CaSA: End-to-end Quantitative Security Analysis of Randomly Mapped Caches

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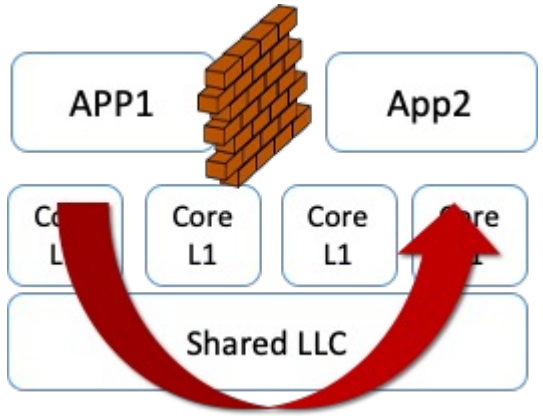
Problem: Incomplete Security Analysis

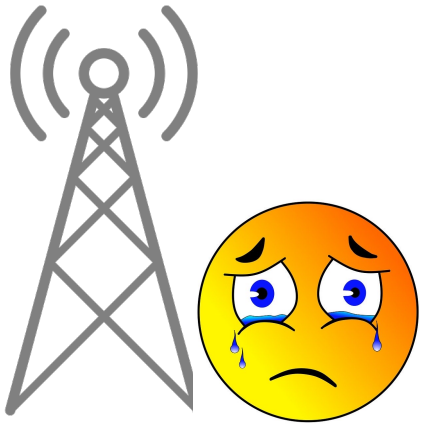
- Cache side channels are a serious security threat

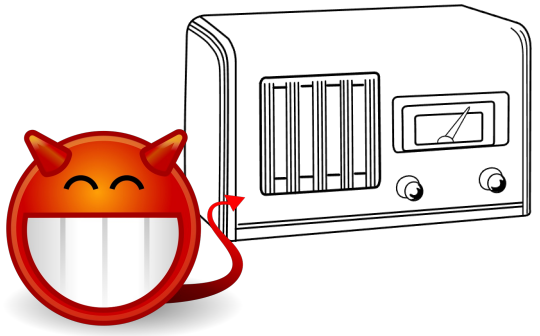


- Promising mitigation: randomly mapped cache

- The security property is not well understood

Key Insights: Telecommunication Analogy



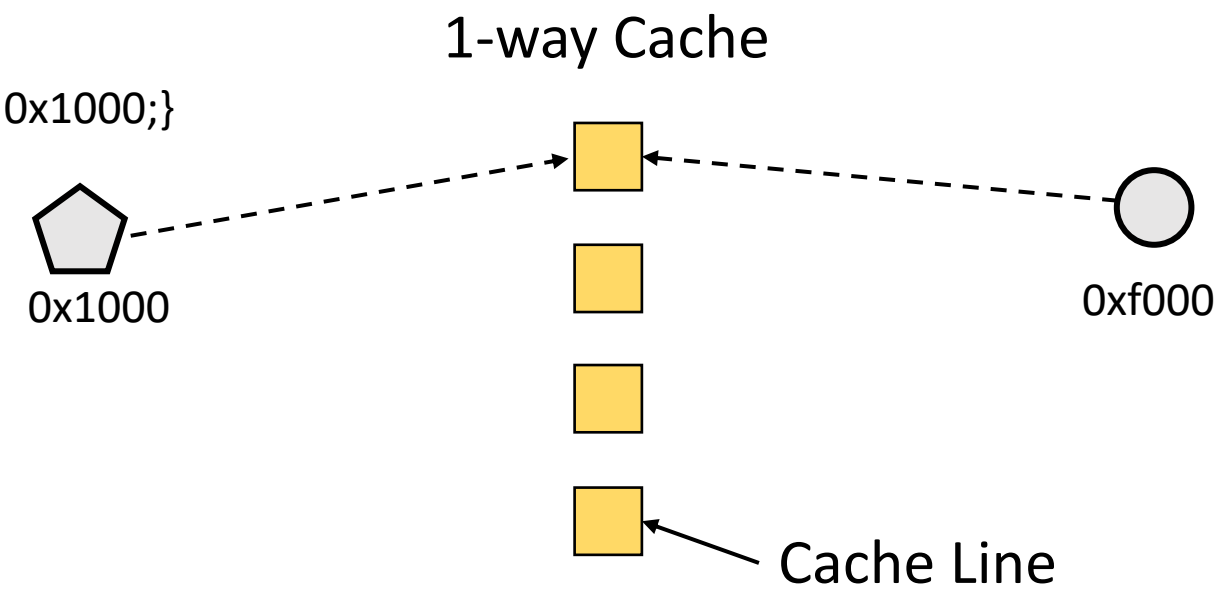


- Contributions:
  - CaSA leverages concepts from telecommunications to enable quantitative analysis
  - An end-to-end communication paradigm to enable comprehensive analysis
  - New findings that refute common beliefs

Cache Side-channel Attacks

Victim code

If (secret==1) { foo = ld 0x1000;}

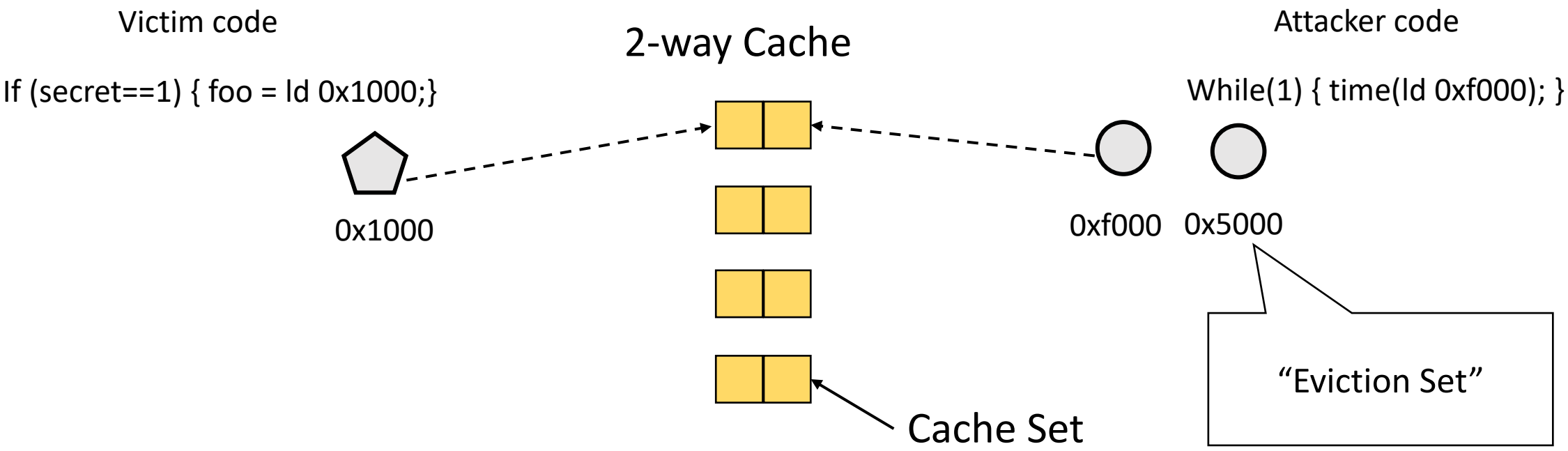


Attacker code

While(1) { time(ld 0xf000); }

Attacker monitor victim's behavior through cache conflicts.

Cache Side-channel Attacks



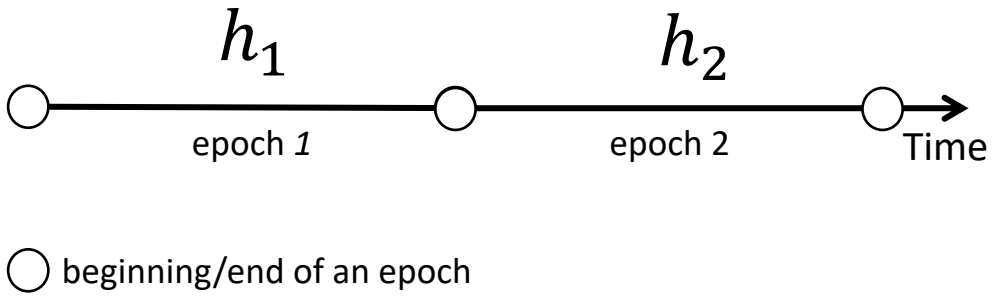
Using black-box mapping function increases the cost to build an Eviction Set to:
O(N) (with N the number of lines in the cache)

Security Metrics

- Community intuition on Security Metrics:
  - "How hard it is to build an eviction set" is a good quantitative notion of security
- State-of-the-art secure cache design approaches:
  - Dynamic mapping
  - Non-deterministic mapping
- Our work:
  - This security metric can be misleading
  - Both design approaches fail to provide security

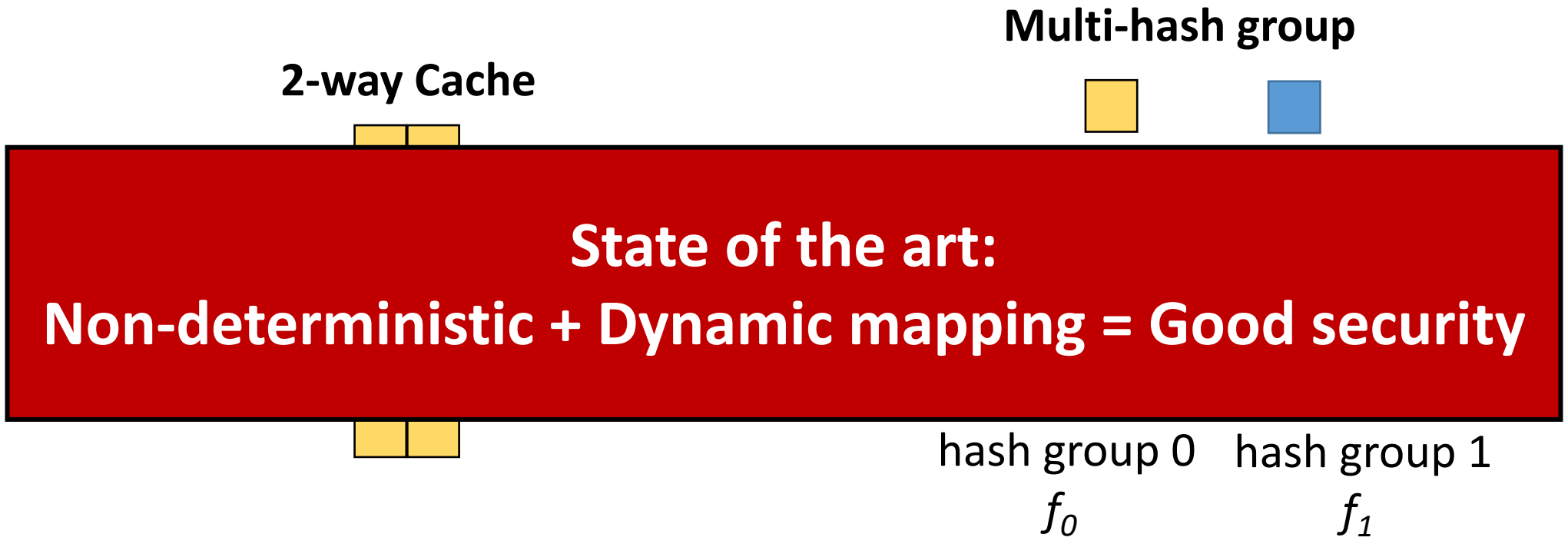
Dynamic Mappings

- Common belief: attacks can not happen across epochs
- Dynamic remapping incurs performance overhead



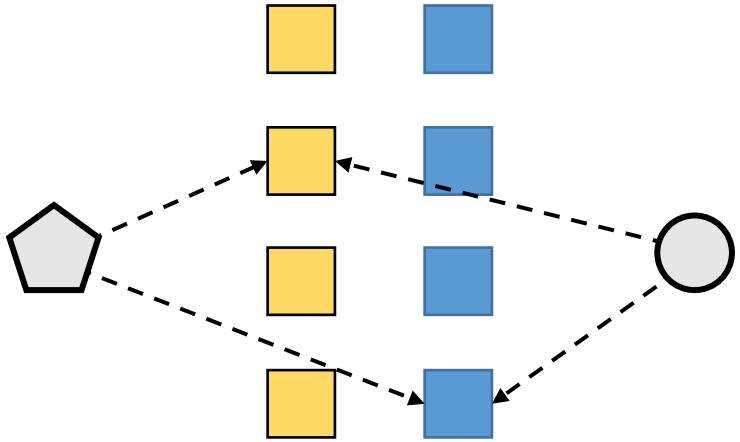
Non-Deterministic mapping

- Make conflict relationship between addresses non-deterministic

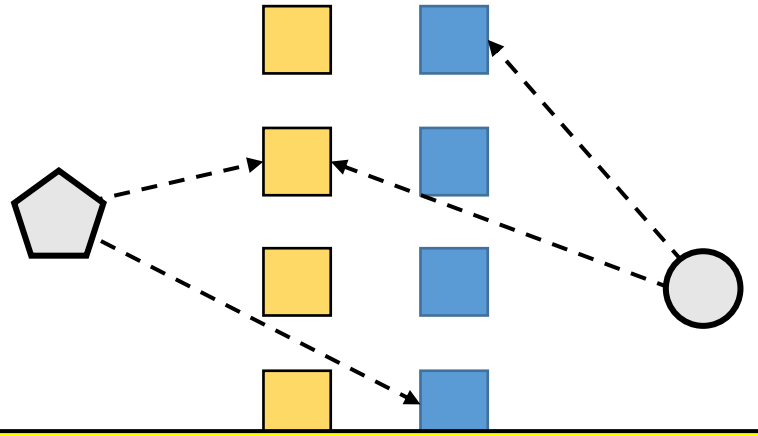


Traditional Analysis

- Hard-conflict addresses:
  - Guarantee eviction
  - Difficult to obtain

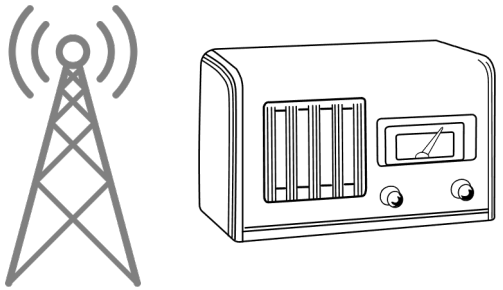


- Soft-conflict addresses:
  - Easy to obtain
  - Need many of such addresses to reliably evict addresses



- Narrowly focus on eviction set construction and lose the bigger picture.
- Only want to create a one-to-one map from micro-architecture events to secret

End-to-end Communication Paradigm



- Leverage the concepts from telecommunication

- Trade-off between calibration and signaling
  - Long time on calibration → shorter time needed for signaling
  - Short time on calibration → longer time needed for signaling

New Security Metric

~~"How difficult to construct an eviction set"~~

End-to-end communication cost in **Calibration + Signaling**

Statistical Representation of Signals

- Signal: a random variable “X”
  - Describes the number of misses observed by the attacker
  - Follow a probability distribution
- Example:

	Prob observing 0 miss	Prob observing 1 miss
Victim accesses	0.75	0.25
No victim accesses	1	0

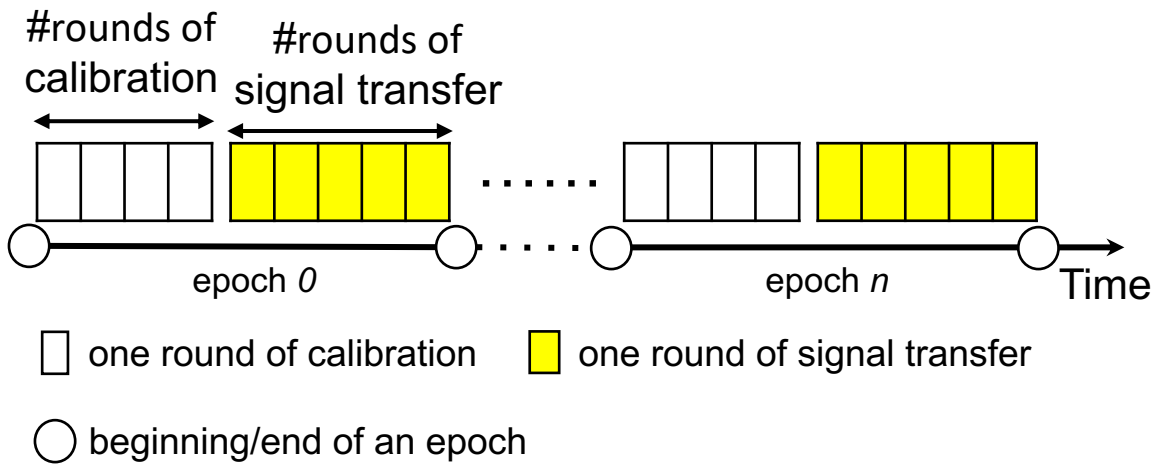
- Successfully covert the problem to a statistical analysis problem
  - How many samples are needed to distinguish the two distributions?

Two Insightful Findings

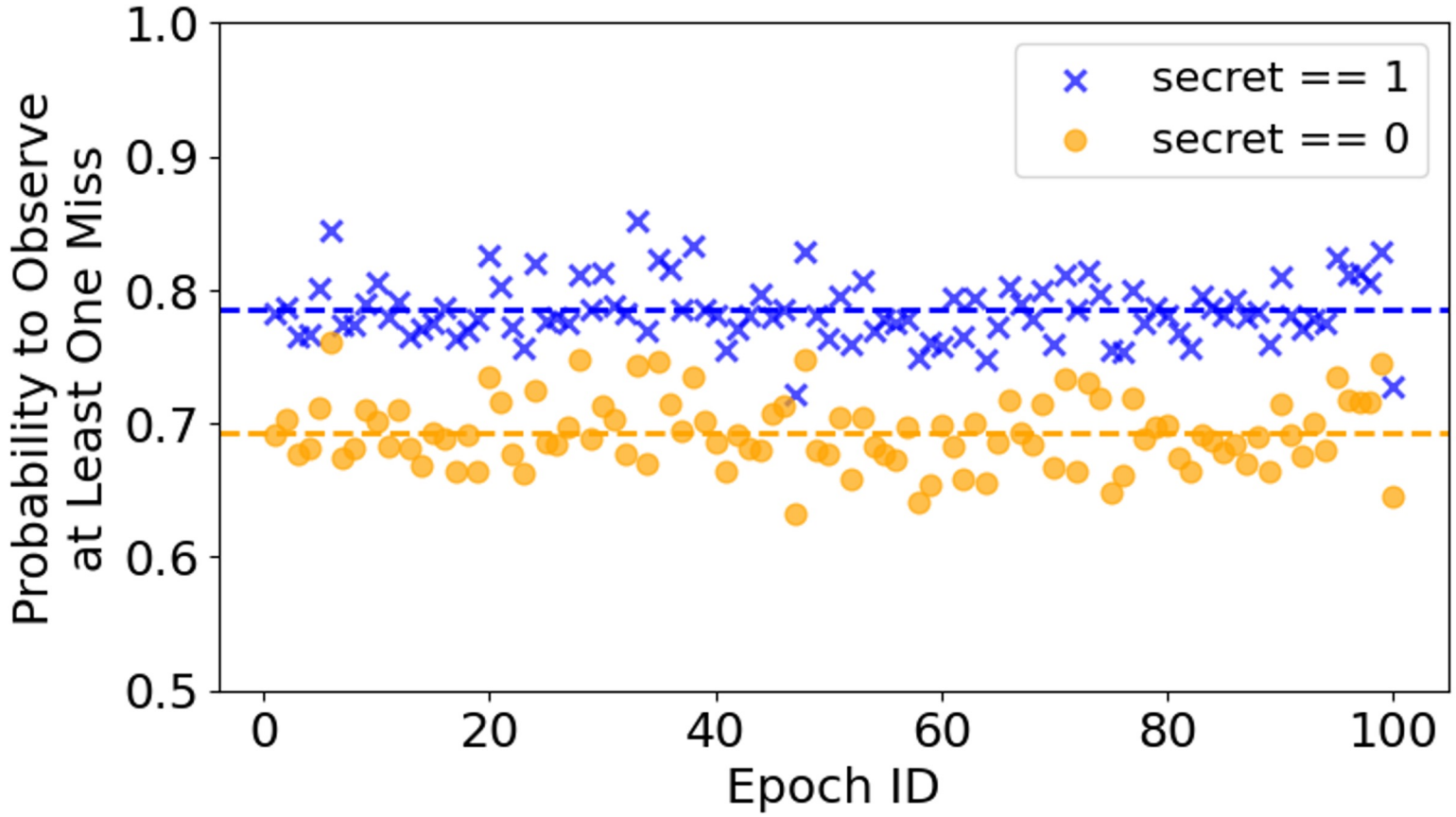
- Cross-epoch communication is possible
- Spending maximum resources on calibration is not the best strategy

Cross-epoch Communication

- In each epoch:



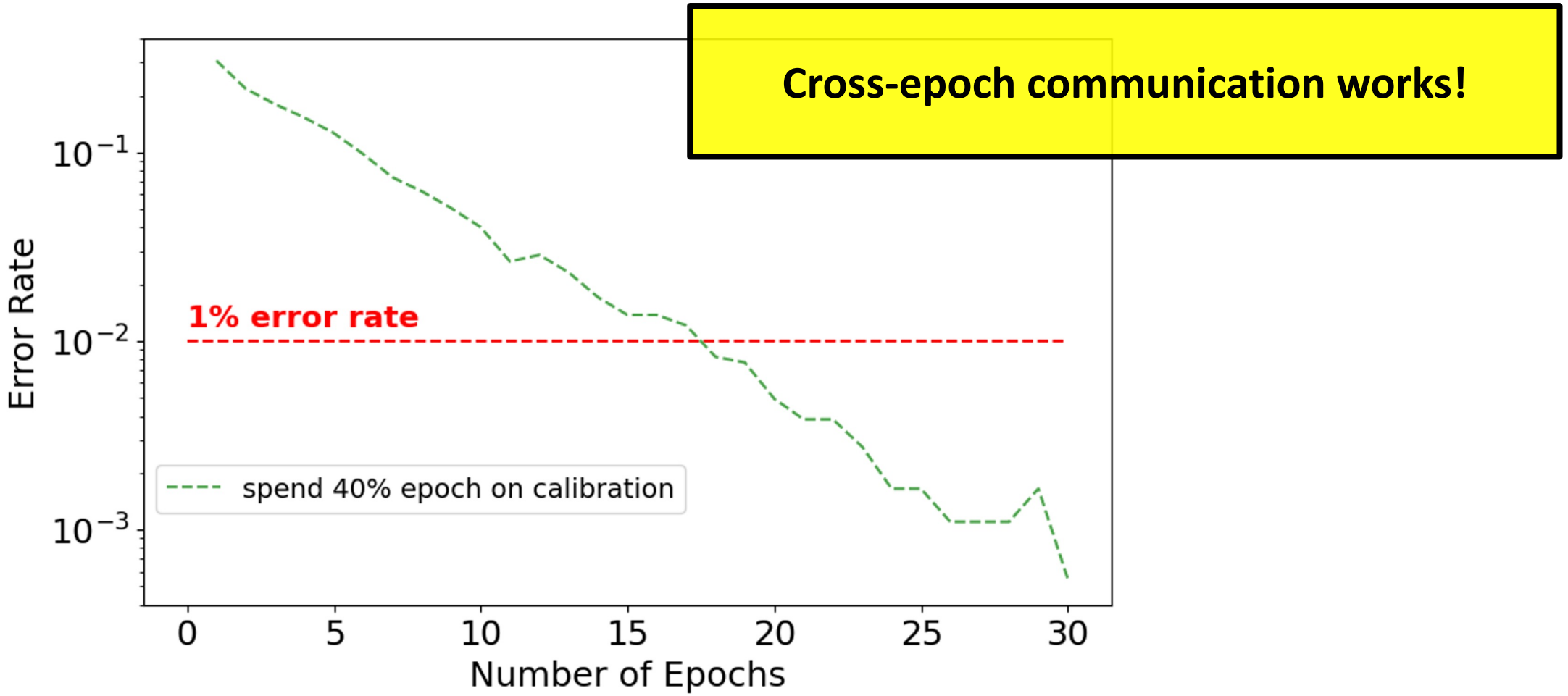
Cross-epoch Communication



Signals across epochs when attacking the RSA square-and-multiple function.

Cache configuration: 16 hash-groups / 1 way per hash-group/ 16k cache lines

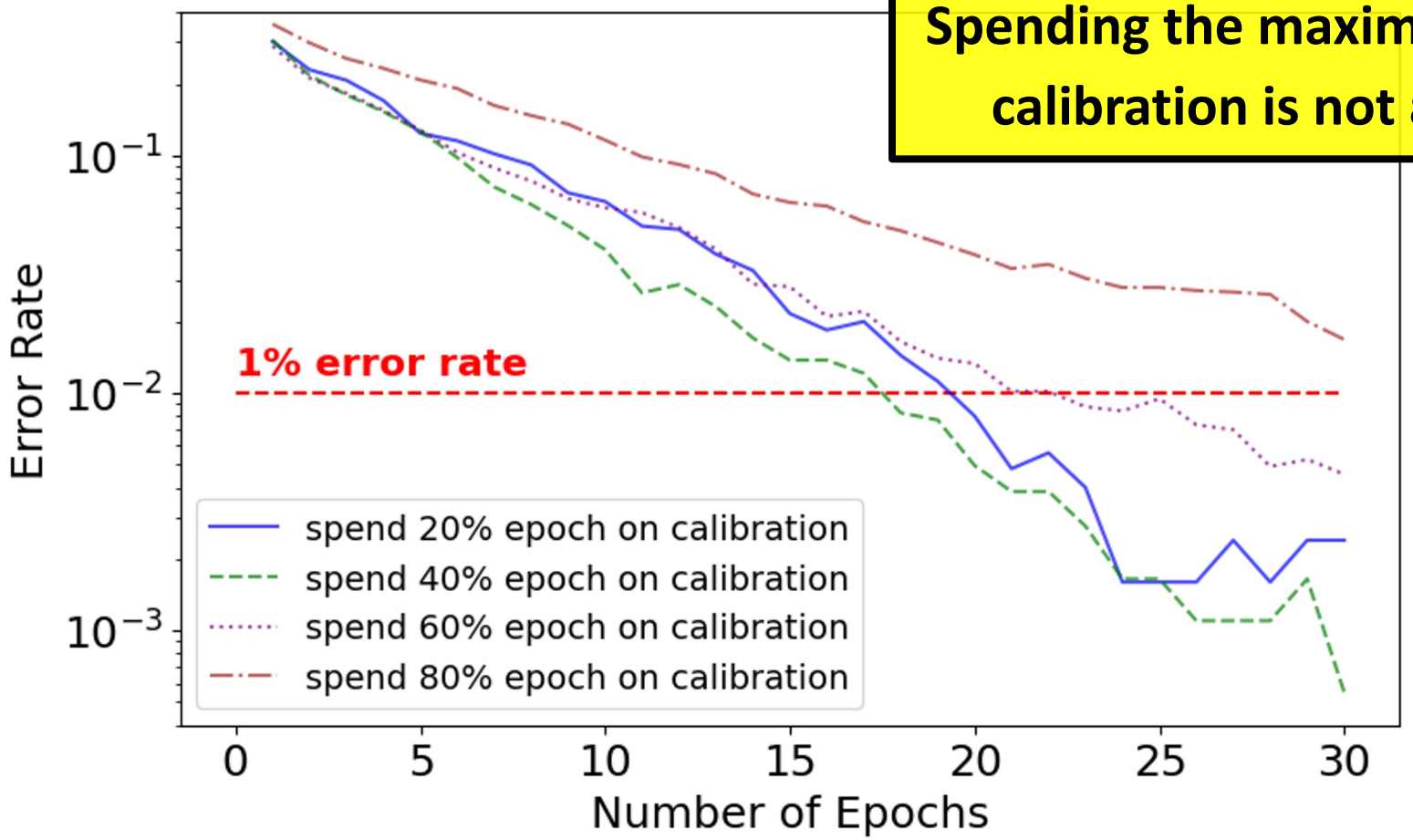
Cross-epoch Communication



Cache configuration: 16 hash-groups / 1 way per hash-group/ 16k cache lines
Epoch size = 100*16K accesses

Trade-off between Calibration and Signaling

Spending the maximum amount of resources in calibration is not always the best strategy.



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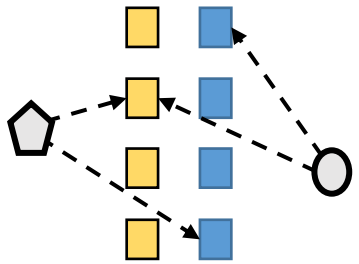
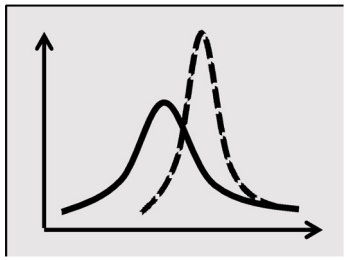
Conclusion & Long-term Impact

- Comprehensive security analysis for micro-architecture side channels should focus on end-to-end communication
- CaSA formalize the analysis of micro-architecture behavior to the analysis of random variables.



- Cache Occupancy Attack
- Memory Controller
- Front End
- Execution Engine
- ……

Micro-architecture Behavior



Random Variable Analysis