FIU
Computing &
Information Sciences

LEARNING CACHE REPLACEMENT WITH CACHEUS

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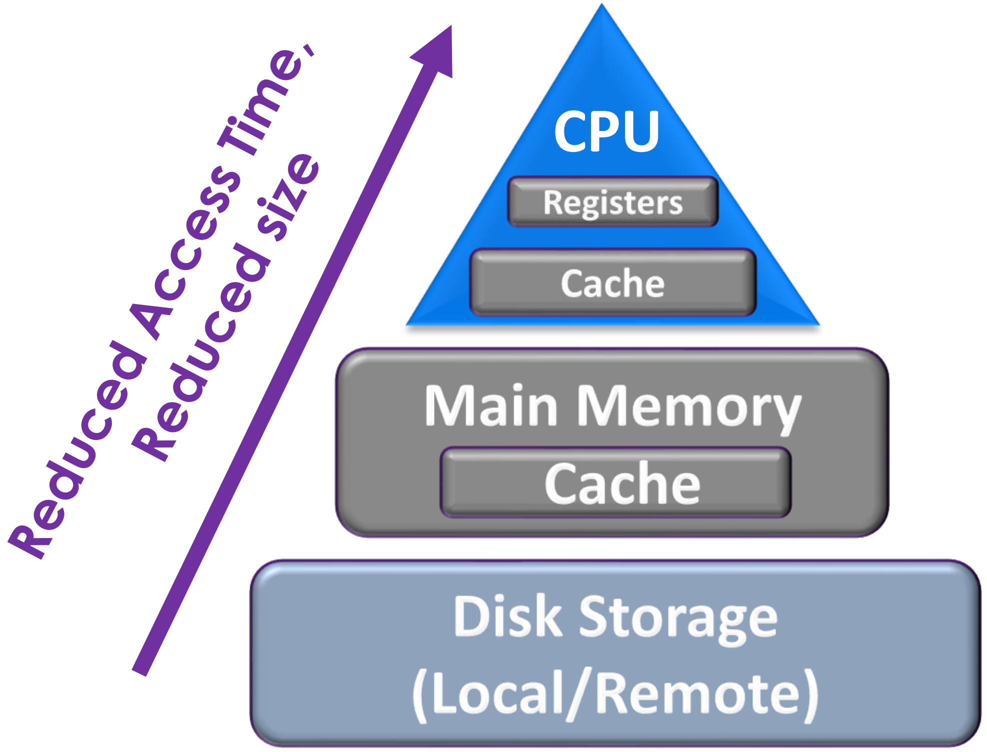
Introduction

- Cache
  - Fast but relatively small in capacity



- Machine Learning
  - Improves decision processes

Cache management + ML

↓

Improved performance

Cache Replacement Algorithms

- Non-adaptive
  - Least Recently Used (LRU)
  - Least Frequently Used (LFU)
  - Low Inter-reference Recency Set (LIRS) [Jiang et al., ‘02]
- Adaptive
  - Adaptive Replacement Cache (ARC) [Modha, Megiddo, ‘02]
  - Dynamic LIRS (DLIRS) [Li, ‘18]
- ML-based Adaptive
  - Adaptive Caching Using Multiple Experts (ACME) [Ari et al., ‘02]
  - Reinforcement **Le**arning On **Ca**che **R**eplacement (LeCaR) [Vietri et al., ‘18]
  - Reinforcement **Le**arning (Cacheus) [This Work]

WORKLOAD PRIMITIVES

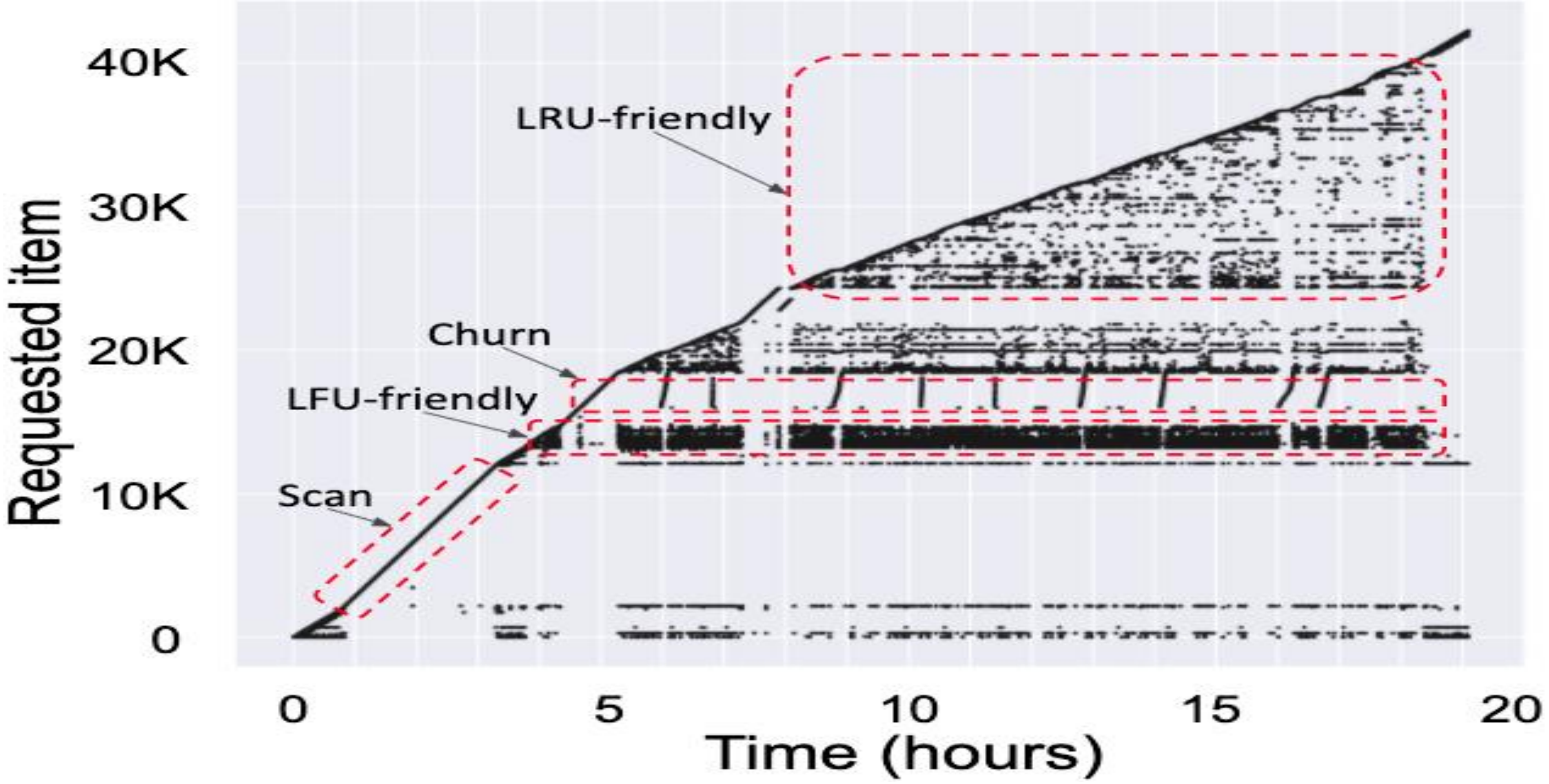
LRU-Friendly

LFU-Friendly

Churn

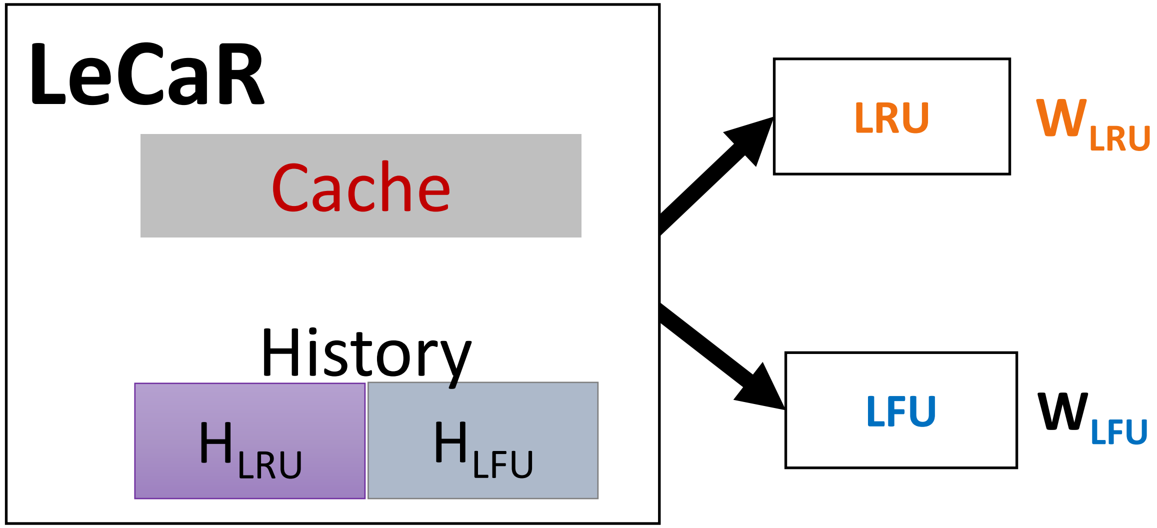
Scan

Algorithm	LRU	LFU	Churn	Scan
ARC	✓	✗	✗	✓
LIRS	✗	✗	✗	✓
LeCaR	✓	✓	✓	✗
DLIRS	✓	✗	✗	✓



Prior Work: LeCaR

- ML-Based: Reinforcement **Le**arning On **Ca**che **R**eplacement
  - Simple
    - LRU, LFU as experts
  - Adaptive
    - Update weights
  - Outperforms state-of-the-art
    - Small cache sizes

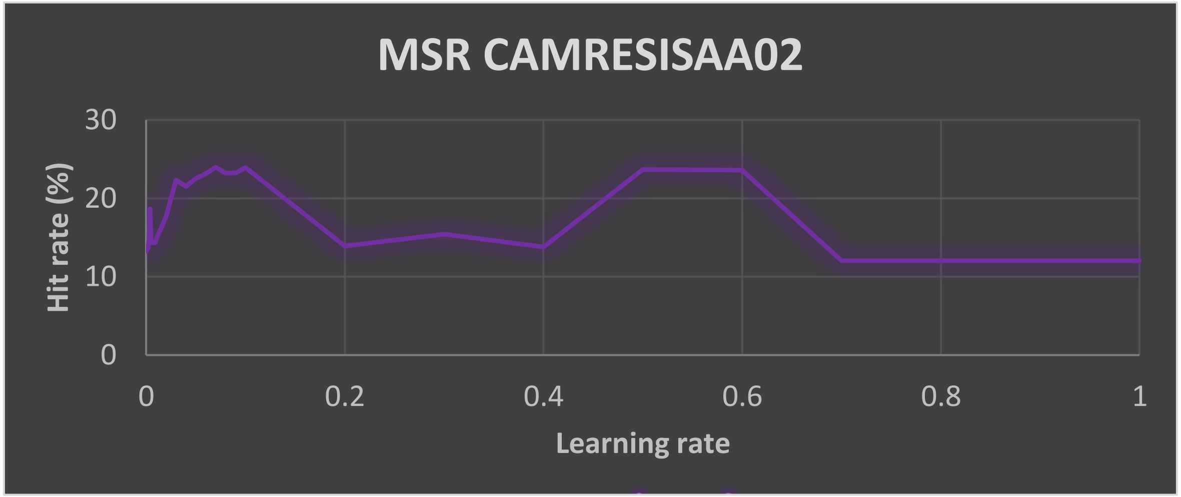


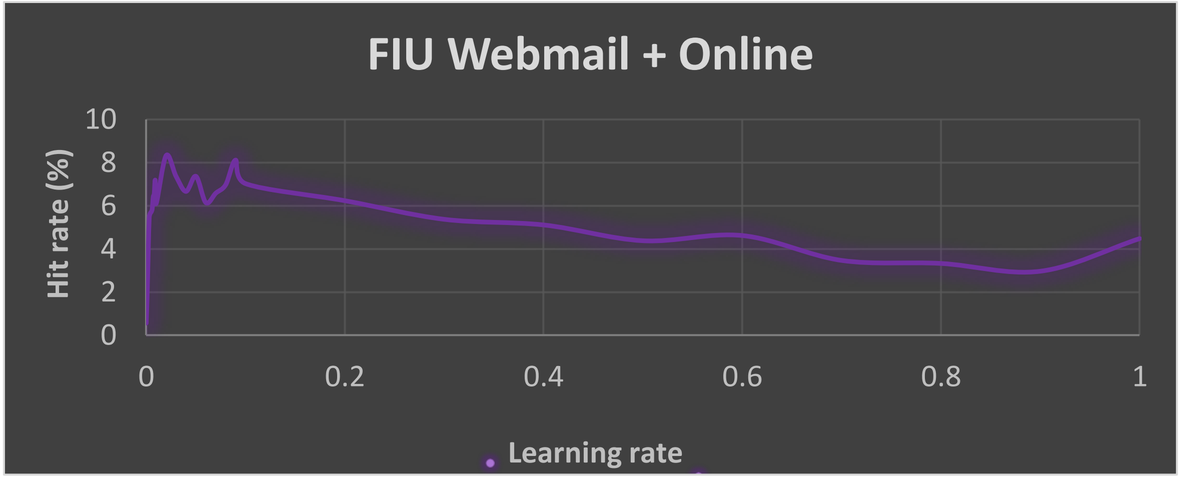
Vietri, et al., “Driving cache replacement with ML-based LeCaR.” HotStorage ‘18.

Limitations of LeCaR

- Fixed Learning rate
  - 0.45 (empirically chosen)
- Can’t handle Scan

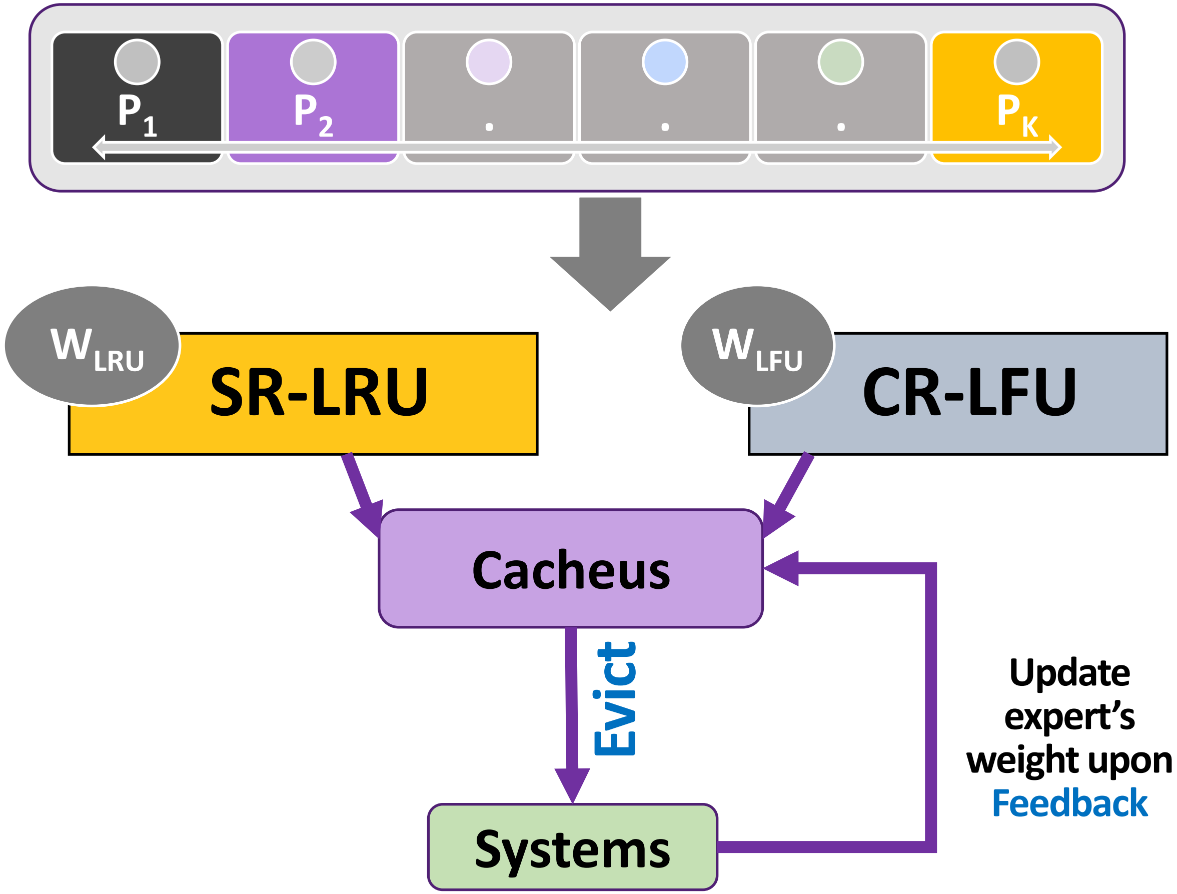
Algorithm	LRU	LFU	Churn	Scan
ARC	✓	✗	✗	✓
LIRS	✗	✗	✗	✓
LeCaR	✓	✓	✓	✗
DLIRS	✓	✗	✗	✓





CACHEUS: Improving LeCaR

- Adapt Learning Rate
- Improve experts
  - Introduce scan resistance
    - Replace LRU with
      - ARC (C1)
      - LIRS (C2)
      - DLIRS
    - Scan resistant LRU: SR-LRU (C3)
  - Improve churn resistance
    - Churn resistant LFU (CR-LFU)



CACHEUS: Learning Rate Adaptation

- Learning rate changed
  - Performance change
    - Positive, reinforce latest direction
    - Negative, reverse the latest direction
- Learning rate unchanged
  - Performance change
    - Positive, no update
    - Negative, random jump
- Performance zero for 10 intervals (Einziger et. Al, Middleware '18)
  - Restart Learning

$$w_t = w_{t-1} e^{\boxed{\eta} r}$$

Learning rate

CACHEUS: Scan Resistance LRU (SR-LRU)

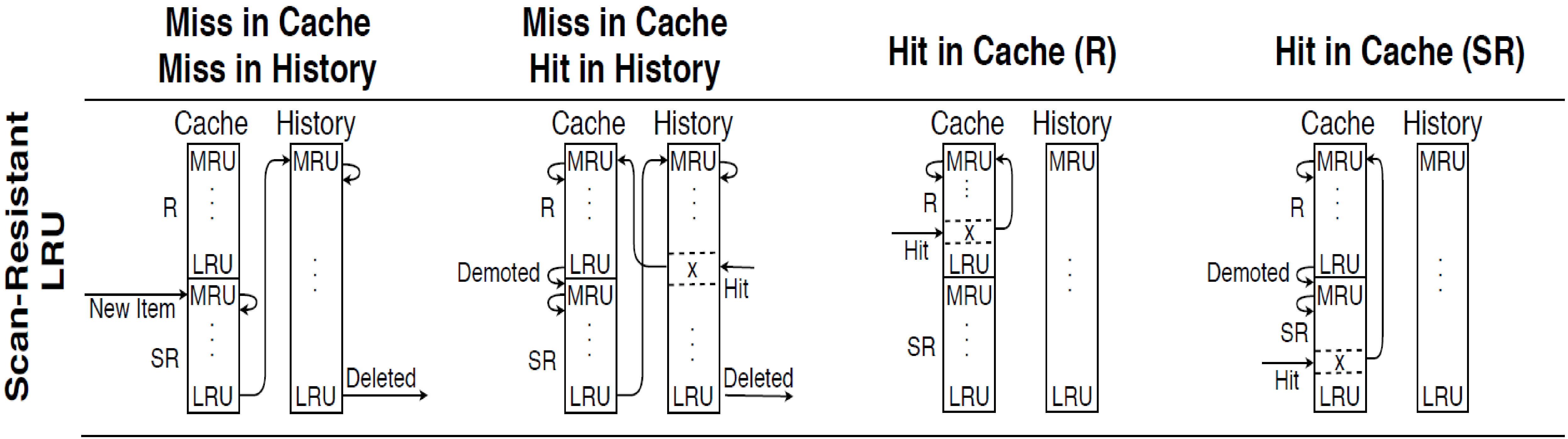


Figure: Understanding SR-LRU. Actions taken to handle request x for: cache miss, cache miss with x in history, cache hit with x in SR, and cache hit with x in R.

CACHEUS: Churn Resistance LFU (CR-LFU)

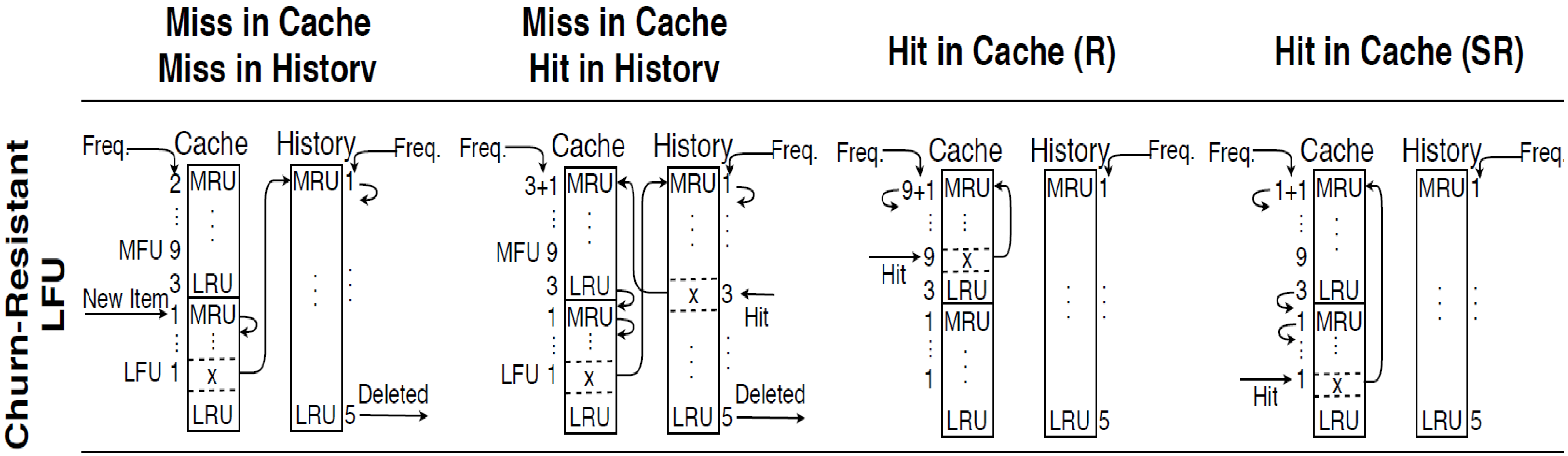


Figure: Understanding CR-LFU. Actions taken to handle request x for: cache miss, cache miss with x in history, cache hit with x in SR, and cache hit with x in R.

CACHEUS: Scan And Churn Resistance (Cont.)

SR-LRU

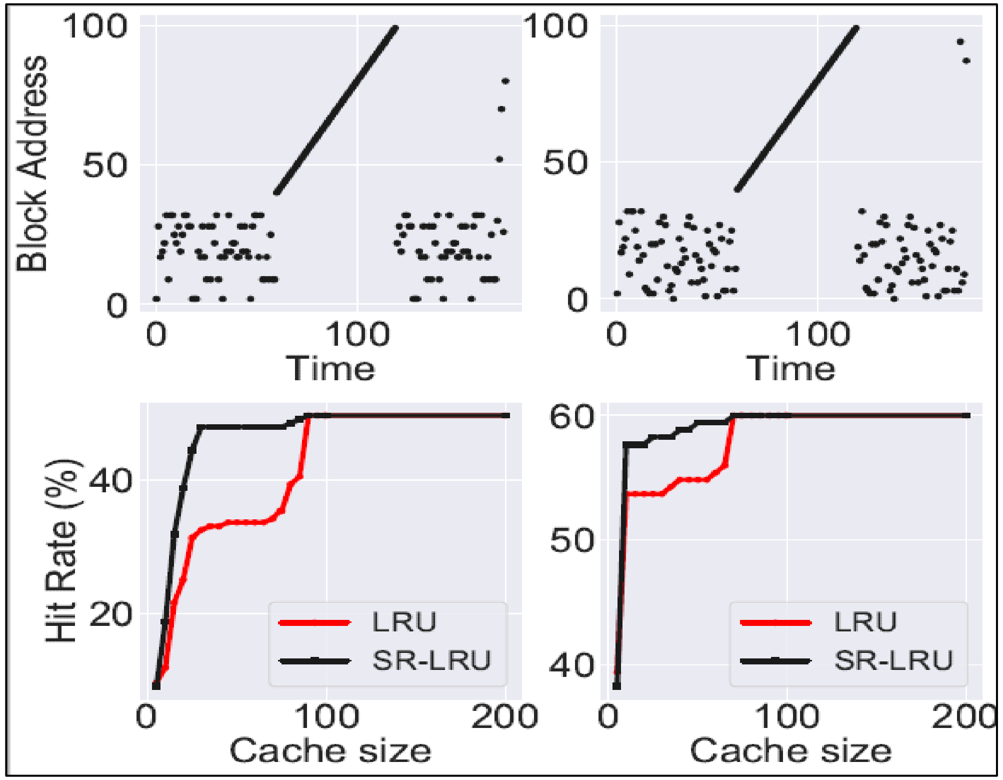


Figure: SR-LRU with the scan workload primitive type. Two synthetic workloads: LFU-friendly pattern (left column) and LRU-Friendly pattern (right column). The working set is 175 items with a single inserted scan of size 60.

CR-LFU

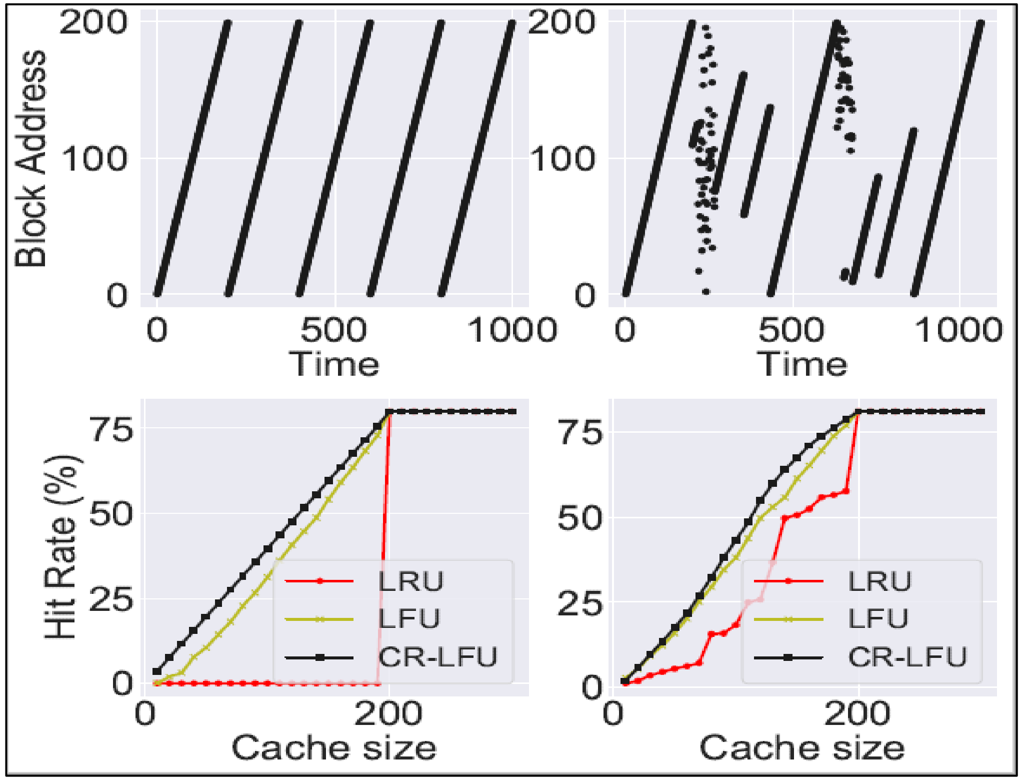


Figure: CR-LFU with the churn workload primitive type. Two synthetic workloads: a churn pattern (left column) and a combination of churn and LRU-friendly pattern (right column). The working set is 200 items.

Experiments

- **Datasets**: 5 different sources
- **Cache sizes**: 0.05, 0.1, 0.5, 1, 5, 10%
- 6+1 **Algorithms compared**
  - LRU, LFU, ARC, LIRS, LeCaR, DLIRS, CACHEUS (3 variants)
- **Total experiments: 17,766**

Dataset	# of Traces
FIU	184
MSR	22
CloudPhysics	99
CloudVPS	18
CloudCache	6
Total	329

Evaluation of CACHEUS

- Paired t-test used
- **Significance**: p-value
  - Green: Significantly better
  - Red: Significantly worse
  - Gray: Not significant
- **Magnitude**: Effect size (Cohen’s d-measure)
  - Dark: High effect
  - Light: Low effect

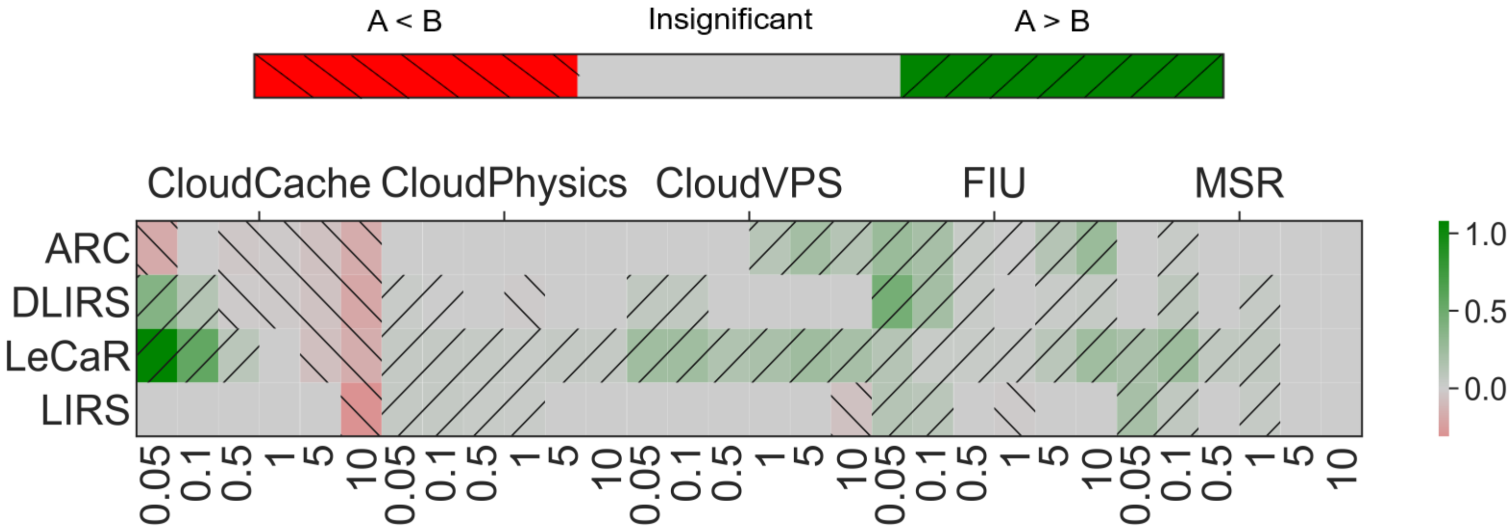


Figure: CACHEUS vs. others

	Effect size	Better	Insignificant	Worse
CACHEUS	[-0.31 , **2.08**]	47%	40%	13%

Contributions

- **Workload Primitive Types**
  - LRU-friendly, LFU-friendly, Churn, Scan
- **CACHEUS**: Improved Cache replacement algorithm
  - **Adaptive** learning rate
  - **Improved** experts: LRU and LFU algorithm
    - SR-LRU and
    - CR-LFU
  - **Comprehensive** evaluations (17,766 simulations)
  - **Outstanding** Performance

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