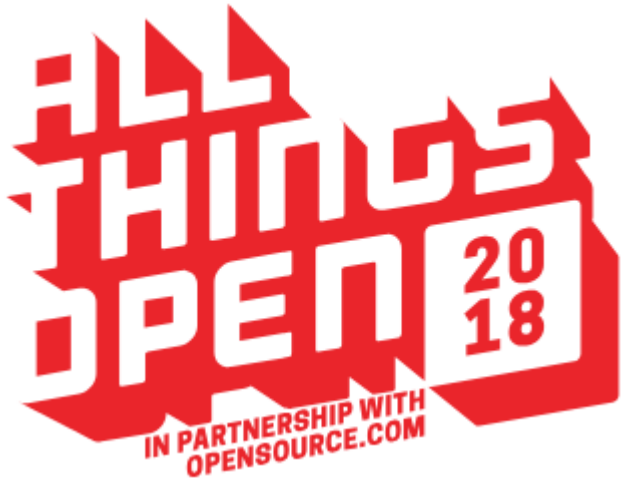
Linux Performance 2018

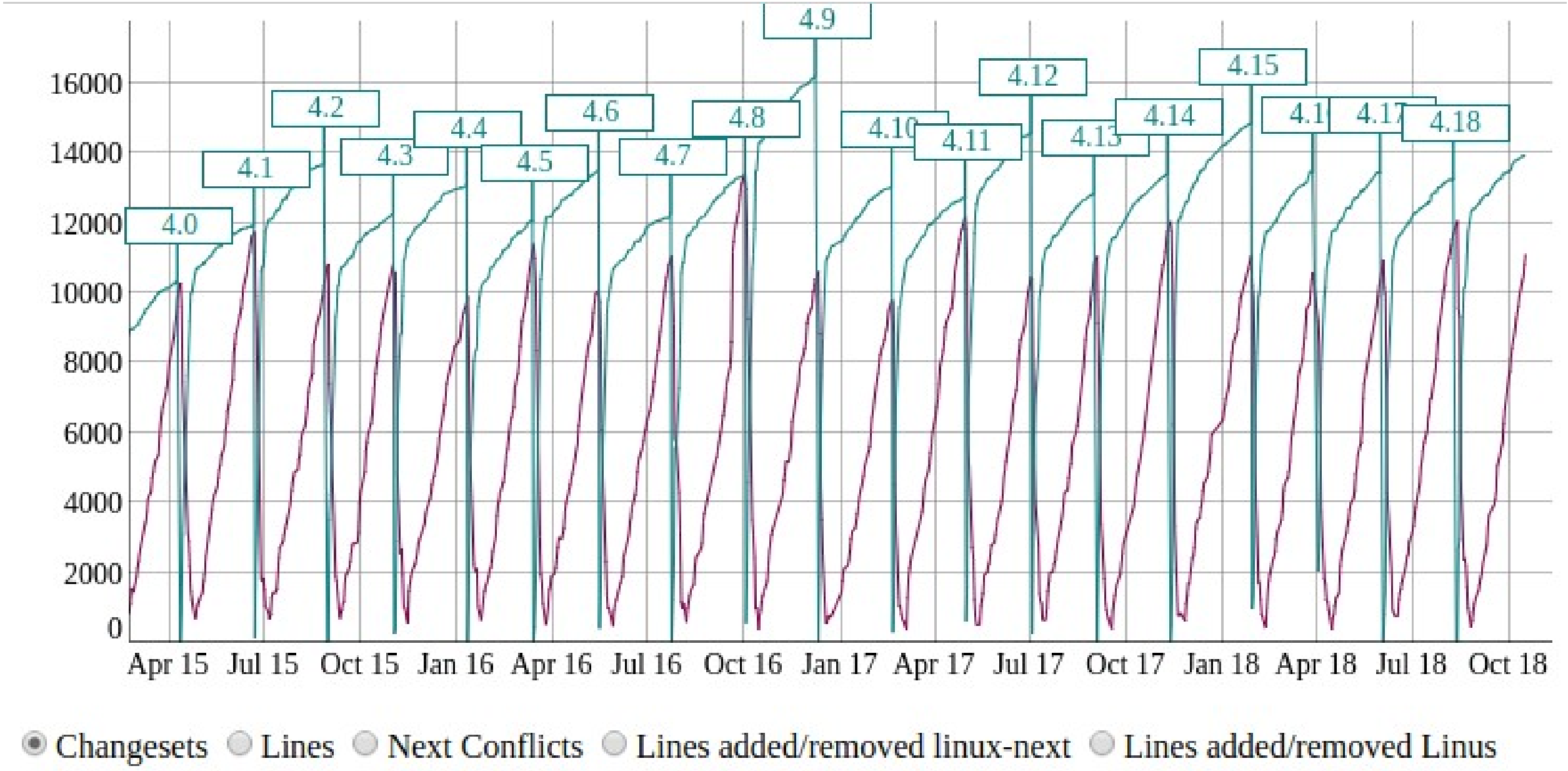


Brendan Gregg

Senior Performance Architect

NETFLIX

Oct 2018



http://neuling.org/linux-next-size.html

Post frequency:

4 per year

https://kernelnewbies.org/Linux_4.18

4 per week

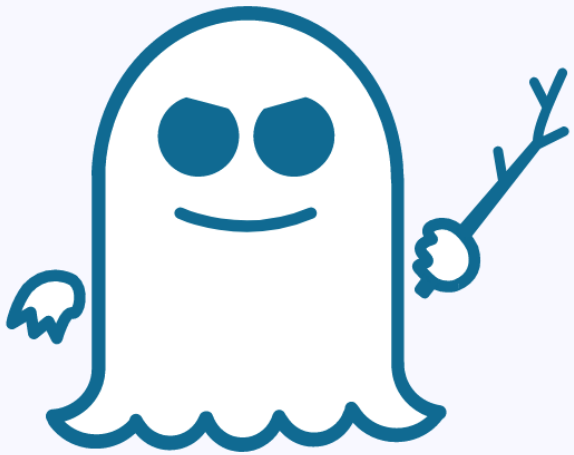
https://lwn.net/Kernel/

400 per day

LKML

http://vger.kernel.org/vger-lists.html
#linux-kernel

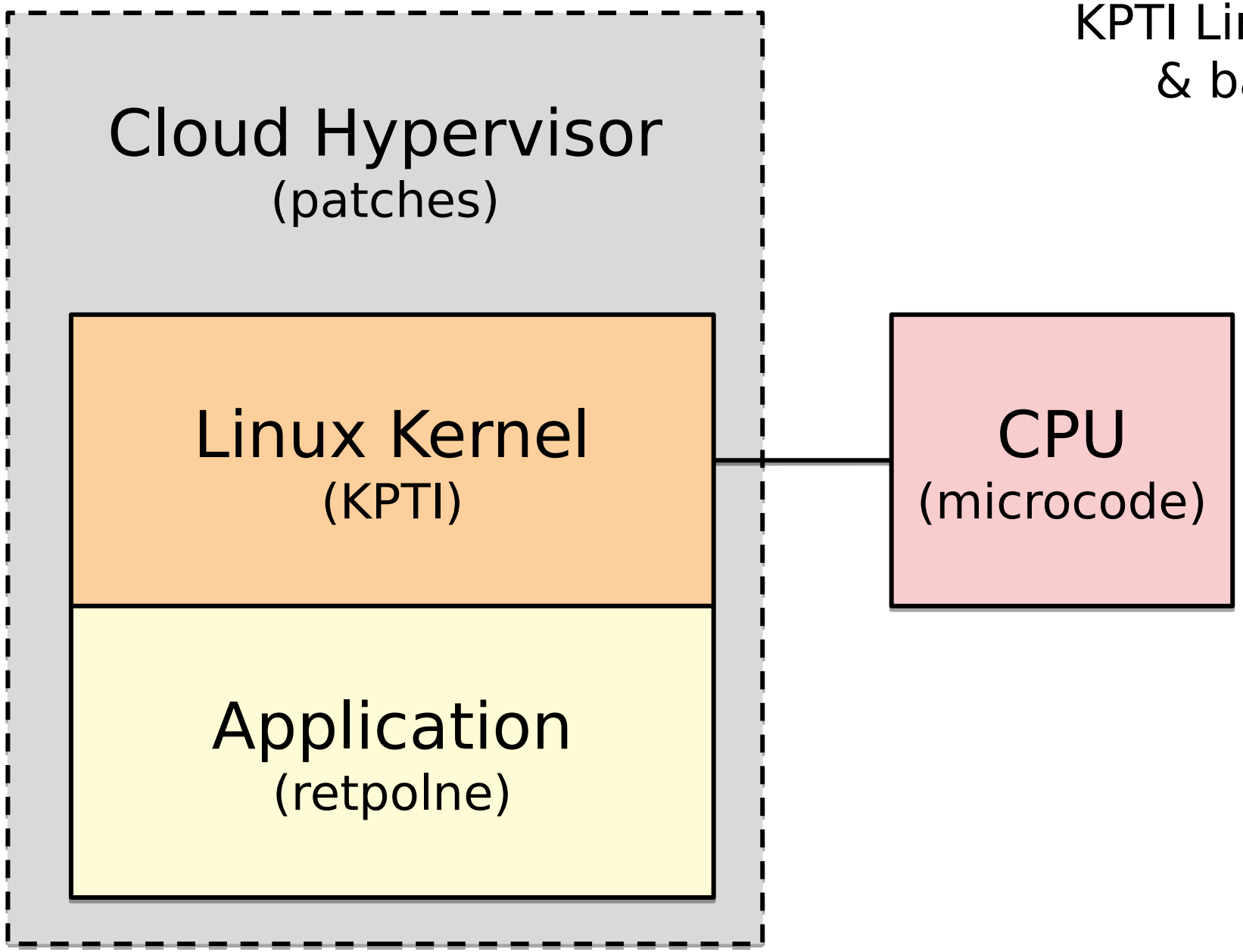
Meltdown



Spectre

https://meltdownattack.com/

KPTI Linux 4.15
& backports



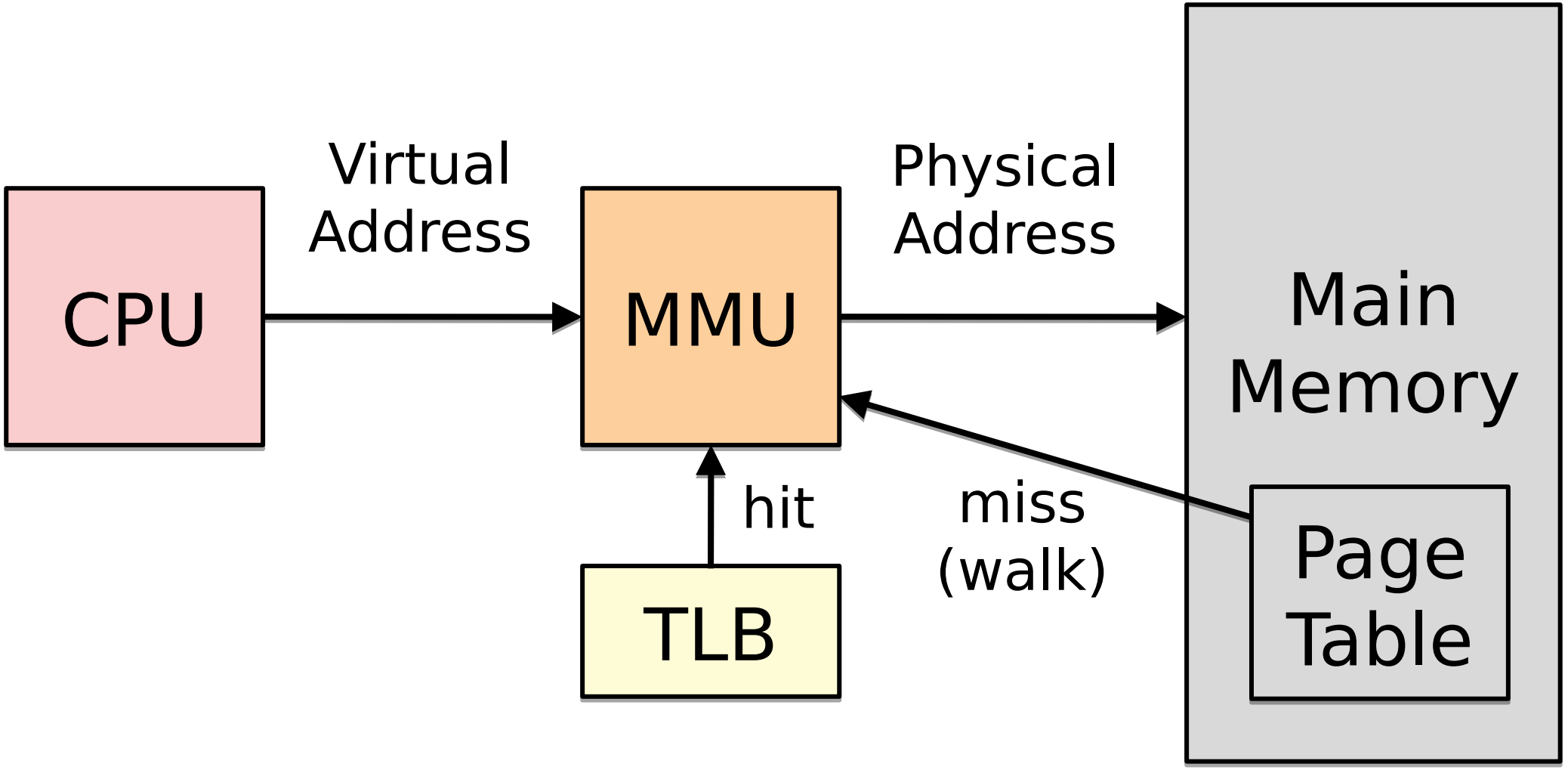
Server A: 31353 MySQL queries/sec

```
serverA# mpstat 1
Linux 4.14.12-virtual (bgregg-c5.9xl-i-xxx)      02/09/2018      _x86_64_        (36 CPU)
01:09:13 AM  CPU    %usr   %nice    %sys %iowait    %irq   %soft  %steal  %guest  %gnice   %idle
01:09:14 AM  all   86.89    0.00   13.08    0.00    0.00    0.00    0.00    0.00    0.00    0.03
01:09:15 AM  all   86.77    0.00   13.23    0.00    0.00    0.00    0.00    0.00    0.00    0.00
01:09:16 AM  all   86.93    0.00   13.02    0.00    0.00    0.00    0.03    0.00    0.00    0.03
[...]
```

Server B: 22795 queries/sec (27% slower)

```
serverB# mpstat 1
Linux 4.14.12-virtual (bgregg-c5.9xl-i-xxx)      02/09/2018      _x86_64_        (36 CPU)
01:09:44 AM  CPU    %usr   %nice    %sys %iowait    %irq   %soft  %steal  %guest  %gnice   %idle
01:09:45 AM  all   82.94    0.00   17.06    0.00    0.00    0.00    0.00    0.00    0.00    0.00
01:09:46 AM  all   82.78    0.00   17.22    0.00    0.00    0.00    0.00    0.00    0.00    0.00
01:09:47 AM  all   83.14    0.00   16.86    0.00    0.00    0.00    0.00    0.00    0.00    0.00
[...]
```

Linux KPTI patches for Meltdown flush the Translation Lookaside Buffer

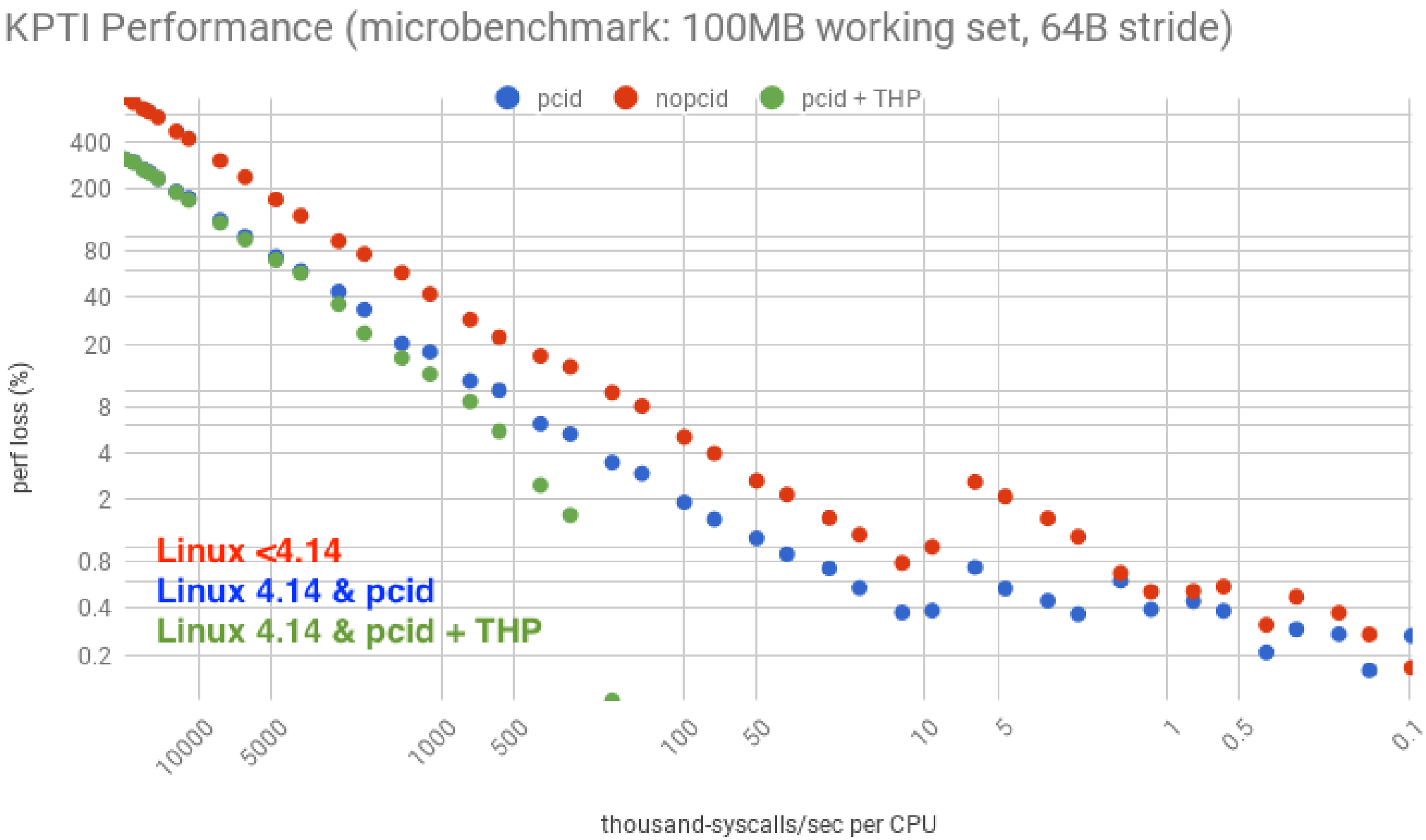


Server A: TLB miss walks 3.5%

```
serverA# ./tlbstat 1
K_CYCLES   K_INSTR      IPC DTLB_WALKS ITLB_WALKS K_DTLBCYC  K_ITLBCYC  DTLB% ITLB%
95913667   99982399    1.04 86588626   115441706  1507279    1837217     1.57  1.92
95810170   99951362    1.04 86281319   115306404  1507472    1842313     1.57  1.92
95844079   100066236   1.04 86564448   115555259  1511158    1845661     1.58  1.93
95978588   100029077   1.04 86187531   115292395  1508524    1845525     1.57  1.92
[...]
```

Server B: TLB miss walks 19.2% (16% higher)

```
serverB# ./tlbstat 1
K_CYCLES   K_INSTR      IPC DTLB_WALKS ITLB_WALKS K_DTLBCYC  K_ITLBCYC  DTLB% ITLB%
95911236   80317867    0.84 911337888  719553692  10476524   7858141    10.92  8.19
95927861   80503355    0.84 913726197  721751988  10518488   7918261    10.96  8.25
95955825   80533254    0.84 912994135  721492911  10524675   7929216    10.97  8.26
96067221   80443770    0.84 912009660  720027006  10501926   7911546    10.93  8.24
[...]
```

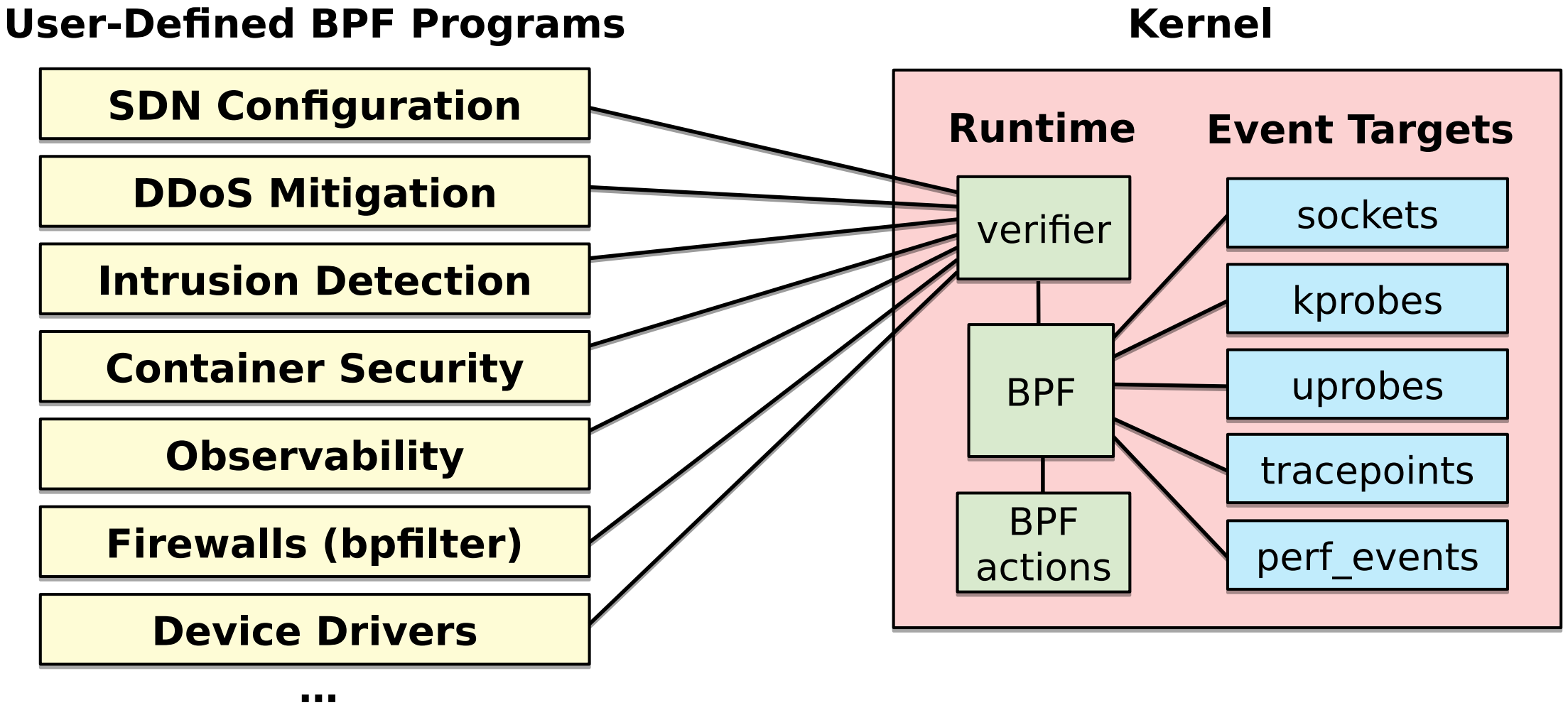


http://www.brendangregg.com/blog/2018-02-09/kpti-kaiser-meltdown-performance.html

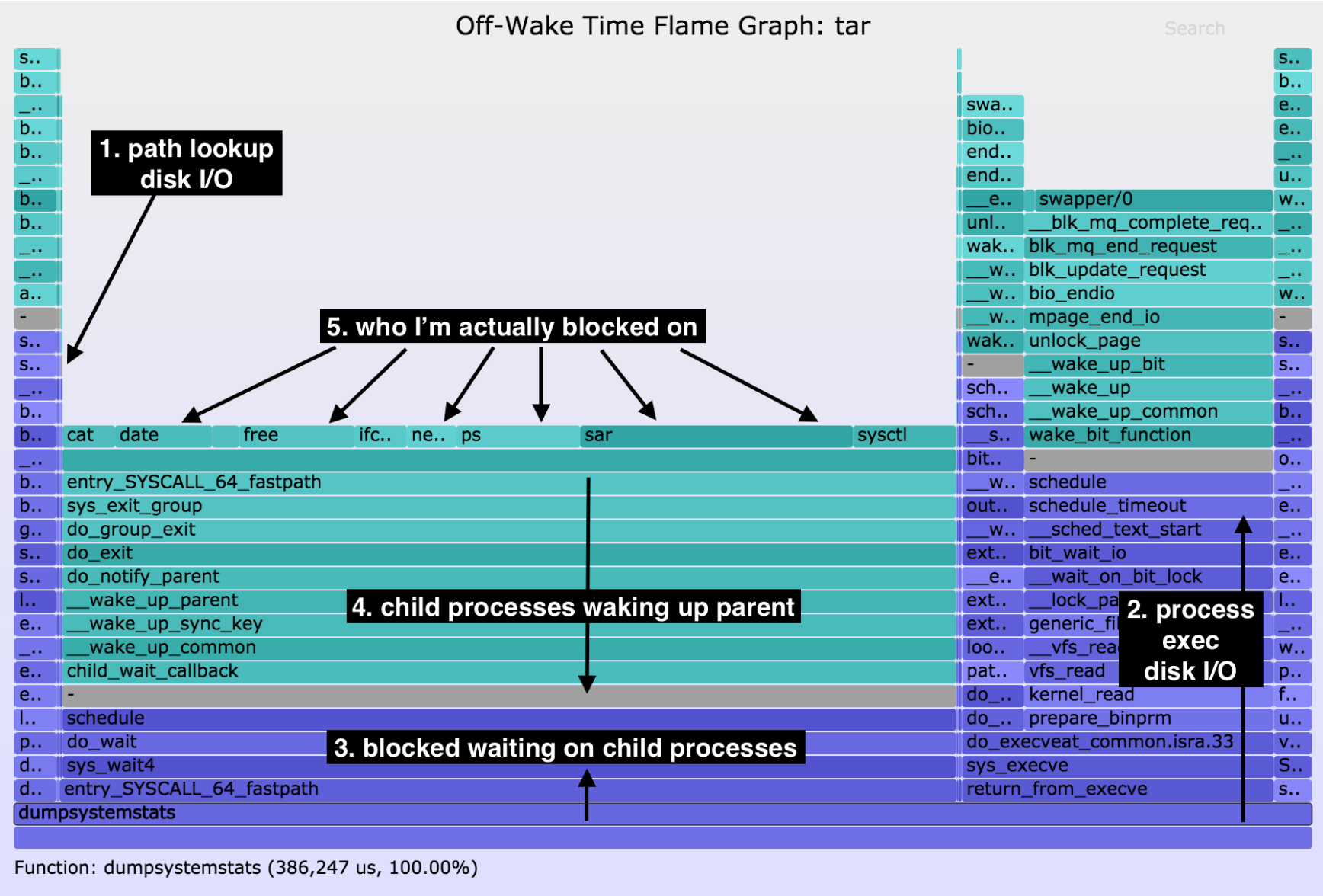
Enhanced BPF

Linux 4.*

also known as just "BPF"

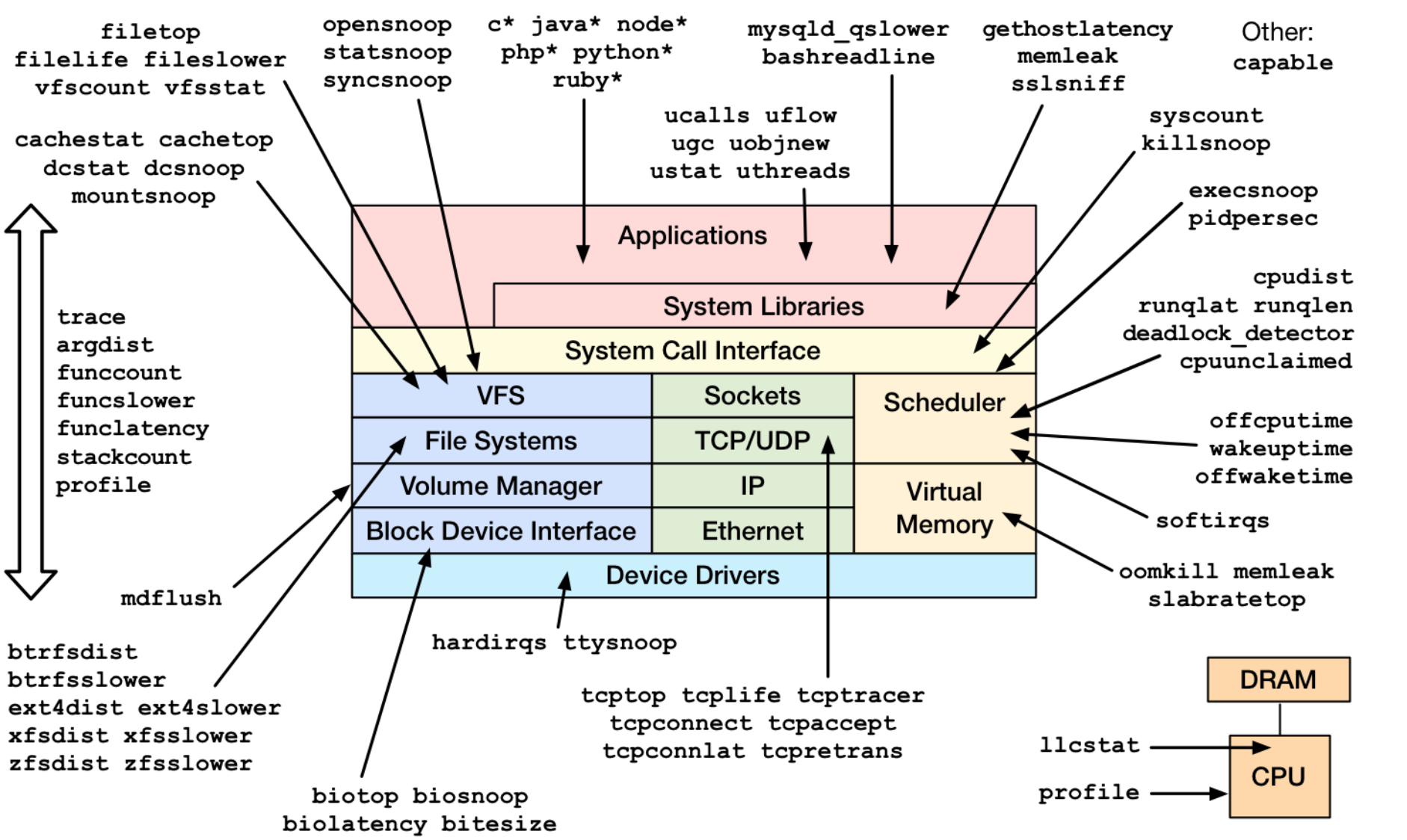


eBPF is solving new things: off-CPU + wakeup analysis



eBPF bcc

Linux 4.4+



https://github.com/iovisor/bcc

e.g., identify multimodal disk I/O latency and outliers with bcc/eBPF `biolatency`

```
# biolatency -mT 10
Tracing block device I/O... Hit Ctrl-C to end.

19:19:04
     msecs               : count     distribution
         0 -> 1          : 238      |*********                               |
         2 -> 3          : 424      |*****************                       |
         4 -> 7          : 834      |********************************        |
         8 -> 15         : 506      |*******************                     |
        16 -> 31         : 986      |****************************************|
        32 -> 63         : 97       |***                                     |
        64 -> 127        : 7        |                                        |
       128 -> 255        : 27       |*                                       |

19:19:14
     msecs               : count     distribution
         0 -> 1          : 427      |*****************                       |
         2 -> 3          : 424      |*****************                       |
[…]
```

bcc/eBPF programs are laborious: biolatency

```
# define BPF program
bpf_text = """
#include <uapi/linux/ptrace.h>
#include <linux/blkdev.h>

typedef struct disk_key {
    char disk[DISK_NAME_LEN];
    u64 slot;
} disk_key_t;
BPF_HASH(start, struct request *);
STORAGE

// time block I/O
int trace_req_start(struct pt_regs *ctx, struct request *req)
{
    u64 ts = bpf_ktime_get_ns();
    start.update(&req, &ts);
    return 0;
}

// output
int trace_req_completion(struct pt_regs *ctx, struct request *req)
{
    u64 *tsp, delta;

    // fetch timestamp and calculate delta
    tsp = start.lookup(&req);
    if (tsp == 0) {
        return 0;   // missed issue
    }
    delta = bpf_ktime_get_ns() - *tsp;
    FACTOR

    // store as histogram
    STORE

    start.delete(&req);
    return 0;
}
"""

# code substitutions
if args.milliseconds:
    bpf_text = bpf_text.replace('FACTOR', 'delta /= 1000000;')
    label = "msecs"
else:
    bpf_text = bpf_text.replace('FACTOR', 'delta /= 1000;')
    label = "usecs"
```

```
if args.disks:
    bpf_text = bpf_text.replace('STORAGE',
        'BPF_HISTOGRAM(dist, disk_key_t);')
    bpf_text = bpf_text.replace('STORE',
        'disk_key_t key = {.slot = bpf_log2l(delta)}; ' +
        'void *__tmp = (void *)req->rq_disk->disk_name; ' +
        'bpf_probe_read(&key.disk, sizeof(key.disk), __tmp); ' +
        'dist.increment(key);')
else:
    bpf_text = bpf_text.replace('STORAGE', 'BPF_HISTOGRAM(dist);')
    bpf_text = bpf_text.replace('STORE',
        'dist.increment(bpf_log2l(delta));')
if debug or args.ebpf:
    print(bpf_text)
    if args.ebpf:
        exit()

# load BPF program
b = BPF(text=bpf_text)
if args.queued:
    b.attach_kprobe(event="blk_account_io_start", fn_name="trace_req_start")
else:
    b.attach_kprobe(event="blk_start_request", fn_name="trace_req_start")
    b.attach_kprobe(event="blk_mq_start_request", fn_name="trace_req_start")
b.attach_kprobe(event="blk_account_io_completion",
    fn_name="trace_req_completion")

print("Tracing block device I/O... Hit Ctrl-C to end.")

# output
exiting = 0 if args.interval else 1
dist = b.get_table("dist")
while (1):
    try:
        sleep(int(args.interval))
    except KeyboardInterrupt:
        exiting = 1

    print()
    if args.timestamp:
        print("%-8s\n" % strftime("%H:%M:%S"), end="")

    dist.print_log2_hist(label, "disk")
    dist.clear()

    countdown -= 1
    if exiting or countdown == 0:
        exit()
```

… rewritten in bpftrace (launched Oct 2018)!

```
#!/usr/local/bin/bpftrace

BEGIN
{
   printf("Tracing block device I/O... Hit Ctrl-C to end.\n");
}

kprobe:blk_account_io_start
{
   @start[arg0] = nsecs;
}

kprobe:blk_account_io_completion
/@start[arg0]/

{
   @usecs = hist((nsecs - @start[arg0]) / 1000);
   delete(@start[arg0]);
}
```

eBPF bpftrace (aka BPFtrace)

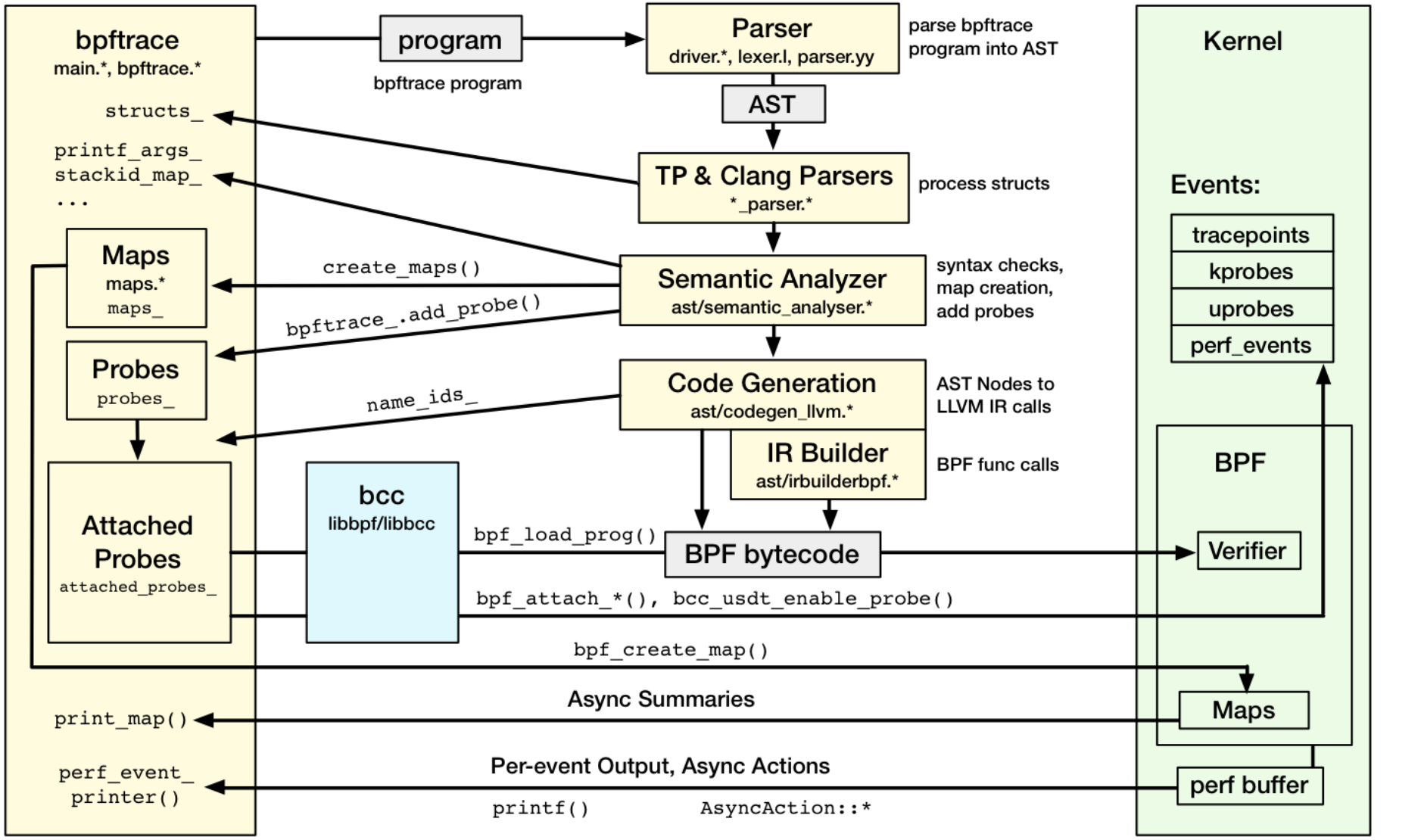
Linux 4.9+

```
# Syscall count by program
bpftrace -e 'tracepoint:raw_syscalls:sys_enter { @[comm] = count(); }'

# Read size distribution by process:
bpftrace -e 'tracepoint:syscalls:sys_exit_read { @[comm] = hist(args->ret); }'

# Files opened by process
bpftrace -e 'tracepoint:syscalls:sys_enter_open { printf("%s %s\n", comm,
    str(args->filename)); }'

# Trace kernel function
bpftrace -e 'kprobe:do_nanosleep { printf(“sleep by %s”, comm); }'

# Trace user-level function
Bpftrace -e 'uretprobe:/bin/bash:readline { printf(“%s\n”, str(retval)); }’
```

¨ Good for one-liners & short scripts; bcc is good for complex tools

https://github.com/iovisor/bpftrace

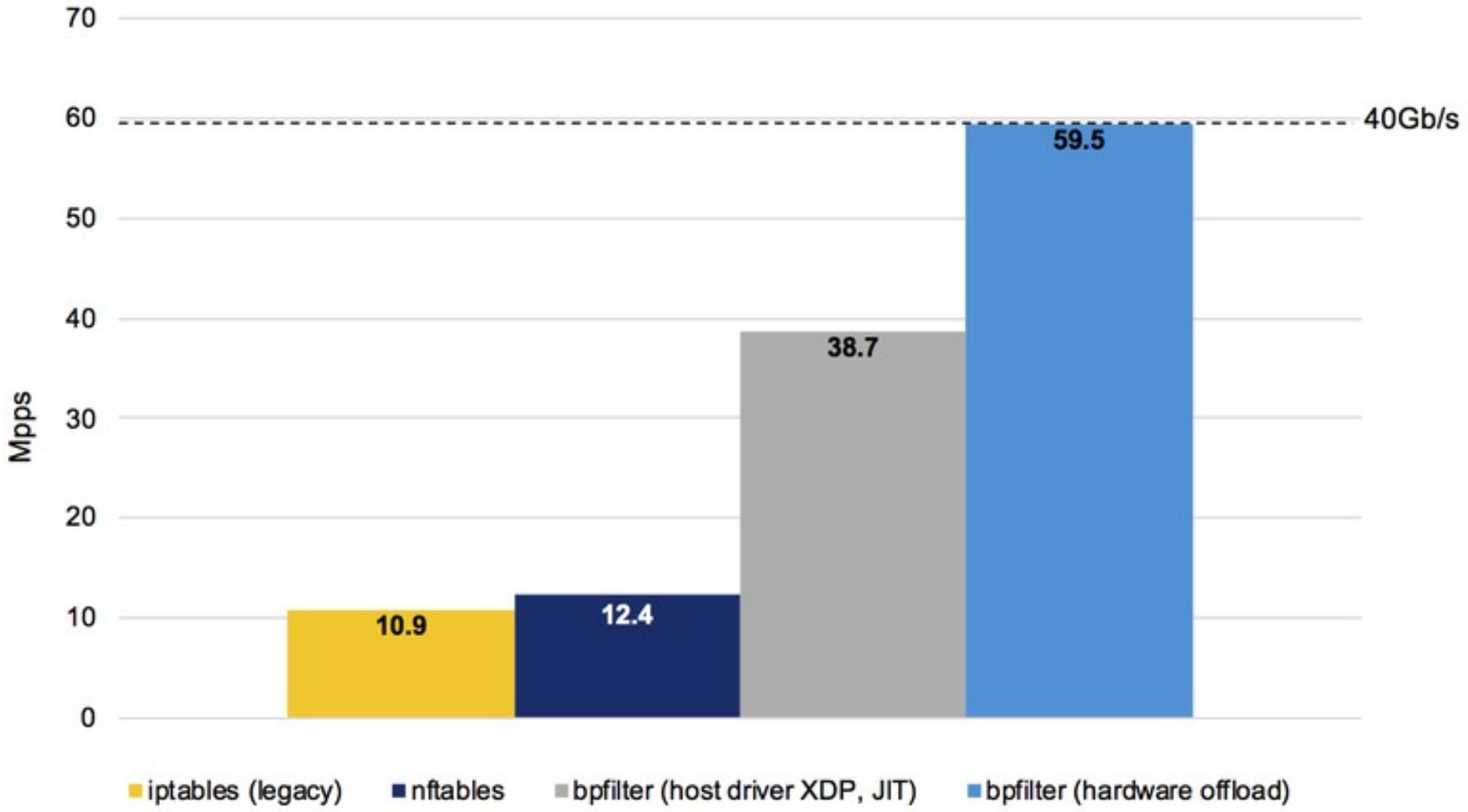
bpftrace Internals



https://github.com/iovisor/bpftrace 2018

eBPF XDP

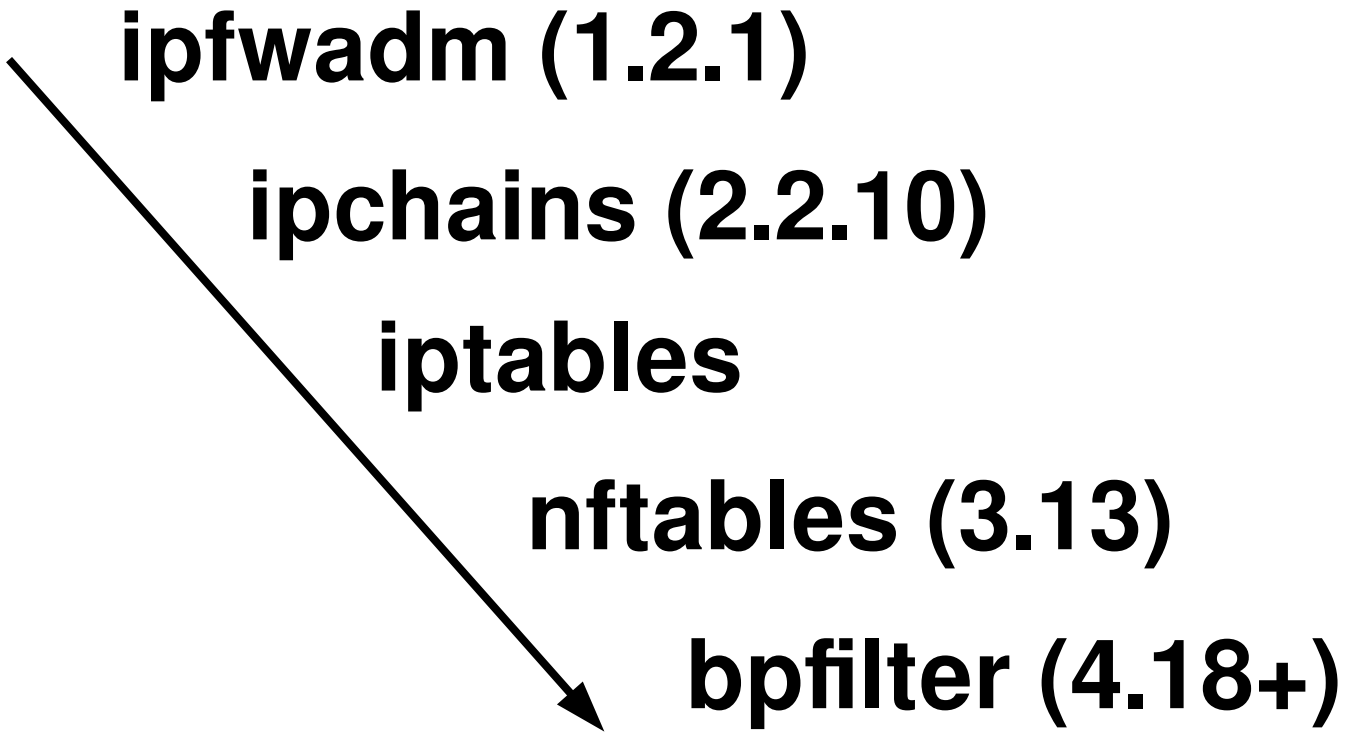
Linux 4.8+



https://www.netronome.com/blog/frnog-30-faster-networking-la-francaise/

eBPF bpfilter

Linux 4.18+



jit-compiled
NIC offloading

https://lwn.net/Articles/747551/

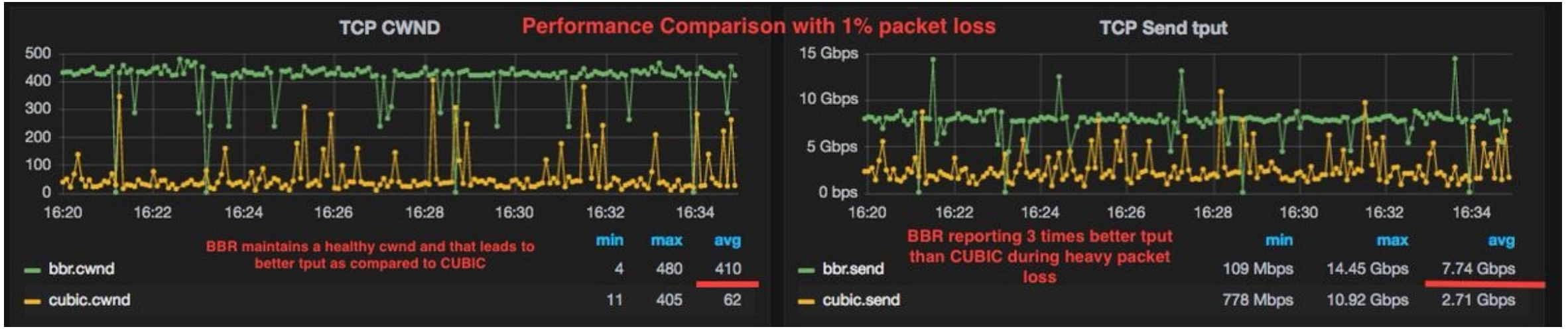
Linux 4.9

BBR

TCP congestion control algorithm

Bottleneck Bandwidth and RTT

1% packet loss: we see 3x better throughput



https://twitter.com/amernetflix/status/892787364598132736

https://blog.apnic.net/2017/05/09/bbr-new-kid-tcp-block/ https://queue.acm.org/detail.cfm?id=3022184

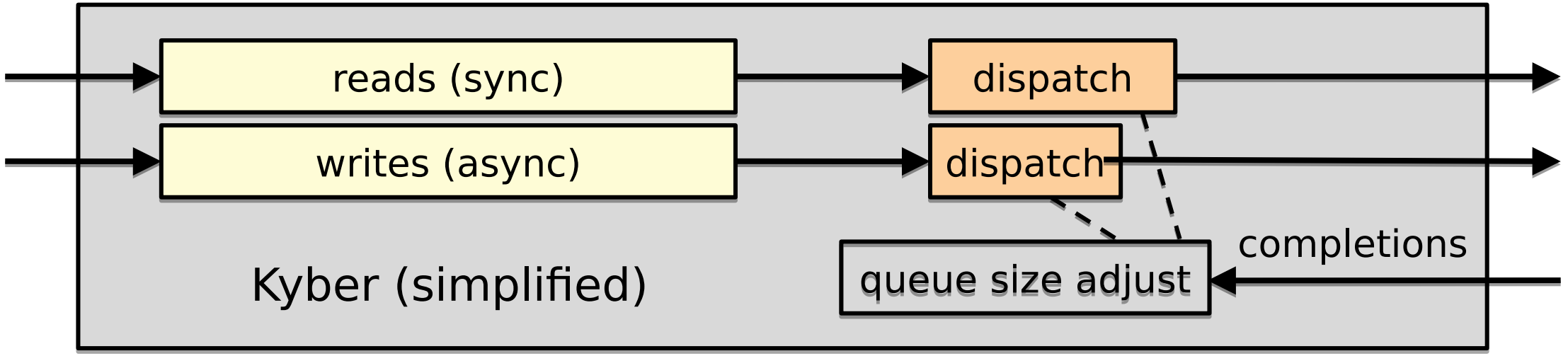
Linux 4.12

Kyber

Multiqueue block I/O scheduler

Tune target read & write latency

Up to 300x lower 99th latencies in our testing



https://lwn.net/Articles/720675/

Linux 4.17

Hist Triggers

```
# cat /sys/kernel/debug/tracing/events/kmem/kmalloc/hist
# trigger info:
hist:keys=stacktrace:vals=bytes_req,bytes_alloc:sort=bytes_alloc:size=2048
[active]
[…]
{ stacktrace:
     __kmalloc+0x11b/0x1b0
     seq_buf_alloc+0x1b/0x50
     seq_read+0x2cc/0x370
     proc_reg_read+0x3d/0x80
     __vfs_read+0x28/0xe0
     vfs_read+0x86/0x140
     SyS_read+0x46/0xb0
     system_call_fastpath+0x12/0x6a
} hitcount:      19133  bytes_req:   78368768  bytes_alloc:   78368768
```

ftrace
advanced
summaries

https://www.kernel.org/doc/html/latest/trace/histogram.html

PSI

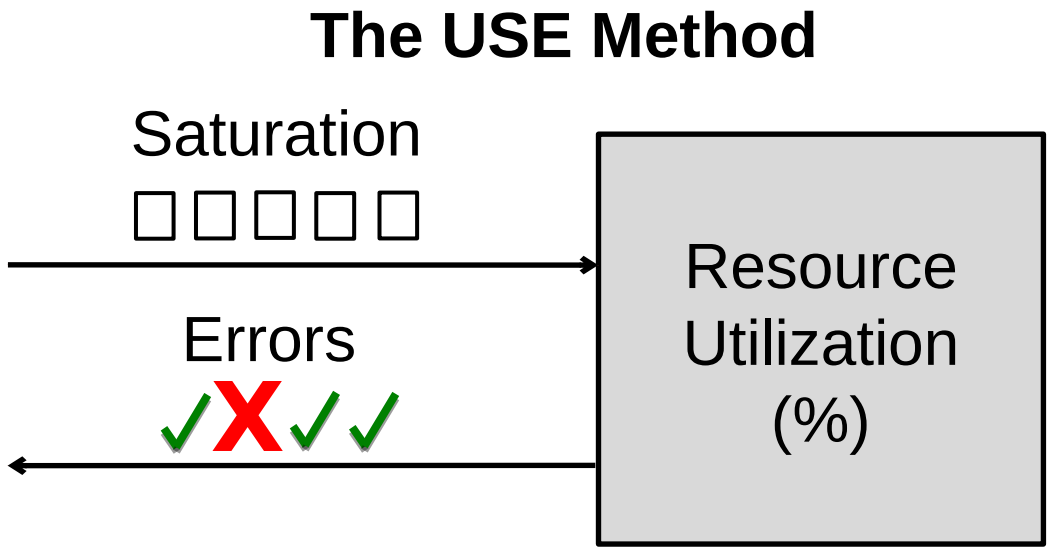
Linux 4.?
not merged yet

Pressure Stall Information

More saturation metrics!

```
/proc/pressure/cpu
/proc/pressure/memory
/proc/pressure/io
```

10-, 60-, and 300-second averages



https://lwn.net/Articles/759781/

More perf 4.4 - 4.19 (2016 - 2018)

- TCP listener lockless (4.4)
- copy_file_range() (4.5)
- madvise() MADV_FREE (4.5)
- epoll multithread scalability (4.5)
- Kernel Connection Multiplexor (4.6)
- Writeback management (4.10)
- Hybrid block polling (4.10)
- BFQ I/O scheduler (4.12)
- Async I/O improvements (4.13)
- In-kernel TLS acceleration (4.13)
- Socket MSG_ZEROCOPY (4.14)
- Asynchronous buffered I/O (4.14)
- Longer-lived TLB entries with PCID (4.14)
- mmap MAP_SYNC (4.15)
- Software-interrupt context hrtimers (4.16)
- Idle loop tick efficiency (4.17)
- perf_event_open() [ku]probes (4.17)
- AF_XDP sockets (4.18)
- Block I/O latency controller (4.19)
- CAKE for bufferbloat (4.19)
- New async I/O polling (4.19)

… and many minor improvements to:

- perf
- CPU scheduling
- futexes
- NUMA
- Huge pages
- Slab allocation
- TCP, UDP
- Drivers
- Processor support
- GPUs

Take Aways

1. Run latest
2. Browse major features

eg, https://kernelnewbies.org/Linux_4.19

Some Linux perf Resources

- http://www.brendangregg.com/linuxperf.html
- https://kernelnewbies.org/LinuxChanges
- https://lwn.net/Kernel
- https://github.com/iovisor/bcc
- http://blog.stgolabs.net/search/label/linux
- http://www.brendangregg.com/blog/2018-02-09/kpti-kaiser-meltdown-performance.html