RAIN: Refinable Attack Investigation with On-demand Inter-process Information Flow Tracking

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More and more data breaches



Is attack investigation accurate?

Dependency confusion!





Related work

- System-call-based
 - DTrace, Protracer, LSM, Hi-Fi
- Dynamic Information Flow Tracking (DIFT)
 - Panorama, Dtracker
- DIFT + Record replay
 - Arnold



RAIN

- We use
 - Record replay
 - Graph-based pruning
 - Selective DIFT
- We achieve
 - High accuracy
 - Runtime efficiency
 - Highly improved analysis efficiency



Threat model

- Trusts the OS
 - RAIN tracks user-level attacks.
- Tracks explicit channels
 - Side or covert channel is out of scope.
- Records all attacks from their inception
 - Hardware trojans or OS backdoor is out of scope.

Architecture





OS-level record replay



1.Records external inputs
2.Captures the thread switching from the pthread interface, not the produced internal data
3.Records system-wide executions

Coarse-level logging and graph building

- Keeps logging system-call events
- Constructs a graph to represent:
 - the processes, files, and sockets as nodes
 - the events as causality edges



A: Attacker site

Pruning

- Does every recorded execution need replay and DIFT? No!
- Prunes the data in the graph based on trigger analysis results
 - Upstream
 - Downstream
 - Point-to-point
 - Interference



Downstream





Interference

- Insight: only inbound and outbound files that interfere in a process will possibly produce causality.
 - We determine interference according to the time order of inbound and outbound IO events.



Refinement - selective DIFT

- Replays and conducts DIFT to the necessary part of the execution
 - Aggregation
 - Upstream
 - Downstream
 - Point-to-point



Implementation summary

- RAIN is built on top of:
 - Arnold, the record replay framework
 - Dtracker (Libdft) and Dytan, the taint engines

Host	Module	LoC
Target host	Kernel module	2,200 C (Diff)
	Trace logistics	1,100 C
Analysis host	Provenance graph	6,800 C++
	Trigger/Pruning	1,100 Python
	Selective refinement	900 Python
	DIFT Pin tools	3,500 C/C++ (Diff)

Evaluations

- Runtime performance
- Accuracy
- Analysis cost
- Storage footprint

Runtime overhead: 3.22% SPEC CPU2006



Multi-thread runtime overhead: 5.35% SPLASH-3



IO intensive application: less than 50%



High analysis accuracy



Scenarios from red team exercise of DARPA Transparent Computing program

Pruning effectiveness: ~94.2% reduction



Storage cost: ~4GB per day (1.5TB per year)



Discussion

- Limitations
 - RAIN trusts the OS that needs kernel integrity protection.
 - Over-tainting issue
- Direction
 - Hypervisor-based RAIN
 - Further reduce storage overhead

Conclusion

- RAIN adopts a multi-level provenance system to facilitate finegrained analysis that enables accurate attack investigation.
- RAIN has low runtime overhead, as well as significantly improved analysis cost.