FIFO Queues

are all You Need for Cache Eviction

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Software cache and eviction

- Ubiquitous deployments of software caches
  - page cache, block cache, database cache
  - key-value cache, object cache…
- Cache metrics
  - efficiency / effectiveness: miss ratio
  - throughput and scalability: requests/sec
  - simplicity
- A core component of cache design: **eviction**

traffic server™

VARNISH CACHE

Cachelib

Pelikan

ALLUXIO

A long history of research centered around LRU

- Least-recently-used (LRU)
  - maintain objects in a queue with last-access order
  - update metadata (with locking) on each read request
- Problems
  - not scalable
  - not scan-resistant

A long history of research centered around LRU

- Improve LRU's efficiency
  - **add more techniques/queues/metrics**: LIRS[SIGMETRICS'02], LRU-K[SIGMOD'93], 2Q[VLDB'94], MQ[ATC'01], ARC[FAST'03], TinyLFU[TOS'17], LRB[NSDI'20], CACHEUS[FAST'21]…
  - sacrifice throughput and/or scalability
- Improve LRU's throughput and scalability
  - **reduce #operations/locks per-request**: relaxed LRU, CLOCK variants[NSDI'13], FrozenHot[Eurosys'23]
  - conventional wisdom: sacrifice efficiency, our finding[HotOS'23] shows not true
- **State-of-the-arts: tradeoff between efficiency and throughput**

[HotOS'23] FIFO queues can be better than LRU

An alternative: FIFO eviction algorithm

- First-in-first-out (FIFO)
  - simpler
  - fewer metadata
  - less computation
  - more scalable
  - flash-friendly

Can we design an efficient FIFO-based algorithm?

Observation

More one-hit wonders than you would have expected

- One-hit wonder: objects appeared once in the sequence
- Zipfian workloads: One-hit-wonder ratio **decreases with sequence length (measured in #obj)**
- Why short sequences? A cache starts eviction after seeing a short request sequence

start time	end time	sequence length (# objects)	# one-hit wonder	one-hit wonder ratio
1	17	5	1 (E)	20%
1	7	4	2 (C, D)	50%
1	4	3	2 (B, C)	66%

Observation

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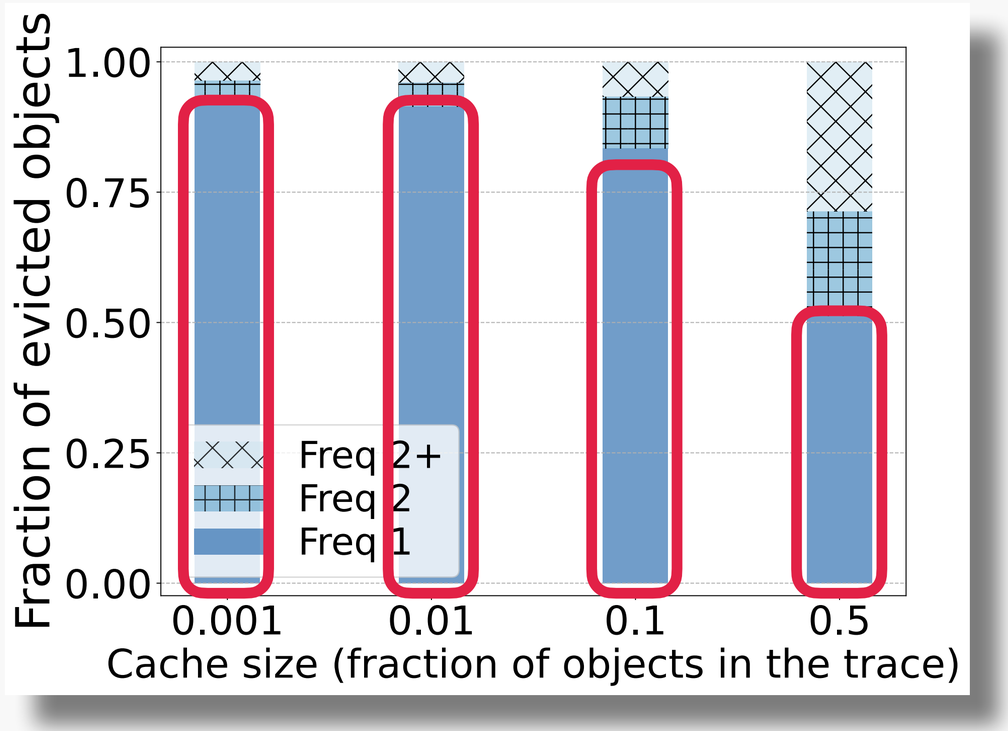
the one-hit-wonder ratio of 10% of week-long traces:

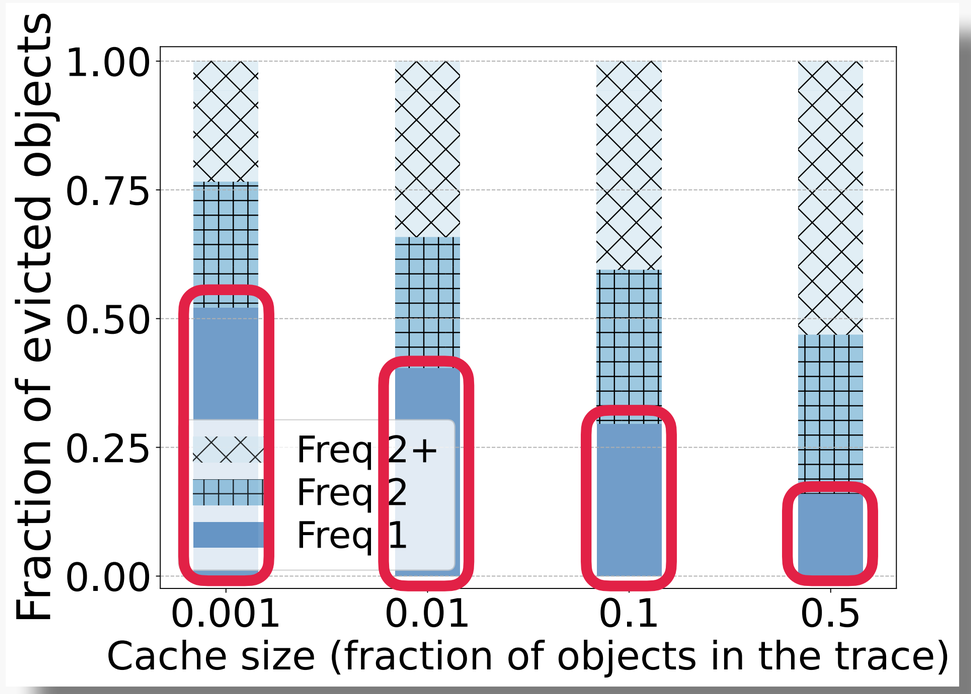
72% (mean on **6594** traces)

Observation

most objects in the cache are one-hit wonders



LRU cache running MSR workload



LRU cache running Twitter workload

S3-FIFO Design

Simple, Scalable caching with three Static FIFO queues

https://s3fifo.com

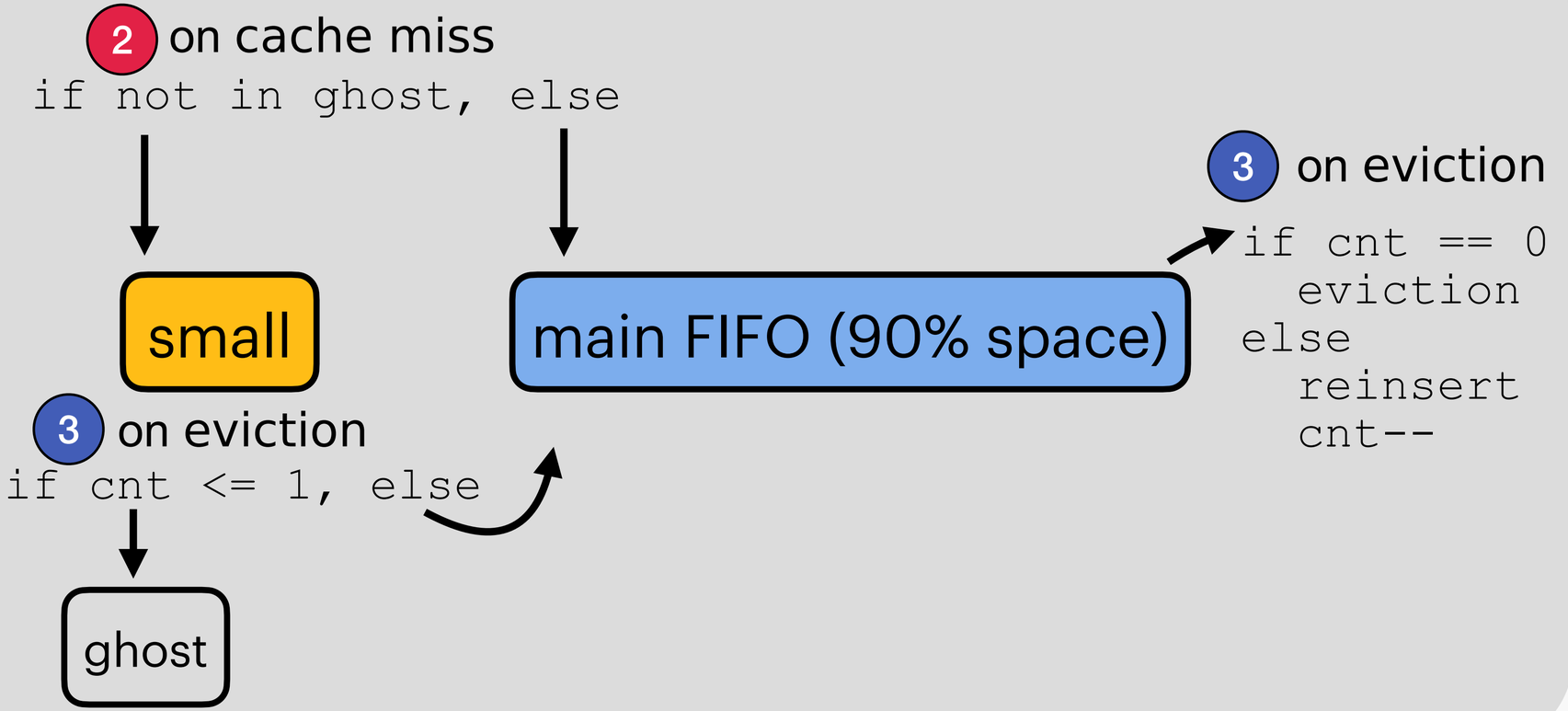
S3-FIFO design

Simple, Scalable eviction algorithm with three Static FIFO queues

```
struct object {
  …
  uint8_t cnt:2;
}
```

1 on cache hit

```
cnt++
```



*using 1-bit flag also is sufficient for most workloads

S3-FIFO features

- **Simple and robust:** static queues
- **Fast**: no metadata update for most requests
- **Scalable**: no lock
- **Tiny metadata**: 2 bits
- **Flash-friendly**: sequential writes

Implementation: one, two or three FIFO-queues

S3-FIFO evaluation

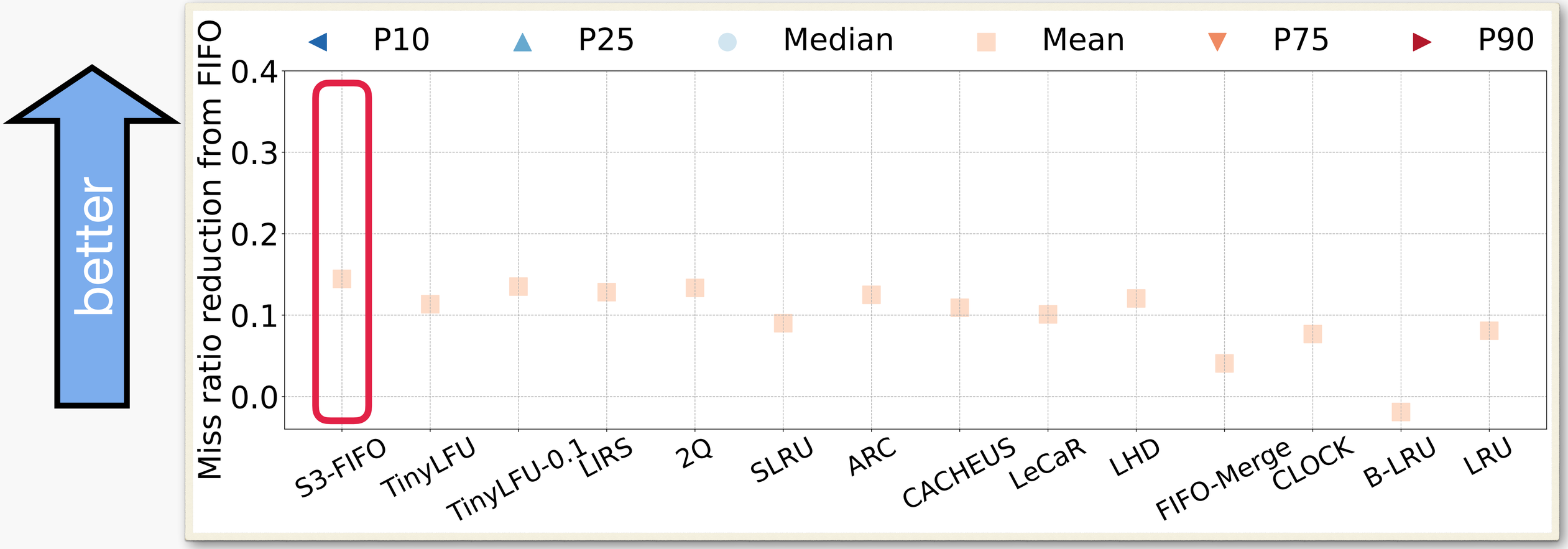
Evaluation setup

- Data
  - 14 datasets, **6594** traces from Twitter, Meta, Microsoft, Wikimedia, Tencent, Alibaba, major CDNs…
  - **848 billion** requests, **60 billion** objects
  - collected between 2007 and 2023
  - block, key-value, object caches
- Platform
  - libCacheSim, cachelib
  - CloudLab with 1 million core·hours
- Data and software are all open-sourced
- Metric
  - miss ratio reduction from FIFO
  - throughput in Mops/sec

CloudLab

Efficiency

Miss ratio reduction distribution across all traces



Efficiency

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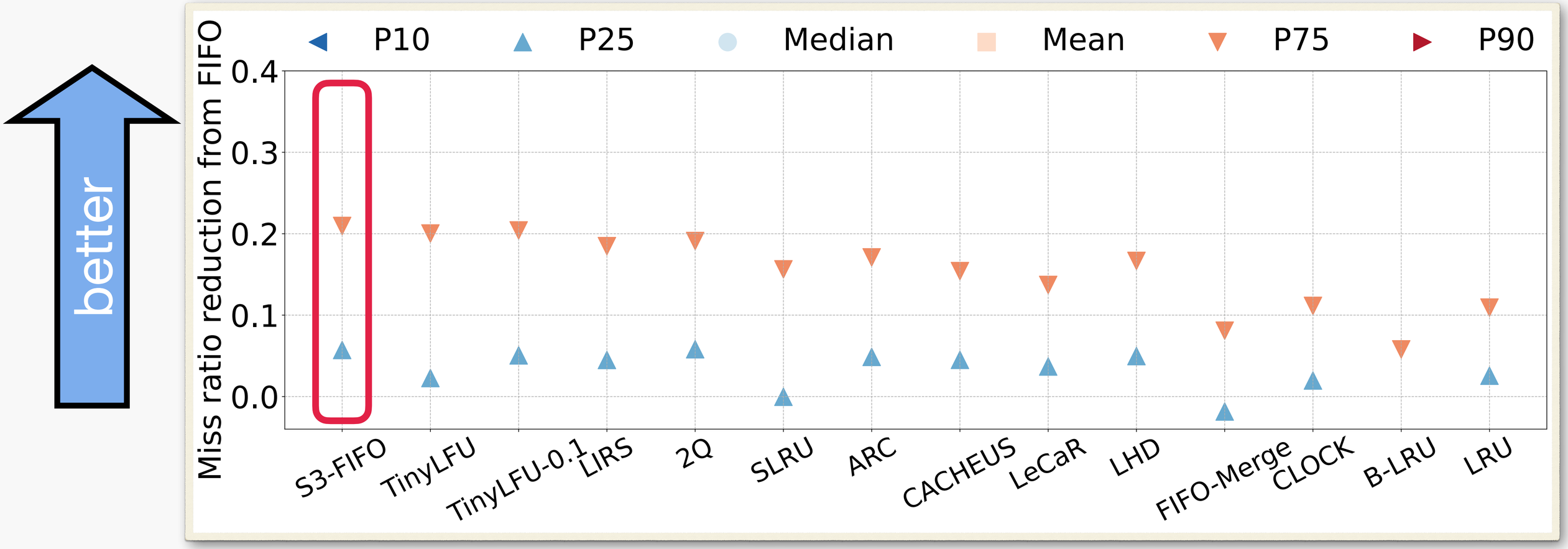

Efficiency

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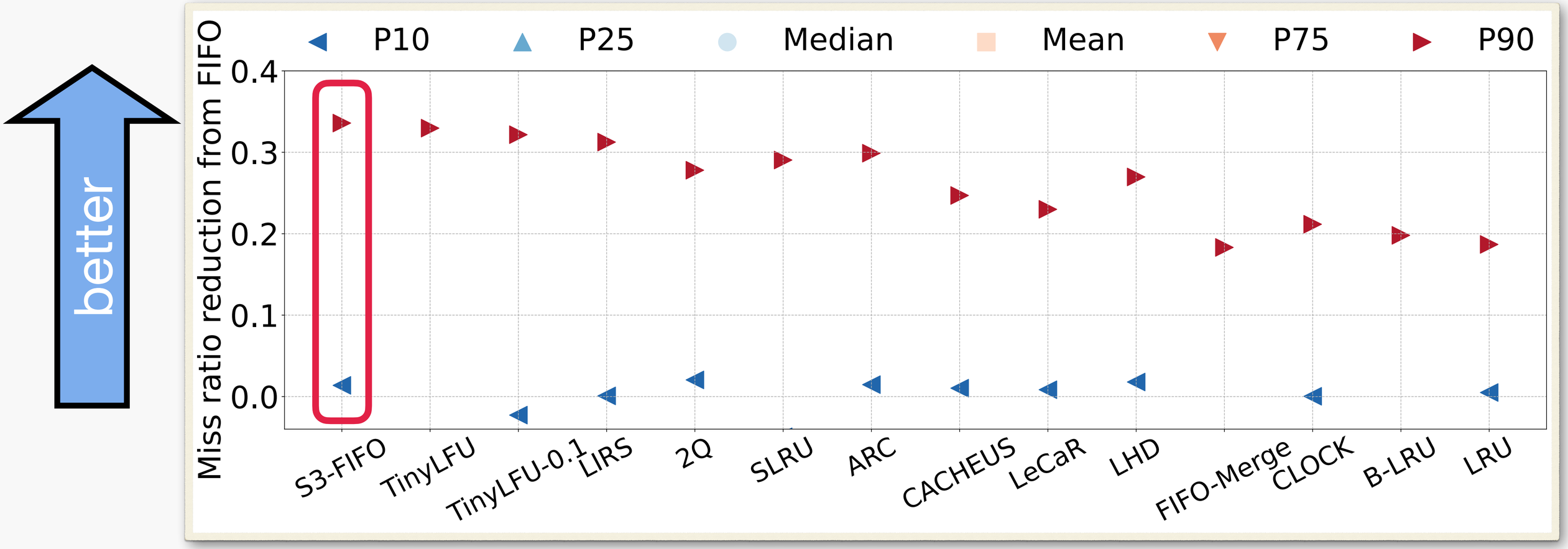

Efficiency

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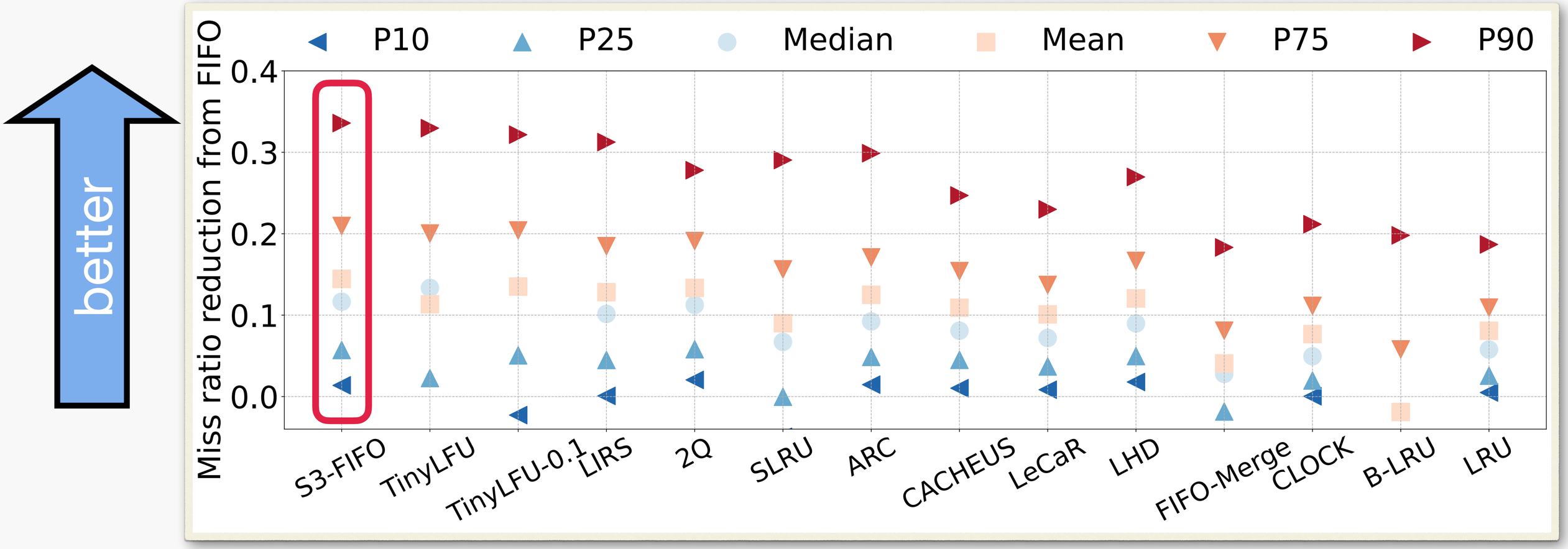
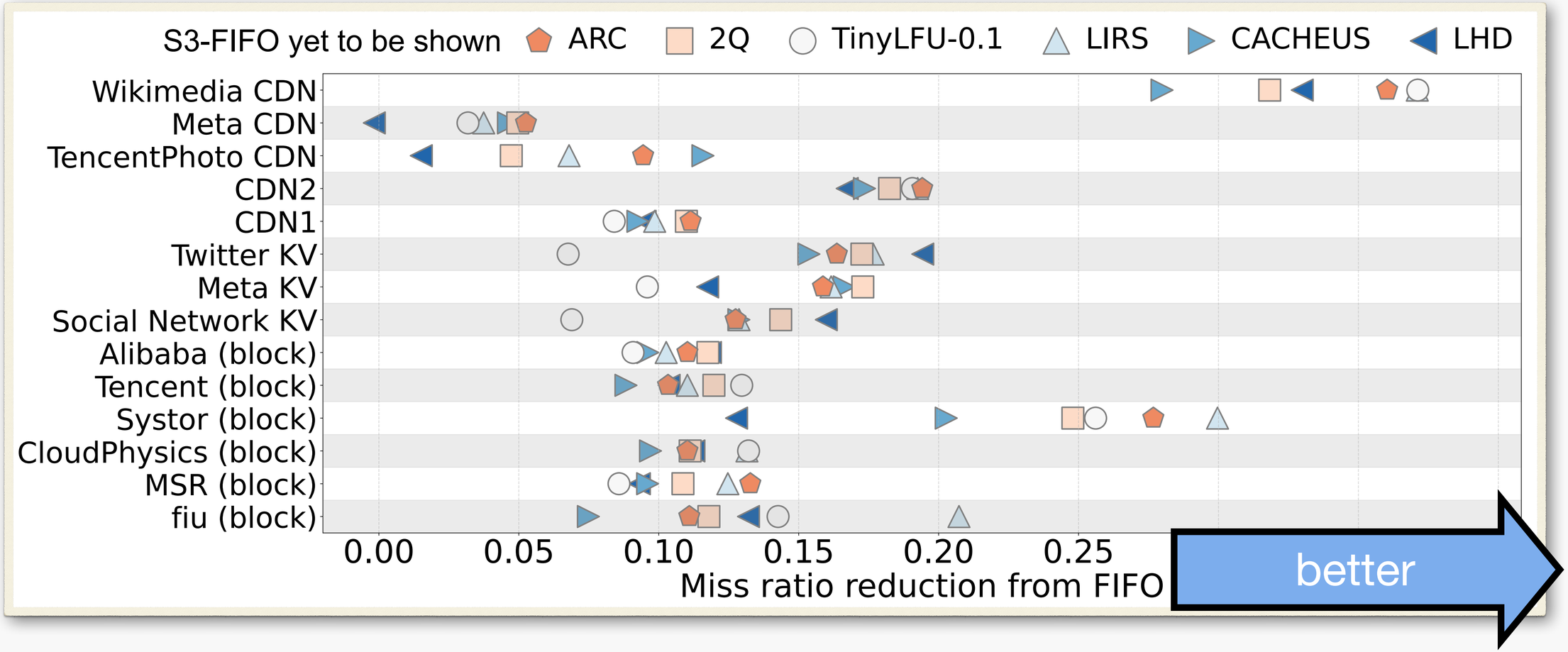


More efficient than state-of-the-art algorithms, up to 72% lower miss ratio than LRU

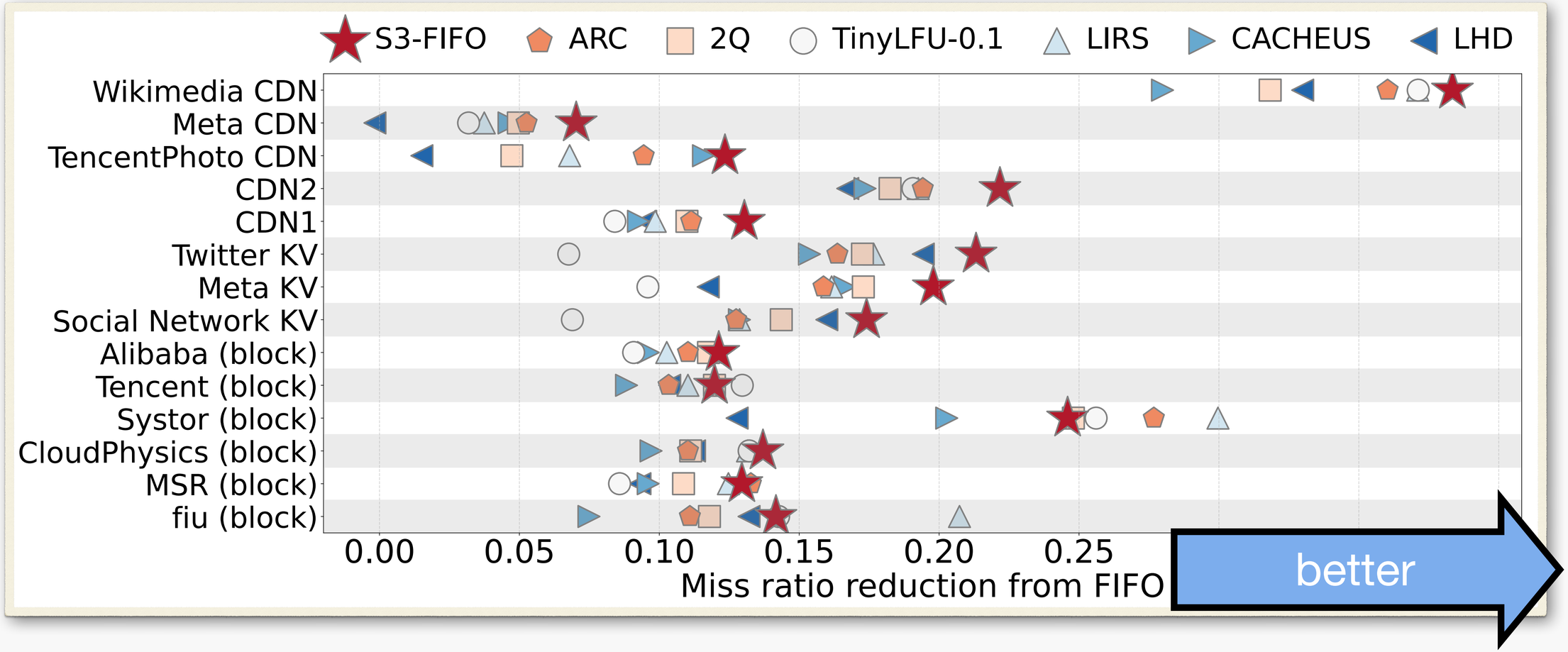
Efficiency

Mean miss ratio reduction on each dataset



Efficiency

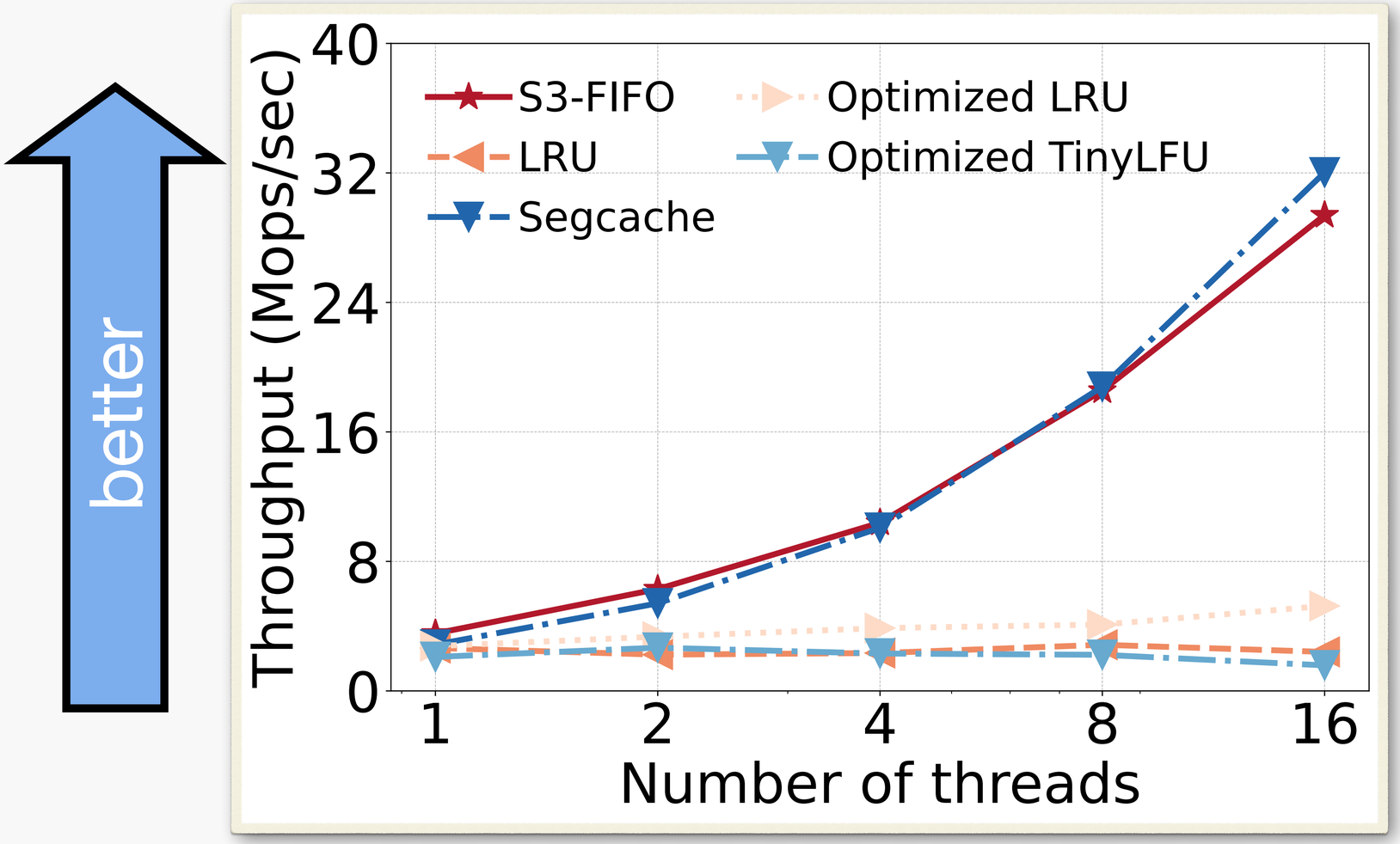
Mean miss ratio reduction on each dataset



- **efficient**: the best algorithm or is close to the best
- **robust**: the best on 10 of the 14 datasets

Throughput and scalability

Zipf workloads

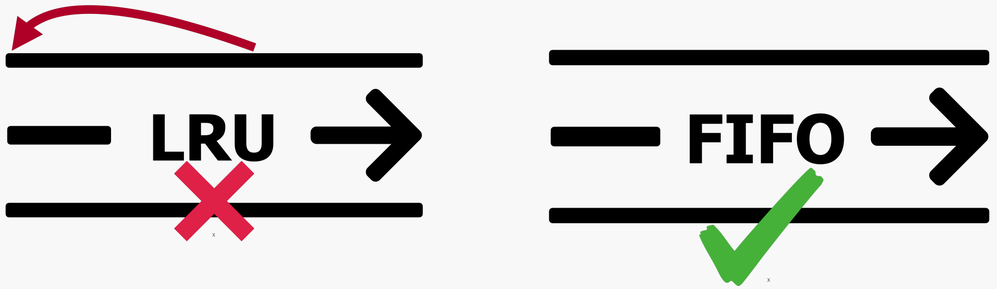


- the fastest on a single thread
- more scalable than optimized LRU, 6x higher throughput
- close to Segcache[NSDI'21]

More in the paper

- Why S3-FIFO is effective
- Implication for flash cache
- Byte miss ratio results
- Impact of FIFO sizes
- What if we replace FIFO with LRU

Takeaway



- **Cache workloads exhibit high one-hit-wonder ratio**
  - most objects in the cache are not re-accessed before being evicted
  - critical to remove the one-hit wonders early
- **S3-FIFO**: **s**imple, **s**calable caching with **three** **s**tatic **FIFO** queues
  - reinsertion to keep popular objects, a small FIFO queue to *quickly* filter out one-hit wonders
  - adoption
    - being evaluated at Google, VMWare, Cloudflare, Kuaishou, etc.
    - Python/C++/Rust version of S3-FIFO on GitHub implemented by external parties

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https://s3fifo.com

https://github.com/Thesys-lab/sosp23-s3fifo