Towards Provenance for Cybersecurity in Cloud-Native Production Infrastructure

FOSAD 2025 PhD Forum

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Provenance Graphs

- interactions between system subjects and objects
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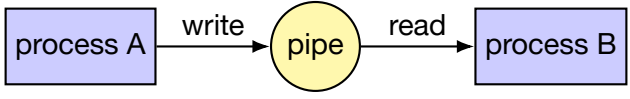
Provenance Graphs

- interactions between system subjects and objects
- understand system behavior, establish causality
- threat detection
  - sub-graph embedding [1]
  - graph queries [2]
  - benign behavior model [1, 3]
- forensics
  - post-mortem root cause analysis [4]
  - active threat hunting [5]

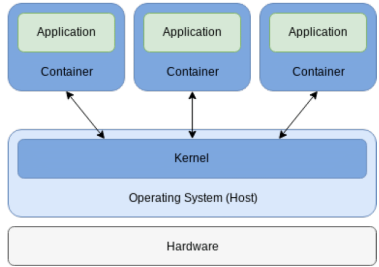


PhD Research Plan

Cloud-Native: An emerging infrastructure shift

Telemetry Collection for Cloud-Native production environments

- fine-grained, per-container telemetry
- distinguish container and host activity
- handle large system activity
- uniquely identify system objects



Telemetry Collection for Provenance

Location	Approach	Efficiency	Visibility	Safety	Portability	Example
user land	ptrace, fs snapshot	❍	❍	●	●	strace [6], ARTISAN [7]
kernel	integrated tool	●	●	●	❍	ftrace [8], auditd [9]
	kernel module	●	●	❍	●	CamFlow [4]
	eBPF	●	●	●	●	falco [10], tetragon [11]

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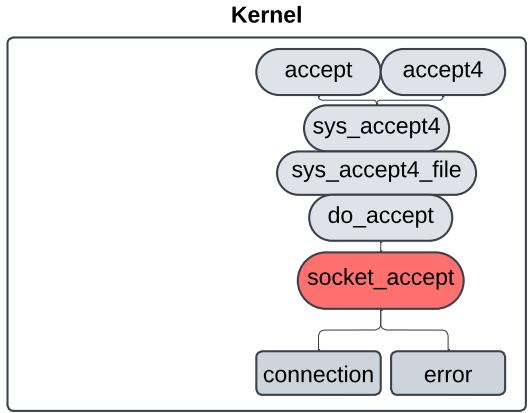
Linux Security Module (LSM) hooks



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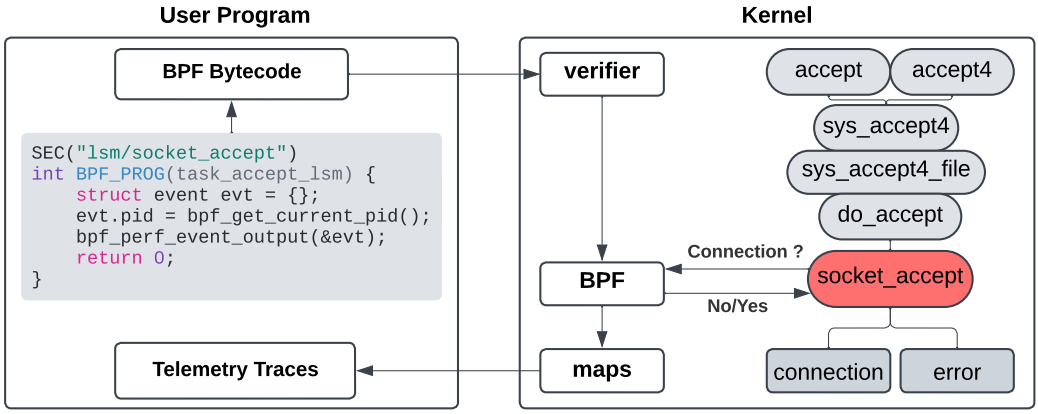

Preliminary Results and Future Work

Coverage: sufficient system visibility for sound provenance ?

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Objective

relationship between system calls and LSM hooks

Method

static analysis of Linux kernel source code (v6.13)

- cflow (call graphs) [12]
- cscope (code navigation) [13]

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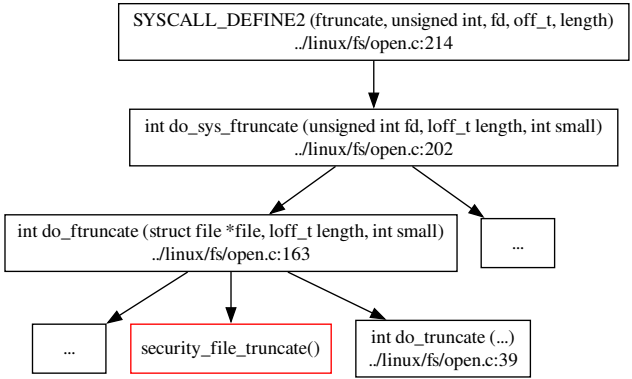
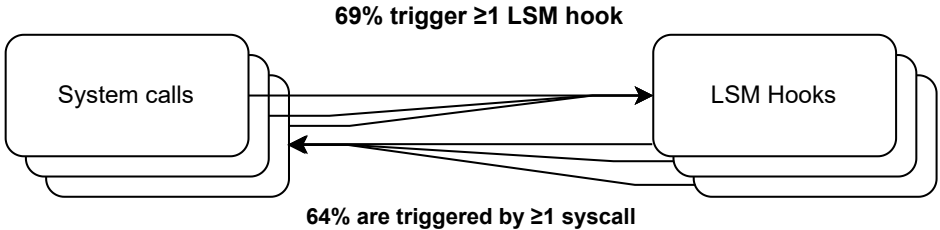


Coverage Analysis ($Syscall \leftrightarrow LSM$)

Limitations



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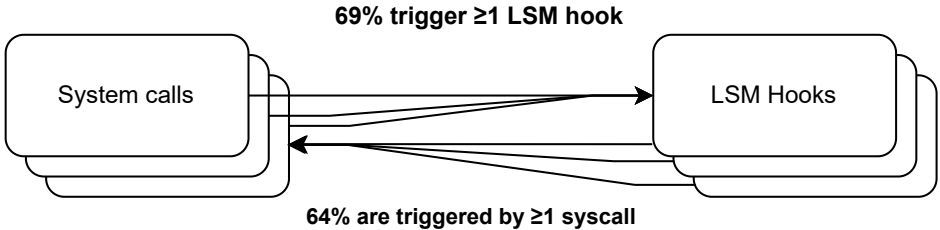

- indirect function calls
- function exported from a kernel module
- conditional branching is not considered

Stability across kernel versions compared to system calls

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Objective

compare the rate of change in LSM hook interfaces vs. system call interfaces

Method

track Application Binary Interface (ABI) changes across kernel versions

- added functions
- removed functions
- signature changes

Stability across kernel versions compared to system calls

- backwards compatibility
- LSM and interface has grown substantially
- frequent changes:
  - additions
  - removals
  - renaming
  - argument modifications

Linux version	Release date	LSM hooks	Argument changes	System calls	Argument changes
2.6.12	2005-06-17	=131	–	=251	–
2.6.30	2009-06-09	+72/-22	19	+79/-0	8
3.1	2011-10-24	+17/-14	8	+17/-1	15
3.12	2013-11-03	+12/-4	12	+13/-0	16
4.1	2015-06-21	+7/-2	3	+9/-0	4
4.12	2017-07-02	+8/-3	19	+10/-0	5
5.1	2019-05-05	+23/-4	24	+37/-0	27
5.12	2021-04-25	+16/-2	26	+15/-1	13
6.1	2022-12-11	+10/-2	10	+8/-1	0
6.12	2024-11-17	+33/-8	20	+14/-1	7
6.13	2025-01-19	+6/-4	1	+4/-0	0

Performance overhead among eBPF programs at LSM operation equivalence (excluding tracepoint programs)

Activity context	Prog. type	Perf. overhead	Execution counts	Written traces
network	LSM kprobe tracing	1.07% 1.81% **0.90%**	50,002	50,002
file	LSM kprobe tracing	5.83% 6.39% **5.14%**	50,507	50,507
process	LSM kprobe tracing	0.74% 0.79% **0.47%**	50,035	50,035

Conclusion

Future Work

- refine coverage analysis
  - advanced static tools like Kayrebt [14]
  - fuzzing-based dynamic analysis [15]
- identify missing LSM hooks to cover kernel object
  - allocation
  - activity
  - information flow
- qualify the ABI changes

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Stability Analysis (ABI Evolution)

Kernel	Release Date	# LSM Hook name changes	Modified function names	# LSM Hook Parameter changes	Modified Parameters	Total Syscalls	Changes from Previous	# Syscall Parameter changes
6.13	2025-01-19	+6/-4	current_getlsmprop_subj, lsmprop_to_secctx, inode_getlsmprop, cred_getlsmprop, task_getlsmprop_obj, ipc_getlsmprop ~~task_getsecid_obj~~, ~~ipc_getsecid~~, ~~current_getsecid_subj~~, ~~inode_getsecid~~	1	audit_rule_match: structlsm_prop*prop, ~~u32secid~~	+4/-0	removexattrat, getxattrat, listxattrat, setxattrat	0

eBPF attachements

Program type	Attach type	TOCTOU resistant [16]	Granularity					Stable	Kernel ≥
			system Calls	kfunc.	ufunc.	AC op.	cgroup		
LSM	LSM_MAC	●	❍	❍	❍	●	●	●	5.7
tracepoint	tracepoint	◗	●	◗	❍	❍	❍	●	4.7
kprobe	kprobe	◗	●	●	●	●	❍	❍	4.1
tracing	fentry	◗	●	●	●	●	❍	❍	5.1