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

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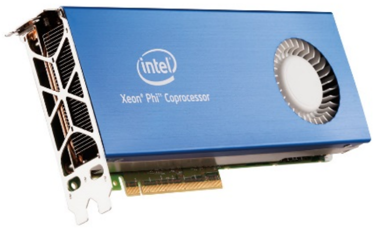
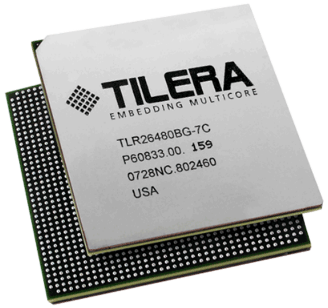
Motivation(1)

- The era of single-core CPU speed-up is over.
- Number of cores on a chip is increasing exponentially
  - Increase computation power by thread level parallelism
  - 1000-core chips are near…



Xeon Phi (up to 61 cores)



Tilera (up to 100 cores)

Motivation(2)

- Is the DBMS ready to be scaled ?
  - Most DBMSs still focus on single-threaded performance
  - Existing works on multi-cores focus on small core count

Objective

- To evaluate transaction processing at 1000 cores.
- Focus on one scalability challenge : Concurrency control.
- Discuss the bottlenecks and improvements needed.

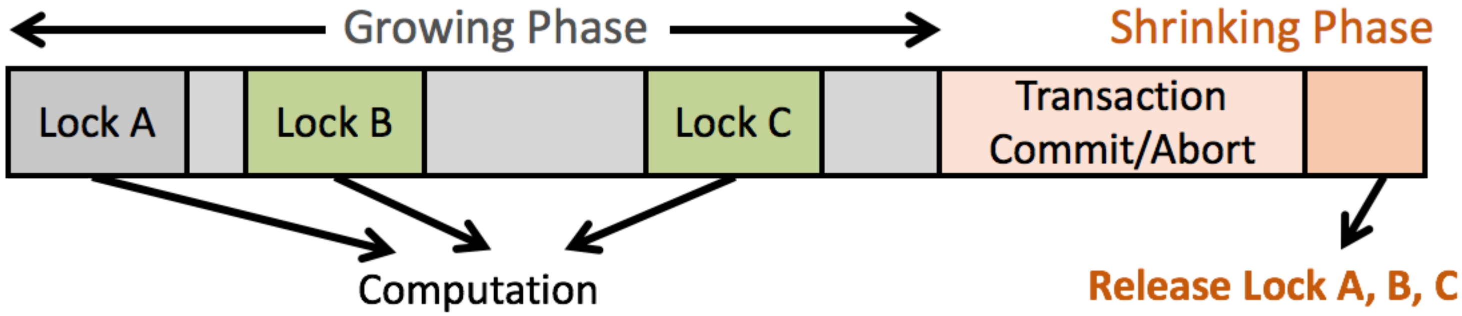
Implementation

- Concurrency Control Schemes
- DBMS TestBed

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

Two-Phase Locking (1)



Two-Phase Locking (2)

- Lock conflict
  - DL_DETECT: always wait. — deadlock detection
  - NO_WAIT: always abort.
  - WAIT_DIE: wait if older, otherwise abort

  } deadlock prevention
- Example systems
  - Ingres, Informix, IBM DB2, MS SQL Server, MySQL (InnoDB)

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Timestamp Ordering (T/O) (1)

Each transaction has a unique timestamp indicating the serial order.

1. **TIMESTAMP (**Basic Timestamp Ordering**)**

- R/W request rejected if tx timestamp < timestamp of last write.

2. **MVCC (M**ulti-**V**ersion **C**oncurrency **C**ontrol**)**

- Every write op creates a new timestamped version
- For read op, DBMS decides which version it accesses.

Timestamp Ordering (T/O) (2)

3. **OCC (O**ptimistic **C**oncurrency **C**ontro**l)**

- Private workspace of each transaction.
- At commit time, if any overlap, tx is aborted and restarted.
- Advantage : short contention period.

Example systems

Oracle, Postgres, MySQL (InnoDB), SAP HANA, MemSQL, MS Hekaton

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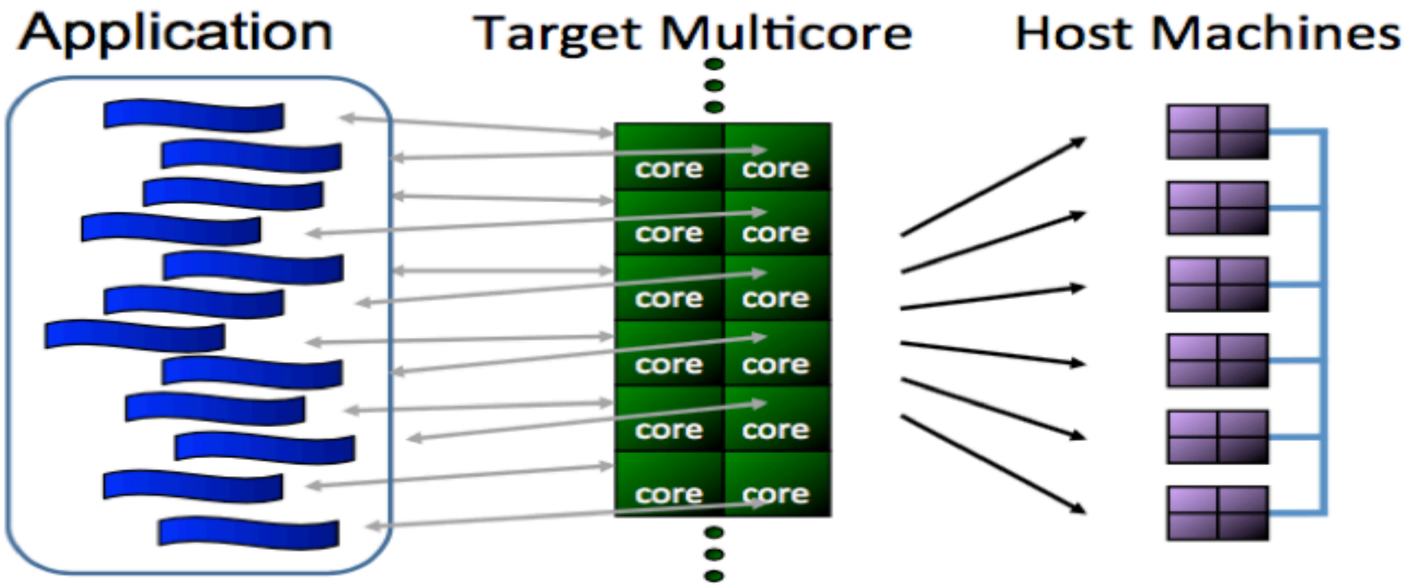
H-Store

- Database divided into disjoint memory subsets called partitions.
- Each partition protected by locks.
- Tx acquires locks to all partitions it needs to access.
- DBMS assigns it a timestamp and adds it to lock queues.

DBMS Test Bed (1)

Graphite : **CPU simulator**, scales upto 1024 cores.

- Application threads mapped to simulated core threads.
- Simulated threads mapped to multiple processes on host machines.



DBMS Test Bed (2)

- Implemented light-weight pthread based **DBMS**.
- Allows to swap different concurrency schemes.
- Ensures no other bottlenecks than concurrency control.
- Reports transaction statistics.

General Optimizations

1. Memory Allocation:

Custom malloc , resizable memory pool for each thread.

2. Lock Table:

Instead of centralized lock table, per-tuple locks

3. Mutexes:

Avoid mutex on critical path.

- For 2PL, centralized deadlock detector
- For t/o : allocating unique timestamps.

Scalable 2PL

1. <u>Deadlock Detection</u>

- Making deadlock detector lock free by keeping local wait-for graph.
- Thread searches for cycles in partial wait-for graph.

2. <u>Lock Thrashing</u>

- Holding locks until commit => bottleneck in concurrent Txs.
- Timeout threshold : abort Tx if wait time exceeds timeout.

Scalable T/O

1. Timestamp Allocation

a) Batched atomic addition

- Manager returns multiple timestamps for a request.

b) CPU clocks

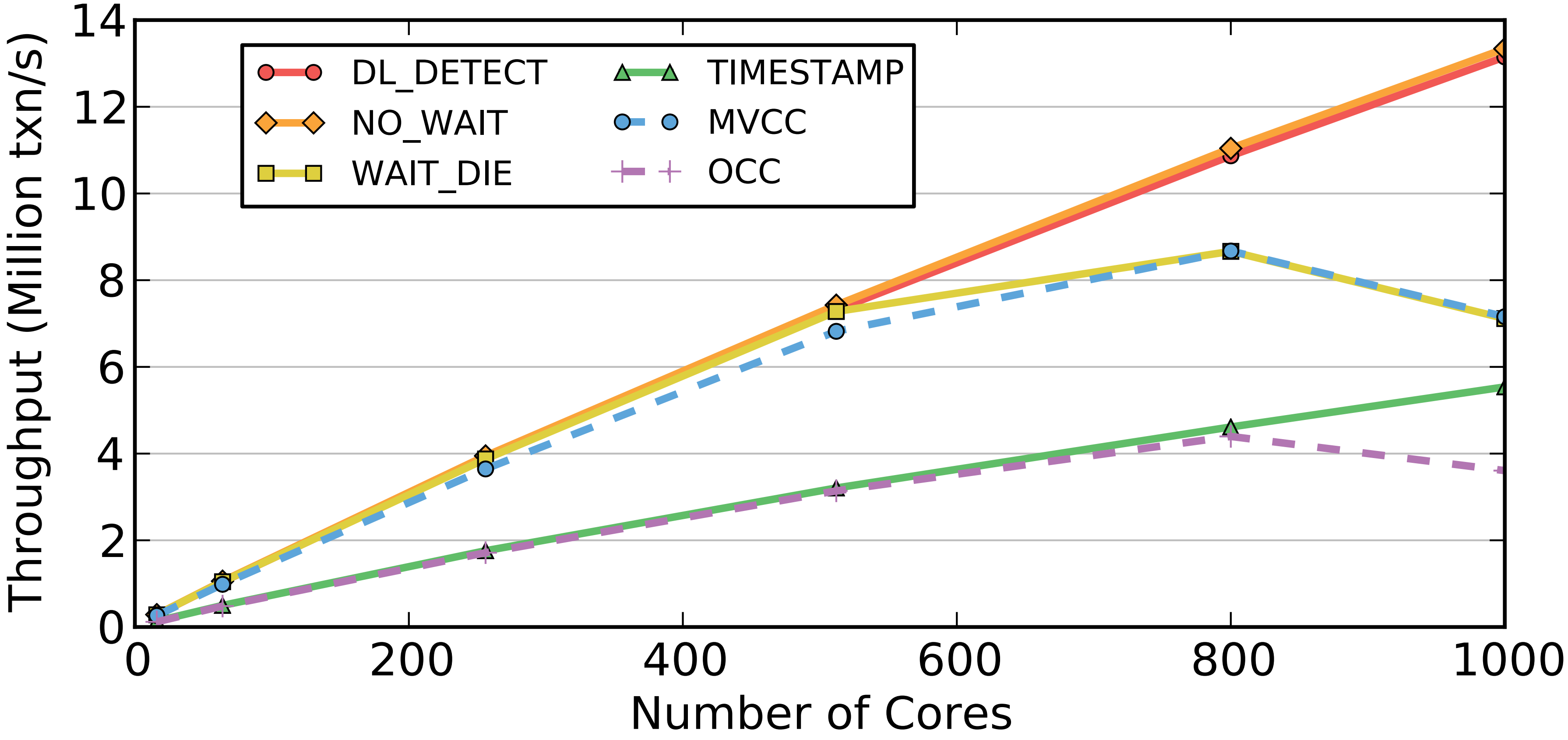
- Read logical clock of core, concatenate with thread id.
- requires synchronized clocks.

c) Hardware counters

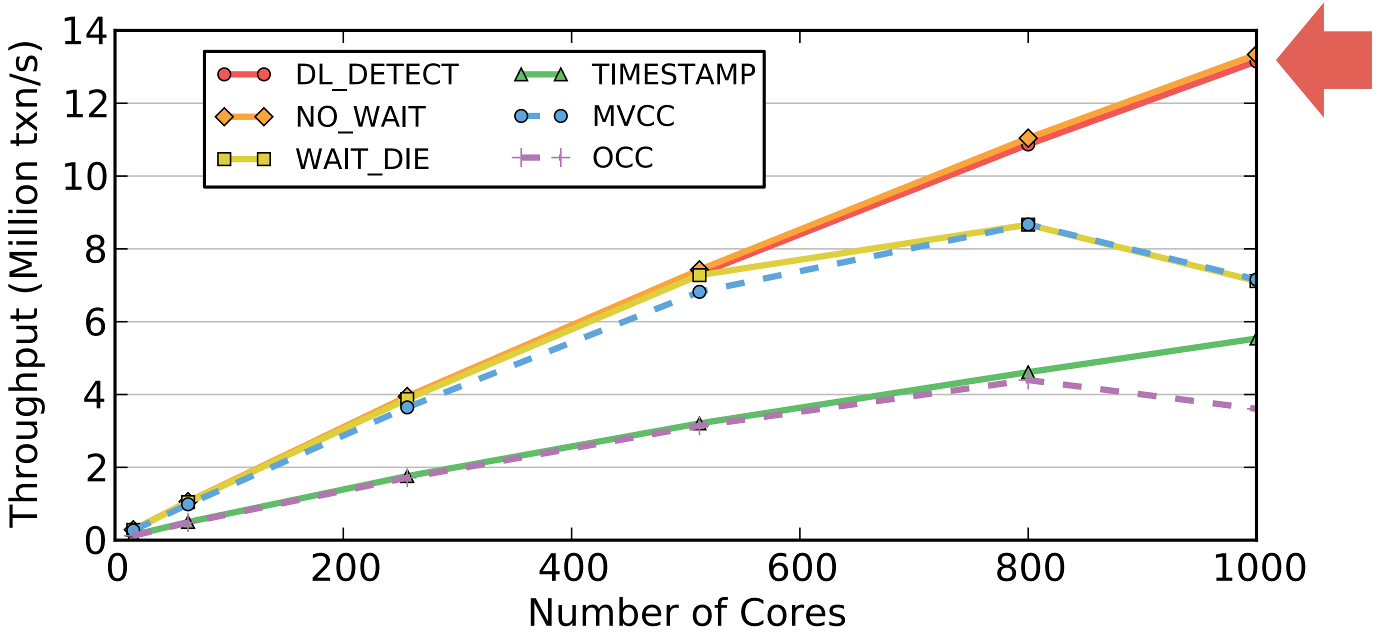
- Physically located at center of CPU.

Evaluation

Read-Only Workload

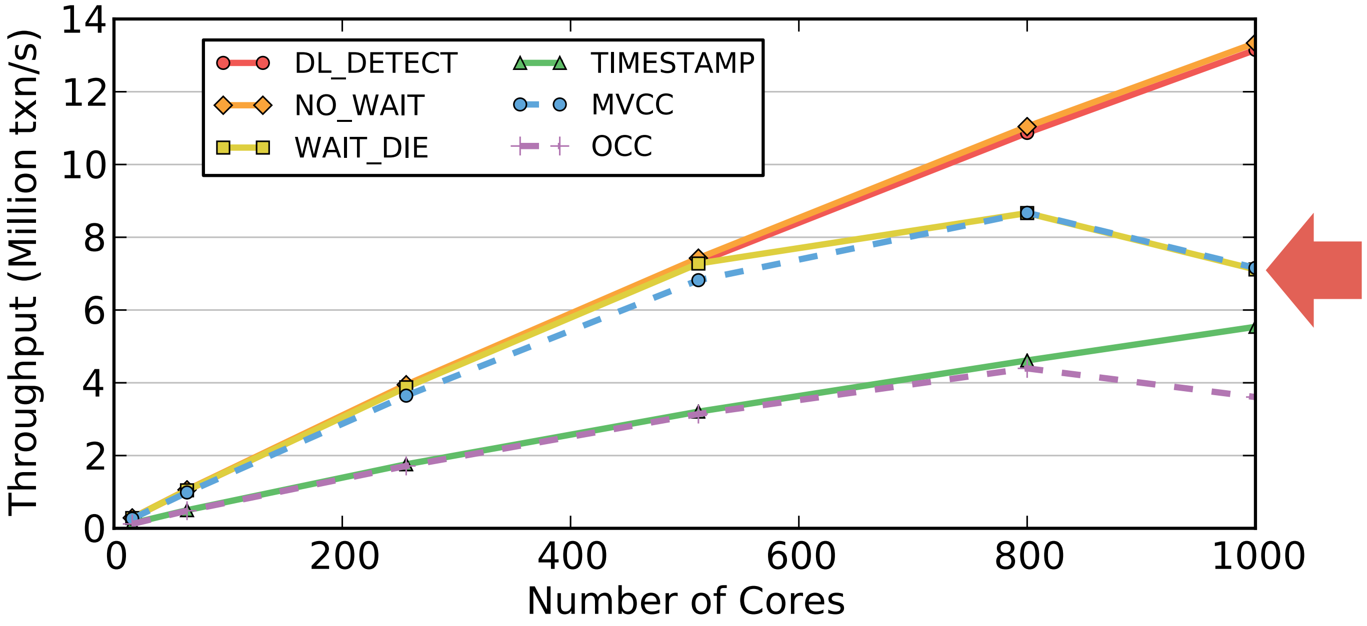


Read Only Workload



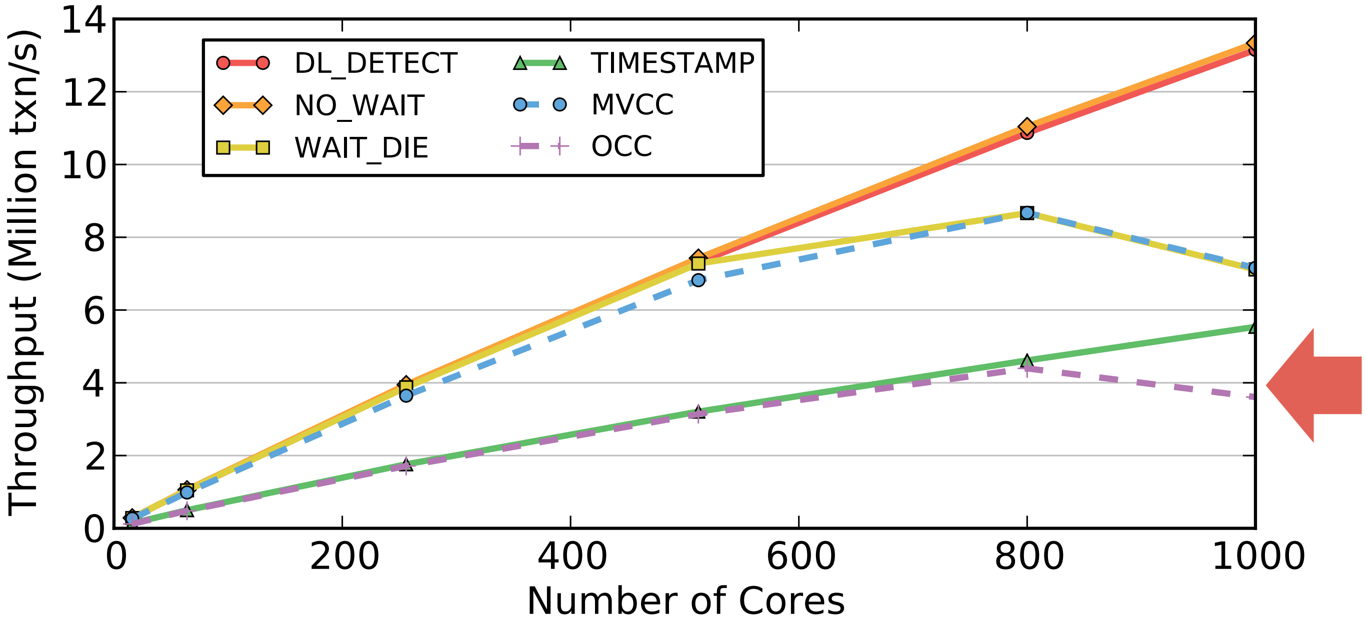
➢ 2PL schemes are scalable for read only benchmarks

Read Only Workload



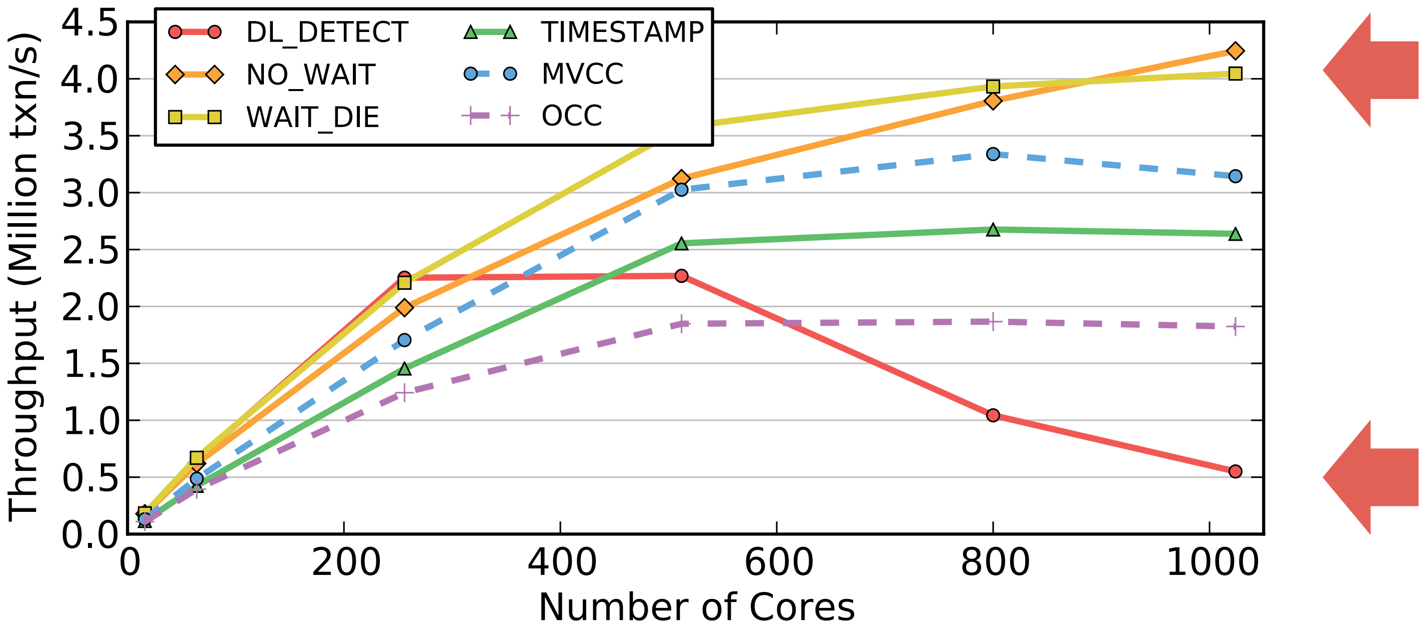
- ➢ 2PL schemes are scalable for read only benchmarks
- ➢ Timestamp allocation limits scalability

Read Only Workload



- 2PL schemes are scalable for read only benchmarks
- Timestamp allocation limits scalability
- Memory copy hurts performance

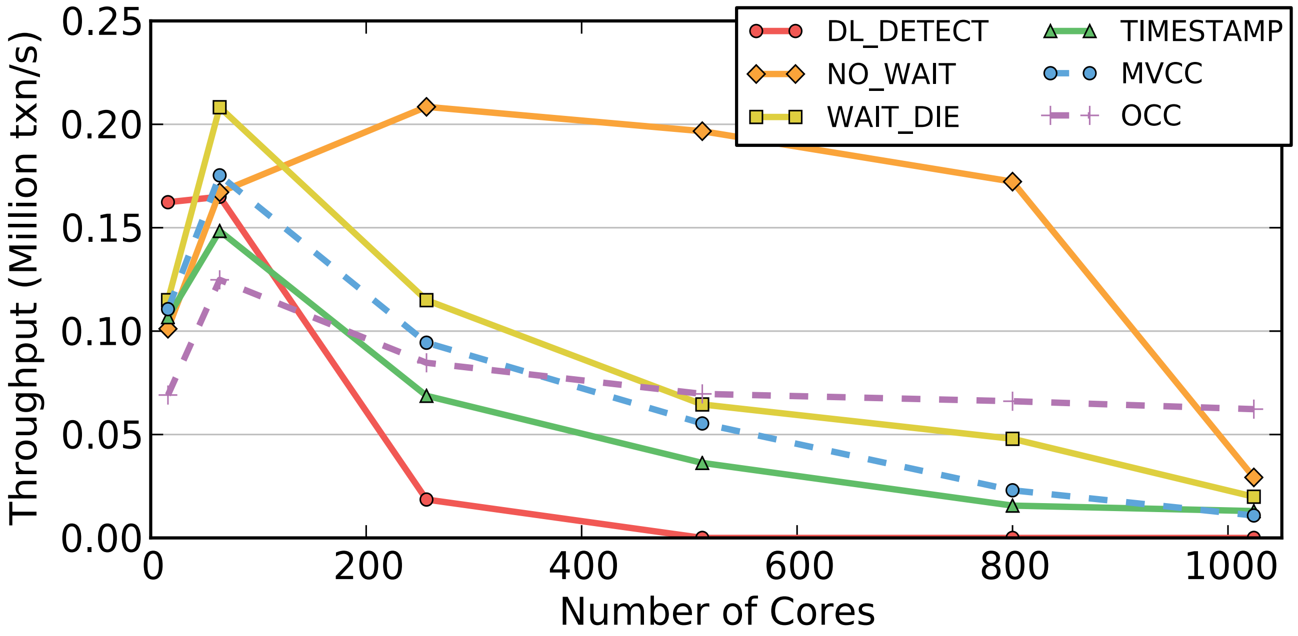
Write Intensive (medium contention)



No_Wait, Wait_Die scales better than others.

DL_Detect inhibited by lock thrashing.

Write Intensive (High contention)



- Scaling stops at small core count(64)

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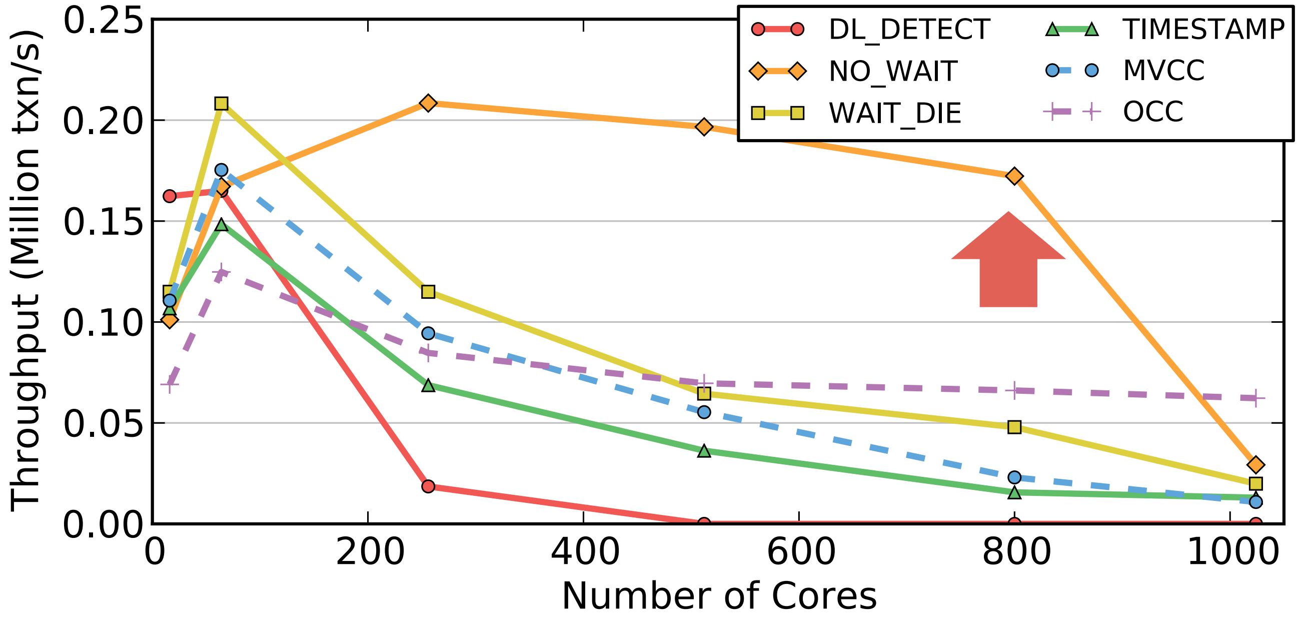

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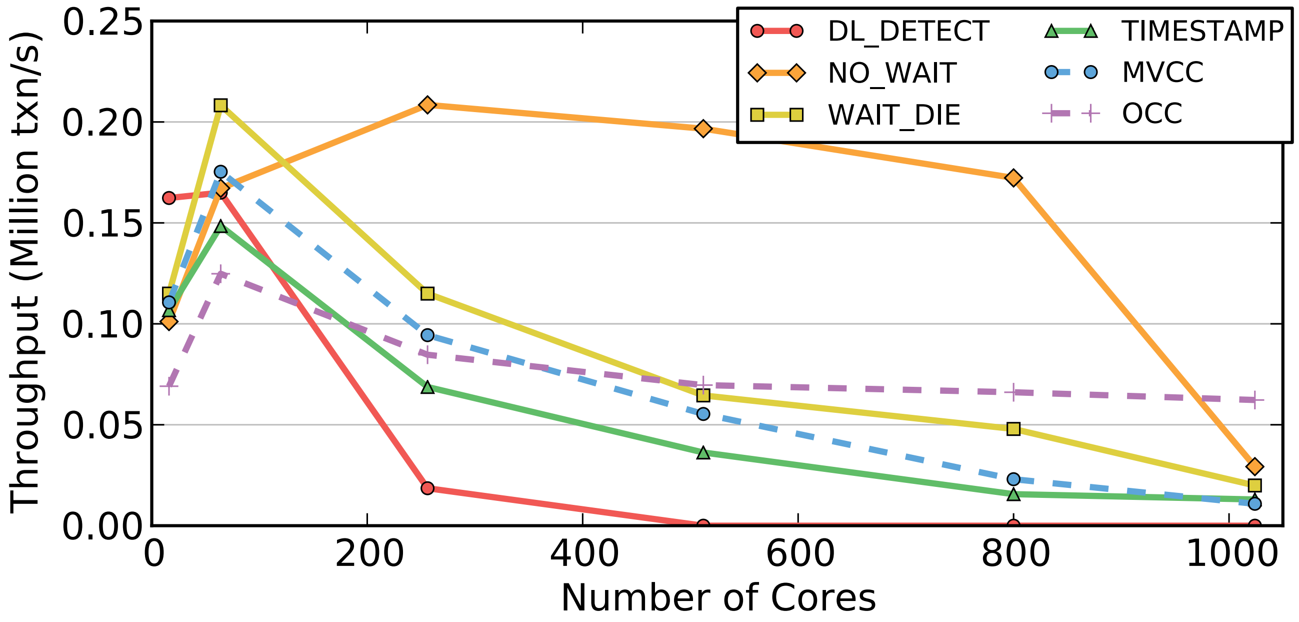

- Scaling stops at small core count (64)
- NO_WAIT has good performance but falls due to thrashing.
- OCC wins at 1000 cores as one Tx always commits.

More Analysis

1. Short Transactions => Low Lock contention

   Longer Transactions => Timestamp allocation not a bottleneck.

2. More read transactions => Better throughput.

3. Multi partition transactions => H-Store scheme performs bad.

   Partitioned workloads => H-Store best algorithm

Bottlenecks Summary

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

Summary

All algorithms fail to scale as core increases.

- **Thrashing** limits the scalability of 2PL algorithms
- **Timestamp allocation** limits the scalability of T/O algorithms

Project Ideas

- New concurrency control approaches to tackle scalability problem.
- Hardware solutions to DBMS bottlenecks unsolvable in software side.
- Hybrid approach : Switch b/w schemes depending on workload.

Questions

Thrashing