An Evaluation of Distributed Concurrency Control

Harding, Aken, Pavlo and Stonebraker

Presented by: Thamir Qadah

For CS590-BDS

Outline

- Motivation
- System Architecture
- Implemented Distributed CC protocols
  - 2PL
  - TO
  - OCC
  - Deterministic
- Commitment Protocol
  - 2PC
  - Why CALVIN does not need 2PC
    - What is the tradeoff
- Evaluation environment
  - Workload Specs
  - Hardware Specs
- Discussion
  - Bottlenecks
  - Potentiual soluutions

Motivation

- Concerned with:
    - When does distributing concurrency control benefit performance?
    - When is distribution strictly worse for a given workload?
- Costs of distributed transaction processing are well known [Bernstein et. al ‘87, Ozsu and Valduriez ‘11]
    - But, in cloud environments providing high scalability and elasticity, trade-offs are less understood.
- With new proposals of distributed concurrency control protocols, there is no comprehensive performance evaluation.

Publication	Experimental Comparisons Performed Lock	TS	MV	OCC	Det	None
Tango [7]	✓					
Spanner [20]						✗
Granola [21]	✓					
Centiman [25]						✗
FaRM [26]						✗
Warp [27]						✗
MaaT [39]	✓					
Rococo [41]	✓			✓		
Ren et al. [45]	✓			✓		
F1 [47]						✗
Calvin [54]						✗
Wei et al. [58]					✓	
TaPiR [61]	✓			✓		
Lynx [62]						✗
Deneva (this study)	✓×2	✓	✓	✓	✓	

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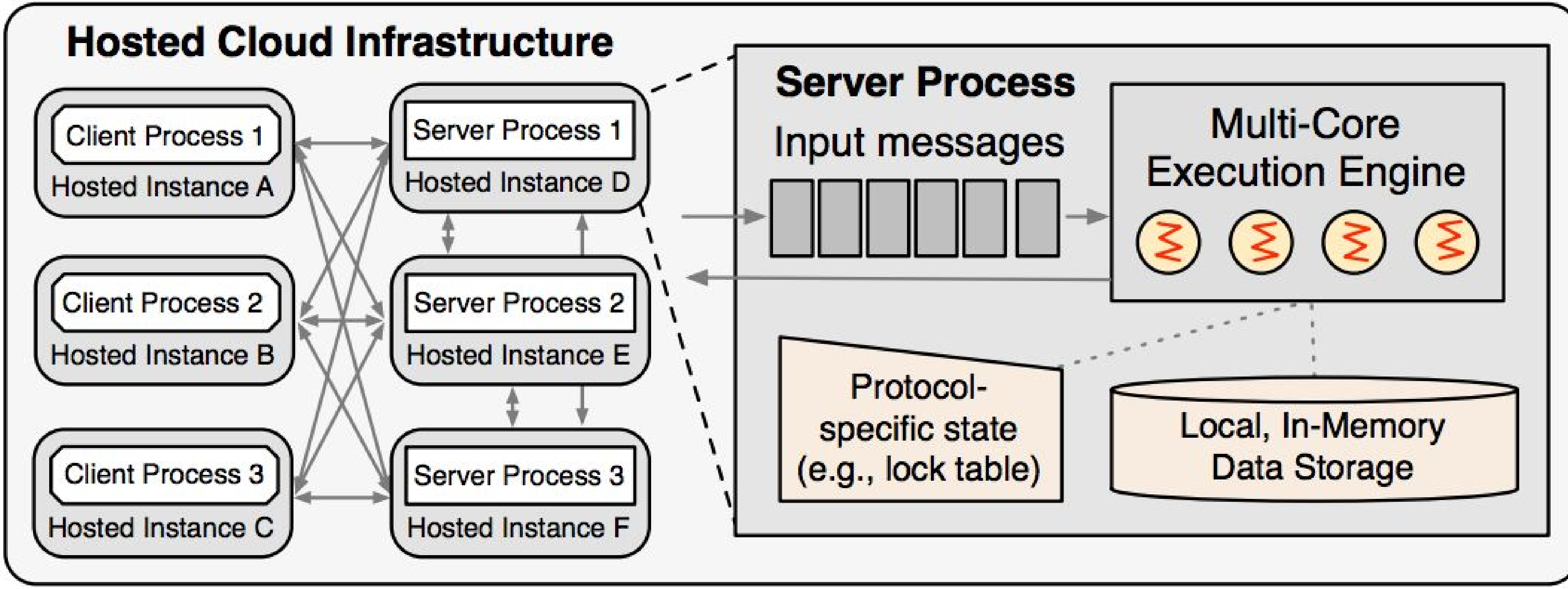
Deneva (this study)	✓×2	✓	✓	✓	✓	

Note: Lock-based implementations may be different (e.g. deadlock detection/avoidance)

Transaction Model

- Deneva uses the concept of stored procedures to model transactions.
  - No client stalls in-between transaction logical steps
- Support for protocols (e.g. CALVIN) that require READ-SET and WRITE-SET to be known in-advanced
  - DBMS needs to compute that.
    - Simplest way: run transaction without any CC measures

High Level System Architecture



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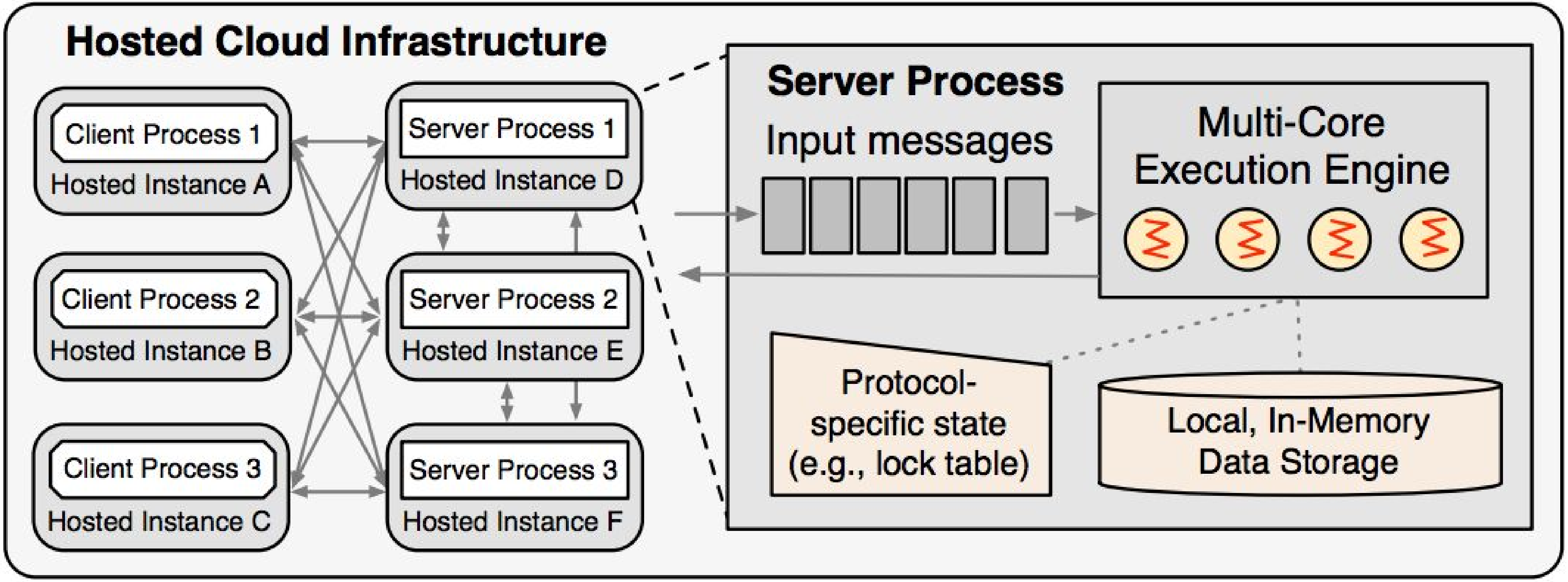
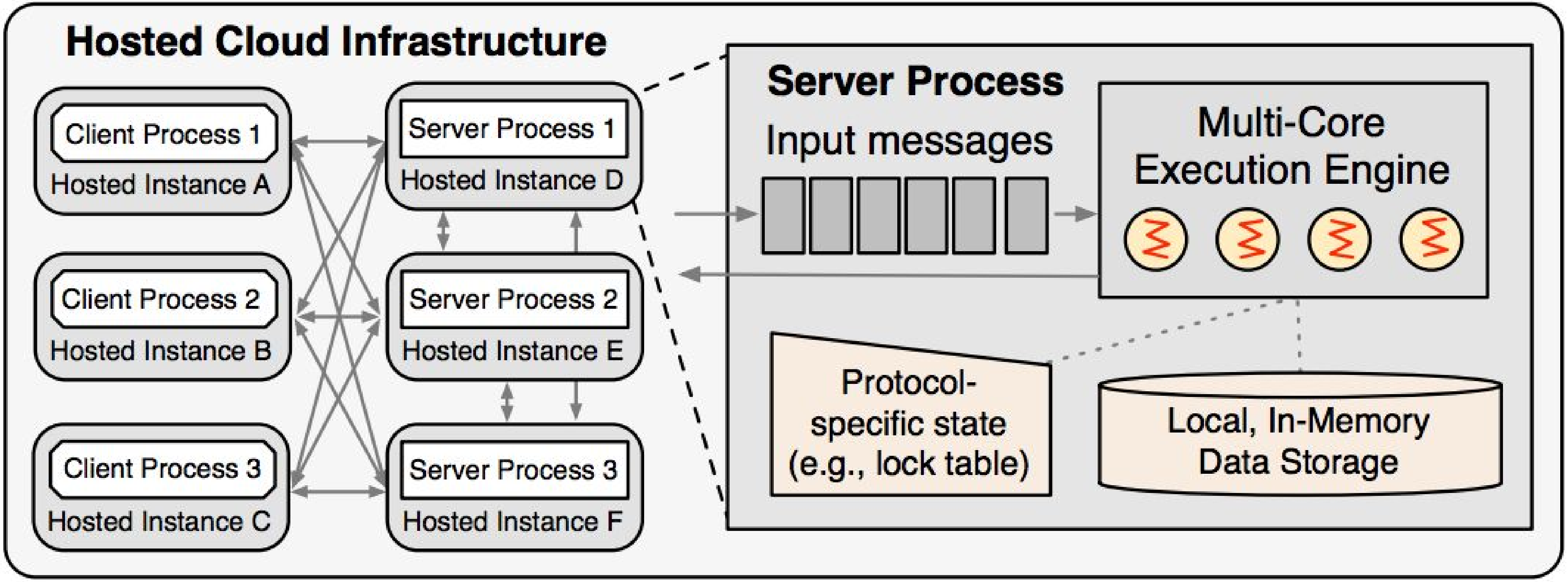
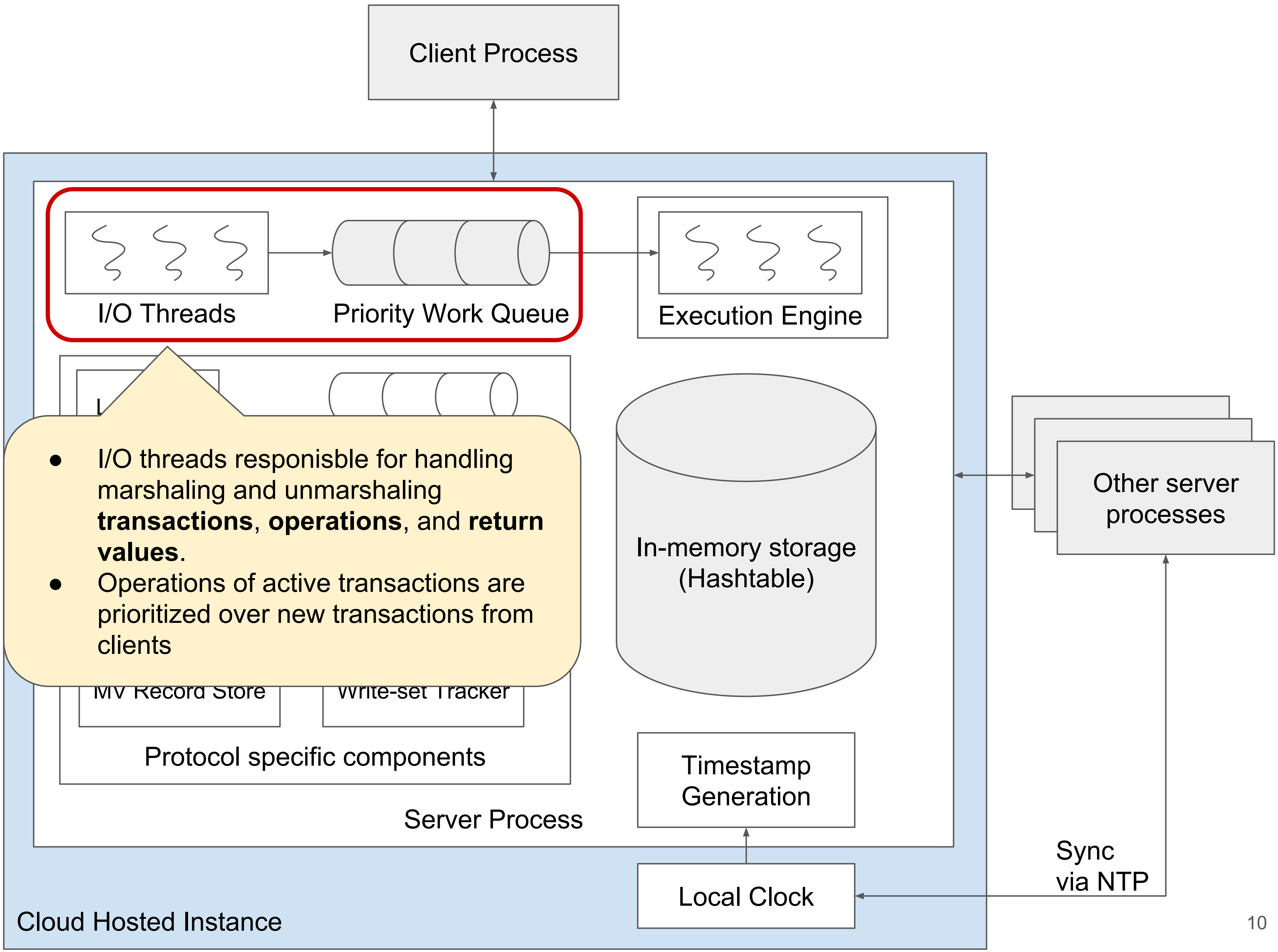


Client and Server processes are deployed on different hosted cloud instance

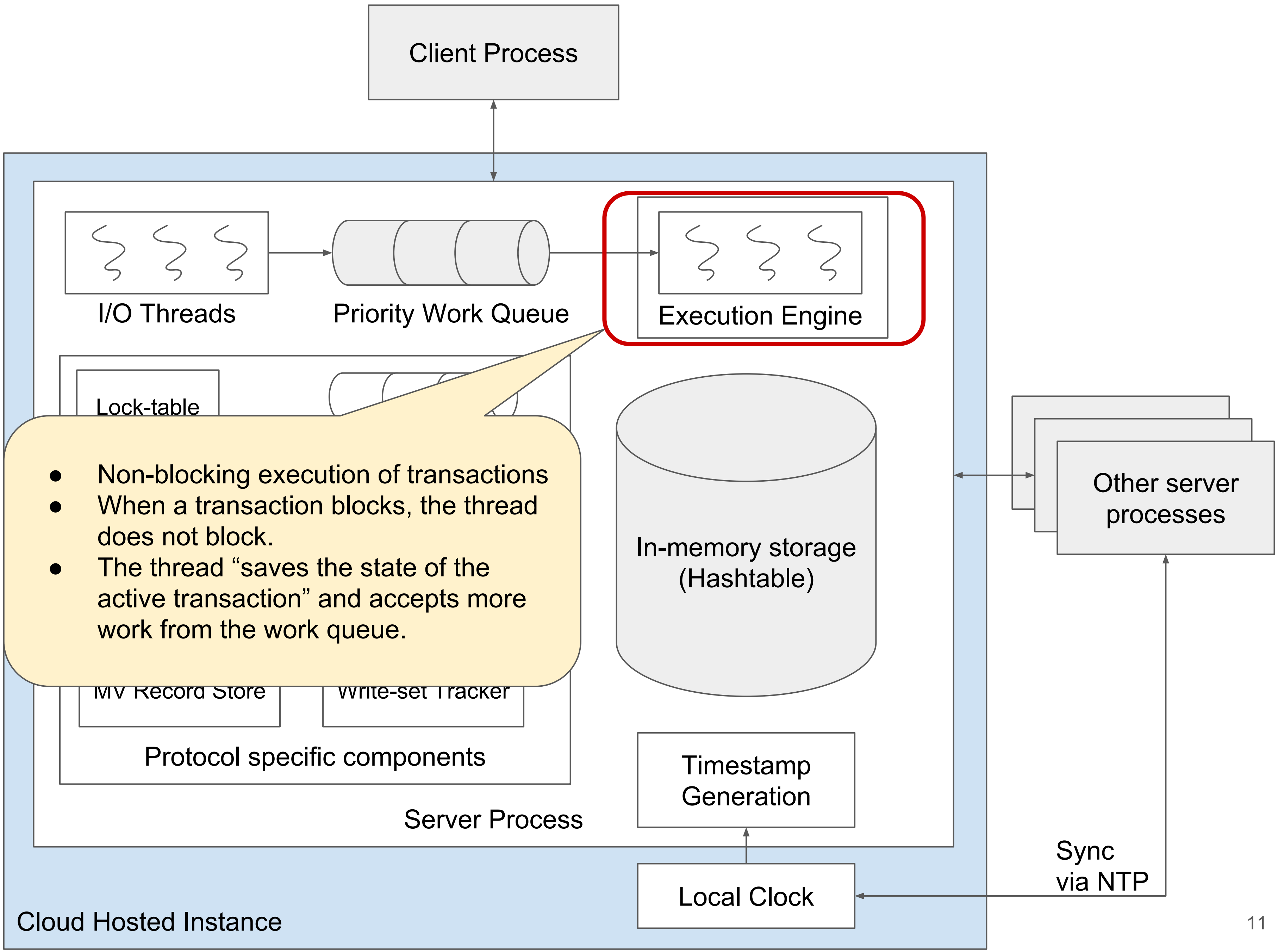
High Level System Architecture



Communication among processes uses nanomsg socket library



Client Process
I/O Threads
Priority Work Queue
Execution Engine
I/O threads responisble for handling marshaling and unmarshaling **transactions**, **operations**, and **return values**.
Operations of active transactions are prioritized over new transactions from clients
MV Record Store
Write-set Tracker
Protocol specific components
In-memory storage (Hashtable)
Other server processes
Timestamp Generation
Server Process
Sync via NTP
Local Clock
Cloud Hosted Instance


Client Process
I/O Threads
Priority Work Queue
Execution Engine
Lock-table
Non-blocking execution of transactions
When a transaction blocks, the thread does not block.
The thread “saves the state of the active transaction” and accepts more work from the work queue.
MV Record Store
Write-set Tracker
Protocol specific components
In-memory storage (Hashtable)
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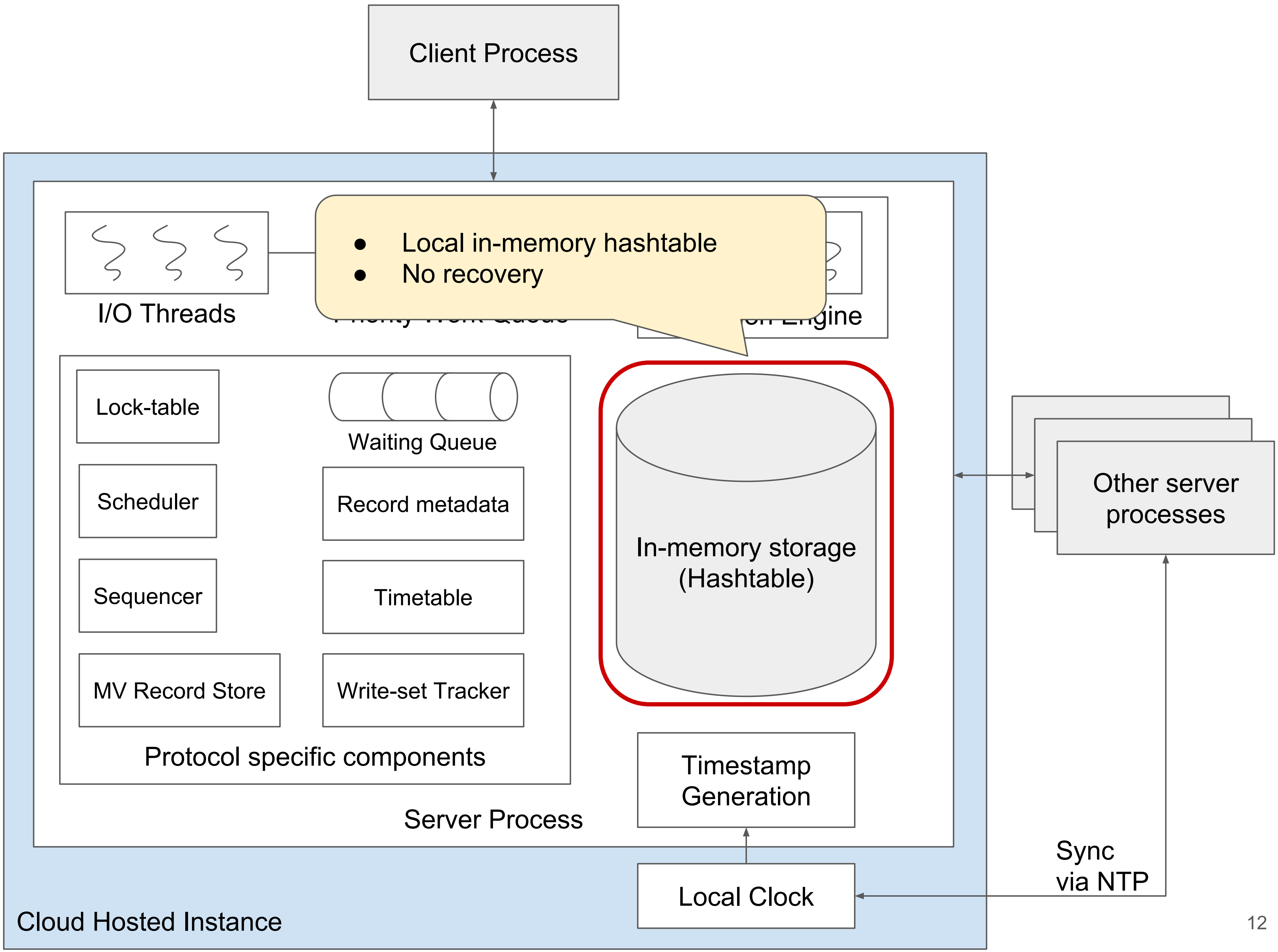

Client Process
Local in-memory hashtable
No recovery
I/O Threads
Lock-table
Waiting Queue
Scheduler
Record metadata
Sequencer
Timetable
MV Record Store
Write-set Tracker
Protocol specific components
In-memory storage (Hashtable)
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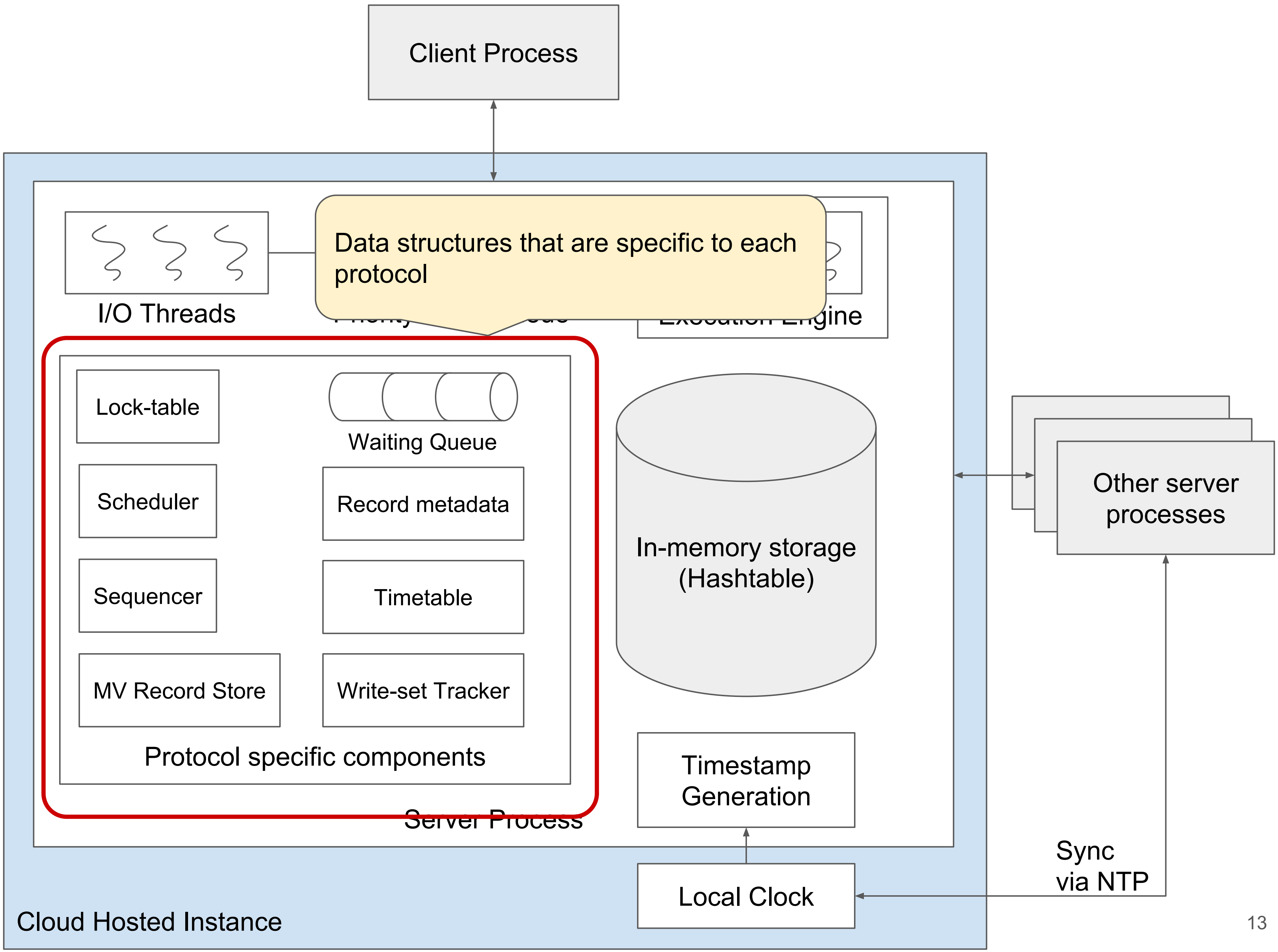

Client Process
Data structures that are specific to each protocol
I/O Threads
Lock-table
Waiting Queue
Scheduler
Record metadata
Sequencer
Timetable
MV Record Store
Write-set Tracker
Protocol specific components
Server Process
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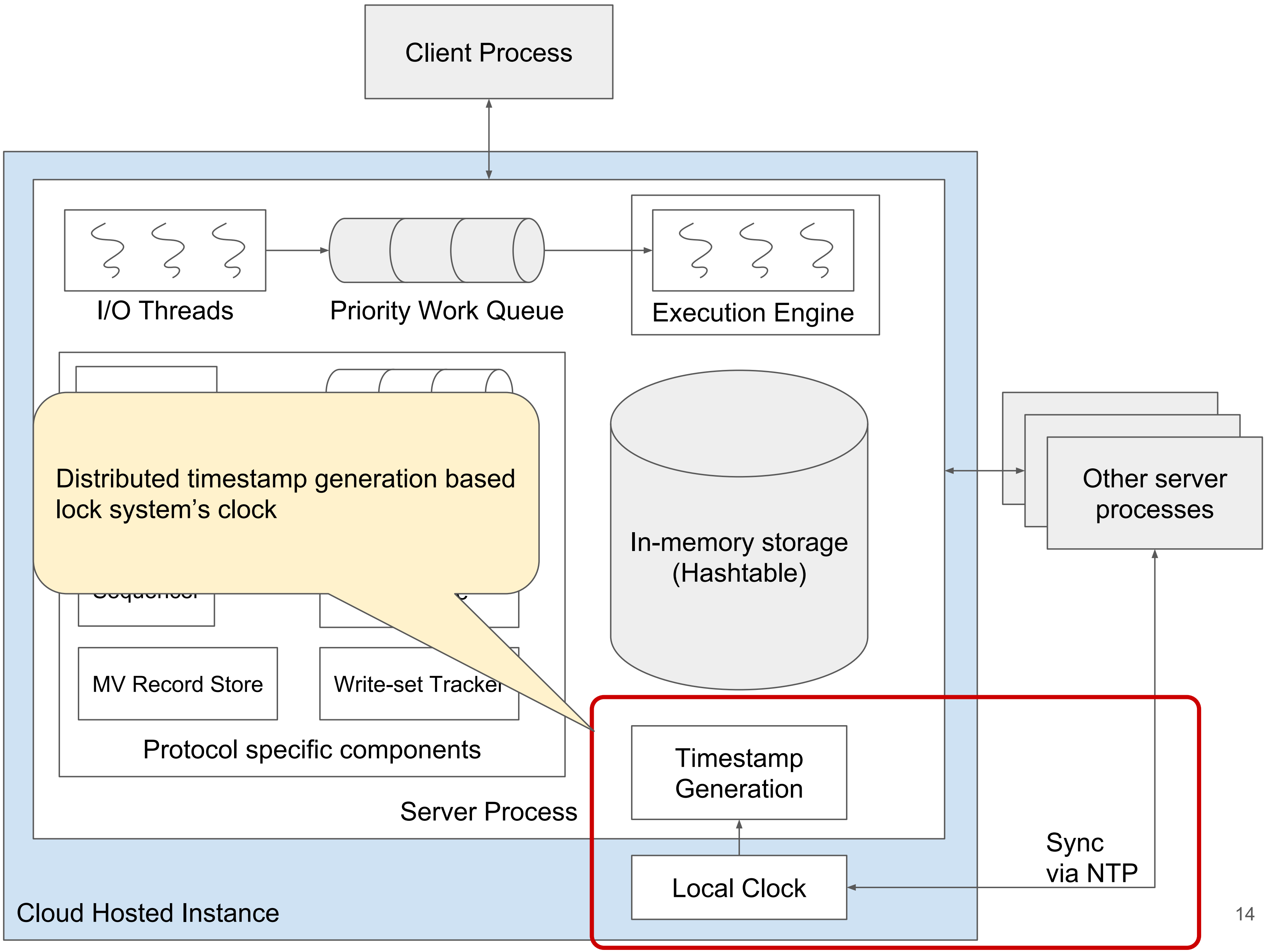

Client Process
I/O Threads
Priority Work Queue
Execution Engine
Distributed timestamp generation based lock system's clock
In-memory storage (Hashtable)
Other server processes
MV Record Store
Write-set Tracker
Protocol specific components
Timestamp Generation
Server Process
Local Clock
Sync via NTP
Cloud Hosted Instance

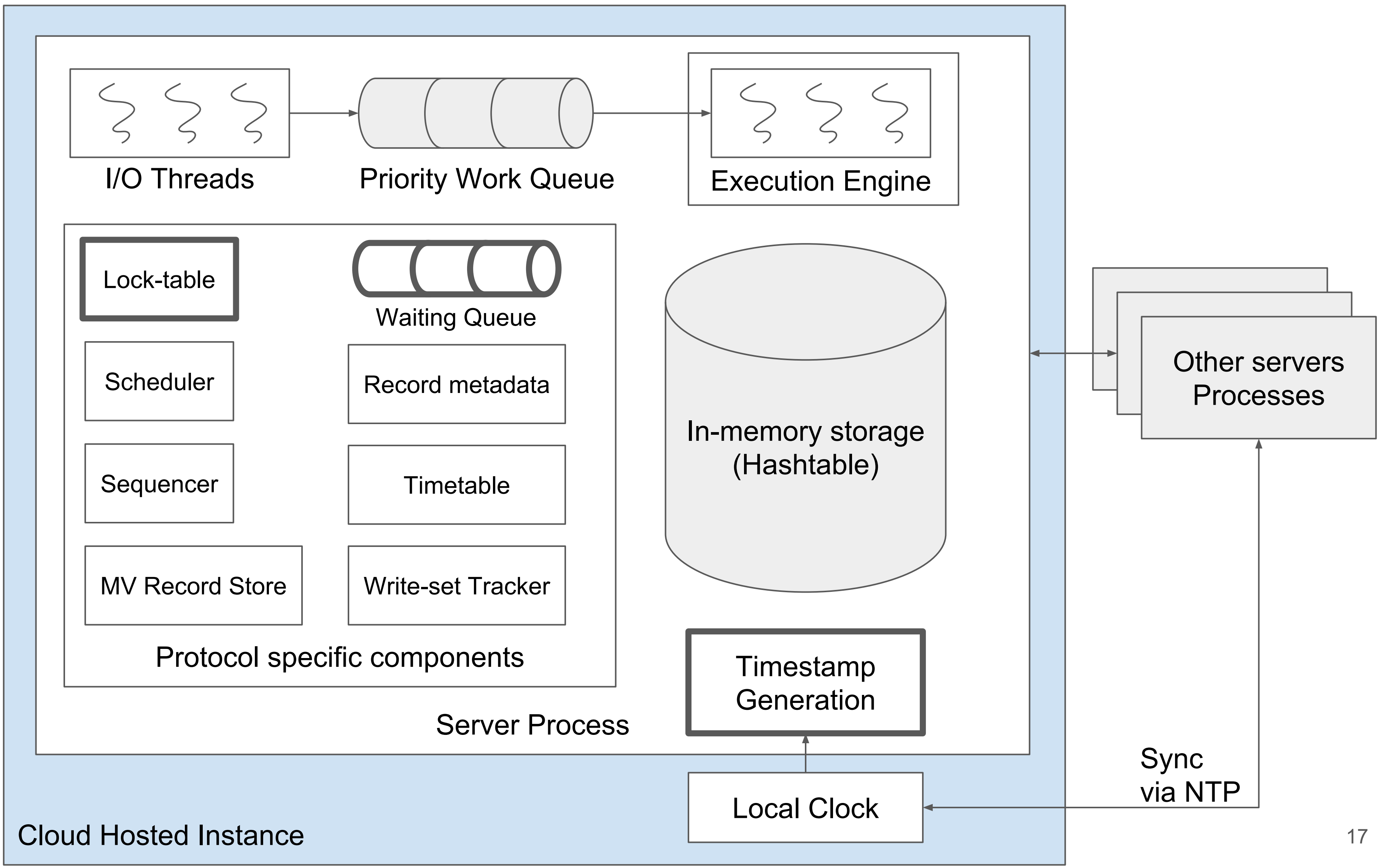
Transaction Protocols

- Concurrency Control
  - Two-phase Locking (2PL)
    - NO_WAIT
    - WAIT_DIE
  - Timestamp Ordering (TIMESTAMP)
  - Multi-version concurrency control (MVCC)
  - Optimistic concurrency control (OCC)
  - Deterministic (CALVIN)
- Commitment Protocols
  - Two-phase Commit (2PC)

Two-phase Locking (2PL)

- Two phase:
  - Growing phase: lock acquisition (no lock release)
  - Shrink phase: lock release (no more acquisition)
- NO_WAIT
  - Aborts and restarts the transaction if lock is not available
  - No deadlocks (suffers from excessive aborts)
- WAIT_DIE
  - Utilizes timestamp
  - Older transactions wait, younger transactions abort
  - Locking in shared mode bypasses lock queue (which contains waiting writers)

2PL



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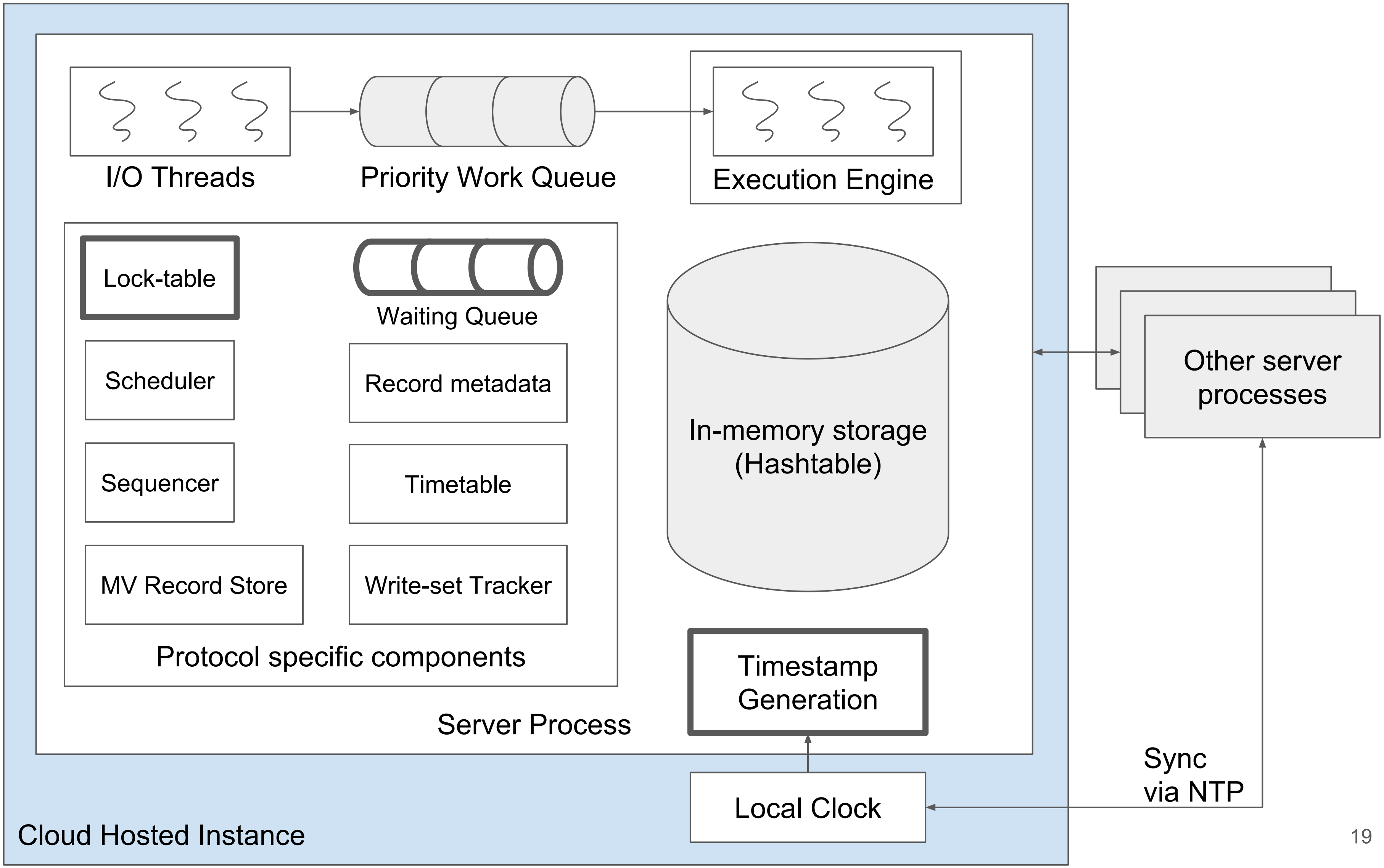
Timestamp Ordering (TIMESTAMP)

- Executes transactions based on the assigned timestamp order
- No bypassing of wait queue
- Avoids deadlocks by aborting older transactions when they conflict with transactions holding records exclusively

TIMESTAMP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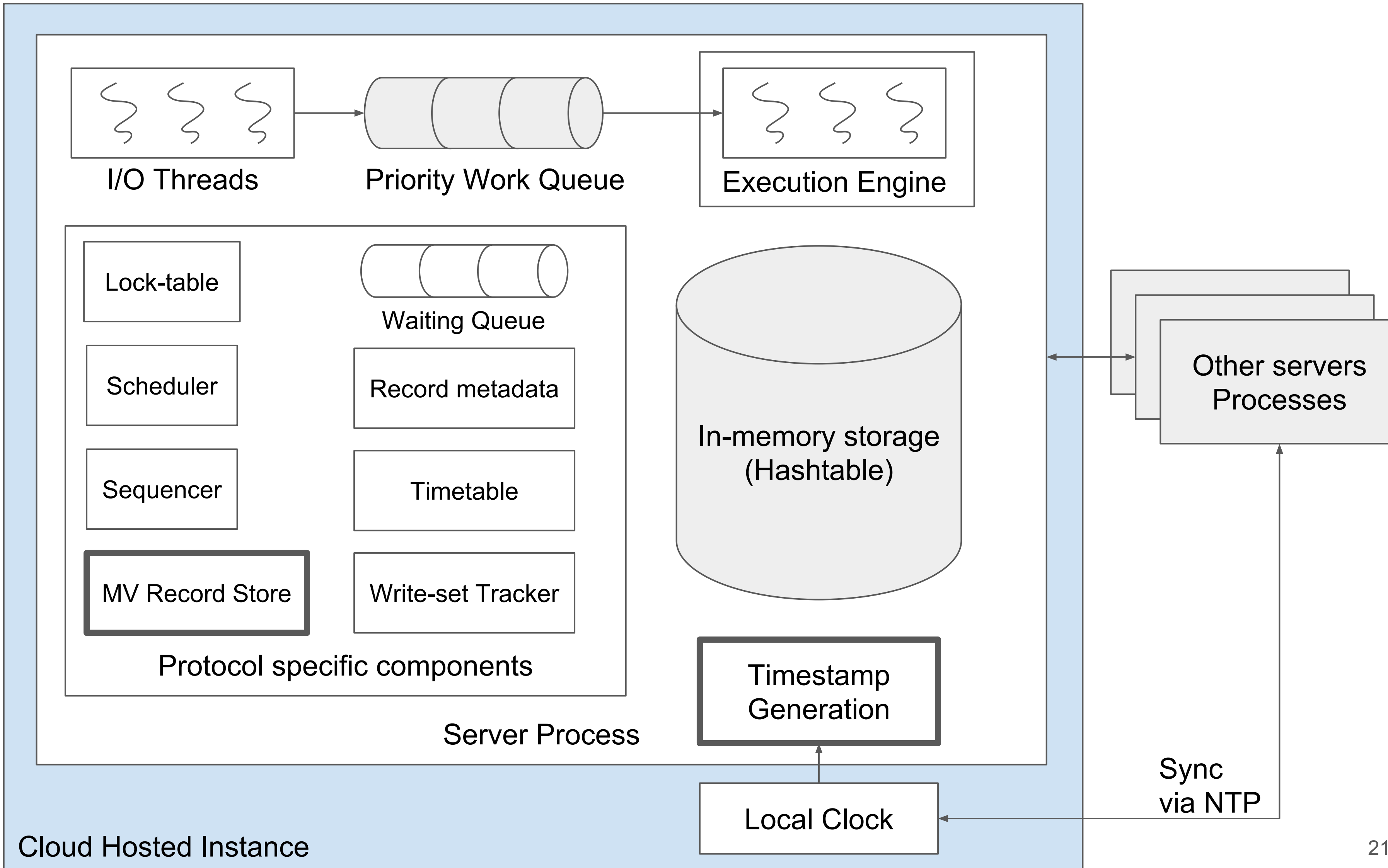
Multi-version Concurrency Control (MVCC)

- Maintain multiple timestamped copies of each record
- Minimizes conflict between reads and writes
- Limit the number of copies stored
- Abort transactions that try to access records that have been garbage collected

MVCC



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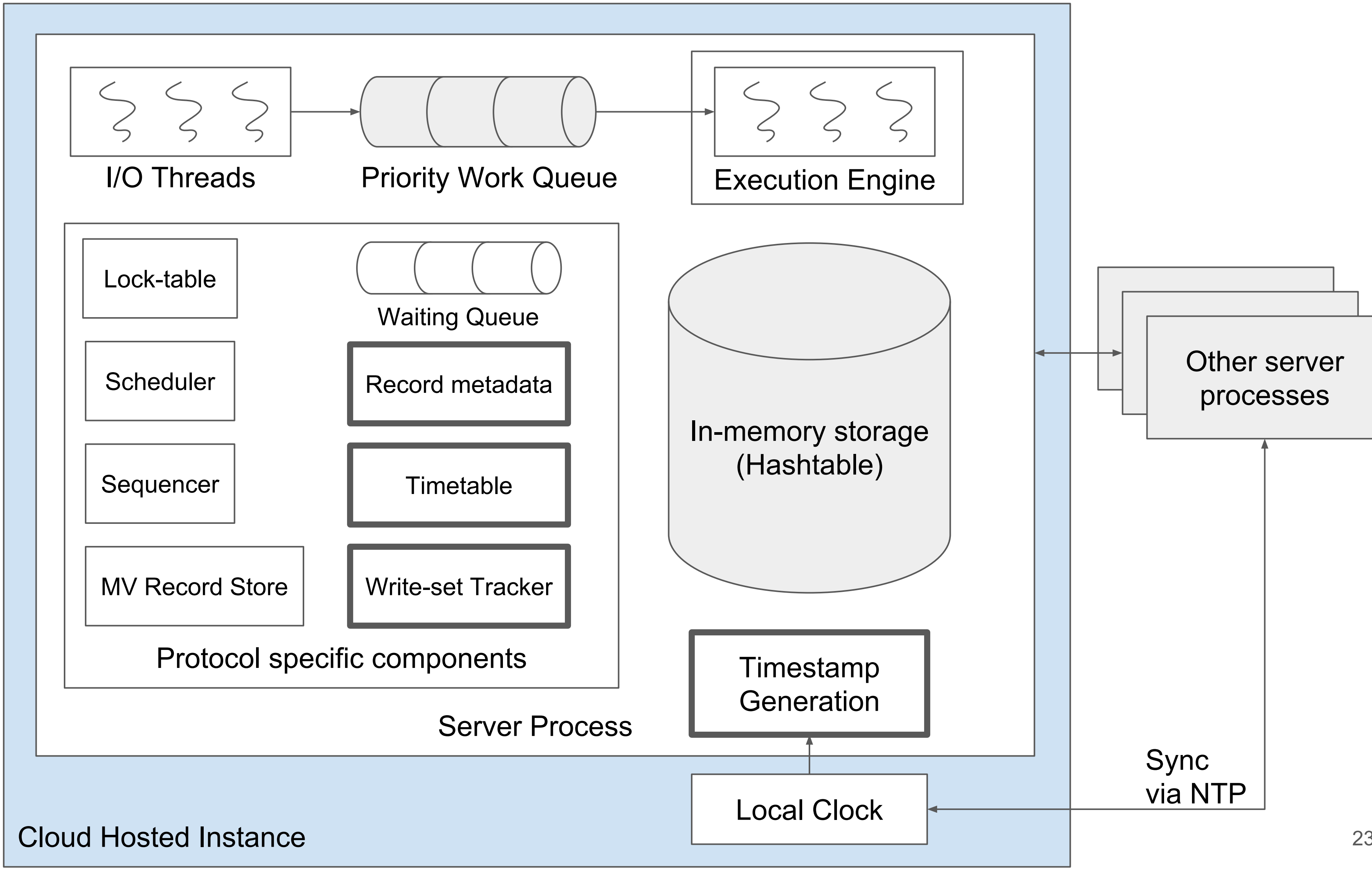
Optimistic Concurrency Control (OCC)

- Based on MaaT [Mahmoud et. al, MaaT protocol, VLDB'14]
- Strong-coupling with 2PC:
  - CC's Validation == 2PC's Prepare phase
- Maintains time ranges for each transaction
- Validation by constraining the time range of the transaction
  - If time range is valid => COMMIT
  - Otherwise => ABORT

OCC



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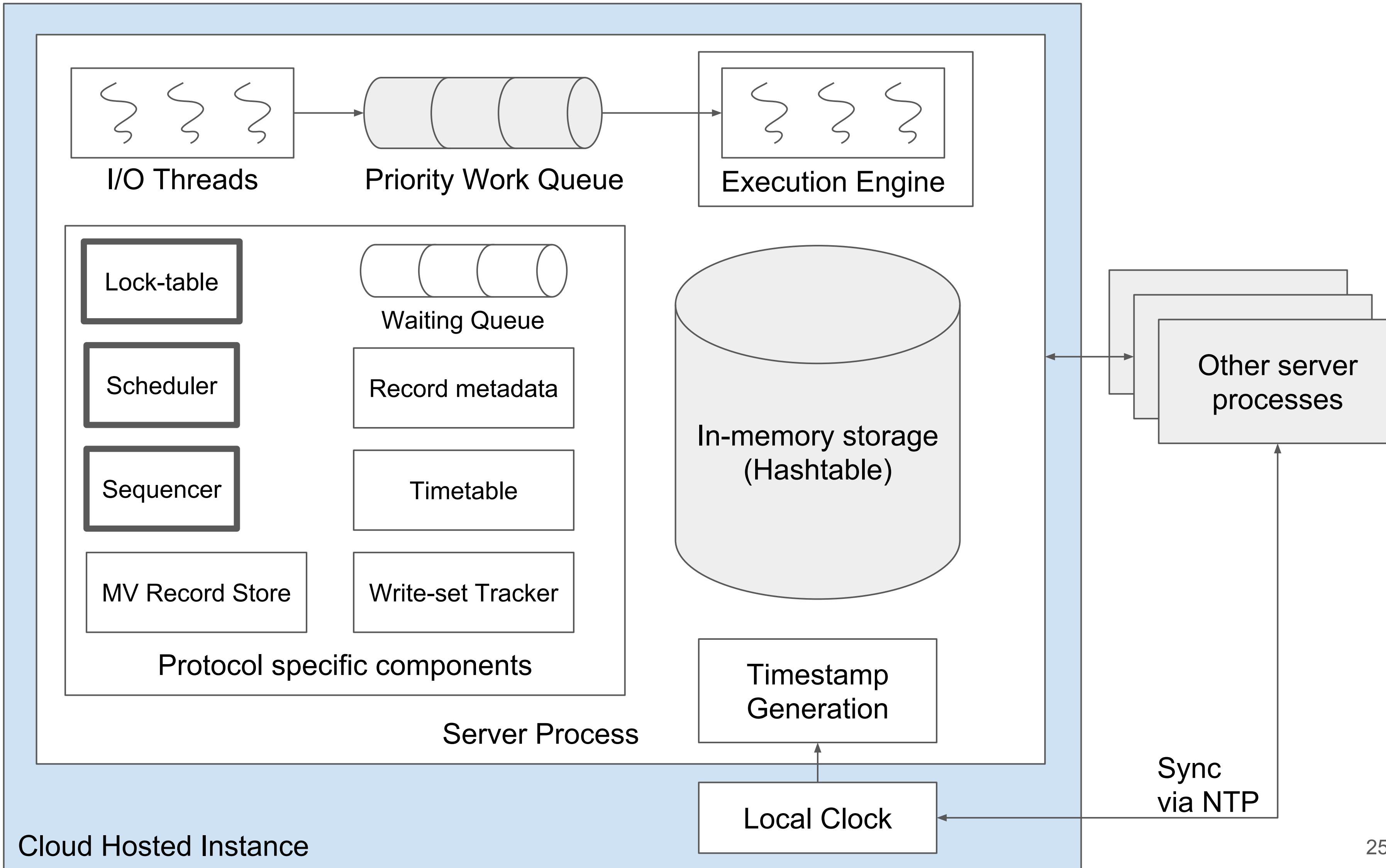
Deterministic (CALVIN)

- Discussed in previous class
- Key idea: impose a deterministic order on a batch of transactions
- Avoids 2PC
- Unlike others, requires READ_SET and WRITE_SET of transactions to be known a priori, otherwise needs to be computed before starting the execution of the transaction
- In Deneva, a dedicated thread is used for each of sequencer and scheduler.

CALVIN



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Evaluation "Hardware"

- Amazon EC2 instances (m4.2xlarge)

M4 instances are the latest generation of General Purpose Instances. This family provides a balance of compute, memory, and network resources, and it is a good choice for many applications.

Features:

- 2.3 GHz Intel Xeon® E5-2686 v4 (Broadwell) processors or 2.4 GHz Intel Xeon® E5-2676 v3 (Haswell) processors
- EBS-optimized by default at no additional cost
- Support for Enhanced Networking
- Balance of compute, memory, and network resources

Model	vCPU	Mem (GiB)	SSD Storage (GB)	Dedicated EBS Bandwidth (Mbps)
m4.large	2	8	EBS-only	450
m4.xlarge	4	16	EBS-only	750
m4.2xlarge	8	32	EBS-only	1,000
m4.4xlarge	16	64	EBS-only	2,000

Evaluation Methodology

- Table partitions are loaded on each server before each experiment
- Number of open client connections: 10K
- 60 seconds warmup
- 60 seconds measurements
- Throughput measure as the number of successfully completed
- Restart an aborted transaction (due to CC) after a penalization period

Evaluation Workload

- YCSB
- TPC-C: warehouse order processing system
- Product-Part-Supplier

Evaluation Workload

- **YCSB**
  - Single table with 1 primary key and 10 columns of 100B each
    - ~ 16 million records per partition => 16GB per node
  - Each transaction accesses 10 records with independent read and write operation in random order
  - Zipfian distribution of access with theta in [0,0.9]
- TPC-C: warehouse order processing system
- Product-Part-Supplier

Evaluation Workload

- YCSB
- **TPC-C: warehouse order processing system**
  - 9 tables partitioned by warehouse_id
  - Item table is read-only and replicated at every server
  - Implemented two transaction of TPCC specs (88% of workload)
    - Payment: 15% chance to access a different partition
    - NewOrder: ~10% are multi-partition transactions
- Product-Part-Supplier

Evaluation Workload

- YCSB
- TPC-C: warehouse order processing system
- **Product-Part-Supplier**
  - 5 tables: 1 for each products, parts and suppliers. 1 table maps products to parts. 1 table maps partos to suppliers
  - Transactions:
    - Order-Product (MPT): reads parts of a product and decrement the stock quantity of the parts
    - LookupProduct (MPT): (read-only) retrieve parts and their stock quantities
    - UpdateProductPart (SPT): updates product-to-parts mapping

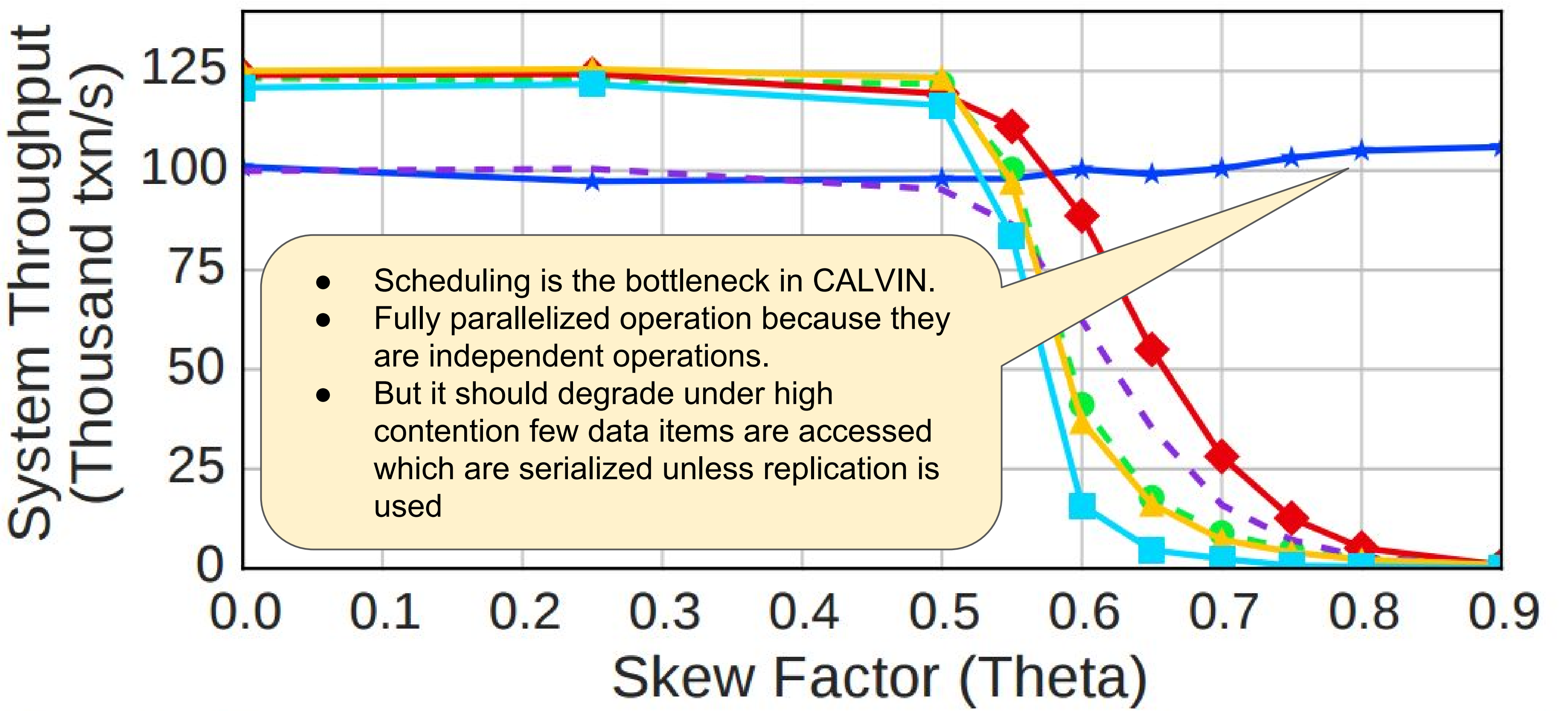
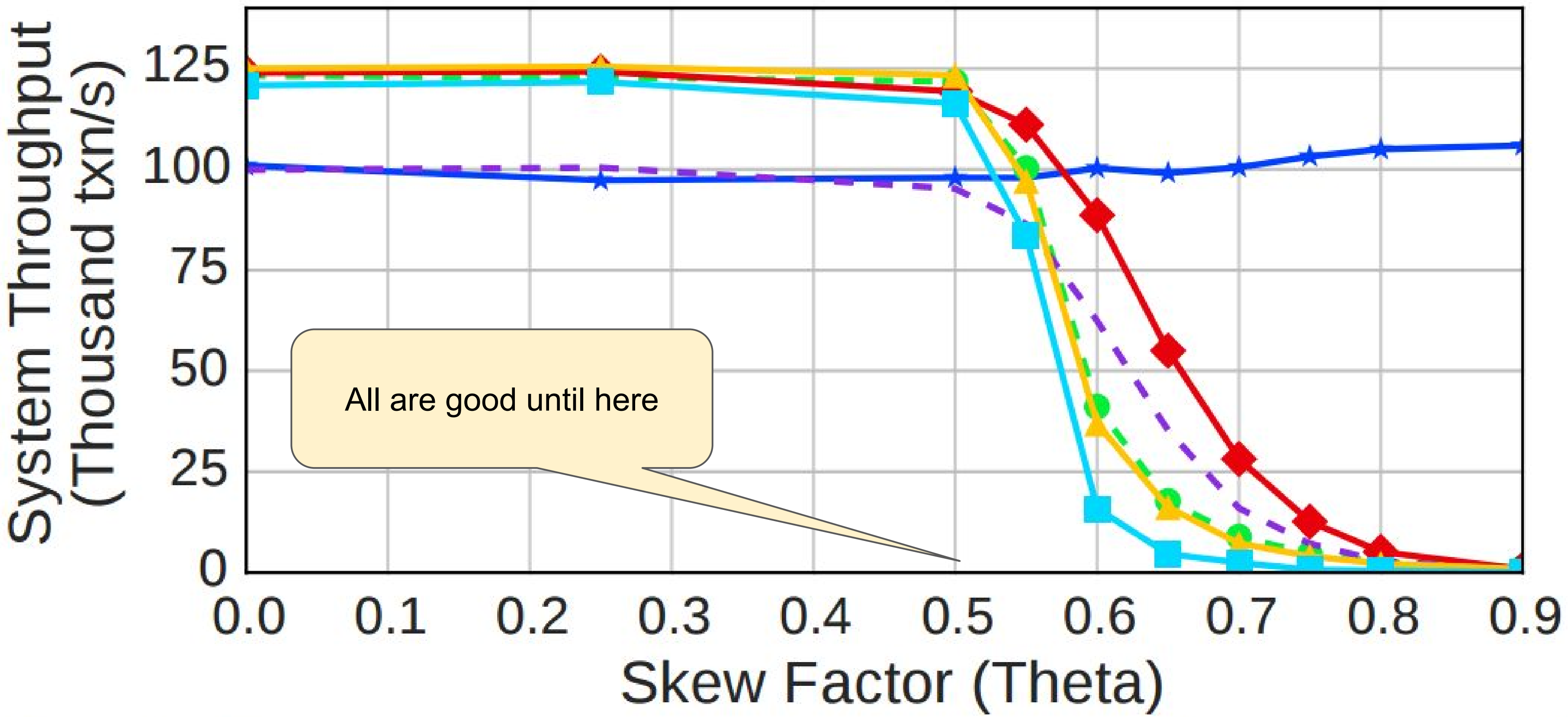


Figure 2: Contention – The measured throughput of the protocols on 16 servers when varying the skew factor in the YCSB workload.



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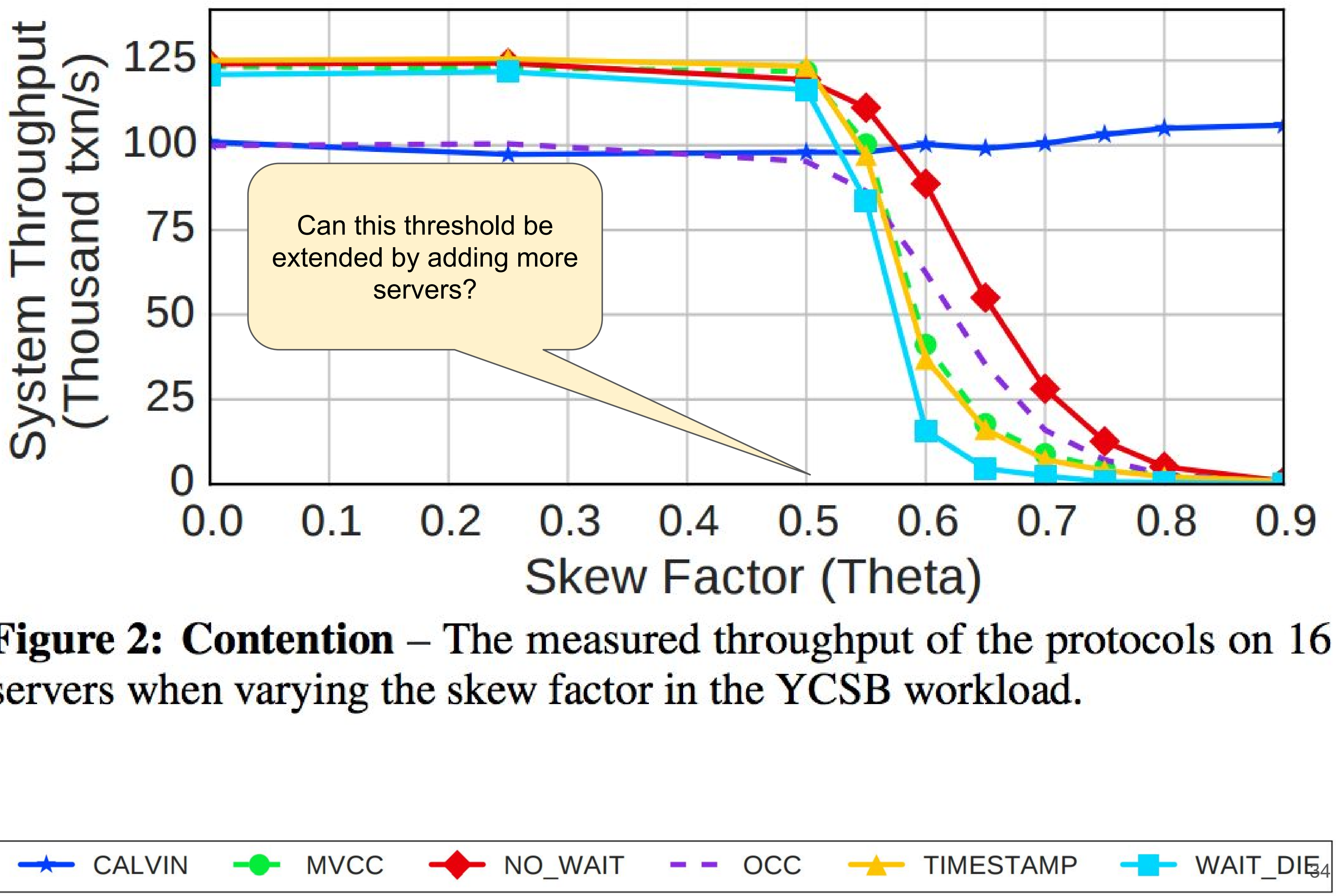

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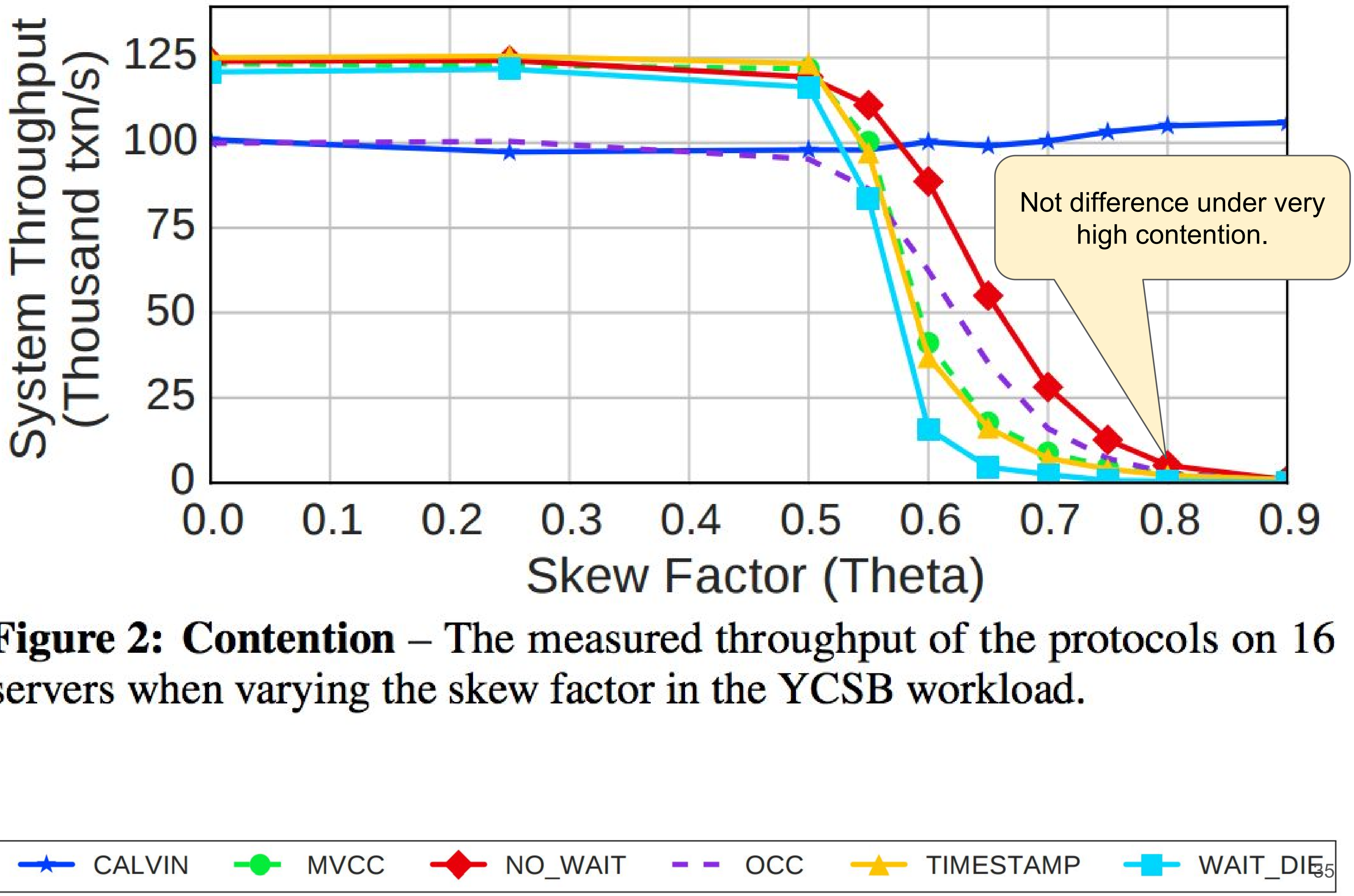

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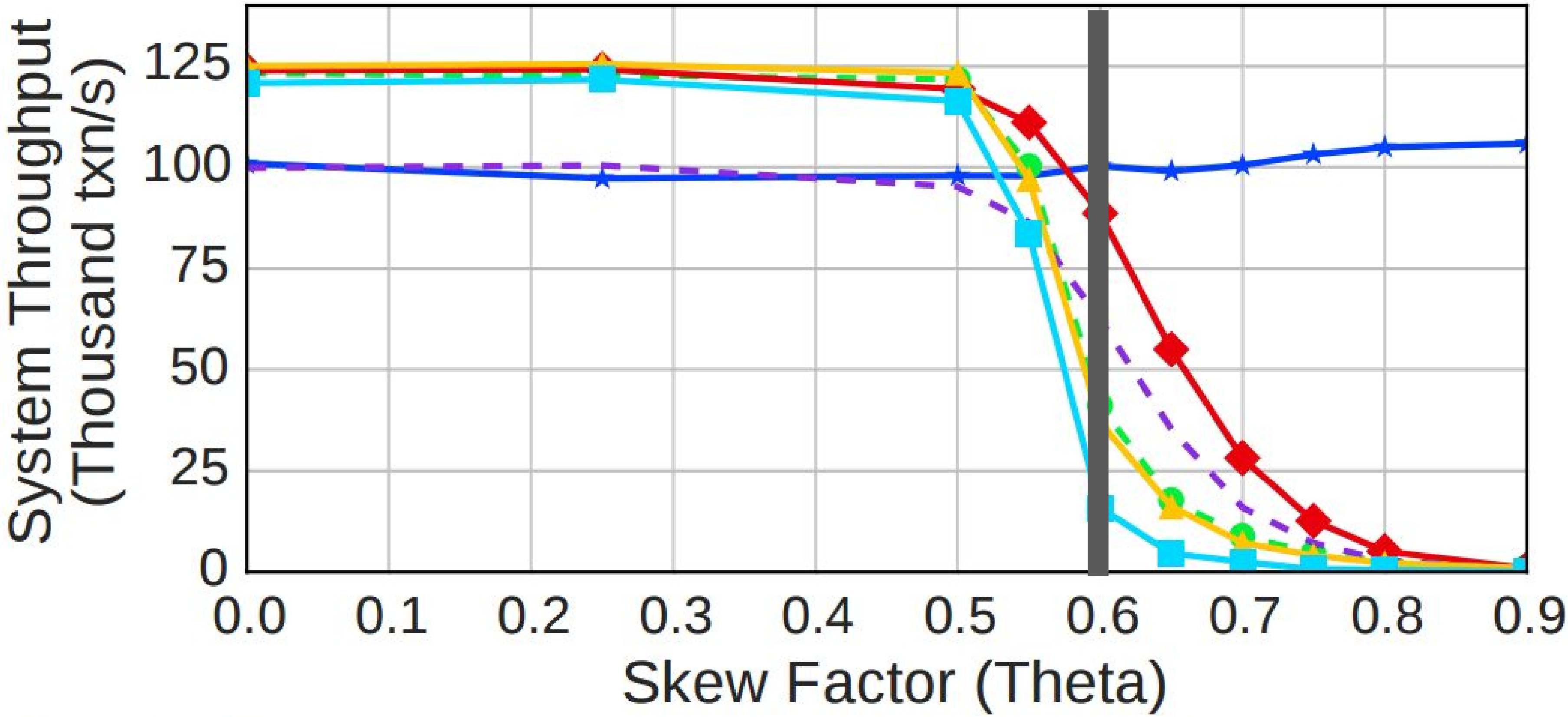

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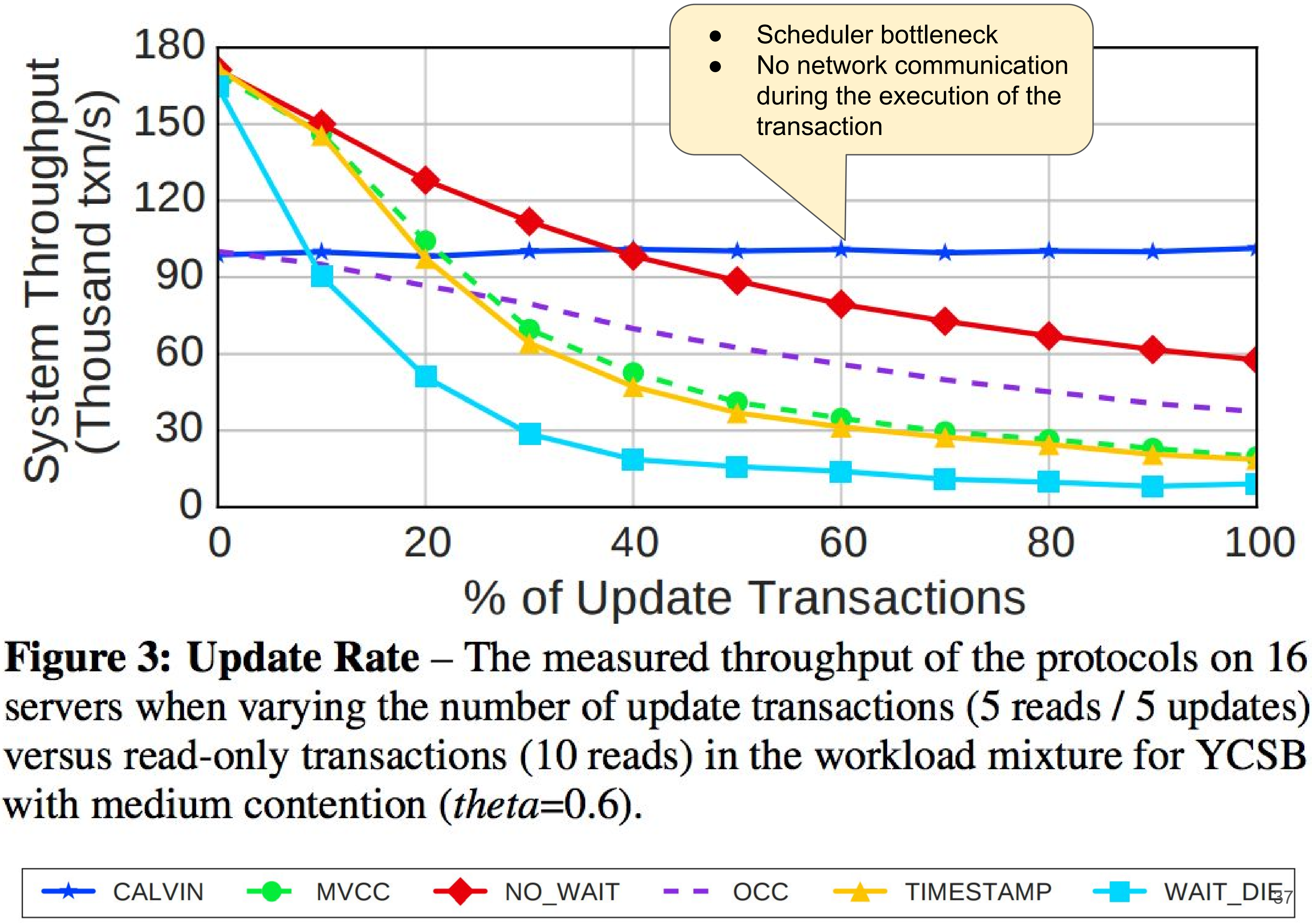


Figure 3: Update Rate – The measured throughput of the protocols on 16 servers when varying the number of update transactions (5 reads / 5 updates) versus read-only transactions (10 reads) in the workload mixture for YCSB with medium contention (*theta*=0.6).

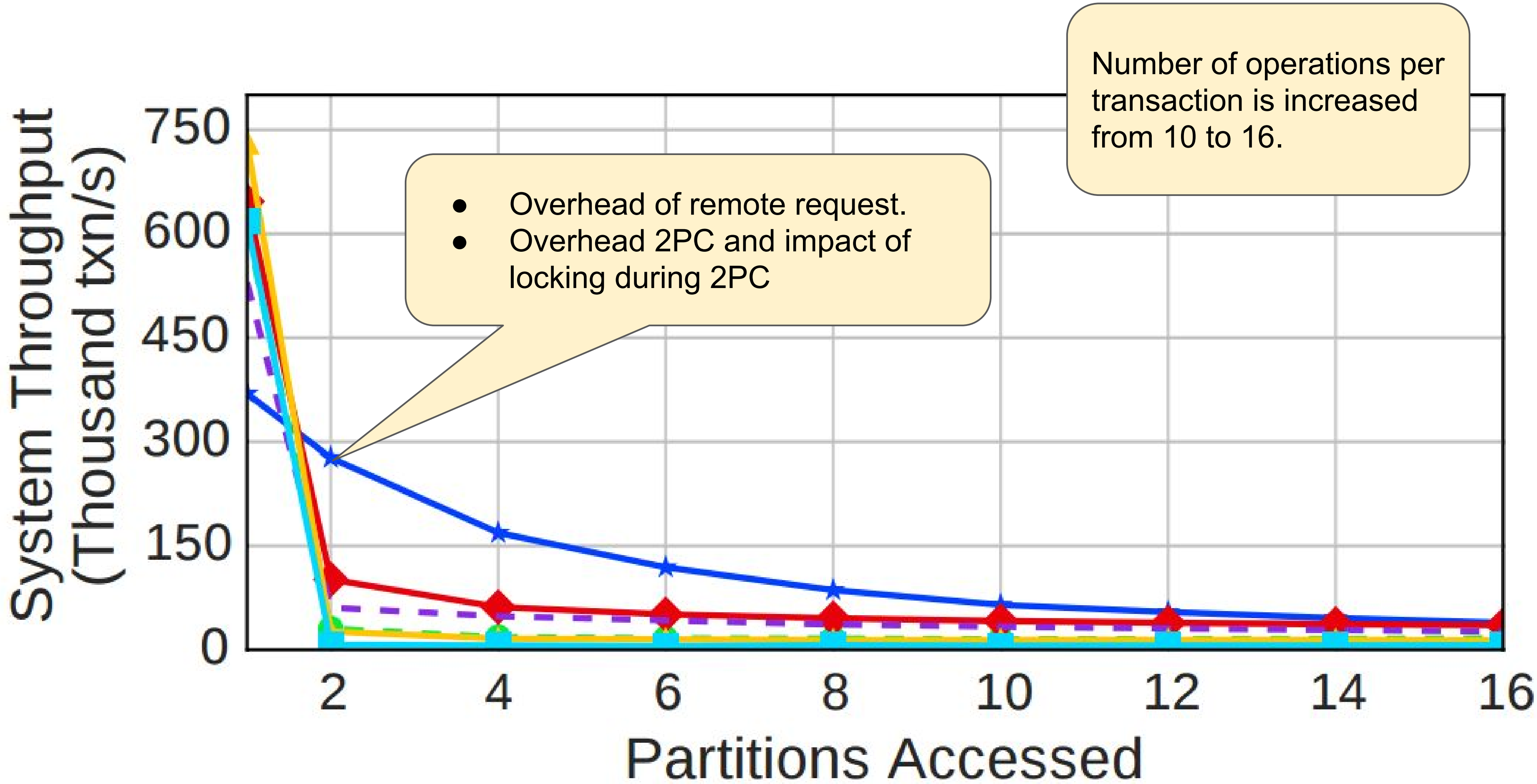
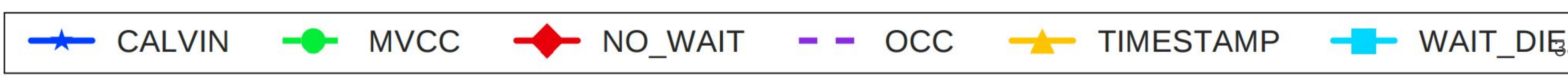


Figure 4: Multi-Partition Transactions – Throughput with a varying number of partitions accessed by each YCSB transaction.



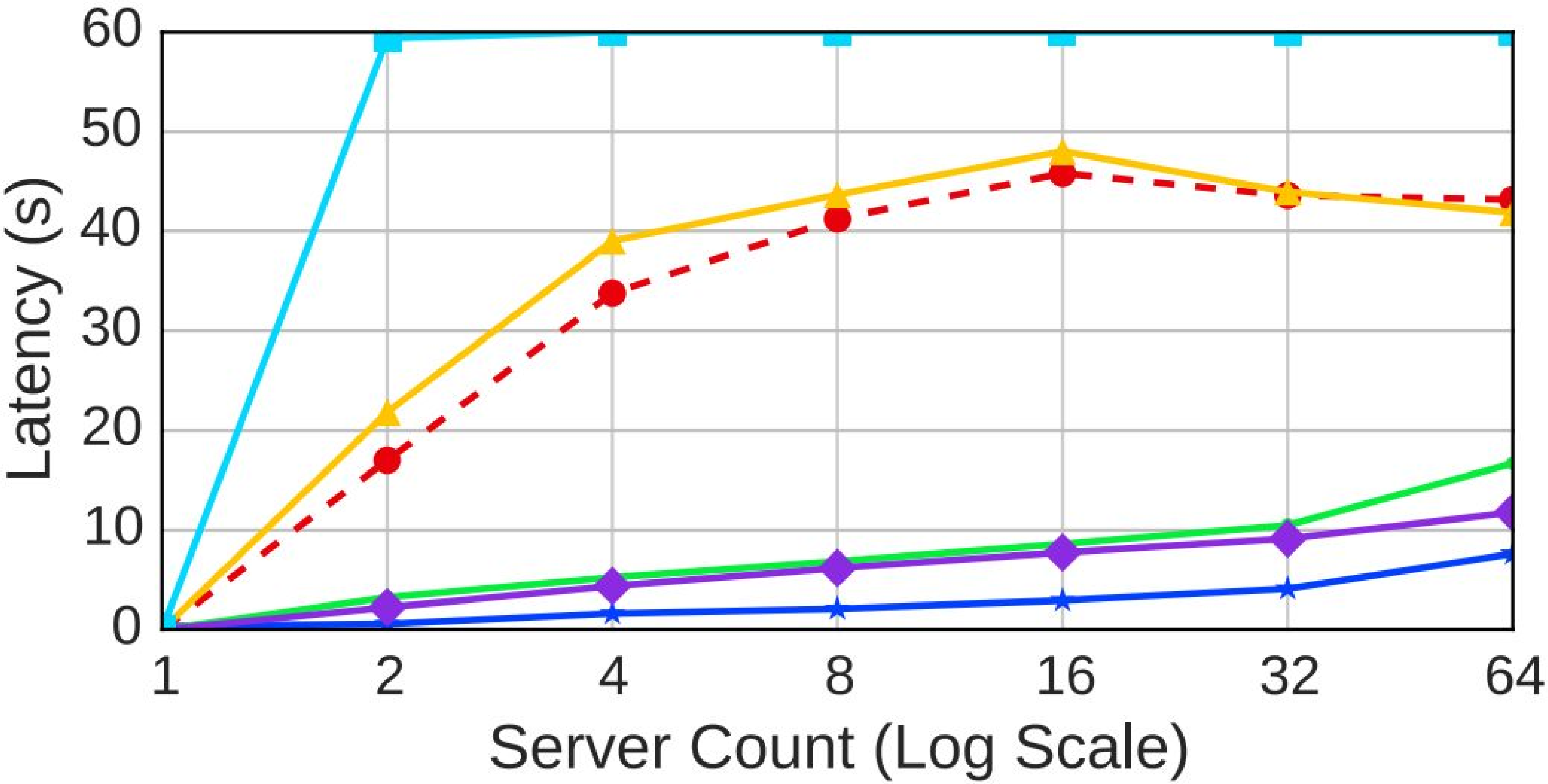
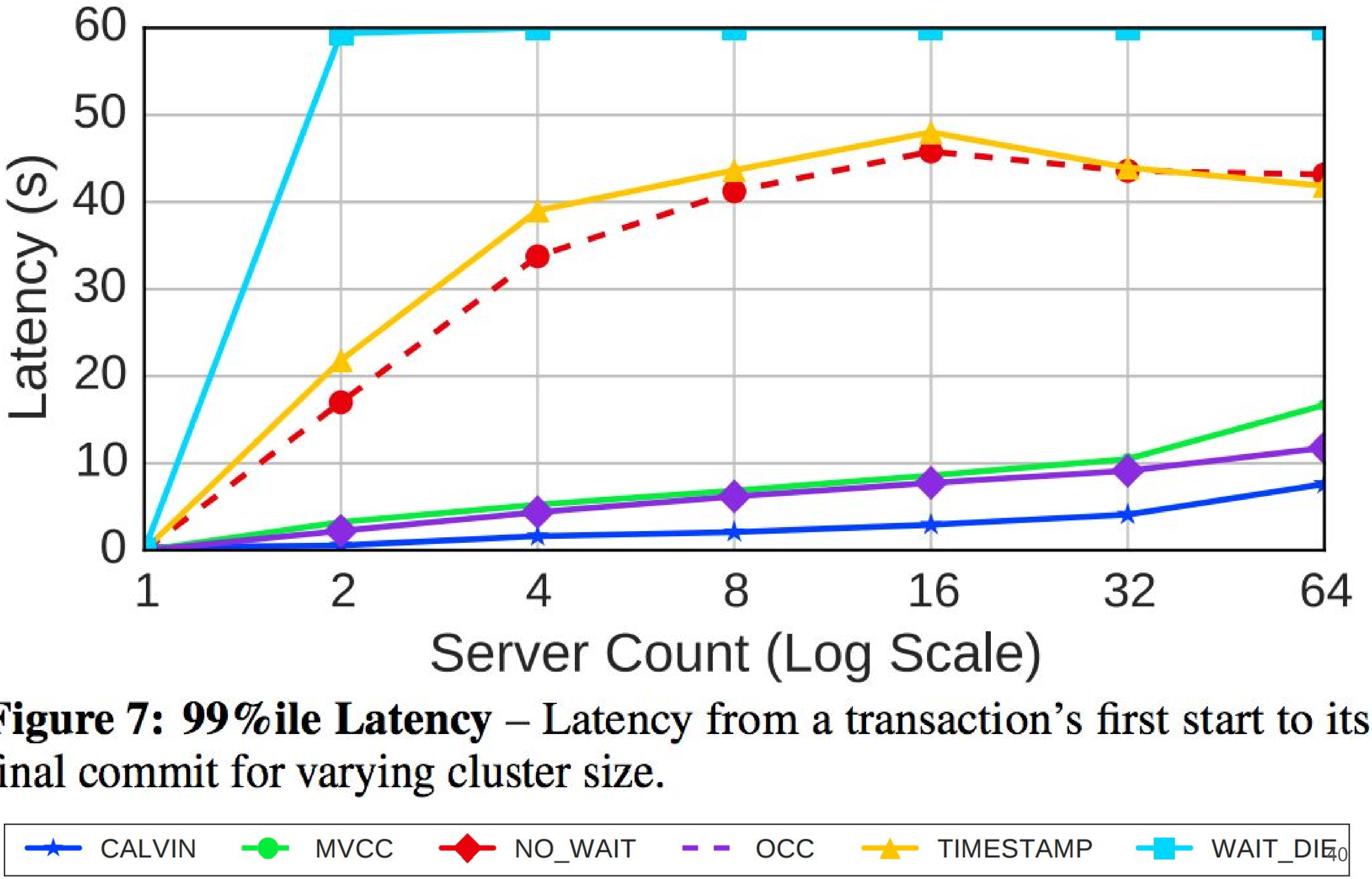


Figure 7: 99%ile Latency – Latency from a transaction's first start to its final commit for varying cluster size.



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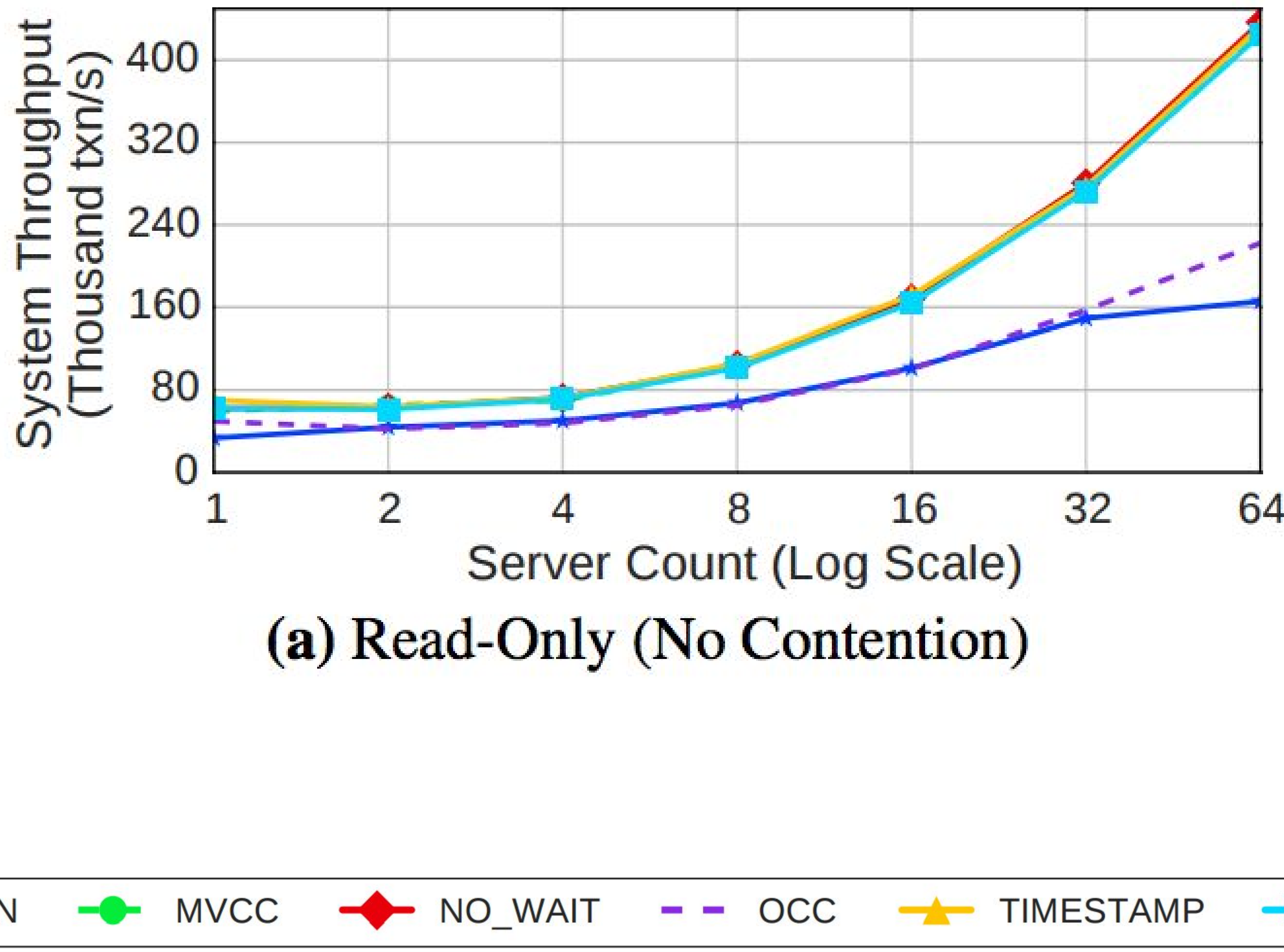
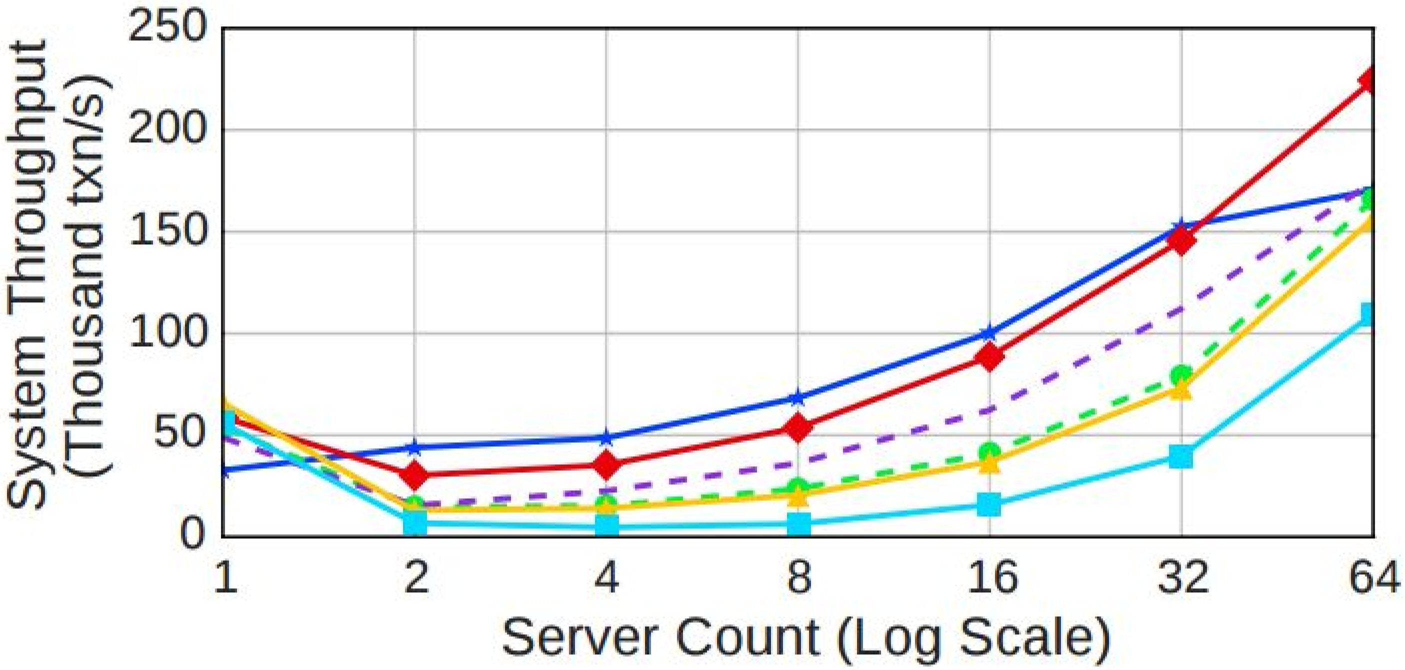
Scalability (no contention)



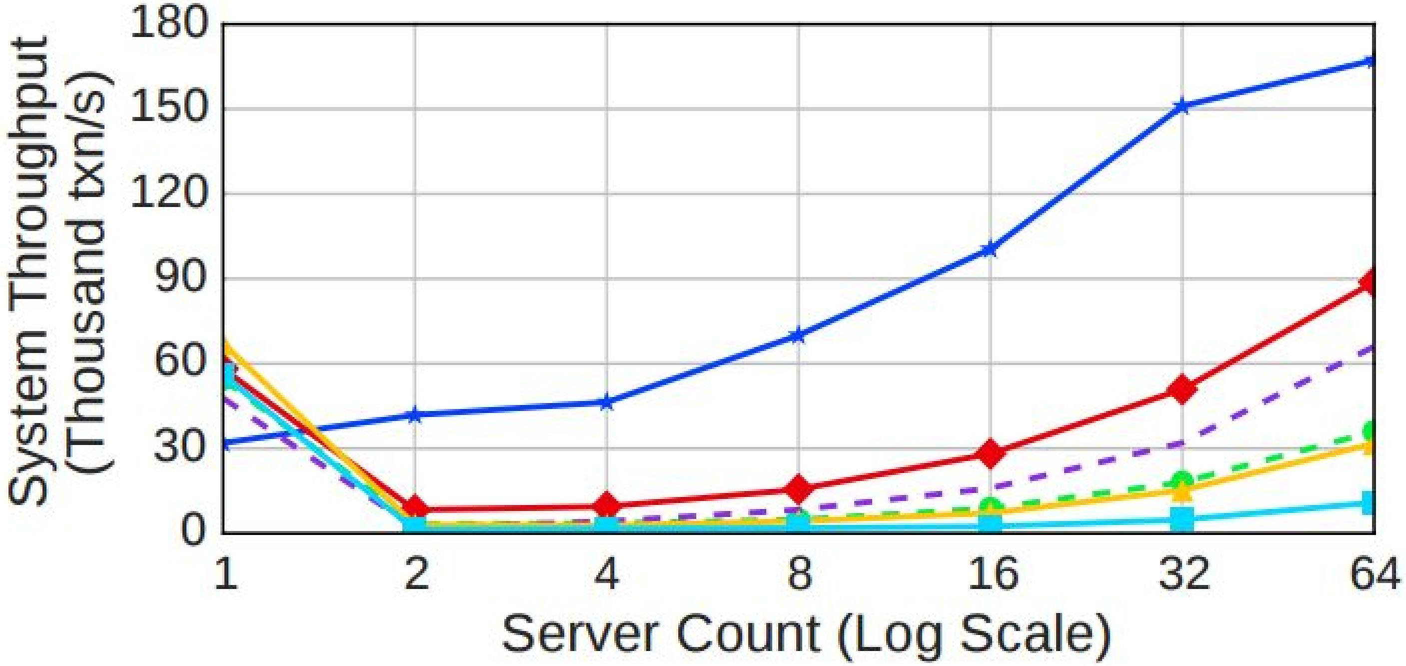
(a) Read-Only (No Contention)

Scalability (medium contention)



(b) Read-Write (Medium Contention)

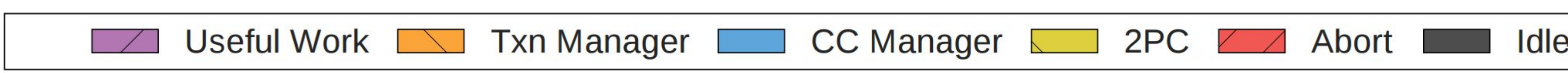
Scalability (high contention)



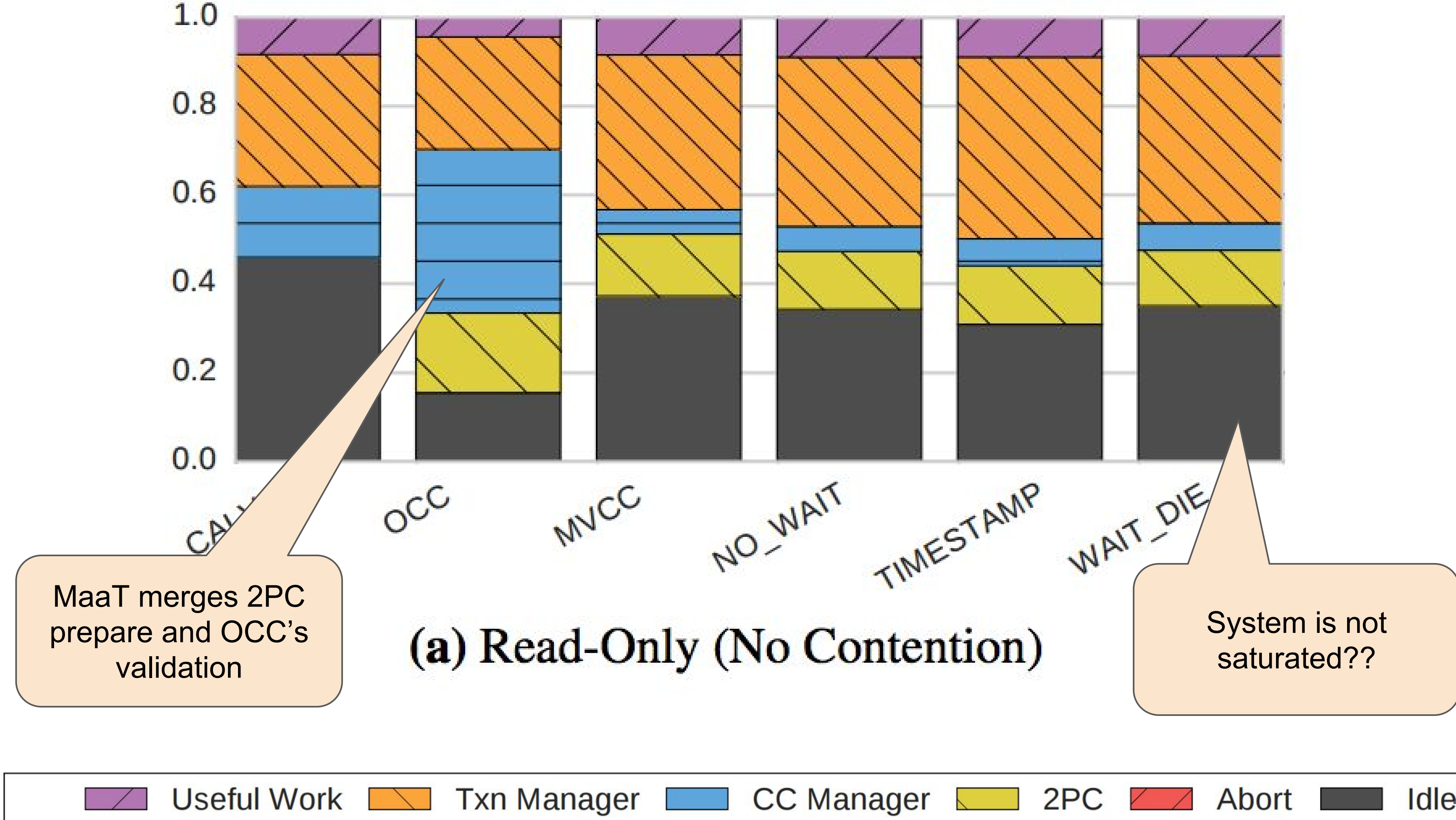
(c) Read-Write (High contention)

Scalability (Breakdown)

- **USEFUL WORK**: All time that the workers spend doing computation on behalf of read or update operations.
- **TXN MANAGER**: The time spent updating transaction metadata and cleaning up committed transactions.
- **CC MANAGER**: The time spent acquiring locks or validating as part of the protocol. For CALVIN, this includes time spent by the sequencer and scheduler to compute execution orders.
- **2PC**: The overhead from two-phase commit.
- **ABORT**: The time spent cleaning up aborted transactions.
- **IDLE**: The time worker threads spend waiting for work.



Scalability (Breakdown - no contention)



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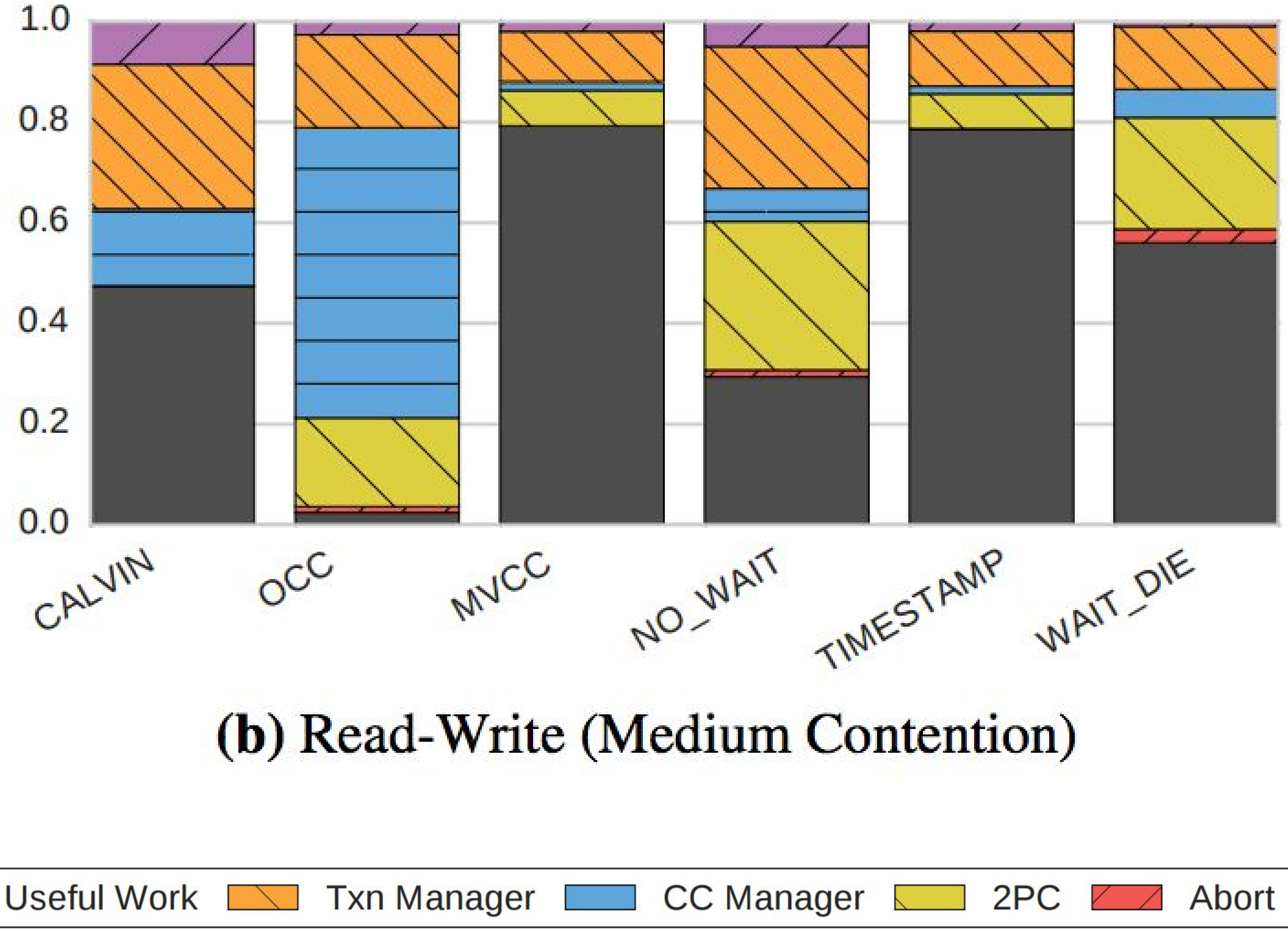

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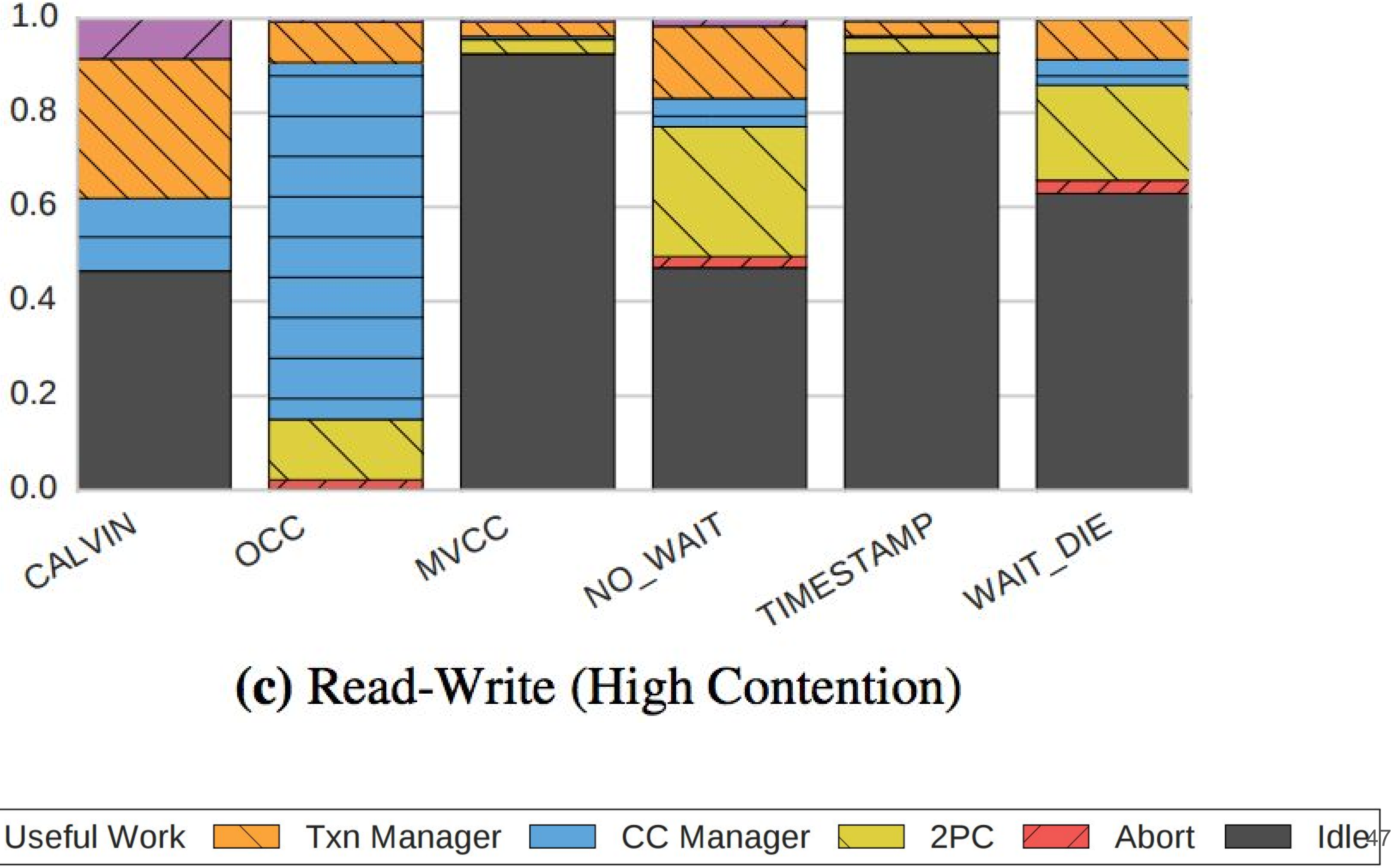


(c) Read-Write (High Contention)

Latency breakdown

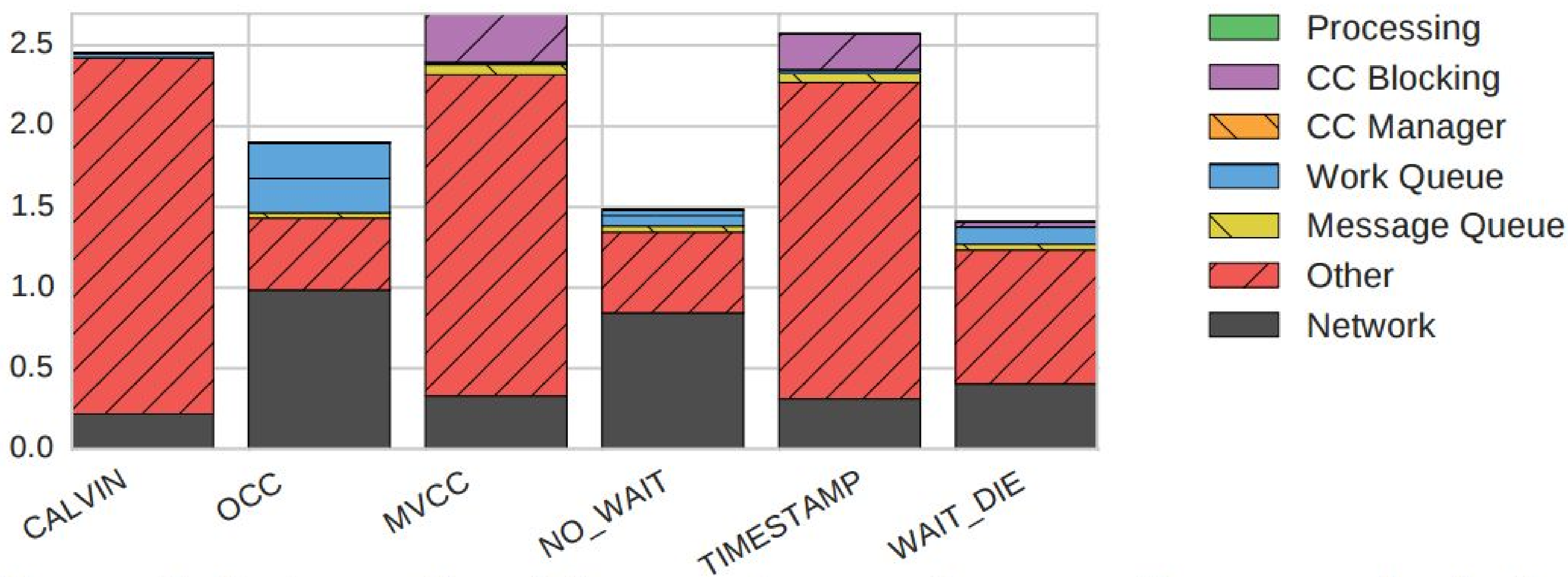


Figure 8: Latency Breakdown – Average latency of a transaction's final execution before commit.

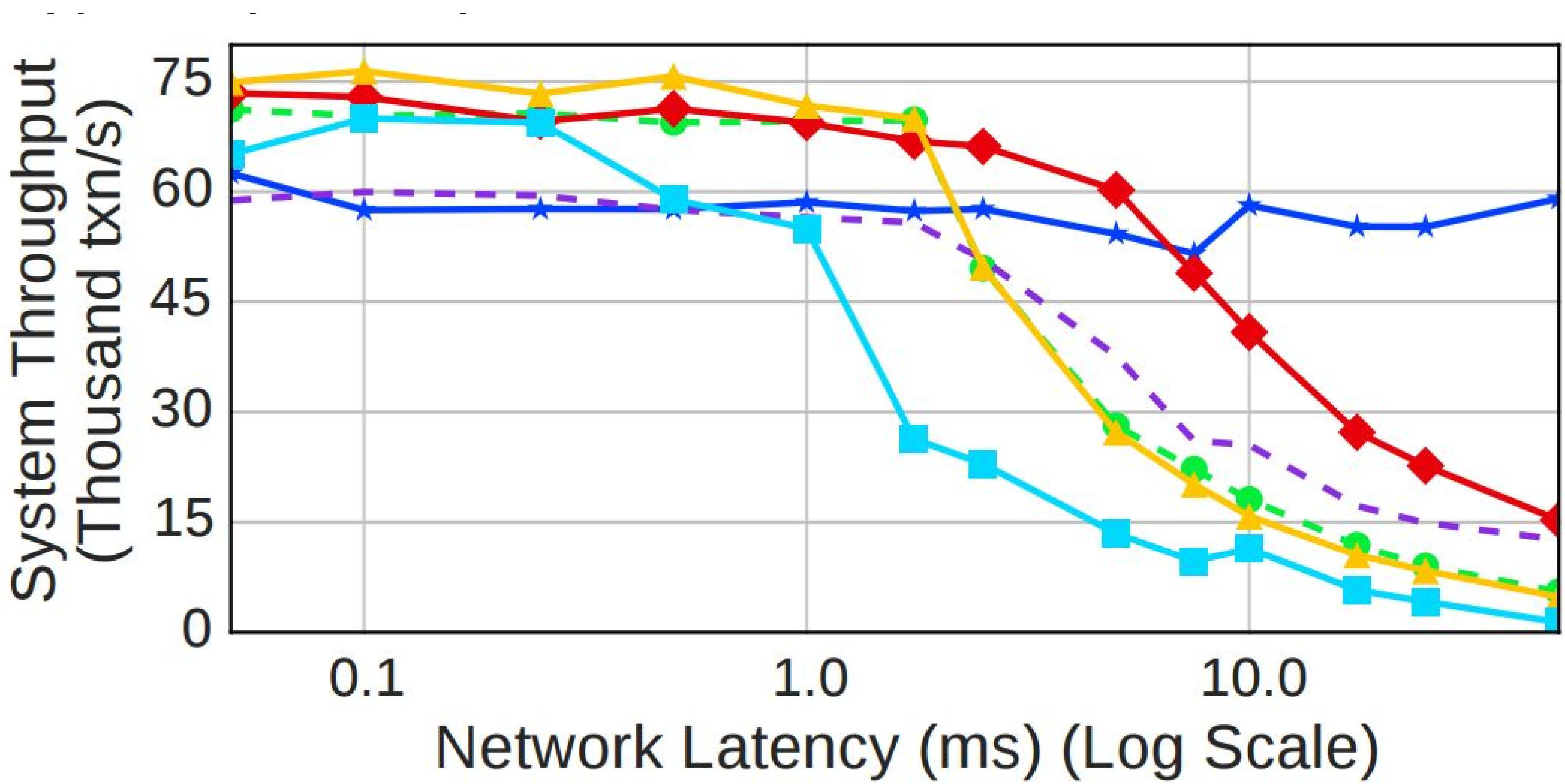


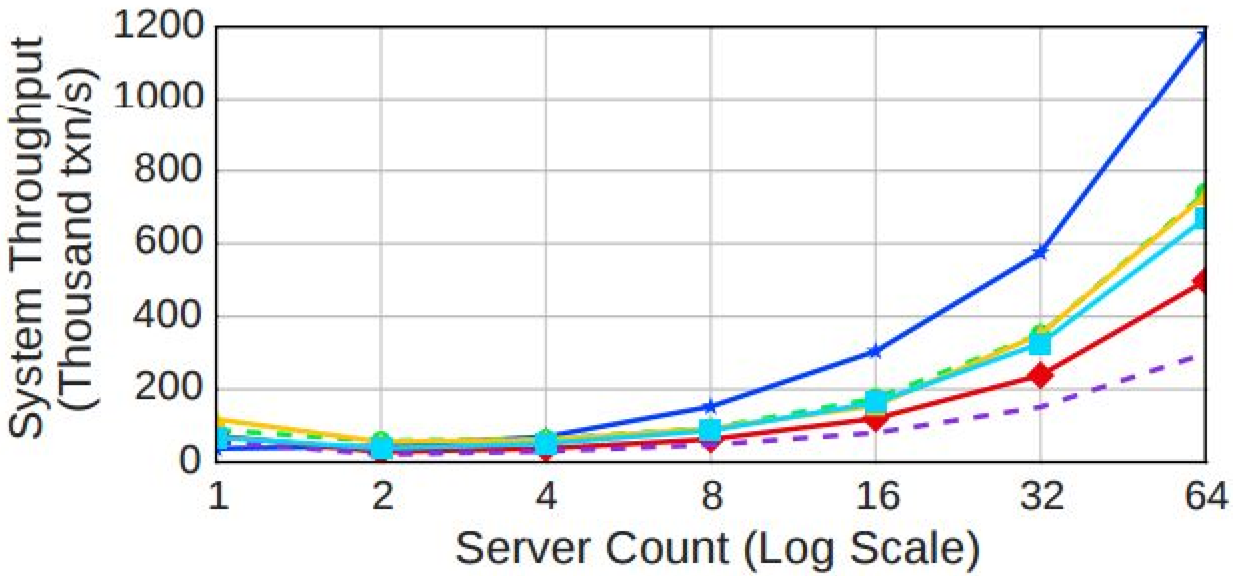
Figure 9: Network Speed – The sustained throughput measured for the concurrency protocols for YCSB with artificial network delays.

Table 2: Multi-Region Cluster – Throughput of a 2-node cluster with servers in AWS US East and US West regions.

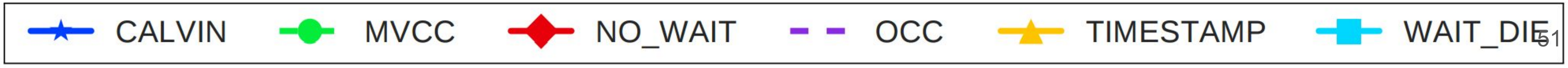
Algorithm	CALVIN	OCC	MVCC
Throughput	8,412	11,572	5,486

Algorithm	NO_WAIT	TIMESTAMP	WAIT_DIE
Throughput	15,921	4,635	4,736

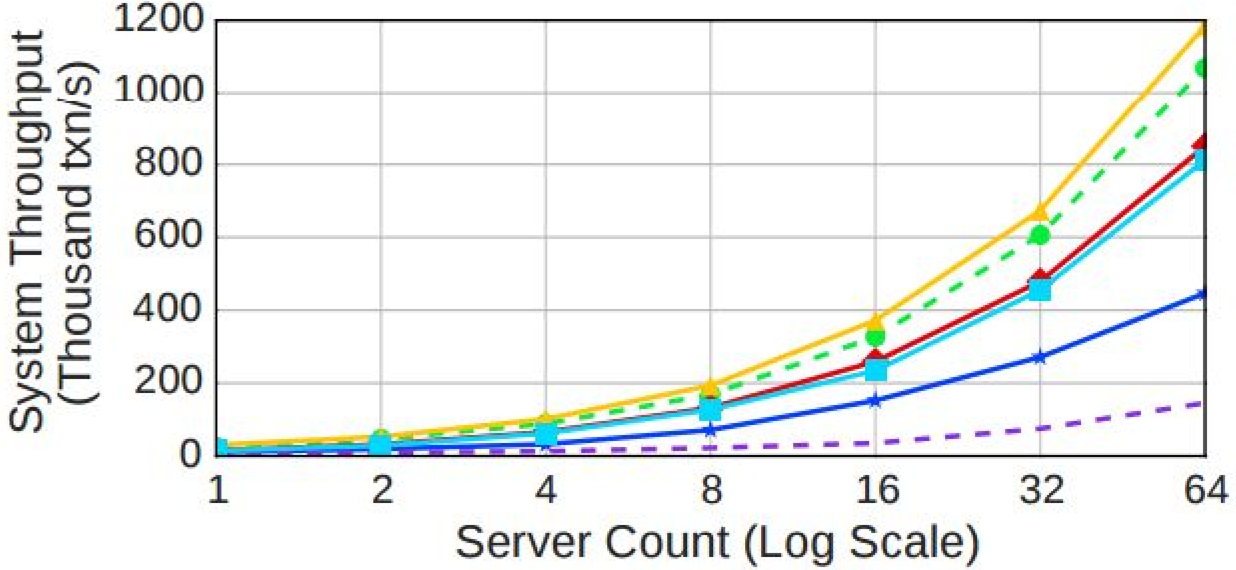
Scalability - TPCC - Payment transaction



(a) Payment Transaction



Scalability - TPCC - NewOrder transaction



(b) NewOrder Transaction

Data dependant aborts

- YCSB operation are independent
- Modified YCSB transction to have conditional abort based a value read.
- 36% decrease in performance compared to 2%-10% descease on other protocols.
    - theta=0.6 , 50% updates
- CALVIN performs worse with higher contention (drops 73K to 19K txn/s)

Results Summary

Class	Algorithm	2PC delay	MPT	Low Contention	High Contention
Locking	NO_WAIT, WAIT_DIE	B	B	A	B
Timestamp	TIMESTAMP, MVCC	B	B	A	B
Optimistic	OCC	B	B	B	A
Deterministic	CALVIN	NA	B	B	A

Bottlenecks in DDBMS

- According to the paper, it boils down to the following bottlenecks:
- 2PC delay
  - CALVIN is designed to eliminate that but in case a transaction will need to abort. It needs to pay the cost of broadcasting the abort decision
- Data access contention
  - Read-only contention can be trivially solved by replication
  - Write contention is difficult

Further research and additional potential solutions

- Authors mentions many aspects for future research and solutions:
  - Impact of recovery mechanisms
  - Leverage better network technologies (e.g. RDMA)
  - Automatic repartitioning [Schism, H-Store]
  - Force a data model adaptation on application developers
    - (e.g. entity group- Helland CIDR'07, G-Store)
  - Semantic based concurrency control methods

- Is there a way to generalize CC protocols into a framework that admits different configurations and yield different CC protocols implementation?
  - e.g. Similar to GiST generalizes search tree for indexes, and SP-GiST generalizes space-partitioning trees.

- Contention-aware adaptive concurrency control
  - 2PL or Timestamp under low contention and switch to OCC or CALVIN under high contention

- Evaluating abort rate