CS 795 Distributed Systems & Cloud Computing

Fall 2018

Lec 9: Datacenter storage management

Yue Cheng

Announcements

- Office hours on 11/29 and 12/06 open for project wrap-up discussion
  - Or, send me an email to make an appointment for other time that works for you

- Final project presentation
  - When: 4:30—7:30pm, 12/14
  - Where: Room 4201, Engineering Building

An In-Memory Object Caching Framework with Adaptive Load Balancing

Yue Cheng (George Mason)

Aayush Gupta (IBM Research – Almaden)

Ali R. Butt (Virginia Tech)

ACM EuroSys 2015

Memcached is an essential component in datacenters

Local deployment

Cloud deployment

Amazon ElastiCache

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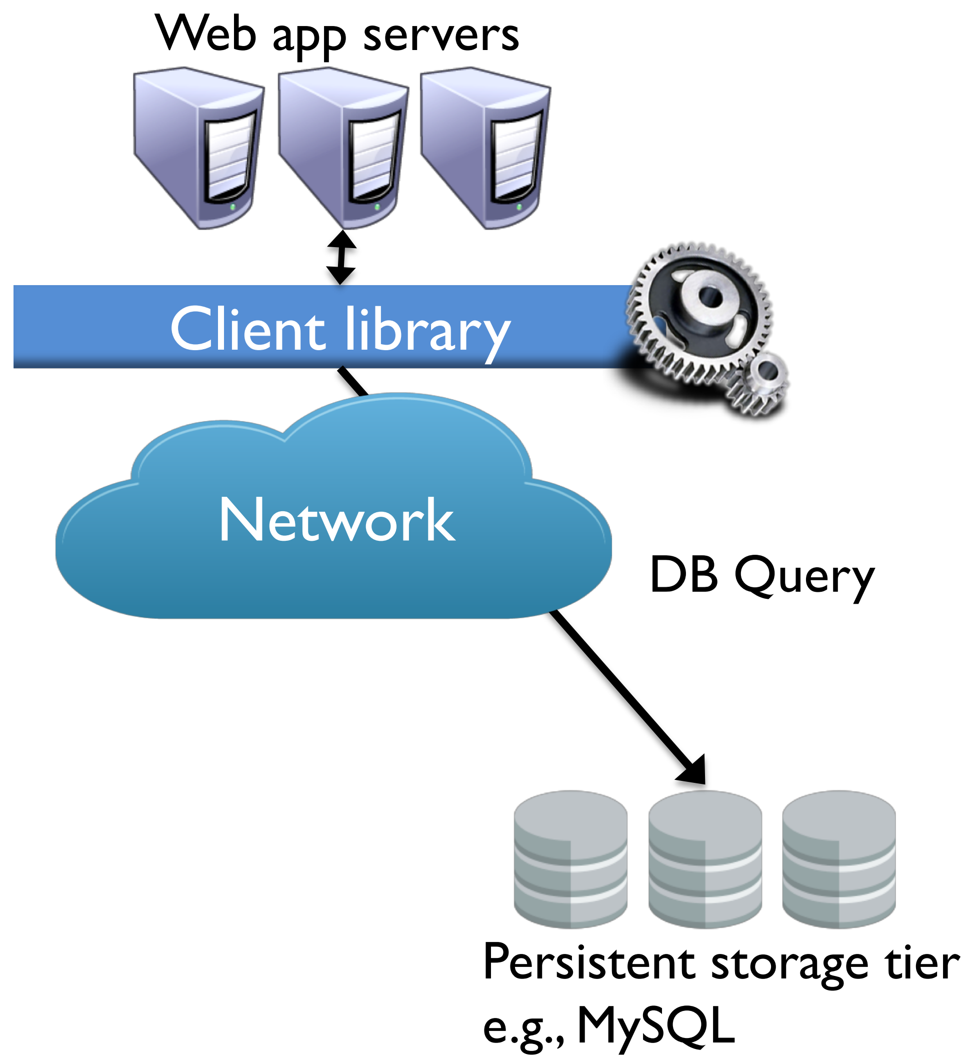

Memcached is an essential component in datacenters

Local deployment

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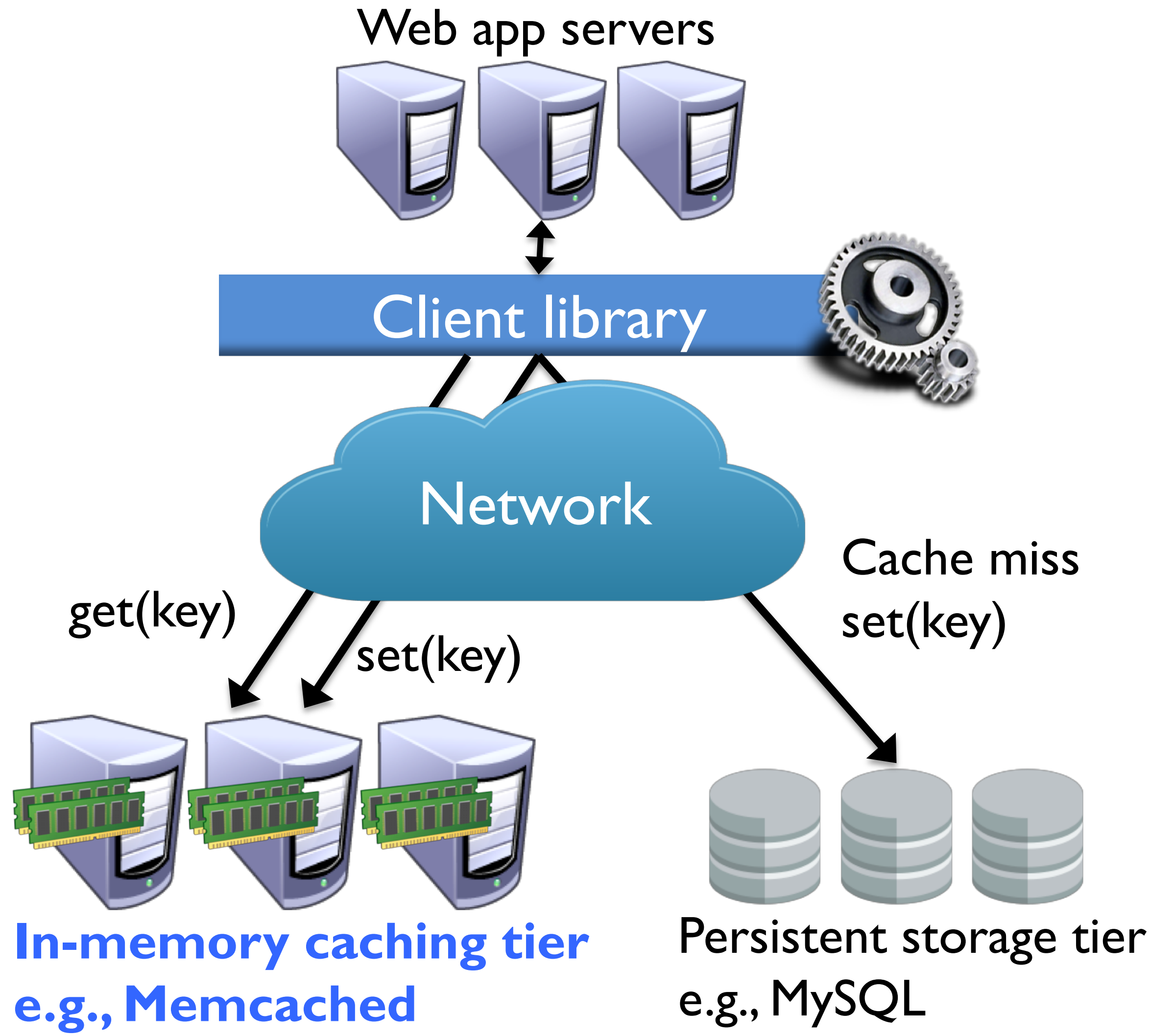
airbnb

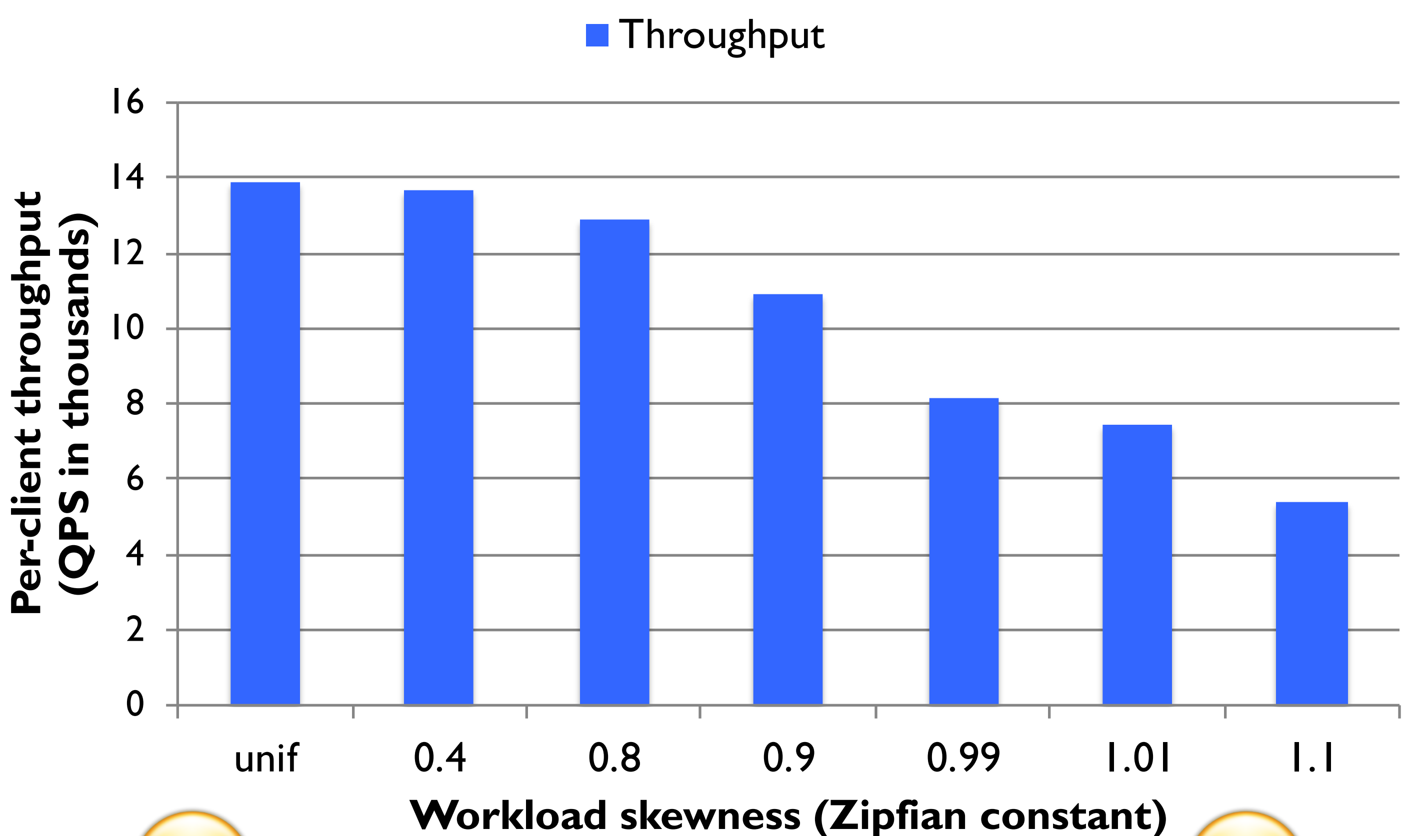


Memcached is desirable

- Offers high performance
- Enables quick deployment
- Provides ease of use

- **Problem:** Load imbalance impacts performance

Access load imbalance

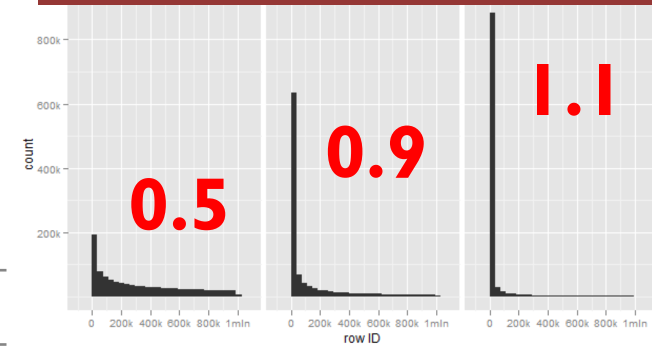


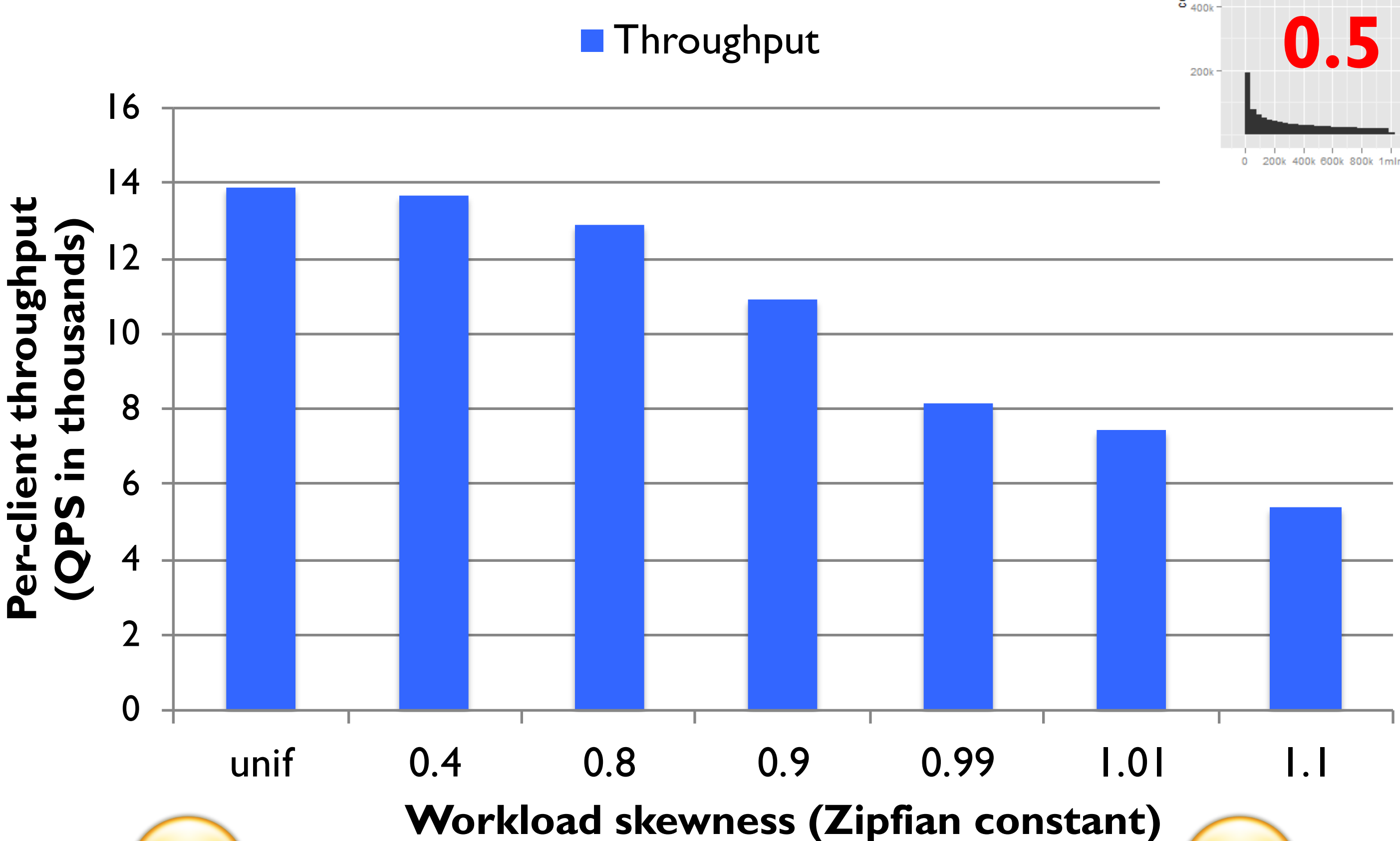
Ideal balance → high imbalance

95% GET, 5% SET, Zipfian, 20 cache servers

Access load imbalance

Key popularity distribution: different Zipfian constant





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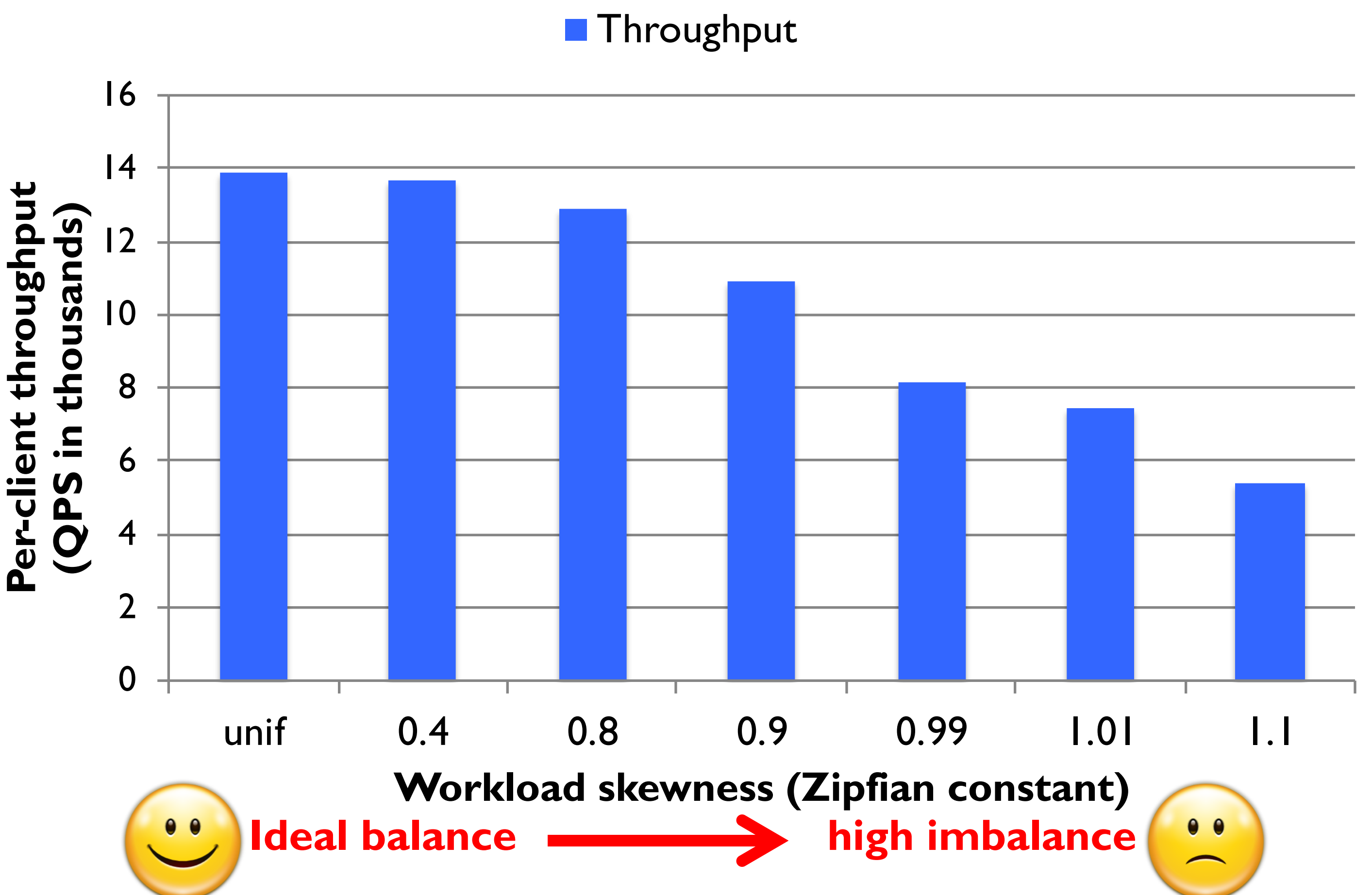

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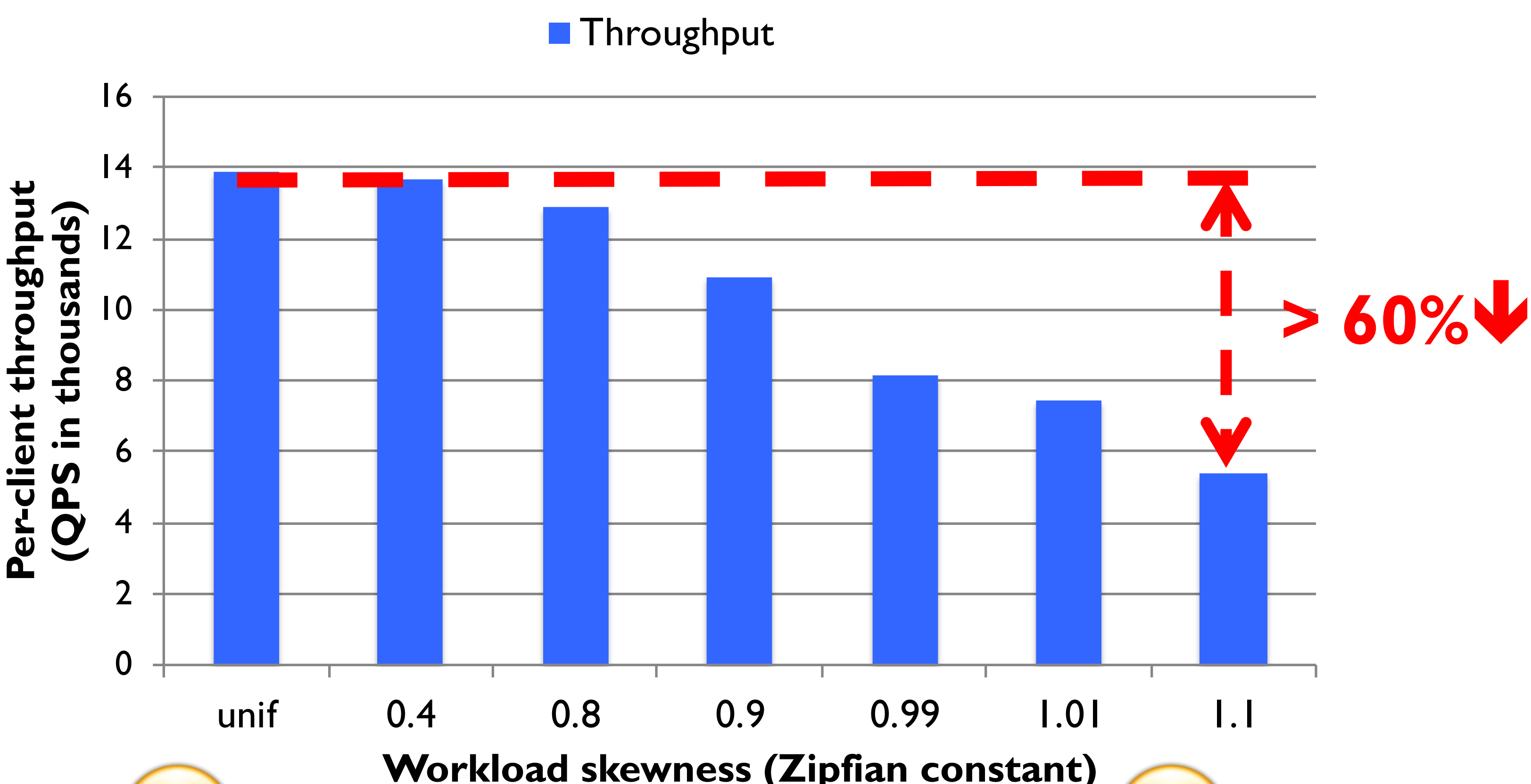

Ideal balance → **high imbalance**

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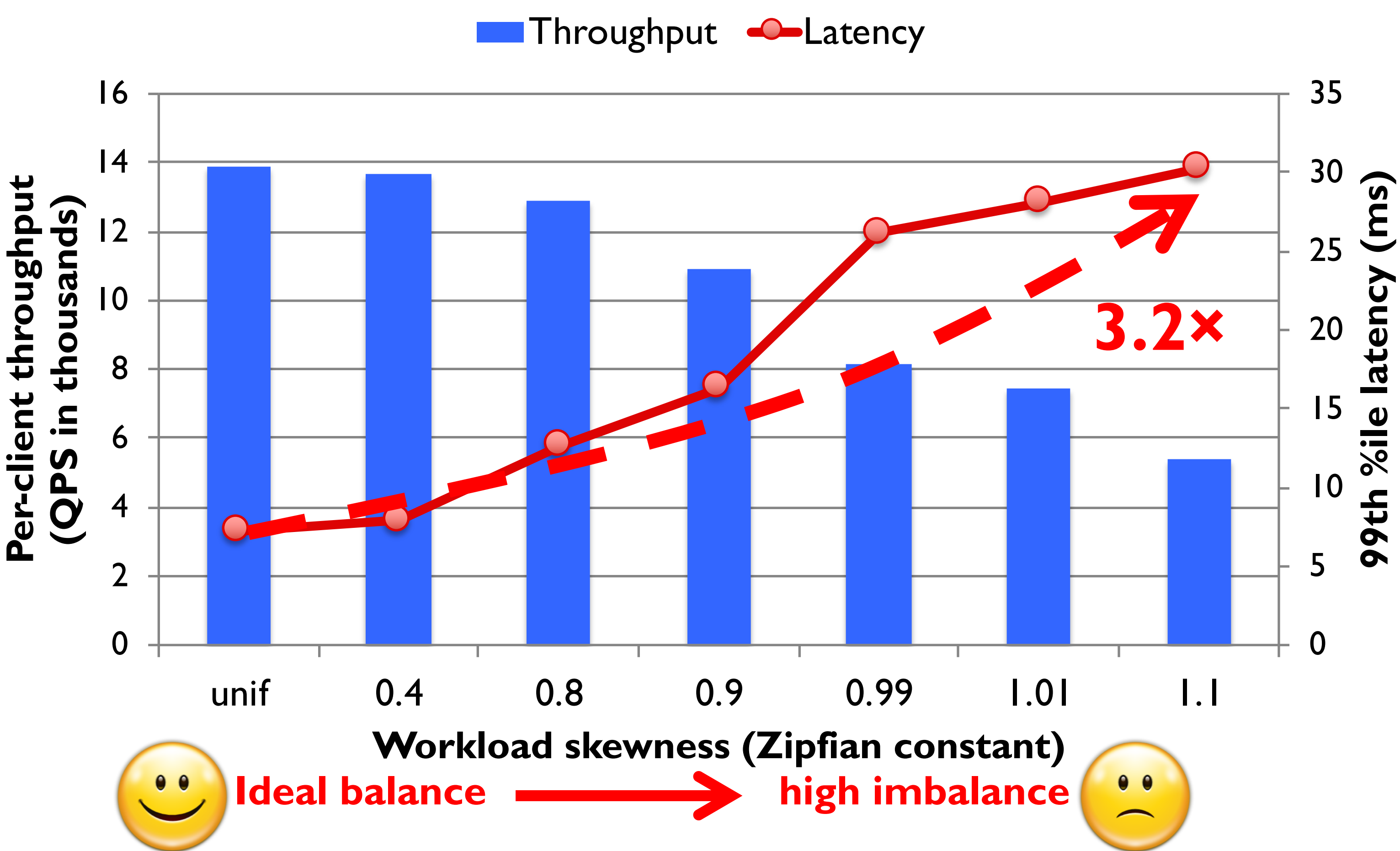

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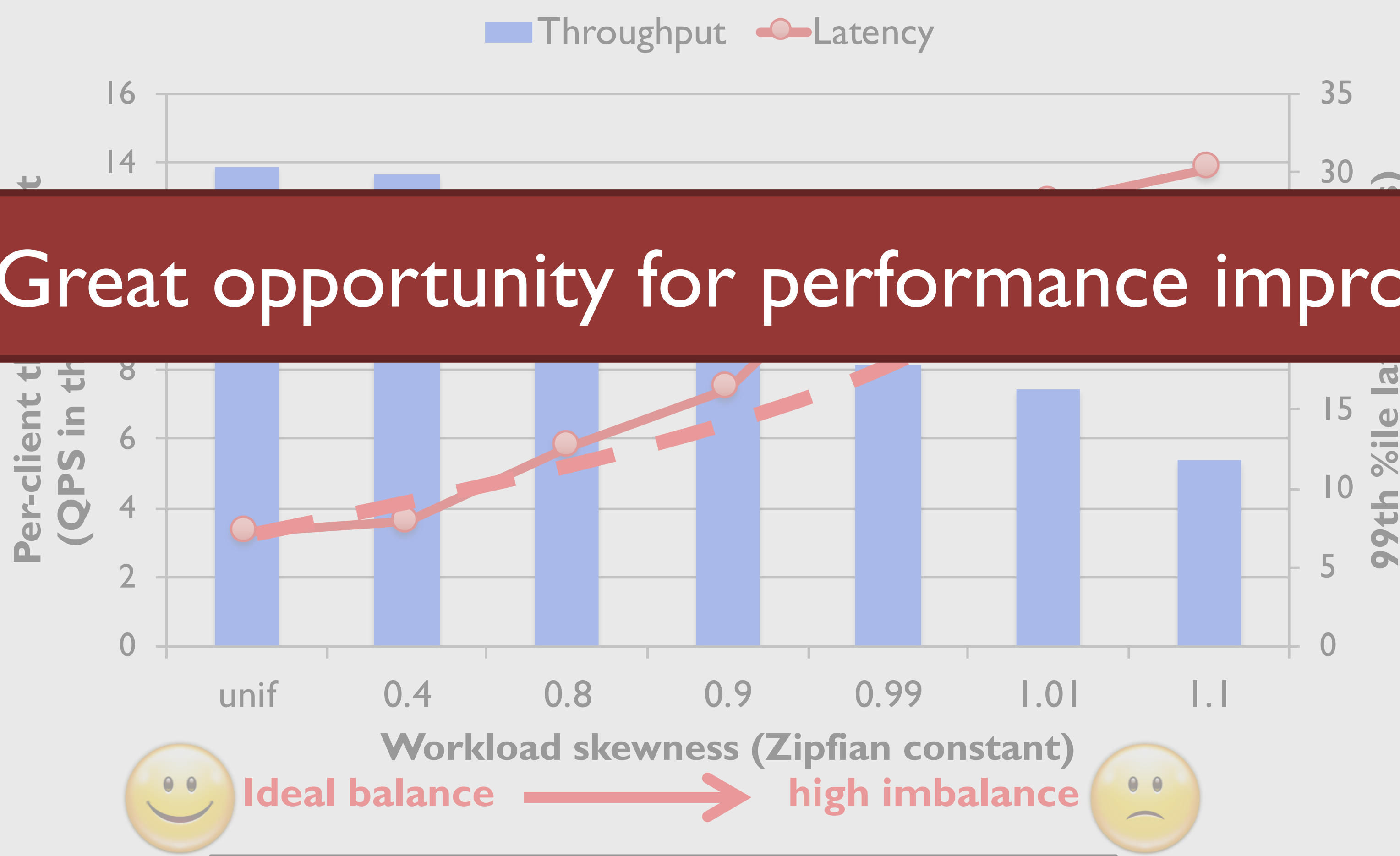

Great opportunity for performance improvement

95% GET, 5% SET, Zipfian, 20 cache servers

Our contribution: **MBal**

Revisiting in-memory cache design

A novel holistic in-memory caching framework with adaptive Multi-phase load Balancing

- Synthesizes different load balancing techniques
  - Key replication
  - Server-local cachelet migration
  - Coordinated cachelet migration
- Improves scale-up gains
- Mitigates load imbalance

Outline

MBal cache design

MBal load balancer design

Evaluation

Related work

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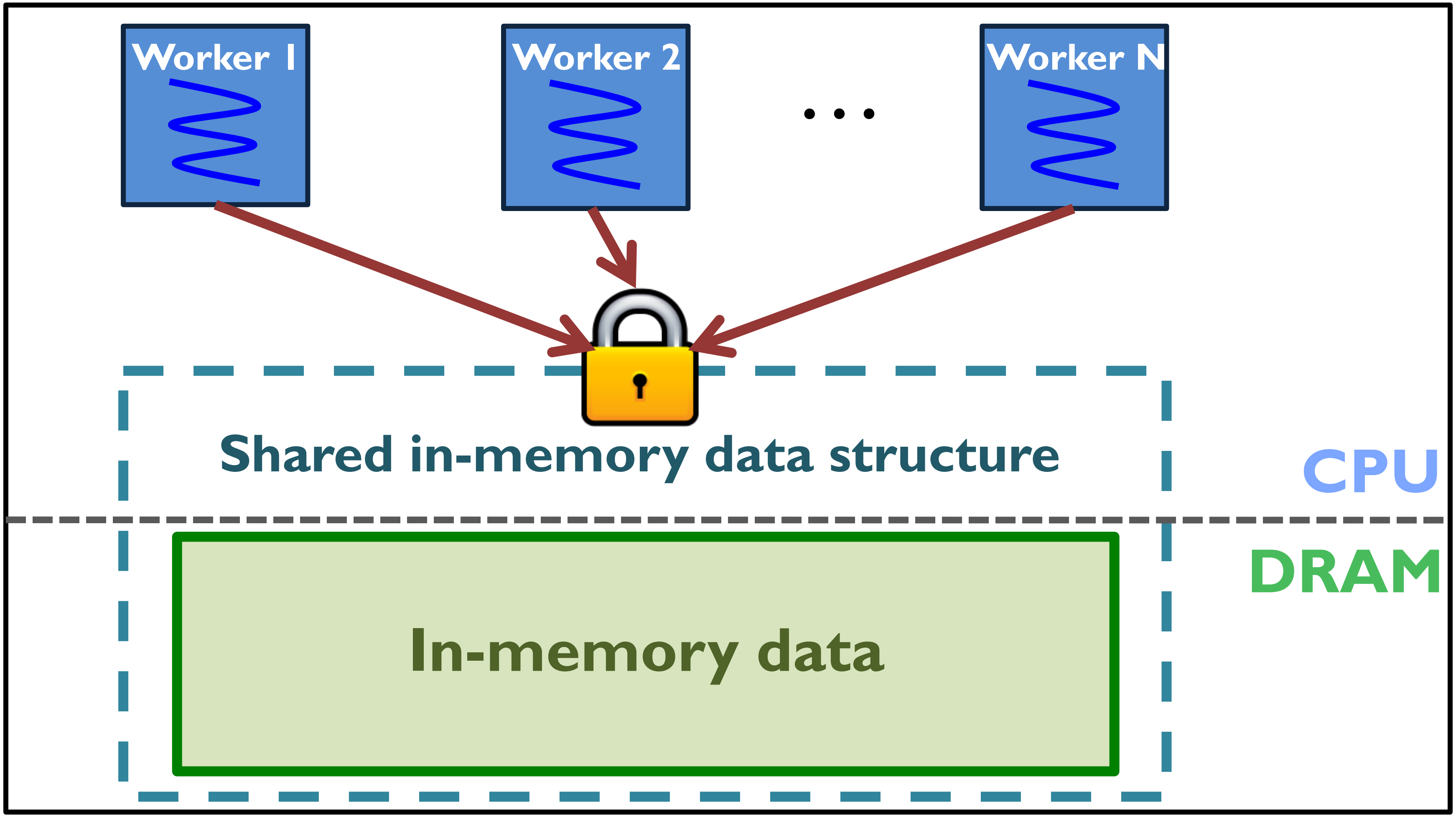
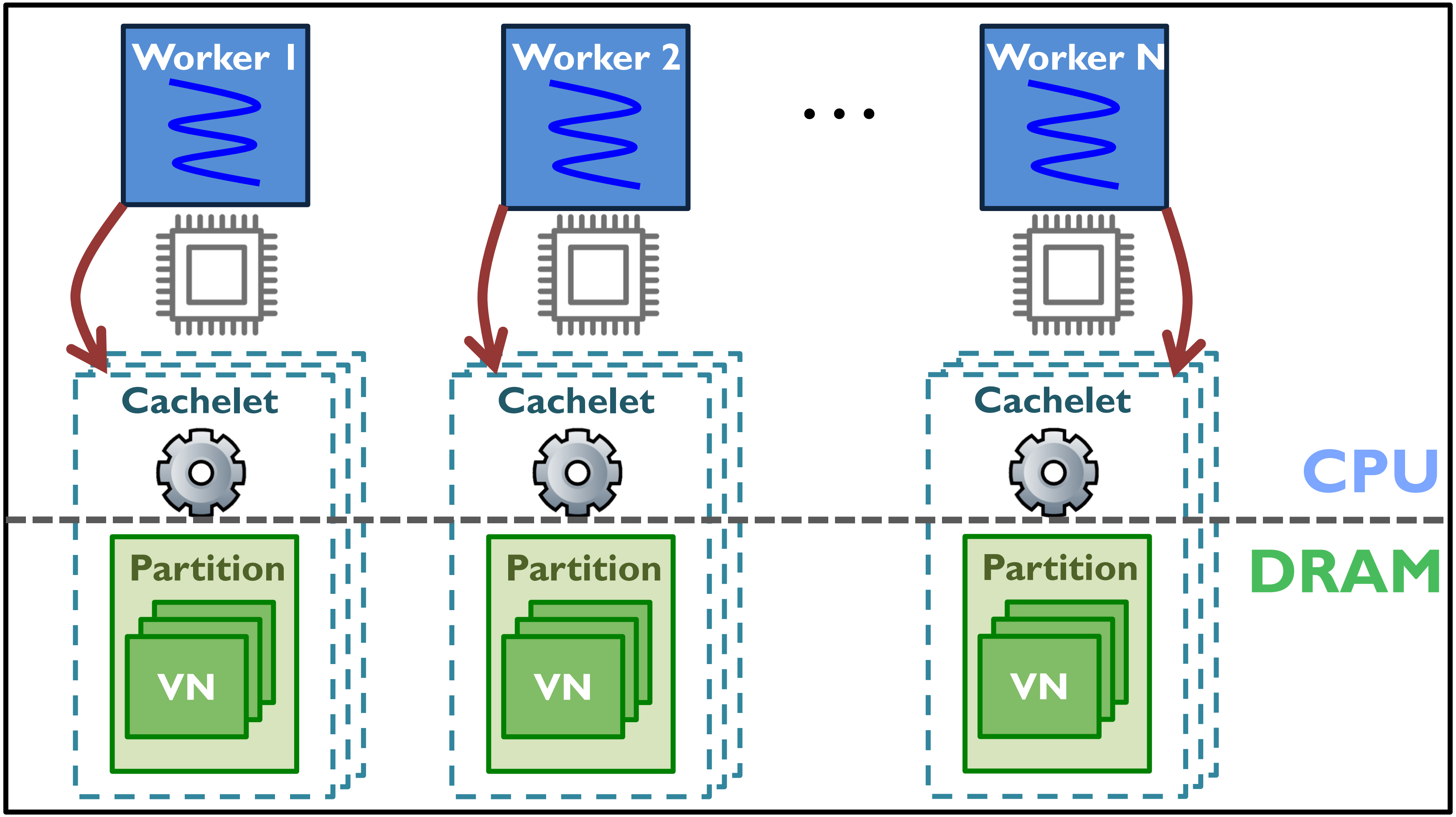
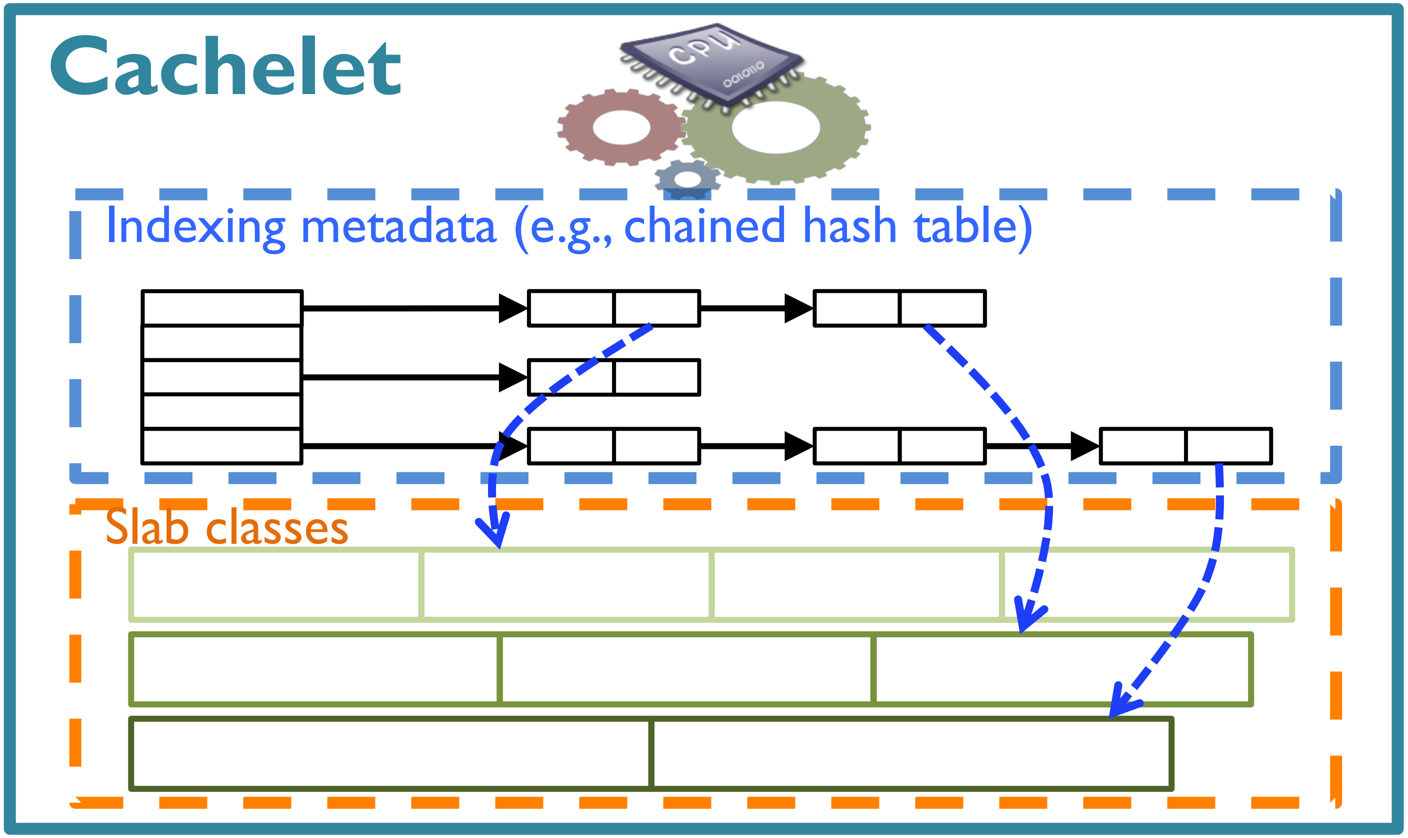
In-memory data structure in Memcached



Fine-grained data structures in MBal

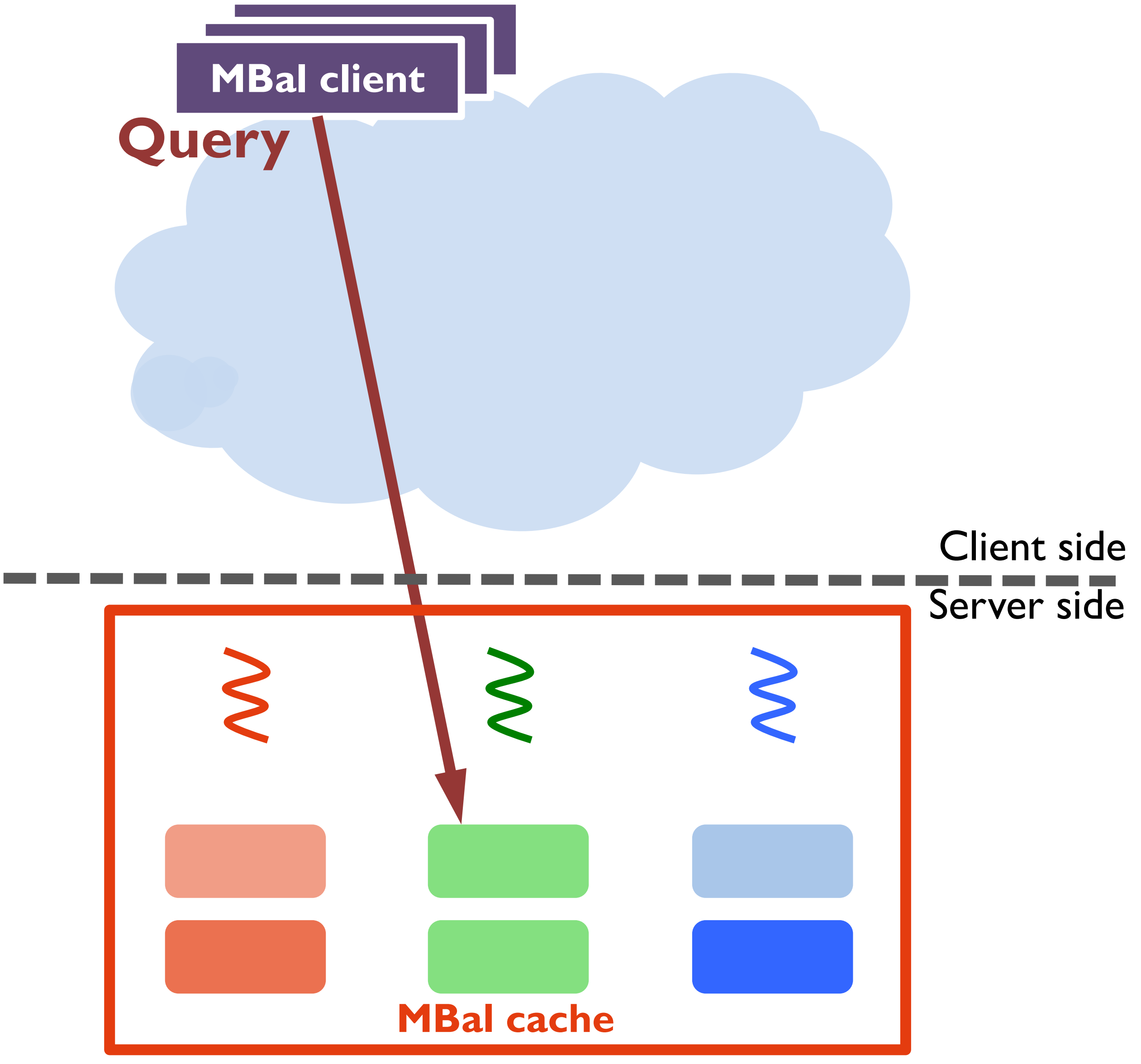


MBal cachelet: a partition with associated resources



- Cachelet encapsulates resources
- Avoid lock contention

Key-to-thread mapping



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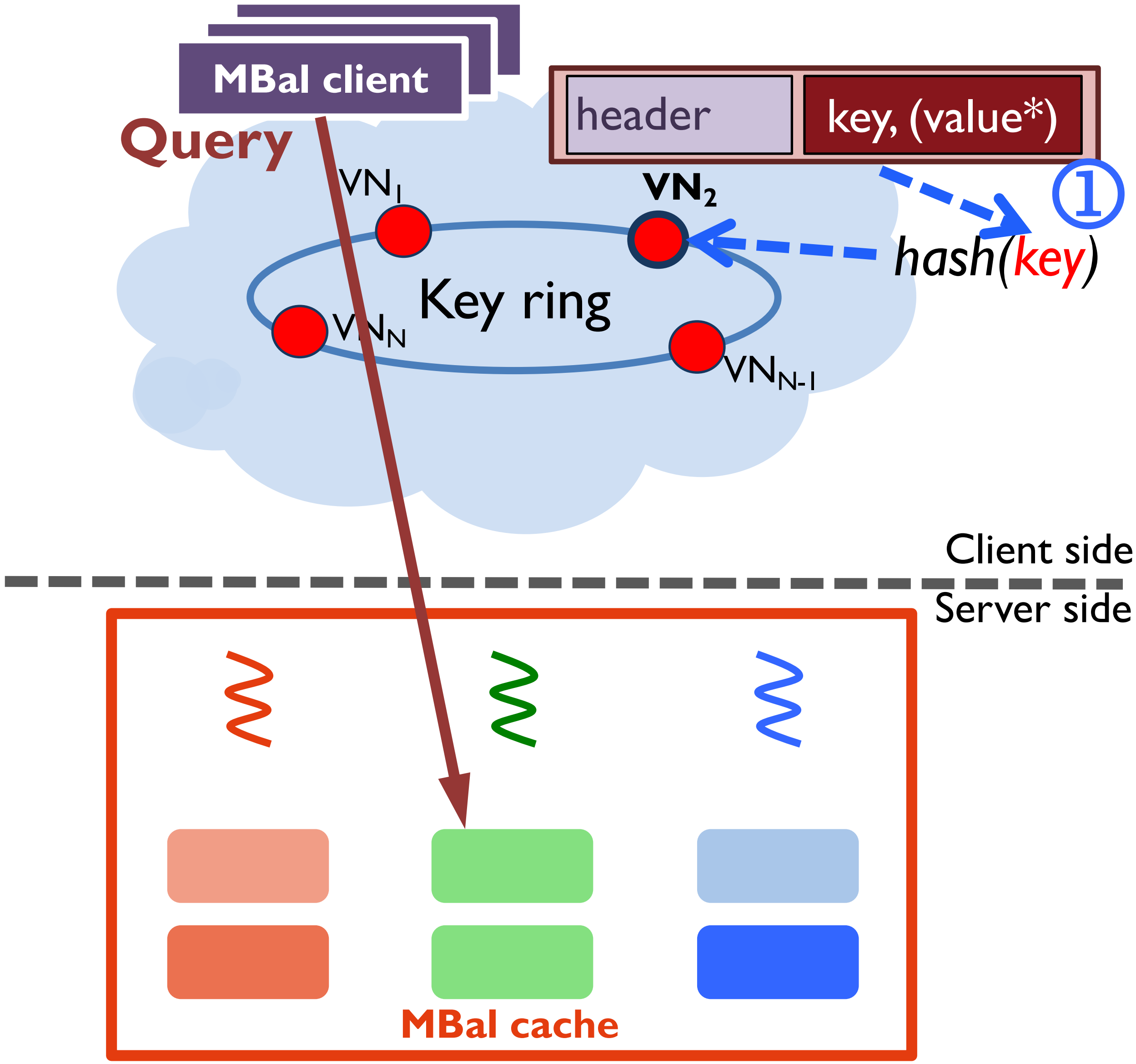
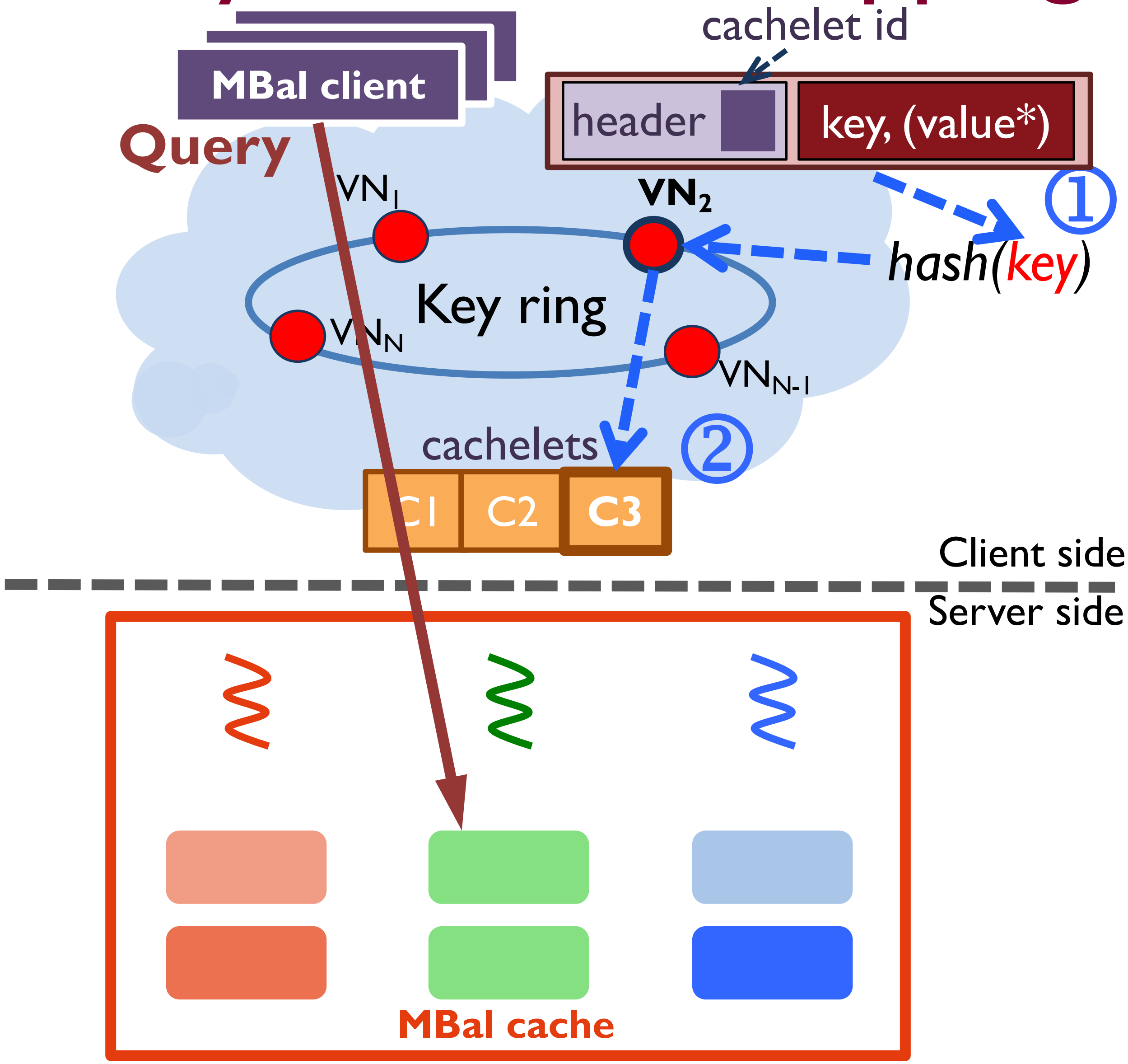


① Compute VN # with hash

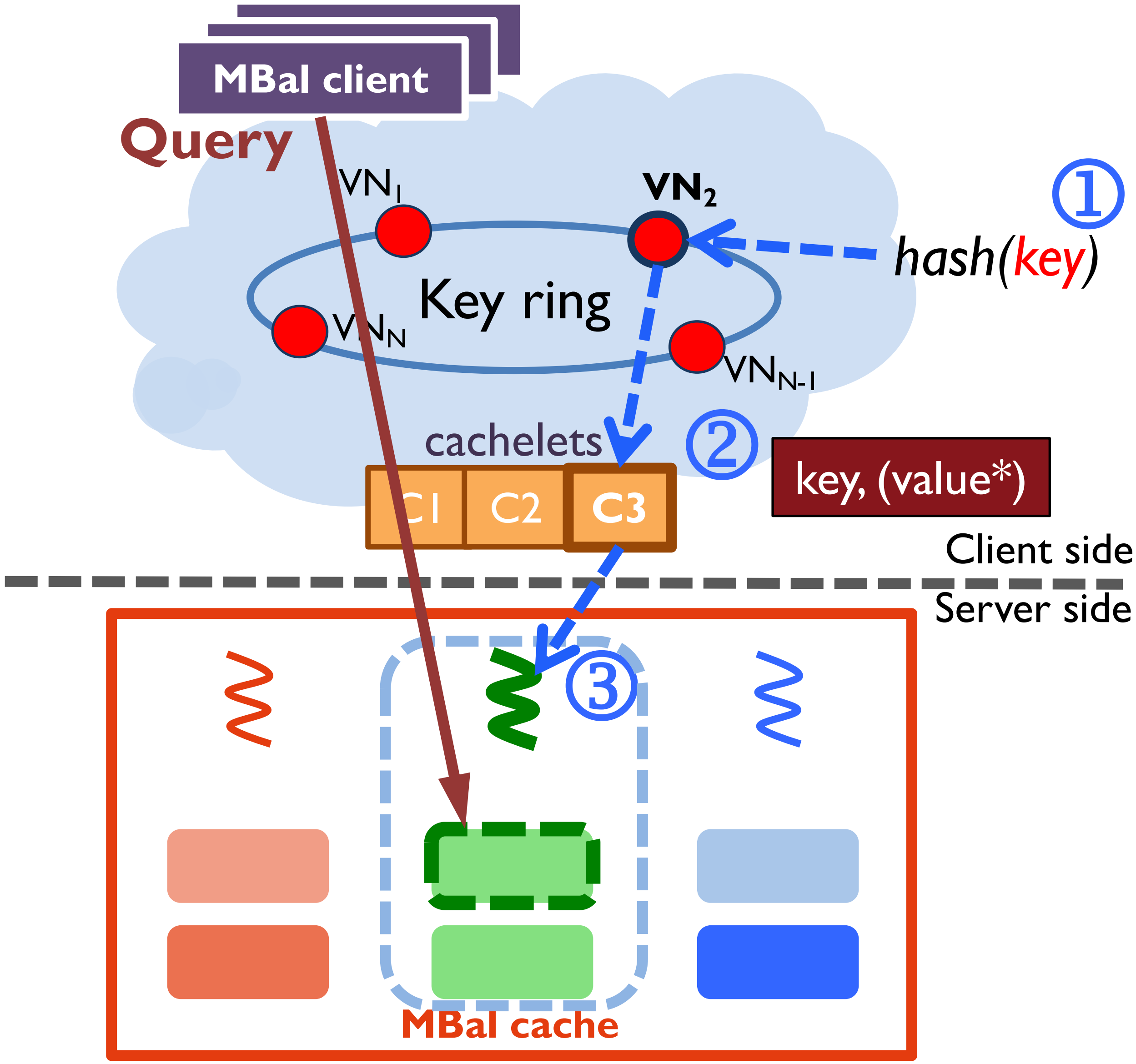
Key-to-thread mapping



① Compute VN # with hash

② Map VN # to Cachelet ID

Key-to-thread mapping



① Compute VN # with hash

② Map VN # to Cachelet ID

③ *Map Cachelet ID to the worker thread*

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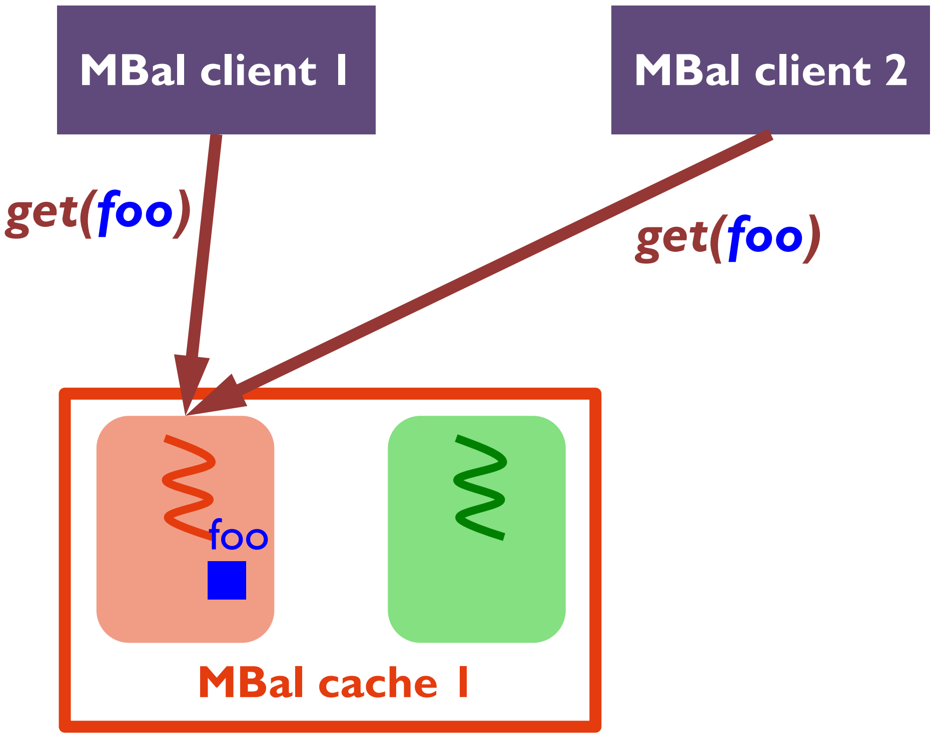
MBal cache design

MBal Multi-Phase Load Balancer

Evaluation

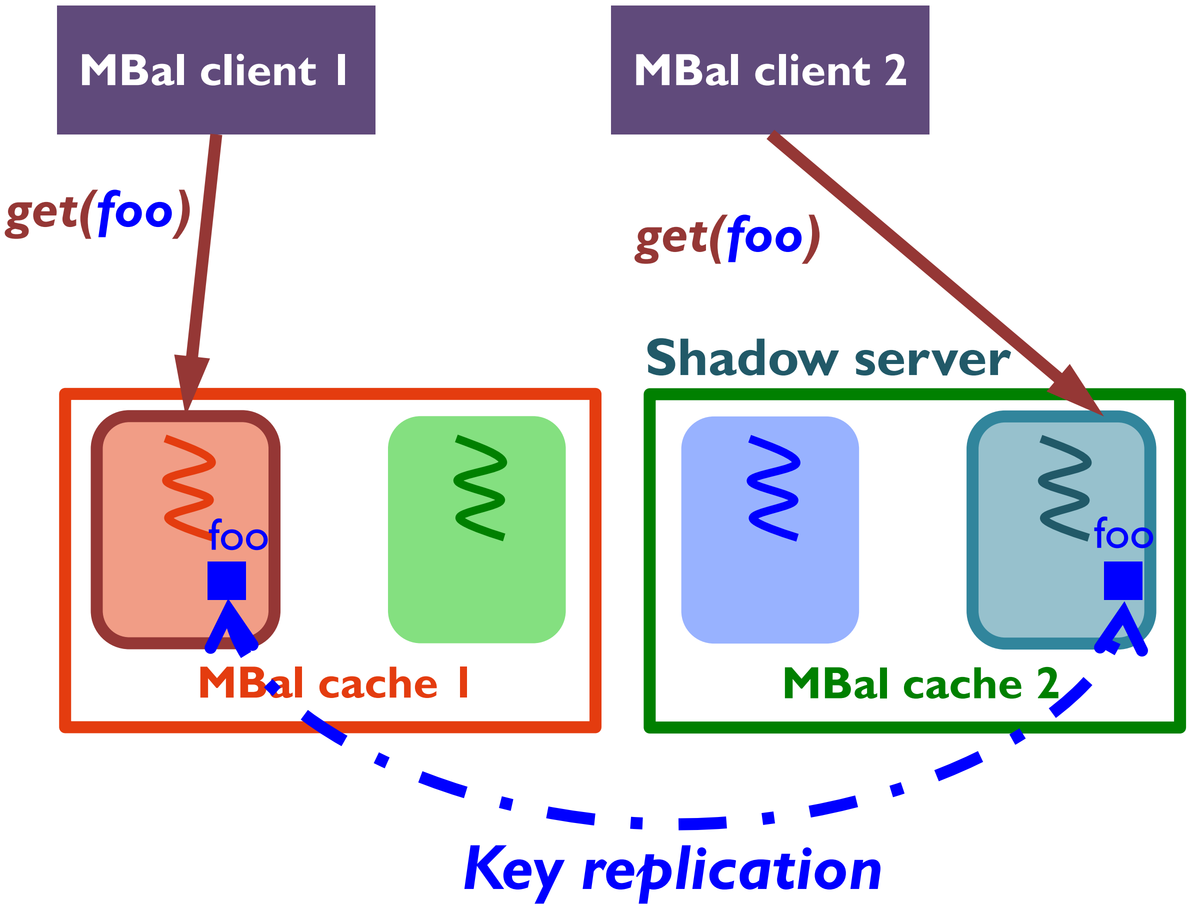
Related work

Phase 1: key replication



- TRIGGER?
  - EWMA access > threshold
- ACTION?
  - Randomly pick a shadow server
  - replicate hot keys
  - Proportional sampling
- FEATURES?
  - Fine-grained
  - Temporary

Phase 1: key replication



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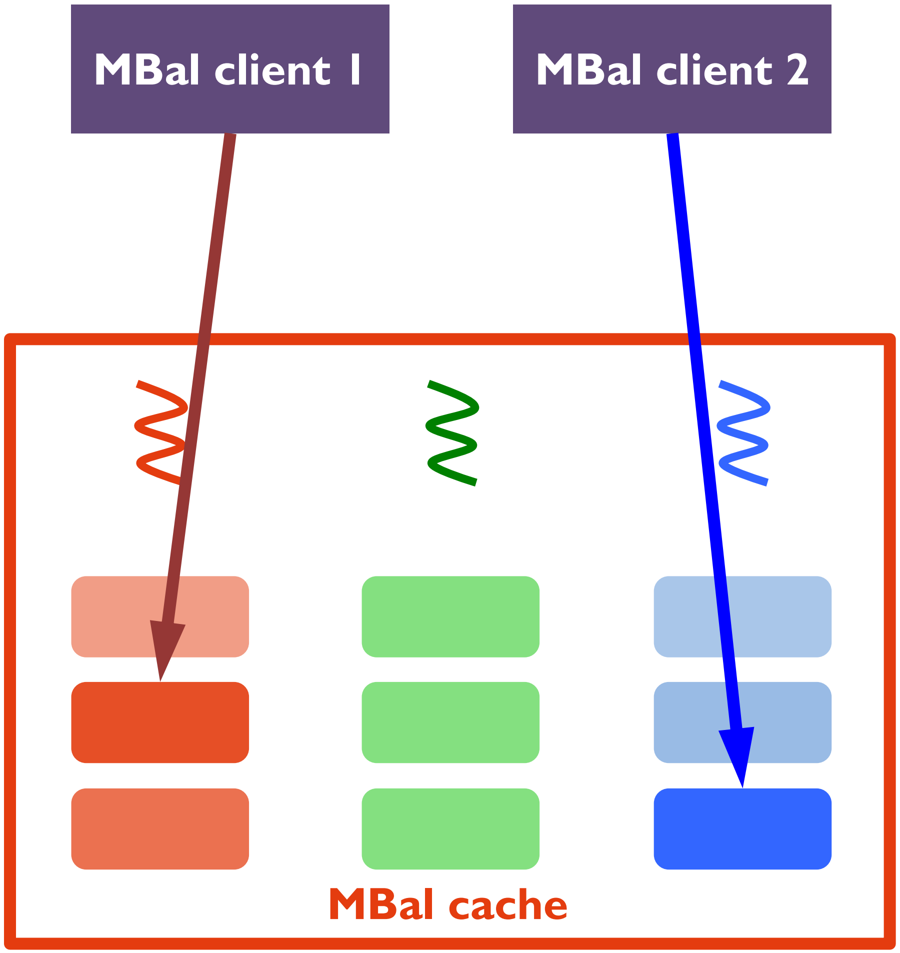
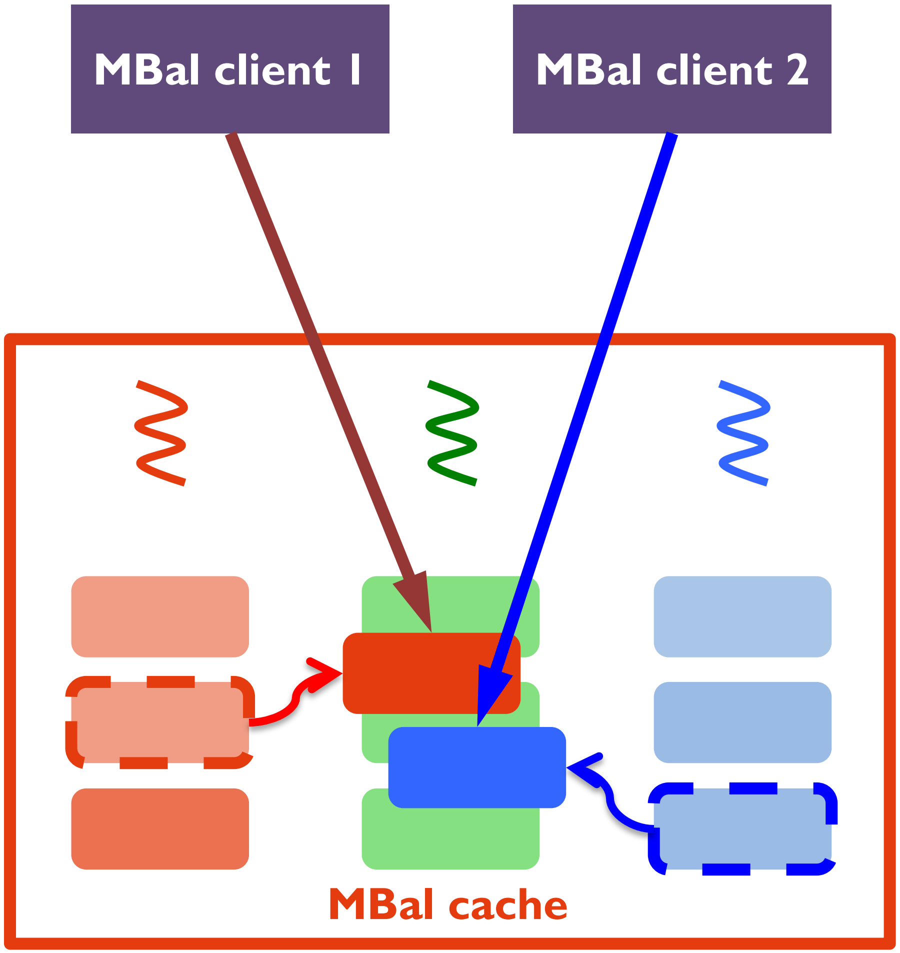
Phase 2: server-local cachelet migration



- TRIGGER?
  - # hot keys > $REPL_{HIGH}$
  - Enough local headroom
- ACTION?
  - Migrate/swap cachelet(s) within a server
  - ILP
- FEATURES?
  - Coarse-grained
  - Temporary

Phase 2: server-local cachelet migration



Server-local migration

- TRIGGER?
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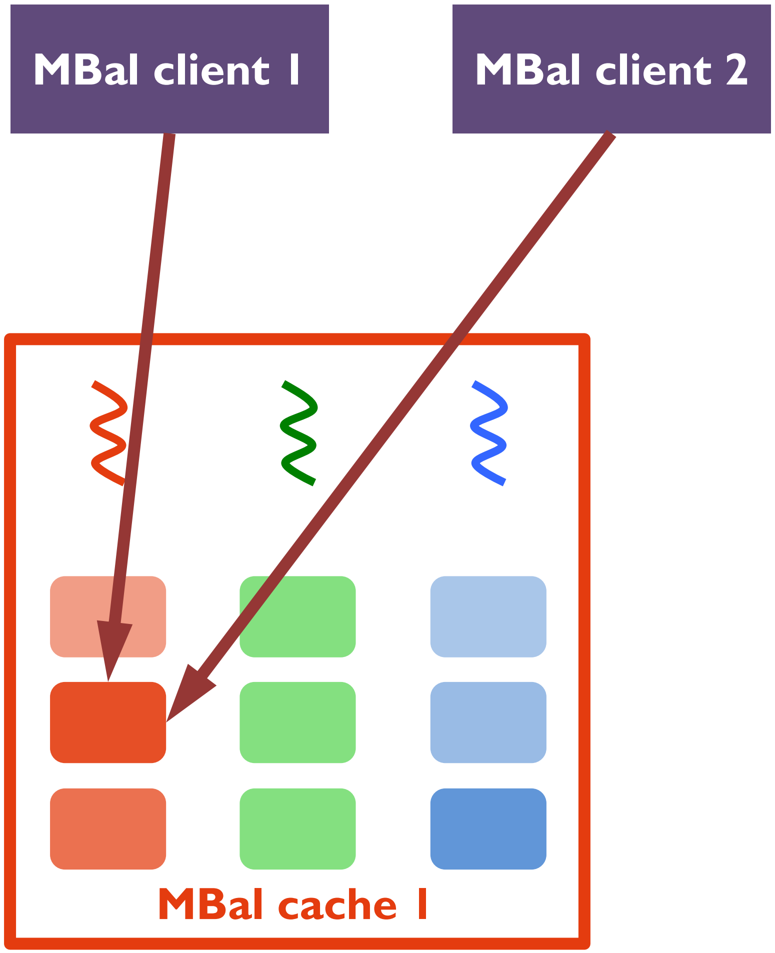
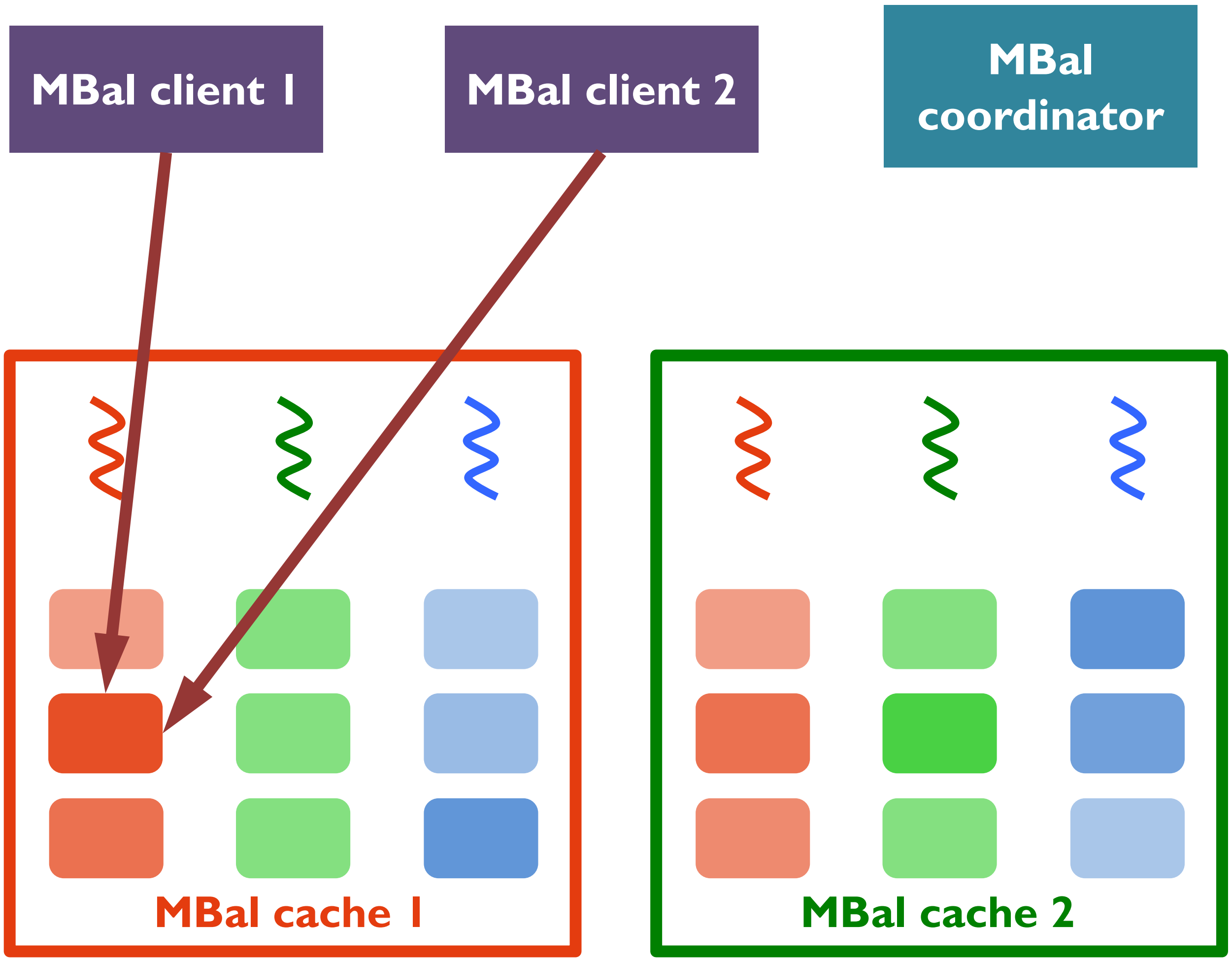
Phase 3: coordinated cachelet migration



- TRIGGER?
  - # hot keys > $REPL_{HIGH}$
  - Not enough local headroom
- ACTION?
  - Migrate/swap cachelet(s) across servers
  - ILP
- FEATURES?
  - Coarse-grained
  - Permanent

Phase 3: coordinated cachelet migration



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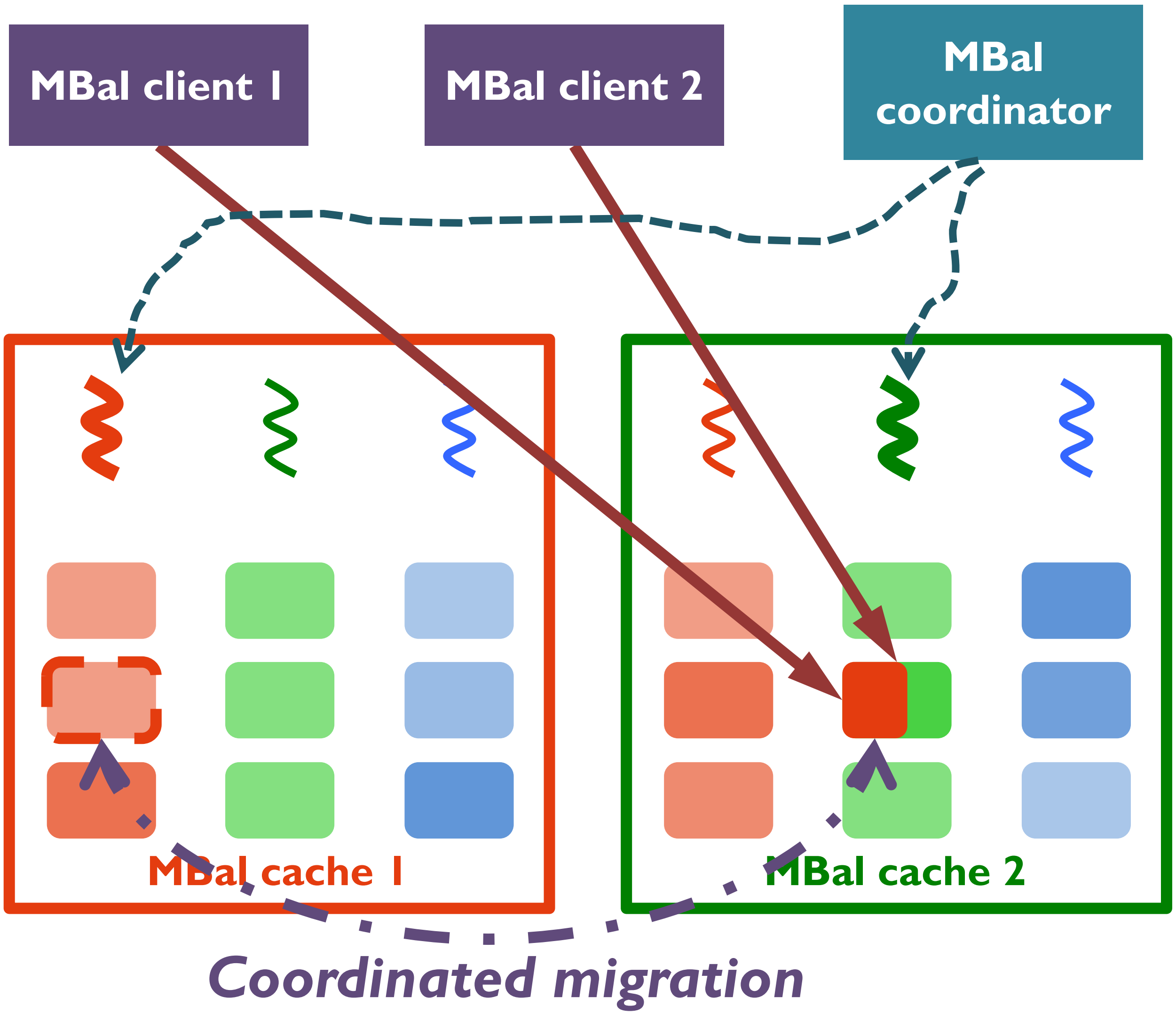

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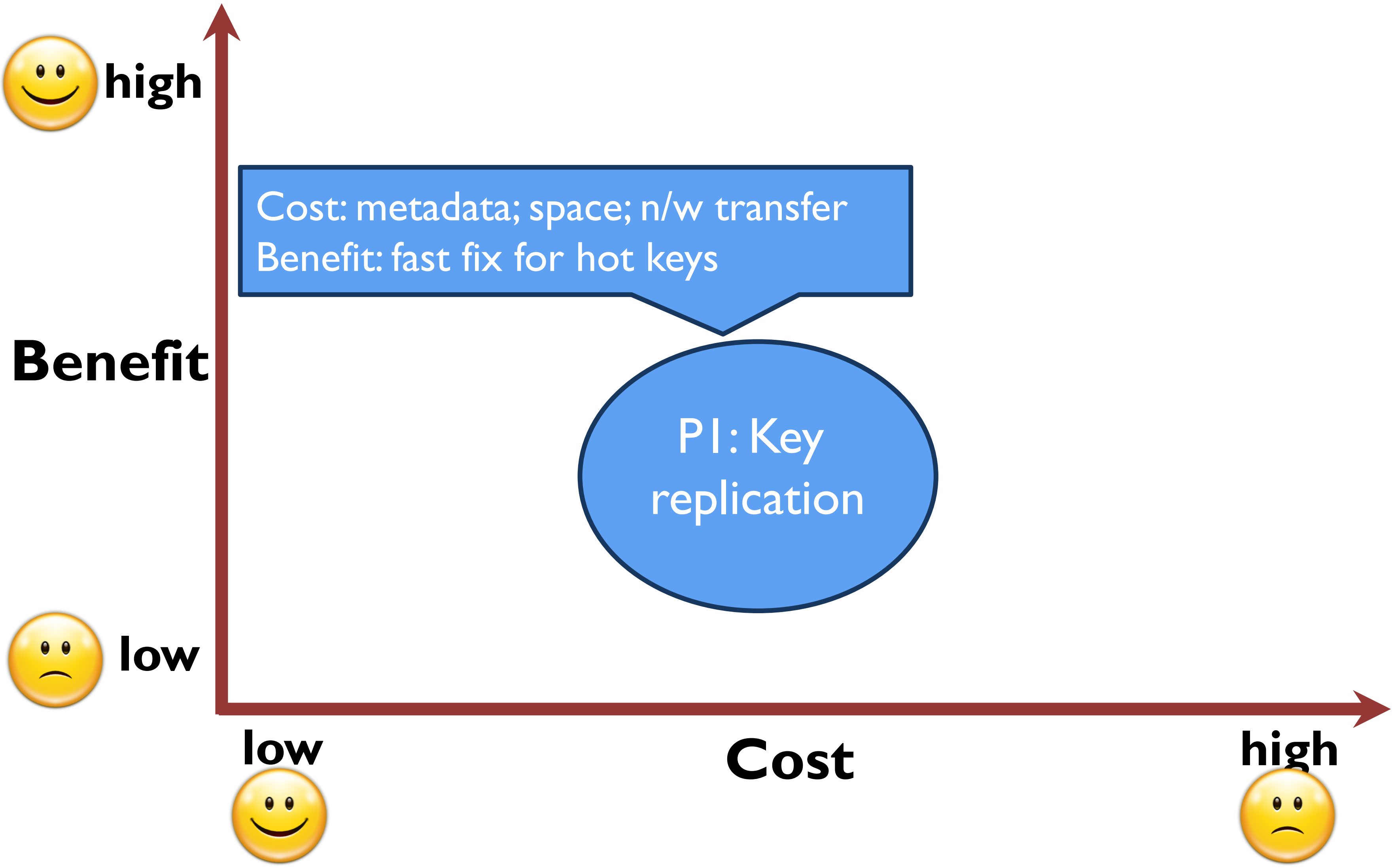
Cost/benefit tradeoffs in MBal



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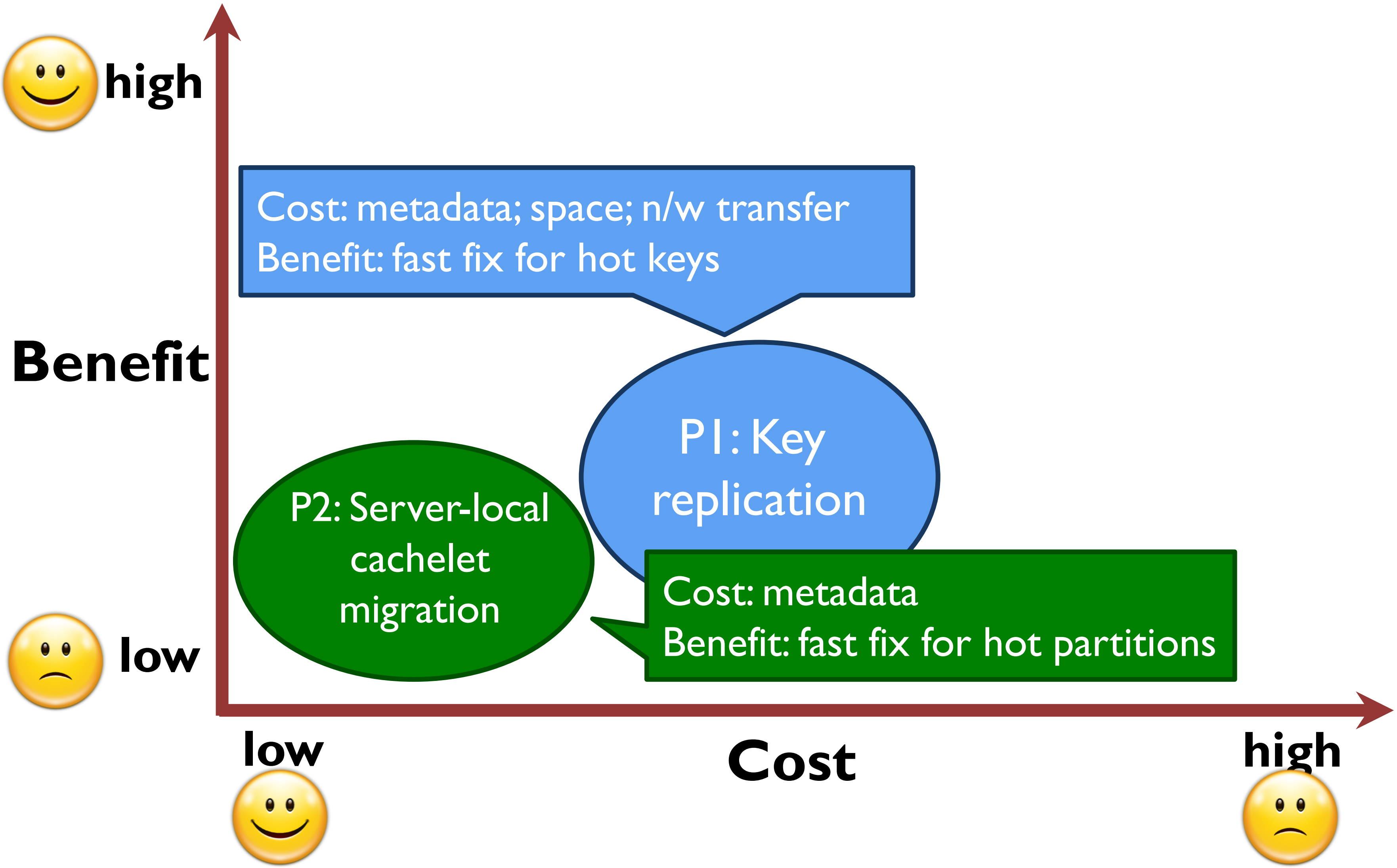

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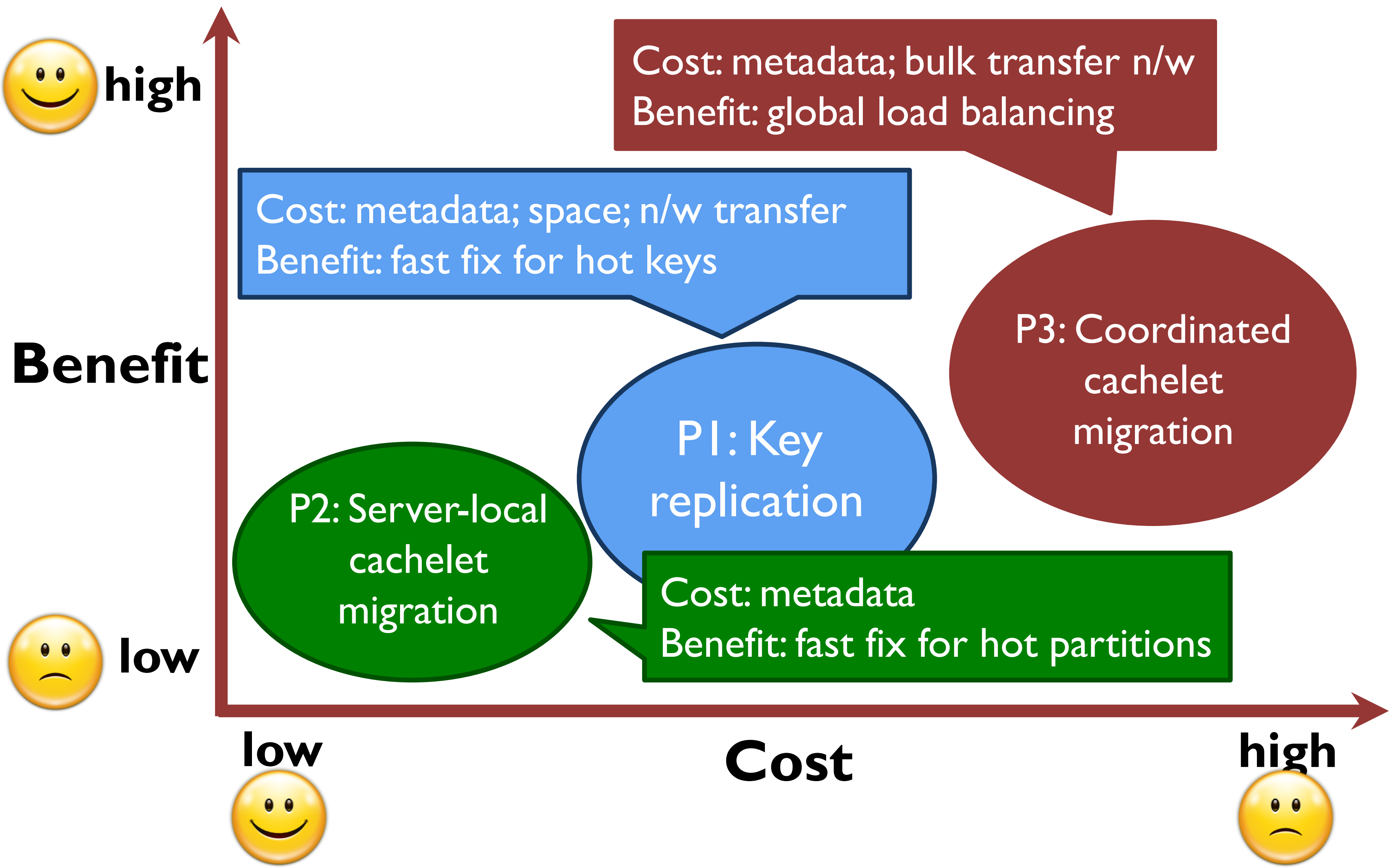


Outline

MBal cache design

MBal load balancer design

Evaluation

Related work

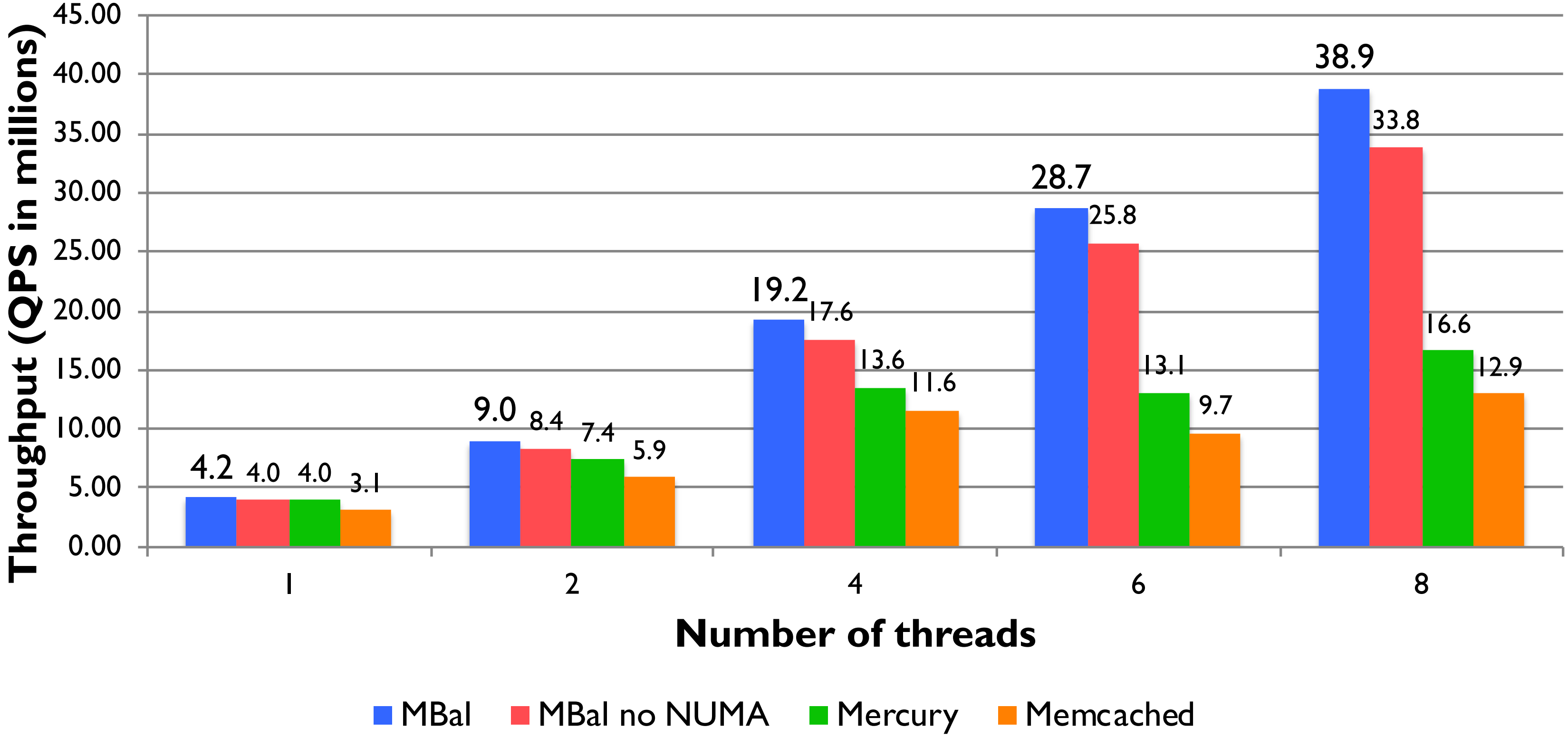
Methodology

- Scale-up cache performance tests
  - Local testbed
  - Single instance (8-core and 32-core server)

- End-to-end load balancer evaluation
  - 20-VM cluster (EC2, c3.large)

MBal evaluation – micro-benchmark

- 8-core 2.5GHz, 2×10MB L3 LLC, 64GB DRAM
- Uniform workload, 100% GET, 10B key 20B value
- Without network



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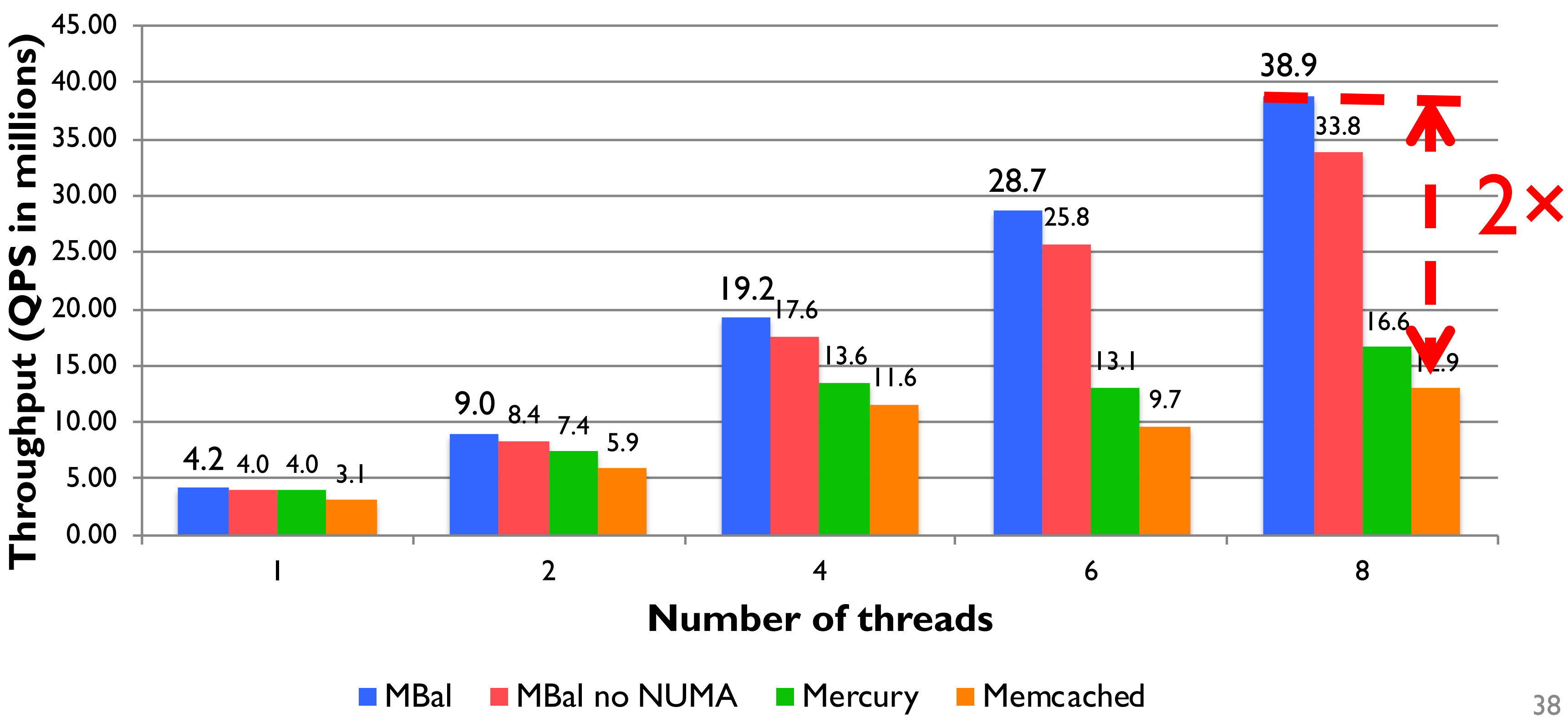
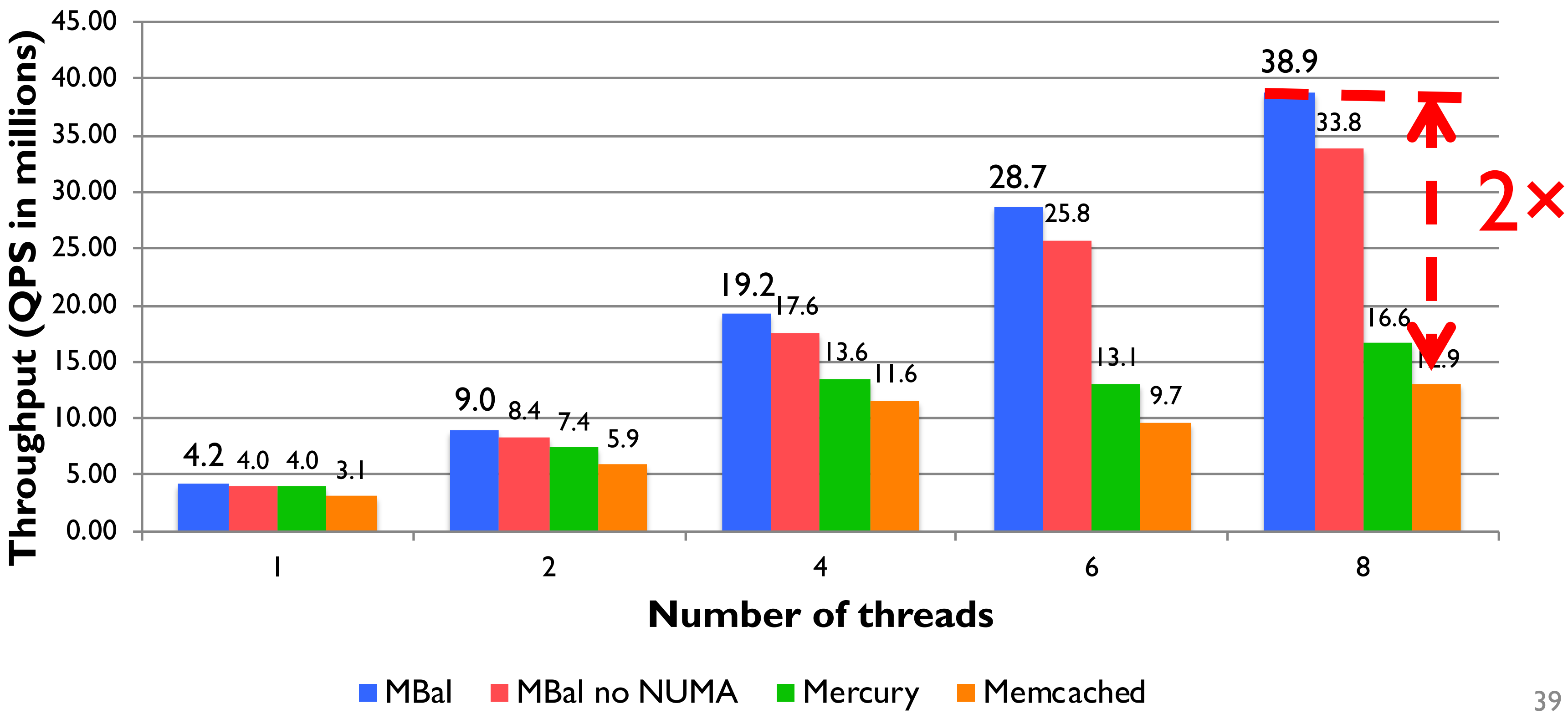


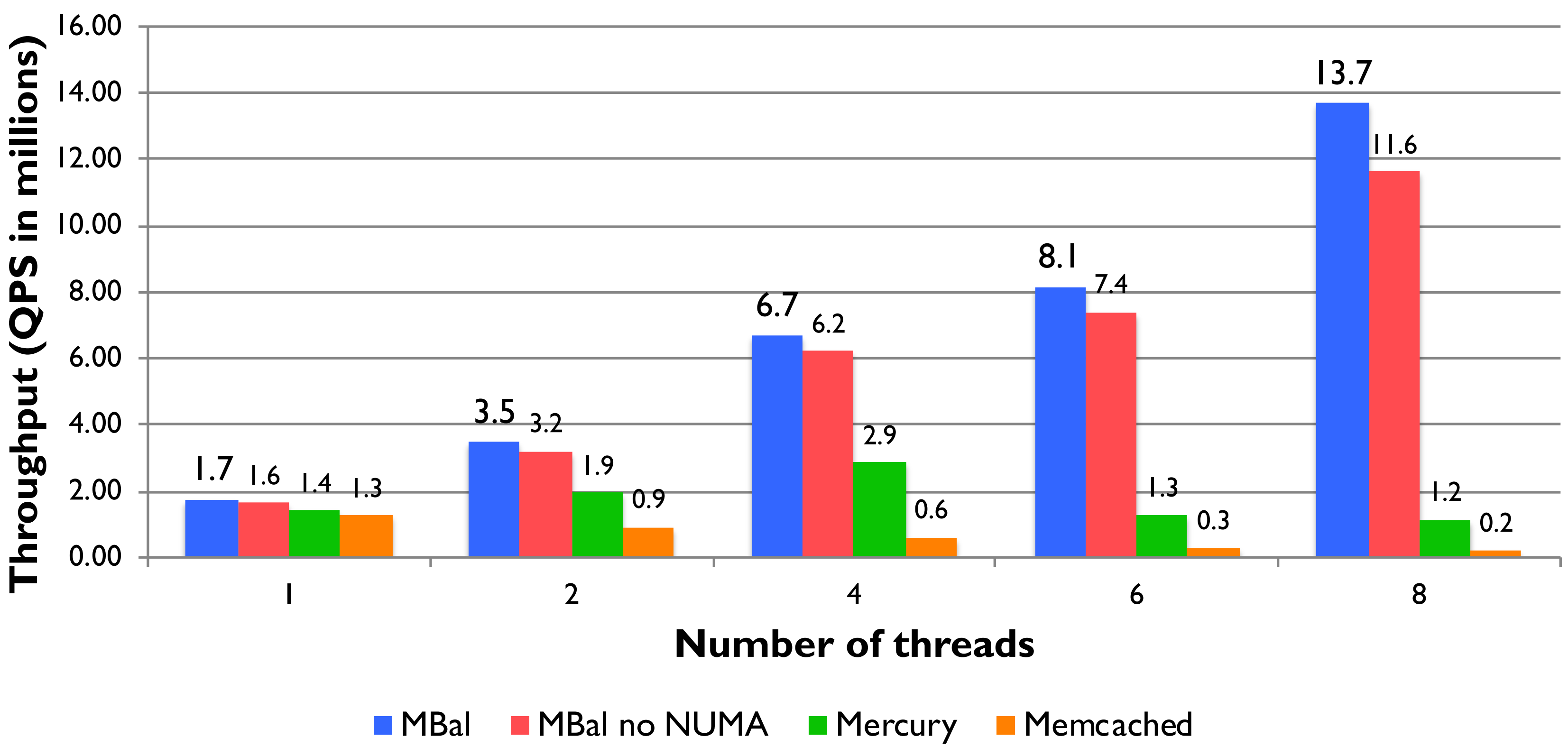
MBal evaluation – micro-benchmark

✓ MBal eliminates bucket-level lock contention!



MBal evaluation – micro-benchmark

- 8-core 2.5GHz, 2×10MB L3 LLC, 64GB DRAM
- Uniform workload, 100% SET, 10B key 20B value
- Without network



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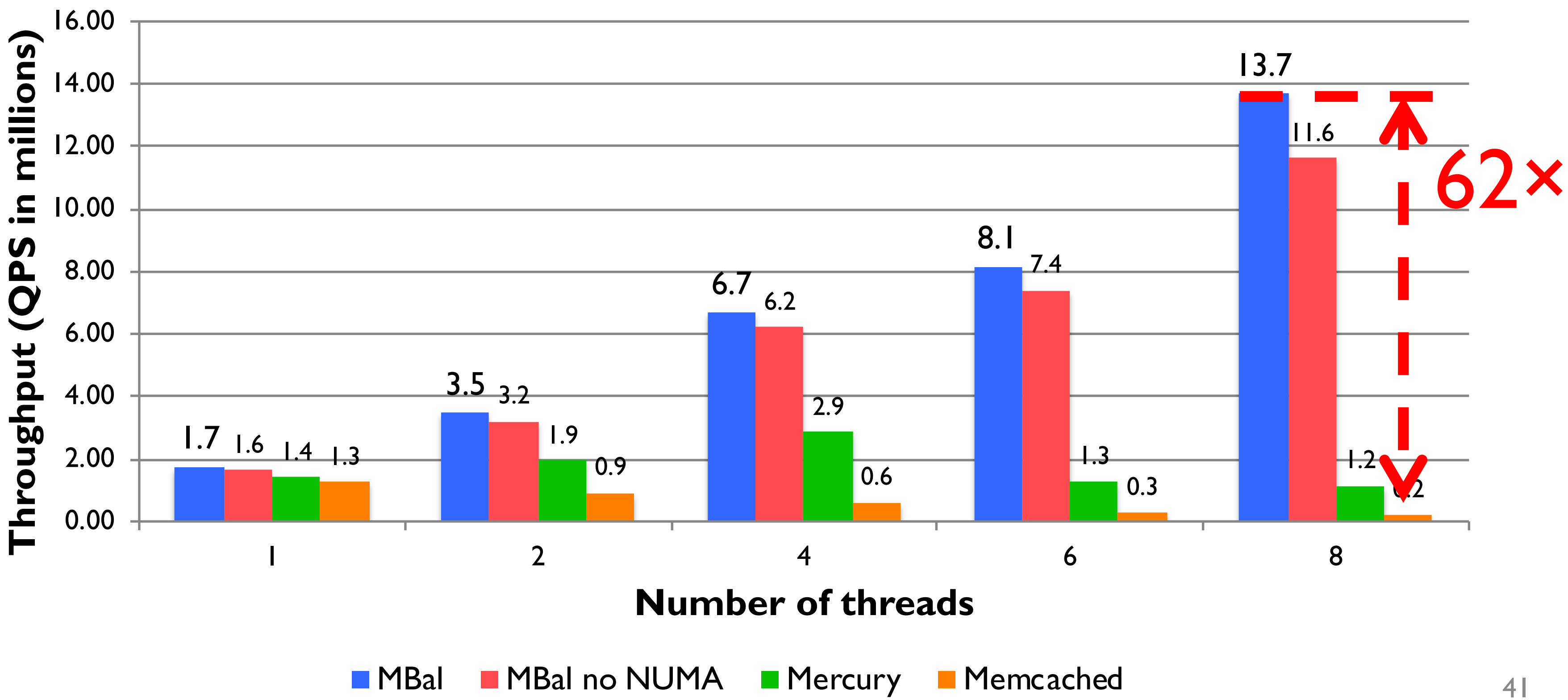
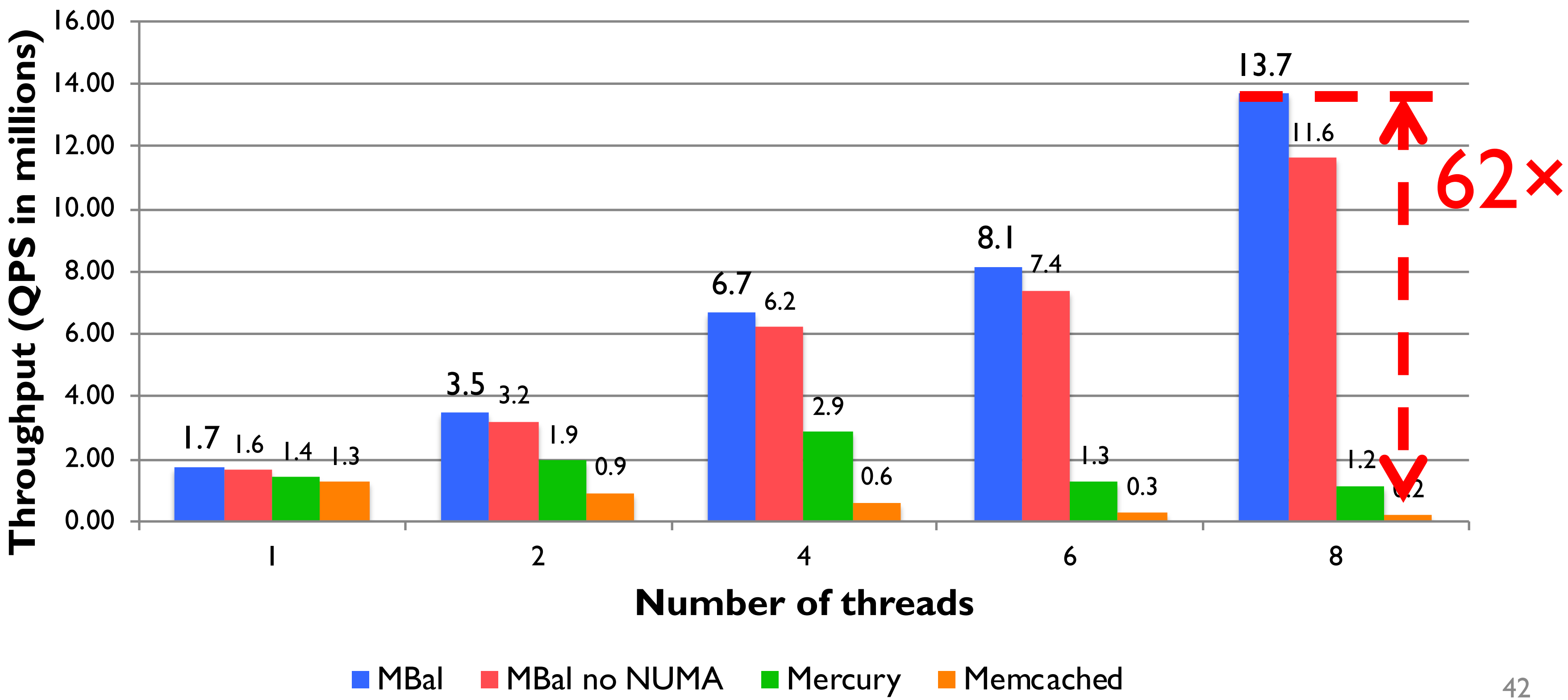


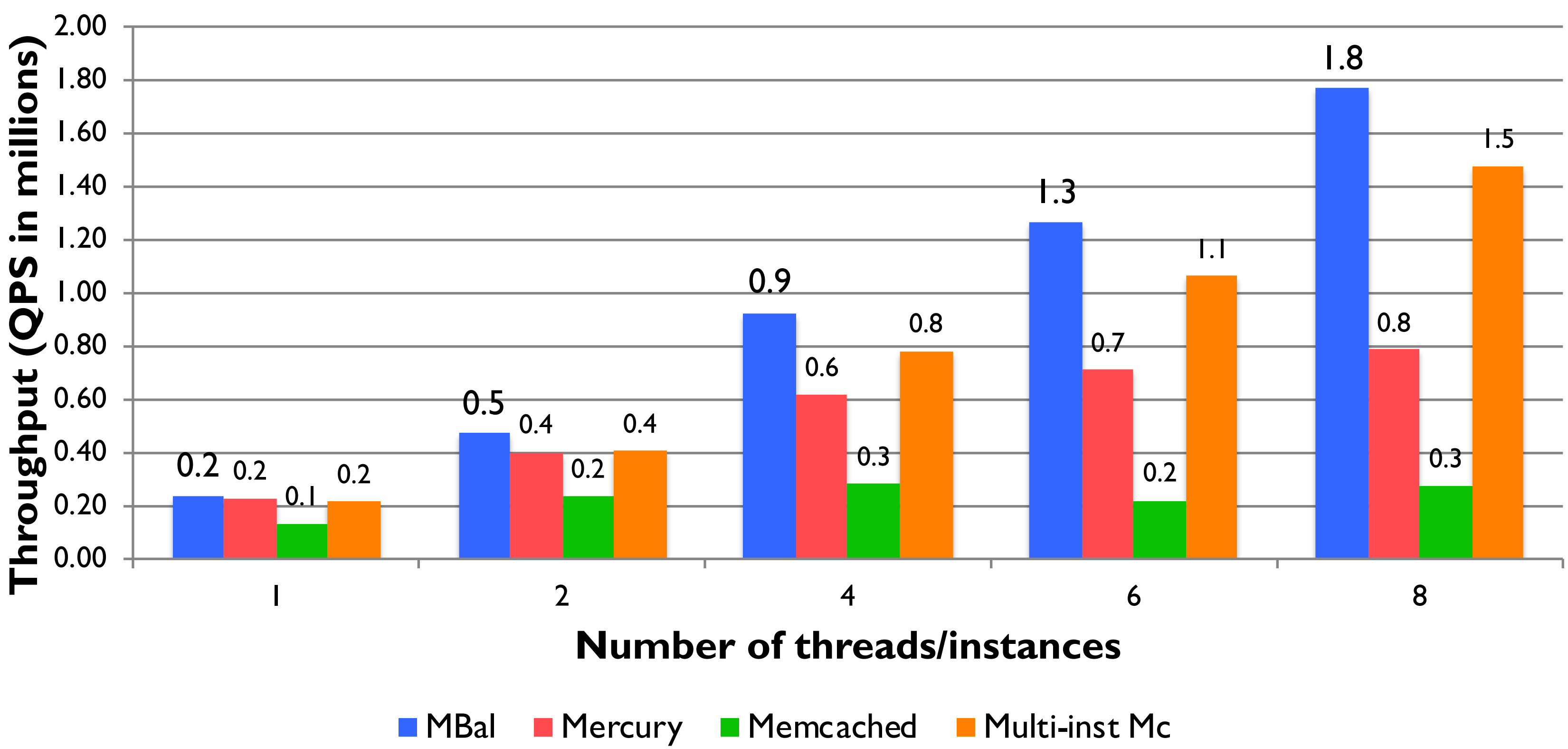
MBal evaluation – micro-benchmark

✓ MBal eliminates global cache lock contention!



MBal evaluation – complete system

- 8-core 2.5GHz, 2×10MB L3 LLC, 64GB DRAM
- Zipfian workload, 75% GET, 10B key 20B value
- 10Gb Ethernet, MultiGET



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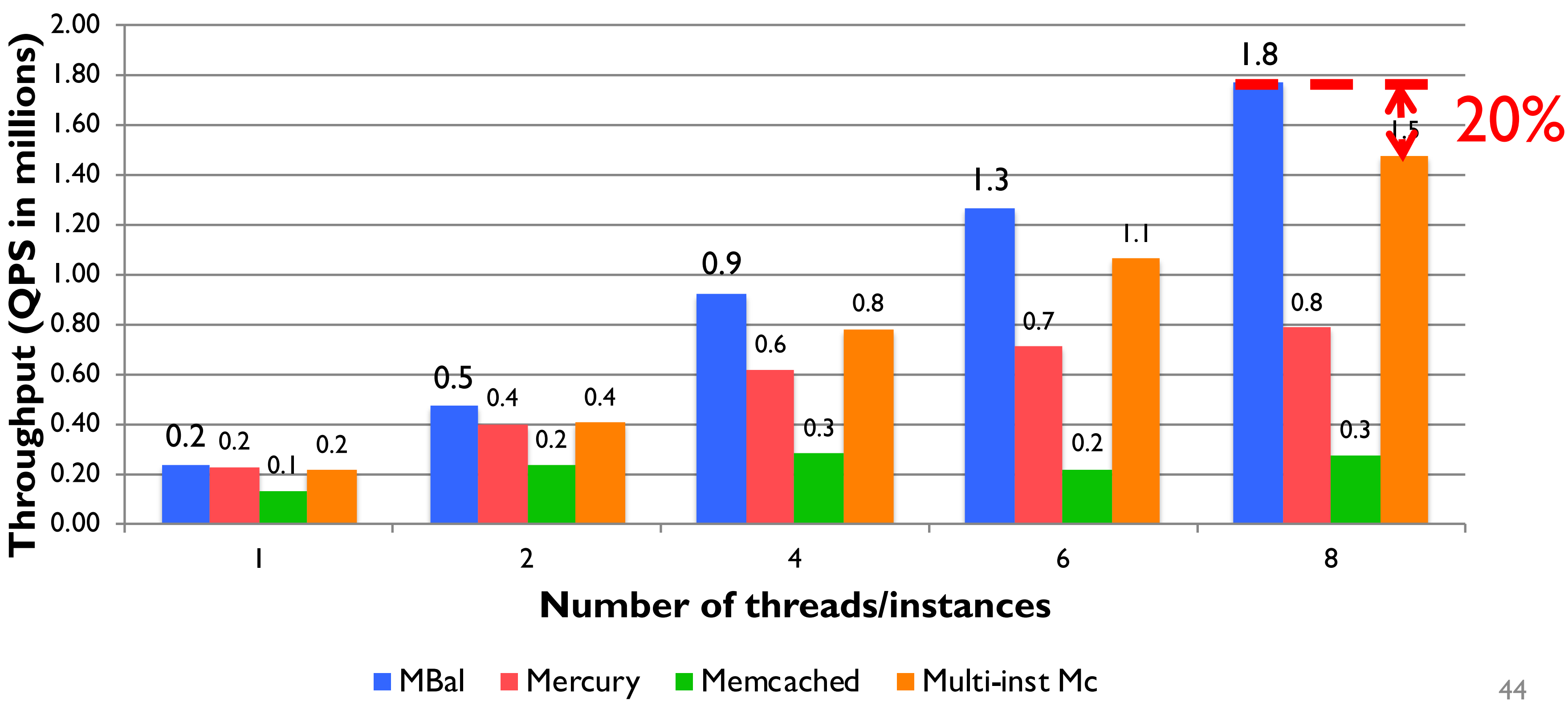
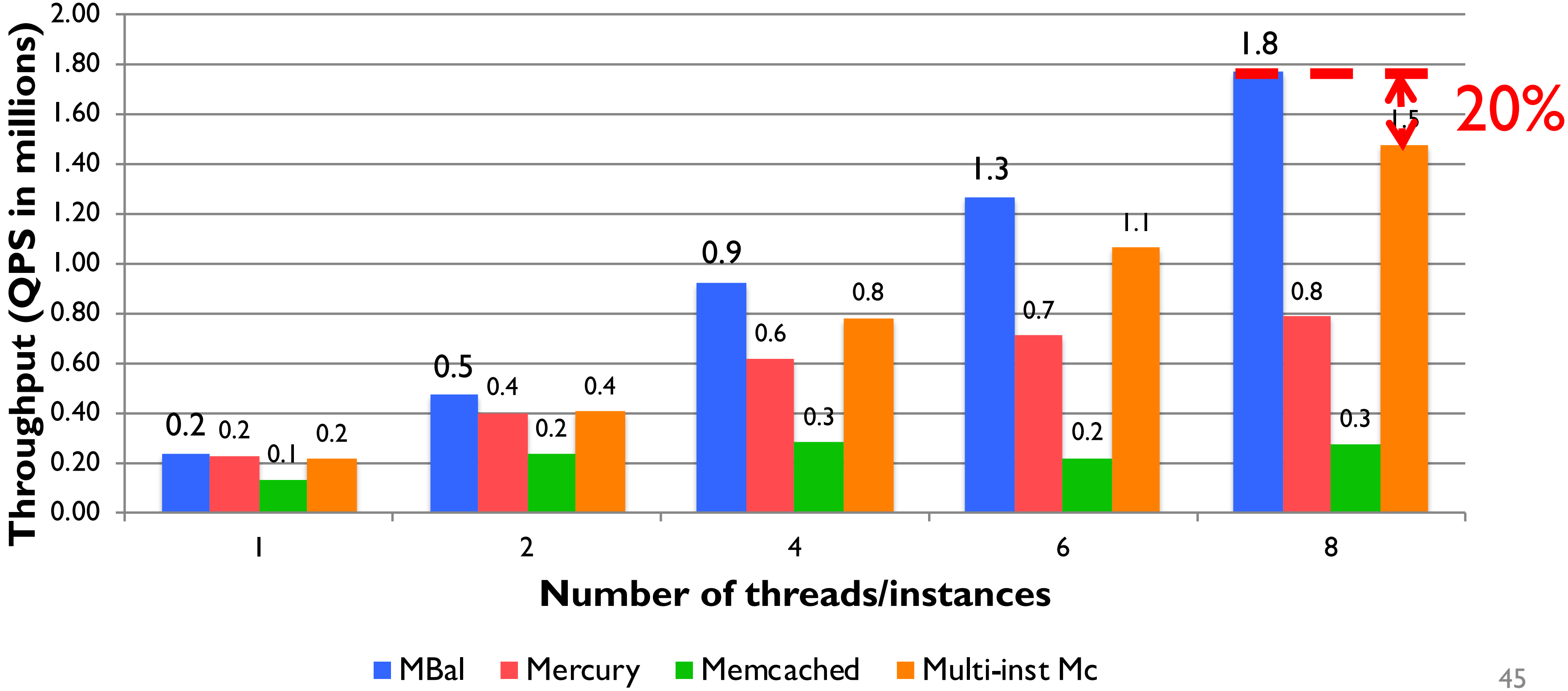


MBal evaluation – complete system

✓ MBal uses lightweight CPU cache-aligned bucket locks!



End-to-end load balancer evaluation

Workload	Characteristics	Application scenario
Workload A	**100% read, Zipfian**	**User account status info**
Workload B	**95% read, 5% update, hotspot (95% ops on 5% data)**	**Photo tagging**
Workload C	**50% read, 50% update, Zipfian**	**Session store recording actions**

Amazon EC2, us-west-2b, Clients on 36 instances (c3.2xlarge), 20-node VM cluster (c3.large)

Load balancer evaluation

Workload	Characteristics
Workload A	100% read, Zipfian
Workload B	95% read, 5% update, hotspot
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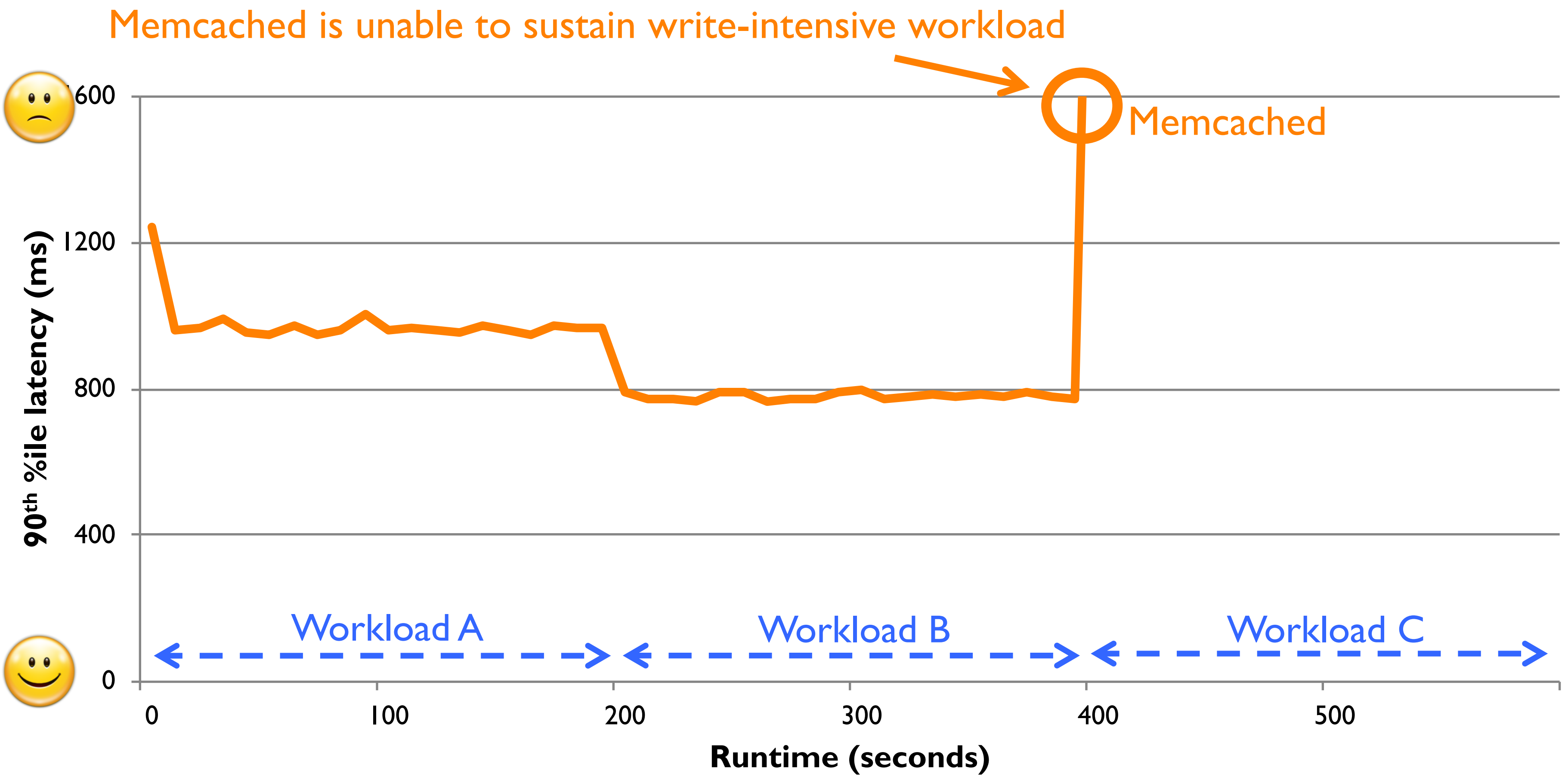

Load balancer evaluation

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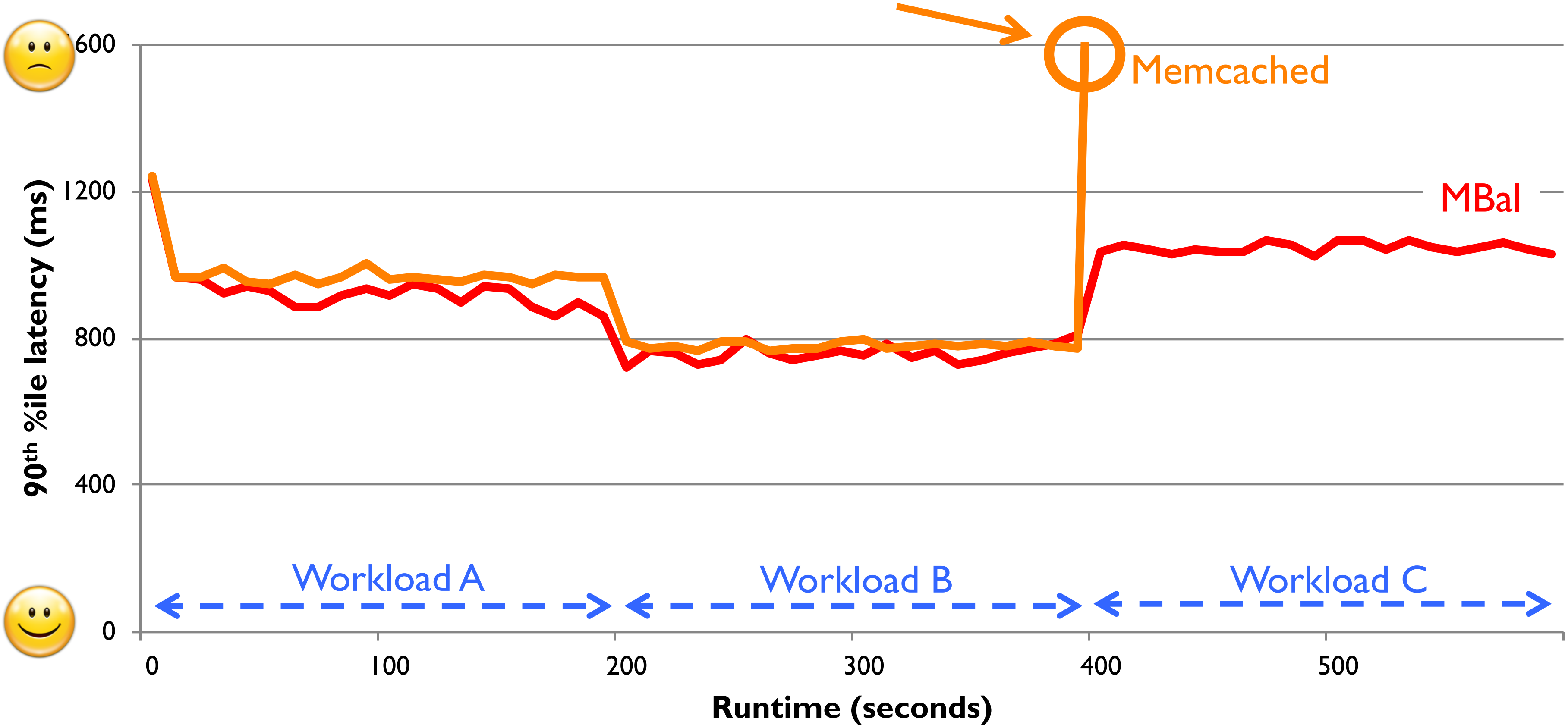
Memcached is unable to sustain write-intensive workload



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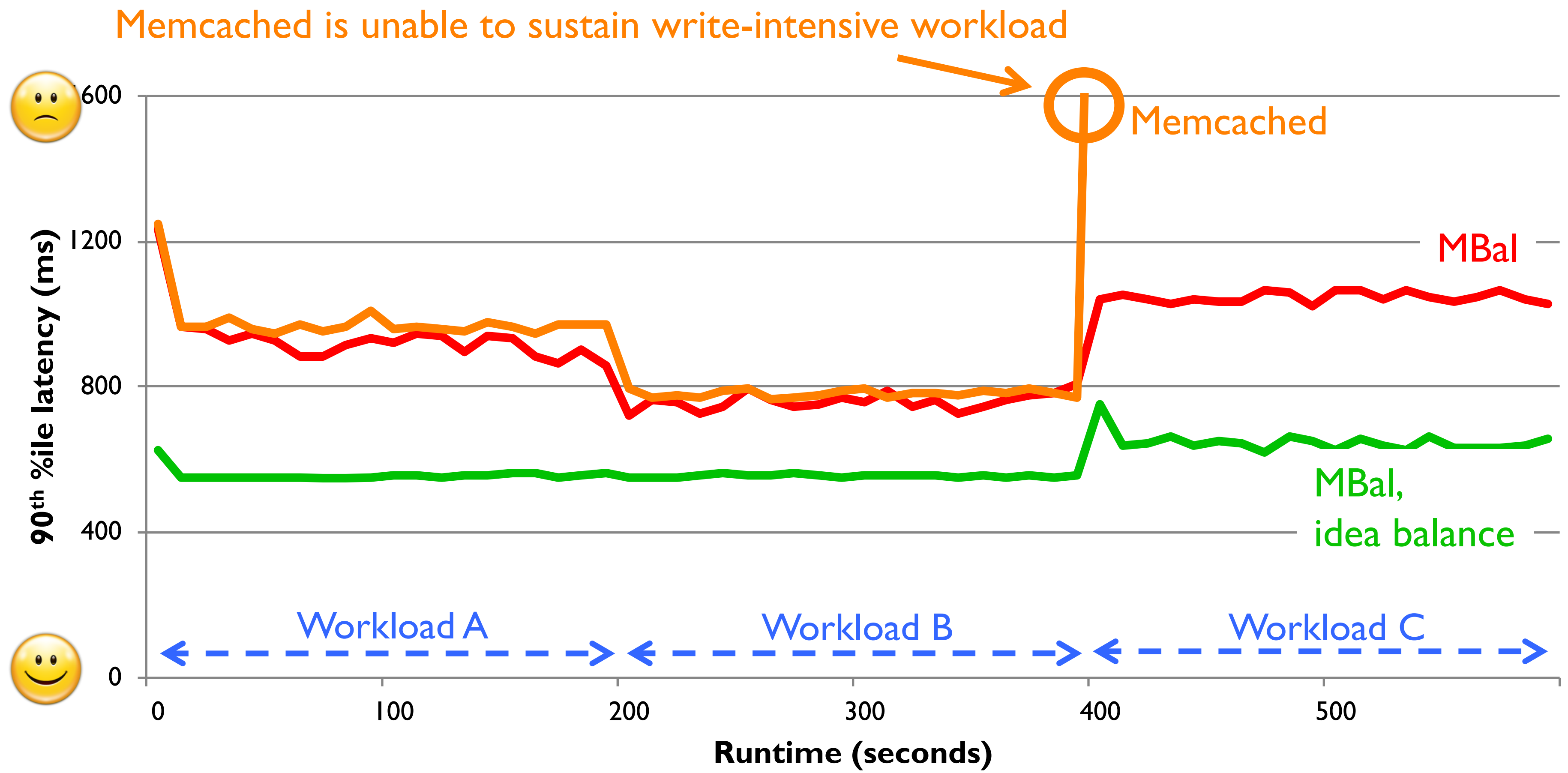

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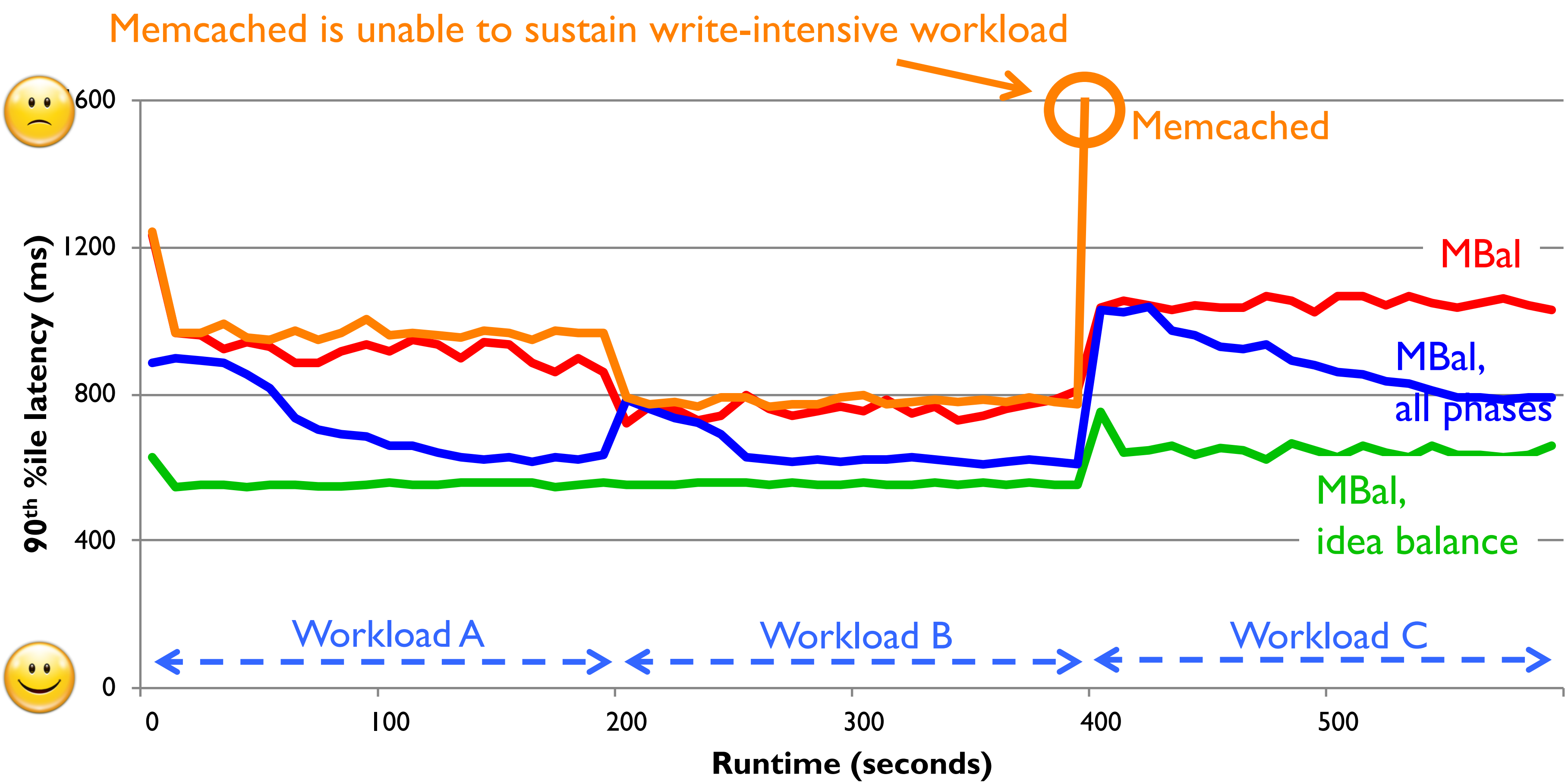

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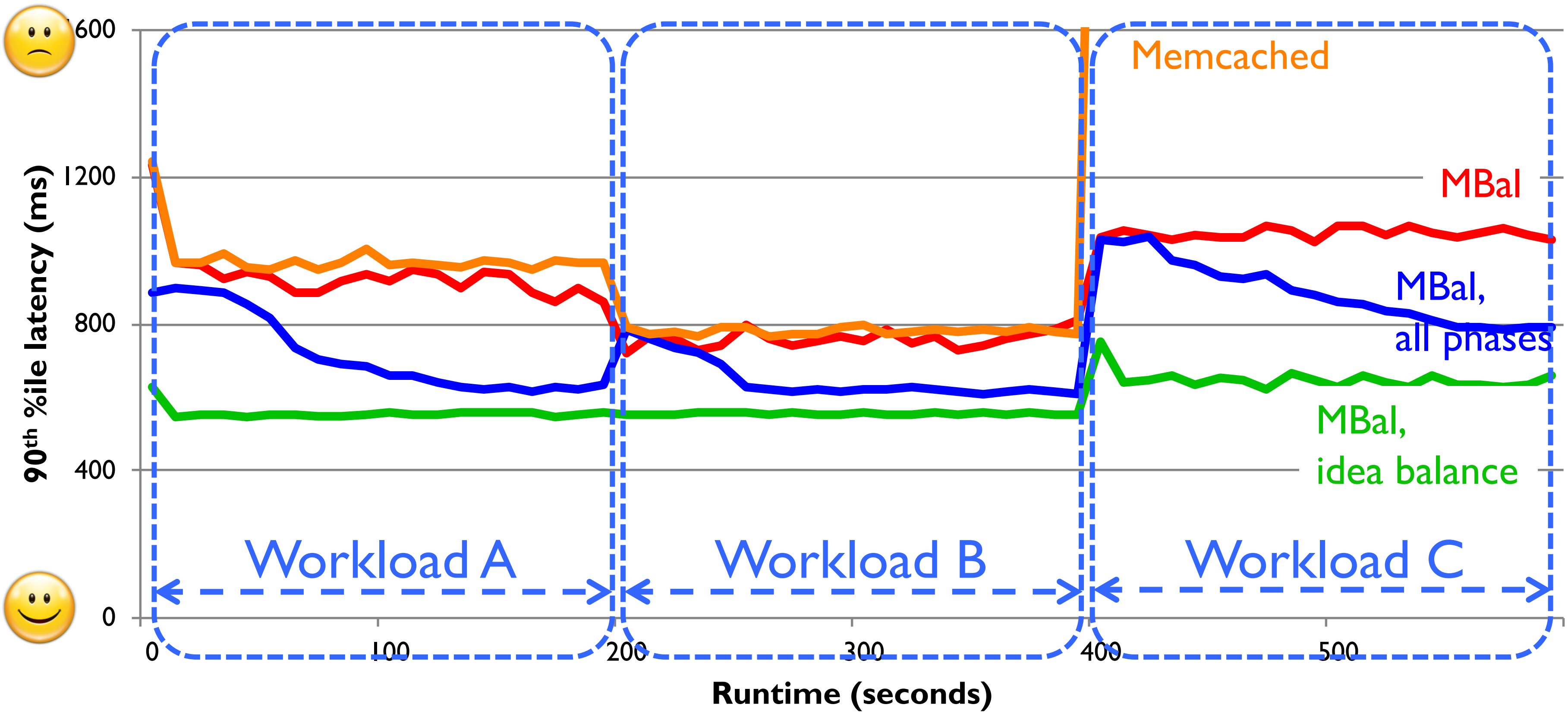

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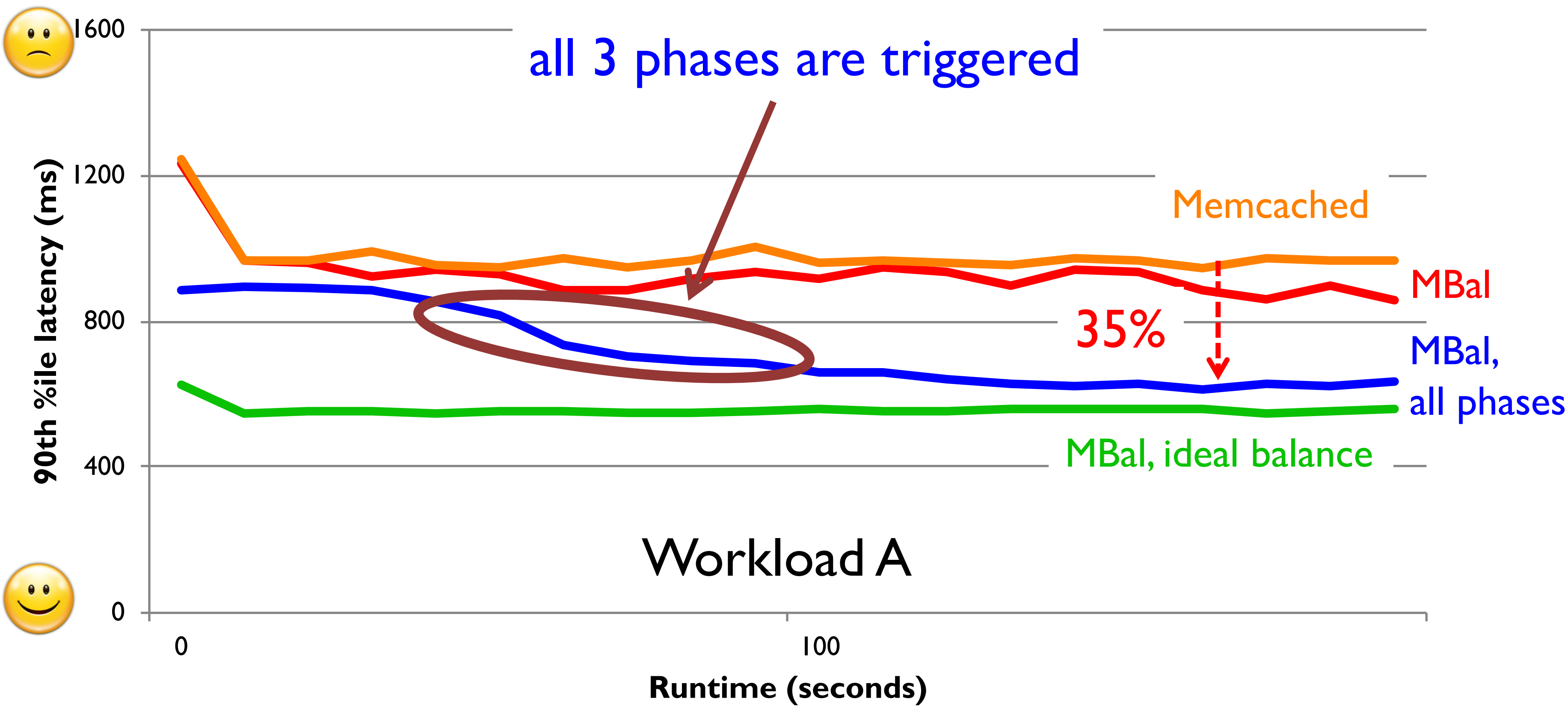

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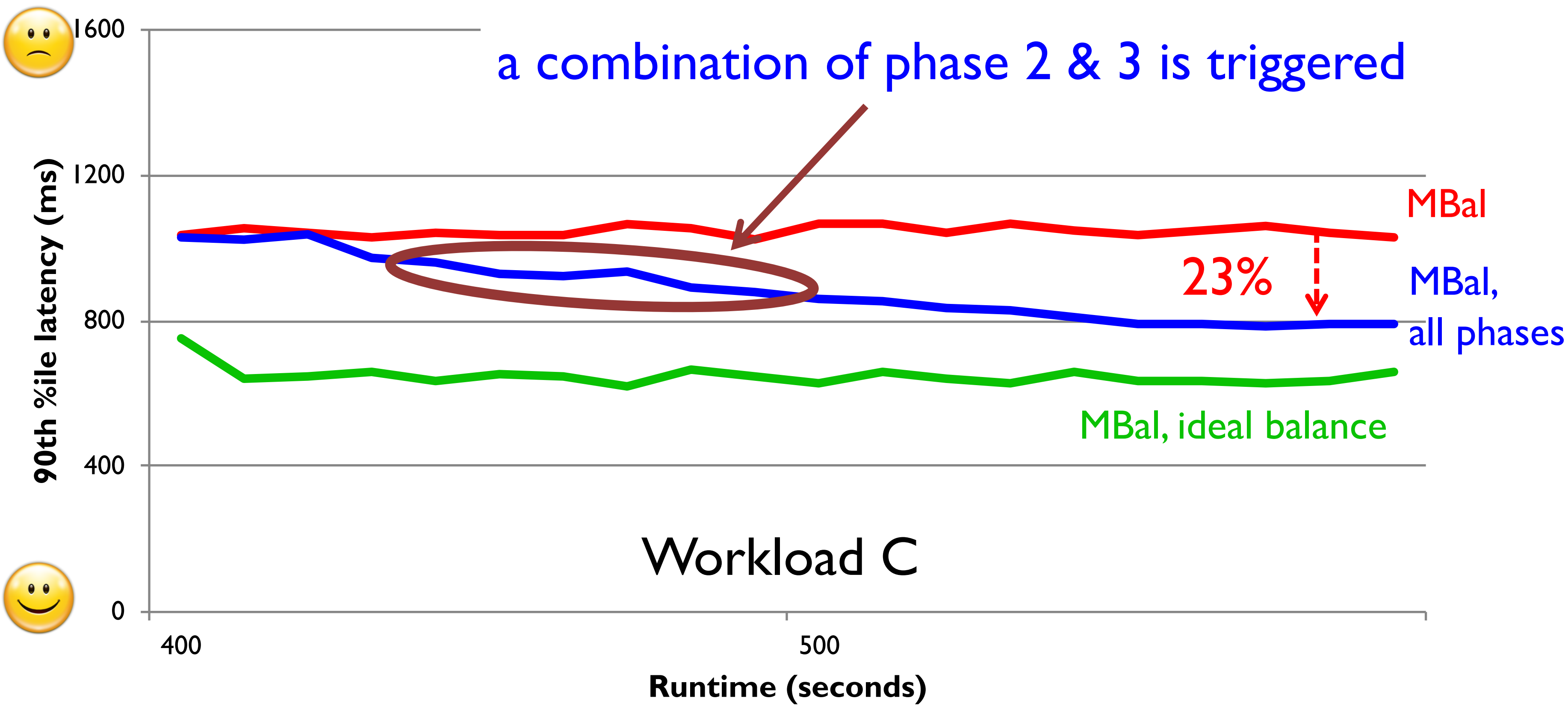

Summary of results

- MBal fine-grained partitioning design
  - **2×** more QPS for GETs
  - **62×** more QPS for SETs

- MBal multi-phase load balancer
  - **35%** lower tail latency
  - **20%** higher throughput

  → Effectively improves QPS/$

Outline

MBal cache design

MBal load balancer design

Evaluation

Related work

Related work

- High performance in-memory KV store
  - Masstree [**EuroSys'12**], MemC3 [**NSDI'12**], MICA [**NSDI'14**]
- Storage load balancing
  - DHT (Pastry [**Middleware'01**], CFS [**SOSP'01**], Chord [**SIGCOMM'01**]), Proteus [**ICDCS'13**]
- Access load balancing
  - SmallCache [**SoCC'11**], Chronos [**SoCC'12**], SPORE [**SoCC'13**], Streaming Analytics [**Feedback'14**]

Conclusions

- Fine-grained, horizontal partitioning of in-memory data structure
  - eliminates sync overhead
  - enables load balancing
- MBal synthesizes three replication and migration techniques into a holistic system
  - reduces load imbalance
  - Improves tail latency