BPF and the future of the kernel extensibility

June 2018

ast@kernel.org

facebook

Goal

-- This presentation focuses on past, present and the future of BPF --

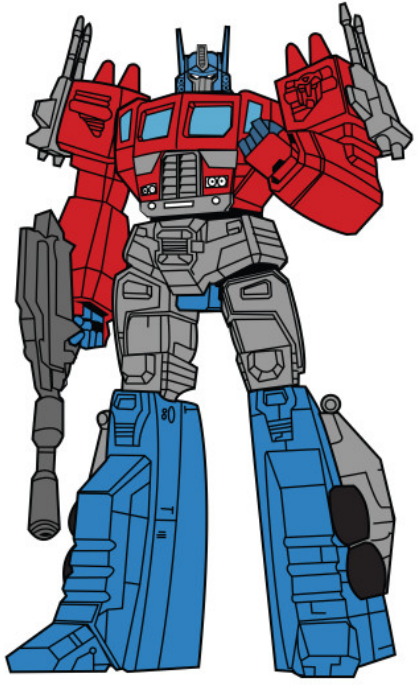
- Let non-kernel developers safely and easily modify kernel behavior

==

- Make BPF easy to use

BPF in the past

- Either a truck or a robot
- Cool and powerful, but only in these two forms
- tcpdump, dhclient, pcap, nmap, solarflare – packet filtering
- seccomp – chrome sandbox



BPF in the present

- Giant lego set where instruction manual was not printed

BPF in the present

- Despite lack of instructions people built lots of REAL rocket ships:
  - Katran, droplet, tcpeventd, fbflow, blklatencyd, dynolog, strobelight, ttld, ila
  - Lots of BCC tools, bpftrace, ply, systemtap-bpf
  - Cilium, weaveworks, sysdig, systemd per-cgroup
- ships do look similar

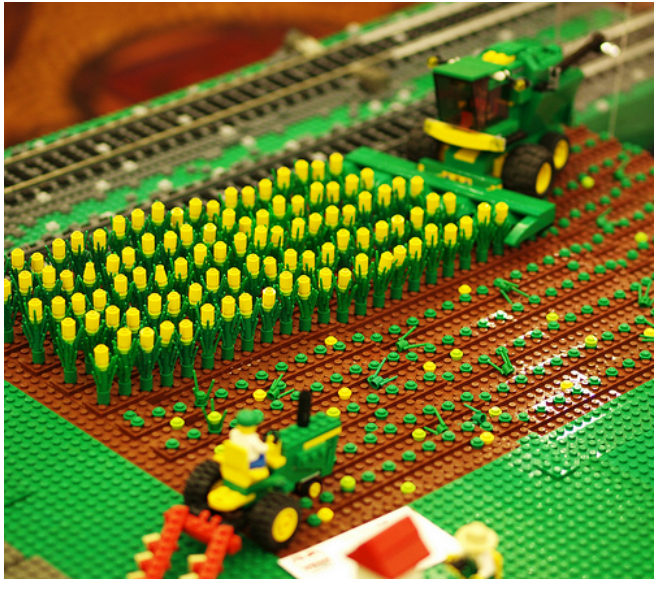
Why folks learn BPF ?

- NOT because it's cool
- To solve real production issues the user space only solution is not good enough
- Kernel behavior needs to be modified
- Best solutions appear when kernel and user space work together

- when kernel is difficult to extend and roll in production, it is bypassed
  - ex: dpdk/spdk, seastar/scylladb, snabb, odp, vpp
- kernel needs BPF to stay relevant

How BPF programs look today?

- Loop-free, lock-free, short BPF programs that glue lots of kernel helpers and invoked at specified hooks



BPF hooks in tracing

- kprobe – read only access to arguments of any kernel function
- uprobe – read and write access to any user space process
- syscalls – read only access to syscall args
- pmu events (timers, hw/sw counters) – read only pt_regs
- tracepoint – read only access to tracepoint record defined in events/…/format
- raw_tracepoint – read only access to kernel internal tracepoint args

BPF hooks in networking

- sockets – read only access to skb
- XDP – raw dma buffer of the NIC
- lwt – routing in/out/xmit partial read/write of skb
- clsbpf – tc ingress/egress full read/write of skb
- cgroup scoped
  - socket create
  - L3 socket ingress/egress read only and drop
  - tcp-bpf variety (timeout_init, rwnd_init, tcp_connect, active_established, passive_established, needs_ecn, base_rtt, rto, retrains, state_change)
  - sockmap (L7 parsing on ingress before recvmsg with redirect) == in-kernel tcp proxy
  - device (mknod, read, write)
  - bind/connect

BPF helpers

- map access (lookup, update, delete)
- tail_call – jump into next bpf program
- perf_event_output – ring buffer communication with user space
- probe_read, probe_read_str, probe_write_user – probe kernel memory and write into user
- get_stackid – kernel/user stack collection
- ktime_get_ns, prandom, processor_id, numa_node_id
- get_current_task
- override_return – fault injection

BPF helpers in networking

- load_bytes, store_bytes – batch modify skb
- change_head, change_tail – modify skb size
- csum_replace, csum_update, csum_diff
- change_proto – ipv4->ipv6
- set/get_tunnel, push/pop_vlan – encap/decap
- set_hash/get_hash
- get_socket_cookie, get_socket_uid – android traffic accounting
- setsockopt, getsockopt – tcp-bpf
- redirect – xdp and skb level redirect
- sk_redirect – L7 tcp stream redirect

BPF verifier

BPF verifier in the present

- Loop-free, lock-free, short BPF programs with single argument (context) that call BPF helpers

- BPF-to-BPF calls started new era of verifier analysis
    - arbitrary arguments (up to 5) and arbitrary return value

BPF verifier in the future

- track pointer life time within program (the work is done by Joe Stringer from Covalent)
  - use-case: return socket pointer from bpf helper and make sure that program does sock_put() on it
  - allows lock/unlock, malloc/free to be called by the program

BPF verifier in the future

- bounded loops (competing proposals from John Fastabend from Covalent and Ed Cree from Solarflare)
    - safe loops inside programs!

BPF verifier in the future

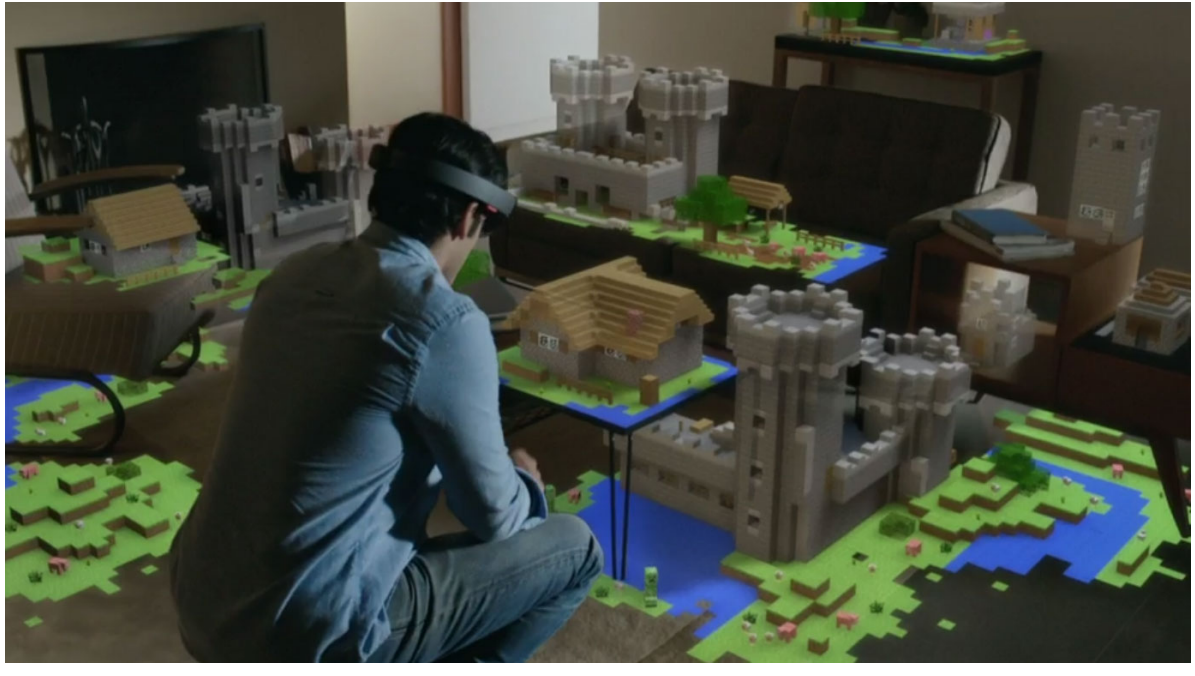
- local storage to eliminate hash lookups
- global variables
- indirect calls that are statically verified and patched
- libraries
- dynamic linking

BPF verifier in the future

- move away from existing brute force "walk all instructions" approach to proper compiler technology and static analysis
- remove #define BPF_COMPLEXITY_LIMIT 128k crutch
- remove #define BPF_MAXINSNS 4k
- support arbitrary large programs and libraries
    - 1 Million BPF instructions
- an algorithm to solve Rubik's cube will be expressible in BPF

BPF in the future

- easy to use
- easy to learn



Thank you!
Please ask questions
Part 2 is coming

Agenda

- btf update
- libbpf elf loader, elf->c codegen
- katran
- fd-based networking and cgroups
- cgroup local storage
- common driver core
- firmware no more

BTF update

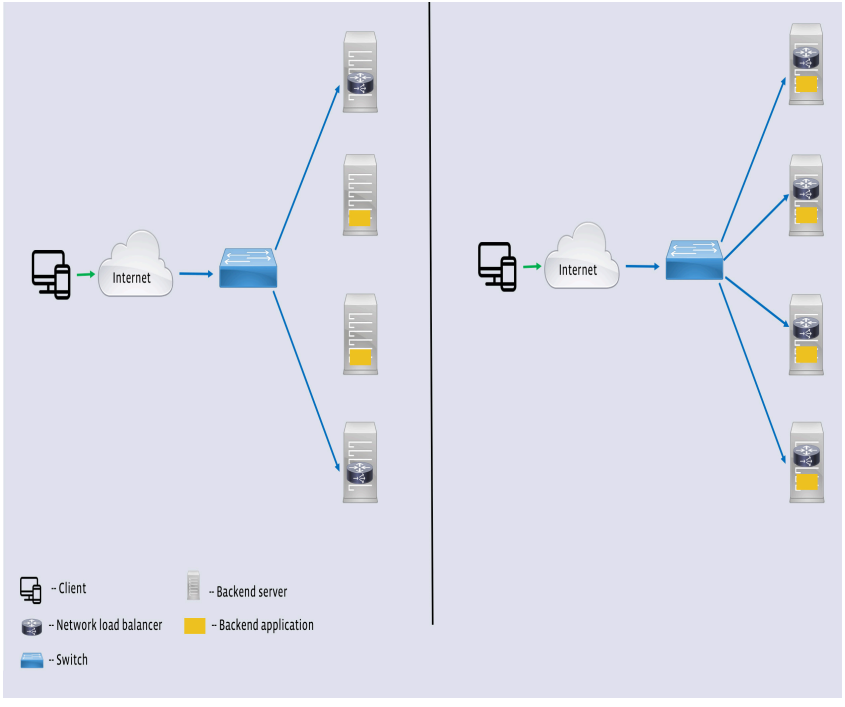
- similar to old Compat Type Format yet different encoding
- landed
  - all basic types, structs, unions
  - support for map key and value
  - btf_id, btf_fd, get_next introspection
- implemented
  - support for 'function pointer type'
  - pahole -> btf
- upcoming
  - reuse 'function pointer type' to describe bpf progs
    (yet another difference vs CTF)
  - describes prog name, arguments, return type
  - integrate with verifier for safety checks
  - llvm btf backend
  - libbpf and bpftool support
- future
  - vmlinux dwarf->btf section
  - llvm pointer dereference (bpf_probe_read) annotation with symbolic field name

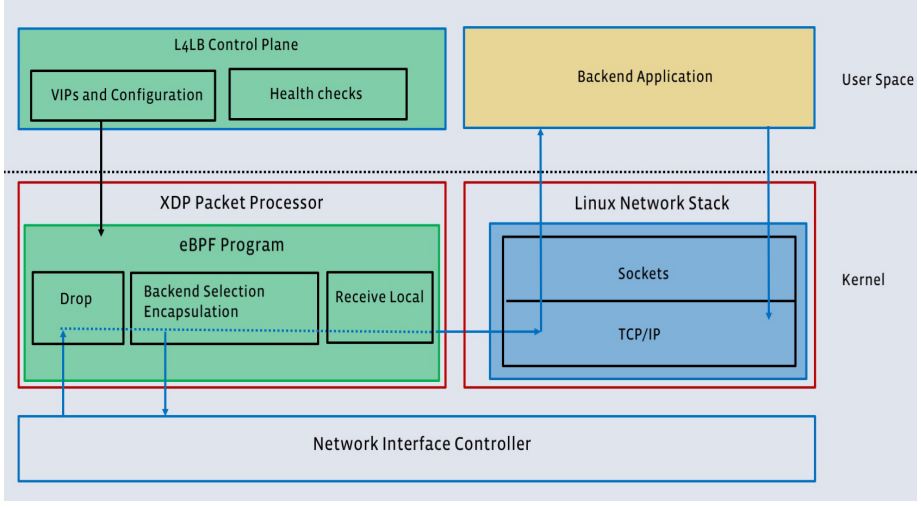
libbpf

- todays libbpf is elf loader only
- implemented
  - btf reader from kernel and pretty print
- future
  - write into bpf maps with btf info from kernel
  - extend with dwarf->btf converter and push btf to kernel
  - convert .o bpf files into standalone .c files where bpf progs represented as hex bytes and C code that can load progs/maps as a sequence of sys_bpf() calls.
    That removes elf/dwarf from dependency for final app that compiles and links these generated .c

katran

- facebook open sourced production L4 load balancer (katran)
- https://github.com/facebookincubator/katran
- gpl-2
- https://code.facebook.com/posts/1906146702752923/open-sourcing-katran-a-scalable-network-load-balancer/
- key advantage enabled by XDP:





FD based APIs

- all bpf attachments points can be either global (xdp, tc, cgroup) or local (sockets, perf_events)
- global -> the progs stay attached even when user space exits
- local -> attached to FDs. auto-detach, auto-unload when user space exits
- recently added FD based kprobe, uprobe, raw_tracepoint APIs
- cgroup-bpf is difficult to get right, since cgroup can be cgroup_is_dead() or unmounted
    - centralize cgroup-bpf management into single deamon
    - introduce new cgroup-fd object just for attaching bpf to it
- convert tc ingress/egress hooks to be FD based as well
    - solves concurrency issue (multi process access to the same attach point)
    - solves autocleanup

cgroup local storage

- similar to Thread Local Storage
- new map type. one per program. value_size = requested size of local storage
- bpf_get_local_storage(map, flags)
  - cheap and fast helper to return a pointer to scratch buffer that is uniquily visible to this program only at given cgroup
- storage area allocated once at attach time of bpf prog to cgroup
- destroyed when prog is detached
- access from user space via bpf_map_lookup()/update()

- next steps
  - socket local storage and task local storage
  - clang+llvm extension:

```
__cgroup struct cgroup_buf {
    int var;
} buf;
int bpf_prog(ctx)
{
    access buf.var;
}
```

common driver core

- drivers are slow to add XDP support
- move memory management out of drivers into core

firmware no more

- proprietary firmware in a NIC is a huge security threat. Bigger than spectre/meltdown
- firmware used to be tiny sw shim baked into chip once
- now firmware is a monster blob full of secret features and bugs
- firmware sw teams often several times larger than driver teams
- most of the firmware logic has to become open, become part of the driver, and kernel git
- anything that can be flushed -> open
- baked in forever firmware (analog, phy, power, tpm) -> proprietary for now