A Primer on eBPF 🐝

(Or, *‘WebAssembly for the Linux Kernel’*)

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EOS+ Tech Talk – 13th April, 2023

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eBPF: What?

Figure 1: *'eBee', the eBPF Mascot.*

- *Simple* register machine VM bytecode for user-written code.
- Attach logic to *syscalls* & *hooks*.
- (Somewhat) common compile target 🦀.
- ...and very exciting for host networking via AF_XDP!
- Windows support now, too!

eBPF: Why?

- Lightweight instrumentation and debugging of:
    - the network stack,
    - the file system,
    - kernel functions,
    - drivers and hardware...
- *Network stack programmability*.
- JIT compiled (*x86_64*, *AArch64*).
- Kernel-verified and sanitised – secure & safe.

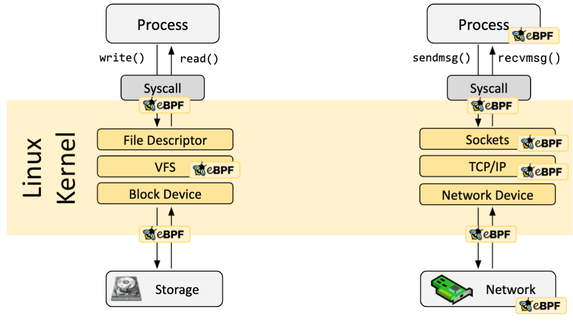

Figure 2: *eBPF Hook points.*

Who's using it?

Cloudflare DDoS attack scrubbing (*flowtrackd*[1]).

Meta Fast in-kernel L4-aware load balancing (*Katran*[2]).

Google, AWS, … Kubernetes load balancing & security (*Cilium*[3]).

Open vSwitch Software routing[4].

…and kernel/userland debugging via *bpftrace* (à la Dtrace).

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[1] Yoachimik, *flowtrackd: DDoS Protection with Unidirectional TCP Flow Tracking*.
[2] Facebook Incubator, *Katran*.
[3] Cilium Authors, *Cilium*.
[4] Tu *et al.*, 'Revisiting the Open vSwitch Dataplane Ten Years Later'.

History & Details

A Little Bit of History

eBPF was once BPF – the Berkeley/BSD Packet Filter[5].

- **2-register**, 32 bit VM.
- Early filtering for `tcpdump` etc.
- Circa 1993.

[5] McCanne and Jacobson, 'The BSD Packet Filter: A New Architecture for User-level Packet Capture'.

Technical details (I)

- 64 bit ISA.
- 10 registers,
- Still RISC at heart – a *very* bare-bones set of instructions.

Technical details (II)

class	value	description	reference
BPF_LD	0x00	non-standard load operations	Load and store instructions
BPF_LDX	0x01	load into register operations	Load and store instructions
BPF_ST	0x02	store from immediate operations	Load and store instructions
BPF_STX	0x03	store from register operations	Load and store instructions
BPF_ALU	0x04	32-bit arithmetic operations	Arithmetic and jump instructions
BPF_JMP	0x05	64-bit jump operations	Arithmetic and jump instructions
BPF_JMP32	0x06	32-bit jump operations	Arithmetic and jump instructions
BPF_ALU64	0x07	64-bit arithmetic operations	Arithmetic and jump instructions

where $ALU = \{+, -, \times, \div, \textit{shifts} \ \& \ \textit{bitwise}, \cdots\}$, with atomic modifiers.

Technical details (III)

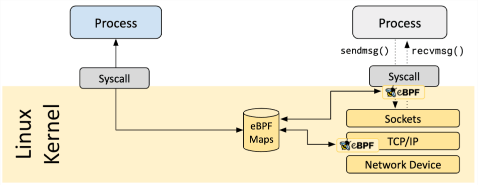
How does most of the magic happen?

BPF Helpers.

- Entry points and types specified by hook location
- This *also* controls what kernel functions can be called – an enforced API.
- E.g., RNG, map accesses, timer & thread information.
- Portable between kernel versions due to CO-RE (BTF).

```
long bpf_trace_printk(const char *fmt,
    u32 fmt_size, ...);

long bpf_skb_vlan_push(struct sk_buff *skb,
    __be16 vlan_proto,
    u16 vlan_tci);

long bpf_xdp_adjust_head(struct xdp_buff *xdp_md,
    int delta);

u32 bpf_get_prandom_u32(void);

u64 bpf_perf_event_read(struct bpf_map *map,
    u64 flags);

u64 bpf_jiffies64(void);

long bpf_tail_call(void *ctx,
    struct bpf_map *prog_array_map,
    u32 index);

// ...
```

Technical details (IV)



- eBPF ↔ Userland comms. via eBPF Maps.
- Hash tables, arrays, per-CPU maps, socket descriptor maps, program maps.
- Also eBPF ↔ eBPF.

Verification

Before loading, *all programs must be verified by the kernel*:

- Bounds-checked pointer accesses.
- Type-checked pointer accesses.
- Program size limited, no unbounded loops.
- Write-protection, constant-blinding of JITed code.

How do we compile to eBPF? 🦀🦀

🦀🦀 How do we write & interact with eBPF programs? 🦀🦀

BCC Write in C, feed to LLVM wrapper built in Python.

Rust 🦀🦀 *redbpf*, *libbpf-cargo*, *aya*, ... 🦀🦀

- Iffy CO-RE, Linux v6 support for redbpf.

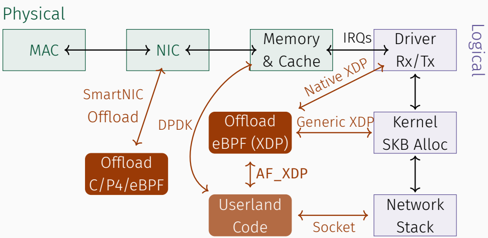
GCC Support for C since 2020.

Cilium Write in C, launch and communicate using maps in Go.

...with no bias from me! 🦀

Networking

How does this relate to networking? XDP & **AF_XDP**!



- XDP is an eBPF hook attached to packet ingress
- Not just inspect – **modify**.
- Variations on hook $\in$ {Offload, Driver, Generic}
  - Perf degrades gracefully according to driver support
- Hook can locally handle packets before forwarding to Linux stack, sending straight to (another) NIC, or drop.
- Since 2019: **AF_XDP** stack bypass!

Limitations

In XDP, Parallel threads limited to num of Rx queues on NIC.

Static verification means different model from e.g. Rust.

❌

```
pub fn handle_pkt(pkt: &mut [u8]) -> Action {
    if pkt.len() >= 12 {
        let mut src_mac = &mut pkt[6..12];
        src_mac.copy_from_slice(&[
            0xaa, 0xbb, 0xcc,
            0xdd, 0xee, 0xff
        ]);
        // FAILS VERIFICATION
    }
    Action::Pass
}
```

✅

```
pub fn handle_pkt(pkt: impl Packet) -> Action {
    if let Some(src_mac) = pkt.slice_from(6, 6) {
        // bytes: &mut [u8]
        src_mac.copy_from_slice(&[
            0xaa, 0xbb, 0xcc,
            0xdd, 0xee, 0xff
        ]);
        // Passes verification!
        // Why? Trait checking pointer
        // against 'end-of-packet' ptr.
    }
    Action::Pass
}
```

Why choose this over DPDK?

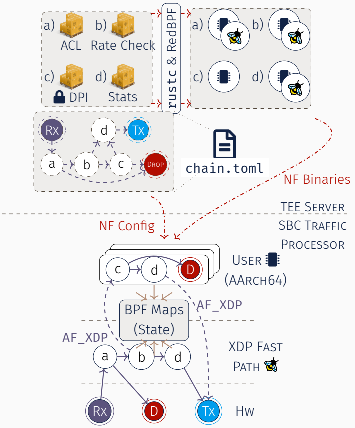
- More CPU- and power-efficient than DPDK[6].
- Arguably easier to write and use.
- Works on any modern Linux box.
    - Even RPi if you recompile the kernel!
- Performance still strong – $\mathcal{O}(20\,\mu s)$ min latency.

[6] Høiland-Jørgensen *et al.*, 'The eXpress data path: fast programmable packet processing in the operating system kernel'.

Composition

A huge limitation of eBPF programs is size. *But we have tail-calls.*

- Packet function chains in datacentres[a], with dynamic PGO[b].
- Doable with more constraints on weaker machines – lat-tput tradeoffs (right).



[a] Miano, Risso *et al.*, 'A Framework for eBPF-Based Network Functions in an Era of Microservices'.
[b] Miano, Sanaee *et al.*, 'Domain specific run time optimization for software data planes'.

Takeaways:

eBPF is a powerful tool for accelerating networked services and host instrumentation.

Easy to program from your favourite systems programming languages!

Portable and actively developed.

A hot topic! *Active SIGCOMM CFP* for networks.

Questions?

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