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Introduction to eBPF (for network packet processing)

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Beba
BEhavioural BAsed forwarding

6WIND

BPF example with tcpdump

```
# tcpdump -i eth0 tcp dst port 22 -d

(000) ldh      [12]                          # Ethertype
(001) jeq      #0x86dd       jt 2    jf 6    # is IPv6?
(002) ldb      [20]                          # IPv6 next header field
(003) jeq      #0x6          jt 4    jf 15   # is TCP?
(004) ldh      [56]                          # TCP dst port
(005) jeq      #0x16         jt 14   jf 15   # is port 22?
(006) jeq      #0x800        jt 7    jf 15   # is IPv4?
(007) ldb      [23]                          # IPv4 protocol field
(008) jeq      #0x6          jt 9    jf 15   # is TCP?
(009) ldh      [20]                          # IPv4 flags + frag. offset
(010) jset     #0x1fff       jt 15   jf 11   # fragment offset is != 0?
(011) ldxb     4*([14]&0xf)                  # x := 4 * header_length (words)
(012) ldh      [x + 16]                      # TCP dest port
(013) jeq      #0x16         jt 14   jf 15   # is port 22?
(014) ret      #262144                       # trim to 262144 bytes, return packet
(015) ret      #0                            # drop packet
```

tcpdump → libpcap → BPF bytecode → kernel interpreter / JIT
BPF filter attached to socket to filter packets and avoid useless copies

Berkeley Packet Filter

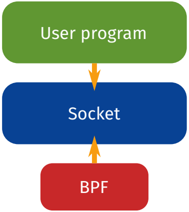
History

- 1993: “cBPF” (*classic* BPF) on BSD, for packet filtering
- 1997: ported to Linux

BPF ~ Basics

BPF is an assembly-like language with registers and stack, integer arithmetic, conditional branches. JIT-compilable, for performances.

Usage: filter packets **in the kernel** with programs coming **from user space**




```
int s = socket (PF_INET, SOCK_RAW, IPPROTO_TCP);
setsockopt(s, SOL_SOCKET, SO_ATTACH_FILTER, &bpf_prog, sizeof(bpf_prog));
```

Safety ensured by in-kernel verifier:

- No backward jumps
- Program limited to 4096 instructions
- Dynamic packet-boundary checks
- Etc.

Re-designing BPF: **e**xtended **BPF**

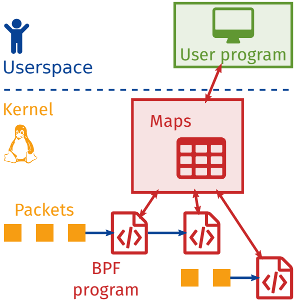
History

- 1993: “cBPF” (*classic* BPF) on BSD, for packet filtering
- 1997: ported to Linux
- **2013+: “eBPF” (*extended* BPF)**, Linux only — Project IO Visor

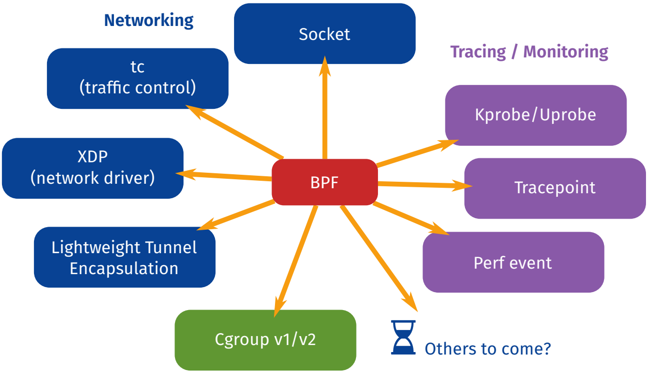
Design goals: better safety, flexibility and performances

How does eBPF improve over cBPF?

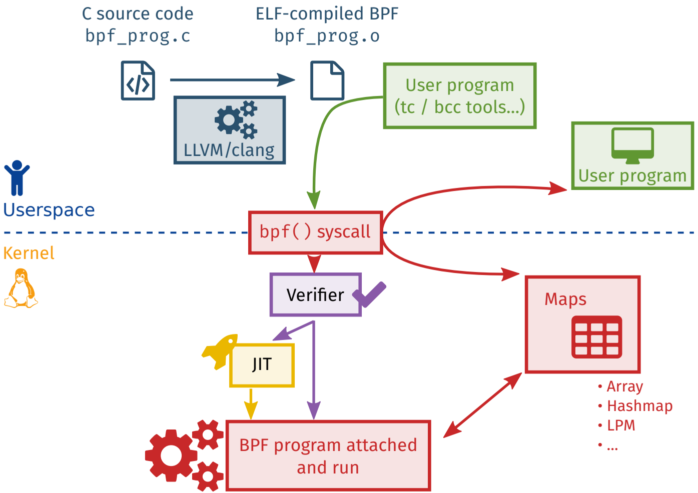
- Technical upgrades
  - From 2 registers (32-bit) to 11 registers (64-bit)
  - New, larger set of instructions, closer to assembly
  - Etc.
- New functionalities
  - **Call instruction**: can call certain (white-listed) kernel helper functions
  - ***Tail calls***, kind of “long jumps” into another eBPF program
  - Can **map memory** to communicate with userland applications or other eBPF programs



New hooks... Lots of them!



How to use eBPF?



bcc tools: C helpers + Python wrappers to help handling BPF programs
Also: Go, Lua helpers; P4 to eBPF-compatible C compiler; ...

Example, for `tc` (traffic control) interface:

```c
/* Drop all packets for TCP port 22 */
#define BLOCKED_TCP_PORT 22

int handle_ingress(struct __sk_buff *skb)
{

    /* Variable declaration & initialization omitted here */
    …

    /* Length check */
    if (data + sizeof(*eth) + sizeof(*iph) + sizeof(*tcp) > data_end)
        return TC_ACT_OK;   /* Forward */

    /* Is it IPv4? */
    if (eth->h_proto != htons(ETH_P_IP))
        return TC_ACT_OK;   /* Forward */

    /* Is it TCP? Is IP header length equal to 5? */
    if (iph->protocol != IPPROTO_TCP || iph->ihl != 5)
        return TC_ACT_OK;   /* Forward */

    /* Is it the port we want to block? */
    if (tcp->dest == htons(BLOCKED_TCP_PORT))
        return TC_ACT_SHOT; /* Drop */

    return TC_ACT_OK;   /* Forward */
}
```

Compile and run

- Compile from C to eBPF:

```
$ clang -O2 -emit-llvm -c bpf_prog.c -o - | \
    llc -march=bpf -filetype=obj -o bpf_prog.o
```

- Attach it as a `tc` classifier

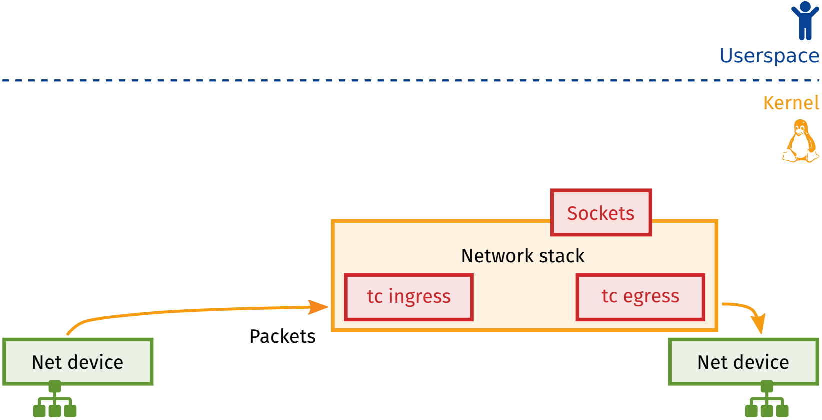
```
# tc qdisc add dev eth0 clsact
# tc filter add dev eth0 ingress \
    bpf direct-action object-file bpf_prog.o
```

- If needed, initialize the maps (user-space program with `bpf()` syscall)

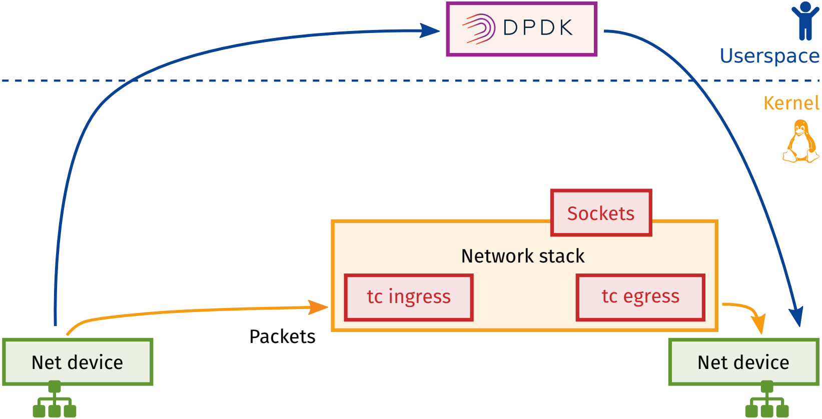
XDP

- *eXpress DataPath* (XDP): in-kernel fast packet processing:
  - Hooks in supported drivers to attach eBPF programs
  - Intercepts packets before packet reaches the stack / before sk_buff allocation
  - For basic use cases. Complex use cases: forward to the stack
- Linux 4.8+; Still in development

XDP


Userspace
Kernel
Sockets
Network stack
tc ingress
tc egress
Packets
Net device
Net device

XDP


DPDK
Userspace
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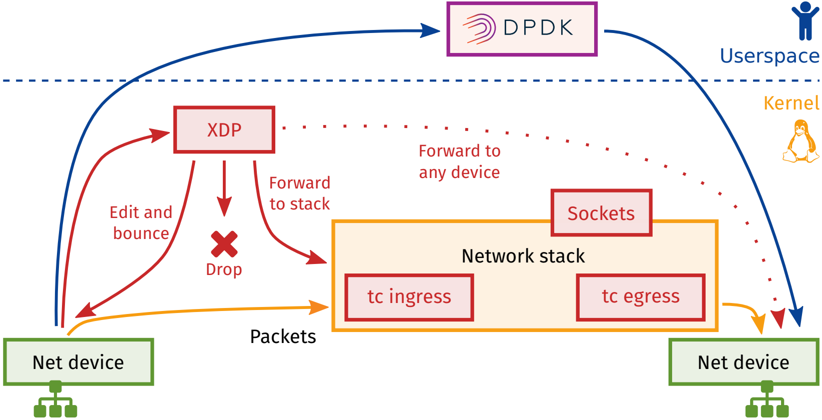

DPDK
Userspace
Kernel
XDP
Forward to
any device
Forward
to stack
Edit and
bounce
Drop
Sockets
Network stack
tc ingress
tc egress
Packets
Net device
Net device

XDP performances

XDP benchmark, single CPU:

- Filter drop all (but read/touch data): 20 Mpps
- TX-bounce forward: 12 Mpps
- TX-bounce with UDP + MAC rewrite: 10 Mpps

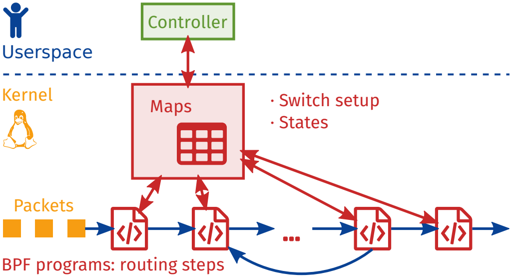
CPU @3.70 GHz; Mellanox 40 Gbps, mlx4 driver, with DDIO
http://people.netfilter.org/hawk/presentations/OpenSourceDays2017/XDP_DDoS_protecting_osd2017.pdf

Hardware offload exists

Use cases for eBPF/XDP ~ Some network functions

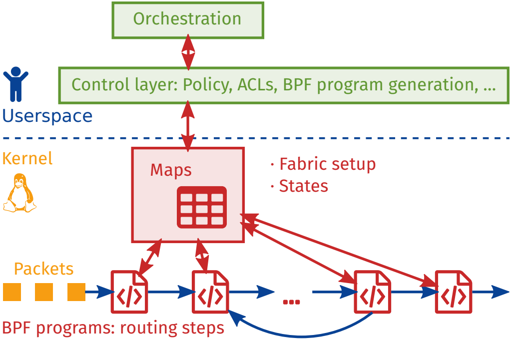
- Protection against DDoS attacks
- Load balancing
- QoS
- ILA (Identifier-Locator Addressing) router
- ...

Use cases for eBPF/XDP ~ Virtual switch



- A new backend for Open vSwitch
- BEBA project: fast and stateful packet processing for vSwitches

Use cases for eBPF/XDP ~ Network fabric



- Open Virtual Network (OVN) backend with IO Modules
- Cilium: Fast networking for containers with BPF/XDP

Summary

- eBPF is fast, stateful
- Runs in kernel, with userspace flexibility
- XDP: in-kernel dataplane acceleration
- Networking, but also Linux tracing / monitoring
- Still under development, growing community

Questions

Resources

GitHub repository of the **IO Visor** project (bcc tools, documentation, and more)
`https://github.com/iovisor/`

Resources on BPF — *Dive into BPF: a list of reading material*
`https://qmonnet.github.io/whirl-offload/2016/09/01/dive-into-bpf/`

BEBA research project
`http://www.beba-project.eu/`

Cilium (code repository, links to presentations), initially scheduled on this slot
`https://github.com/cilium/cilium`