GL-Cache: Group-level learning for efficient and high-performance caching

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What location are they going?

Grouping and the context make prediction easier!

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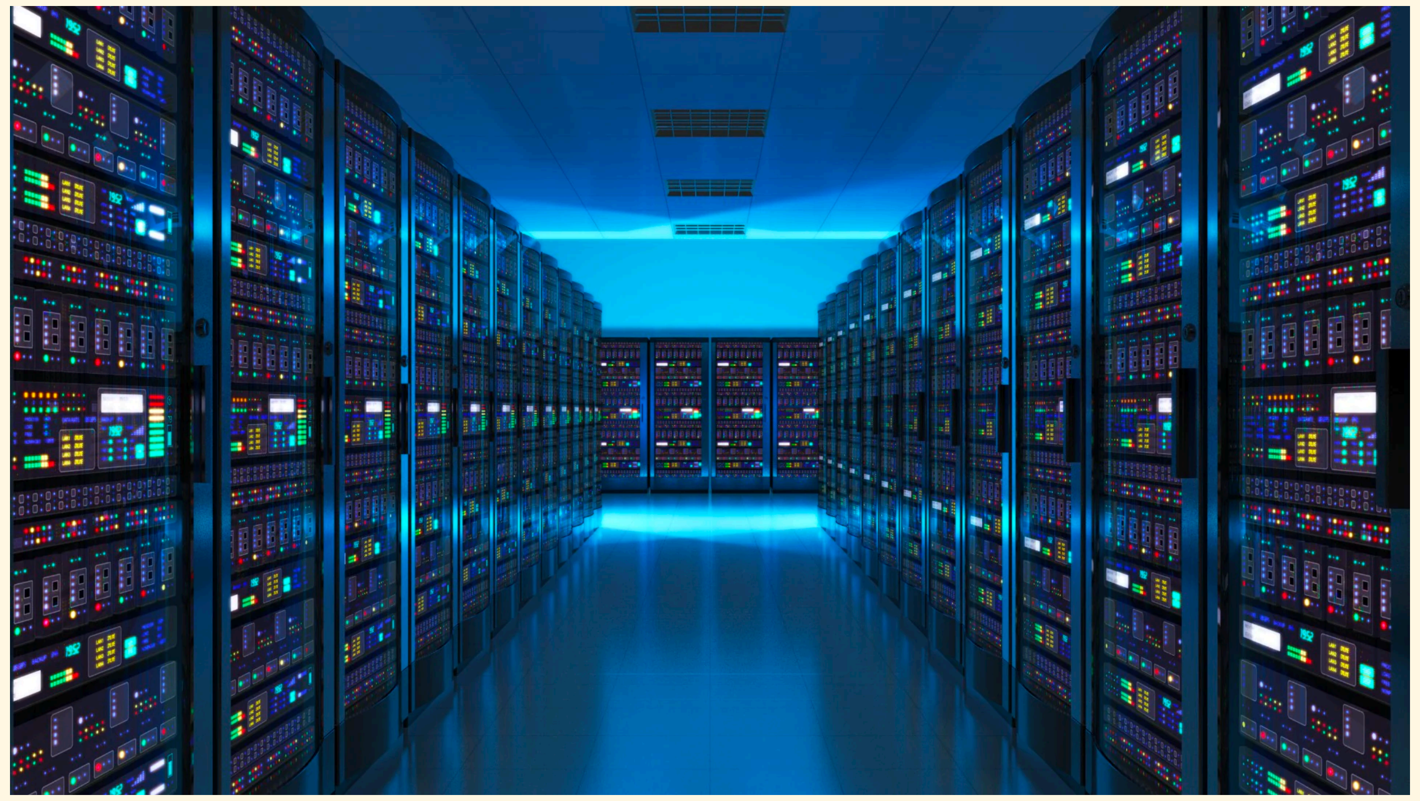
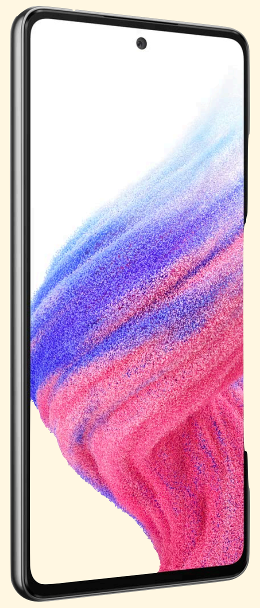
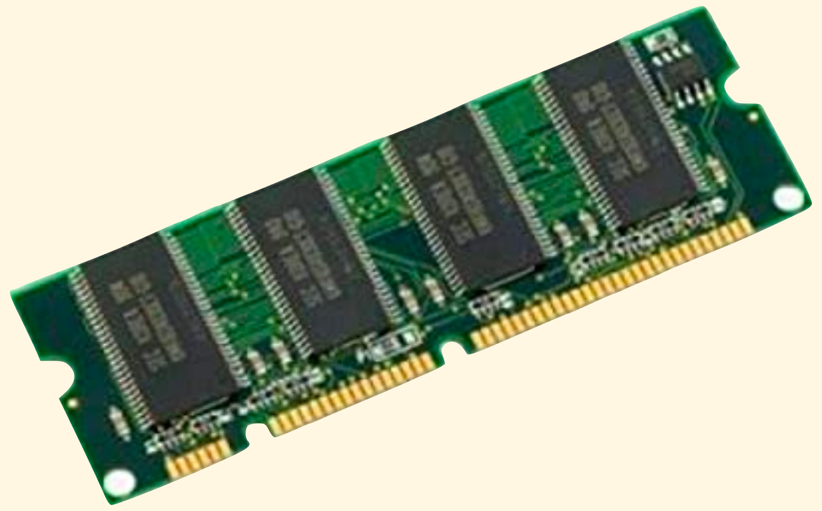
Introduction

Ubiquitous caching

- Different types of caches
  - Block/page cache
  - Key-value cache
  - Object cache (CDN cache)
- Different deployments
  - Data center
  - PC/mobile phone





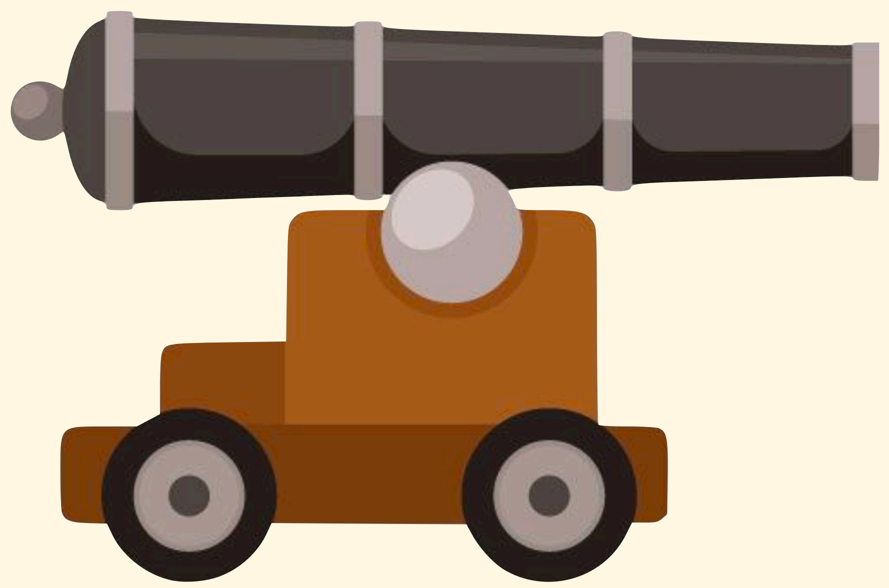


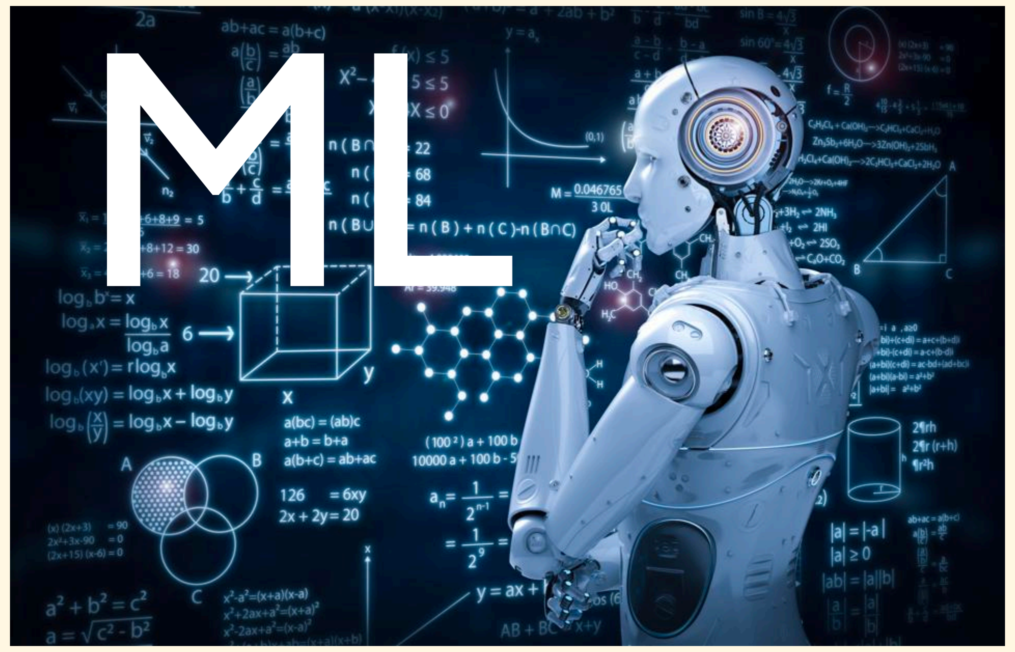
Introduction

Metrics of a cache system

- Efficiency
  - Measured by hit/miss ratio

- Performance
  - Measured by requests/sec



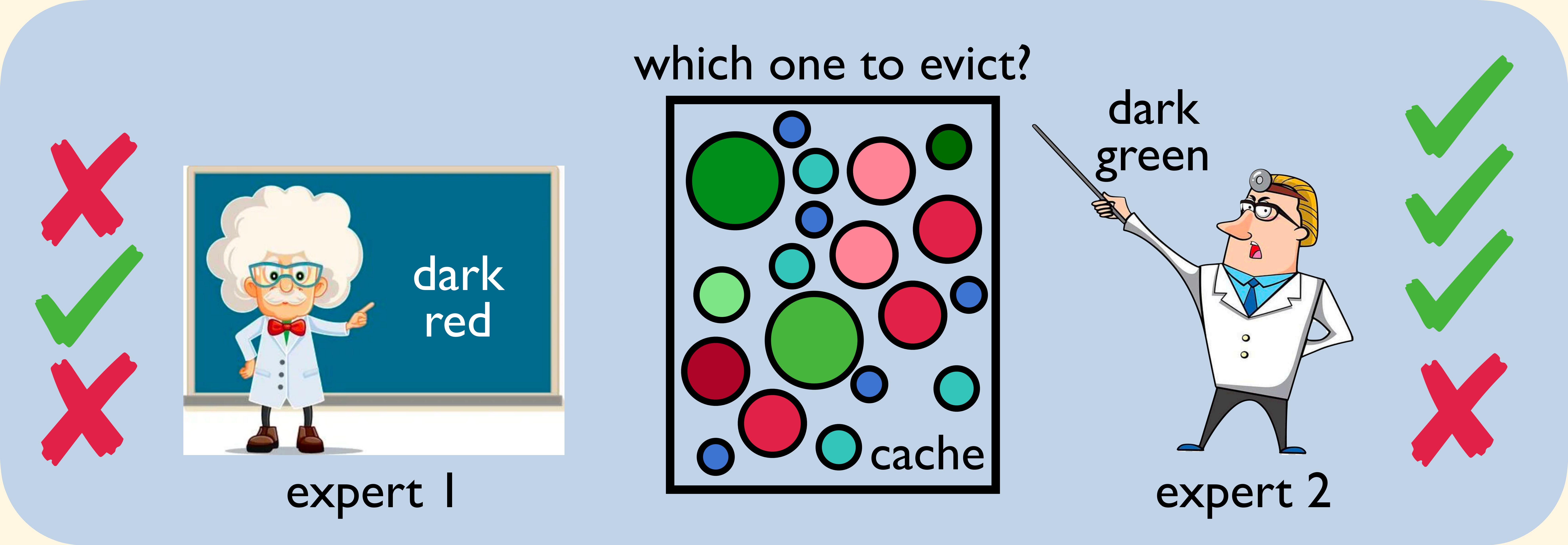


learned cache

Introduction

Learning from simple experts (e.g., LeCaR[1])

Learned caches



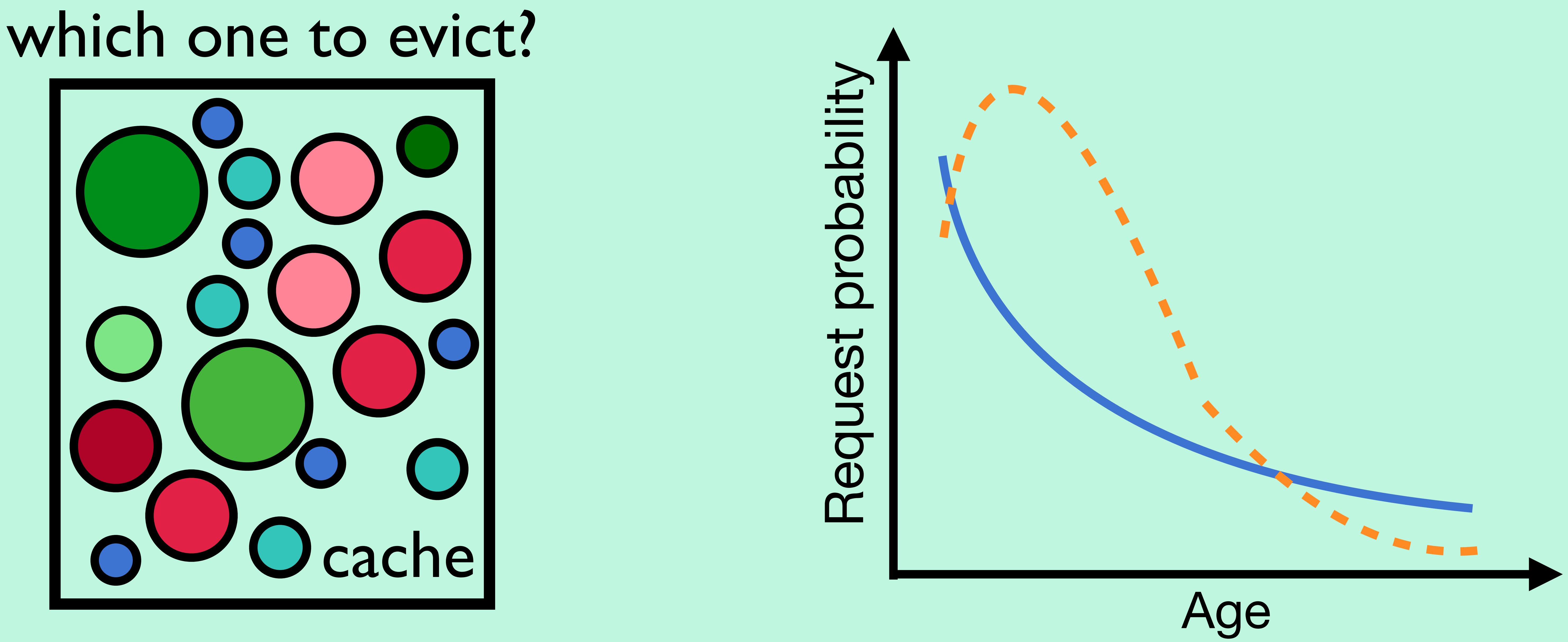
maintain two sets of metadata is expensive and complex
delayed reward

[1] Vietri, Giuseppe, et al. "Driving Cache Replacement with ML-based LeCaR." *HotStorage*. 2018.

Introduction

Learning from distribution (e.g., LHD[2])

Learned caches



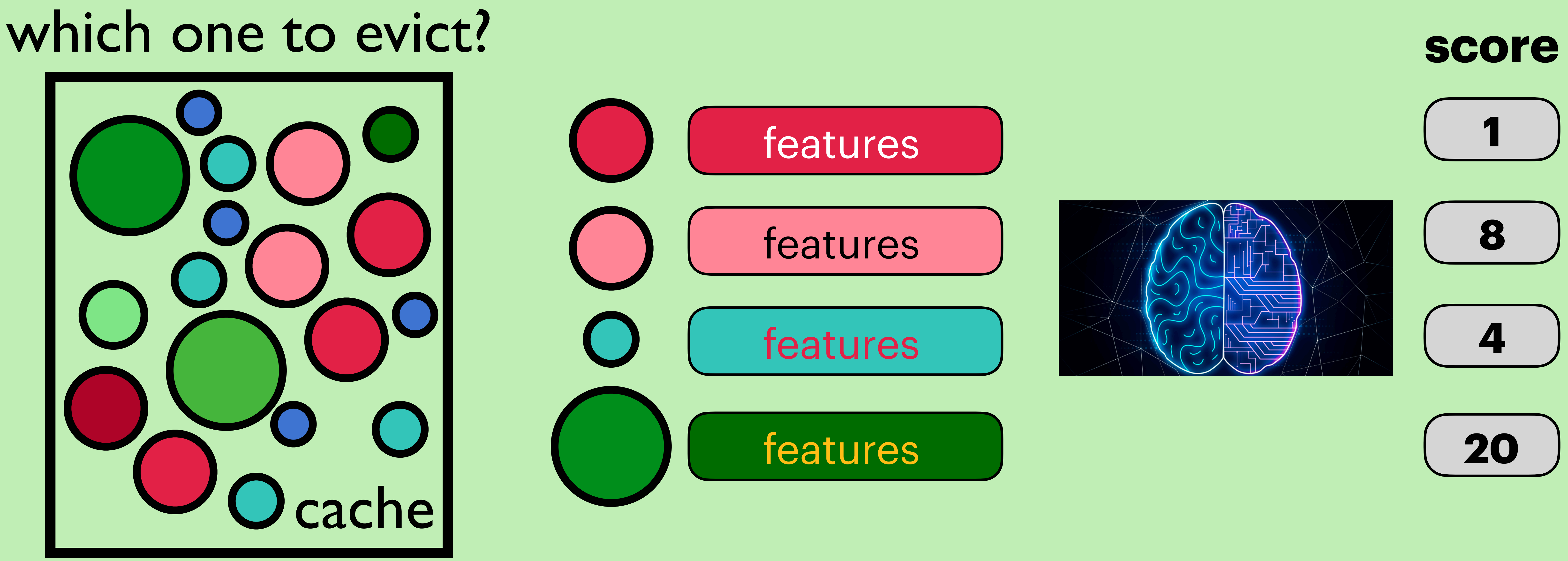
can only use limited number of features => low efficiency upper bound
require sampling many objects to compare at each eviction => low throughput

[2] Beckmann, Nathan, et al. "LHD: Improving Cache Hit Rate by Maximizing Hit Density." *NSDI*. 2018.

Introduction

Object-level learning (e.g., LRB[3])

Learned caches



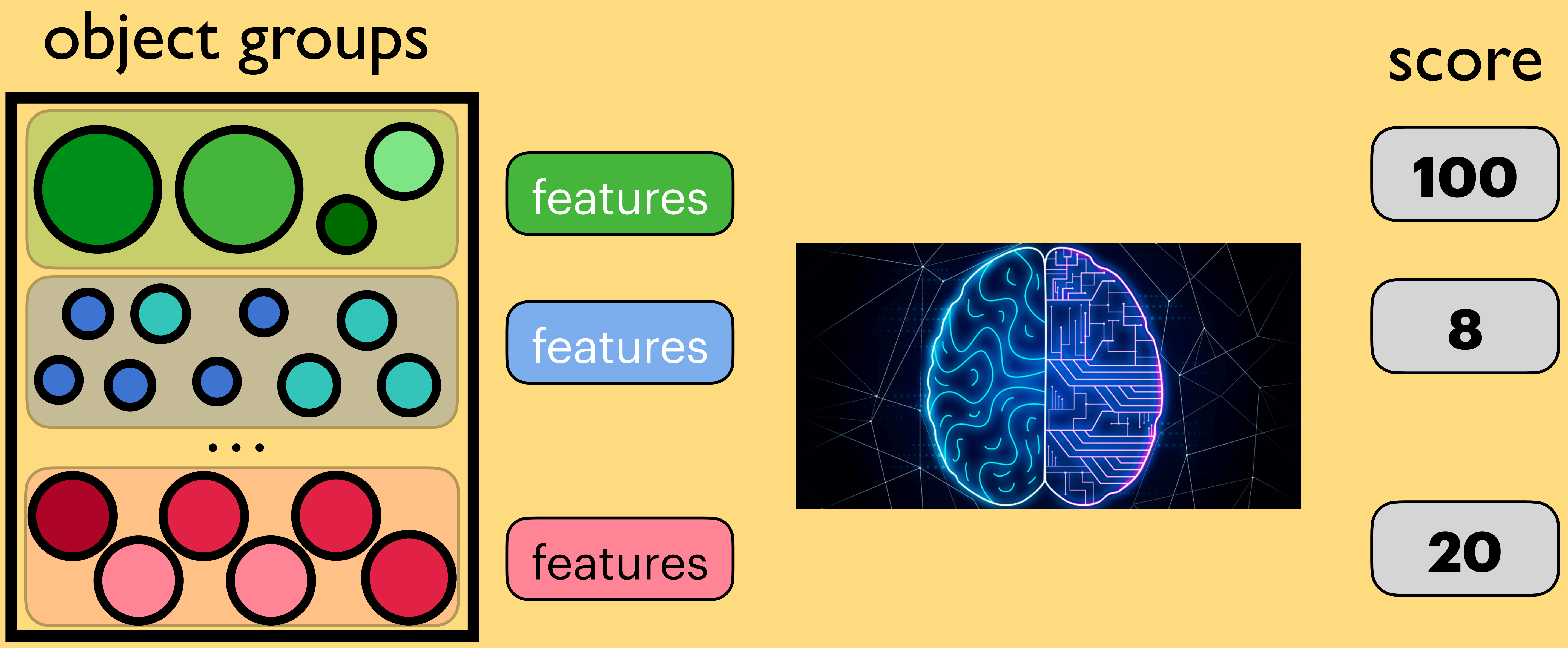
leverage more features than other learned caches
sampling and inference at each eviction => very very very **slow**

[3] Song, Zhenyu, et al. "Learning relaxed belady for content distribution network caching." *NSDI* 2020.

GL-Cache: a group-level learned cache

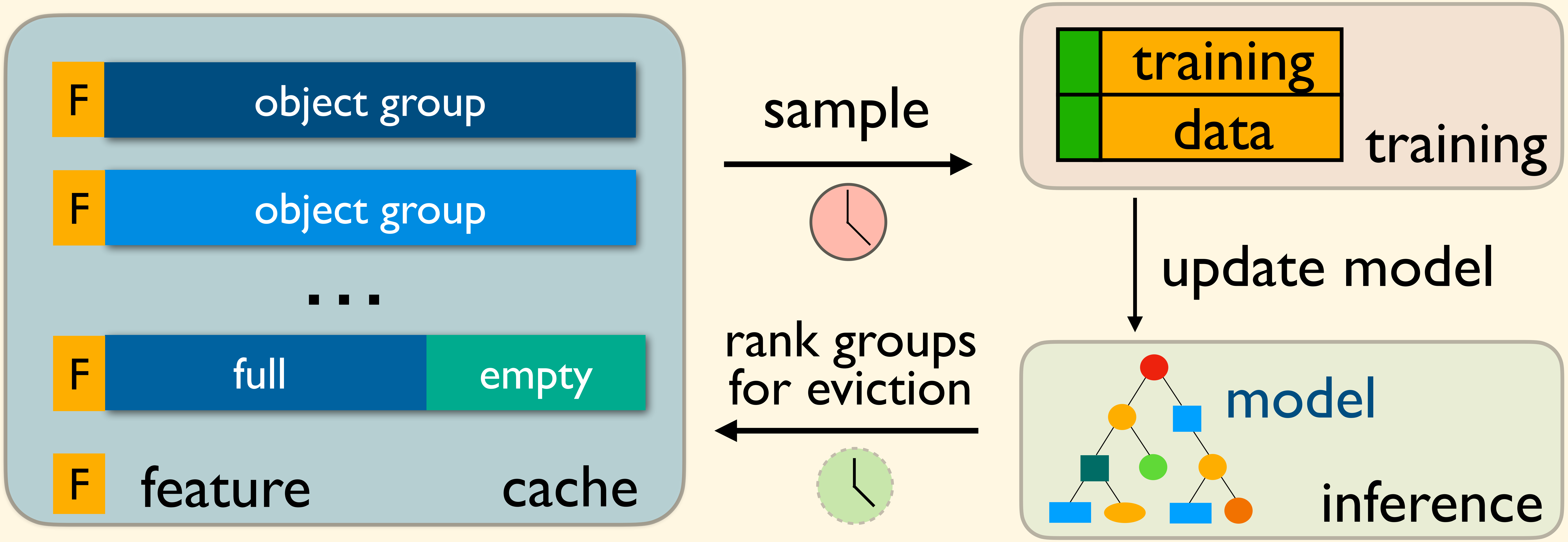
New idea

Group-level Learning (this work)



utilizes multiple features, while amortizes overheads
groups accumulate more information and are easier to learn

GL-Cache architecture

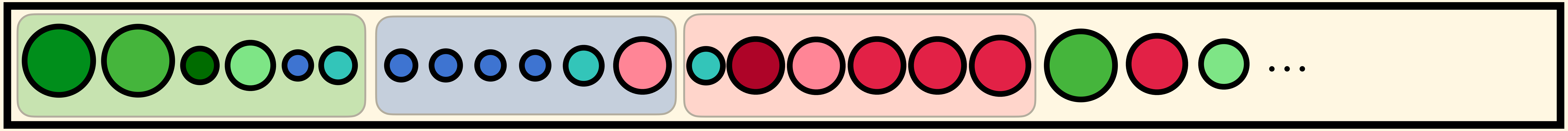


Design decision

- **How** does GL-Cache **group** objects
- **What** does GL-Cache **learn**
- **How** does GL-Cache **learn**
- **How** does GL-Cache **evict**

How does GL-Cache group objects

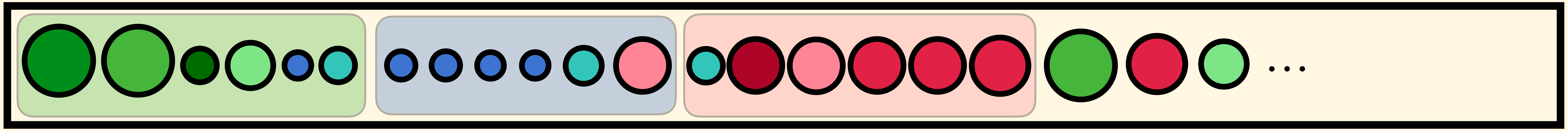
Insertion-time-based grouping



- Why?
  - objects inserted at similar time are similar
  - simple and generally applicable
  - can be implemented on segment/log-structured storage
- But other grouping can also be supported

What does GL-Cache learn

A new utility function



Which group is a better eviction candidate?

- Quantify the usefulness of object groups
- Properties desired
  - smaller object -> larger utility
  - sooner-to-be-accessed -> larger utility
  - group size one -> Belady's MIN (weighted by size)
  - easy and accurate to track online

object utility at time *t*

$$U_o(t) = \frac{1}{T_o(t) \times s_o}$$

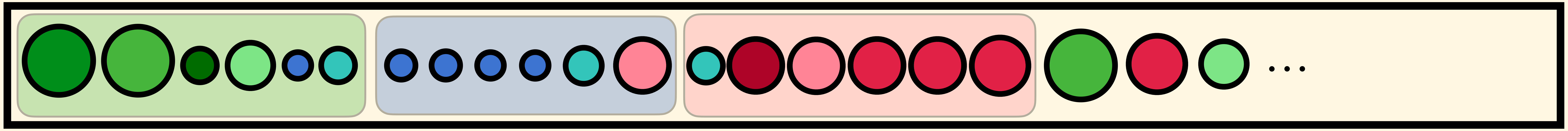
group utility

$$U_{group}(t) = \sum_{o \in group} \frac{1}{T_o(t) \times s_o}$$

$T_o(t)$ time till next request since *t*
s_o object size
* requires future information

How does GL-Cache learn

Features and model



- Dynamic
  - #requests
  - #active objects
- Static
  - write rate at insertion time
  - miss ratio at insertion time
  - request rate at insertion time
  - mean object size
  - age

} contextual features

- Model: gradient boosting tree with regression as the objective

How does GL-Cache use the model

Inference

each ranking result is used to evict a fraction of groups
pick the group with the lowest utility and the groups inserted after it

GL-Cache evaluation

Evaluation setup

- Traces
  - 103 Cloudphysics traces
  - 14 MSR traces
  - 1 Wikipedia trace
- Micro-implementation based on libCacheSim
  - LRU, CACHEUS, LHD, LRB
- Prototype implemented from Segcache
  - Cachelib (LRU), LHD, TinyLFU

- Two modes of GL-Cache:
  - GL-Cache-E, GL-Cache-T
- Metrics
  - hit ratio increase over FIFO
  - throughput relative to FIFO

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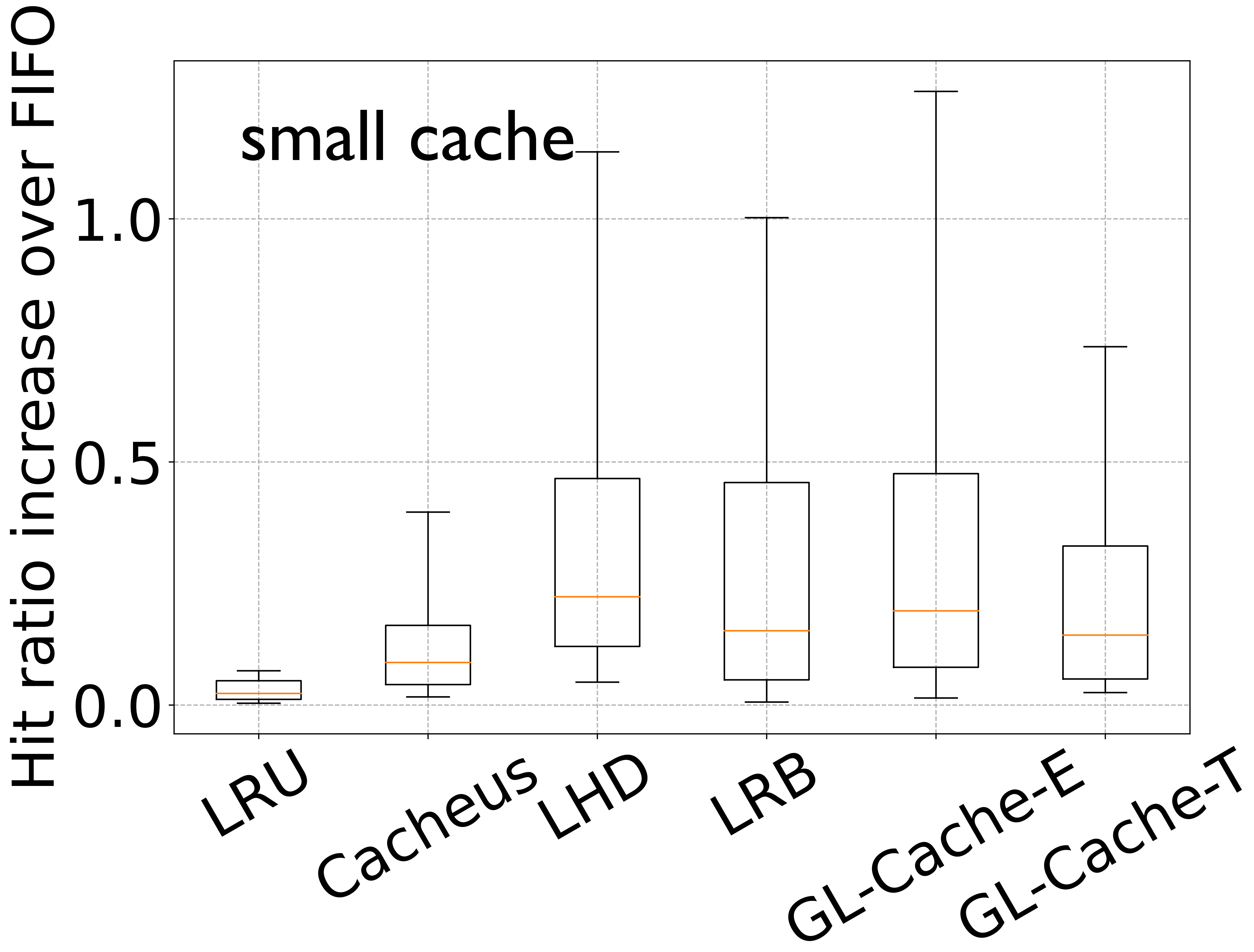
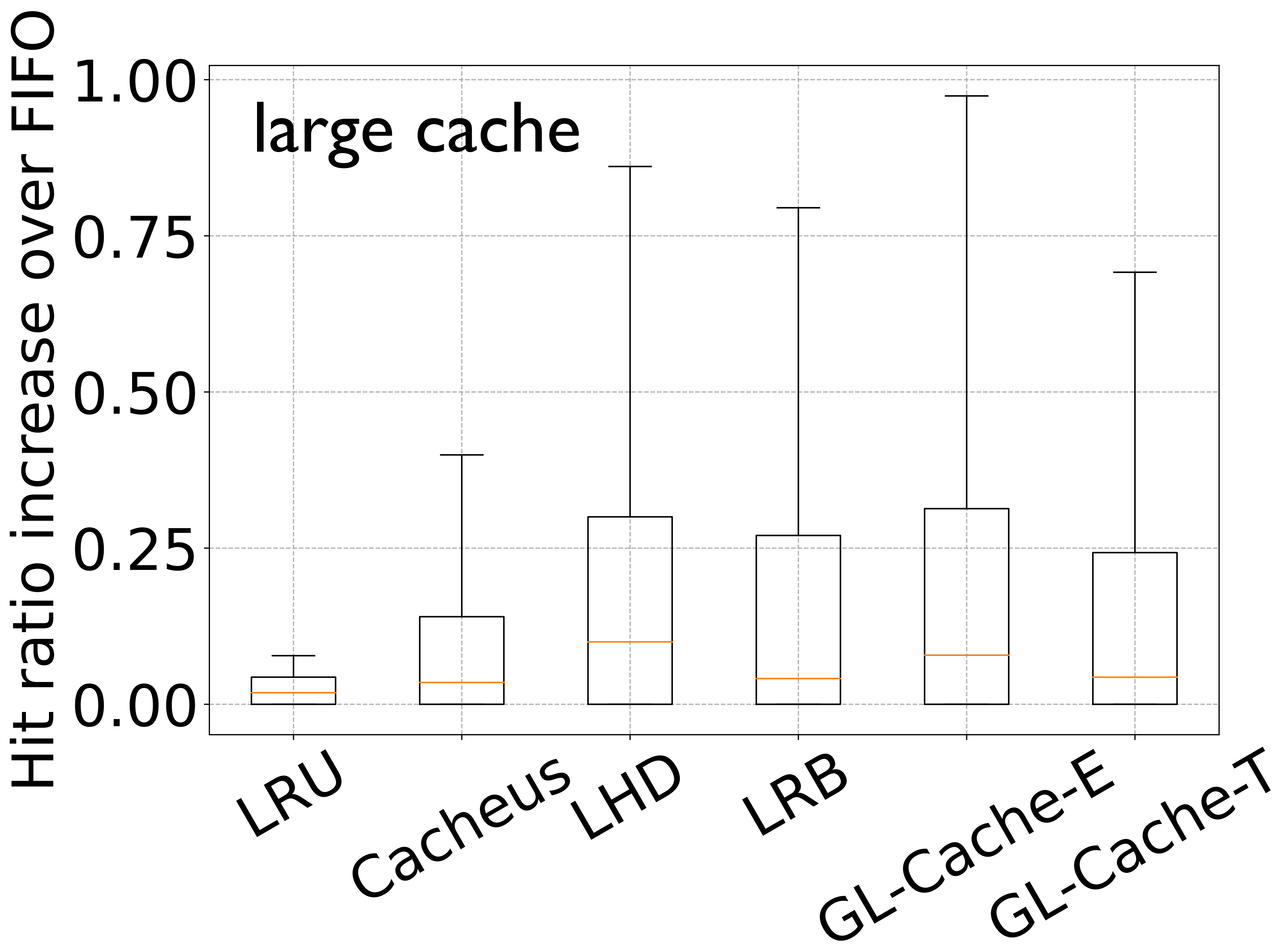
Efficiency

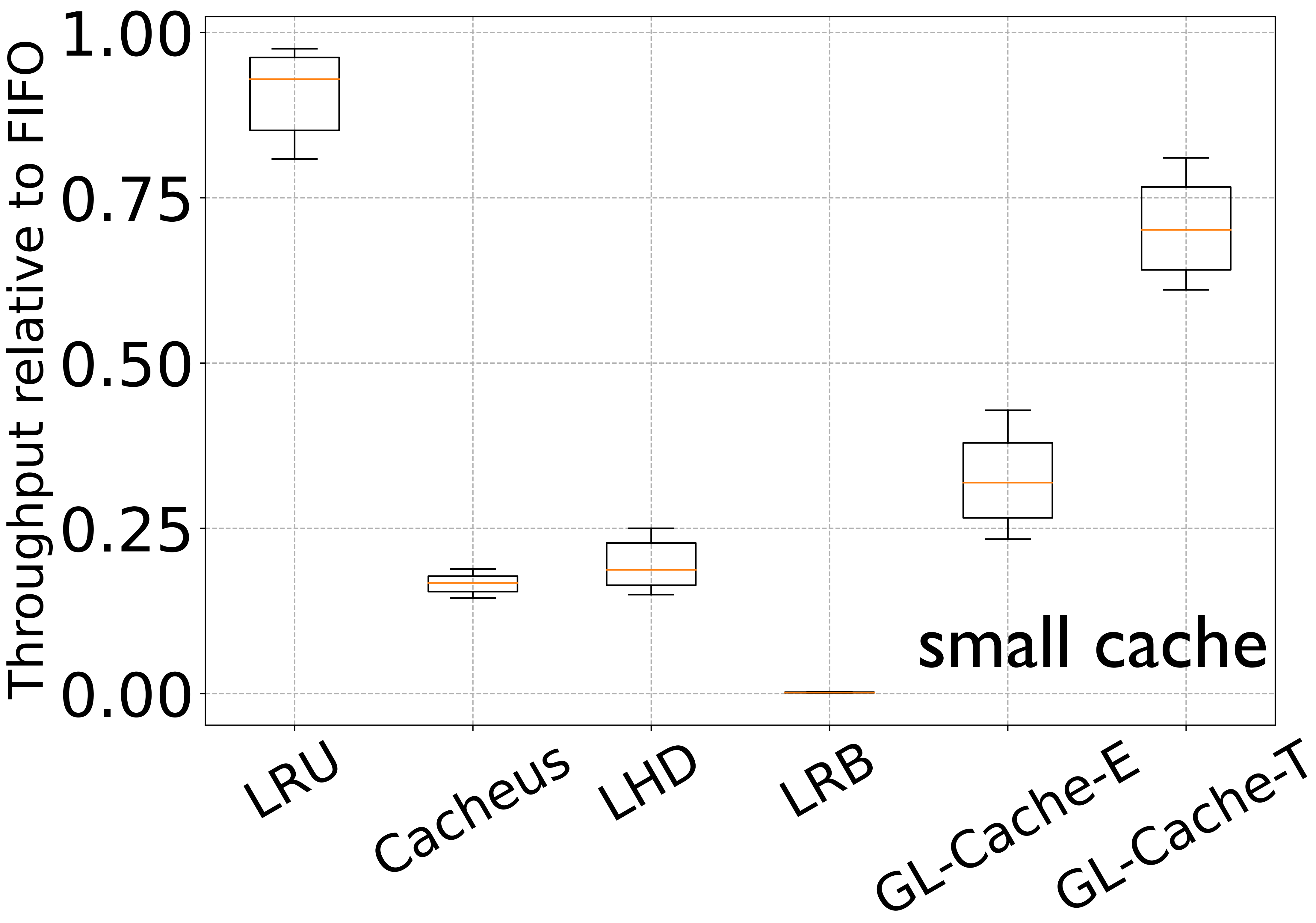
GL-Cache-E is slightly better than state-of-the-art algorithms
GL-Cache-T is close to LRB

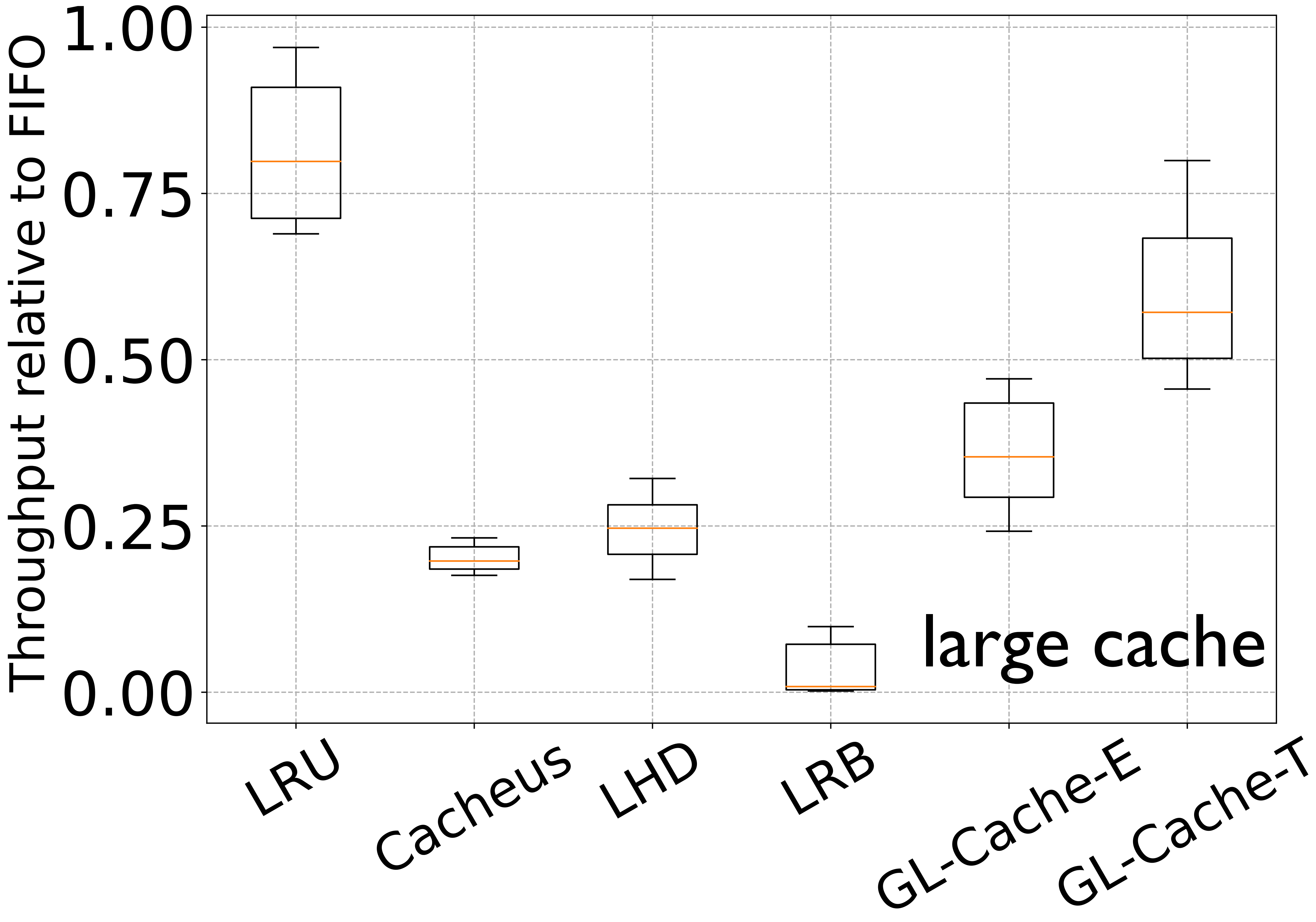




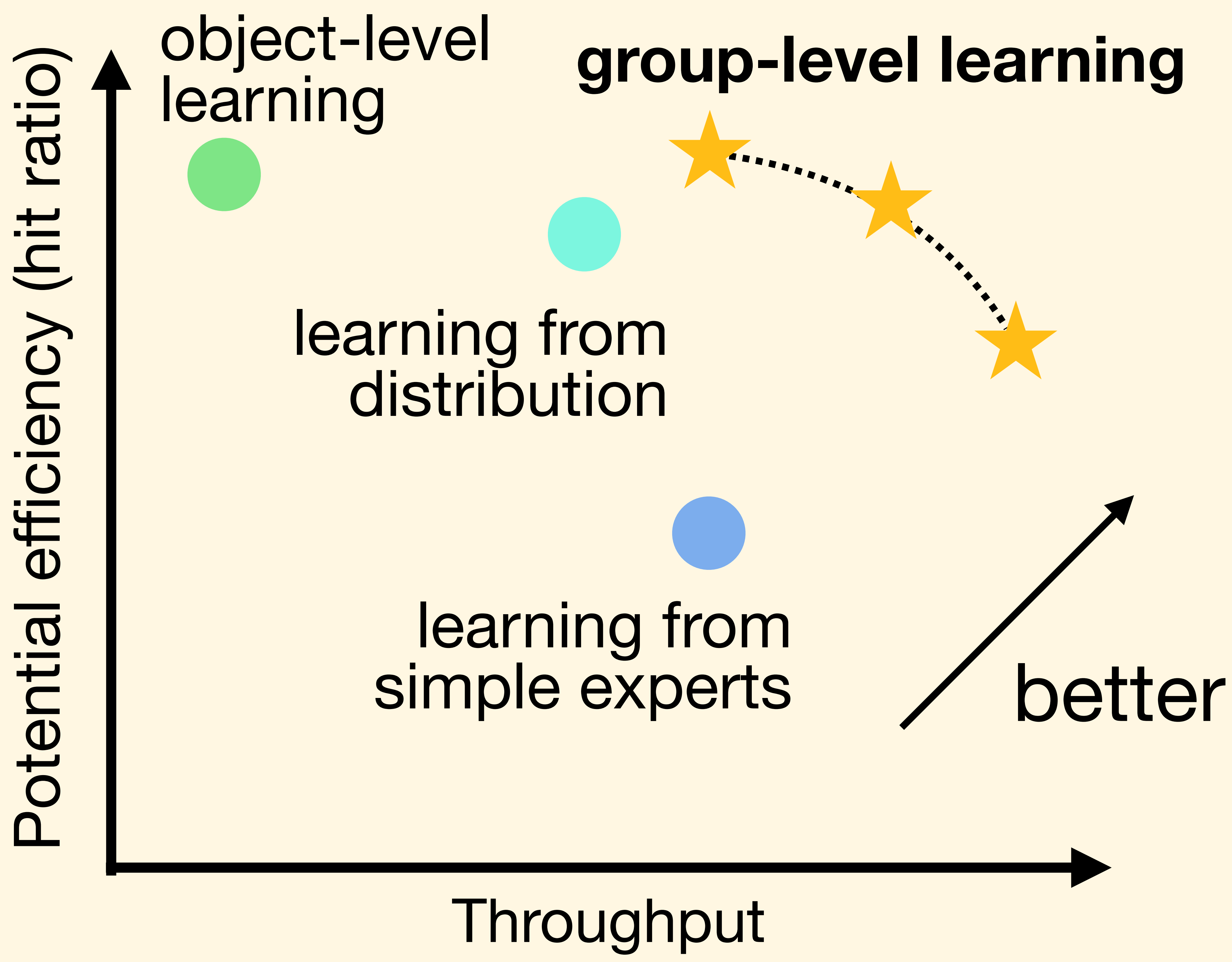
Throughput

GL-Cache-E is faster than all state-of-the-art learned caches
GL-Cache-T is **significantly** faster





Summary



Question?

- Learning from simple experts (e.g., LeCaR)
- Learning from distribution (e.g., LHD)
- Object-level learning (e.g., LRB)
- **Group-level Learning (this work)**

open-sourced at https://github.com/thesys-lab/fast23-GLCache

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