Lock-in-Pop: Securing Privileged Operating System Kernels by Keeping on the Beaten Path

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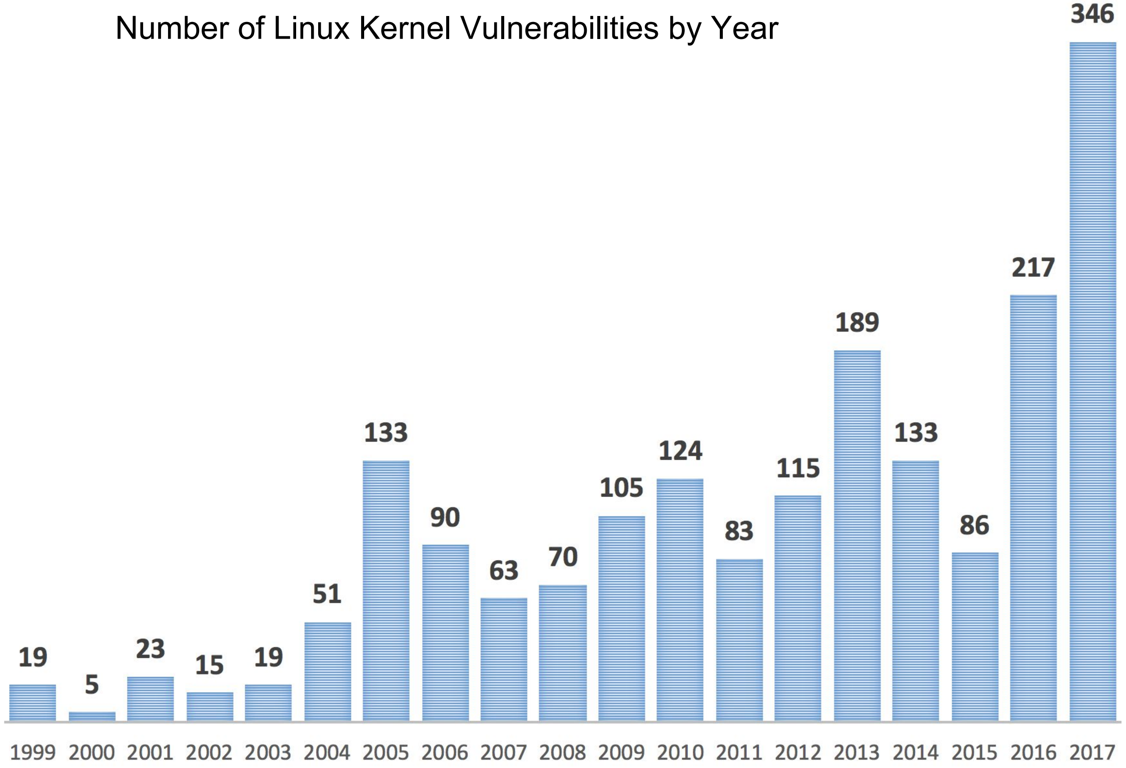
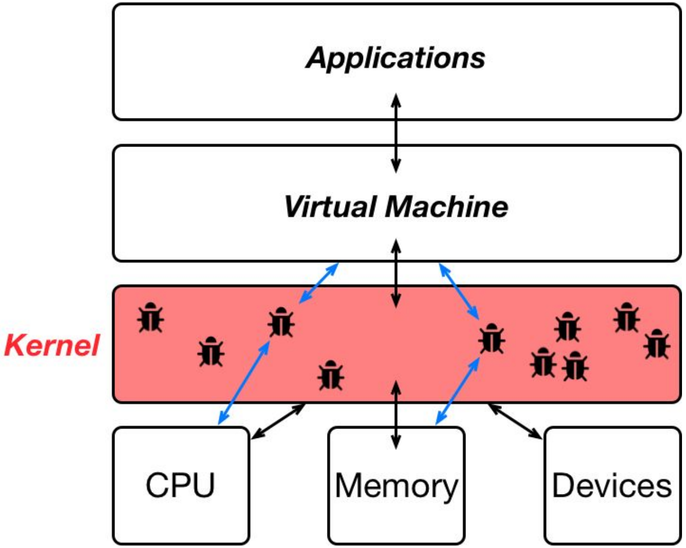
Motivation

1. Many vulnerabilities exist in the host OS kernel
2. These vulnerabilities can be reached and exploited, even with VMs in place

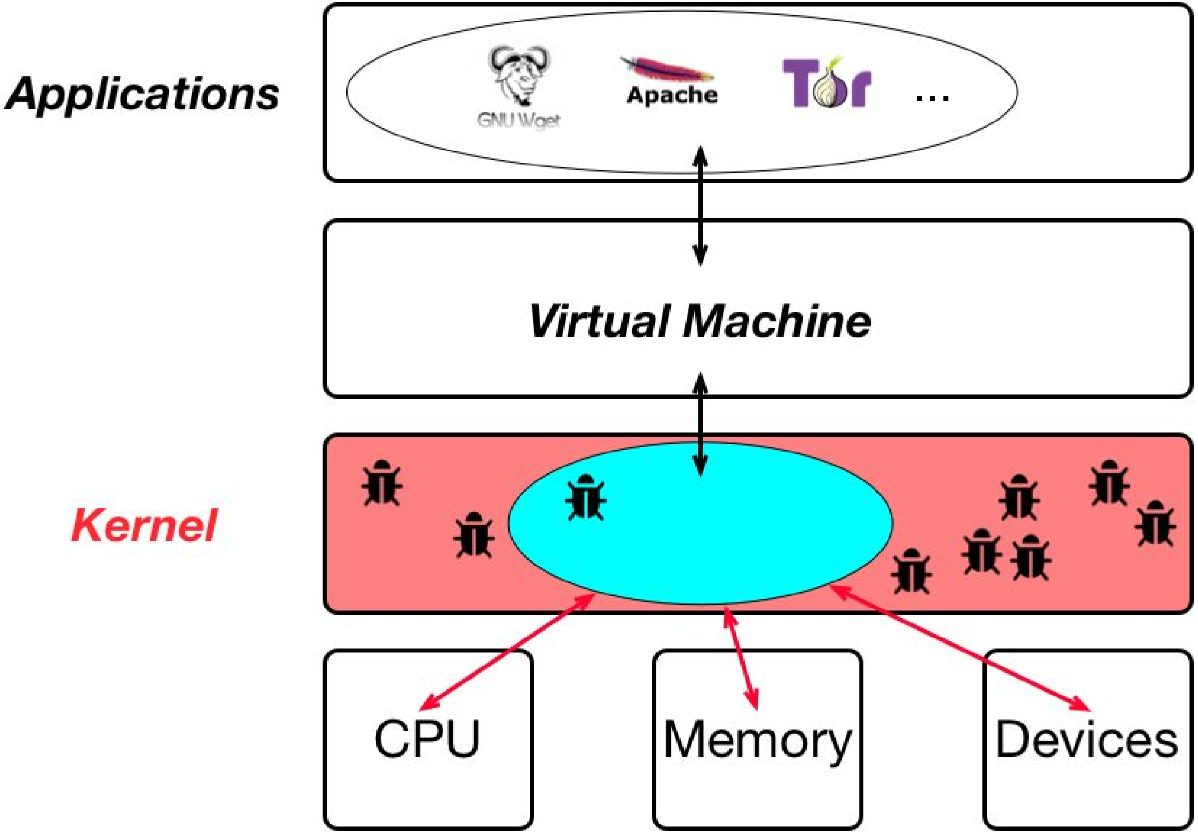




* Data source: National Vulnerability Database(NVD), https://nvd.nist.gov, July 2017.

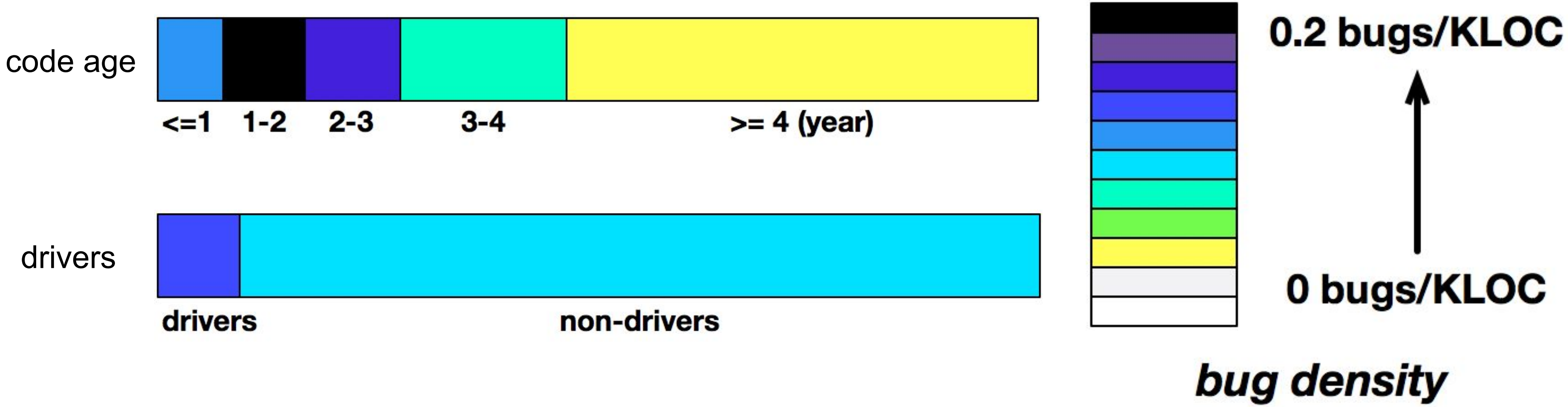
What do we want when building virtual machines?

1. Sufficient functionality
2. Very few zero-day security bugs



The metrics we have don’t meet our needs

1. Predivtive of where bugs will be found
2. Locate areas that have no/very few bugs



code age [1]

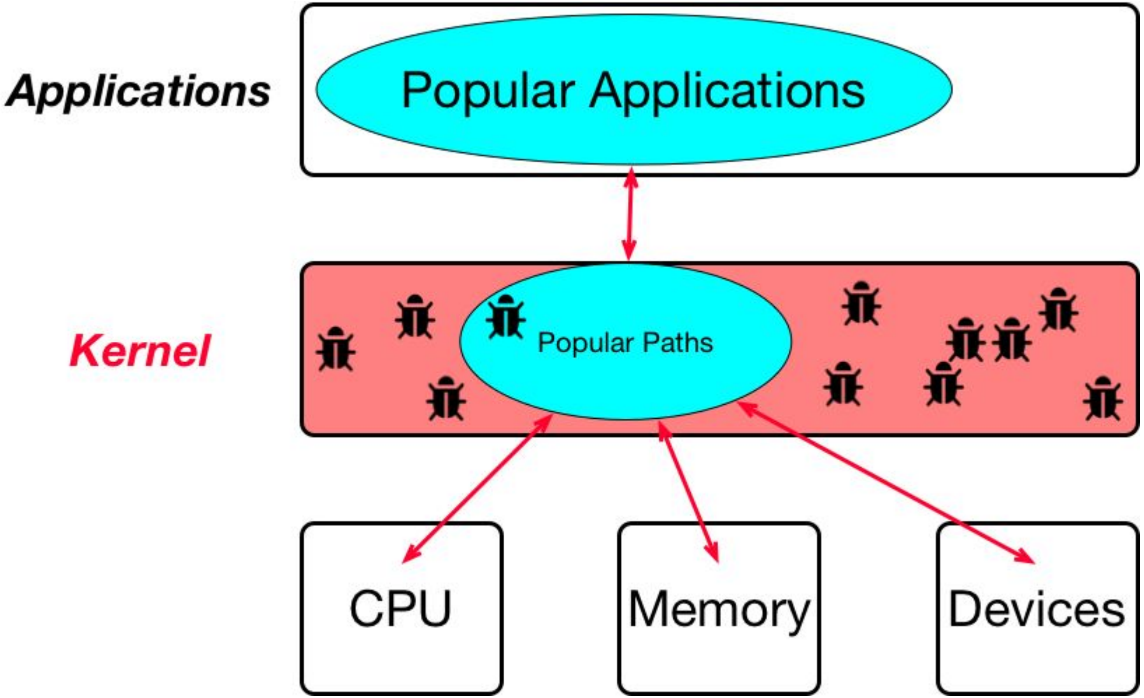
code in device drivers [2]

[1] Ozment, et al. [Usenix Security ’06]

[2] Chou, et al. [SOSP ’01]

Our metric: the popular paths

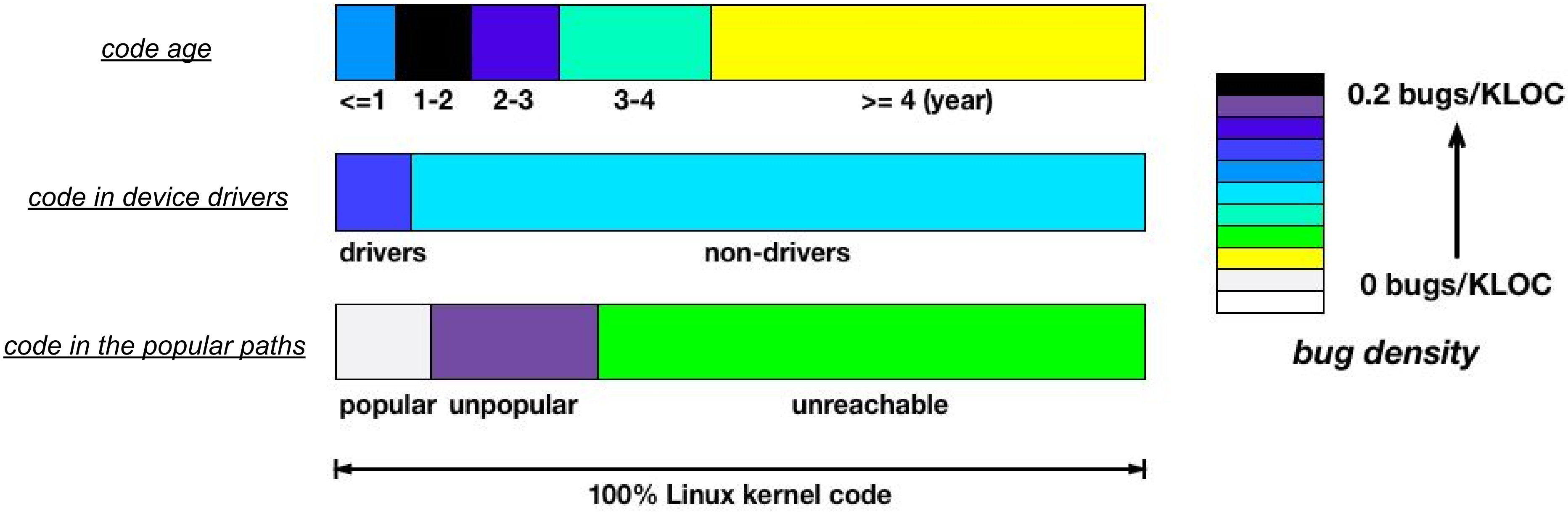
- ***Definition:*** lines of code in the kernel source files, which are commonly executed in the system's normal workload.
- ***Key insight:*** the popular paths contain many fewer bugs!



Our experiments to obtain the popular paths

- Ran top 50 most popular packages according to the Debian popularity contest.
- Two students used their Ubuntu systems for five days.
- We used Gcov 4.8.4 in Ubuntu 14.04 to capture the kernel coverage data.

Bug density comparison among three security metrics



code age [1]

code in device drivers [2]

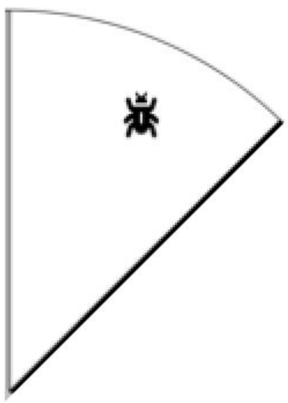
code in the popular paths [3]

[1] Ozment, et al. [Usenix Security ’06]

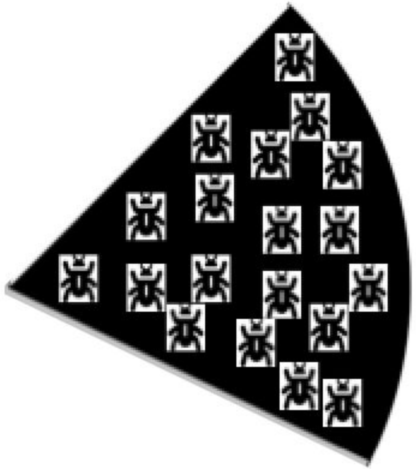
[2] Chou, et al. [SOSP ’01]

[3] Li, et al. [USENIX ATC ’17]

popular paths vs. unpopular paths



popular paths
(1 bug)

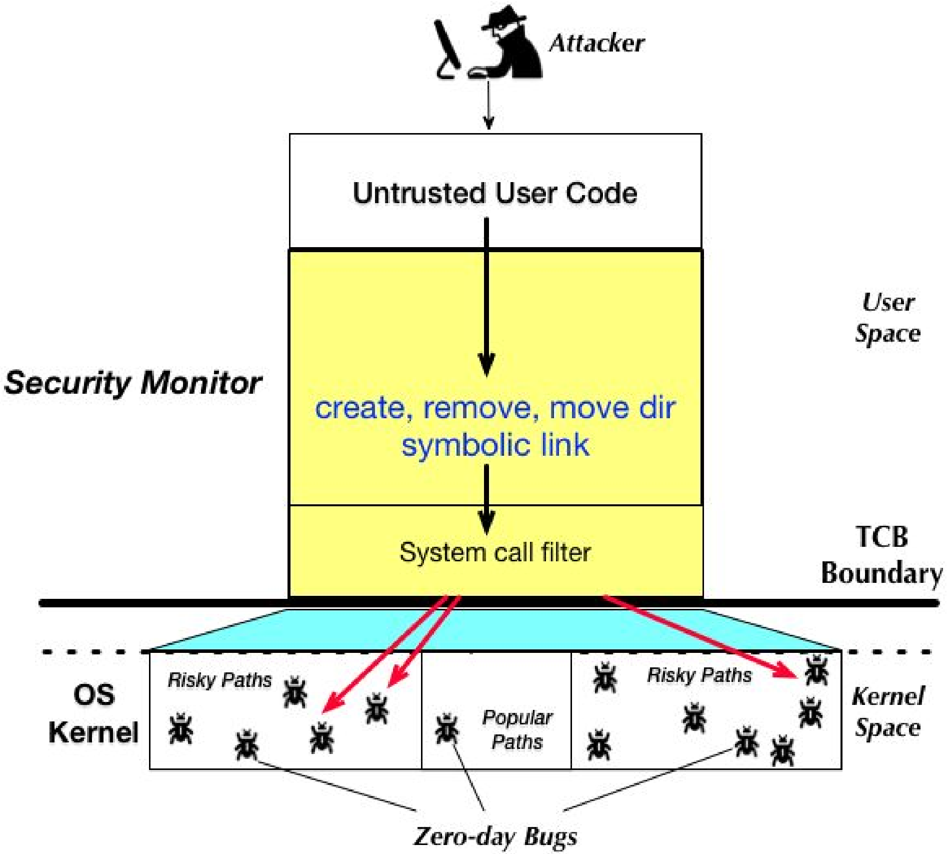


unpopular paths
(19 bugs)

Our metric: the popular paths

- Definition ✓
- How to measure it? ✓
- Is it a good security metric? ✓
- Is it practically useful?

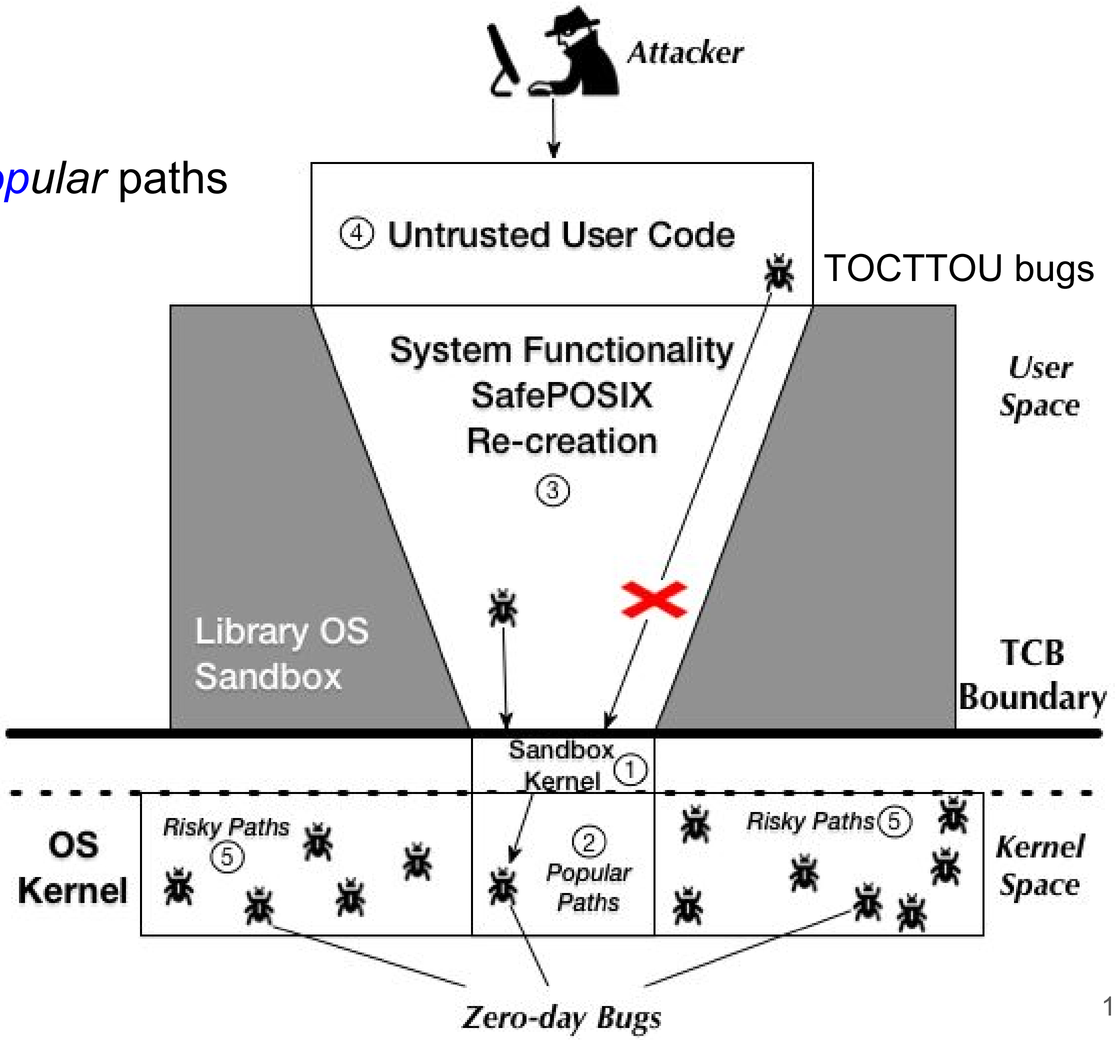
Traditional designs: *check-and-pass-through*



Lock-in-Pop design

lock applications *into* using only *popular* paths

- safely re-create file directories with basic calls like open(), read(), write(), close() to avoid using unpopular paths
- the kernel is used infrequently
- only the popular paths in the kernel is accessed

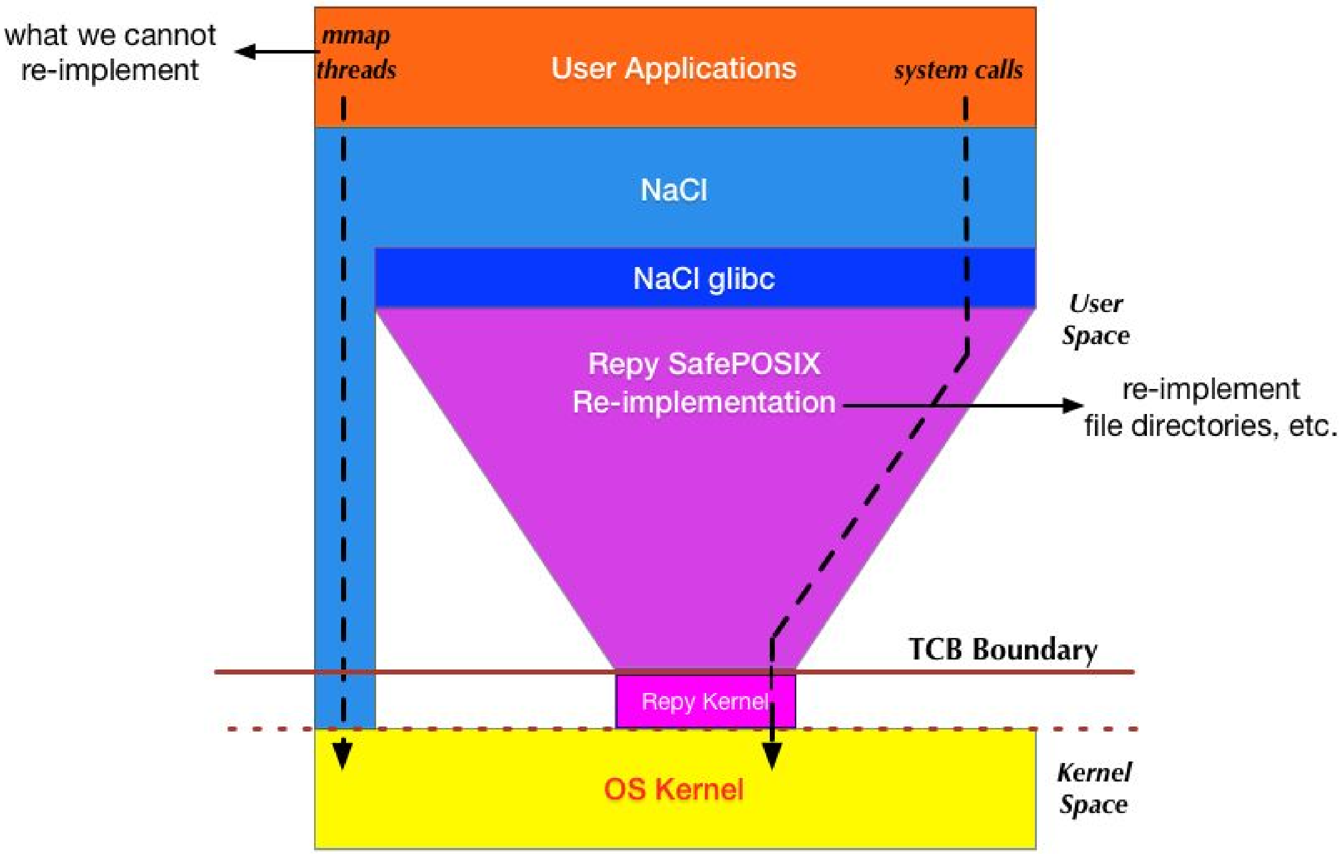


Our prototype implementation: Lind

- Google’s Native Client (NaCl) [IEEE S&P ’09]: software fault isolation

- Repy Sandbox [CCS ’10]
  - Small sandbox kernel (8K LOC)
  - 33 basic API functions
  - Accessed only a subset of the “popular paths”
  - Real-world deployment in the Seattle project, under security audit for 5+ years

Our prototype implementation: Lind



Evaluation results: Linux kernel coverage by fuzzing

Virtualization system	# of bugs	Kernel trace (LOC)		
		Total coverage	In popular paths	In risky paths
LXC	12	127.3K	70.9K	56.4K
Docker	8	119.0K	69.5K	49.5K
Graphene	8	95.5K	62.2K	33.3K
Lind	1	70.3K	70.3K	0
Repy	1	74.4K	74.4K	0

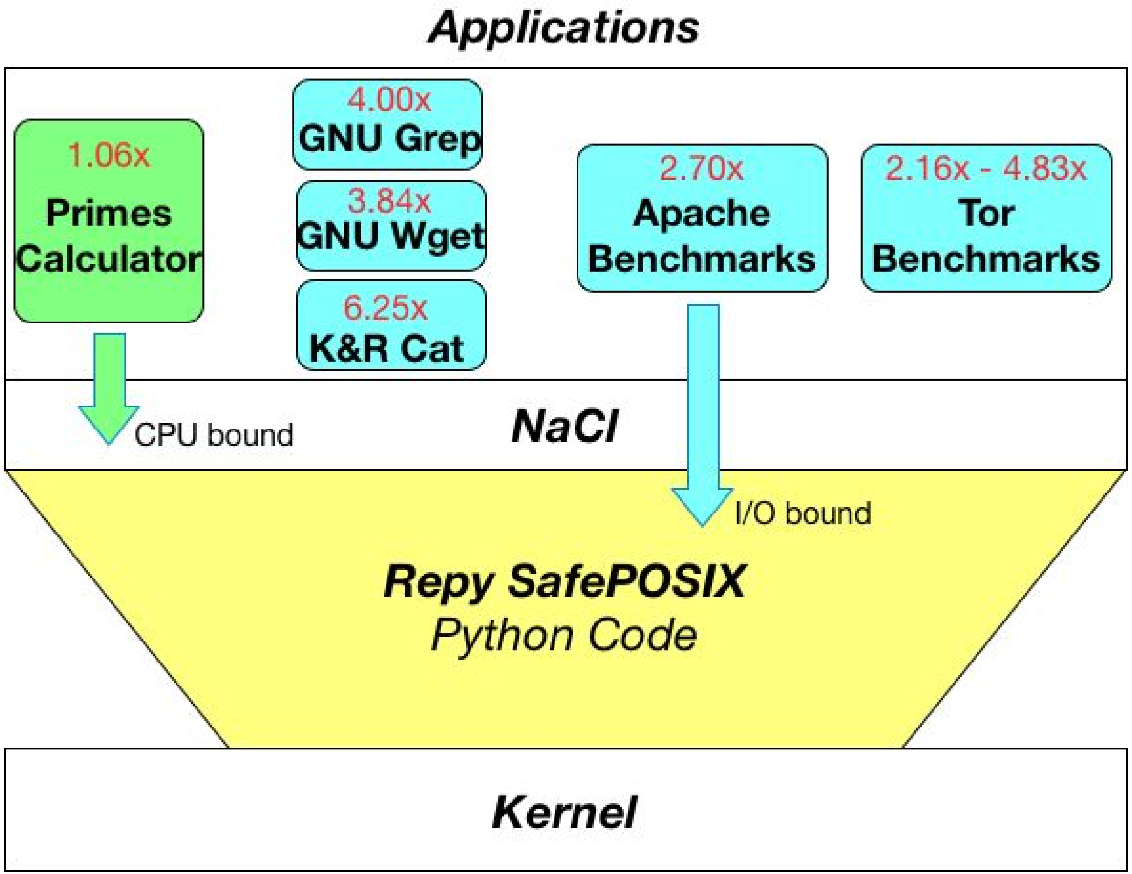
Evaluation results: Linux kernel bugs triggered

VM	**Bugs Triggered**
Native Linux	35/35 (100%)
LXC	12/35 (34.3%)
Docker	8/35 (22.9%)
Graphene	8/35 (22.9%)
Lind	1/35 (2.9%)

Example: CVE-2015-5706, a bug triggered everywhere except Lind

- A rarely-used flag O_TMPFILE reached unpopular lines of code inside fs/namei.c
- Lind is not affacted, because it is avoiding unpopular paths by restricting flags

Evaluation results: performance overhead in Lind



Limitations

- Some bugs are difficult to evaluate using our metric.
- Reaching lines of code may not be sufficient to trigger or exploit a bug.
- Lind’s performance could be improved.

Future work

- Removing risky lines from the kernel.
- Build a minimal OS kernel for Docker’s LinuxKit, etc.

Conclusion

- The popular paths, contain many fewer bugs.
- *Lock-in-Pop* design
- Our prototype system, Lind, exposes fewer zero-day kernel bugs.


Thank You


Q & A