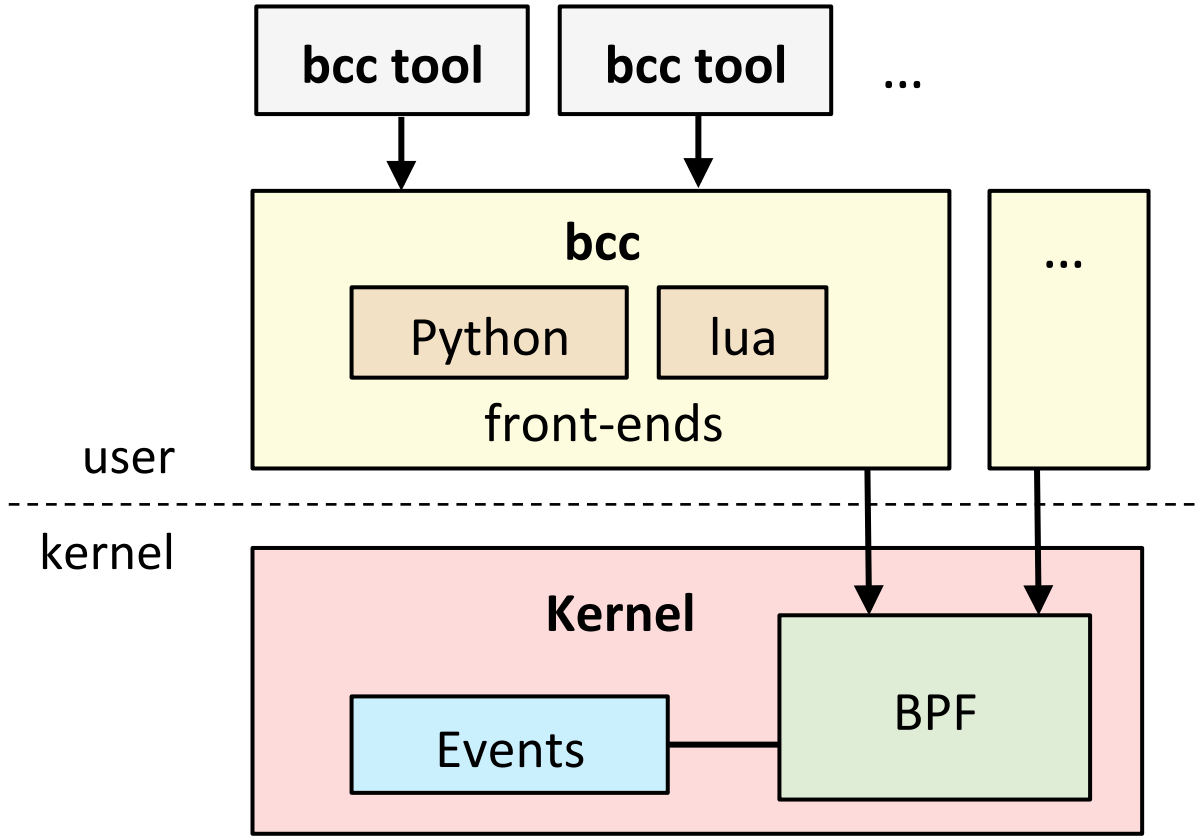
Introducing bcc

# BPF COMPILER COLLECTION

# bcc

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

Tracing layers:



# 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 (C & Python)

```
# 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

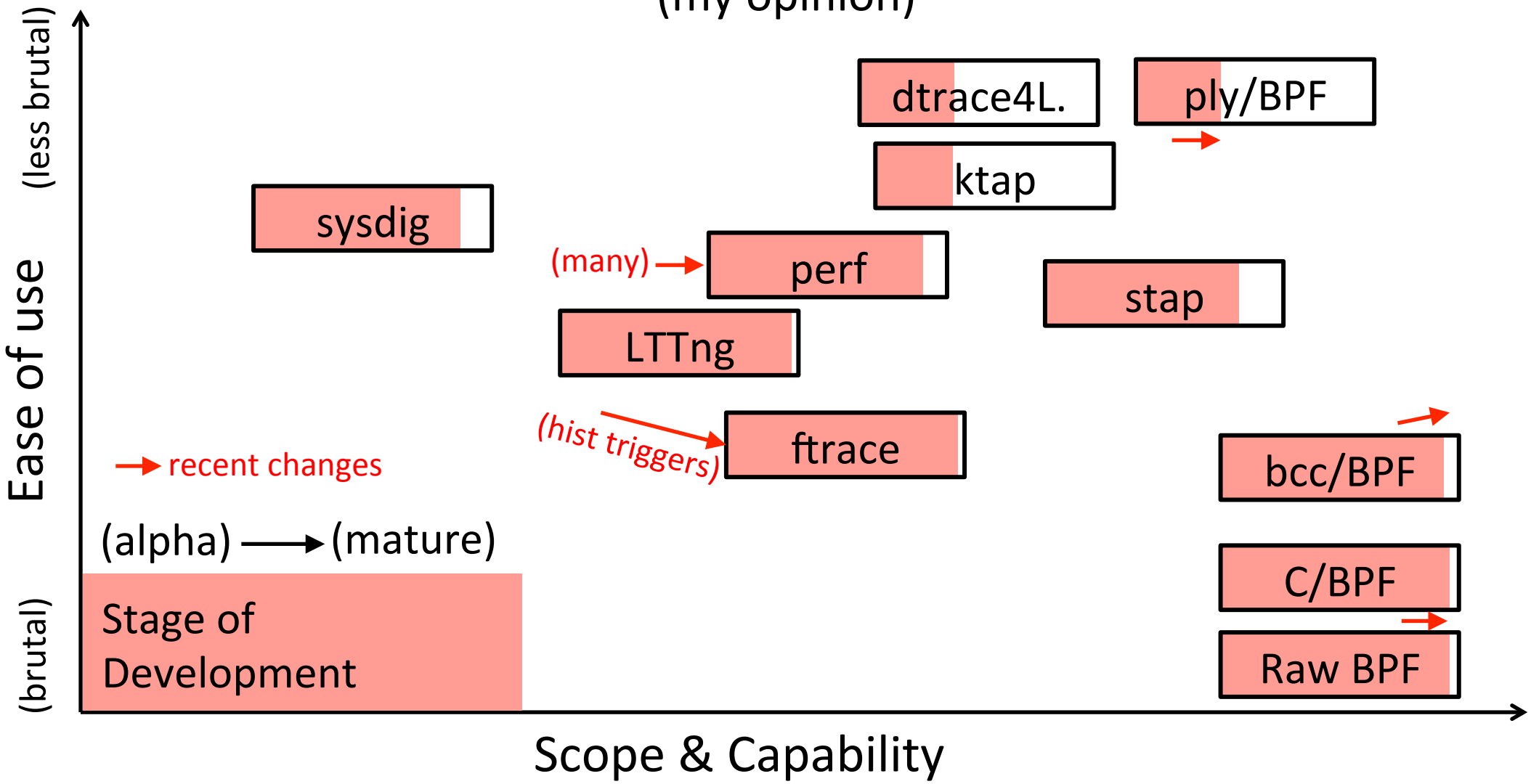
```
kretprobe:SyS_read
{
    @.quantize(retval());
}
```

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

**entire program**

# The Tracing Landscape, Mar 2017

(my opinion)



For end-users

# PERFORMANCE ANALYSIS WITH BCC/BPF

# Pre-BPF: Linux Perf Analysis in 60s

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

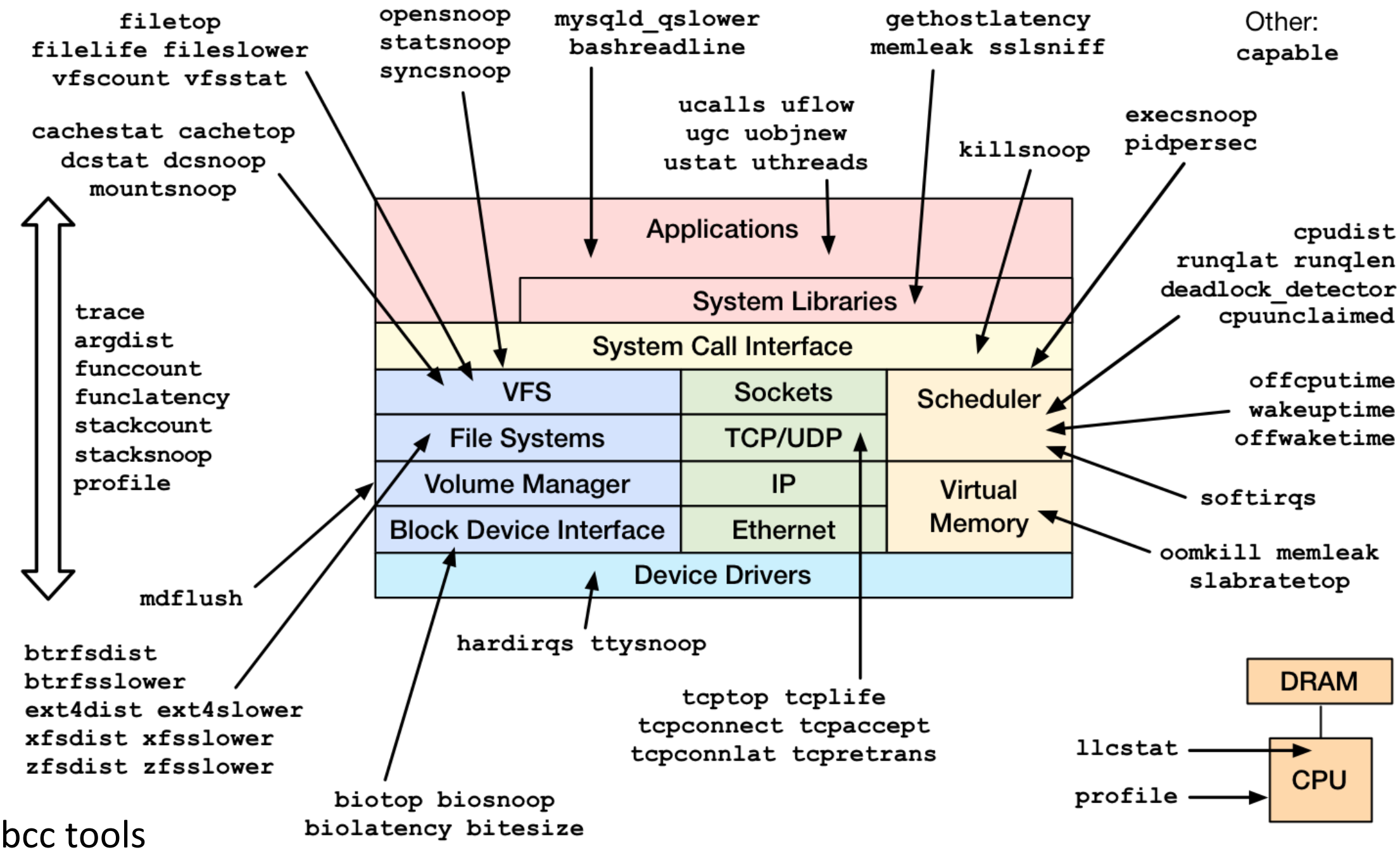

http://techblog.netflix.com/2015/11/linux-performance-analysis-in-60s.html

# bcc 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
```

  - Also available as an Ubuntu snap
  - Ubuntu 16.04 is good, 16.10 better: more tools work
- Installs many tools
  - In /usr/share/bcc/tools, and …/tools/old for older kernels

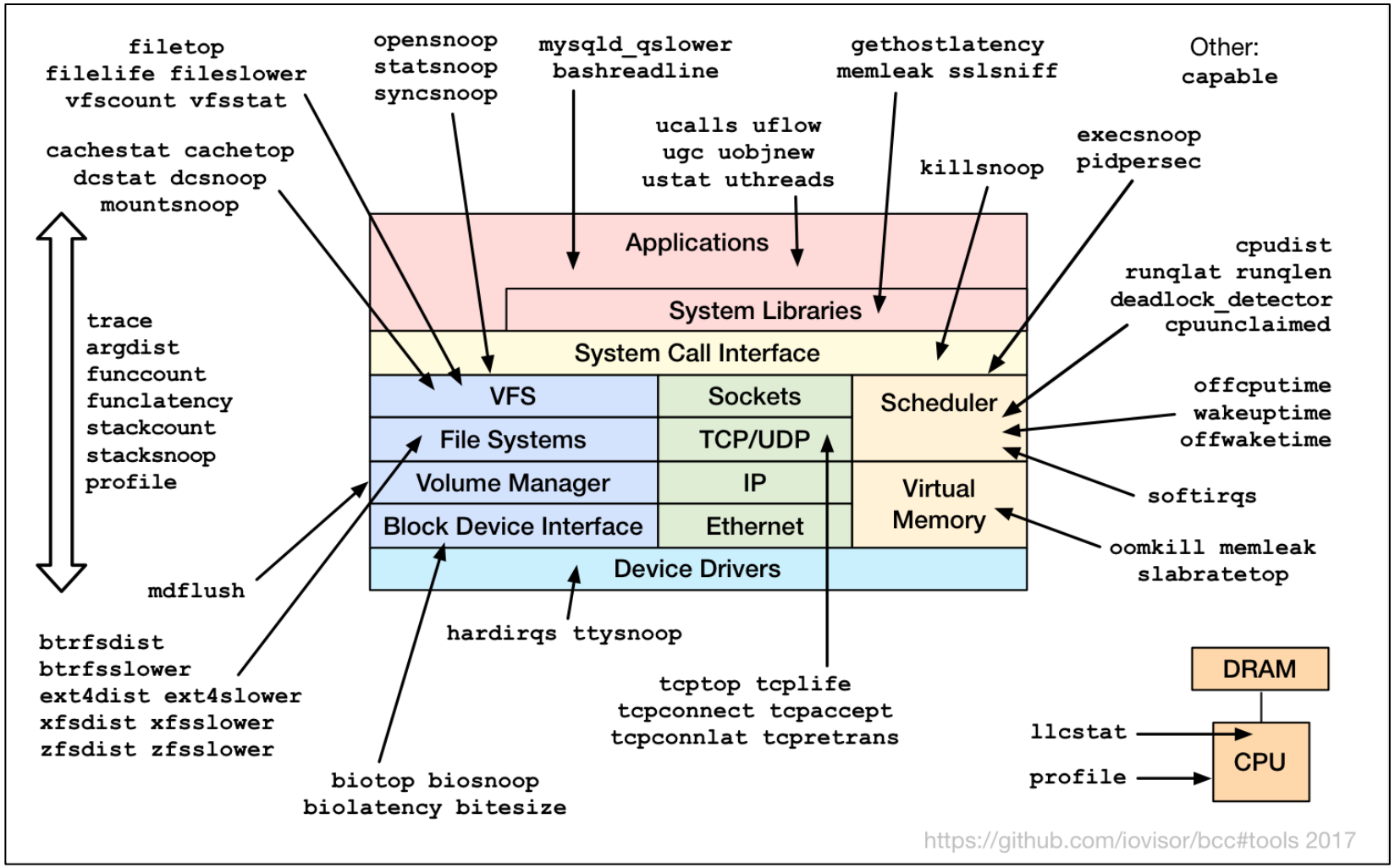



bcc tools

https://github.com/iovisor/bcc#tools 2017

# 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

- Trace new processes and debug short-lived process issues:

```
# 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 ...
groff            15902    0 /usr/bin/troff -mtty-char -mandoc -rLL=169n -rLT=16...
groff            15903    0 /usr/bin/grotty
[…]
```

Efficient: only traces exec()

# 2. opensnoop

- Find config, log, and data files, and inefficient file usage:

```
# 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               -1   2 /var/run/nologin
30668  sshd               -1   2 /etc/nologin
30668  sshd                4   0 /etc/login.defs
30668  sshd                4   0 /etc/passwd
[…]
```

Like "strace -feopen", but system-wide and low overhead

# 3. ext4slower

- Trace slow FS I/O, to better identify I/O issues and outliers:

```
# 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
[…]
```

More reliable and complete indicator than measuring disk I/O latency

Also: btrfsslower, xfsslower, zfsslower

# 4. biolatency

- Identify multimodal latency and outliers with a histogram:

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

The "count" column is summarized in-kernel

Average latency (iostat/sar) may not be representitive with multiple modes or outliers

# 5. biosnoop

- Dump disk I/O events for detailed analysis. tcpdump for disks:

```
# 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
[…]
```

Can import this into a spreadsheet and do a scatter plot of time vs latency, e.t.c.

# 6. cachestat

- Measure file system cache hit ratio statistics:

```
# 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
[…]
```

These stats should be added to /proc

# 7. tcpconnect

- Trace active ("outbound") TCP connections :

```
# 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
[…]
```

Efficient: dynamic tracing of TCP connect functions only; does *not* trace send/receive

# 8. tcpaccept

- Trace passive ("inbound") TCP connections :

```
# 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
[…]
```

Efficiently: no send/receive tracing

# 9. tcpretrans

- Trace TCP retransmits with kernel state (not on the wire):

```
# 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
[…]
```

Efficiently: no send/receive tracing

# 10. gethostlatency

- Trace DNS latency system-wide (it's always DNS):

```
# 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
[…]
```

Instruments getaddrinfo(), gethostbyname(), e.t.c.

# 11. runqlat

- Examine CPU scheduler run queue latency as a histogram:

```
# 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      |**                                      |

[…]
```

As efficient as possible: scheduler calls can become frequent

# 12. profile

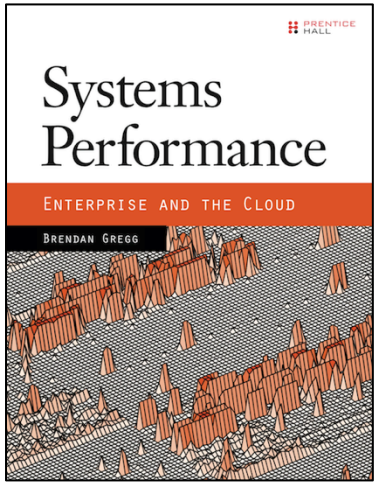
- An efficient profiler. Count unique stacks in kernel:

```
# profile
Sampling at 49 Hertz of all threads by user + kernel stack... 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
[…]
```

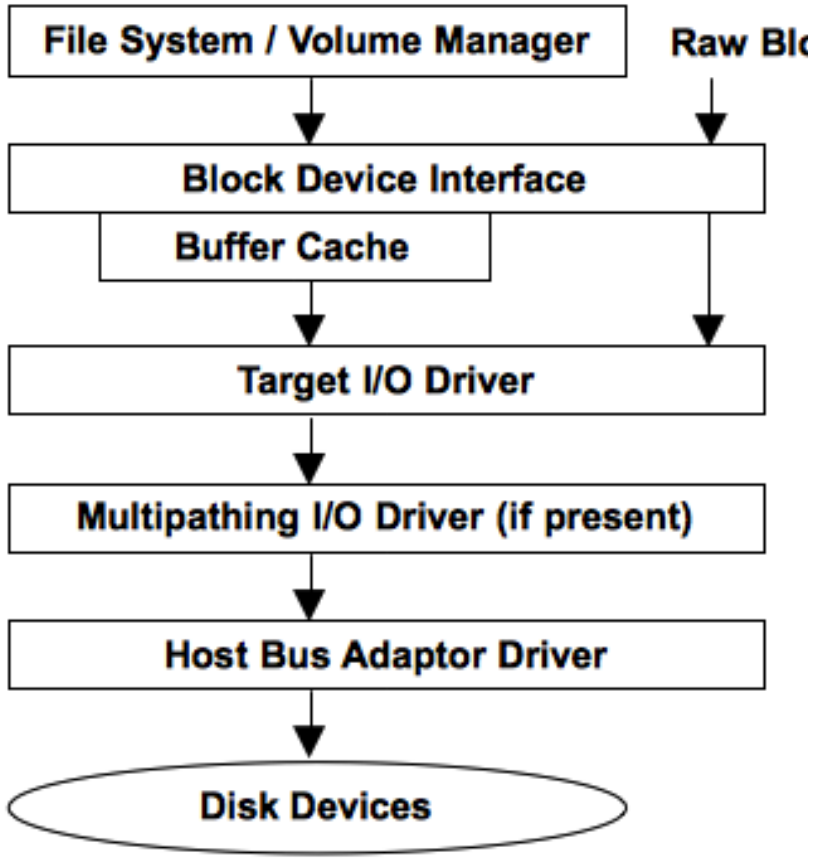
This stack was sampled 7 times

# Advanced Analysis

- Find/draw a functional diagram
- Apply performance methods
  http://www.brendangregg.com/methodology.html
  1. Workload Characterization
  2. Latency Analysis
  3. USE Method
  4. Performance Mantras
- Start with the Q's,
  then find the A's
- Use multi-tools:
  - funccount, trace, argdist, stackcount




e.g., storage I/O subsystem:



# Performance Mantras

1. Don't do it → eliminate unnecessary work
2. Do it, but don't do it again
3. Do it less
4. Do it later
5. Do it when they're not looking
6. Do it concurrently
7. Do it cheaper

from Craig Hanson and Pat Crain, and the performance engineering community

# trace

```
# 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
^C
```

trace custom events

```
# trace -h
[...]
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 't:block:block_rq_complete "sectors=%d", args->nr_sector'
       Trace the block_rq_complete kernel tracepoint and print # of tx sectors
[...]
```

trace -h
lists example
one-liners

by Sasha Goldshtein

# 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        |                                        |
```

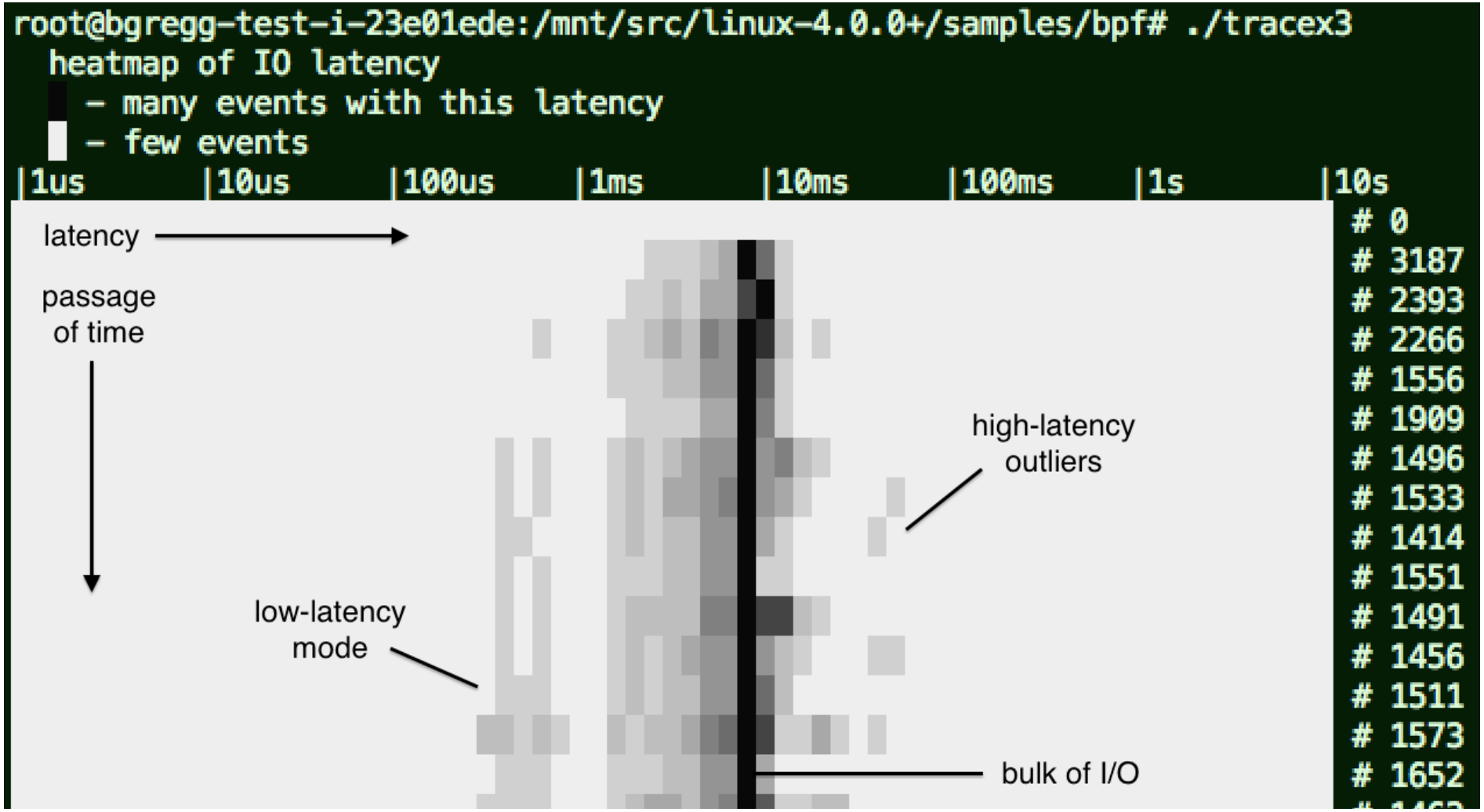
function argument distributions

by Sasha Goldshtein

Coming to a GUI near you

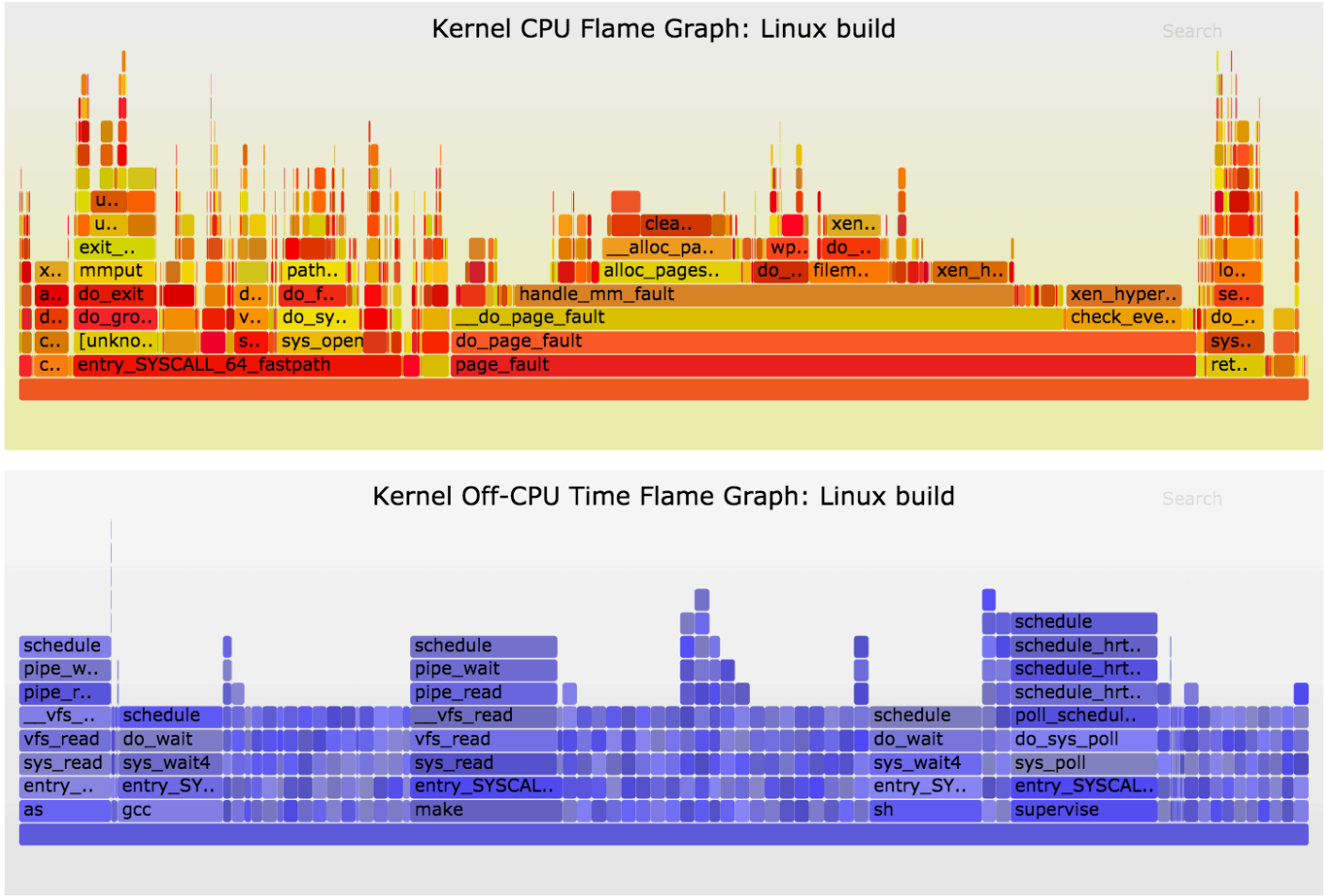
# BCC/BPF VISUALIZATIONS

# Latency Heatmaps



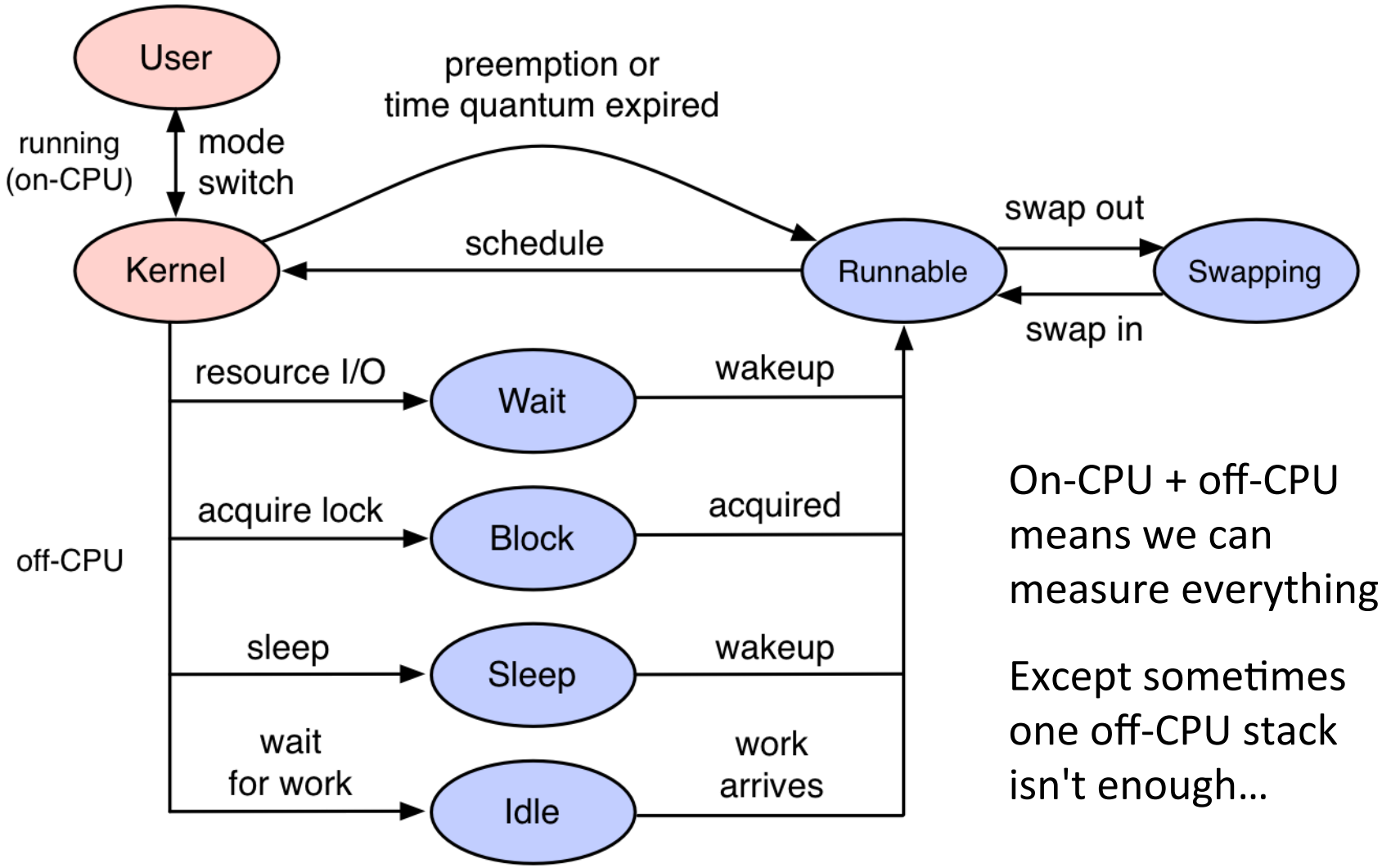
# CPU + Off-CPU Flame Graphs

- Can now be BPF optimized




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

# Conquer Performance

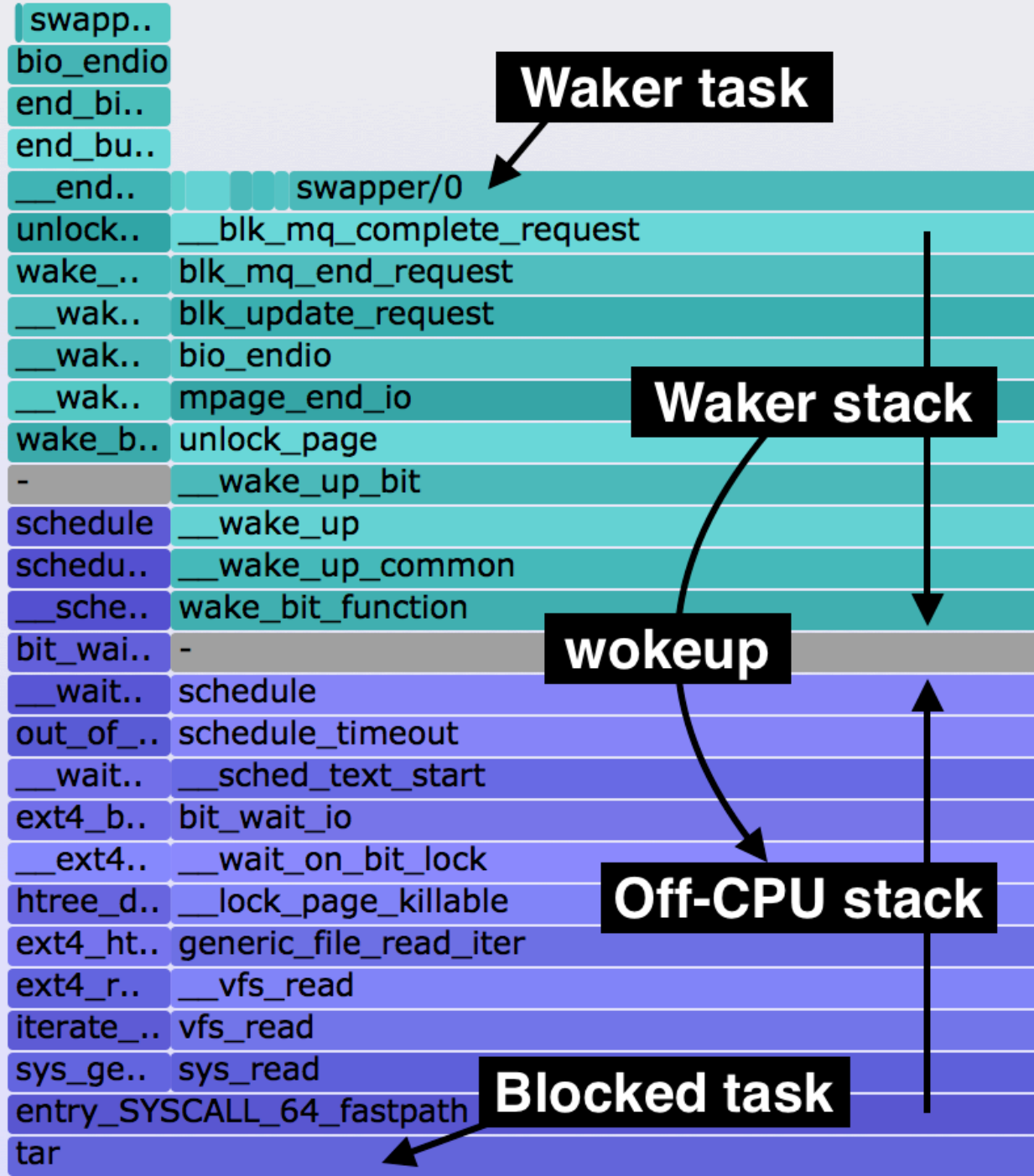



On-CPU + off-CPU means we can measure everything

Except sometimes one off-CPU stack isn't enough…

# 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

# 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

# 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       |****************************************|
```

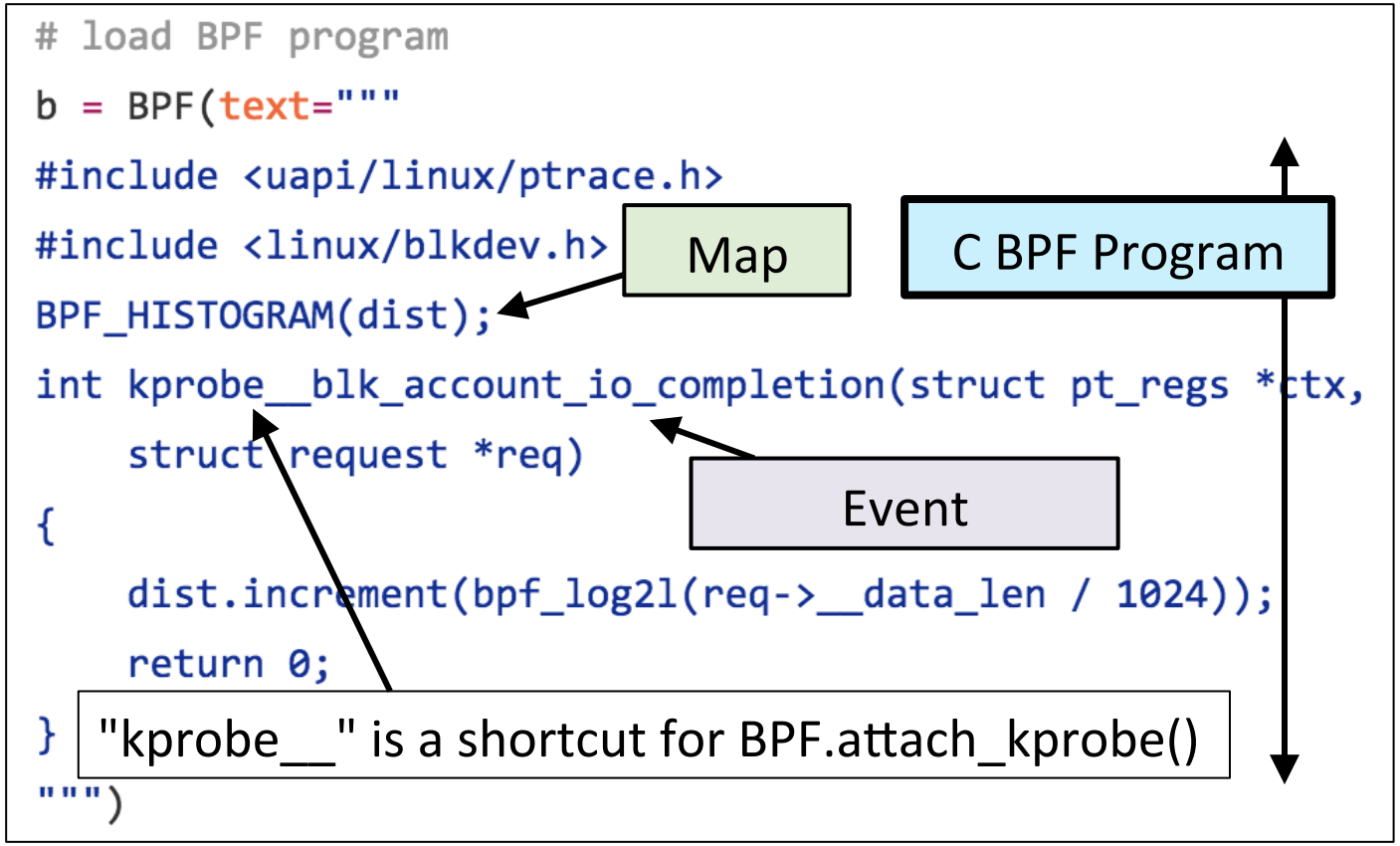
# bitehist.py Code

```
# 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;
}
""")
```

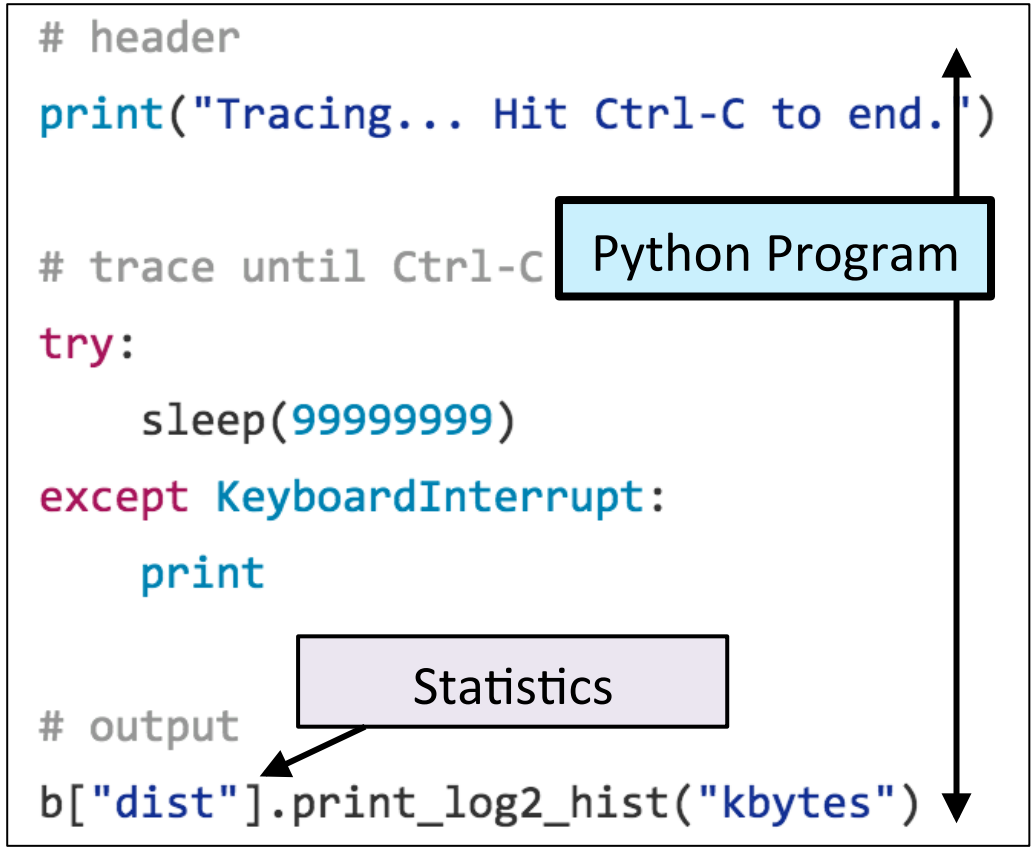
```
# header
print("Tracing... Hit Ctrl-C to end.")


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


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

bcc examples/tracing/bitehist.py

# bytehist.py 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));
```

Bonus Round

# PLY

# File opens

```
# ply -c 'kprobe:do_sys_open { printf("opened: %s\n", mem(arg(1), "128s")); }'
1 probe active
opened: /sys/kernel/debug/tracing/events/enable
opened: /etc/ld.so.cache
opened: /lib/x86_64-linux-gnu/libselinux.so.1
opened: /lib/x86_64-linux-gnu/libc.so.6
opened: /lib/x86_64-linux-gnu/libpcre.so.3
opened: /lib/x86_64-linux-gnu/libdl.so.2
opened: /lib/x86_64-linux-gnu/libpthread.so.0
opened: /proc/filesystems
opened: /usr/lib/locale/locale-archive
opened: .
[...]
```

# Count vfs calls

```
# ply -c 'kprobe:vfs_* { @[func()].count(); }'
WRN kprobe_attach_pattern: 'vfs_caches_init_early' will not be probed
WRN kprobe_attach_pattern: 'vfs_caches_init' will not be probed
49 probes active
^Cde-activating probes

@:
vfs_fstat                      33
vfs_getattr                    34
vfs_getattr_nosec              35
vfs_open                       49
vfs_read                       66
vfs_write                      68
[...]
```

# Read return size

```
# ply -c 'kretprobe:SyS_read { @ret.quantize(retval()); }'
1 probe active
^Cde-activating probes

@ret:
```

# Read return size (ASCII)

```
# ply -A -c 'kretprobe:SyS_read { @ret.quantize(retval()); }'
1 probe active
^Cde-activating probes

@ret:

                   0          7 |####################                     |
                   1         12 |####################################     |
       [    2,     3]          7 |####################                     |
       [    4,     7]          0 |                                         |
       [    8,    15]          1 |###                                      |
       [   16,    31]          2 |#####                                    |
       [   32,    63]          7 |####################                     |
       [   64,   127]          3 |########                                 |
       [  128,   255]          2 |#####                                    |
       [  256,   511]          1 |###                                      |
       [  512,    1k)         11 |##############################           |
```

# Read latency

```
# ply -A -c 'kprobe:SyS_read { @start[tid()] = nsecs(); }
    kretprobe:SyS_read /@start[tid()]/ { @ns.quantize(nsecs() - @start[tid()]);
        @start[tid()] = nil; }'
2 probes active
^Cde-activating probes
[...]
@ns:

     [ 512,   1k)           3 |########                                |
     [  1k,   2k)           7 |####################                    |
     [  2k,   4k)          12 |##################################      |
     [  4k,   8k)           3 |########                                |
     [  8k,  16k)           2 |#####                                   |
     [ 16k,  32k)           0 |                                        |
     [ 32k,  64k)           0 |                                        |
     [ 64k, 128k)           3 |########                                |
     [128k, 256k)           1 |###                                     |
     [256k, 512k)           1 |###                                     |
     [512k,   1M)           2 |#####                                   |
[...]
```

# Counting Off-CPU stacks

```
# ply -c 'kprobe:schedule { @[stack()].count() }'
1 probe active
^Cde-activating probes

@:
      schedule+0x1
      sys_exit+0x17
      do_syscall_64+0x5e
      return_from_SYSCALL_64          1
[...]

      schedule+0x1
      fuse_dev_read+0x63
      new_sync_read+0xd2
      __vfs_read+0x26
      vfs_read+0x96
      sys_read+0x55
      do_syscall_64+0x5e
      return_from_SYSCALL_64       1707

      schedule+0x1
      do_syscall_64+0xa2
      return_from_SYSCALL_64       4647
```

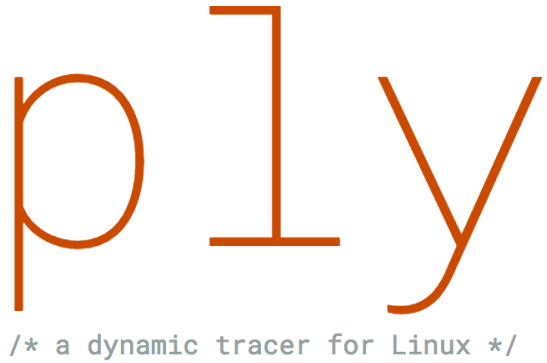
# ply One-Liners

```
# Trace file opens:
ply -c 'kprobe:do_sys_open { printf("opened: %s\n", mem(arg(1), "128s")); }'

# Counting vfs functions by process name:
ply -c 'kprobe:vfs_* { @[comm(), func()].count(); }'

# Counting off-CPU stacks:
ply -c 'kprobe:schedule { @[stack()].count() }'

# Syscall read return size as a histogram:
ply -c 'kretprobe:SyS_read { @ret.quantize(retval()); }'

# Syscall read latency as a histogram:
ply -A -c 'kprobe:SyS_read { @start[tid()] = nsecs(); }
   kretprobe:SyS_read /@start[tid()]/ { @ns.quantize(nsecs() - @start[tid()]);
   @start[tid()] = nil; }'
[...]
```

also see ply/oneliners.md

# ply

- A new BPF-based dynamic tracer for Linux
  - Created by Tobias Waldekranz
  - https://github.com/iovisor/ply https://wkz.github.io/ply/
- High-level language
  - Simple one-liners
  - Short scripts
- In development
  - kprobes and tracepoints only, uprobes/perf_events not yet
  - Successful so far as a proof of concept
  - Not production tested yet (bcc is)



Future work

# CHALLENGES

# Challenges

- Marketing
- Documentation
- Training
- Community

Without these, we may have another ftrace: a built in "secret" of Linux. Not good for adoption!

https://www.iovisor.org project helps, but tracing (observability) is only one part.

# Take aways

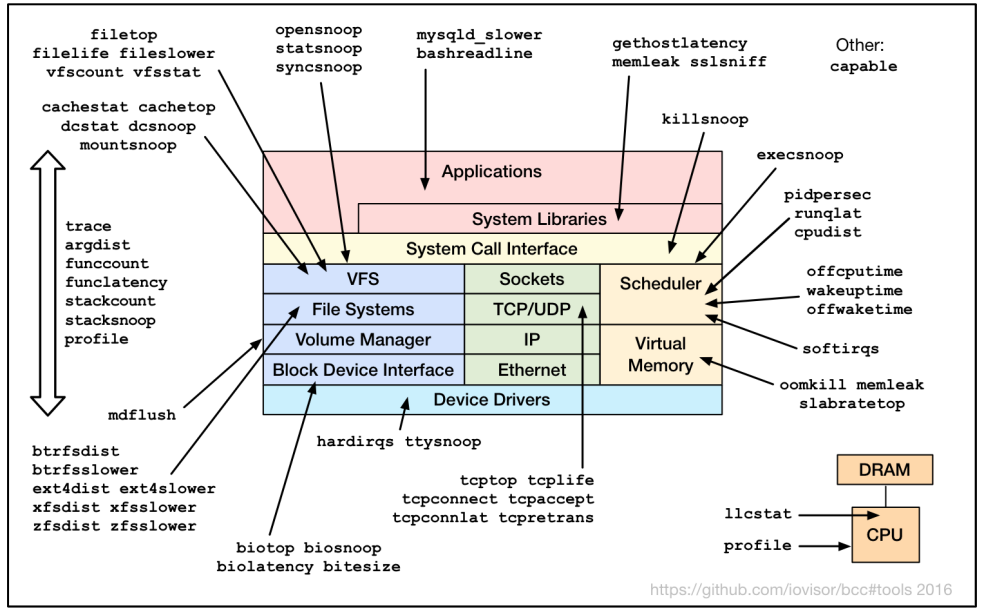
1. Understanding the value of Linux tracing superpowers
2. Upgrade to Linux 4.4+ (4.9 is better)
3. Ask for eBPF support in your perf analysis/monitoring tools

Please contribute:

- https://github.com/iovisor/bcc
- https://github.com/iovisor/ply

**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



# 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://www.brendangregg.com/ebpf.html#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


# Thanks

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

Thanks to Alexei Starovoitov (Facebook), Brenden Blanco (PLUMgrid/ VMware), Sasha Goldshtein (Sela), Daniel Borkmann (Cisco), Wang Nan (Huawei), and other BPF and bcc contributors!