Big and Fast

Anti-Caching in OLTP Systems

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Online Transaction Processing

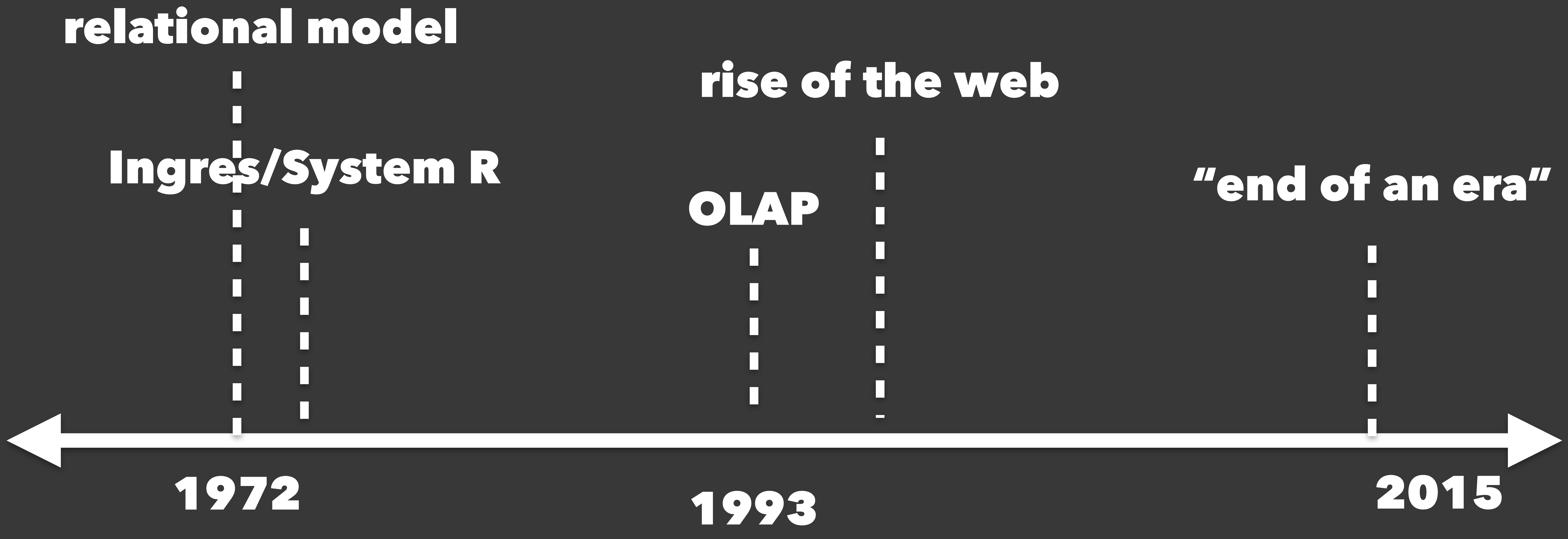
transaction-oriented

small footprint

write-intensive

A bit of history...

OLTP Through the Years



Modern OLTP Requirements

1. web-scale (big)
2. high-throughput (fast)

Thesis Motivation

- traditional disk-based architectures aren't fast enough
- newer main memory architectures aren't big enough

Can we have main-memory performance for larger-than-memory datasets?

Thesis Overview: Contributions

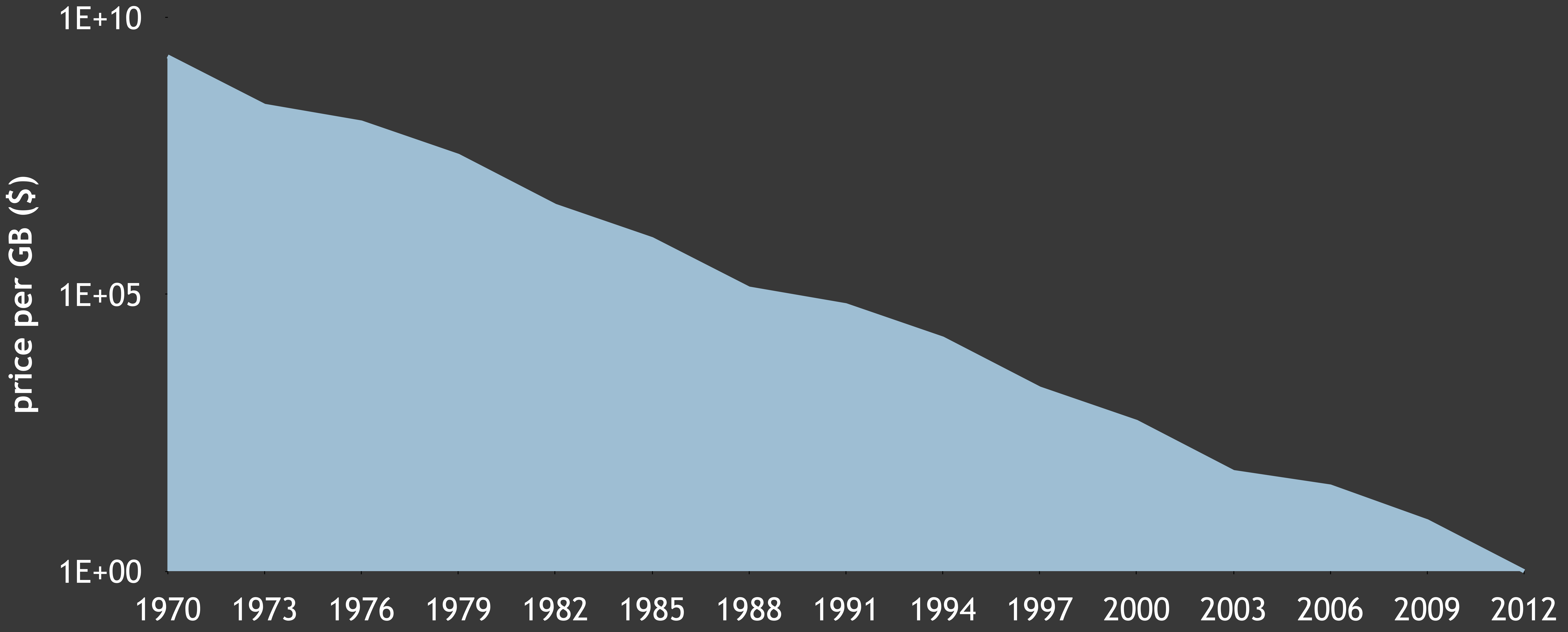
1. **anti-caching architecture**
   - larger than memory datasets in main memory DBMS
2. **anti-caching + persistent memory**
   - exploring next-generation hardware and OLTP systems

Outline

Disk-Oriented Architectures

- assumption: data won't fit in memory
- disk-resident data, main memory buffer pool for execution
- concurrency is a must
  - transaction serialization and locks

Memory Costs



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Now What?

1. DBMS buffer pool
2. distributed cache
3. in-memory DBMS

Buffer Pool

- must still…
  - maintain buffer pool
  - lock/latch data
  - maintain ARIES-style recovery logs
- question: What is the overhead of all these things?

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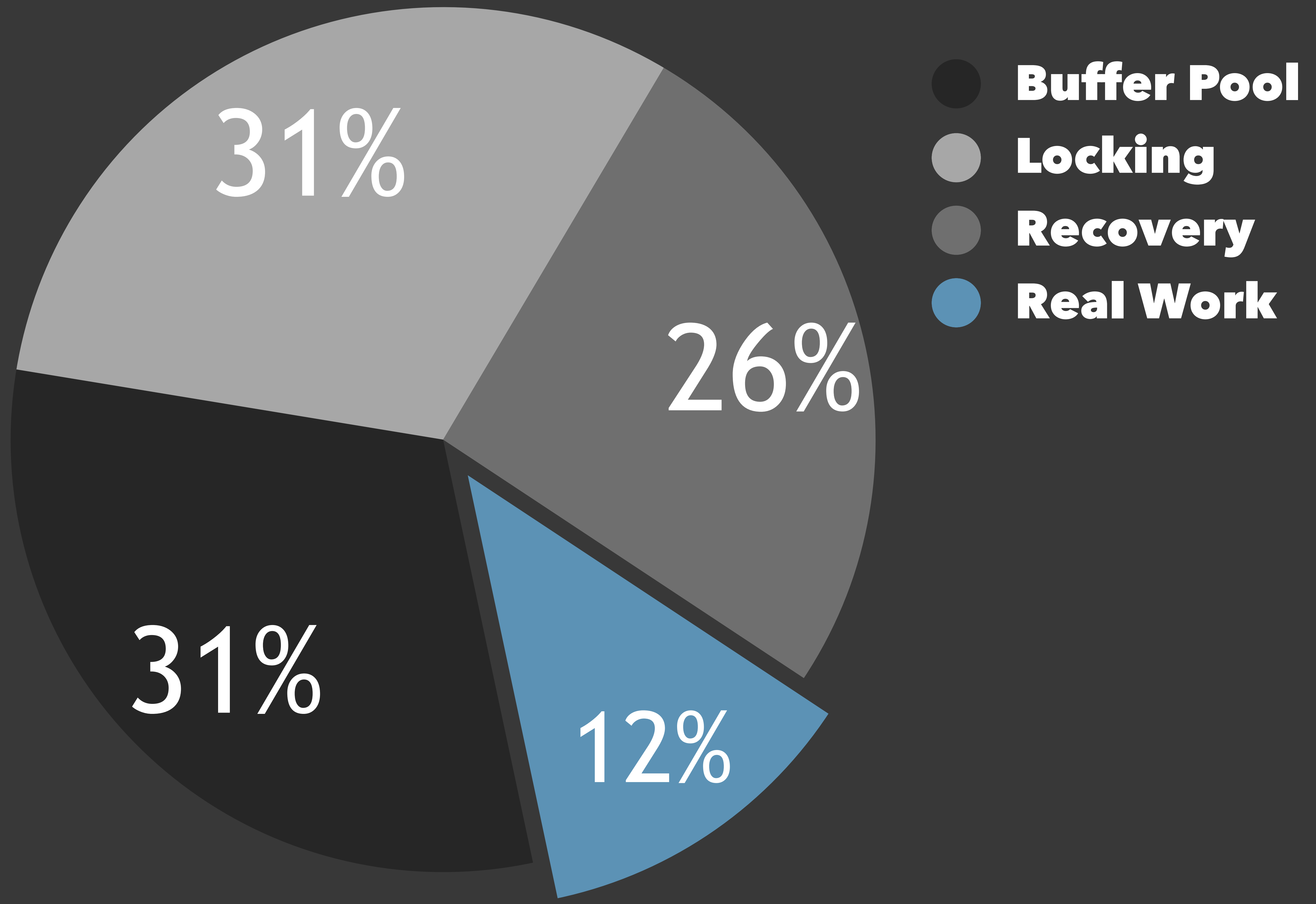

OLTP Through the Looking Glass, and What We Found There
SIGMOD '08

Now What?

1. DBMS buffer pool
2. distributed cache
3. in-memory DBMS

Cache Layer

Persistence Layer

Main Memory Cache

- fast *and* scalable, but…
- key-value interface
- not ACID (AI, not CD)

Consistency and Durability

- reads are easy, writes are not
  - multiple copies of data
  - application's responsibility
- for OLTP, writes are common and consistency is essential

Now What?

1. DBMS buffer pool
2. distributed cache
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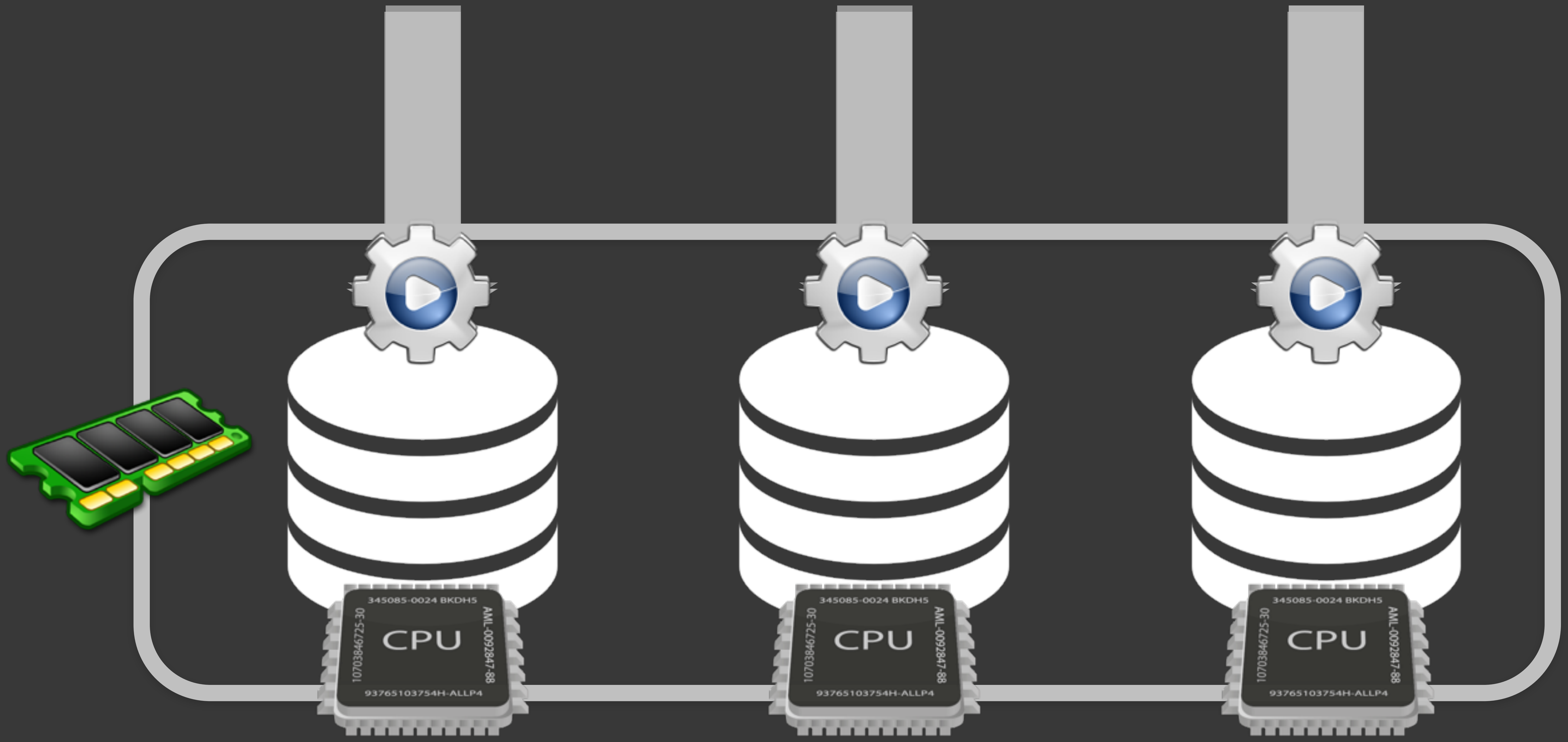
H-Store

H-Store Architecture

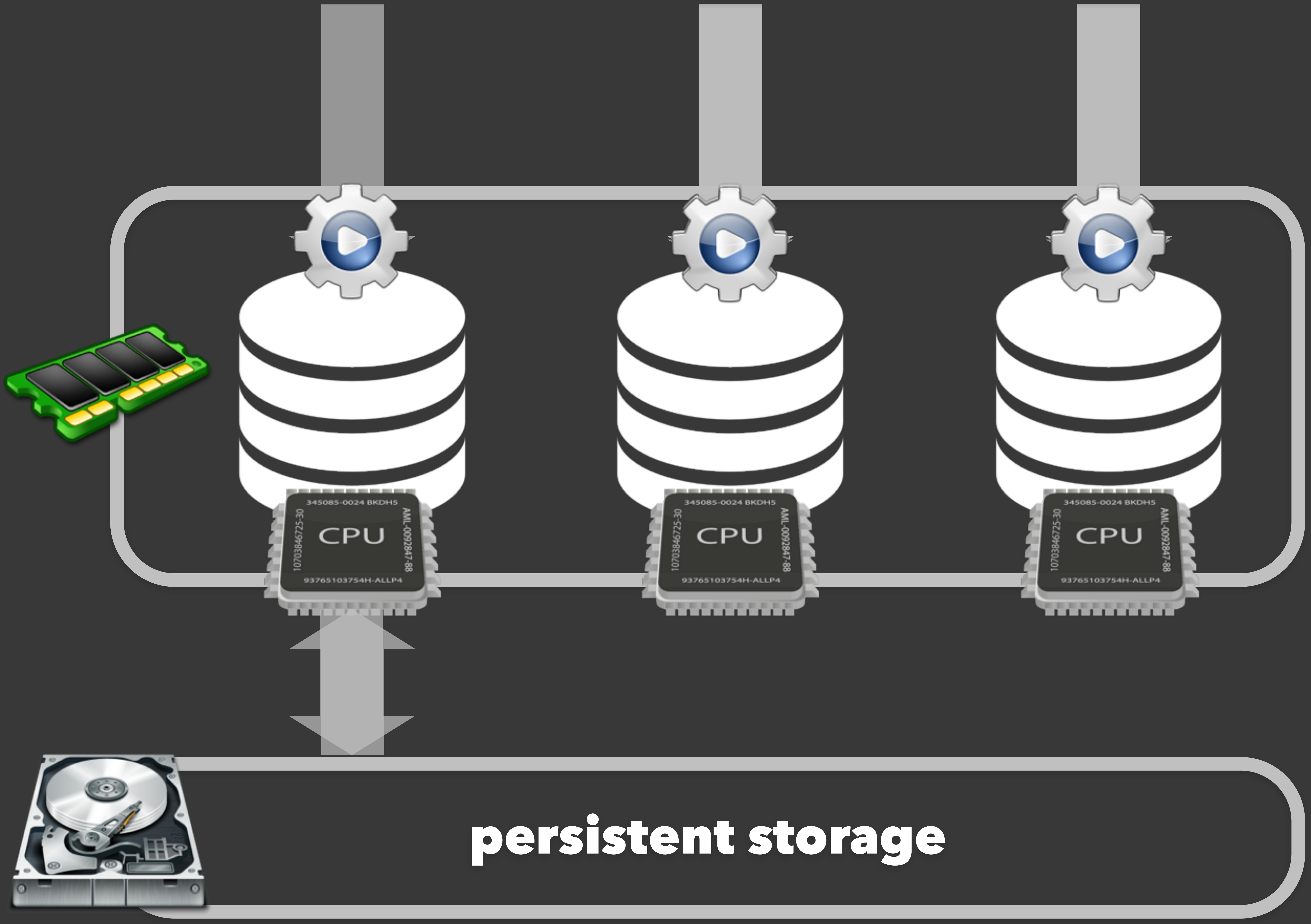
- partitioned, shared-nothing
- single-threaded main memory execution
  - no need for locks and latches
- lightweight recovery
  - snapshots + command log



CPU
CPU
CPU

virtual memory?

data -> memory?


345085-0024 BKDH5
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persistent storage

Big and Fast

big: disk-oriented

fast: memory-oriented

big *and* fast: anti-caching

OLTP workloads are *skewed*

Design Principles

- asynchronous disk fetches
  - don't block
- maintain ordering of evicted data accesses
  - ensures transactional consistency
- single copy of data
  - consistency is free
- efficient memory use, no swizzling

Outline

- Introduction
- Overview and Motivation
- Anti-Caching Architecture
- Memory Optimizations
- Anti-Caching on NVM
- Future Work and Conclusions

Architectural Overview

- memory is primary storage, cold data is evicted to disk-based anti-cache
- reading data from the anti-cache is done in 3 phases
  - avoids blocking, ensures consistency

Anti-Caching Phases

- evict
- pre-pass
- fetch
- merge

Evict

1. data > anti-cache threshold
2. dynamically construct anti-cache blocks of coldest tuples
3. asynchronously write to disk

Pre-Pass

1. a transaction enters pre-pass when evicted data is accessed
2. continues execution, creating list of evicted blocks
3. abort, queue blocks to be fetched

Fetch

1. data is fetched asynchronously from disk
   - avoids blocking
2. moved into merge buffer

Merge

1. data is moved from in-memory merge buffer to in-memory table
2. previously aborted transaction is restarted
3. transaction executes normally

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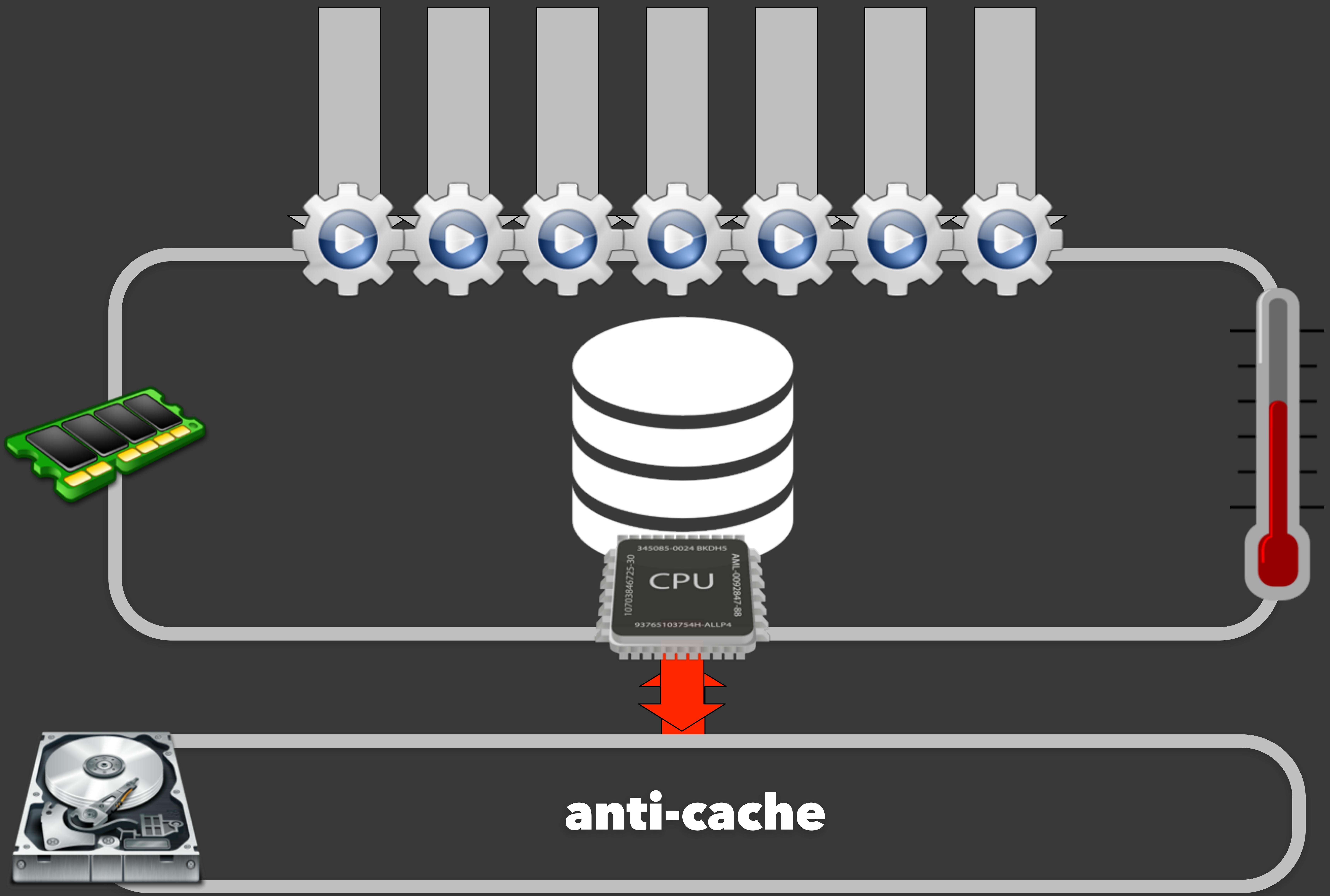

CPU
anti-cache

Tracking Access Patterns

- done online, more responsive to changes in workload
- goal is low CPU and memory overhead
- approximate ordering is OK

Approximate LRU (aLRU)

- maintain LRU chain embedded in tuple headers
- per-partition
- transactions that update LRU chain are sampled randomly
  - configurable sample rate

Anti-Caching vs. Swapping

- fine-grained eviction
  - blocks constructed dynamically
- asynchronous batched fetches
- possible because of transactions

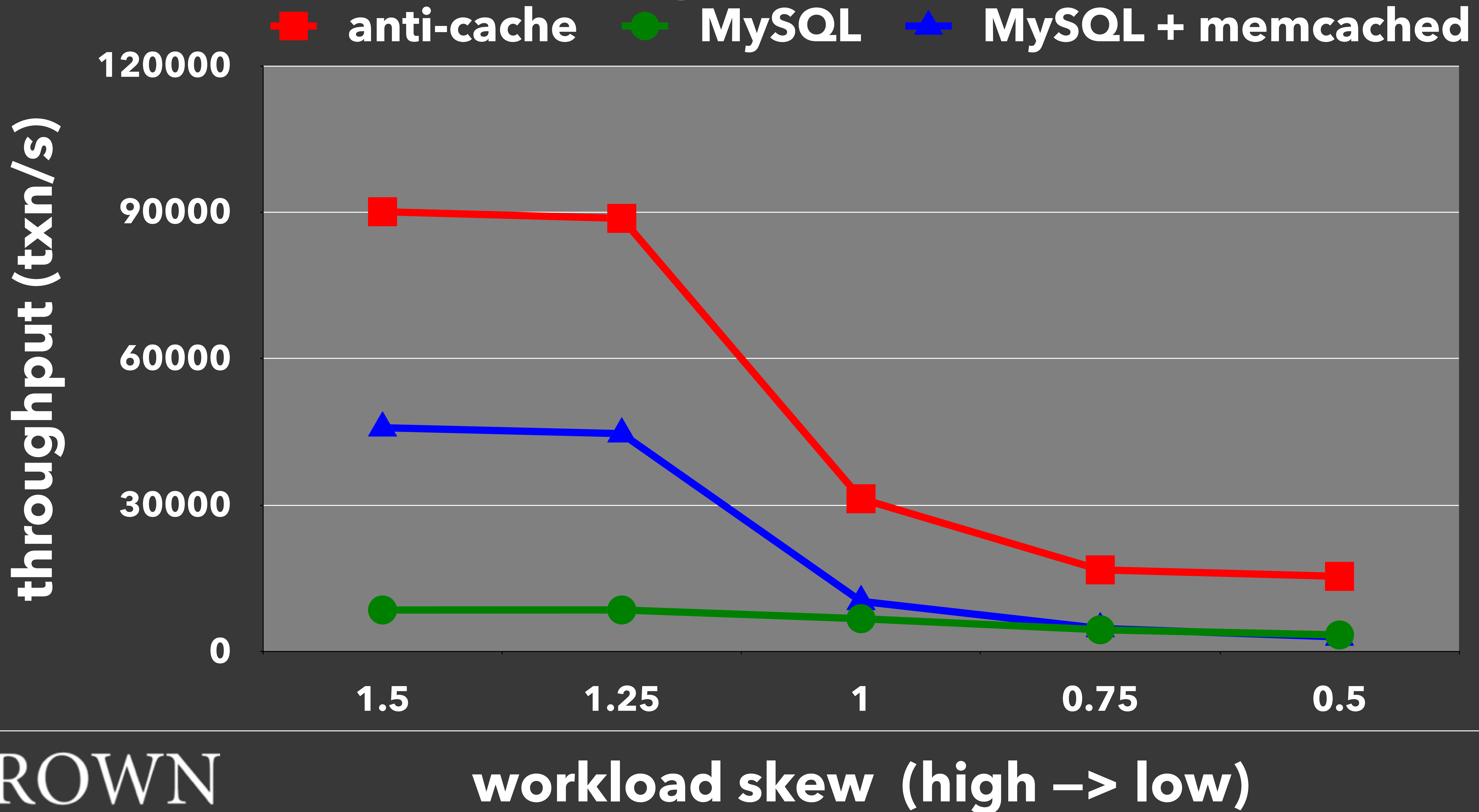
Anti-Caching vs. Caching

- data exists in exactly one location
  - caching architectures have multiple copies, must maintain consistency
  - data is moved, not copied
- goal is increased data size, not throughput

Benchmarking

- YCSB
- Zipfian skew
- data > memory
- read/write mix
- MySQL, MySQL + memcached

YCSB, read-only, data 8X memory



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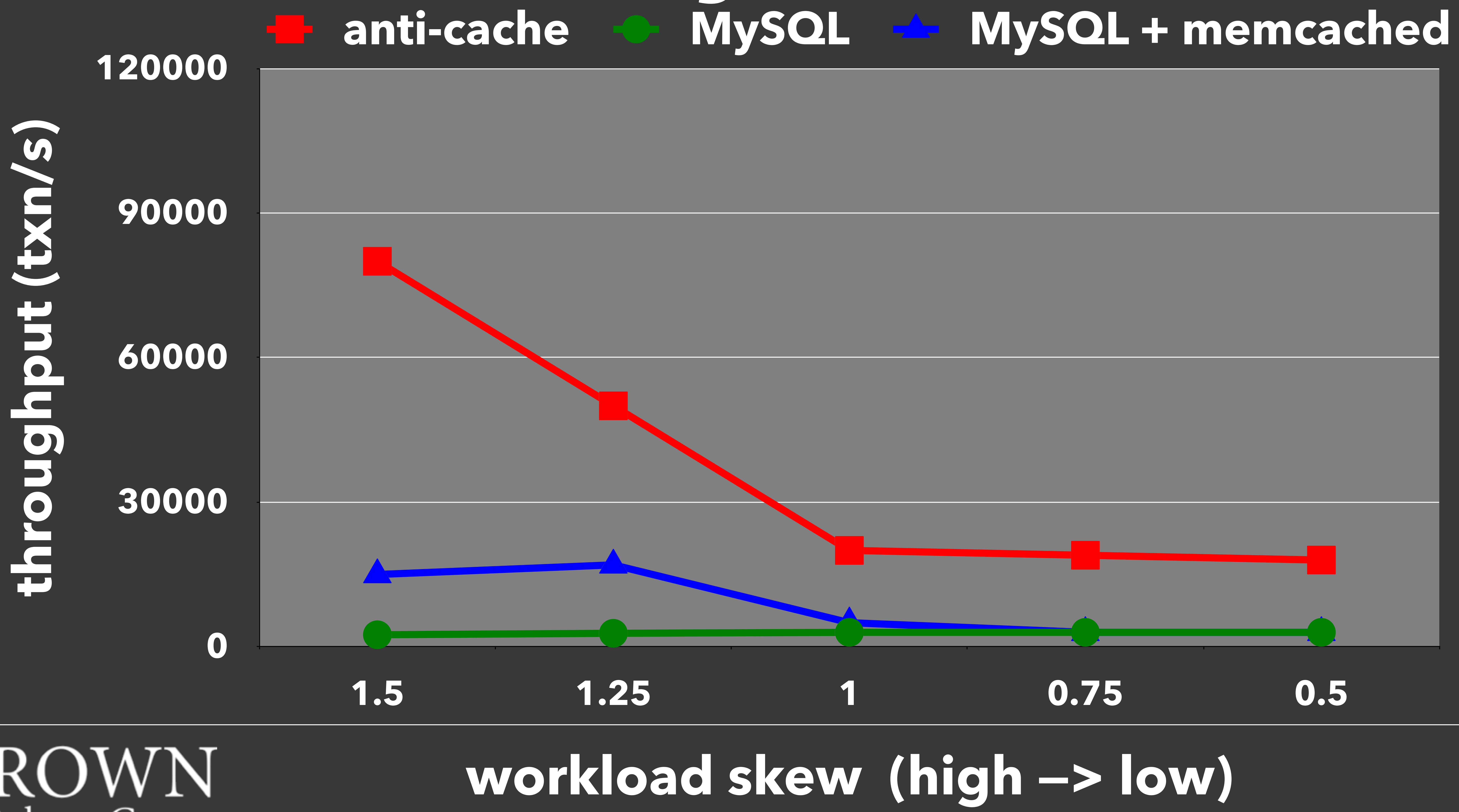
YCSB, read-heavy, data 8X memory



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Tracking Accesses Revisited

- approximate ordering is OK
- original implementation
  - aLRU (linked list)
  - compute vs. memory

Can we reduce the memory overhead?

Timestamp-Based Eviction

- use relative timestamps to track accesses
- to evict, take subset of tuples and evict based on timestamp age
- questions:
  - timestamp granularity
  - sample size (power of two)

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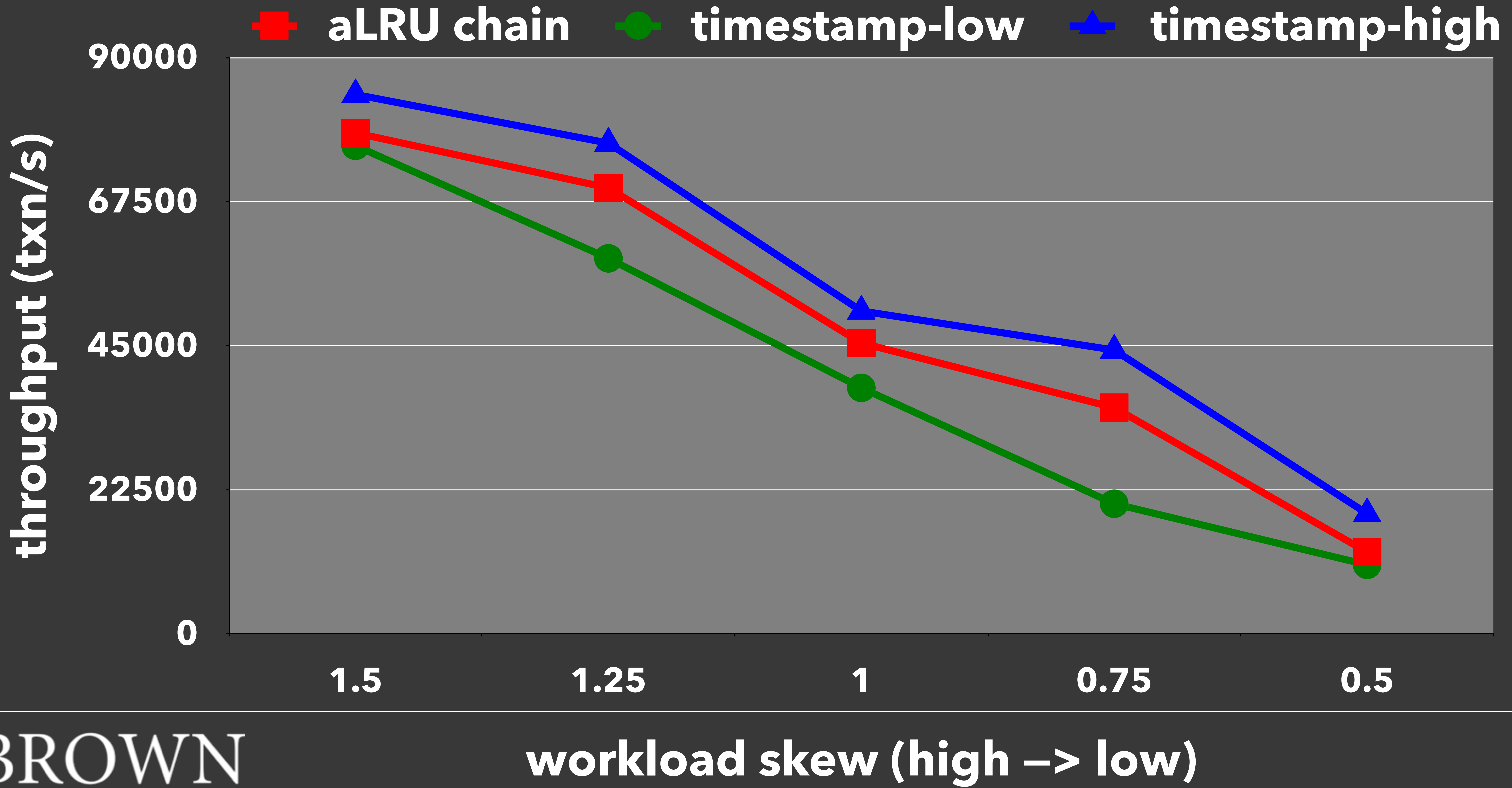
Timestamp Granularity

- 4 byte timestamps
  - use instruction counter
- 2 byte timestamps
  - use epochs, set the timestamp to the current epoch

YCSB, read-heavy, data 8X



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Key Take-Aways

- 8-17X improvement for skewed workloads at larger-than-memory data sizes
- disk becomes the bottleneck for lower skew

Hardware Assumptions are Key

- heavily influence system architectures
- many factors
  - capacity
  - latency
  - volatility

What’s next for OLTP?

Non-Volatile Memory

Properties of NVM

- non-volatile
- random-access
- high write endurance
  - except flash
- byte-addressable
  - except flash

The NVM Arms Race

- FeRAM
  - high write endurance
- MRAM
  - DRAM-like latency
- PCM (PRAM)
  - DRAM-like capacity

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Looking Forward...

- OLTP architectures and NVM
  - anti-cache architecture
  - disk-based architecture
- open questions
  - Which architecture is best suited for NVM?
  - What adaptations are needed?

NVM Emulation

- goal: provide product-independent analysis
- test wide range of latency profiles
- automatically add specified latency
- built by collaborators at Intel

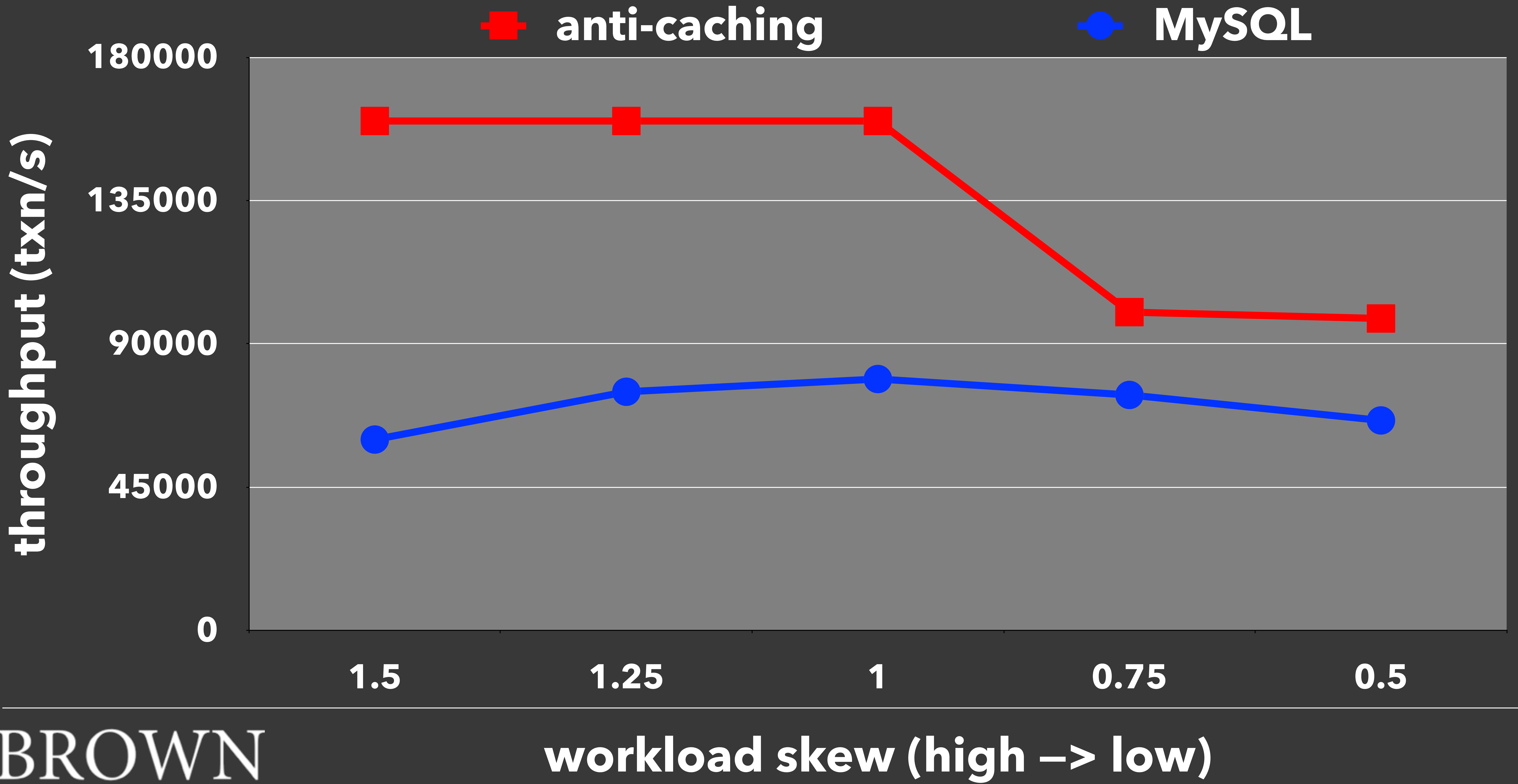
Anti-Caching on NVM

- replace disk with NVM
- several adaptations necessary
  - lightweight array-based anti-cache
    - utilizes mmap interface
  - fine-grained block and tuple eviction interface

Disk-Oriented Architectures on NVM

- must adapt both storage and log files to be use NVM mmap interface
- configure to use fine-grained buffer pool pages

YCSB, read-only, data 8X



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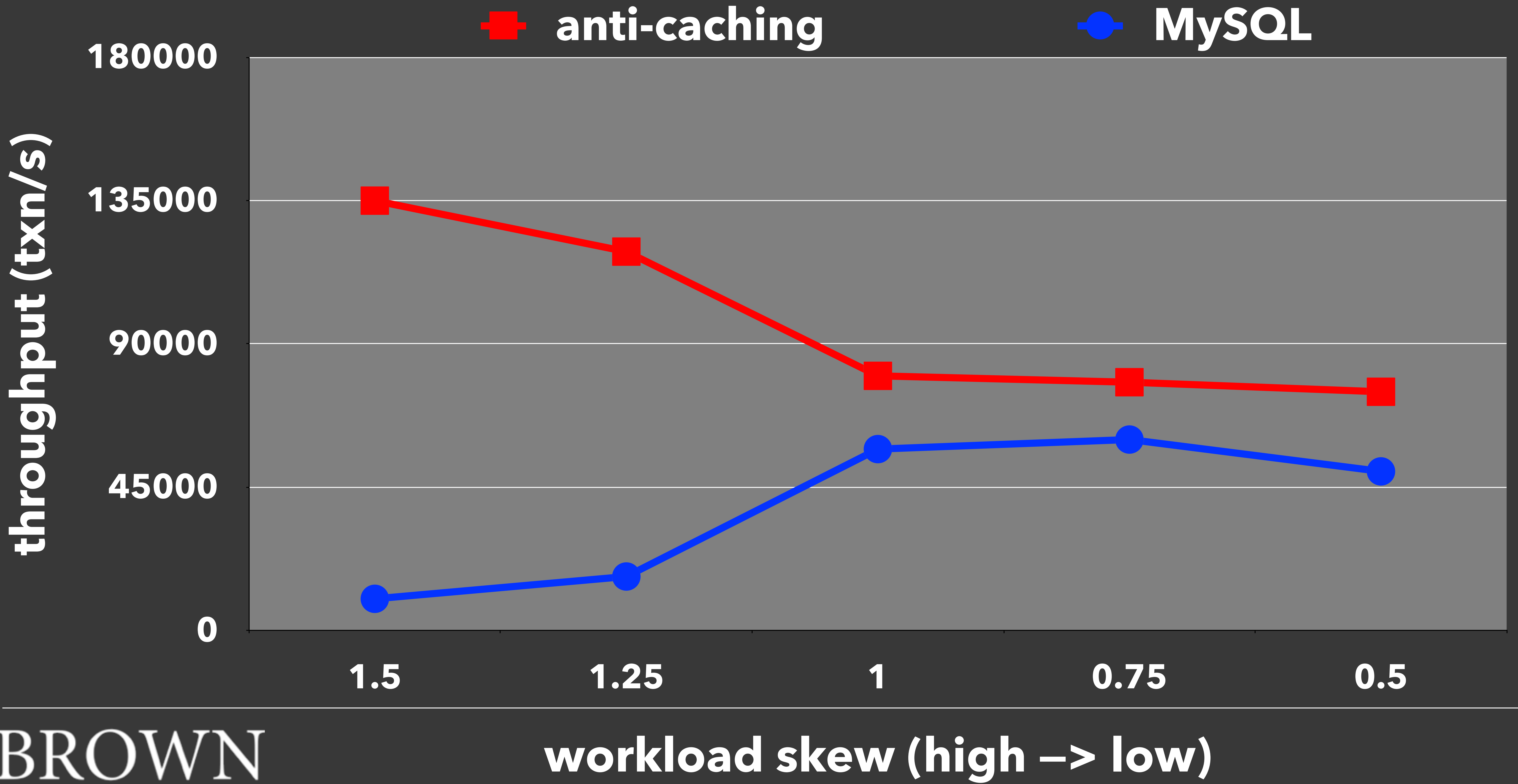
YCSB, read-heavy, data 8X



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Future Work

Multi-Tier Architectures

- DRAM -> NVM -> Disk/SSD
- open questions
  - indexing structures
  - synchronous/asynchronous fetches

Anti-Caching Indexes

- index size can be significant
- can cold index ranges be evicted to an anti-cache?
- open questions
  - how/what to evict
  - execution changes

Semantic Anti-Caching

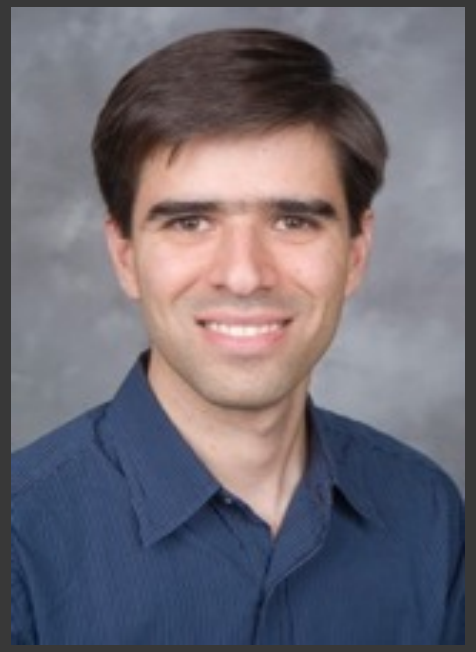
- current implementation makes no assumption about types of skew
- skew typically as semantic meaning
  - e.g., temporal, spatial
- can we leverage these domain semantics?

Conclusions

- anti-caching architecture outperforms and outscales previous OLTP architectures
- well-suited for next-generation NVM-based architectures

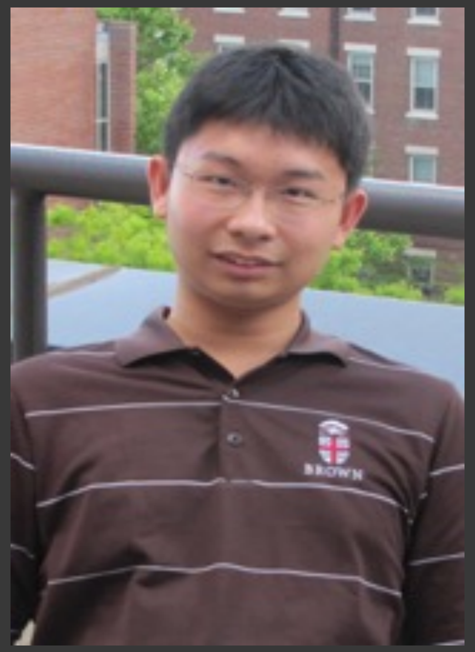












Questions?

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