eBPF and IO Visor:
The what, how, and what next!

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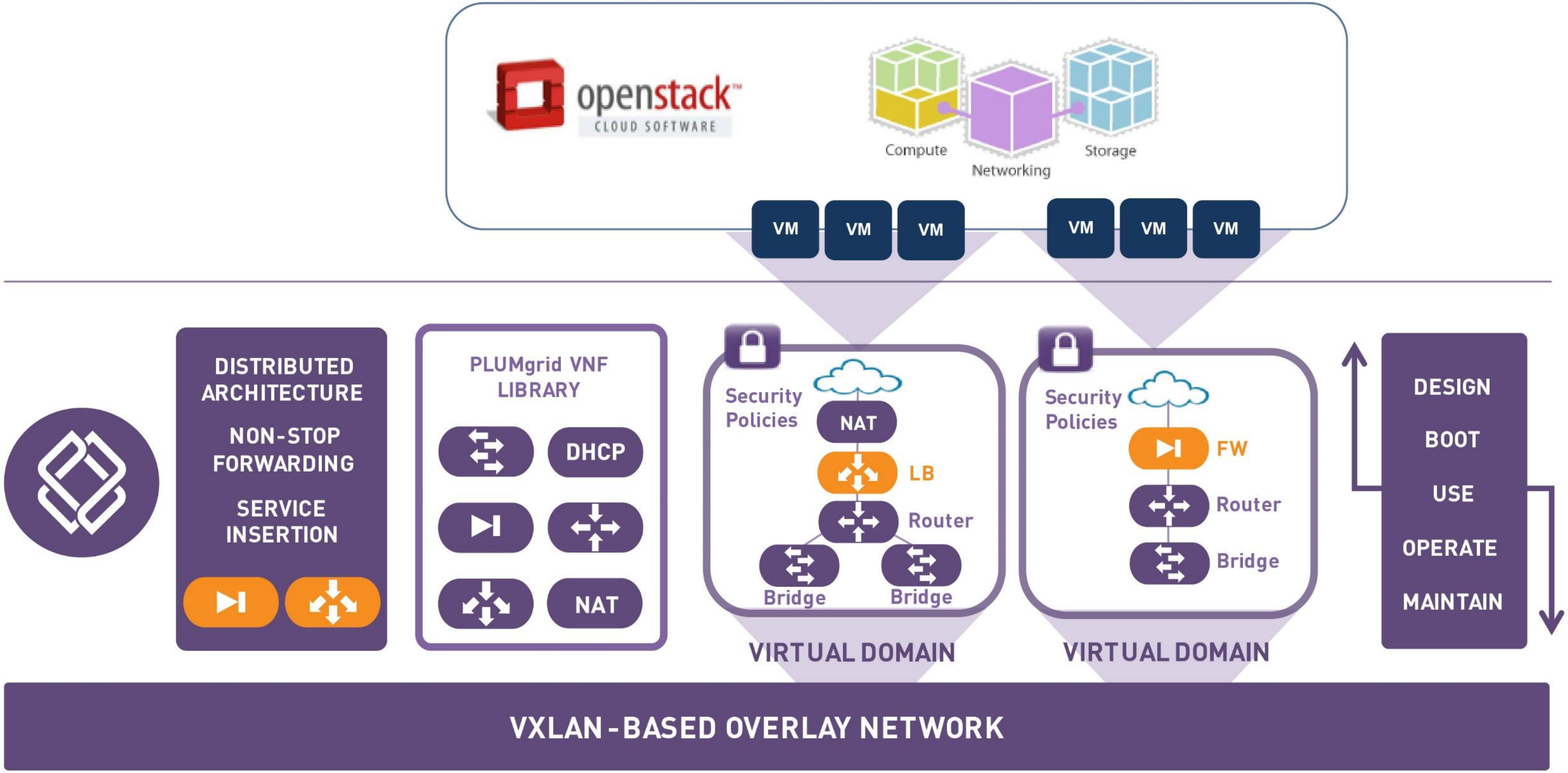
About PLUMgrid

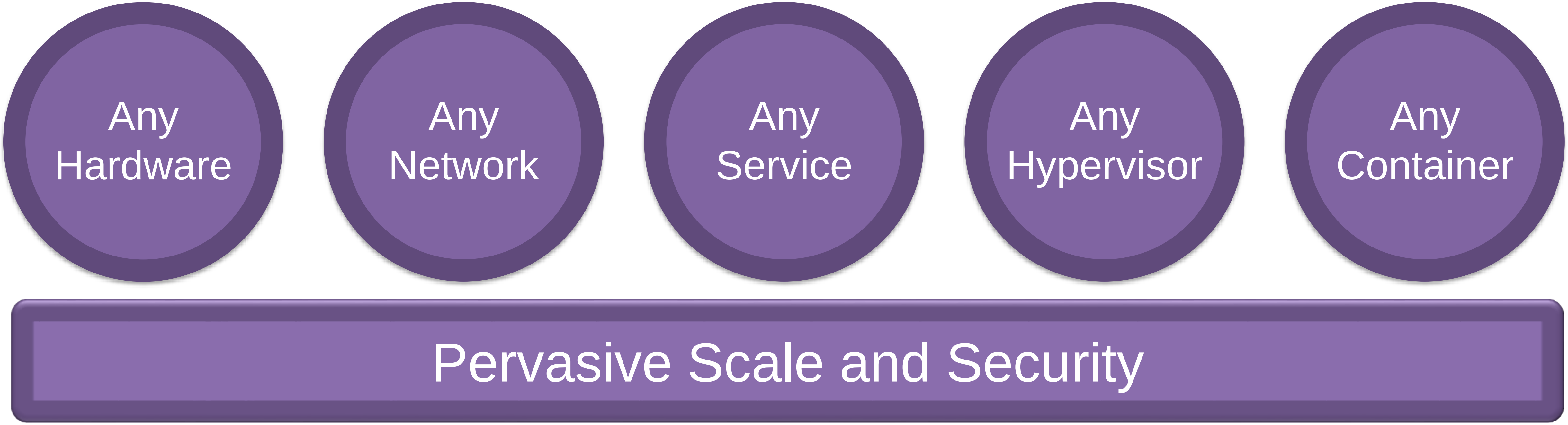


PLUMgrid's Mission

Deliver comprehensive virtual networking solutions that scale, secure, and simplify the modern cloud data center

LINUX FOUNDATION COLLABORATIVE PROJECTS

IOVISOR PROJECT



Talk outline

Outline

- Berkeley Packet Filter (BPF) and bytec
- Extended BPF (eBPF): Motivation and features
- BCC and IO Visor
- Basic demos
- Research Directions

Packet Filters and cBPF

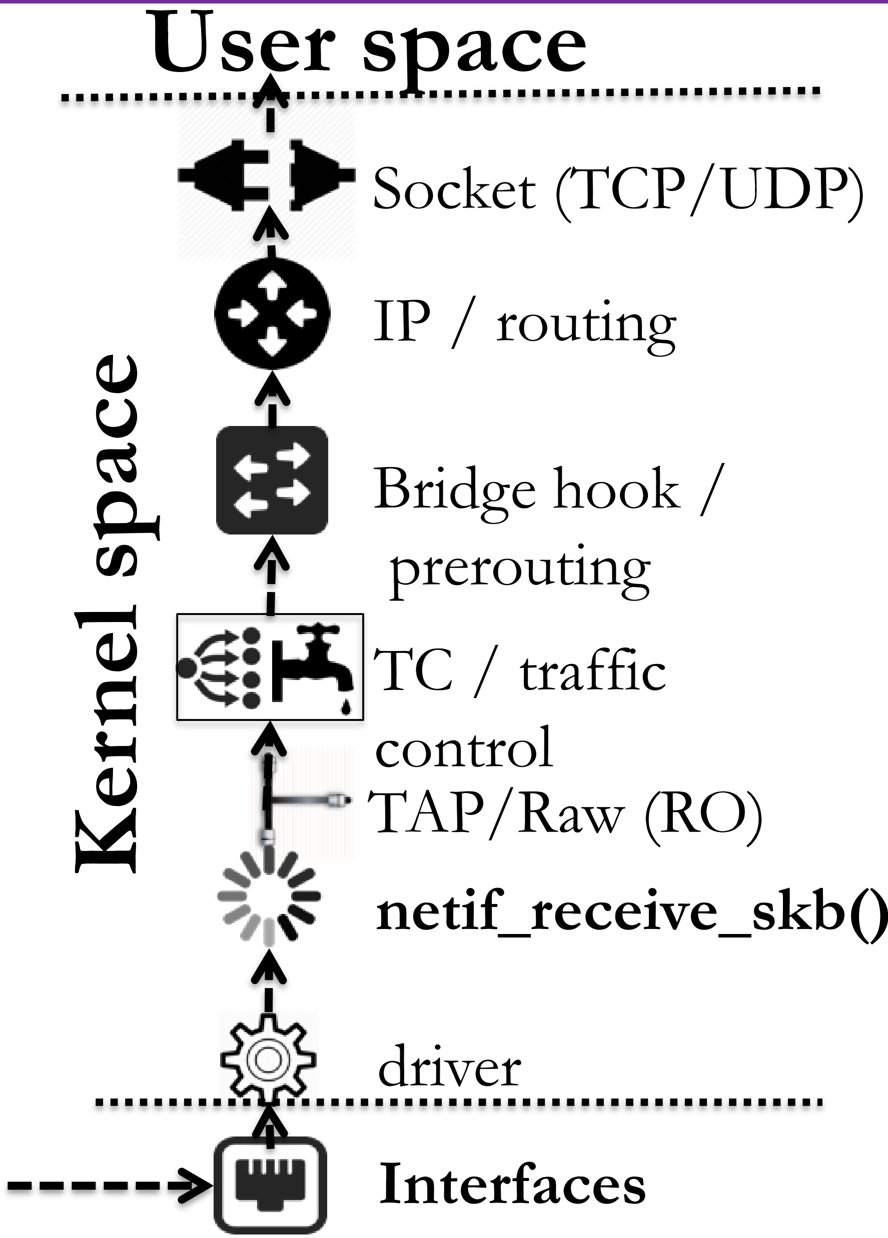
Packet Filters

Objective: To observe **all** traffic but capture only a subset

Problem: Packet traversal through normal stack is slow

Solution: Setup filters **in kernel** where packet dropped if not match

....but these filters need to be secure!



Tcpdump our friend

Lets do: sudo tcpdump -p -ni eth0 "ip and udp“

Now lets do: $ sudo tcpdump -p -ni eth0 **-d** "ip and udp"

```
(000) ldh      [12]
(001) jeq      #0x800          jt 2    jf 5
(002) ldb      [23]
(003) jeq      #0x11           jt 4    jf 5
(004) ret      #65535
(005) ret      #0
```

This code runs for every packet that arrives on eth0

The concept of pseudo-machine

Think Java --- but don’t think VM !

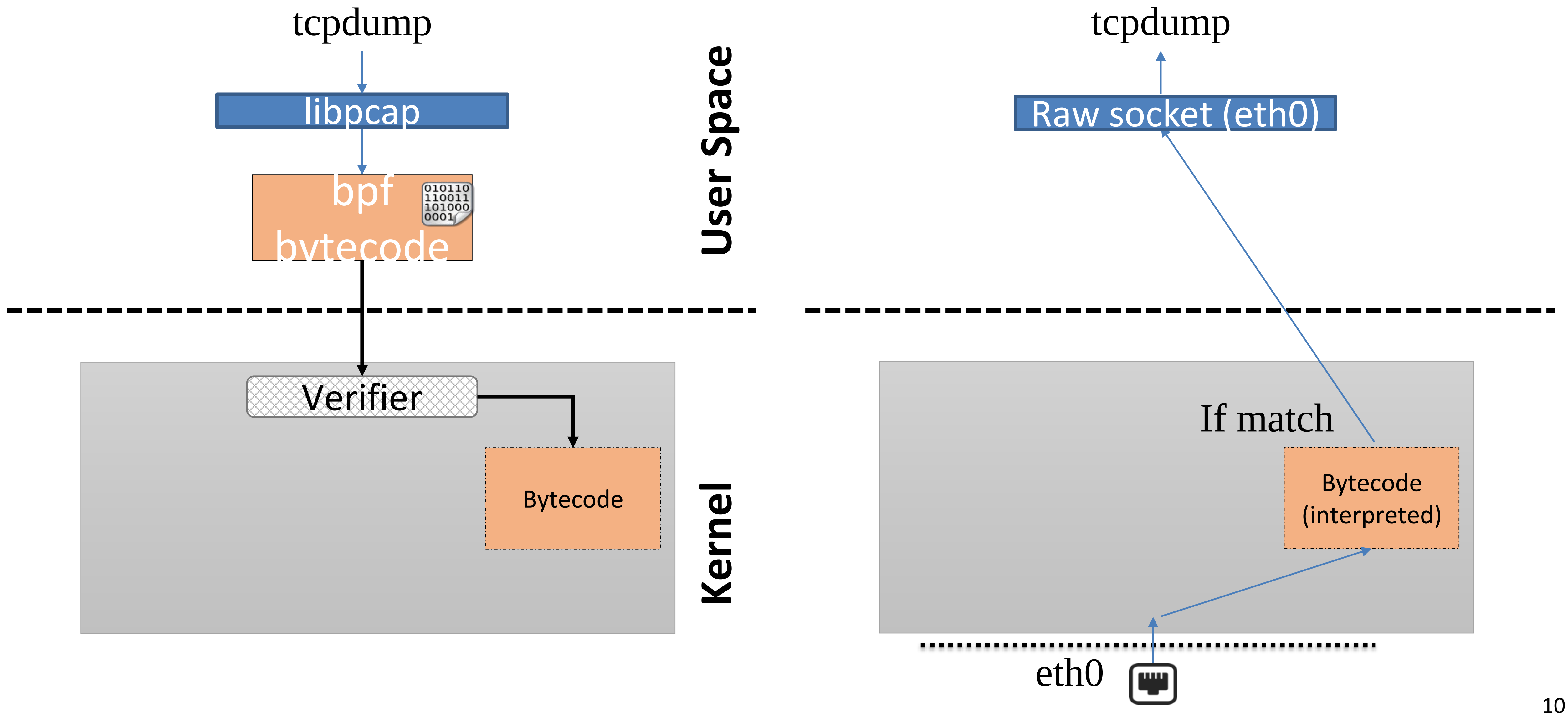
Virtualize a machine instruction set

Write byte code for this “fictional” machine

__verify__ this code is loop free and optimized

Interpret, in-kernel, for *any* real processor

BPF Overview (insertion and usage)



Other uses and extension

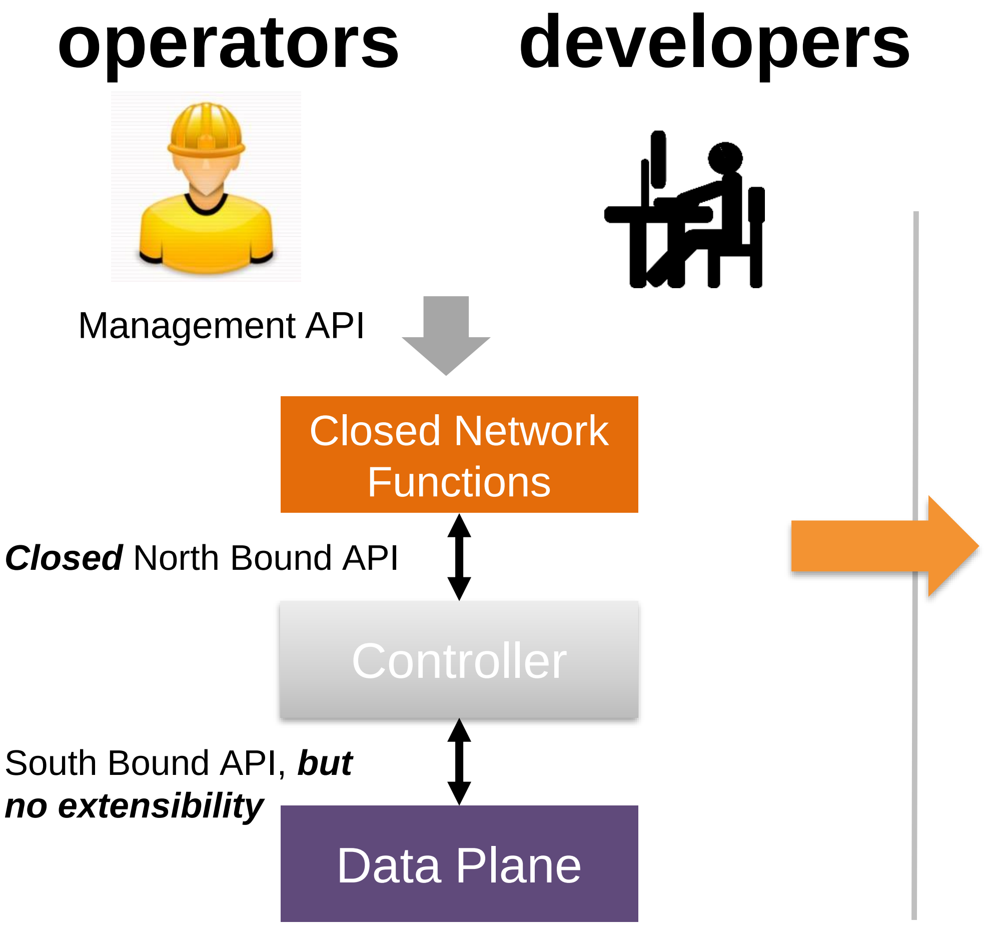
Slowly evolving cBPF

- seccomp support for sandboxing
- *tc* filter for traffic shaping
- JIT compiler

Extending BPF

… while building a programmable Data Plane

A new SDN architecture



operators

developers

Management API

Closed Network Functions

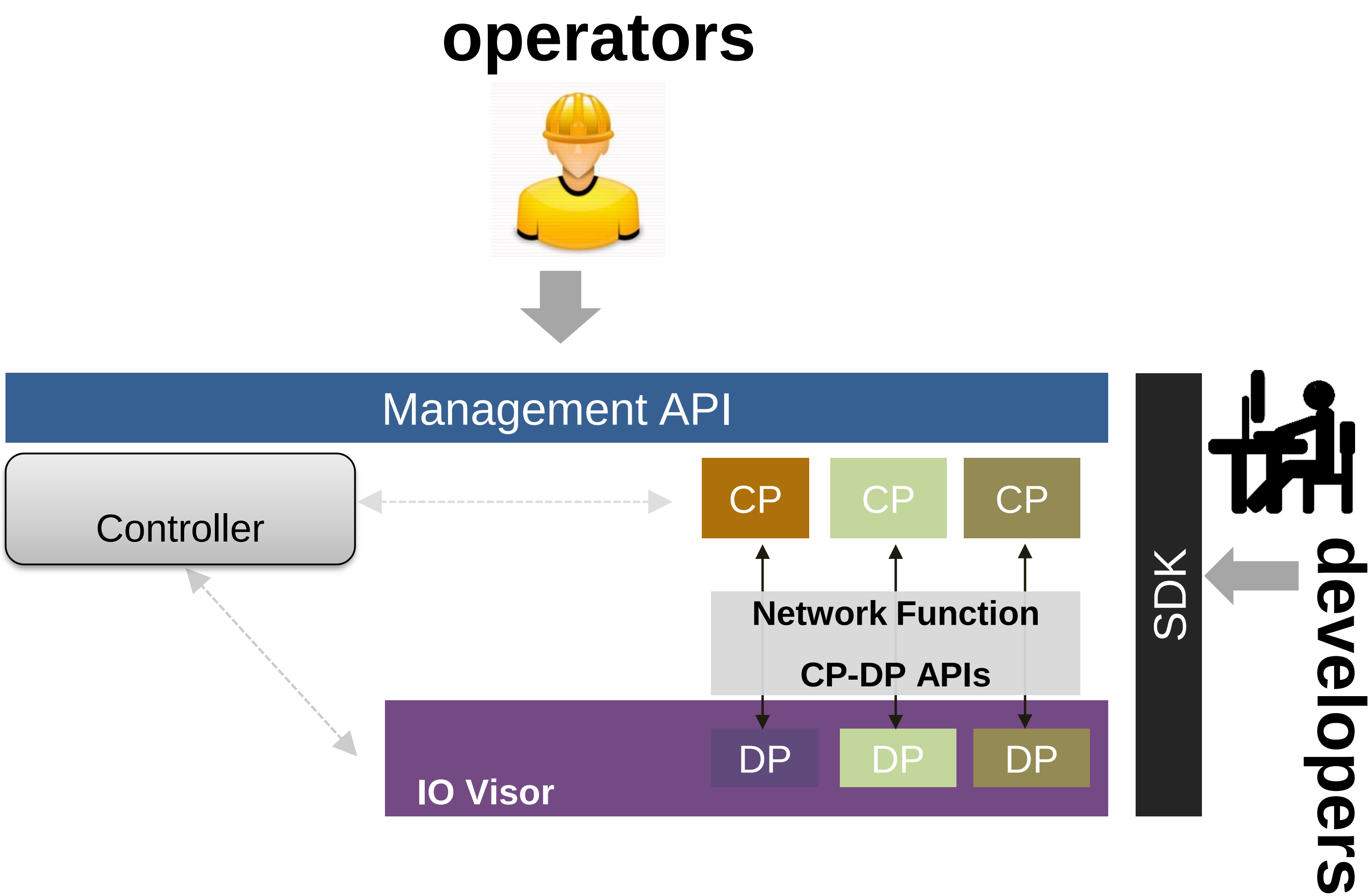
Closed North Bound API

Controller

South Bound API, ***but no extensibility***

Data Plane

Traditional SDN architecture



operators

Management API

Controller

CP

CP

CP

Network Function

CP-DP APIs

DP

DP

DP

IO Visor

SDK

developers

With a programmable DP and controller on the side

Goals for a programmable Data Plane = eBPF

Enable packet parsing, lookup, modification, and updates

Guarantee safety of code run on a production system

Native performance

eBPF as a syscall interface

Introduced as a separate syscall (user space access)

*int bpf(int cmd, union bpf_attr *attr, unsigned int size);*

linux 3.15 and above

Moved out of the networking subsystem

Streamlined use, extensibility through single API

Enhanced architecture

classic BPF	extended BPF
2 registers + stack	**10 registers** + stack
32-bit registers	**64-bit registers** with 32-bit sub-registers
4-byte load/store to stack	1-8 byte load/store to stack, maps, context
1-4 byte load from packet	Same + store to packet
Conditional jump forward	Conditional jump forward and backward
+, -, *, … instructions	Same + signed_shift + endian
	Call instruction
	tail_call
	map lookup/update/delete helpers
	packet rewrite, csum, clone_redirect
	sk_buff read/write

- Can build more complicated program
- Faster interpretation and JIT
- Support for calls to *approved* helper functions

Maps

Maps = <key, value> storage

Save state across invocation of programs in kernel = state machines!

Example: *fd bpf_table_lookup(table_id, key)*

Userspace can create/access/delete these maps (using bpf syscall)

loosely coupled communication between user and kernel space

Maps can be shared between eBPF programs

HASH, ARRAY … and growing

Stateful programmability and async interaction with user space

Helper functions and tail calls

Invoke sanitized functions from within the eBPF program

like a library – but … of course .. In-kernel

*e.g u64 bpf_ktime_get_ns(void), int bpf_trace_printk(const char *fmt, int fmt_size, ...), u32 prandom_u32(void)*

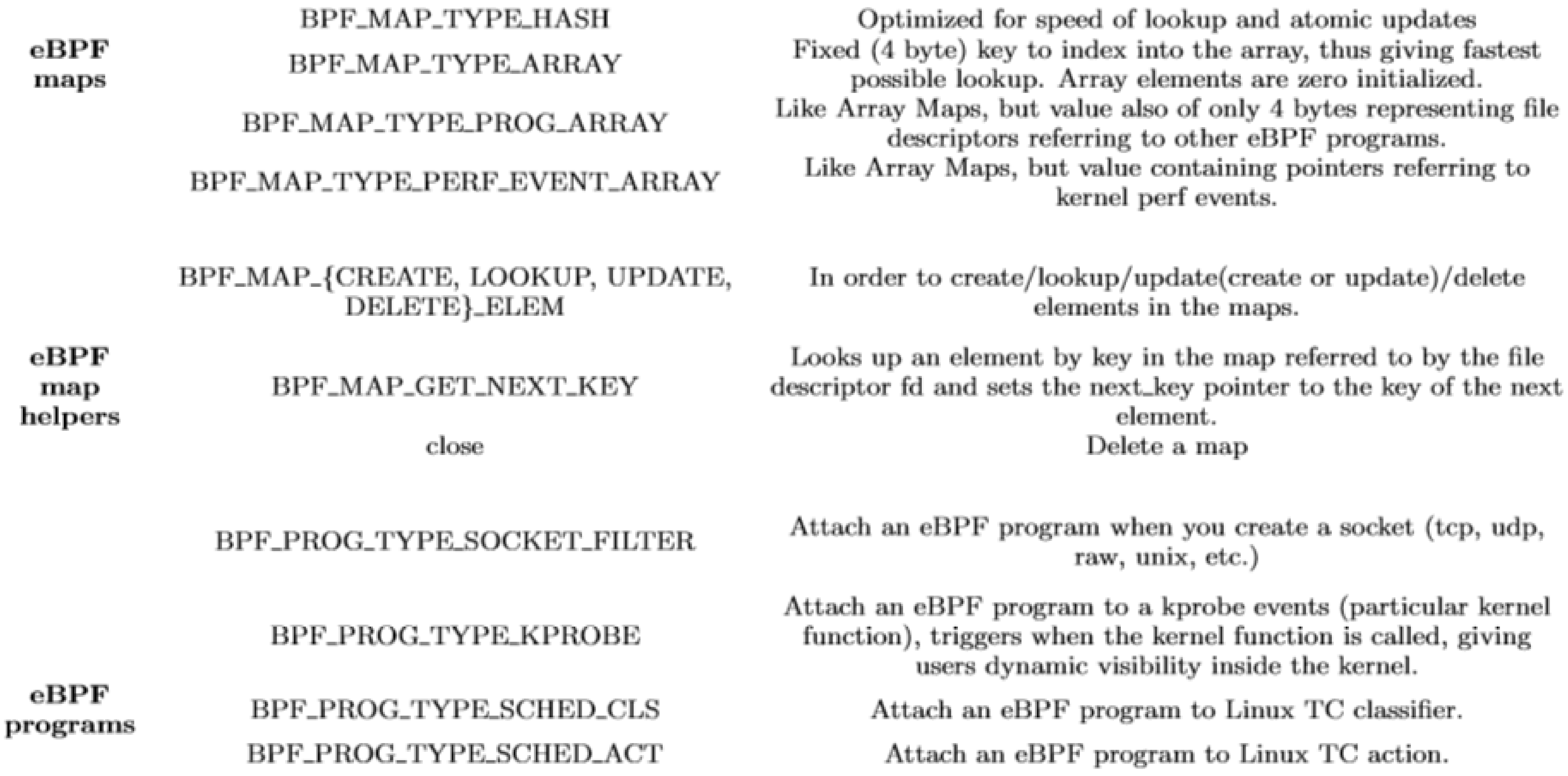
Tail call feature a combo of two components

bpf_tail_call(ctx, prog_array_map,index)

and PROG_ARRAY_MAP

increased capabilities, and sanitized access

Summary (for later reference)



eBPF maps	BPF_MAP_TYPE_HASH	Optimized for speed of lookup and atomic updates
	BPF_MAP_TYPE_ARRAY	Fixed (4 byte) key to index into the array, thus giving fastest possible lookup. Array elements are zero initialized.
	BPF_MAP_TYPE_PROG_ARRAY	Like Array Maps, but value also of only 4 bytes representing file descriptors referring to other eBPF programs.
	BPF_MAP_TYPE_PERF_EVENT_ARRAY	Like Array Maps, but value containing pointers referring to kernel perf events.
eBPF map helpers	BPF_MAP_{CREATE, LOOKUP, UPDATE, DELETE}_ELEM	In order to create/lookup/update(create or update)/delete elements in the maps.
	BPF_MAP_GET_NEXT_KEY	Looks up an element by key in the map referred to by the file descriptor fd and sets the next_key pointer to the key of the next element.
	close	Delete a map
eBPF programs	BPF_PROG_TYPE_SOCKET_FILTER	Attach an eBPF program when you create a socket (tcp, udp, raw, unix, etc.)
	BPF_PROG_TYPE_KPROBE	Attach an eBPF program to a kprobe events (particular kernel function), triggers when the kernel function is called, giving users dynamic visibility inside the kernel.
	BPF_PROG_TYPE_SCHED_CLS	Attach an eBPF program to Linux TC classifier.
	BPF_PROG_TYPE_SCHED_ACT	Attach an eBPF program to Linux TC action.

Verifier and kernel safety

eBPF new architecture more complex

*required a **brand** new verifier*

Provably confirms inserted program **does not**:

create loops, delays execution interminably, illegally dereference pointers

Done statically, one-time, with an exhaustive search

some heuristics to improve verification time

LLVM compiler, Interpreter, and JIT

Restricted “C” code that compiles to bpf bytecode

LLVM backend for this purpose with clang frontend

Once inserted, the code is “hooked” to a kernel event

no sense hooking to userspace events!

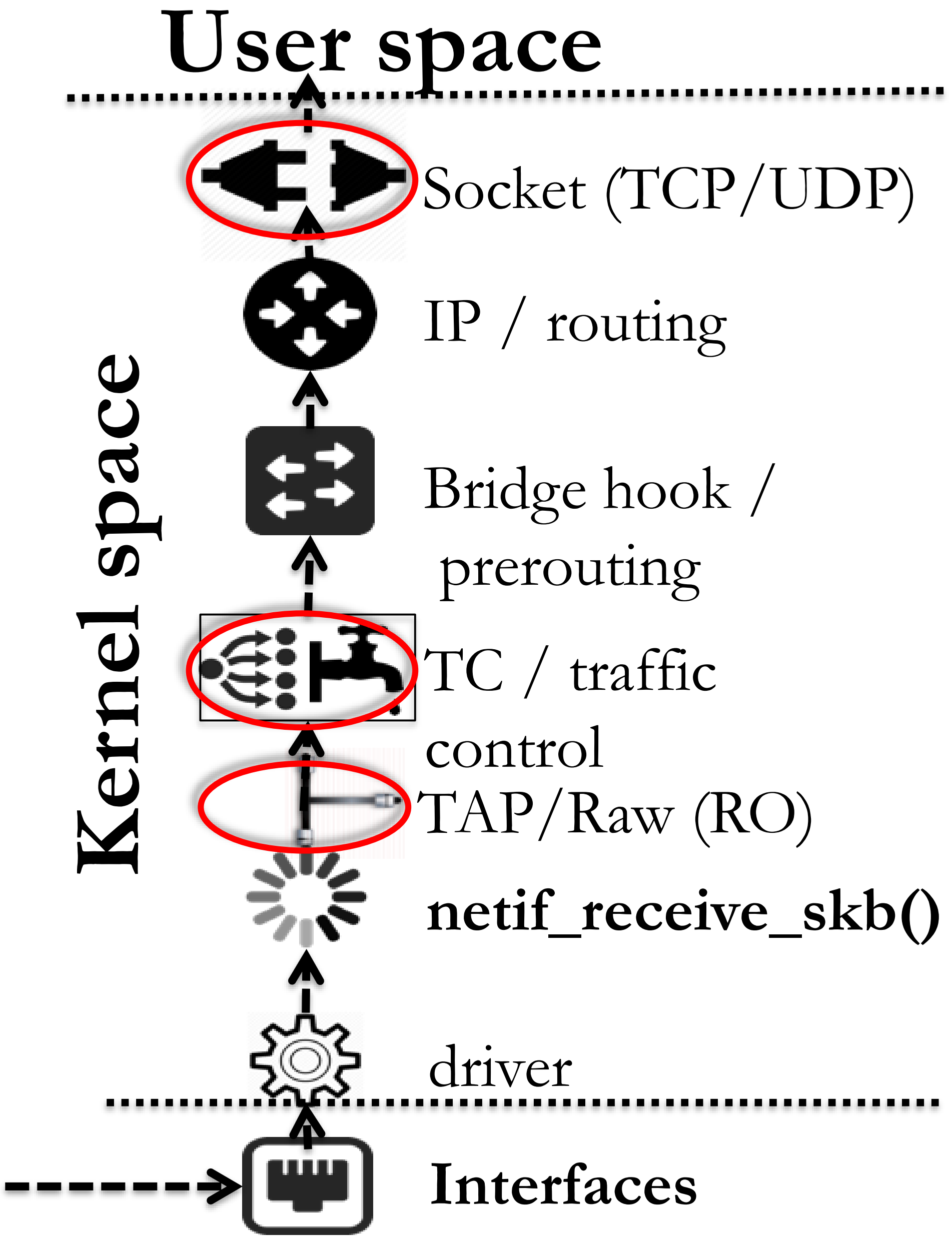
On event firing the appropriate code is run in either *native* or *interpreted* mode

Example Hooks: The networking stack

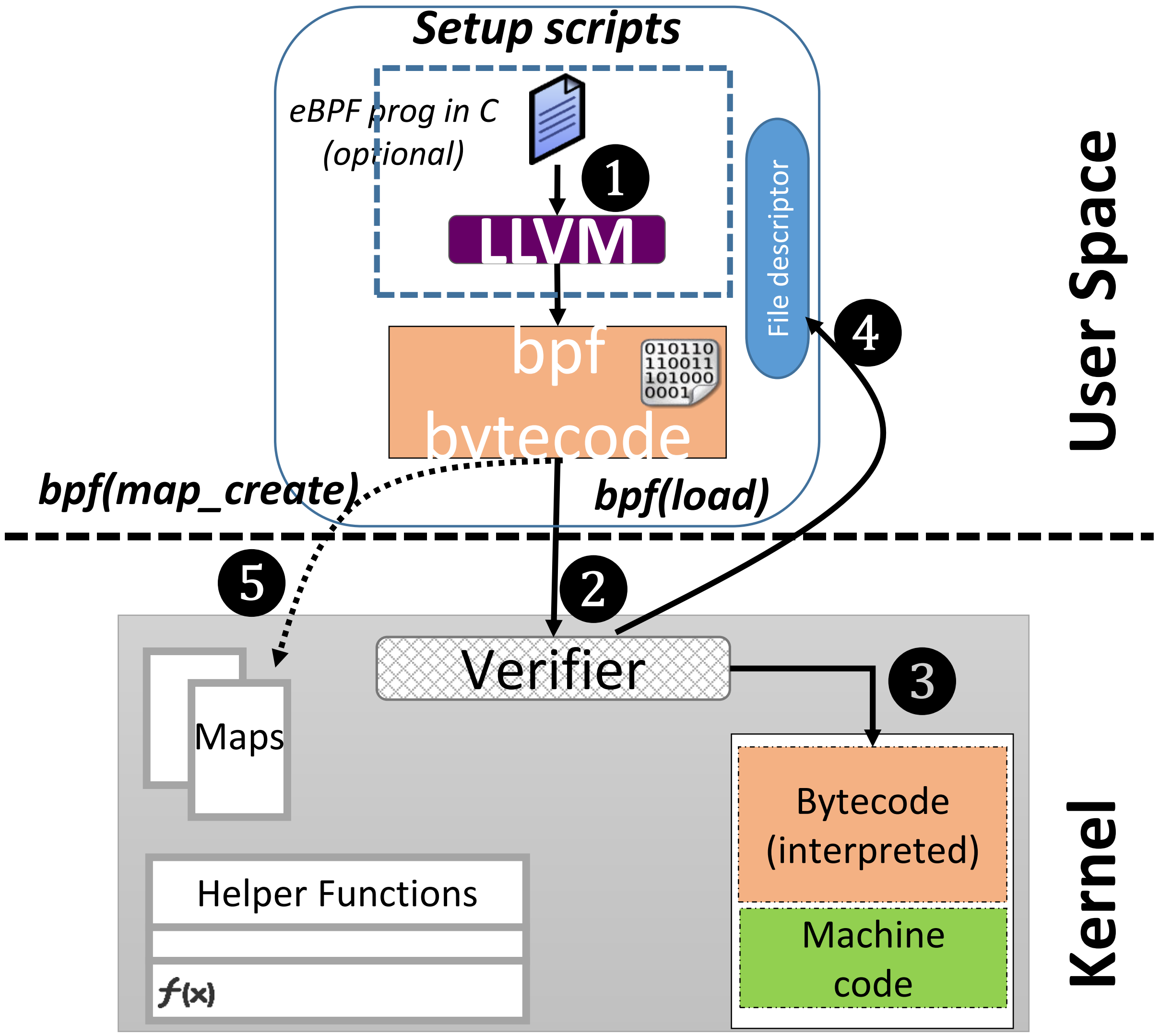
traffic control (TC): queues (classification or action time)

sockets: STREAM (L4/UDP), DATAGRAM (L4/TCP) or RAW

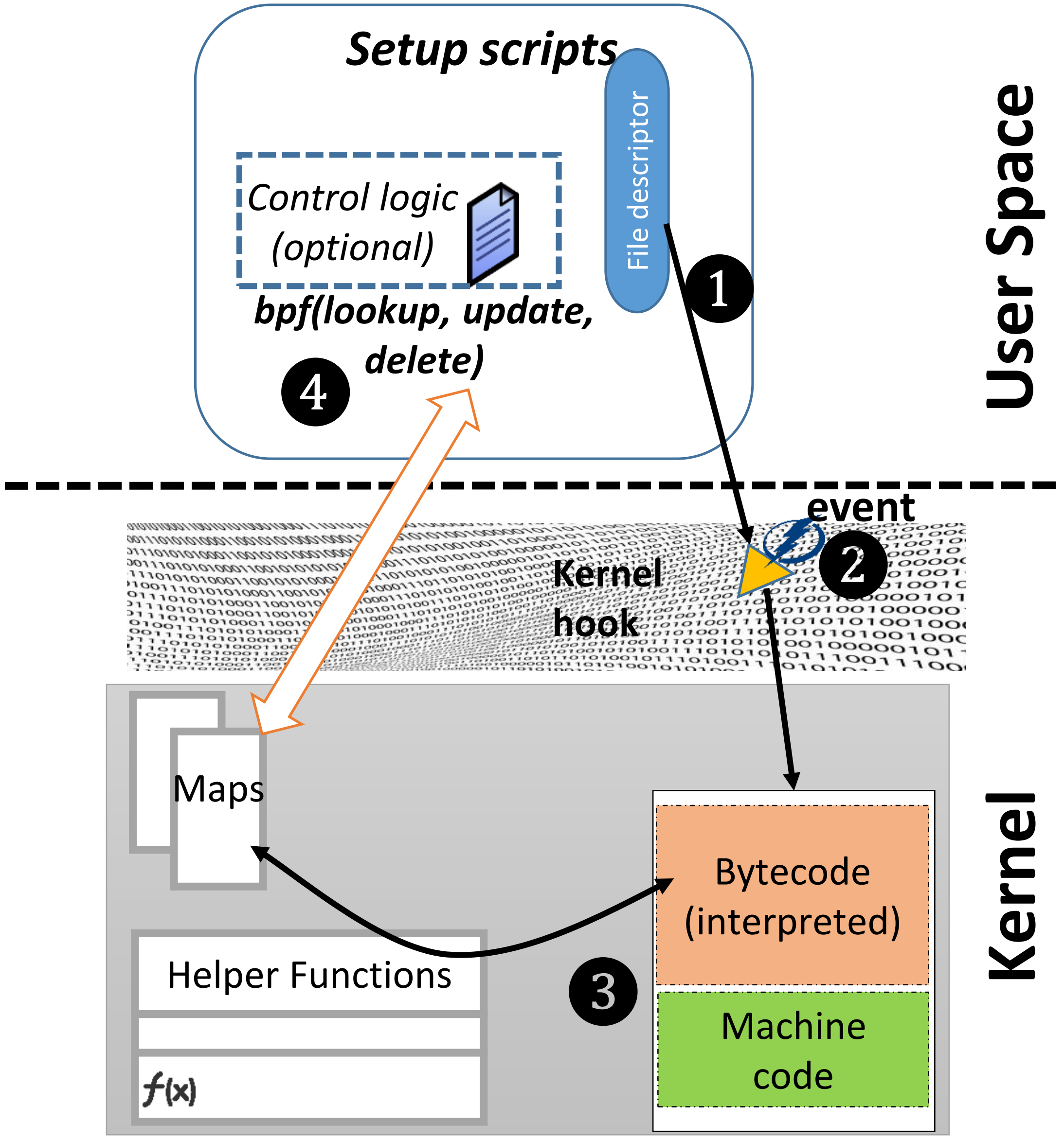
others: kprobes, syscalls, tracepoints ...



Visual Flow of code insertion and use



Code insertion



Event Execution

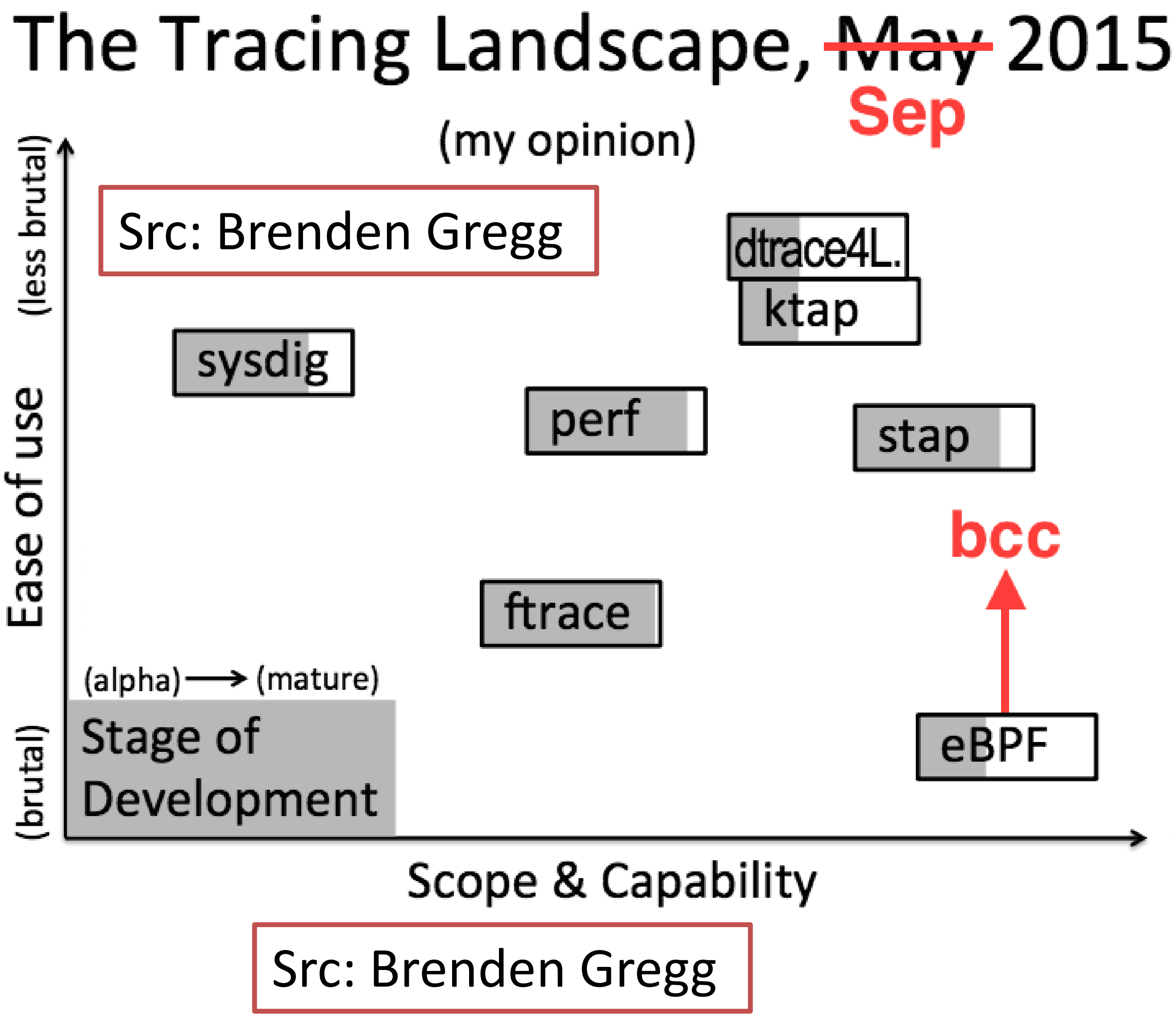
eBPF, IO Visor and BCC

Complexity of making eBPF code

Writing eBPF programs was “brutal”

Even with compiler, the map/code sharing

Enter BPF compiler collection (BCC)



The Tracing Landscape, ~~May~~ 2015 Sep

(my opinion)

Src: Brenden Gregg

Src: Brenden Gregg

BCC (https://github.com/iovisor/bcc)

Make using features of eBPF easier to use

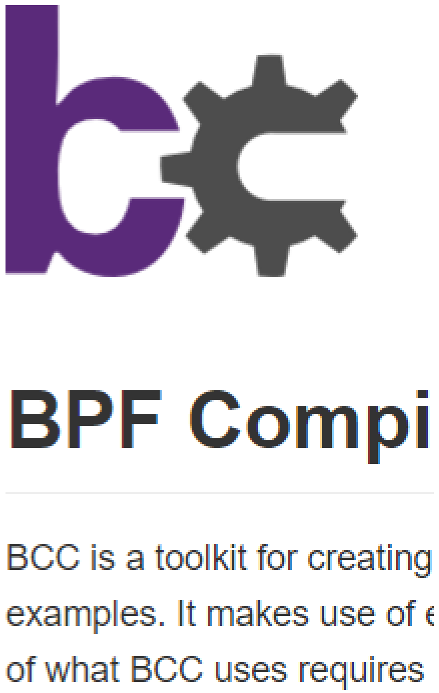
Python front-end and scripts to

create/access/delete maps

load programs from a restricted "C" format

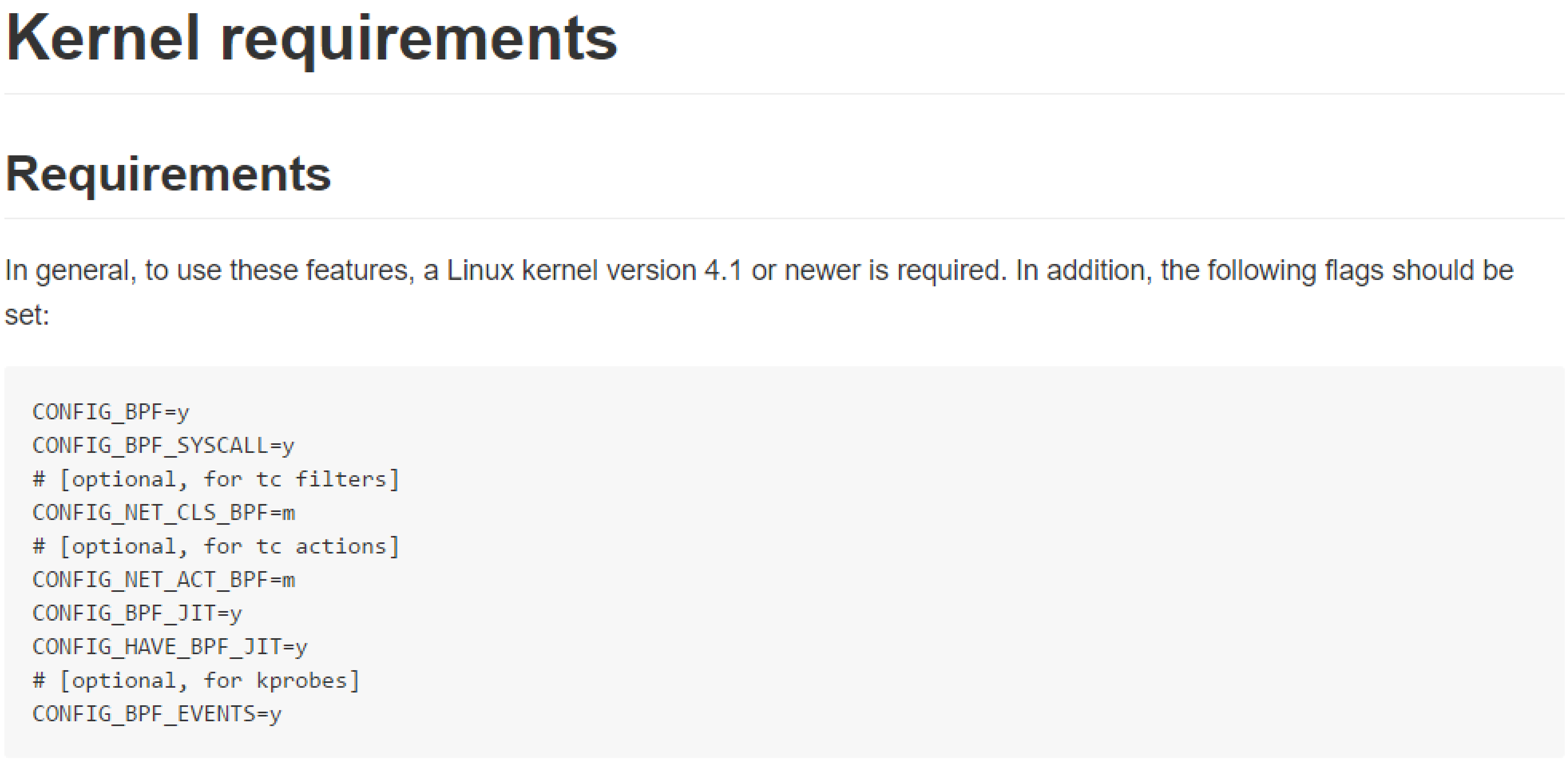
attach to different locations with a simple API

BCC and a few screen-shots!



BPF Compi

BCC is a toolkit for creating
examples. It makes use of e
of what BCC uses requires



Kernel requirements

Requirements

In general, to use these features, a Linux kernel version 4.1 or newer is required. In addition, the following flags should be set:

```
CONFIG_BPF=y
CONFIG_BPF_SYSCALL=y
# [optional, for tc filters]
CONFIG_NET_CLS_BPF=m
# [optional, for tc actions]
CONFIG_NET_ACT_BPF=m
CONFIG_BPF_JIT=y
CONFIG_HAVE_BPF_JIT=y
# [optional, for kprobes]
CONFIG_BPF_EVENTS=y
```

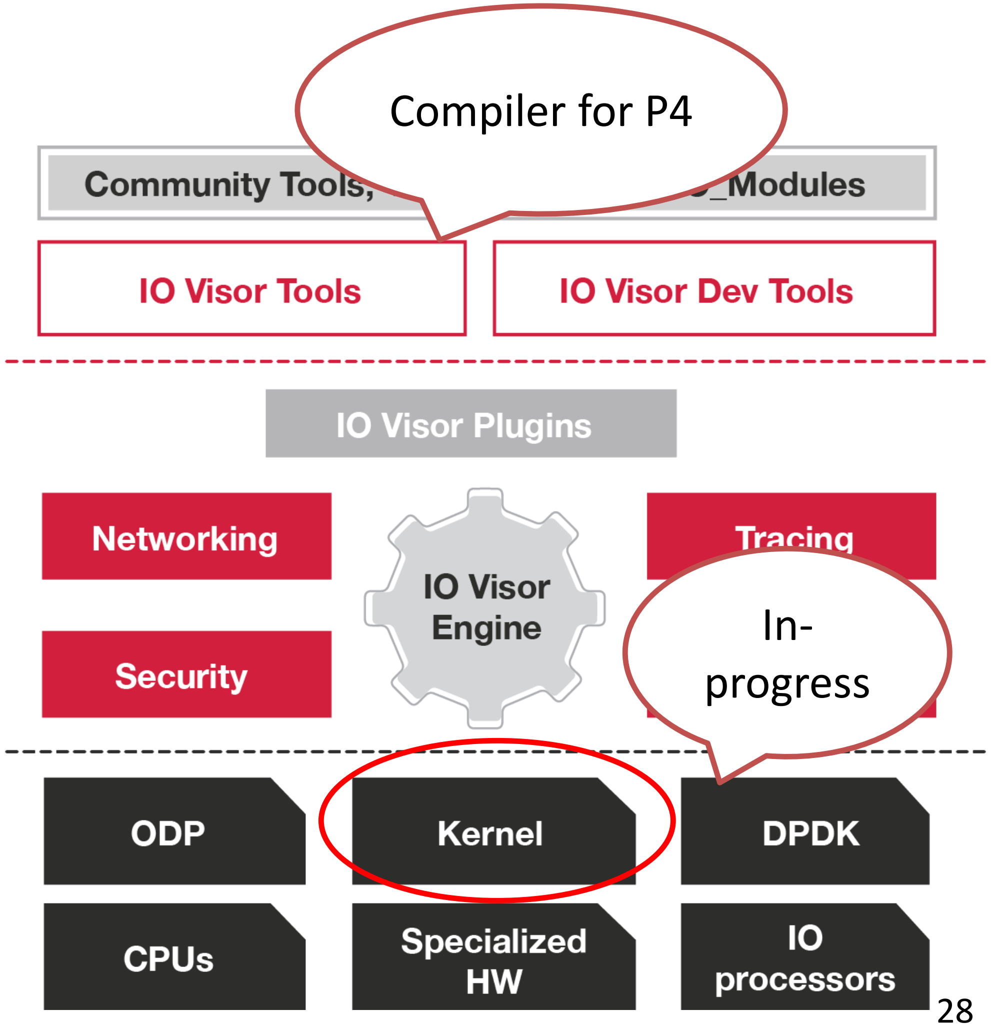
IO Visor Project

Linux Foundation Collaborative Project

IO Visor Engine is an abstraction of an IO execution engine

A set of development tools, **IO Visor Dev and Management**

A set of **use cases & applications** like Networking, Security, Tracing & others



Compiler for P4

Community Tools, _Modules

IO Visor Tools

IO Visor Dev Tools

IO Visor Plugins

Networking

IO Visor Engine

Tracing

Security

In-progress

ODP

Kernel

DPDK

CPUs

Specialized HW

IO processors

Founding Members

CISCO™
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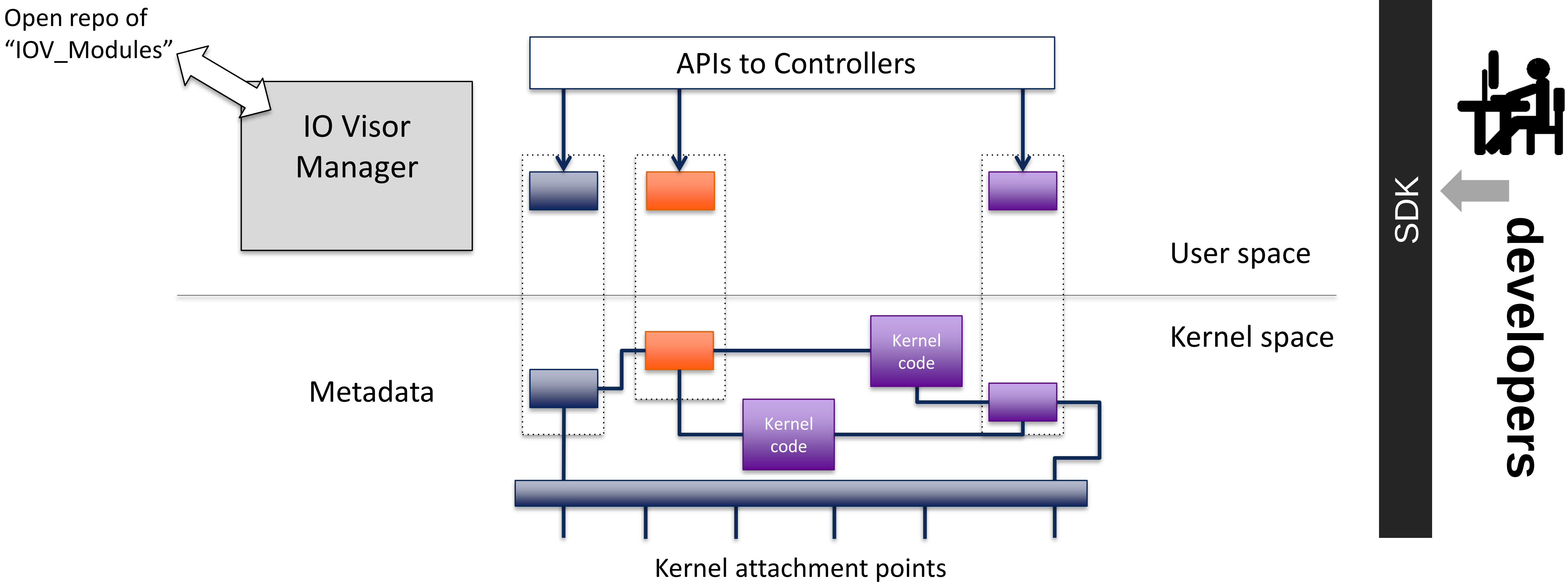
www.iovisor.org

IO Visor Modules



https://github.com/iovisor/

Lots of interesting projects there right now

bpf-based file system (FUSE)

Join and contribute!

Useful links

- https://github.com/iovisor/bcc
- https://github.com/iovisor/bpf-docs
- http://lwn.net/Articles/603984/
- http://lwn.net/Articles/603983/
- https://lwn.net/Articles/625224/
- https://www.kernel.org/doc/Documentation/networking/filter.txt
- http://man7.org/linux/man-pages/man2/bpf.2.html
- https://linuxplumbersconf.org/2015/ocw//system/presentations/3249/original/bpf_llvm_2015aug19.pdf
- https://videos.cdn.redhat.com/summit2015/presentations/13737_an-overview-of-linux-networking-subsystem-extended-bpf.pdf
- https://github.com/torvalds/linux/tree/master/samples/bpf
- http://events.linuxfoundation.org/sites/events/files/slides/tracing-linux-ezannoni-
- https://www.kernel.org/doc/Documentation/prctl/seccomp_filter.txt
- http://lxr.free-electrons.com/source/net/sched/cls_bpf.c

Live Demo

… and prayers!

Things we demo

Hello world

attach to clone event, print hello every time

Hello world and state

sum the number of events

Networking example

more complicated but fun ☺

Research Threads

… for the adventurous amongst you!

Networking and packet manipulations

Increasing application response time

- frequent /cached responses in kernel

Container Networking

- custom encapsulation protocols and metadata

State-full QoS

Security

Fast, flexible and state-full Firewalls

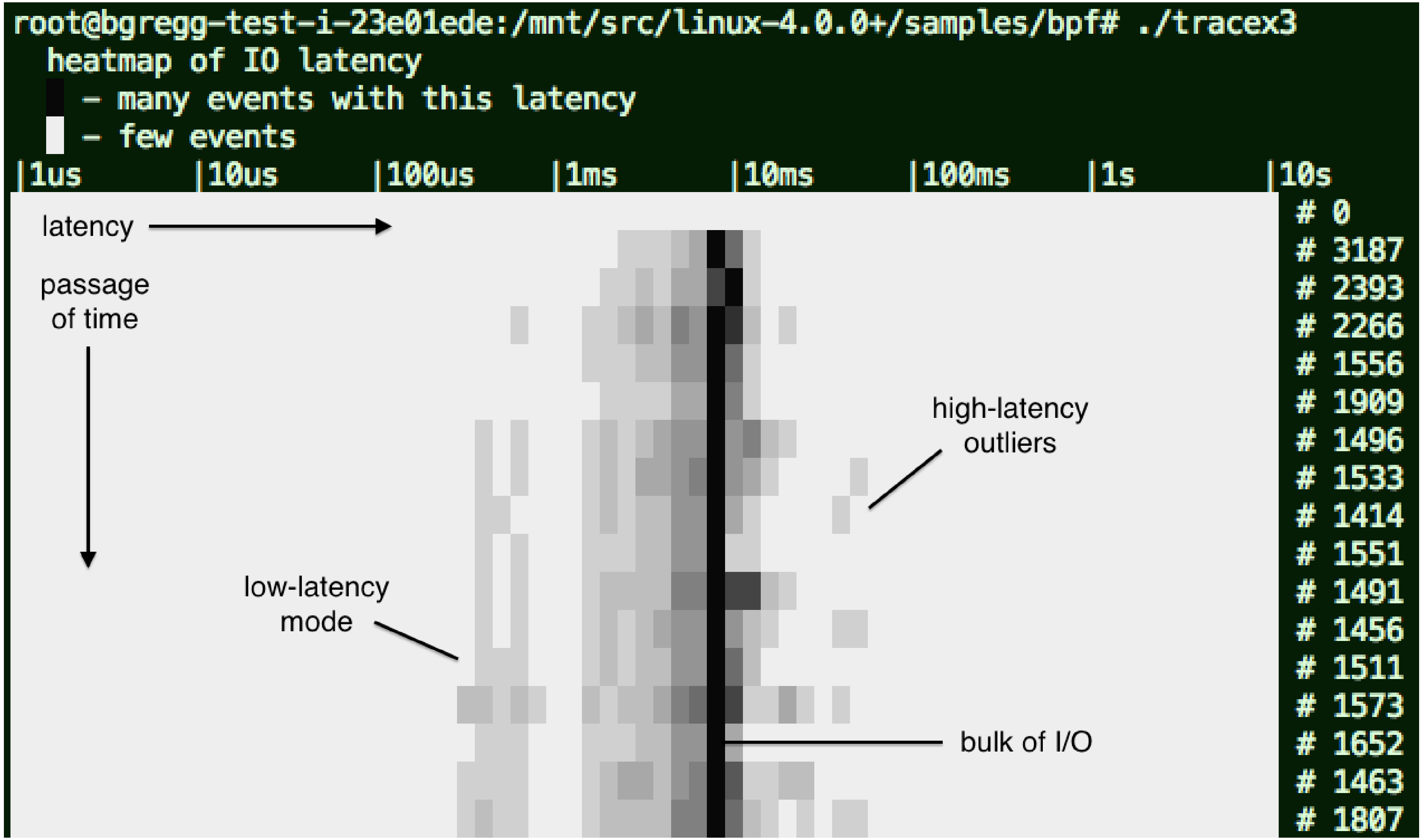
System call trapping and *dynamic* taint analysis

Faster and less resource hungry analysis

Disk latency heat-maps

https://github.com/torvalds/linux/tree/master/samples/bpf/

One map for time-stamp, other for latency



```
root@bgregg-test-i-23e01ede:/mnt/src/linux-4.0.0+/samples/bpf# ./tracex3
  heatmap of IO latency
  █ - many events with this latency
  ▯ - few events
|1us      |10us      |100us     |1ms       |10ms      |100ms     |1s        |10s
                                                                              # 0
                                                                              # 3187
                                                                              # 2393
                                                                              # 2266
                                                                              # 1556
                                                                              # 1909
                                                                              # 1496
                                                                              # 1533
                                                                              # 1414
                                                                              # 1551
                                                                              # 1491
                                                                              # 1456
                                                                              # 1511
                                                                              # 1573
                                                                              # 1652
                                                                              # 1463
                                                                              # 1807
```

Embedded Systems and Internet-of-Things

Event-based, packet-based micro-kernel abstraction

Saving energy with operation in-kernel,

user-space tools for config/mgmt/debug

think tinyOS-inside-Linux

Software defining an API for heterogenous and opportunistic low-power coms

wifi, zigbee, Z-wave

PLUMgrid

Thank you!
Questions?

We are hiring

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