WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

CS 839: Design the Next-Generation Database

Lecture 4: Multicore (Part I)

Xiangyao Yu

1/30/2020

Announcements

Email me if you are not in HotCRP

https://wisc-cs839-ngdb20.hotcrp.com

New deadline for submitting paper review:

Before lecture starts

This course is on PhD breadth requirement list

Please talk to me to discuss project ideas

Discussion Highlights

Transactions on column-store

- Pros: Compression, good for read workload, good for sequential writes
- Cons: More I/O for row selection/update/insert

Data format for HTAP?

- Hot data in row format, convert cold data to column format in background
- Different formats in replicas

Small processor near disk

- Compression/decompression, encryption, filtering, sorting, hashing, hot data
- Coalesce random accesses
- Fast indexing

Today's Paper

Staring into the Abyss: An Evaluation of Concurrency Control with One Thousand Cores

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Story Behind the Paper

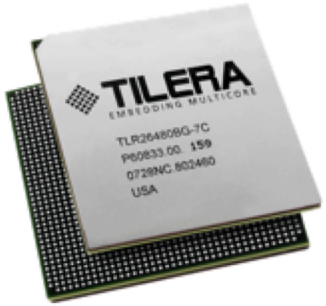
Lesson learned: Talk to people about your research

Many-core systems have arrived

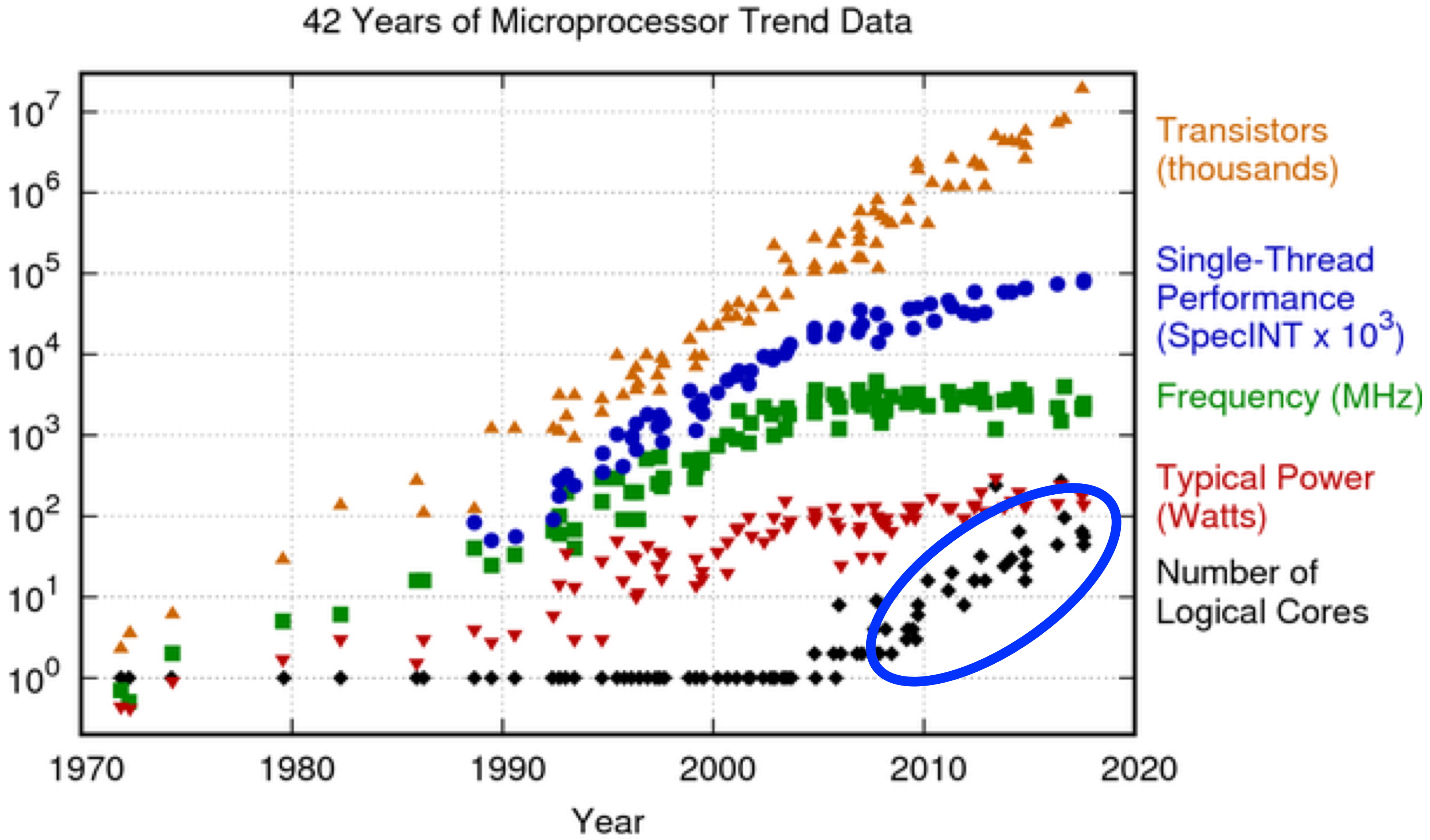
- The era of single-core CPU speed-up is over
- Number of cores on a chip is increasing exponentially
  - 1000-core chips are a near…
- DBMSs are not ready
  - Most DBMSs still focus on single-threaded performance
  - Existing works on multi-cores focus on small core count

Xeon Phi (up to 61 cores)

Tilera (up to 100 cores)



Many-core systems have arrived



Original data up to the year 2010 collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten
New plot and data collected for 2010-2017 by K. Rupp

Databases on 1000-core systems

- DBMS on future computer architectures
- Will DBMSs scale to this level of parallelism?

All classic concurrency control algorithms fail to scale to 1000 cores.

- What are the main bottlenecks to scalability?
- What improvements will be needed from the software and hardware perspectives?

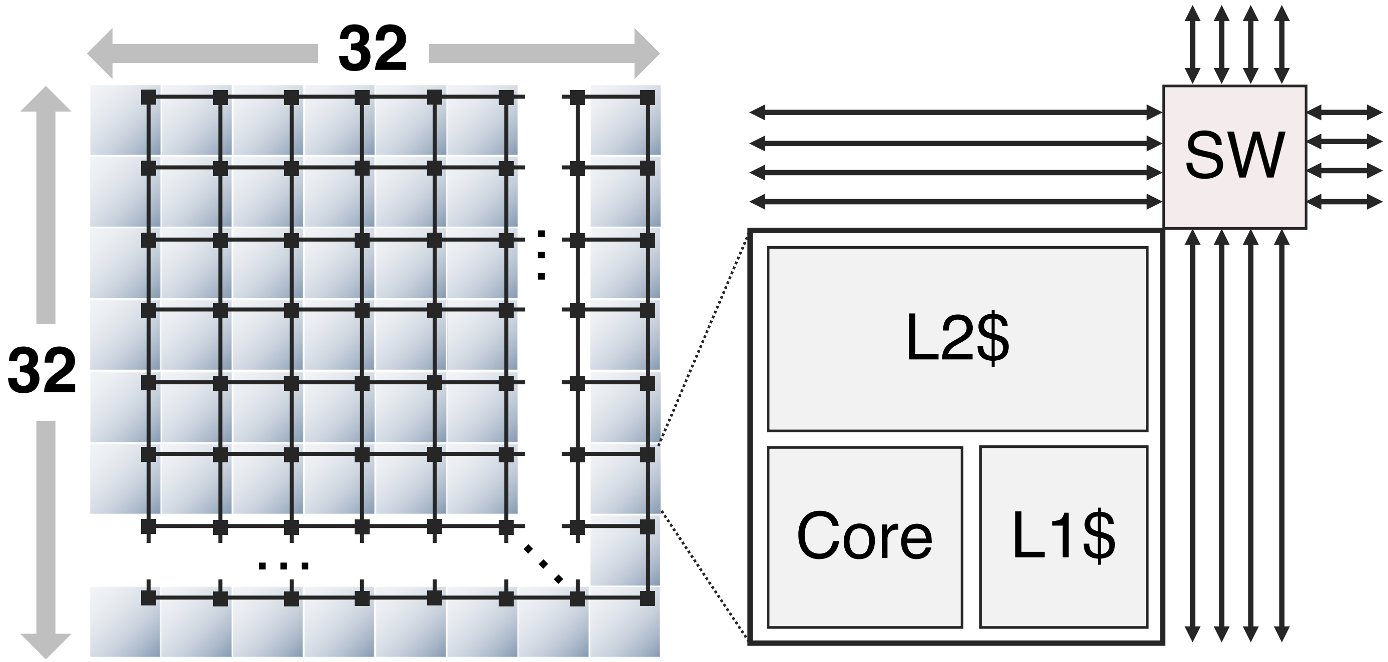
1000-Core DBMS

- **O**n **L**ine **T**ransaction **P**rocessing (OLTP)
- Concurrency control is a key limiting factor to the scalability
- new database: **DBx1000**
  - Support all seven classic concurrency control algorithms
  - Study the fundamental bottlenecks
  - https://github.com/yxymit/DBx1000
- Graphite Multi-core Simulator

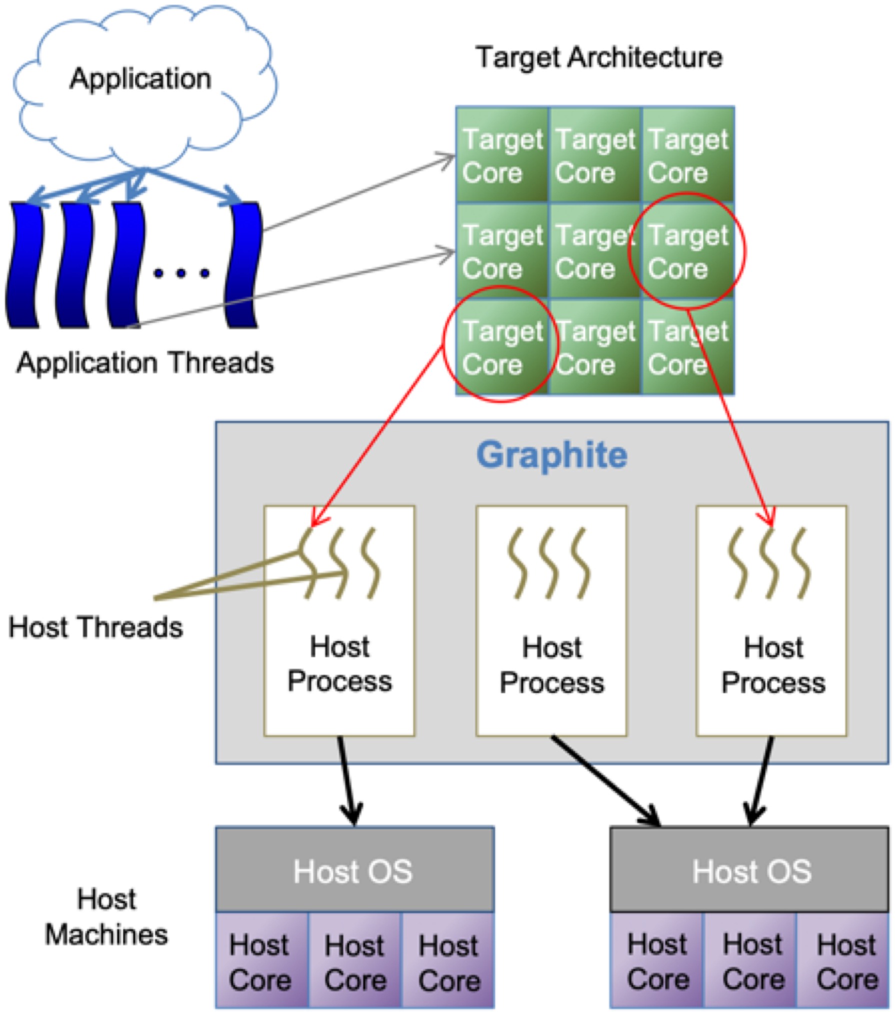
Simulated Hardware

Simulated Hardware

- **CPU:** 1024 in-order core
- **Cache:** 32KB L1, 512KB L2
- **Network:** 2D-mesh



Graphite Simulator[1]



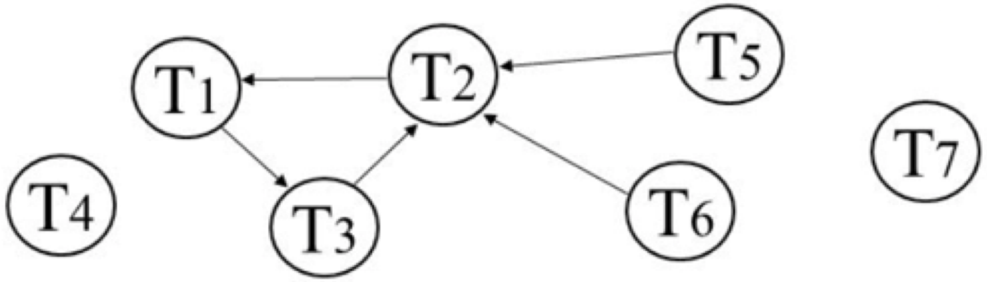
[1] J. Miller, et al. *Graphite: A Distributed Parallel Simulator for Multicores*. HPCA'10

Concurrency Control Schemes

	CC Scheme	Description
Two–Phase Locking (2PL)	DL_DETECT	2PL with deadlock detection
	NO_WAIT	2PL with non-waiting deadlock prevention
	WAIT_DIE	2PL with wait-and-die deadlock prevention
Timestamp Ordering (T/O)	TIMESTAMP	Basic T/O algorithm
	MVCC	Multi-version T/O
	OCC	Optimistic concurrency control
Partitioning	HSTORE	T/O with partition-level locking

2PL – DL_DETECT

Wait-for Graph:



T1 <---- T2 when T2 waits for a lock held by T1

Periodically, detect cycles in the graph and abort the transaction that holds the fewest locks

2PL – NO_WAIT, WAIT_DIE

NO_WAIT: A transaction cannot wait for another transaction. Whenever two transactions conflict, the requesting transaction aborts.

WAIT_DIE: A transaction T1 waits for another transaction T2 **only if T1 has higher priority than T2** (e.g., T1 starts execution before T2).

Pros over NO_WAIT

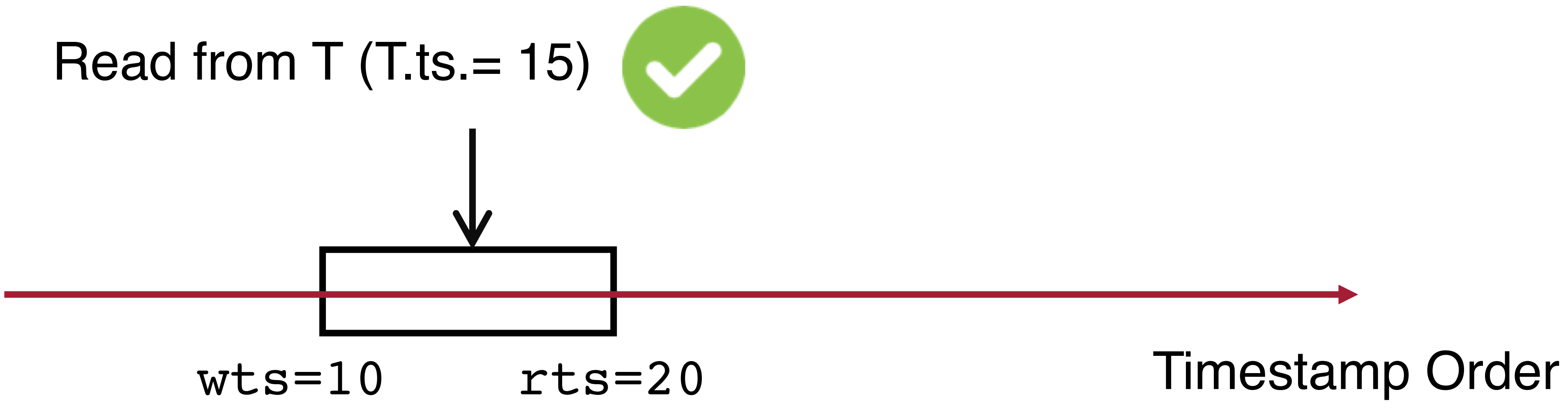
- Guaranteed forward progress (i.e., no starvation)
- Fewer aborts

Cons over NO_WAIT

- Locking logic is more complex

Timestamp Ordering – Basic

Each transaction is assigned a unique timestamp indicating the serial order



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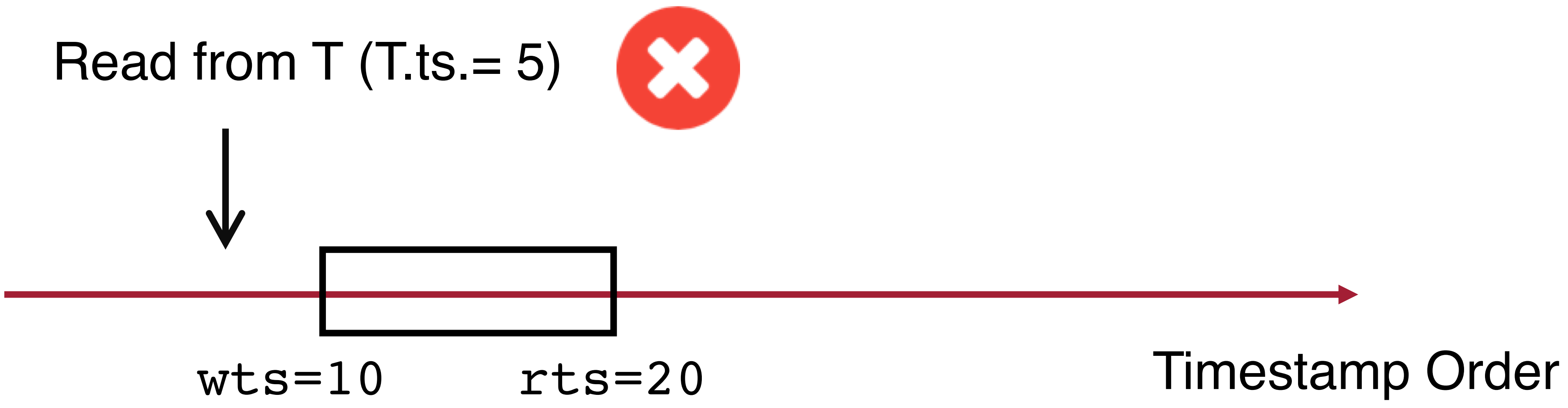

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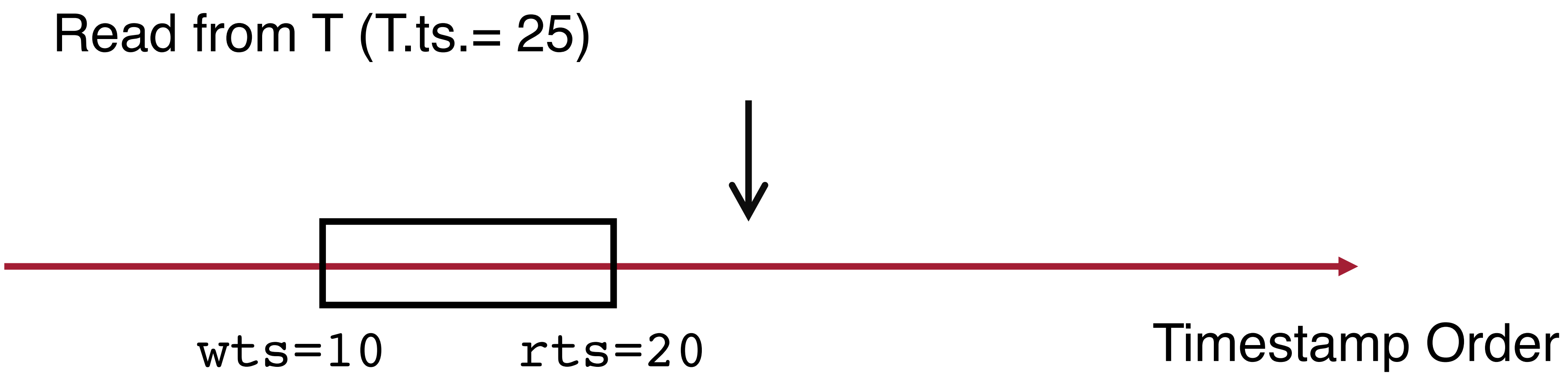

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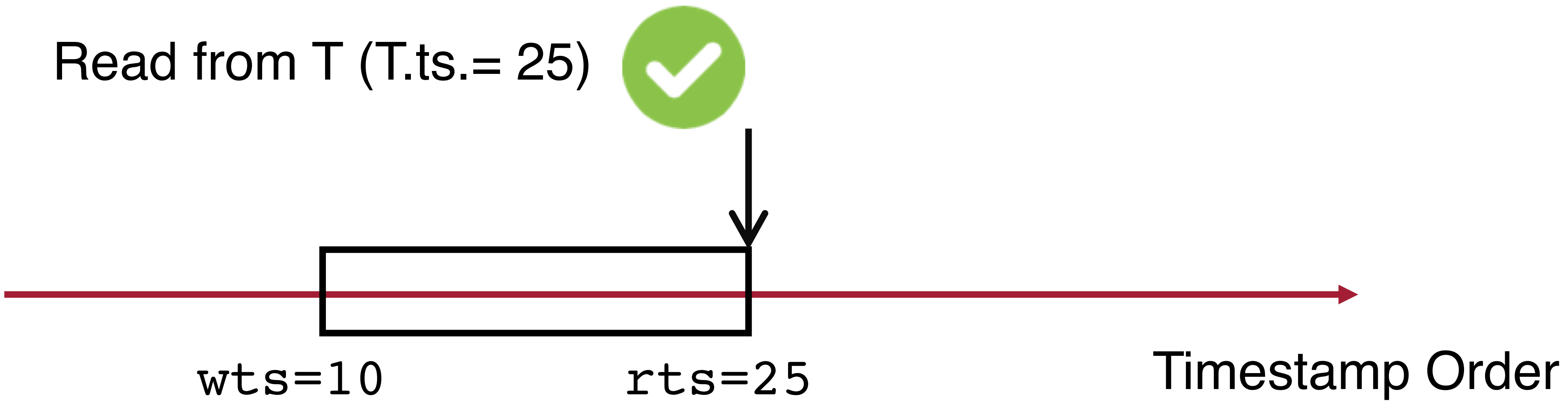

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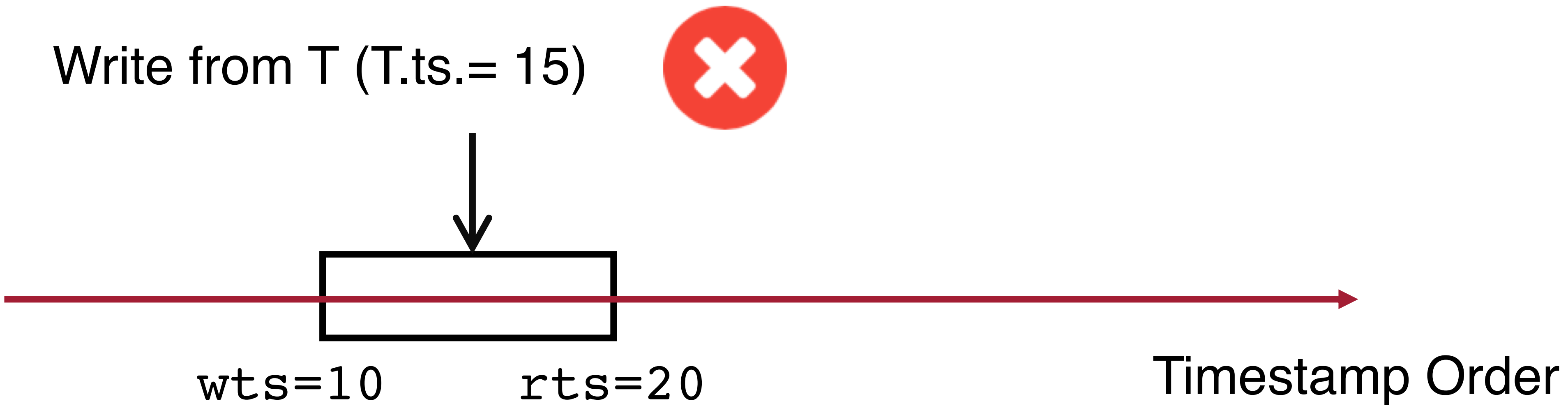

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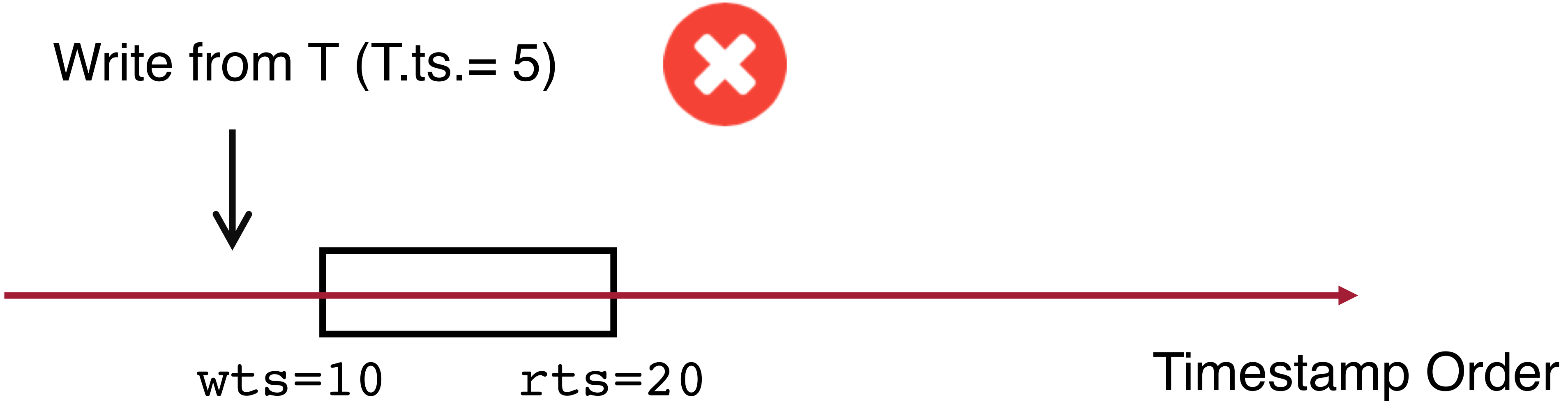

Timestamp Ordering – Basic

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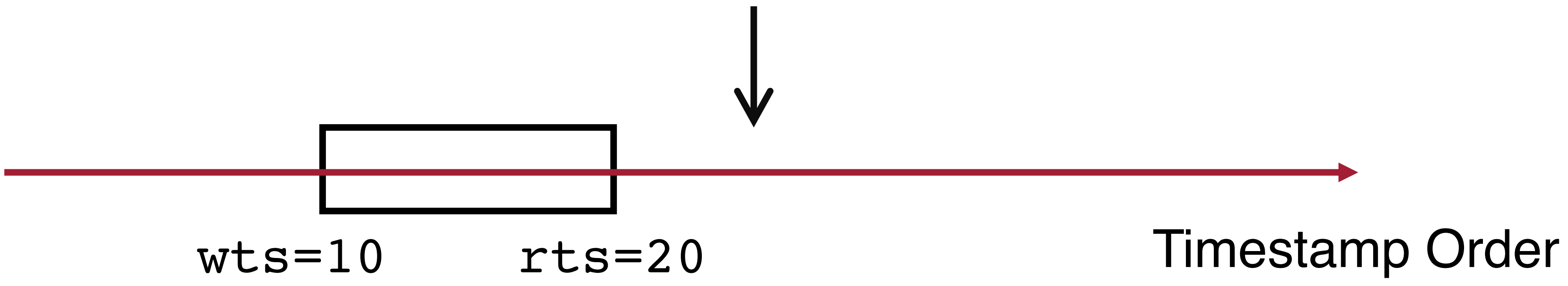
Write from T (T.ts.= 25)



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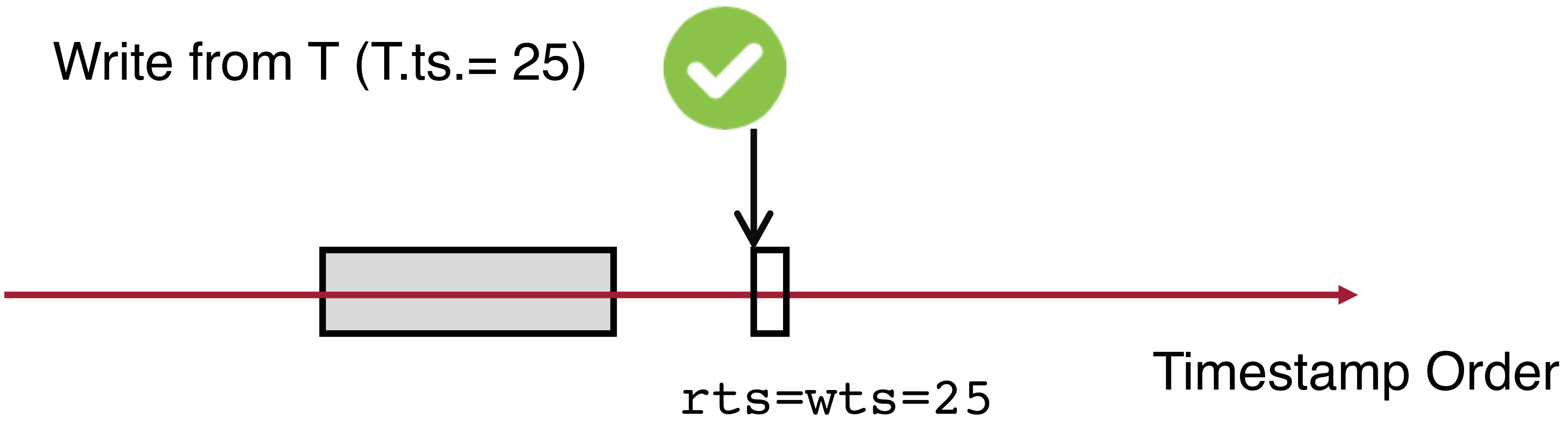
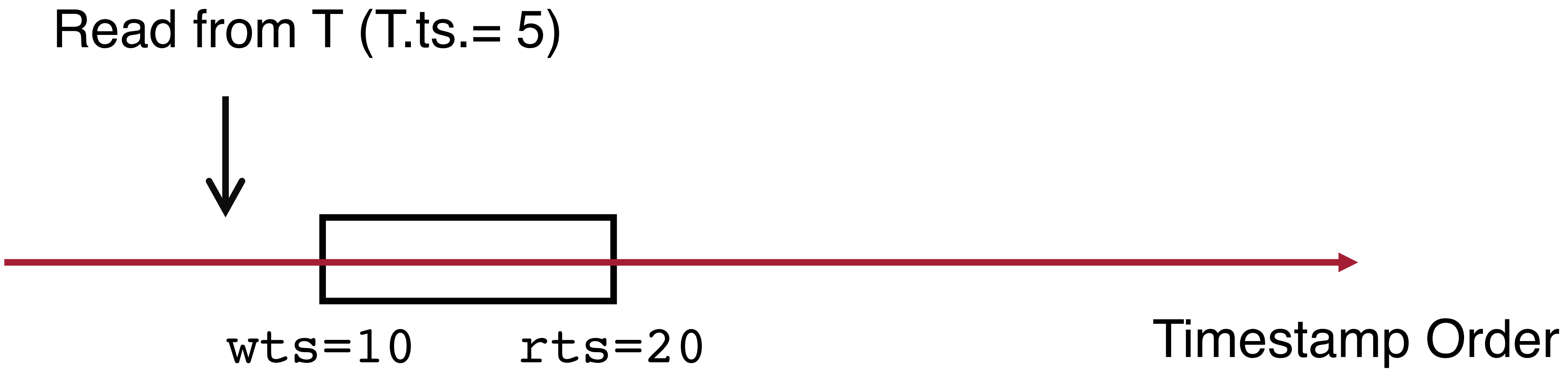


Timestamp Ordering – MVCC

MVCC: Multi-Version Concurrency Control



Timestamp Ordering – MVCC

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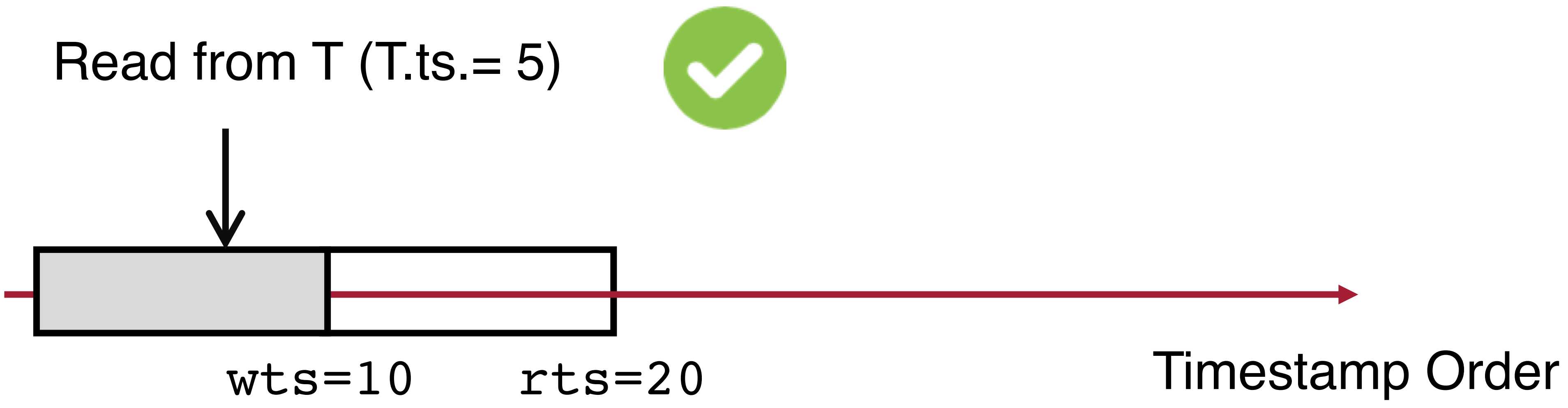


A transaction can read previous versions

Timestamp Ordering

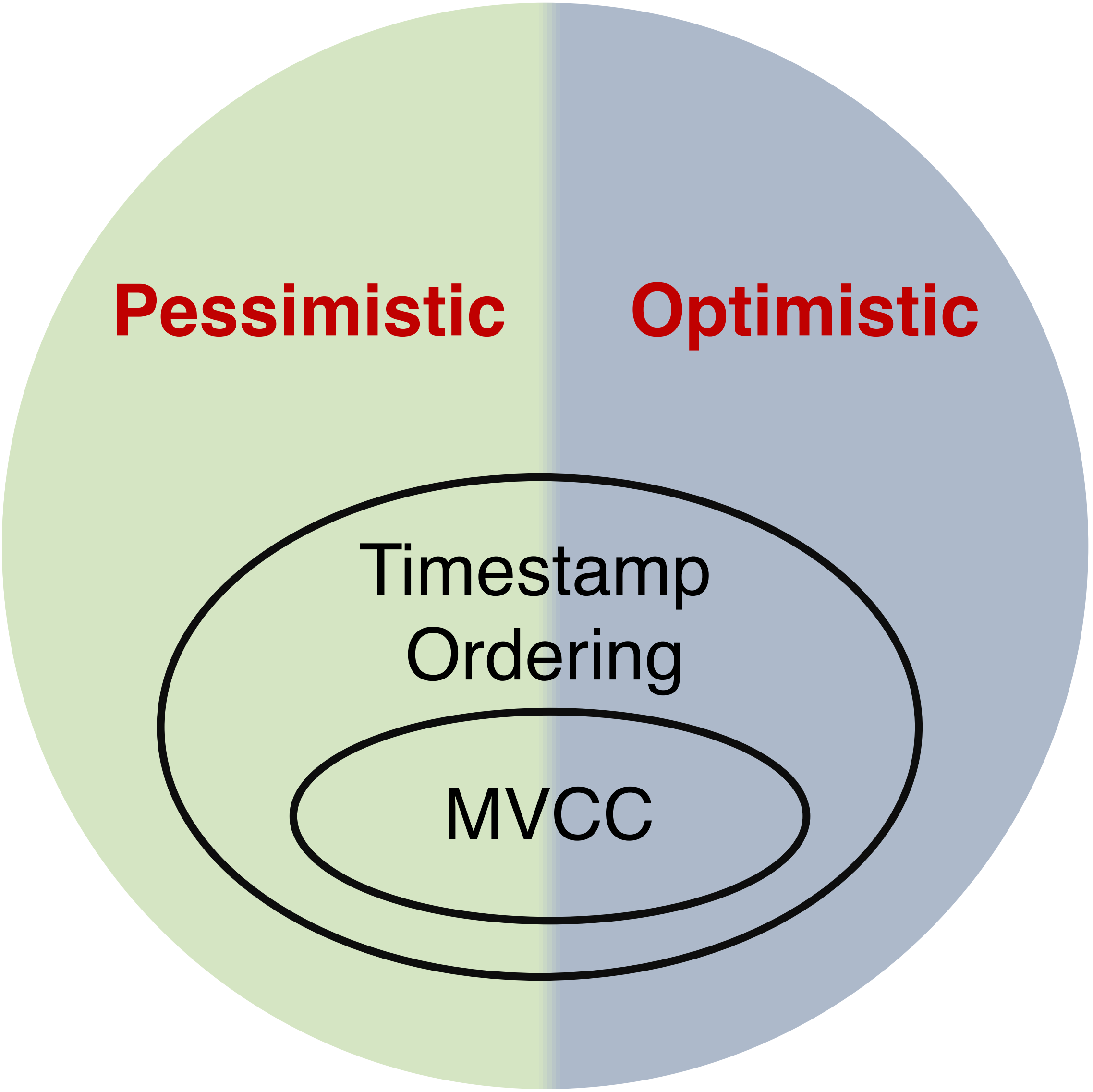
Pros:

- Timestamp order is the serialization order
- Logic for locking is simplified
- In MVCC, read-only and read-write transactions do not conflict

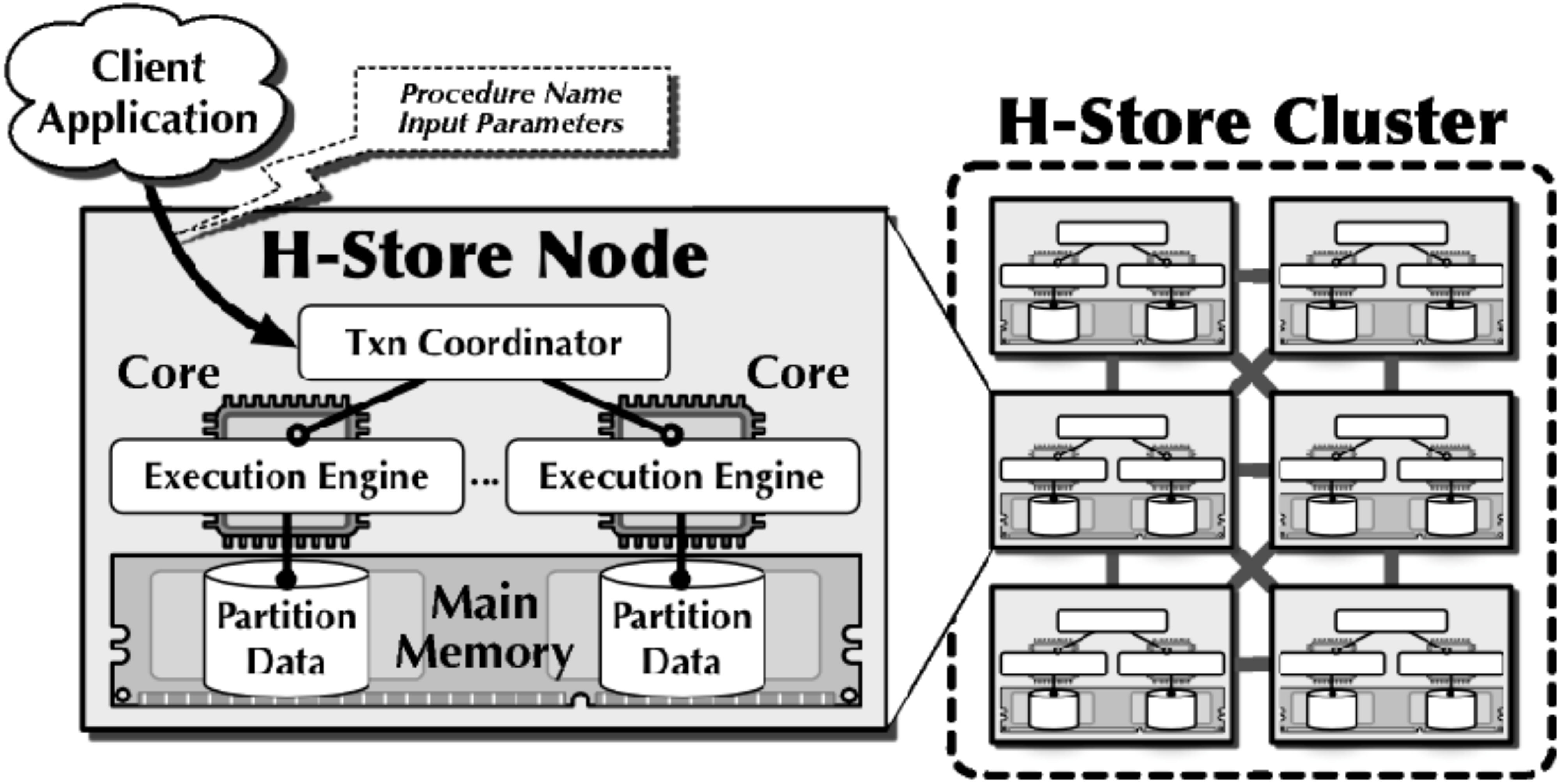
Cons:

- Timestamp allocation is a bottleneck

Pessimistic/Optimistic vs. 2PL/TO



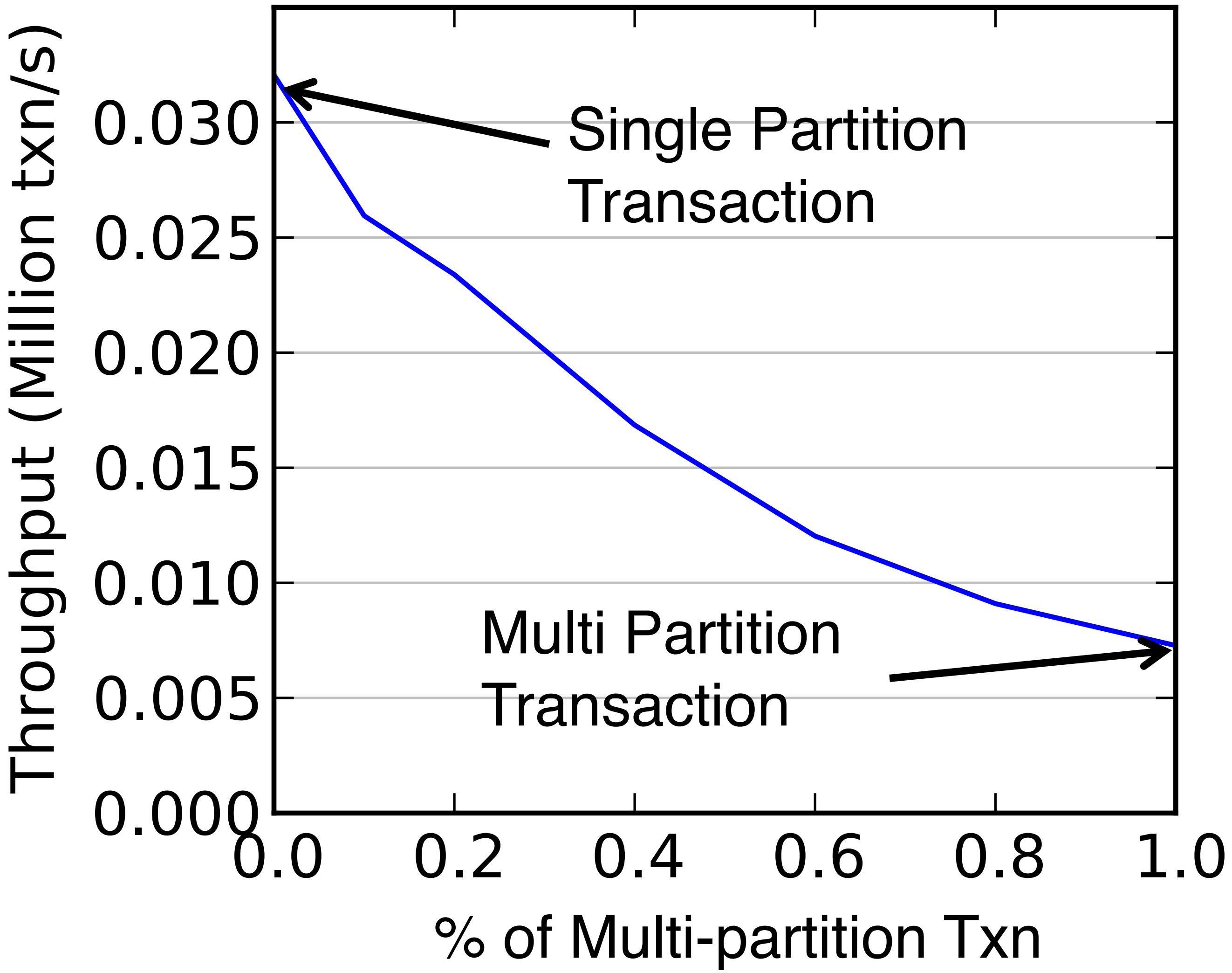
Partition-Level Locking – H-store



Pro: Only one lock per partition

Con: Performance degrades for multi-partition transactions

Partition-Level Locking – H-store



Evaluation – Experimental Setup

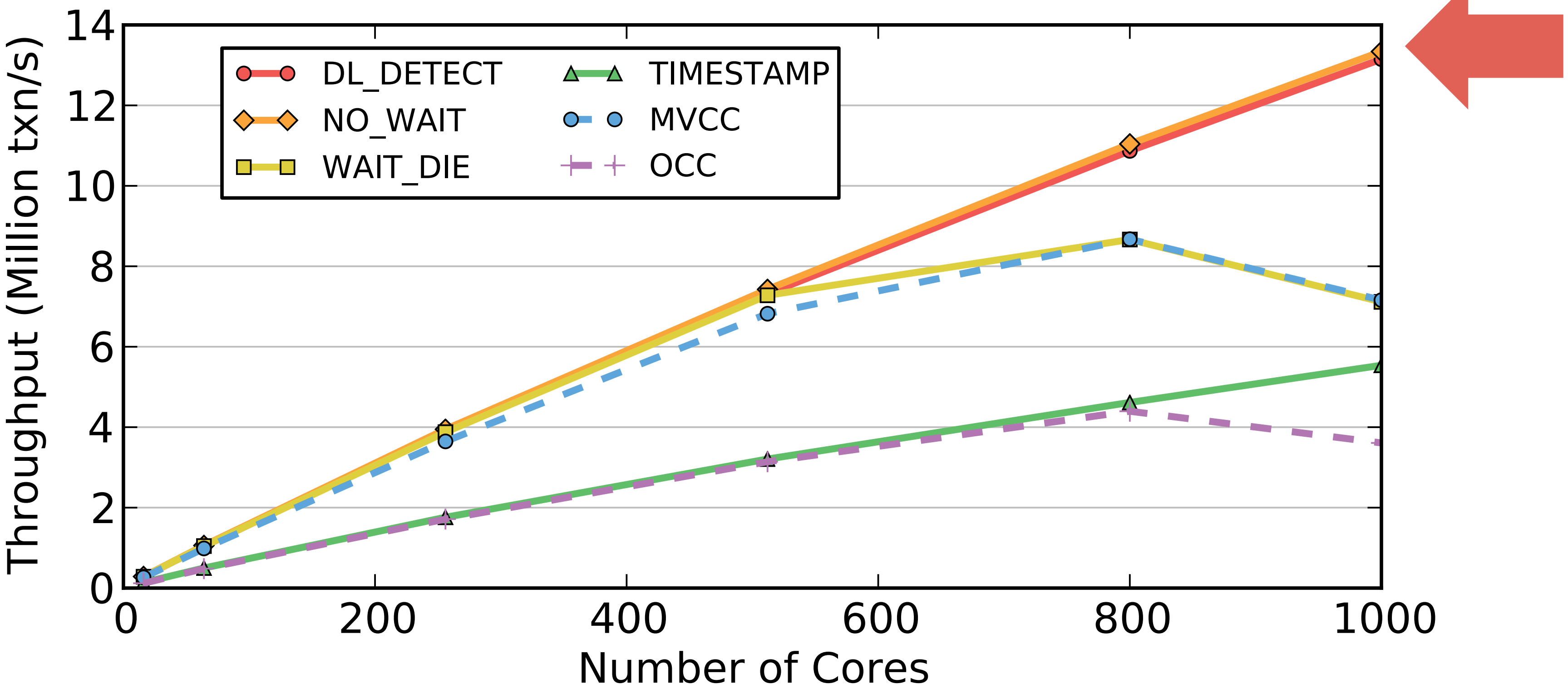
Yahoo! Cloud Serving Benchmark (YCSB)

- 20 million tuples
- Each tuple is 1KB (total database is ~20GB)

Each transaction reads/modifies 16 random tuples following a skewed pattern

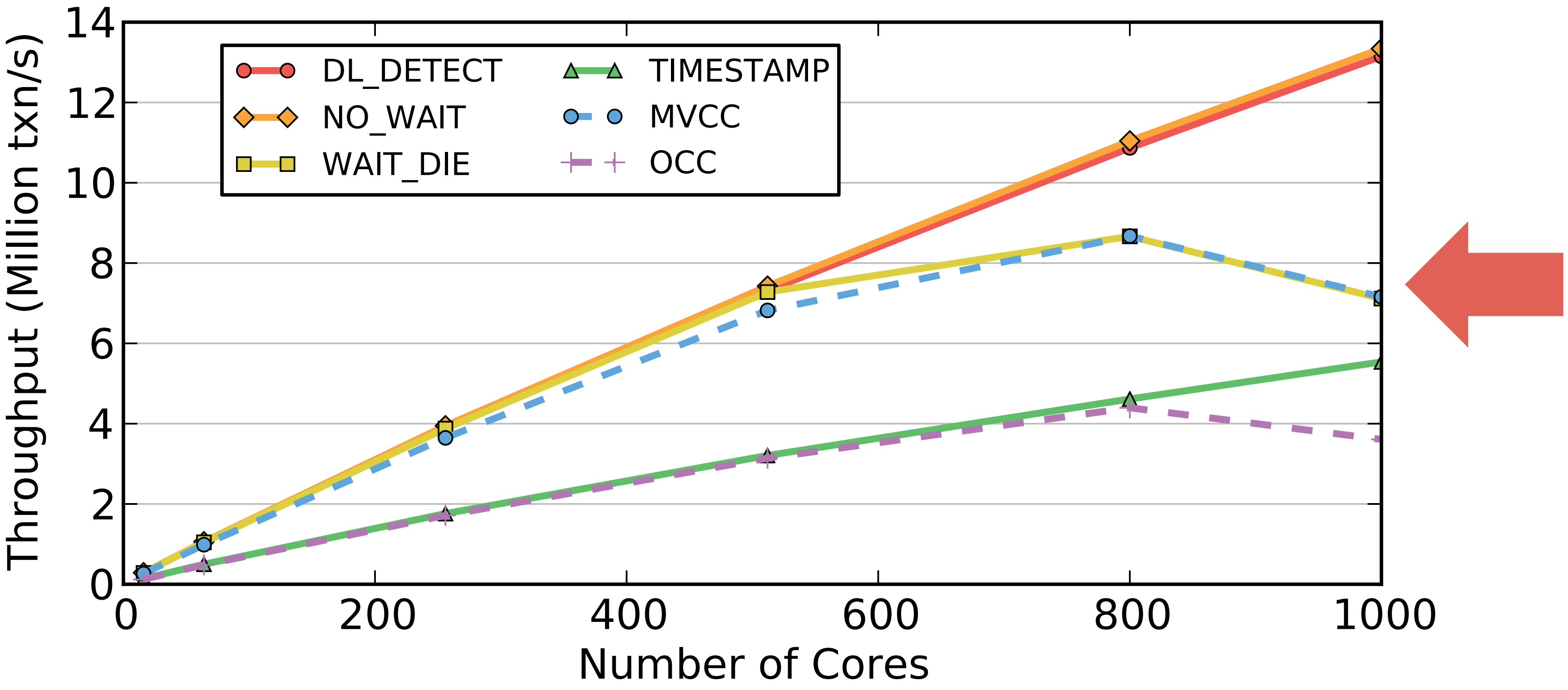
Serializable isolation level

Evaluation – Readonly



2PL schemes are scalable for read-only benchmarks

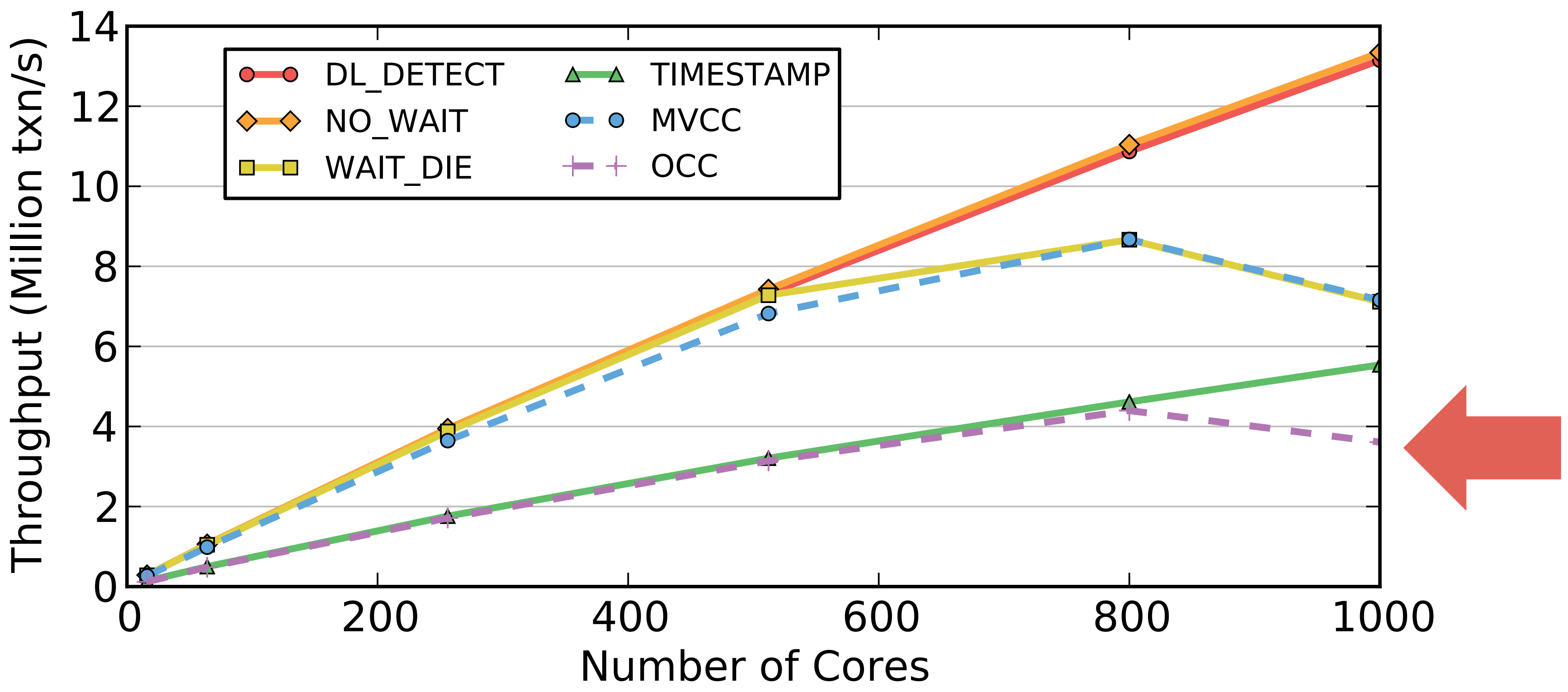
Evaluation – Readonly



2PL schemes are scalable for read-only benchmarks

Timestamp allocation limits scalability

Evaluation – Readonly



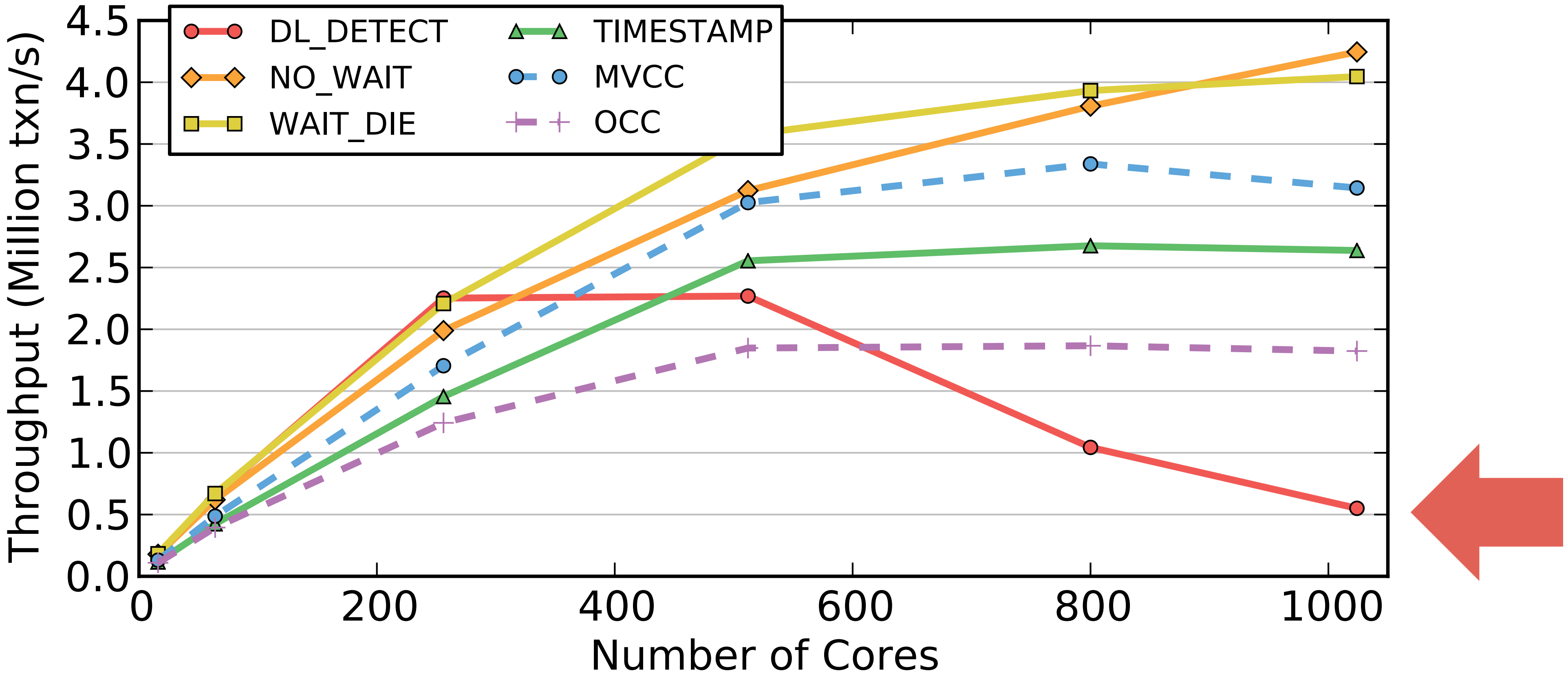
2PL schemes are scalable for read-only benchmarks

Timestamp allocation limits scalability

Memory copy hurts performance

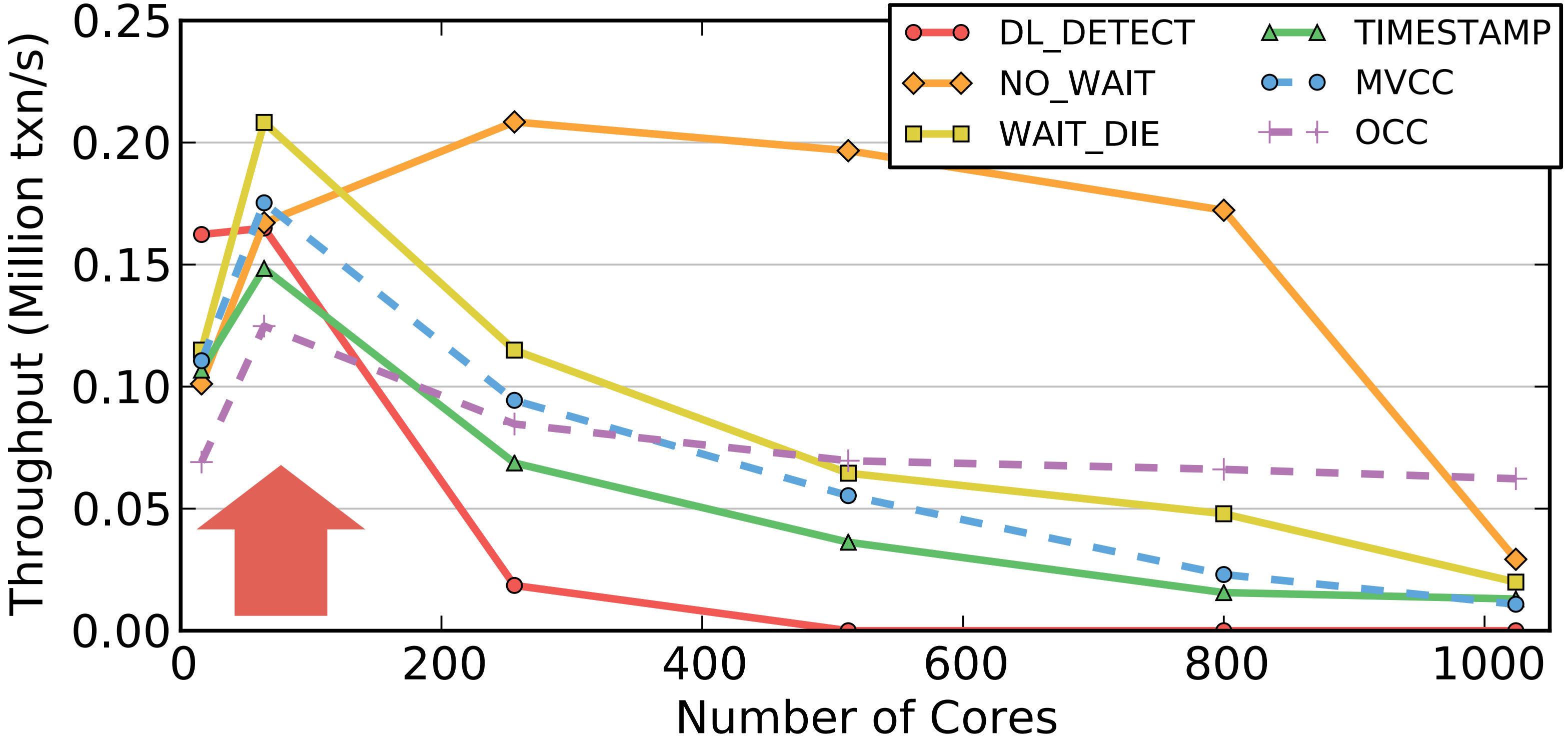
Evaluation – Medium Contention

Write : Read = 50% : 50%



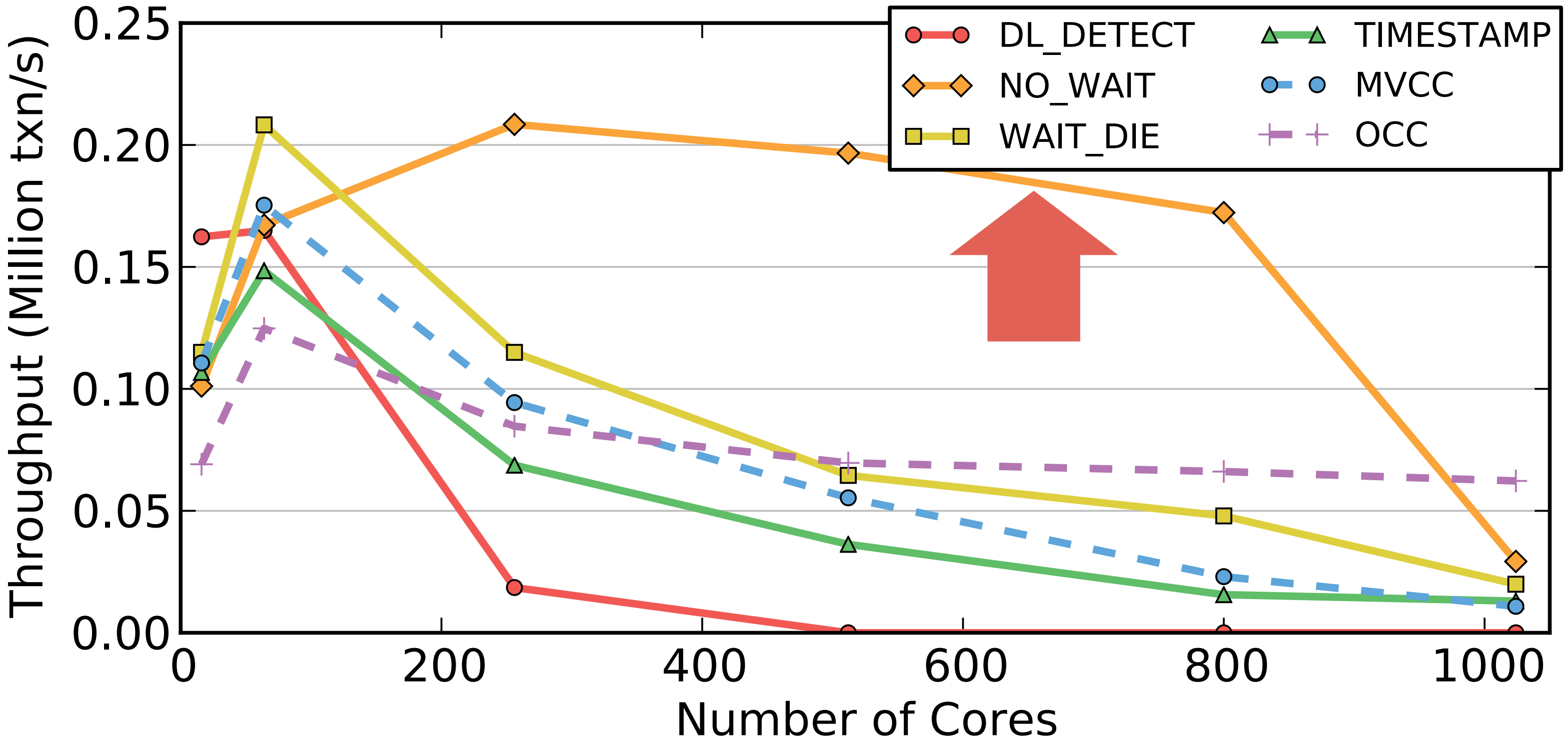
DL_DETECT does not scale due to deadlocks and thrashing

Evaluation – High Contention



Scaling stops at small core count

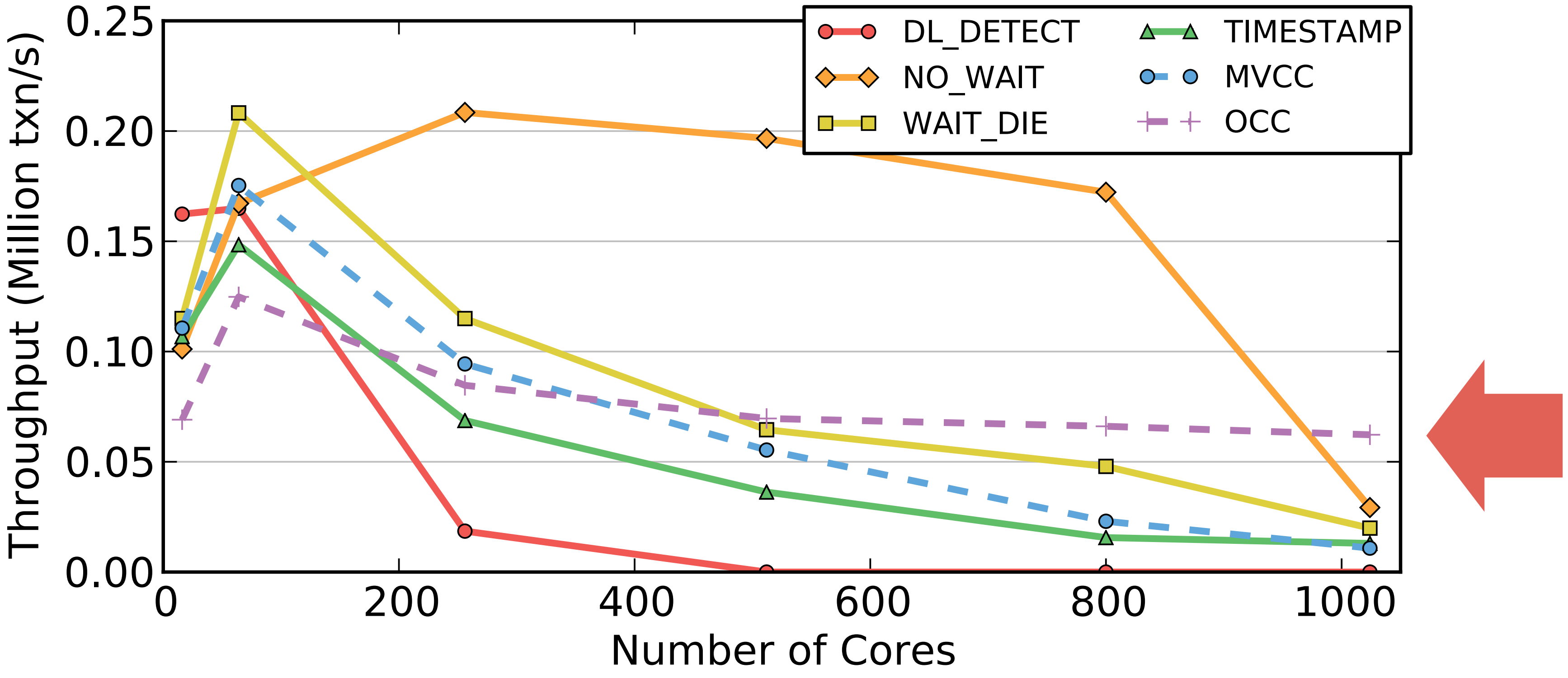
Evaluation – High Contention



Scaling stops at small core count

NO_WAIT has good performance until 1000 cores

Evaluation – High Contention



Scaling stops at small core count

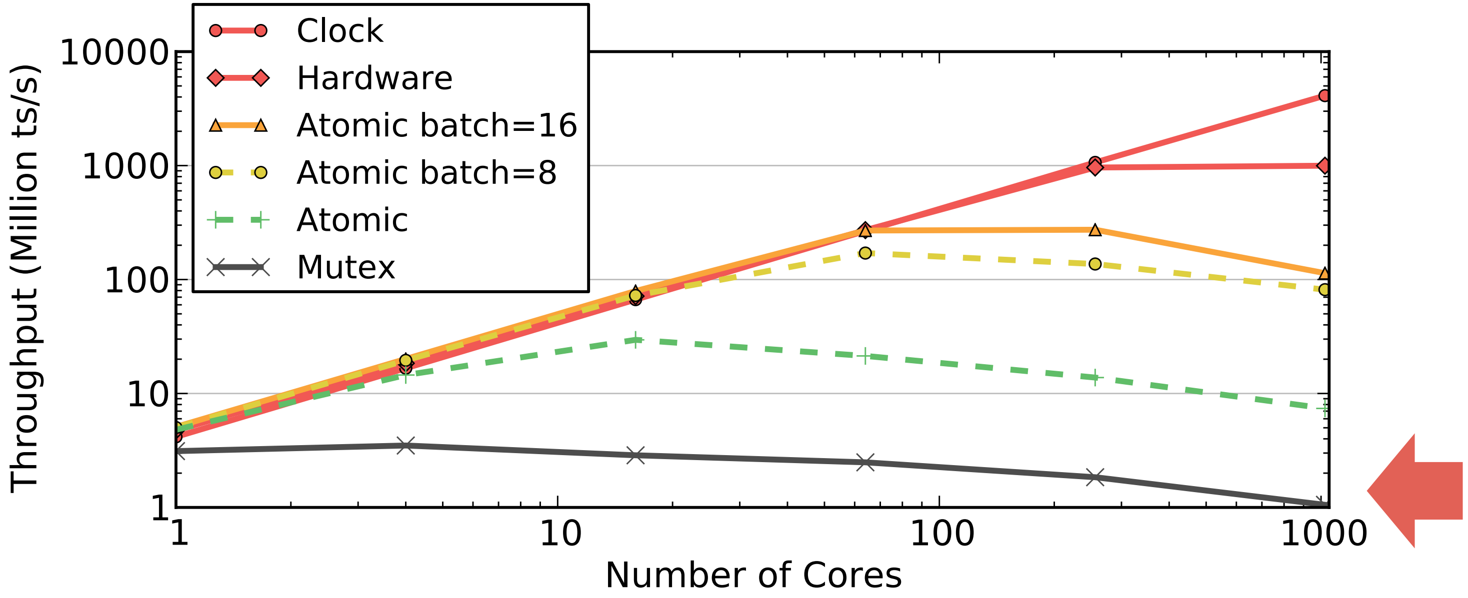
NO_WAIT has good performance until 1000 cores

OCC wins at 1000 cores

Scalability Bottlenecks

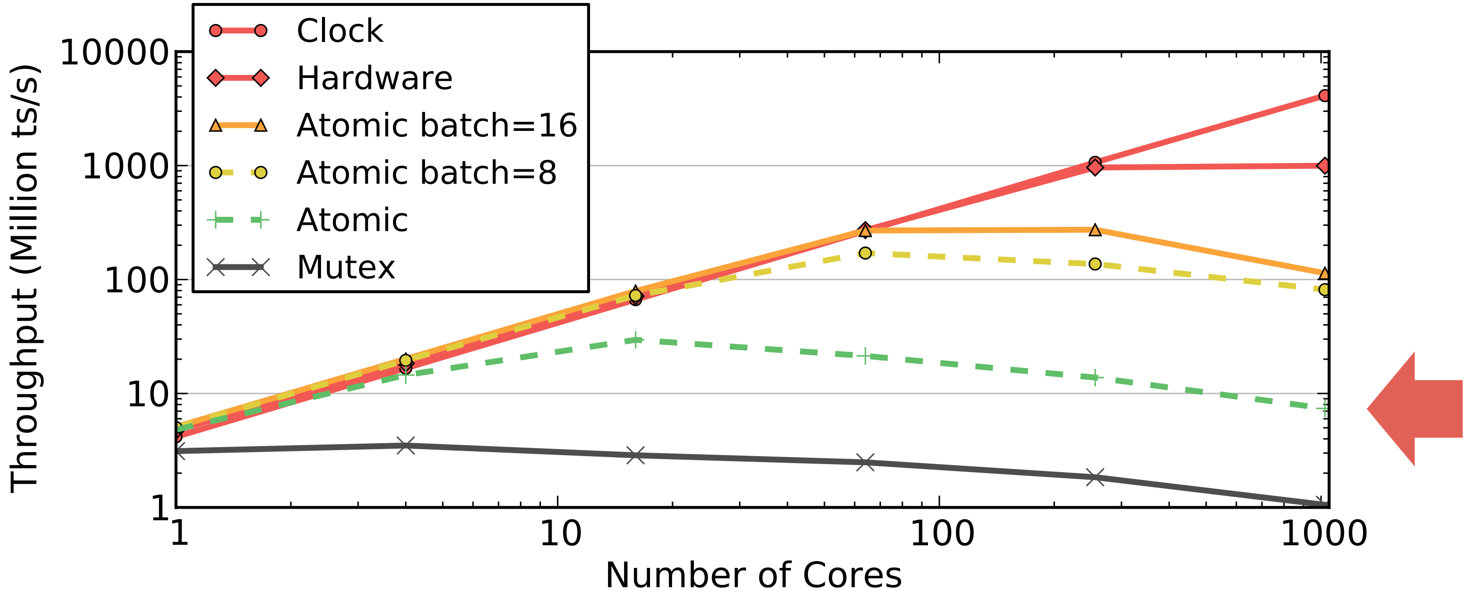
Concurrency Control	Waiting (Thrashing)	High Abort Rate	Timestamp Allocation	Multi-partition
DL_DETECT	✓			
NO_WAIT		✓		
WAIT_DIE	✓		✓	
TIMESTAMP	✓		✓	
MULTIVERSION	✓		✓	
OCC		✓	✓	
HSTORE	✓		✓	✓

Solutions to Timestamp Allocation



Mutex based allocation

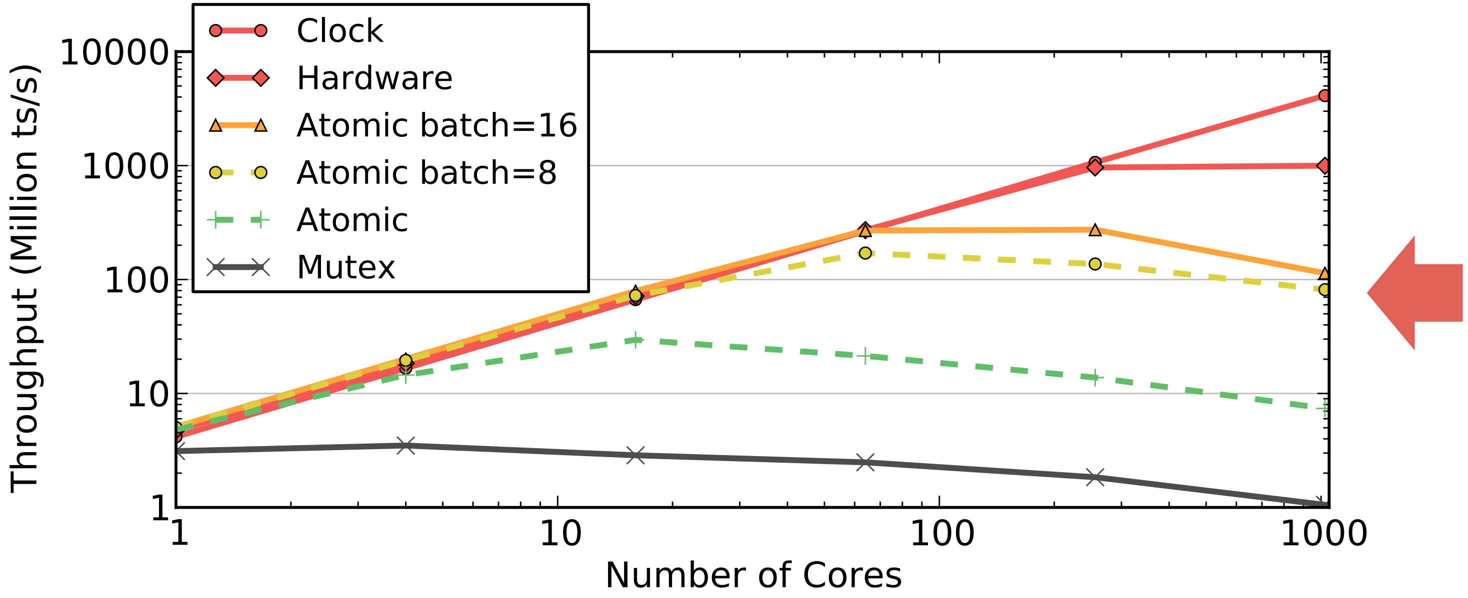
Solutions to Timestamp Allocation



Mutex based allocation

Atomic instruction

Solutions to Timestamp Allocation

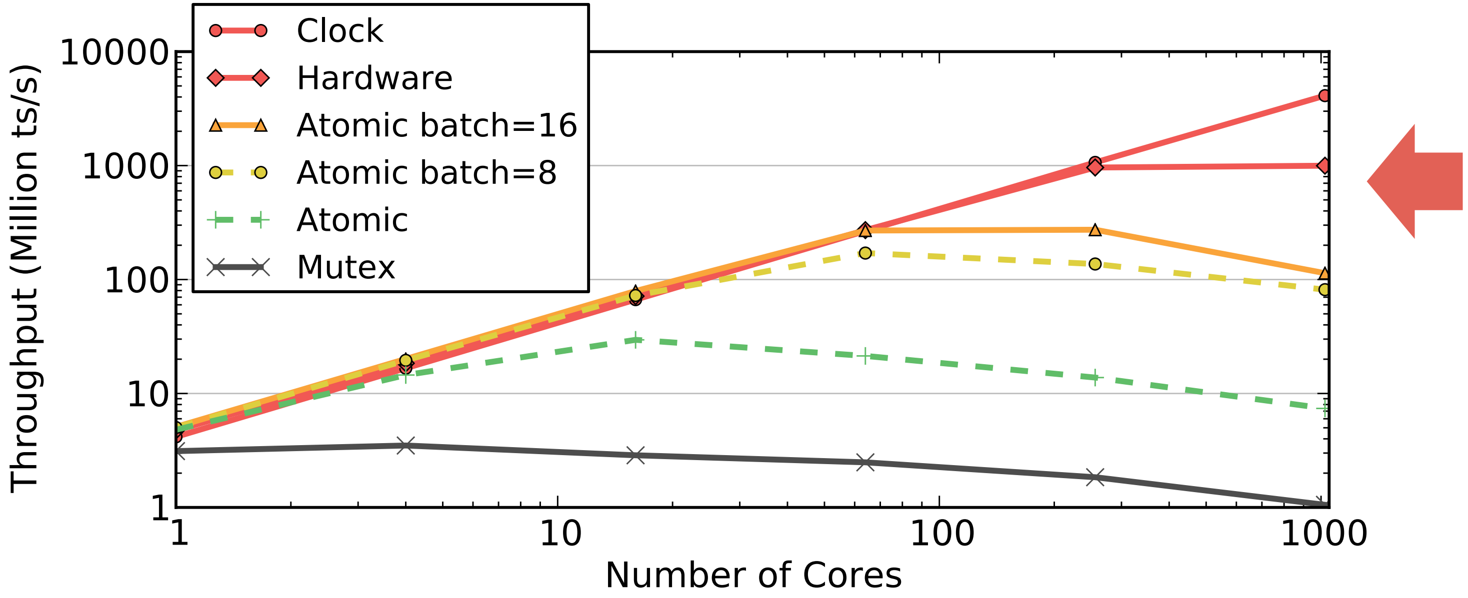


Mutex based allocation

Atomic instruction

Batch allocation

Solutions to Timestamp Allocation



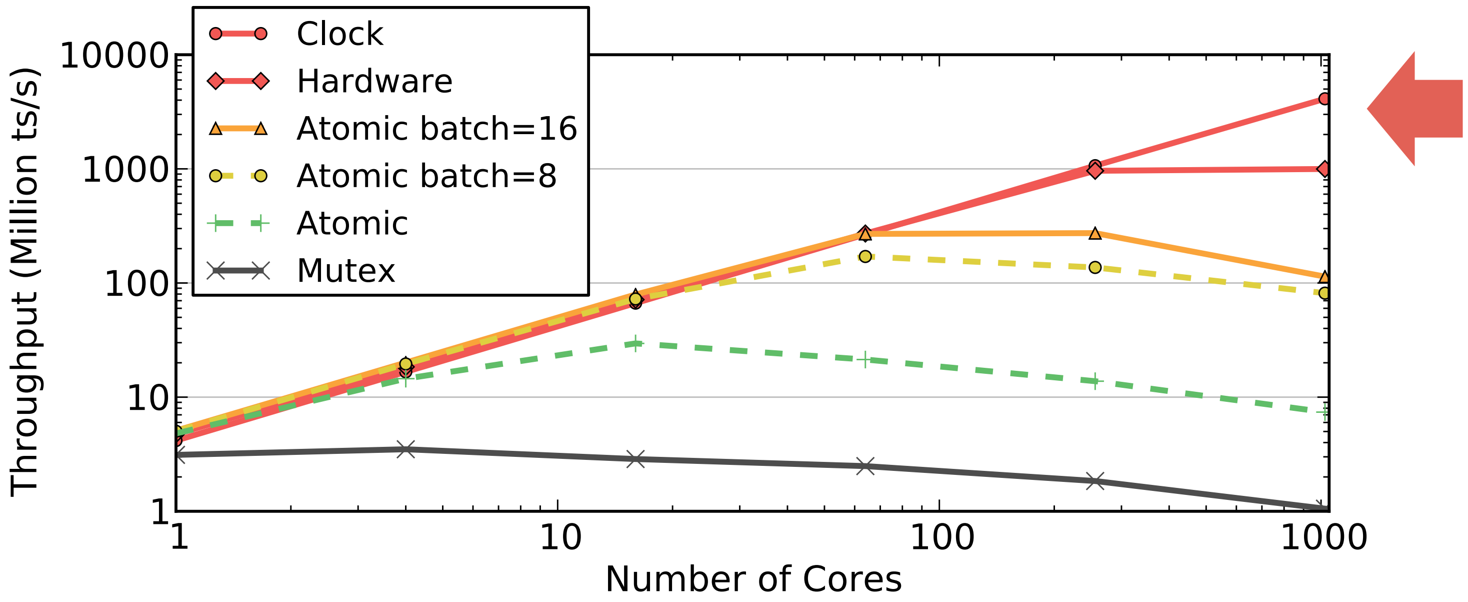
Mutex based allocation

Atomic instruction

Batch allocation

Hardware Counter (~1000 million ts/s)

Solutions to Timestamp Allocation



- Mutex based allocation
- Atomic instruction
- Batch allocation
- **Hardware Counter (~1000 million ts/s)**
- **Distributed Clock (perfect scalability)**
  - All clocks must be synchronized

1000-core – Q/A

Why 1000?

Workload realistic?

Simulator (Graphite) realistic?

Distributed transactions?

- Harding, R., Van Aken, D., Pavlo, A. and Stonebraker, M., *An evaluation of distributed concurrency control*. VLDB 2017
- Similar conclusions

Abyss removed?

Summary

Core counts will keep increasing

Conventional concurrency control protocols do not scale

- Lock trashing
- Timestamp allocation

Need software hardware codesign

(software-only solutions can go a long way)

Group Discussion

What are the pros and cons of timestamp ordering over two-phase locking? Can you think of other examples of using timestamps in other fields of CS?

What are the main pros and cons of a multi-version concurrency control (MVCC) protocol? How is MVCC related to HTAP (Hybrid transactional/analytical processing)?

Can you think of any hardware changes to a multicore CPU that can improve the performance/scalability of concurrency control?

Before Next Lecture

Submit discussion summary to https://wisc-cs839-ngdb20.hotcrp.com

- **Deadline: Friday 11:59pm**

Submit review for

Speedy Transactions in Multicore In-Memory Databases

[optional] TicToc: Time Traveling Optimistic Concurrency Control

[optional] Hekaton: SQL Server's Memory-Optimized OLTP Engine