RIPQ: Advanced Photo Caching on Flash for Facebook

Linpeng Tang (Princeton)

Qi Huang (Cornell & Facebook)

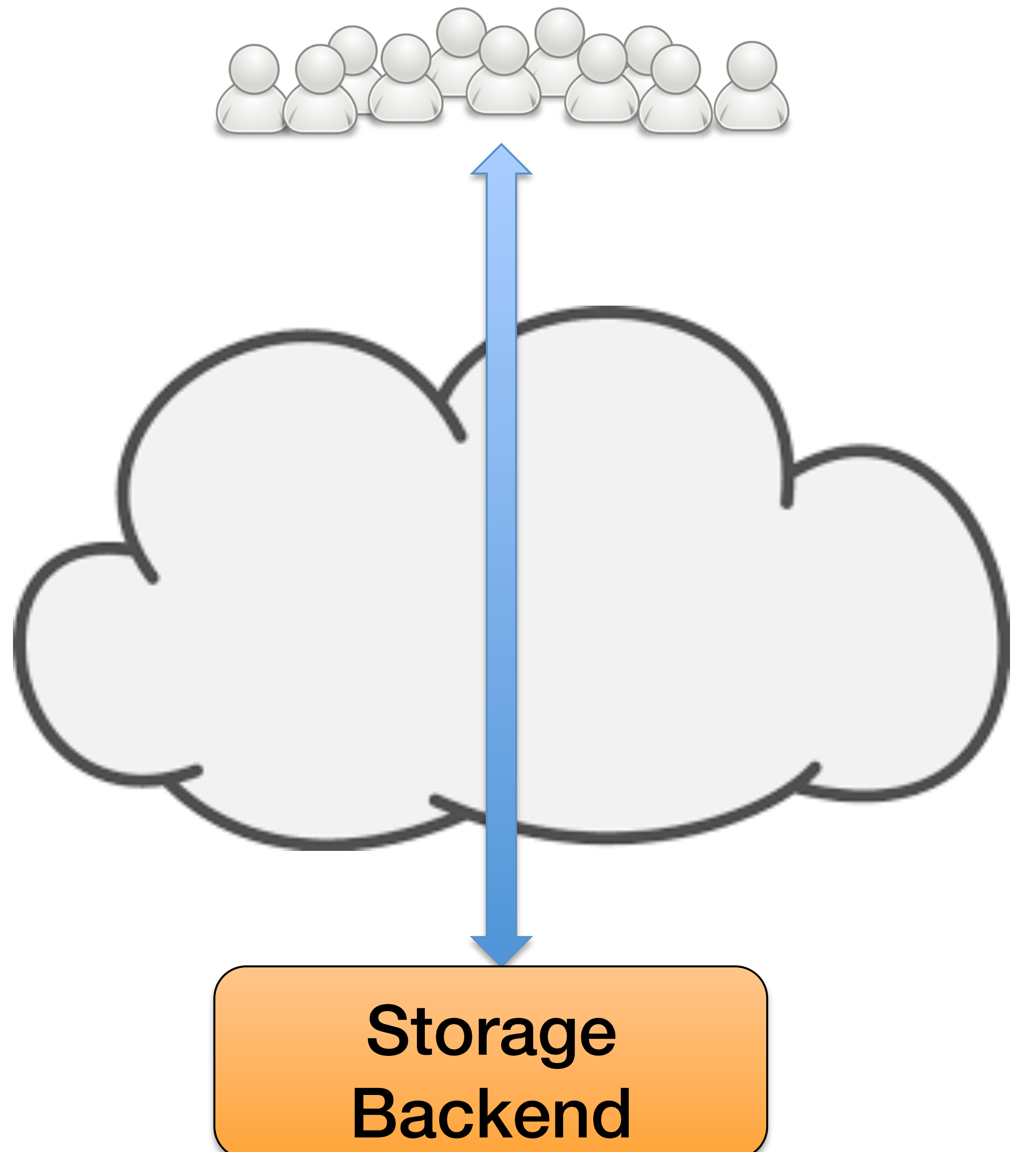
Wyatt Lloyd (USC & Facebook)

Sanjeev Kumar (Facebook)

Kai Li (Princeton)

2 Billion* Photos Shared Daily

Photo Serving Stack



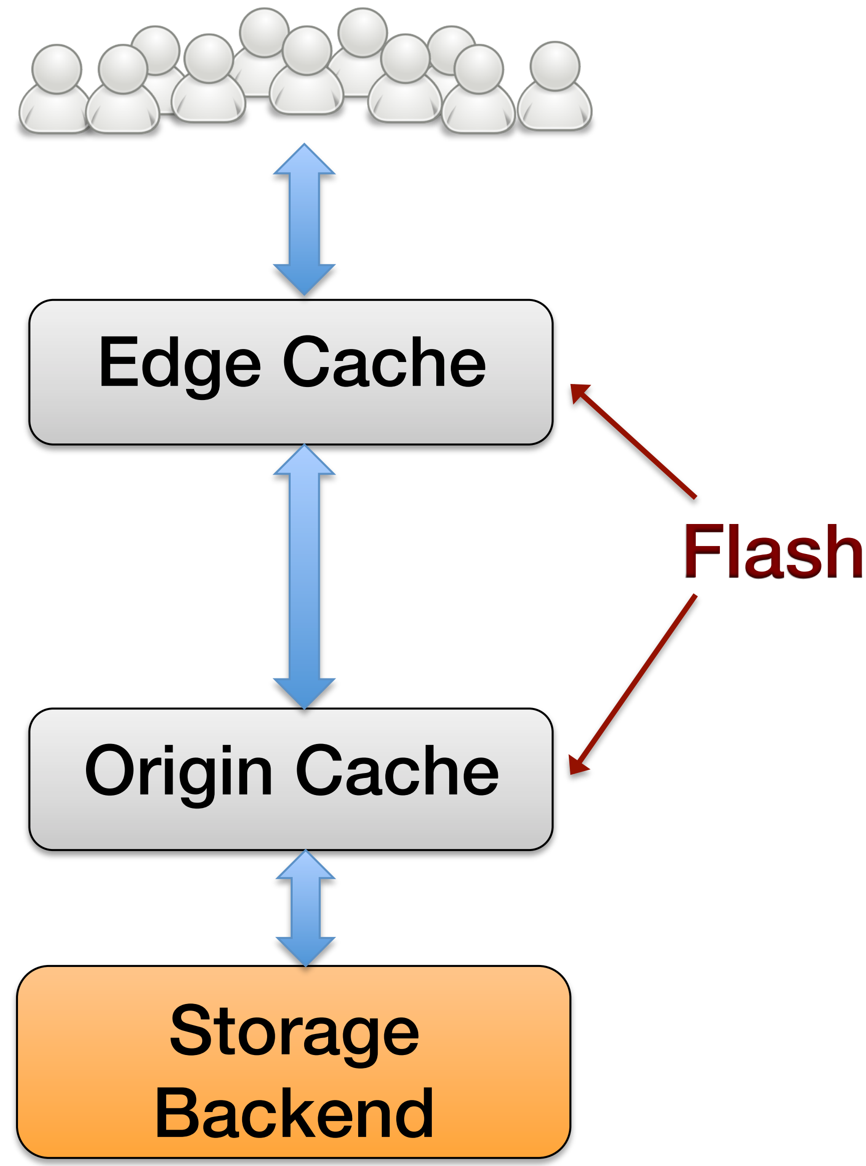
* Facebook 2014 Q4 Report

Photo Caches

Close to users
Reduce backbone traffic

Co-located with backend
Reduce backend IO

Photo Serving Stack



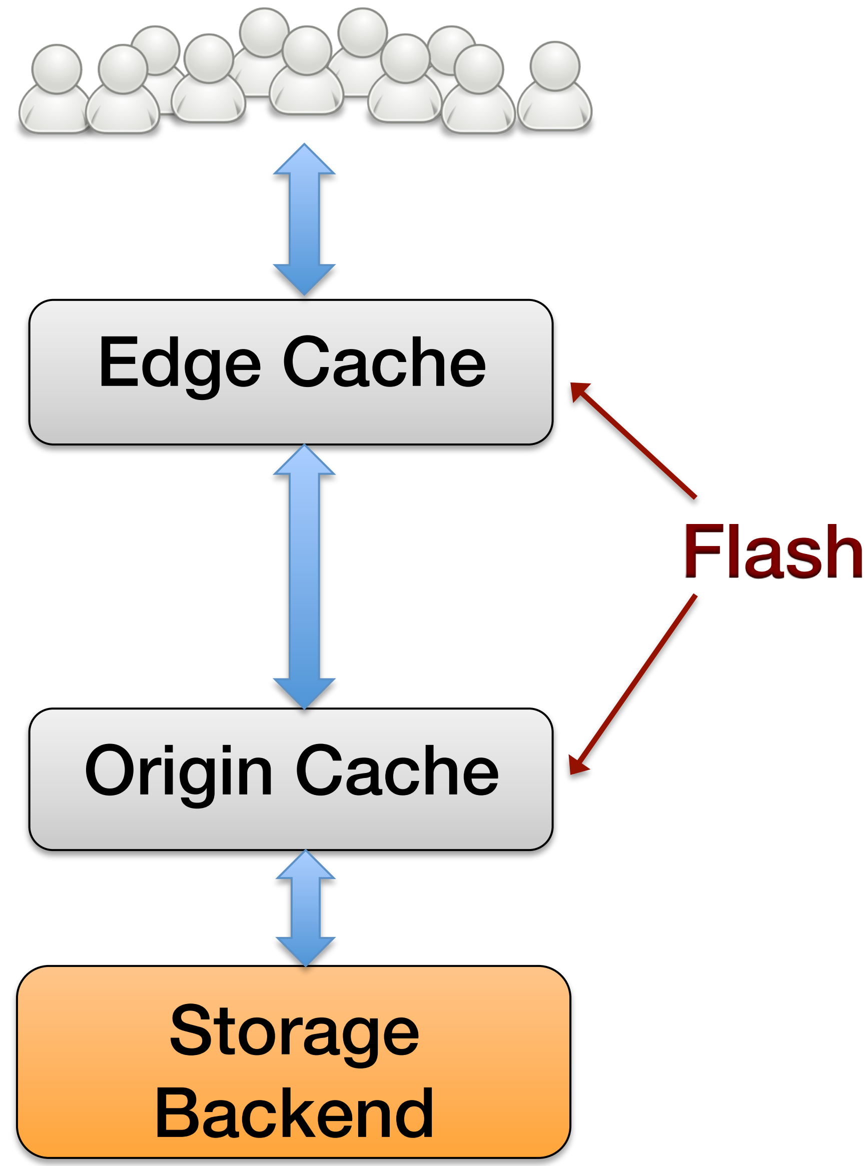
An Analysis of
Facebook Photo Caching
[Huang et al. SOSP'13]

Advanced caching algorithms help!

Segmented LRU-3:
10% less backbone traffic

Greedy-Dual-Size-Frequency-3:
23% fewer backend IOs

Photo Serving Stack

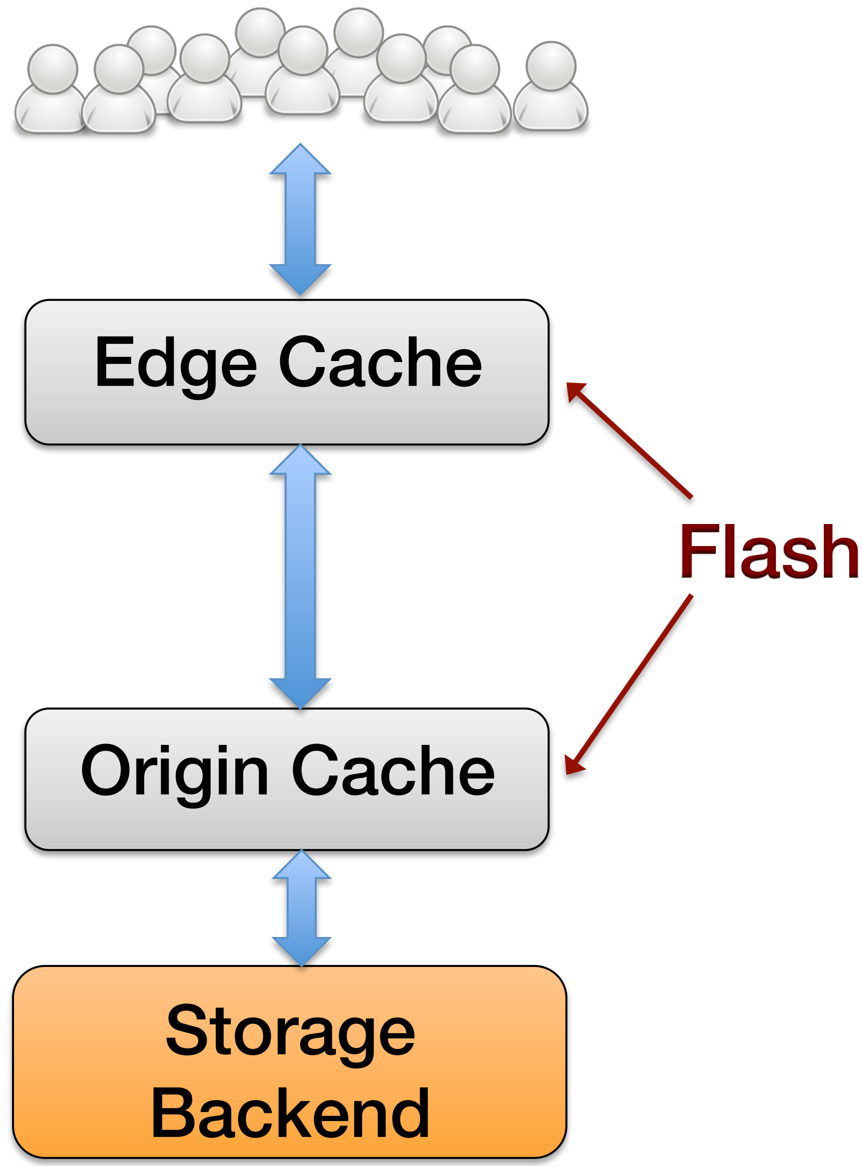


In Practice

FIFO was still used

No known way to implement advanced algorithms efficiently

Photo Serving Stack



Theory

Practice

Advanced caching helps
- 23% fewer backend IC
- 10% less backbone traffi

ult to implement on flash:
FO still used

Restricted Insertion Priority Queue:
efficiently implement advanced caching algorithms on flash

Outline

- Why are advanced caching algorithms difficult to implement on flash efficiently?

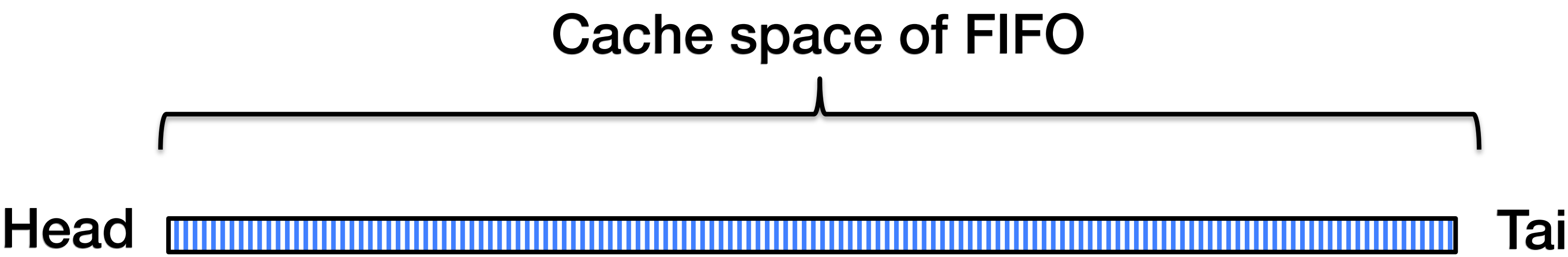
- How RIPQ solves this problem?
  - Why use priority queue?
  - How to efficiently implement one on flash?

- Evaluation
  - 10% less backbone traffic
  - 23% fewer backend IOs

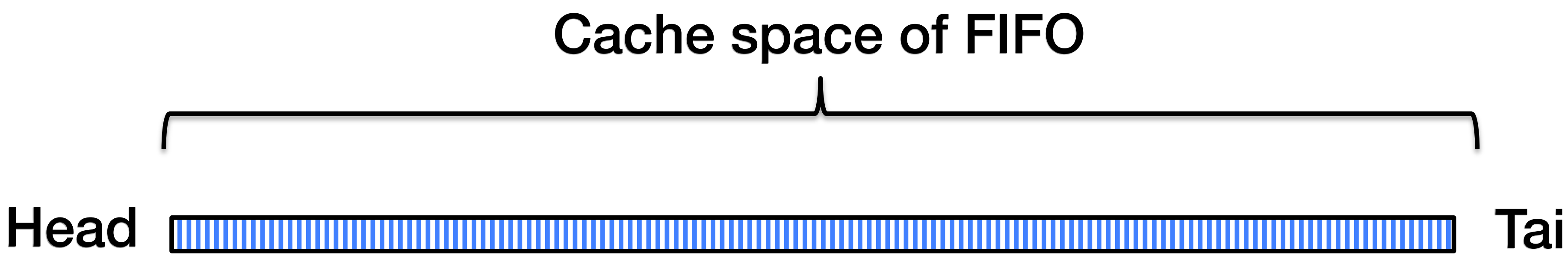
Outline

- Why are advanced caching algorithms difficult to implement on flash efficiently?
  - Write pattern of FIFO and LRU
- How RIPQ solves this problem?
  - Why use priority queue?
  - How to efficiently implement one on flash?
- Evaluation
  - 10% less backbone traffic
  - 23% fewer backend IOs

FIFO Does Sequential Writes

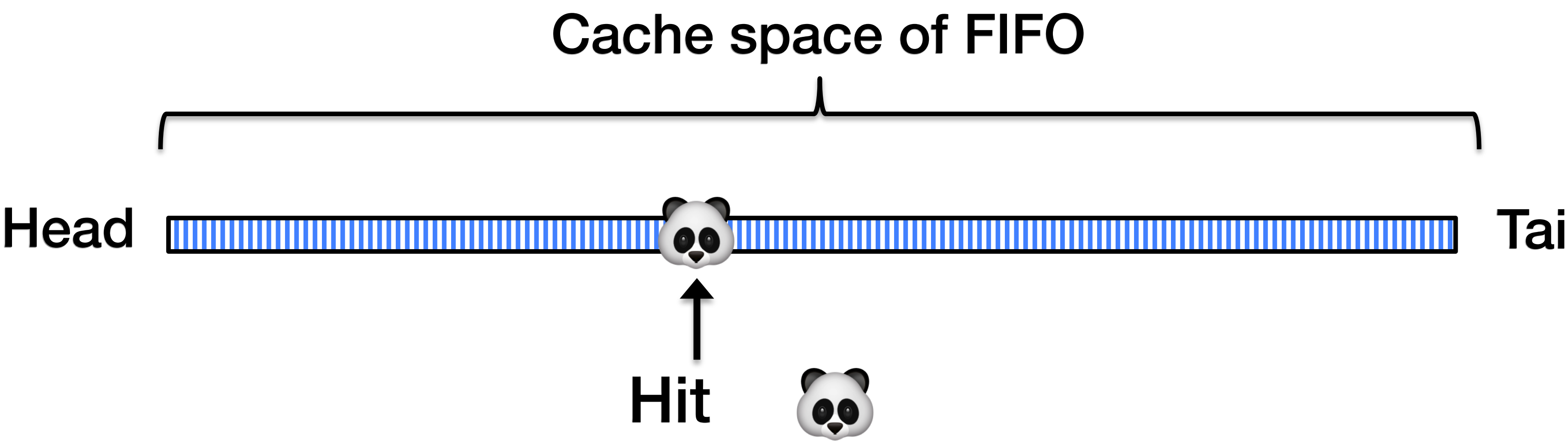


FIFO Does Sequential Writes

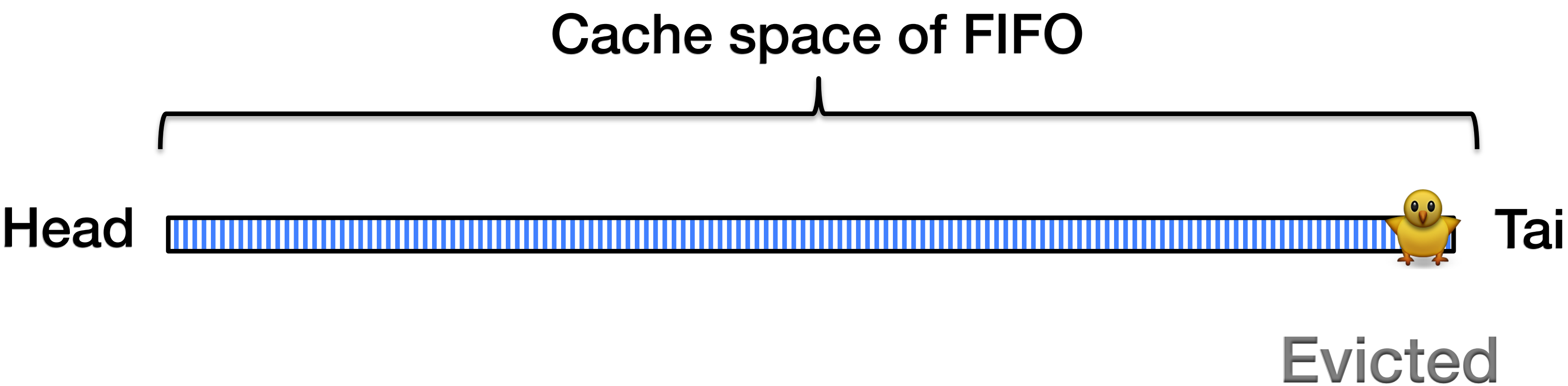


Miss 

FIFO Does Sequential Writes

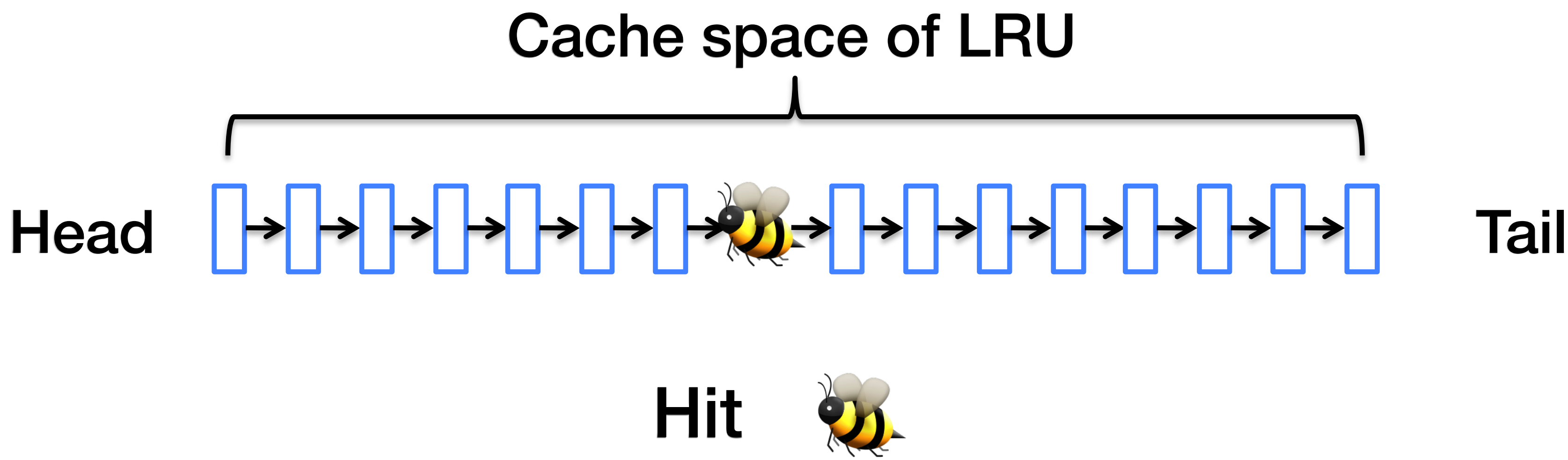


FIFO Does Sequential Writes



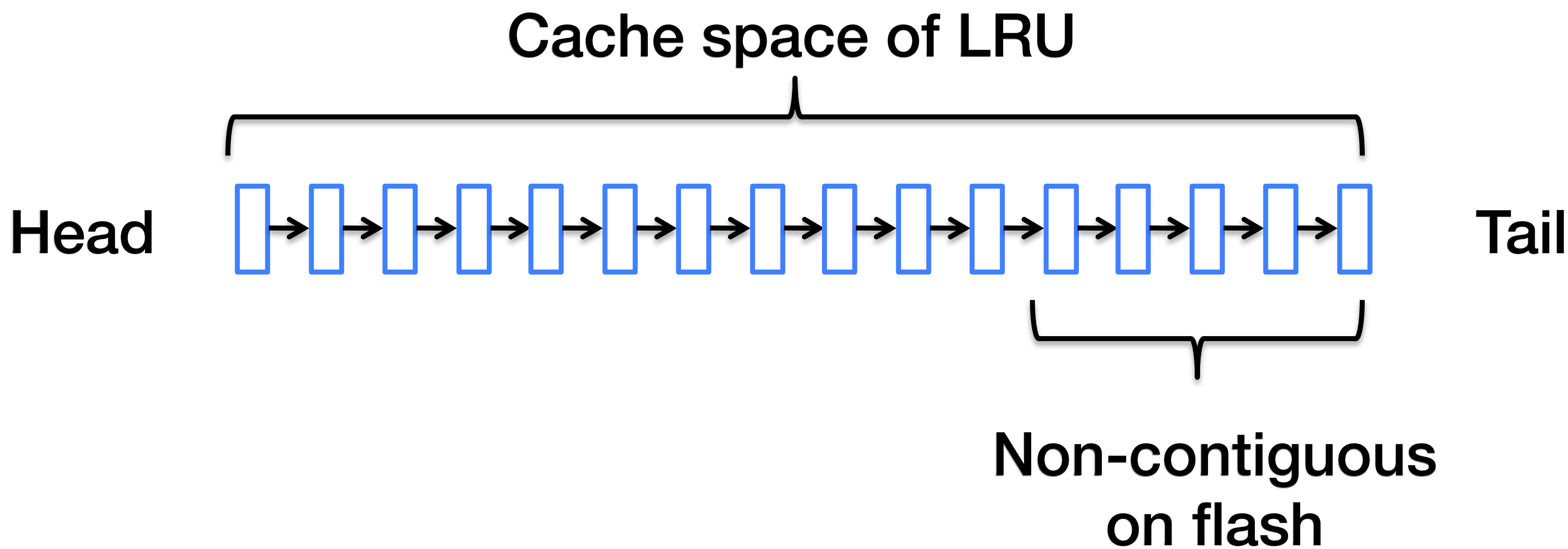
No random writes needed for FIFO

LRU Needs Random Writes



Locations on flash ≠ Locations in LRU queue

LRU Needs Random Writes



Random writes needed to reuse space

Why Care About Random Writes?

- Write-heavy workload
  - Long tail access pattern, moderate hit ratio
  - Each miss triggers a write to cache
- Small random writes are harmful for flash
  - e.g. Min et al. FAST'12
  - High write amplification → Low write throughput; Short device lifetime

What write size do we need?

- Large writes
  - High write throughput at high utilization
  - 16~32MiB in Min et al. FAST'2012

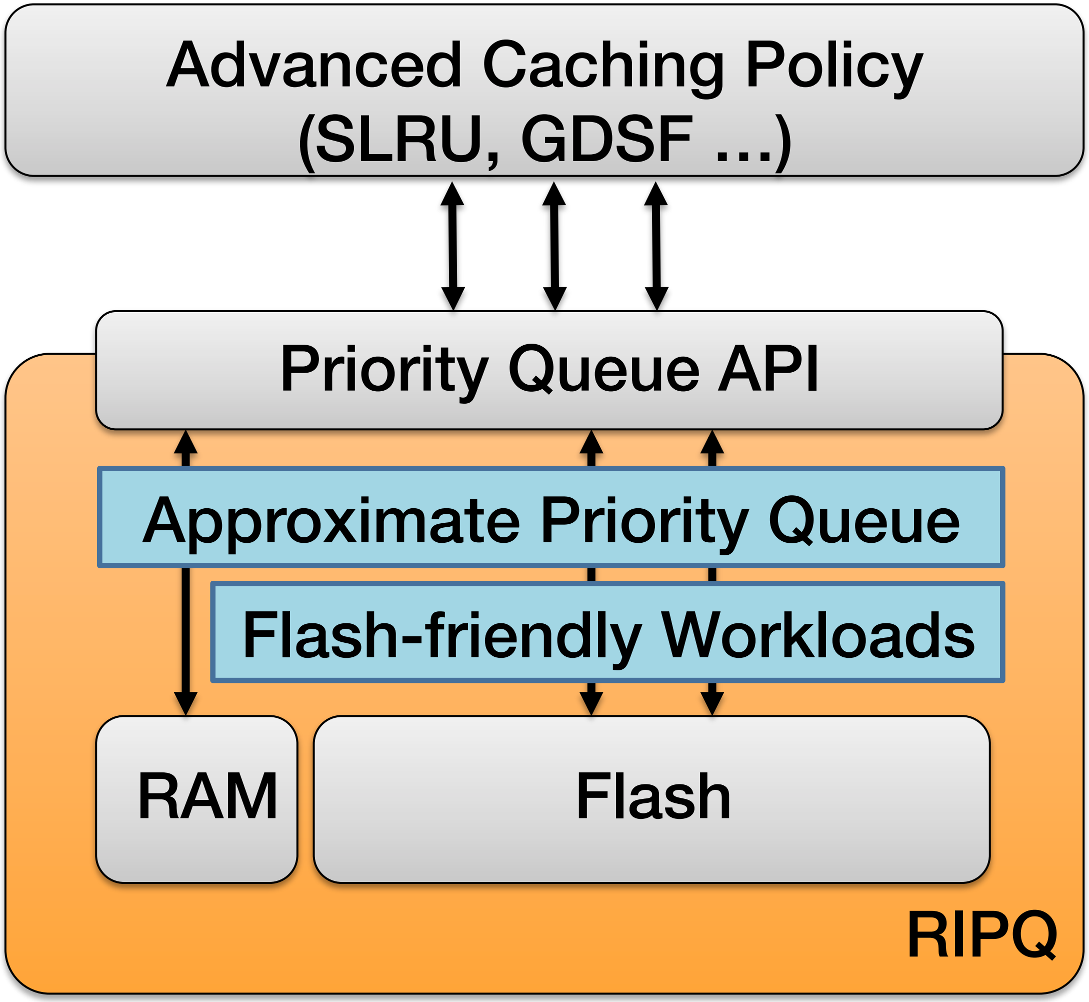
- What's the trend since then?
  - Random writes tested for 3 modern devices
  - 128~512MiB needed now

100MiB+ writes needed for efficiency

Outline

- Why are advanced caching algorithms difficult to implement on flash efficiently?
- How RIPQ solves this problem?
- Evaluation

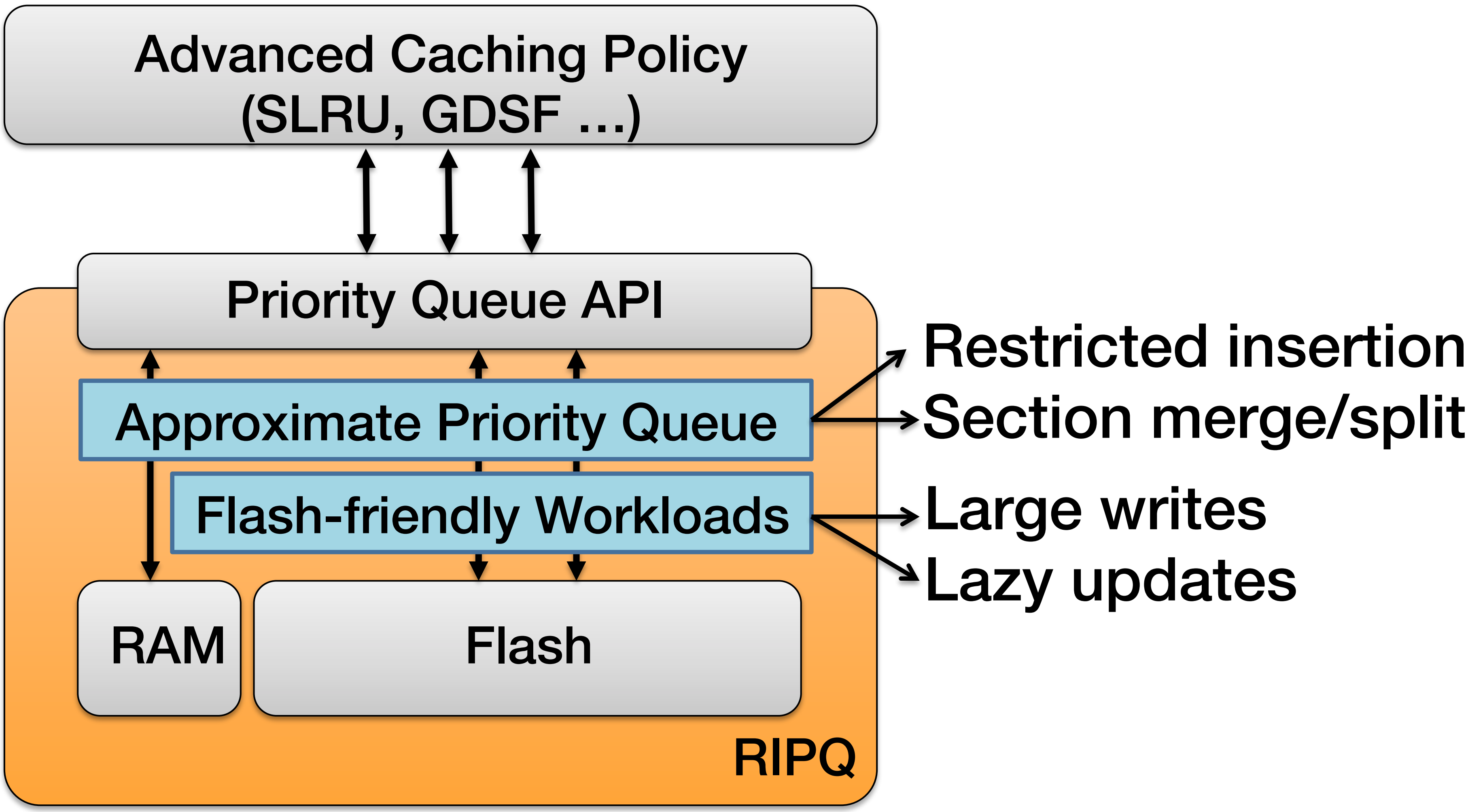
RIPQ Architecture
(Restricted Insertion Priority Queue)



Caching algorithms approximated as well

Efficient caching on flash

RIPQ Architecture
(Restricted Insertion Priority Queue)



Priority Queue API

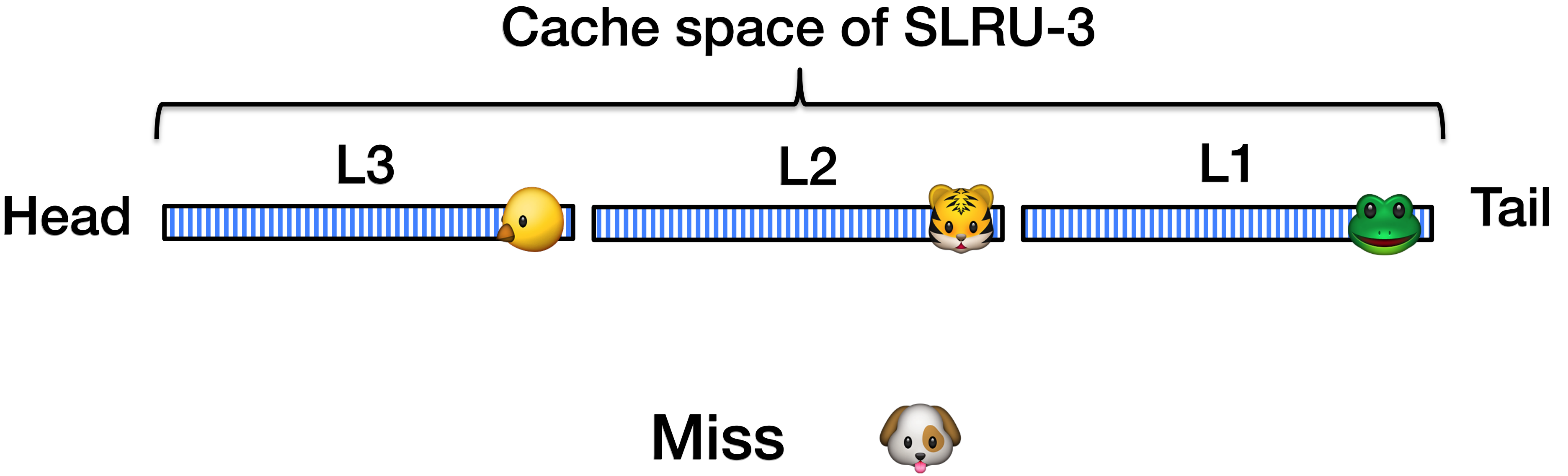
- No single best caching policy

- Segmented LRU [Karedla'94]
  - Reduce both backend IO and backbone traffic
  - SLRU-3: best algorithm for Edge so far

- Greedy-Dual-Size-Frequency [Cherkasova'98]
  - Favor small objects
  - Further reduces backend IO
  - GDSF-3: best algorithm for Origin so far

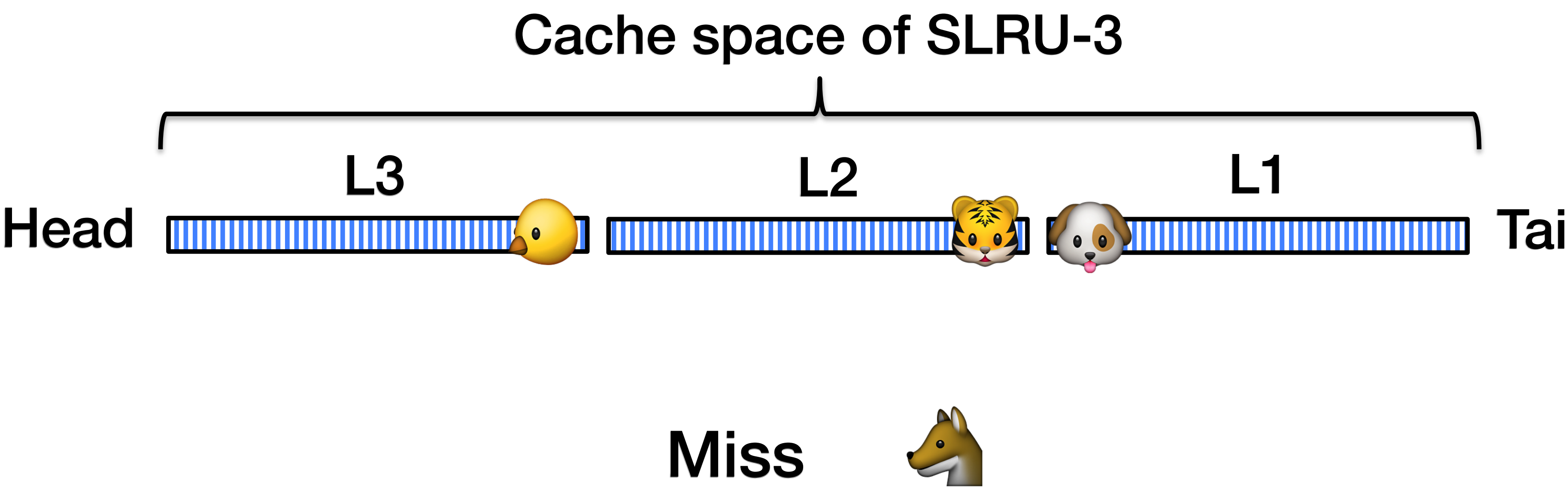
Segmented LRU

- Concatenation of K LRU caches



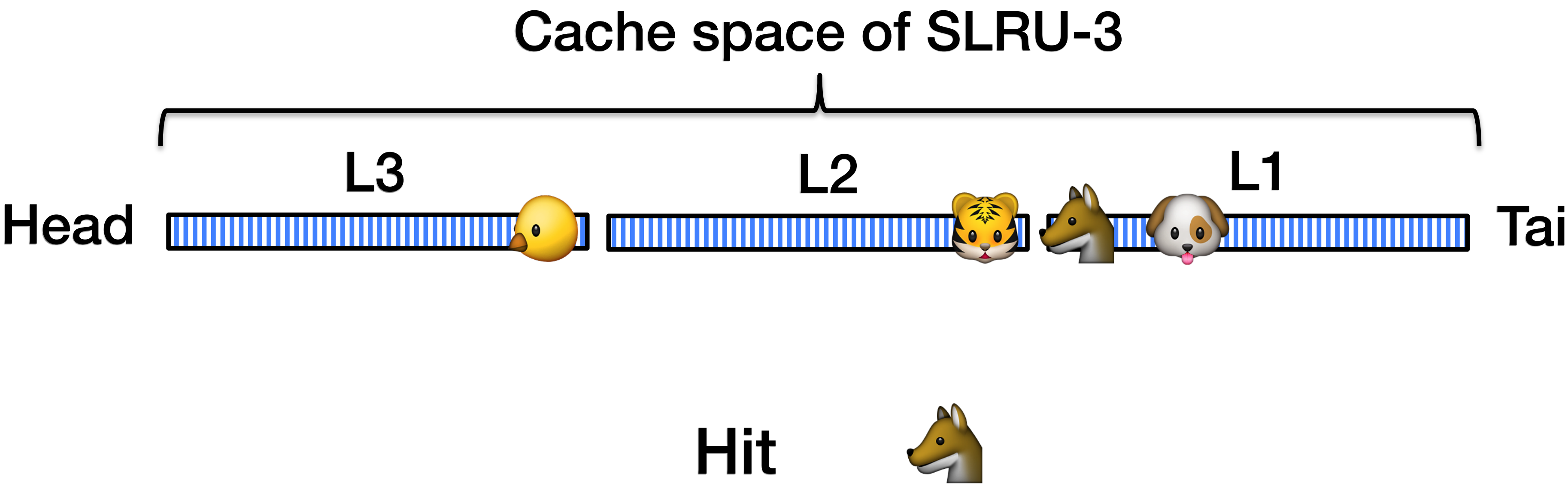
Segmented LRU

- Concatenation of K LRU caches



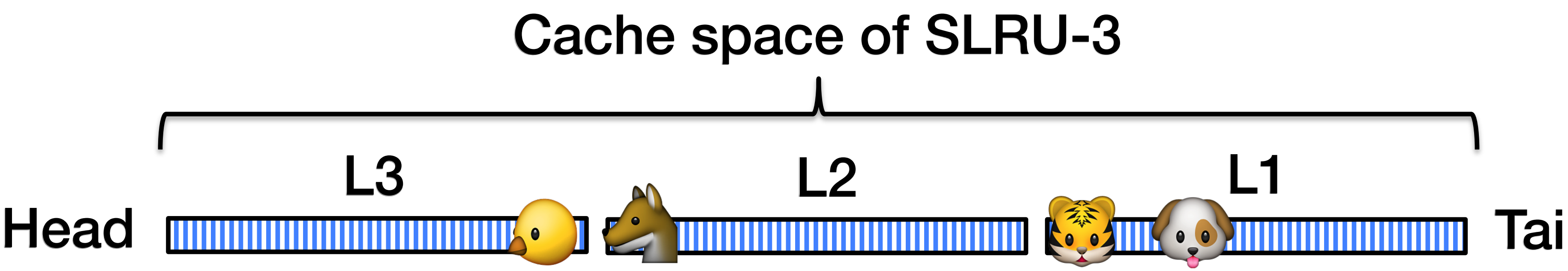
Segmented LRU

- Concatenation of K LRU caches



Segmented LRU

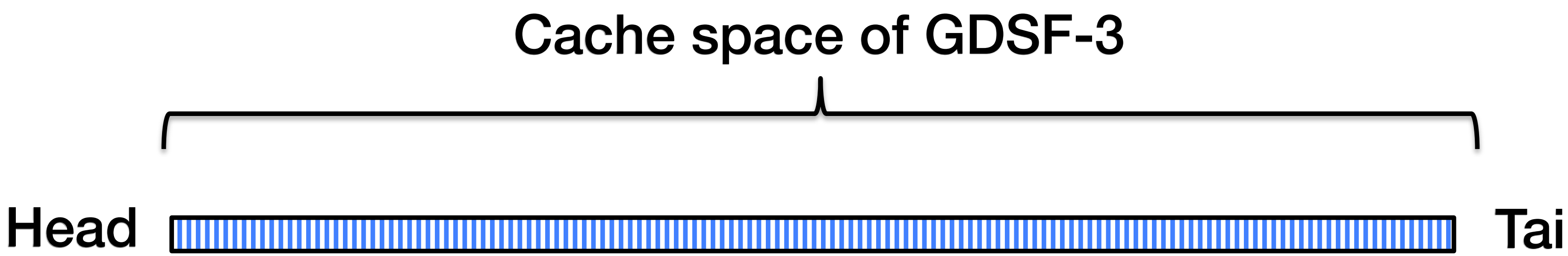
- Concatenation of K LRU caches



Hit  again

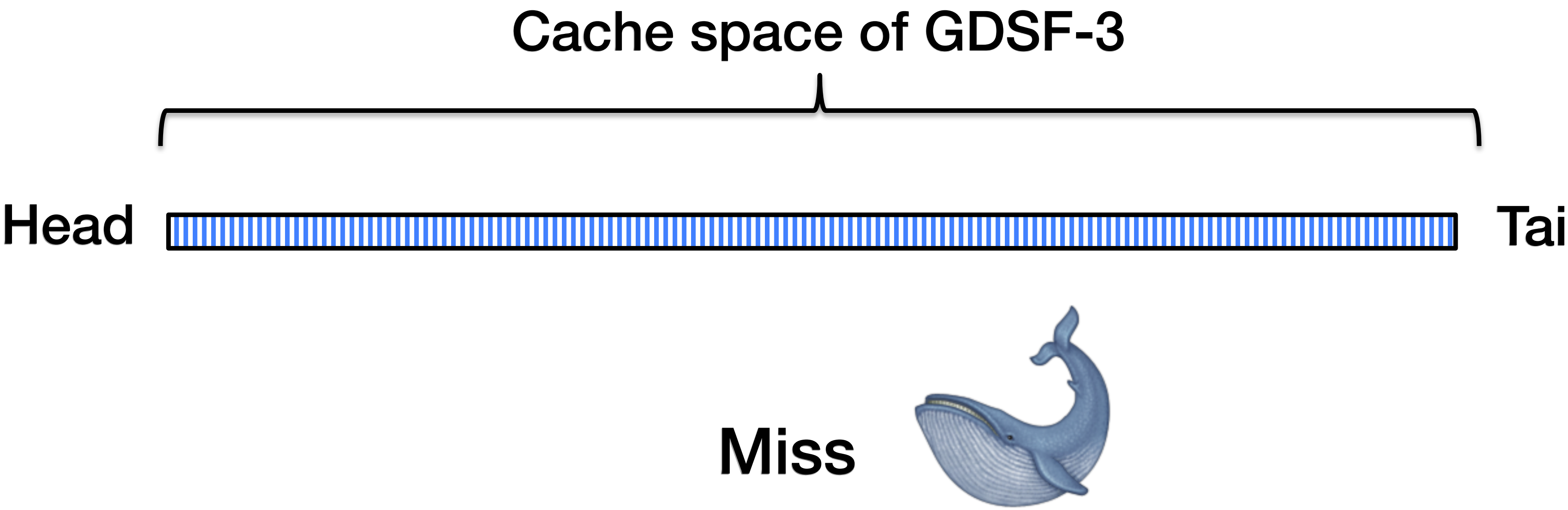
Greedy-Dual-Size-Frequency

- Favoring small objects



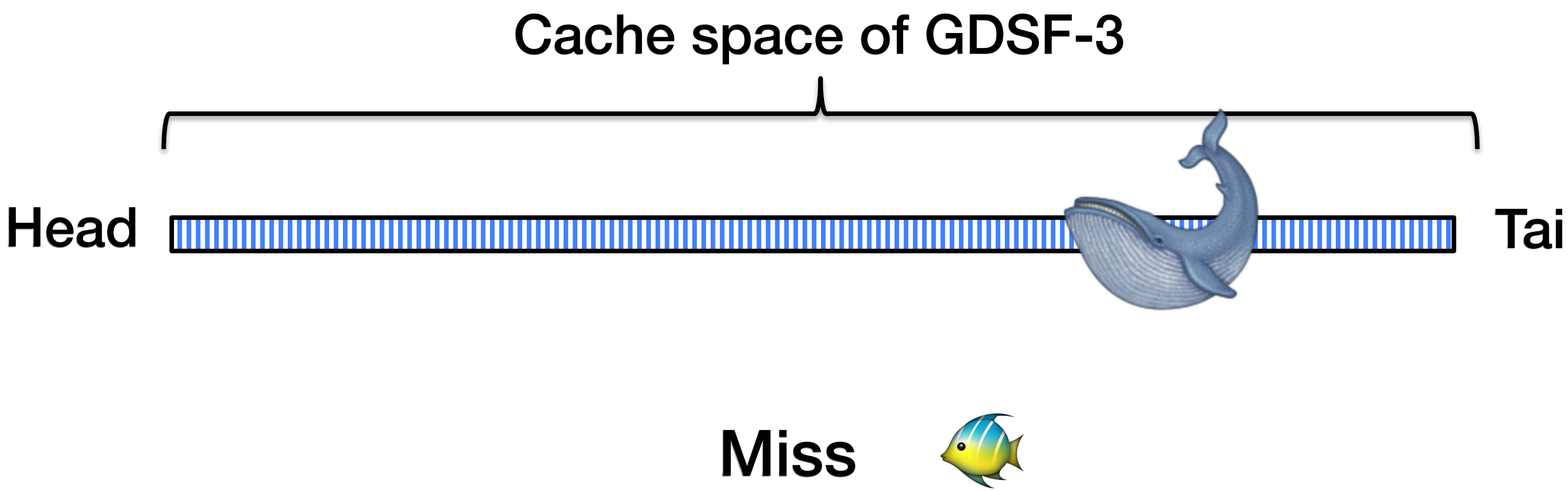
Greedy-Dual-Size-Frequency

- Favoring small objects



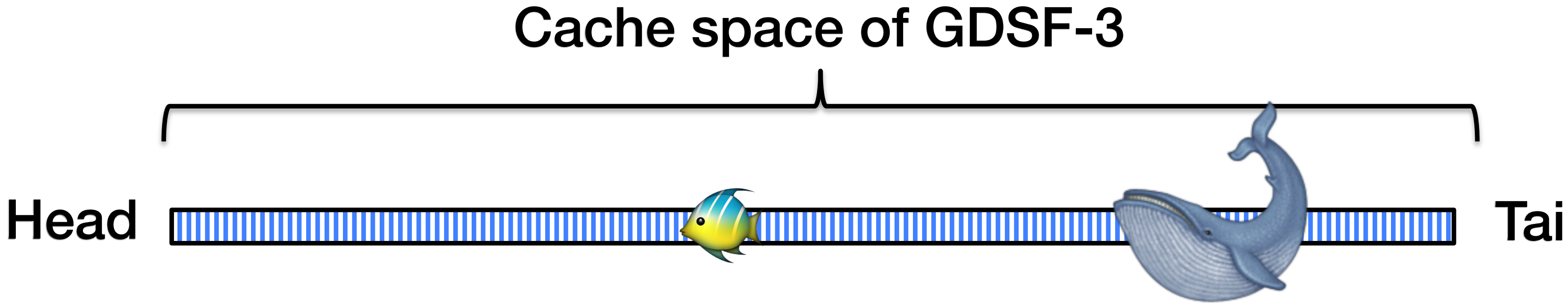
Greedy-Dual-Size-Frequency

- Favoring small objects



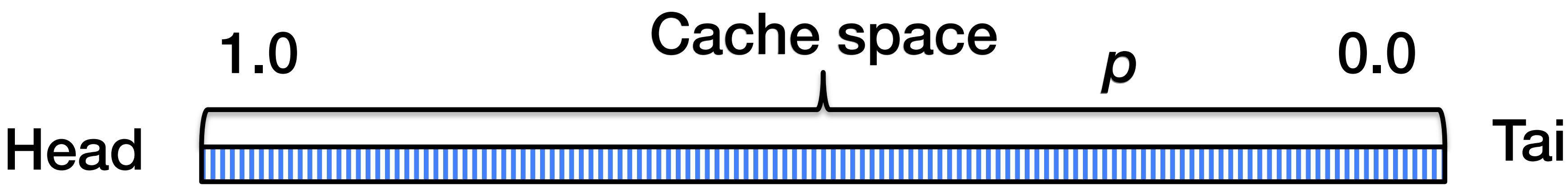
Greedy-Dual-Size-Frequency

- Favoring small objects



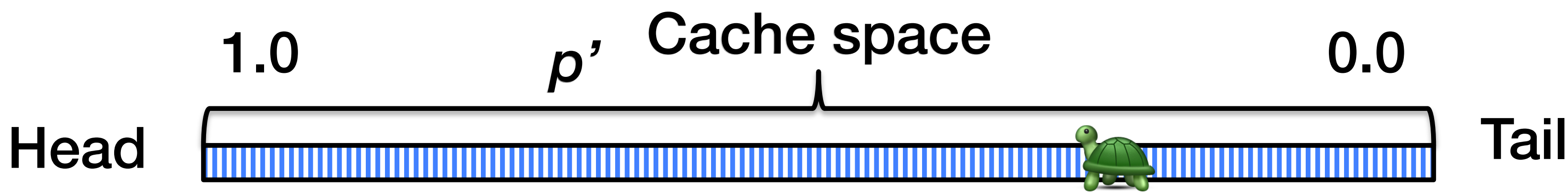
- Write workload more random than LRU
- Operations similar to priority queue

Relative Priority Queue for Advanced Caching Algorithms



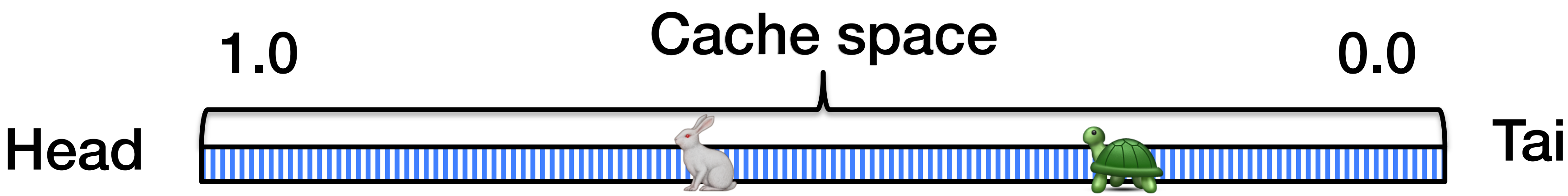
Miss object: insert(x, *p*)

Relative Priority Queue for Advanced Caching Algorithms



Hit object: increase(x, *p’*)

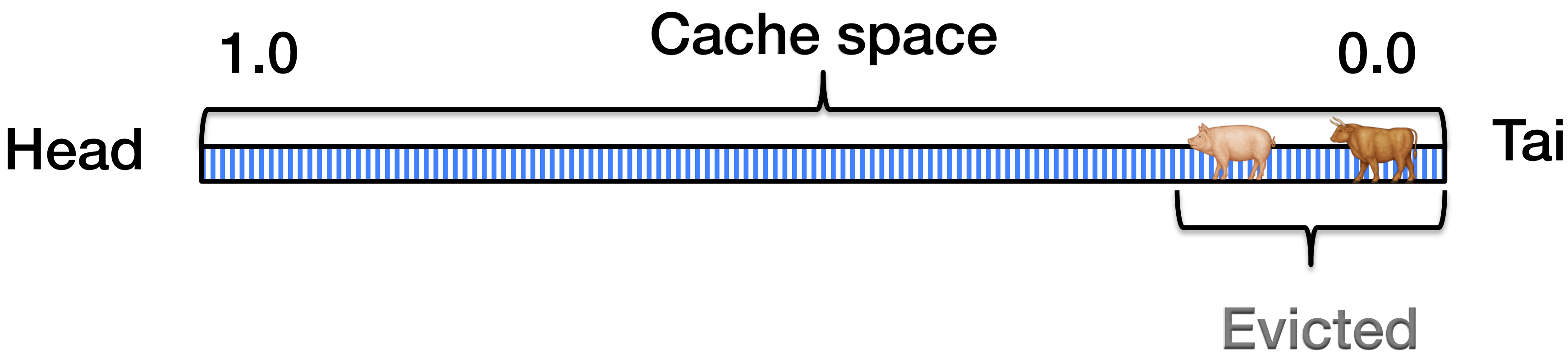
Relative Priority Queue for Advanced Caching Algorithms



Implicit demotion on insert/increase:

- Object with lower priorities moves towards the tail

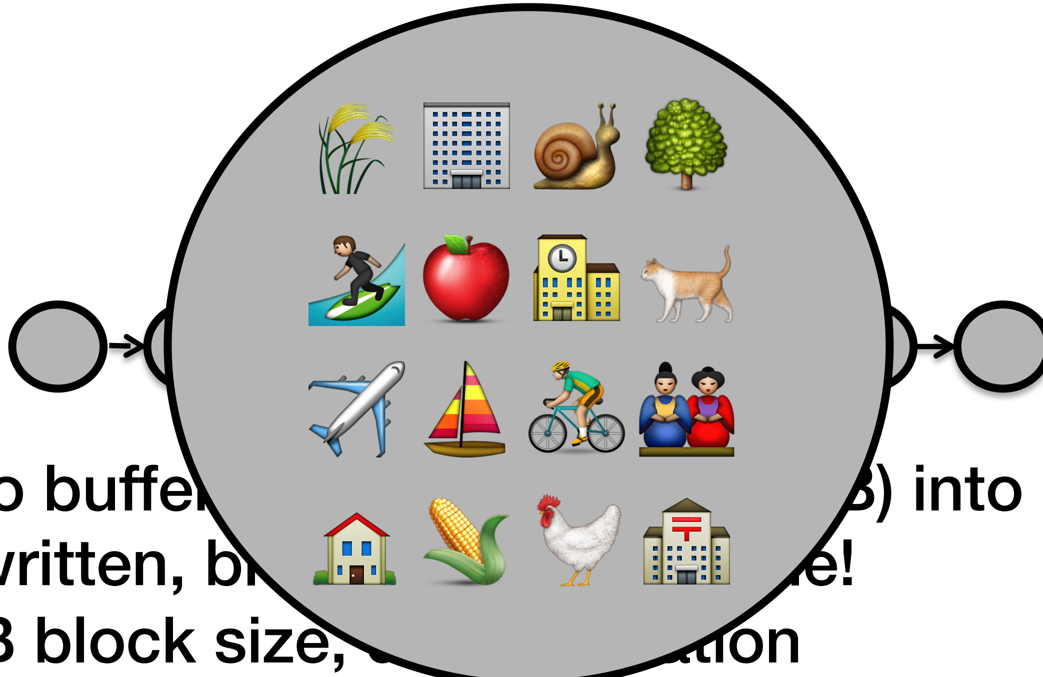
Relative Priority Queue for Advanced Caching Algorithms



Evict from queue tail

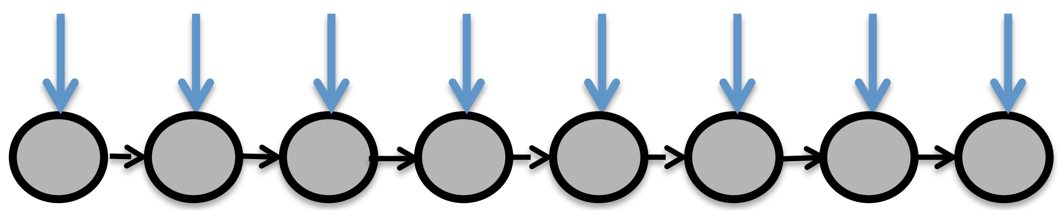
Relative priority queue captures the dynamics of many caching algorithms!

RIPQ Design: Large Writes



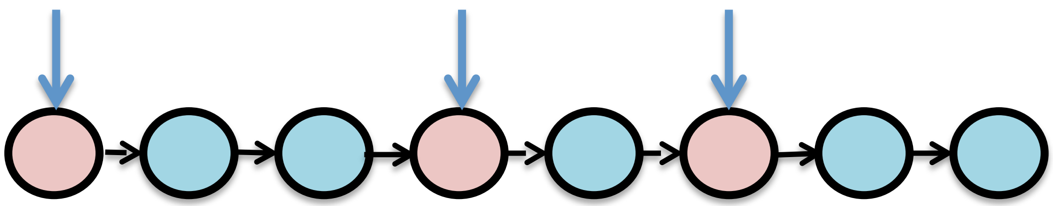
- Need to buffe[obscured] B) into block writes
- Once written, b[obscured] e!
- 256MiB block size, [obscured] ation
  - Large caching capacity
  - High write throughput

RIPQ Design:
Restricted Insertion Points



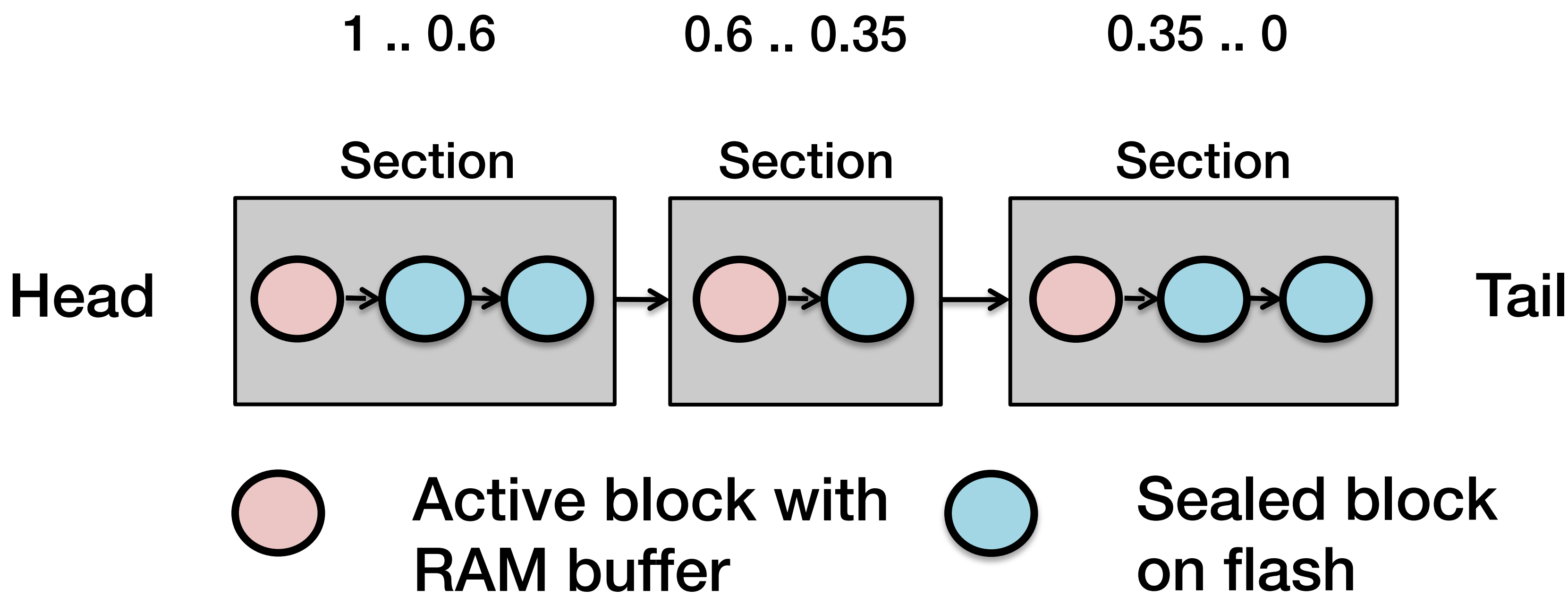
- Exact priority queue
  - Insert to any block in the queue
- Each block needs a separate buffer
  - Whole flash space buffered in RAM!

RIPQ Design: Restricted Insertion Points



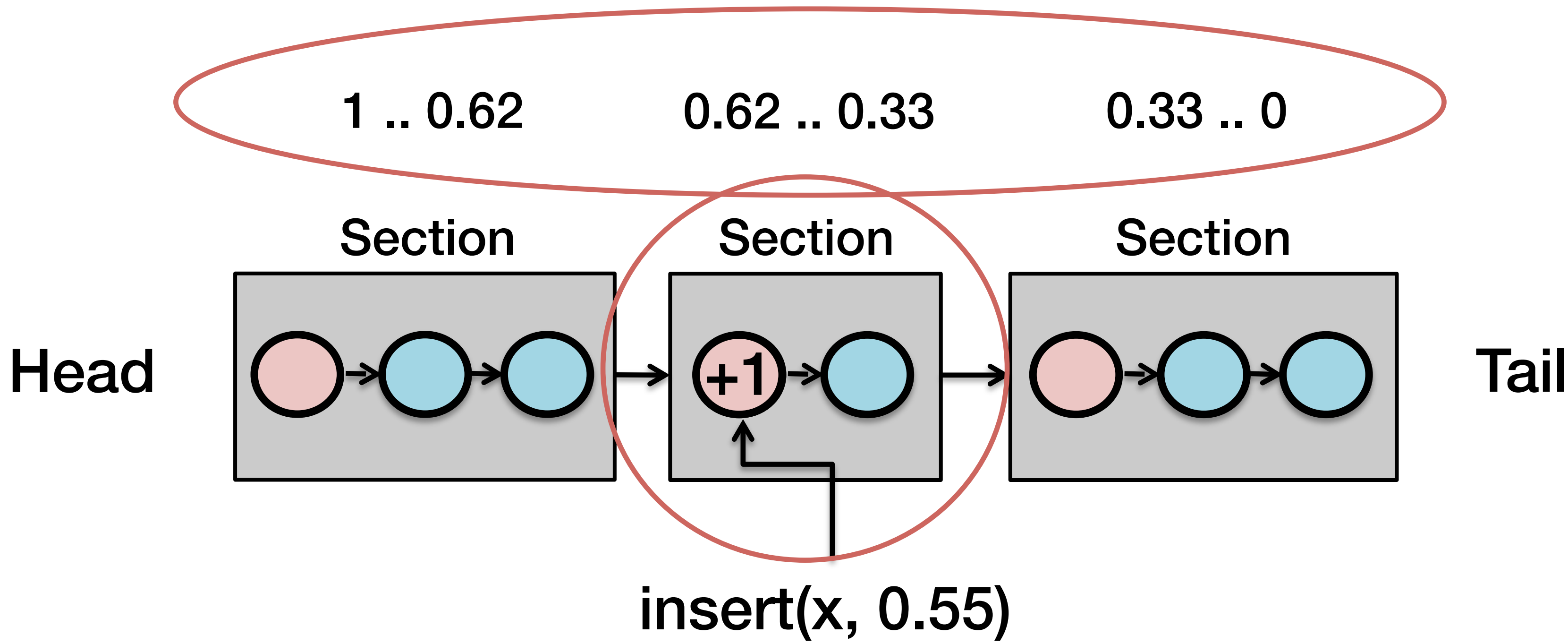
Solution: restricted insertion points

Section is Unit for Insertion



Each section has one insertion point

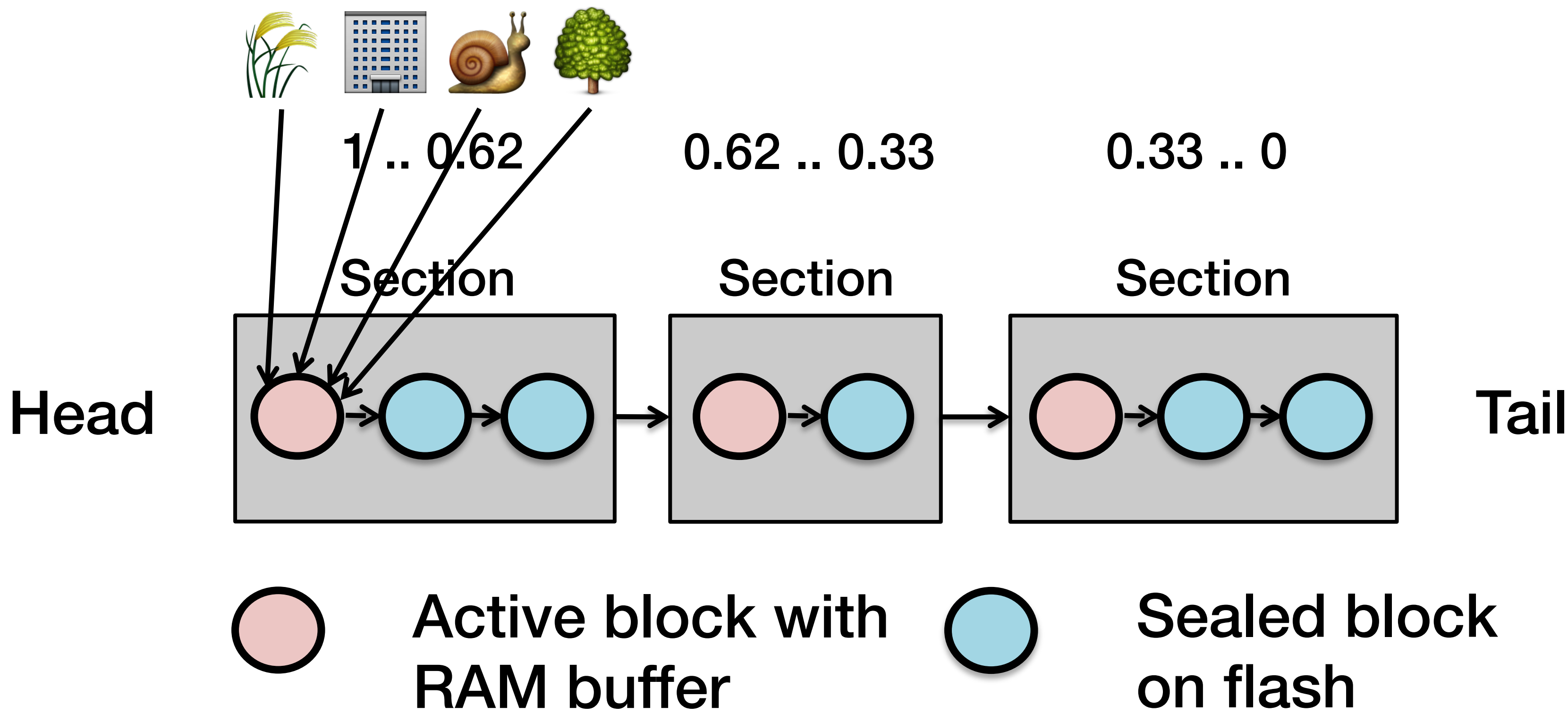
Section is Unit for Insertion



Insert procedure

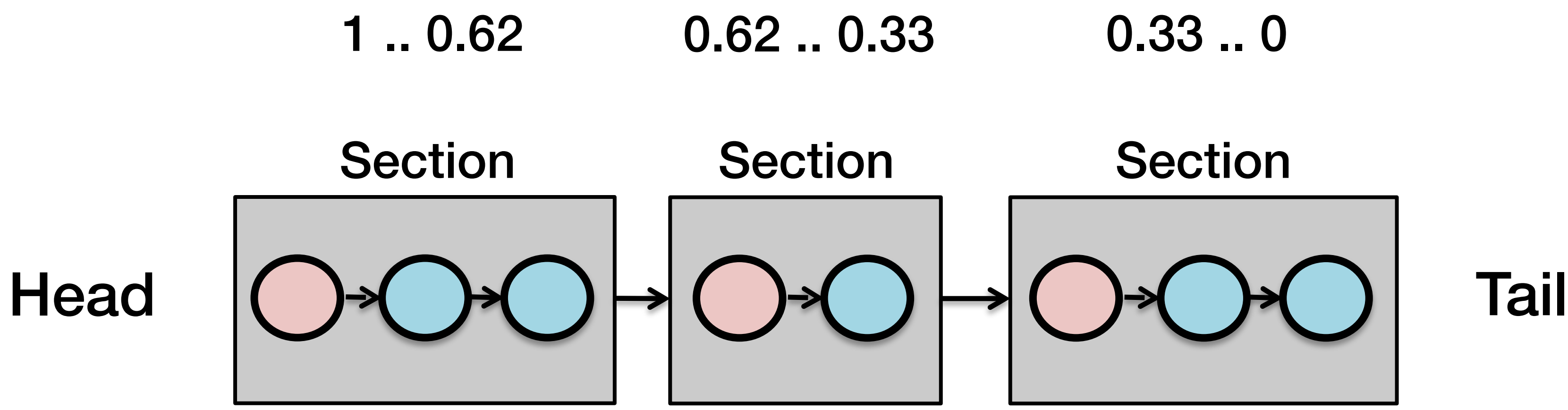
- Find corresponding section
- Copy data into active block
- Updating section priority range

Section is Unit for Insertion



Relative orders within one section not guaranteed!

Trade-off in Section Size

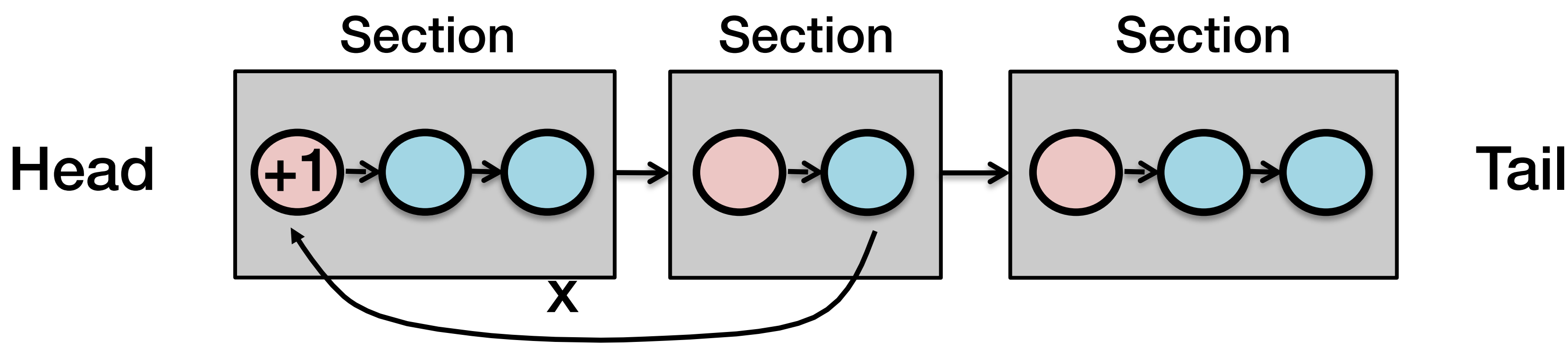


Section size controls approximation error

- Sections ↑, approximation error ↓
- Sections ↓, RAM buffer ↓

RIPQ Design: Lazy Update

Naïve approach: copy to the corresponding active block

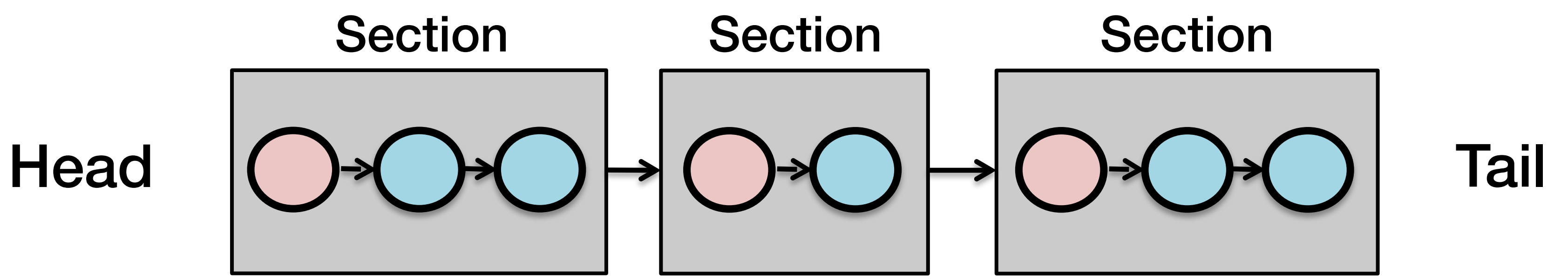


increase(x, 0.9)

Problem with naïve approach

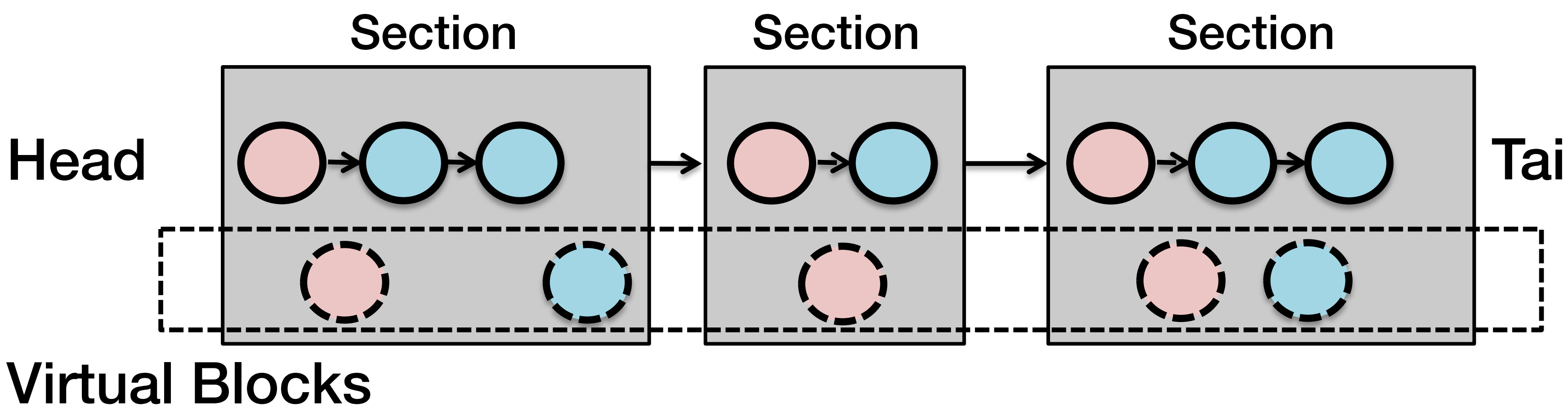
- Data copying/duplication on flash

RIPQ Design: Lazy Update



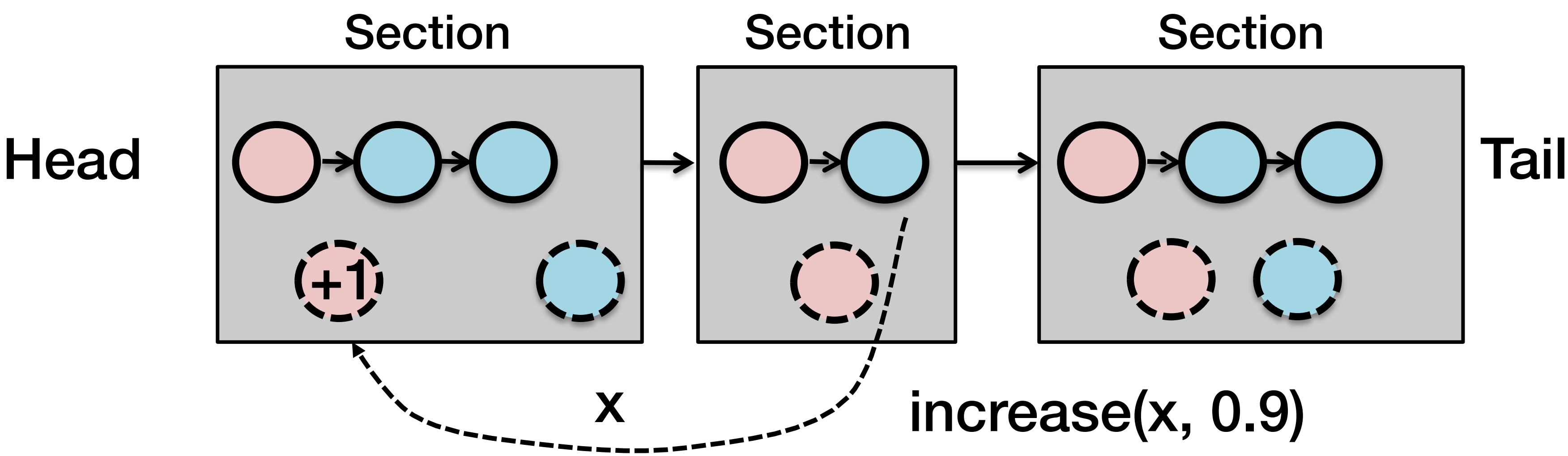
Solution: use virtual block to track the updated location!

RIPQ Design: Lazy Update



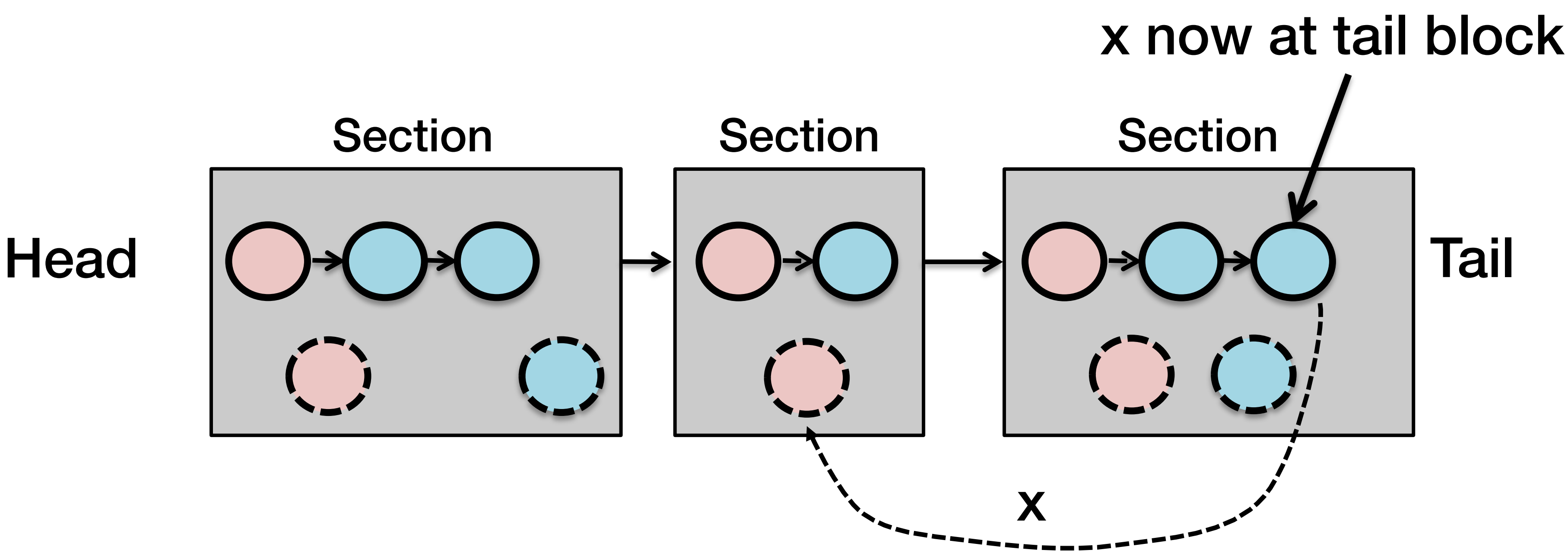
Solution: use virtual block to track the updated location!

Virtual Block Remembers Update Location

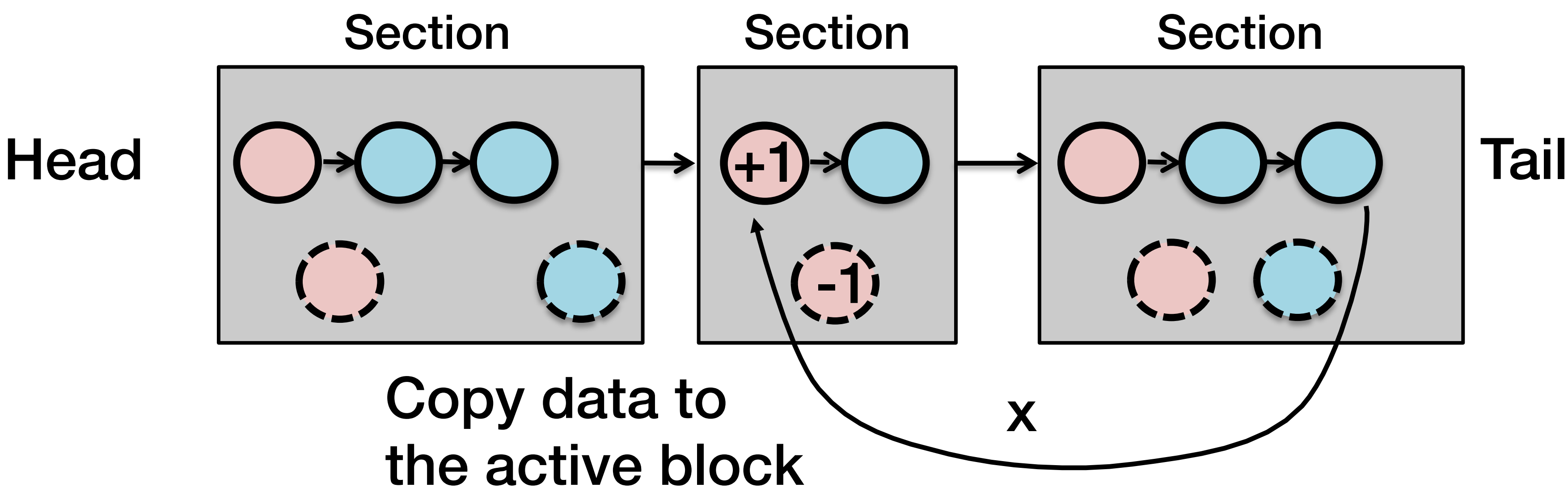


No data written during virtual update

Actual Update During Eviction



Actual Update During Eviction



Always one copy of data on flash

RIPQ Design

- Relative priority queue API
- RIPQ design points
  - Large writes
  - Restricted insertion points
  - Lazy update
  - Section merge/split
    - Balance section sizes and RAM buffer usage

- Static caching
  - Photos are static

Outline

- Why are advanced caching algorithms difficult to implement on flash efficiently?
- How RIPQ solves this problem?
- Evaluation

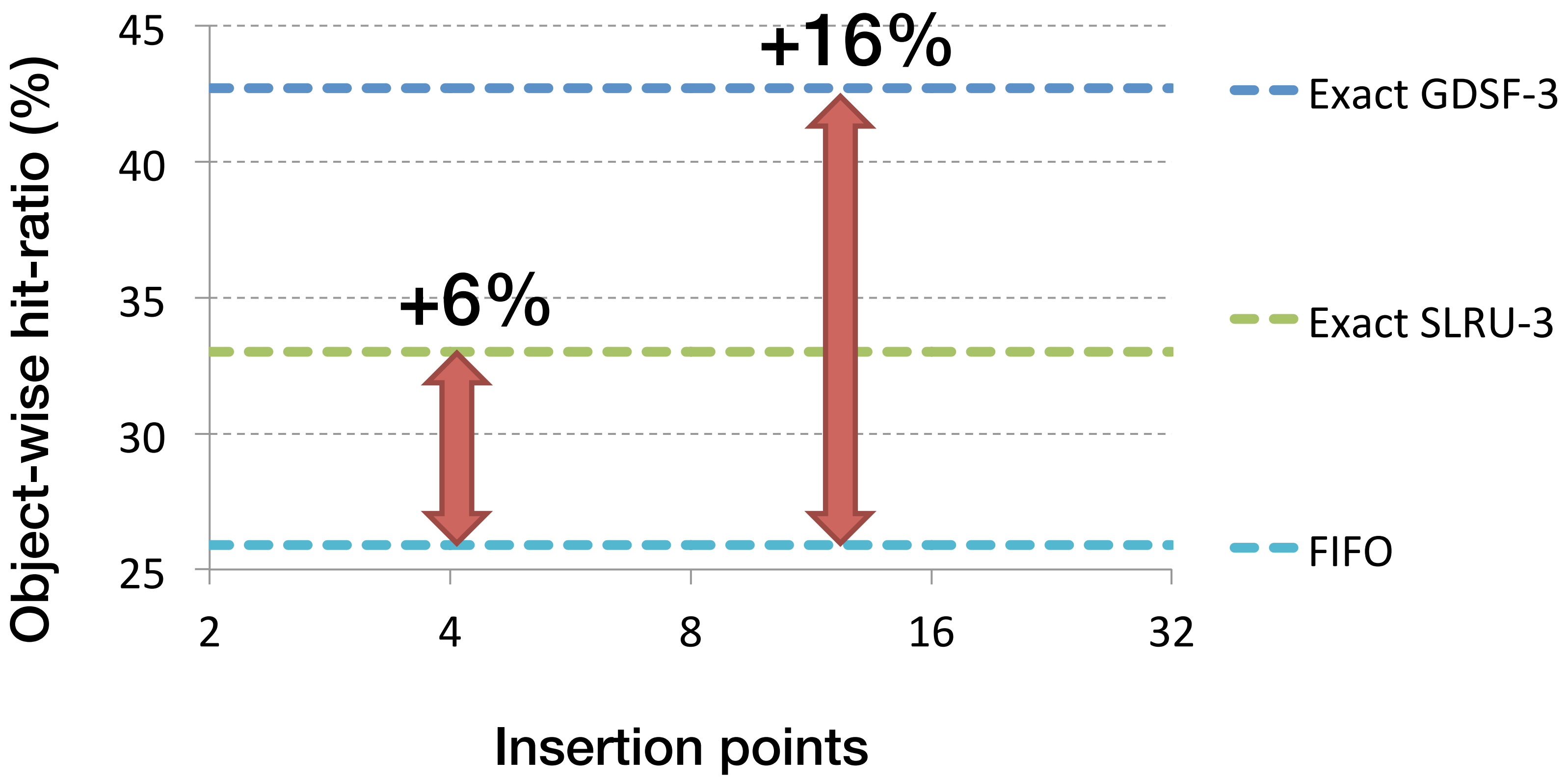
Evaluation Questions

- How much RAM buffer needed?
- How good is RIPQ's approximation?
- What's the throughput of RIPQ?

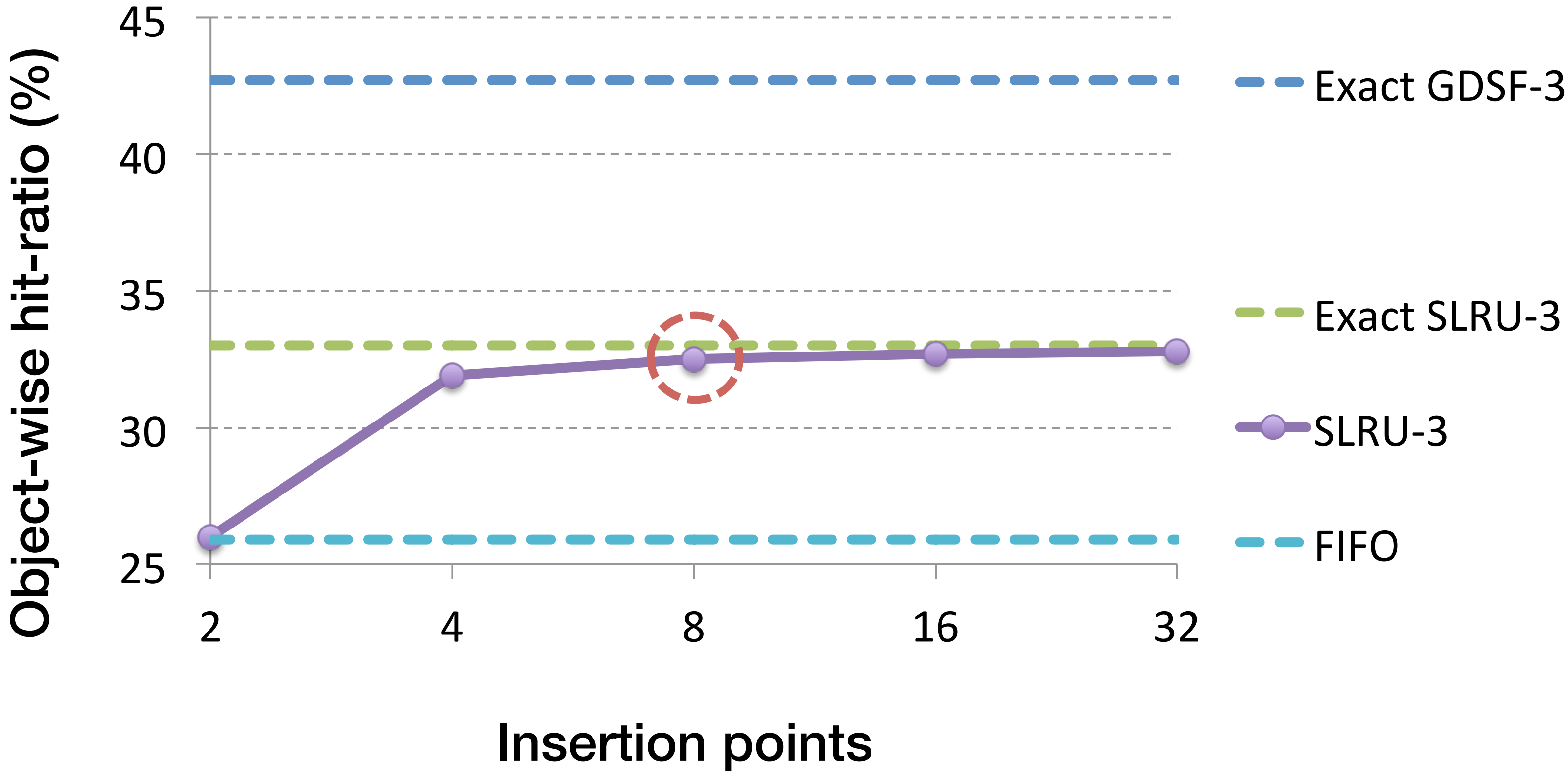
Evaluation Approach

- Real-world Facebook workloads
  - Origin
  - Edge
- 670 GiB flash card
  - 256MiB block size
  - 90% utilization
- Baselines
  - FIFO
  - SIPQ: Single Insertion Priority Queue

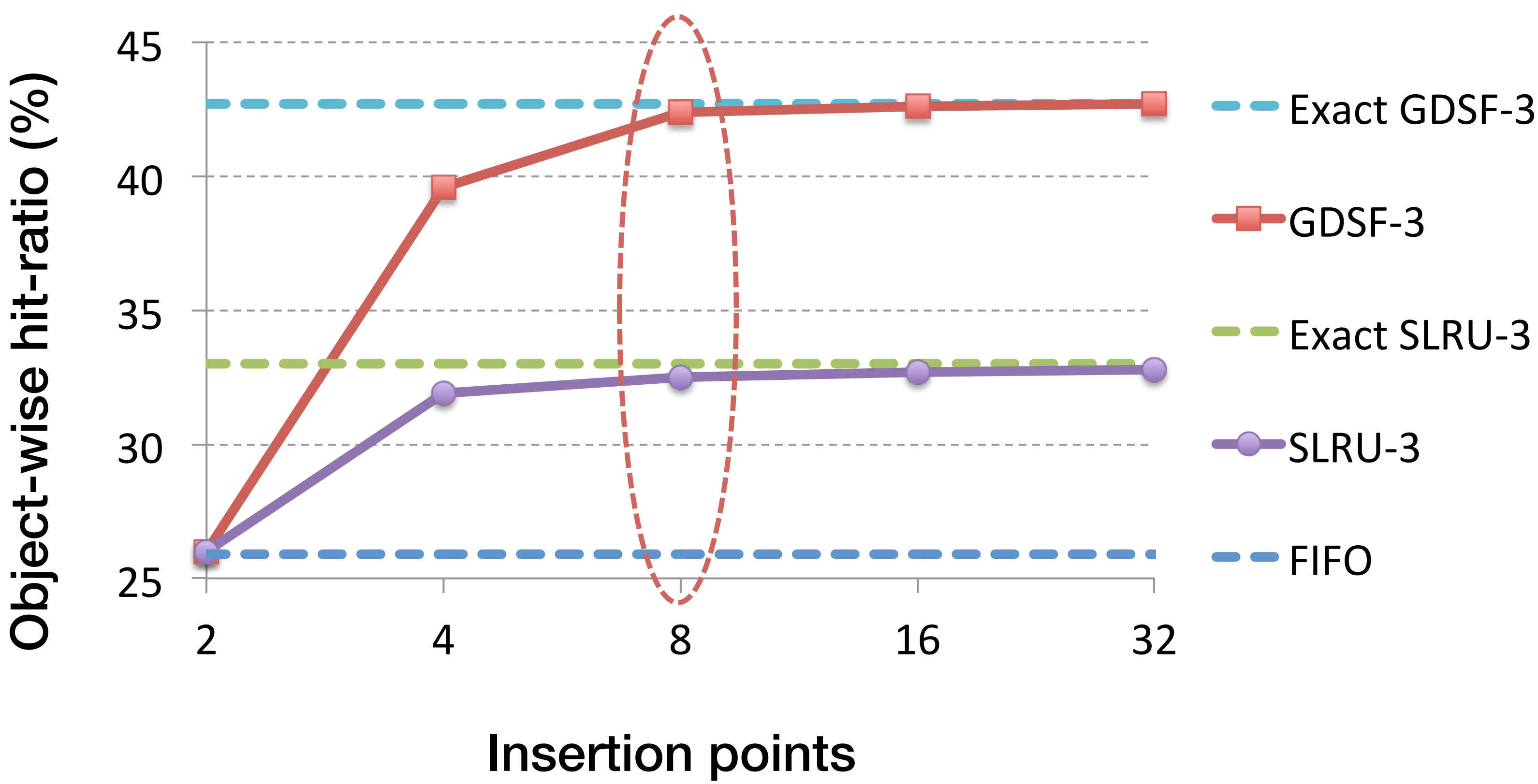
RIPQ Needs Small Number of Insertion Points



RIPQ Needs Small Number of Insertion Points

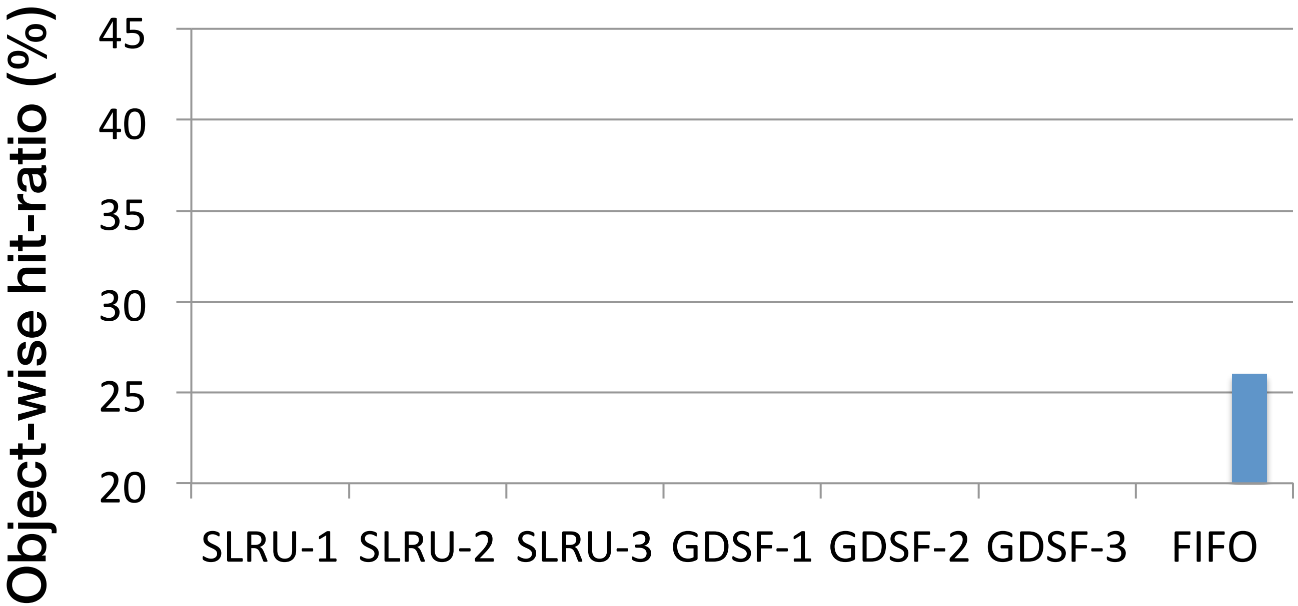


RIPQ Needs Small Number of Insertion Points

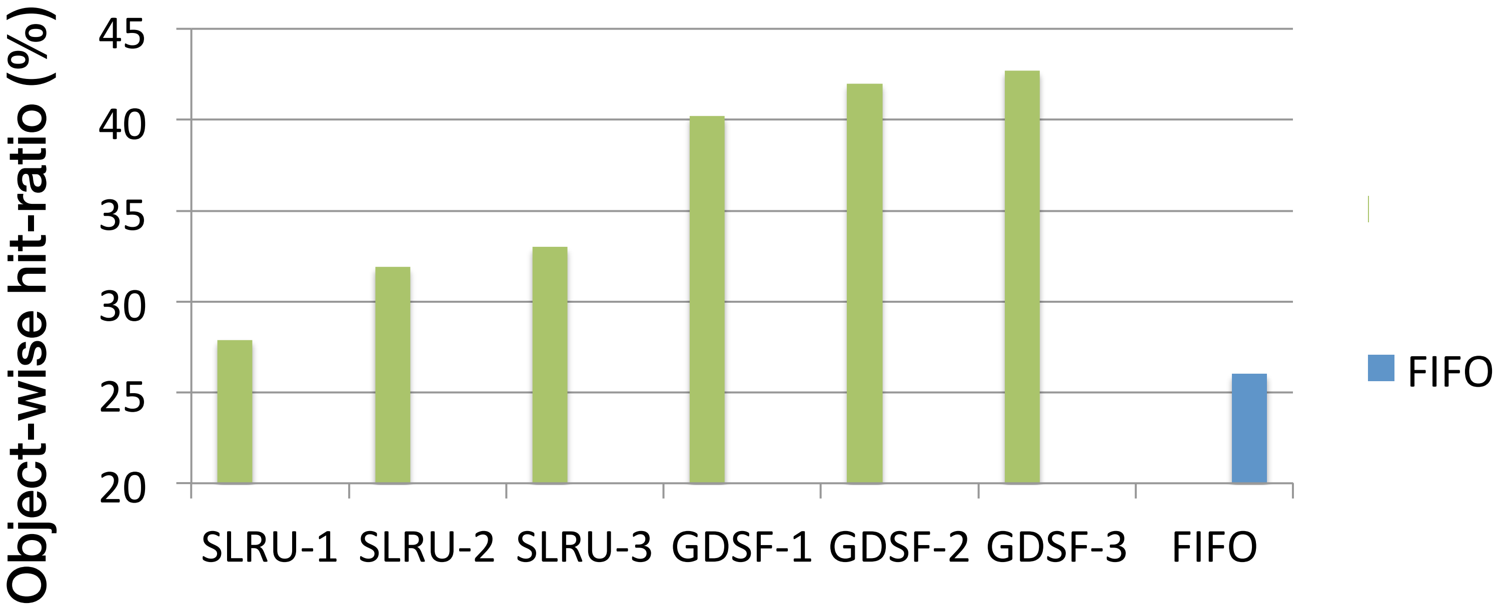


You don't need much RAM buffer (2GiB)!

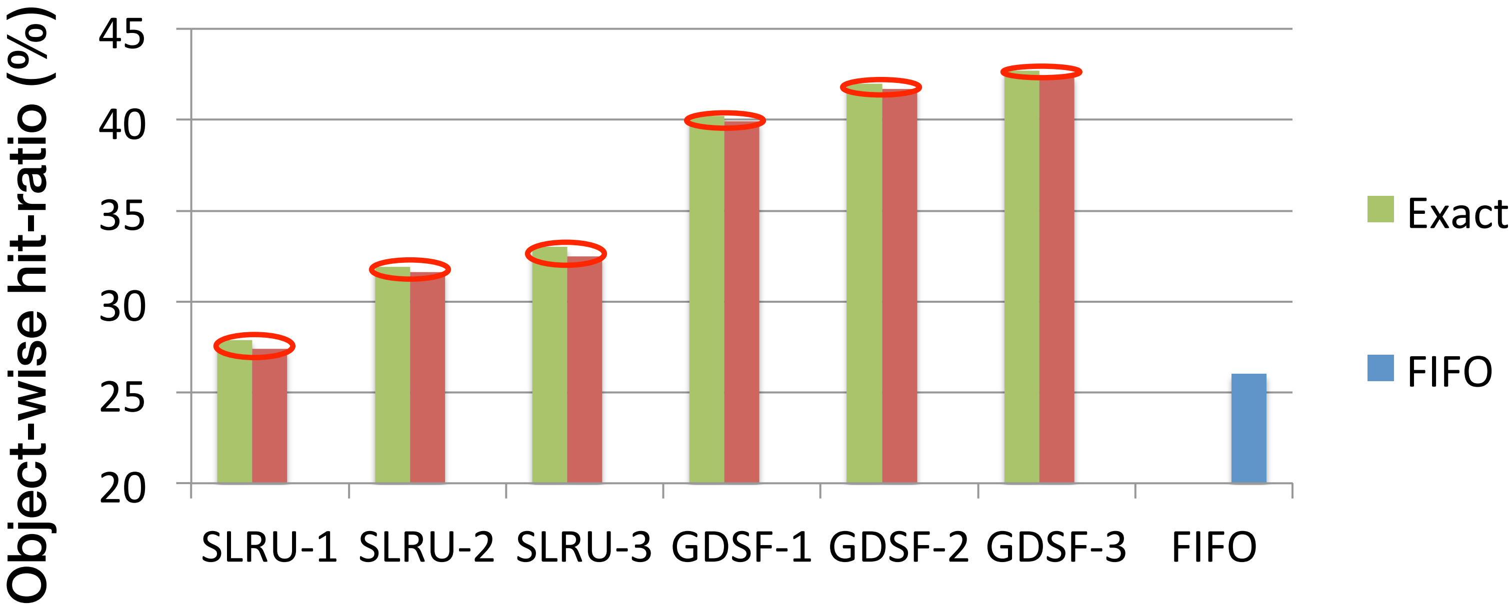
RIPQ Has High Fidelity



RIPQ Has High Fidelity

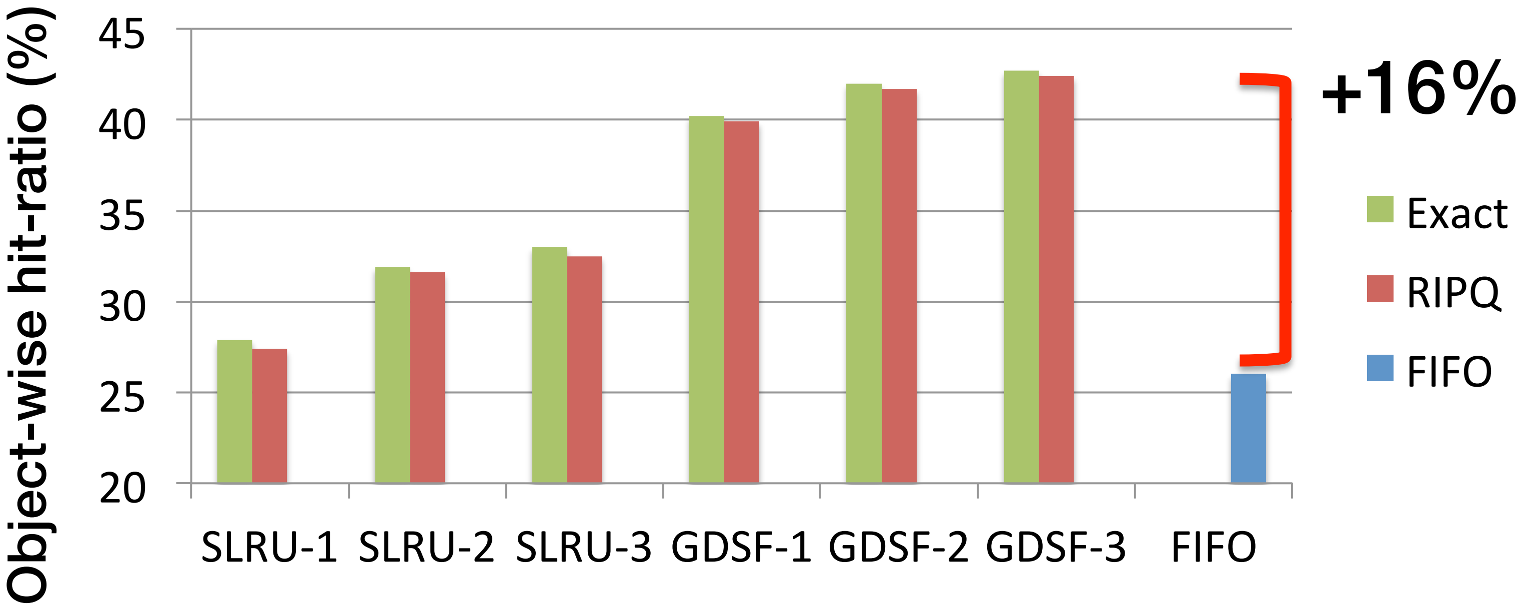


RIPQ Has High Fidelity



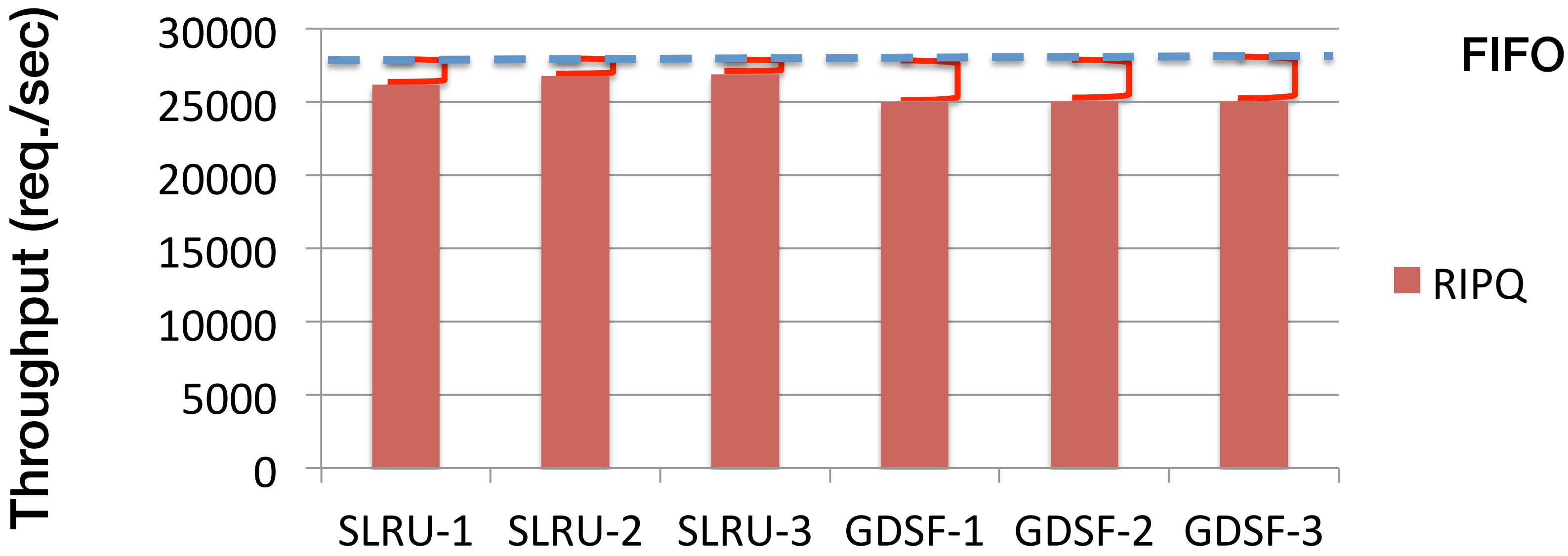
RIPQ achieves ≤0.5% difference for all algorithms

RIPQ Has High Fidelity



+16% hit-ratio ➔ 23% fewer backend IOs

RIPQ Has High Throughput



RIPQ throughput comparable to FIFO (≤10% diff.)

Related Works

RAM-based advanced caching

SLRU(Karedla'94), GDSF(Young'94, Cao'97, Cherkasova'01), SIZE(Abrams'96), LFU(Maffeis'93), LIRS (Jiang'02), ...

RIPQ enables their use on flash

Flash-based caching solutions

Facebook FlashCache, Janus(Albrecht '13), Nitro(Li'13), OP-FCL(Oh'12), FlashTier(Saxena'12), Hec(Yang'13), ...

RIPQ supports advanced algorithms

Flash performance

Stoica'09, Chen'09, Bouganim'09, Min'12, ...

Trend continues for modern flash cards

RIPQ

- First framework for advanced caching on flash
  - Relative priority queue interface
  - Large writes
  - Restricted insertion points
  - Lazy update
  - Section merge/split
- Enables SLRU-3 & GDSF-3 for Facebook photos
  - 10% less backbone traffic
  - 23% fewer backend IOs