ReplayConfusion: Detecting Cache-based Covert Channel Attacks Using Record and Replay

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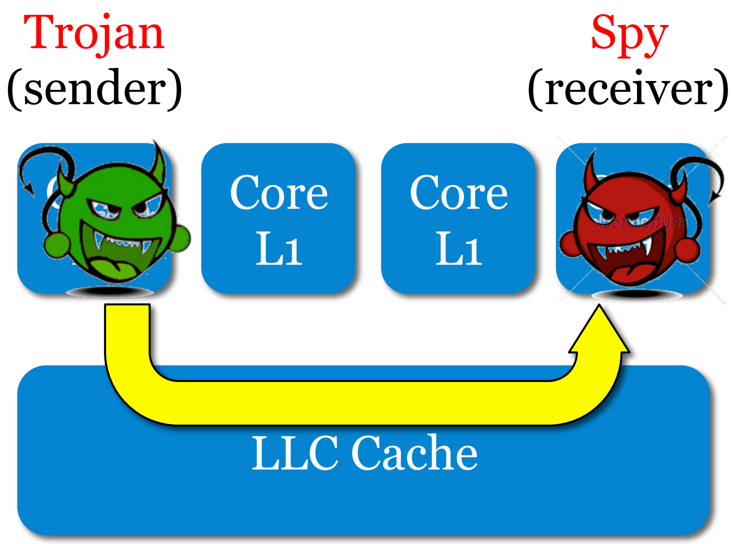
Motivation

- Cache-based covert channel attacks
  - Communicate through cache conflicts
- Serious security threat
  - Ubiquitous attack scenario: cloud
  - Bypass security policy; no trace left
- Existing solutions unable to detect all attacks
- Contribution: *ReplayConfusion*
  - High-coverage detection mechanism



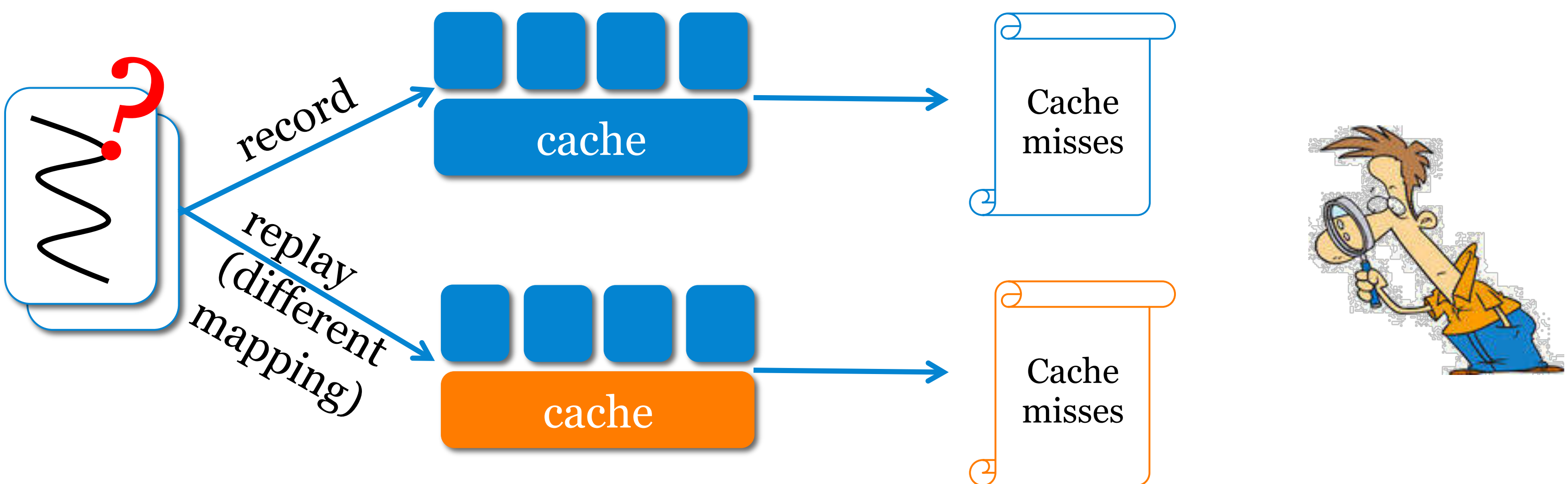
Contribution: *ReplayConfusion*

Observations:
1. Trojan/Spy rely on specific mapping addresses→caches
2. Attack follows a repeating pattern when transmitting

Change mapping of addresses→caches

Re-mapping is different for each process

Effects:
1. Substantially disrupt cache miss pattern
2. Retain the repeating pattern

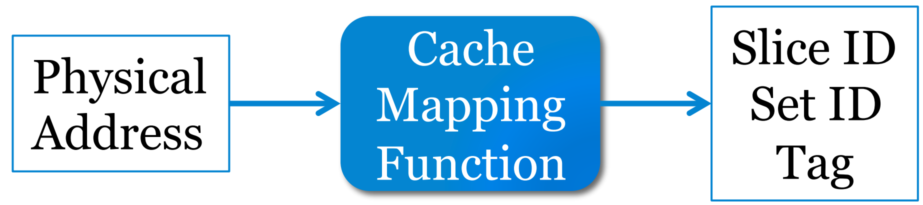


Outline

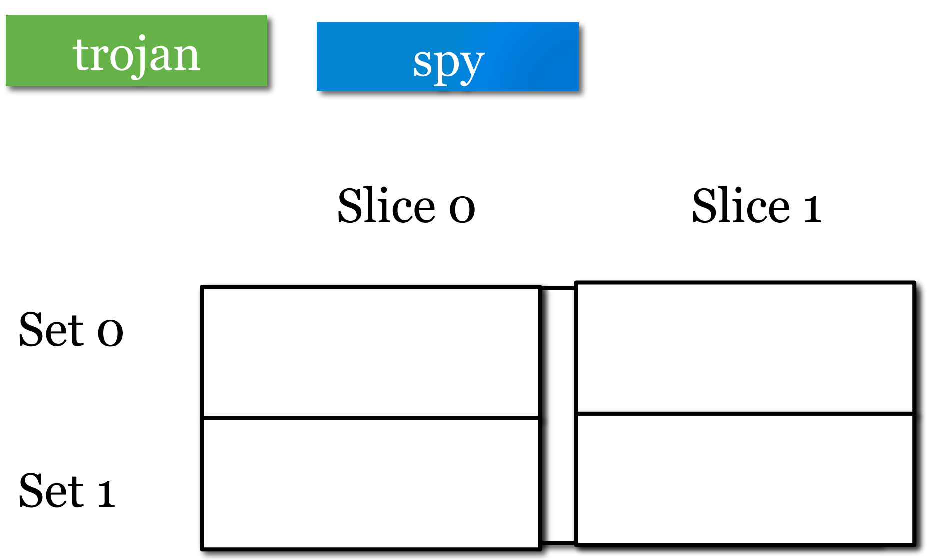
- Background
- Attack Protocols
- ReplayConfusion
  - Observations
  - Detection Framework
- Detection Example
- Summary

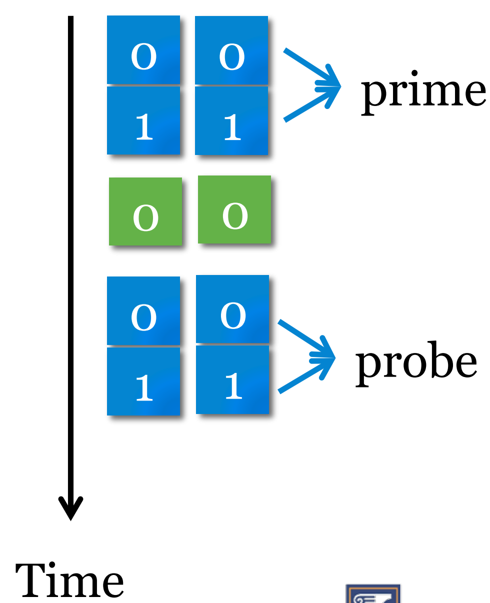
Cache-based Covert Channel Attack

- Basic cache organization:
  - Slice(i.e. Bank), Set, Way
  - Cache mapping function
- Approach: Prime+Probe

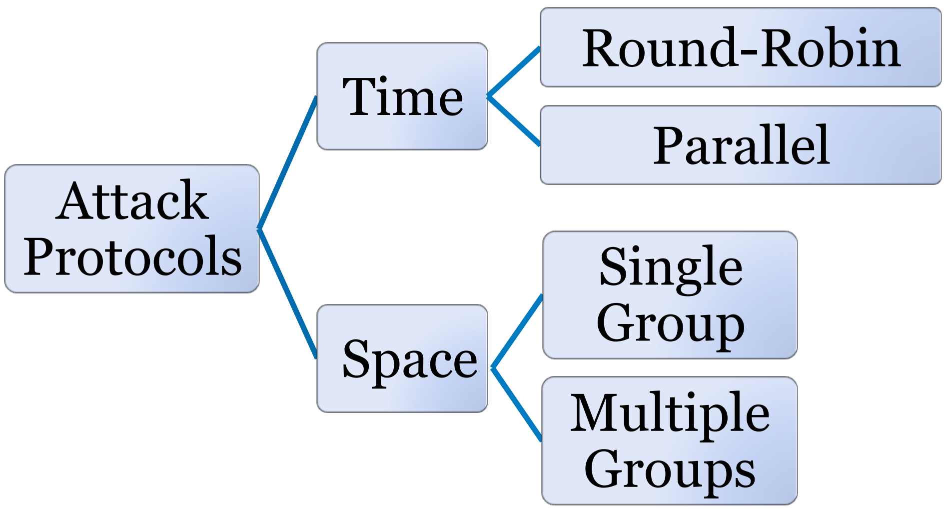


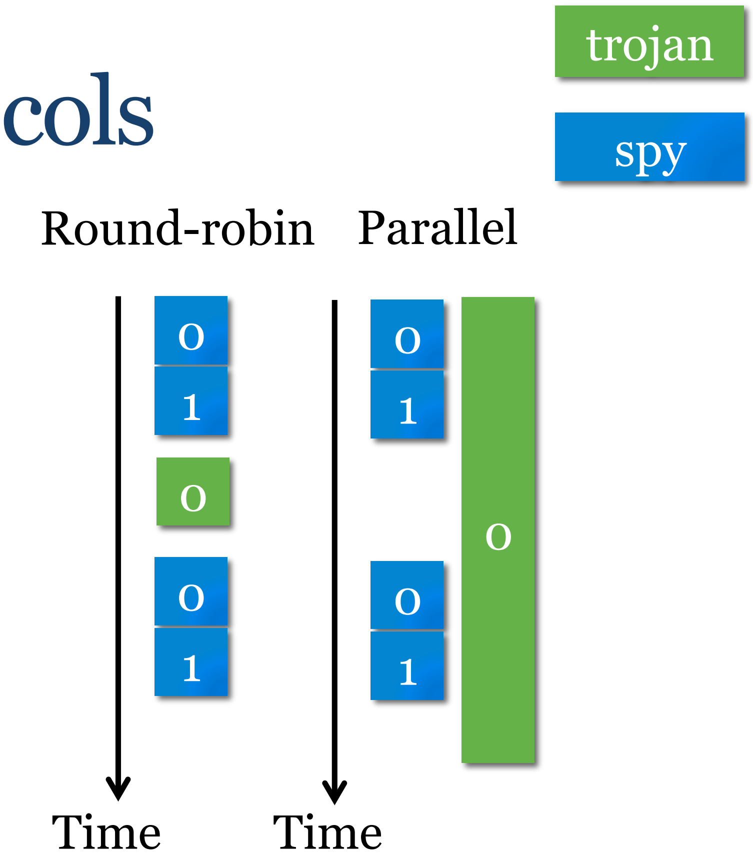
Can be reverse engineered

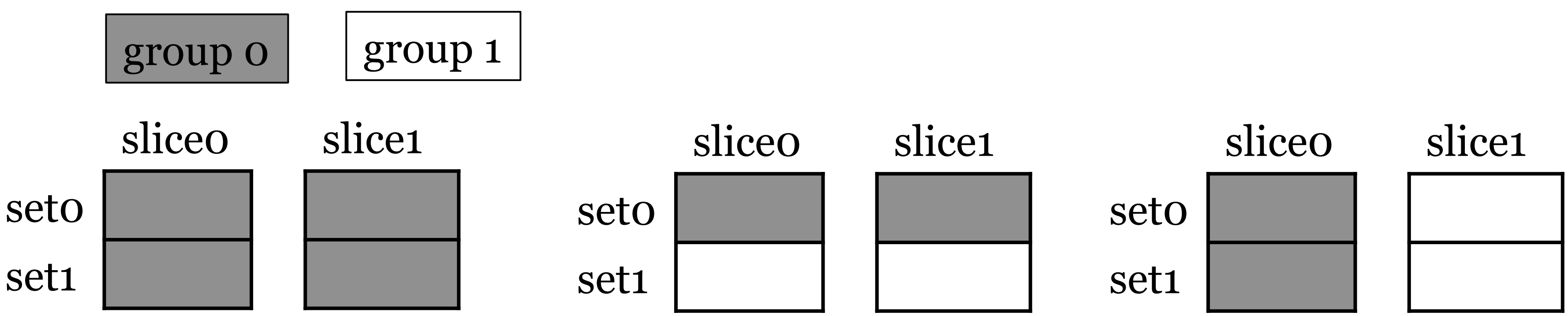




Taxonomy of Attack Protocols



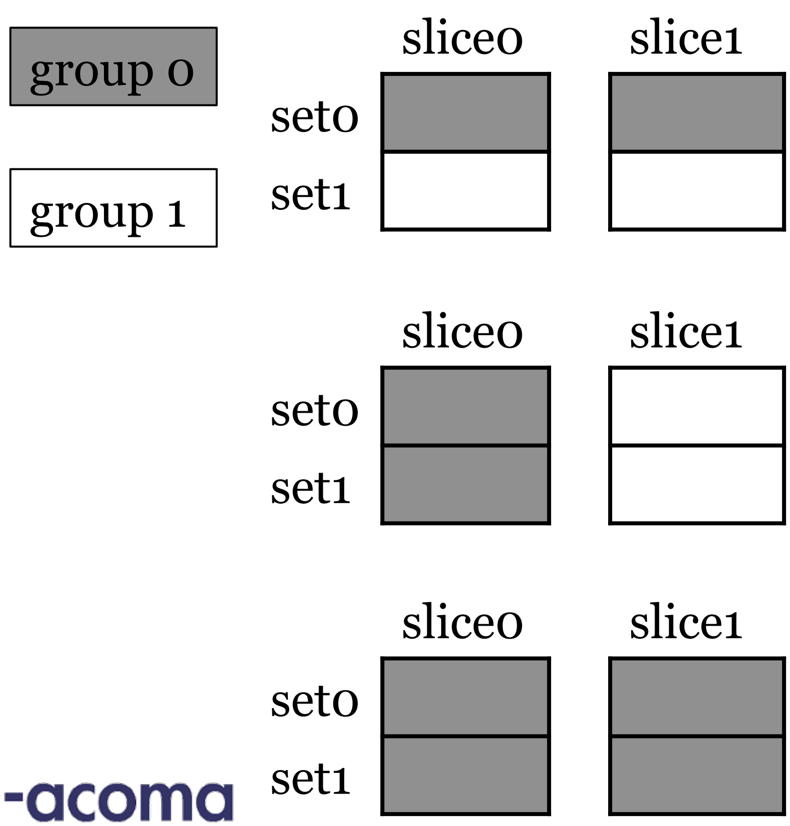




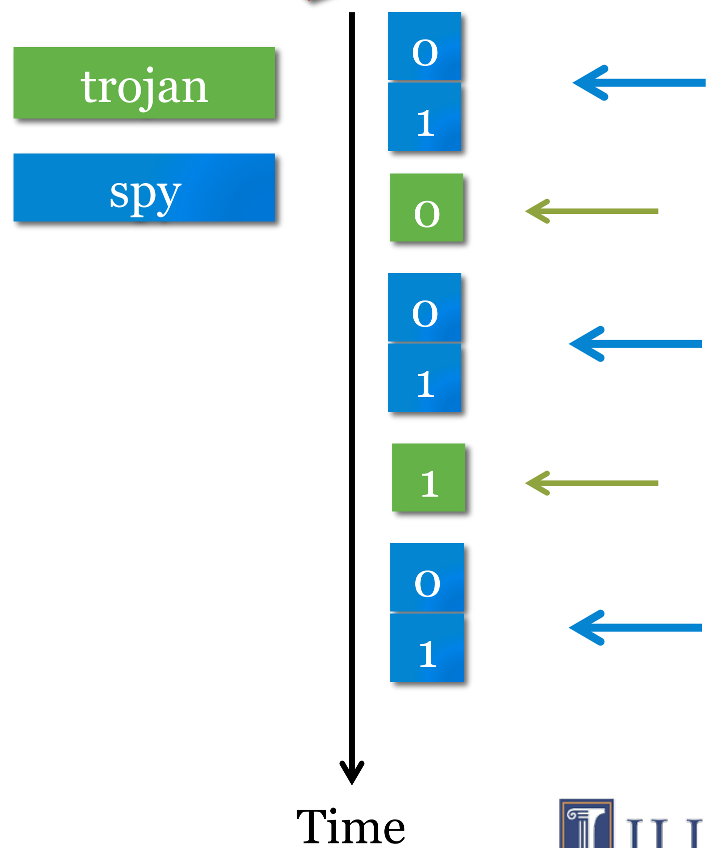
ReplayConfusion detects all the attacks

Observations

Observation 1:
Trojan/spy rely on a specific cache mapping function



Observation 2:
Attack follows a repeating pattern when transmitting



ReplayConfusion Detection Approach

Observations:

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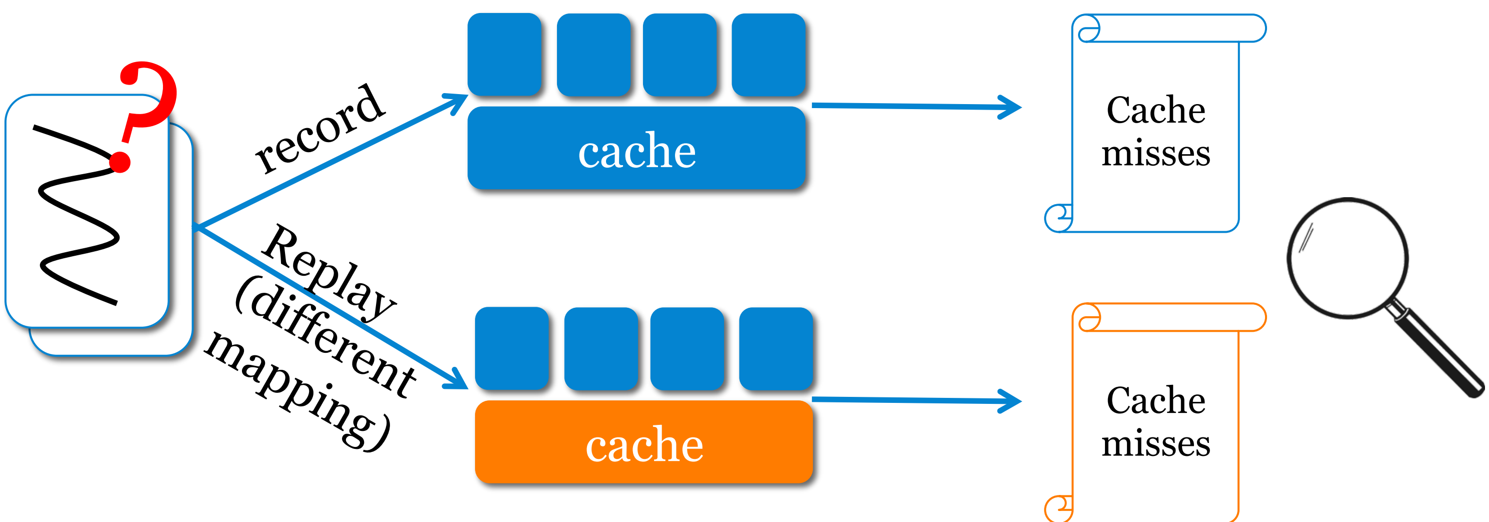
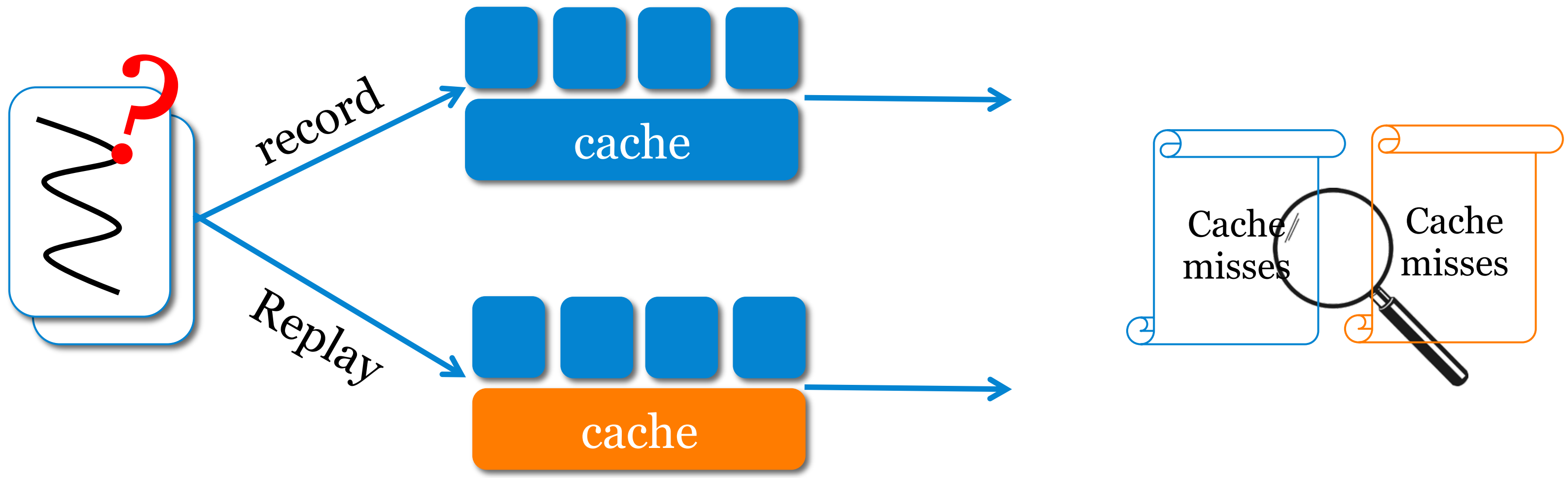


Replay Confusion Detection Approach



Record and Replay

- Existing mature technique
- e.g. Capo, Cyrus …

Design new HW mapping addresses → caches

- Requirements:
  - Small impact on benign programs
  - Big impact on attacks

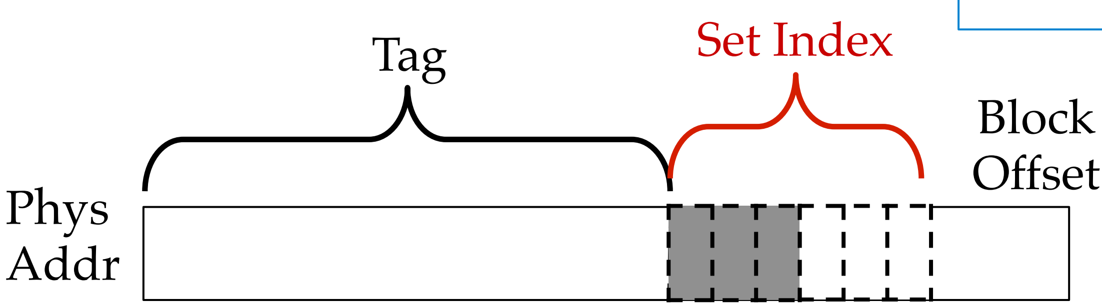
Analyze cache miss rate timelines

- Look for a repeating pattern in the timeline of the cache miss rate **difference**

Designing New Cache Mapping Functions

- Goal
  - Small impact on benign programs
  - Big impact on attacks

- Set Index Function
  - Swap or flip bits within index field



Designing New Cache Mapping Functions

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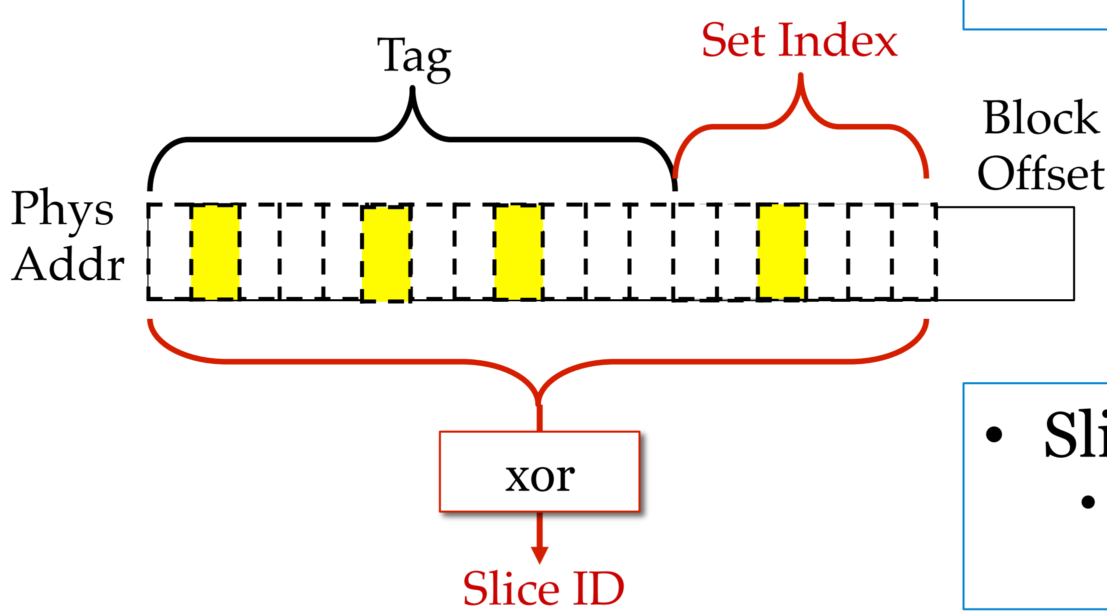


- Set Index Function
  - Swap or flip bits within index field

- Slice Selection Function
  - Replace the bits in the function with nearby ones

Analyzing Cache Miss Rate Timelines

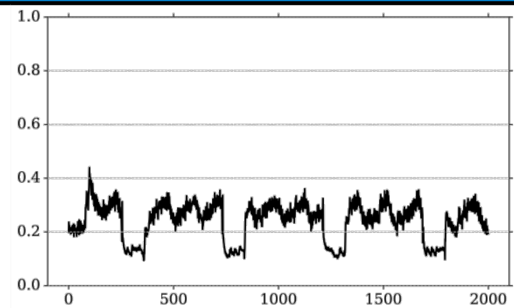
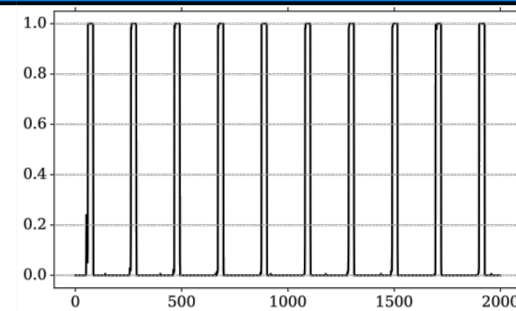
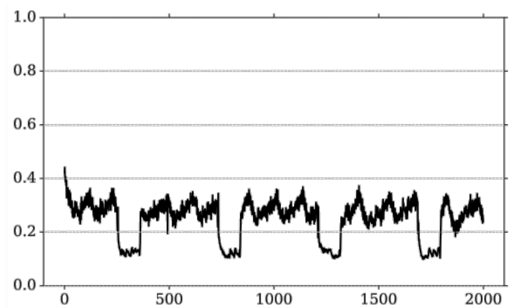
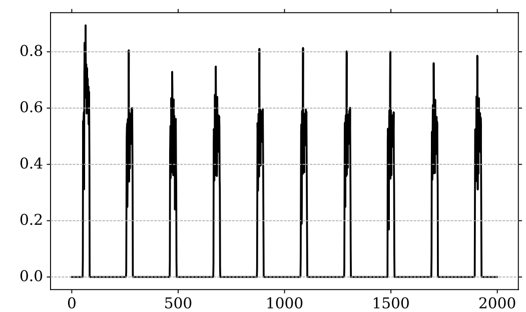
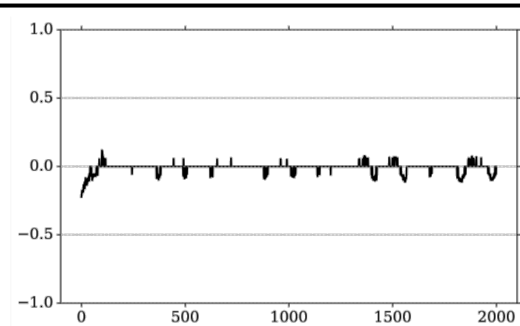
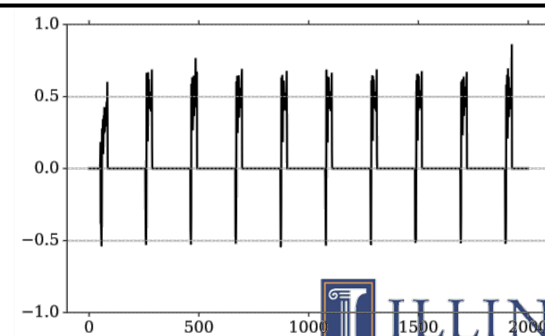
- Compute timeline of the difference in cache miss rates
  - (Recording miss rate timeline) – (Replay miss rate timeline)

	Benign programs	Attacks
Diff Value	Small values mostly	Large values when transmitting
Diff Pattern	No pattern	Repeating pattern

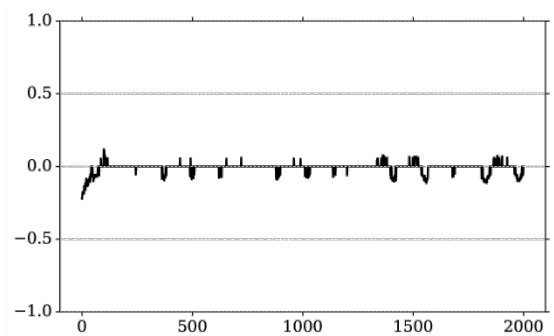
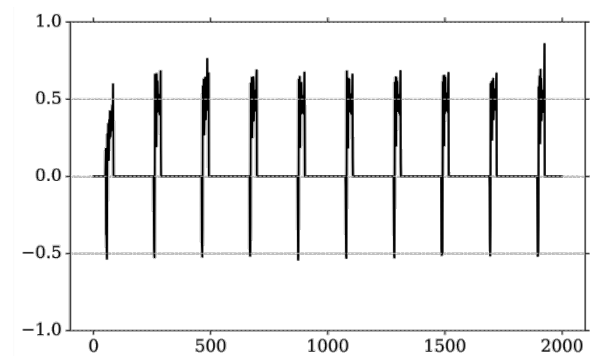
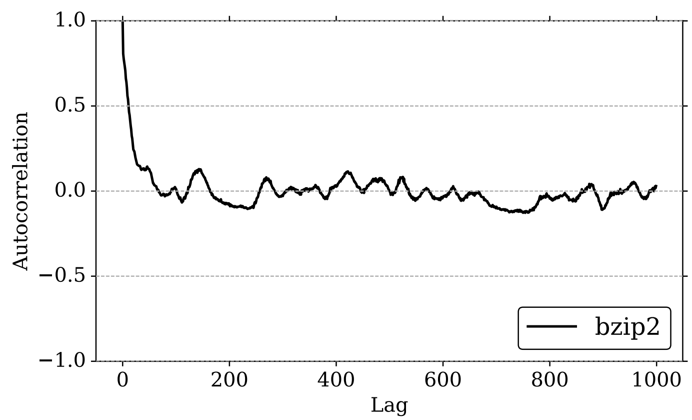
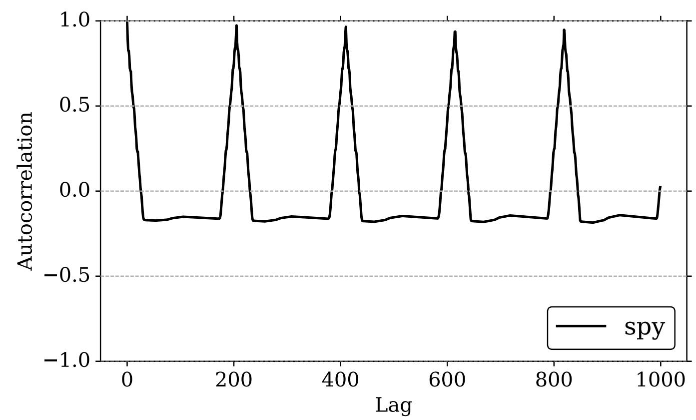
- Use auto-correlation* to detect repeating pattern in the timeline of the cache miss rate difference
  - Look for a fluctuating pattern in the auto-correlation

*A statistical technique that discovers repeating patterns in a signal.

Detection Example

	Experiment #1: Bzip2 (co-run with h264ref)	Experiment #2: Spy in attack (co-run with Trojan)
Miss Rate Timeline in Record		
Miss Rate Timeline in Replay		
Miss Rate Difference Timeline		

Detection Example

	Experiment #1: Bzip2 (co-run with h264ref)	Experiment #2: Spy in attack (co-run with Trojan)
Miss Rate Timeline Difference		
Auto-correlation		

More in the Paper

- Details on the taxonomy of cache-based covert channel attacks
- More detection results
  - Attacks using different protocols
  - Attacks with background noise
  - Attacks with small group size
  - More benign programs
- Detailed discussion about robustness of ReplayConfusion
- Discussion of related works

Conclusion

- Characteristics of cache-based covert channel attacks:
  - Trojan/spy communication is tuned to mapping of addresses to caches
  - Miss rate pattern repeats when transmitting bits
- ReplayConfusion
  - Use RnR to execute the same program on machines with different mappings of addresses to caches in replay
  - Compute the timeline of the miss rate difference between record and replay
  - Detect repeating patterns → detect attack

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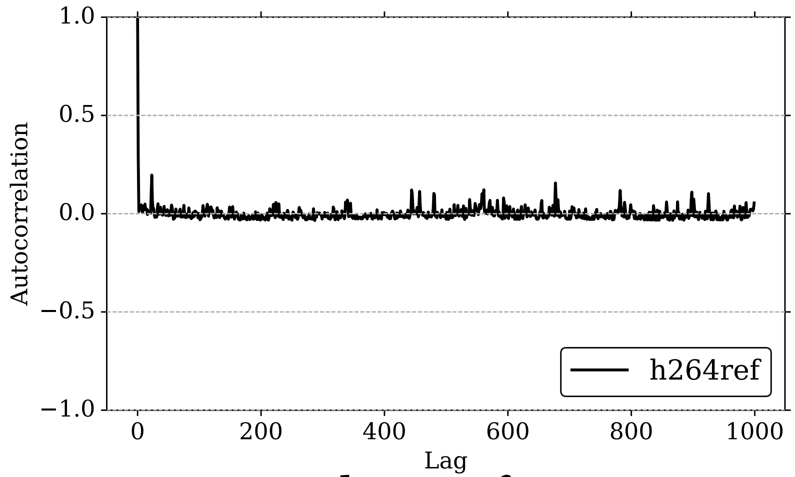
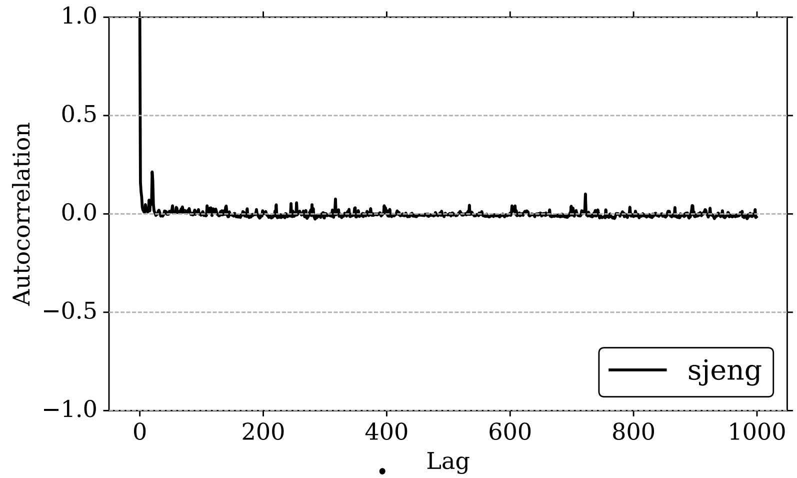
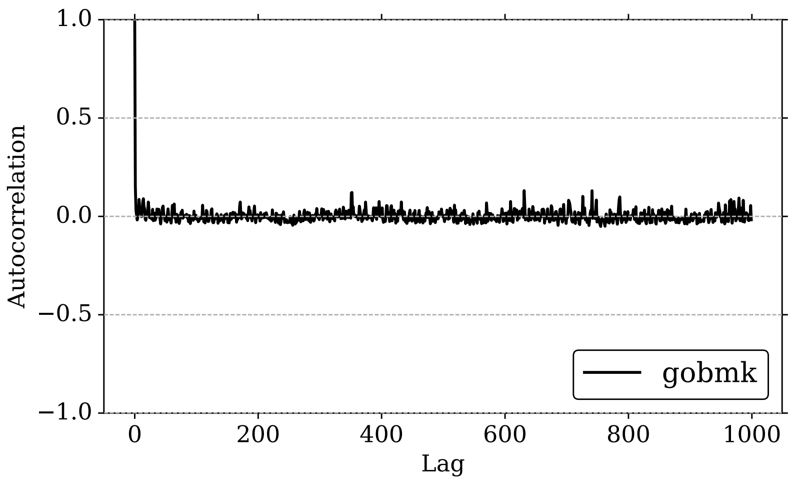
Evaluation Result
Benign Programs



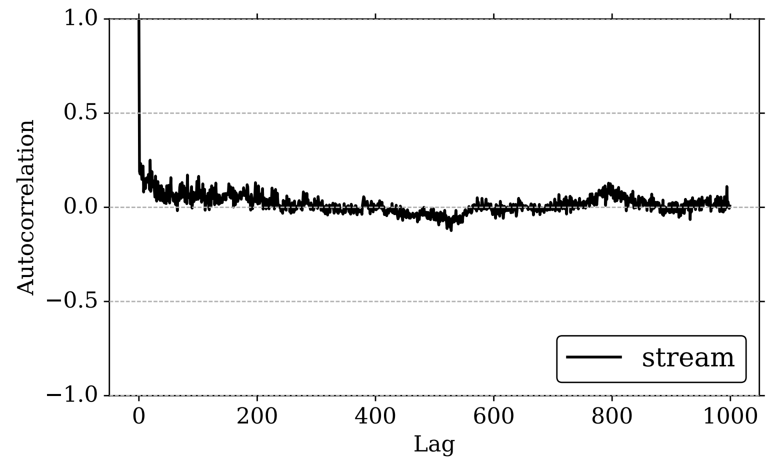
h264ref



sjeng



gobmk



stream

Experiment Setup

- System: Ubuntu 10.4 with 4GB memory
- 4 in-order core, 32KB private L1 cache, 2MB shared L2 cache
- L2: 8-way associative, 4 slices, 64B/block

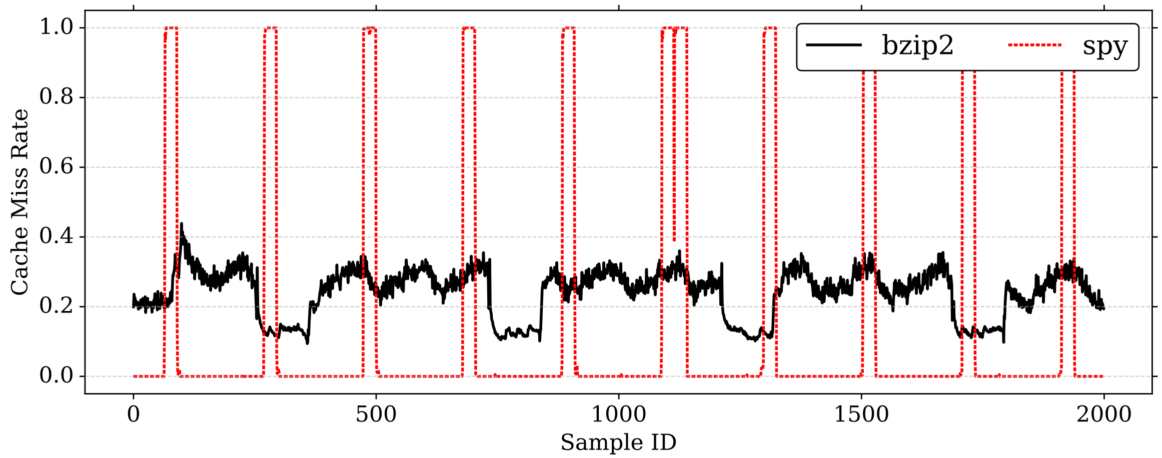
F_{def}

f_{set}	$(pa/64)\%1024$
f_{sli}	bit$_0$: $p18 \oplus p19 \oplus p21 \oplus p23 \oplus p25 \oplus p27 \oplus p29 \oplus p30 \oplus p31$ bit$_1$: $p17 \oplus p19 \oplus p20 \oplus p21 \oplus p22 \oplus p23 \oplus p24 \oplus p26 \oplus p28 \oplus p29 \oplus p31$

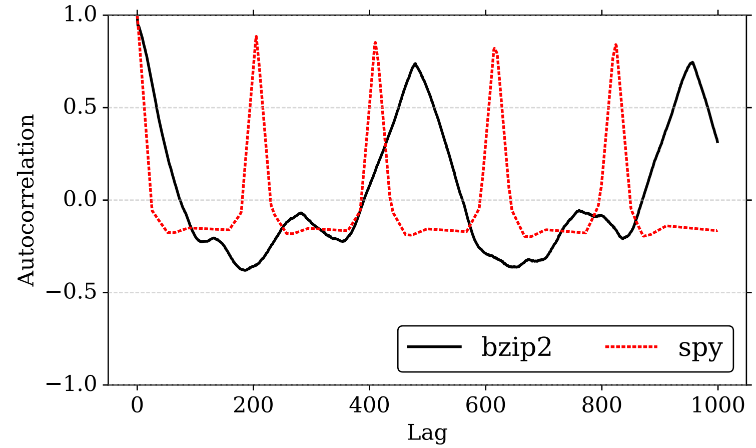
F_{new} for replay

f_{set}	Take f_{set} from F_{def} and swap the most significant and least significant 5 bits
f_{sli}	bit$_0$: $p17 \oplus p19 \oplus p20 \oplus p22 \oplus p24 \oplus p26 \oplus p28 \oplus p30 \oplus p31$ bit$_1$: $p18 \oplus p20 \oplus p21 \oplus p22 \oplus p23 \oplus p24 \oplus p25 \oplus p27 \oplus p29 \oplus p30$

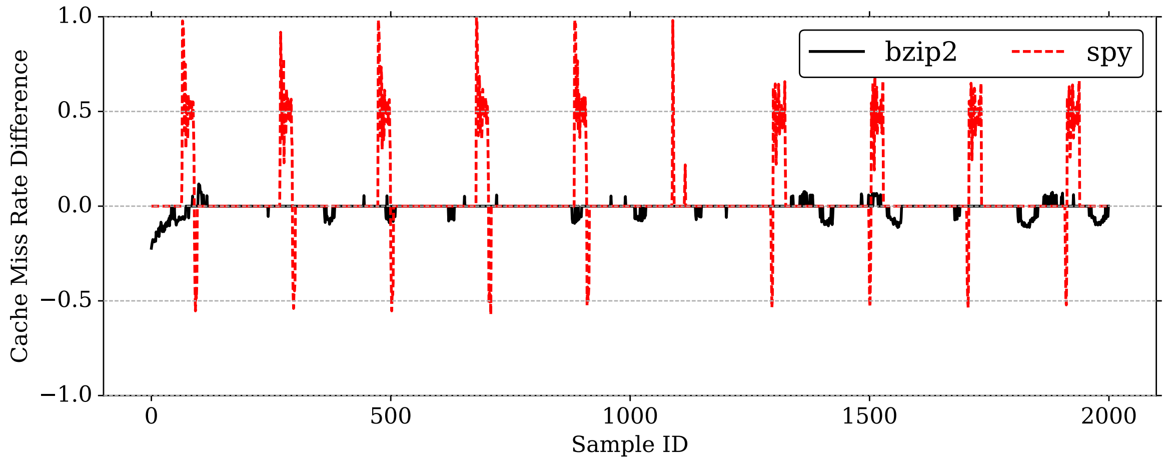
Example



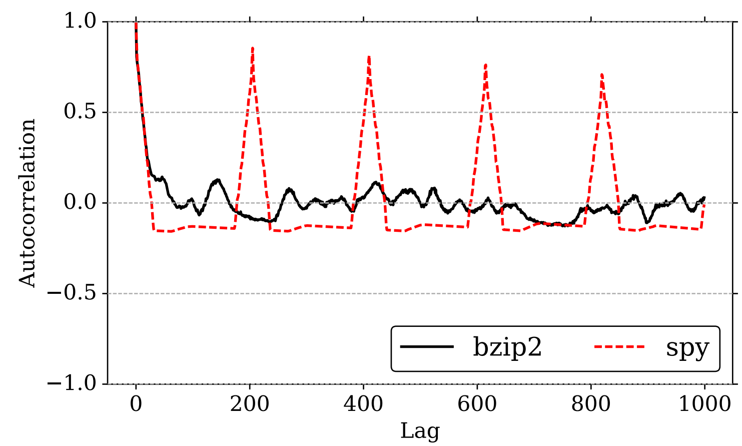
(a) Cache miss rate timeline



(b) Cache miss rate autocorrelogram

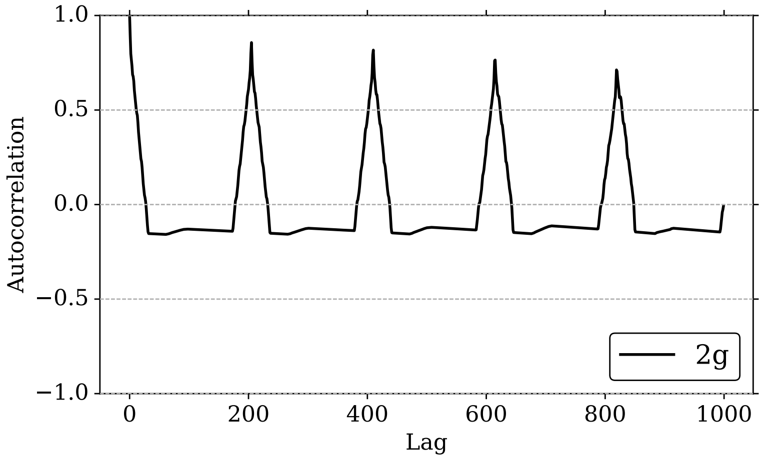


(c) Cache miss rate difference timeline

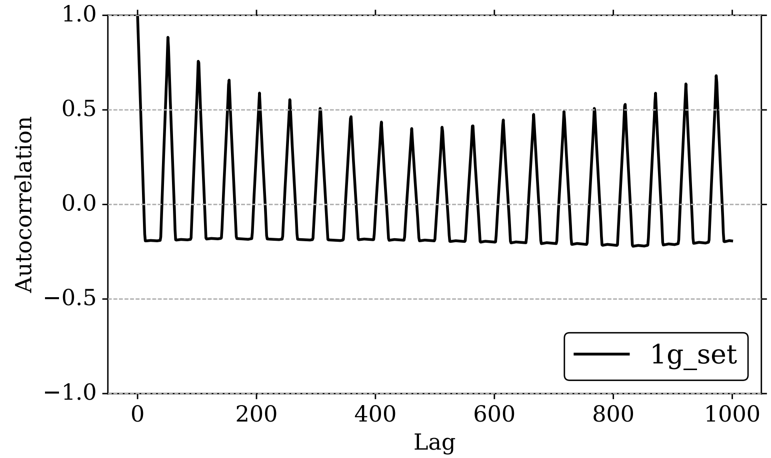


(d) Cache miss rate difference autocorrelogram

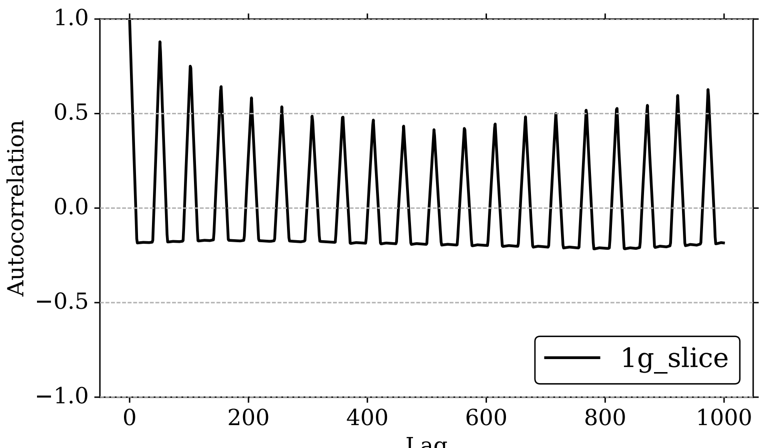
Evaluation Result
Attacks using parallel protocols



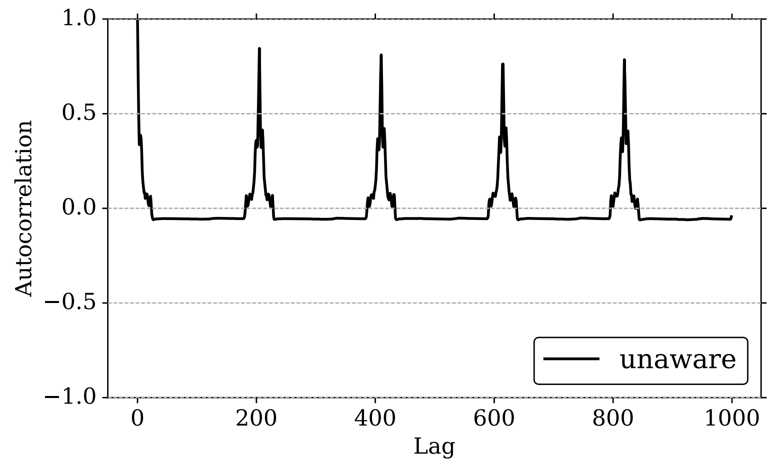
2-group



1-group, ¼ cache, set-based



1-group, ¼ cache, slice-based



1-group, unaware

Related Work

- Defense
  - Cache Partition
  - Add noise to timer
- Detection
  - Hexpad: high cache access rate
  - Chiappetta et al. : correlation between sender and receiver
  - CC-Hunter: detect alternate pattern of conflicts

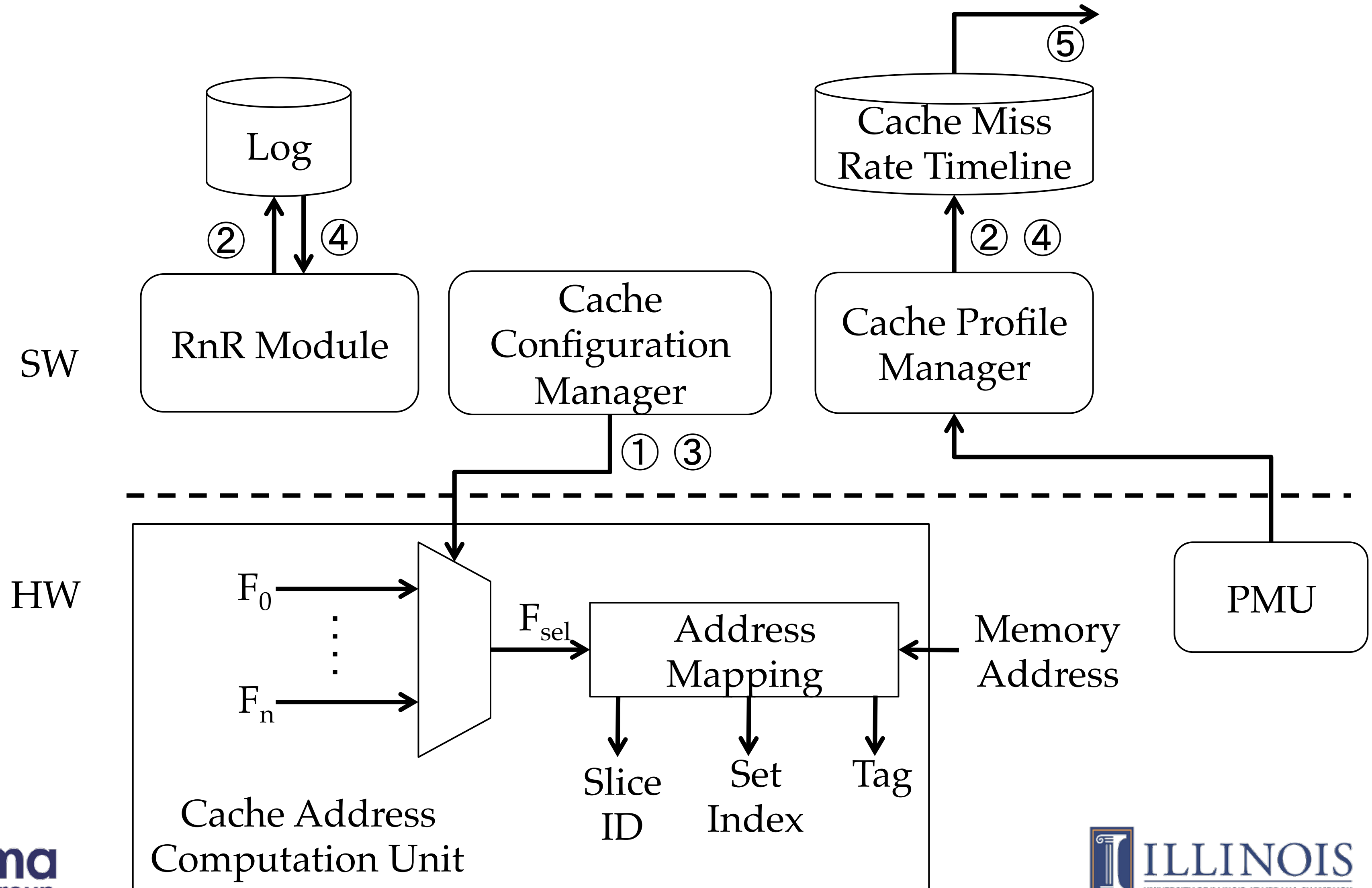
Either not not applicable or too much overhead

Not work effectively

Unable to detect advanced attacks
May have high false positives

Only effective to attacks using a specific type of protocols

Operations of ReplayConfusion



i-acoma group

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