bpfbox: Simple Precise Process Confinement with eBPF

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Outline of Talk

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2. The Status Quo
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4. bpfbox Overview
5. bpfbox Design and Implementation
6. bpfbox Performance Evaluation
7. The Future of eBPF and Security
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The Process Confinement Problem

What is Process Confinement?

We want to be able to **confine** our **processes**.

- Also known as *sandboxing*

Why do we want to do this?

- Default protection mechanisms are too:
    - Granular
    - User-centric
    - Discretionary
- Protection can be **overridden**
    - Superuser (*nix)
    - Administrator (Windows)

How do we protect the user from *themselves* and *their own processes*?

An Interesting Question

How many processes do you think are running on your computer **right now**?

- Probably a lot more than you think
- You probably didn't start most of them yourself
- You might not even know what some of them are for

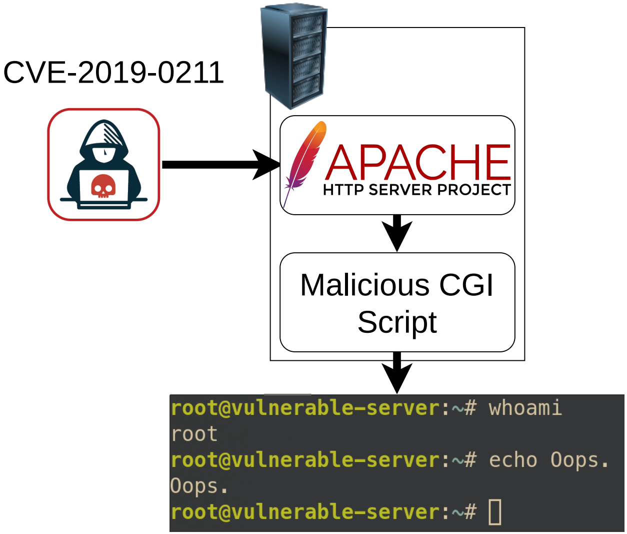
Threat Model

Compromised Processes

- Web servers
- Daemons
- Chat applications
- etc.

The Morris Worm

- Backdoor in `sendmail` daemon
- Buffer overflow in `fingerd`
- Estimated damage: $100,000–$10,000,000

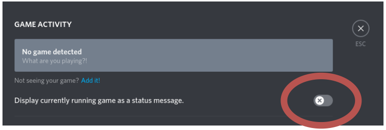


Threat Model

Semi-Honest Software

- Software that does its job...
- But also performs potentially **unwanted actions**

```
[16:13] hh@arch:~ | strace -fqo /tmp/discord.log discord-canary
```



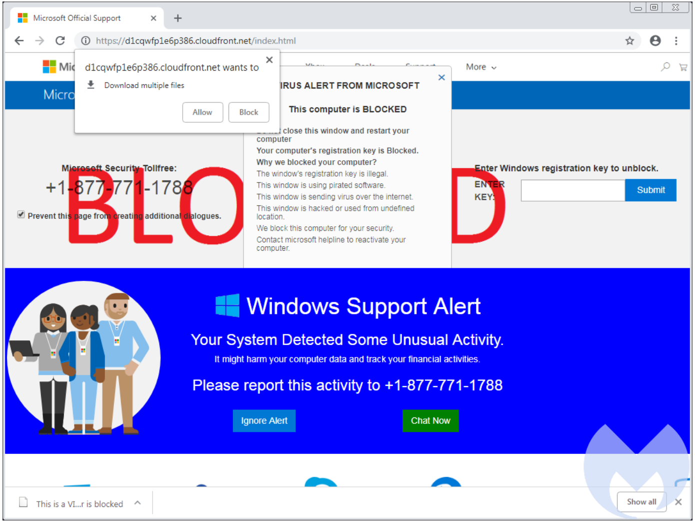

```
912433 readlink("/proc/506824/exe", "/opt/draw.io/drawio", 1023) = 19
912433 readlink("/proc/634535/exe", "/usr/lib/firefox/firefox", 1023) = 24
912433 readlink("/proc/909407/exe", "/usr/bin/alacritty", 1023) = 18
912433 readlink("/proc/3205375/exe", "/usr/bin/tmux", 1023) = 13
912433 readlink("/proc/3244098/exe", "/usr/bin/zsh", 1023) = 12
912433 readlink("/proc/3387/exe", "/usr/bin/picom", 1023) = 14
912433 readlink("/proc/3412/exe", "/usr/bin/xbindkeys", 1023) = 18
912433 readlink("/proc/3421/exe", "/usr/bin/volnoti", 1023) = 16
912433 readlink("/proc/3449/exe", "/usr/bin/pulseaudio", 1023) = 19
```

Umm... What?

Threat Model

Malicious Software

- Viruses
- Trojans
- Ransomware
- Spyware
- etc.



Threat Model

Attack goals?

- Installing backdoors/rootkits
- Information leakage
- Denial of service
- Data ransom
- Setting up a botnet

Process confinement reduces the attack surface.

The Process Confinement Problem

- “A Note on the Confinement Problem” (Lampson, 1973)

Operating Systems — C. Weissman, Editor

A Note on the Confinement Problem

Butler W. Lampson
Xerox Palo Alto Research Center

- An open problem for nearly **five decades**

The Status Quo

Unix DAC

POSIX Capabilities

Namespaces and Cgroups

System Call Interposition

Linux MAC

Containers / Containerized Package Management

eBPF 101

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 original goal was fine-grained, cross-layer **system introspection**

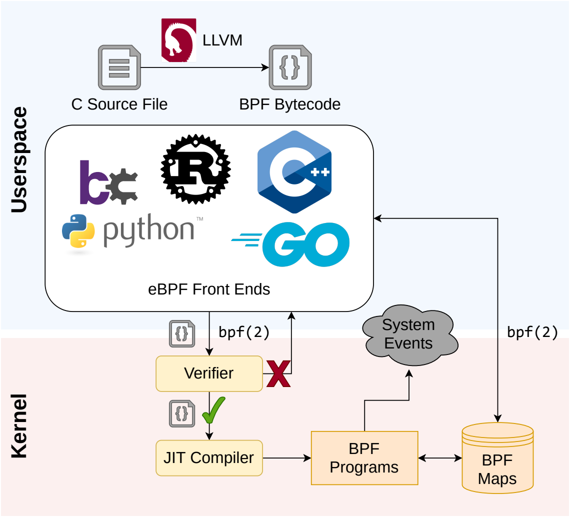
What Can eBPF Do?

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



Verifiably Safe Programs

- TODO explain verifier

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 $\rightarrow$ KRSI (**K**ernel **R**untime **S**ecurity **I**nstrumentation)

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

KRSI: BPF LSM Programs

- TODO explain KRSI with a picture

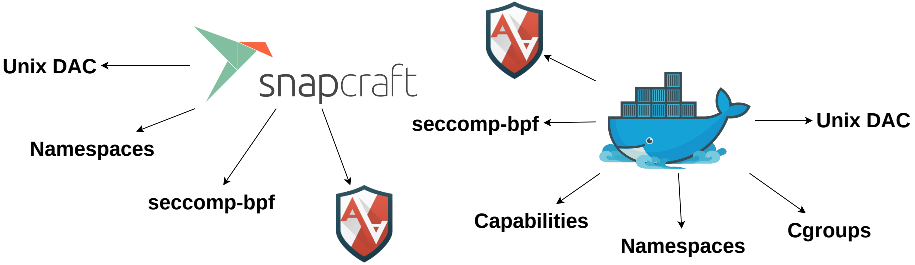
bpfbox Overview

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**



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

SELinux AppArmor TOMOYO

- Can we do any better?

eBPF Changes the Game

eBPF enables:

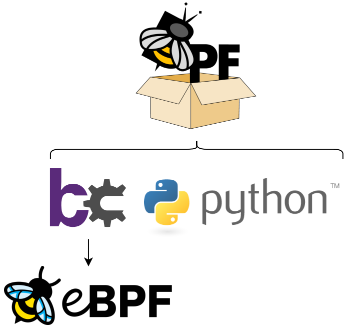
- Fine-grained system introspection
- Integration of **cross-layer state** with policy enforcement
- Rapid prototyping
- Safe production deployment of new security solutions

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

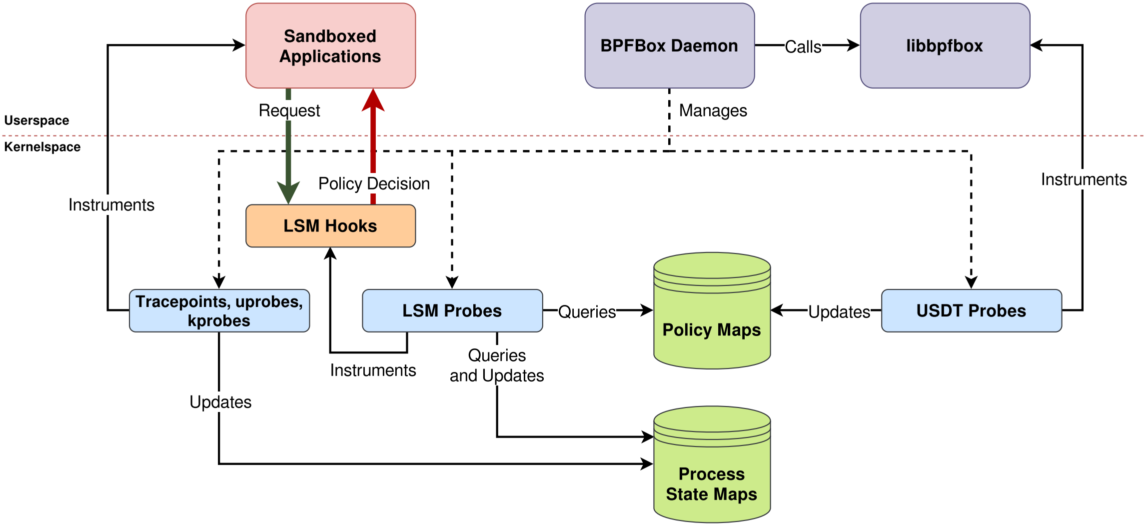
bpfbox Design and Implementation

bpfbox Implementation

- Userspace daemon using the Python3 bcc framework
- Kernelspace components are all written in 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



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)
}

/* ... */
```

bpfbox 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

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

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

The Future of eBPF and Security

Conclusion

Acknowledgements

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- **Alexei Starovoitov** and **Daniel Borkmann** (creators of eBPF)
- **K.P. Singh** (creator of KRSI)
- Fellow **bcc contributors** (an awesome eBPF framework)
- Anonymous **CCSW'2020 reviewers** (valuable feedback)

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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**

github.com/willfindlay/bpfbox

Check out the project on GitHub!