bpfbox: Simple Precise Process Confinement with eBPF

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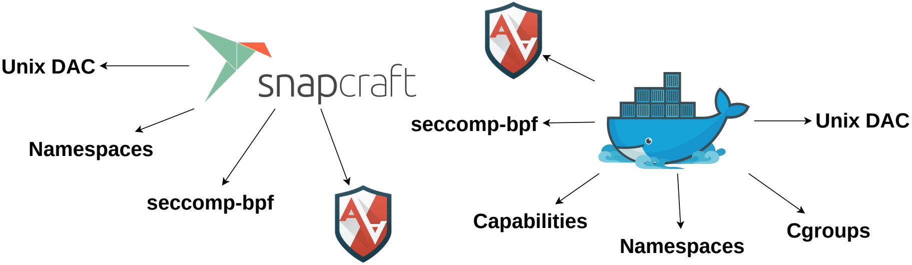
bpfbox at a Glance

- bpfbox is a novel **process confinement mechanism** for Linux
    - Using a new Linux technology called eBPF
- Users write per-application policy in a **simple policy language**
- Policy is enforced by attaching **eBPF programs** to **LSM hooks**
    - Integrates cross-layer state into policy decisions

Motivation

- Existing process confinement mechanisms are **complex**



Unix DAC

Namespaces

seccomp-bpf

seccomp-bpf

Unix DAC

Capabilities

Namespaces

Cgroups

- Existing process confinement mechanisms are **difficult to use**

SELinux AppArmor TOMOYO

- Can we do any better?

eBPF Changes the Game

eBPF enables:

- Fine-grained system introspection
- Integration of **cross-layer state** with policy enforcement
- Rapid prototyping
- Safe production deployment of new security solutions

We have an opportunity to **rethink process confinement** from the ground up.

eBPF in the Beginning

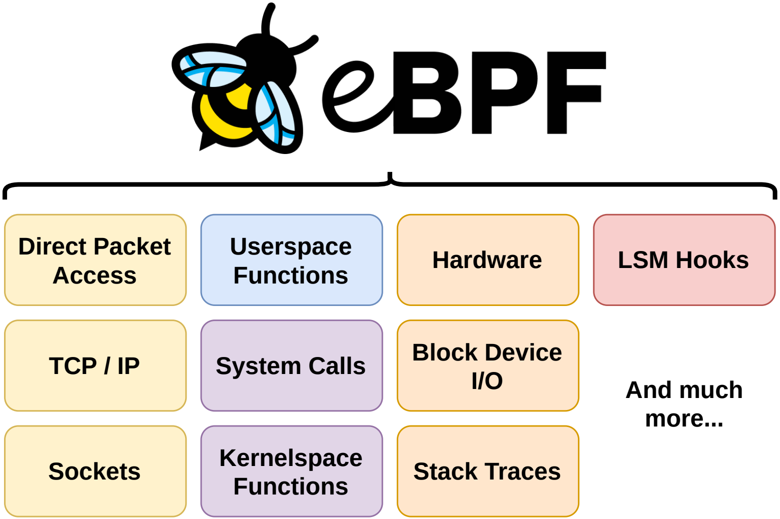
eBPF $\equiv$ **E**xtended **B**erkley **P**acket **F**ilter...

- But it has little to do with Berkley, packets, or filtering nowadays
- The name BPF is preserved for historical reasons

So then **what is eBPF?**

- A major re-write of the Linux BPF engine
  - Alexei Starovoitov and Daniel Borkmann
- Merged into the Linux kernel in 2014
- The point was fine-grained, cross-layer **system introspection**

What Can eBPF Do?



eBPF

Direct Packet Access

Userspace Functions

Hardware

LSM Hooks

TCP / IP

System Calls

Block Device I/O

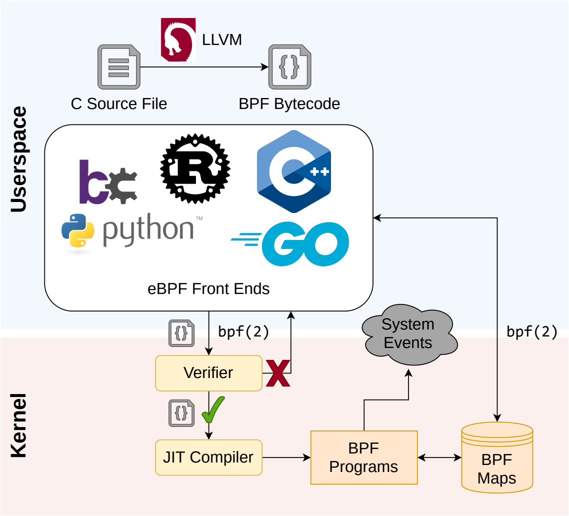
Sockets

Kernelspace Functions

Stack Traces

And much more...

How eBPF Works



eBPF in 2020

eBPF is now **more than just an observability tool**.

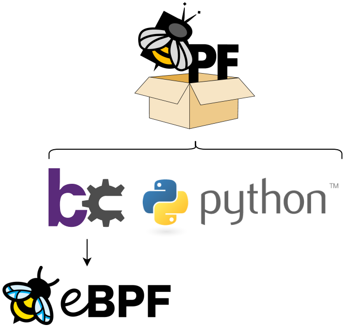
- eBPF provides a **safe**, **efficient**, and **flexible** way for privileged users to extend the kernel
- eBPF turns Linux into a **programmable kernel**

Linux 5.7 → KRSI (**K**ernel **R**untime **S**ecurity **I**nstrumentation)

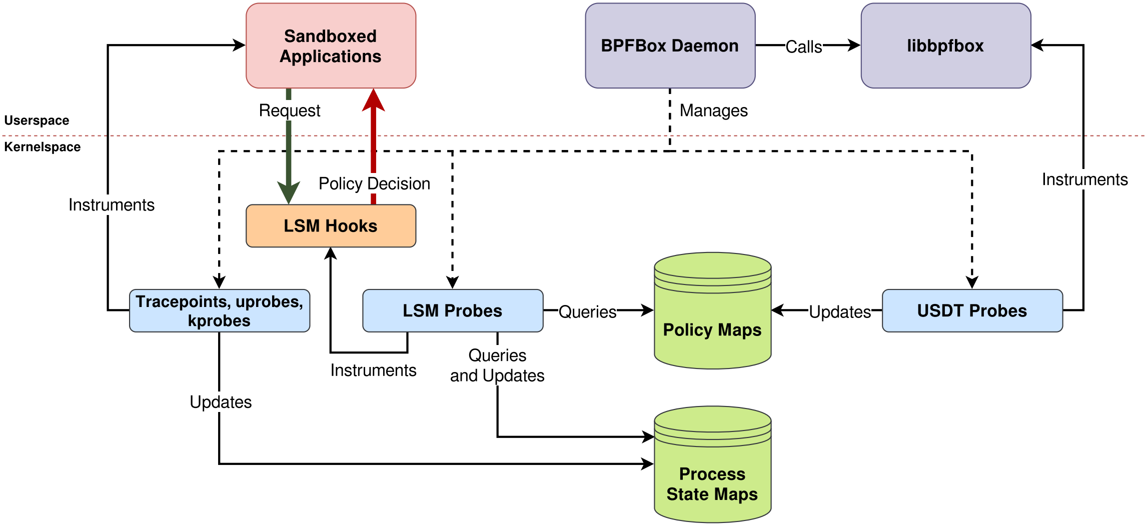
- Attach BPF programs to LSM hooks
- Make security decisions and generate audit logs with eBPF

bpfbox Implementation

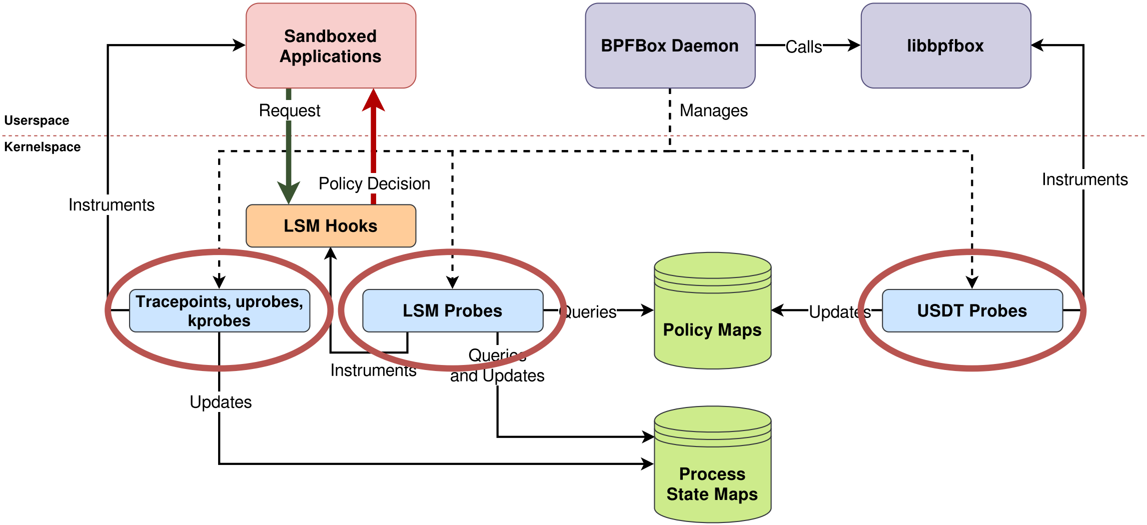
- Userspace daemon using the Python3 bcc framework
- Kernelspace components are all eBPF
  - LSM probes (KRSI), kprobes, uprobes
  - Under 2000 source lines of kernelspace code
- Thanks to eBPF, bpfbox is **light-weight**, **flexible**, and **production-safe**
  - Works out of the box on any vanilla Linux kernel ≥ 5.8



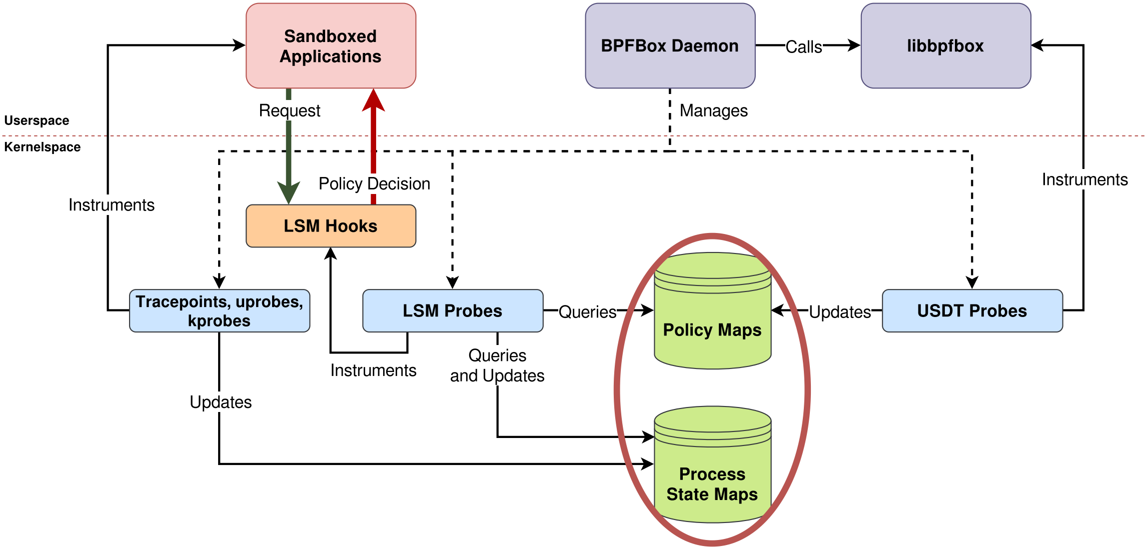
bpfbox Architecture



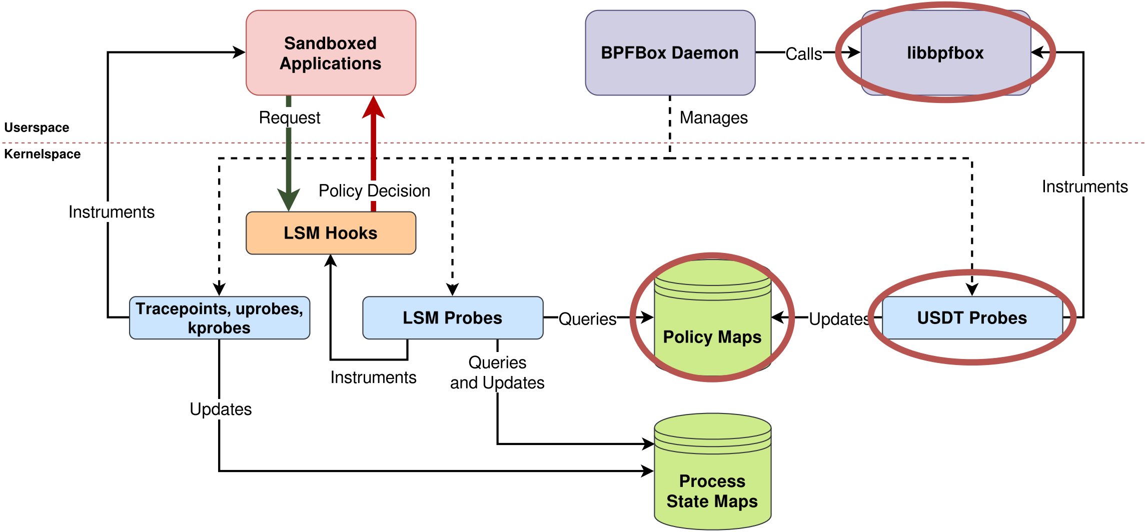
bpfbox Architecture



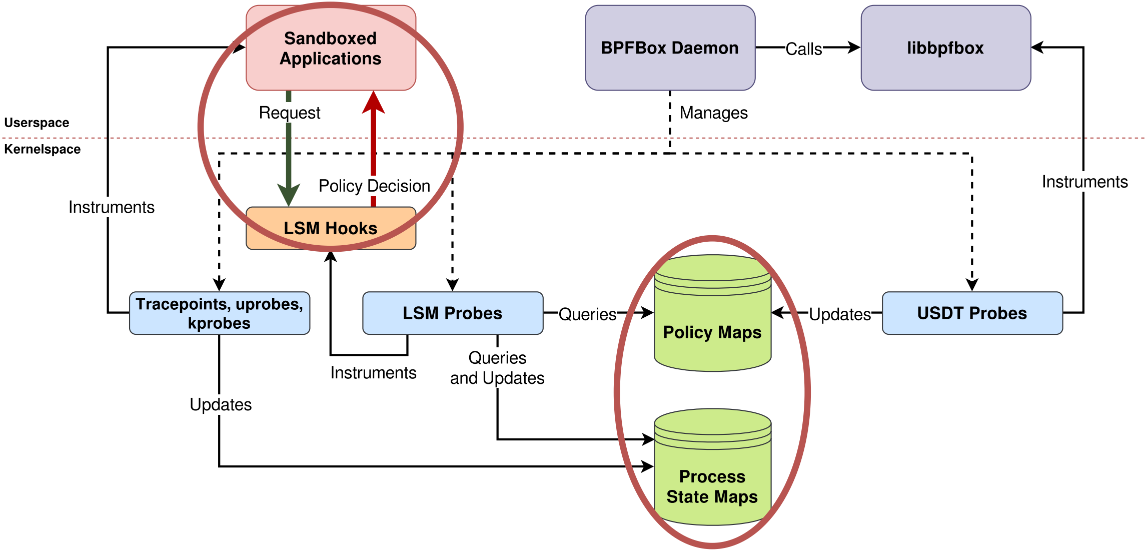
bpfbox Architecture



bpfbox Architecture



bpfbox Architecture



Policy Design Goals

1. **Simplicity**
   - Policy should be simple enough for ad hoc confinement
2. **Application transparency**
   - Policy should not require changes to the confined application
3. **Flexibility**
   - Policy should offer optional layers of granularity
4. **Security**
   - Policy should follow the principle of least privilege
   - It should be difficult to write an insecure policy

Rules and Directives

Rules specify access to system objects:

- `fs(file, access)`
- `net(socket, access)`
- `signal(prog, sig)`
- etc.

Directives augment blocks of rules:

- `#[directive]` syntax
- Specify **actions to be taken** on a block of rules
- Add **additional context** to a block of rules

Taints and Transitions

- #[taint] → Start confinement
- #[transition] → Switch profiles on execve

```
#![profile "/bin/mywebdaemon"]

#[taint] {
    net(inet, any)
    net(inet6, any)
}

/* ... */

#[transition] {
    fs("/bin/myhelper", getattr|read|exec)
}
```

Policy at the Function Call Level

- `#[func "foo"]` → Apply rules only within a call to `foo()`
- `#[kfunc "foo"]` → Same thing, but for kernel functions

```
#![profile "/sbin/mylogin"]

#[func "check_password"]
#[allow] {
    fs("/etc/passwd", read)
    fs("/etc/shadow", read)
}

#[func "add_user"]
#[allow] {
    fs("/etc/passwd", read|append)
    fs("/etc/shadow", read|append)
}

/* ... */
```

Performance Evaluation

Methodology

- Phoronix Test Suite OSBench
  - Measures basic OS functionality
  - (spawning processes, memory allocations, etc.)
- Phoronix Test Suite Apache
  - Benchmark Apache `httpd` packets per second
- Kernel compilation benchmarks
  - Measure Linux kernel compilation performance
  - Heavy workload, spawning lots of processes

Performance Evaluation

Methodology

Two modes of operation for each test.

- Passive mode
  - bpfbox and AppArmor instrument hooks, but do not enforce or audit
  - Test lowest possible overhead
- Complaining mode
  - bpfbox and AppArmor complain about (log) every security-sensitive operation
  - Test worst case overhead

Performance Evaluation

Results

- Phoronix OSBench
  - Passive: bpfbox is **roughly equivalent** to AppArmor
  - Complaining: bpfbox performs **significantly better** than AppArmor
- Phoronix Apache
  - bpfbox and AppArmor are **roughly equivalent**
- Kernel compilation
  - Passive: bpfbox is **roughly equivalent** to AppArmor
  - Complaining: bpfbox performs **better in kernelspace** overhead and **worse in userspace** overhead

Contributions

- First **policy enforcement engine** written in **eBPF**
- Integration of **userspace** and **kernelspace** state with **LSM layer enforcement**
- A simple policy language for **ad hoc process confinement**
    - But with optional complexity for **fine-grained protection**

Acknowledgements

Special thanks to:

- **Alexei Starovoitov** and **Daniel Borkmann** (creators of eBPF)
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- Fellow **bcc contributors** (an awesome eBPF framework)
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github.com/willfindlay/bpfbox

Check out the project on GitHub!