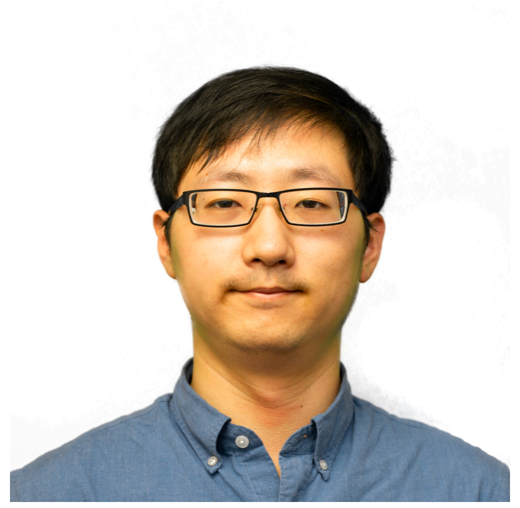
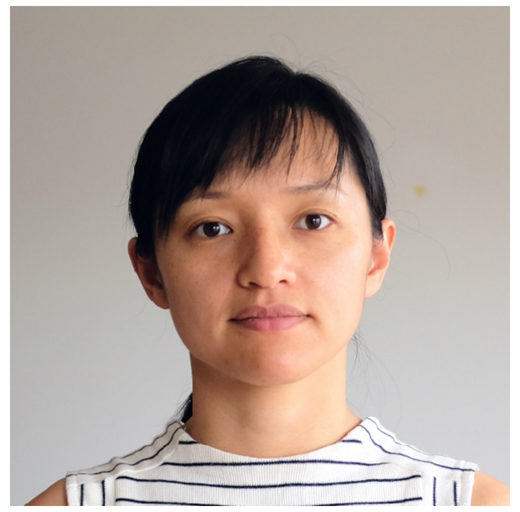
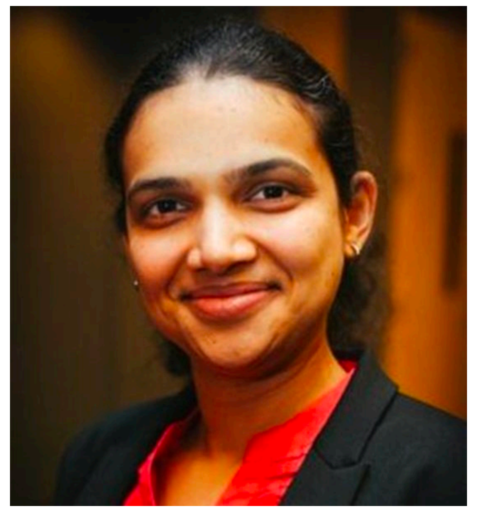
Segcache: a memory-efficient and scalable in-memory key-value cache for small objects

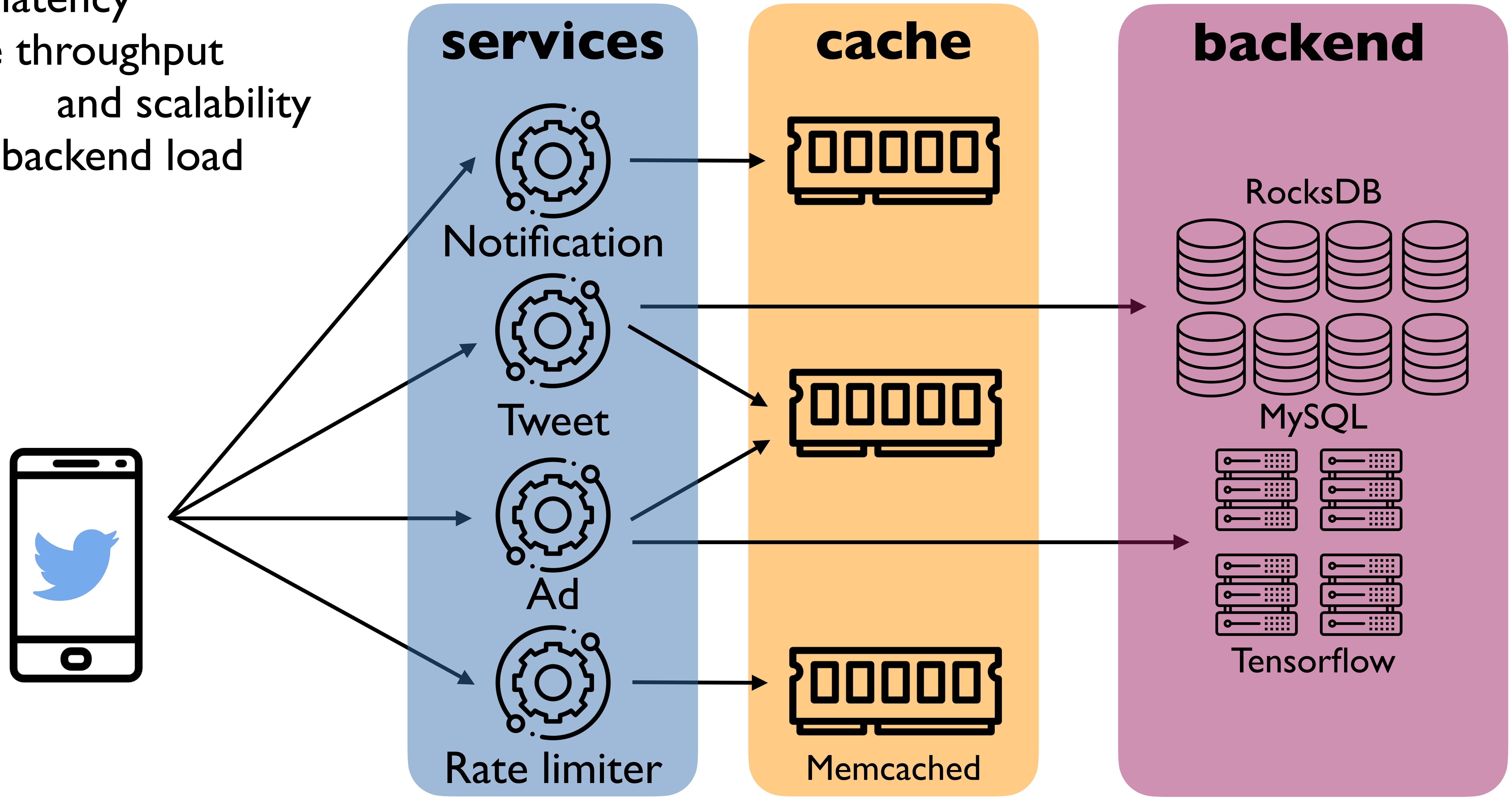




Juncheng Yang Yao Yue Rashmi Vinayak

Carnegie Mellon University, Twitter

In-memory key-value caches

Reduce latency
Increase throughput and scalability
Reduce backend load



Today's in-memory caching systems

Have significant room for improvement

- Memory efficiency
  - TTL and expiration
  - Huge per-object metadata
  - Memory fragmentation

- Throughput and scalability
  - Tradeoff between efficiency and throughput or scalability

TTL and expiration

Time-to-live (TTL)

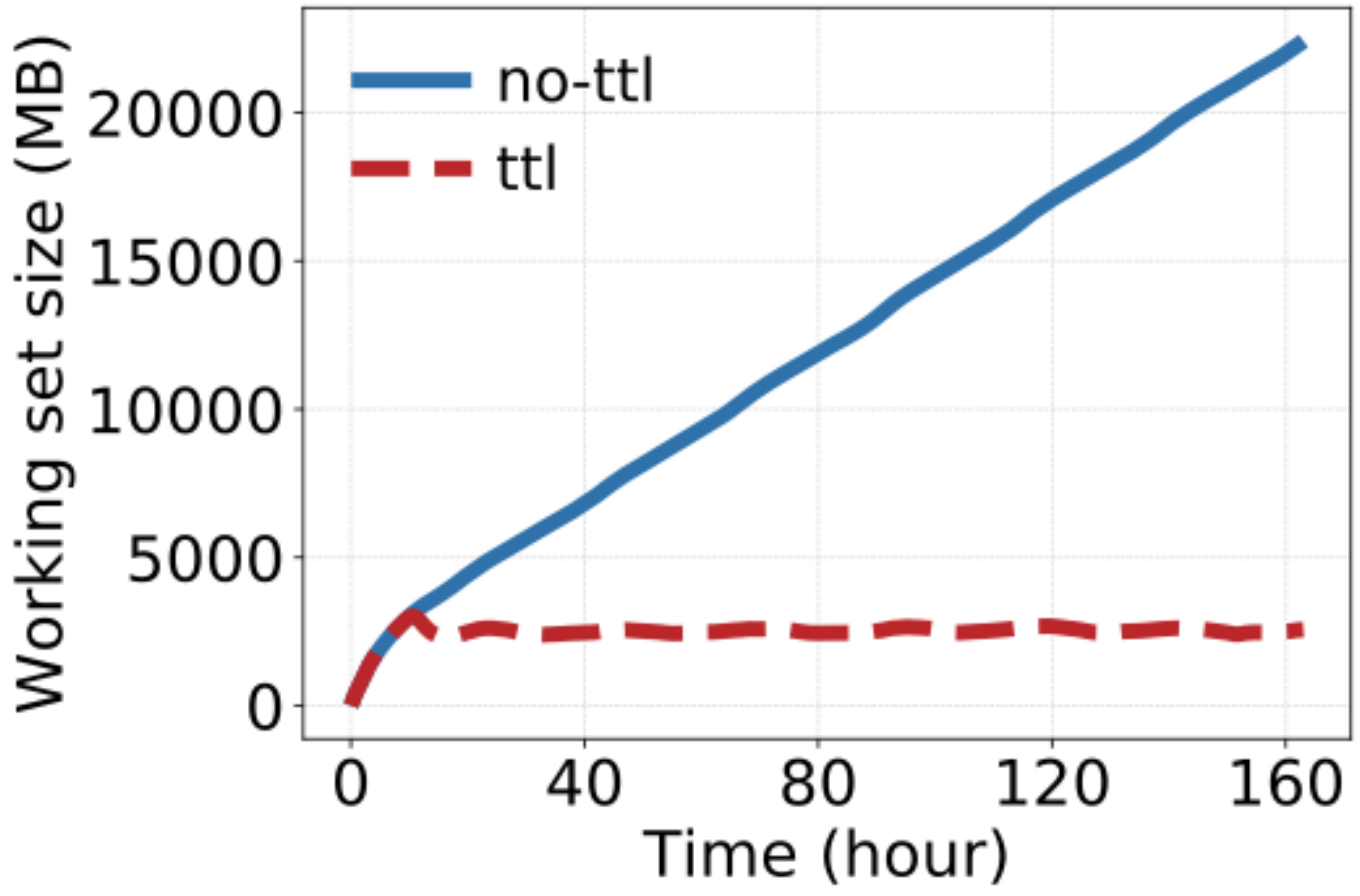
- TTL is set during object write
- Expired objects cannot be served
- Short TTLs are widely used in production

TTL usages

- Reduce stale data (cache writes are best-effort)
- Periodic refresh (e.g. ML predictions)
- Implicit deletions (e.g. limiters, GDPR)

Impact of TTL

- Reduce effective working set size
- Removing expired objects is critical



Smaller working set if expired objects are not considered

TTL and expiration: takeaway

Timely removal of expired objects is critical for memory efficiency

- expiration: remove objects that **cannot** be used in the future
- eviction: remove objects that **could** potentially be used in the future

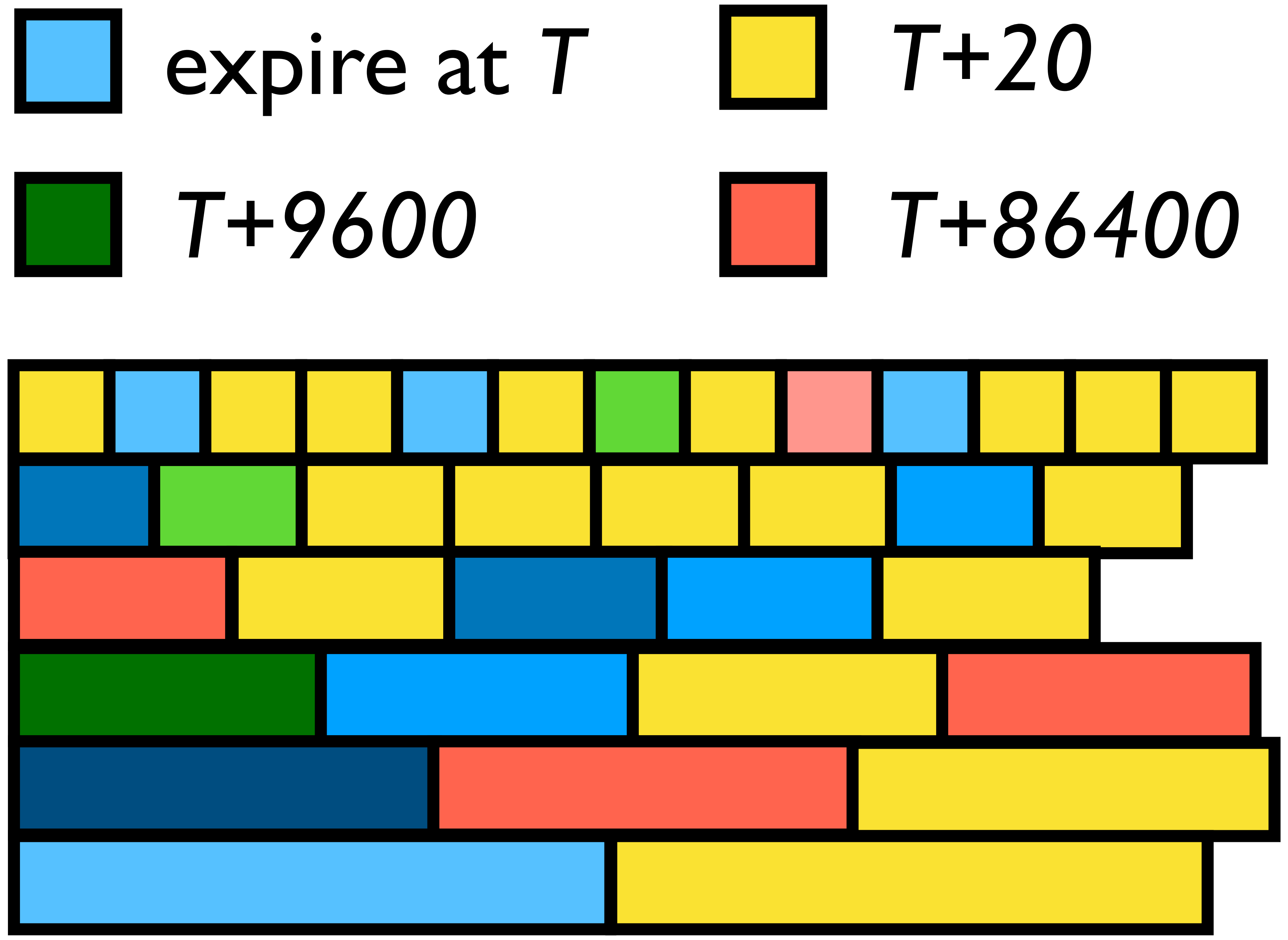
Existing solutions for TTL expiration

Efficient: low overhead
Sufficient: can remove all or most expired objects

Category	Technique	Efficient	Sufficient
Lazy expiration	Delete upon re-access	✓	✗
	Check LRU tail	✓	✗
Proactive expiration	Scanning	✗	✓
	Sampling	✗	✗
	Transient object pool	✓	✗

either not efficient or not sufficient

Color: expiration time



How can I find expired objects

Motivation summary

Today's in-memory caching systems:

- Memory efficiency
  - Cannot efficiently and timely remove expired objects
  - Have huge per-object metadata (56 bytes in Memcached), but objects are small (10s-100s bytes)
  - Suffer from memory fragmentation
- Throughput and scalability
  - Tradeoff between efficiency and throughput or scalability

	MICA	MemC3	Memshare	LHD	Hyperbolic	pRedis
Memory efficiency	✗	✗	✓	✓	✓	✓
Throughput/scalability	✓	✓	✗	✗	✗	✗

Segcache: a memory-efficient and scalable in-memory key-value cache for small objects

Segcache overview

Segcache: segment-structured cache

High memory efficiency

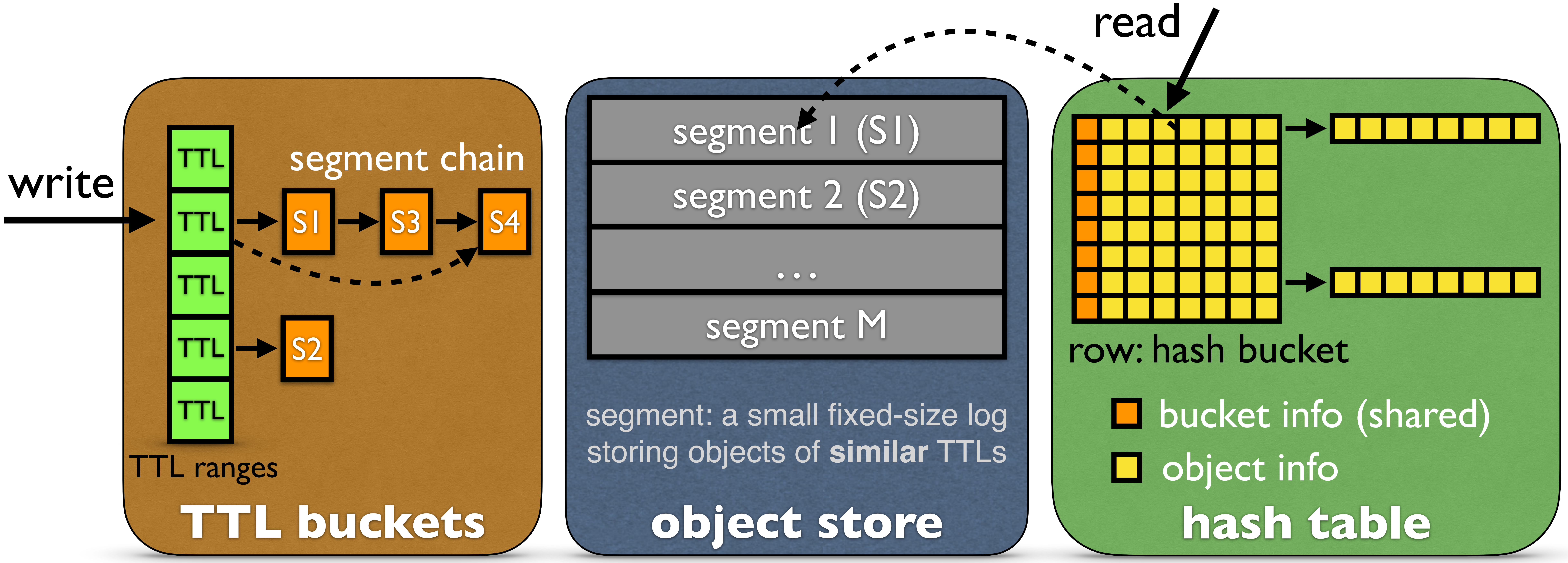
- Efficient and sufficient TTL expiration
- Tiny object metadata (5-byte)
- Almost no memory fragmentation
- Merge-based eviction for low miss ratio

High performance

- High throughput
- Close-to-linear scalability

Expect to enter Twitter production this year

Segcache design

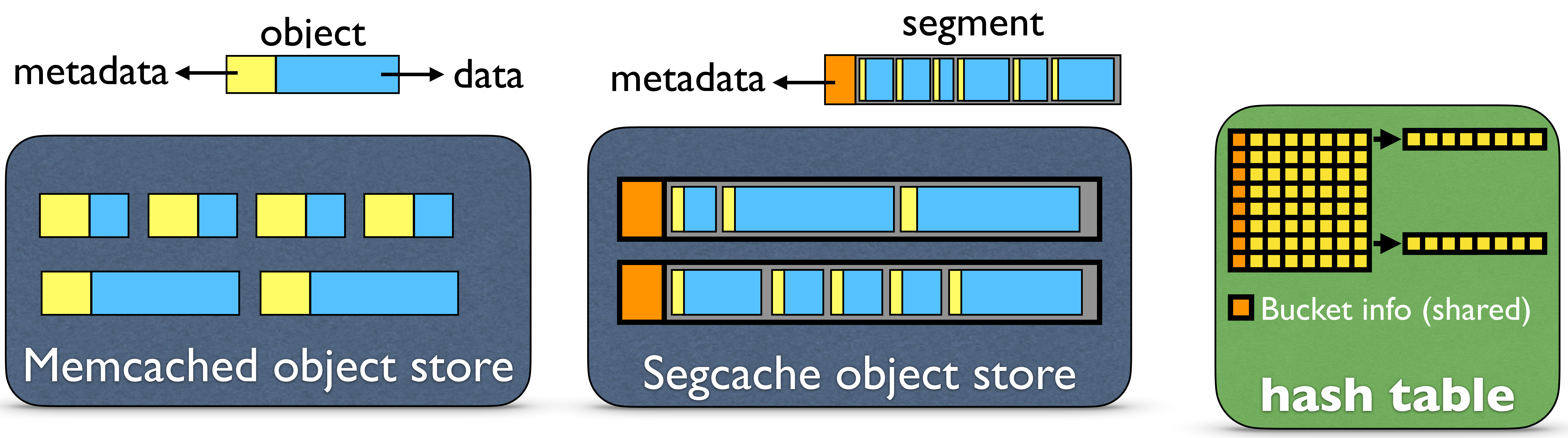


Design principles

Design principle 1: Maximize metadata approximation and sharing

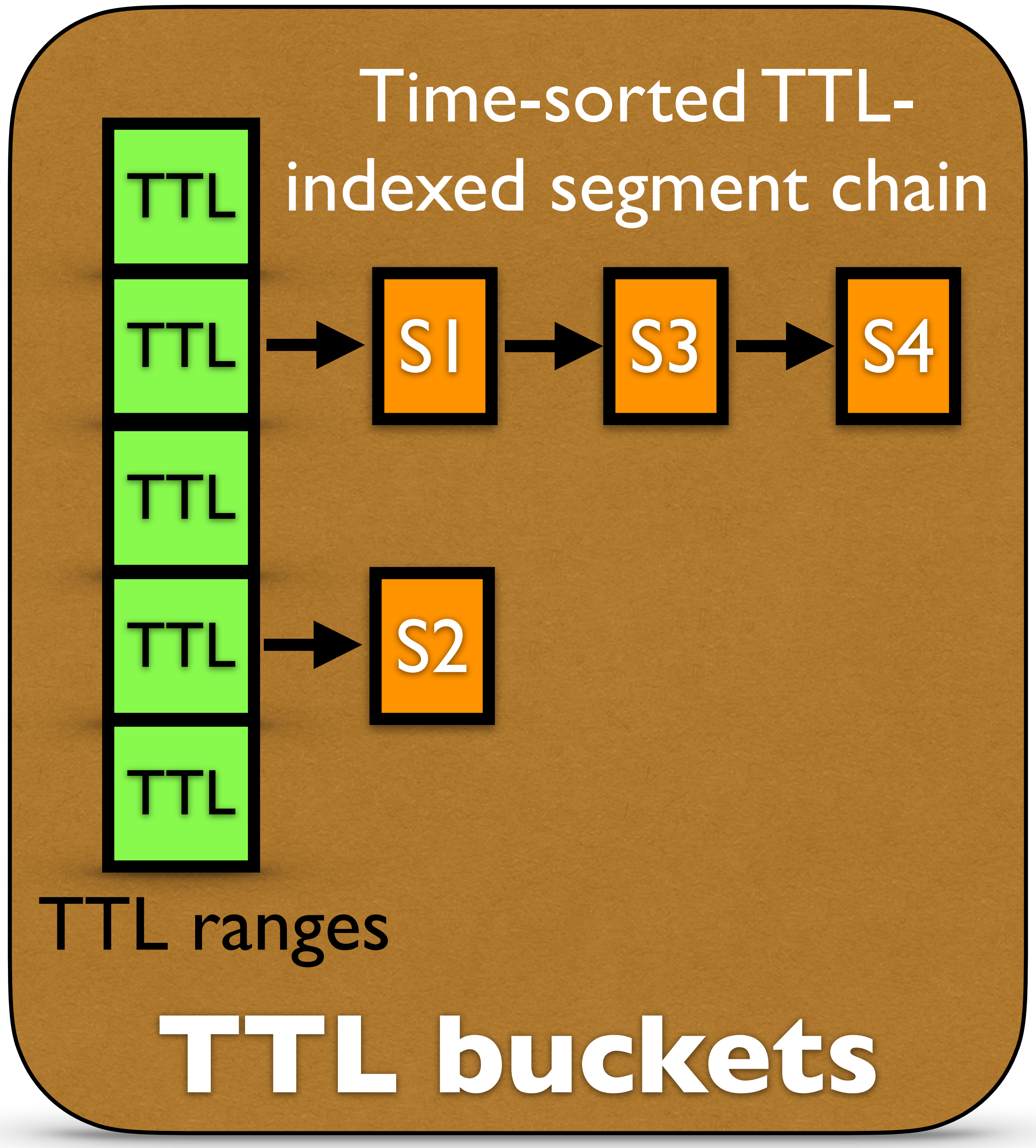
Group objects into segments to approximate and share metadata

Segment: a small fixed-size log storing objects of similar TTLs



Design principle 2: Be proactive, don't be lazy

Efficiently and *proactively* remove expired objects



objects in a segment share creation time and TTL
=> expire at the same time

segments in a chain have same TTL with sorted creation time
=> examine the first segment only

background thread scans TTL buckets (small array of metadata)
=> efficient and proactive expiration

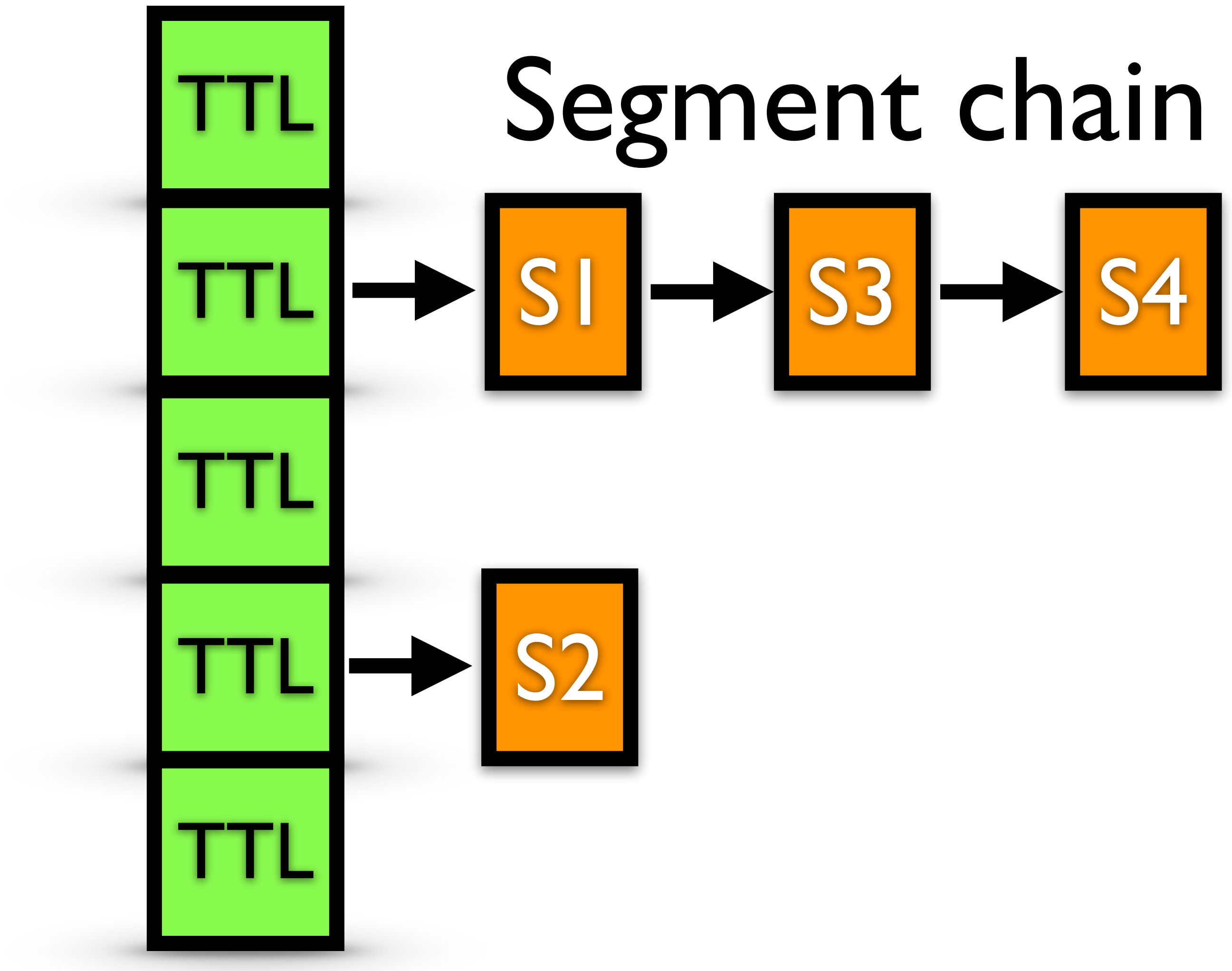
Design principle 3: Perform macro management

Manage segments (groups of objects), not objects

Perform less bookkeeping in batched sequential fashion with high throughput

Achieve a close-to-linear scalability

Expiration and eviction happen on the segment level



Only segment chain changes needs locking

In the paper (not covered in the talk)

- Segment homogeneity
- Merge-based eviction
  - Approximate and smoothed frequency counter
    - Low overhead
    - Burst-resistant
    - Scan-resistant
    - Eviction-friendly

Evaluation

Implemented on Pelikan

- Twitter's open-source caching framework

Setup

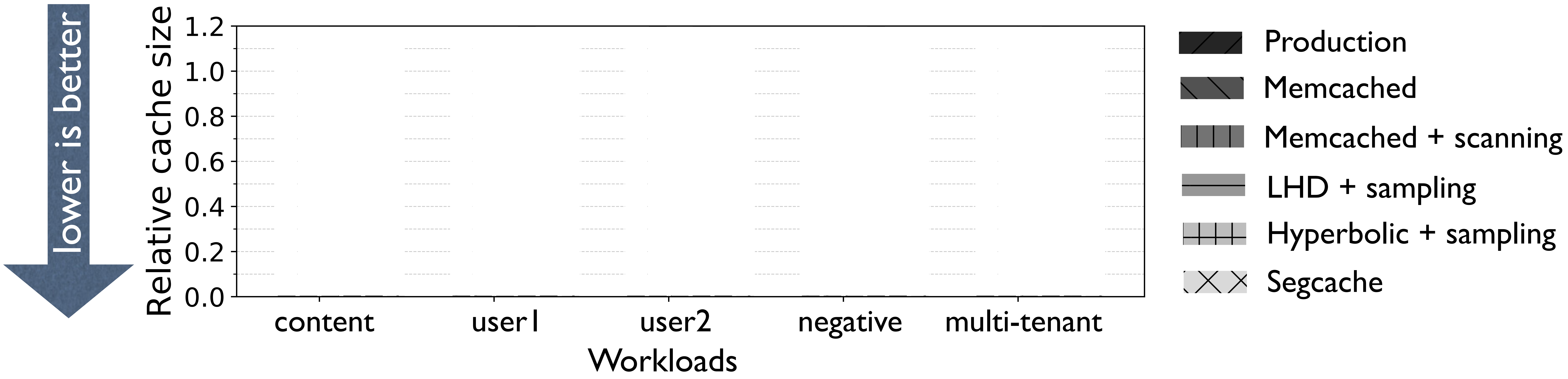
- Five systems (research + production)
  - Production
  - Memcached and Memcached + scanning
  - LHD + sampling
  - Hyperbolic + sampling
  - Segcache
- Five production traces
- Twitter production fleet

Evaluation: memory efficiency

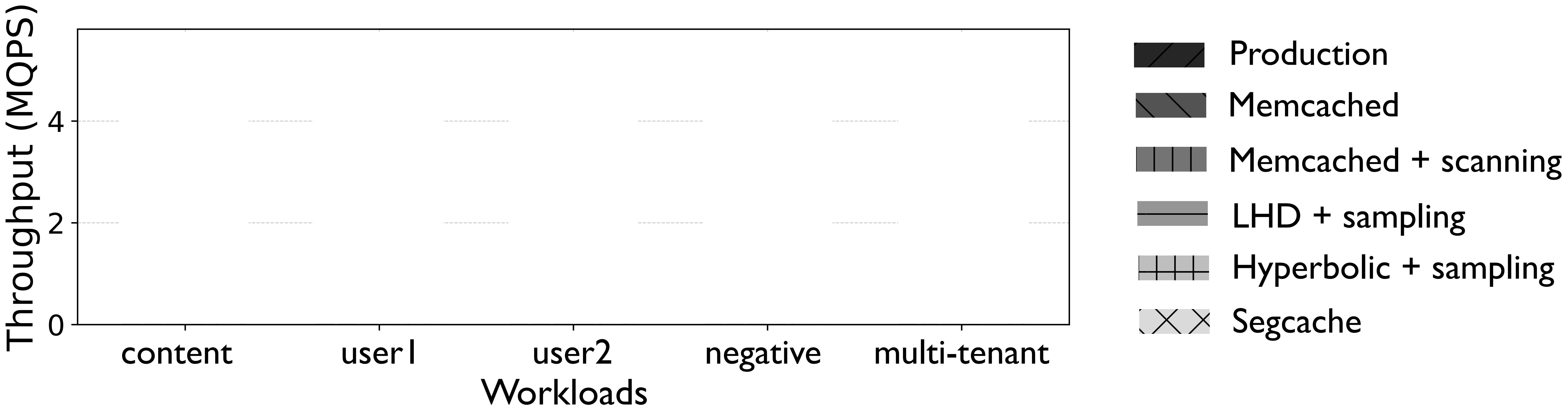
Metric: relative cache size to achieve production miss ratio

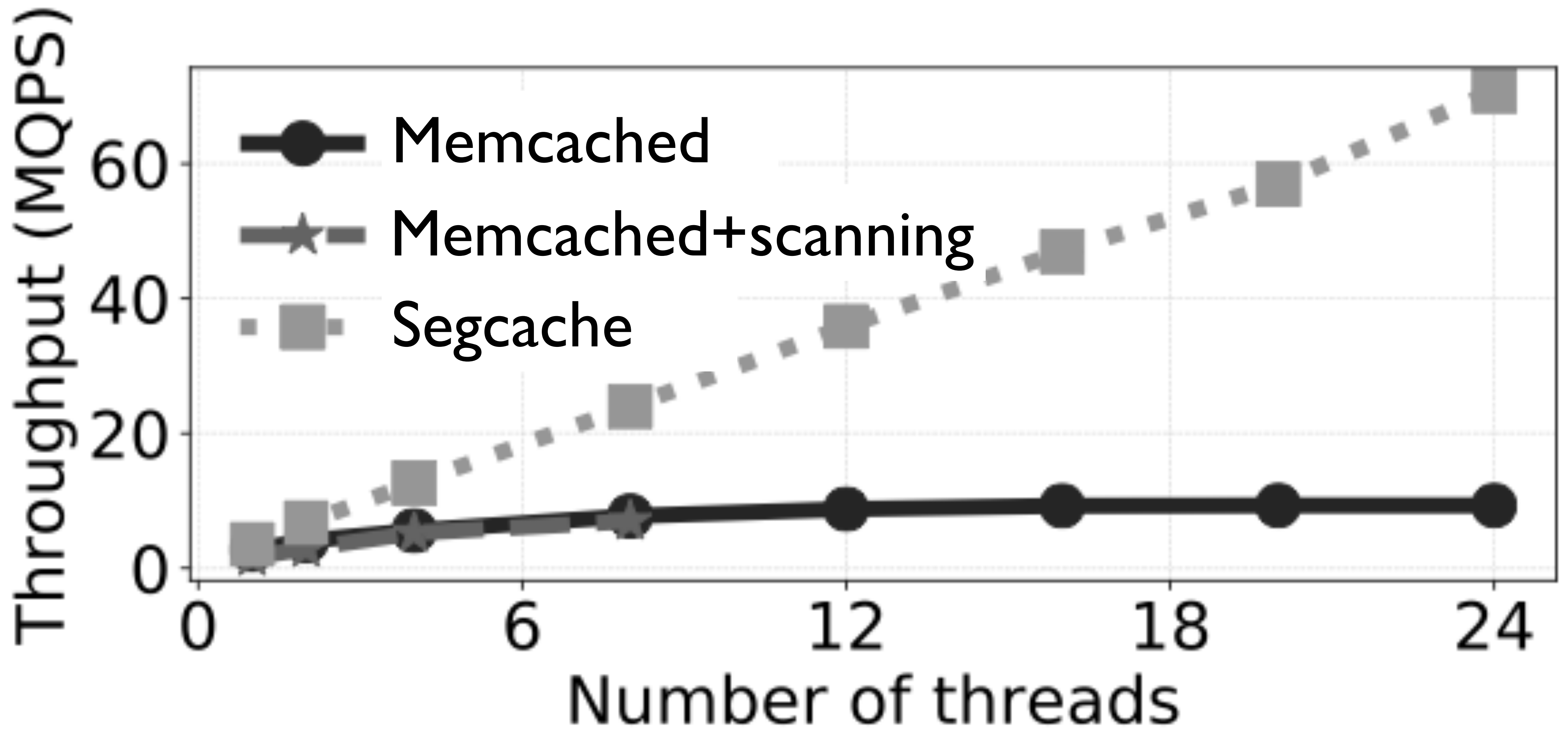
Reduce memory footprint by

- 40-90% compared to production
  - 60% on Twitter's largest cache cluster
- 22-60% compared to state-of-the-art



Evaluation: throughput and scalability





Single-thread

- similar to production
- up to 40% higher than Memcached
- significantly higher than the rest

Multi-thread

- 8x improvement with 24 threads

Summary

Segcache: segment-structured cache, groups objects into segments for

- high memory efficiency and high performance
  - Efficient proactive TTL expiration
  - Object metadata reduction using metadata approximation and sharing
  - Almost no memory fragmentation
  - Small miss ratio/memory footprint with merge-based eviction
  - High throughput and high scalability using macro management

Traces: https://www.github.com/twitter/cache-trace
Code: https://www.github.com/thesys-lab/segcache
Production code: https://www.github.com/twitter/pelikan

Thank you!

Acknowledgement: Jack Kosaian from CMU,
Rebecca Isaacs, Xi Wang, Dan Luu, Brian Martin from Twitter,
IOP, cache, HWEng team from Twitter,
Parallel Data Lab at CMU, Siobiosys lab at Emory University.