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

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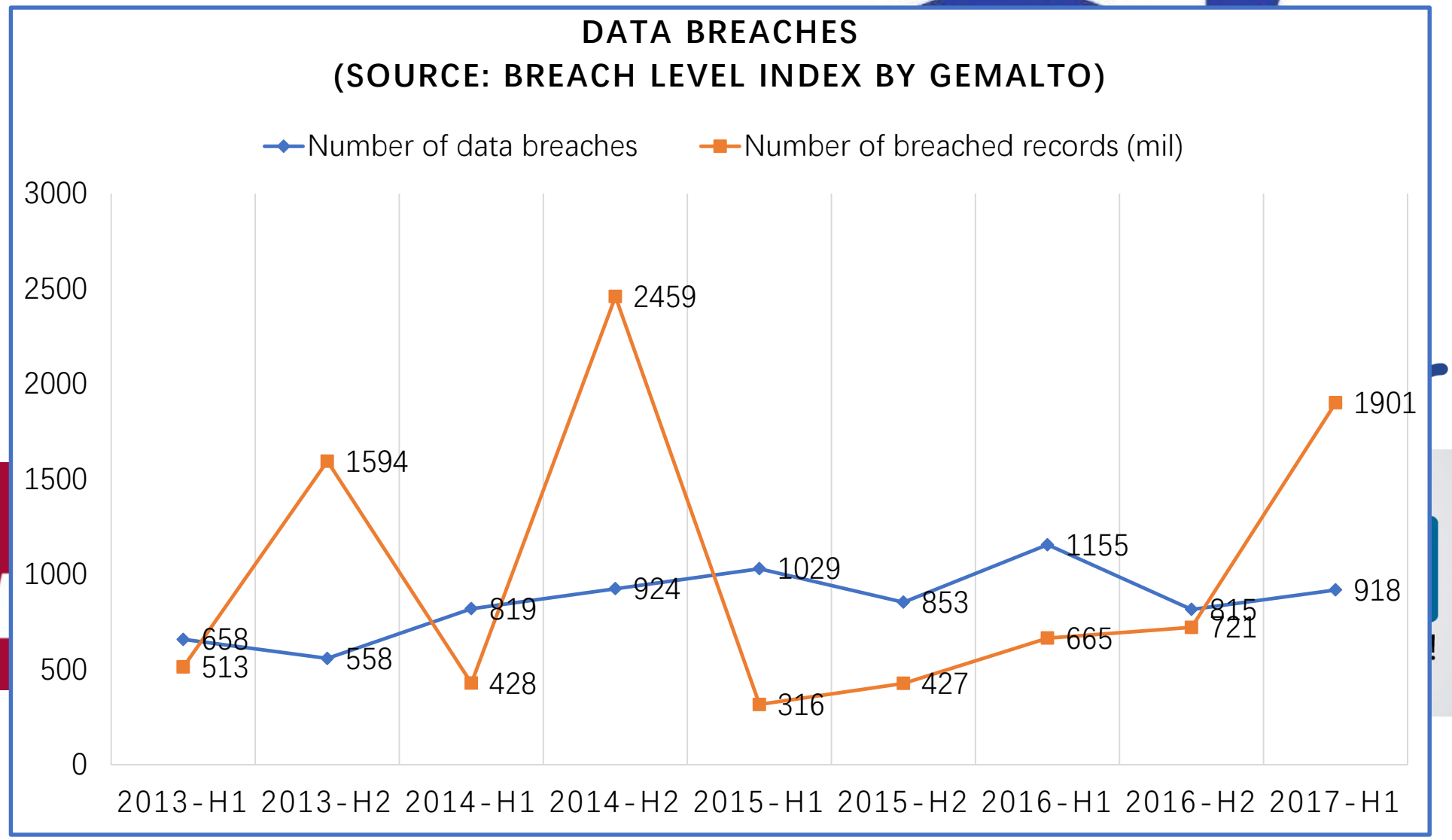
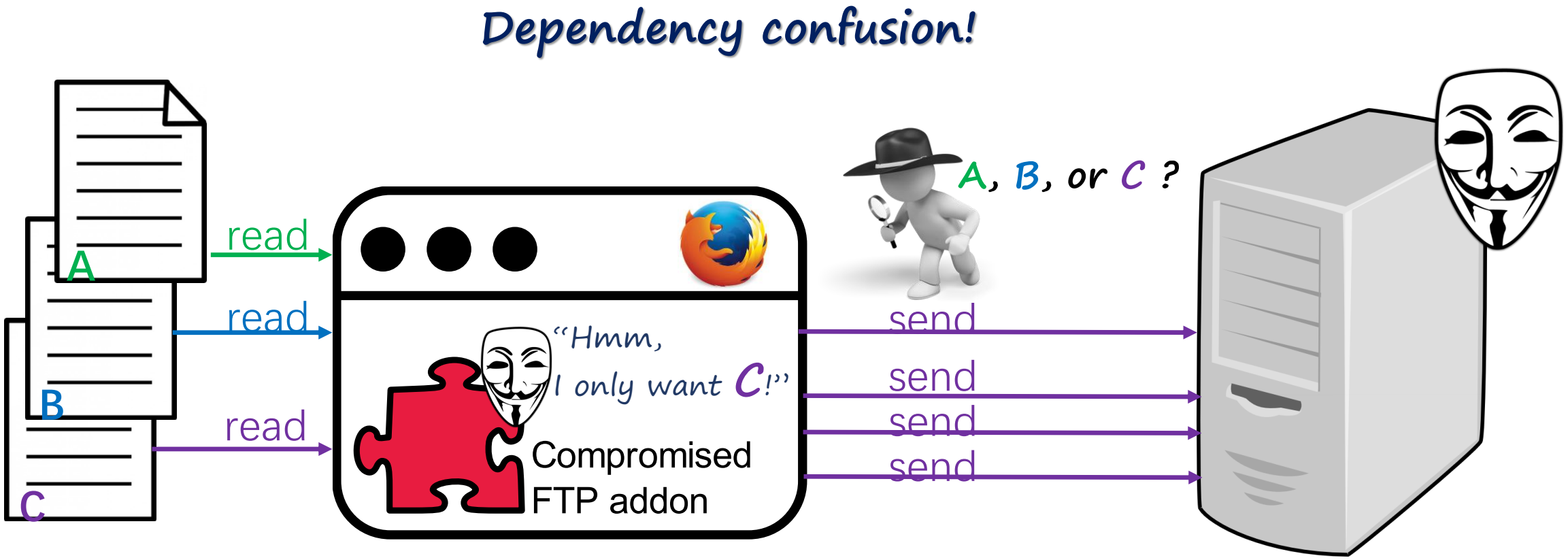
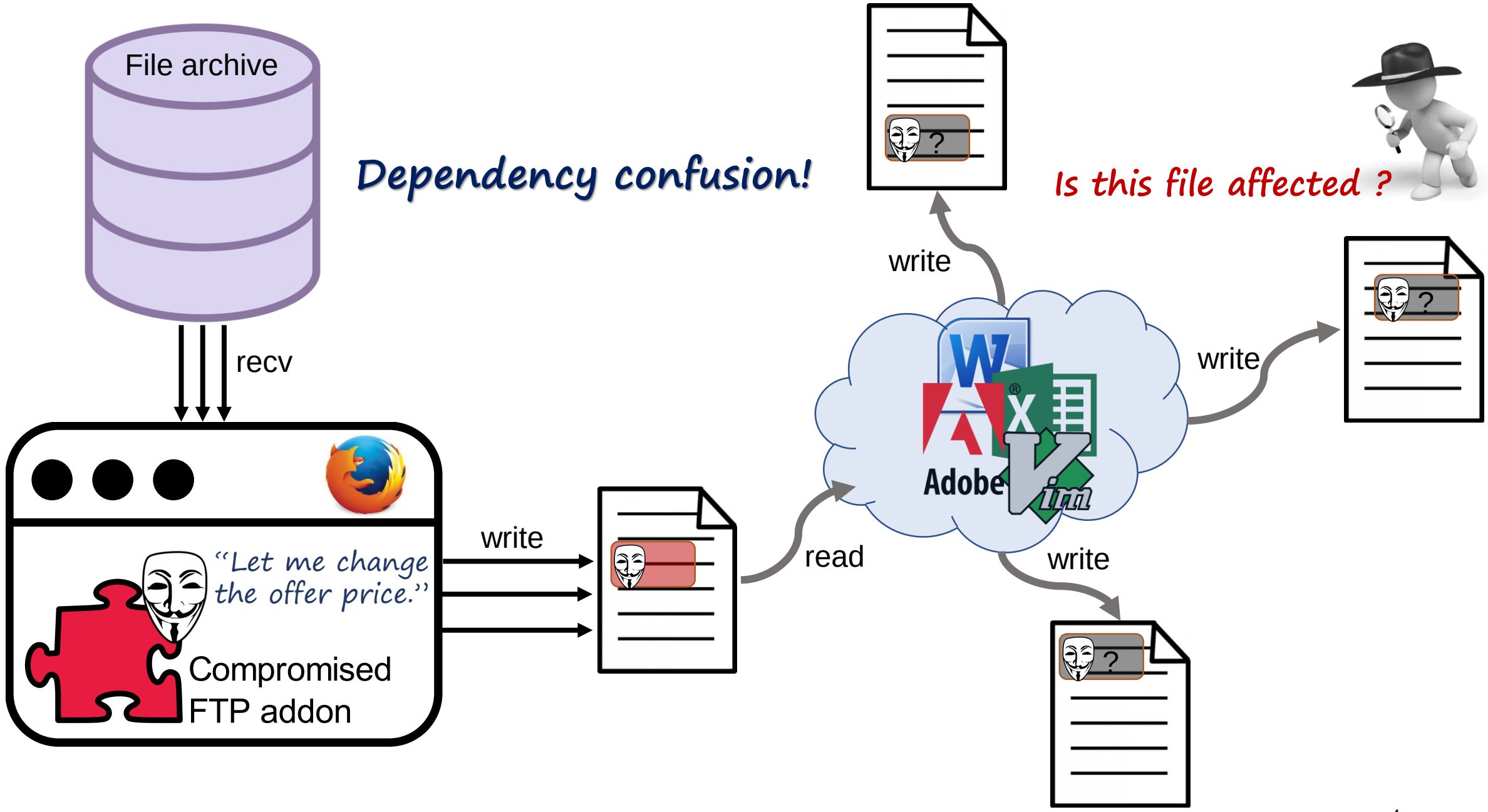
Georgia Tech

More and more data breaches



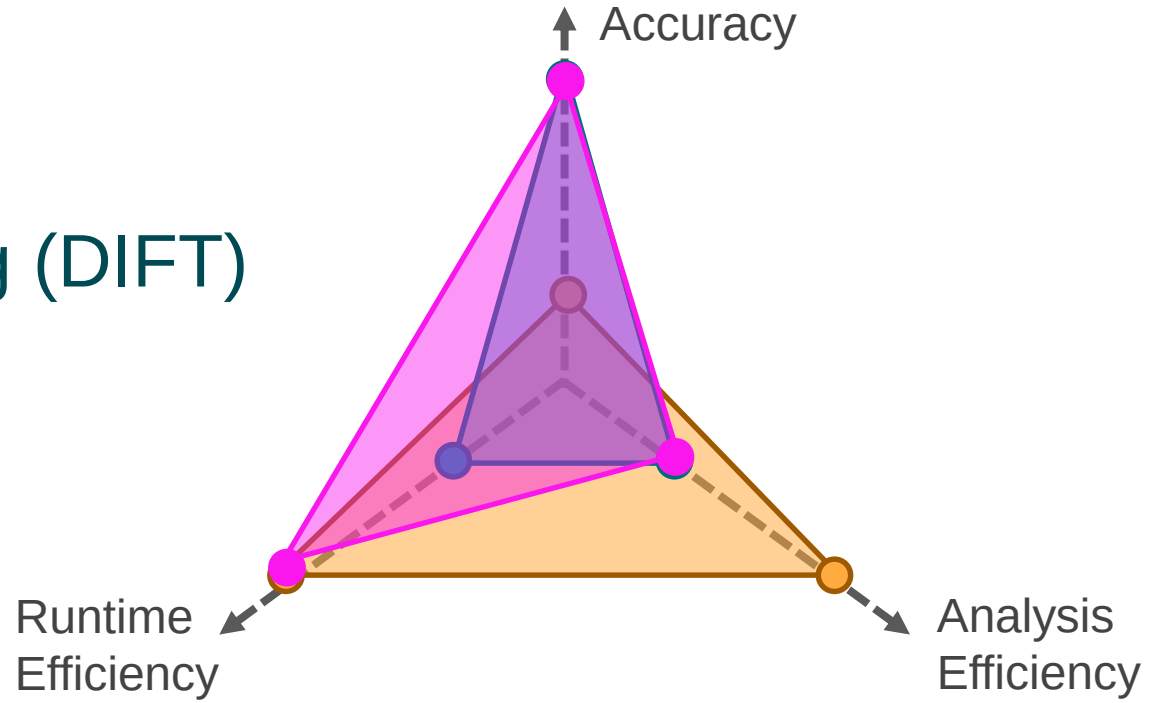
Is attack investigation accurate?




File archive
recv
Dependency confusion!
"Let me change the offer price."
Compromised FTP addon
write
read
write
write
write
Adobe
Is this file affected ?

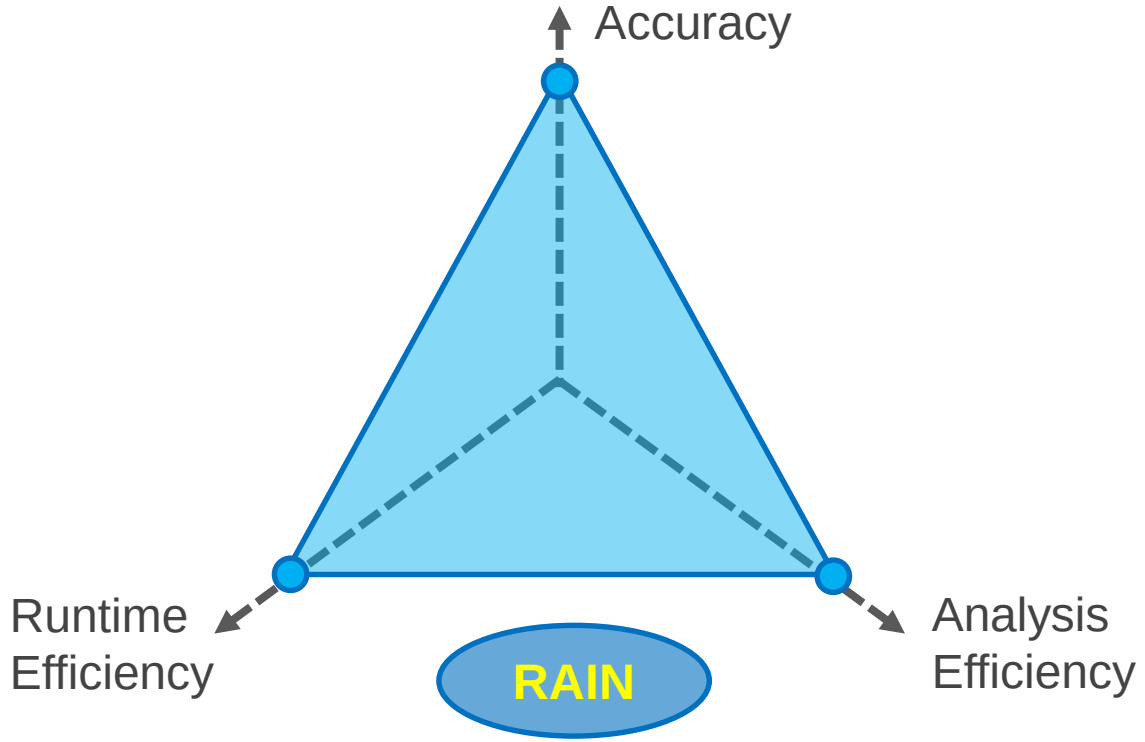
Related work

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



RAIN

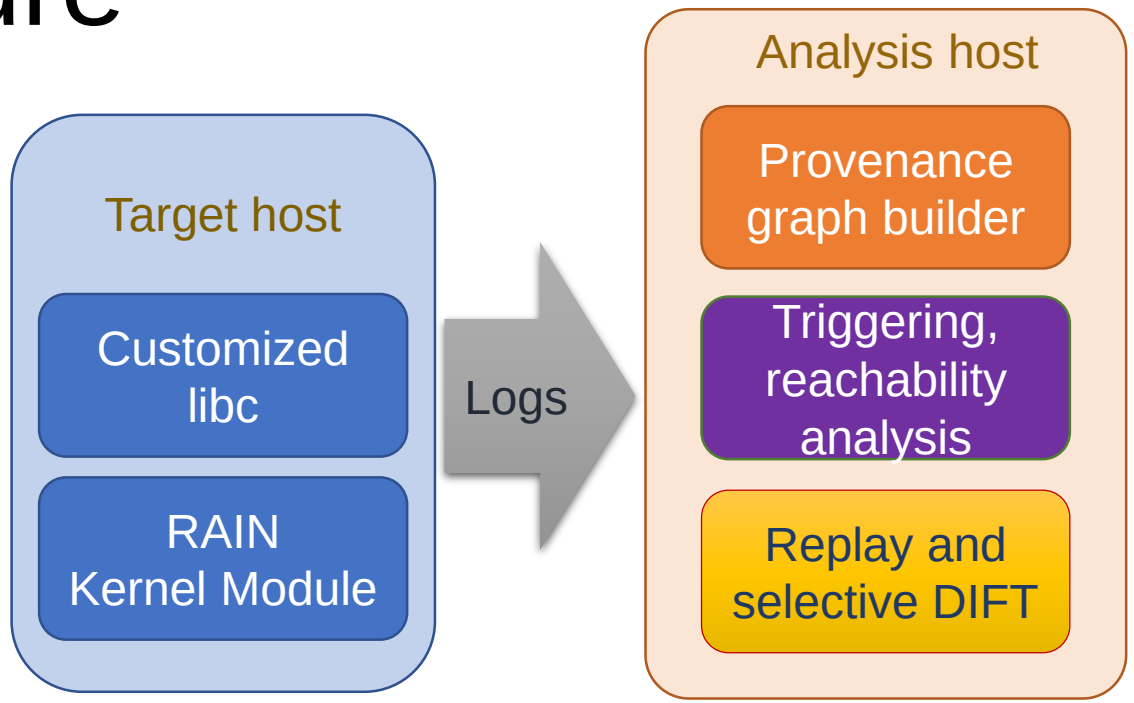
- We use
  - Record replay
  - Graph-based pruning
  - Selective DIFT
- We achieve
  - High accuracy
  - Runtime efficiency
  - Highly improved analysis efficiency

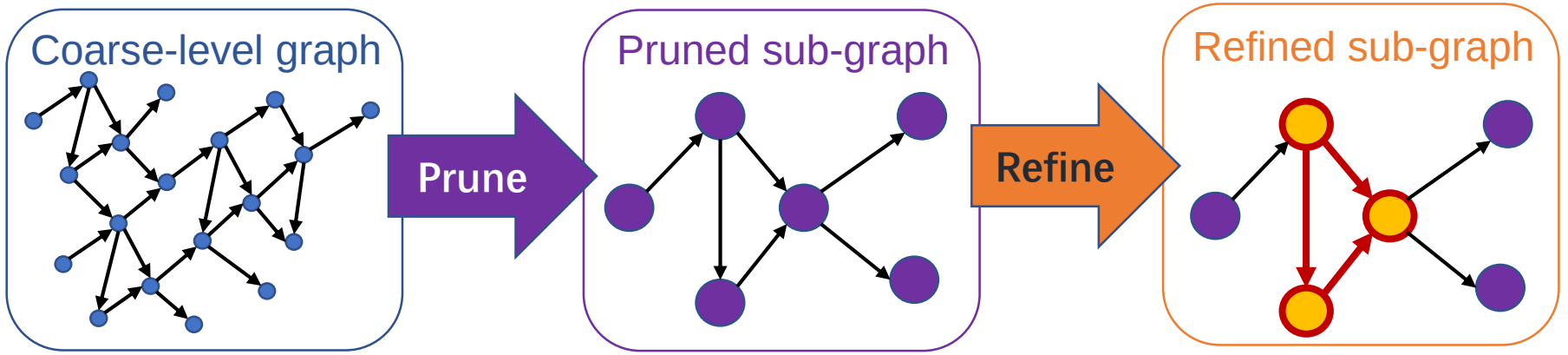


Threat model

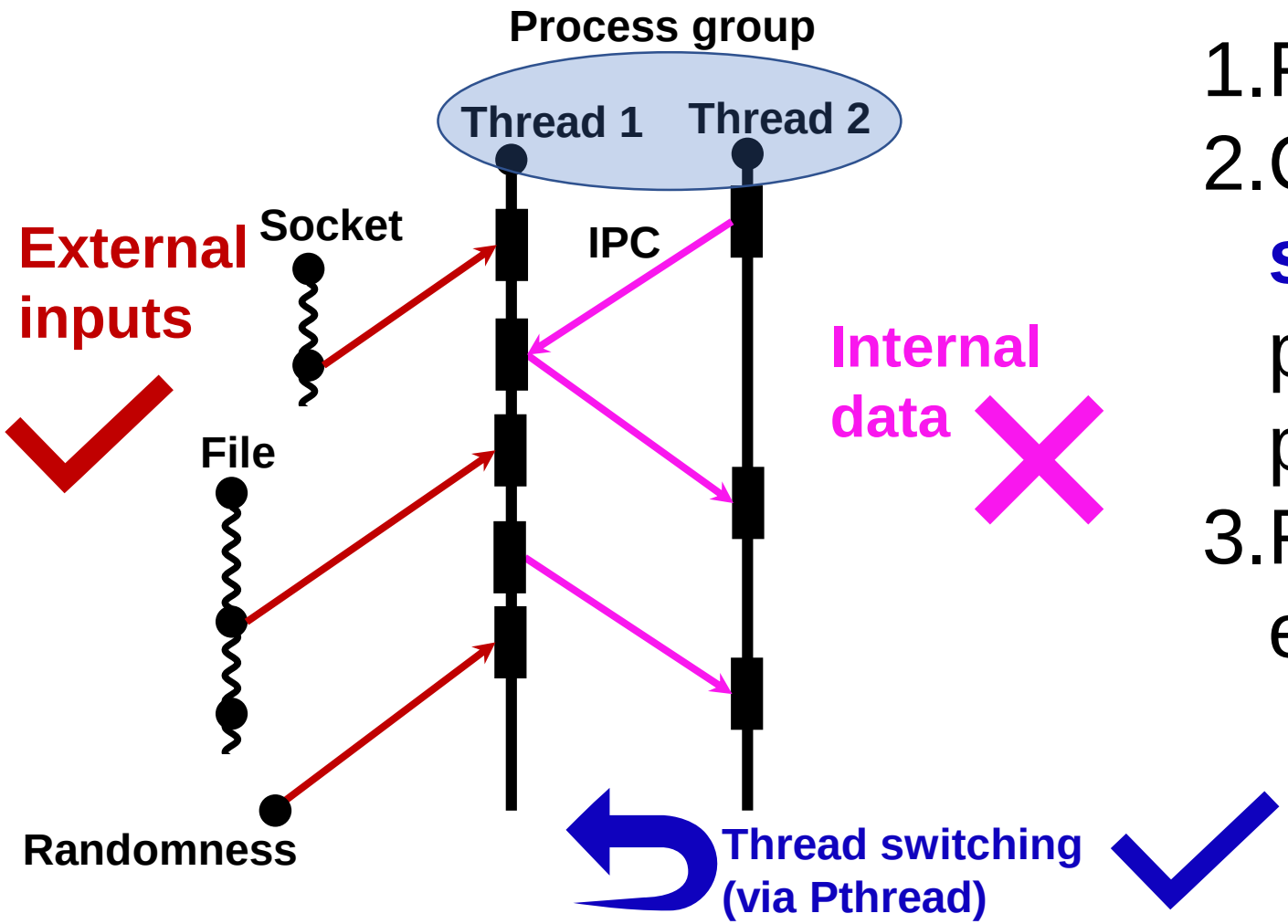
- Trusts the OS
  - RAIN tracks user-level attacks.
- Tracks explicit channels
  - Side or covert channel is out of scope.
- Records all attacks from their inception
  - Hardware trojans or OS backdoor is out of scope.

Architecture





OS-level record replay



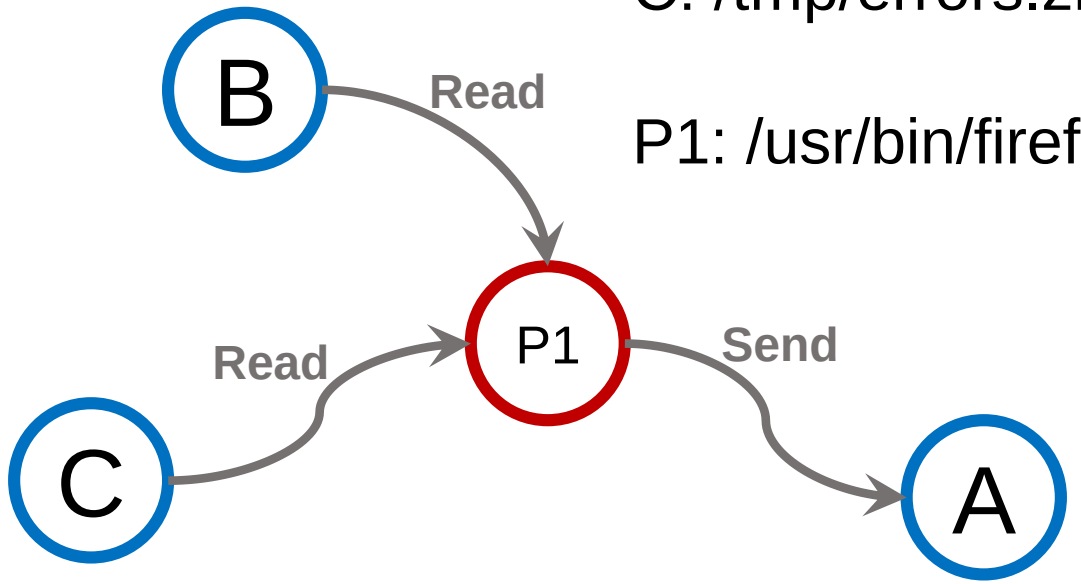
1. Records **external inputs**
2. Captures the **thread switching** from the pthread interface, not the produced **internal data**
3. Records ***system-wide*** executions

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
B: /docs/report.doc
C: /tmp/errors.zip

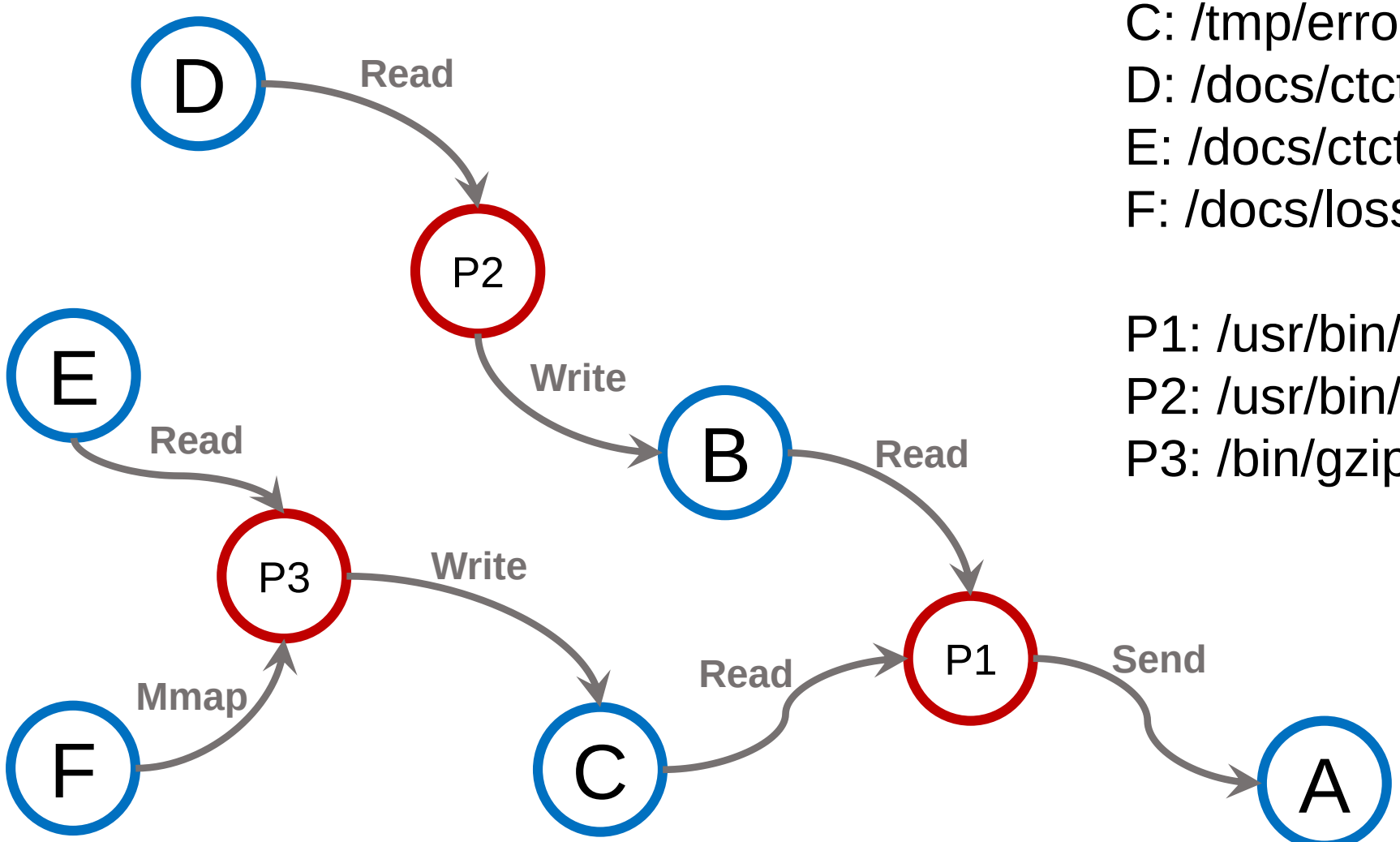
P1: /usr/bin/firefox



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

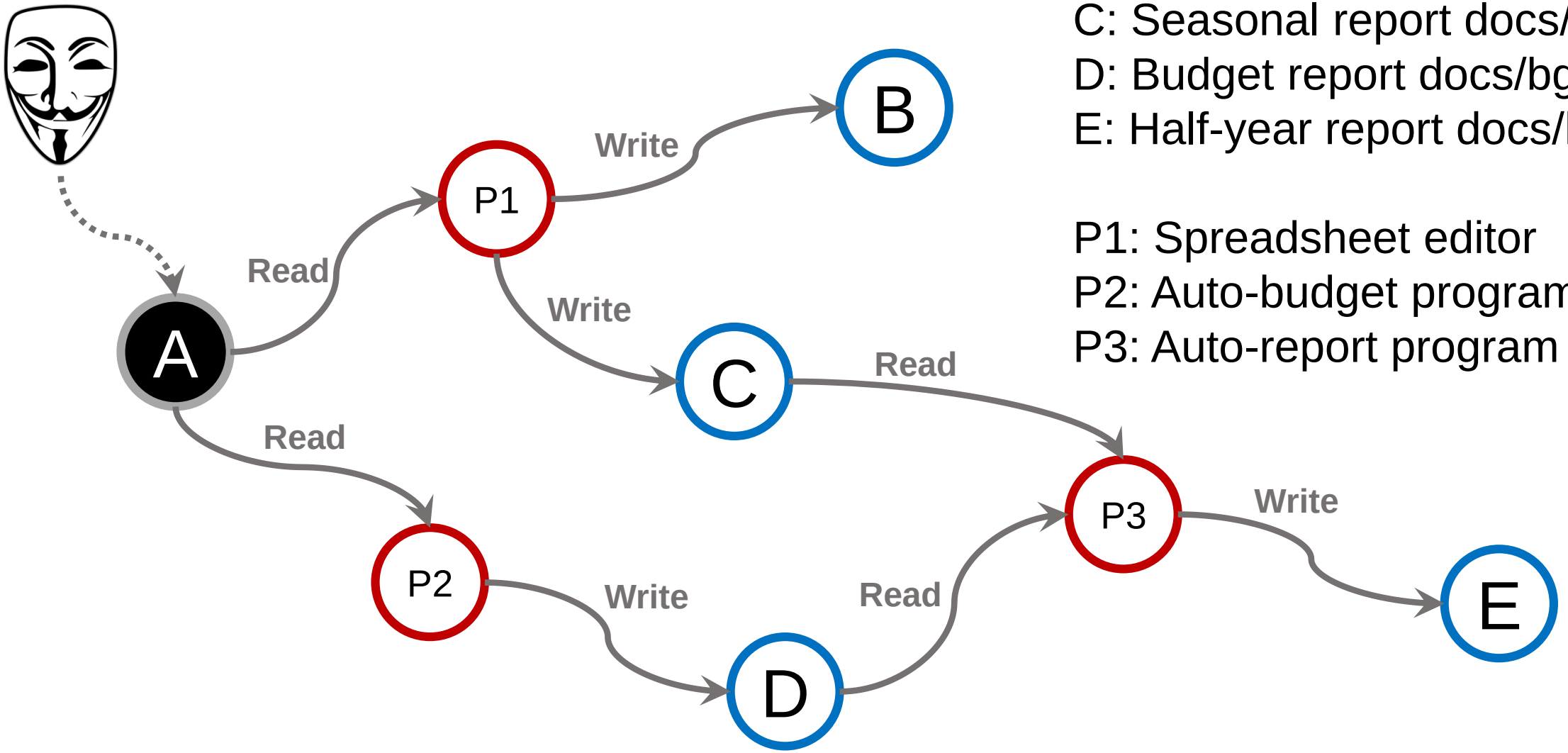
Upstream



A: Attacker site
B: /docs/report.doc
C: /tmp/errors.zip
D: /docs/ctct1.csv
E: /docs/ctct2.pdf
F: /docs/loss.csv

P1: /usr/bin/firefox
P2: /usr/bin/TextEditor
P3: /bin/gzip

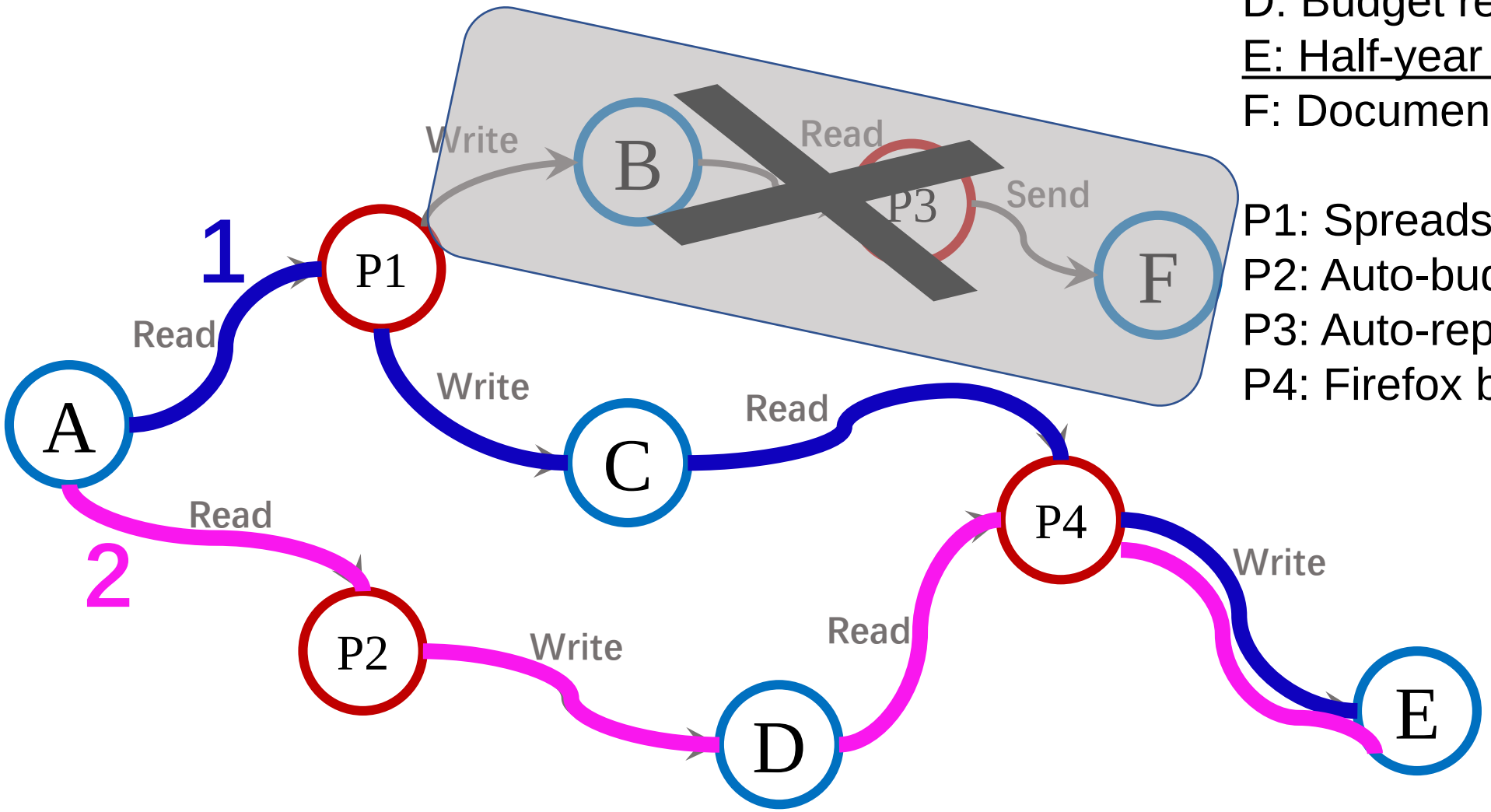
Downstream



A: **Tampered file** /docs/ctct.csv
B: Seasonal report docs/s1.csv
C: Seasonal report docs/s2.csv
D: Budget report docs/bgt.csv
E: Half-year report docs/h2.pdf

P1: Spreadsheet editor
P2: Auto-budget program
P3: Auto-report program

Point-to-point



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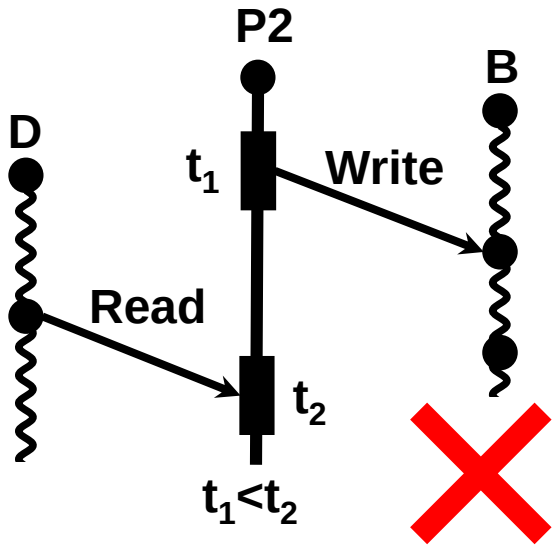
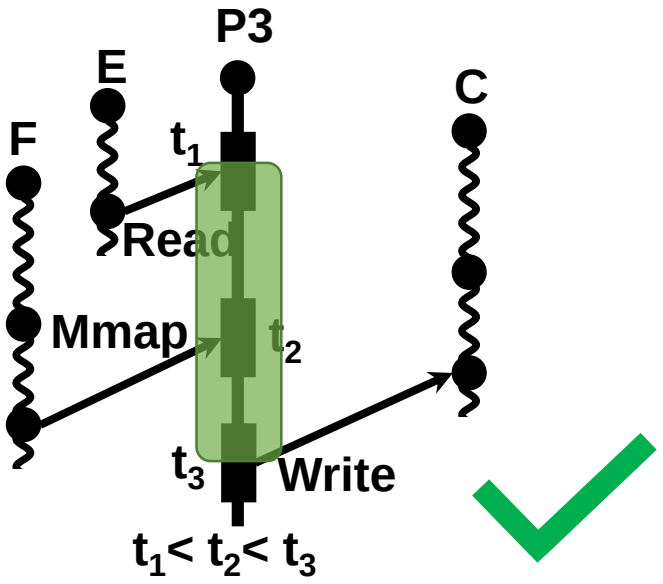
F: Document archive server

P1: Spreadsheet editor
P2: Auto-budget program
P3: Auto-report program
P4: Firefox browser

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.

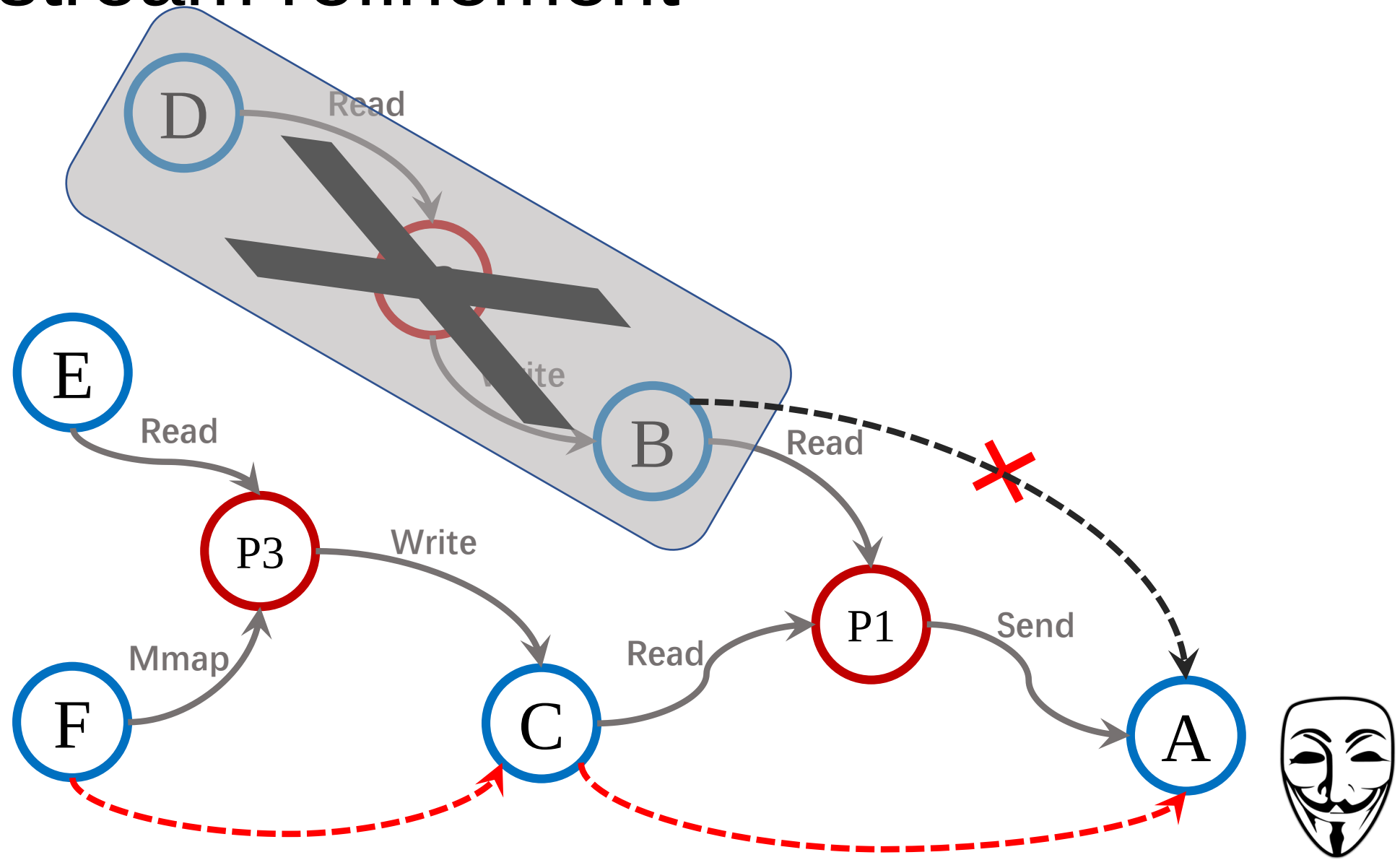




Refinement - selective DIFT

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

Upstream refinement



Implementation summary

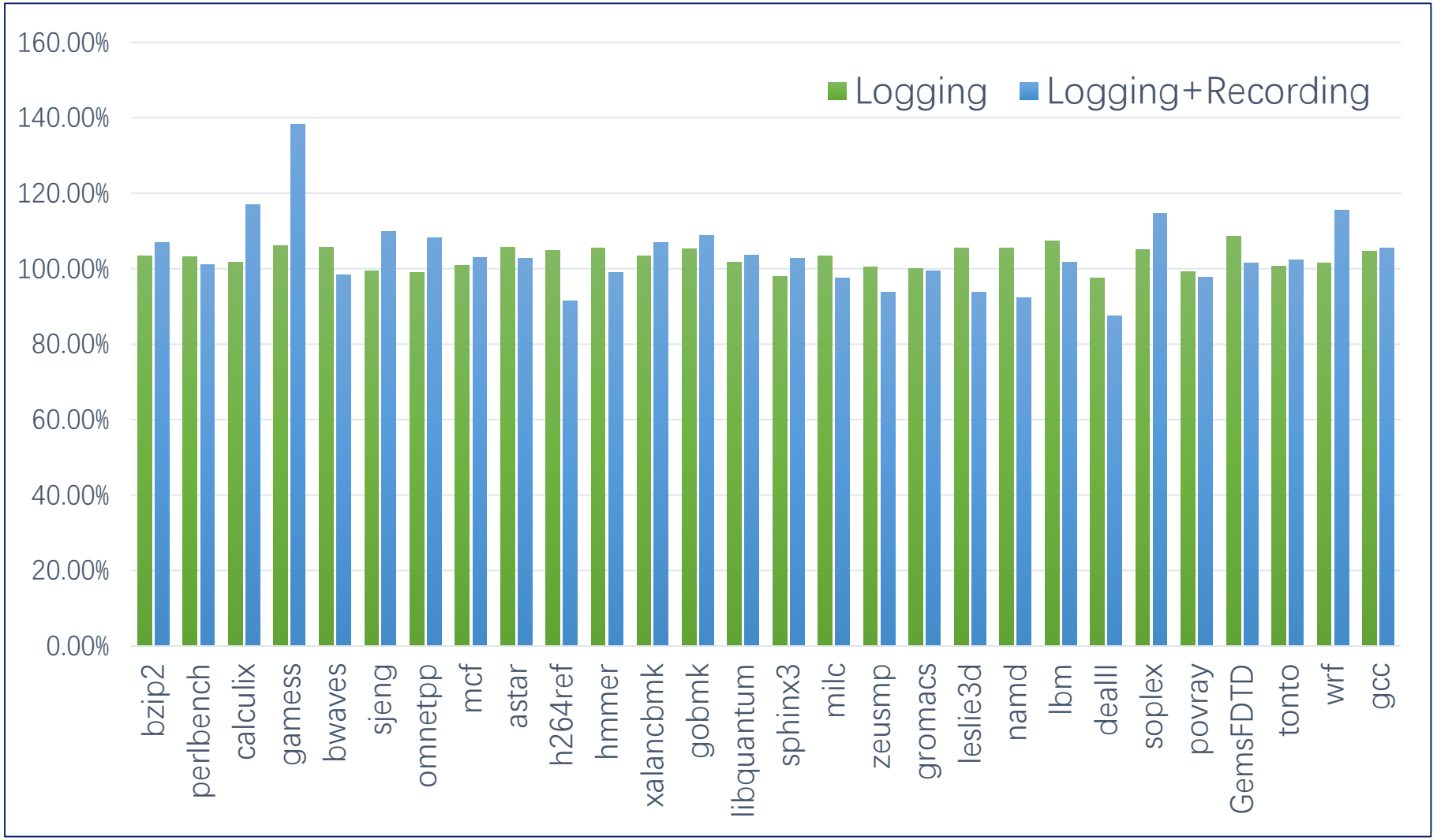
- RAIN is built on top of:
  - Arnold, the record replay framework
  - Dtracker (Libdft) and Dytan, the taint engines

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)

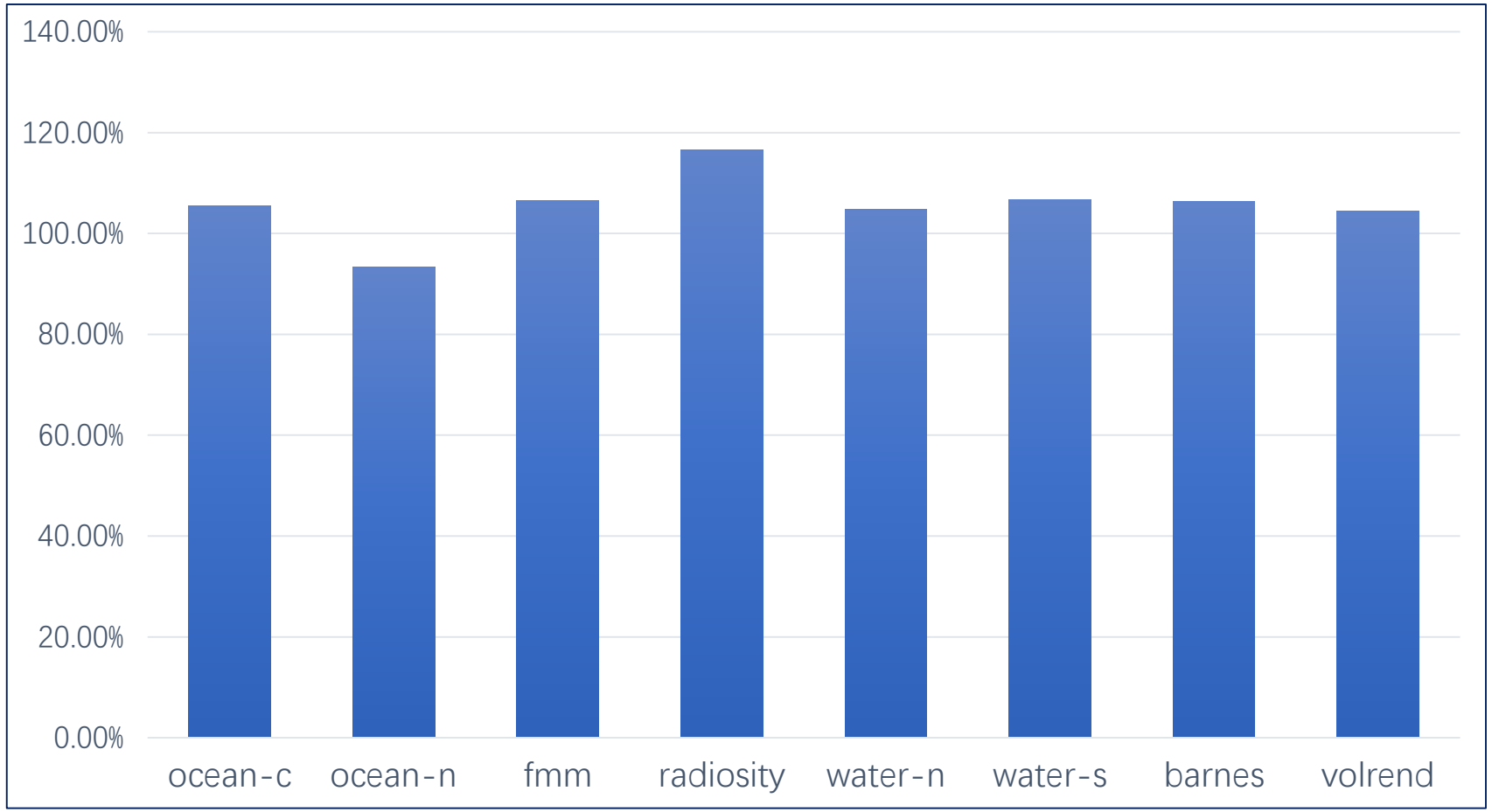
Evaluations

- Runtime performance
- Accuracy
- Analysis cost
- Storage footprint

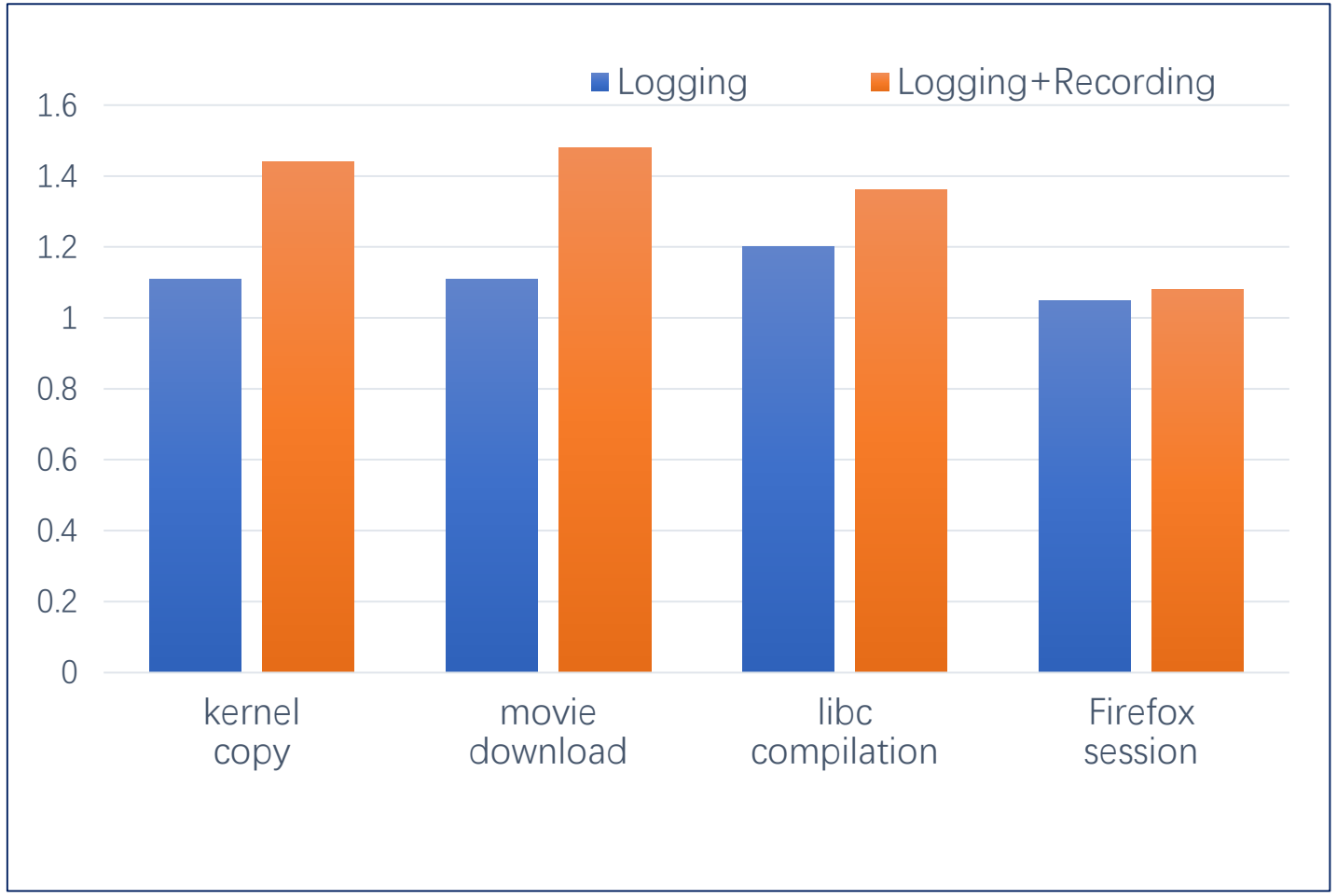
Runtime overhead: 3.22% SPEC CPU2006



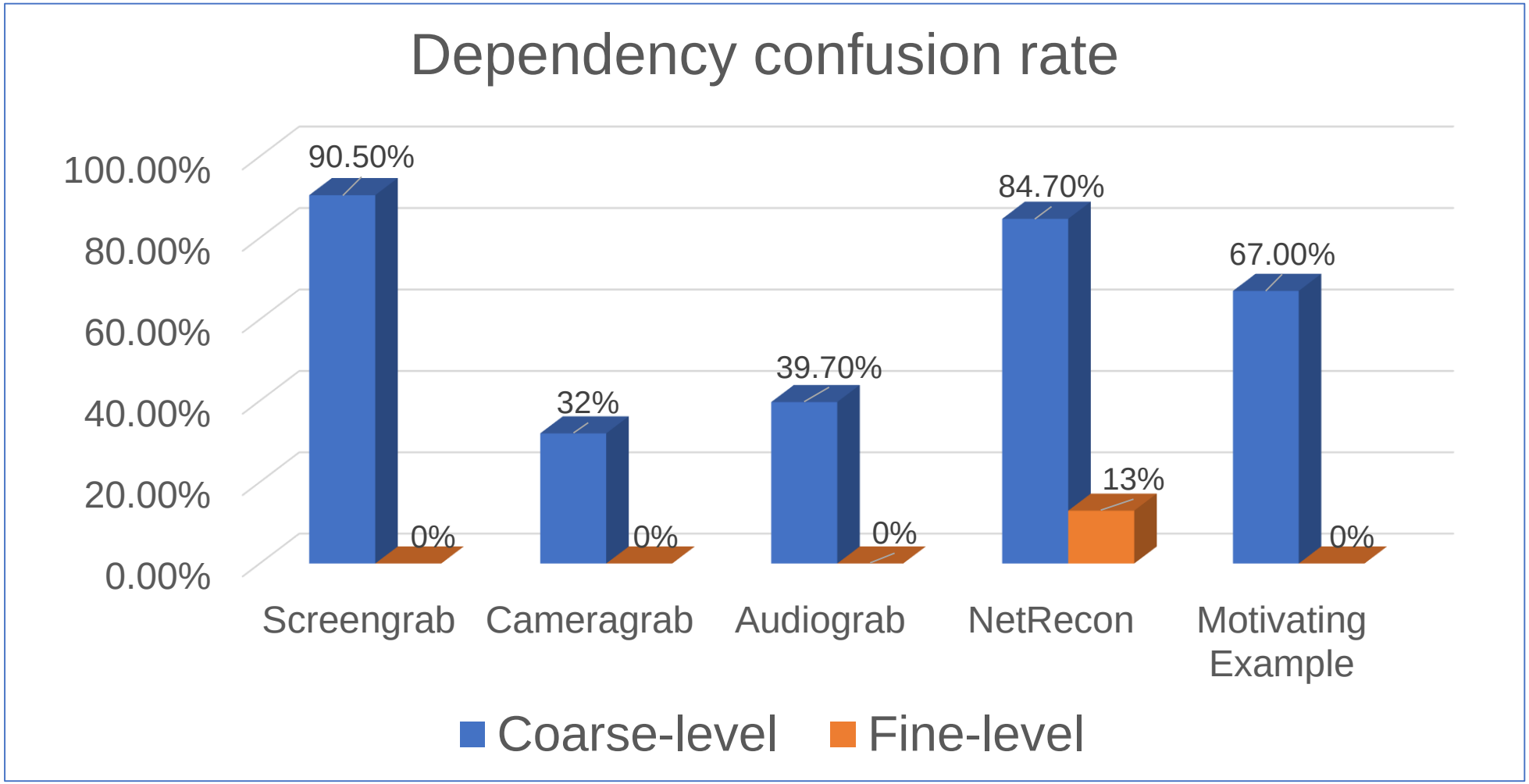
Multi-thread runtime overhead: 5.35% SPLASH-3



IO intensive application: less than 50%

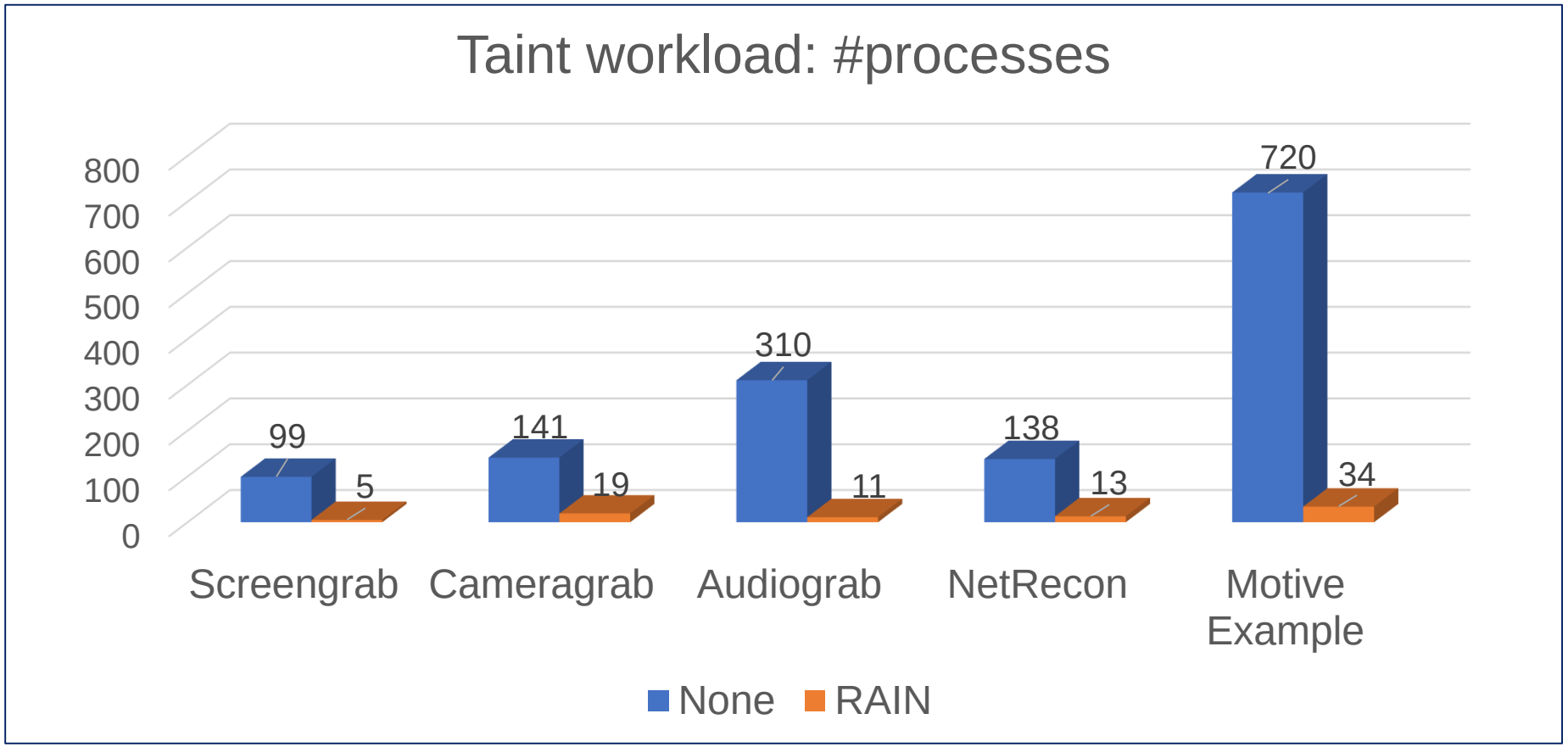


High analysis accuracy

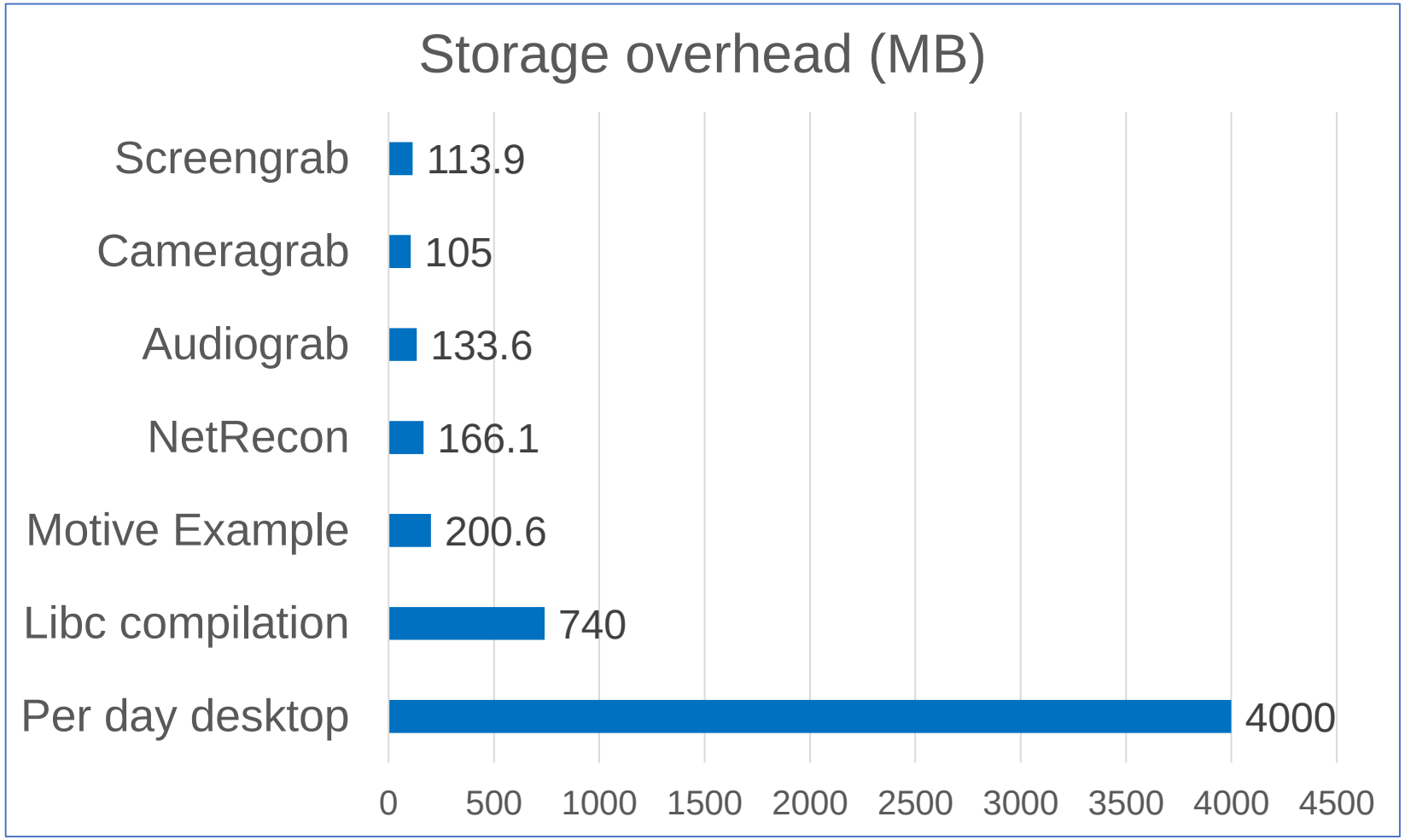


Scenarios from red team exercise of DARPA Transparent Computing program

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 fine-grained analysis that enables accurate attack investigation.

- RAIN has low runtime overhead, as well as significantly improved analysis cost.