


KubeCon | CloudNativeCon

Europe 2020

Virtual

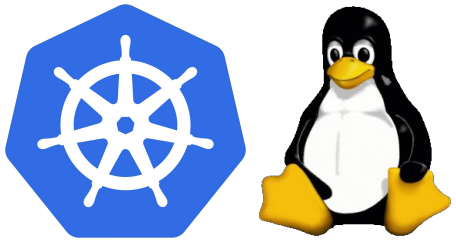
eBPF and Kubernetes: Little Helper Minions for Scaling Microservices

Daniel Borkmann (Isovalent), eBPF kernel co-maintainer

Kubernetes is eating the world

Kubernetes widely regarded as the **Cloud OS** these days.

- ➔ Linux kernel as a base foundation to provide all building blocks
- ➔ Major core parts of critical path delivered via CNI networking plugin



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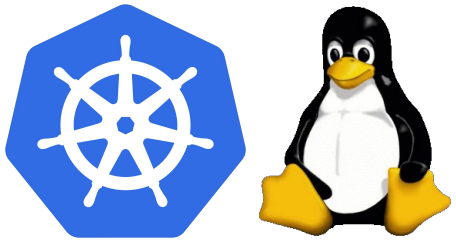

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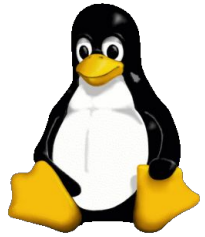
Clear trends: increasing Pod density and decreasing Pod lifespans

CNCF'19 survey report: https://www.cncf.io/wp-content/uploads/2020/03/CNCF_Survey_Report.pdf
sysdig'19 container usage report: https://sysdig.com/blog/sysdig-2019-container-usage-report/



Challenges from OS kernel side

Keeping up with **performance** & **scalability** requirements while having ever-increasing **complexity** of subsystems.

Partially due to “never break user space” paradigm.

The kernel often suffers a feature creeping normality.

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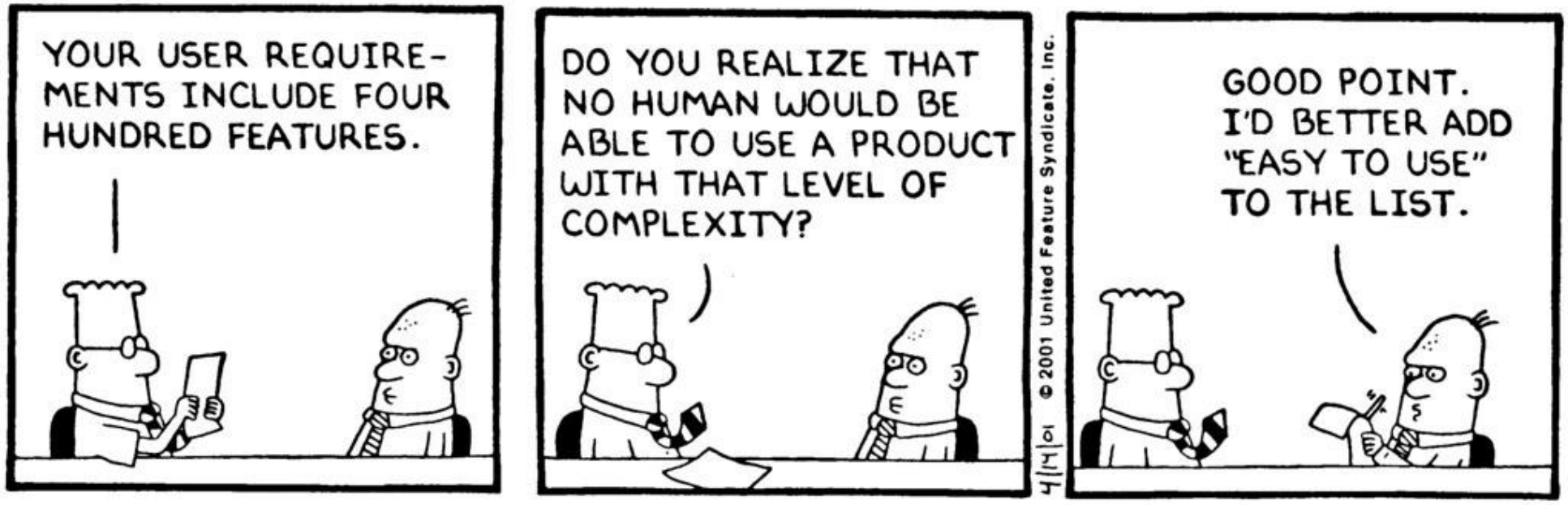


Challenges from OS kernel side

Def. **creeping normality**:

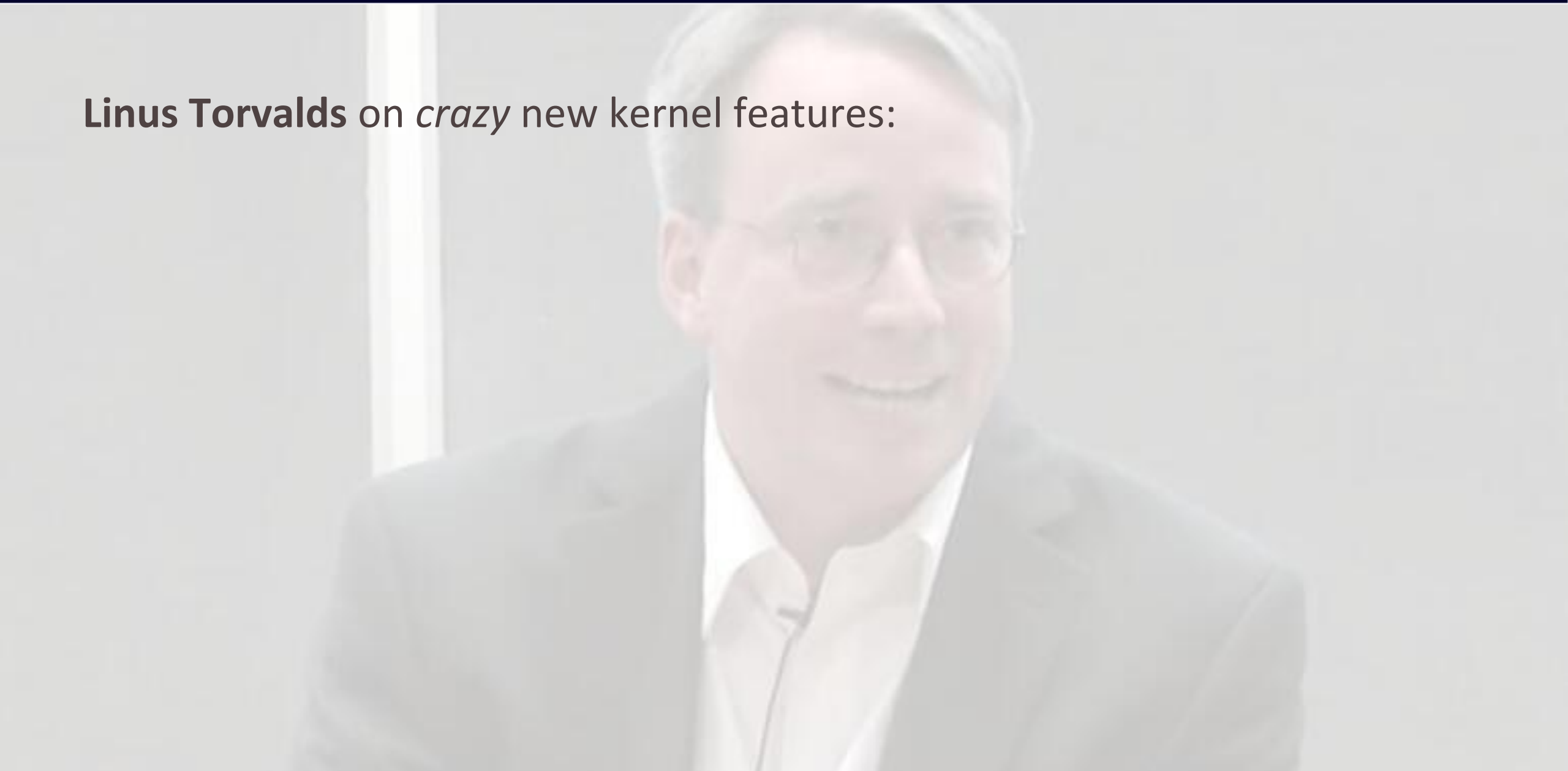
Challenges from OS kernel side

Def. **creeping normality**: … is a process by which a major change can be accepted as normal and acceptable if it happens slowly through small, often unnoticeable, increments of change. The change could otherwise be regarded as objectionable if it took place in a single step or short period.

https://en.wikipedia.org/w/index.php?title=Death_by_a_thousand_cuts_(psychology)

Challenges from OS kernel side

Linus Torvalds on *crazy* new kernel features:



Challenges from OS kernel side

Linus Torvalds on *crazy* new kernel features:

> So I can work with crazy people, that's not the problem. They just need to _sell_ their crazy stuff to me using non-crazy arguments, and in small and well-defined pieces. When I ask for killer features, I want them to lull me into a safe and cozy world where the stuff they are pushing is actually useful to mainline people _first_.
>
> In other words, every new crazy feature should be hidden in a nice solid "Trojan Horse" gift: something that looks _obviously_ good at first sight.

Linus Torvalds, https://lore.kernel.org/lkml/alpine.LFD.2.00.1001251002430.3574@localhost.localdomain/

eBPF - beginning to present

This is what actually happened to eBPF back in the initial days when we tried to get it merged.

Except: It's a crazy new kernel feature which ...

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Except: It's a crazy new kernel feature which ...

- ➔ Reduces the kernel's feature creeping normality
- ➔ Keeps the kernel's fast-path fast
- ➔ Allows users to fully & safely make the kernel programmable to solve their real-world production problems

eBPF for networking in a nutshell

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```
section(“to_netdev”)
int handle(struct sk_buff *skb) {
    …
    if (tcp->dport == 80)
        redirect(lxc0);
    …
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userspace kernelspace

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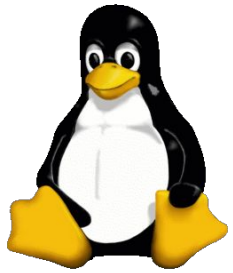
BPF verifier



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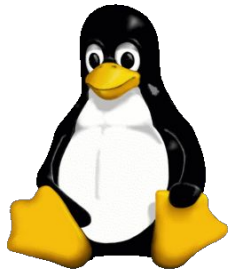

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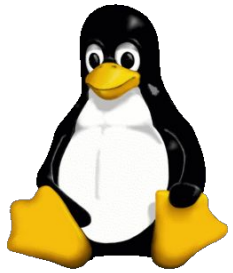

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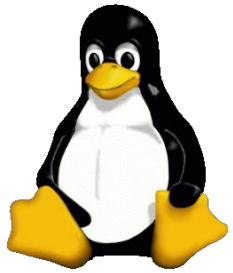

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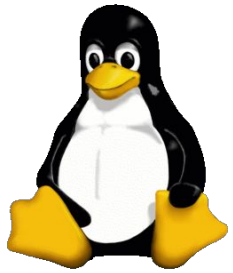

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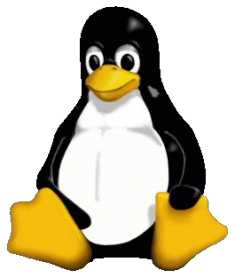

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eBPF for networking in a nutshell

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- cannot crash the kernel
- as fast as kernel module
- stable API guarantees

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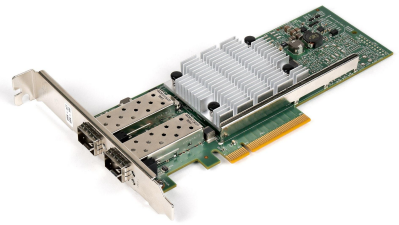
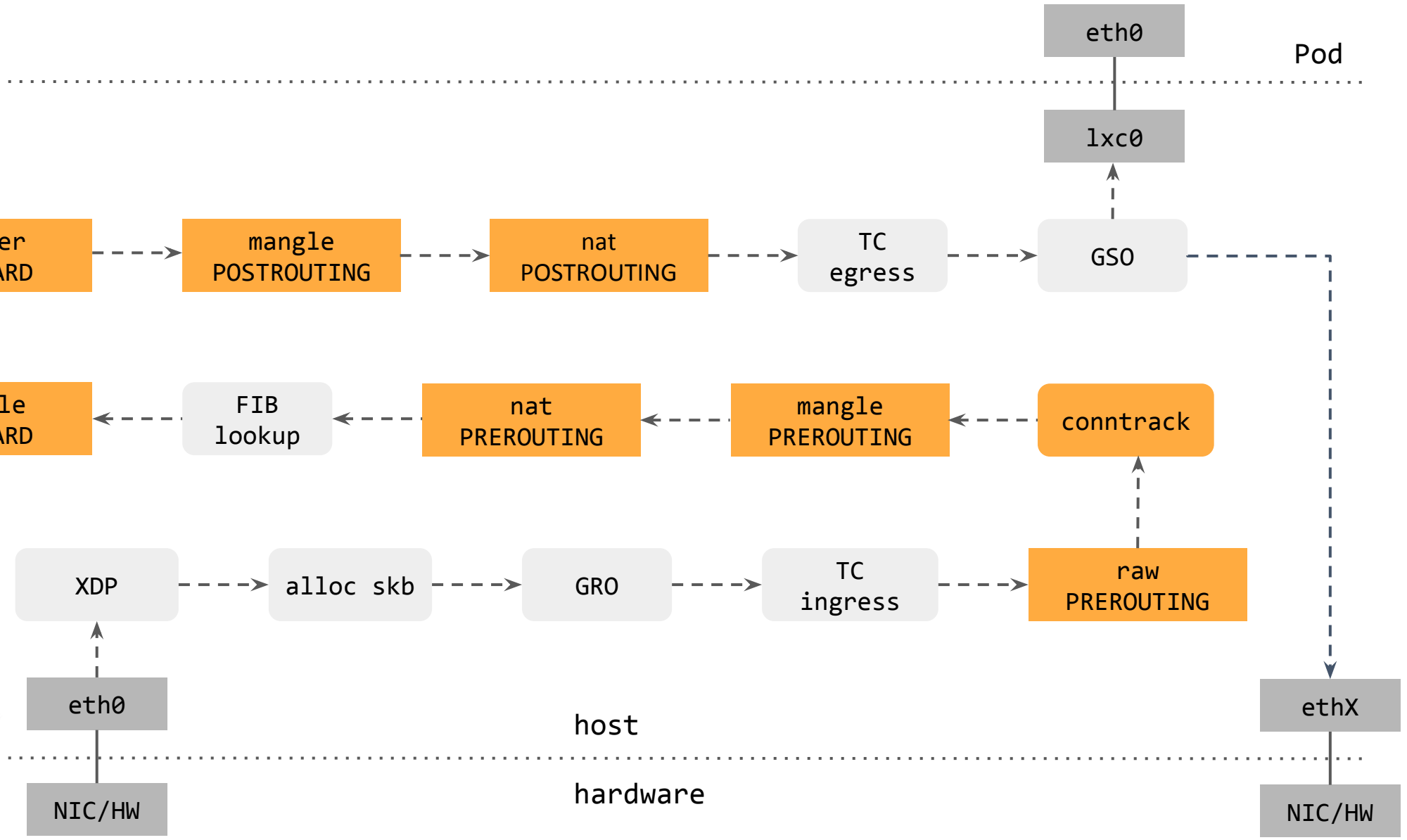
Packet flow for kube-proxy





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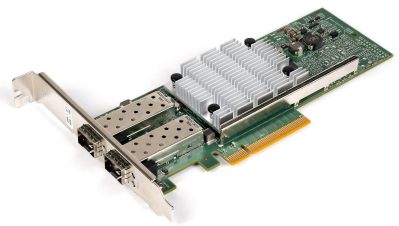

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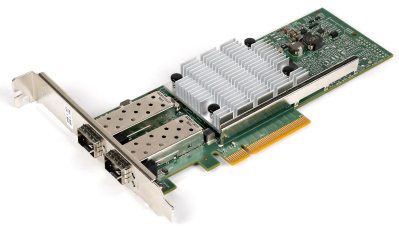

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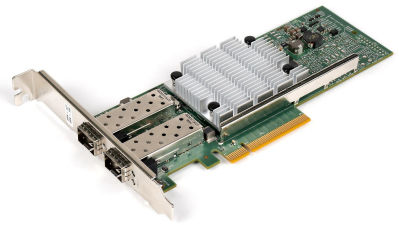

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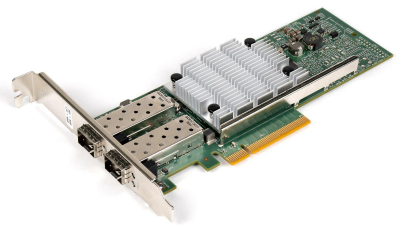

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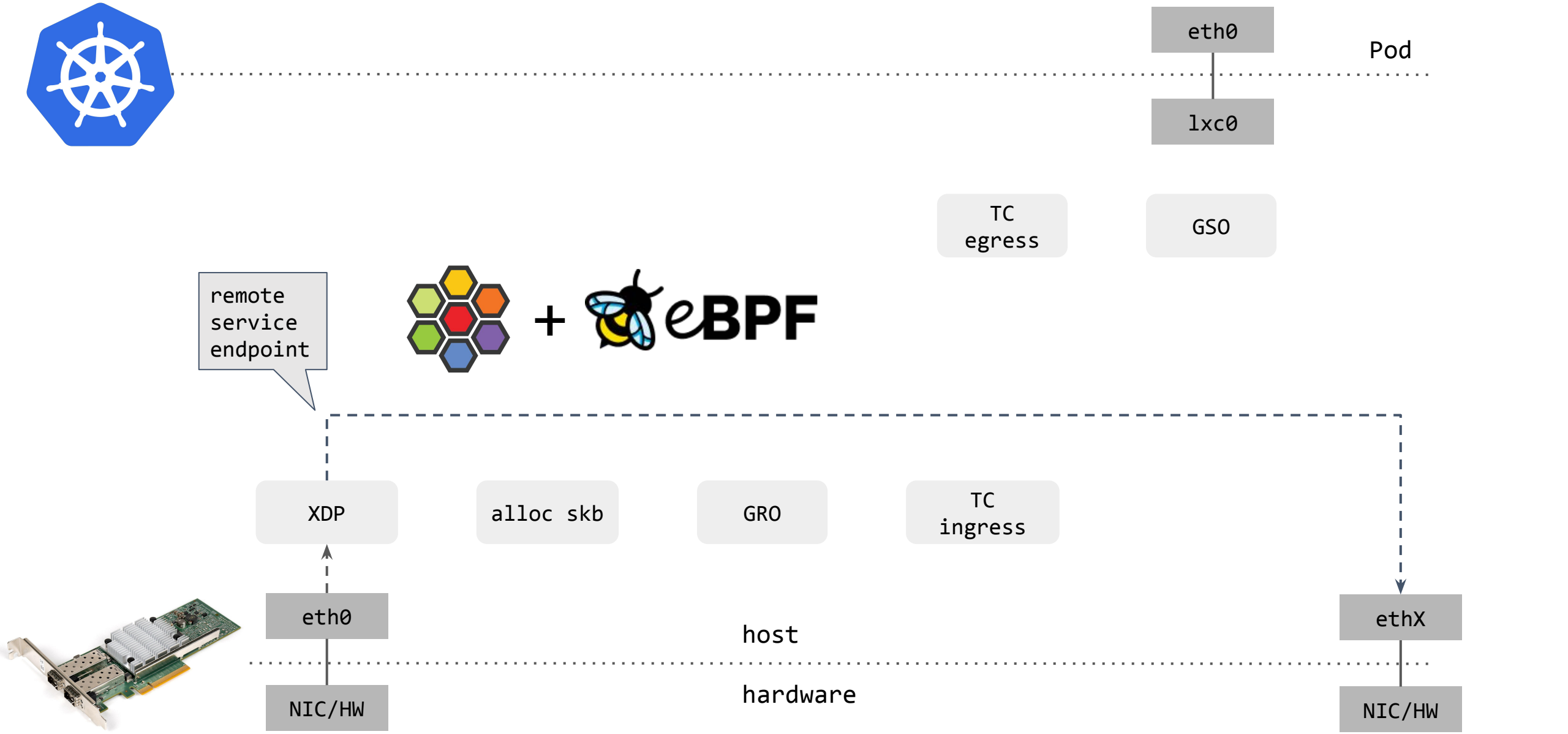

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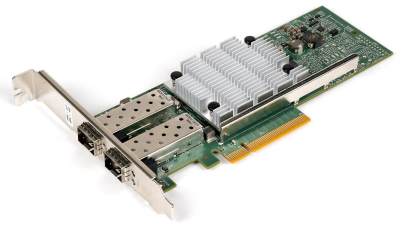

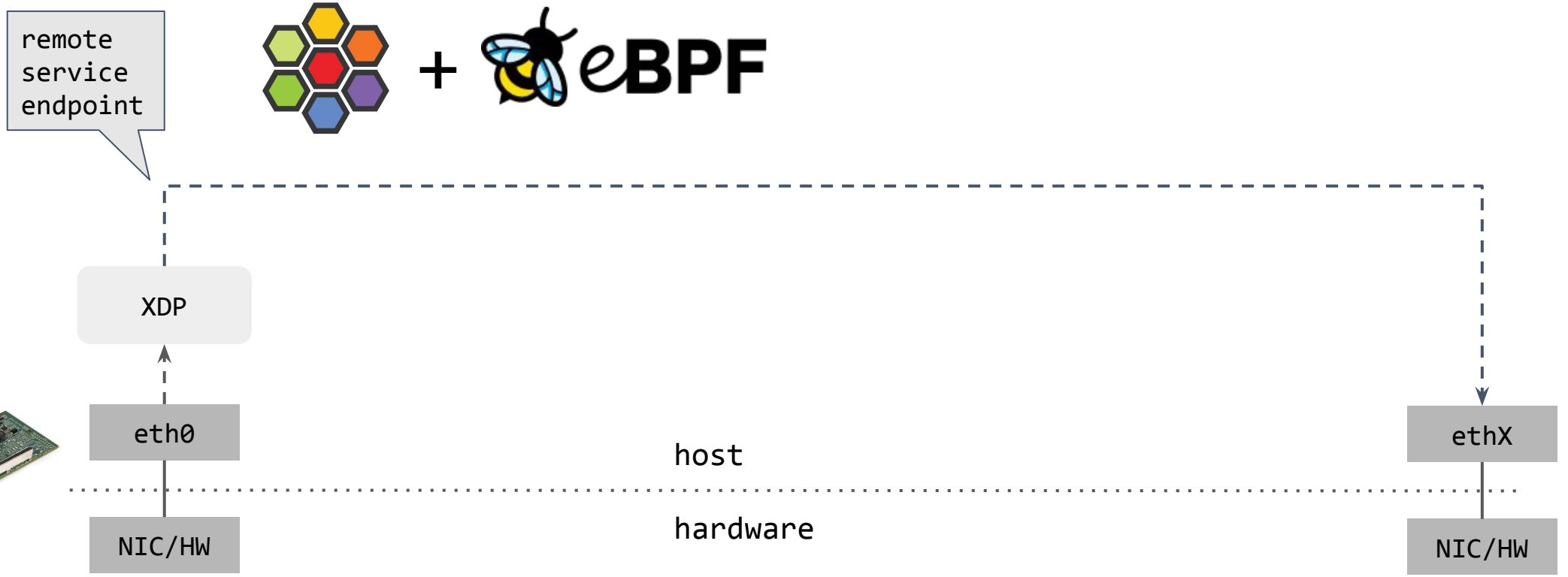

eBPF - beginning to present

Old “SDN” landscape at the time ...

Open vSwitch (**ovs**), traffic control (**tc**), netfilter (**iptables**, **ipvs**, **nftables**) to ‘program’ datapath

BPF at the time used for tcpdump, seccomp and misc other areas

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ovs the most advanced data plane in the kernel back then which did many things right, but seen as ‘Frankenstein’ by core networking devs since it didn’t integrate well with rest of networking

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Open tapath

BPF a

Featu

ovs th but seen

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How do they compare to eBPF? Think of it this way:

- ➔ ovs, tc, netfilter allow you to “program” the datapath, but *only* if the datapath knows what you want to do.
- ➔ eBPF lets you *create* the datapath instead.

< 2013

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Initial big patch bomb to propose ‘extended BPF’

RFCs caused plenty of discussion, too intrusive & nftables (inspired by BPF) was on the rise

Yet another interpreter for BPF itself that needed to be maintained

Eventually got stuck in discussions, and rejected

2013

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First eBPF patch set that was merged into the kernel

Incremental pieces fully **replacing** old BPF interpreter with new one

Instruction set heavily extended, in-kernel translation from old to new

2013 2014

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We effectively became **maintainers** overseeing BPF development since then

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- Incremental pieces
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- We effectively bec

then

2013 2014

```
From: David Miller <davem@davemloft.net>
To: dborkman@redhat.com
Cc: ast@plumgrid.com, netdev@vger.kernel.org
Subject: Re: [PATCH net-next v4 0/9] BPF updates
Date: Mon, 31 Mar 2014 00:46:16 -0400 (EDT)
Message-ID: <20140331.004616.1557779324959569233.davem@davemloft.net> (raw)
In-Reply-To: <1396029506-16776-1-git-send-email-dborkman@redhat.com>

From: Daniel Borkmann <dborkman@redhat.com>
Date: Fri, 28 Mar 2014 18:58:17 +0100

> We sat down and have heavily reworked the whole previous patchset
> from v10 [1] to address all comments/concerns. This patchset therefore
> *replaces* the internal BPF interpreter with the new layout as
> discussed in [1], and migrates some exotic callers to properly use the
> BPF API for a transparent upgrade. All other callers that already use
> the BPF API in a way it should be used, need no further changes to run
> the new internals. We also removed the sysctl knob entirely, and do not
> expose any structure to userland, so that implementation details only
> reside in kernel space. Since we are replacing the interpreter we had
> to migrate seccomp in one patch along with the interpreter to not break
> anything. When attaching a new filter, the flow can be described as
> following: i) test if jit compiler is enabled and can compile the user
> BPF, ii) if so, then go for it, iii) if not, then transparently migrate
> the filter into the new representation, and run it in the interpreter.
> Also, we have scratched the jit flag from the len attribute and made it
> as initial patch in this series as Pablo has suggested in the last
> feedback, thanks. For details, please refer to the patches themselves.
>
> We did extensive testing of BPF and seccomp on the new interpreter
> itself and also on the user ABIs and could not find any issues; new
> performance numbers as posted in patch 8 are also still the same.
>
> Please find more details in the patches themselves.
>
> For all the previous history from v1 to v10, see [1]. We have decided
> to drop the v11 as we have pedantically reworked the set, but of course,
> included all previous feedback

Ok, applied, thanks a lot everyone.
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eBPF - be


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From: David Miller <davem@davemloft.net>
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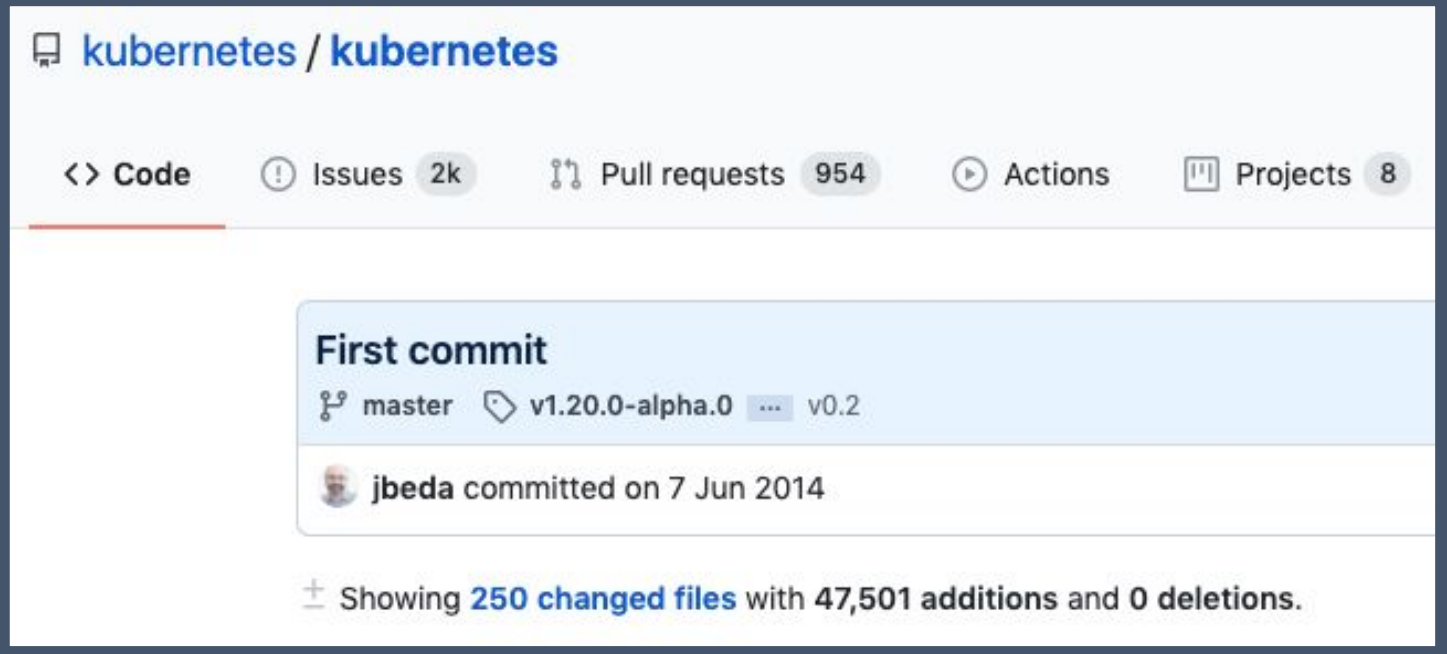
What else happened in that year?



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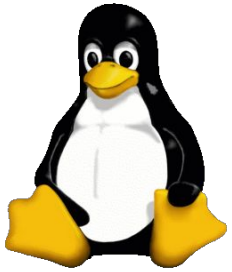
eBPF moved into two directions in parallel: networking & tracing

eBPF backend merged into upstream **LLVM** 3.7



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Brendan Gregg, http://www.brendangregg.com/blog/2015-09-22/bcc-linux-4.3-tracing.html

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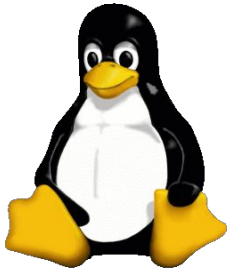

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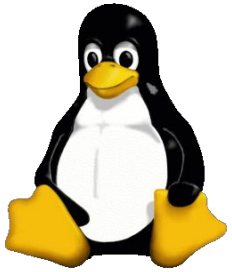

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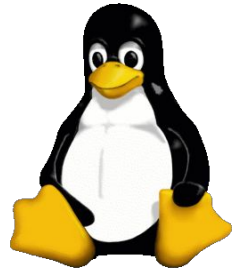

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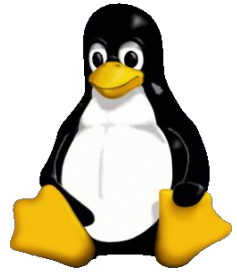
Initial announcement of **bcc** project as tracing frontend for eBPF



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eBPF received a new networking fast-path, Cilium project first announced

eXpress DataPath (**XDP**) merged for attaching eBPF programs at driver's ingress layer

nfp as first NIC and driver to offload eBPF programs at cls_bpf & XDP hook

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Initial announcement of **Cilium** for container networking, mainly targeted at Docker back then

- Efficient label-based policy, NAT64, tunnel mesh, container connectivity all via eBPF
- Entire datapath & forwarding logic in eBPF, no more Docker or ovs bridge devices

cilium

2013 2014 2015 2016

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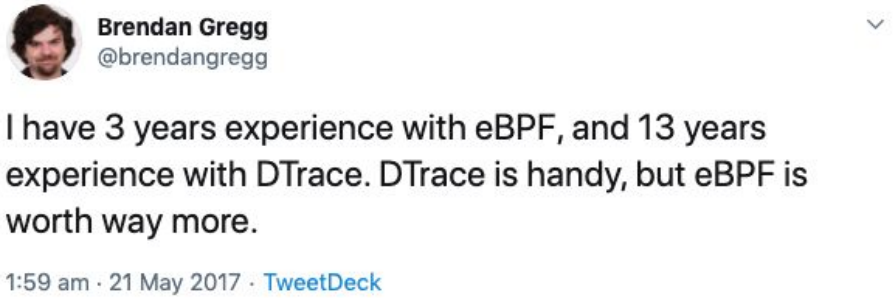
eBPF - beginning to present

eBPF taking over in production environments

Netflix on eBPF for tracing: ‘Linux BPF superpowers’



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Cloudflare integrating XDP + BPF into their DDoS mitigation

- Successively migrating their components from netfilter over to eBPF
- Fully rolled out into production along with their XDP load-balancer in 2018

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eBPF - beginning to present

eBPF community and continued feature growth

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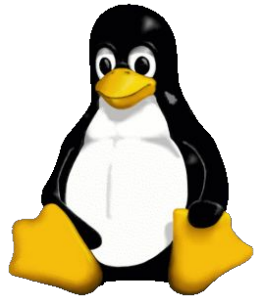

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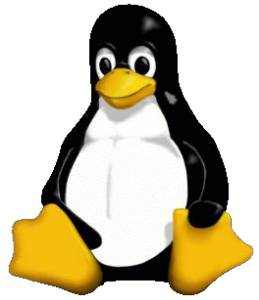
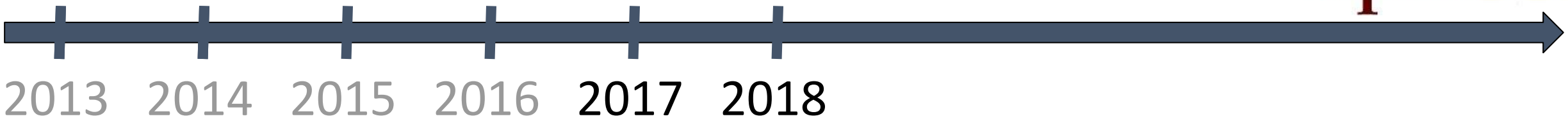
- Fully integrated and supported by openssl these days



OpenSSL



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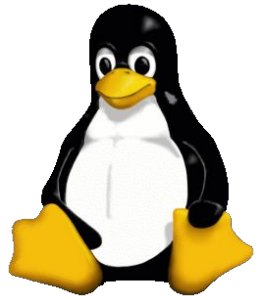

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bpftool & libbpf for introspection, debugging and user space API for applications

BPF supporting BPF to BPF function calls

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eBPF - beginning to present

Cilium 1.0 and eBPF's next big step: BTF (BPF Type Format)

Cilium 1.0: bringing the BPF revolution to K8s networking & security
- K8s CNI integration, identity-based L3-L7 policies, ClusterIP services, ...

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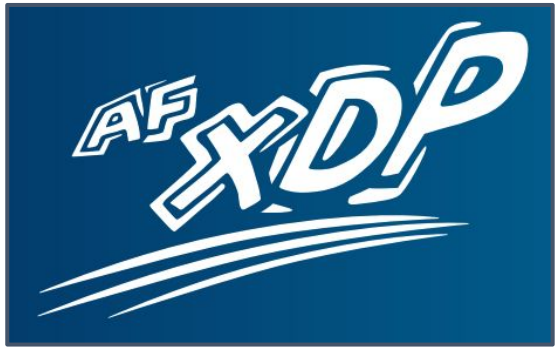

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AF_XDP merged into the kernel for DPDK performance at XDP layer with in-kernel drivers

bpfilter prototype to translate iptables rulesets into BPF via user mode driver

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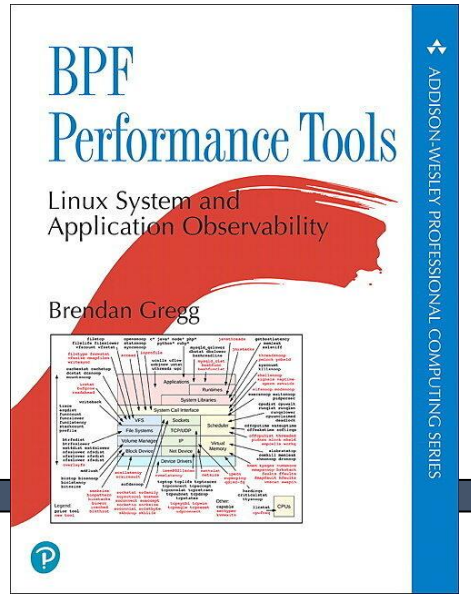

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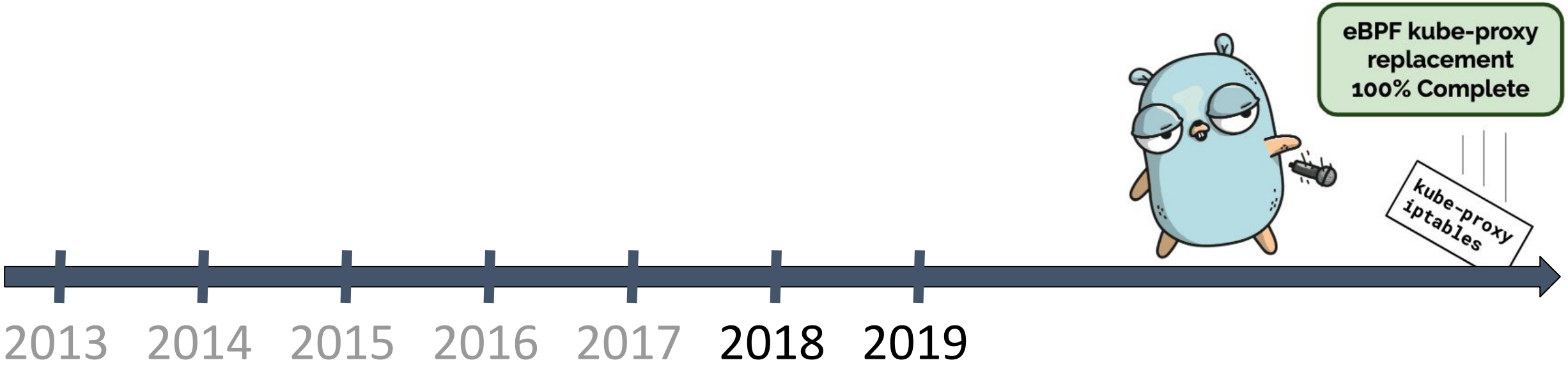

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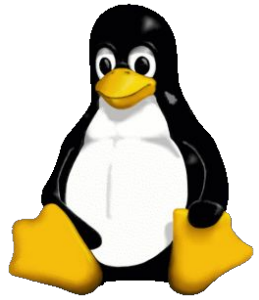

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BPF backend for **GCC** finally merged, BPF gets bounded loops support

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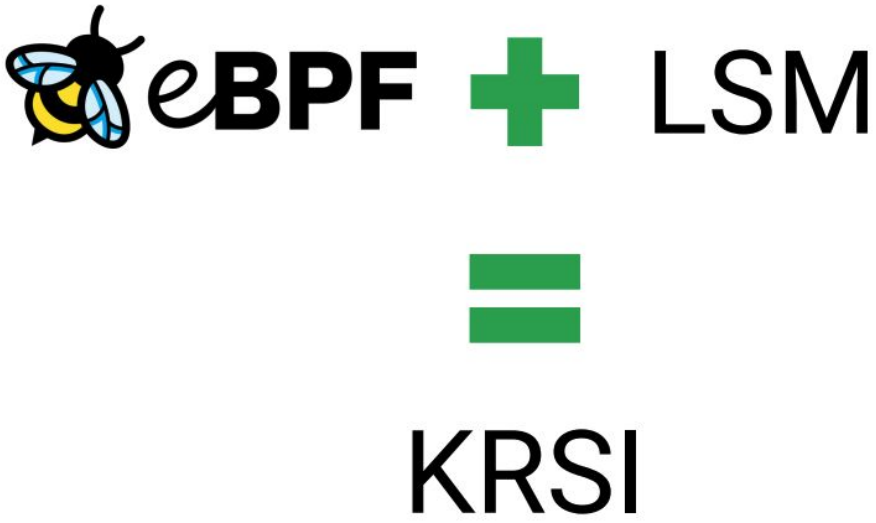
Relentless growth & third major direction for eBPF: Linux security modules

Google upstreaming BPF **LSM** support for their server fleet



KP Singh, https://lore.kernel.org/bpf/20200329004356.27286-1-kpsingh@chromium.org/
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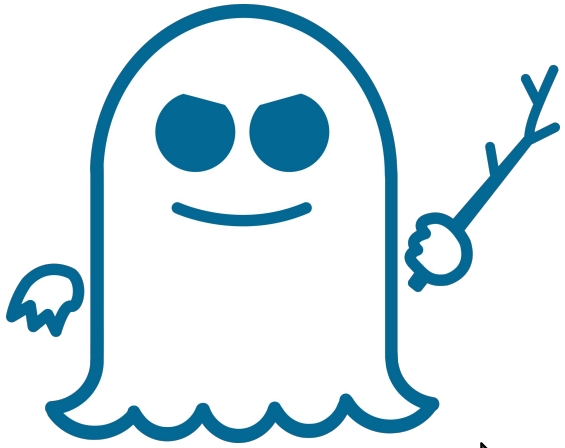
eBPF - beginning to present

Relentless growth & third major direction for eBPF: Linux security modules

Google upstreaming BPF **LSM** support for their server fleet

BPF verifier protecting against **Spectre**, even verifying safety on speculative program paths



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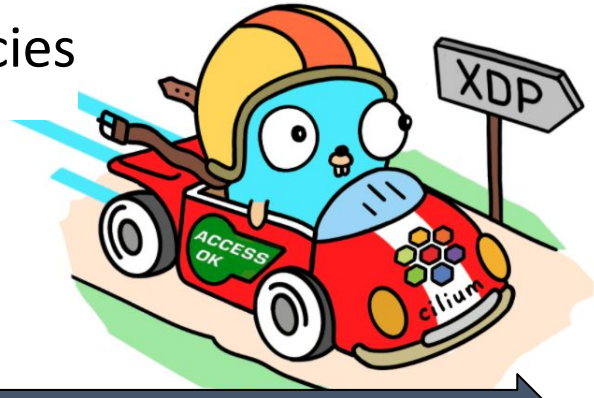

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eBPF - beginning to present

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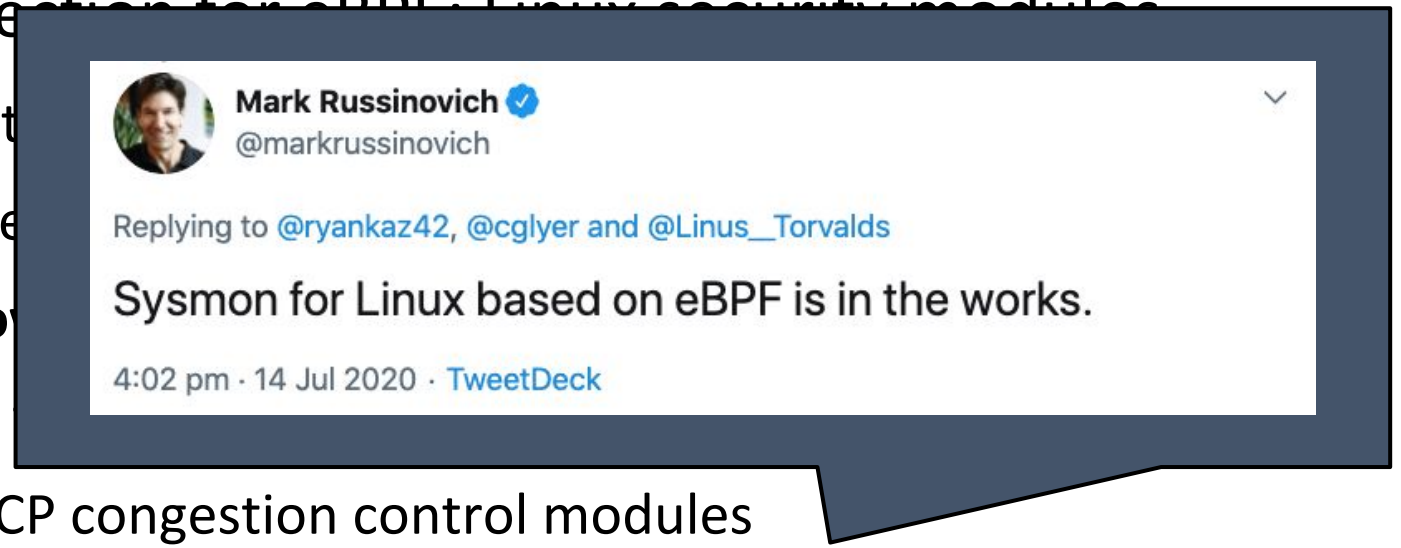

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eBPF - major OS change in 50yrs

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ZDNet

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MUST READ: Ransomware attack locked a football club's turnstiles

Netflix: BPF is a new type of software we use to run Linux apps securely in the kernel

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"BPF is the biggest operating systems change I've seen in my career, and it's thrilling to be a part of it," wrote Gregg.

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eBPF - in numbers (July 2020) ...

eBPF kernel community today:

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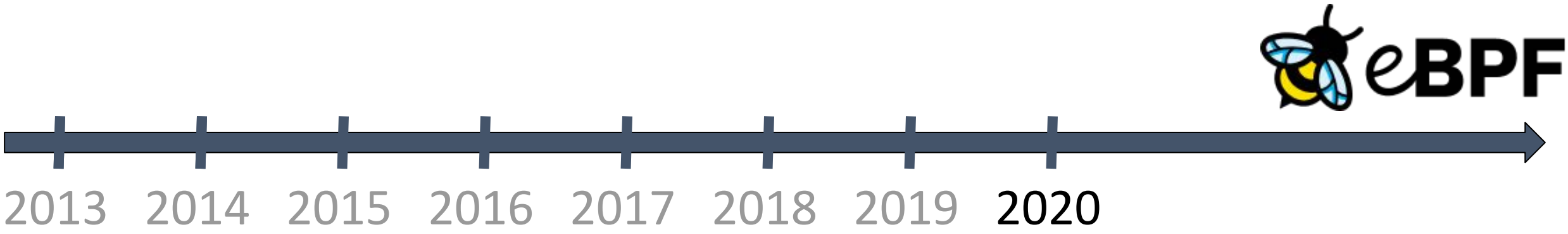

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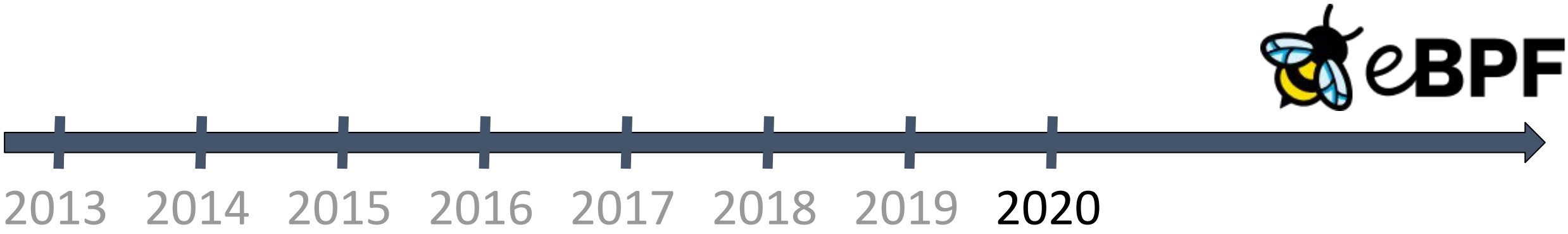

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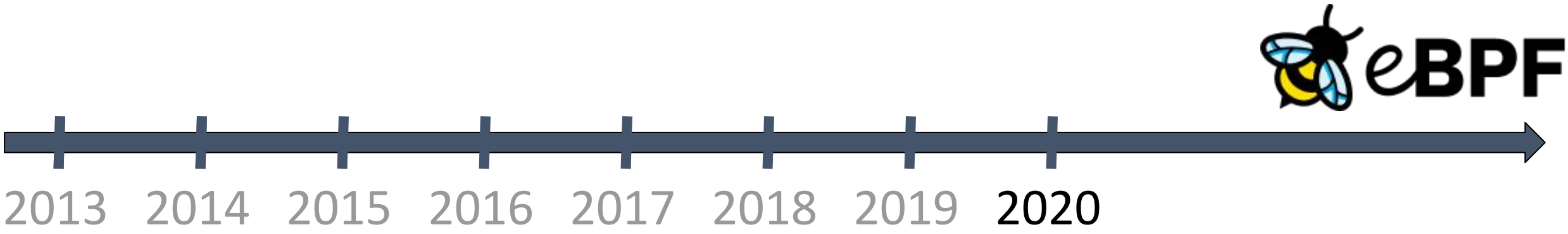

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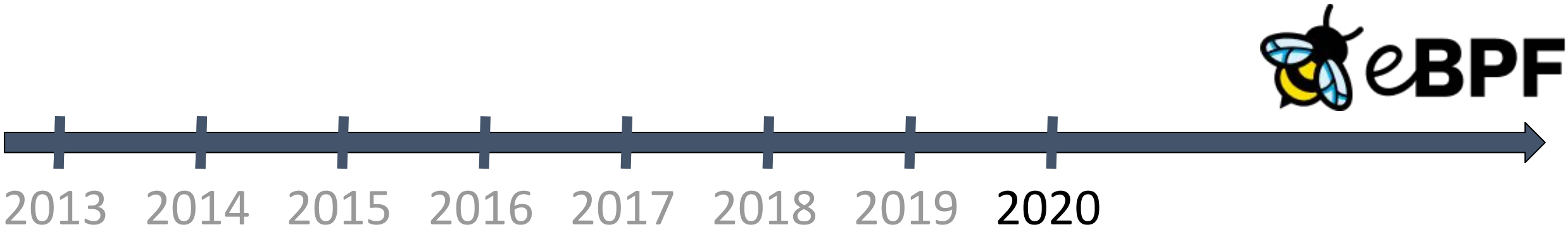

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One of the fastest growing subsystem in the Linux kernel ...

eBPF - the industry shift

eBPF

347 contributors (Jan 2014 to Jul 2020):

- 588 Daniel Borkmann (Isovalent; maintainer)
- 421 Andrii Nakryiko (Facebook)
- 401 Alexei Starovoitov (Facebook; maintainer)
- 224 Yonghong Song (Facebook)
- 209 Jakub Kicinski (Facebook)
- 183 Martin KaFai Lau (Facebook)
- 179 Stanislav Fomichev (Google)
- 165 John Fastabend (Isovalent)
- 161 Quentin Monnet (Isovalent)
- 130 Jesper Dangaard Brouer (Red Hat)
- 117 Andrey Ignatov (Facebook)
- [...]

Large scale BPF production users:

Bringing eBPF revolution to K8s

Bringing eBPF revolution to K8s

KubeCon CloudNativeCon Europe 2020 Virtual


```
:OUTPUT ACCEPT [2893:671491]
:DOCKER - [0:0]
:DOCKER-ISOLATION-STAGE-1 - [0:0]
:DOCKER-ISOLATION-STAGE-2 - [0:0]
:DOCKER-USER - [0:0]
:KUBE-EXTERNAL-SERVICES - [0:0]
:KUBE-FIREWALL - [0:0]
:KUBE-FORWARD - [0:0]
:KUBE-SERVICES - [0:0]
-A INPUT -m conntrack --ctstate NEW -m comment --comment "kubernetes service portals" -j KUBE-SERVICES
-A INPUT -m conntrack --ctstate NEW -m comment --comment "kubernetes externally-visible service portals" -j KUBE-EXTERNAL-SERVICES
-A INPUT -j KUBE-FIREWALL
-A FORWARD -m comment --comment "kubernetes forwarding rules" -j KUBE-FORWARD
-A FORWARD -m conntrack --ctstate NEW -m comment --comment "kubernetes service portals" -j KUBE-SERVICES
-A FORWARD -j DOCKER-USER
-A FORWARD -j DOCKER-ISOLATION-STAGE-1
-A FORWARD -o docker0 -m conntrack --ctstate RELATED,ESTABLISHED -j ACCEPT
-A FORWARD -o docker0 -j DOCKER
-A FORWARD -i docker0 ! -o docker0 -j ACCEPT
-A FORWARD -i docker0 -o docker0 -j ACCEPT
-A FORWARD -o docker_gwbridge -m conntrack --ctstate RELATED,ESTABLISHED -j ACCEPT
-A FORWARD -o docker_gwbridge -j DOCKER
-A FORWARD -i docker_gwbridge ! -o docker_gwbridge -j ACCEPT
-A FORWARD -i docker_gwbridge -o docker_gwbridge -j DROP
-A OUTPUT -m conntrack --ctstate NEW -m comment --comment "kubernetes service portals" -j KUBE-SERVICES
-A OUTPUT -j KUBE-FIREWALL
-A DOCKER-ISOLATION-STAGE-1 -i docker0 ! -o docker0 -j DOCKER-ISOLATION-STAGE-2
-A DOCKER-ISOLATION-STAGE-1 -i docker_gwbridge ! -o docker_gwbridge -j DOCKER-ISOLATION-STAGE-2
-A DOCKER-ISOLATION-STAGE-1 -j RETURN
-A DOCKER-ISOLATION-STAGE-2 -o docker0 -j DROP
-A DOCKER-ISOLATION-STAGE-2 -o docker_gwbridge -j DROP
-A DOCKER-ISOLATION-STAGE-2 -j RETURN
-A DOCKER-USER -j RETURN
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-A KUBE-FORWARD -m conntrack --ctstate INVALID -j DROP
-A KUBE-FORWARD -m comment --comment "kubernetes forwarding rules" -m mark --mark 0x4000/0x4000 -j ACCEPT
-A KUBE-FORWARD -s 10.217.0.0/16 -m comment --comment "kubernetes forwarding conntrack pod source rule" -m conntrack --ctstate RELATED,ESTABLISHED -j ACCEPT
-A KUBE-FORWARD -d 10.217.0.0/16 -m comment --comment "kubernetes forwarding conntrack pod destination rule" -m conntrack --ctstate RELATED,ESTABLISHED -j ACCEPT
-A KUBE-SERVICES -d 10.99.38.155/32 -p tcp -m comment --comment "default/nginx-59: has no endpoints" -m tcp --dport 80 -j REJECT --reject-with icmp-port-unreachable
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-A KUBE-SERVICES -d 10.97.138.144/32 -p tcp -m comment --comment "default/nginx-17: has no endpoints" -m tcp --dport 80 -j REJECT --reject-with icmp-port-unreachable
-A KUBE-SERVICES -d 10.106.49.80/32 -p tcp -m comment --comment "default/nginx-37: has no endpoints" -m tcp --dport 80 -j REJECT --reject-with icmp-port-unreachable
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-A KUBE-SERVICES -d 10.106.234.213/32 -p tcp -m comment --comment "default/nginx-88: has no endpoints" -m tcp --dport 80 -j REJECT --reject-with icmp-port-unreachable
-A KUBE-SERVICES -d 10.109.209.136/32 -p tcp -m comment --comment "default/nginx-33: has no endpoints" -m tcp --dport 80 -j REJECT --reject-with icmp-port-unreachable
-A KUBE-SERVICES -d 10.106.196.105/32 -p tcp -m comment --comment "default/nginx-49: has no endpoints" -m tcp --dport 80 -j REJECT --reject-with icmp-port-unreachable
-A KUBE-SERVICES -d 10.111.101.6/32 -p tcp -m comment --comment "default/nginx-53: has no endpoints" -m tcp --dport 80 -j REJECT --reject-with icmp-port-unreachable
-A KUBE-SERVICES -d 10.110.226.230/32 -p tcp -m comment --comment "default/nginx-79: has no endpoints" -m tcp --dport 80 -j REJECT --reject-with icmp-port-unreachable
-A KUBE-SERVICES -d 10.98.99.136/32 -p tcp -m comment --comment "default/nginx-6: has no endpoints" -m tcp --dport 80 -j REJECT --reject-with icmp-port-unreachable
-A KUBE-SERVICES -d 10.99.75.233/32 -p tcp -m comment --comment "default/nginx-7: has no endpoints" -m tcp --dport 80 -j REJECT --reject-with icmp-port-unreachable
-A KUBE-SERVICES -d 10.108.41.202/32 -p tcp -m comment --comment "default/nginx-14: has no endpoints" -m tcp --dport 80 -j REJECT --reject-with icmp-port-unreachable
-A KUBE-SERVICES -d 10.97.36.249/32 -p tcp -m comment --comment "default/nginx-99: has no endpoints" -m tcp --dport 80 -j REJECT --reject-with icmp-port-unreachable
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-A KUBE-SERVICES -d 10.106.224.55/32 -p tcp -m comment --comment "default/nginx-83: has no endpoints" -m tcp --dport 80 -j REJECT --reject-with icmp-port-unreachable
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-A KUBE-SERVICES -d 10.111.42.123/32 -p tcp -m comment --comment "default/nginx-21: has no endpoints" -m tcp --dport 80 -j REJECT --reject-with icmp-port-unreachable
-A KUBE-SERVICES -d 10.99.47.225/32 -p tcp -m comment --comment "default/nginx-22: has no endpoints" -m tcp --dport 80 -j REJECT --reject-with icmp-port-unreachable
-A KUBE-SERVICES -d 10.104.184.242/32 -p tcp -m comment --comment "default/nginx-51: has no endpoints" -m tcp --dport 80 -j REJECT --reject-with icmp-port-unreachable
```
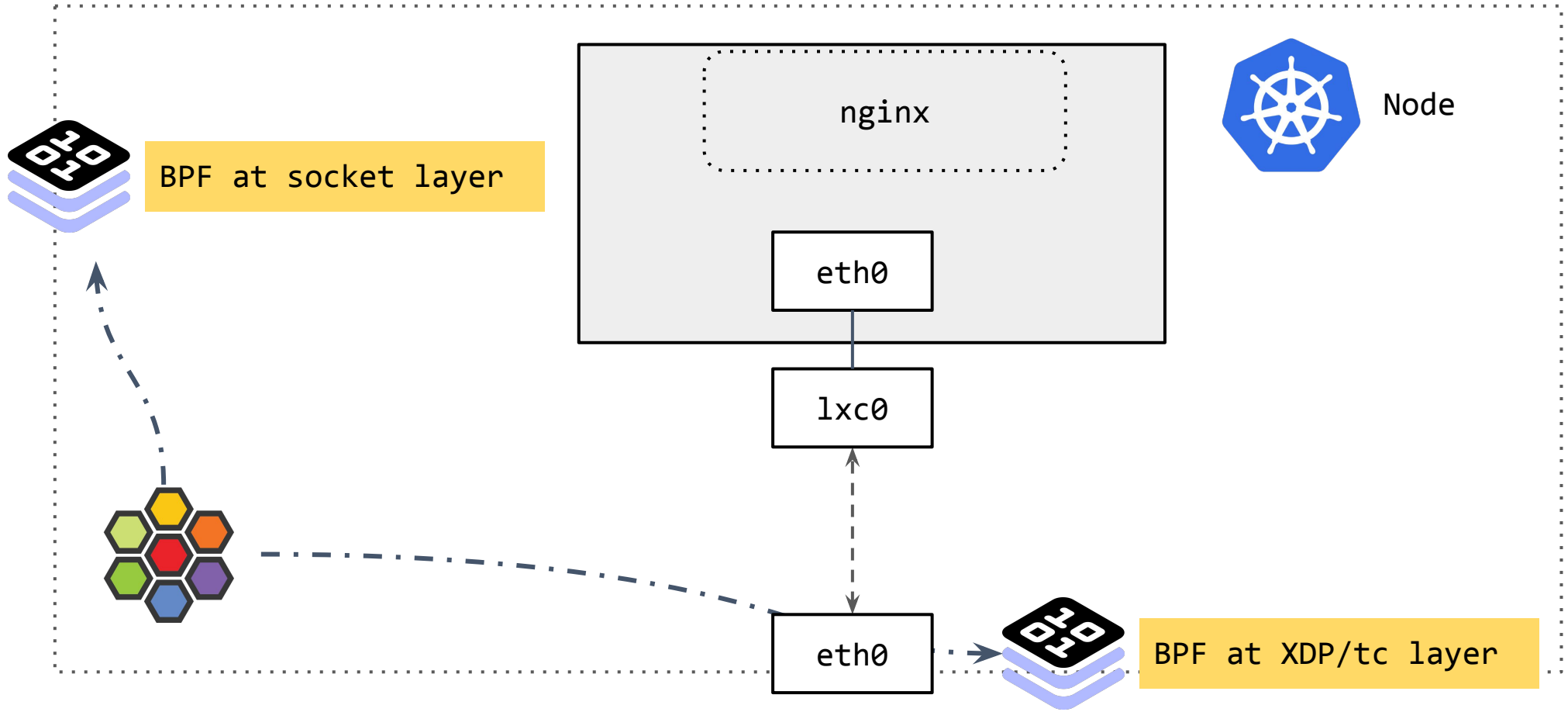

Example: s/kube-proxy/eBPF/


```
$ kubectl -n kube-system delete ds kube-proxy
```

Cilium's service load balancing



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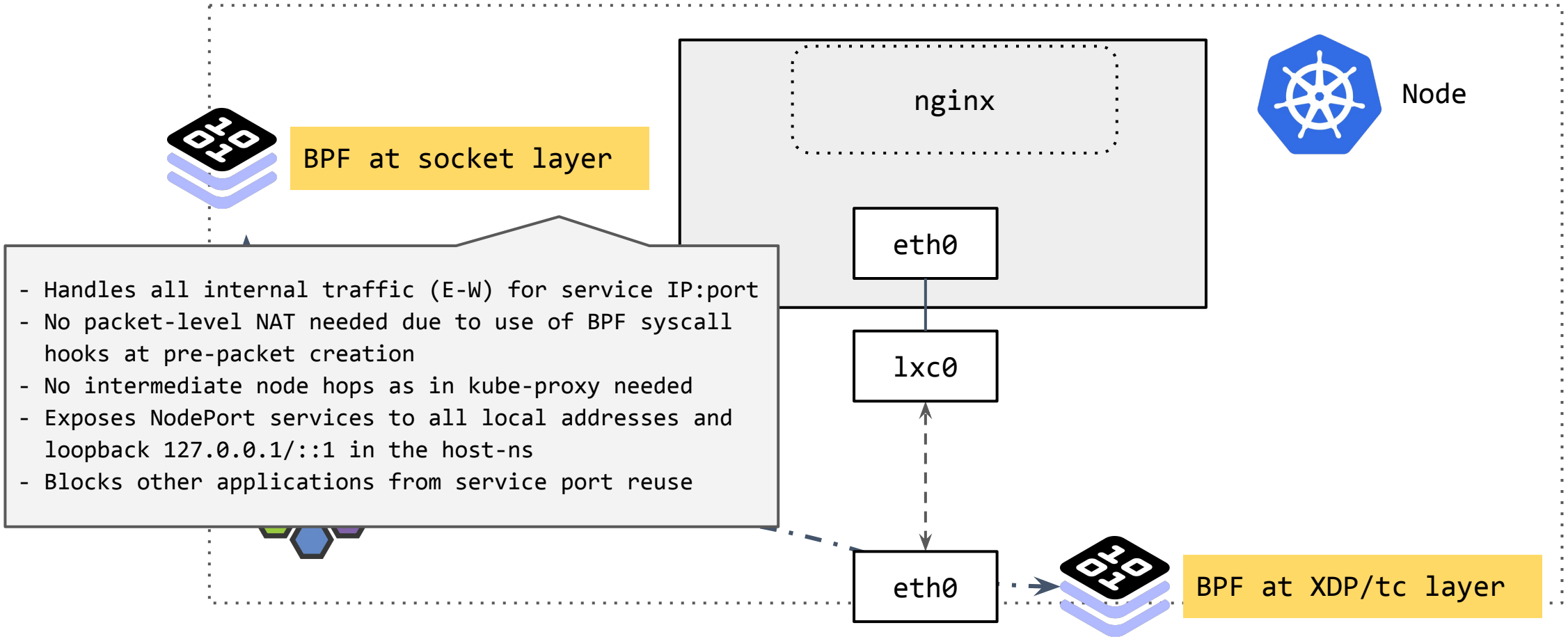

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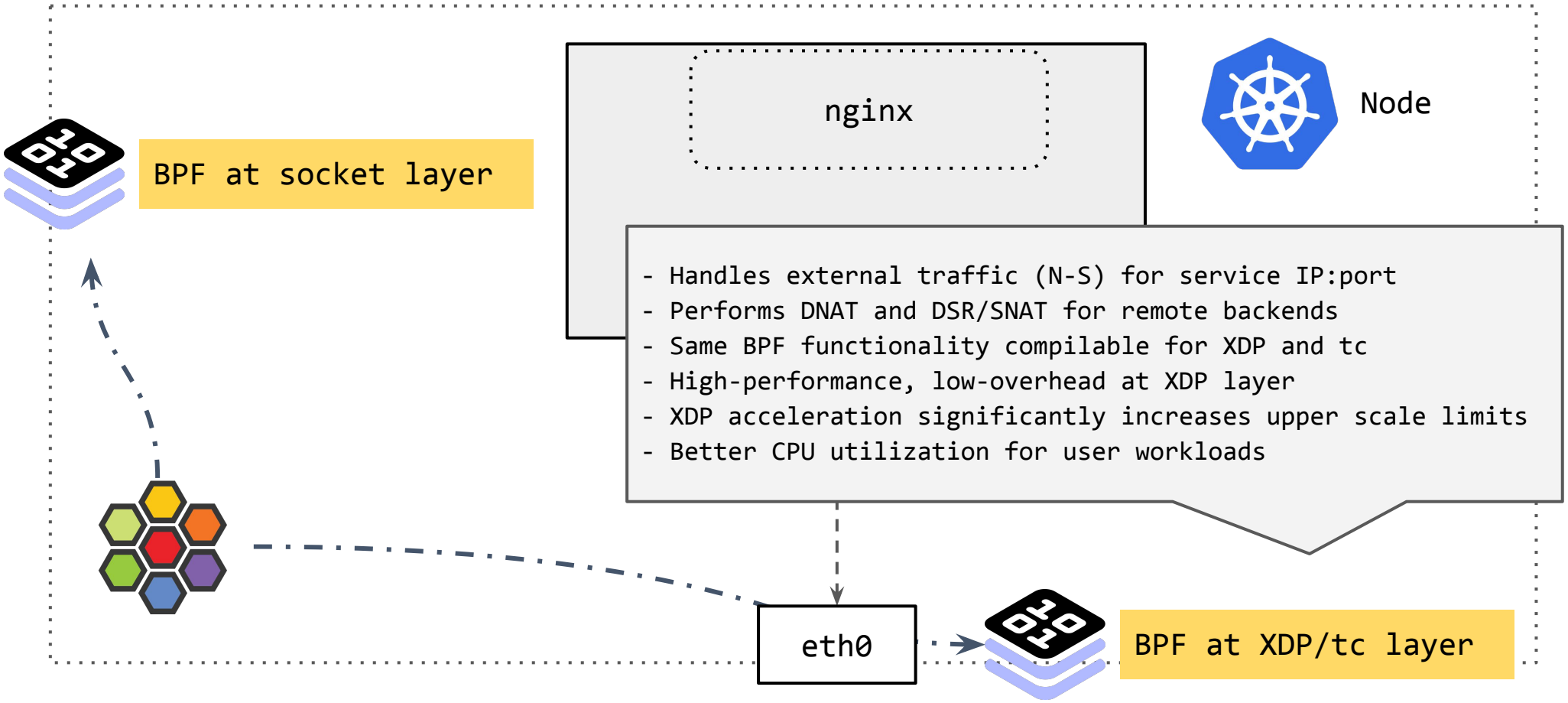

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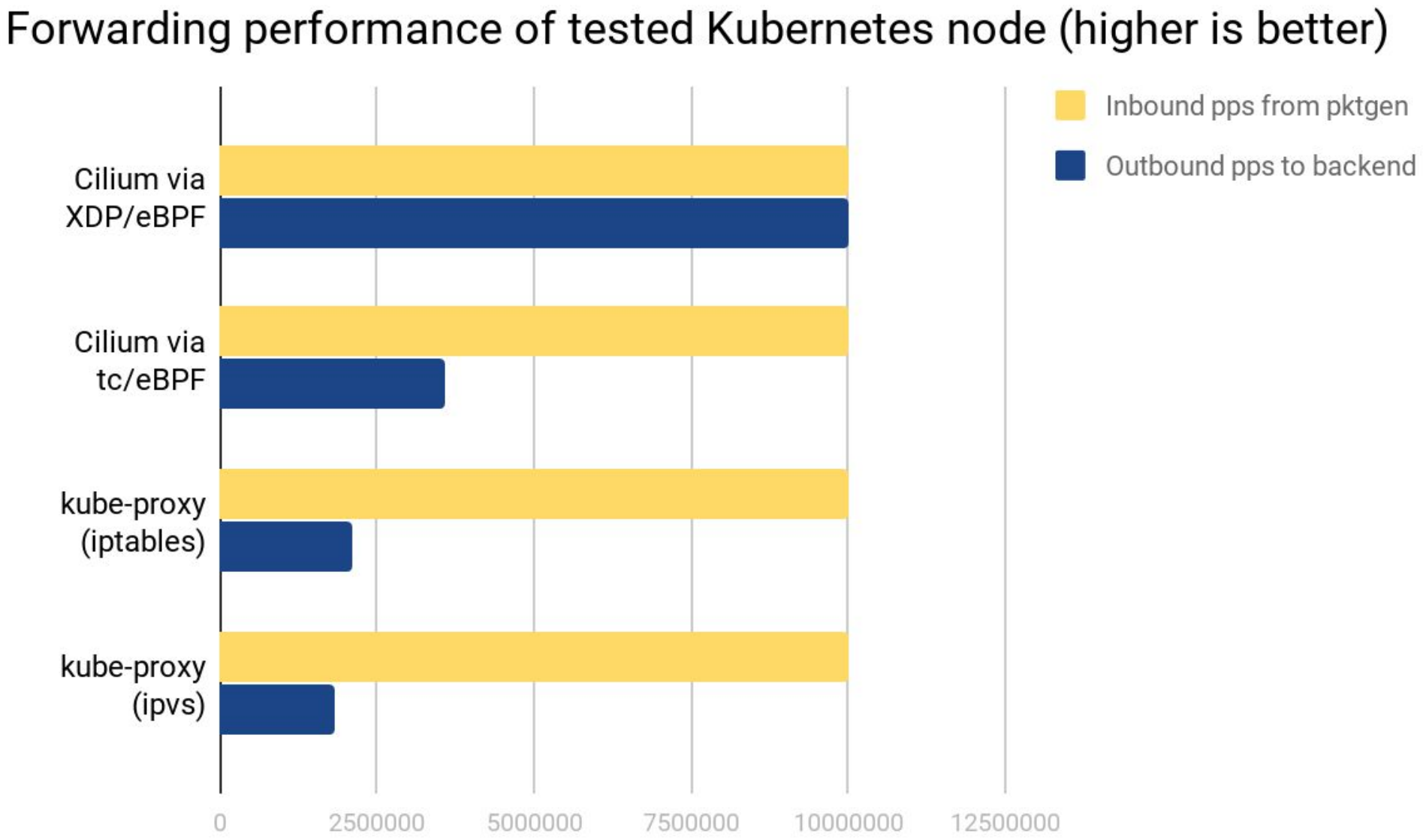
XDP & eBPF vs kube-proxy



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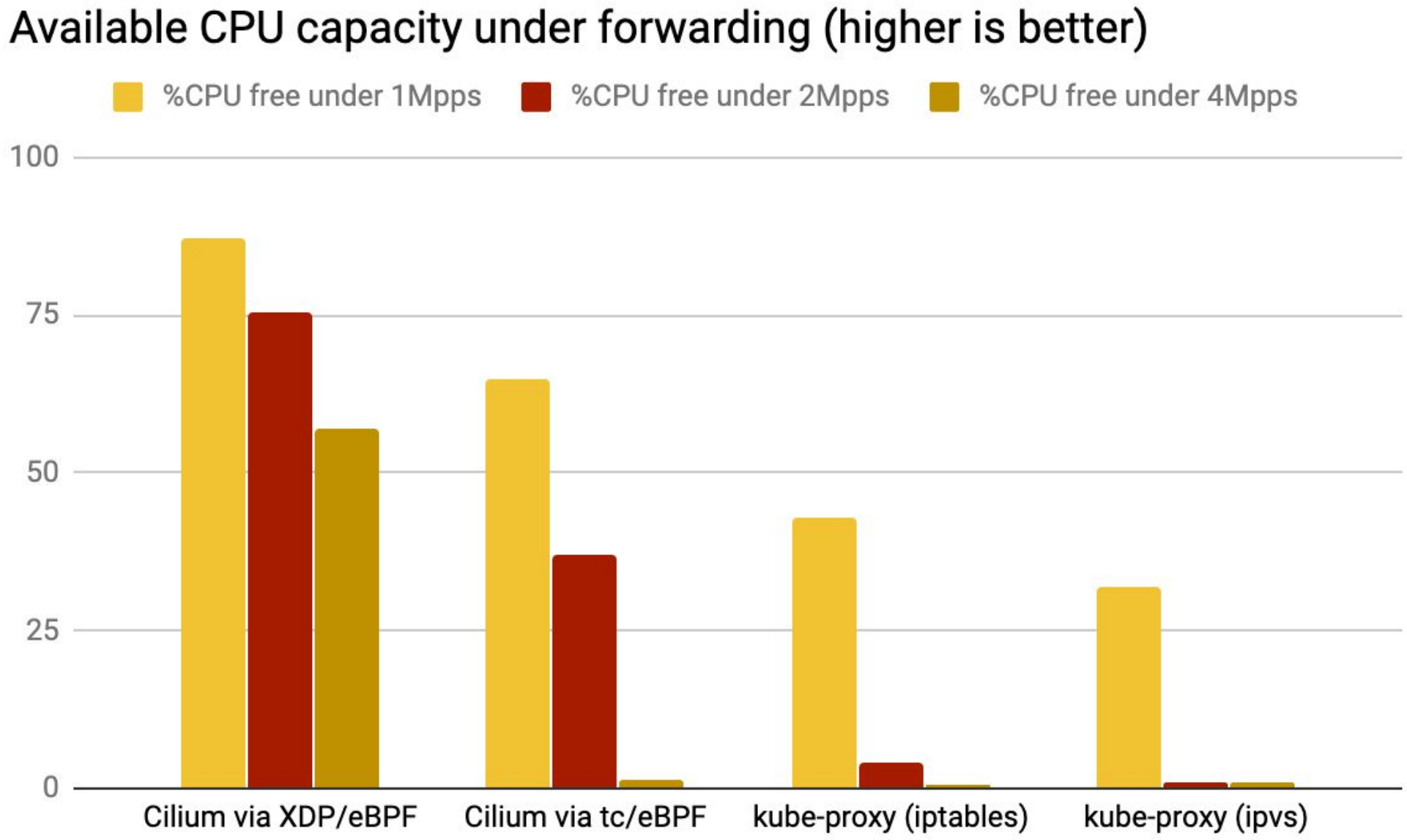

eBPF & Kubernetes - the future

“The Linux kernel continues its march towards becoming BPF runtime-powered microkernel.”

Tiny core kernel with user definable kernel functionality in BPF (instead of kernel modules)

Toke Høiland-Jørgensen, https://lwn.net/ml/bufferbloat/87bls8bnsm.fsf@toke.dk/

eBPF & Kubernetes - the future

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Today’s kube-proxy replacement through BPF is just a tiny dot in that universe ...

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Thanks a lot! Questions?

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- ➔ Pod-to-Pod Network Connectivity (CNI)
- ➔ Service-based load balancing
- ➔ Security Enforcement (NetworkPolicy)
- ➔ Transparent Encryption
- ➔ Observability, Metrics & Troubleshooting

Try it out: https://cilium.link/kubeproxy-free

Contribute: https://github.com/cilium/cilium

See also: Hubble - eBPF Based Observability for Kubernetes – Sebastian Wicki


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CONNECTED