

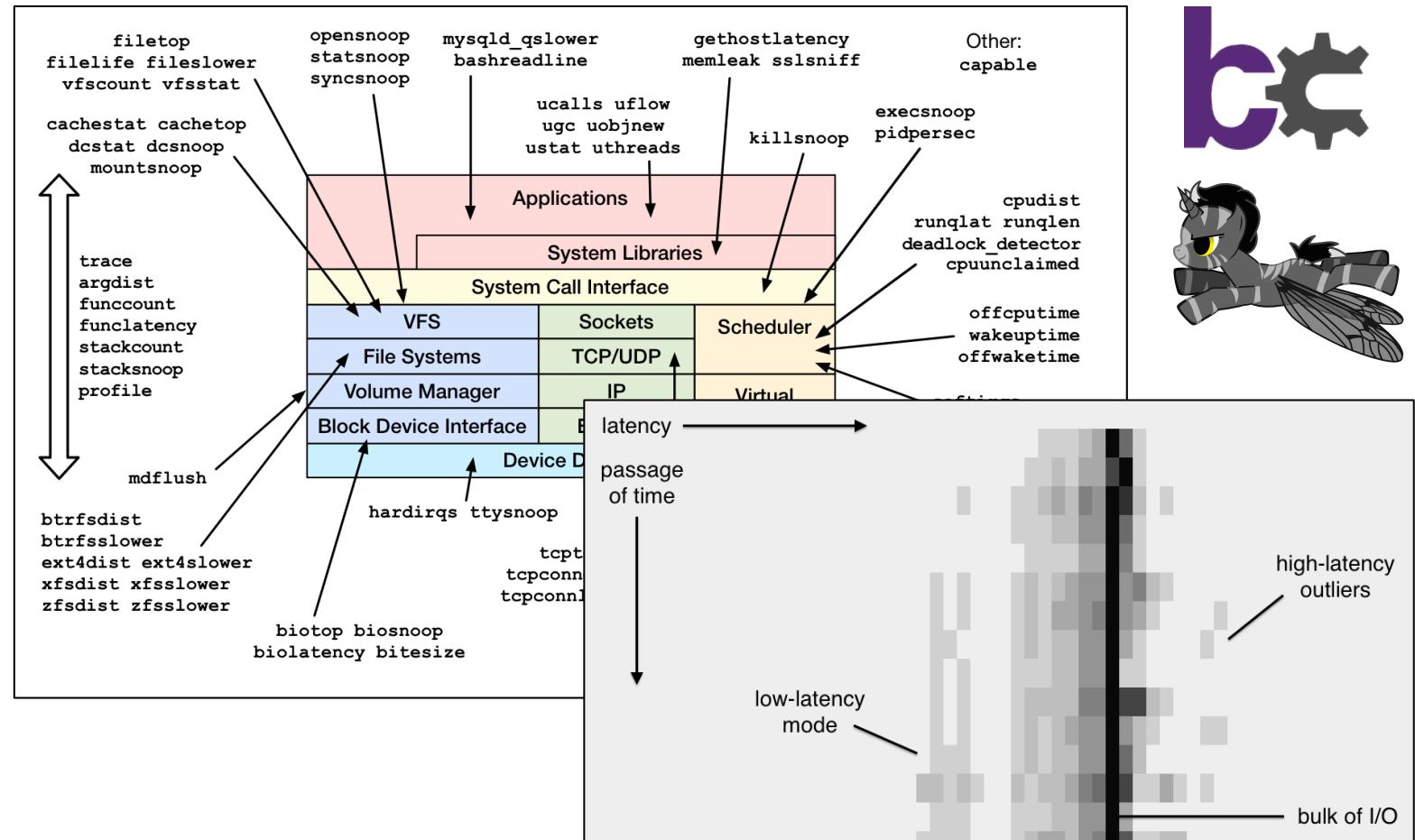
Linux 4.x Tracing: Performance Analysis with bcc/BPF



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Mar 2017

NETFLIX



Linux tracing
in the last 3 years...

How do we
use these
superpowers?

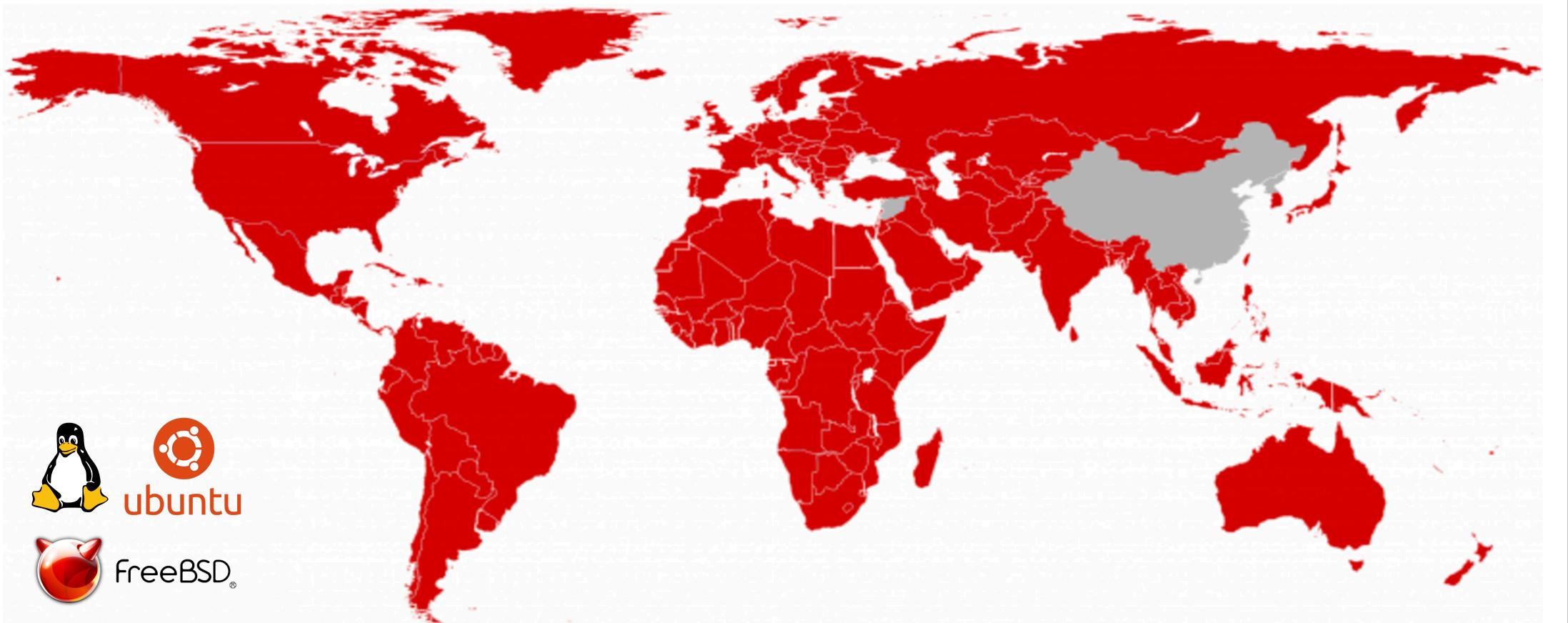


Take aways

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

REGIONS WHERE NETFLIX IS AVAILABLE



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     #0xffff     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

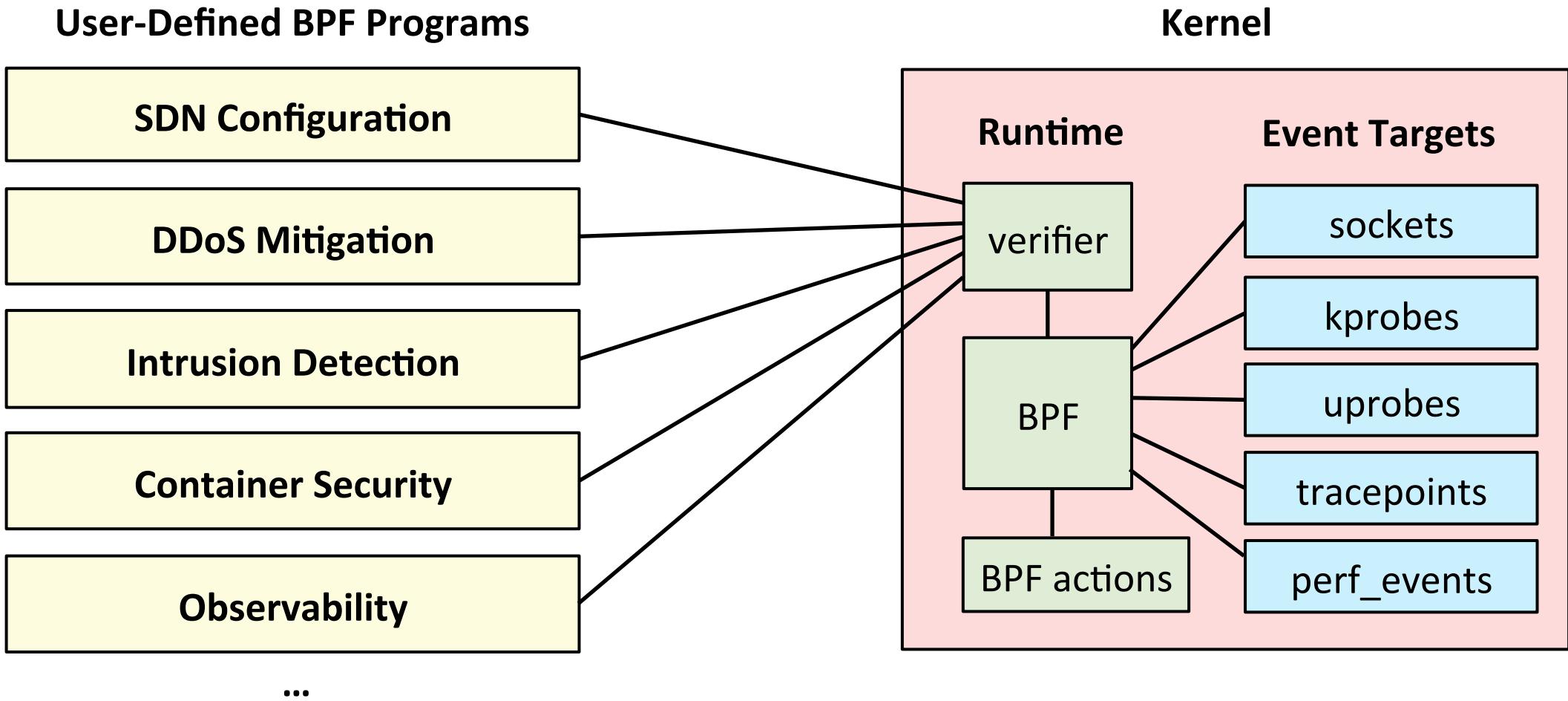
aka eBPF or just "BPF"

```
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



Eg, Netflix self-service UI:



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

BPF output
Linux 4.4

BPF stacks
Linux 4.6

(version
BPF
support
arrived)

Dynamic
Tracing

uprobes
Linux 4.3

kprobes
Linux 4.1

Tracepoints
Linux 4.7

ext4:

Operating System

Applications

System Libraries

VFS

Sockets

syscalls:

sock:
sched:
task:
signal:
timer:
workqueue:

File Systems

TCP/UDP

CPU
Interconnect

Volume Manager

IP

Block Device Interface

Ethernet

kmem:
vmscan:
writeback:

jbd2:

net:
skb:

irq:

Software Events

Linux 4.9

cpu-clock
cs migrations

page-faults
minor-faults
major-faults

PMCs

Linux 4.9

cycles

instructions

branch-*

L1-*

LLC-*

CPU

1

Memory
Bus

DRAM

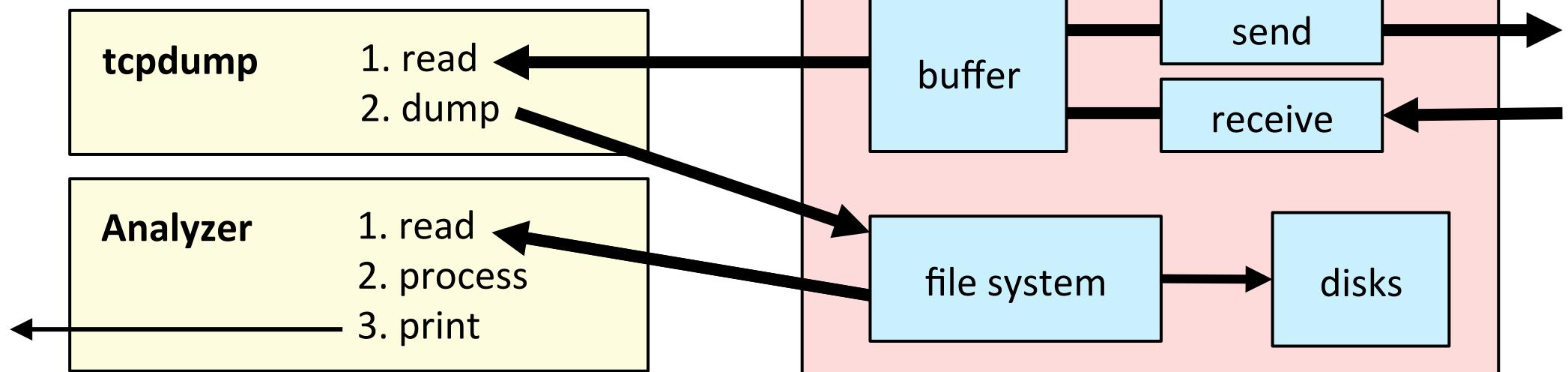
mem-load

mem-store

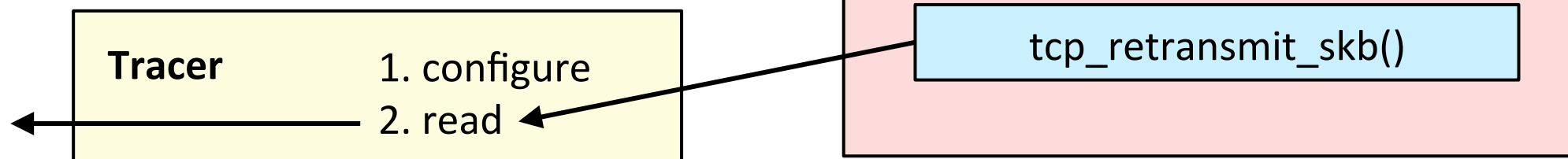
Event Tracing Efficiency

E.g., tracing TCP retransmits

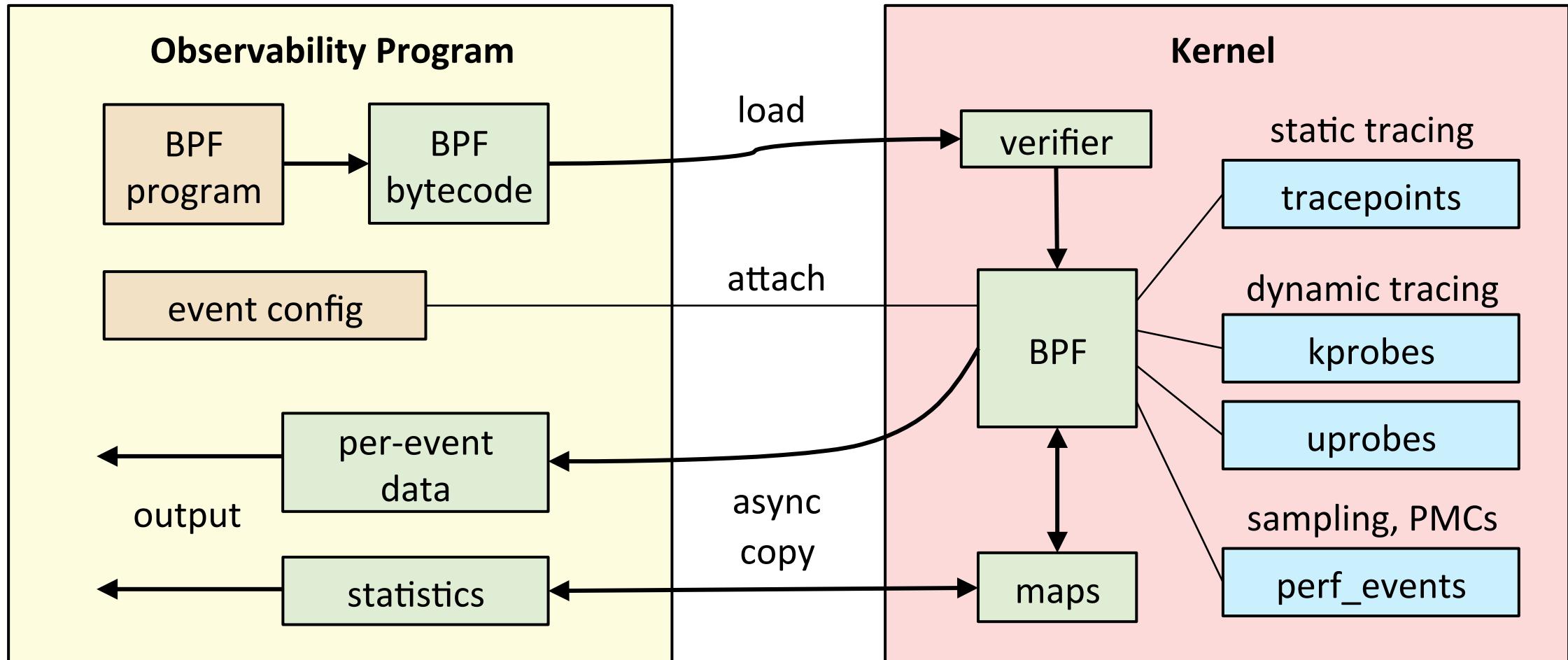
Old way: packet capture



New way: dynamic tracing



BPF Tracing Internals



Introducing bcc

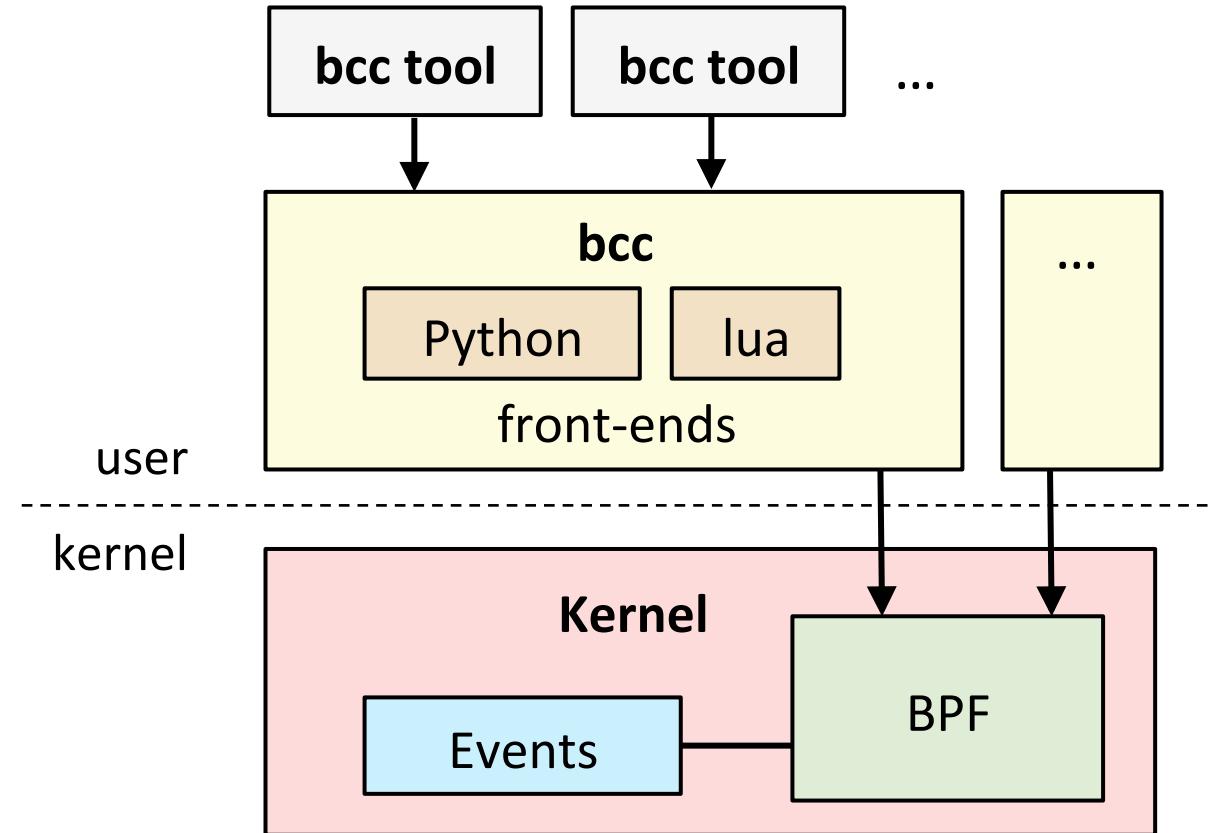
BPF COMPILER COLLECTION

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(),
};
```

C/BPF

```
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(9999999)
except KeyboardInterrupt:
    print

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

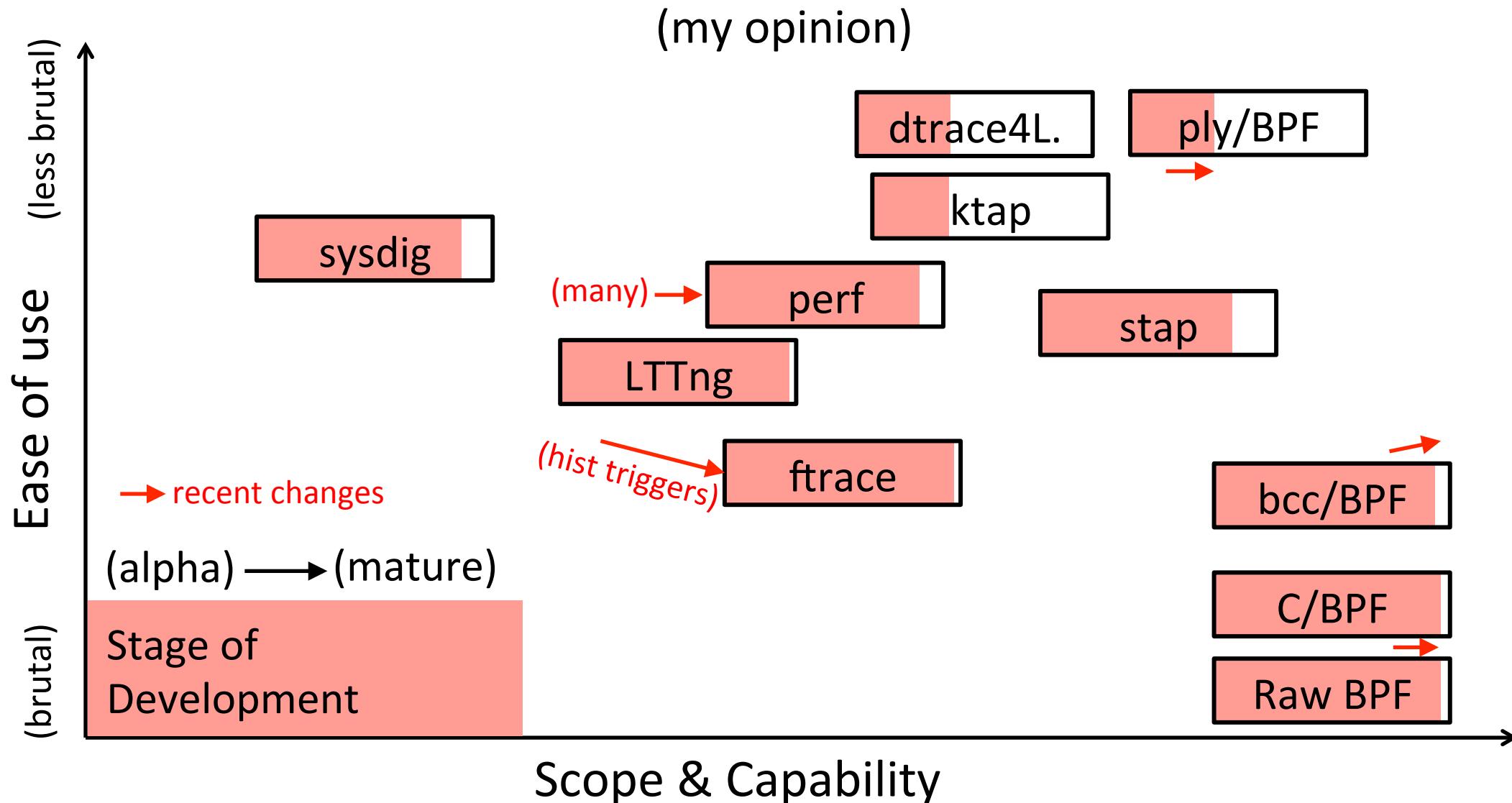
bcc examples/tracing/bitehist.py
entire program

ply/BPF

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

<https://github.com/iovisor/ply/blob/master/README.md>
entire program

The Tracing Landscape, Mar 2017



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`



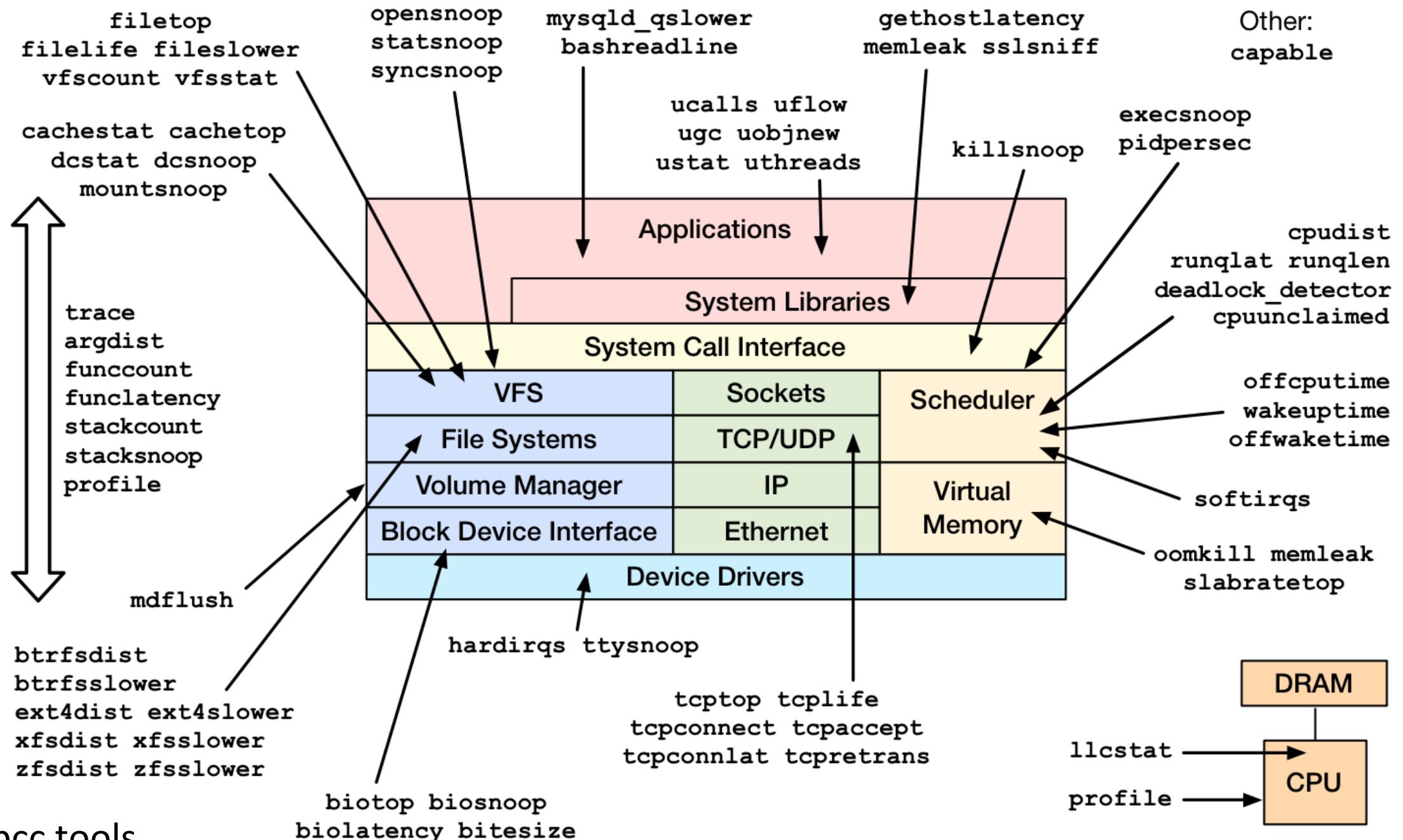
<http://techblog.netflix.com/2015/11/linux-performance-analysis-in-60s.html>

bcc Installation

- <https://github.com/iovisor/bcc/blob/master/INSTALL.md>
- eg, Ubuntu Xenial:

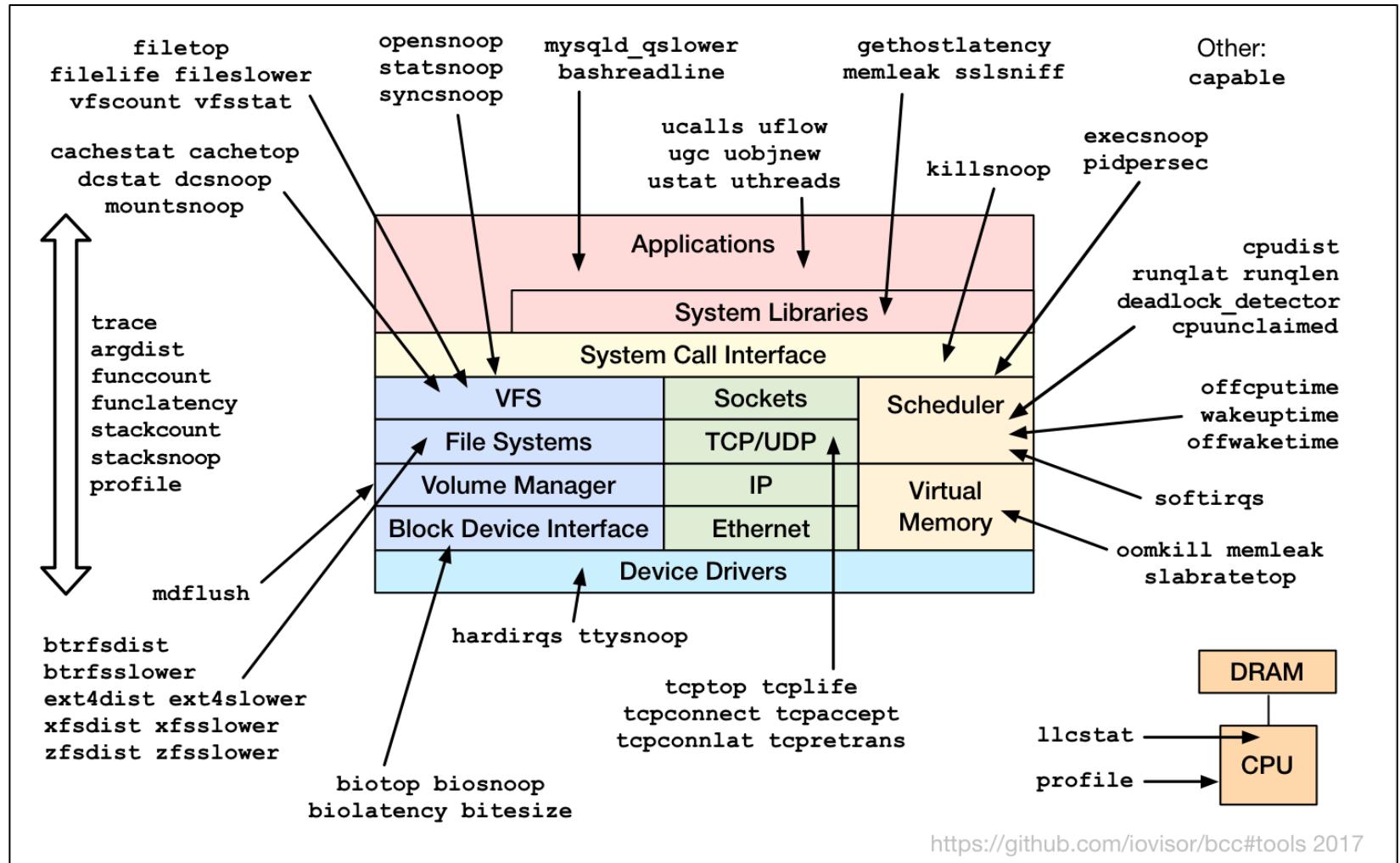
```
# echo "deb [trusted=yes] https://repo.iovisor.org/apt/xenial xenial-nightly main" | \
    sudo tee /etc/apt/sources.list.d/iovisor.list
# sudo apt-get update
# sudo apt-get install bcc-tools
```

- 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 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 -fopen", 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: btrfslower, 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 representative 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
1		170610	41607	33	80.4%	19.6%	11	288
2		157693	6149	33	96.2%	3.7%	11	311
3		174483	20166	26	89.6%	10.4%	12	389
4		434778	35	40	100.0%	0.0%	12	389
5		435723	28	36	100.0%	0.0%	12	389
6		846183	83800	332534	55.2%	4.5%	13	553
7		96387	21	24	100.0%	0.0%	13	553
8		120258	29	44	99.9%	0.0%	13	553
9		255861	24	33	100.0%	0.0%	13	553
10		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
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

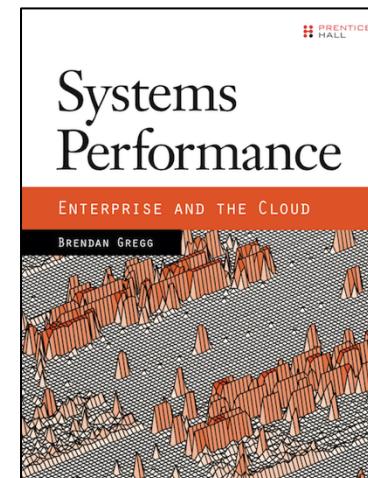
- An efficient profiler. Count unique stacks in kernel:

```
# profile
Sampling at 49 Hertz of all threads by user + kernel stack... Ctrl-C to end.
^C
[...]
ffffffffff813d0af8 __clear_user
ffffffffff813d5277 iov_iter_zero
ffffffffff814ec5f2 read_iter_zero
ffffffffff8120be9d __vfs_read
ffffffffff8120c385 vfs_read
ffffffffff8120d786 sys_read
ffffffffff817cc076 entry_SYSCALL_64_fastpath
00007fc5652ad9b0 read
-
dd (25036)
[...]
```

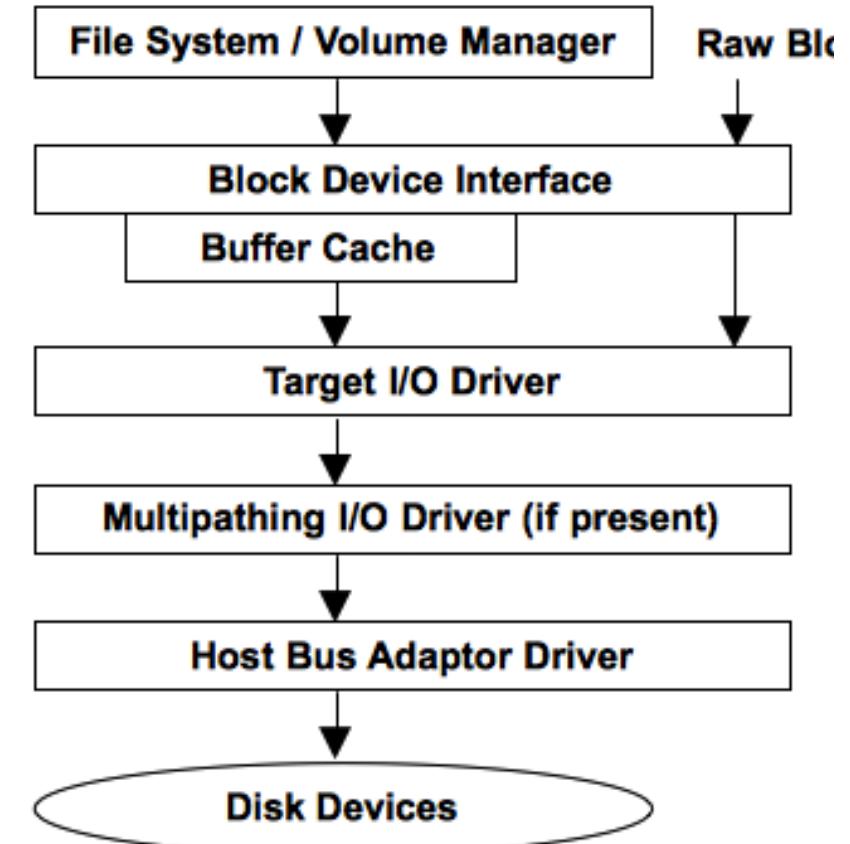
This stack was sampled 7 times

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:
 - funcount, 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      -  
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

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     |              |

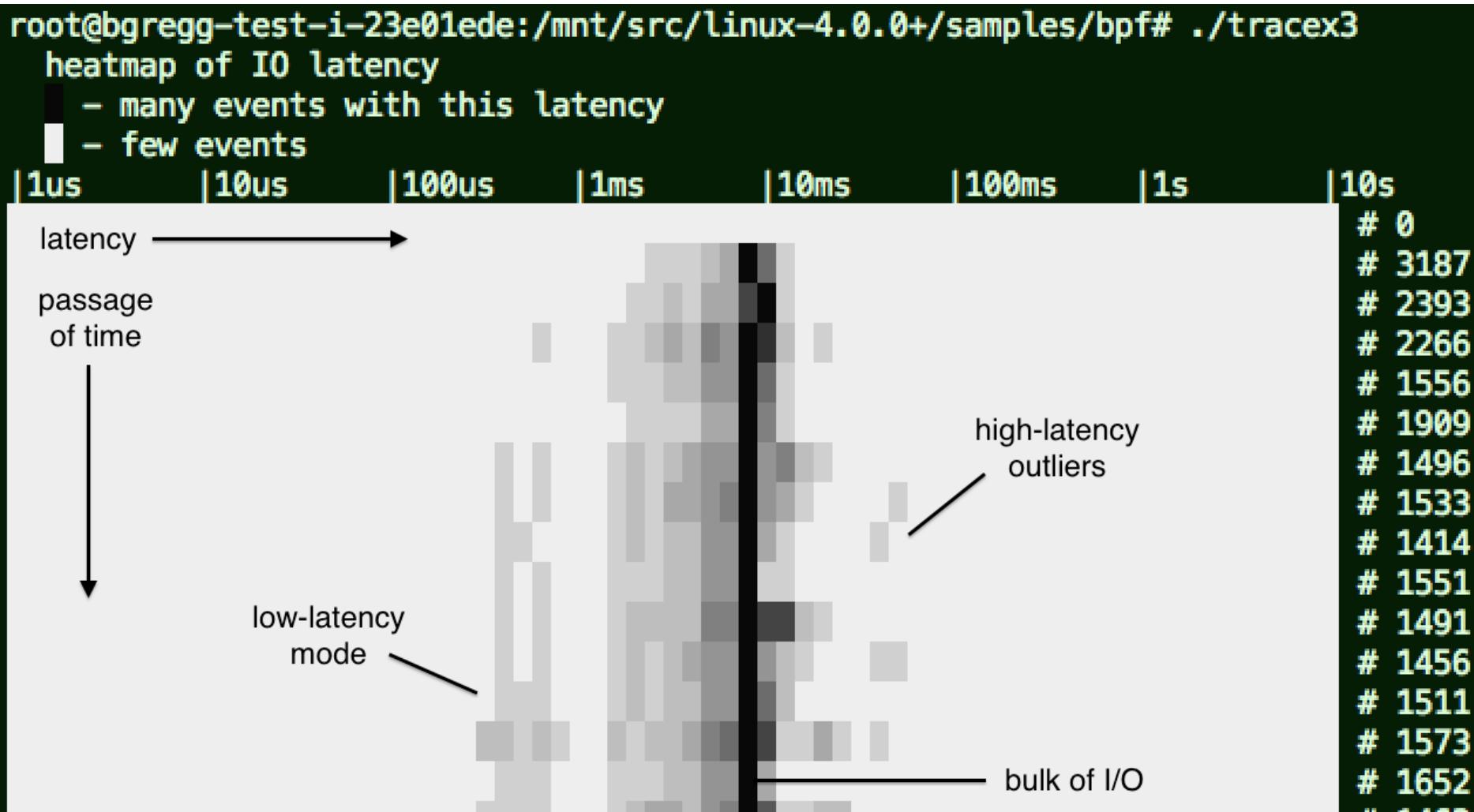

```

function
argument
distributions

Coming to a GUI near you

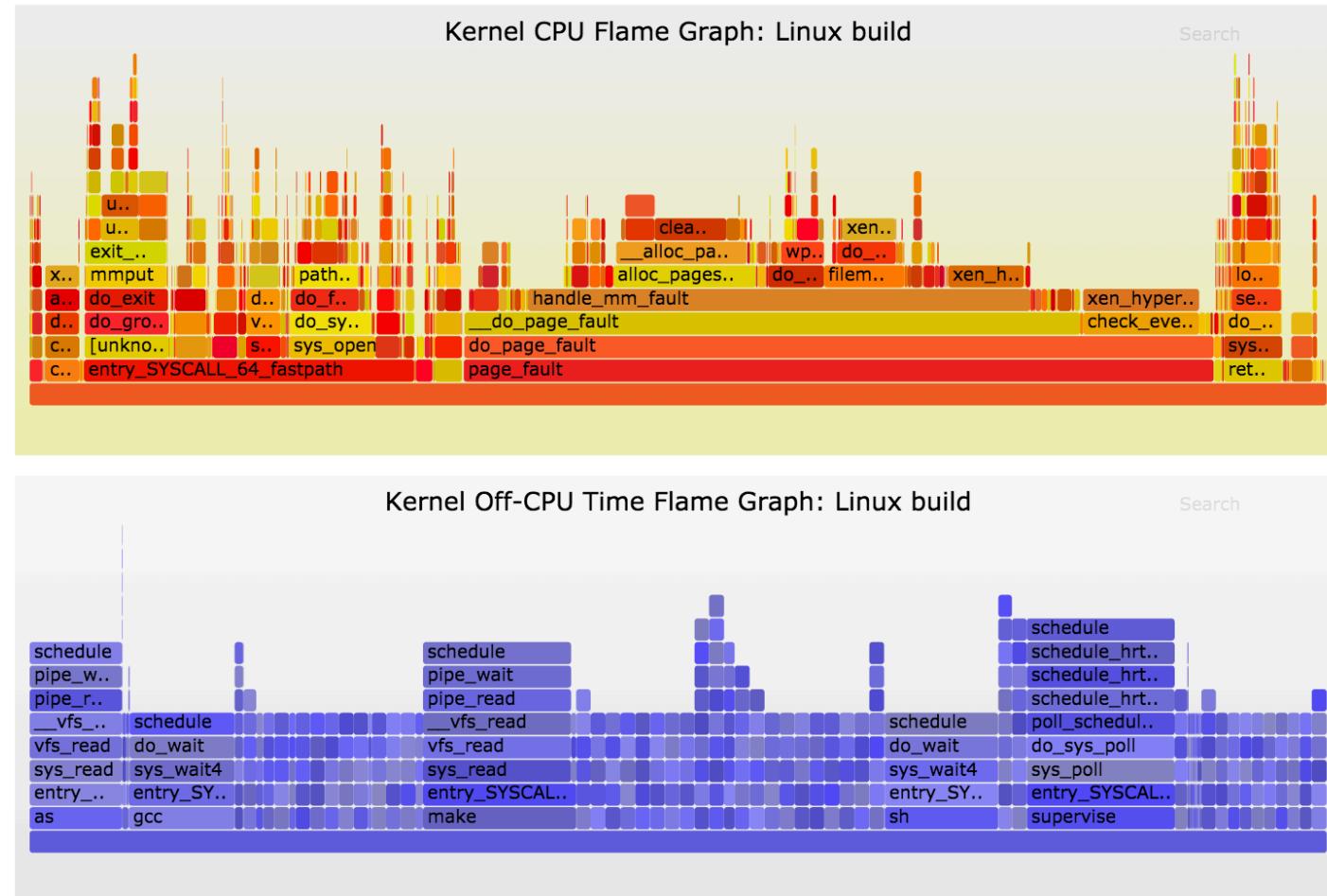
BCC/BPF VISUALIZATIONS

Latency Heatmaps



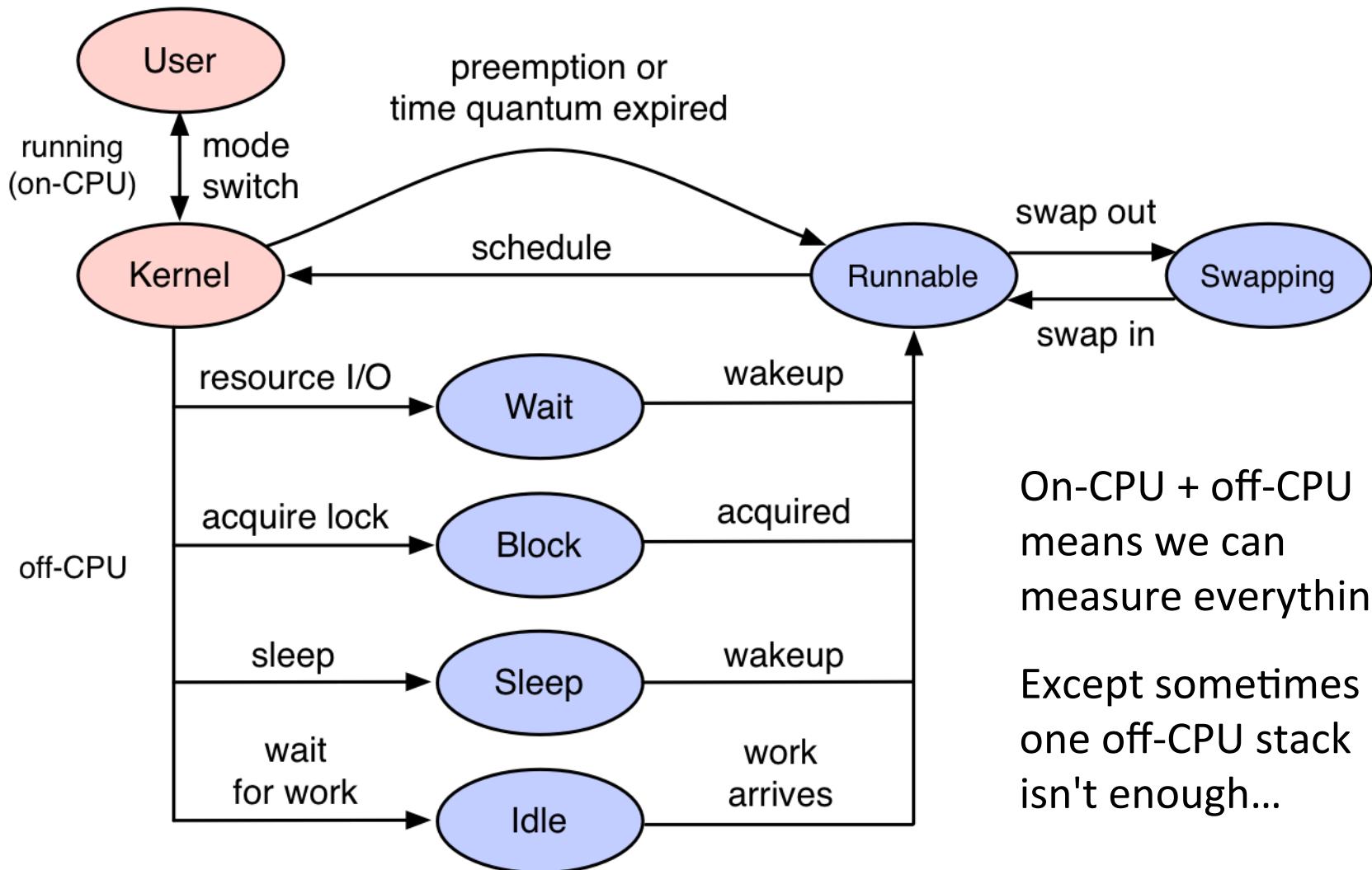
CPU + Off-CPU Flame Graphs

- Can now be BPF optimized



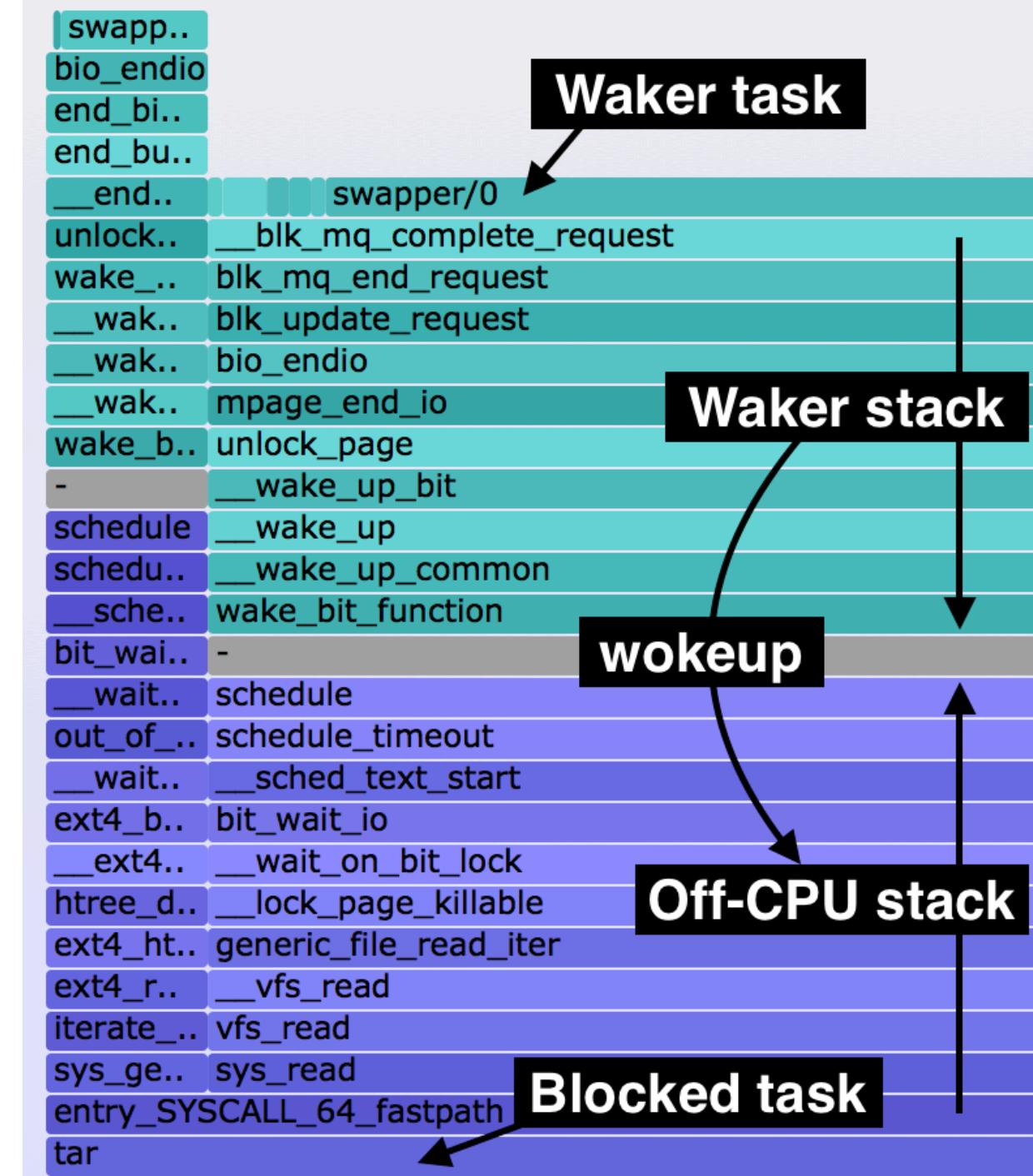
<http://www.brendangregg.com/flamegraphs.html>

Conquer Performance



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(9999999)
except KeyboardInterrupt:
    print

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

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;
} "kprobe__" is a shortcut for BPF.attach_kprobe()
""")
```

The diagram illustrates the flow of data and control between the components:

- C BPF Program**: Represented by a blue box at the top.
- Map**: Represented by a green box, which receives an arrow from the BPF code.
- Event**: Represented by a light purple box, which receives an arrow from the BPF code.
- Python Program**: Represented by a blue box on the right, which receives an arrow from the C BPF Program.

Arrows indicate the flow of data and control:

- An arrow points from the **Map** box to the **C BPF Program** box.
- An arrow points from the **Event** box to the **C BPF Program** box.
- An arrow points from the **C BPF Program** box up to the **Python Program** box.
- An arrow points from the **Python Program** box down to the **Statistics** box.

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

# trace until Ctrl-C
try:
    sleep(9999999)
except KeyboardInterrupt:
    print

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

The diagram illustrates the flow of data and control between the components:

- Python Program**: Represented by a blue box on the right.
- Statistics**: Represented by a light purple box, which receives an arrow from the Python Program.

Arrows indicate the flow of data and control:

- An arrow points from the **Python Program** box up to the **Statistics** box.
- An arrow points from the **Statistics** box down to the **Python Program** box.

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:

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

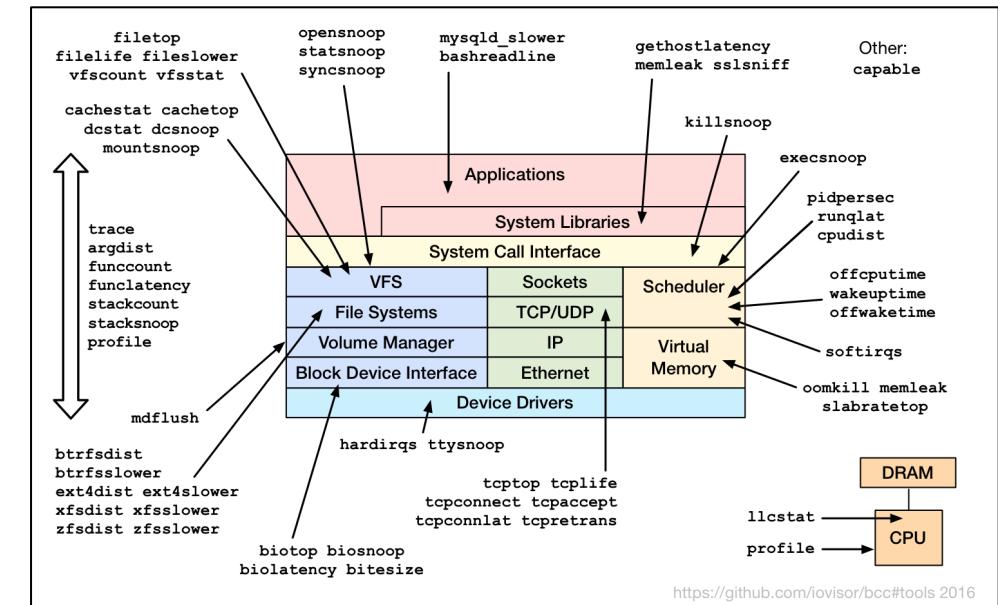
1. Understanding the value of Linux tracing superpowers
2. Upgrade to Linux 4.4+ (4.9 is better)
3. Ask for eBPF support in your perf analysis/monitoring tools

Please contribute:

- [https://github.com/
iovisor/bcc](https://github.com/iovisor/bcc)
- [https://github.com/
iovisor/ply](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](https://twitter.com/brendangregg)

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