Precursors of Security and Performance

Instrumentation and Tracing of Systems

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17th August 2017

Security and DevOps Meetup, Santa Clara

ShiftLeft

Le Plan

Observability Layers

Instrumentation of Systems

- Challenges
- Techniques

Foundations

- Performance
- Security

Security Tooling

- Preventive (Isolation)
- Passive (Monitoring)
- Active (Protection)

whoami

Suchakra

- Staff Scientist, ShiftLeft Inc.
- PhD, DORSAL Lab, *Polytechnique Montréal - University of Montréal*
- Loves tracing, security, performance analysis, hardware dev, poutine and samosas
- @tuxology

Observability Layers

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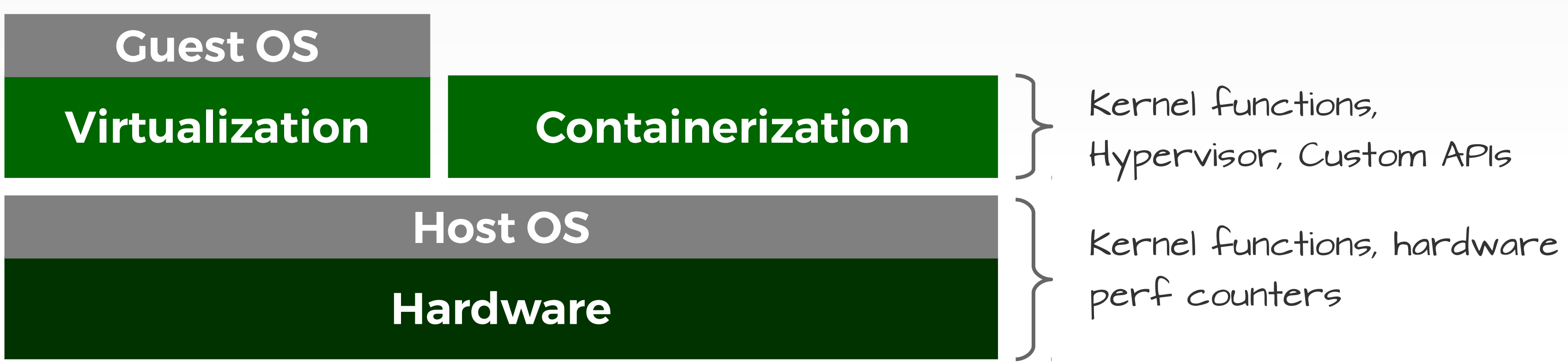

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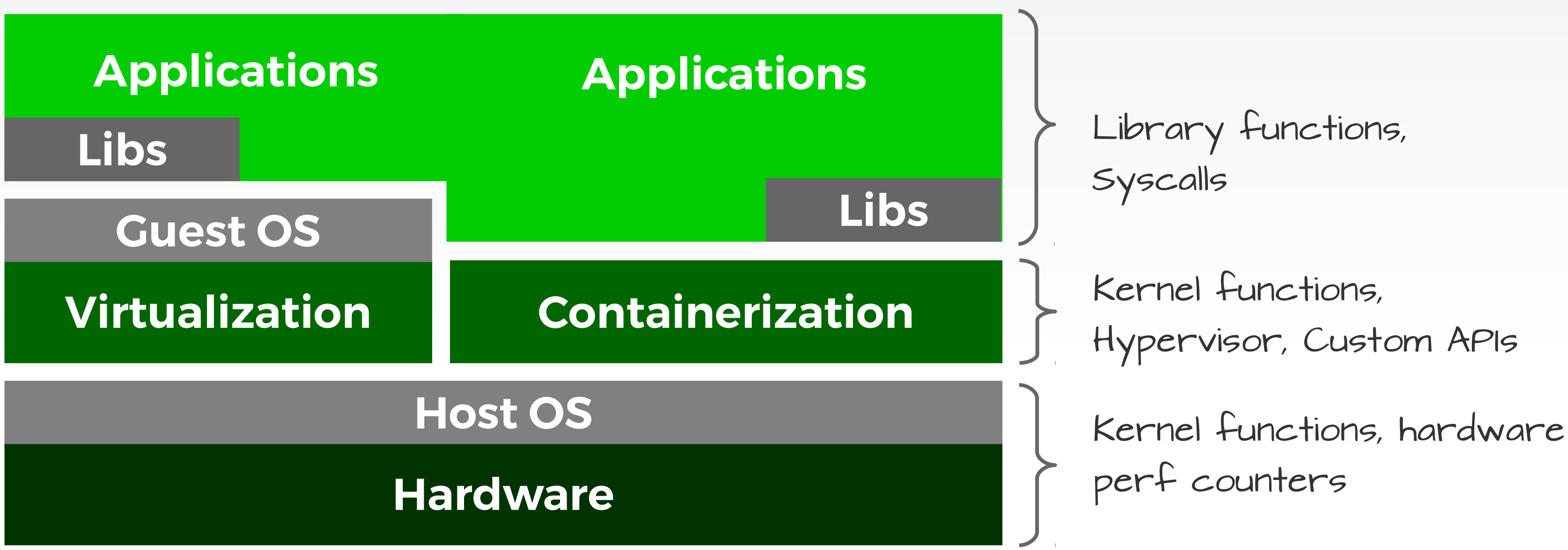

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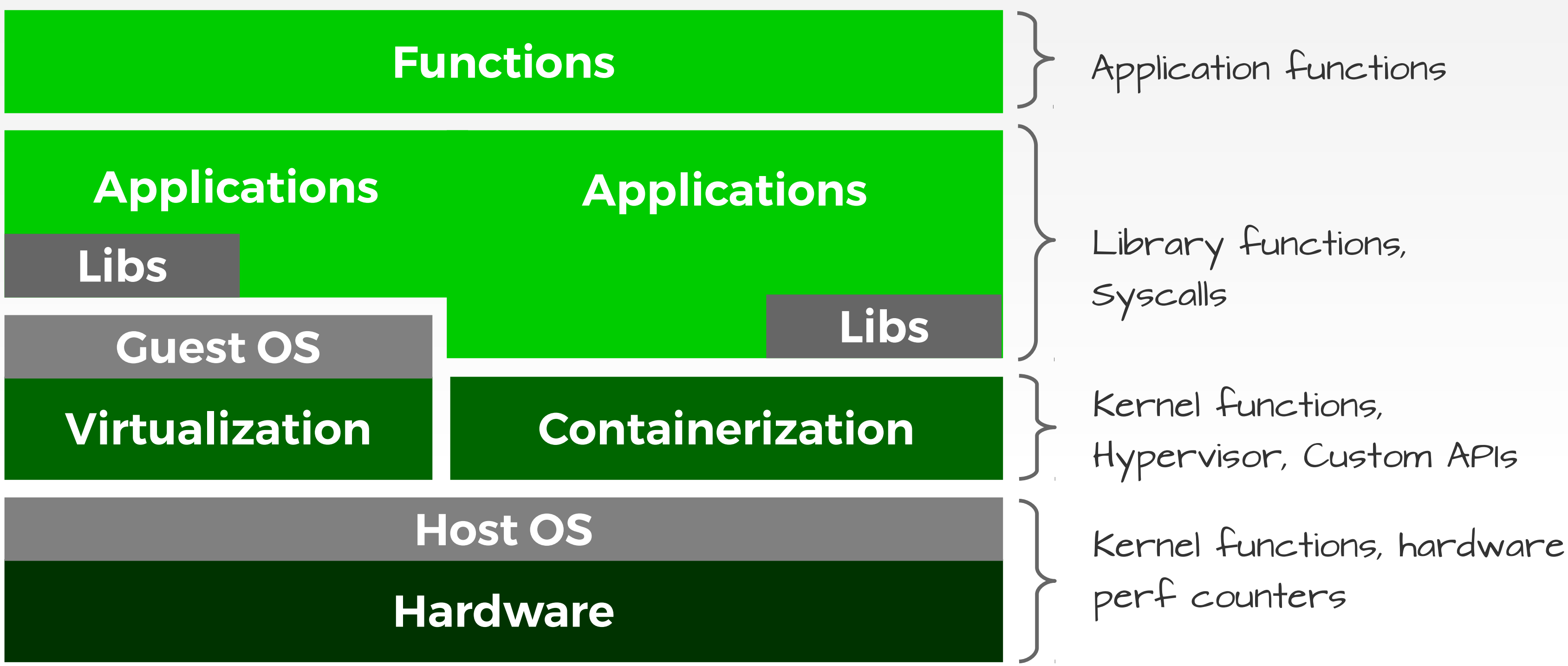

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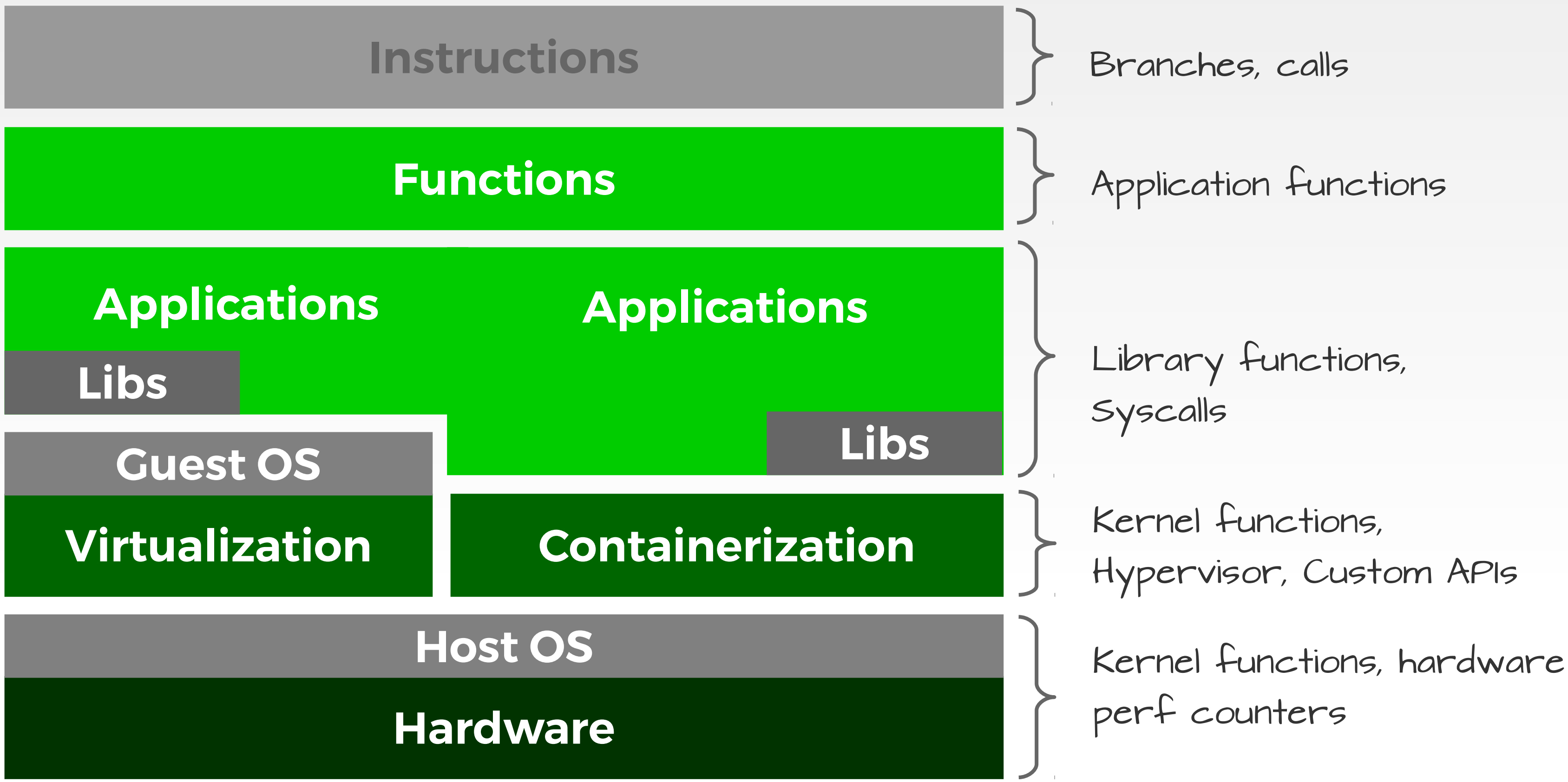

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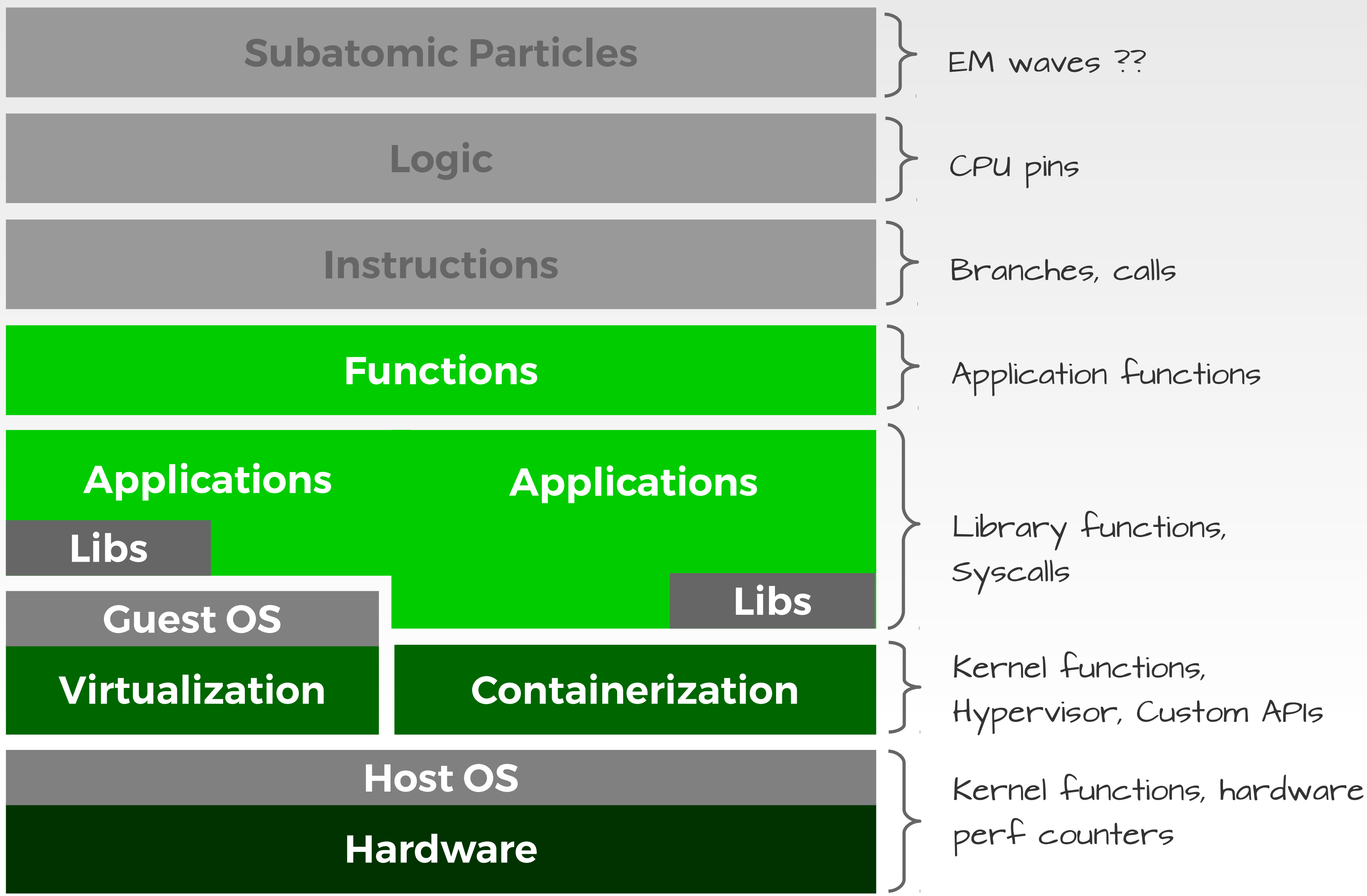
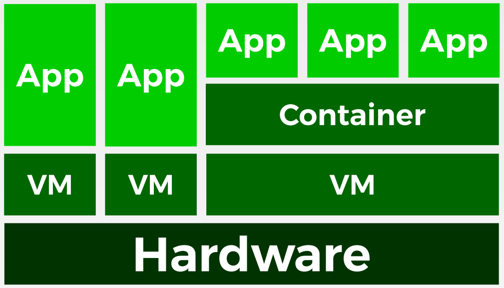


Observing Modern Systems

Challanges

- Horizontal spread of services has increased



- Apps are distributed across machines and geographies
- Visibility across horizontal and vertical layers
- Preventive, Monitoring and Enforcing security for cloud-native applications is non-trivial now
- Developers need awareness of production setups in the modern world

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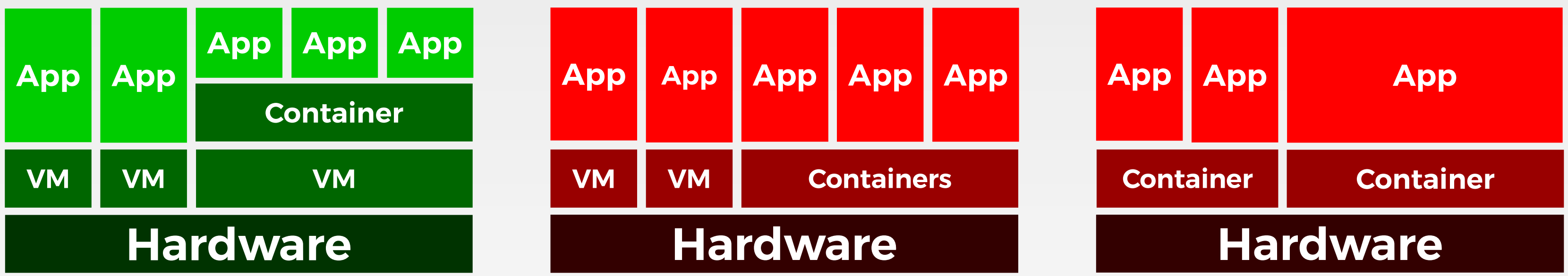

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Instrumenting Systems

Why

- Applications can now assist you in performance and security analysis
  - Understand program and data flow
  - Analyze timings and compare executions
- Powerful debugging using traces where debugging is prohibitively expensive

How

- Simple. Insert extra code at desired locations in any layer of the system (app, library, host OS)
- Add a `printf()`. Congrats ☺

Tracing

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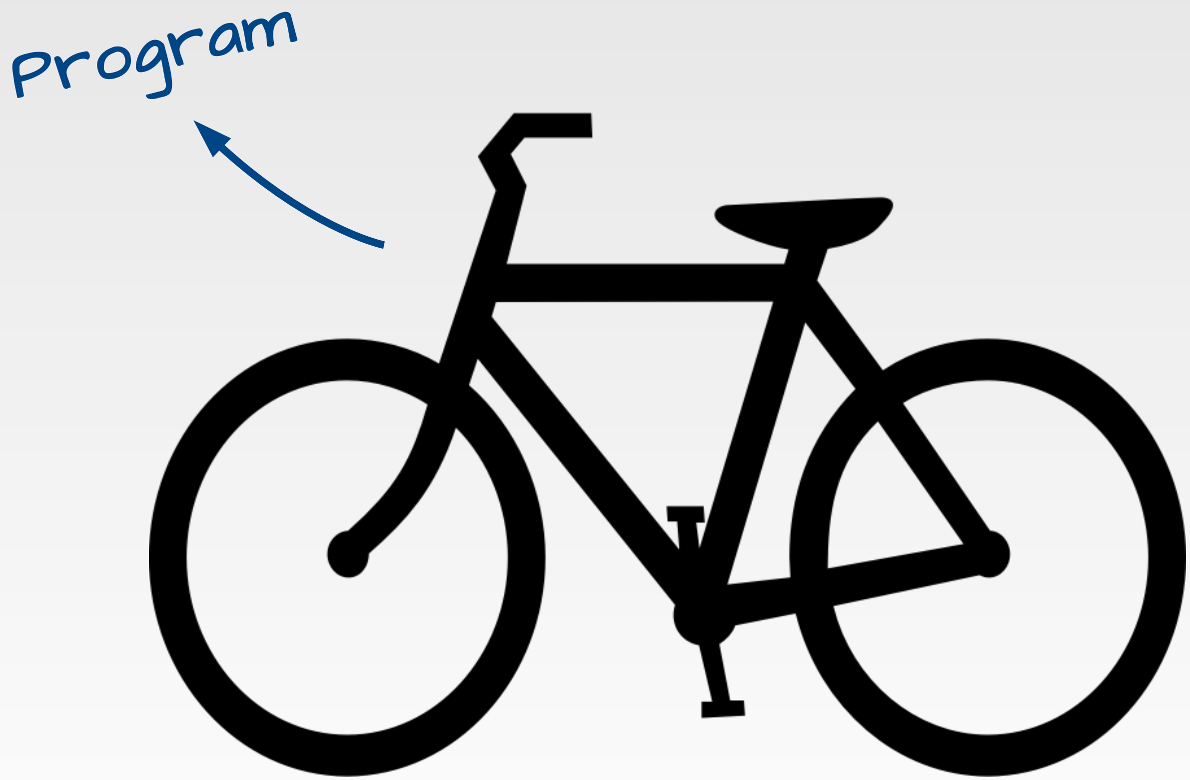
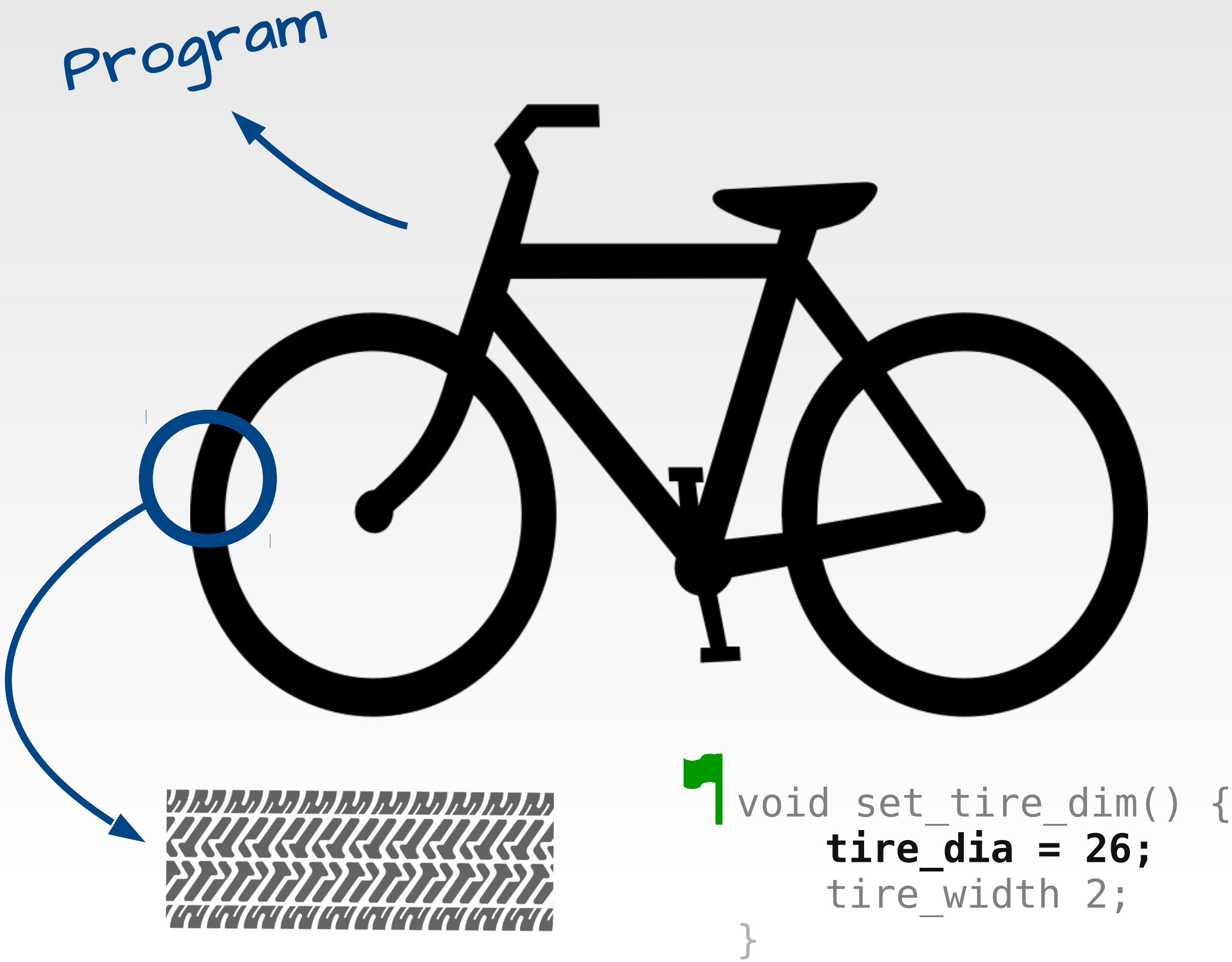

Program



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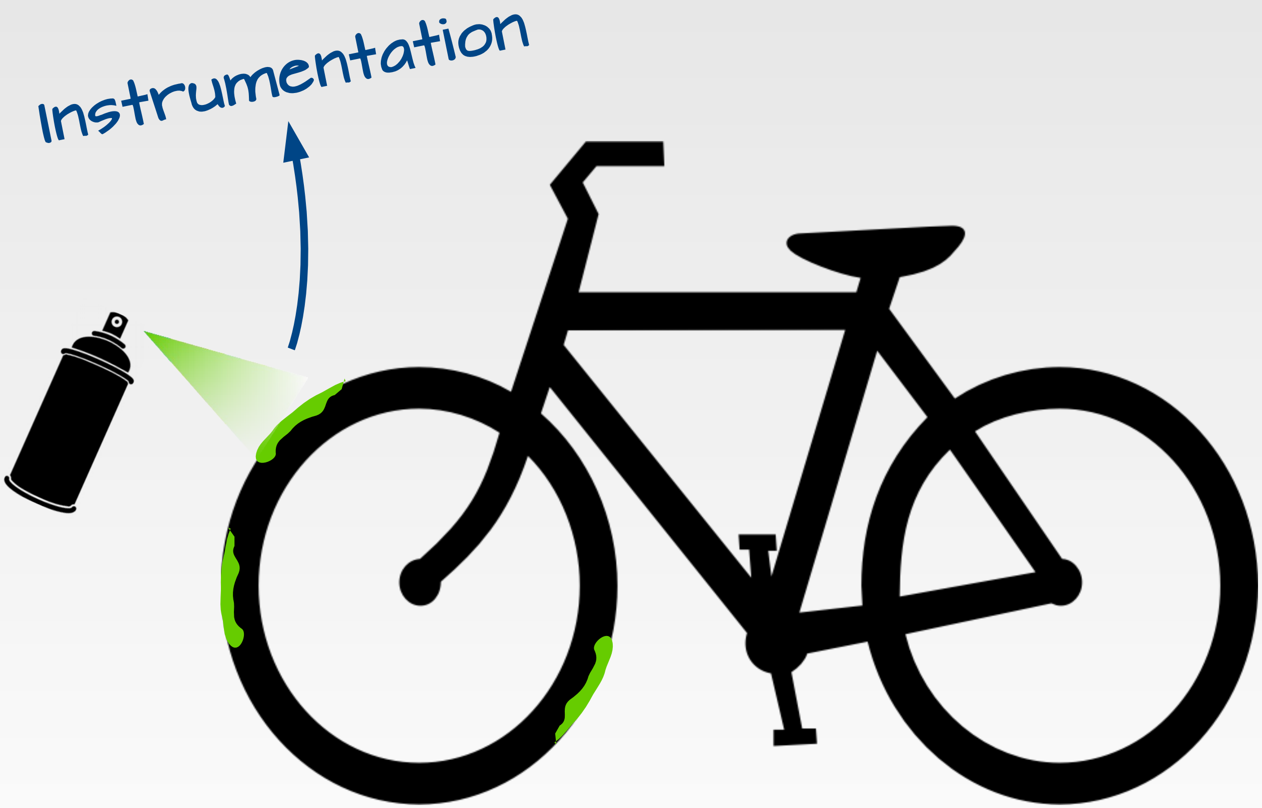
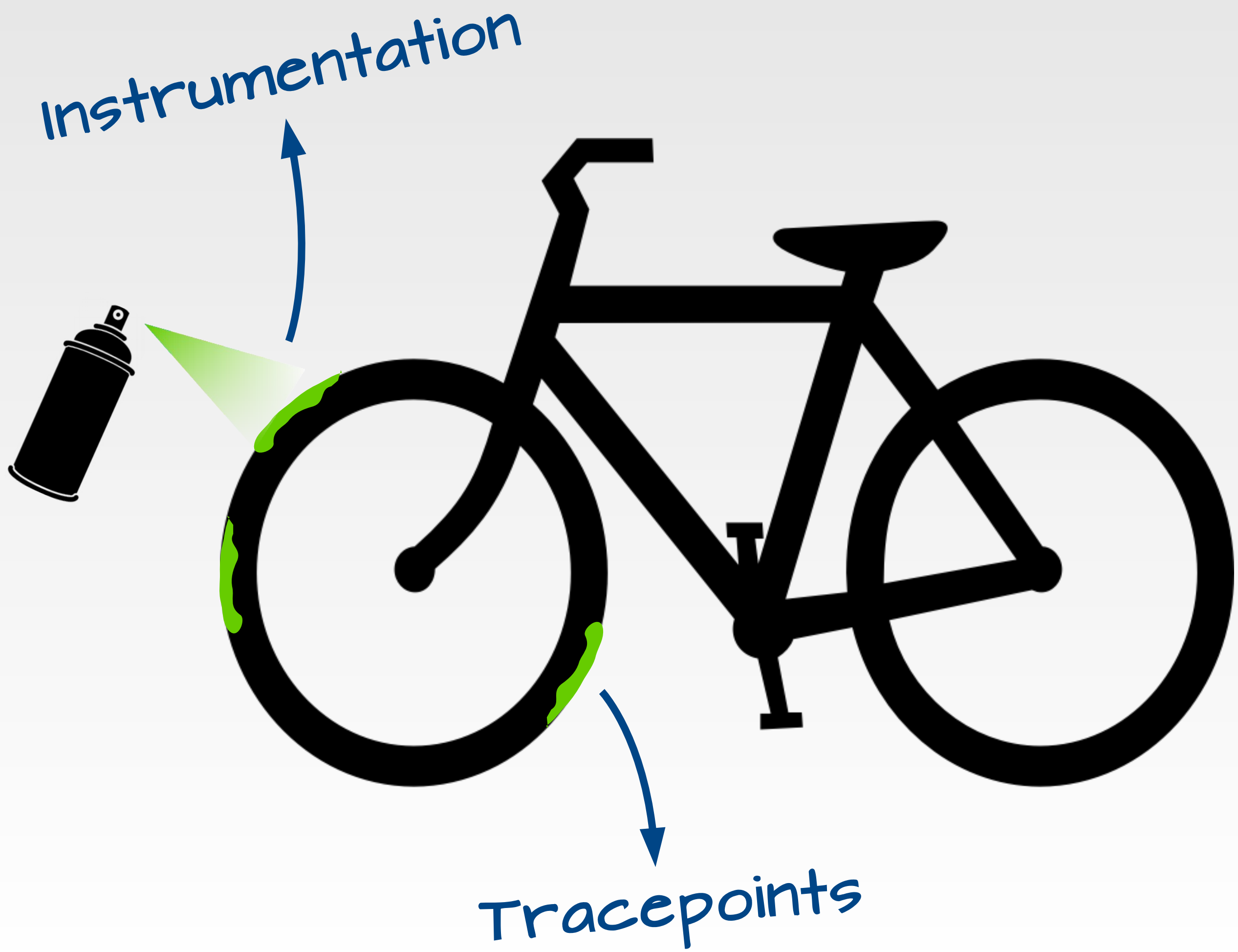
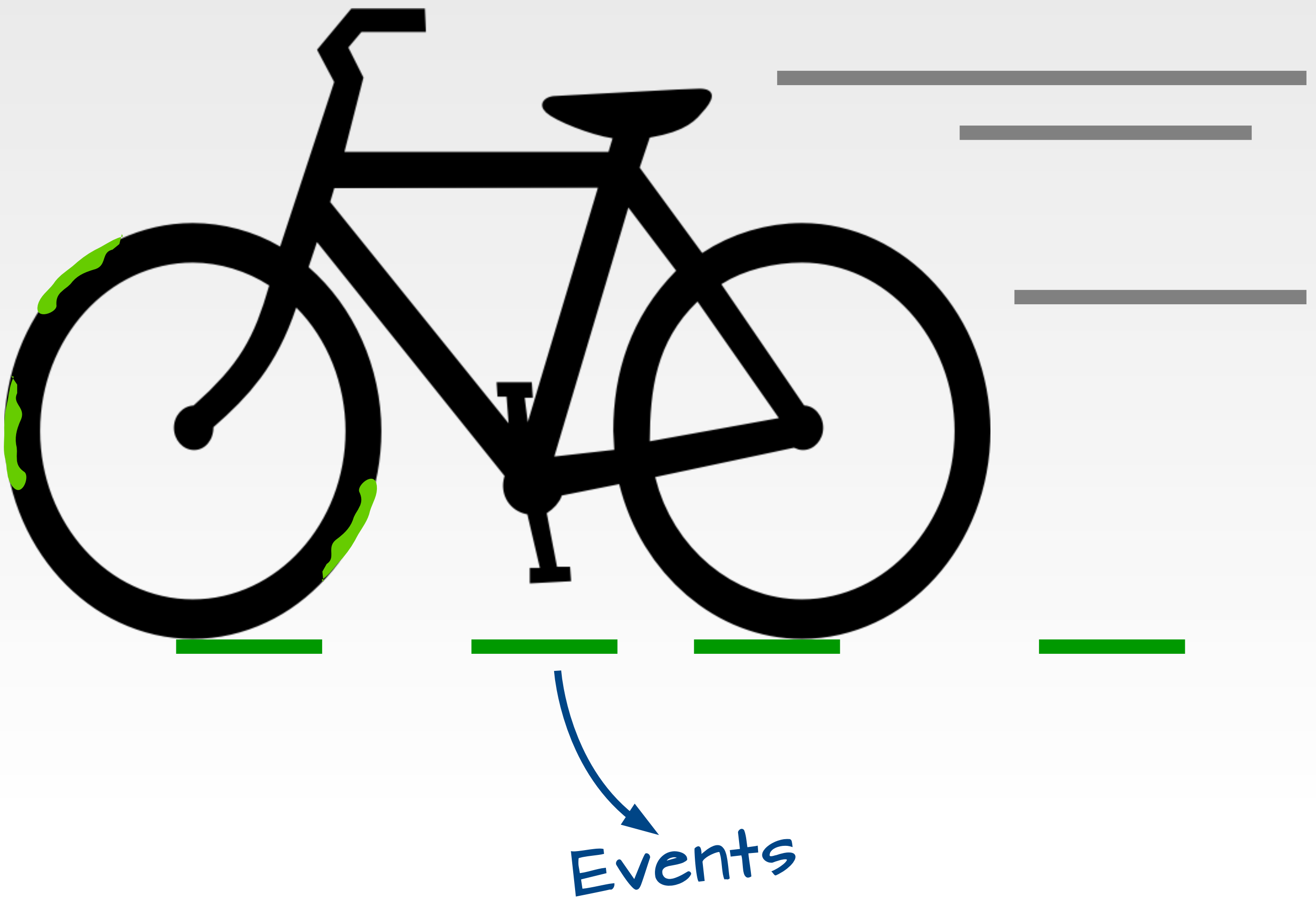
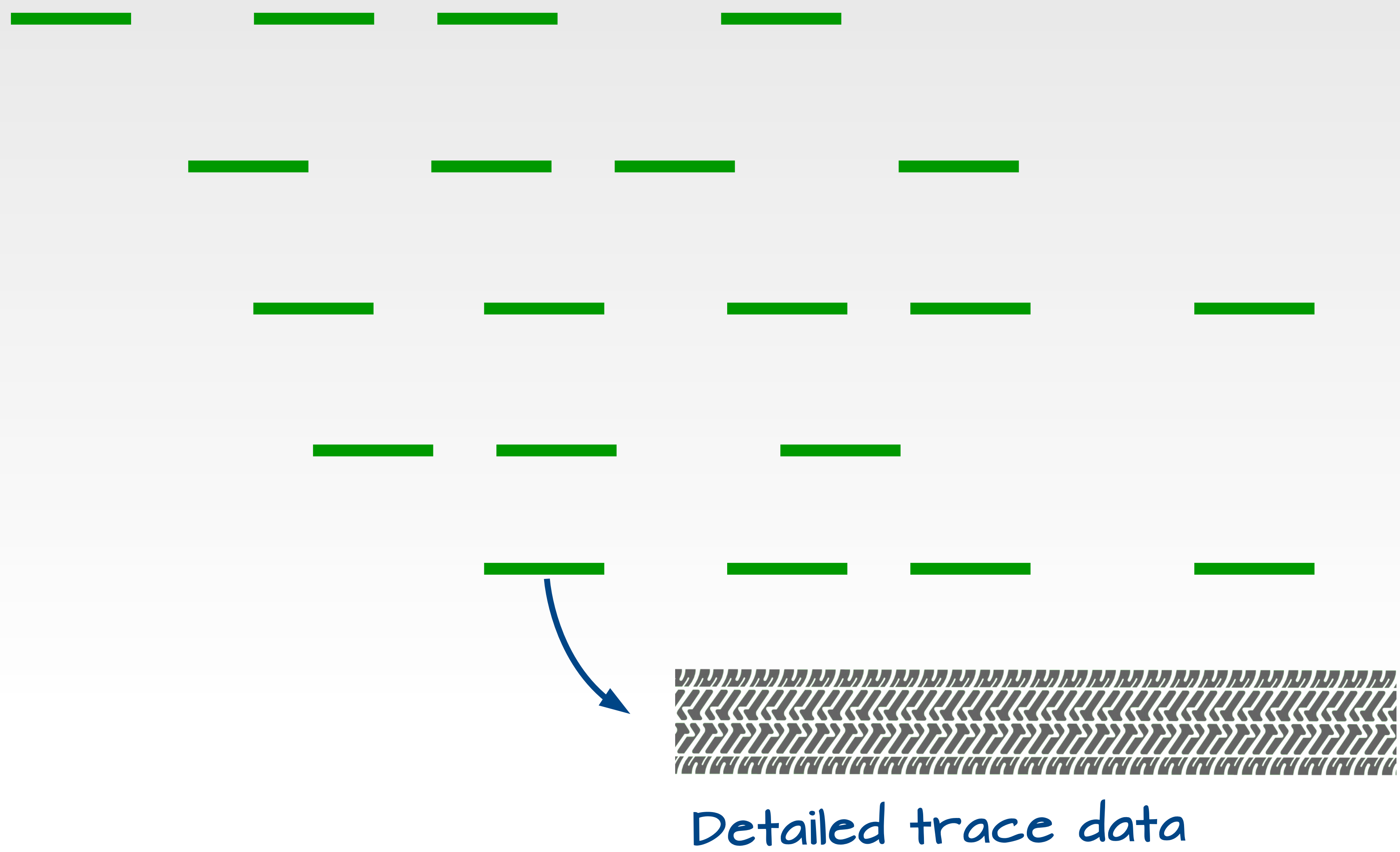
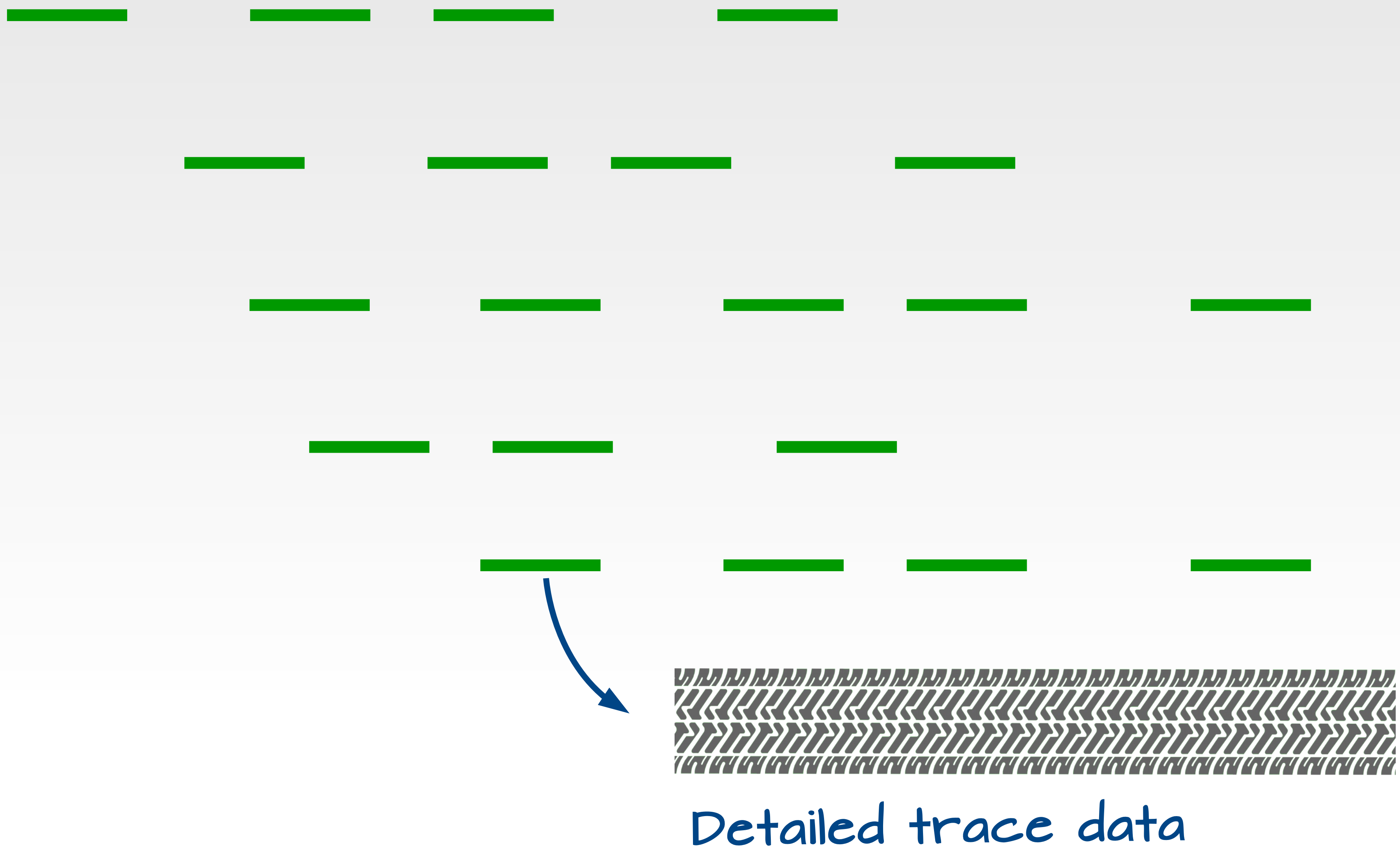

Instrumentation


Instrumentation
Tracepoints


Events


Detailed trace data



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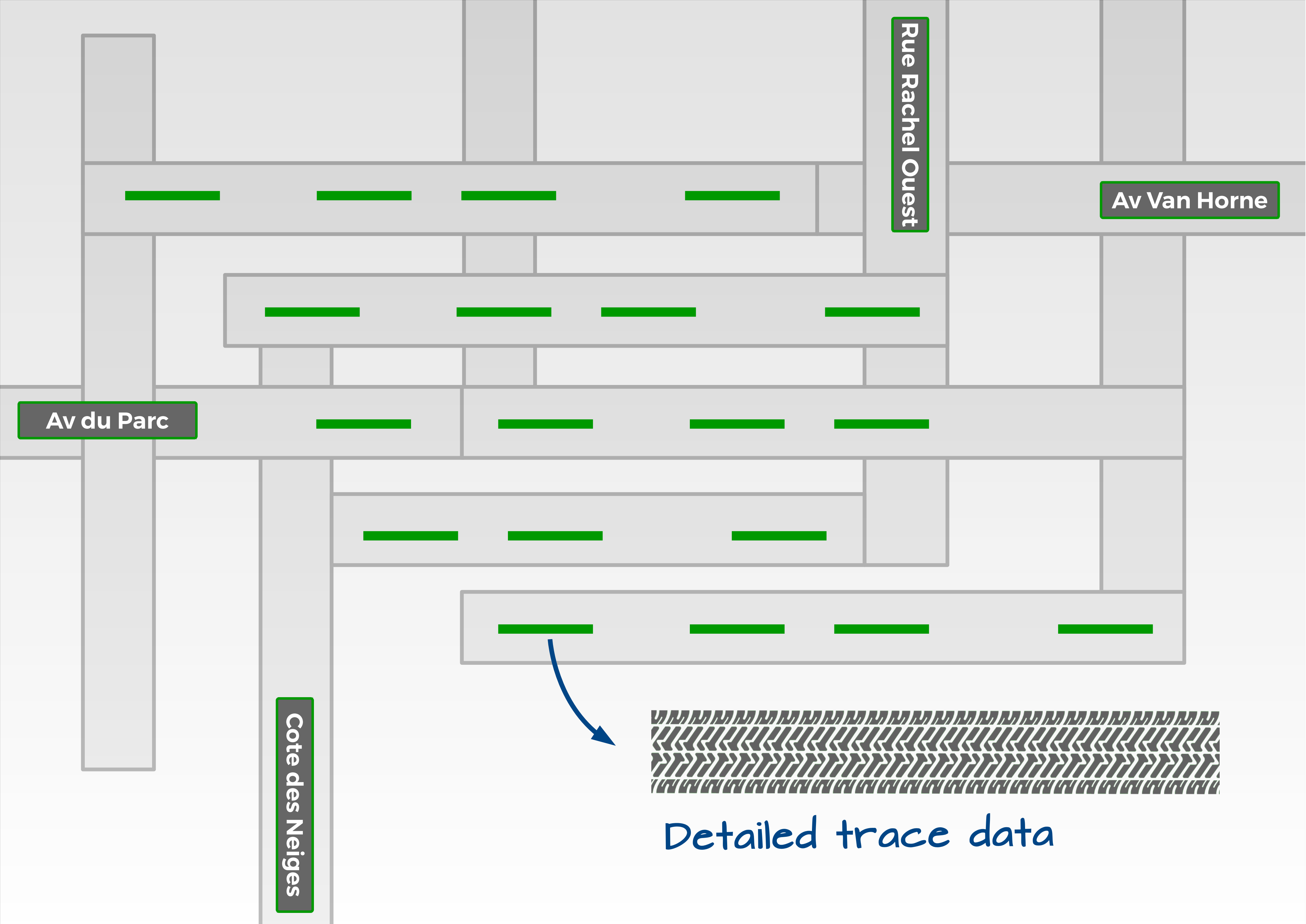

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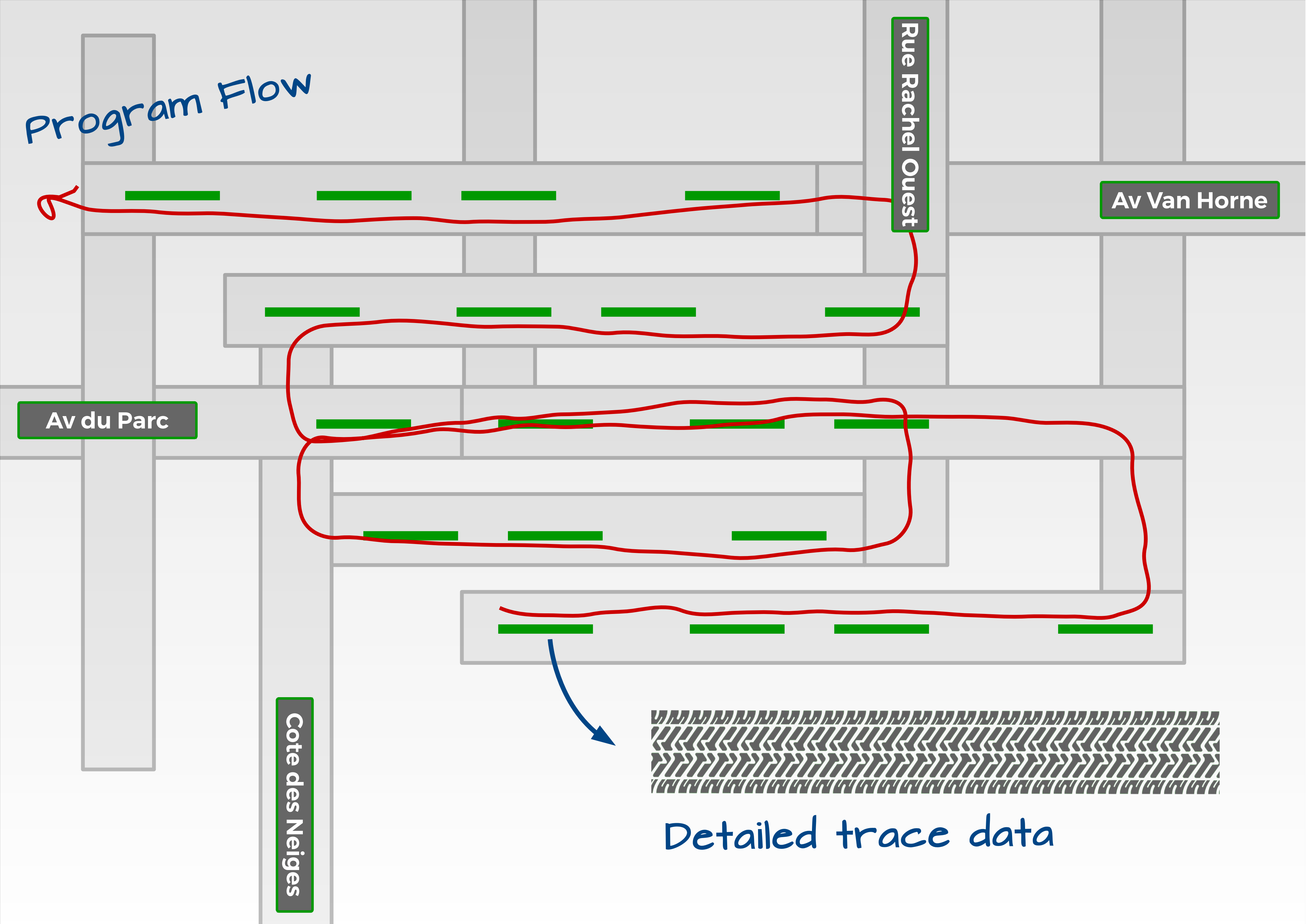

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Deep Dive

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Instrumenting Systems

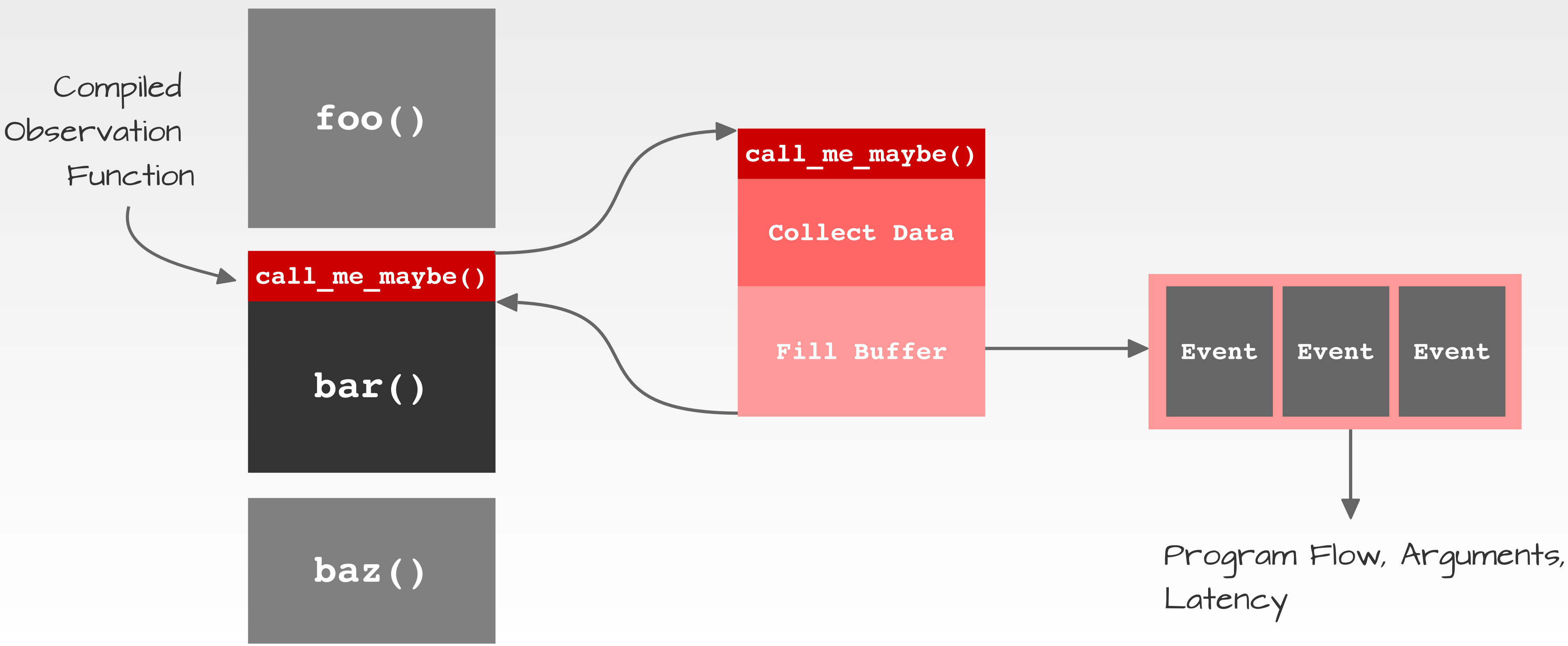
Static Instrumentation

- Development time, eg. insert code that takes a timestamp at function entry and saves it
- Compile time. Compiler inserts hooks that you can latch onto at runtime

Dynamic Instrumentation

- Patch a live application, insert your own observation code, let it run
  - Reliability
  - Security
- Translate code to another form, instrument it, run it *synthetically*

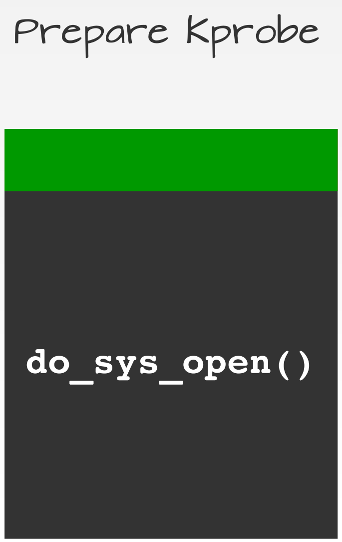
Instrumenting Systems



Case Study - I

Kernel Tracing with Kprobes

- Dynamic instrumentation based on trap or jump-pad based instrumentation



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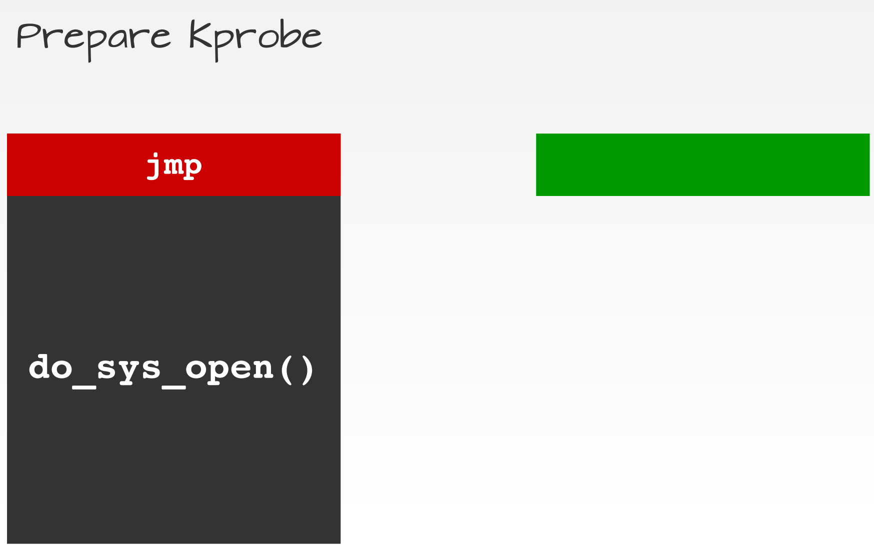

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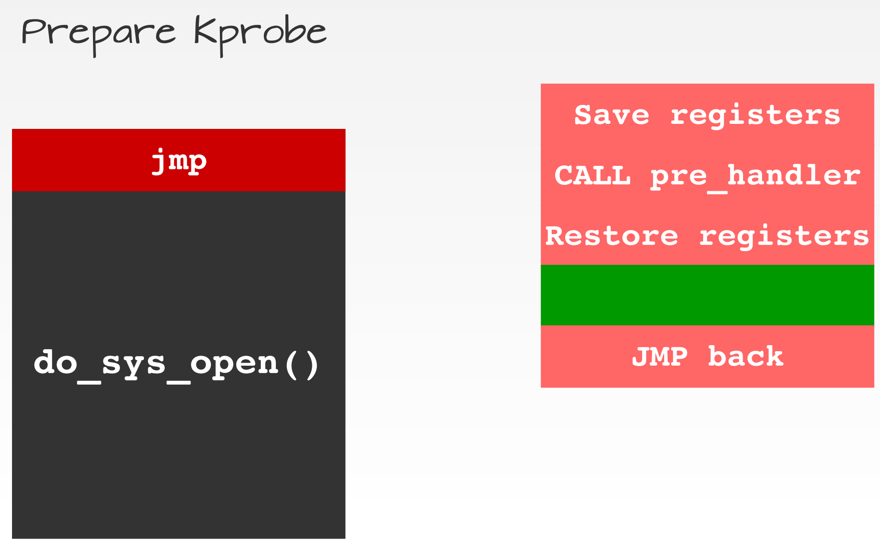

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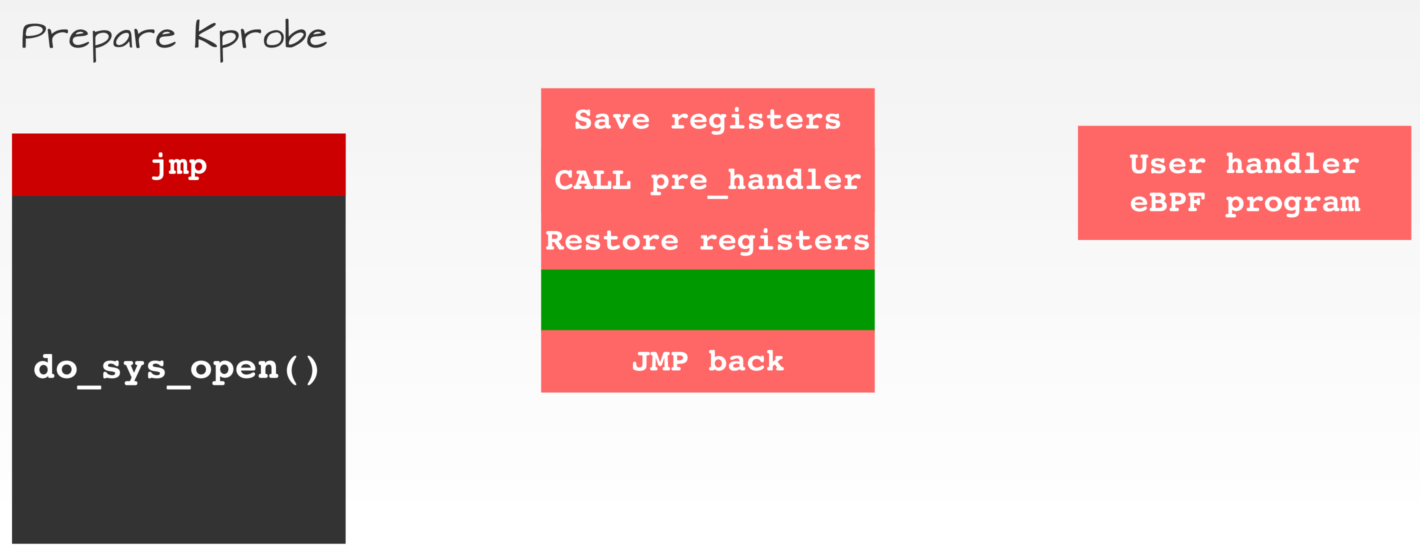

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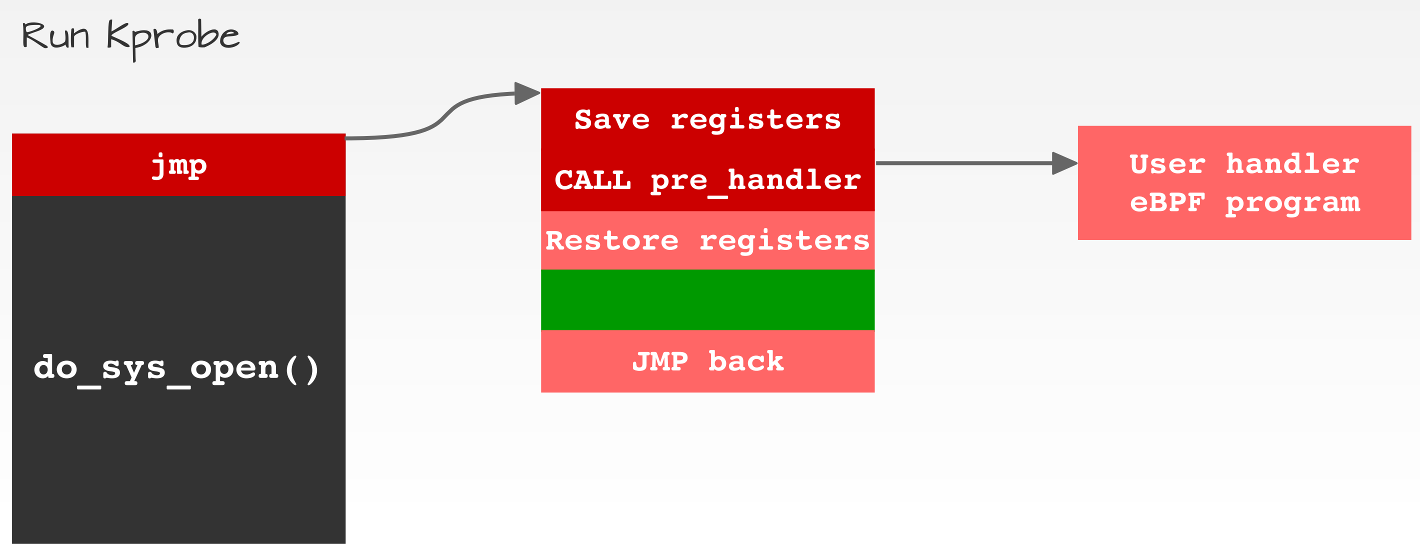

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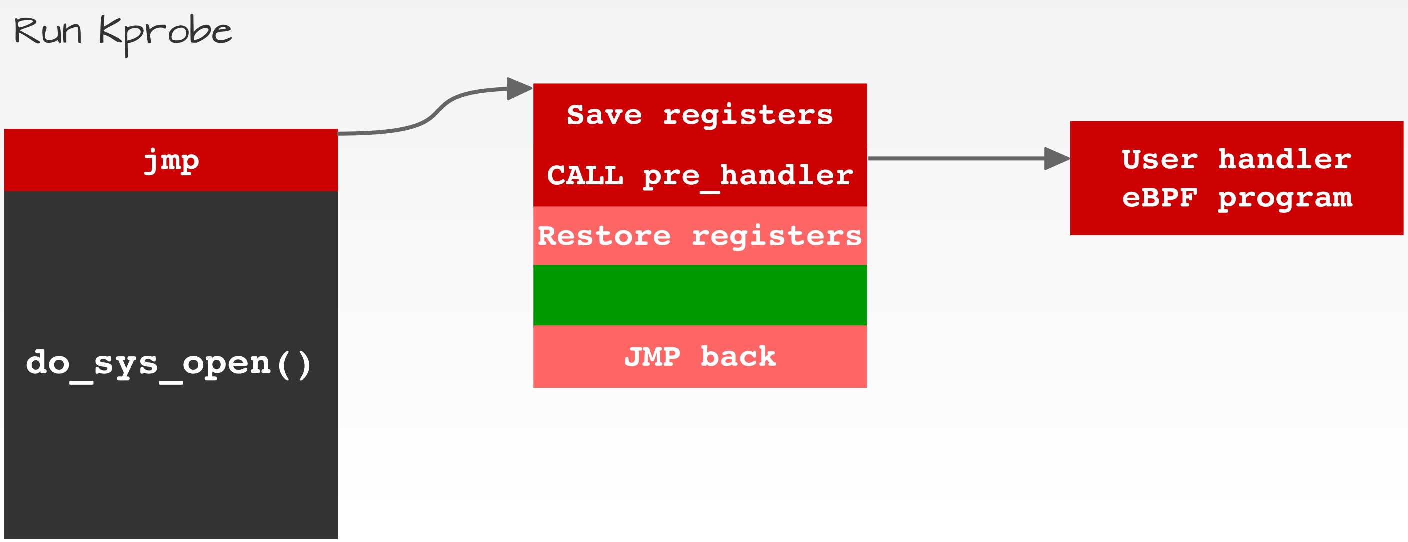

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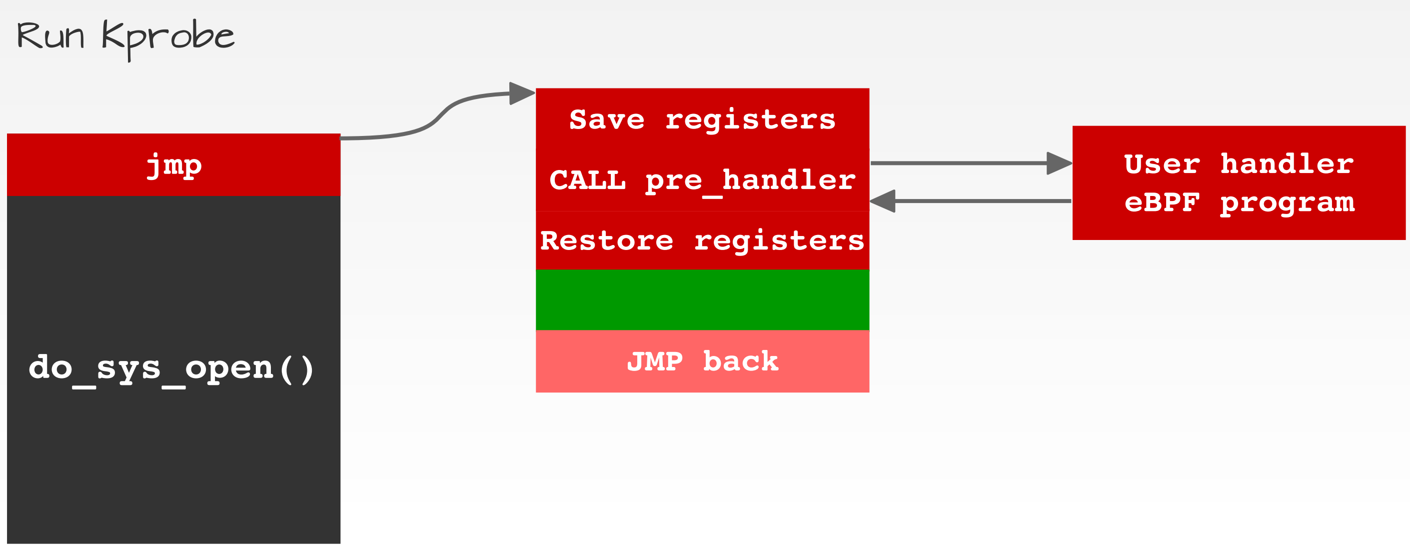

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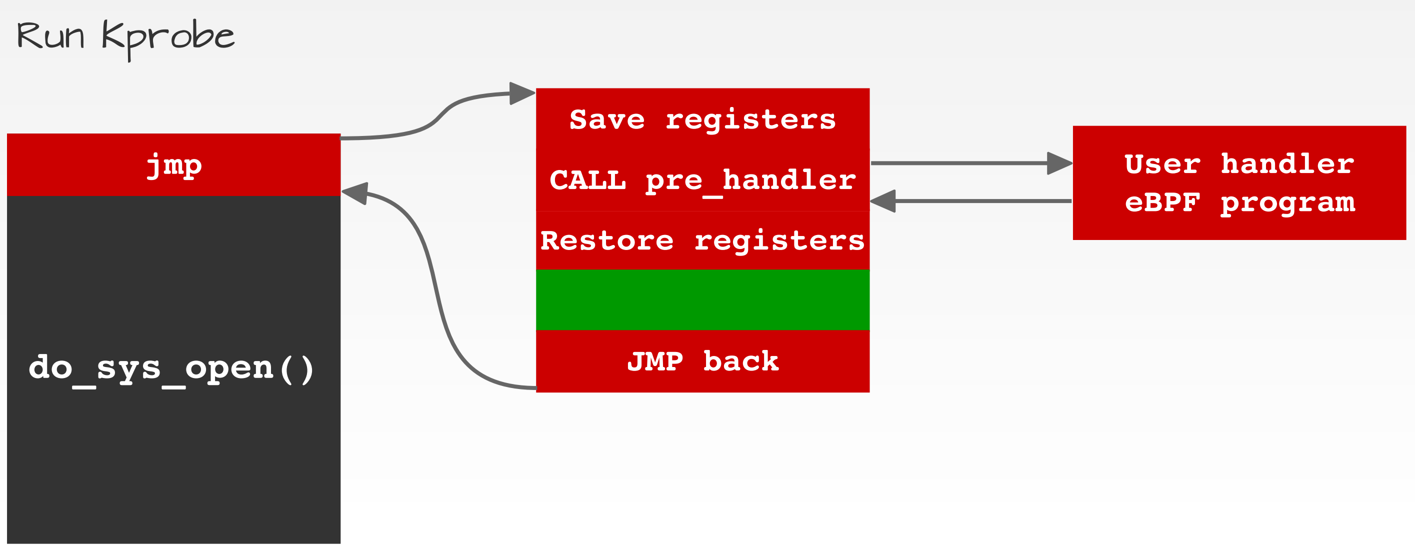


Other Techniques

Ftrace - Dynamic (Kernel)

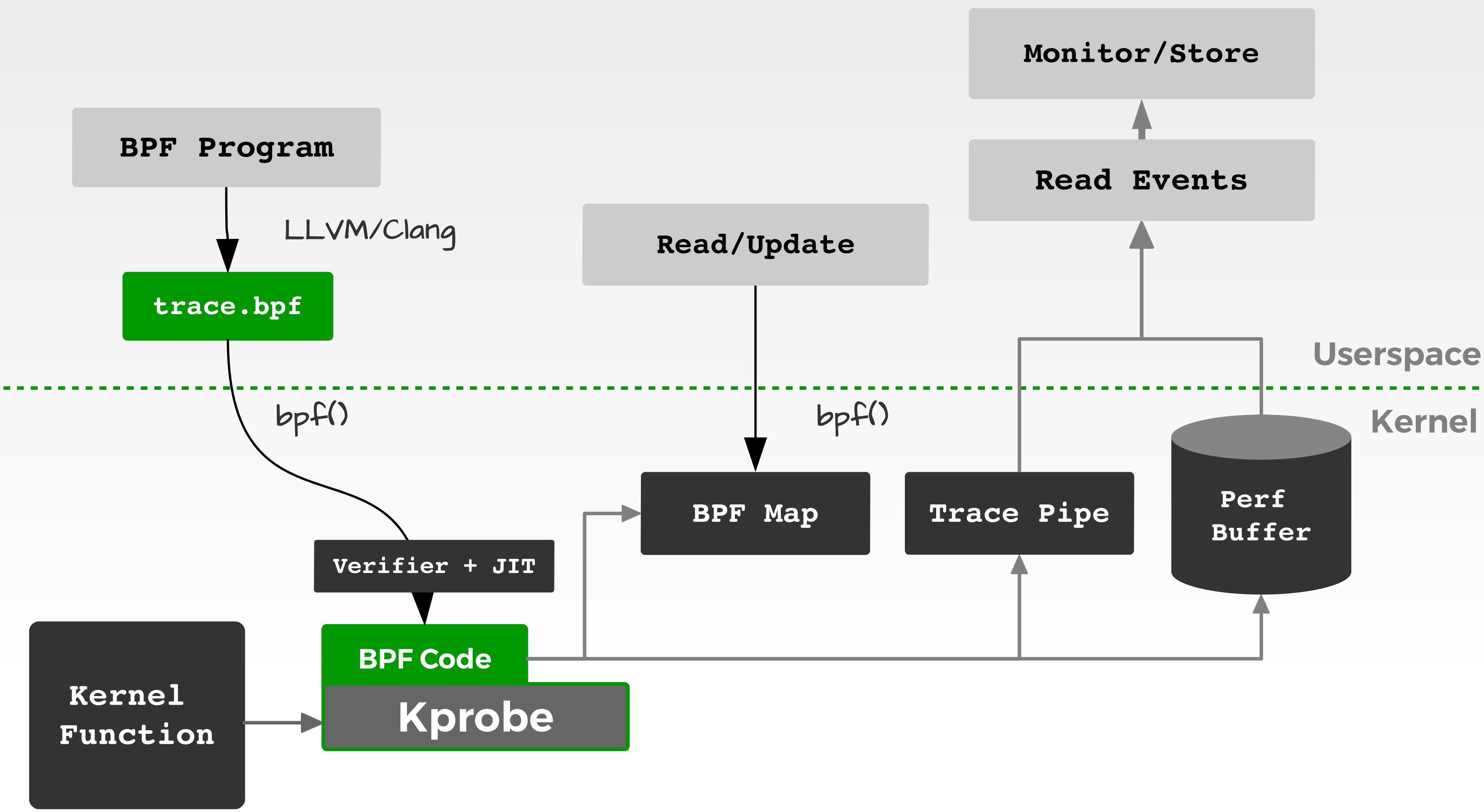
- Build kernel functions with `mcount` (`-pg` in GCC)
- Patch it to NOPs at boot. Add `jmp` to handler for activated functions
- Add hooks, save function arguments, timestamp
- Generate function graph

Static Tracepoints (Kernel)

- trace_* in most kernel functions
- Uses TRACE_EVENT based static tracepoints
- Well defined kernel trace events, can be attached to perf, Ftrace (Static)

Case Study - I

eBPF + Kprobe



Case Study

eBPF + Kprobe

- **IOVisor BCC** – Python, C++, Lua, Go (**gobpf**) APIs
- Compile BPF programs directly via LLVM interface
- Helper functions to manage maps, buffers, probes

Example

Complete Program
trace_fields.py

```
from bcc import BPF

prog = """
int hello(void *ctx) {
  bpf_trace_printk("Hello, World!\\n");
  return 0;
}
"""
b = BPF(text=prog)
b.attach_kprobe(event="sys_clone", fn_name="hello")
print "PID MESSAGE"
b.trace_print(fmt="{1} {5}")
```

prog compiled to BPF bytecode

Attach to Kprobe event

Print trace pipe

Case Study

eBPF + Uprobes Example

Program Excerpt

```
bpf_text = """
#include <uapi/linux/ptrace.h>
#include <uapi/linux/limits.h>

int get_fname(struct pt_regs *ctx) {
    if (!ctx->si)
      return 0;
    char str[NAME_MAX] = {};
    bpf_probe_read(&str, sizeof(str), (void *)ctx->si);
    bpf_trace_printk("%s\\n", &str);
    return 0;
};
"""
b = BPF(text=bpf_text)
b.attach_uprobe(name="/usr/bin/vim", sym="readfile", fn_name="get_fname")
```

Get 2nd argument → ctx->si

Process → "/usr/bin/vim"

Symbol → "readfile"

Output

```
# ./vim-test.py
TASK    PID     FILENAME
vim     23707   /tmp/wololo
```

Case Study - II

Linux Security Modules (LSM)

- Static Instrumentation in the kernel code
- Hooks to attach LSM implementations for defining and inserting MAC policies
  - **SELinux**
  - AppArmor, LandLock LSM (eBPF)

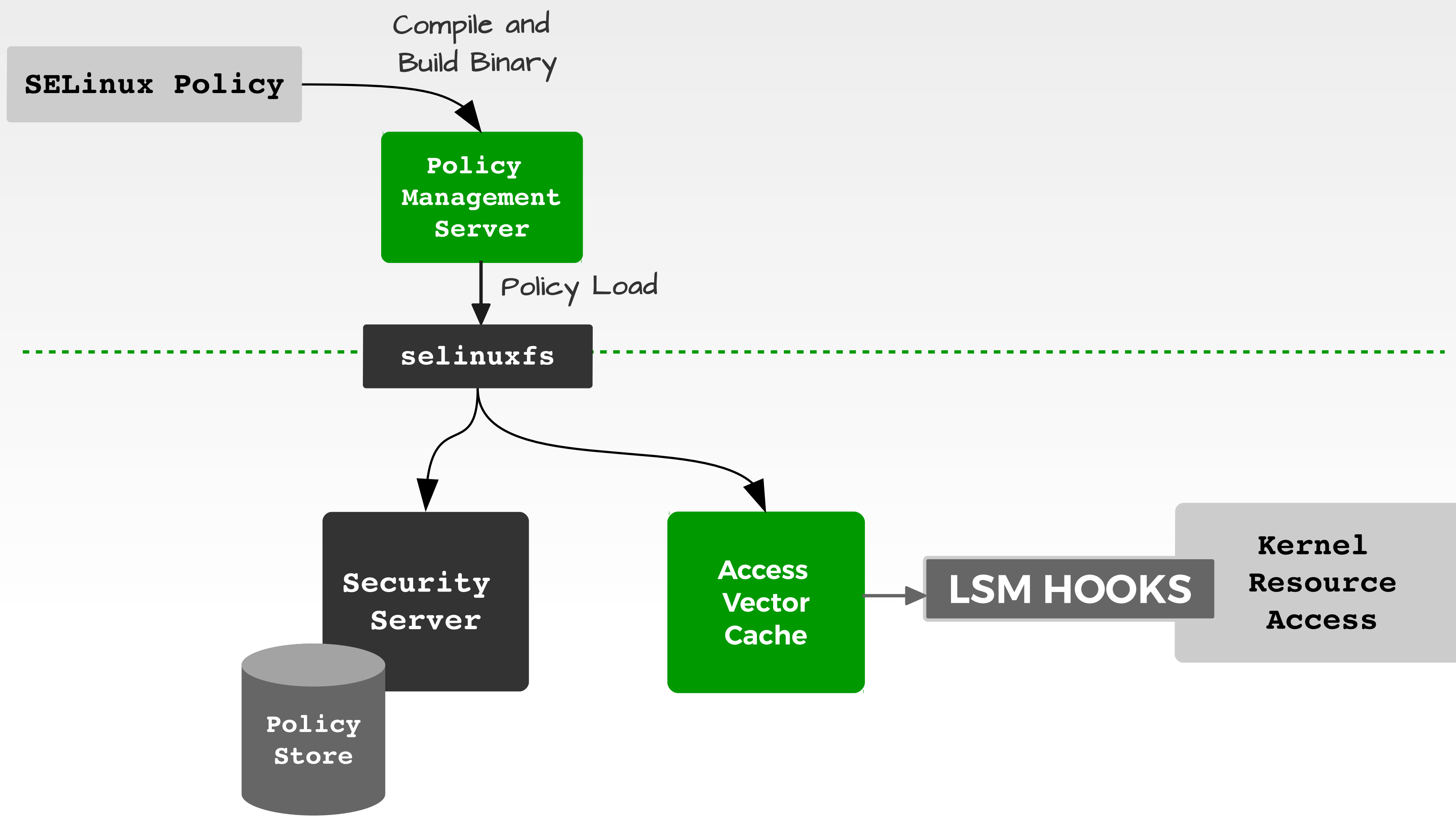
Syscall from userspace

```
open()
  do_sys_open()
    do_filp_open()
      path_openat()
      ..
        vfs_open()
          do_dentry_open()
            security_file_open()
```

LSM call

Case Study - II

SELinux



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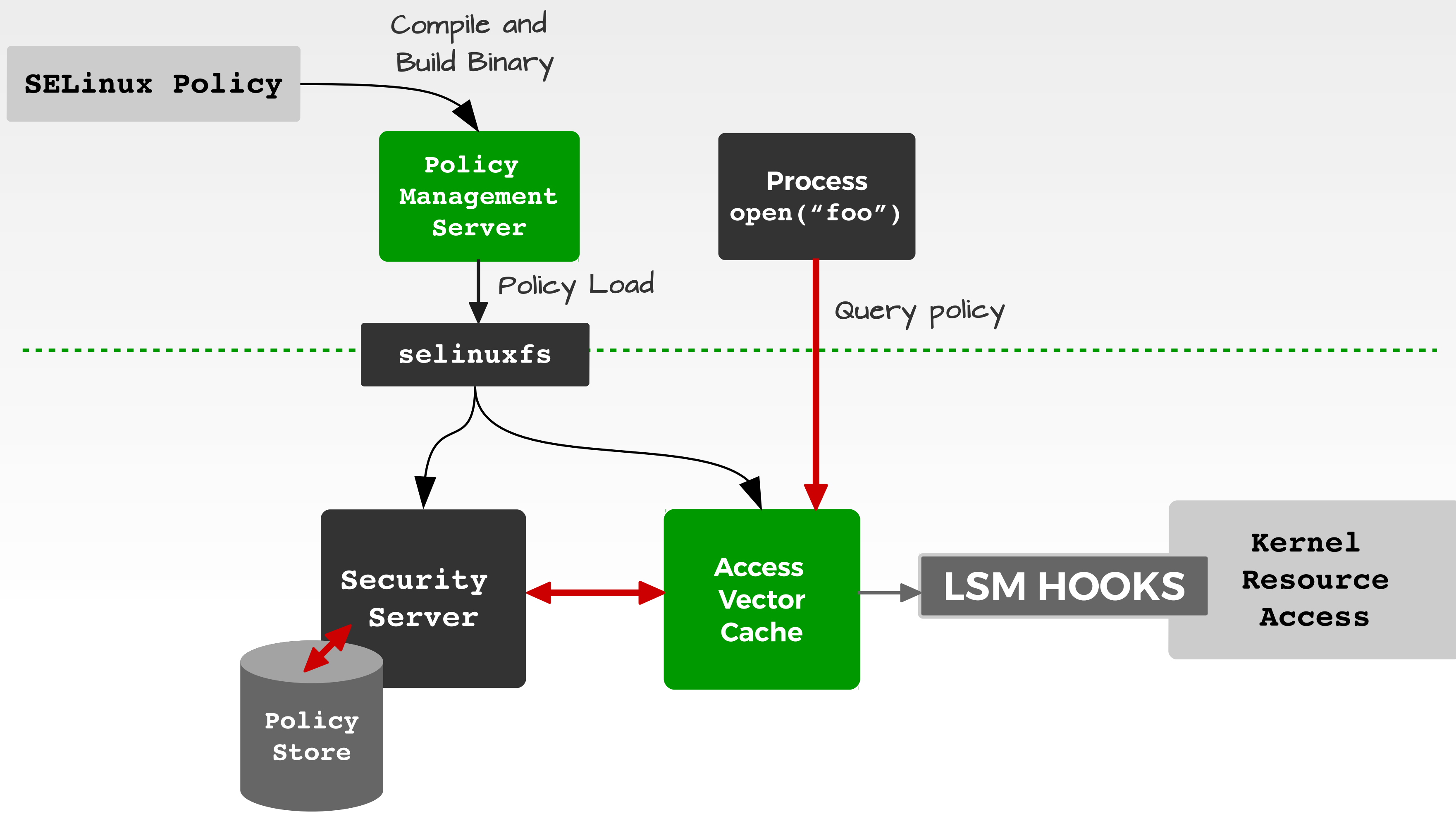

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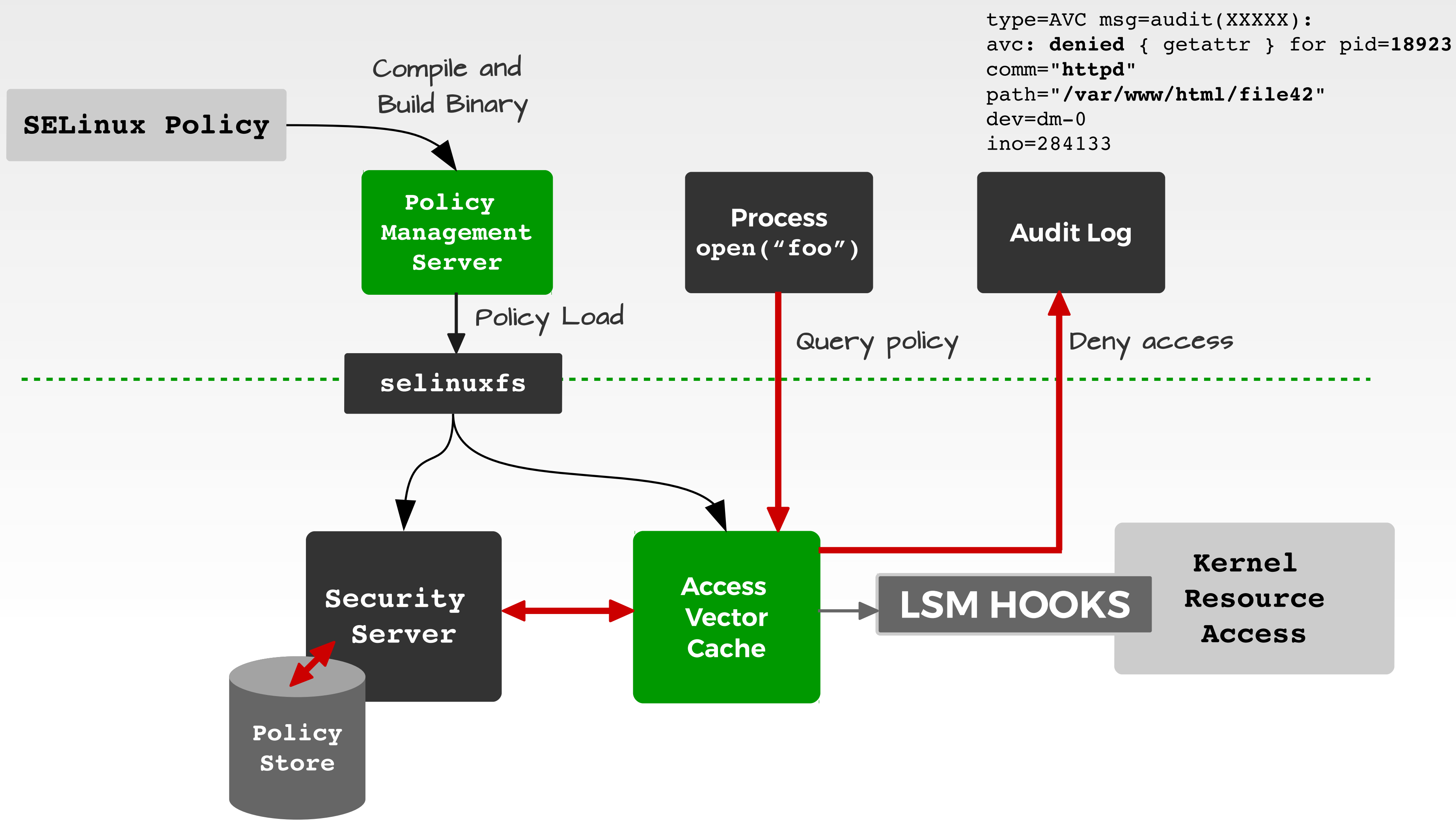


Securing **Stuff**

Securing Strategy

Preventive (Isolation)

- Virtualization **(Hypervisor/VMs)**
  – Inherent isolation, by virtue of hardware/software design
  – Robust, smaller attack surface
- Linux Namespaces/Cgroups **(Containers)**
  – Isolation by host kernel/userspace support
  – Isolate resources and groups of processes
  – Used to *define* containers
- Linux Capabilities: Not just root/non-root now
- SECCOMP* **(Application)**
  – Can be used to sandbox process and allow/deny syscalls

Securing Strategy

Passive (Monitoring)

- System level logs and audit messages (Auditd)
  - Get summary of AVC denials/syscalls to keep track of interesting events
- Hook to system events such as capability, syscalls custom userspace events
- Monitor network events across layers

Securing Strategy

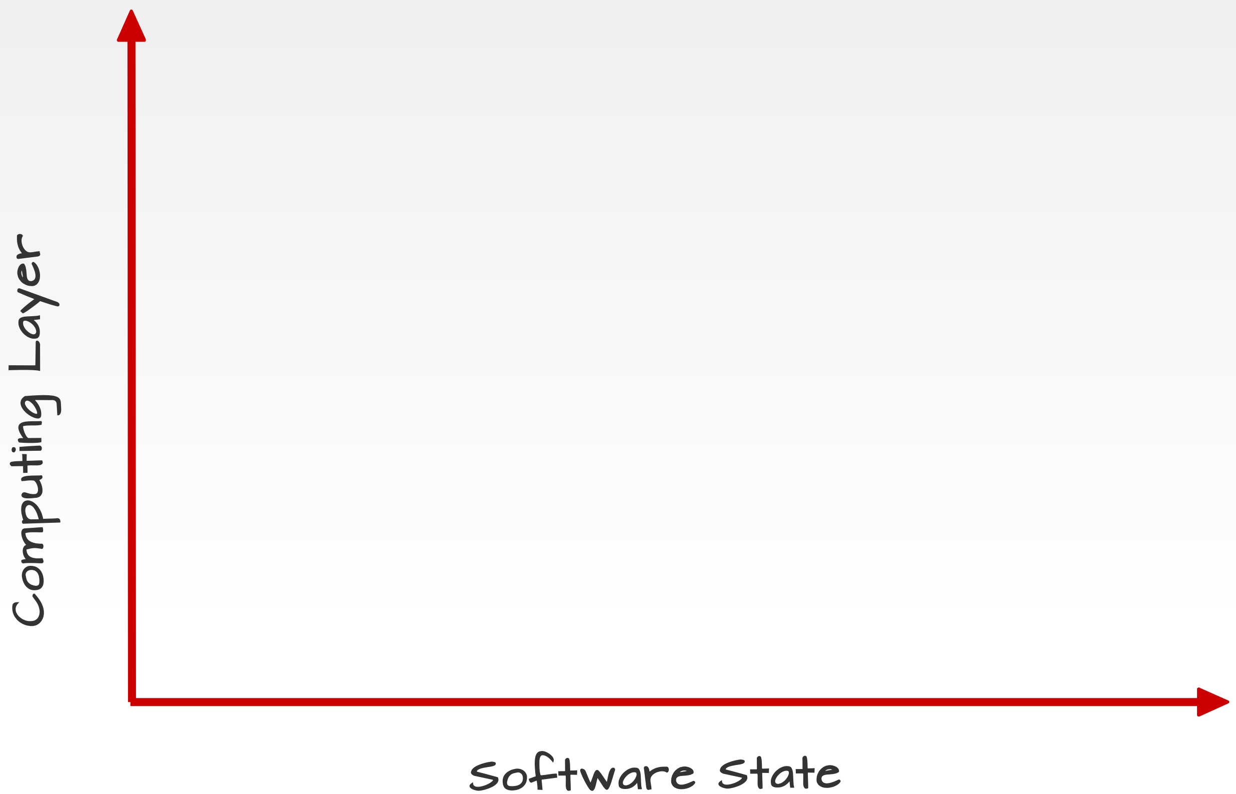
Active (Protection)

- LSM Modules
  - Protect infrastructure and implement policies
  - Policies can now be programmable (eBPF)
  - Support with modern containers (policies for Docker, rkt, K8s)
- SECCOMP
  - Policies for Docker, rkt, runc
- Custom application/library instrumentation

Securing Strategy

Insertion Spectrum

- Two variables for defining and inserting security



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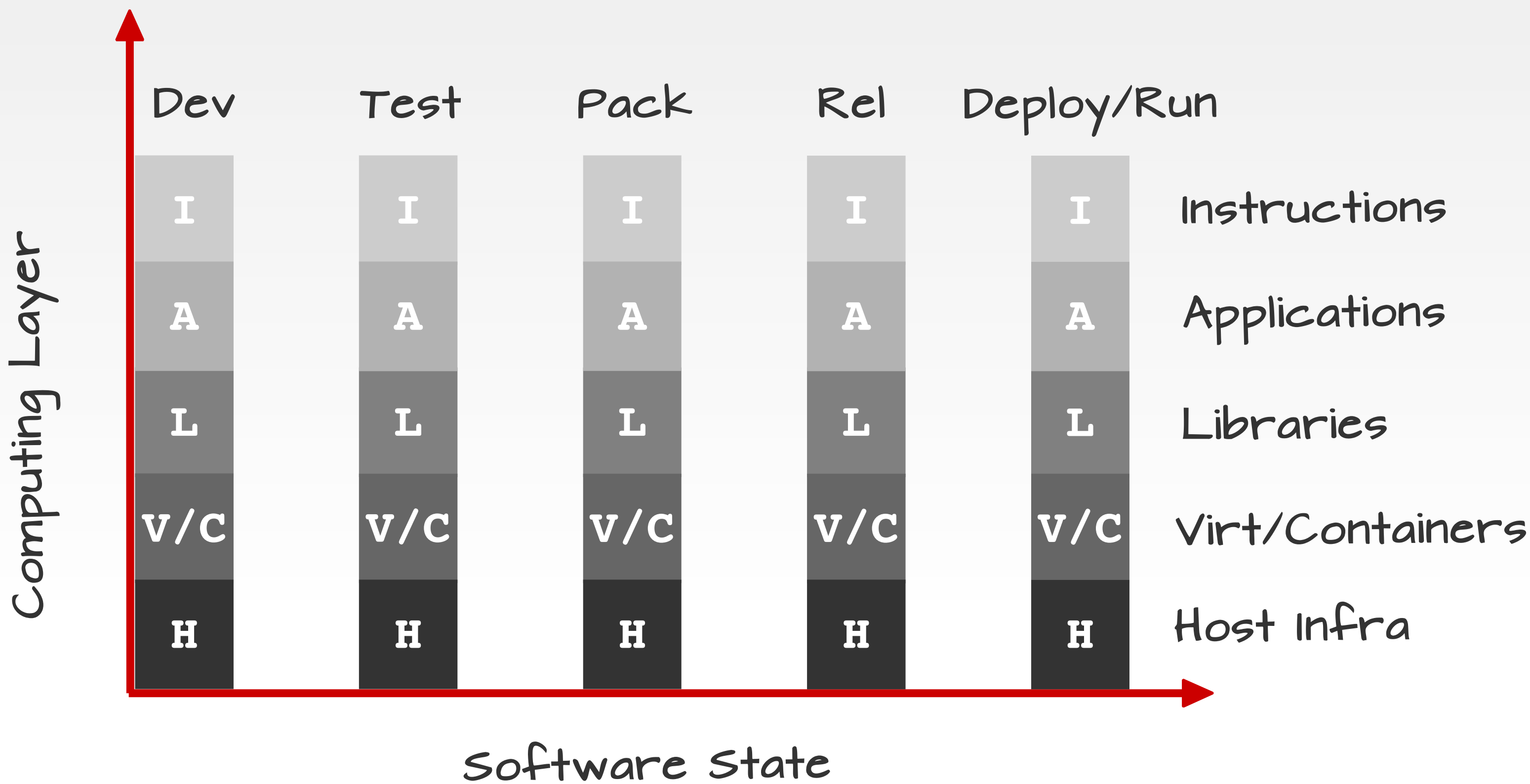

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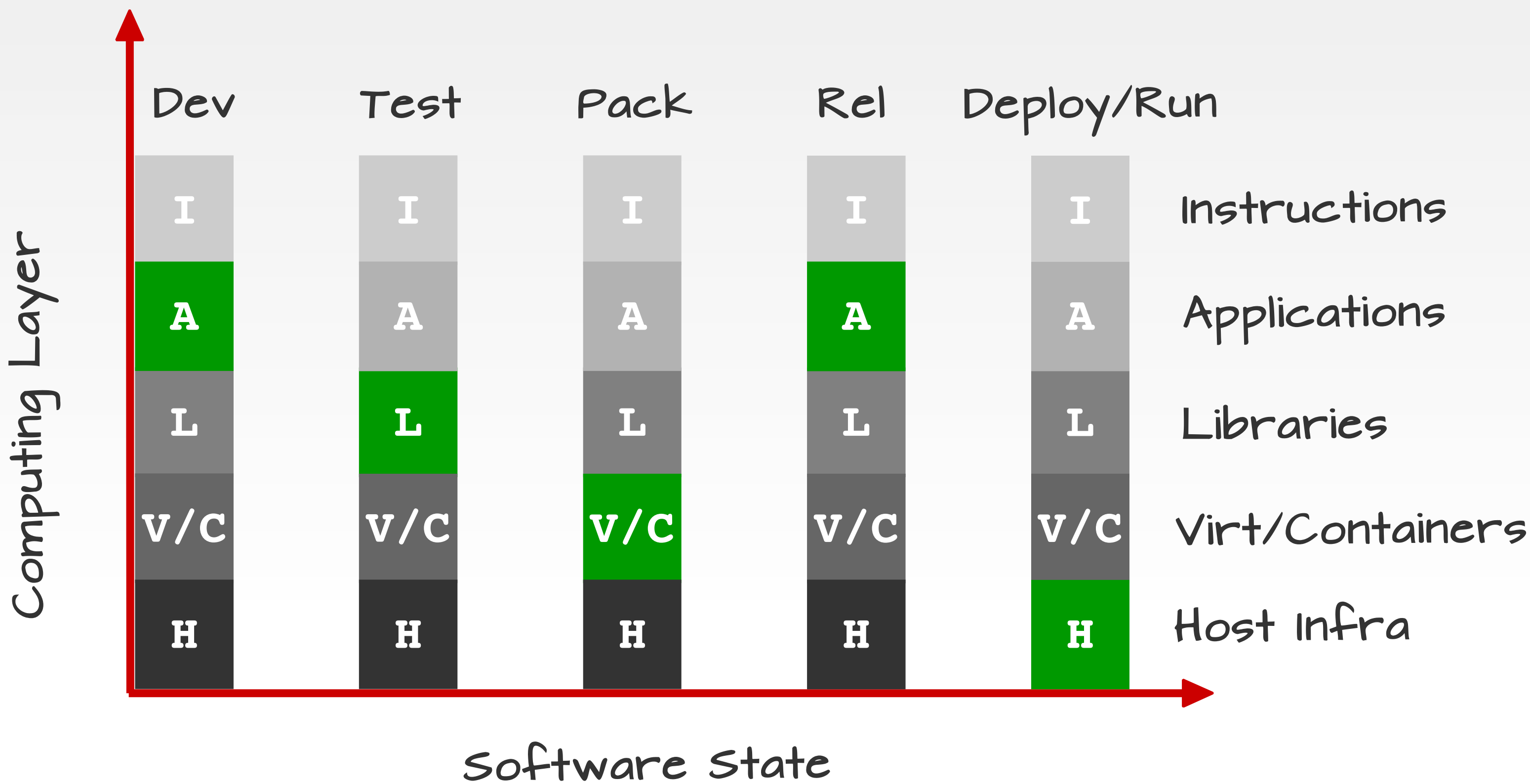

References

Links

- *Kprobes Kernel Docs*
  - https://www.kernel.org/doc/Documentation/kprobes.txt

- *Secrets of Ftrace Function Tracer (Steven Rostedt)*
  - https://lwn.net/Articles/370423/

- *Linux Performance/Tracing (Brendan Gregg & Julia Evans & Honeycomb)*
  - http://www.brendangregg.com/linuxperf.html
  - https://jvns.ca/blog/2017/07/05/linux-tracing-systems/
  - https://honeycomb.io/blog/categories/instrumentation/

- *Linux Security/Containers (Jessie Frazelle & Jérôme Petazzoni)*
  - *https://blog.jessfraz.com/post/a-rant-on-usable-security/*
  - *https://www.slideshare.net/jpetazzo/anatomy-of-a-container-namespaces-cgroups-some-filesystem-magic-linuxcon)*

- *eBPF/Landlock LSM (IOVisor devs, Mickaël Salaün et al.)*
  - *https://landlock-lsm.github.io/linux-doc/landlock-v5/security/landlock/index.html*
  - *http://www.brendangregg.com/ebpf.html*
  - *http://blogs.microsoft.co.il/sasha/2016/12/23/usdtbpf-tracing-tools-java-python-ruby-node-mysql-postgresql/*

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