Analyzing the Impact of System Architecture on the Scalability of OLTP Engines for High-Contention Workloads

by R. Appuswamy, A. Anadiotis, D. Porobic, M. Iman, A. Ailamaki

Max Gilbert

m_gilbert13@cs.uni-kl.de

Lehrgebiet Informationssysteme

Technische Universität Kaiserslautern

July 16, 2018

Section 1

Introduction

Requirements for a DBMS

- Reliability
  - ACID Transactions
  - high availability
  - etc.
- Functionality
  - simple to use programming model
  - simple to use API
  - etc.

Performance isn't everything, but without it, everything else is nothing.

- Performance
  - high transaction throughput
  - low latency
  - etc.

Some Implications of those Requirements

- work purely in-memory when the working set completely fits in main memory
- proper utilization of the computational resources is required
  - available CPU time (usually not the bottleneck)
  - available hardware contexts (simultaneous threads)
  - Cache Oblivious Algorithms (e.g. partitioning Hash-JOINs)
  - → Interleaved transaction execution to exploit abundant thread-level parallelism without violating the ACID properties!
  - → Interleaved operation execution to exploit intra-transaction parallelism!
- → physical & logical Synchronization

Some Implications of those Requirements

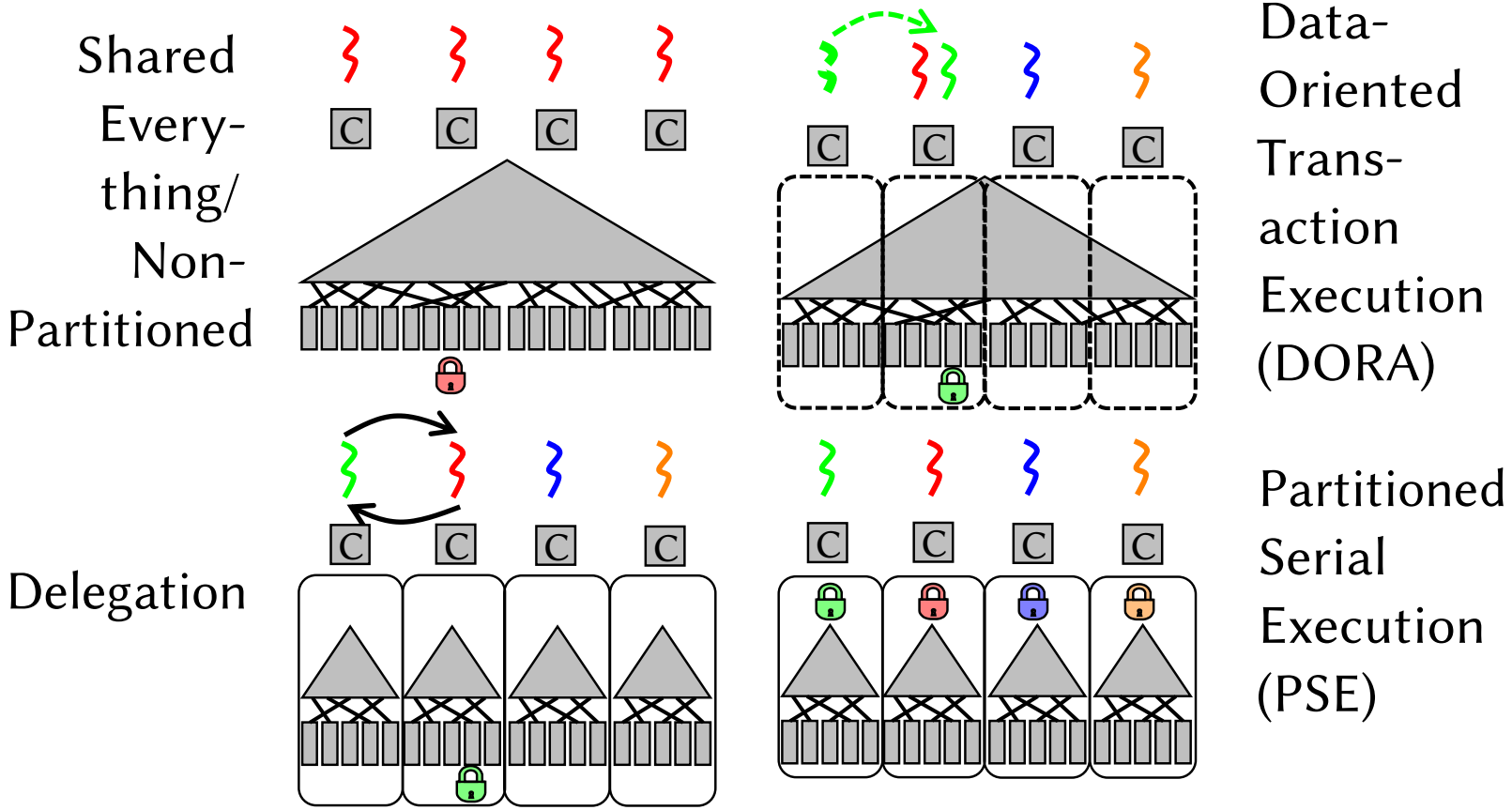
- work purely in-memory when the working set completely fits in main memory
- proper utilization of the computational resources is required
  - available CPU time (usually not the bottleneck)
  - available hardware contexts (simultaneous threads)
  - Cache Oblivious Algorithms (e.g. partitioning Hash-JOINs)
  - → Interleaved transaction execution to exploit abundant thread-level parallelism without violating the ACID properties!
  - → Interleaved operation execution to exploit intra-transaction parallelism!

→ physical & logical Synchronization

→ **Limits concurrency for high-contention workloads!**

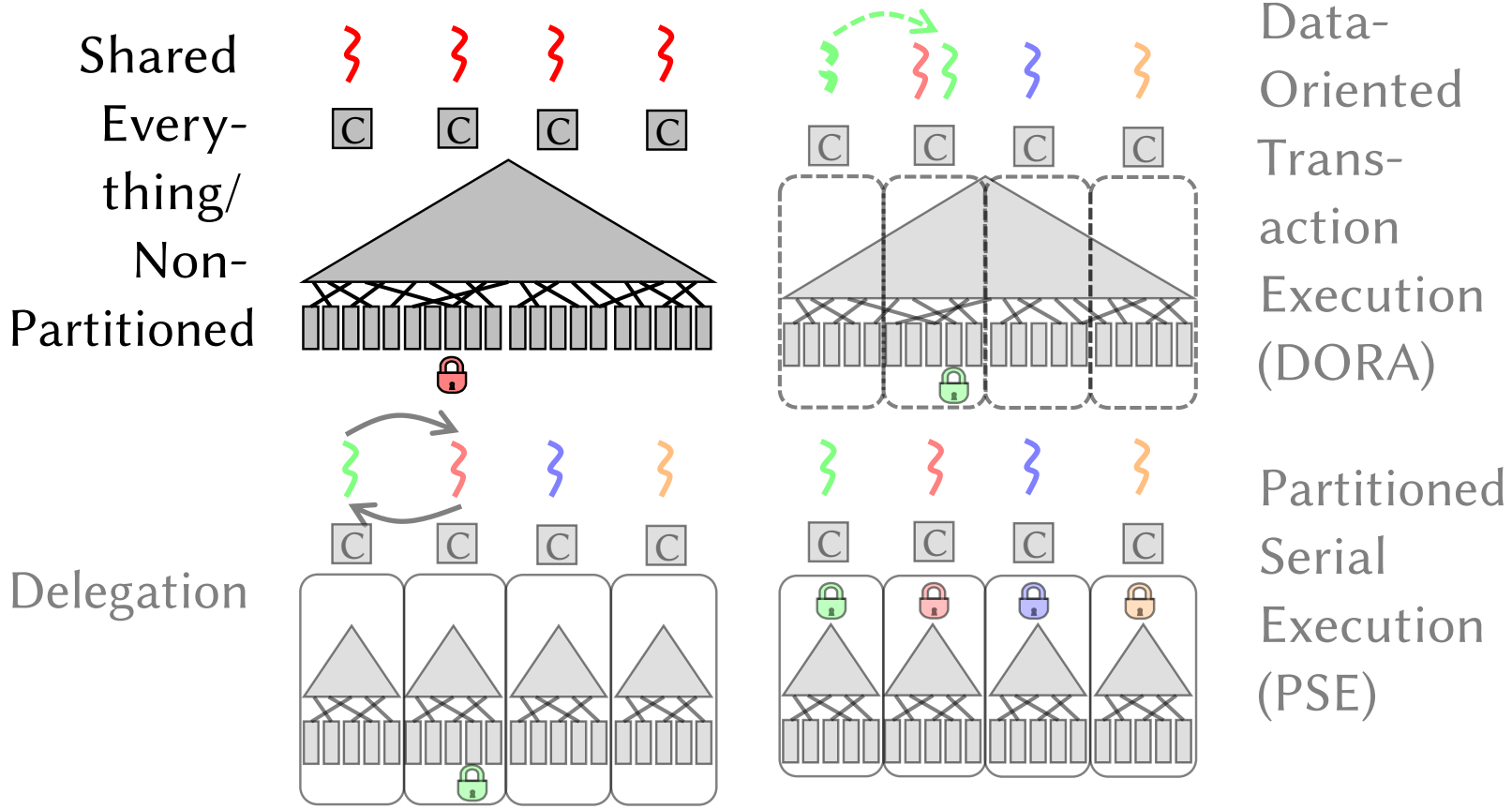
Section 2

Database Architectures



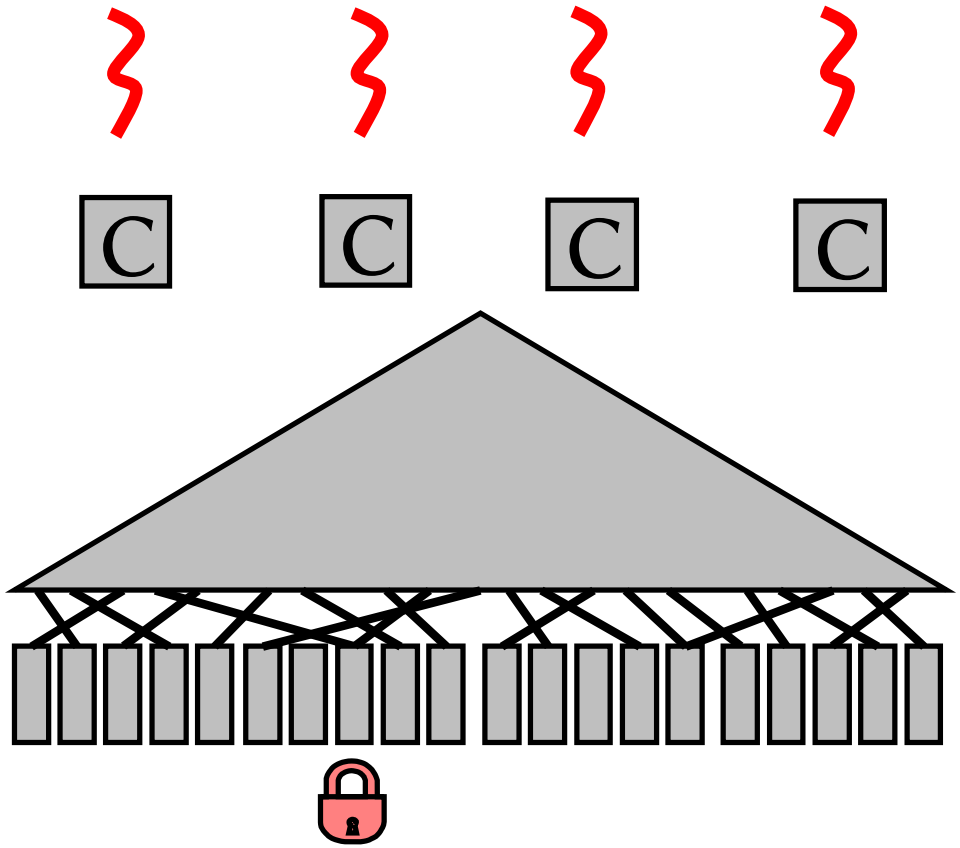
Subsection 1

Shared Everything/Non-Partitioned (SE/NP)



Subsection 1

Shared Everything/Non-Partitioned (SE/NP)



Properties of SE/NP

- metadata (incl. locks) are not partitioned

→ physical synchronization (latches, atomics) required

- data and indices are not partitioned

→ logical synchronization using a concurrency control protocol also required

- transactions completely executed by one thread
- thread-assignment depends only on load

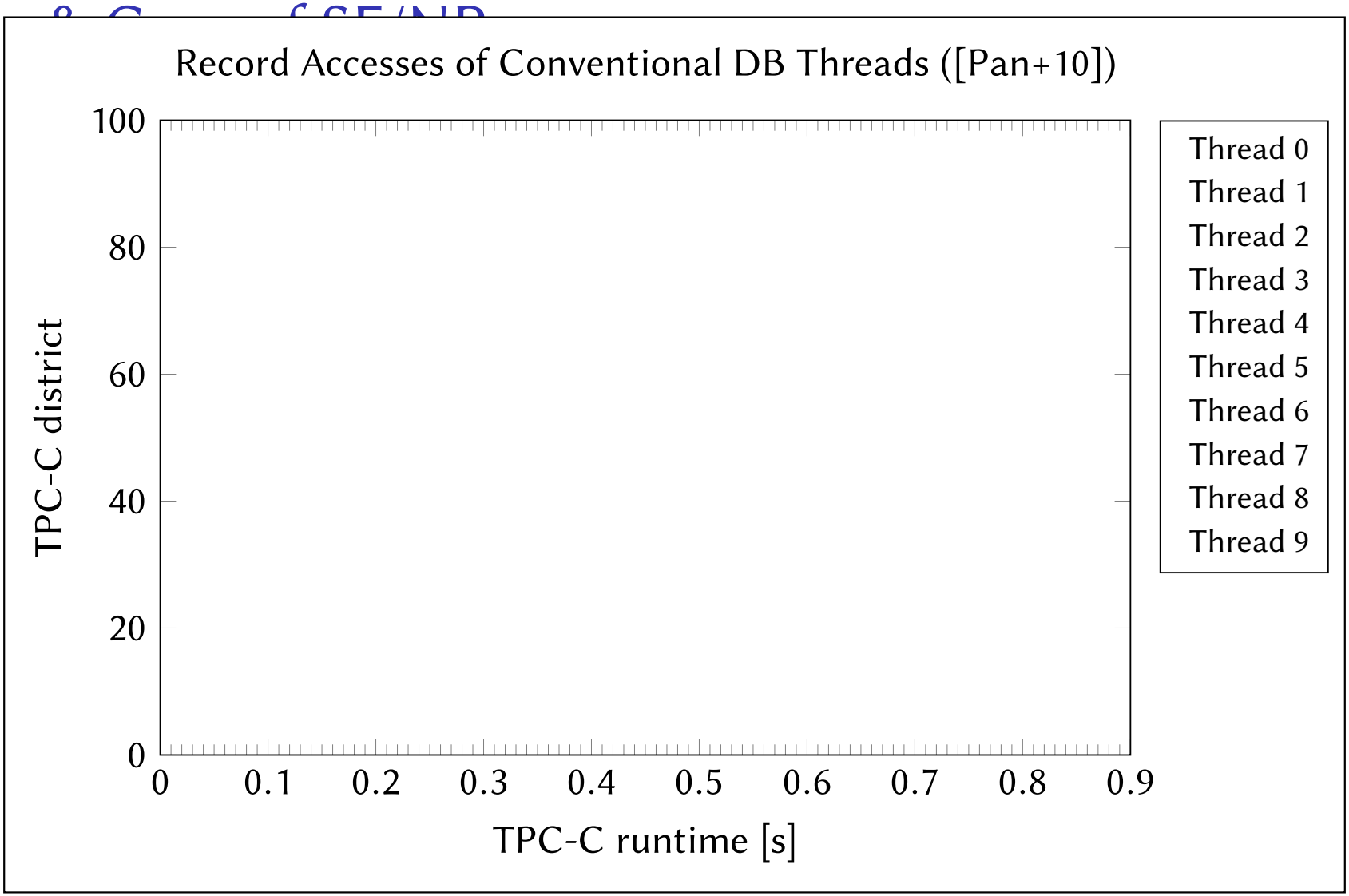
Pros & Cons of SE/NP

+ no partitioning required (e.g. manual selection of a strategy)
+ partitioning would be sensitive to the workload
+ changed workloads would require repartitioning to benefit from partitioning

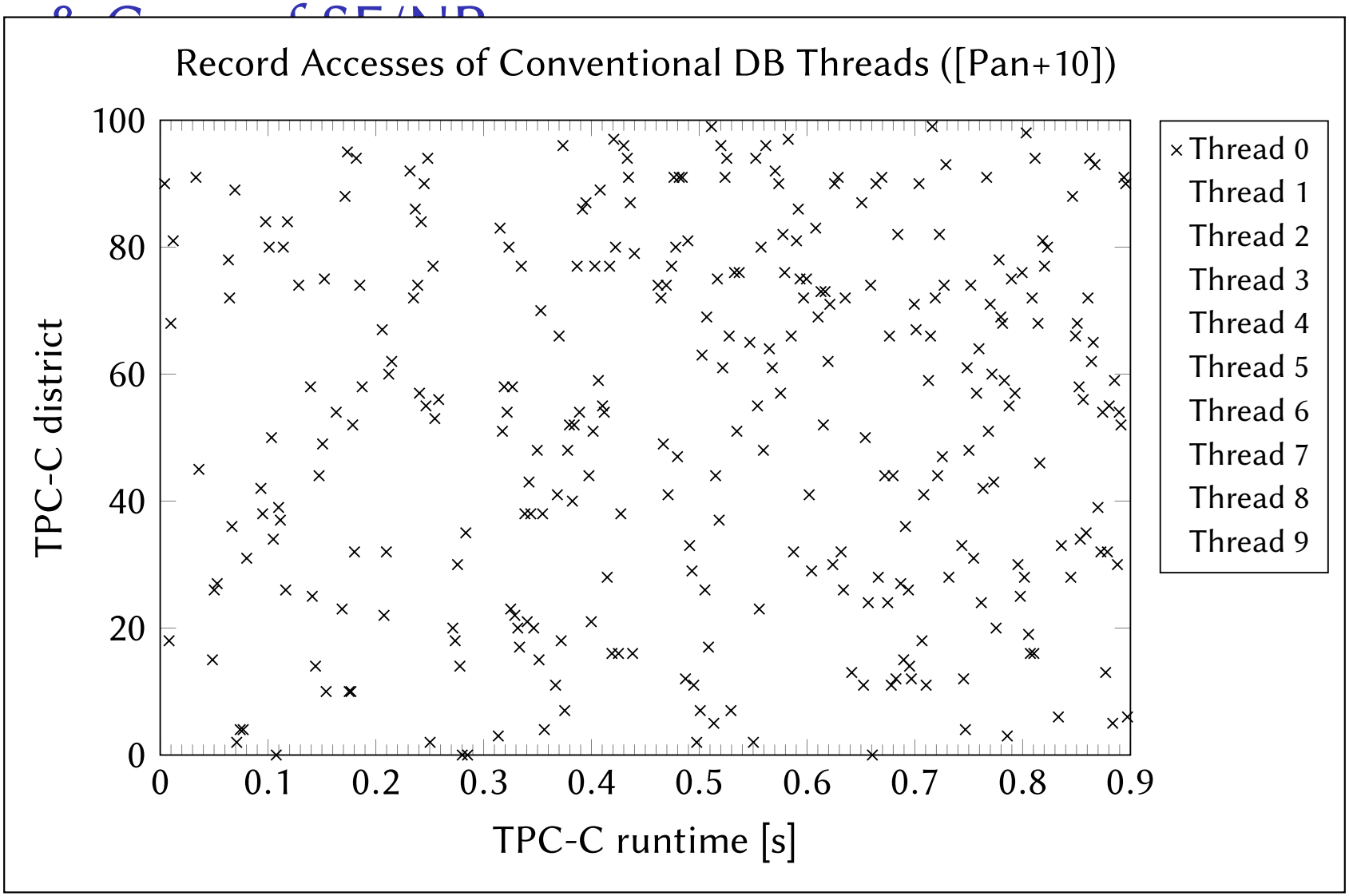
Pros & Cons of SE/NP

+ no partitioning required (e.g. manual selection of a strategy)
+ partitioning would be sensitive to the workload
+ changed workloads would require repartitioning to benefit from partitioning
– each thread might access every record at arbitrary times
  – each CPU cache may contain any part of the data
    → cache pollution
  – each CPU may access any part of the data
    → data movement between NUMA regions
  – each CPU may acquire any latch
    → data movement between NUMA regions
  – each CPU may atomically write to any semaphore
    → hardware cache coherence overhead

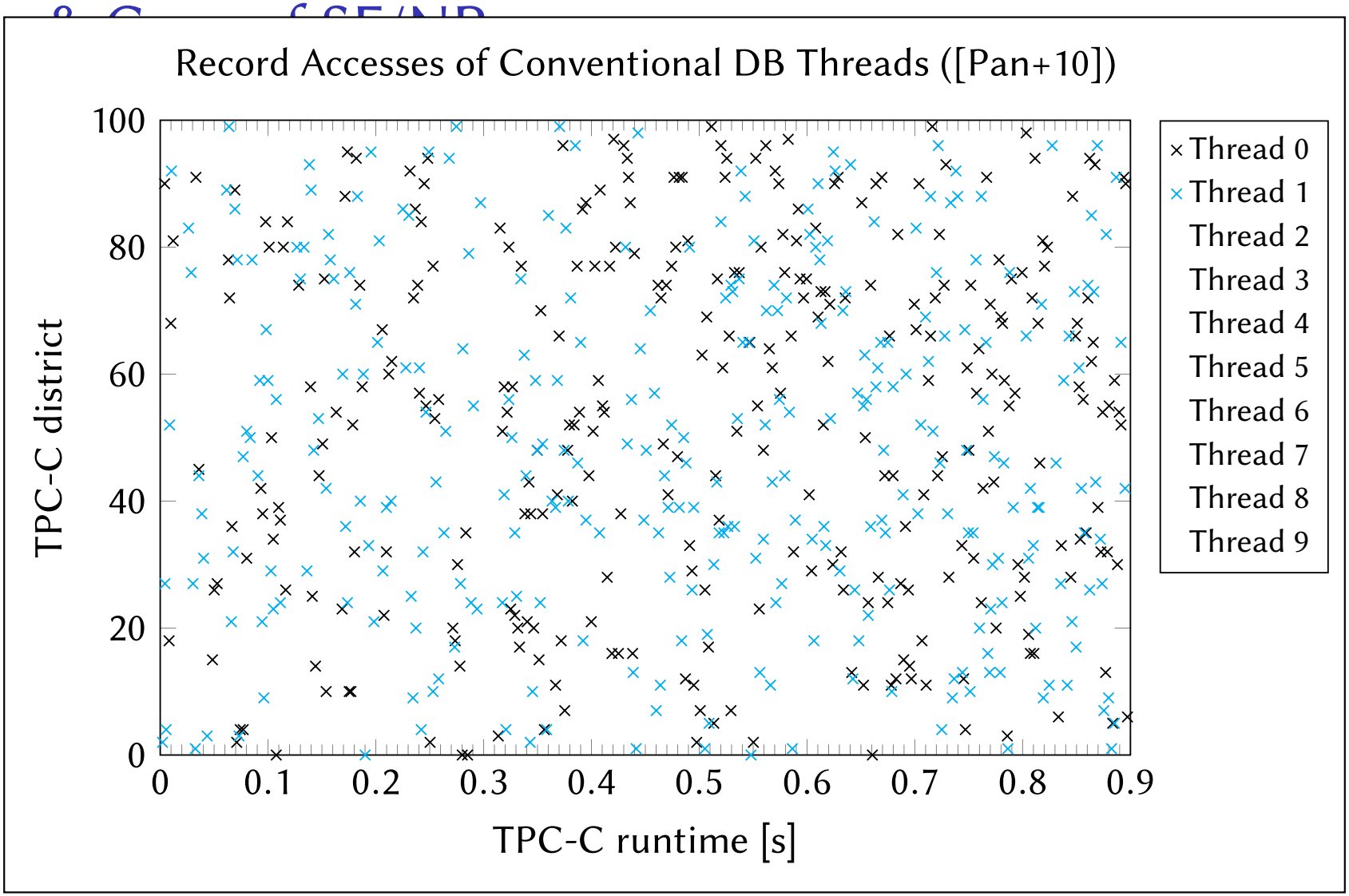
Pro & C... of SE/NP


Record Accesses of Conventional DB Threads ([Pan+10])
TPC-C district
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
TPC-C runtime [s]
Thread 0
Thread 1
Thread 2
Thread 3
Thread 4
Thread 5
Thread 6
Thread 7
Thread 8
Thread 9

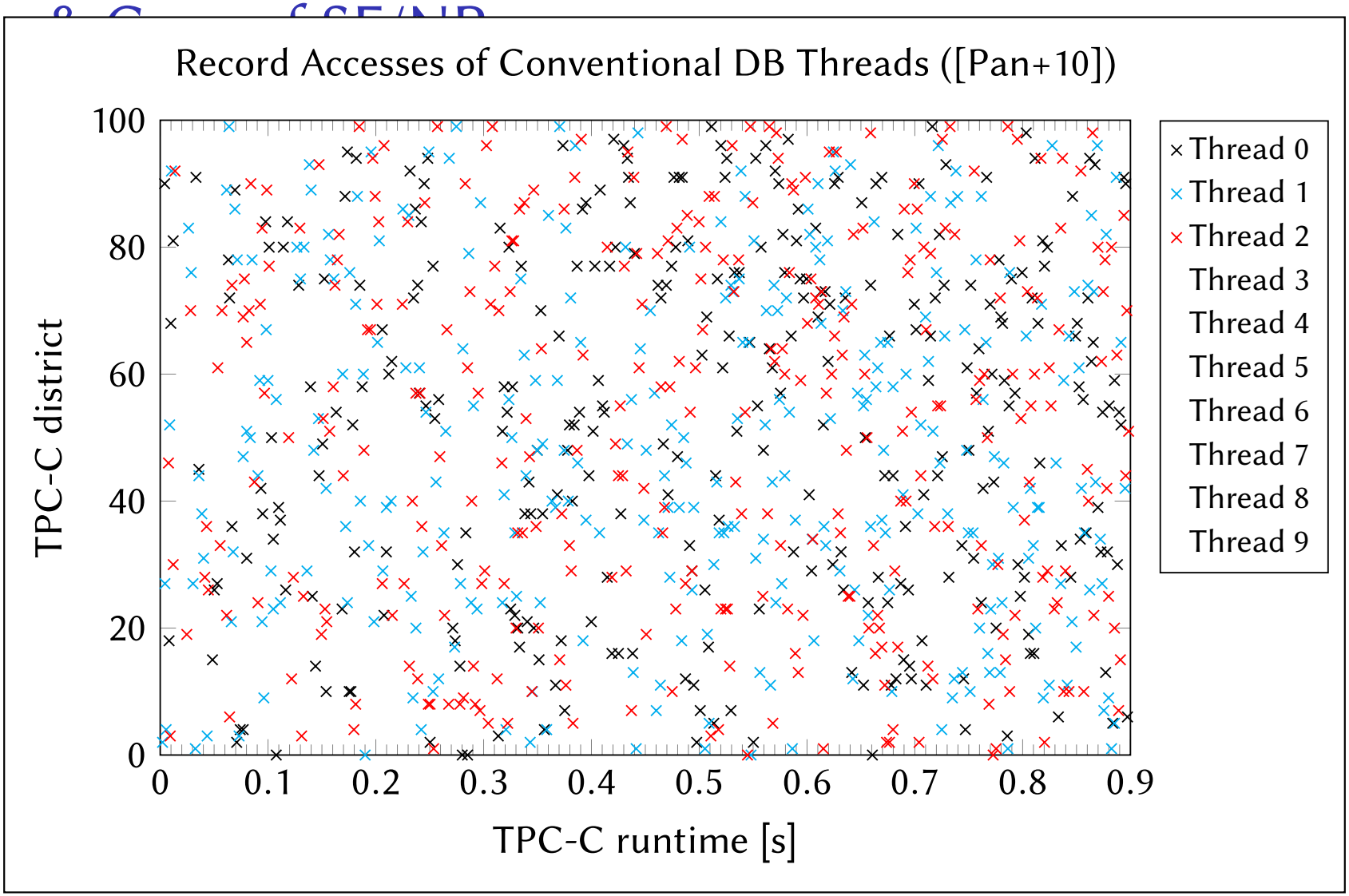
Pro & C of SE/NP


Record Accesses of Conventional DB Threads ([Pan+10])
TPC-C district
TPC-C runtime [s]
0
20
40
60
80
100
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Thread 0
Thread 1
Thread 2
Thread 3
Thread 4
Thread 5
Thread 6
Thread 7
Thread 8
Thread 9

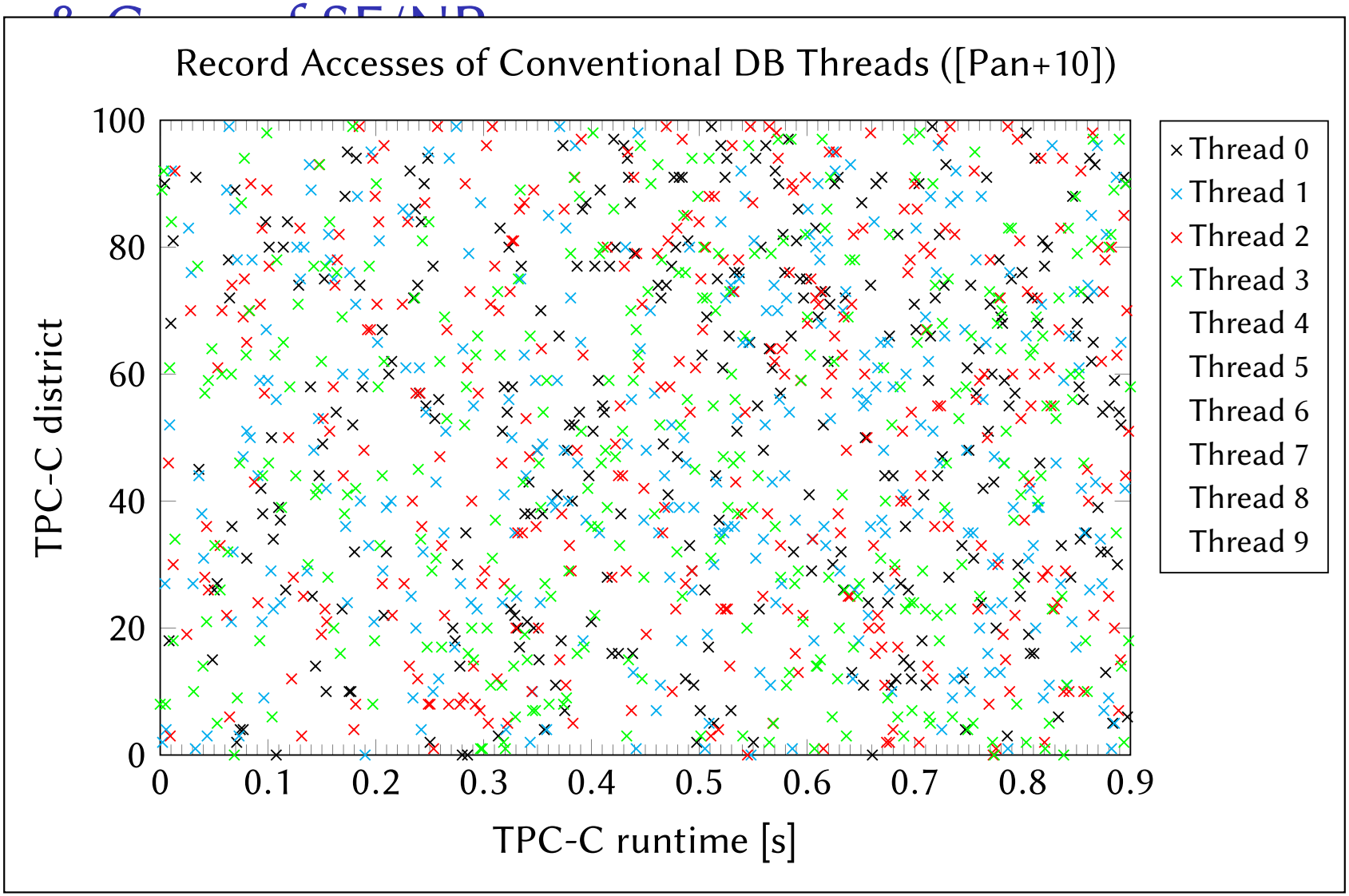
Pro & C of SE/NP


Record Accesses of Conventional DB Threads ([Pan+10])
TPC-C district
TPC-C runtime [s]
0
20
40
60
80
100
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Thread 0
Thread 1
Thread 2
Thread 3
Thread 4
Thread 5
Thread 6
Thread 7
Thread 8
Thread 9

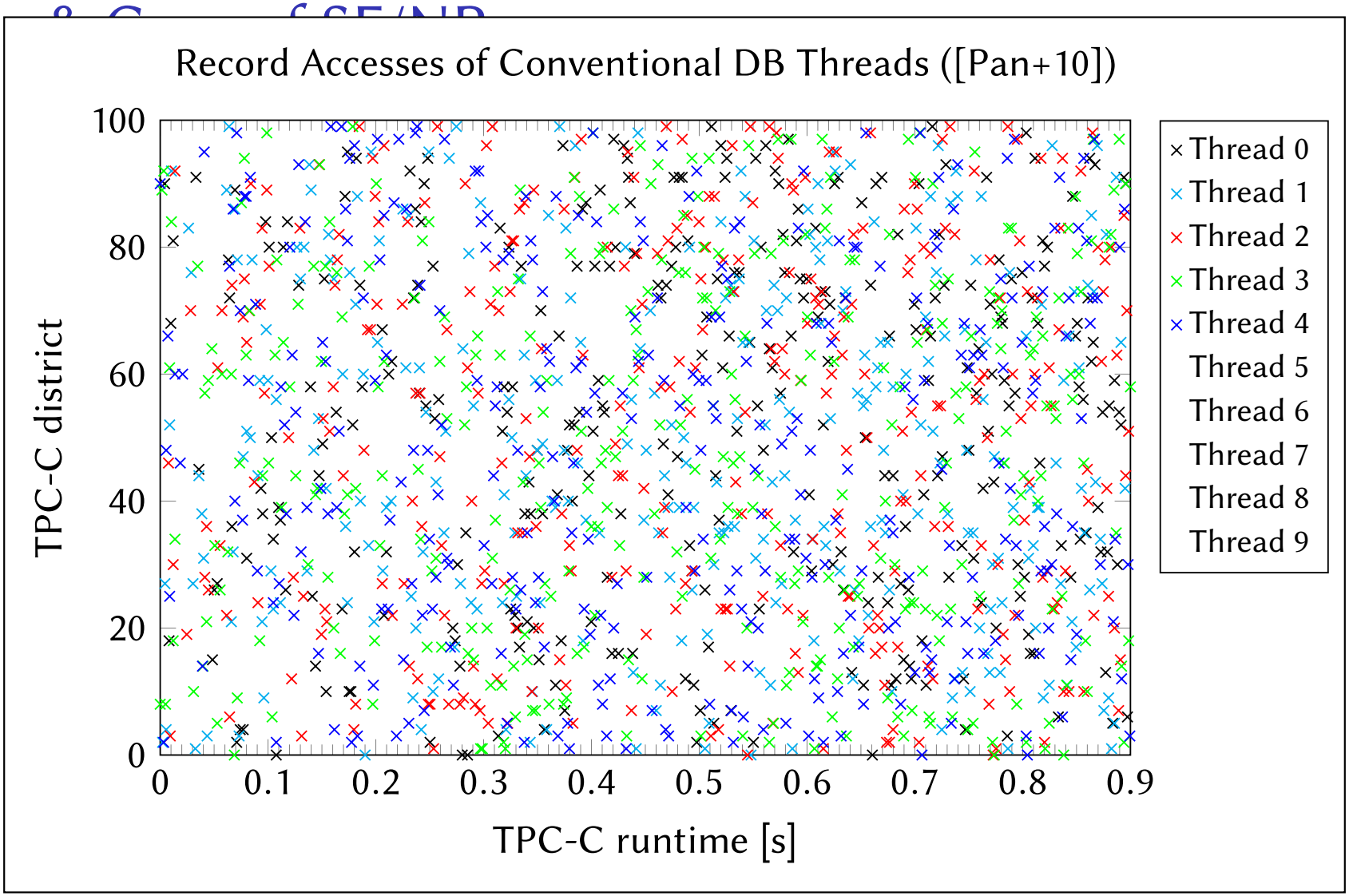
Pro & C of SE/NP


Record Accesses of Conventional DB Threads ([Pan+10])
TPC-C district
TPC-C runtime [s]
0
20
40
60
80
100
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Thread 0
Thread 1
Thread 2
Thread 3
Thread 4
Thread 5
Thread 6
Thread 7
Thread 8
Thread 9

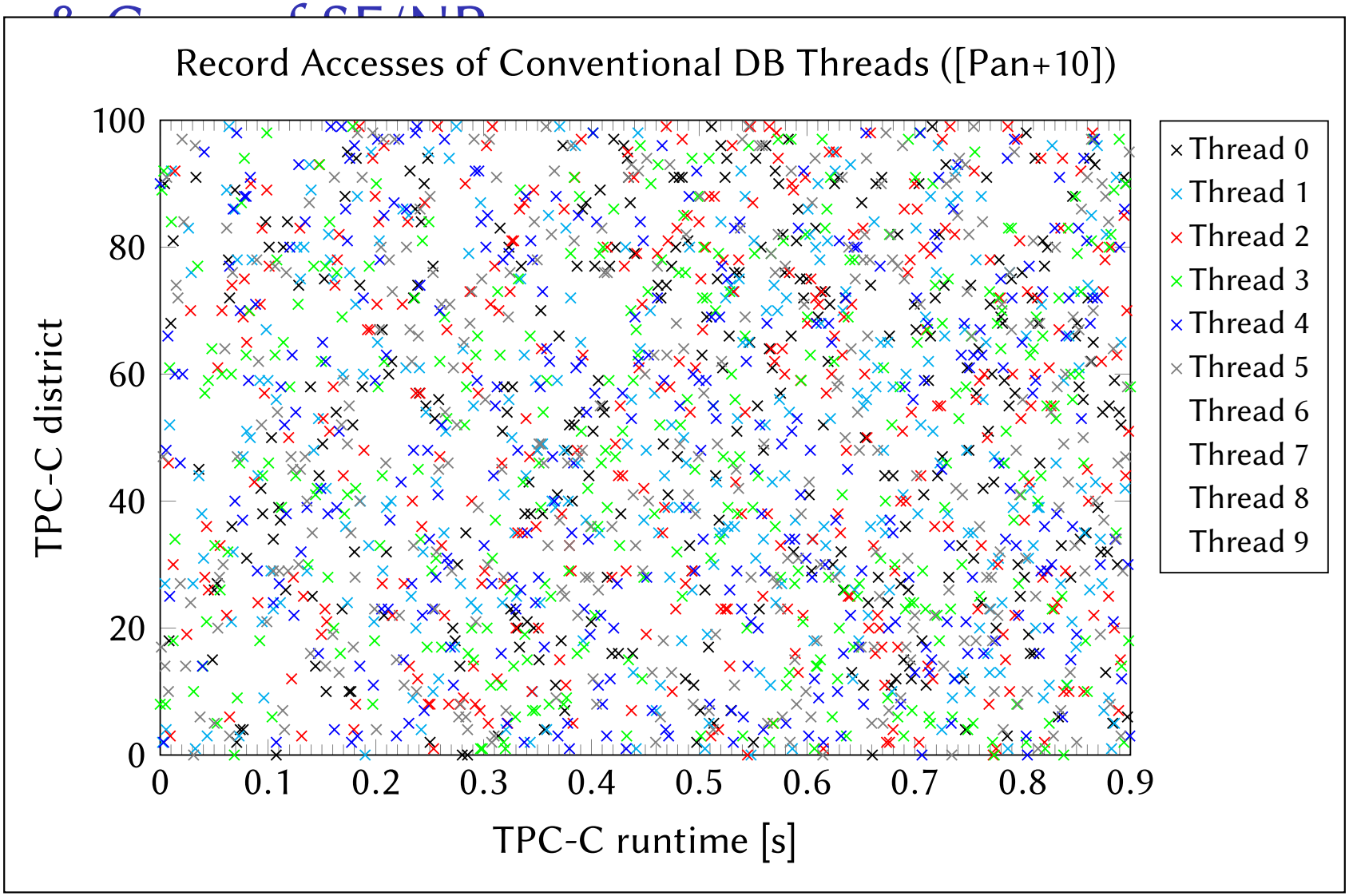
Pro & C of SE/NP


Record Accesses of Conventional DB Threads ([Pan+10])
TPC-C district
TPC-C runtime [s]
0
20
40
60
80
100
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Thread 0
Thread 1
Thread 2
Thread 3
Thread 4
Thread 5
Thread 6
Thread 7
Thread 8
Thread 9

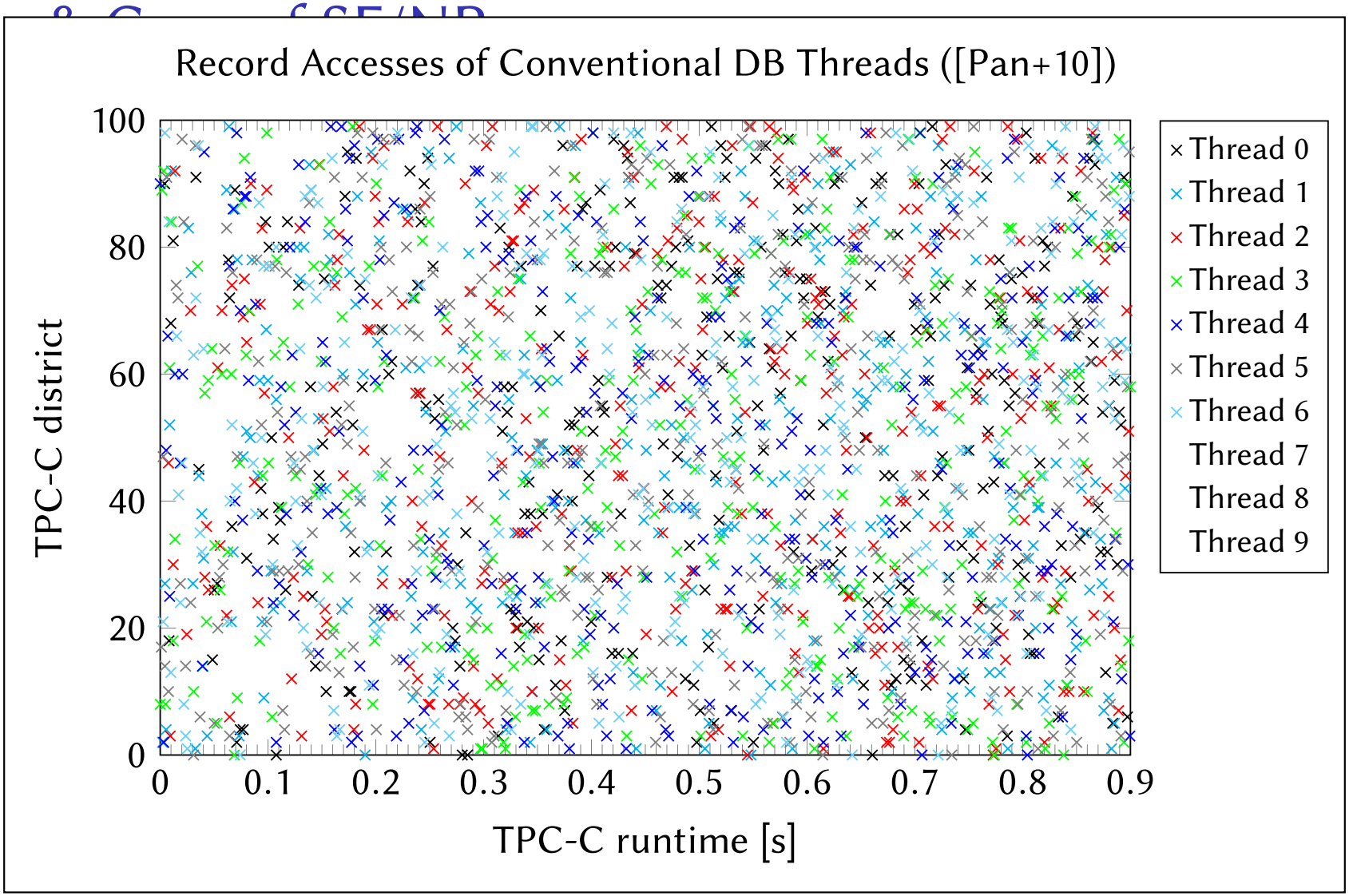
Pro & C of SE/NP


Record Accesses of Conventional DB Threads ([Pan+10])
TPC-C district
TPC-C runtime [s]
0
20
40
60
80
100
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Thread 0
Thread 1
Thread 2
Thread 3
Thread 4
Thread 5
Thread 6
Thread 7
Thread 8
Thread 9

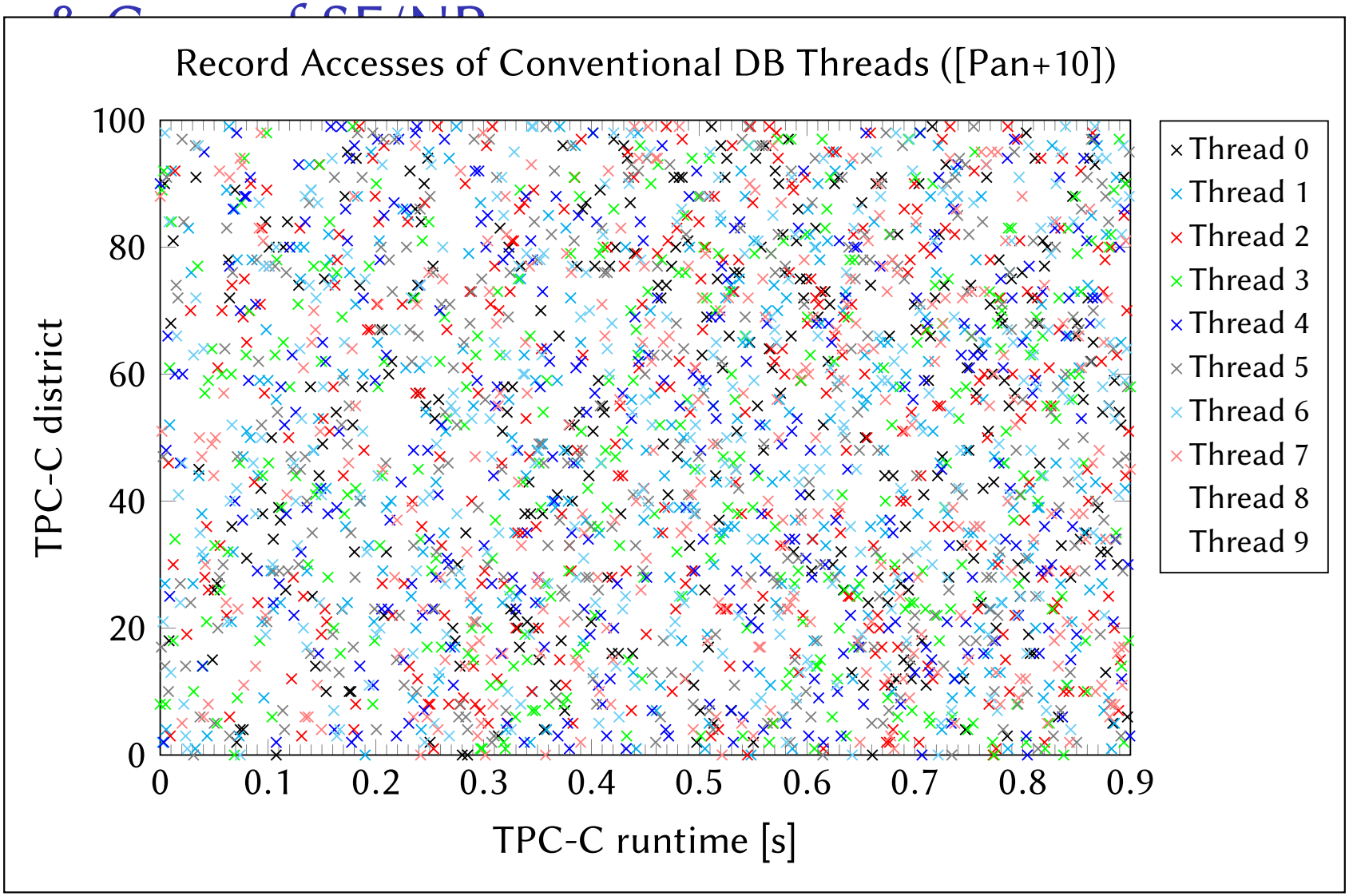
Pro & C of SE/NP


Record Accesses of Conventional DB Threads ([Pan+10])
TPC-C district
TPC-C runtime [s]
0
20
40
60
80
100
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Thread 0
Thread 1
Thread 2
Thread 3
Thread 4
Thread 5
Thread 6
Thread 7
Thread 8
Thread 9

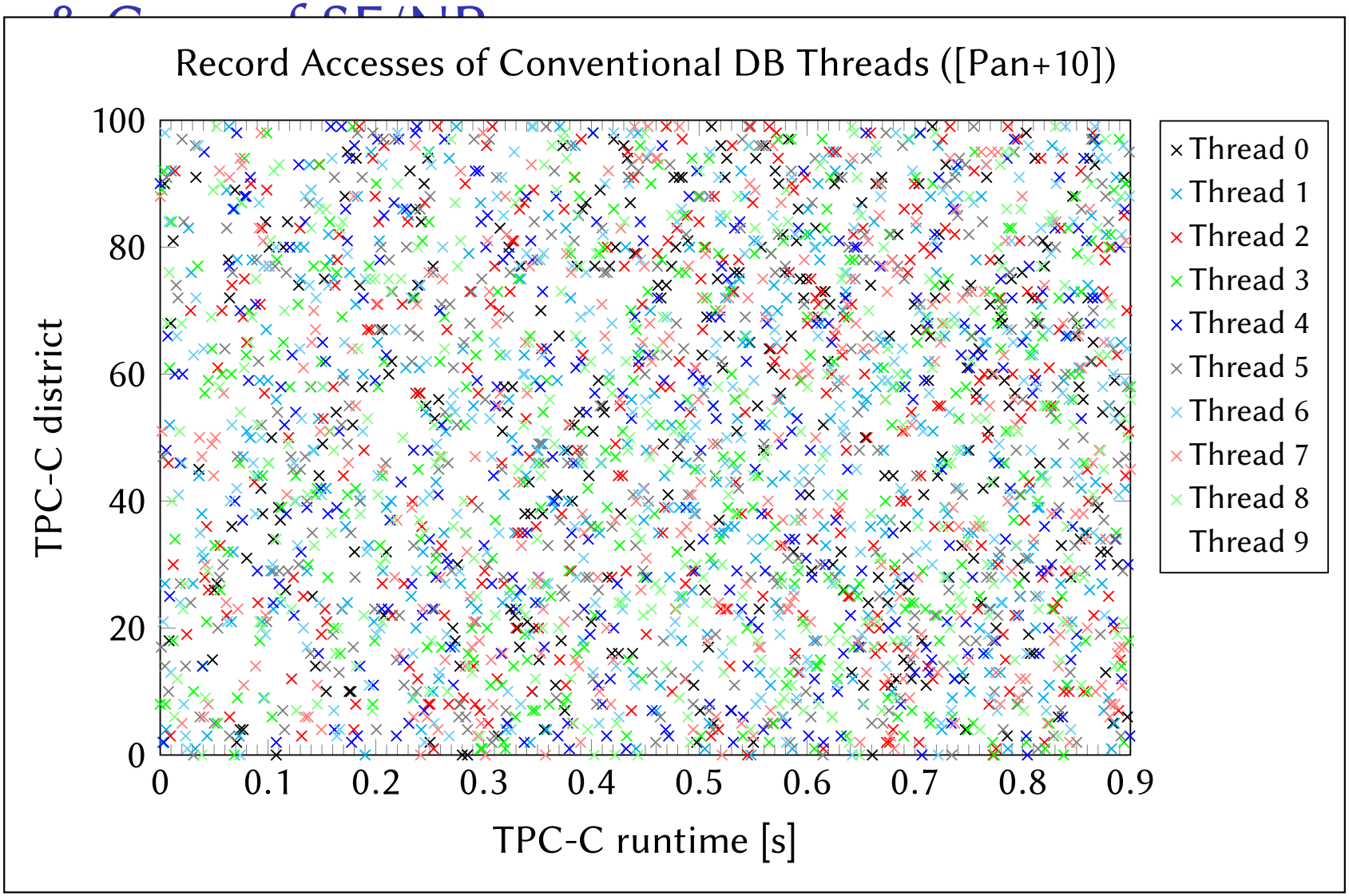
Pro & C of SE/NP


Record Accesses of Conventional DB Threads ([Pan+10])
TPC-C district
TPC-C runtime [s]
0
20
40
60
80
100
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Thread 0
Thread 1
Thread 2
Thread 3
Thread 4
Thread 5
Thread 6
Thread 7
Thread 8
Thread 9

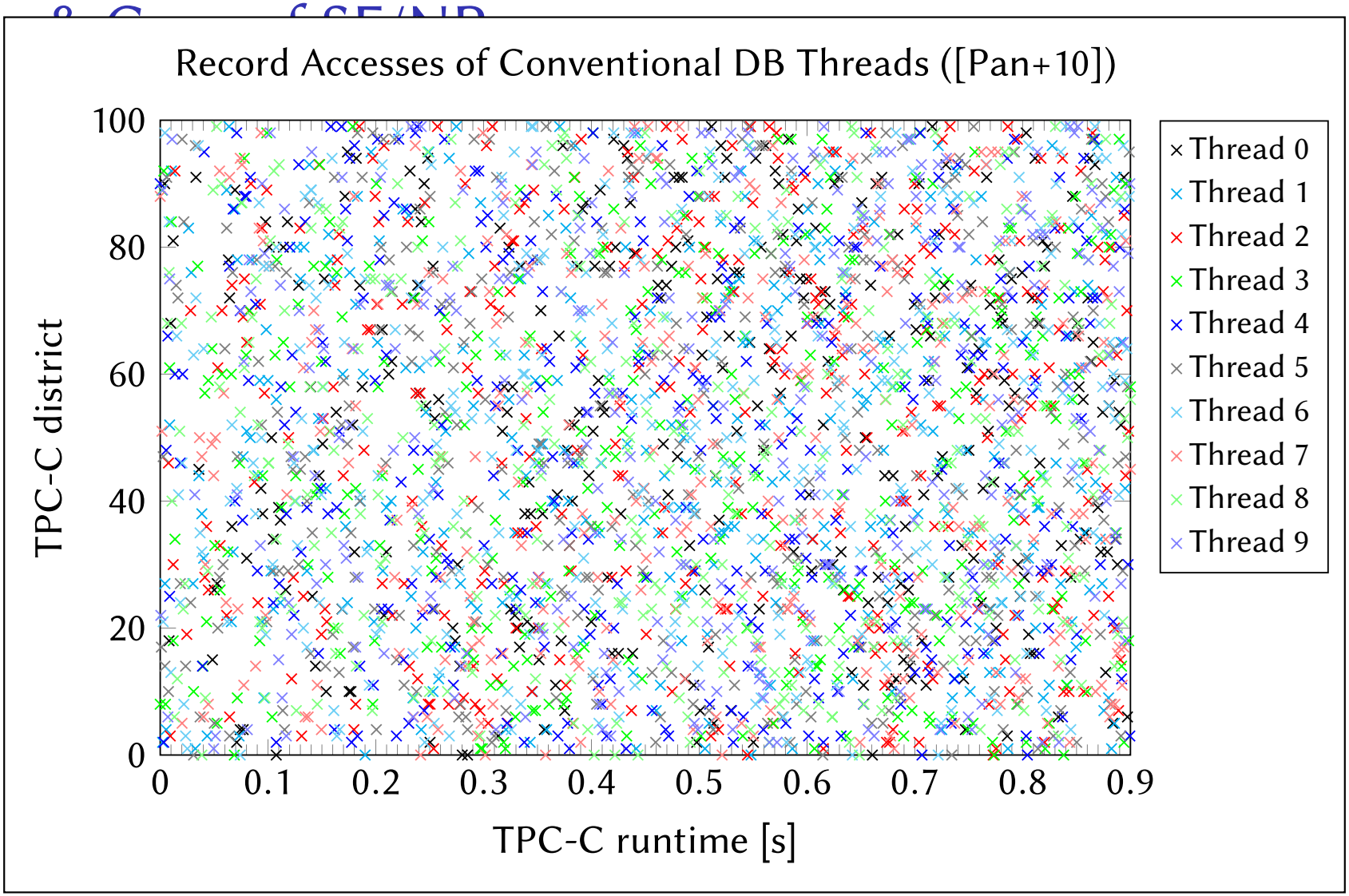
Pro & C of SE/NP


Record Accesses of Conventional DB Threads ([Pan+10])
TPC-C district
TPC-C runtime [s]
0
20
40
60
80
100
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Thread 0
Thread 1
Thread 2
Thread 3
Thread 4
Thread 5
Thread 6
Thread 7
Thread 8
Thread 9

Pro & C of SE/NP


Record Accesses of Conventional DB Threads ([Pan+10])
TPC-C district
TPC-C runtime [s]
0
20
40
60
80
100
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Thread 0
Thread 1
Thread 2
Thread 3
Thread 4
Thread 5
Thread 6
Thread 7
Thread 8
Thread 9

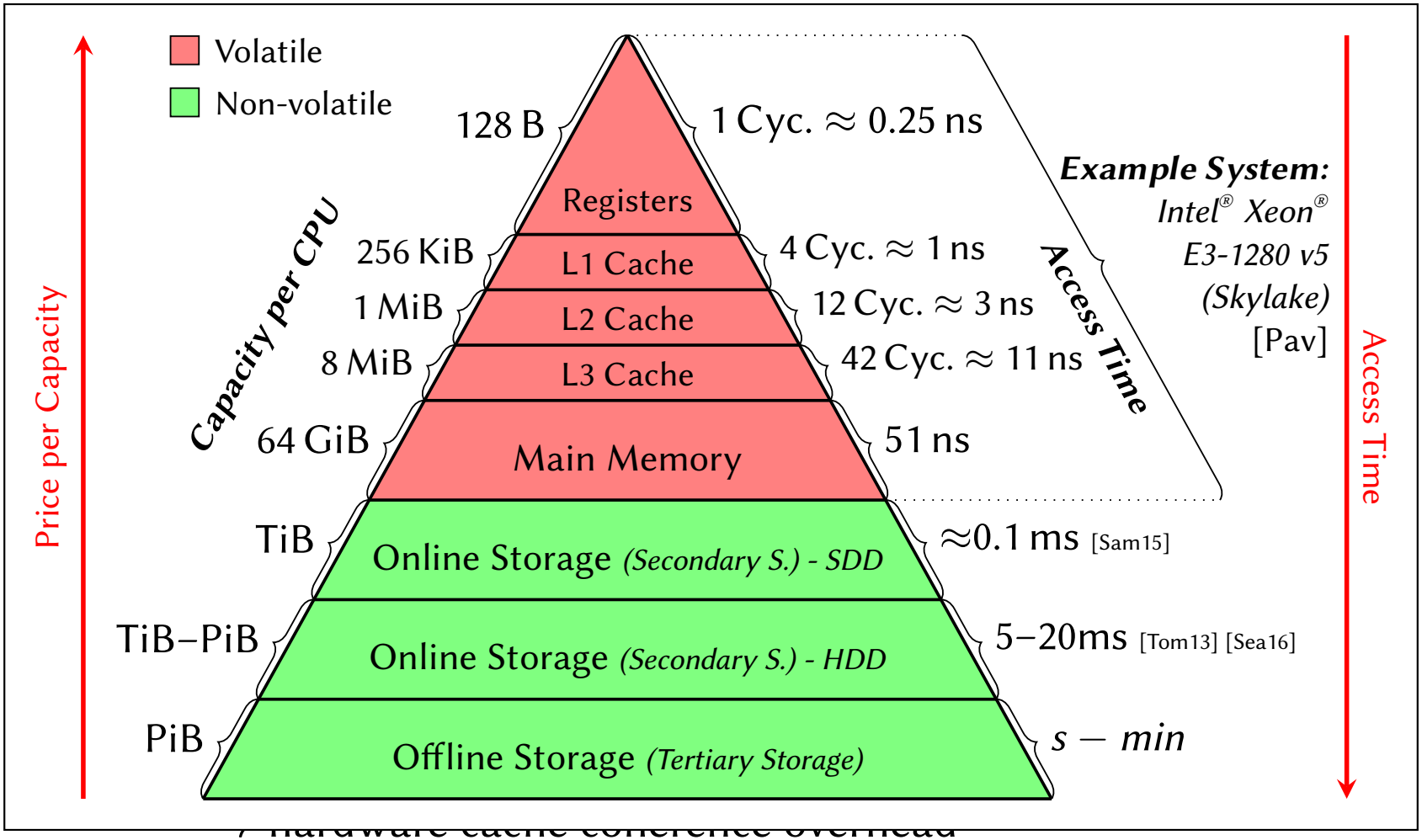
Pro & C… of SE/NP


Record Accesses of Conventional DB Threads ([Pan+10])
TPC-C district
TPC-C runtime [s]
0
20
40
60
80
100
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Thread 0
Thread 1
Thread 2
Thread 3
Thread 4
Thread 5
Thread 6
Thread 7
Thread 8
Thread 9

Pros & Cons of SE/NP

+ no partitioning required (e.g. manual selection of a strategy)
+ partitioning would be sensitive to the workload
+ changed workloads would require repartitioning to benefit from partitioning
– each thread might access every record at arbitrary times
  – each CPU cache may contain any part of the data
    → cache pollution
  – each CPU may access any part of the data
    → data movement between NUMA regions
  – each CPU may acquire any latch
    → data movement between NUMA regions
  – each CPU may atomically write to any semaphore
    → hardware cache coherence overhead

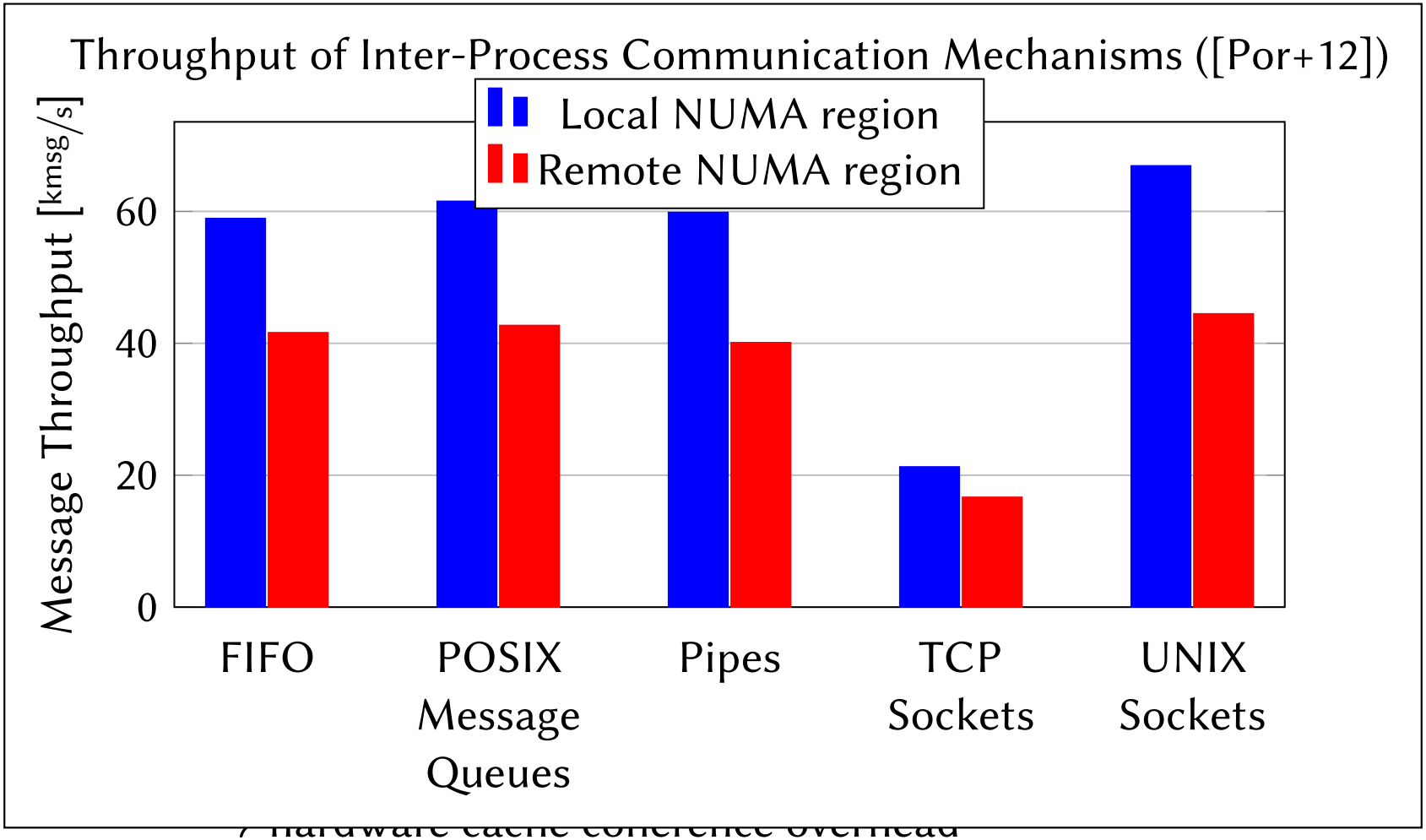
Pros & Cons of SE/NP



Pros & Cons of SE/NP

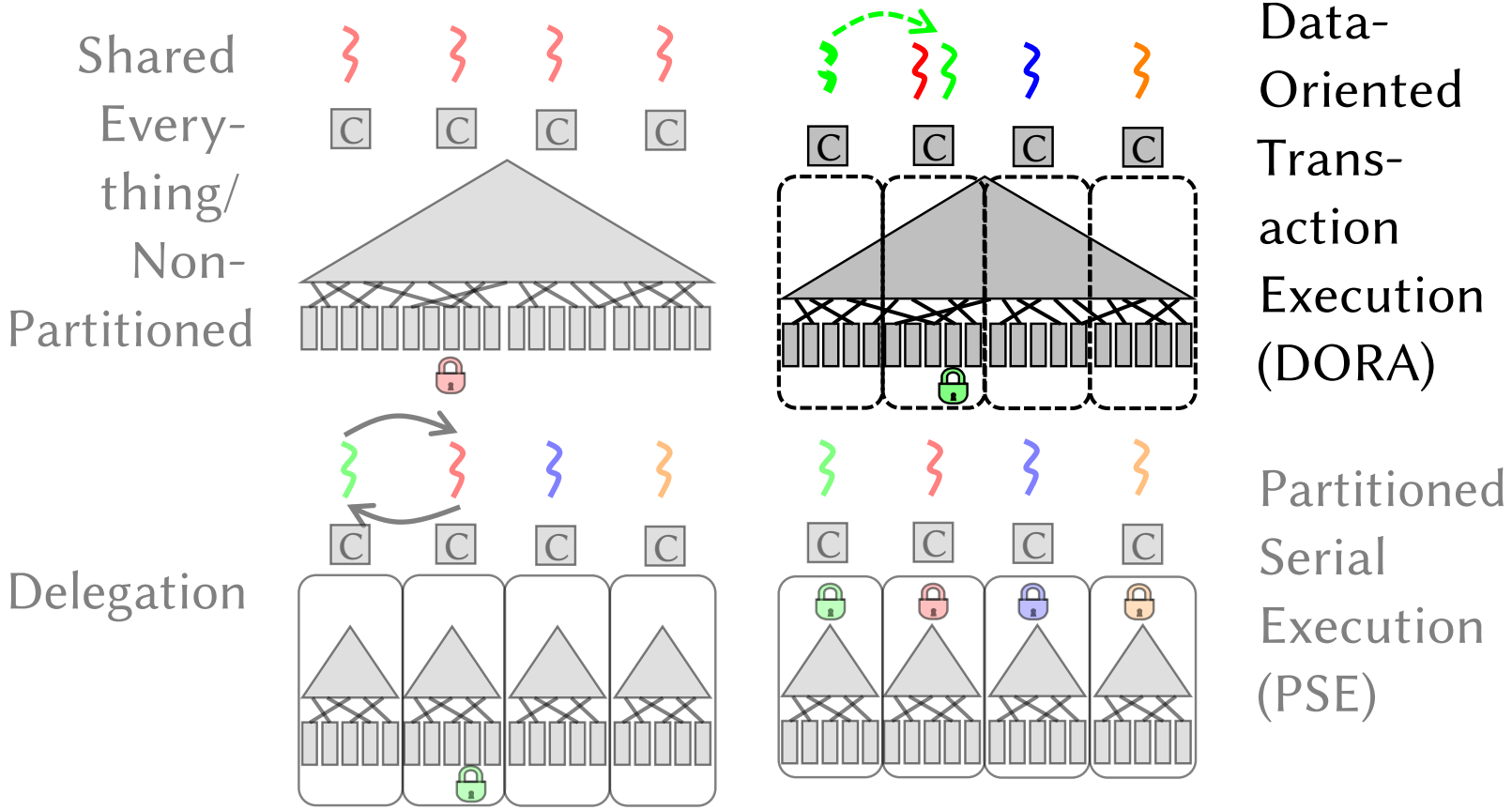
+ no partitioning required (e.g. manual selection of a strategy)
+ partitioning would be sensitive to the workload
+ changed workloads would require repartitioning to benefit from partitioning
– each thread might access every record at arbitrary times
  – each CPU cache may contain any part of the data
    → cache pollution
  – each CPU may access any part of the data
    → data movement between NUMA regions
  – each CPU may acquire any latch
    → data movement between NUMA regions
  – each CPU may atomically write to any semaphore
    → hardware cache coherence overhead

Pros & Cons of SE/NP



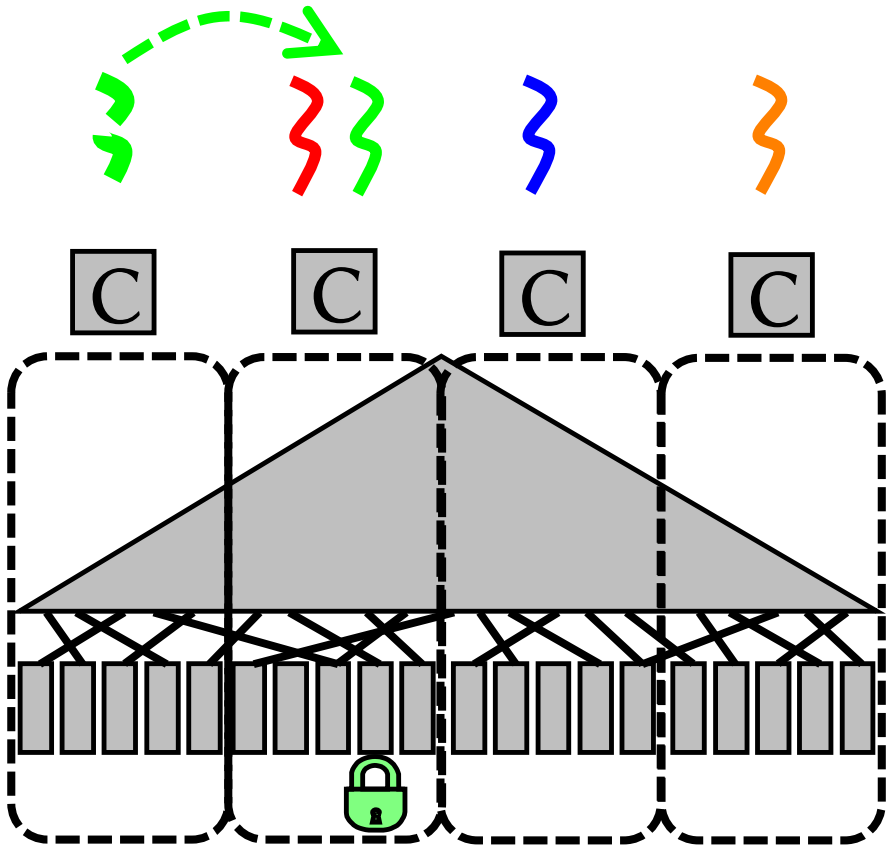
Subsection 2

Data-Oriented Transaction Execution (DORA)



Subsection 2

Data-Oriented Transaction Execution (DORA)



Properties of DORA

- metadata (incl. locks) are physically partitioned

→ no physical synchronization (latches, atomics) required

- data and indices are logically partitioned

→ logical synchronization using a concurrency control protocol only locally required

- threads are assigned to data
- transactions migrate to threads owning the accessed data

Interactive Example

Thread 0	
Fibers:	*idle*
Locks:	
Partition:	$0 - 1, \ldots$

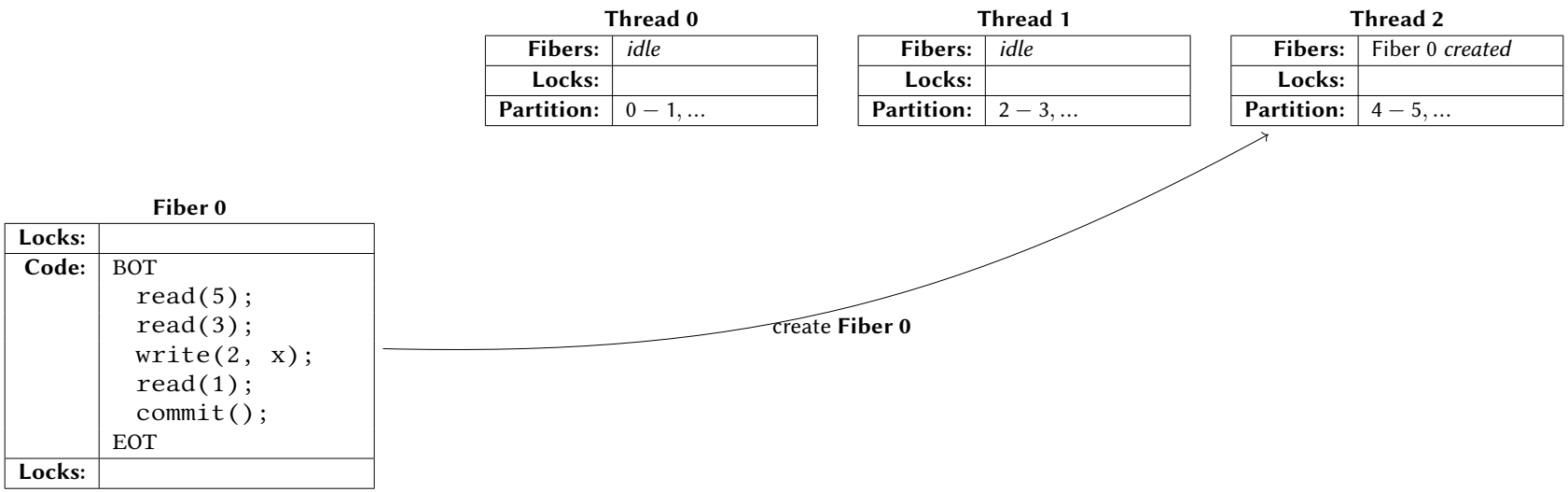
Thread 1	
Fibers:	*idle*
Locks:	
Partition:	$2 - 3, \ldots$

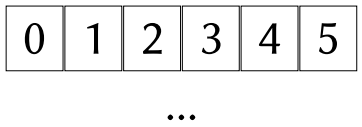
Thread 2	
Fibers:	*idle*
Locks:	
Partition:	$4 - 5, \ldots$

0	1	2	3	4	5

...

Interactive Example





Interactive Example

Thread 0

Fibers:	*idle*
Locks:	
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	*idle*
Locks:	
Partition:	$2 - 3, \ldots$

Thread 2

Fibers:	Fiber 0 *waiting*
Locks:	
Partition:	$4 - 5, \ldots$

Fiber 0

Locks:	

Code:	`BOT`
	`  read(5);`
	`  read(3);`
	`  write(2, x);`
	`  read(1);`
	`  commit();`
	`EOT`

Locks:	

0	1	2	3	4	5

...

Interactive Example

Thread 0

Fibers:	*idle*
Locks:	
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	*idle*
Locks:	
Partition:	$2 - 3, \ldots$

Thread 2

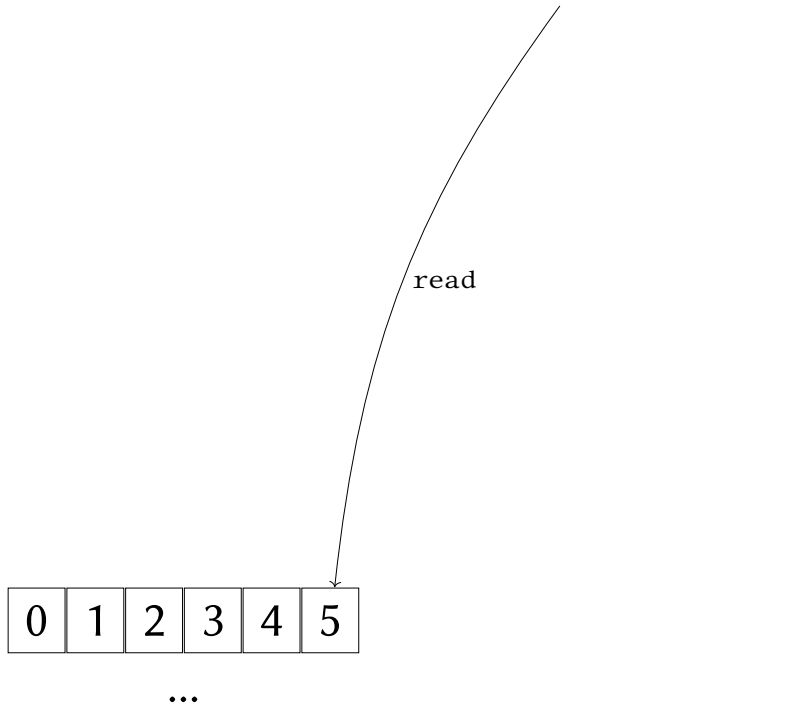
Fibers:	Fiber 0 *running*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \ldots$

Fiber 0

Locks:	$(5, S)$

Code:	BOT
	`read(5); <-`
	`read(3);`
	`write(2, x);`
	`read(1);`
	`commit();`
	EOT

Locks:	



Interactive Example

Thread 0

Fibers:	*idle*
Locks:	
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	*idle*
Locks:	
Partition:	$2 - 3, \ldots$

Thread 2

Fibers:	Fiber 0 *suspended*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \ldots$

Fiber 0

Locks:	$(5, S)$

Code:	BOT
	`read(5);`
	`read(3);`
	`write(2, x);`
	`read(1);`
	`commit();`
	EOT

Locks:	

0	1	2	3	4	5

...

Interactive Example

Thread 0

Fibers:	*idle*
Locks:	
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	Fiber 0 *suspended*
Locks:	
Partition:	$2 - 3, \ldots$

Thread 2

Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \ldots$

migrate **Fiber 0**

Fiber 0

Locks:	$(5, S)$

Code:	BOT
	`read(5);`
	`read(3);`
	`write(2, x);`
	`read(1);`
	`commit();`
	EOT

Locks:	

0	1	2	3	4	5

...

Interactive Example

Thread 0

Fibers:	*idle*
Locks:	
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	Fiber 0 *waiting*
Locks:	
Partition:	$2 - 3, \ldots$

Thread 2

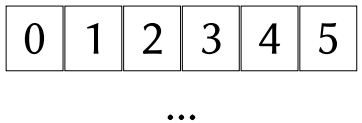
Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \ldots$

Fiber 0

Locks:	$(5, S)$

Code:	BOT
	`read(5);`
	`read(3);`
	`write(2, x);`
	`read(1);`
	`commit();`
	EOT

Locks:	



Interactive Example

Thread 0

Fibers:	*idle*
Locks:	
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	Fiber 0 *running*
Locks:	$(3, S)_0$
Partition:	$2 - 3, \ldots$

Thread 2

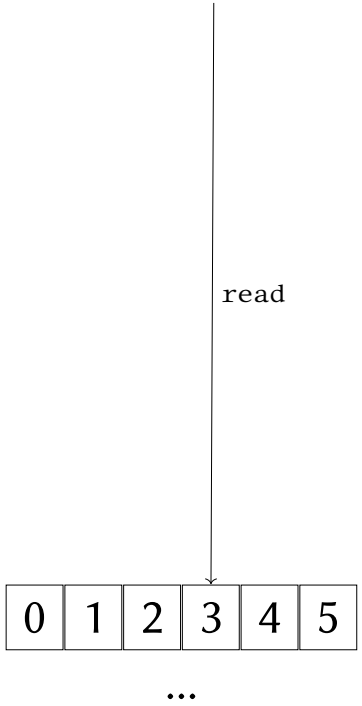
Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \ldots$

Fiber 0

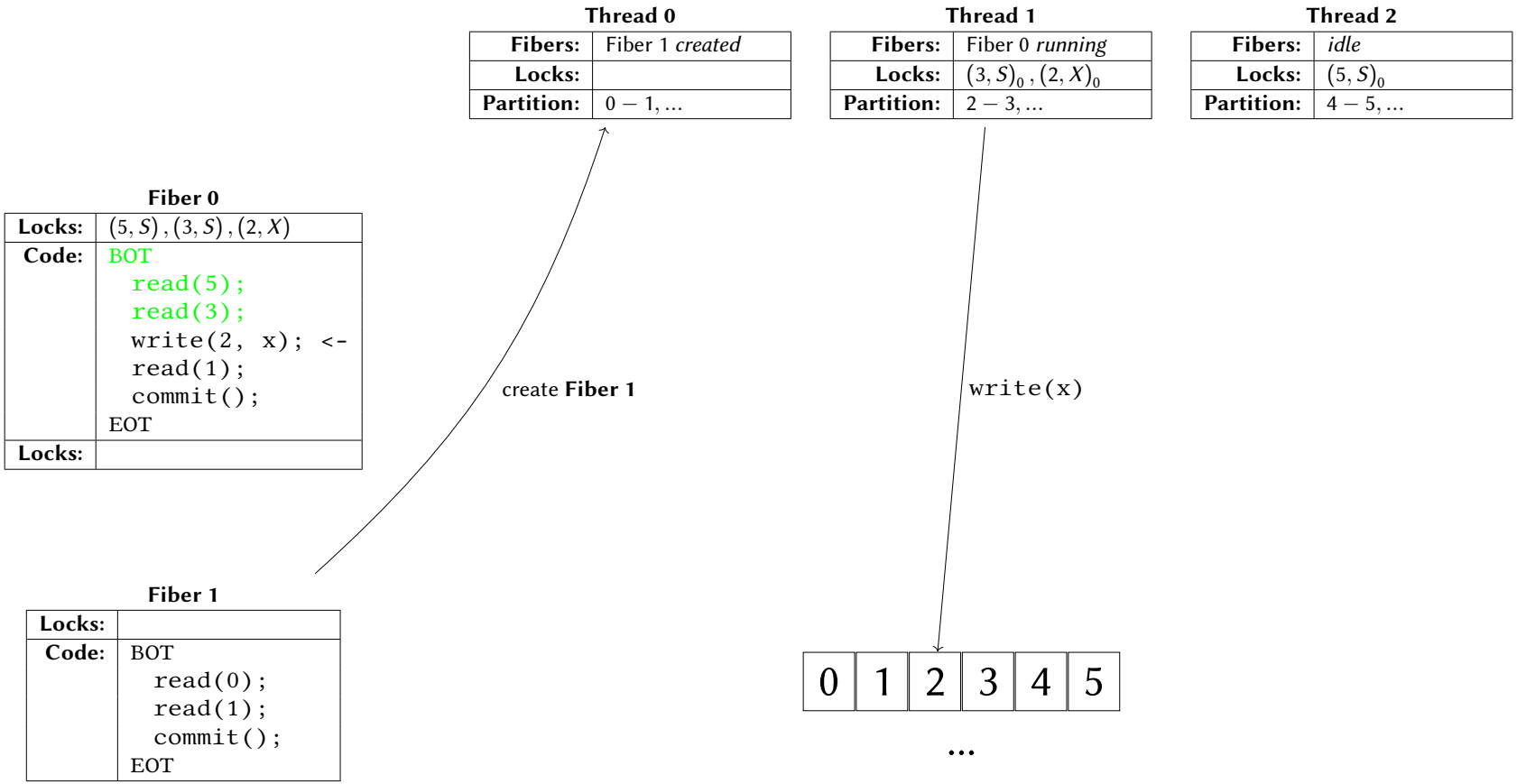
Locks:	$(5, S), (3, S)$

Code:	BOT
	`read(5);`
	`read(3); <-`
	`write(2, x);`
	`read(1);`
	`commit();`
	EOT

Locks:	



Interactive Example



Interactive Example

Thread 0

Fibers:	Fiber 1 *waiting*
Locks:	
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	Fiber 0 *suspended*
Locks:	$(3, S)_0, (2, X)_0$
Partition:	$2 - 3, \ldots$

Thread 2

Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \ldots$

Fiber 0

Locks:	$(5, S), (3, S), (2, X)$

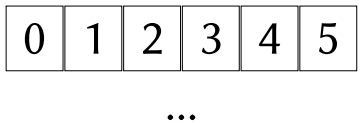
Code:	BOT
	read(5);
	read(3);
	write(2, x);
	read(1);
	commit();
	EOT

Locks:	

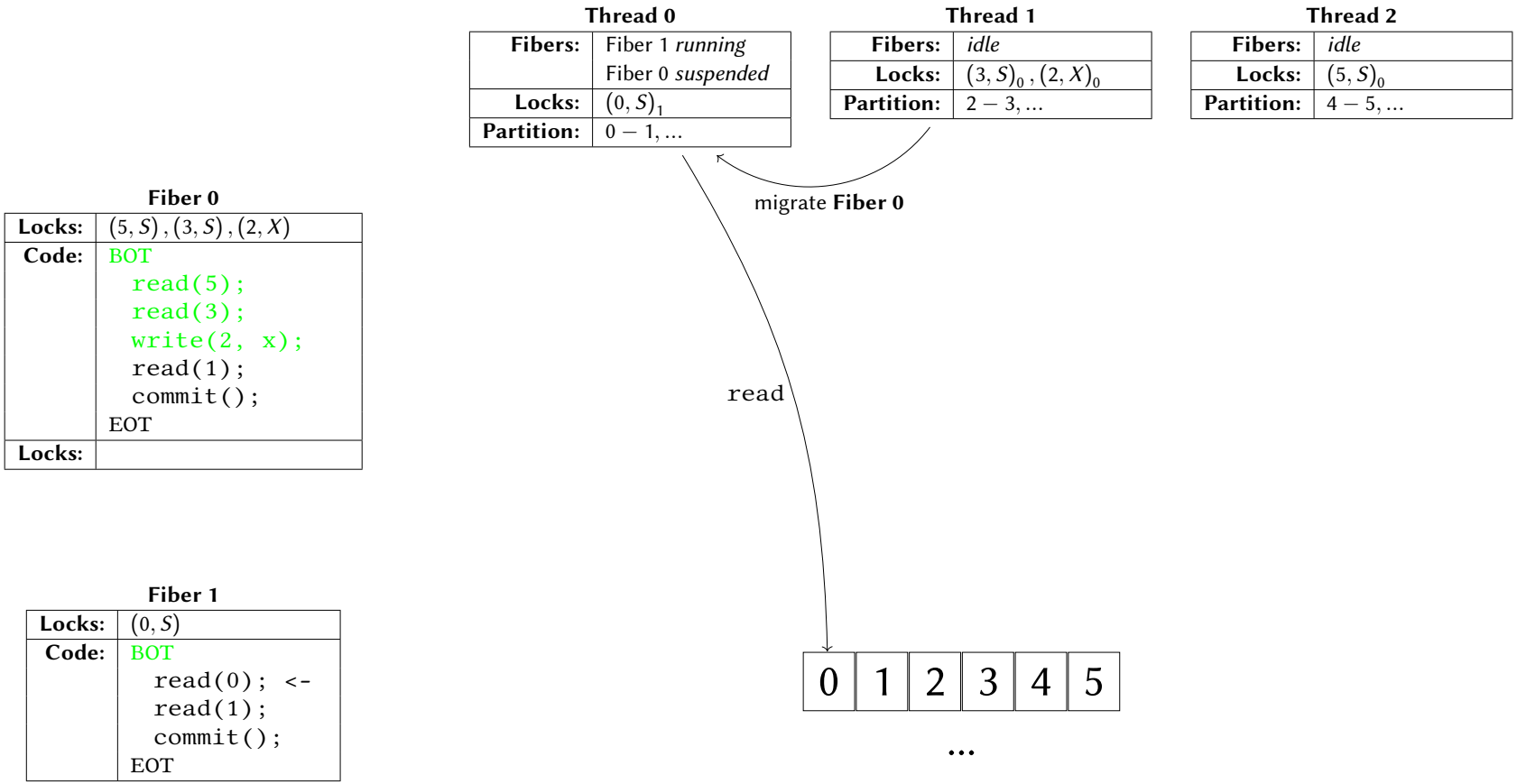
Fiber 1

Locks:	

Code:	BOT
	read(0);
	read(1);
	commit();
	EOT



Interactive Example



Interactive Example

Thread 0

Fibers:	Fiber 1 *running* Fiber 0 *waiting*
Locks:	$(0, S)_1, (1, S)_1$
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	*idle*
Locks:	$(3, S)_0, (2, X)_0$
Partition:	$2 - 3, \ldots$

Thread 2

Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \ldots$

Fiber 0

Locks:	$(5, S), (3, S), (2, X)$

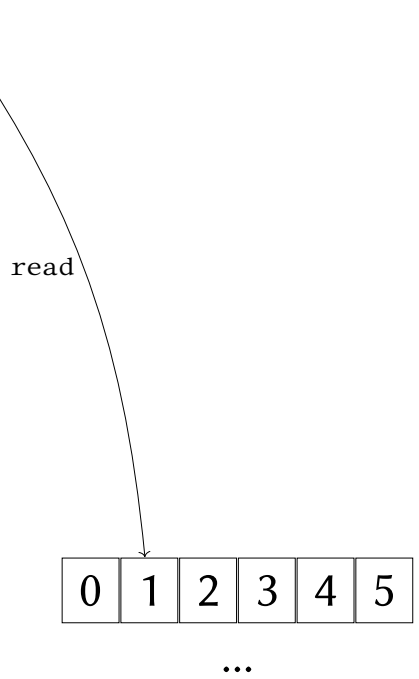
Code:	BOT
	`read(5);`
	`read(3);`
	`write(2, x);`
	`read(1);`
	`commit();`
	EOT

Locks:	

Fiber 1

Locks:	$(0, S), (1, S)$

Code:	BOT
	`read(0);`
	`read(1); <-`
	`commit();`
	EOT



Interactive Example

Thread 0

Fibers:	Fiber 1 *committing* Fiber 0 *waiting*
Locks:	
Partition:	$0-1,\ldots$

Thread 1

Fibers:	*idle*
Locks:	$(3,S)_0, (2,X)_0$
Partition:	$2-3,\ldots$

Thread 2

Fibers:	*idle*
Locks:	$(5,S)_0$
Partition:	$4-5,\ldots$

Fiber 0

Locks:	$(5,S), (3,S), (2,X)$

Code:	BOT
	`read(5);`
	`read(3);`
	`write(2, x);`
	`read(1);`
	`commit();`
	EOT

Locks:	

Fiber 1

Locks:	

Code:	BOT
	`read(0);`
	`read(1);`
	`commit(); <-`
	EOT

0	1	2	3	4	5

...

Interactive Example

Thread 0

Fibers:	Fiber 1 *terminated* Fiber 0 *waiting*
Locks:	
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	*idle*
Locks:	$(3, S)_0, (2, X)_0$
Partition:	$2 - 3, \ldots$

Thread 2

Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \ldots$

Fiber 0

Locks:	$(5, S), (3, S), (2, X)$

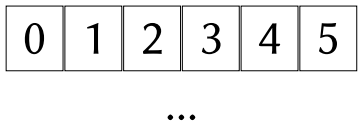
Code:	BOT
	read(5);
	read(3);
	write(2, x);
	read(1);
	commit();
	EOT

Locks:	

Fiber 1

Locks:	

Code:	BOT
	read(0);
	read(1);
	commit();
	EOT



Interactive Example

Thread 0

Fibers:	Fiber 0 *running*
Locks:	$(0, S)_0$
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	*idle*
Locks:	$(3, S)_0, (2, X)_0$
Partition:	$2 - 3, \ldots$

Thread 2

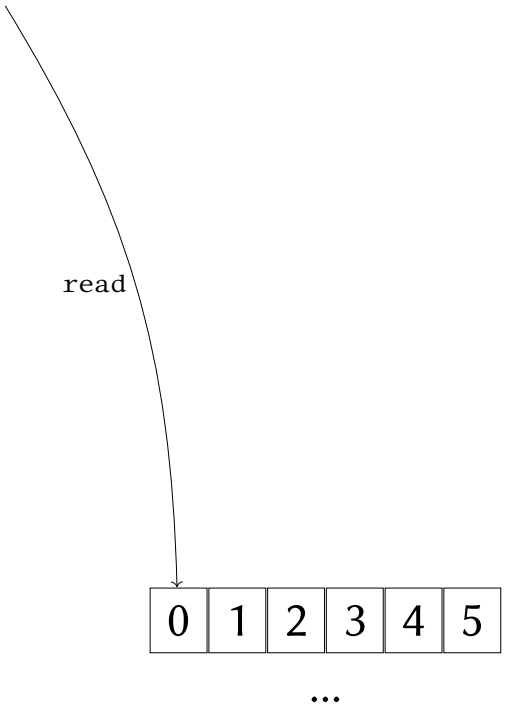
Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \ldots$

Fiber 0

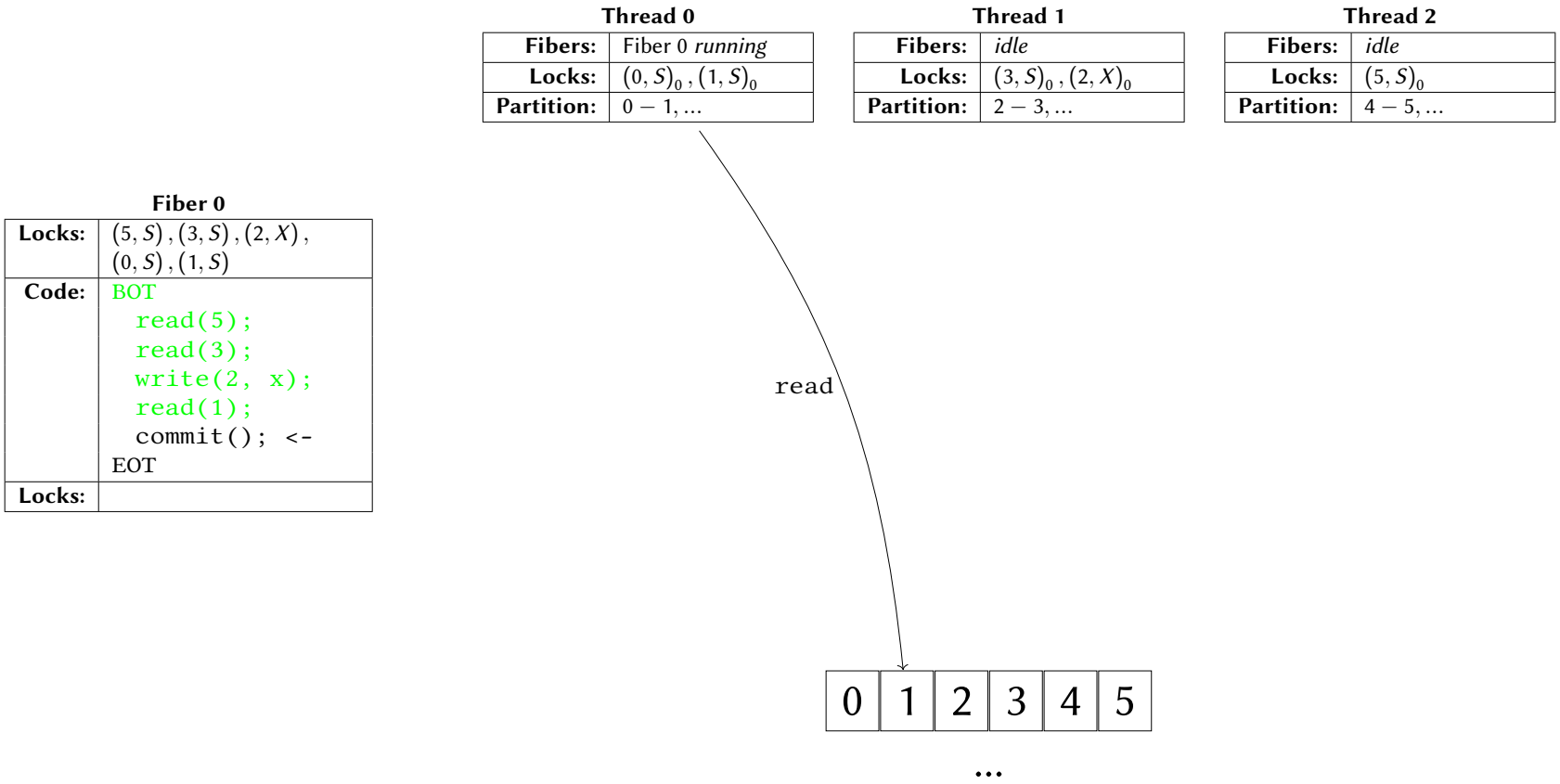
Locks:	$(5, S), (3, S), (2, X), (0, S)$

Code:	BOT
	`read(5);`
	`read(3);`
	`write(2, x);`
	`read(1); <-`
	`commit();`
	EOT

Locks:	



Interactive Example



Interactive Example

Thread 0

Fibers:	Fiber 0 *committing*
Locks:	
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	*idle*
Locks:	$(3, S)_0, (2, X)_0$
Partition:	$2 - 3, \ldots$

Thread 2

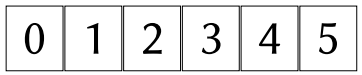
Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \ldots$

Fiber 0

Locks:	$(5, S), (3, S), (2, X)$

Code:	BOT
	read(5);
	read(3);
	write(2, x);
	read(1);
	commit(); <-
	EOT

Locks:	



...

Interactive Example

Thread 0

Fibers:	Fiber 0 *suspended*
Locks:	
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	*idle*
Locks:	$(3, S)_0, (2, X)_0$
Partition:	$2 - 3, \ldots$

Thread 2

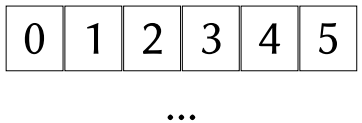
Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \ldots$

Fiber 0

Locks:	$(5, S), (3, S), (2, X)$

Code:	BOT
	`read(5);`
	`read(3);`
	`write(2, x);`
	`read(1);`
	`commit(); <-`
	EOT

Locks:	



Interactive Example

Thread 0	
Fibers:	*idle*
Locks:	
Partition:	$0-1,\ldots$

Thread 1	
Fibers:	Fiber 0 *suspended*
Locks:	$(3,S)_0, (2,X)_0$
Partition:	$2-3,\ldots$

Thread 2	
Fibers:	*idle*
Locks:	$(5,S)_0$
Partition:	$4-5,\ldots$

migrate **Fiber 0**

Fiber 0

Locks:	$(5,S), (3,S), (2,X)$

Code:	BOT
	`read(5);`
	`read(3);`
	`write(2, x);`
	`read(1);`
	`commit(); <-`
	EOT

Locks:	

0	1	2	3	4	5

...

Interactive Example

Thread 0

Fibers:	*idle*
Locks:	
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	Fiber 0 *waiting*
Locks:	$(3, S)_0, (2, X)_0$
Partition:	$2 - 3, \ldots$

Thread 2

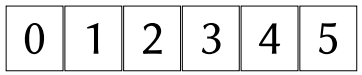
Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \ldots$

Fiber 0

Locks:	$(5, S), (3, S), (2, X)$

Code:	BOT
	`read(5);`
	`read(3);`
	`write(2, x);`
	`read(1);`
	`commit(); <-`
	EOT

Locks:	



...

Interactive Example

Thread 0

Fibers:	*idle*
Locks:	
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	Fiber 0 *committing*
Locks:	
Partition:	$2 - 3, \ldots$

Thread 2

Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \ldots$

Fiber 0

Locks:	$(5, S)$

Code:	BOT
	read(5);
	read(3);
	write(2, x);
	read(1);
	commit(); <-
	EOT

Locks:	

0	1	2	3	4	5

...

Interactive Example

Thread 0

Fibers:	*idle*
Locks:	
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	Fiber 0 *suspended*
Locks:	
Partition:	$2 - 3, \ldots$

Thread 2

Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \ldots$

Fiber 0

Locks:	$(5, S)$

Code:	BOT
	`read(5);`
	`read(3);`
	`write(2, x);`
	`read(1);`
	`commit(); <-`
	EOT

Locks:	

0	1	2	3	4	5

...

Interactive Example

Thread 0

Fibers:	*idle*
Locks:	
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	*idle*
Locks:	
Partition:	$2 - 3, \ldots$

Thread 2

Fibers:	Fiber 0 *suspended*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \ldots$

migrate **Fiber 0**

Fiber 0

Locks:	$(5, S)$

Code:	BOT
	`read(5);`
	`read(3);`
	`write(2, x);`
	`read(1);`
	`commit(); <-`
	EOT

Locks:	

0	1	2	3	4	5

...

Interactive Example

Thread 0

Fibers:	*idle*
Locks:	
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	*idle*
Locks:	
Partition:	$2 - 3, \ldots$

Thread 2

Fibers:	Fiber 0 *waiting*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \ldots$

Fiber 0

Locks:	$(5, S)$

Code:	BOT
	`read(5);`
	`read(3);`
	`write(2, x);`
	`read(1);`
	`commit(); <-`
	EOT

Locks:	

0	1	2	3	4	5

...

Interactive Example

Thread 0

Fibers:	*idle*
Locks:	
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	*idle*
Locks:	
Partition:	$2 - 3, \ldots$

Thread 2

Fibers:	Fiber 0 *committing*
Locks:	
Partition:	$4 - 5, \ldots$

Fiber 0

Locks:	

Code:	BOT
	read(5);
	read(3);
	write(2, x);
	read(1);
	commit(); <-
	EOT

Locks:	

0	1	2	3	4	5

...

Interactive Example

Thread 0

Fibers:	*idle*
Locks:	
Partition:	$0 - 1, \ldots$

Thread 1

Fibers:	*idle*
Locks:	
Partition:	$2 - 3, \ldots$

Thread 2

Fibers:	Fiber 0 *terminated*
Locks:	
Partition:	$4 - 5, \ldots$

Fiber 0

Locks:	

Code:	`BOT`
	`  read(5);`
	`  read(3);`
	`  write(2, x);`
	`  read(1);`
	`  commit();`
	`EOT`

Locks:	

0	1	2	3	4	5

...

Interactive Example

Thread 0	
Fibers:	*idle*
Locks:	
Partition:	$0 - 1, \ldots$

Thread 1	
Fibers:	*idle*
Locks:	
Partition:	$2 - 3, \ldots$

Thread 2	
Fibers:	*idle*
Locks:	
Partition:	$4 - 5, \ldots$

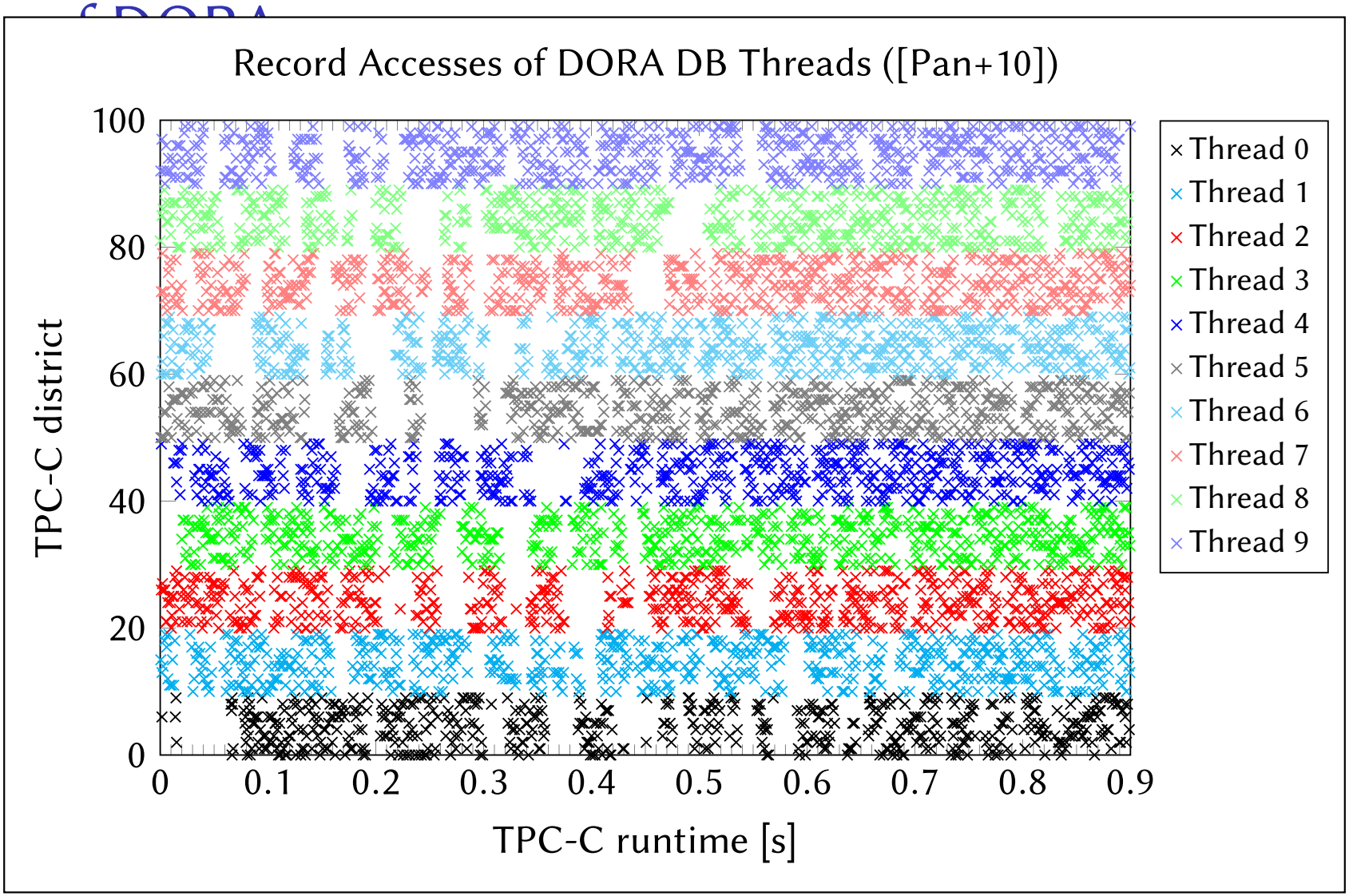
0	1	2	3	4	5

...

Pros of DORA

+ each thread accesses only the records of its partition
  + each CPU cache may contain only data of its partition
    → lower cache pollution
  + each CPU may access only data of its partitions
    → no data movement between NUMA regions (for single-CPU transactions)
  → No physical synchronization required!
+ logical partitioning allows fast repartitioning when the workload changes
+ intra-transaction parallelism could be exploited for multi-site transactions

Pro[illegible] of DORA

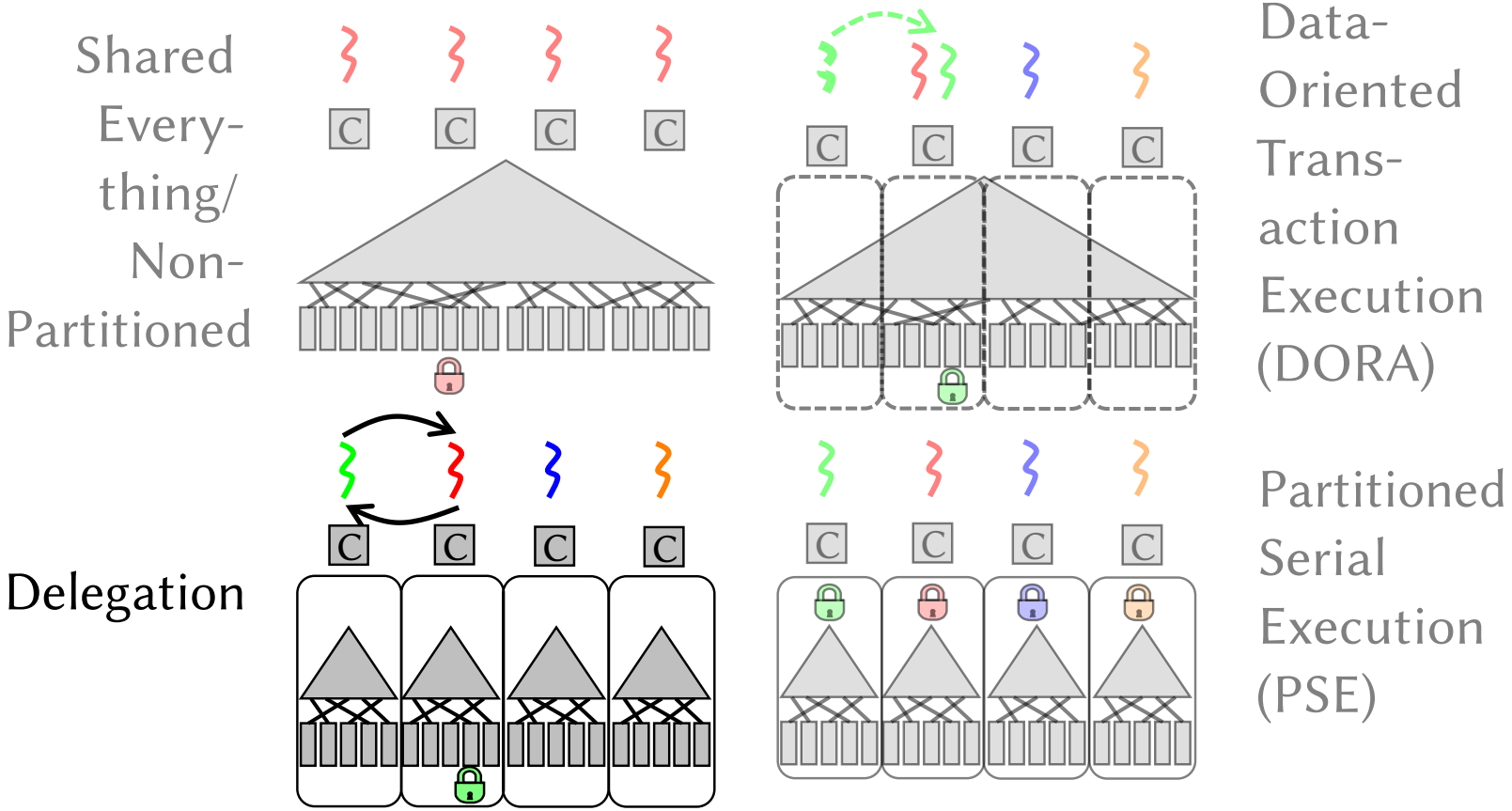

Record Accesses of DORA DB Threads ([Pan+10])
TPC-C district
TPC-C runtime [s]
0
20
40
60
80
100
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Thread 0
Thread 1
Thread 2
Thread 3
Thread 4
Thread 5
Thread 6
Thread 7
Thread 8
Thread 9

Cons of DORA

- partitioning required (e.g. manual selection of a partitioning strategy—*called routing rule*)
- partitioning is sensitive to the workload
- multi-site transactions require expensive fiber-migration (probably between NUMA regions)
- accessed partitions need to be calculated during query analysis for optimal performance
  $\longrightarrow$ slower accesses with secondary index
- primary index is shared
  $\longrightarrow$ centralized latching for inserts/deletes still required
  $\longrightarrow$ some contention on the shared latch
- centralized deadlock detection still required (for DL_DETECT)

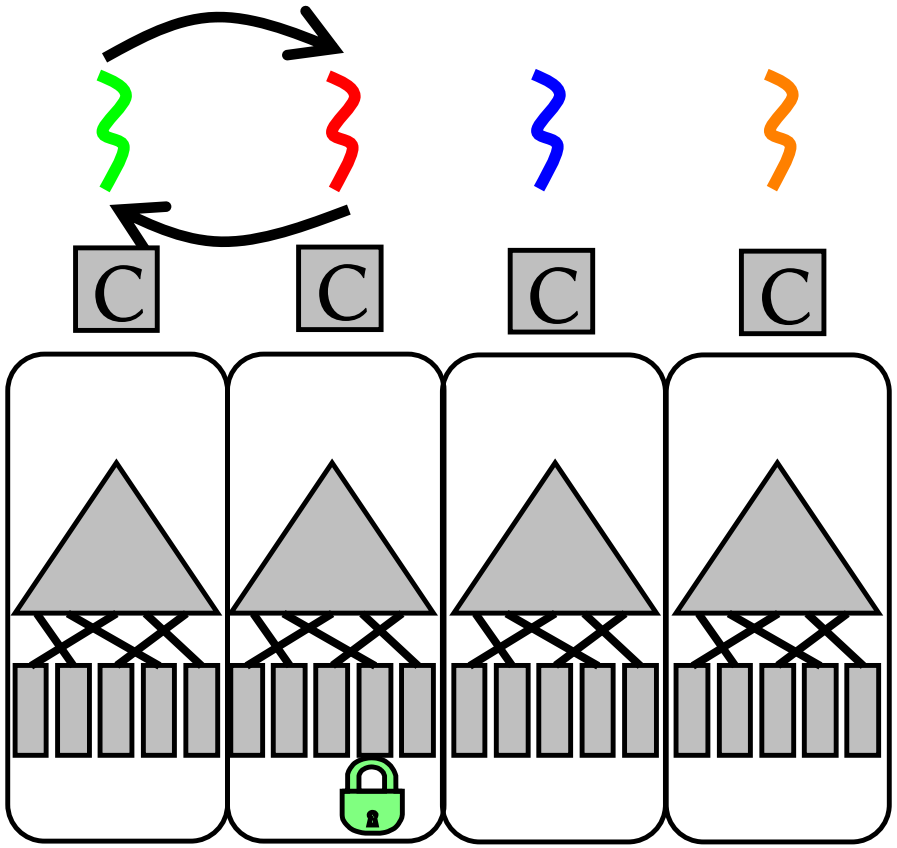
Subsection 3

Delegation



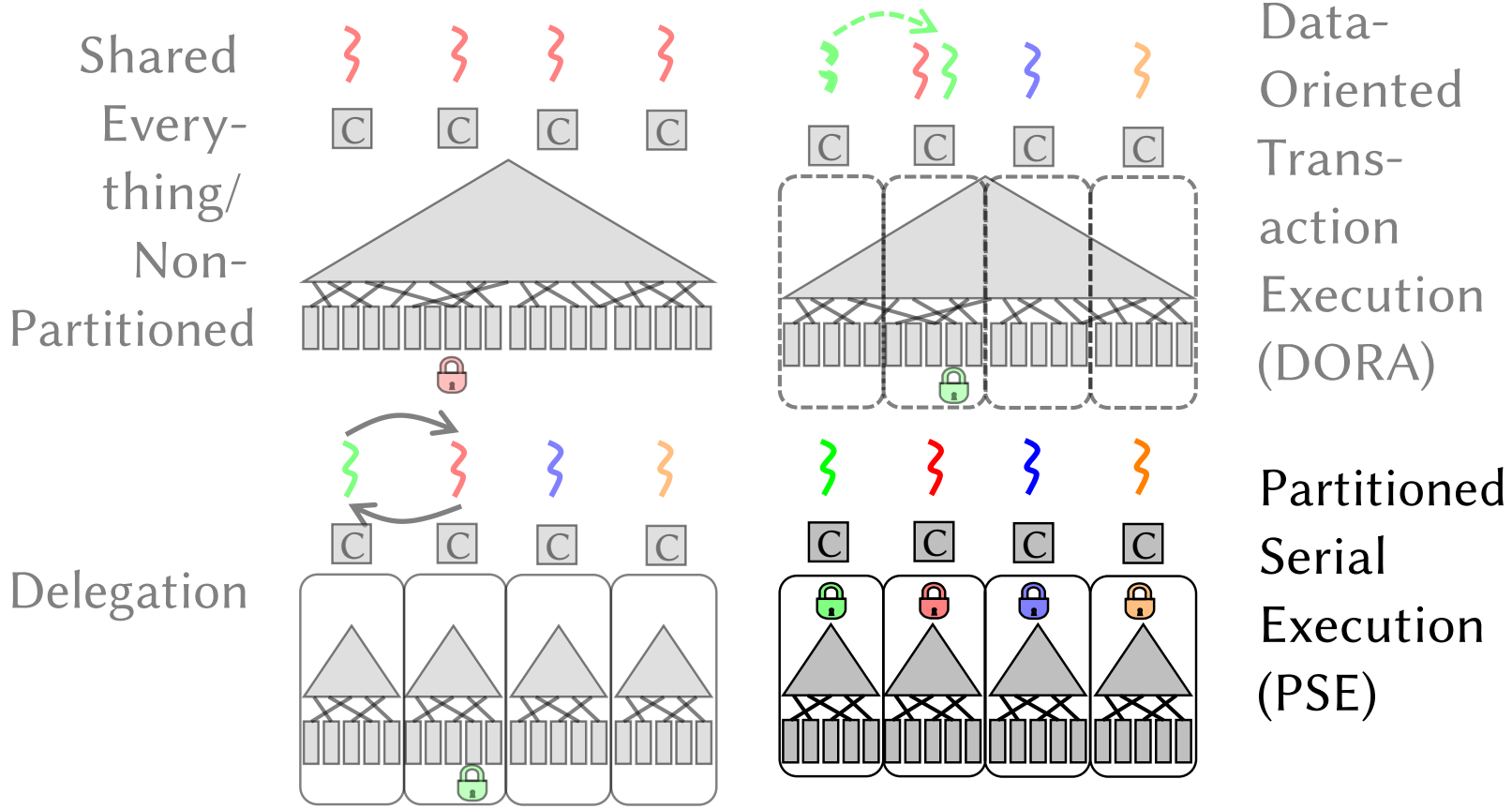
Subsection 3

Delegation



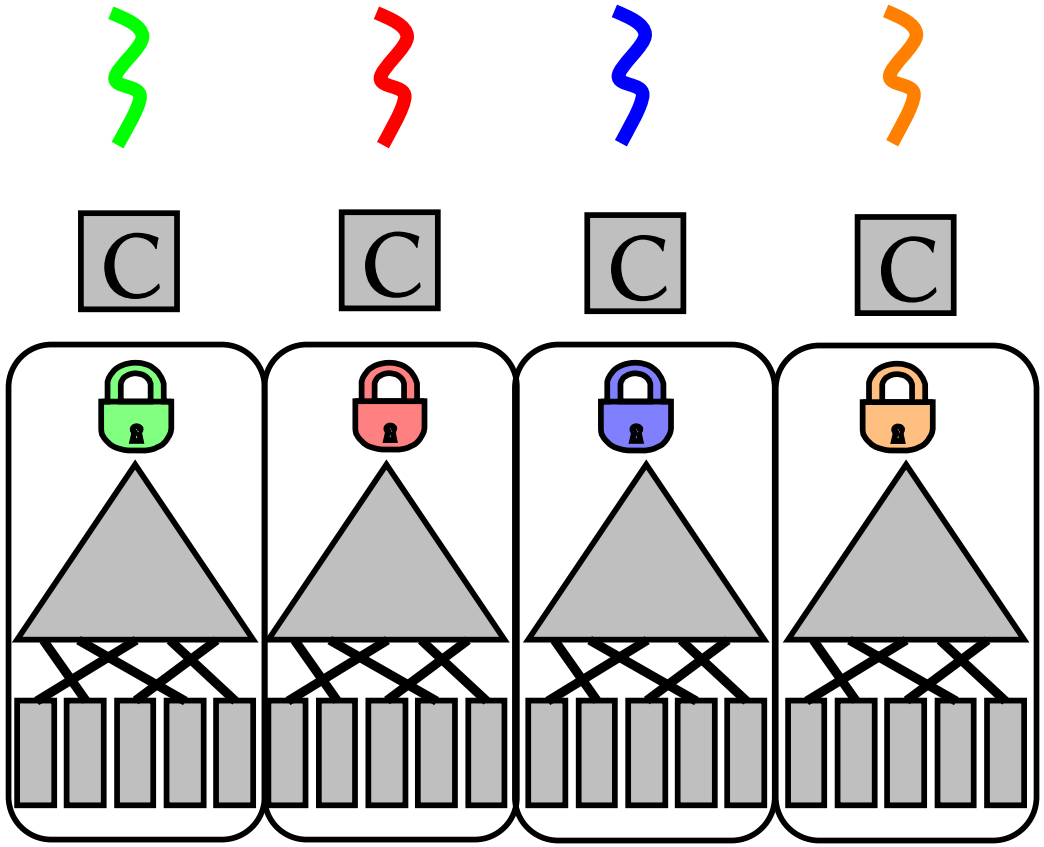
Subsection 4

Partitioned Serial Execution (PSE)



Subsection 4

Partitioned Serial Execution (PSE)



Summary

Architecture				
SE/NP				
PSE				
Delegation				
DORA				

Summary

Archi-tec-ture	**Process Management**			
	Paral-lelism			
SE/NP	Shared Memory			
PSE	Shared Nothing			
Dele-gation	Message Passing			
DORA	Shared Memory			

Summary

Architecture	Process Management			
	Parallelism	Thread Assignment		
SE/NP	Shared Memory	thread-to-txn		
PSE	Shared Nothing	thread-to-txn		
Delegation	Message Passing	thread-to-txn		
DORA	Shared Memory	thread-to-data		

Summary

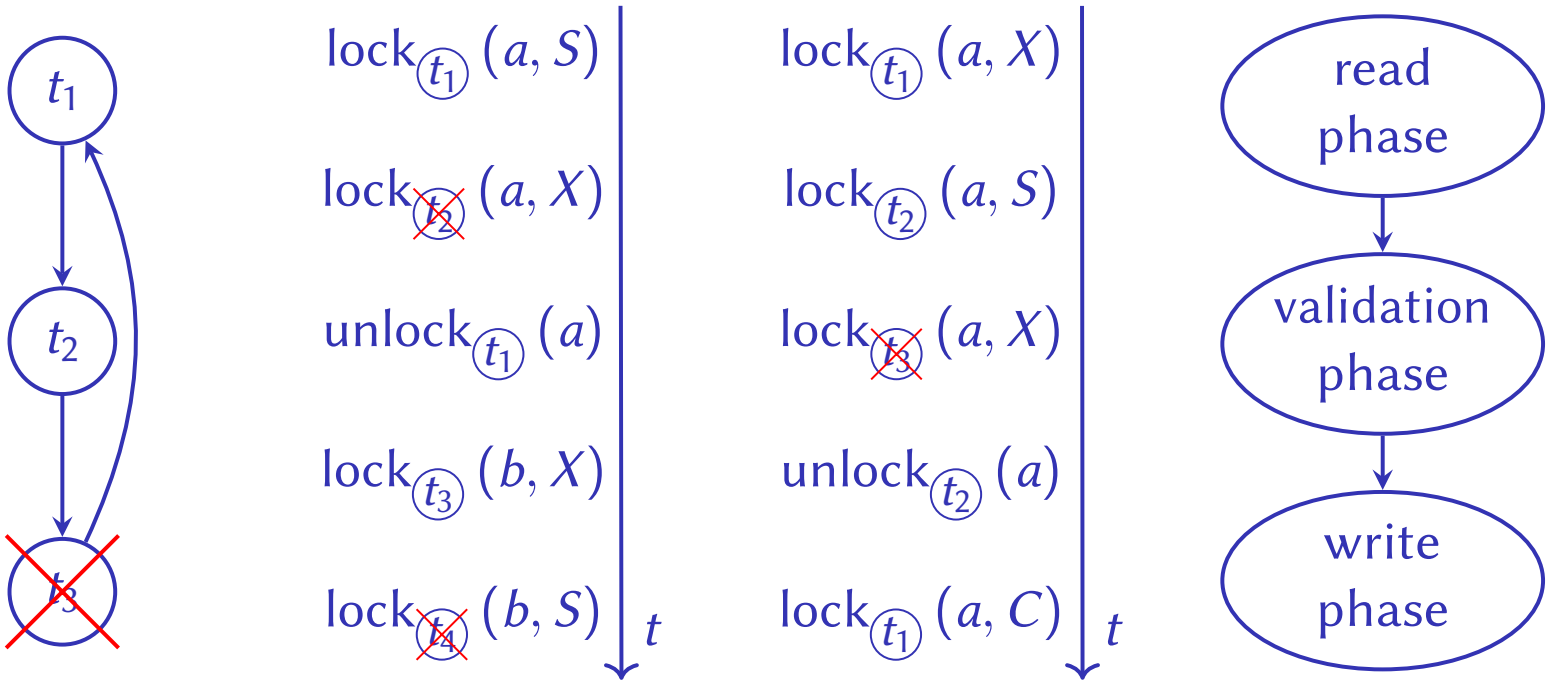
Architecture	Process Management		Transactional Storage Management	
	Parallelism	Thread Assignment	Logical Synchronization	
SE/NP	Shared Memory	thread-to-txn	CC Protocols	
PSE	Shared Nothing	thread-to-txn	Partition Lock	
Delegation	Message Passing	thread-to-txn	CC Protocols	
DORA	Shared Memory	thread-to-data	CC Protocols	

Summary

Architecture	Process Management		Transactional Storage Management	
	Parallelism	Thread Assignment	Logical Synchronization	Physical Synchronization
SE/NP	Shared Memory	thread-to-txn	CC Protocols	latch/-atomics
PSE	Shared Nothing	thread-to-txn	Partition Lock	partition lock
Delegation	Message Passing	thread-to-txn	CC Protocols	Message Passing
DORA	Shared Memory	thread-to-data	CC Protocols	Transaction Migration

Section 3

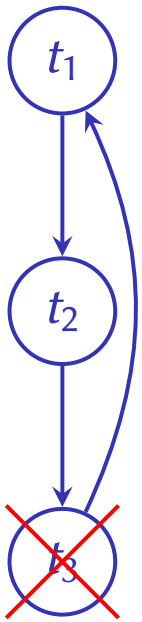
Concurrency Control Algorithms



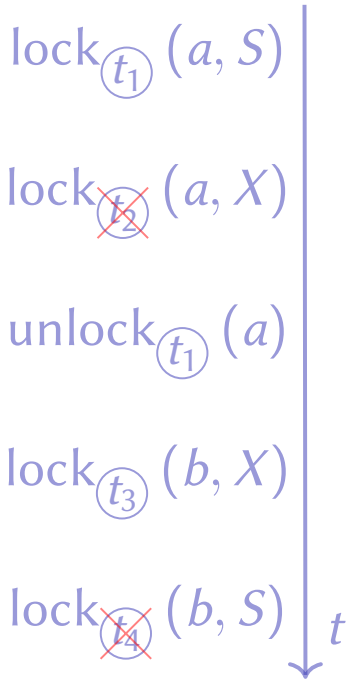
DL_DETECT (2PL) | NO_WAIT (No-Waiting-2PL) | 2V_NO_WAIT (Two-Version-2PL) | SILO (OCC)

Subsection 1

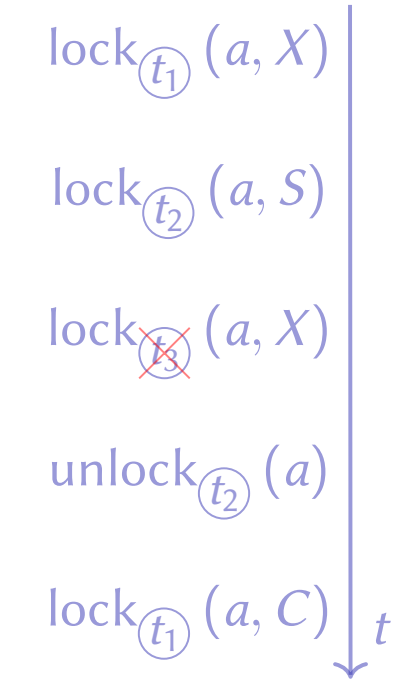
DL_DETECT (2PL)



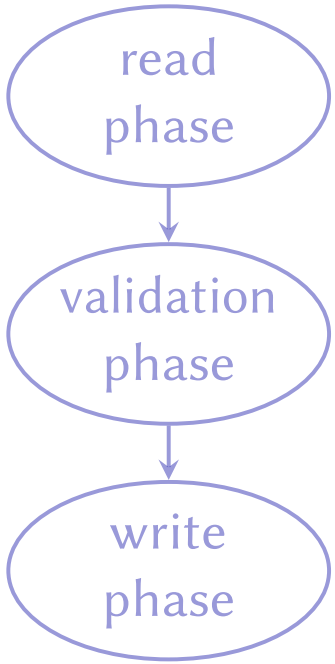
DL_DETECT
(2PL)



NO_WAIT
(No-Waiting-2PL)



2V_NO_WAIT
(Two-Version-2PL)



SILO
(OCC)

Properties of DL_DETECT (2PL)

- pessimistic concurrency control protocol
- transactions lock database objects (databases, tables, records, key ranges, etc.) before reading (shared mode S) or updating (exclusive mode X) them [Moh90]
- t_0 tries to acquire lock held by t_1 in compatible mode
  $\longrightarrow$ t_0 can immediately acquire lock as well (starvation needs to be prevented)
- t_0 tries to acquire lock held by t_1 in incompatible mode
  $\longrightarrow$ t_0 waits until t_1 releases lock
- deadlock detection using a repeatedly generated and analyzed wait-for graph

compatibility	shared mode	exclusive mode
shared mode	⊕	⊖
exclusive mode	⊖	⊖

Interactive Example

Transactions:

t_0 t_1 t_2

Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	NL	Current Mode:	NL	Current Mode:	NL	
Waiters:		Waiters:		Waiters:		
Data:	x_0	Data:	x_1	Data:	x_2	

Wait-for Graph:

Interactive Example

Transactions:

t_0 t_1 t_2

— BOT

Locks:

Record 0		Record 1		Record 2		⋯
Current Mode:	NL	Current Mode:	NL	Current Mode:	NL	
Waiters:		Waiters:		Waiters:		
Data:	x_0	Data:	x_1	Data:	x_2	

Wait-for Graph:

Interactive Example

Transactions:

t_0 t_1 t_2

BOT
r_0

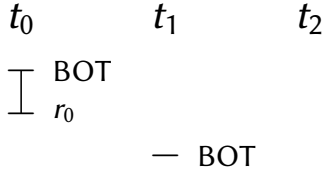
Locks:

Record 0		Record 1		Record 2		⋯
Current Mode:	S (1)	Current Mode:	NL	Current Mode:	NL	
Waiters:		Waiters:		Waiters:		
Data:	x_0	Data:	x_1	Data:	x_2	

Wait-for Graph:

Interactive Example

Transactions:



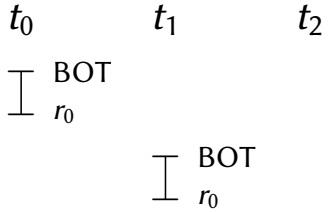
Locks:

Record 0		Record 1		Record 2		⋯
Current Mode:	S (1)	Current Mode:	NL	Current Mode:	NL	
Waiters:		Waiters:		Waiters:		
Data:	x_0	Data:	x_1	Data:	x_2	

Wait-for Graph:

Interactive Example

Transactions:



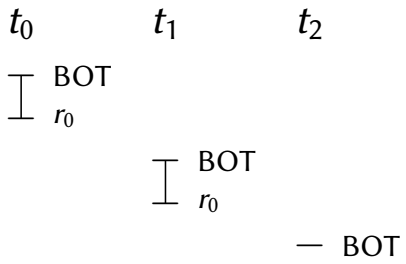
Locks:

Record 0		Record 1		Record 2		⋯
Current Mode:	S (2)	Current Mode:	NL	Current Mode:	NL	
Waiters:		Waiters:		Waiters:		
Data:	x_0	Data:	x_1	Data:	x_2	

Wait-for Graph:

Interactive Example

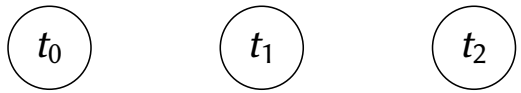
Transactions:



Locks:

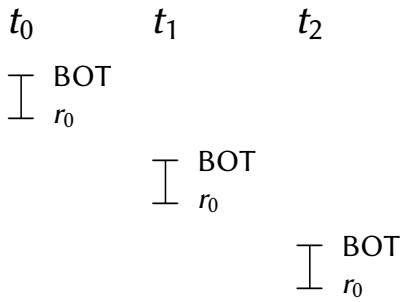
Record 0		Record 1		Record 2		⋯
Current Mode:	S (2)	Current Mode:	NL	Current Mode:	NL	
Waiters:		Waiters:		Waiters:		
Data:	x_0	Data:	x_1	Data:	x_2	

Wait-for Graph:



Interactive Example

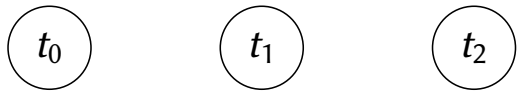
Transactions:



Locks:

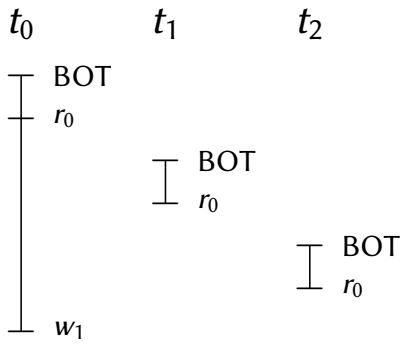
Record 0		Record 1		Record 2		⋯
Current Mode:	S (3)	Current Mode:	NL	Current Mode:	NL	
Waiters:		Waiters:		Waiters:		
Data:	x_0	Data:	x_1	Data:	x_2	

Wait-for Graph:



Interactive Example

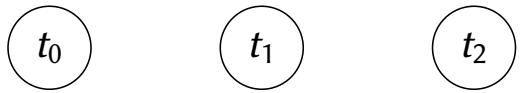
Transactions:



Locks:

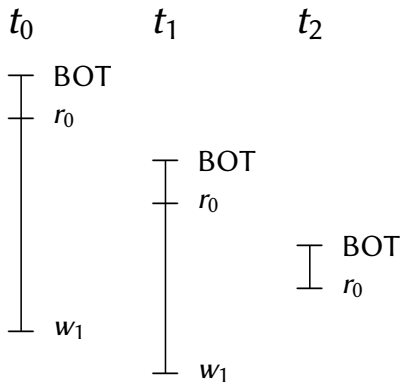
Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	S (3)	Current Mode:	X (t_0)	Current Mode:	NL	
Waiters:		Waiters:		Waiters:		
Data:	x_0	Data:	x_1	Data:	x_2	

Wait-for Graph:



Interactive Example

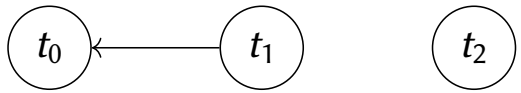
Transactions:



Locks:

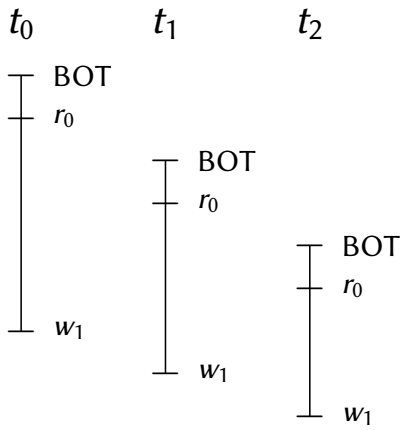
Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	S (3)	Current Mode:	X (t_0)	Current Mode:	NL	
Waiters:		Waiters:	(X, t_1)	Waiters:		
Data:	x_0	Data:	x_1'	Data:	x_2	

Wait-for Graph:



Interactive Example

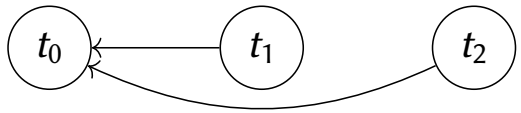
Transactions:



Locks:

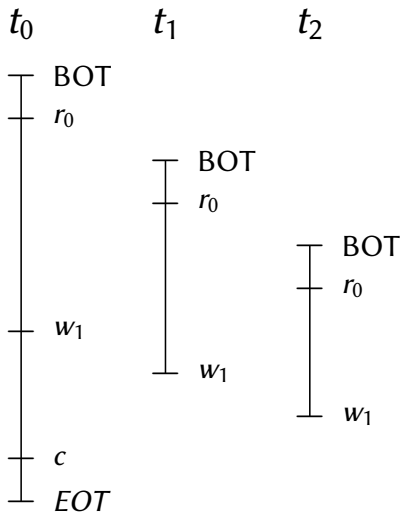
Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	S (3)	Current Mode:	X (t_0)	Current Mode:	NL	
Waiters:		Waiters:	(X, t_1)	Waiters:		
Data:	x_0		(X, t_2)	Data:	x_2	
		Data:	x_1'			

Wait-for Graph:



Interactive Example

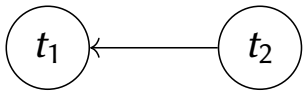
Transactions:



Locks:

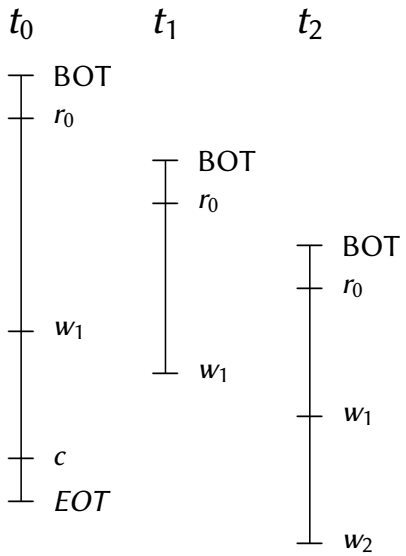
Record 0		Record 1		Record 2		⋯
Current Mode:	S (2)	Current Mode:	X (t_1)	Current Mode:	NL	
Waiters:		Waiters:	(X, t_2)	Waiters:		
Data:	x_0	Data:	x_1'	Data:	x_2	

Wait-for Graph:



Interactive Example

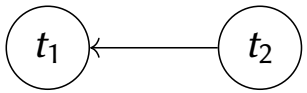
Transactions:



Locks:

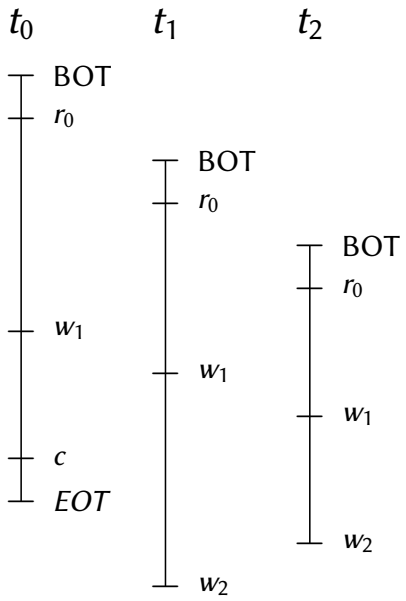
Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	S (2)	Current Mode:	X (t_1)	Current Mode:	X (t_2)	
Waiters:		Waiters:	(X, t_2)	Waiters:		
Data:	x_0	Data:	x_1''	Data:	x_2	

Wait-for Graph:



Interactive Example

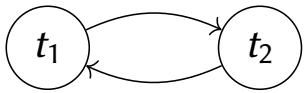
Transactions:



Locks:

Record 0		Record 1		Record 2		⋯
Current Mode:	S (2)	Current Mode:	X (t_1)	Current Mode:	X (t_2)	
Waiters:		Waiters:	(X, t_2)	Waiters:	(X, t_1)	
Data:	x_0	Data:	x_1''	Data:	x_2'	

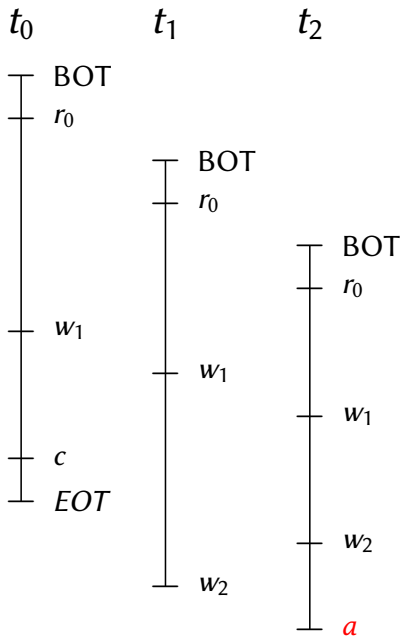
Wait-for Graph:



Cycle → Deadlock → Rollback a blocked Transaction

Interactive Example

Transactions:



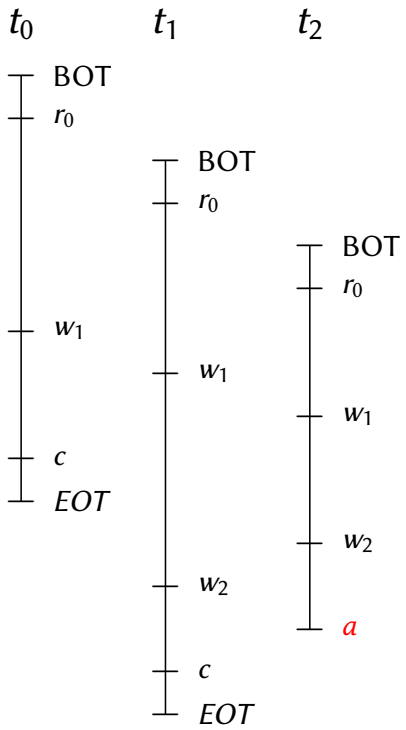
Locks:

Record 0		Record 1		Record 2		⋯
Current Mode:	S (1)	Current Mode:	X (t_1)	Current Mode:	X (t_1)	
Waiters:		Waiters:		Waiters:		
Data:	x_0	Data:	x_1''	Data:	x_2	

Wait-for Graph:

Interactive Example

Transactions:



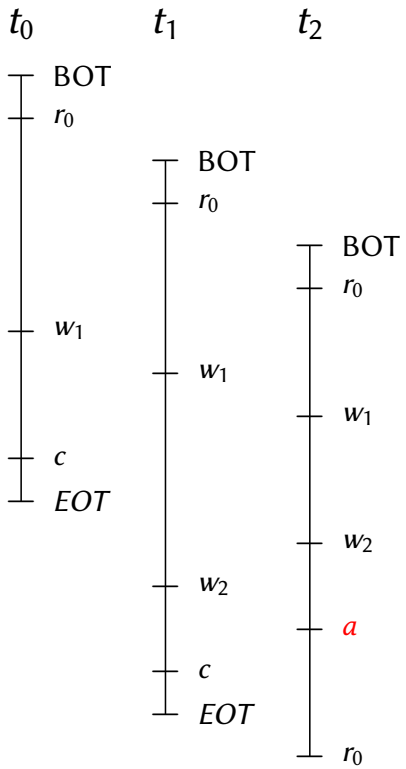
Locks:

Record 0		Record 1		Record 2		⋯
Current Mode:	NL	Current Mode:	NL	Current Mode:	NL	
Waiters:		Waiters:		Waiters:		
Data:	x_0	Data:	x_1''	Data:	x_2''	

Wait-for Graph:

Interactive Example

Transactions:



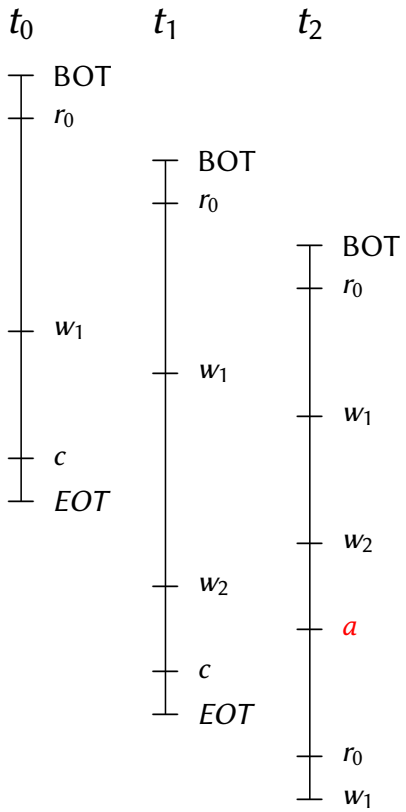
Locks:

Record 0		Record 1		Record 2		⋯
Current Mode:	S (1)	Current Mode:	NL	Current Mode:	NL	
Waiters:		Waiters:		Waiters:		
Data:	x_0	Data:	x_1''	Data:	x_2''	

Wait-for Graph:

Interactive Example

Transactions:



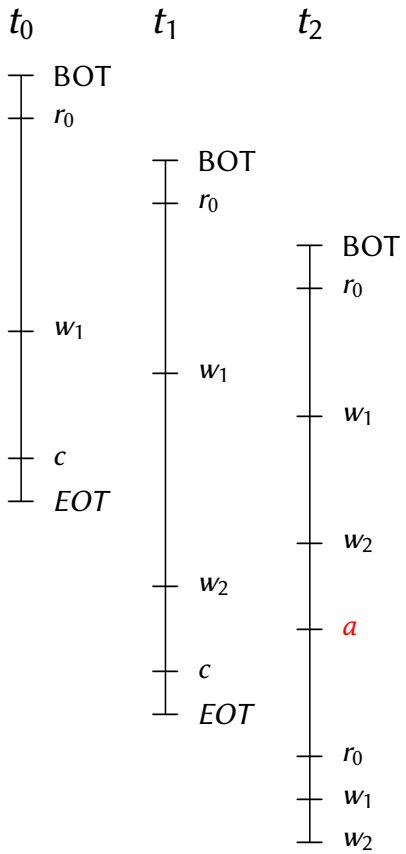
Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	S (1)	Current Mode:	X (t_2)	Current Mode:	NL	
Waiters:		Waiters:		Waiters:		
Data:	x_0	Data:	x_1''	Data:	x_2''	

Wait-for Graph:

Interactive Example

Transactions:



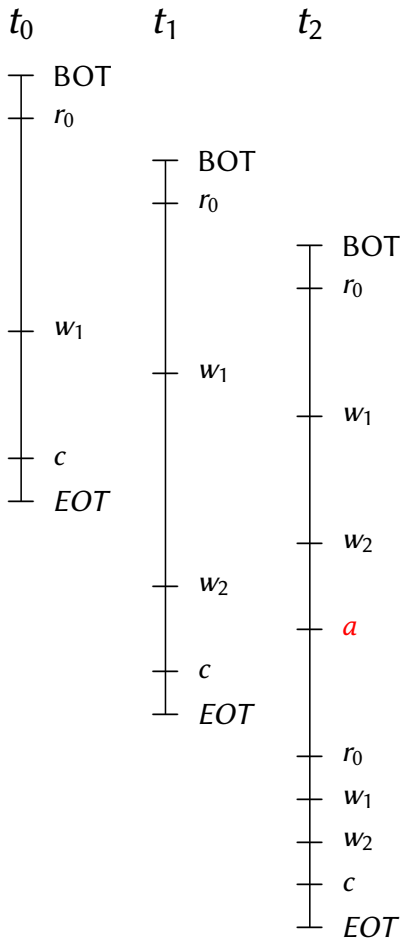
Locks:

Record 0		Record 1		Record 2		⋯
Current Mode:	S (1)	Current Mode:	X (t_2)	Current Mode:	X (t_2)	
Waiters:		Waiters:		Waiters:		
Data:	x_0	Data:	x_1'''	Data:	x_2''	

Wait-for Graph:

Interactive Example

Transactions:



Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	NL	Current Mode:	NL	Current Mode:	NL	
Waiters:		Waiters:		Waiters:		
Data:	x_0	Data:	x_1'''	Data:	x_2'	

Wait-for Graph:

Pros & Cons of DL_DETECT (2PL)

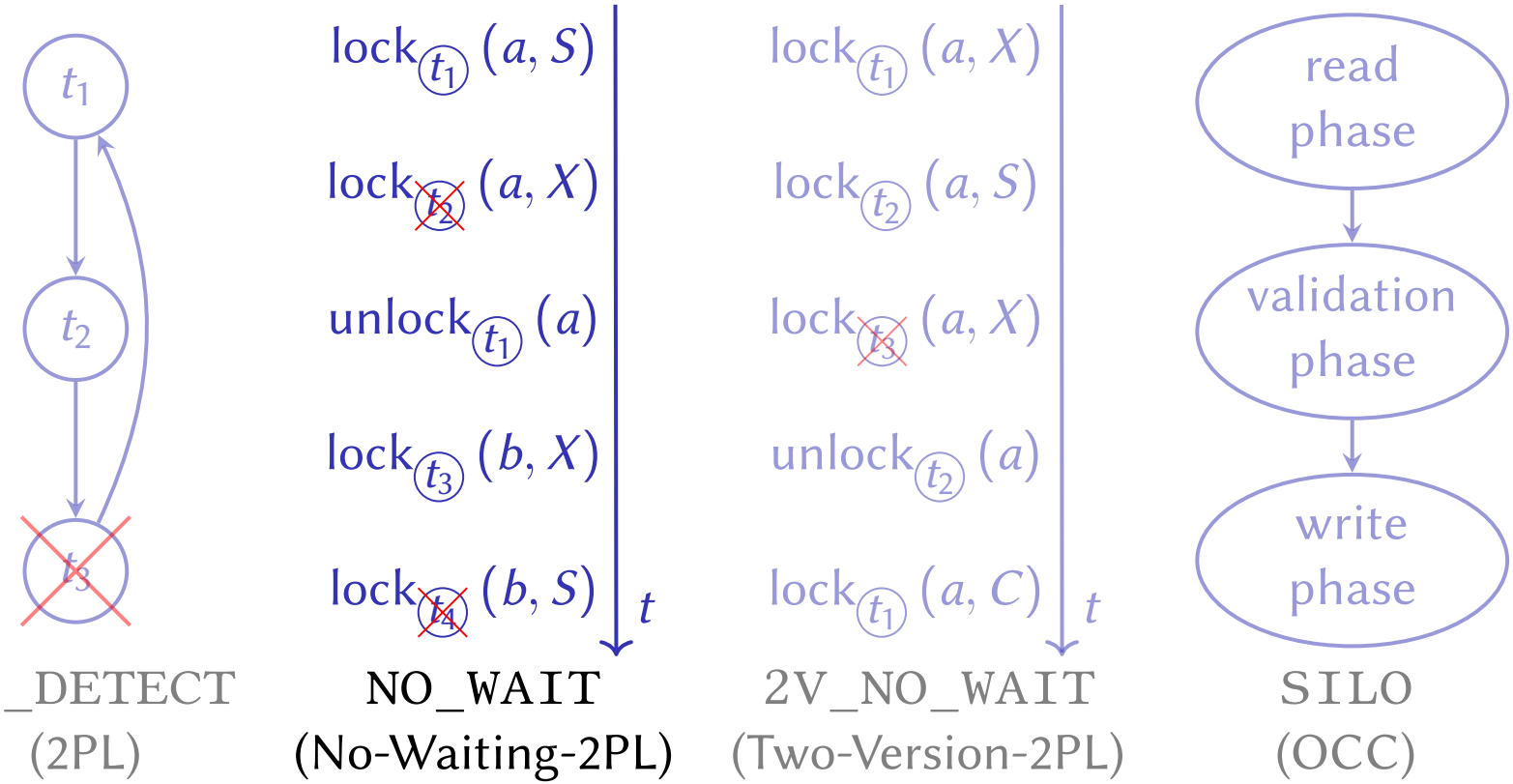
+ aborts only after deadlocks

Pros & Cons of DL_DETECT (2PL)

+ aborts only after deadlocks
- deadlocks are possible
- locks prevent concurrency too often (e.g. blind writes)
- calculation and analysis of wait-for graph expensive
  $\rightarrow$ done offline $\rightarrow$ transactions deadlocked for a while
- aborts happen
  $\rightarrow$ work done before needs to be repeated
- queue of waiters requires latching
  $\rightarrow$ limits scalability
- even writes need to acquire latches and wait

Subsection 2

NO_WAIT (No-Waiting-2PL)



DL_DETECT (2PL) | NO_WAIT (No-Waiting-2PL) | 2V_NO_WAIT (Two-Version-2PL) | SILO (OCC)

Properties of NO_WAIT (No-Waiting-2PL)

- pessimistic concurrency control protocol
- transactions lock database objects (databases, tables, records, key ranges, etc.) before reading (shared mode S) or updating (exclusive mode X) them [Moh90]
- t_0 tries to acquire lock held by t_1 in compatible mode
  $\longrightarrow$ t_0 can immediately acquire lock as well (starvation needs to be prevented)
- t_0 tries to acquire lock held by t_1 in incompatible mode
  $\longrightarrow$ t_0 aborts

compatibility	shared mode	exclusive mode
shared mode	⊕	⊖
exclusive mode	⊖	⊖

Interactive Example

Transactions:

t_0 t_1 t_2

Locks:

Record 0		**Record 1**		**Record 2**	
Current Mode:	0	Current Mode:	0	Current Mode:	0
Data:	x_0	Data:	x_1	Data:	x_2

$\cdots$

Interactive Example

Transactions:

t_0 t_1 t_2

— BOT

Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	0	Current Mode:	0	Current Mode:	0	
Data:	x_0	Data:	x_1	Data:	x_2	

Interactive Example

Transactions:

t_0 t_1 t_2

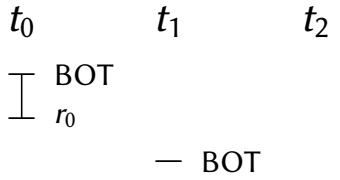
BOT
r_0

Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	2	Current Mode:	0	Current Mode:	0	
Data:	x_0	Data:	x_1	Data:	x_2	

Interactive Example

Transactions:

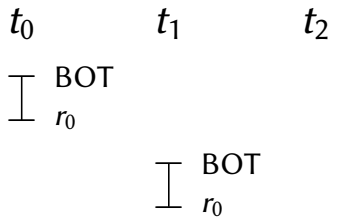


Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	2	Current Mode:	0	Current Mode:	0	
Data:	x_0	Data:	x_1	Data:	x_2	

Interactive Example

Transactions:

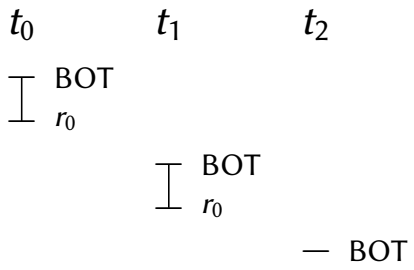


Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	4	Current Mode:	0	Current Mode:	0	
Data:	x_0	Data:	x_1	Data:	x_2	

Interactive Example

Transactions:

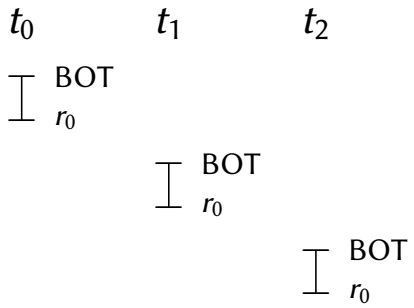


Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	4	Current Mode:	0	Current Mode:	0	
Data:	x_0	Data:	x_1	Data:	x_2	

Interactive Example

Transactions:

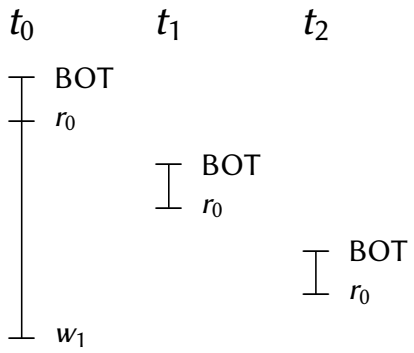


Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	6	Current Mode:	0	Current Mode:	0	
Data:	x_0	Data:	x_1	Data:	x_2	

Interactive Example

Transactions:

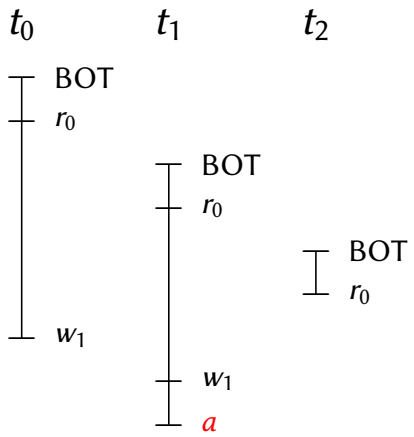


Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	6	Current Mode:	1	Current Mode:	0	
Data:	x_0	Data:	x_1	Data:	x_2	

Interactive Example

Transactions:

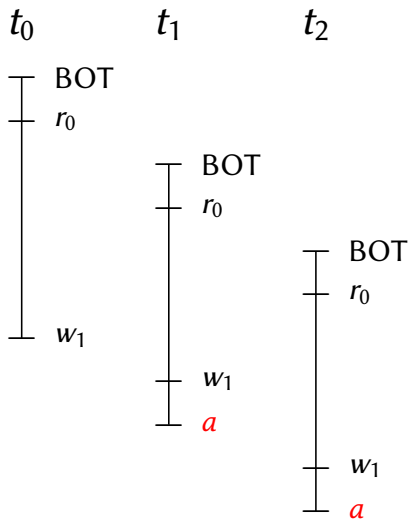


Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	4	Current Mode:	1	Current Mode:	0	
Data:	x_0	Data:	x_1'	Data:	x_2	

Interactive Example

Transactions:

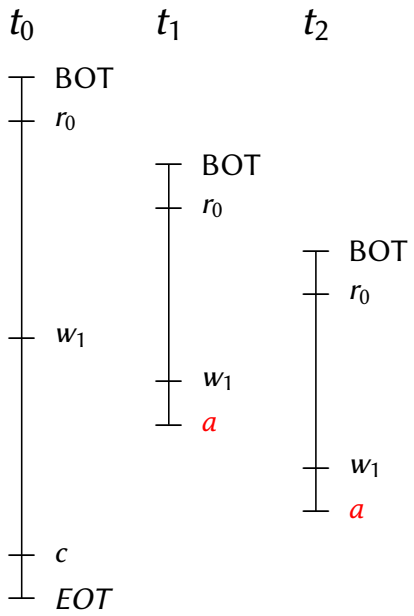


Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	2	Current Mode:	1	Current Mode:	0	
Data:	x_0	Data:	x_1'	Data:	x_2	

Interactive Example

Transactions:

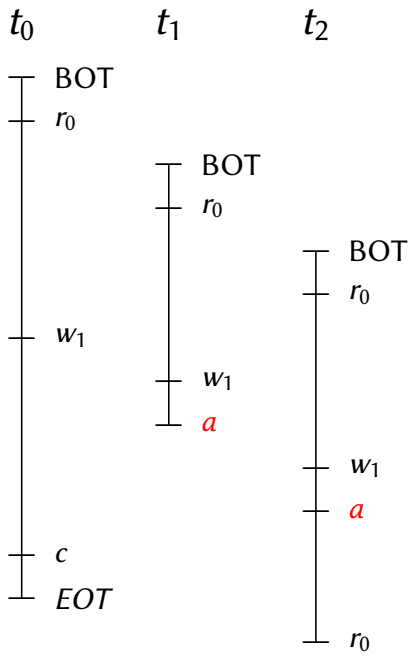


Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	0	Current Mode:	0	Current Mode:	0	
Data:	x_0	Data:	x_1'	Data:	x_2	

Interactive Example

Transactions:

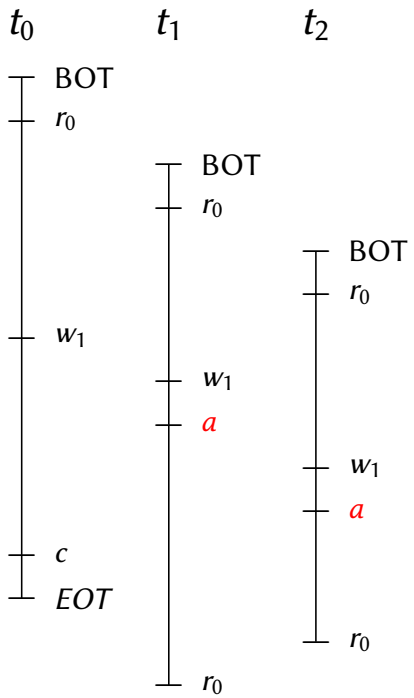


Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	2	Current Mode:	0	Current Mode:	0	
Data:	x_0	Data:	x_1'	Data:	x_2	

Interactive Example

Transactions:

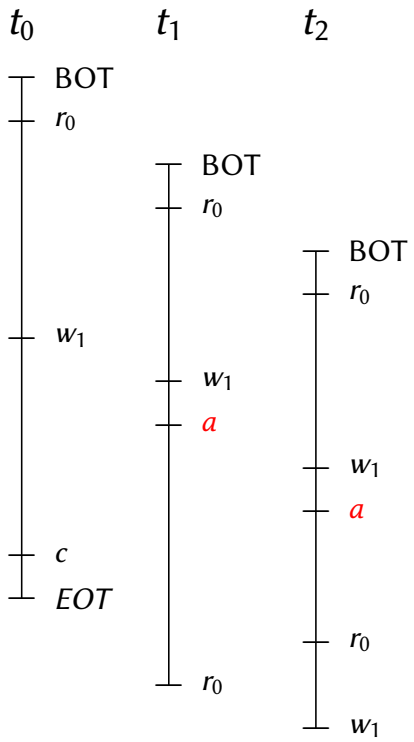


Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	4	Current Mode:	0	Current Mode:	0	
Data:	x_0	Data:	x_1'	Data:	x_2	

Interactive Example

Transactions:

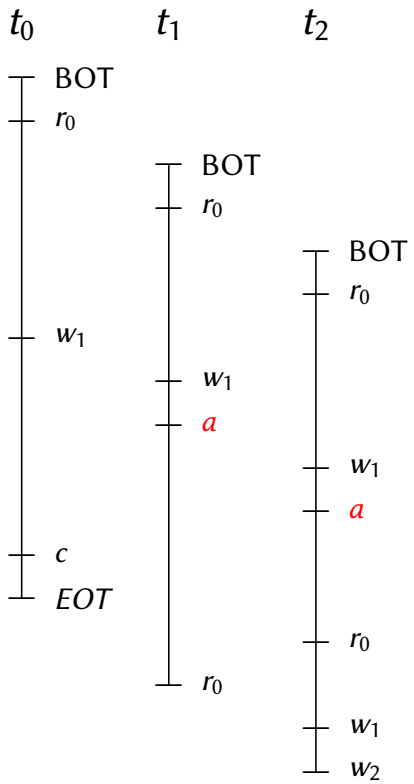


Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	4	Current Mode:	1	Current Mode:	0	
Data:	x_0	Data:	x_1'	Data:	x_2	

Interactive Example

Transactions:

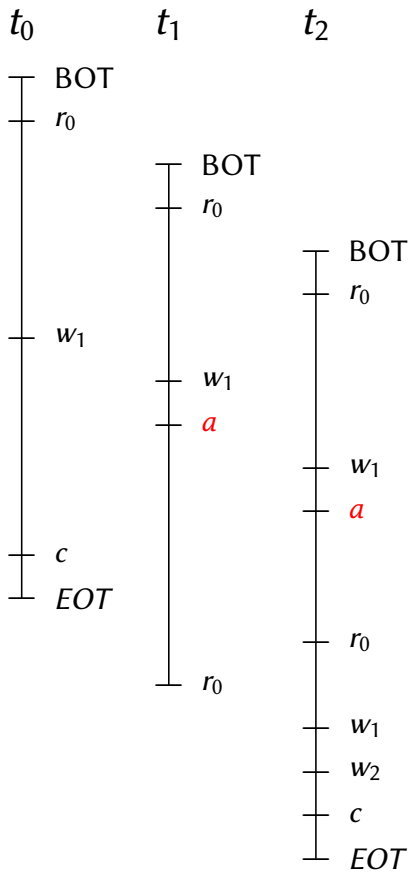


Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	4	Current Mode:	1	Current Mode:	1	
Data:	x_0	Data:	x_1''	Data:	x_2	

Interactive Example

Transactions:

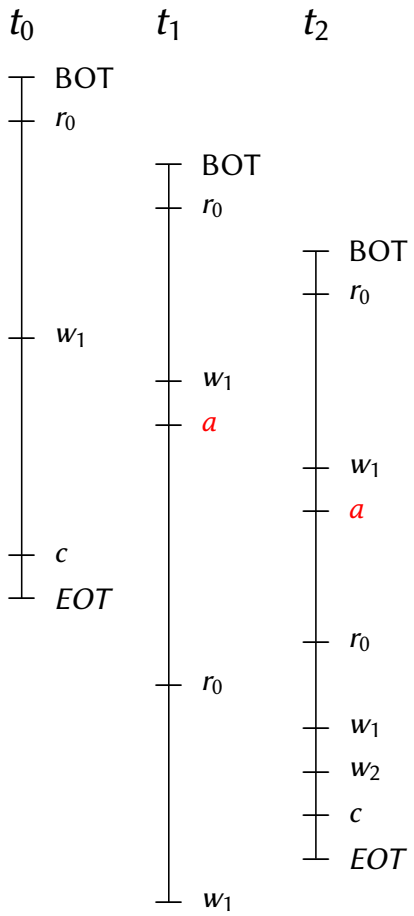


Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	2	Current Mode:	0	Current Mode:	0	
Data:	x_0	Data:	x_1''	Data:	x_2'	

Interactive Example

Transactions:

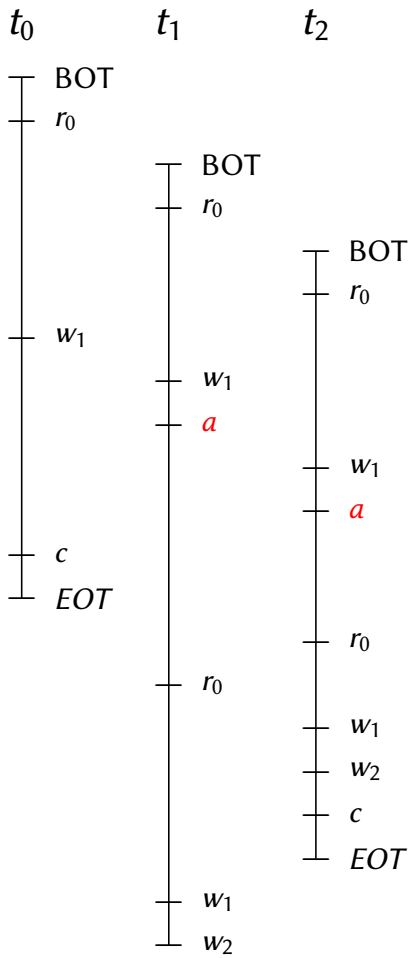


Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	2	Current Mode:	1	Current Mode:	0	
Data:	x_0	Data:	x_1''	Data:	x_2'	

Interactive Example

Transactions:

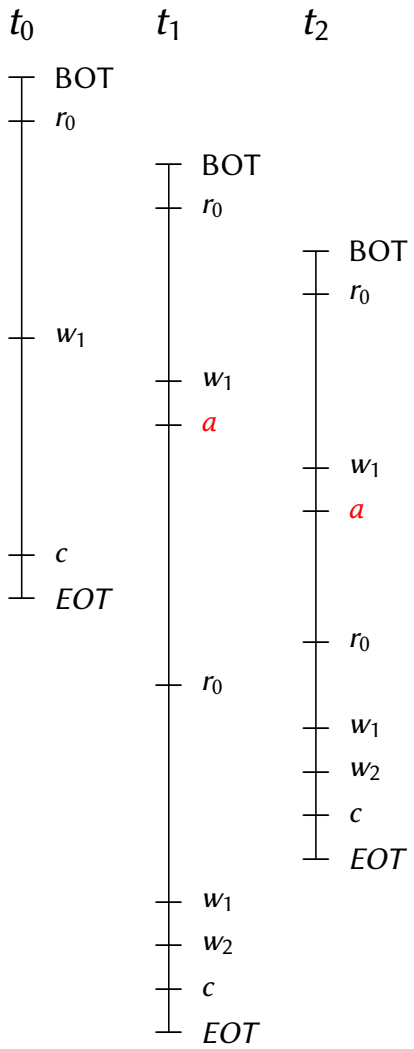


Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	2	Current Mode:	1	Current Mode:	1	
Data:	x_0	Data:	x_1'''	Data:	x_2'	

Interactive Example

Transactions:



Locks:

Record 0		**Record 1**		**Record 2**		⋯
Current Mode:	0	Current Mode:	0	Current Mode:	0	
Data:	x_0	Data:	x_1'''	Data:	x_2''	

Pros & Cons of NO_WAIT (No-Waiting-2PL)

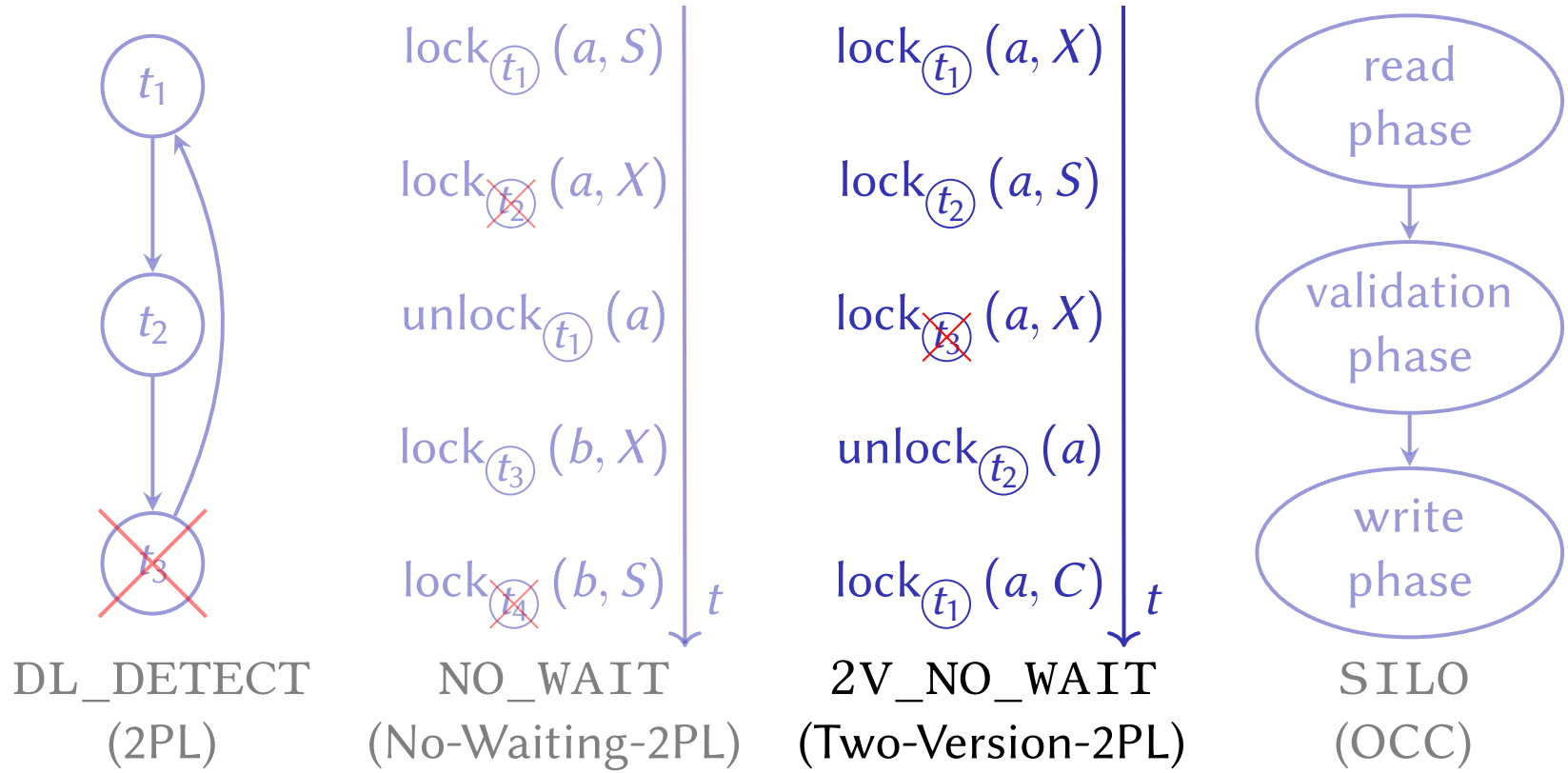
+ deadlocks are impossible
+ locks can be implemented using a semaphore and atomics
  $\rightarrow$ scales better than latches
+ no need to expensively calculate and analysis a wait-for graph

Pros & Cons of NO_WAIT (No-Waiting-2PL)

+ deadlocks are impossible
+ locks can be implemented using a semaphore and atomics
  $\longrightarrow$ scales better than latches
+ no need to expensively calculate and analysis a wait-for graph
− many lock conflicts for update-intensive high-contention workloads
  $\longrightarrow$ many aborts $\longrightarrow$ work done before needs to be repeated
− locks prevent concurrency too often (e.g. blind writes)

Subsection 3

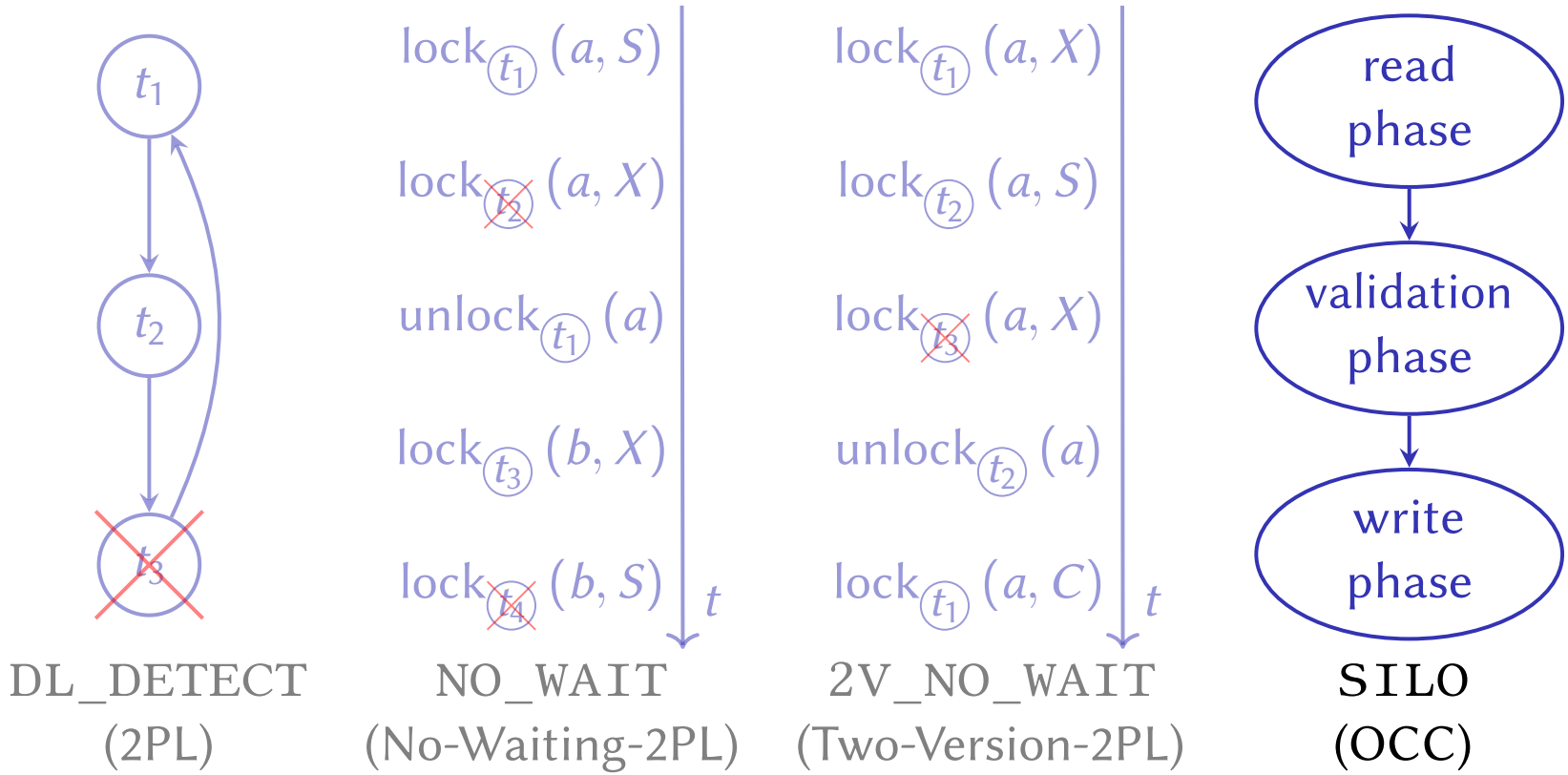
2V_NO_WAIT (Two-Version-2PL)



DL_DETECT (2PL) | NO_WAIT (No-Waiting-2PL) | 2V_NO_WAIT (Two-Version-2PL) | SILO (OCC)

Subsection 4

SILO (OCC)



DL_DETECT (2PL) | NO_WAIT (No-Waiting-2PL) | 2V_NO_WAIT (Two-Version-2PL) | SILO (OCC)

Section 4

Performance Evaluation

	SE/NP	DORA	Delegation	PSE
DL_DETECT	⊕	⊕	⊕	⊙
NO_WAIT	⊕	⊕	⊕	
2V_NO_WAIT	⊕	⊕	⊕	
SILO	⊕	⊖	⊕	

Evaluation Set-Up

- 4x Intel Xeon E7-8890 v3 NUMA machine (72 cores @ 2.5 GHz)
- 32 kB L1I cache and 32 kB L1D cache per core
- 256 kB L2 cache per core
- 45 MB L3 cache per CPU
- 512 GB DDR4 RAM
- hyperThreading not used
- threads pinned to physical cores
- sockets filled sequentially with threads

Benchmarks

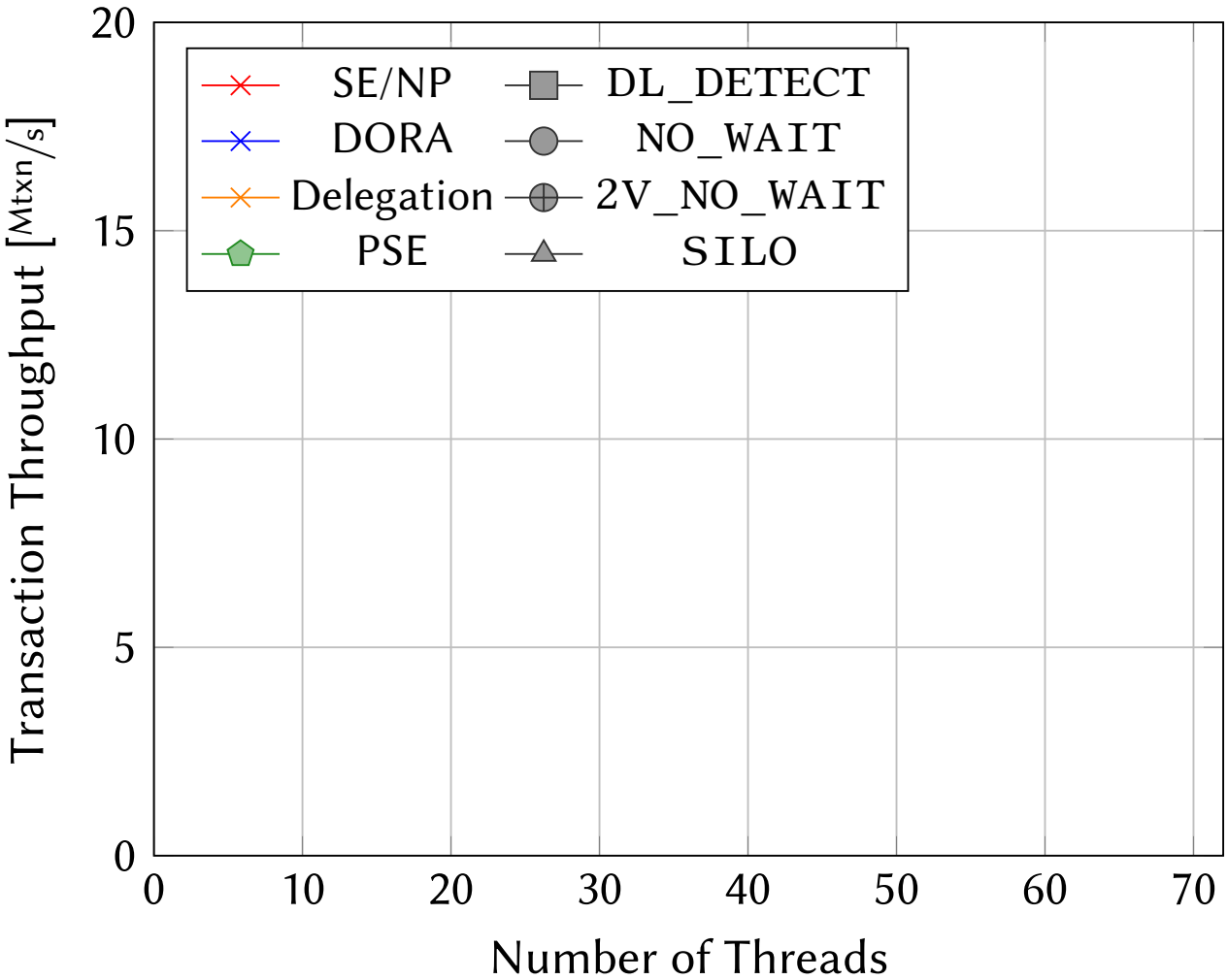
Microbenchmark

- 13 GB database
- Hot Set: 16 records *distributed to 16 partitions*
- Cold Set: 100 000 000 − 16 records
- Txn: 2 accesses to Hot Set & 8 accesses to *(thread-local)* Cold Set

Yahoo! Cloud Serving Benchmark (YCSB)

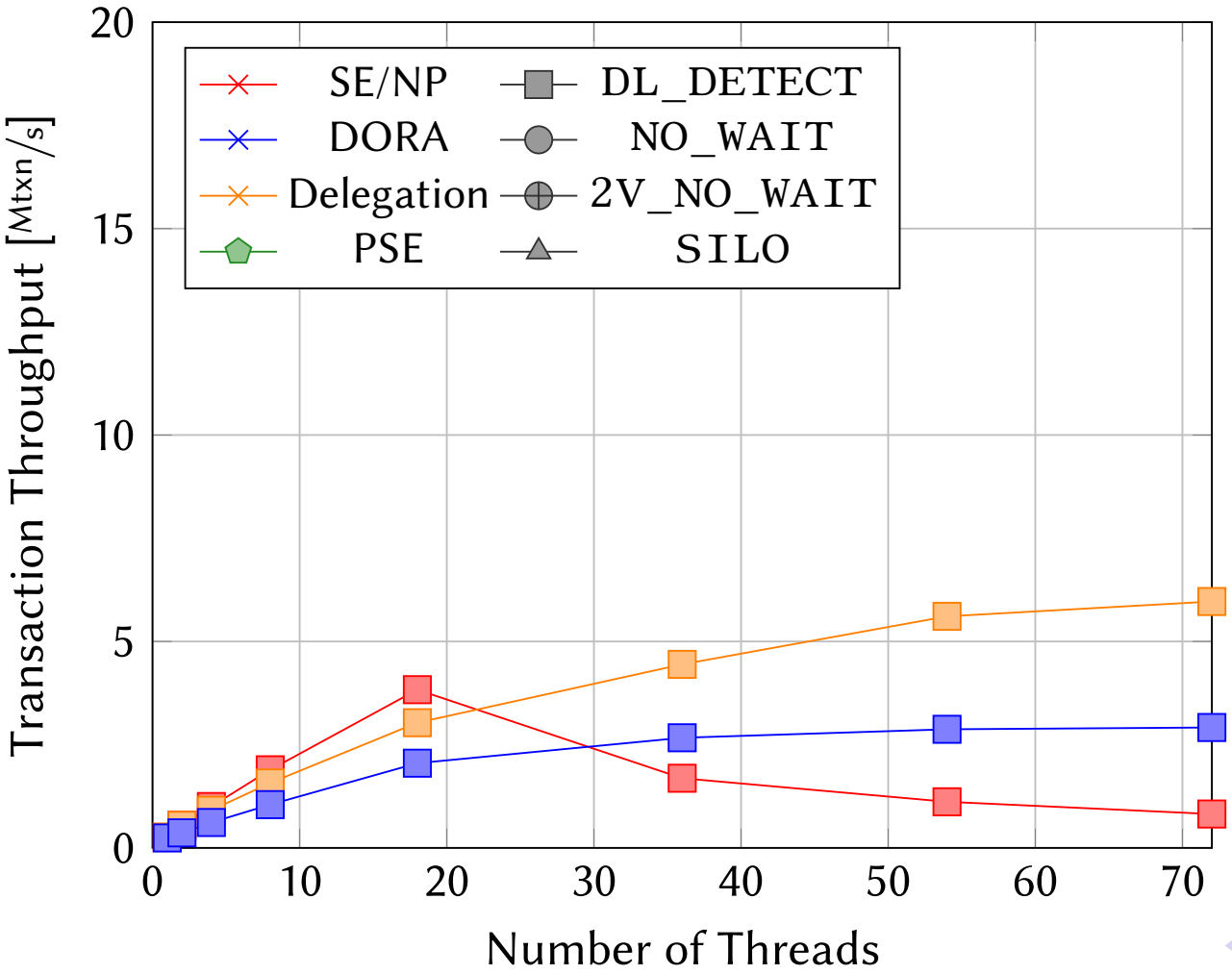
- 20 GB database
- 20 000 000 records
- Txn: reads/updates 16 records following Zipfian distribution according to parameter Θ

Read-Only Microbenchmark



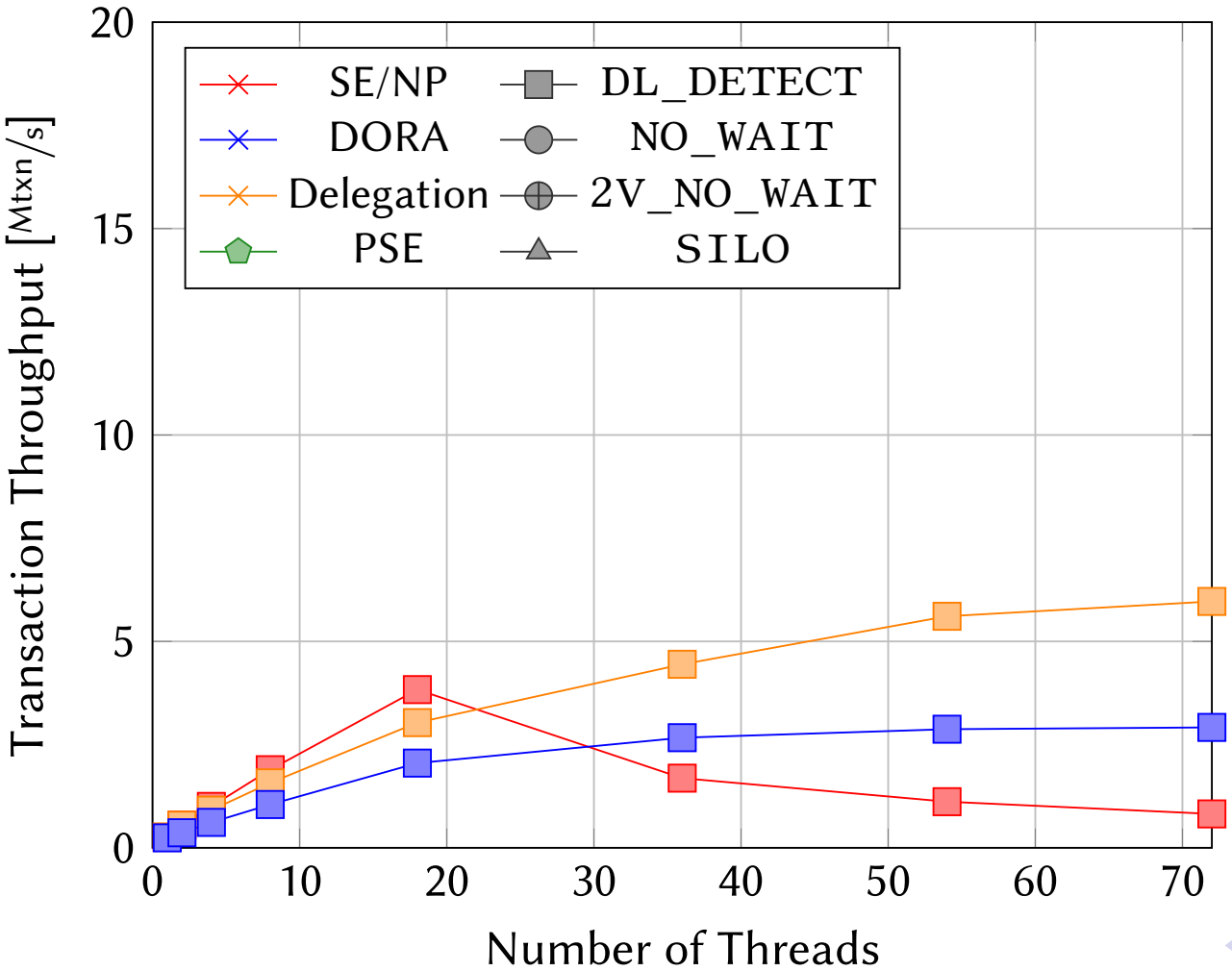
Observations

Read-Only Microbenchmark



Observations

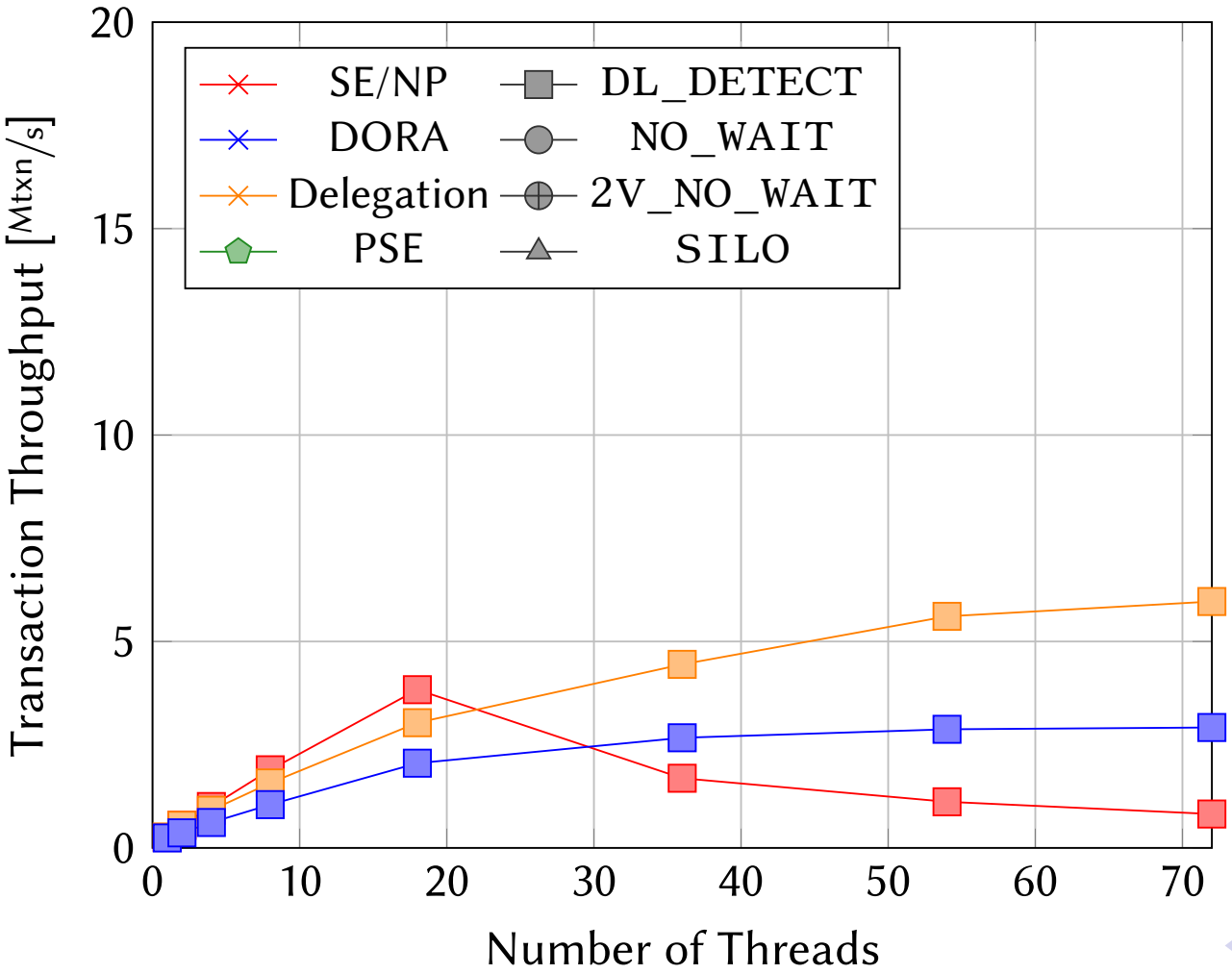
Read-Only Microbenchmark



Observations

- ✳/✳ suffer from remote data access overhead

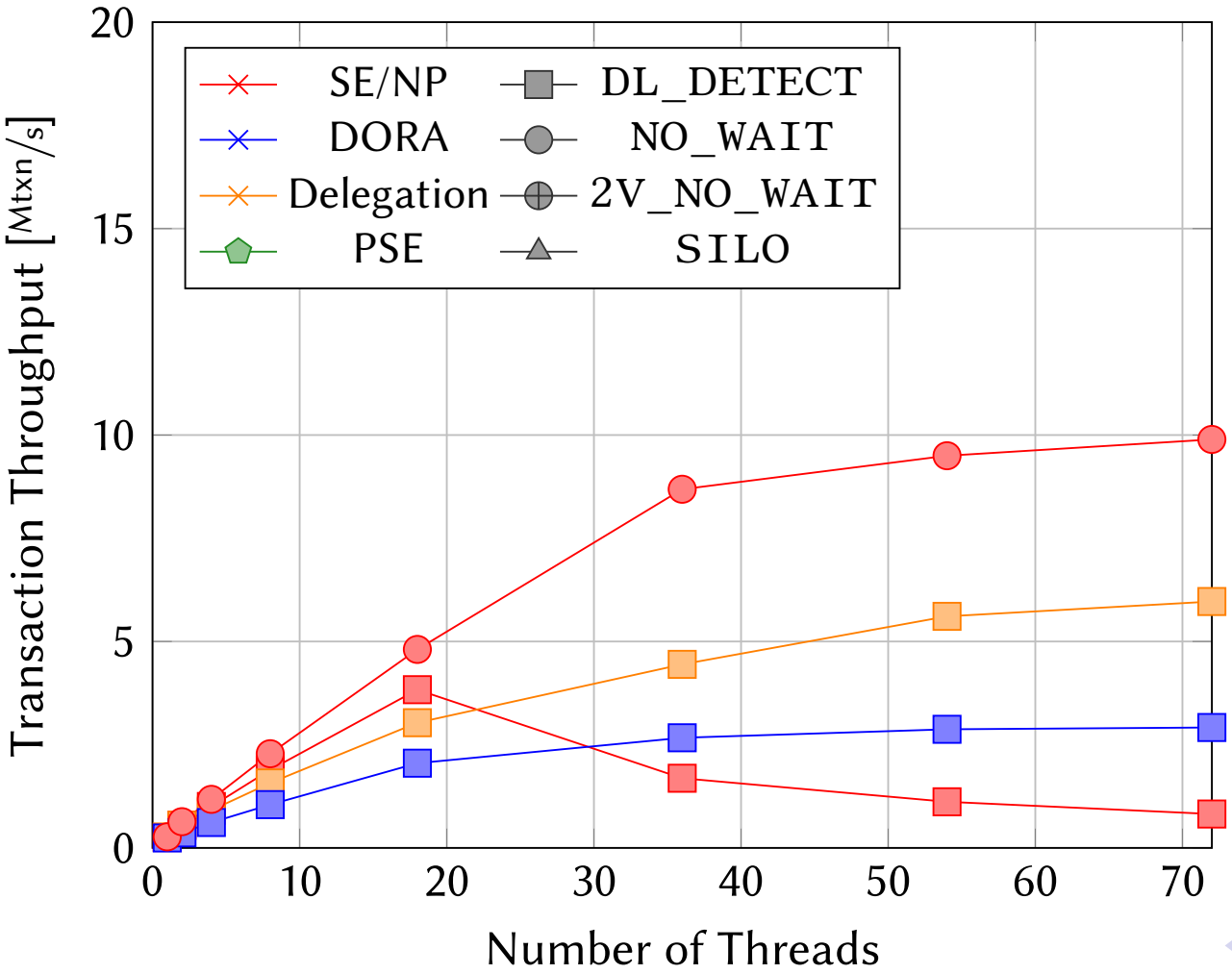
Read-Only Microbenchmark



Observations

- ✳/✳ suffer from remote data access overhead
- ✳ suffers from latch contention on locks

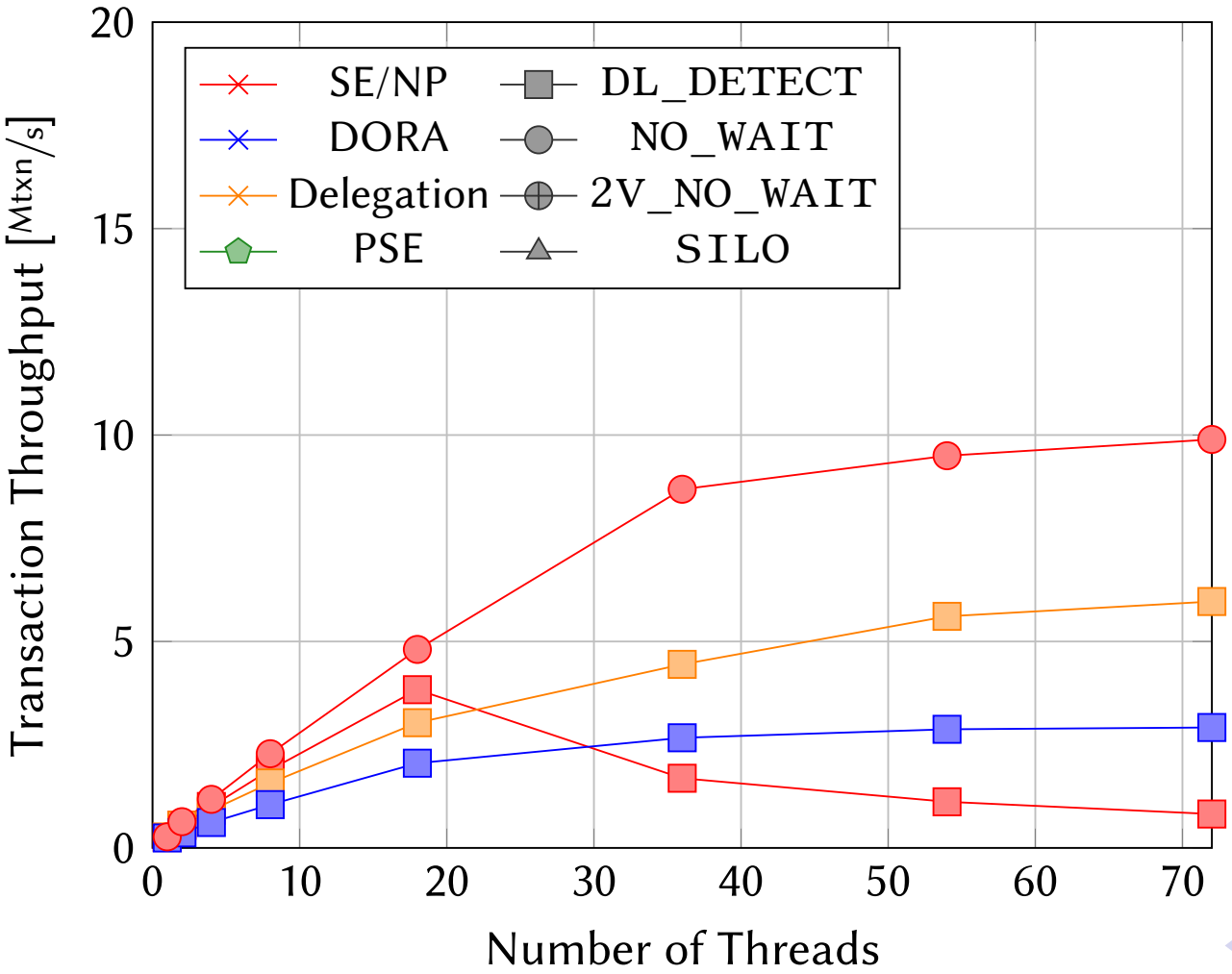
Read-Only Microbenchmark



Observations

- ✳/✳ suffer from remote data access overhead
- ✳ suffers from latch contention on locks

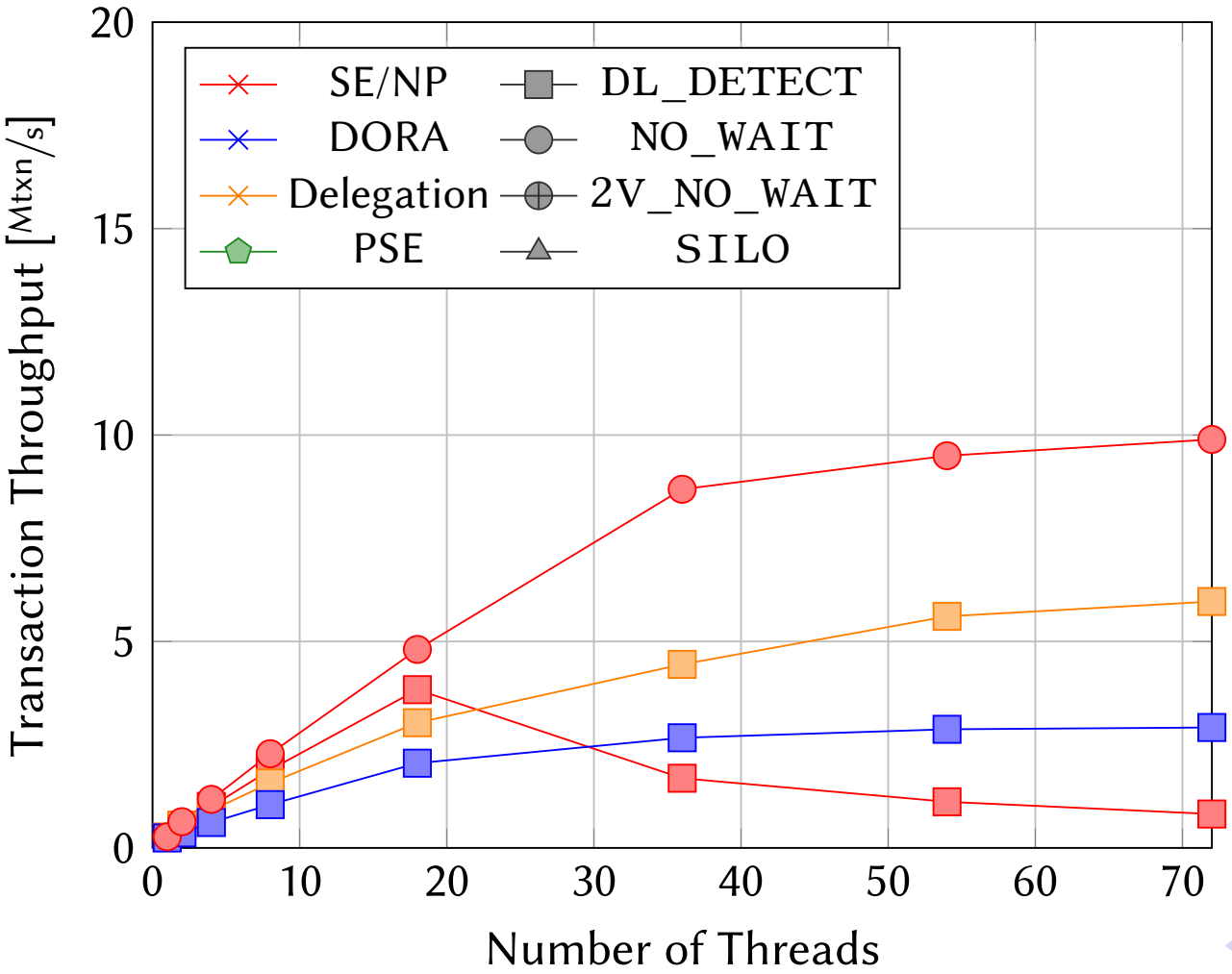
Read-Only Microbenchmark



Observations

- ✳/✳ suffer from remote data access overhead
- ✳ suffers from latch contention on locks
- atomics of ● outperform latches of ■

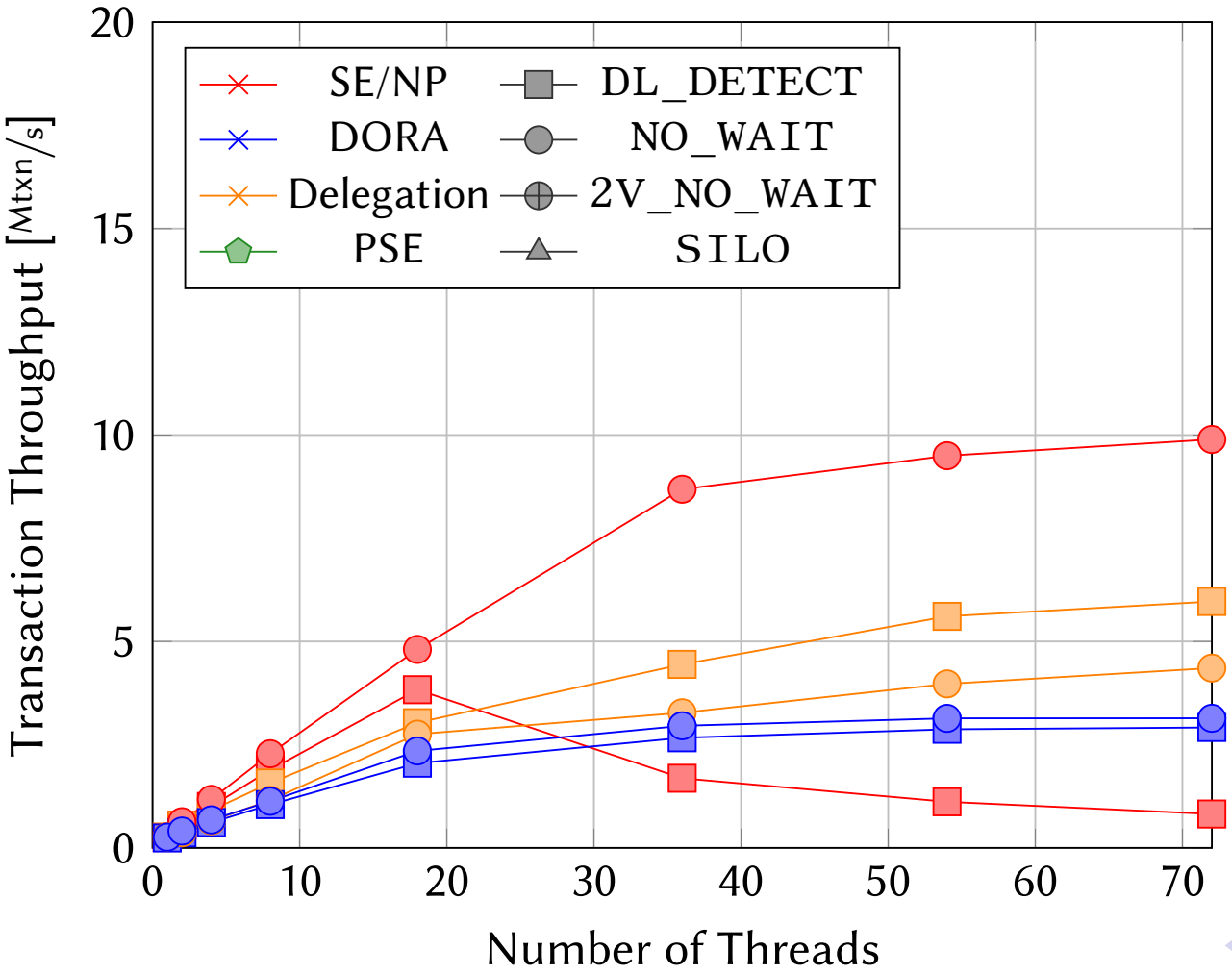
Read-Only Microbenchmark



Observations

- ✳/✳ suffer from remote data access overhead
- ✳ suffers from latch contention on locks
- atomics of ● outperform latches of ■
- scaling of ● limited by hardware cache coherence mechanism

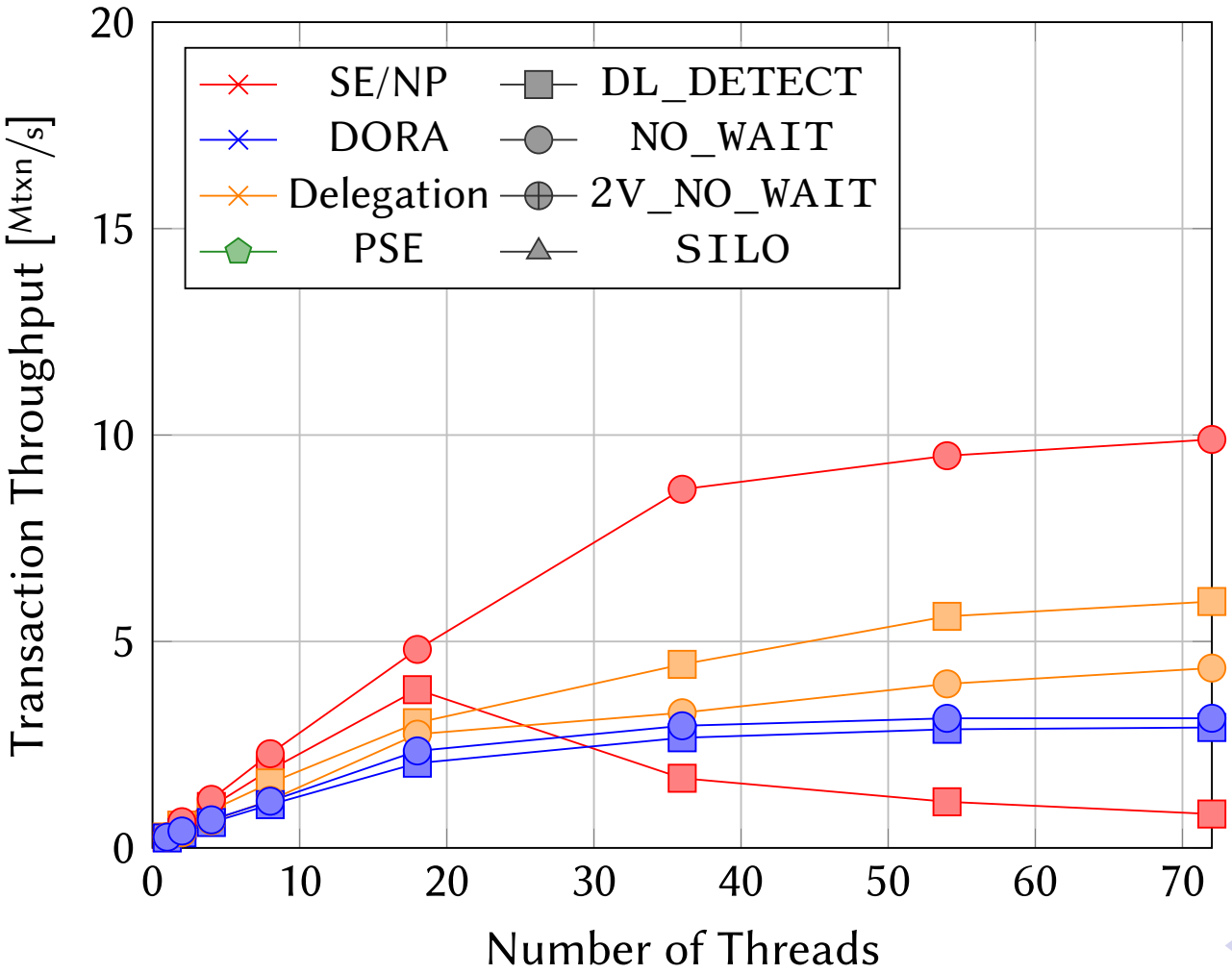
Read-Only Microbenchmark



Observations

- ✳/✳ suffer from remote data access overhead
- ✳ suffers from latch contention on locks
- atomics of ● outperform latches of ■
- scaling of ● limited by hardware cache coherence mechanism

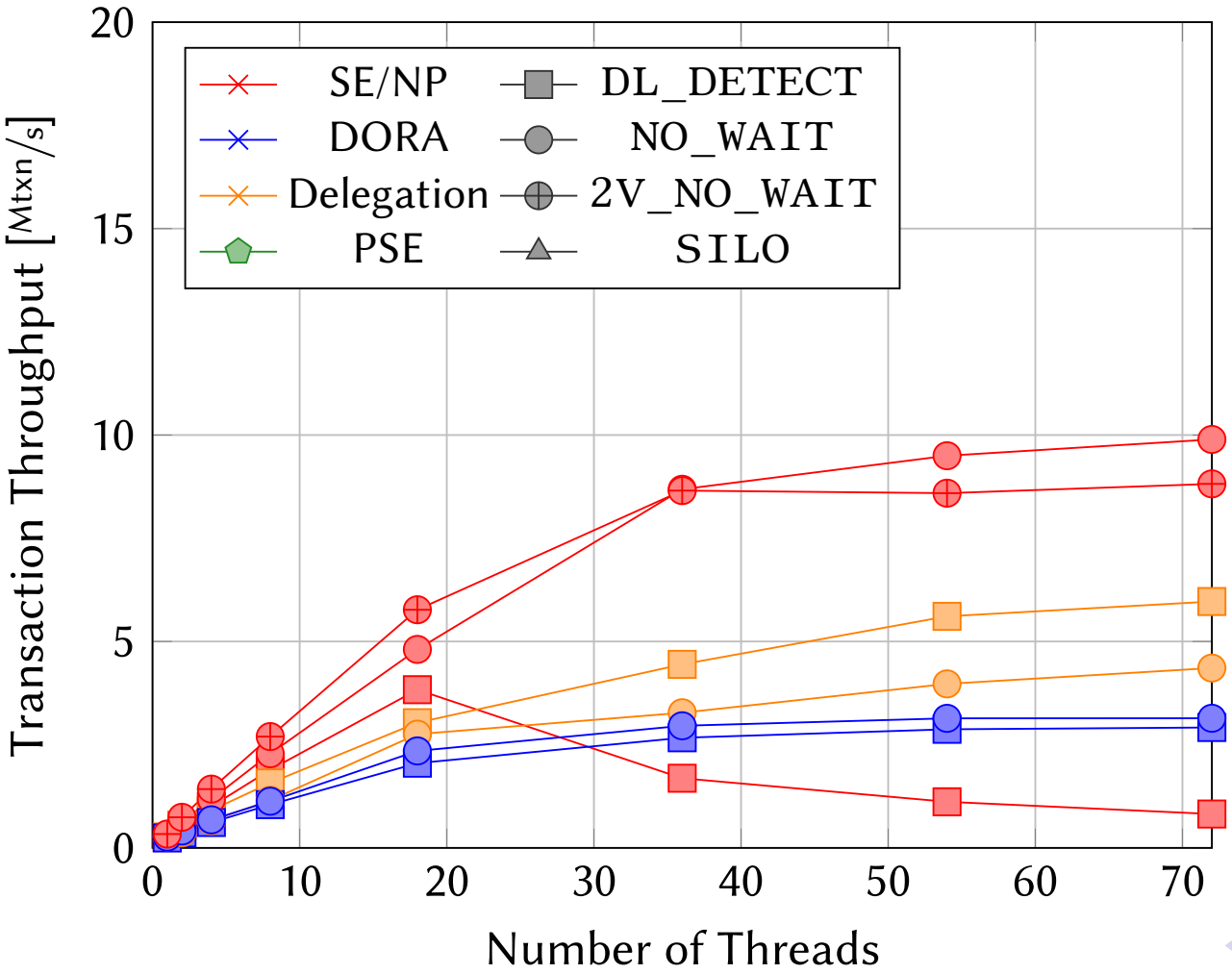
Read-Only Microbenchmark



Observations

- ✕ suffers from latch contention on locks
- atomics of ● outperform latches of ■
- scaling of ● limited by hardware cache coherence mechanism
- ✕/✕ suffer more from remote data accesses than ✕ suffers from cache coherence

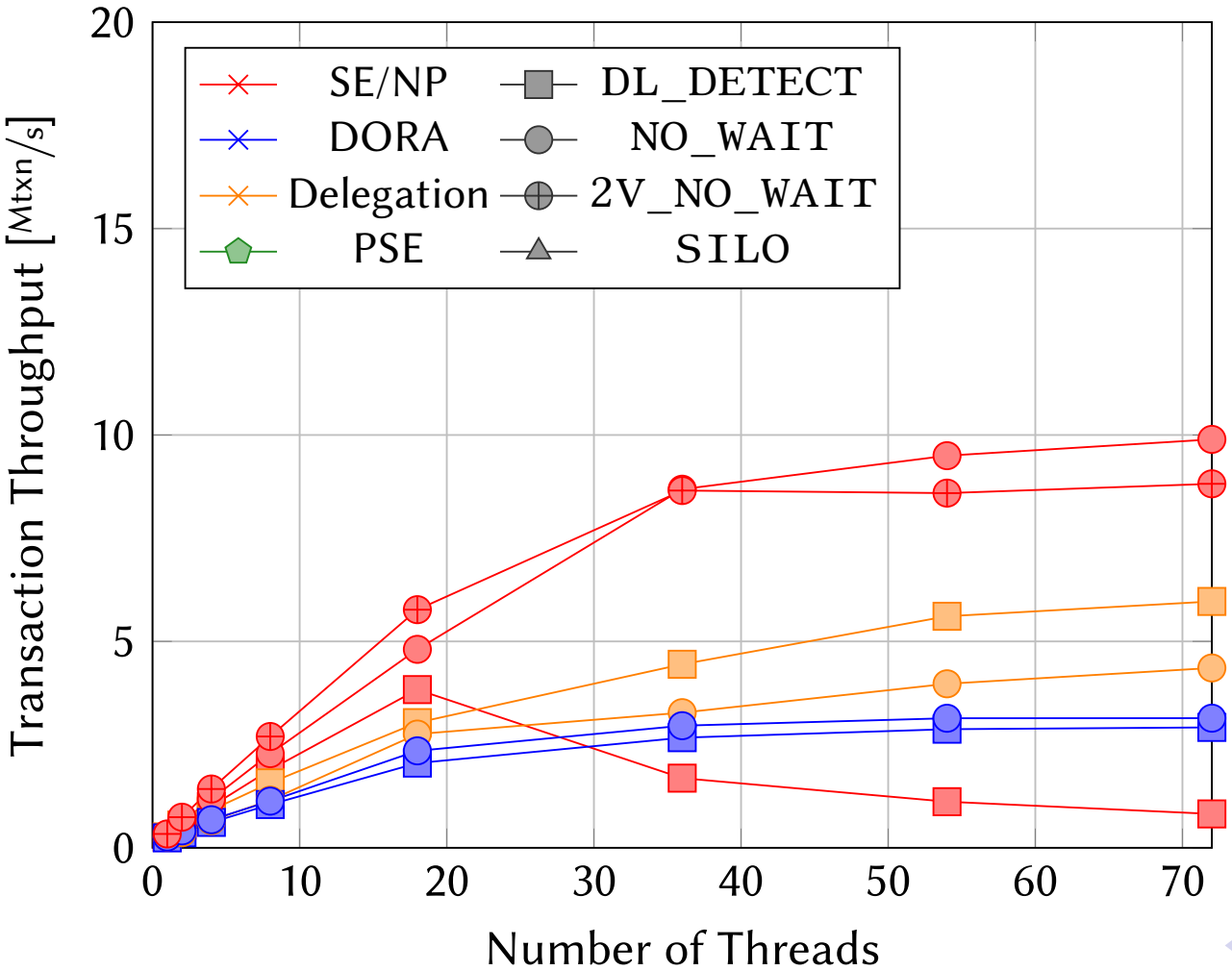
Read-Only Microbenchmark



Observations

- ✕ suffers from latch contention on locks
- atomics of ● outperform latches of ■
- scaling of ● limited by hardware cache coherence mechanism
- ✕/✕ suffer more from remote data accesses than ✕ suffers from cache coherence

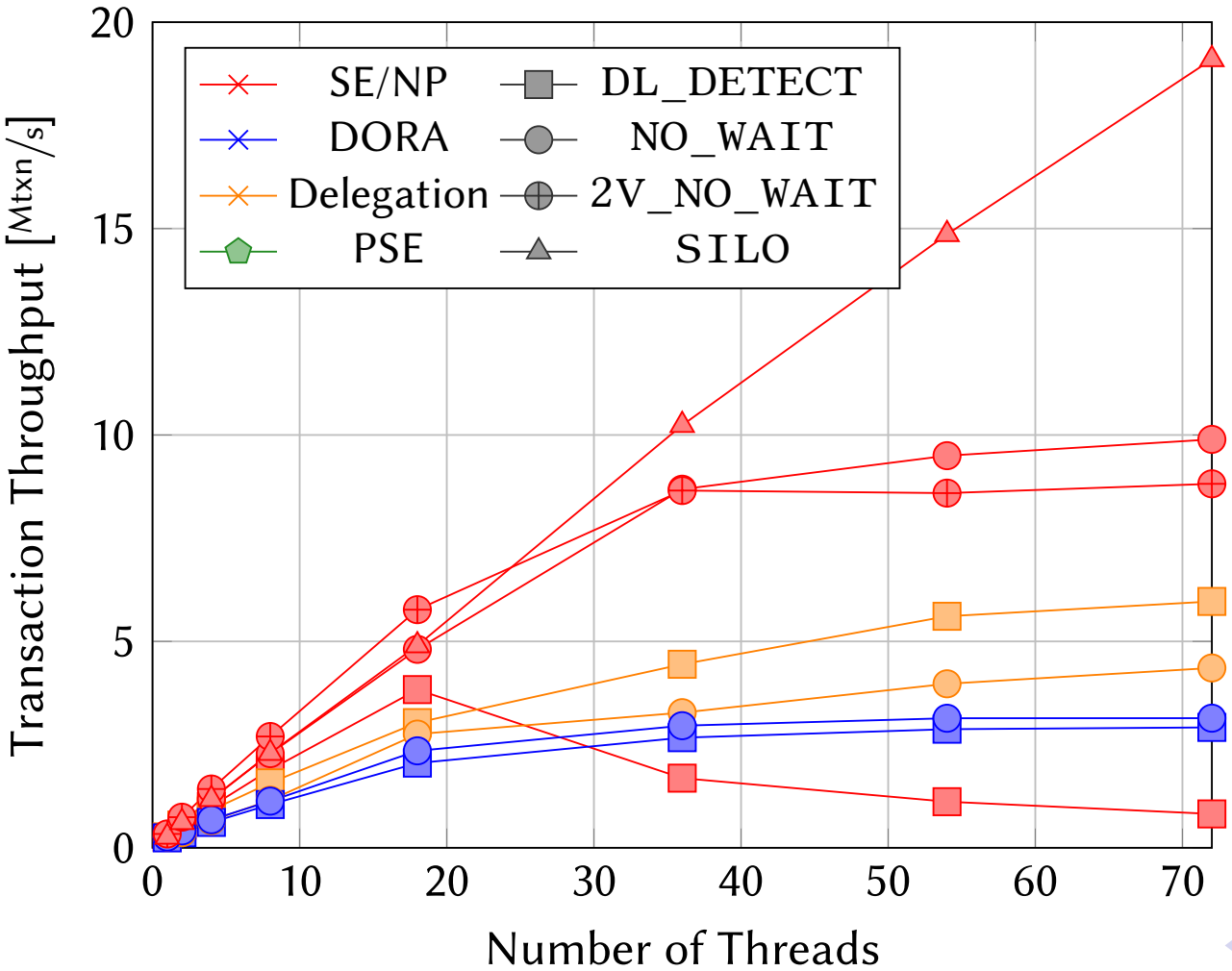
Read-Only Microbenchmark



Observations

- atomics of ● outperform latches of ■
- scaling of ● limited by hardware cache coherence mechanism
- ✳/✳ suffer more from remote data accesses than ✳ suffers from cache coherence
- ⊕ and ● perform identical for read-only

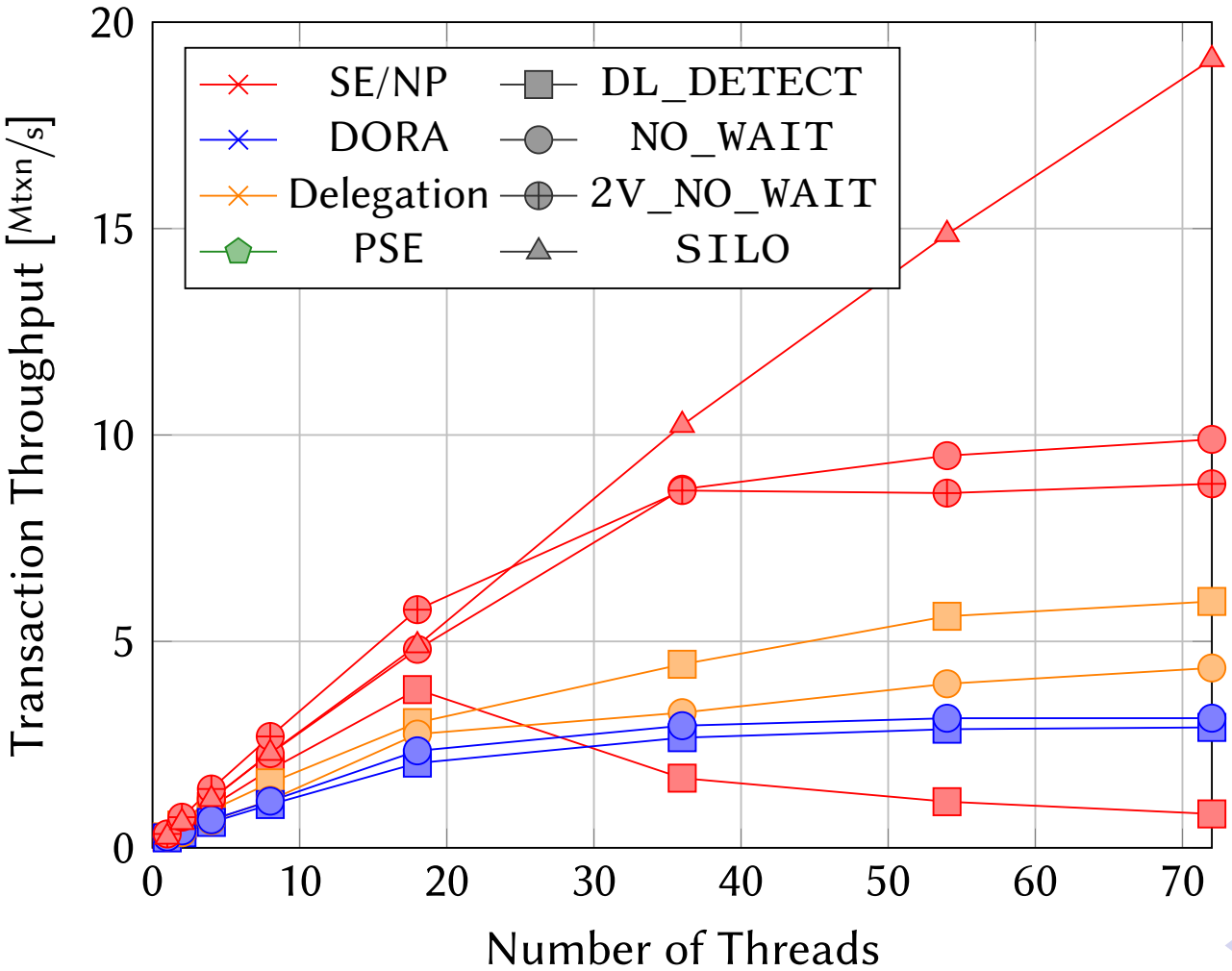
Read-Only Microbenchmark



Observations

- atomics of ● outperform latches of ■
- scaling of ● limited by hardware cache coherence mechanism
- ✳/✳ suffer more from remote data accesses than ✳ suffers from cache coherence
- ⊕ and ● perform identical for read-only

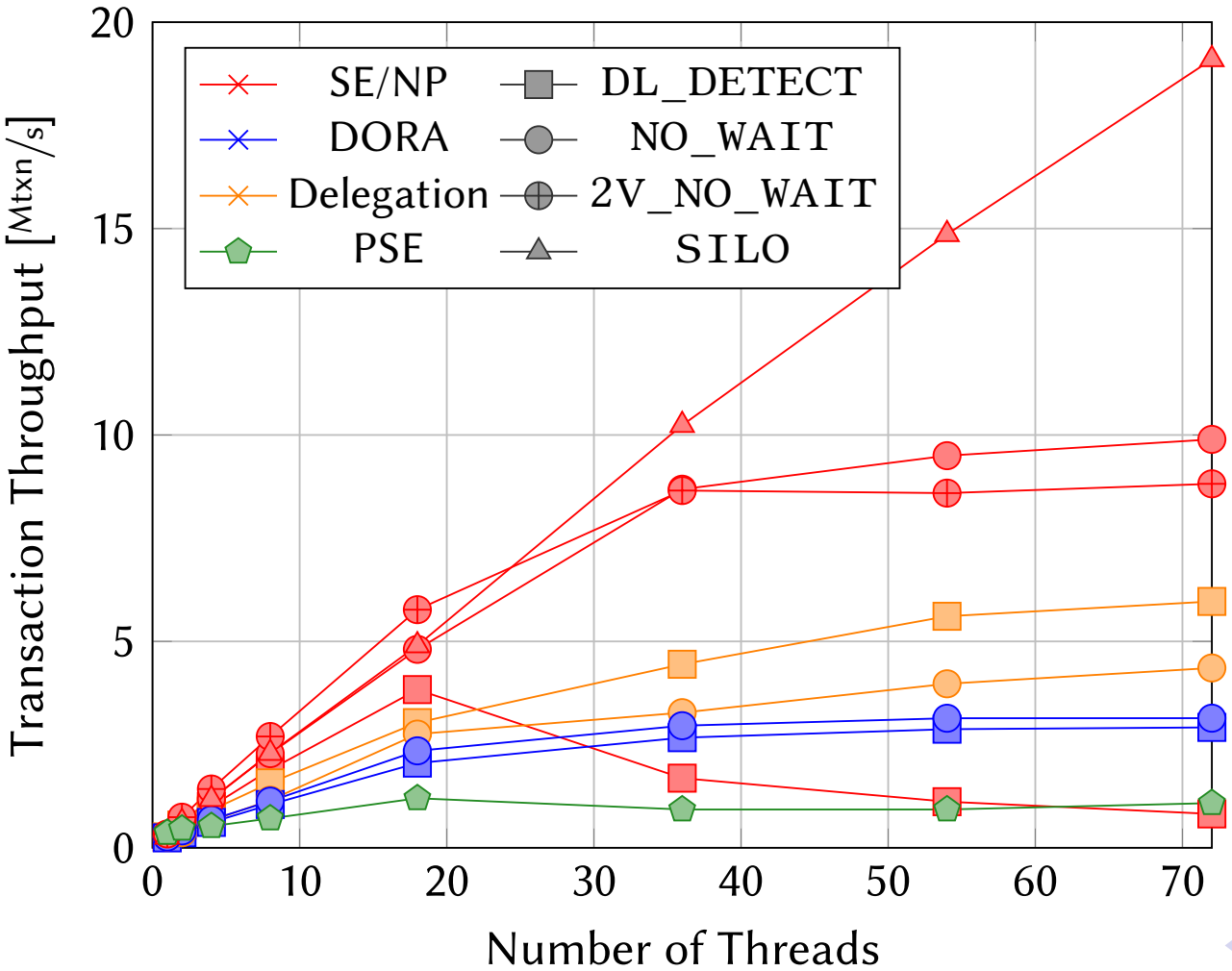
Read-Only Microbenchmark



Observations

- scaling of ● limited by hardware cache coherence mechanism
- ✳/✳ suffer more from remote data accesses than ✳ suffers from cache coherence
- ⊕ and ● perform identical for read-only
- ▲ behaves identical for ✳ and ✳ for read-only

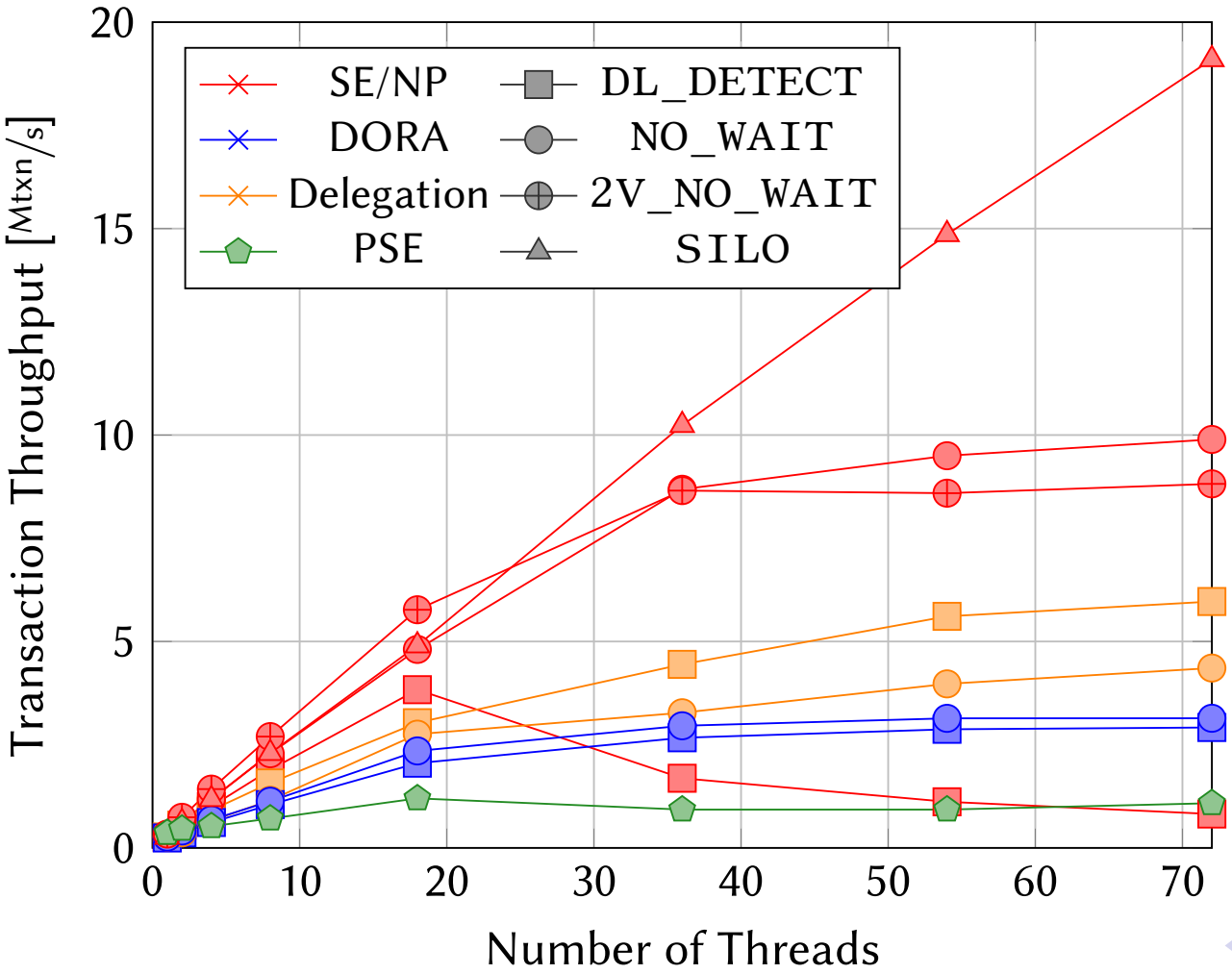
Read-Only Microbenchmark



Observations

- scaling of ● limited by hardware cache coherence mechanism
- ✳/✳ suffer more from remote data accesses than ✳ suffers from cache coherence
- ⊕ and ● perform identical for read-only
- ▲ behaves identical for ✳ and ✳ for read-only

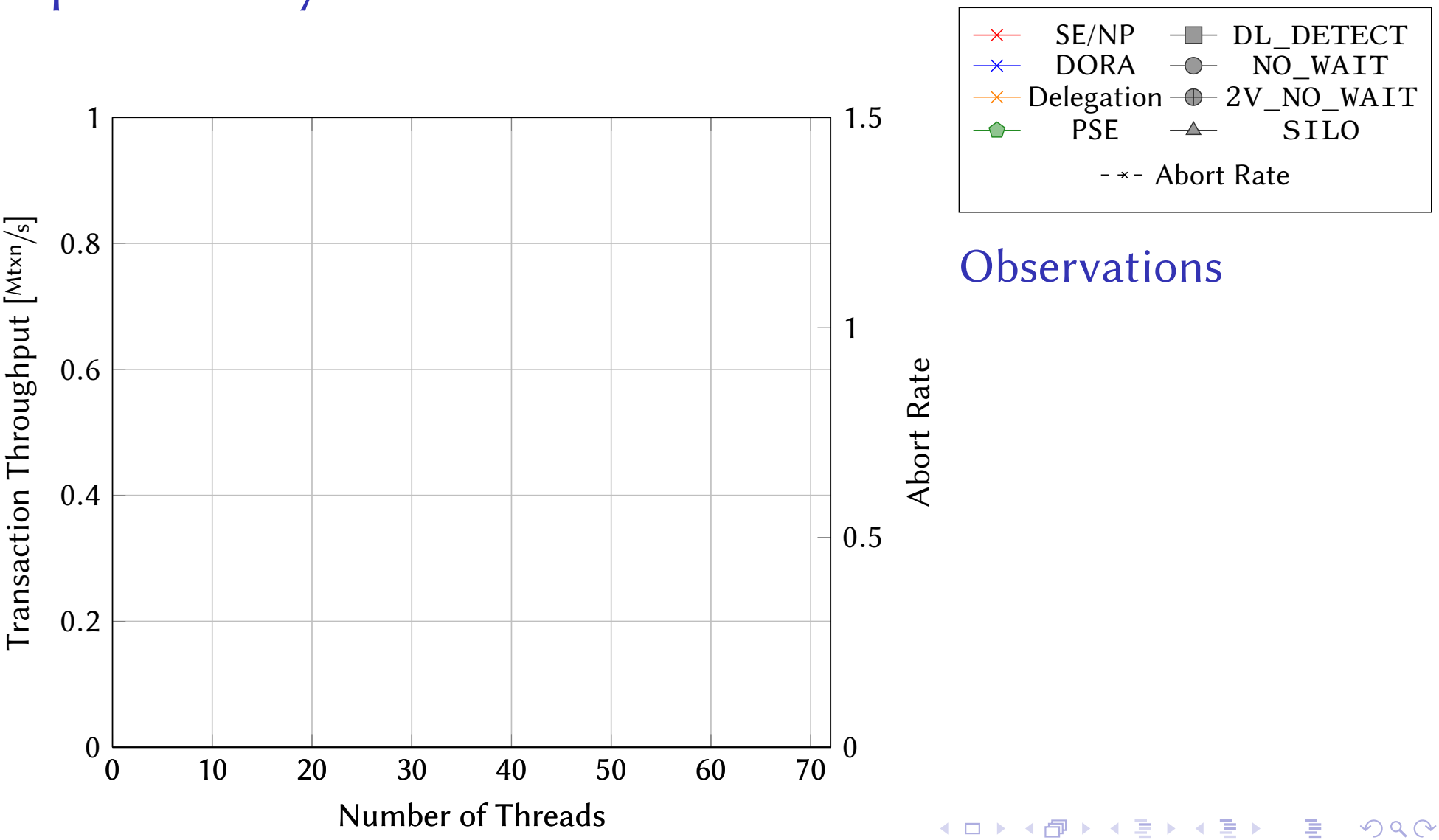
Read-Only Microbenchmark



Observations

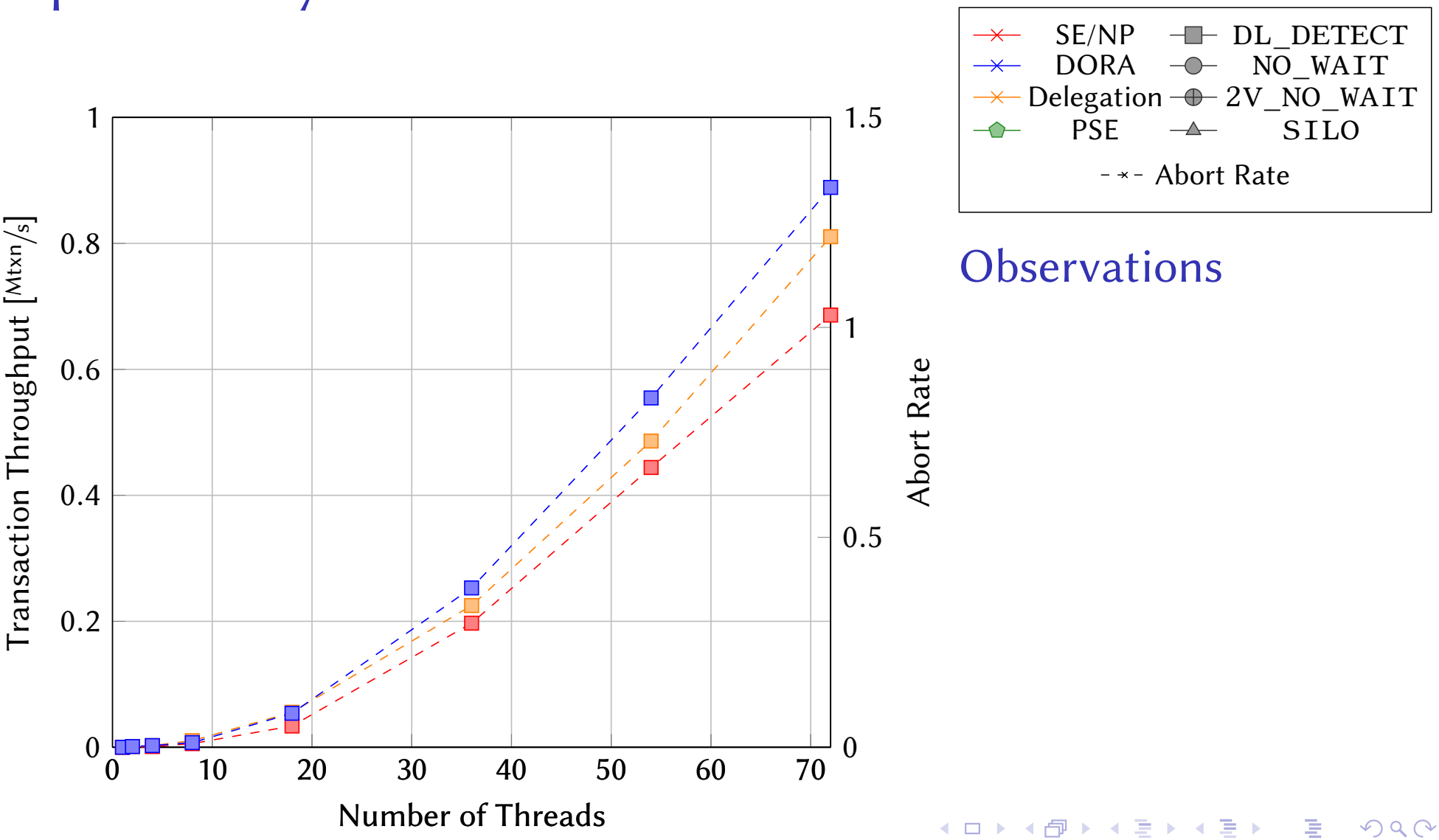
- ✳/✳ suffer more from remote data accesses than ✳ suffers from cache coherence
- ⊕ and ● perform identical for read-only
- ▲ behaves identical for ✳ and ✳ for read-only
- coarse-grained partition locking of ⬟ does not scale due to multi-site workload

Update-Only Microbenchmark



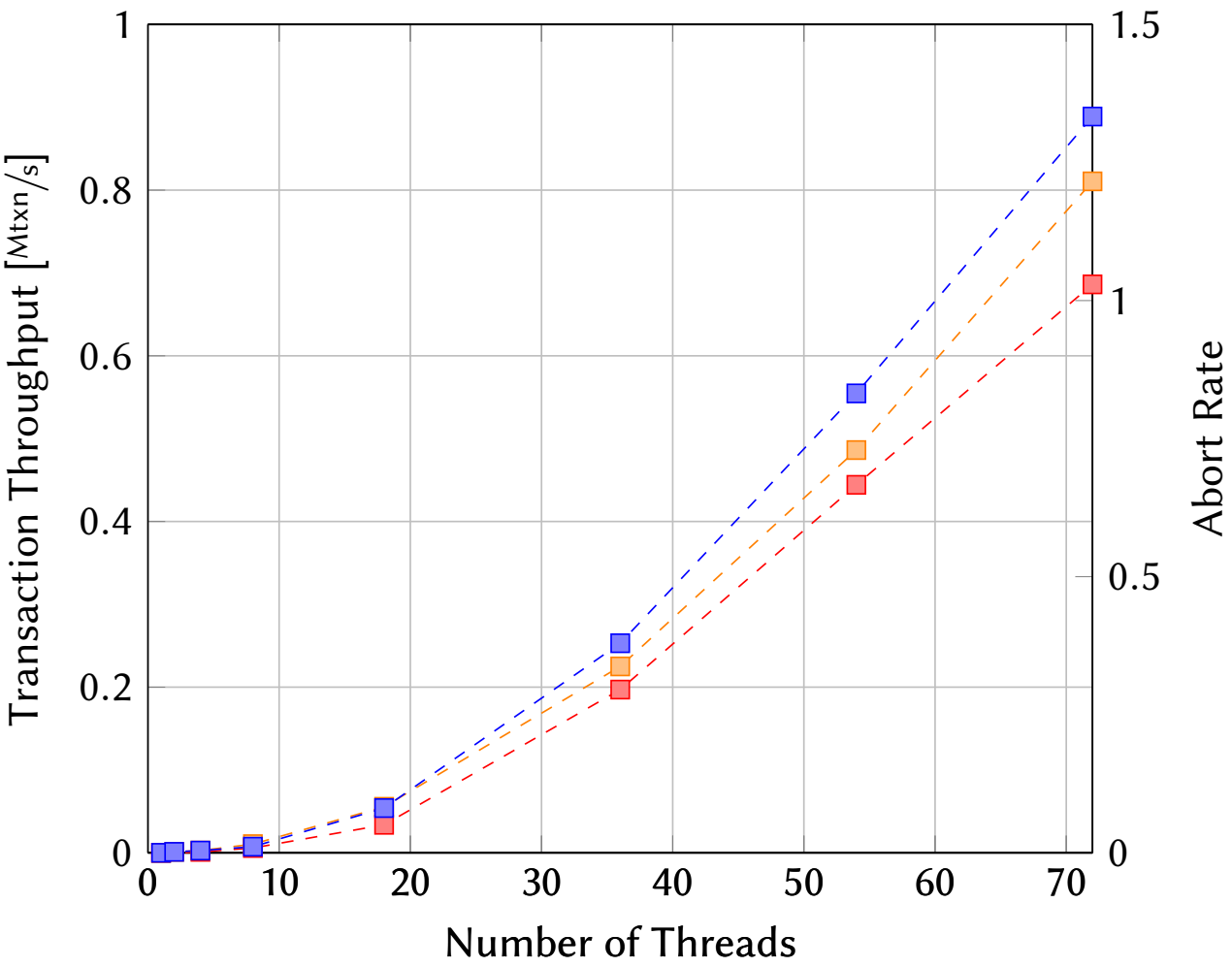
Observations

Update-Only Microbenchmark



Observations

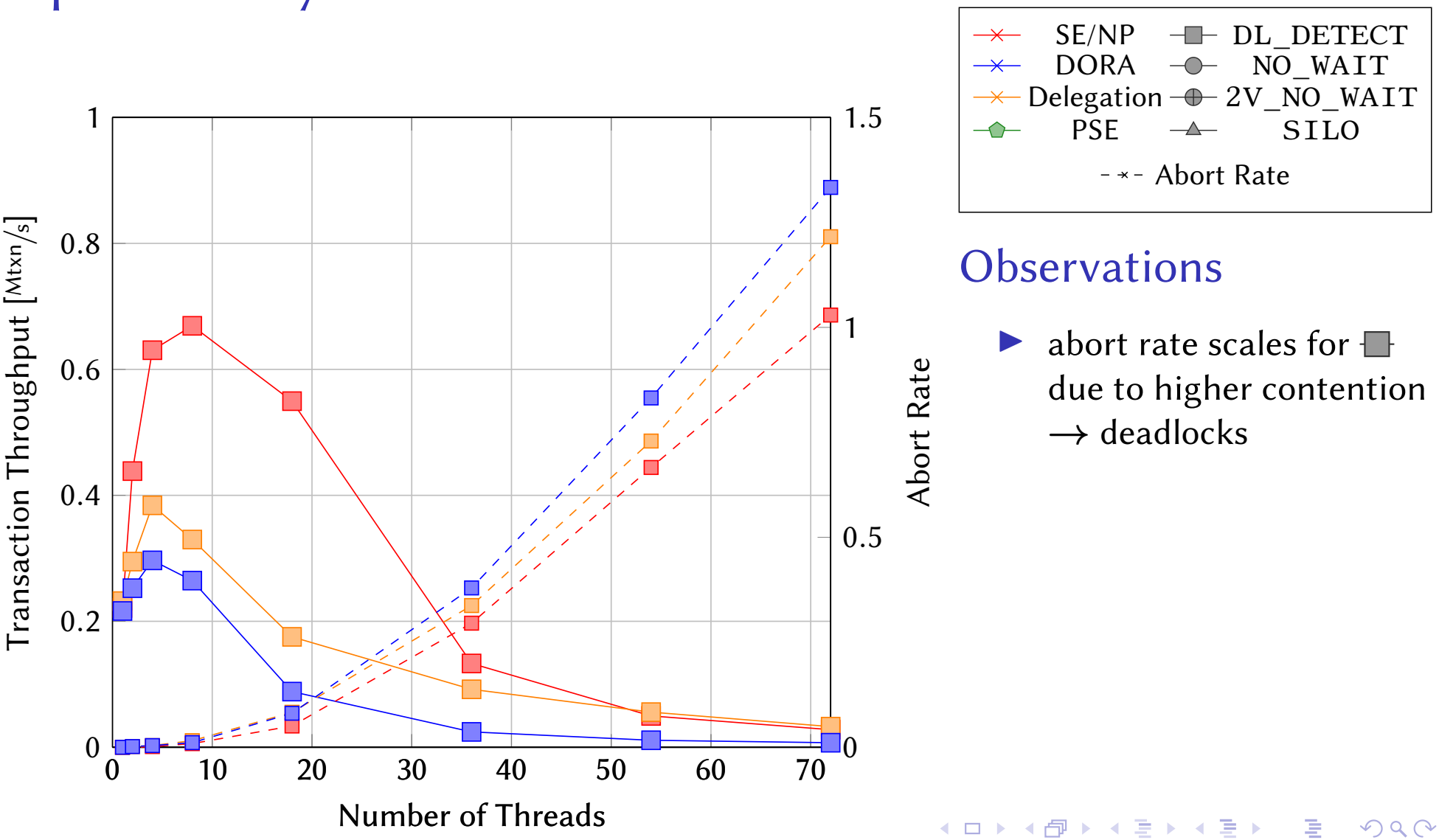
Update-Only Microbenchmark



Observations

- abort rate scales for ■ due to higher contention → deadlocks

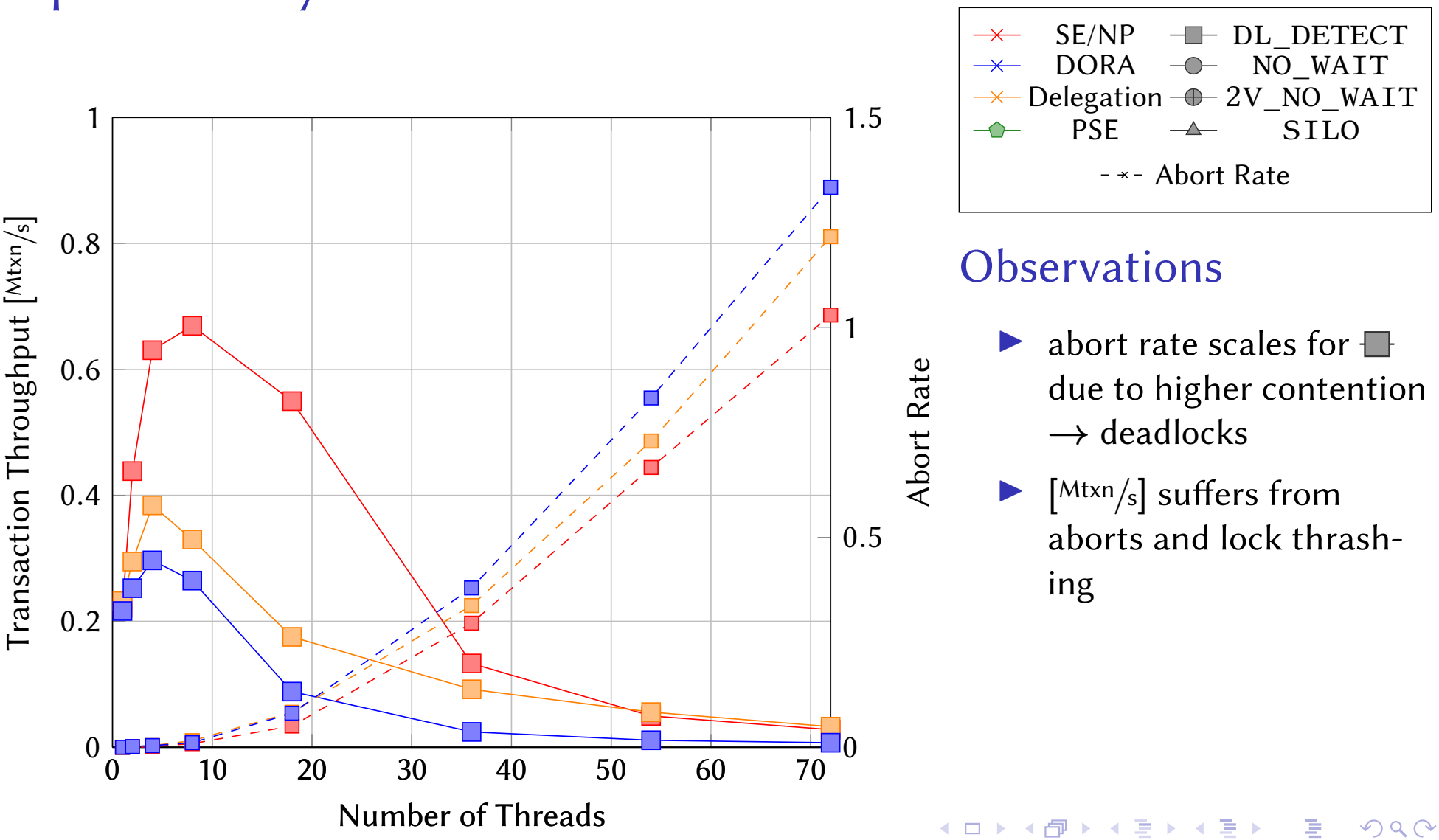
Update-Only Microbenchmark



Observations

- abort rate scales for ■ due to higher contention → deadlocks

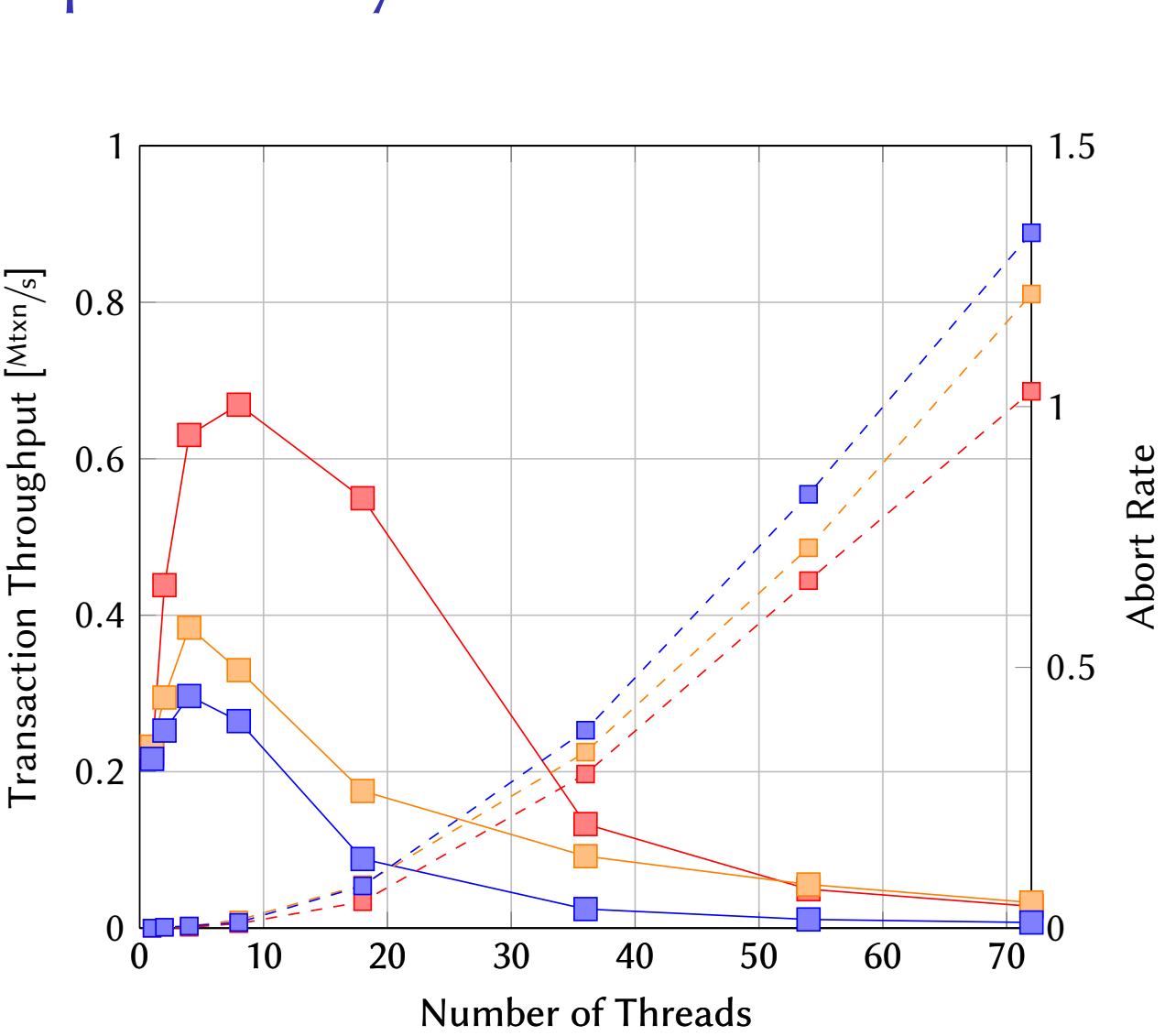
Update-Only Microbenchmark



Observations

- abort rate scales for ■ due to higher contention → deadlocks
- [Mtxn/s] suffers from aborts and lock thrashing

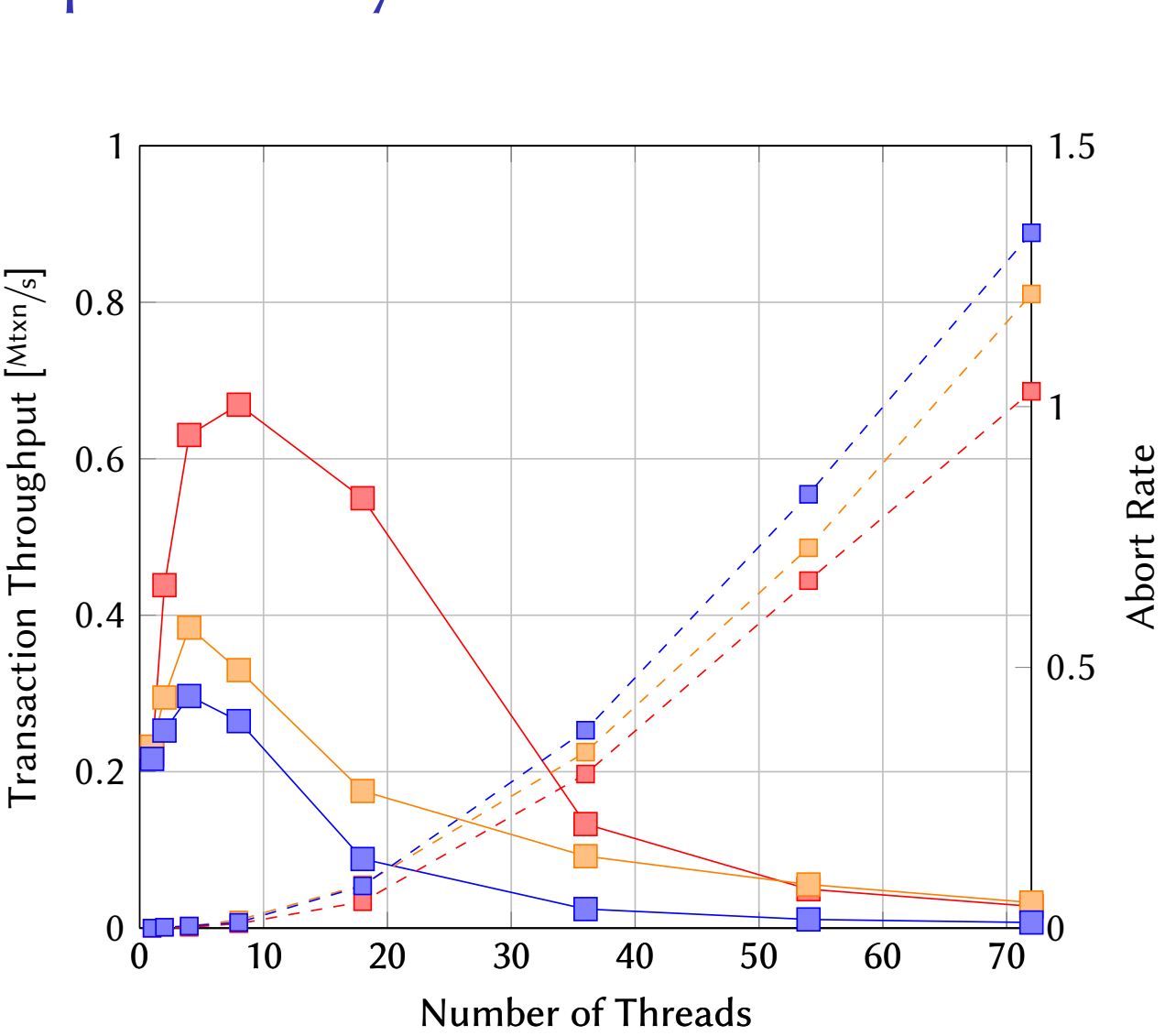
Update-Only Microbenchmark



Observations

- abort rate scales for ■ due to higher contention → deadlocks
- [Mtxn/s] suffers from aborts and lock thrashing
- ✕/✕ suffer more from remote data access overhead

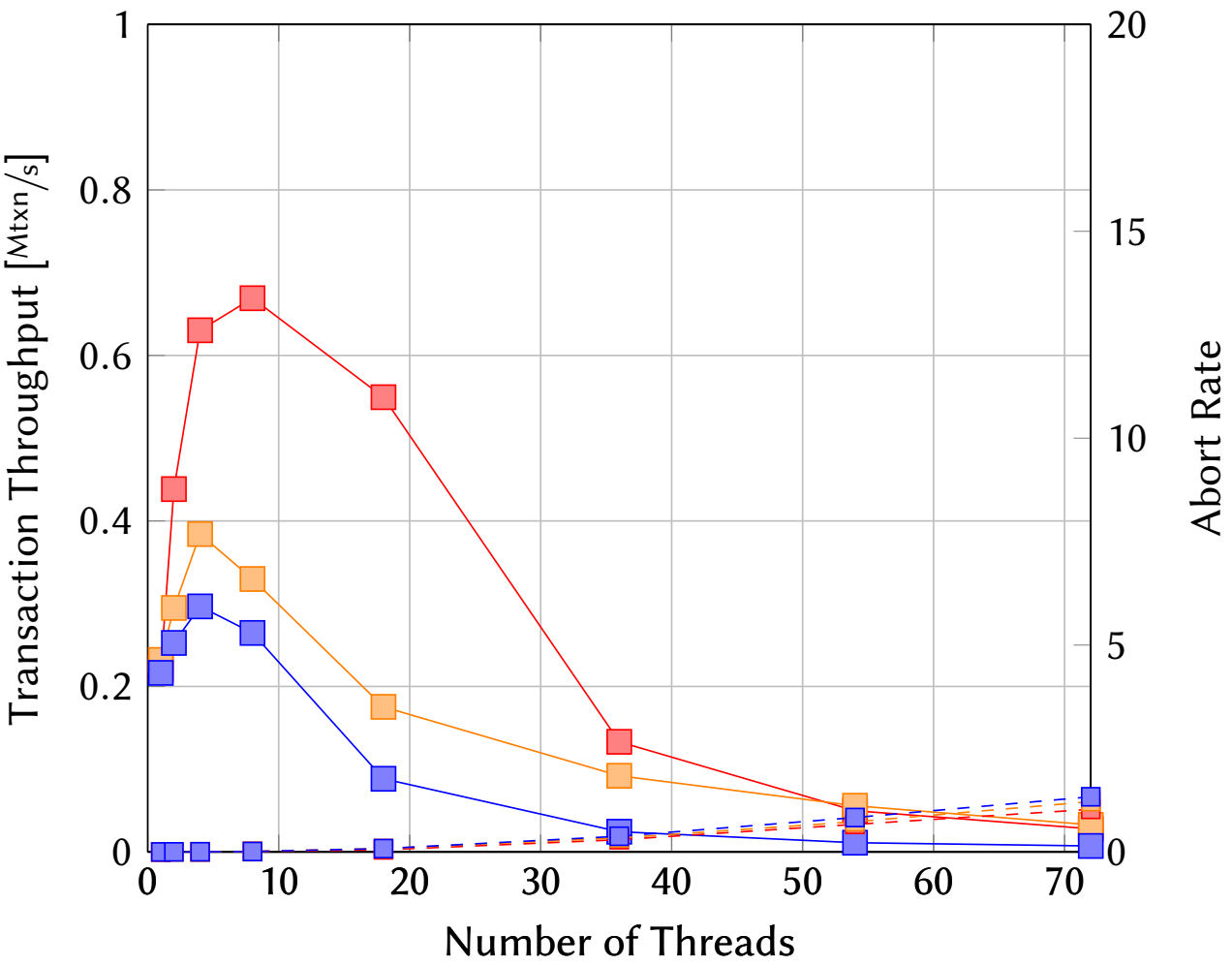
Update-Only Microbenchmark



Observations

- [Mtxn/s] suffers from aborts and lock thrashing
- ✳/✳ suffer more from remote data access overhead
- latch contention is not the bottleneck → ✳ can outperform ✳/✳

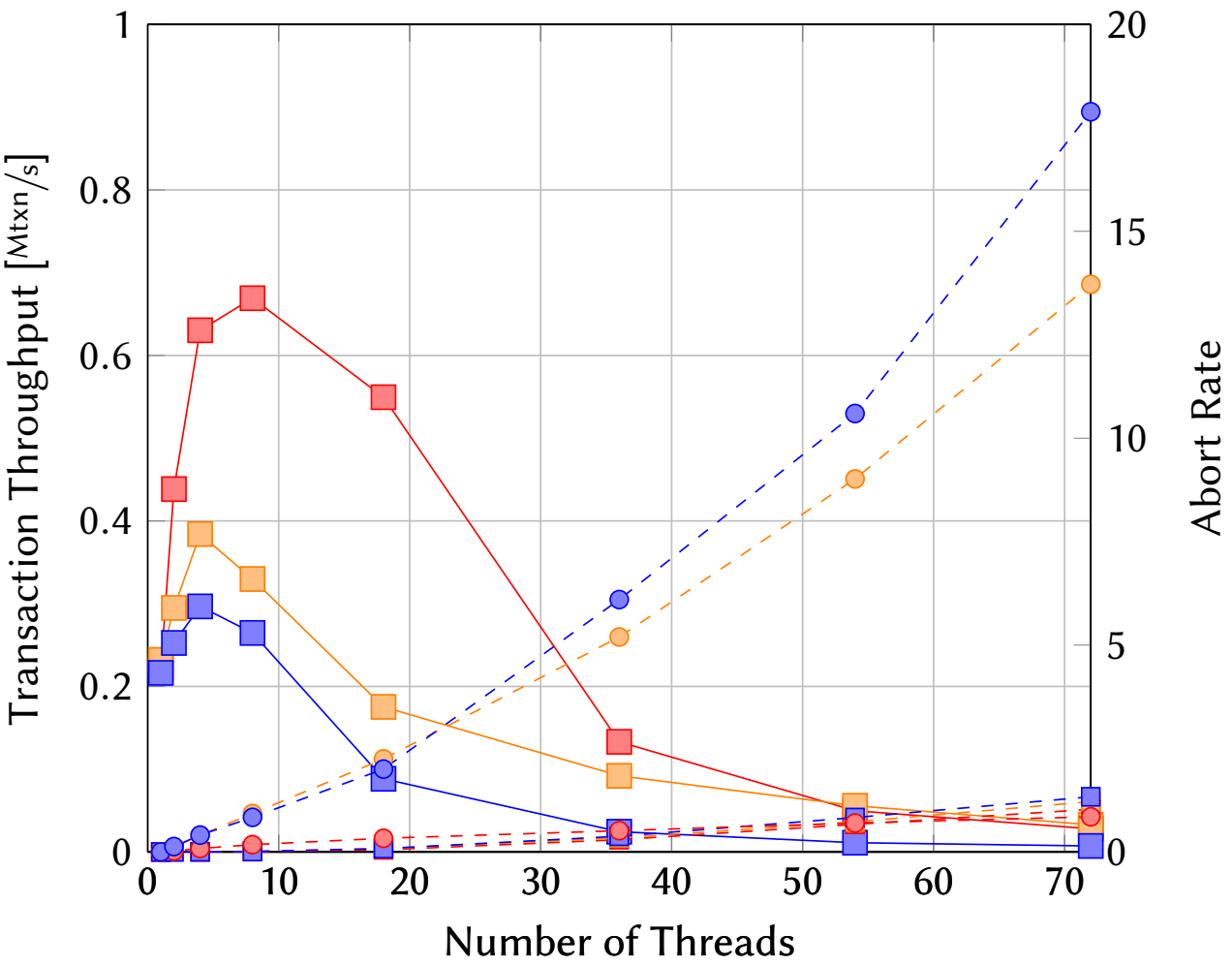
Update-Only Microbenchmark



Observations

- [Mtxn/s] suffers from aborts and lock thrashing
- ✳/✳ suffer more from remote data access overhead
- latch contention is not the bottleneck → ✳ can outperform ✳/✳

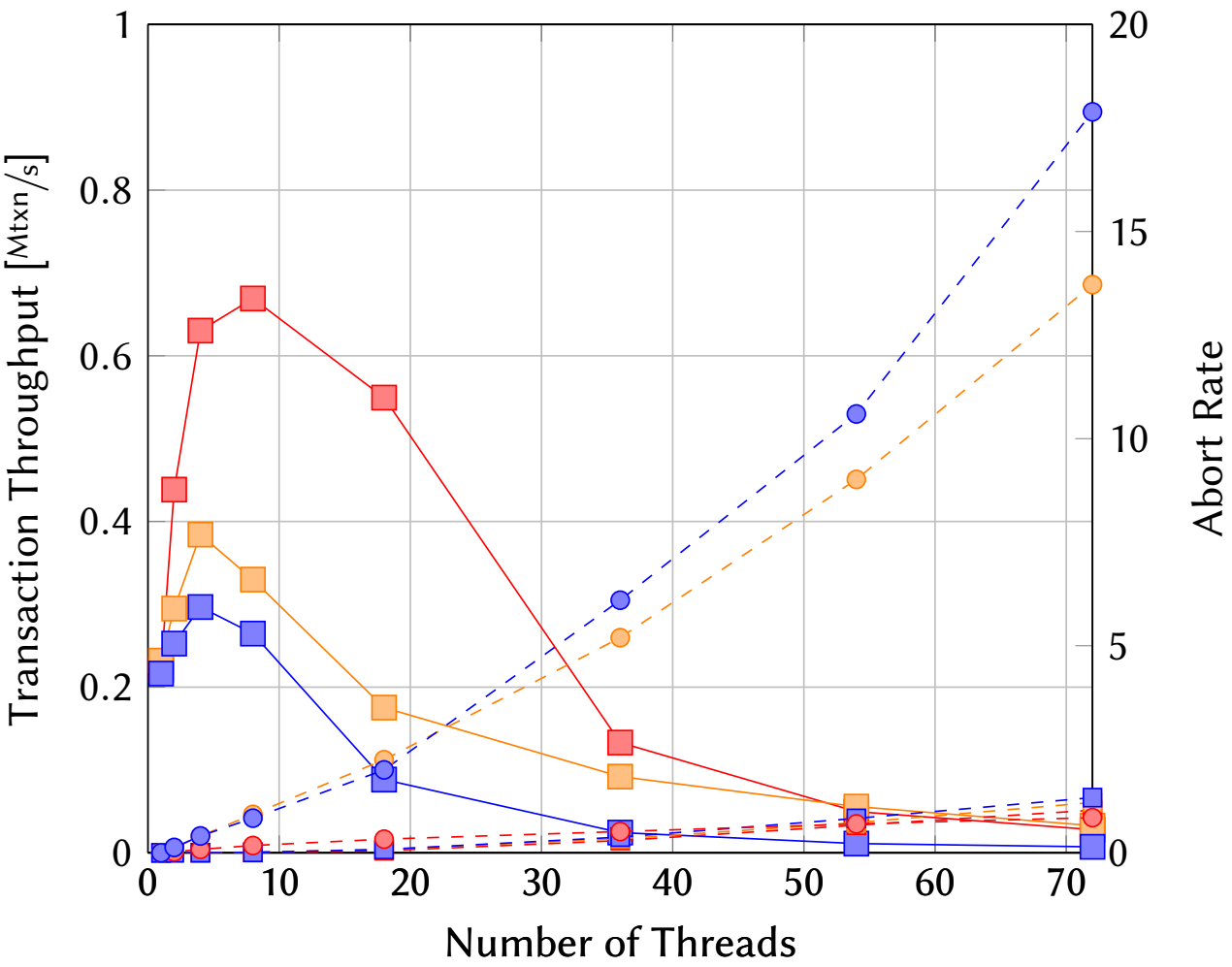
Update-Only Microbenchmark



Observations

- [Mtxn/s] suffers from aborts and lock thrashing
- ✳/✳ suffer more from remote data access overhead
- latch contention is not the bottleneck → ✳ can outperform ✳/✳

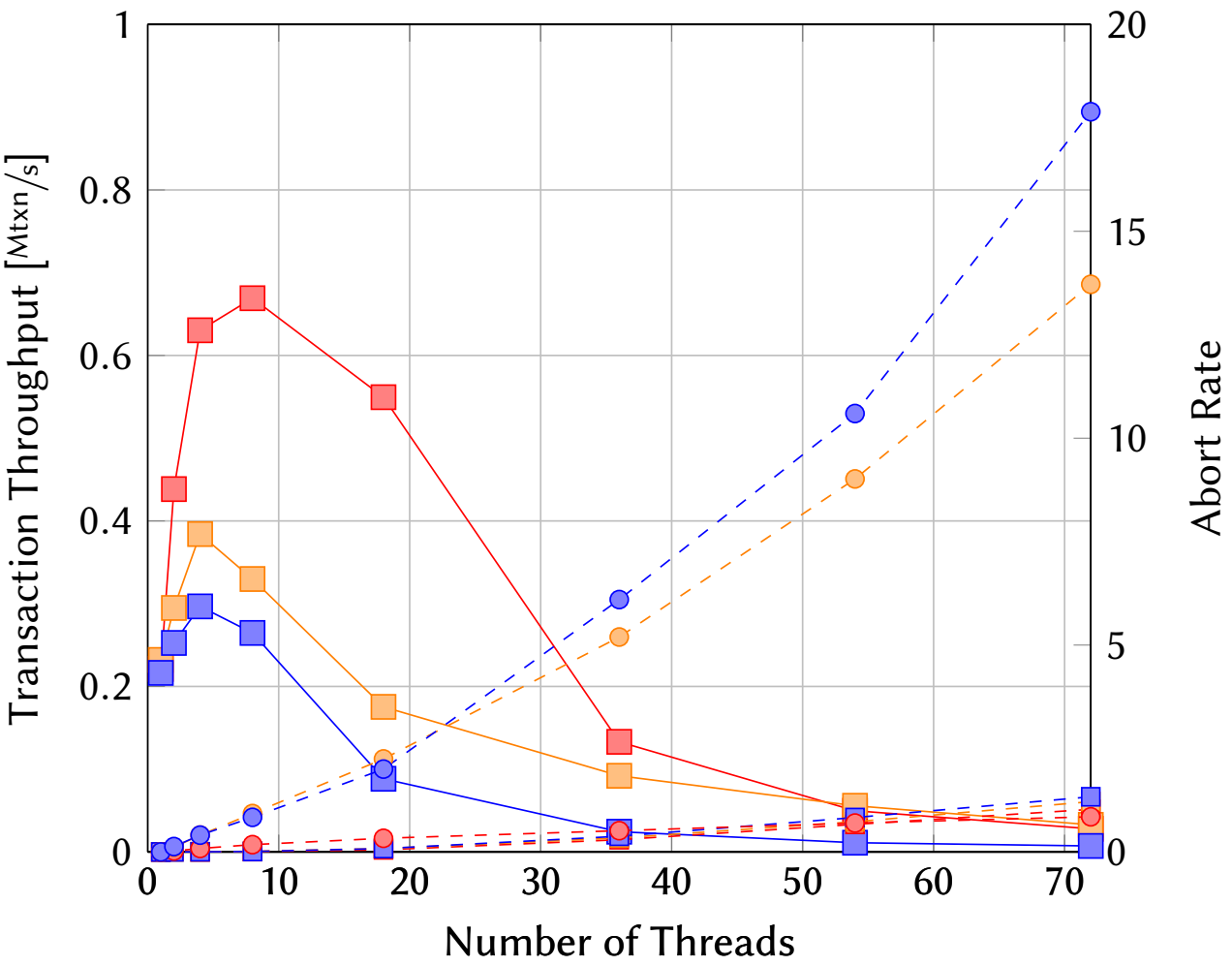
Update-Only Microbenchmark



Observations

- ✳/✳ suffer more from remote data access overhead
- latch contention is not the bottleneck → ✳ can outperform ✳/✳
- lock thrashing does not cause many aborts for ● with ✳ for few threads

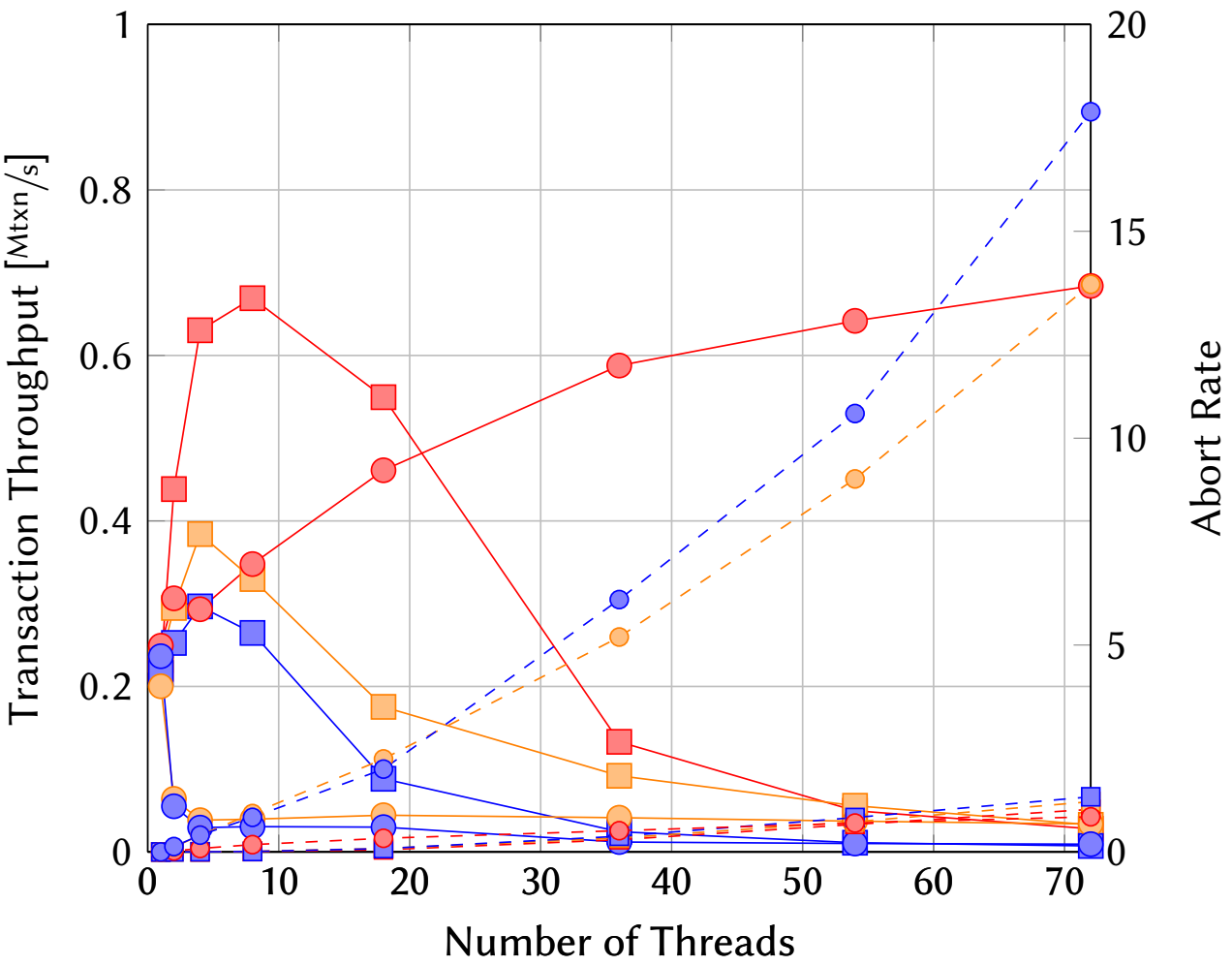
Update-Only Microbenchmark



Observations

- lock thrashing does not cause many aborts for ● with ✕ for few threads
- lock thrashing caused by long commit latencies caused by overloaded (hot) partitions causes many aborts for ✕/✕

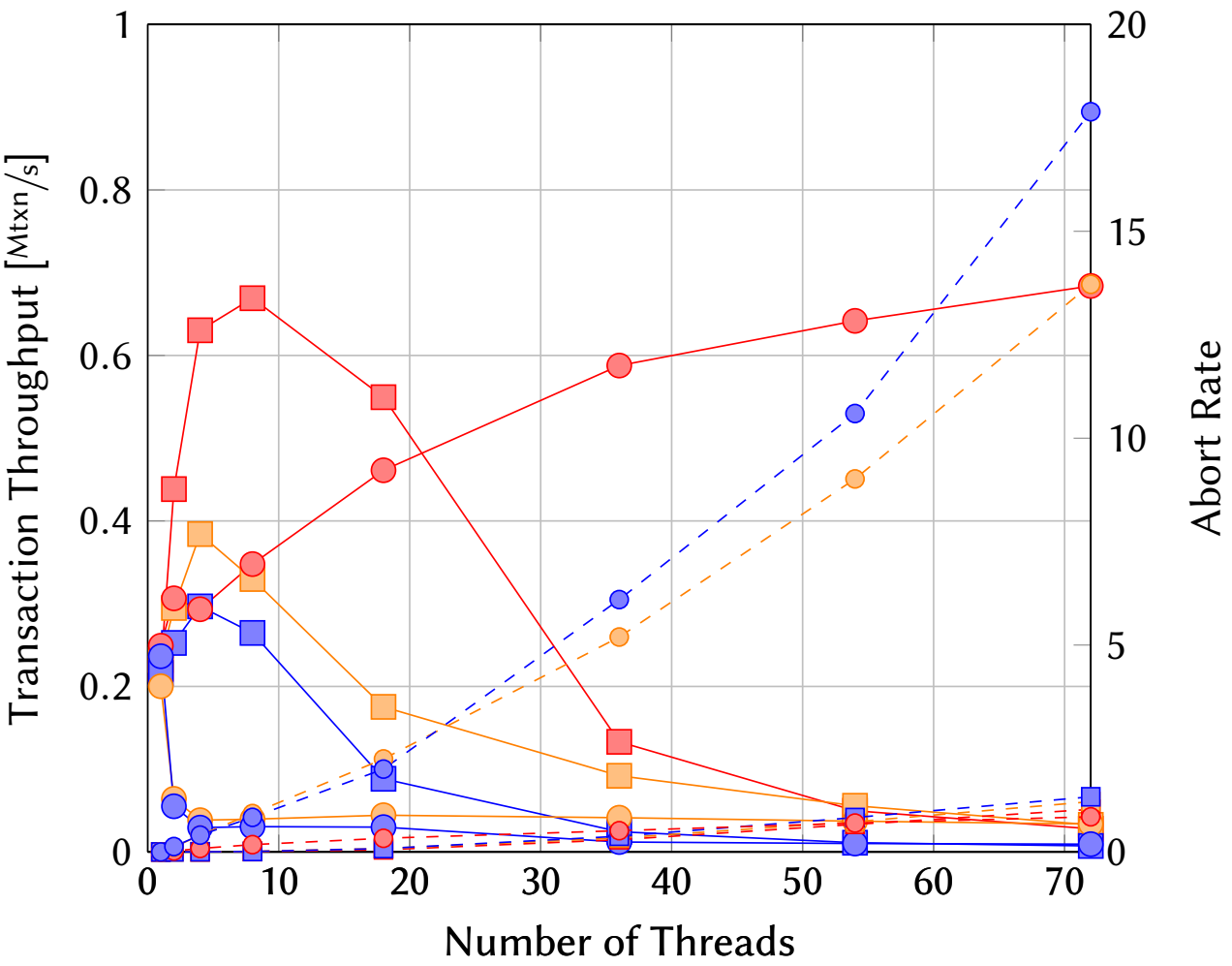
Update-Only Microbenchmark



Observations

- lock thrashing does not cause many aborts for ● with ✕ for few threads
- lock thrashing caused by long commit latencies caused by overloaded (hot) partitions causes many aborts for ✕/✕

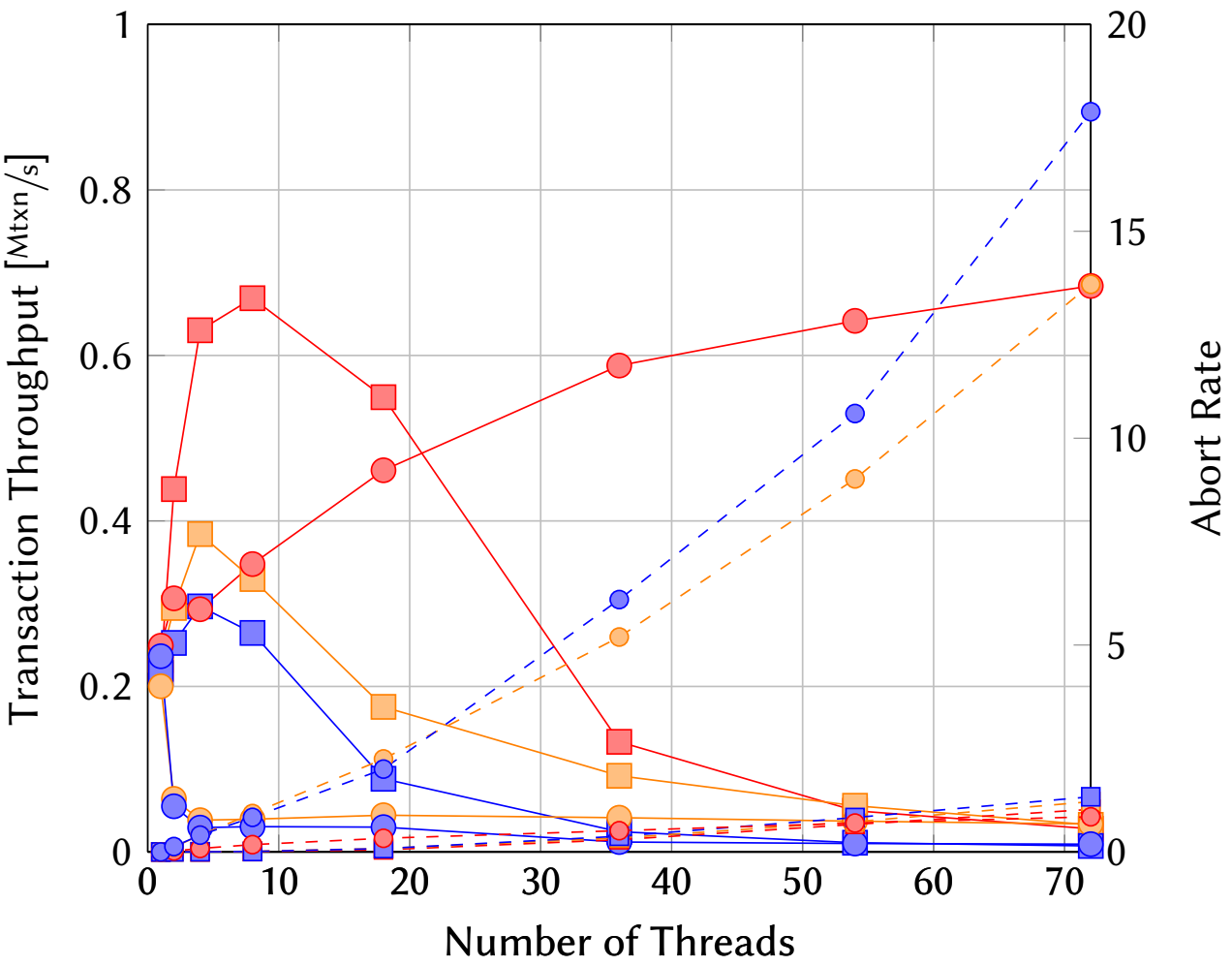
Update-Only Microbenchmark



Observations

- lock thrashing does not cause many aborts for ● with ✕ for few threads
- lock thrashing caused by long commit latencies caused by overloaded (hot) partitions causes many aborts for ✕/✕
- the aborts are the major bottleneck for ●

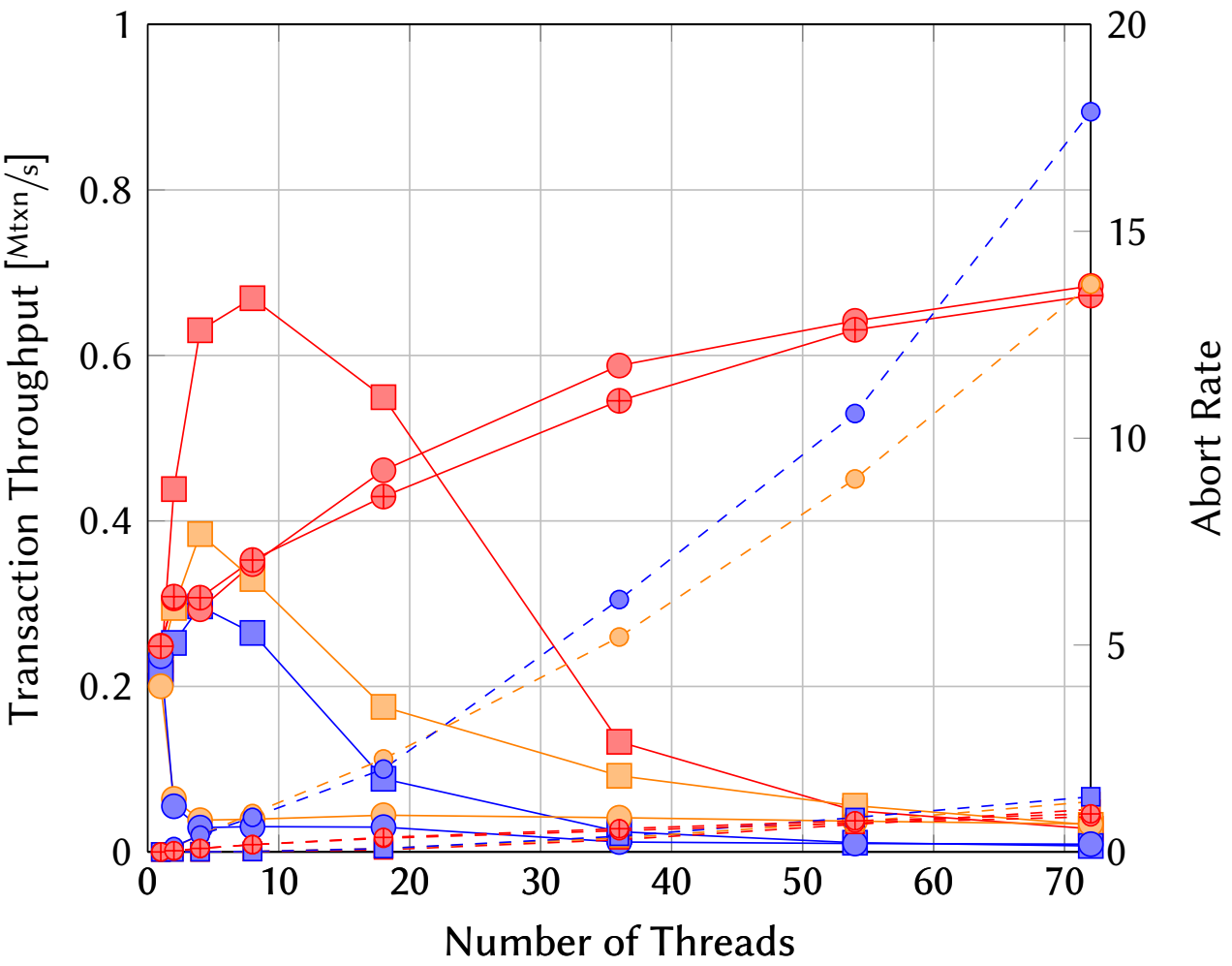
Update-Only Microbenchmark



Observations

- lock thrashing caused by long commit latencies caused by overloaded (hot) partitions causes many aborts for ✳/✳
- the aborts are the major bottleneck for ●
- latching overhead and deadlocks → ● outperforms ■ for ✳

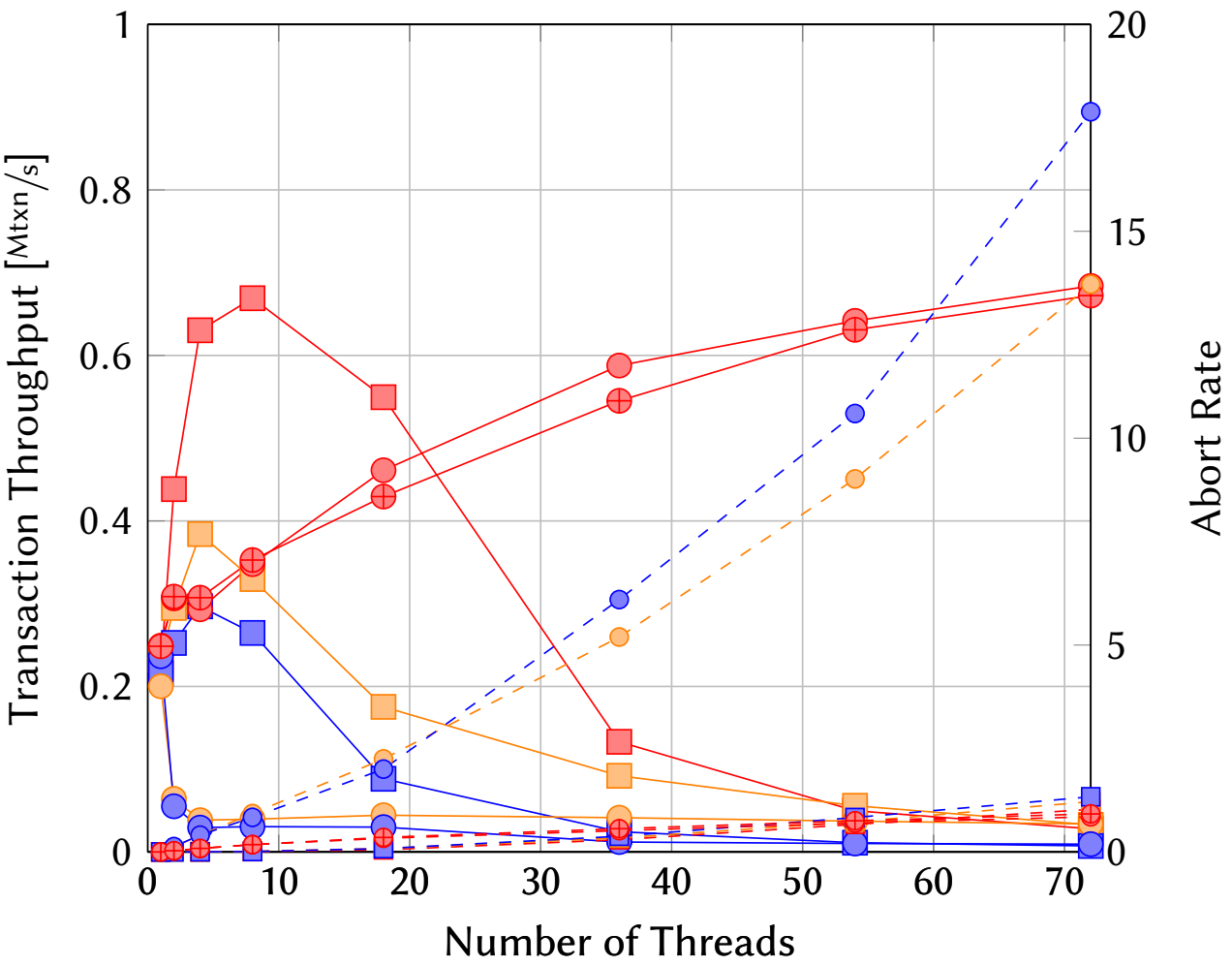
Update-Only Microbenchmark



Observations

- lock thrashing caused by long commit latencies caused by overloaded (hot) partitions causes many aborts for ✳/✳
- the aborts are the major bottleneck for ●
- latching overhead and deadlocks → ● outperforms ■ for ✳

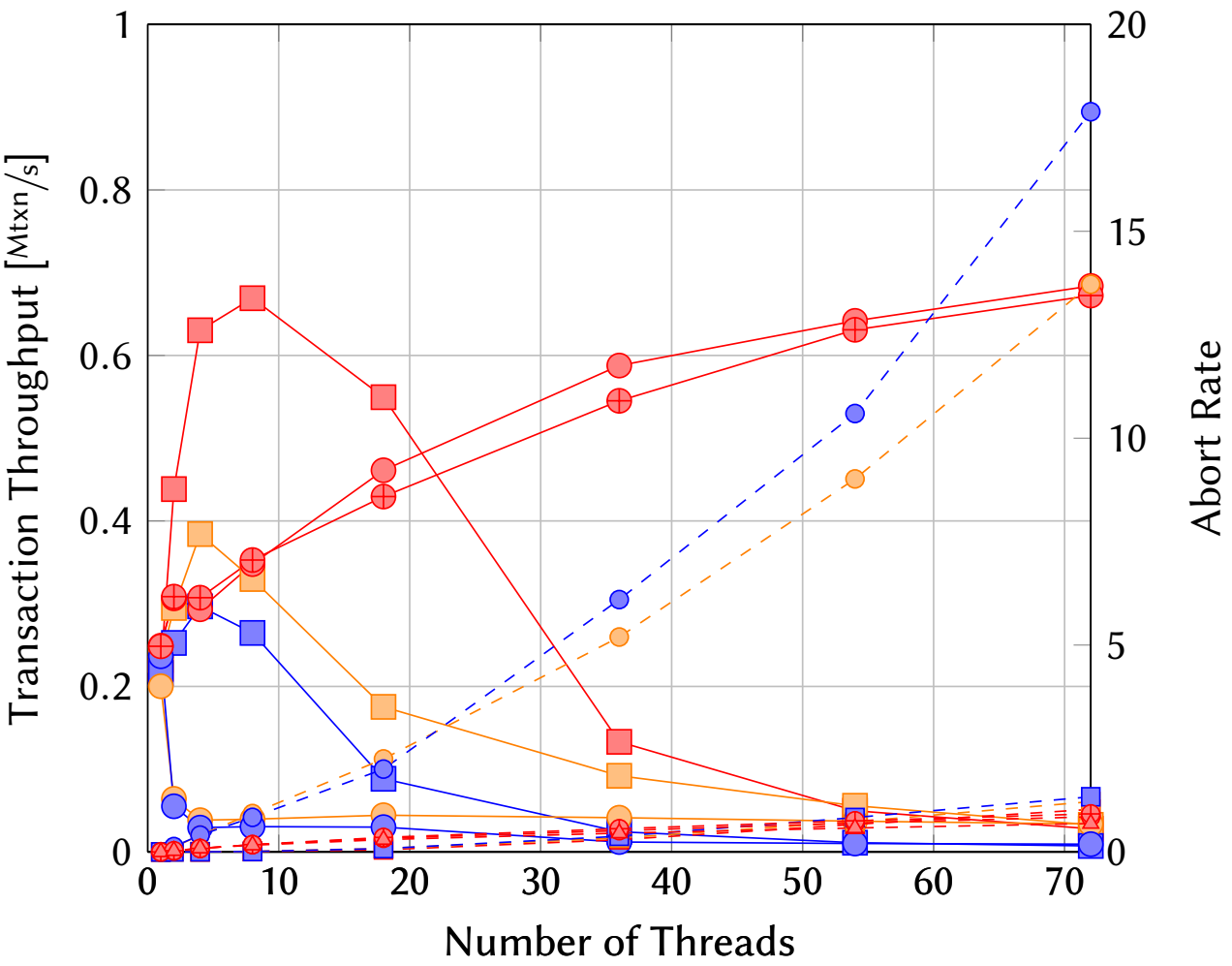
Update-Only Microbenchmark



Observations

- the aborts are the major bottleneck for ●
- latching overhead and deadlocks → ● outperforms ■ for ✳
- for update-only ● and ⊕ behave identical

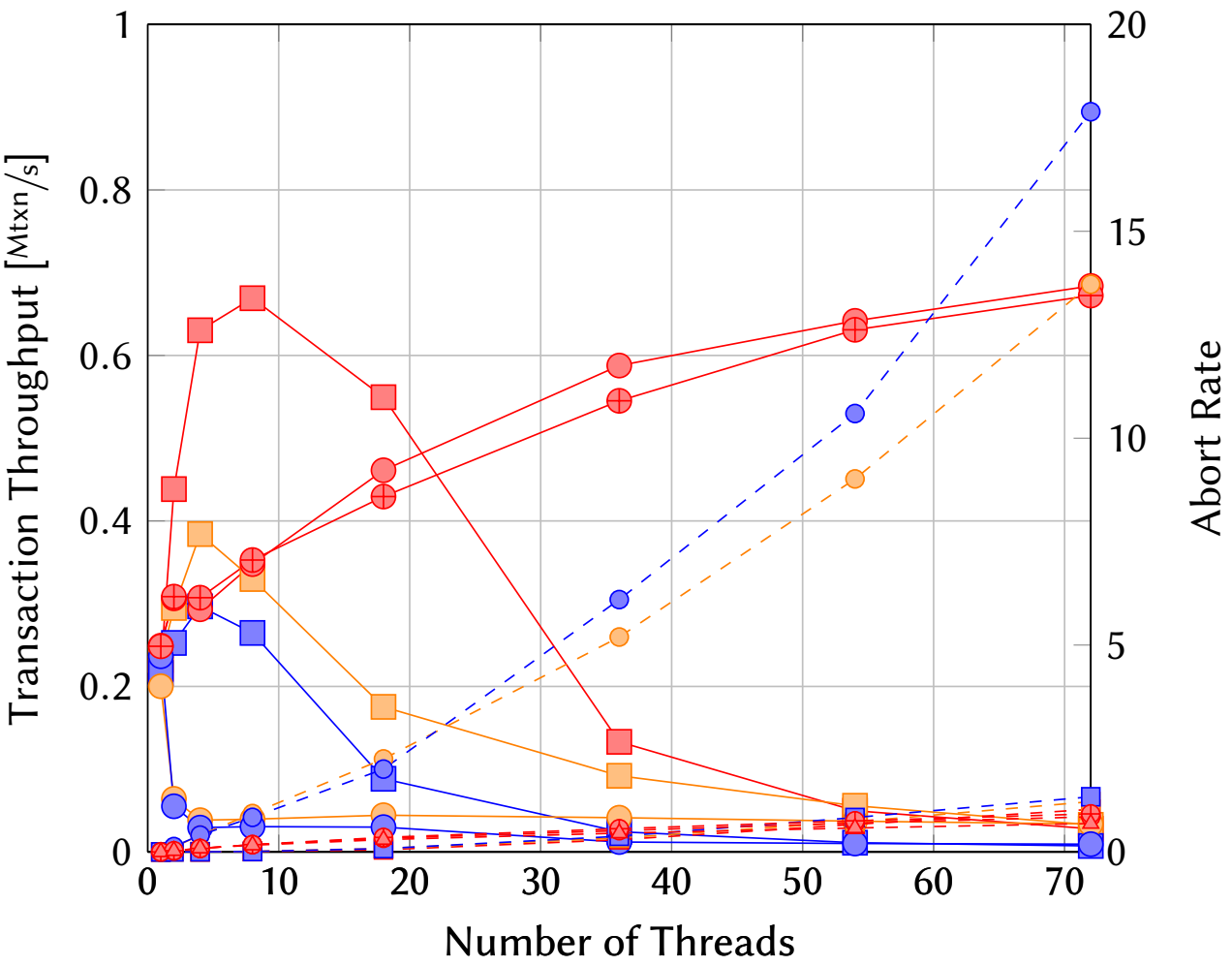
Update-Only Microbenchmark



Observations

- the aborts are the major bottleneck for ⊕
- latching overhead and deadlocks → ● outperforms ■ for ✳
- for update-only ● and ⊕ behave identical

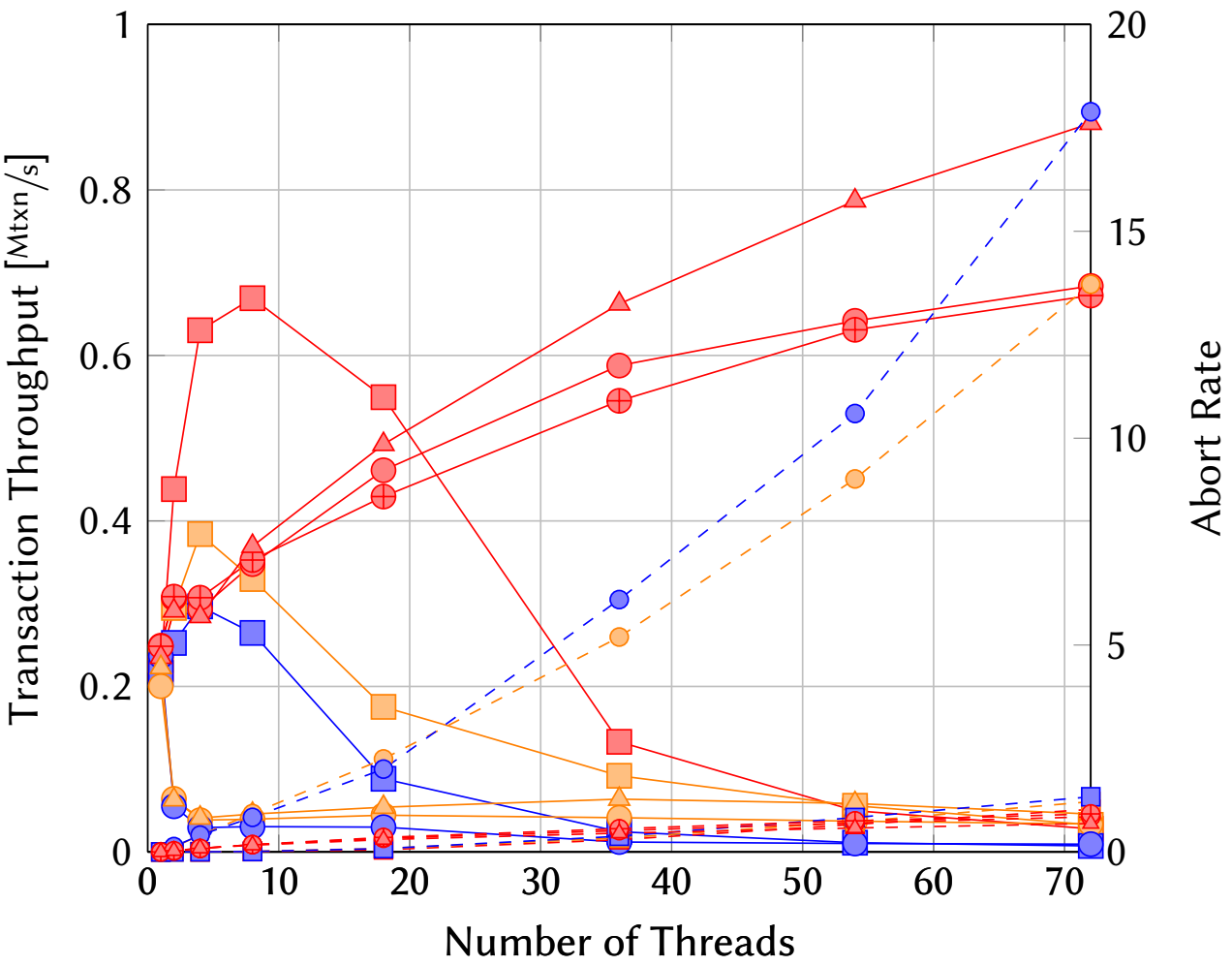
Update-Only Microbenchmark



Observations

- the aborts are the major bottleneck for ●
- latching overhead and deadlocks → ● outperforms ■ for ✕
- for update-only ● and ⊕ behave identical
- ▲ causes less aborts than ■ due its optimism

Update-Only Microbenchmark

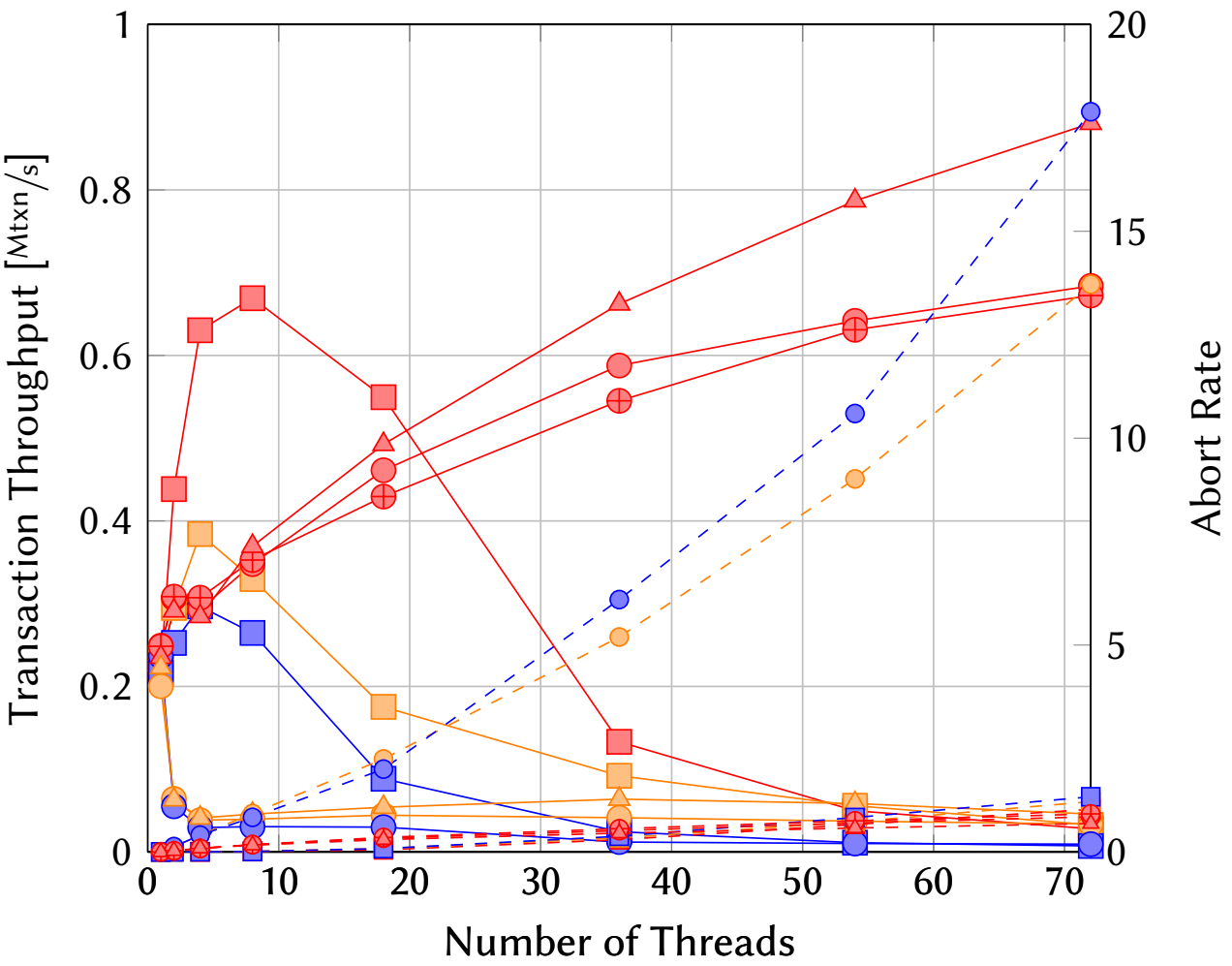


SE/NP
DORA
Delegation
PSE
DL_DETECT
NO_WAIT
2V_NO_WAIT
SILO
Abort Rate

Observations

- the aborts are the major bottleneck for ●
- latching overhead and deadlocks → ● outperforms ■ for ✕
- for update-only ● and ⊕ behave identical
- ▲ causes less aborts than ■ due its optimism

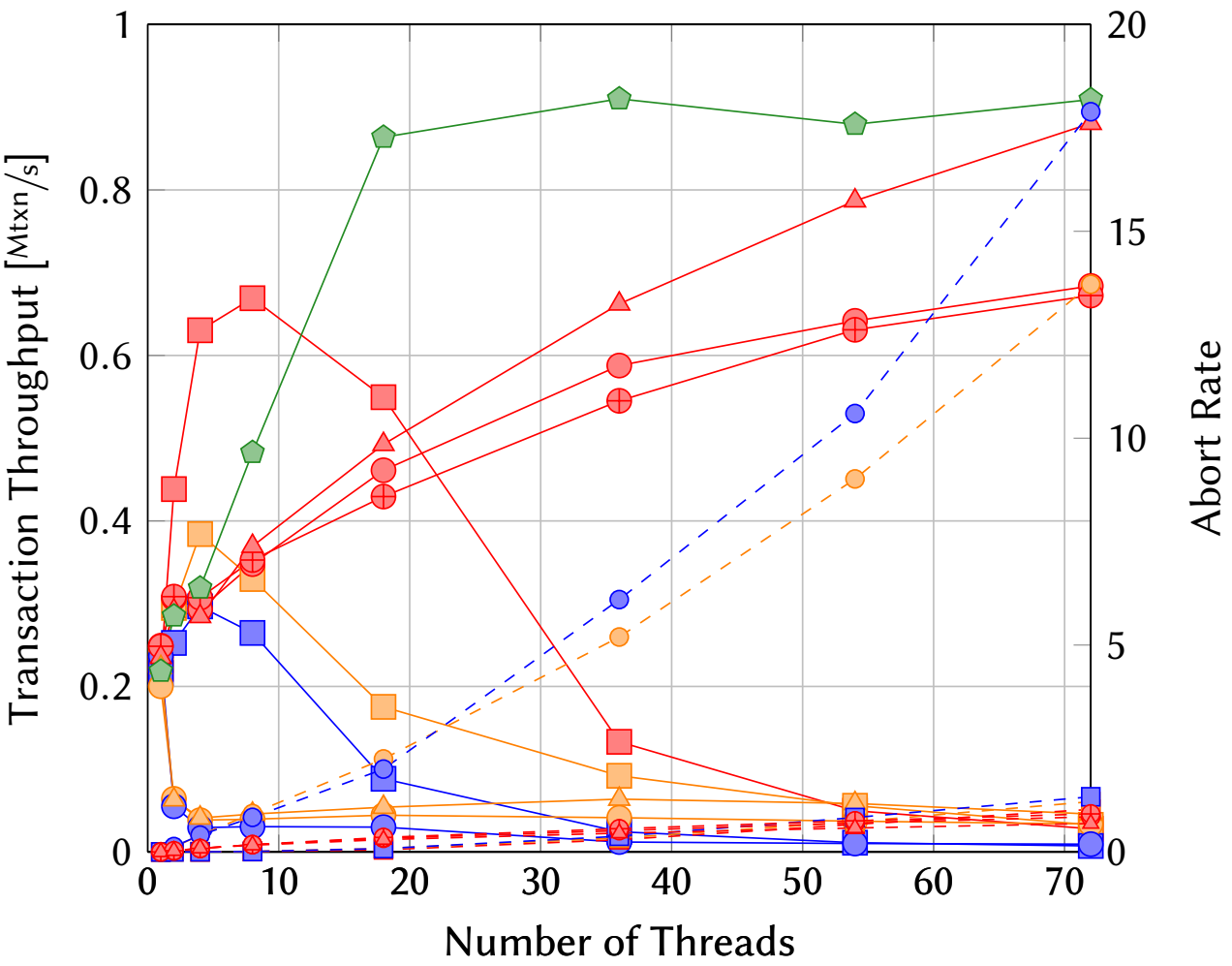
Update-Only Microbenchmark



Observations

- for update-only ● and ⊕ behave identical
- △ causes less aborts than ■ due its optimism
- long commit latencies of ✕ cause high update contention and therefore many aborts (low [Mtxn/s]) for △

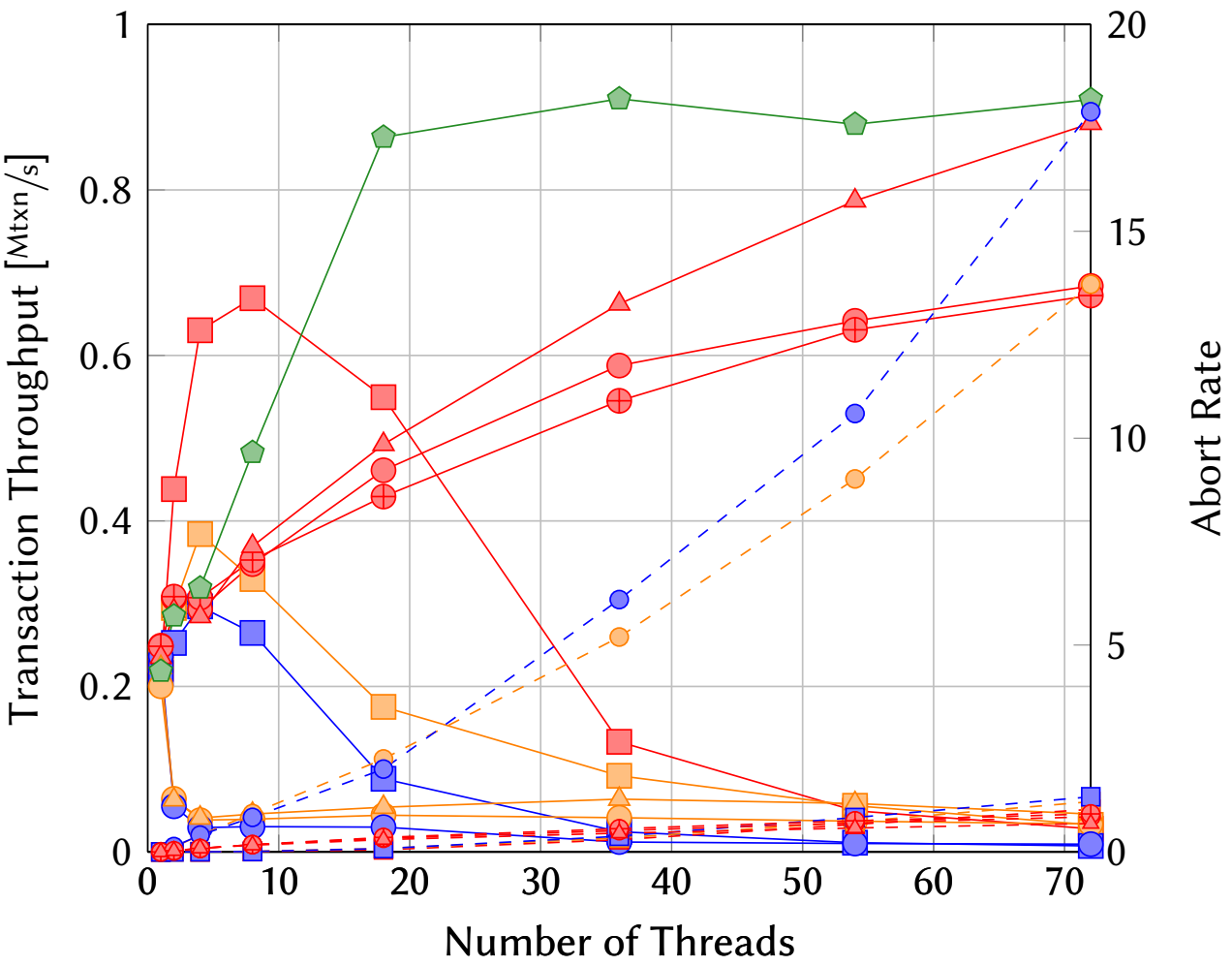
Update-Only Microbenchmark



Observations

- for update-only ● and ⊕ behave identical
- △ causes less aborts than ■ due its optimism
- long commit latencies of ✕ cause high update contention and therefore many aborts (low [Mtxn/s]) for △

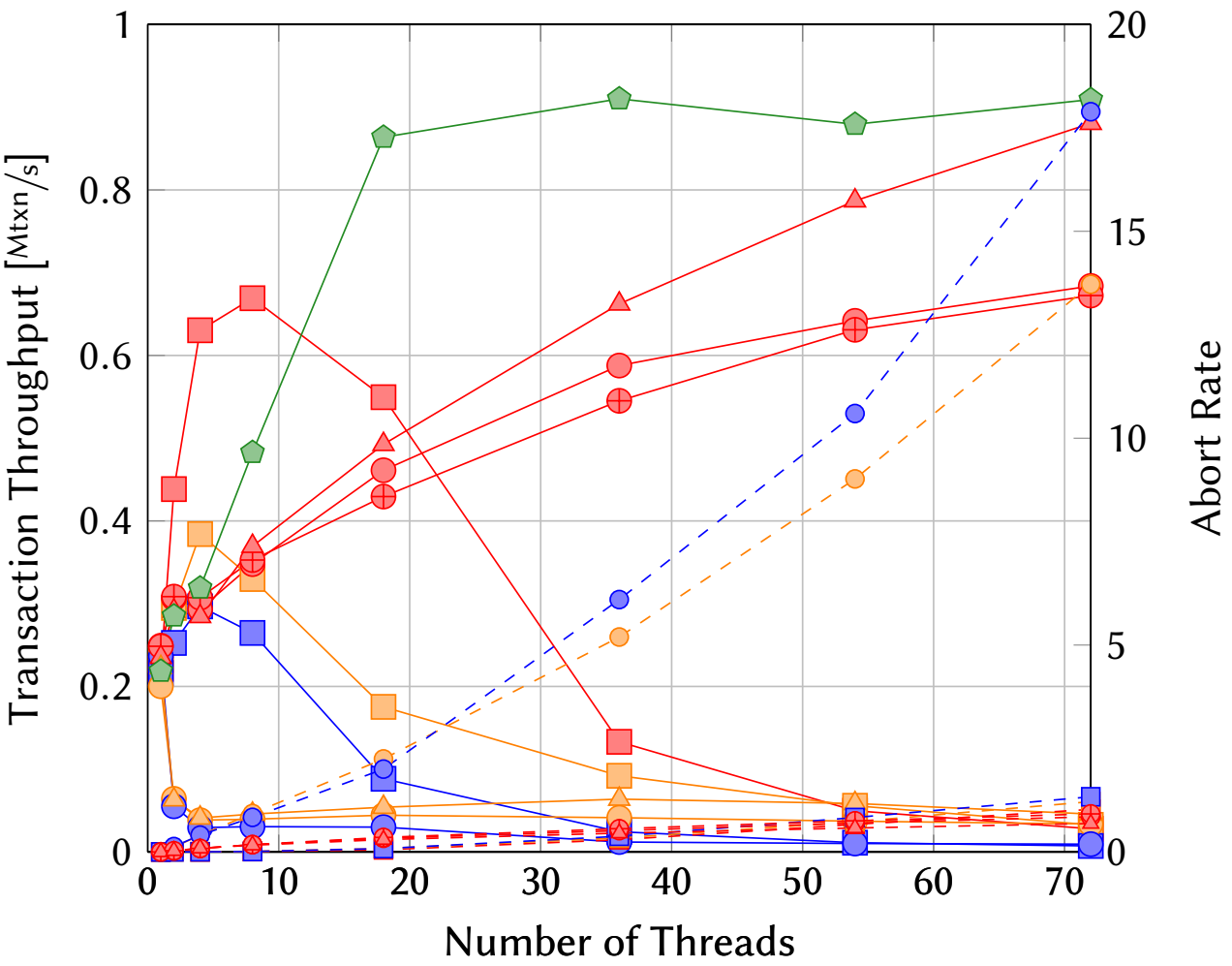
Update-Only Microbenchmark



Observations

- △ causes less aborts than ■ due its optimism
- long commit latencies of ✕ cause high update contention and therefore many aborts (low [Mtxn/s]) for △
- coarse-grained partition locking of ⬠ is identical for read and update

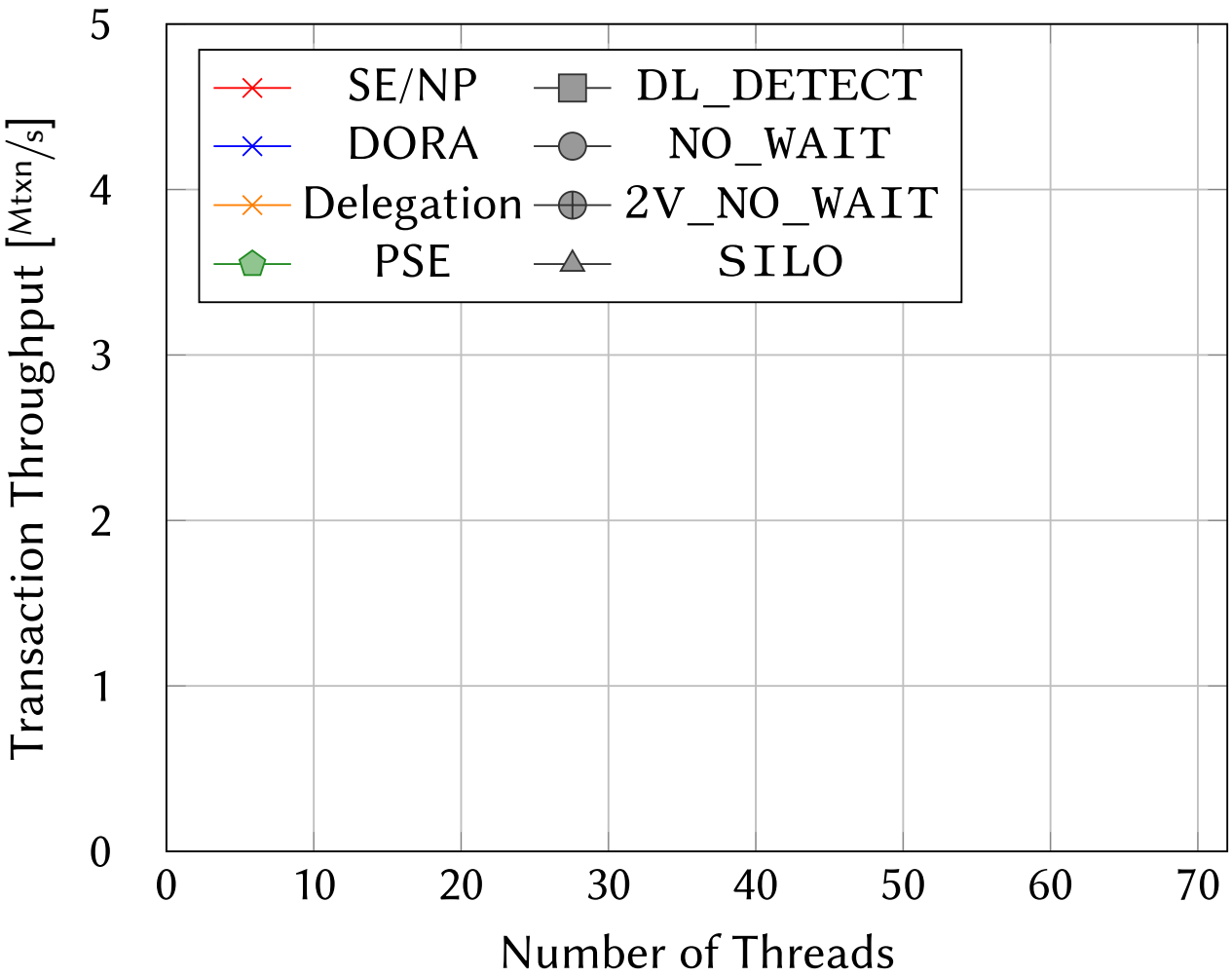
Update-Only Microbenchmark



Observations

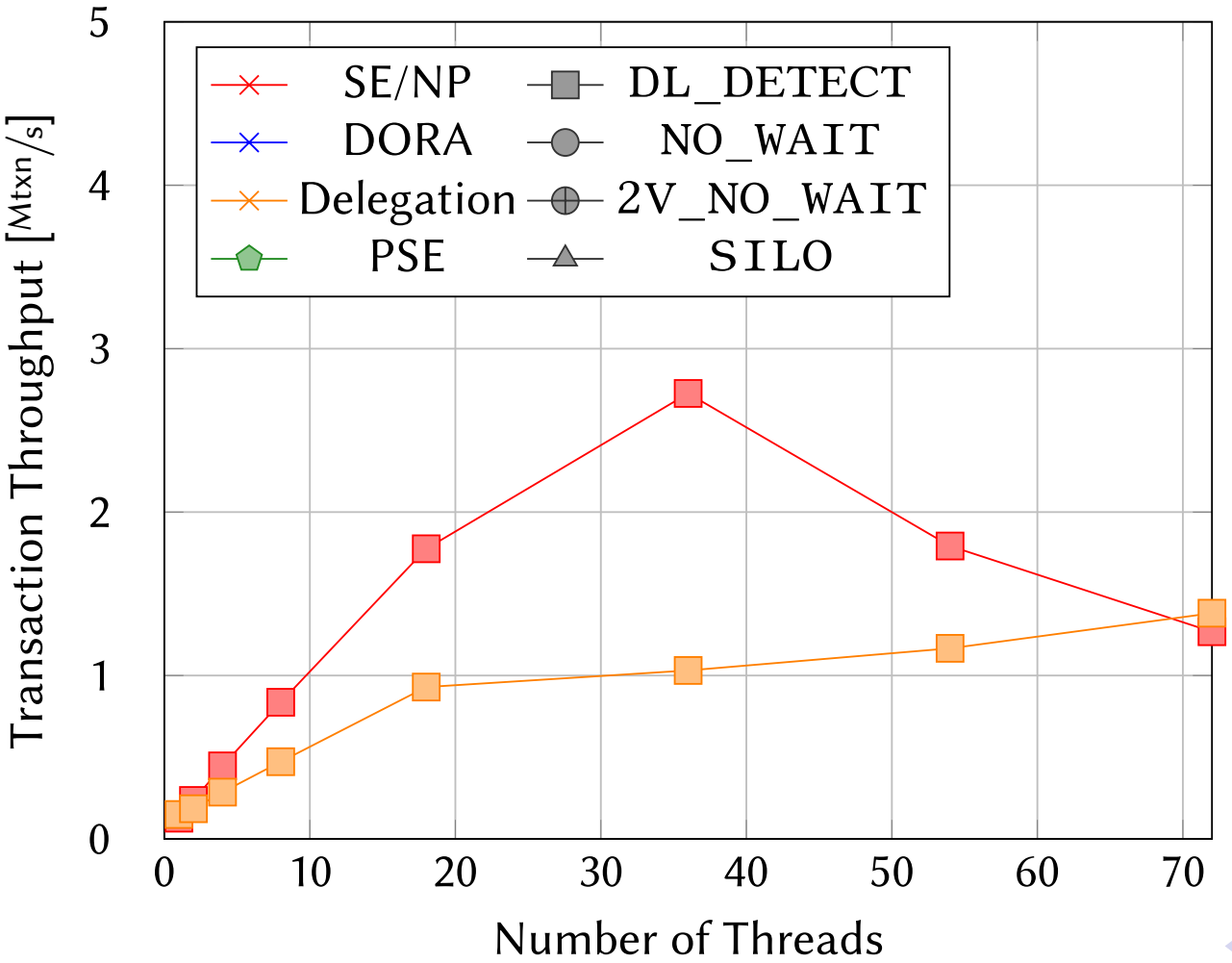
- coarse-grained partition locking of ⬟ is identical for read and update
- ⬟ scales according to the number of hot records (each transaction locks 2 of 16 (hot) partitions)

Read-Only YCSB ($\Theta = 0.8$)



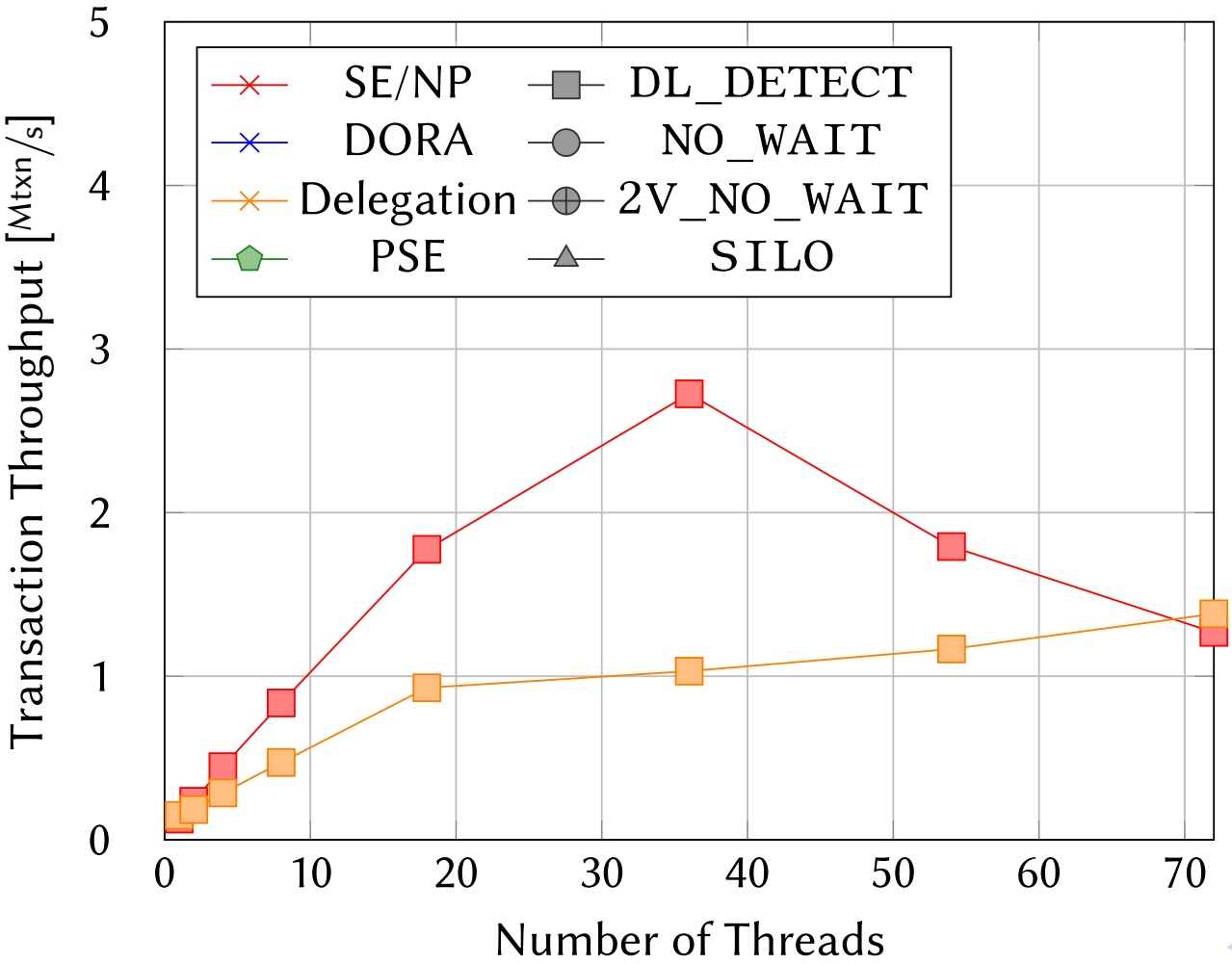
Observations

Read-Only YCSB ($\Theta = 0.8$)



Observations

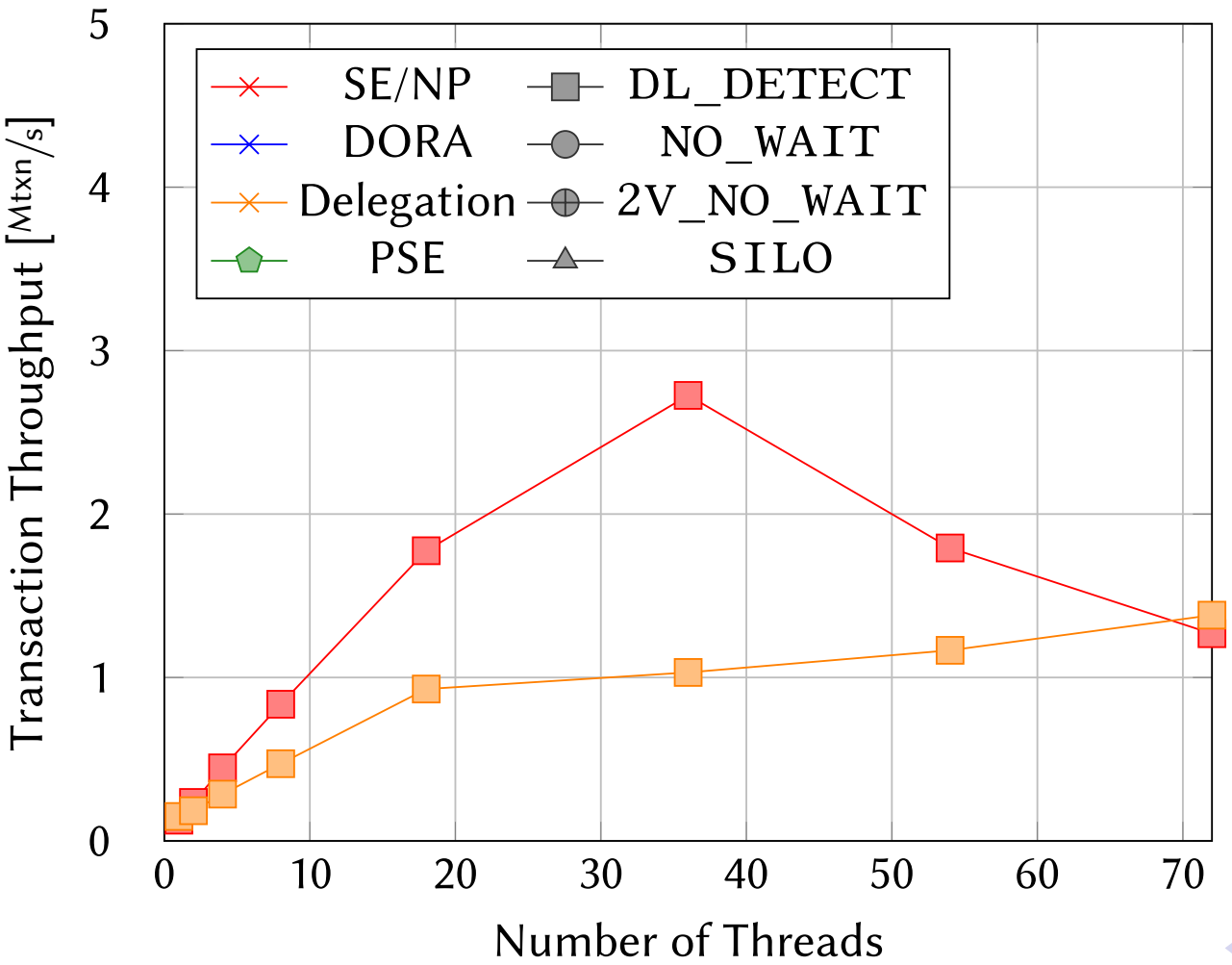
Read-Only YCSB ($\Theta = 0.8$)



Observations

- ✳ scales well with ■ until the latch contention becomes a bottleneck

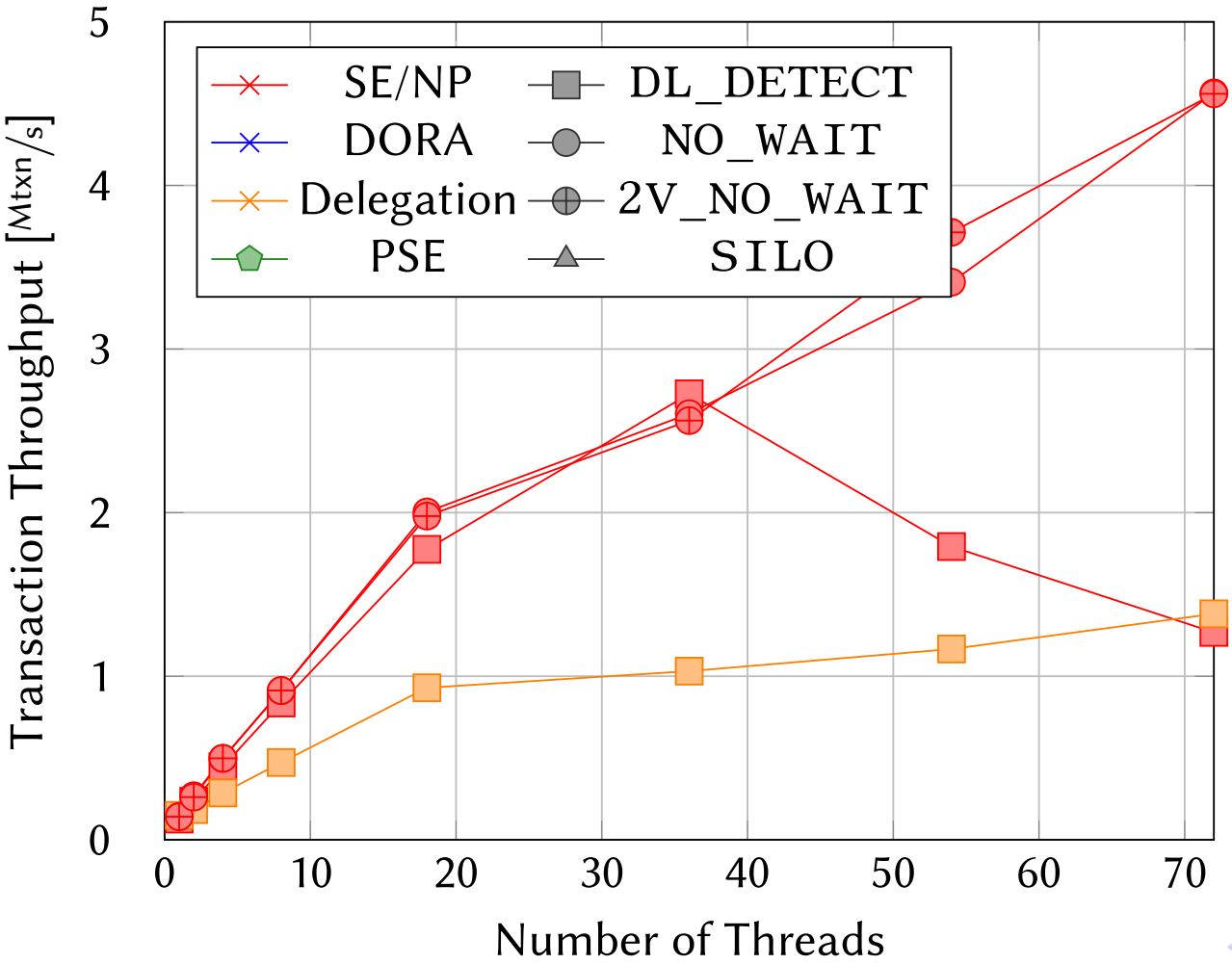
Read-Only YCSB ($\Theta = 0.8$)



Observations

- ✳ scales well with ■ until the latch contention becomes a bottleneck
- ✳ (and ✳) does not scale well due to partition-unfriendly Zipfian access distribution

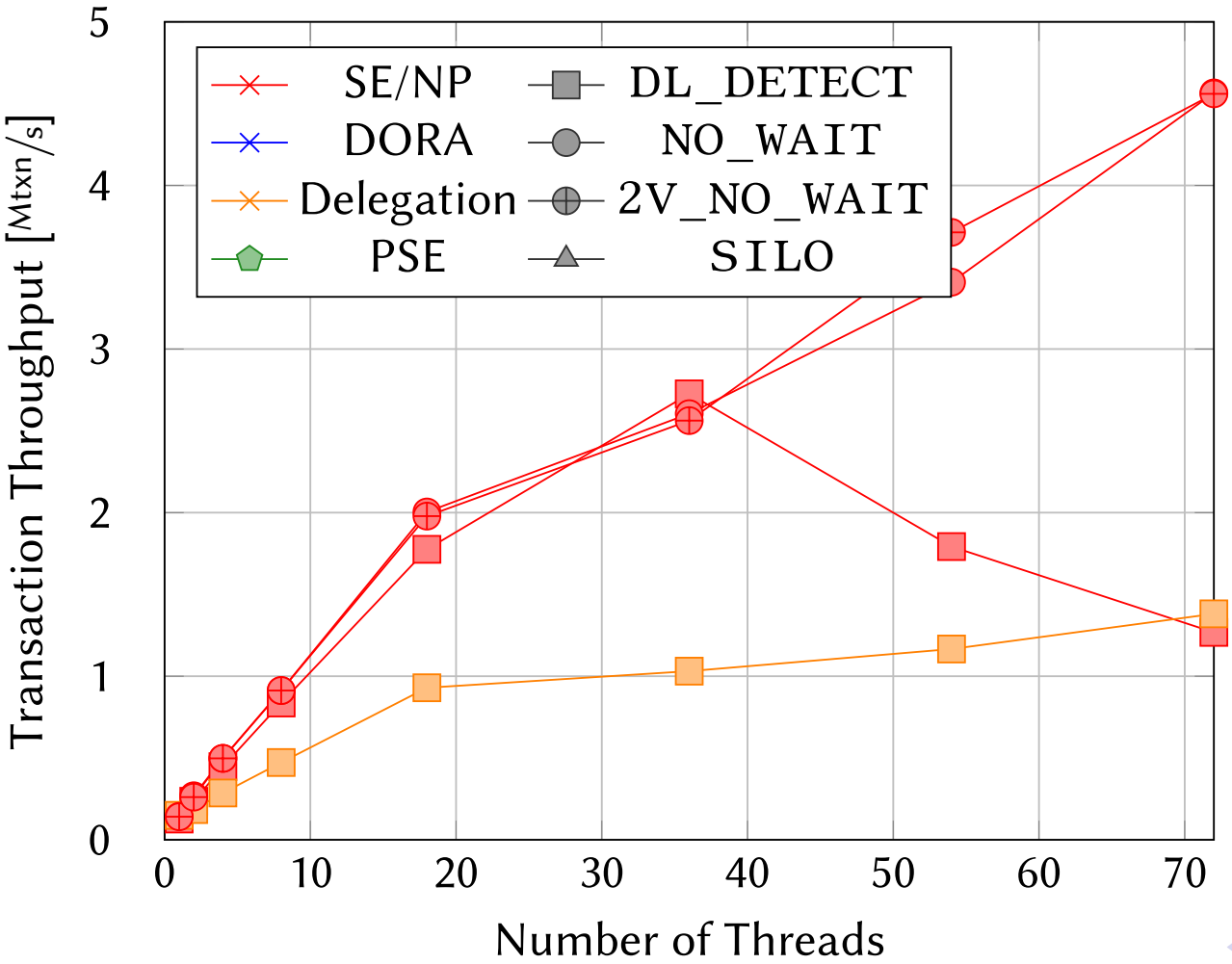
Read-Only YCSB ($\Theta = 0.8$)



Observations

- ✳ scales well with ■ until the latch contention becomes a bottleneck
- ✳ (and ✳) does not scale well due to partition-unfriendly Zipfian access distribution

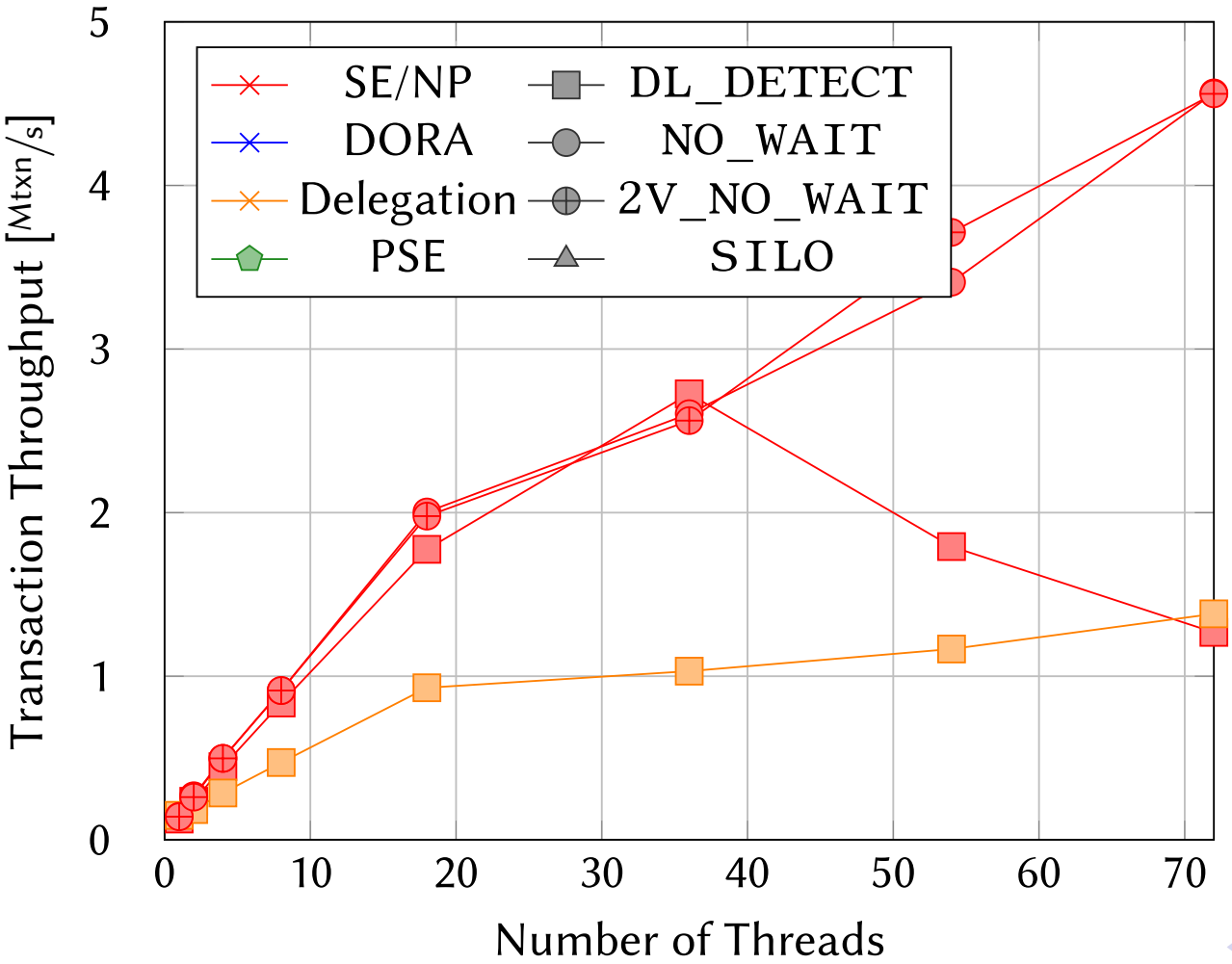
Read-Only YCSB ($\Theta = 0.8$)



Observations

- ✳ scales well with ■ until the latch contention becomes a bottleneck
- ✳ (and ✳) does not scale well due to partition-unfriendly Zipfian access distribution
- atomics of ● scale better than latches of ■

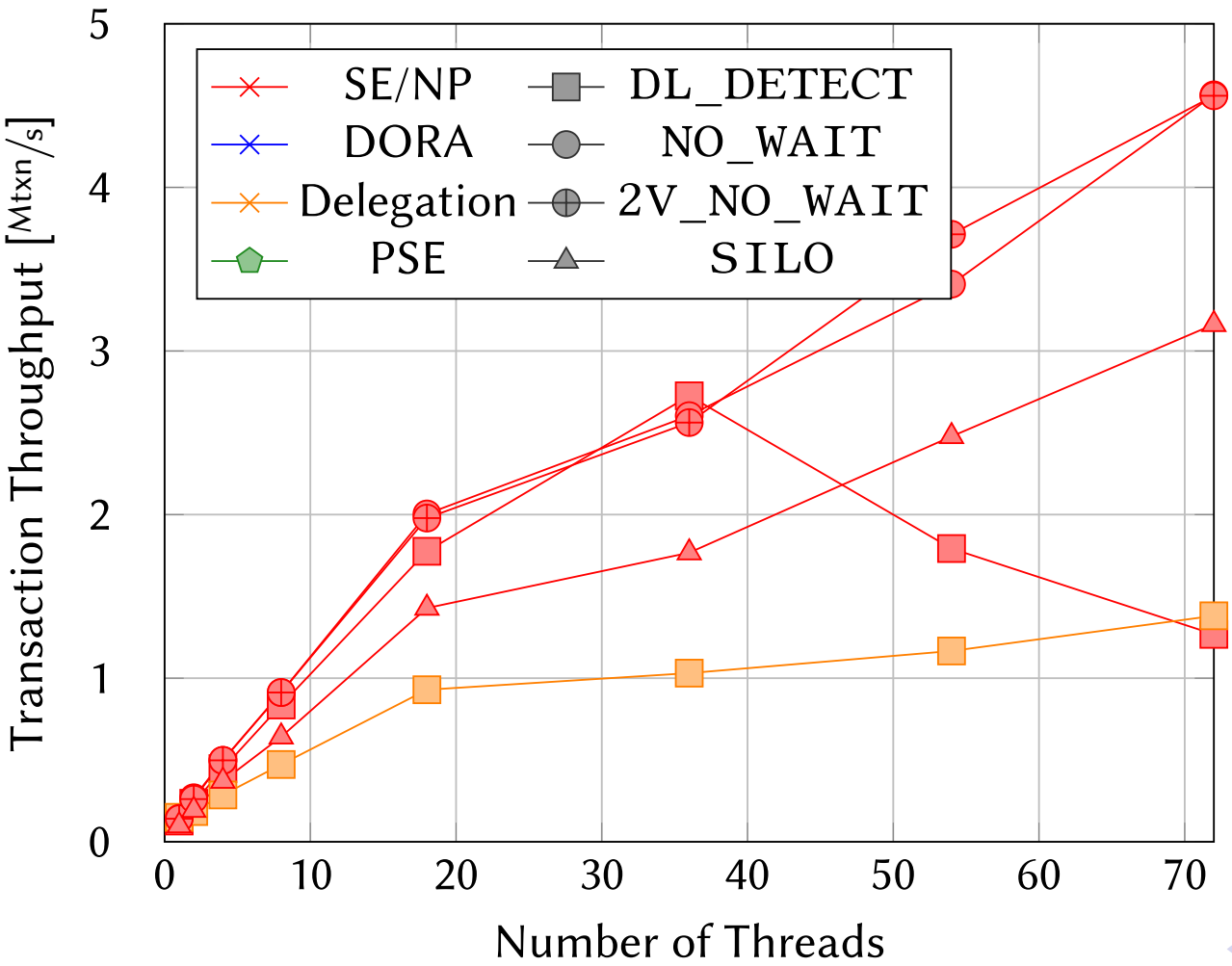
Read-Only YCSB ($\Theta = 0.8$)



Observations

- ✳ scales well with ■ until the latch contention becomes a bottleneck
- ✳ (and ✳) does not scale well due to partition-unfriendly Zipfian access distribution
- atomics of ● scale better than latches of ■
- ⊕ and ● perform identical for read-only

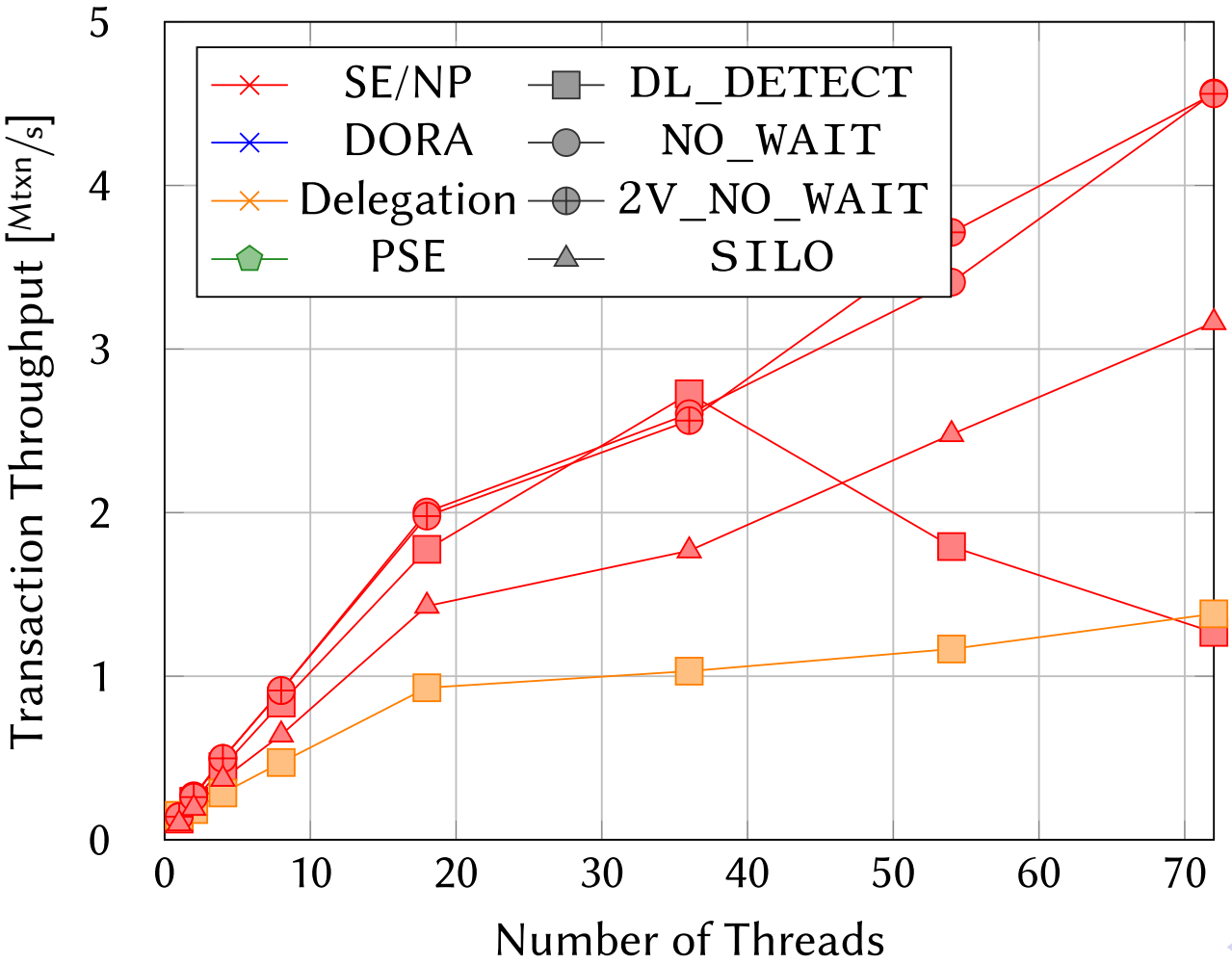
Read-Only YCSB ($\Theta = 0.8$)



Observations

- ✳ scales well with ■ until the latch contention becomes a bottleneck
- ✳ (and ✳) does not scale well due to partition-unfriendly Zipfian access distribution
- atomics of ● scale better than latches of ■
- ⊕ and ● perform identical for read-only

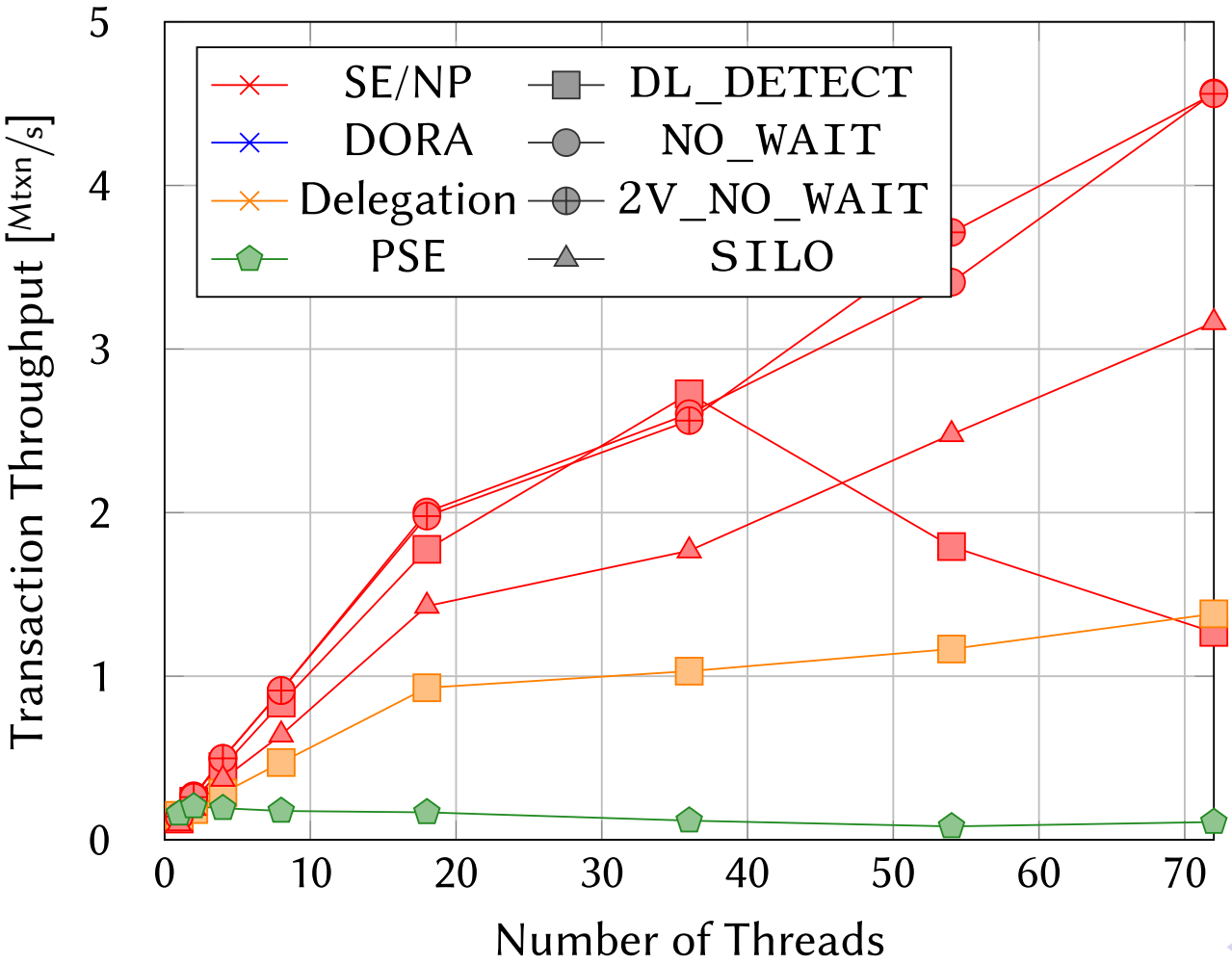
Read-Only YCSB ($\Theta = 0.8$)



Observations

- ✕ (and ✕) does not scale well due to partition-unfriendly Zipfian access distribution
- atomics of ● scale better than latches of ■
- ⊕ and ● perform identical for read-only
- ▲ lags behind ⊕ due to the overhead of copying read (large) records for validation

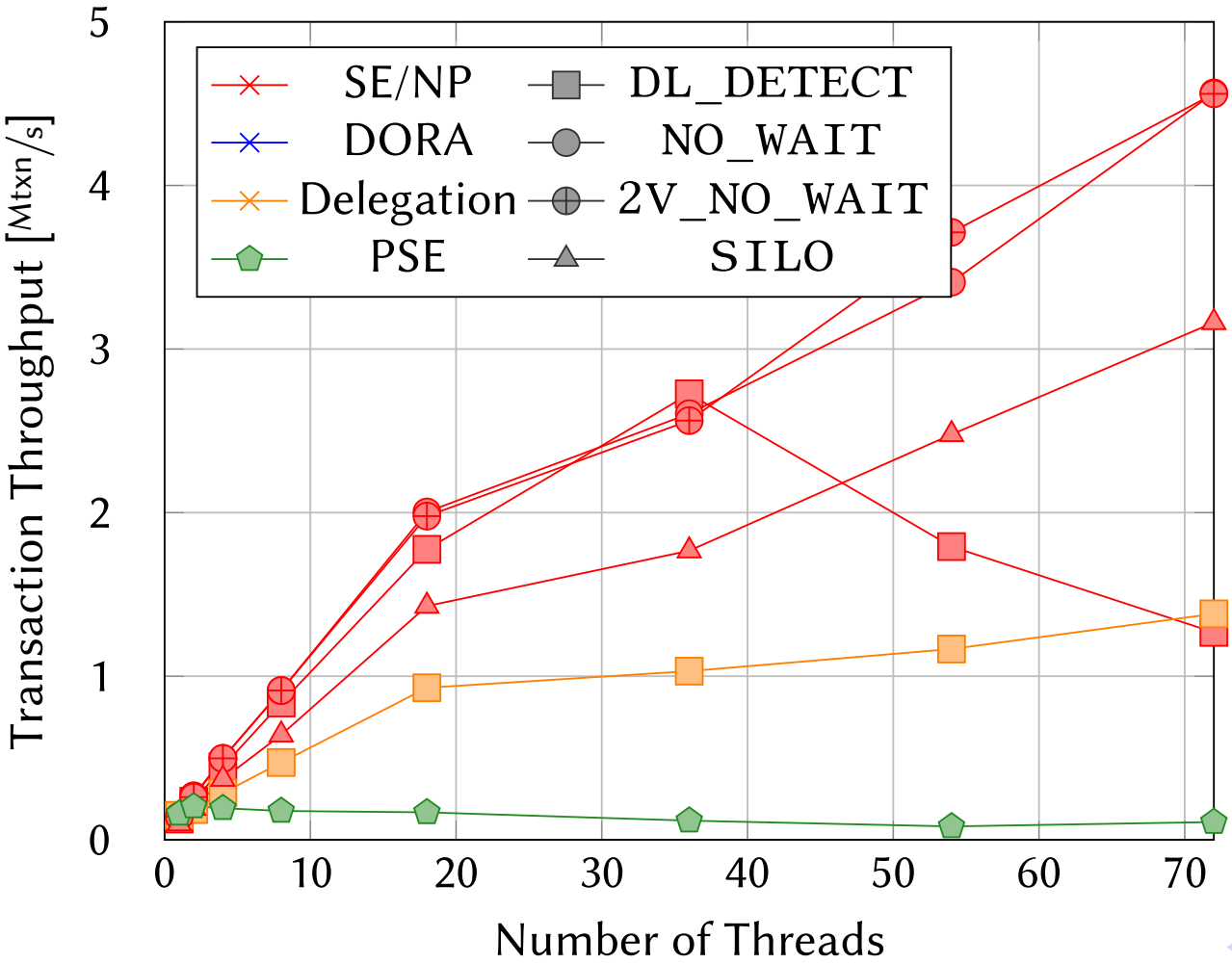
Read-Only YCSB ($\Theta = 0.8$)



Observations

- ✕ (and ✕) does not scale well due to partition-unfriendly Zipfian access distribution
- atomics of ● scale better than latches of ■
- ⊕ and ● perform identical for read-only
- ▲ lags behind ⊕ due to the overhead of copying read (large) records for validation

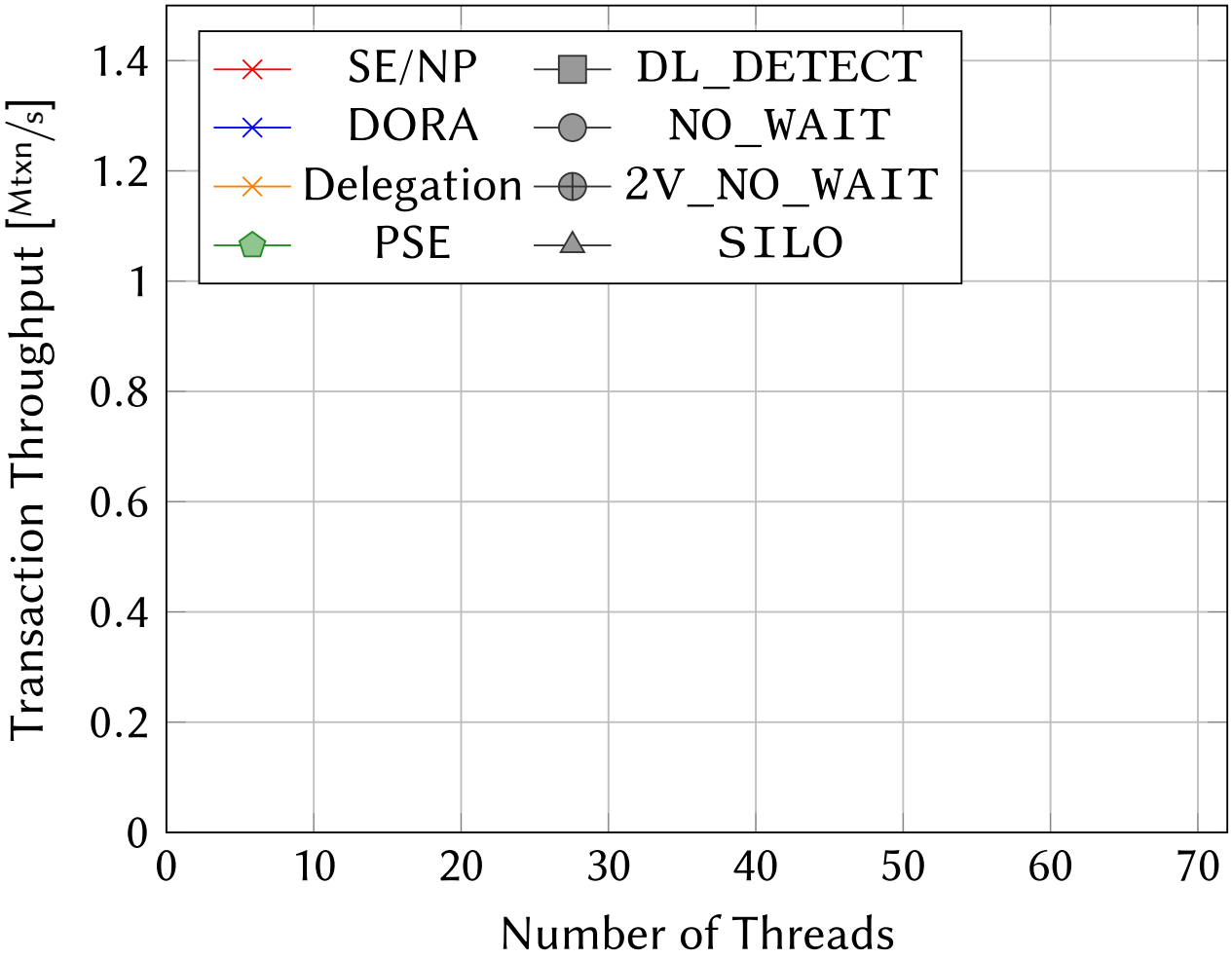
Read-Only YCSB ($\Theta = 0.8$)



Observations

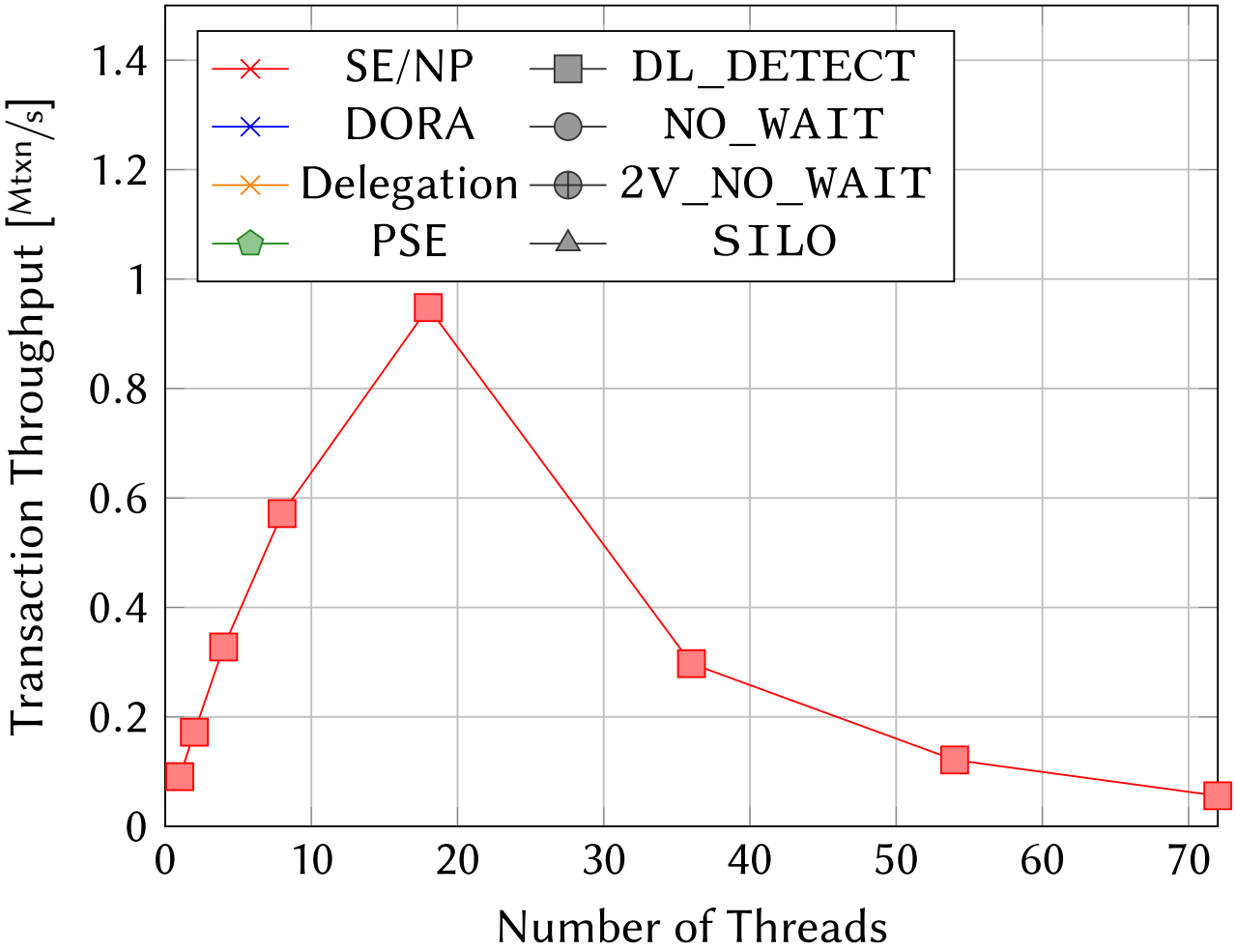
- atomics of ● scale better than latches of ■
- ⊕ and ● perform identical for read-only
- ▲ lags behind ⊕ due to the overhead of copying read (large) records for validation
- coarse-grained partition locking of ⬟ is identical for read and update

Update-Only YCSB ($\Theta = 0.8$)



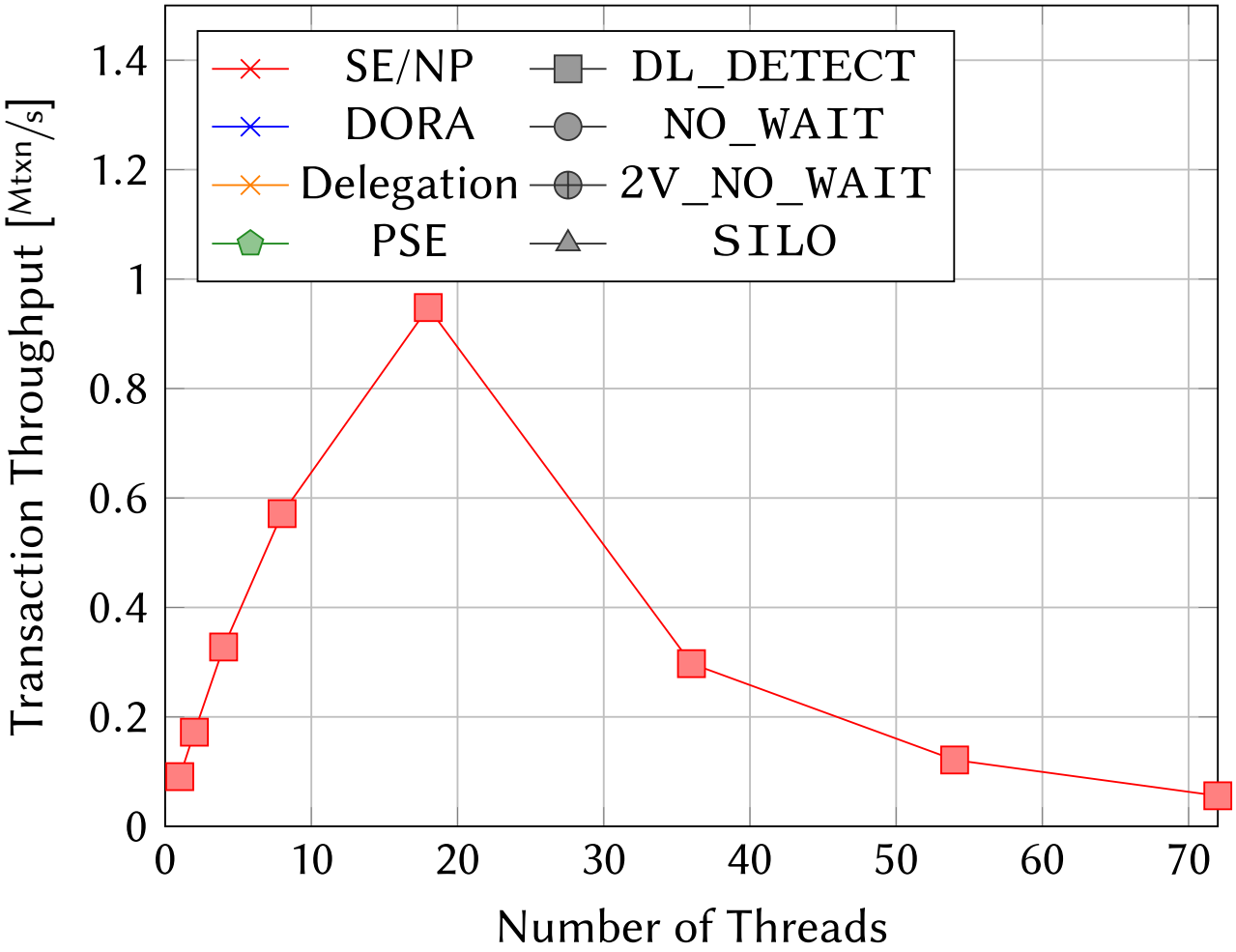
Observations

Update-Only YCSB ($\Theta = 0.8$)



Observations

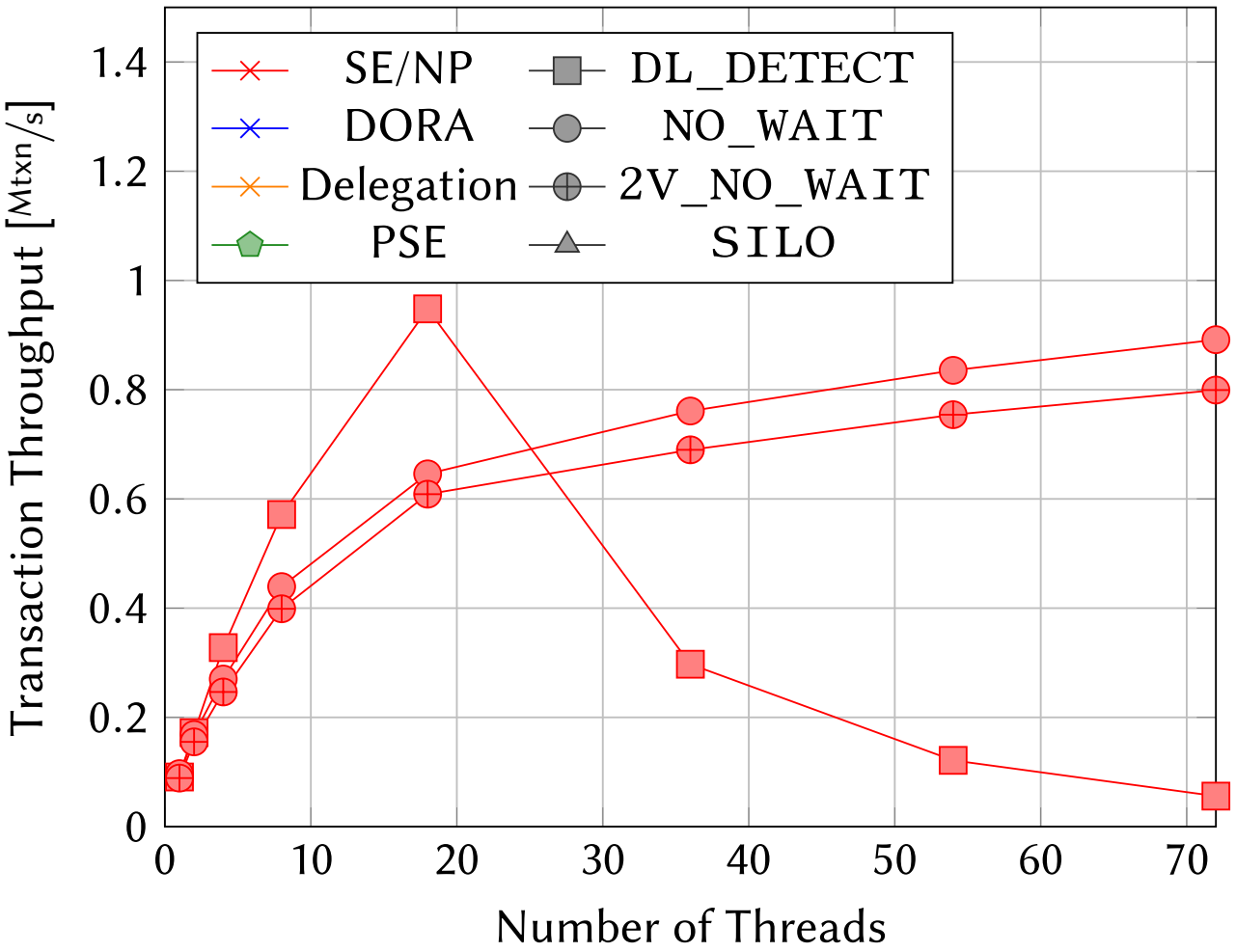
Update-Only YCSB ($\Theta = 0.8$)



Observations

- ■ suffers from deadlocks for many threads

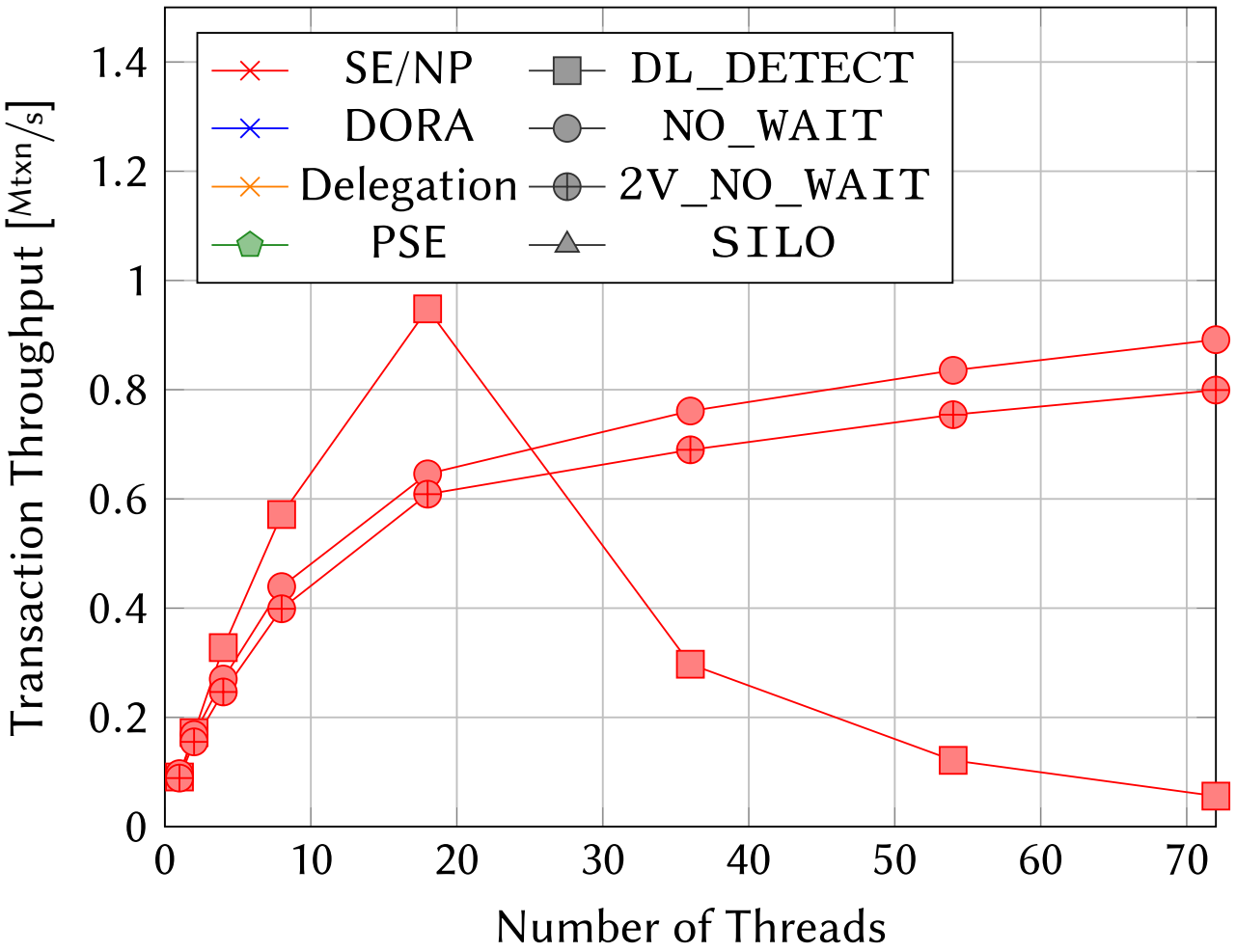
Update-Only YCSB ($\Theta = 0.8$)



Observations

- ■ suffers from deadlocks for many threads

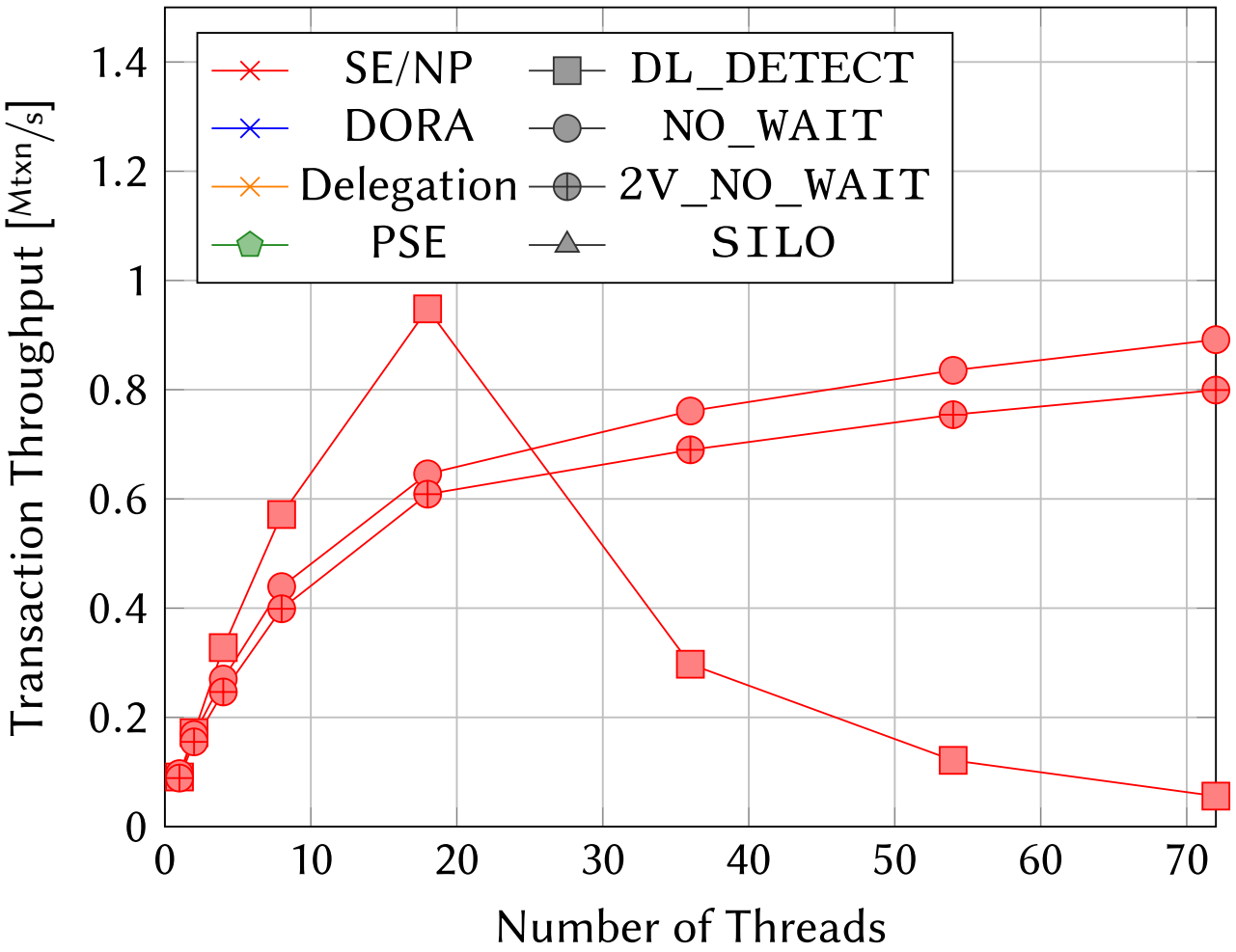
Update-Only YCSB ($\Theta = 0.8$)



Observations

- ■ suffers from deadlocks for many threads
- lock thrashing (aborts for ●) is not a bottleneck due to lower contention

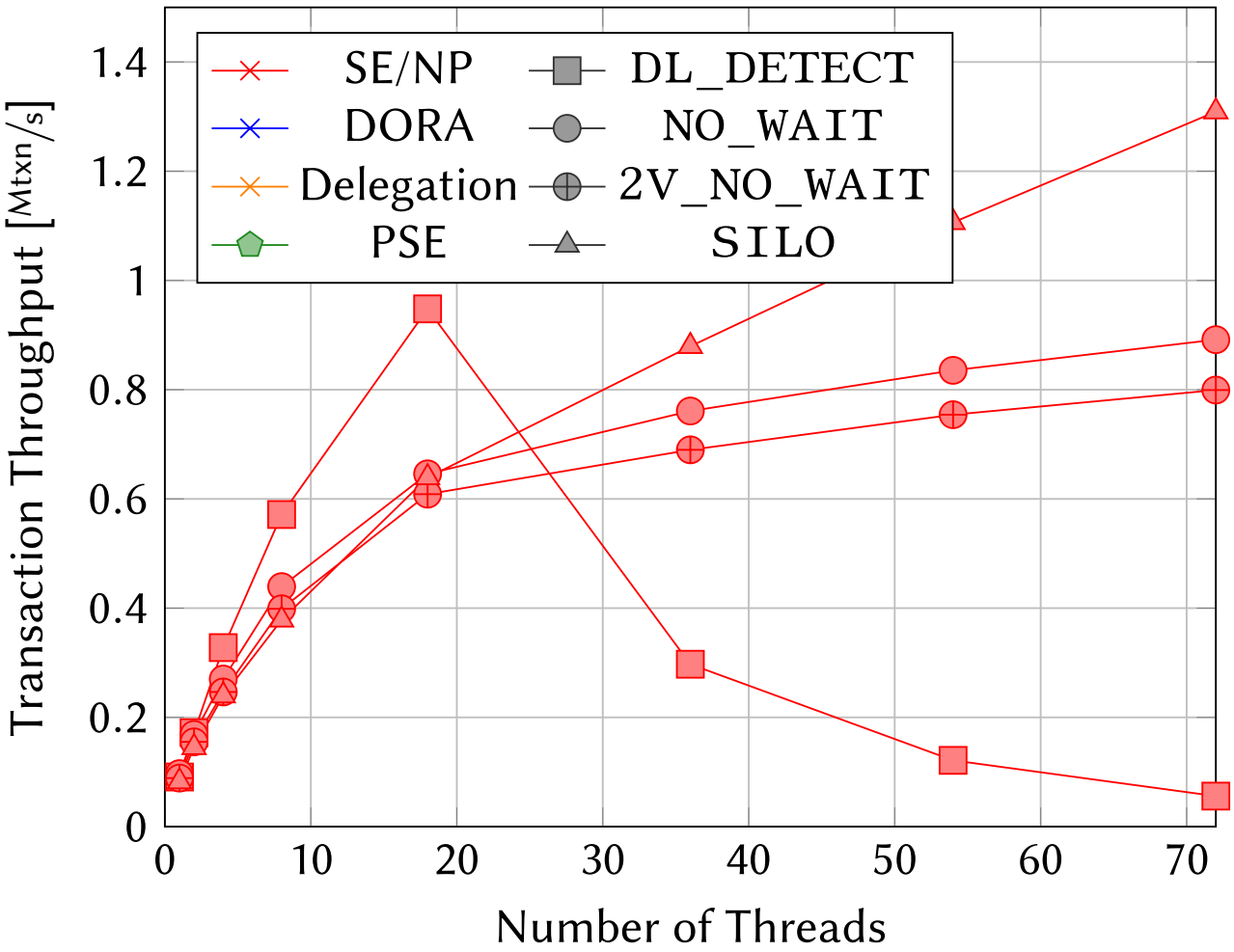
Update-Only YCSB ($\Theta = 0.8$)



Observations

- ■ suffers from deadlocks for many threads
- lock thrashing (aborts for ●) is not a bottleneck due to lower contention
- ⊕ and ● perform identical for update-only

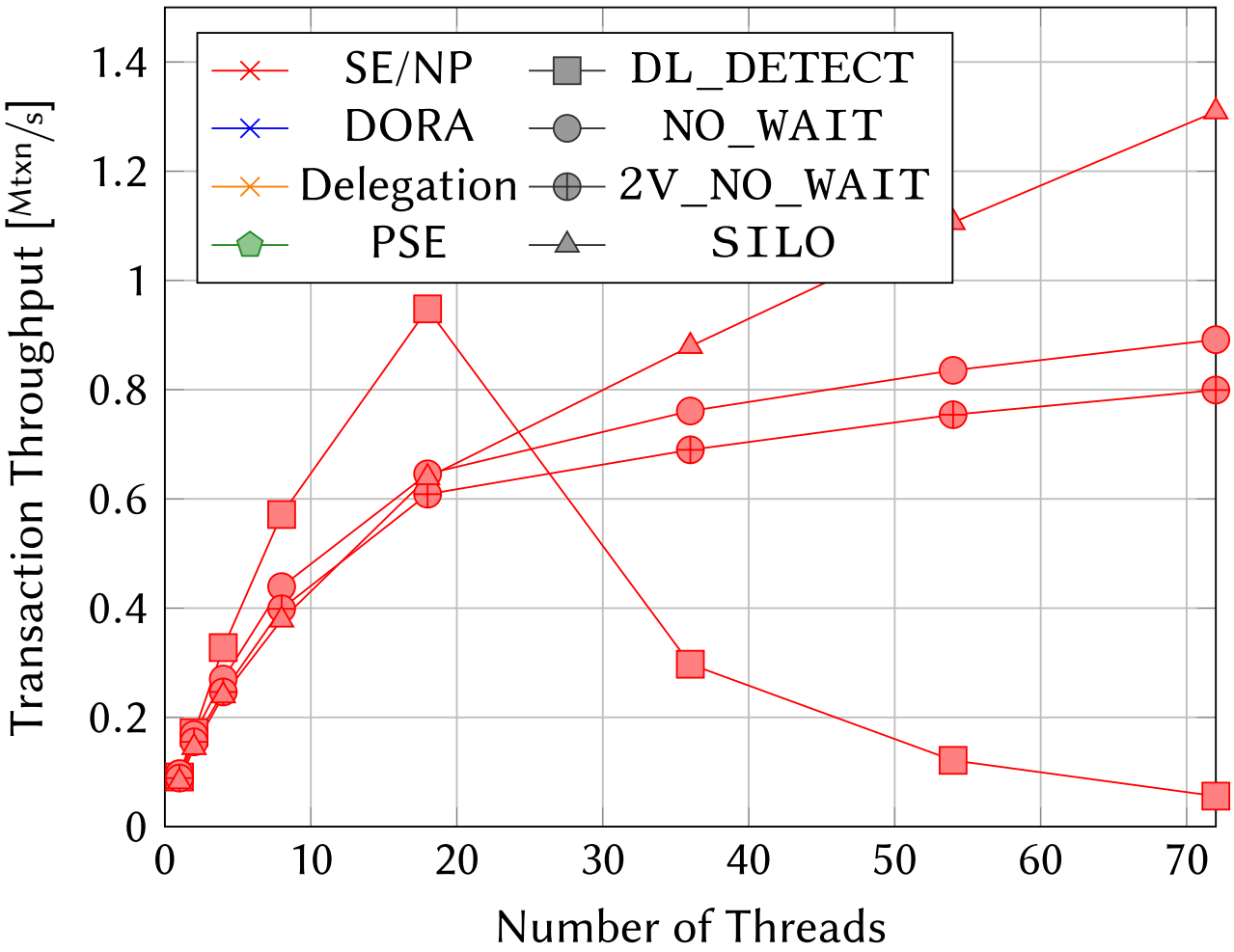
Update-Only YCSB ($\Theta = 0.8$)



Observations

- ■ suffers from deadlocks for many threads
- lock thrashing (aborts for ●) is not a bottleneck due to lower contention
- ⊕ and ● perform identical for update-only

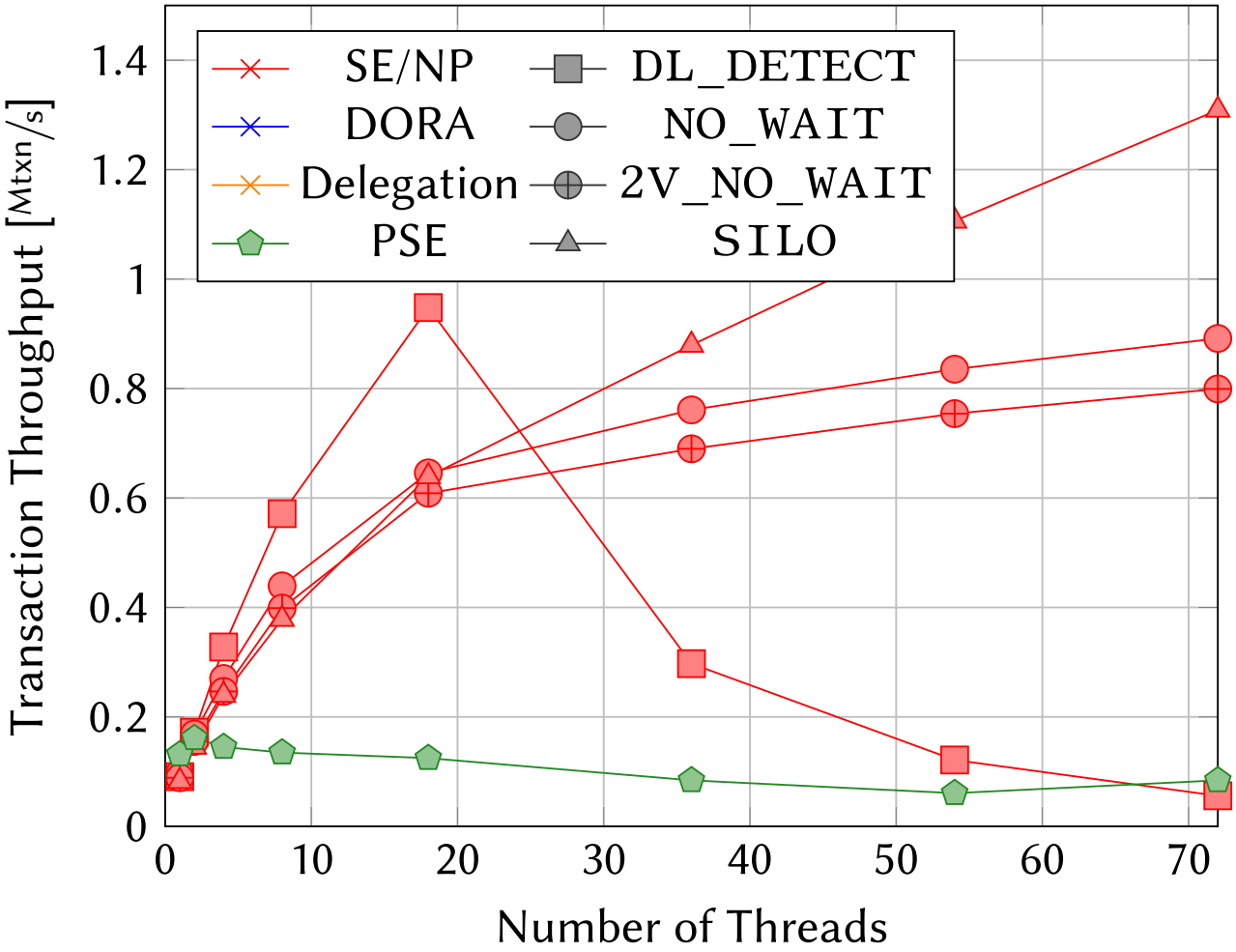
Update-Only YCSB ($\Theta = 0.8$)



Observations

- ■ suffers from deadlocks for many threads
- lock thrashing (aborts for ●) is not a bottleneck due to lower contention
- ⊕ and ● perform identical for update-only
- ▲ causes less aborts than ● due its optimism → higher [Mtxn/s]

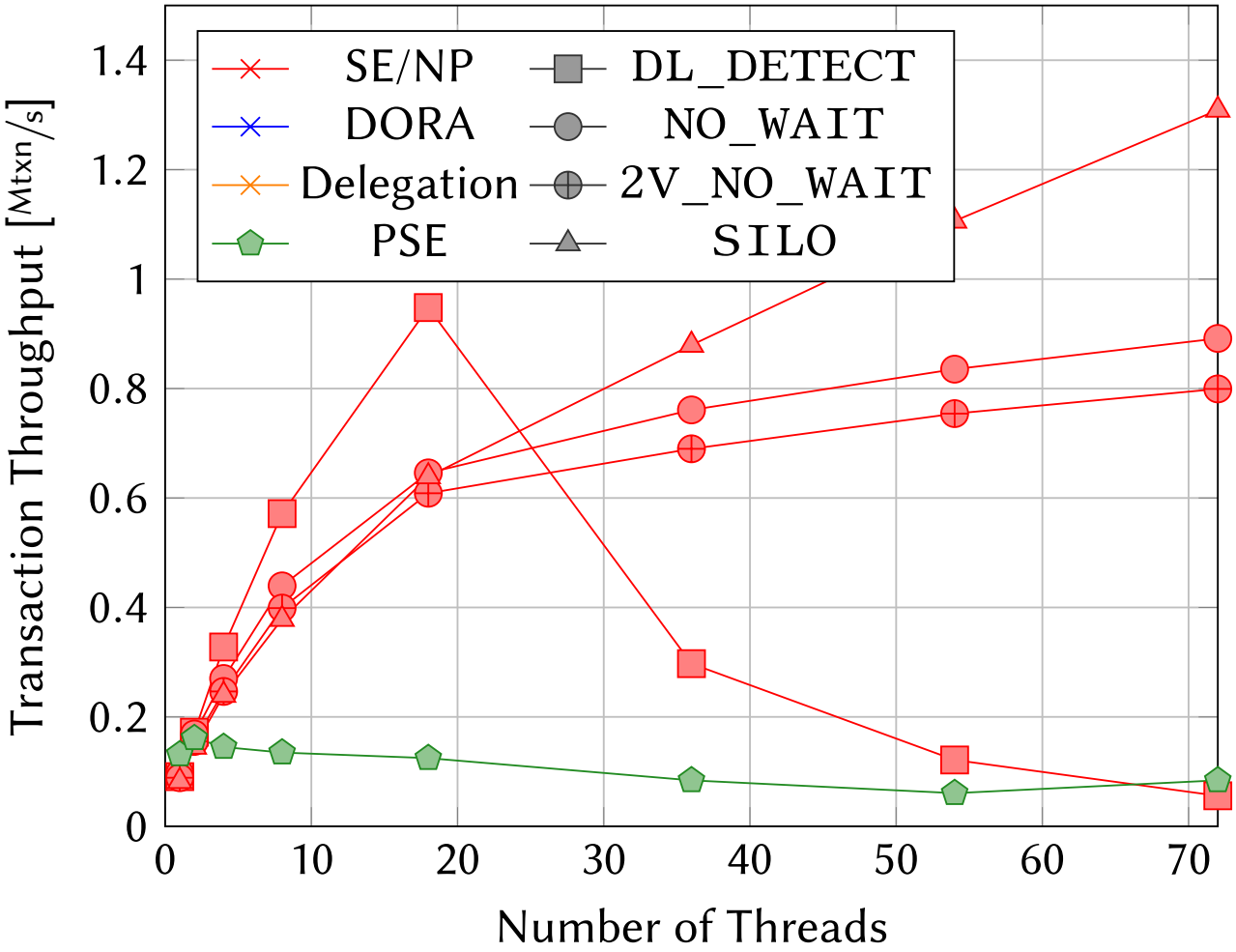
Update-Only YCSB ($\Theta = 0.8$)



Observations

- ■ suffers from deadlocks for many threads
- lock thrashing (aborts for ●) is not a bottleneck due to lower contention
- ⊕ and ● perform identical for update-only
- ▲ causes less aborts than ● due its optimism → higher [Mtxn/s]

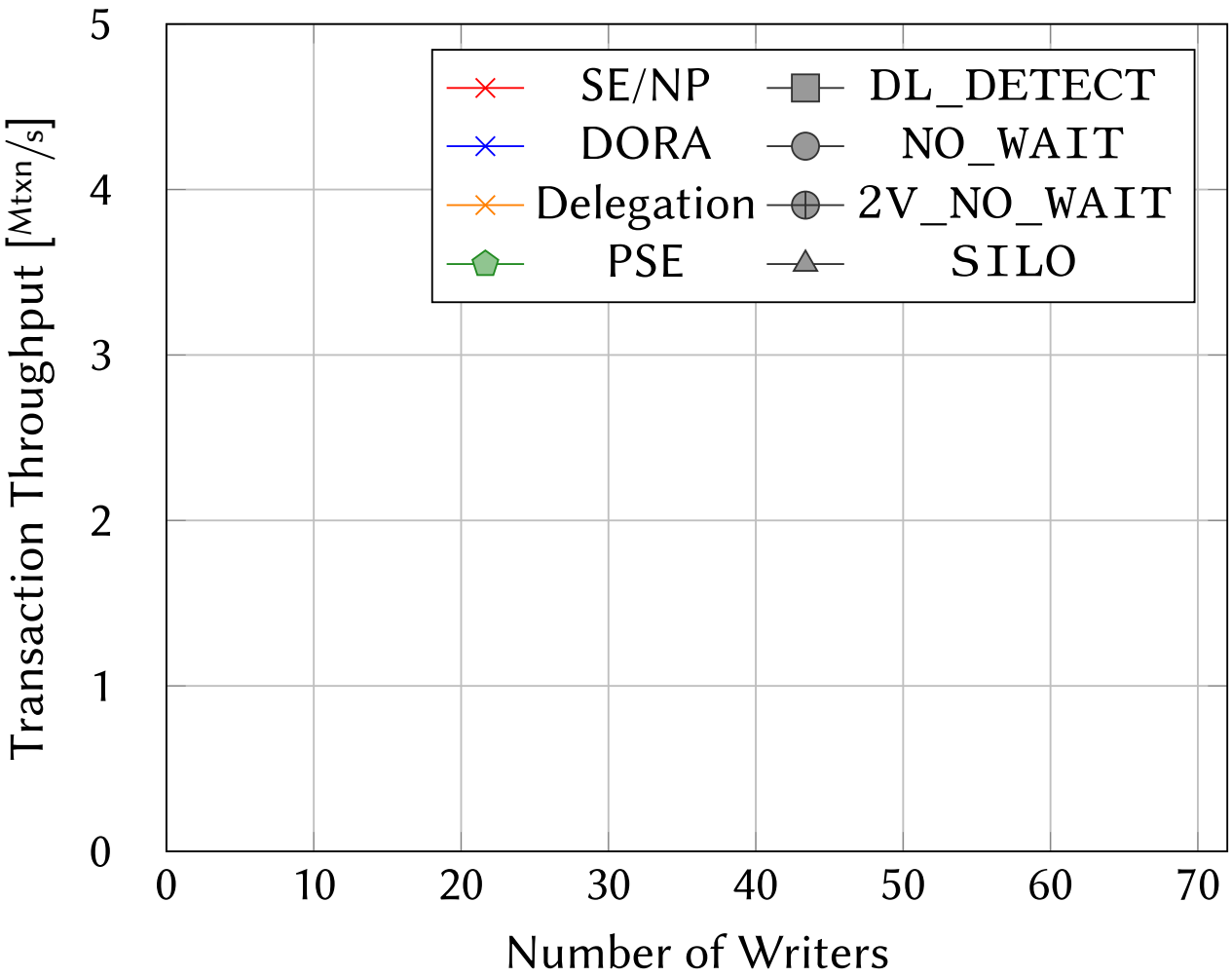
Update-Only YCSB ($\Theta = 0.8$)



Observations

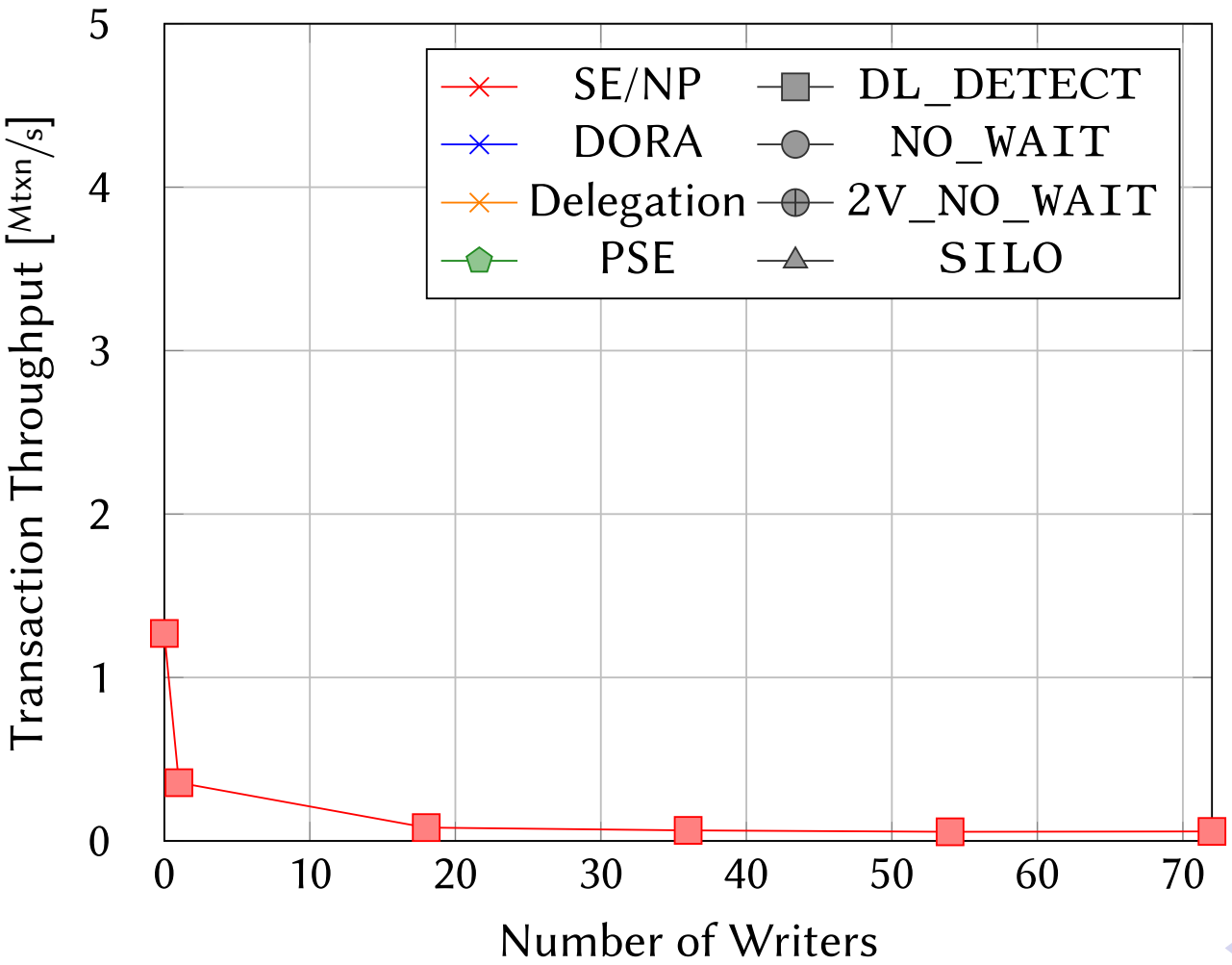
- lock thrashing (aborts for ●) is not a bottleneck due to lower contention
- ⊕ and ● perform identical for update-only
- △ causes less aborts than ● due its optimism → higher [Mtxn/s]
- ⬟ (and ✳/✳) does not scale well due to partition-unfriendly Zipfian access distribution

Mixed YCSB ($\Theta = 0.8$, 72 Threads)



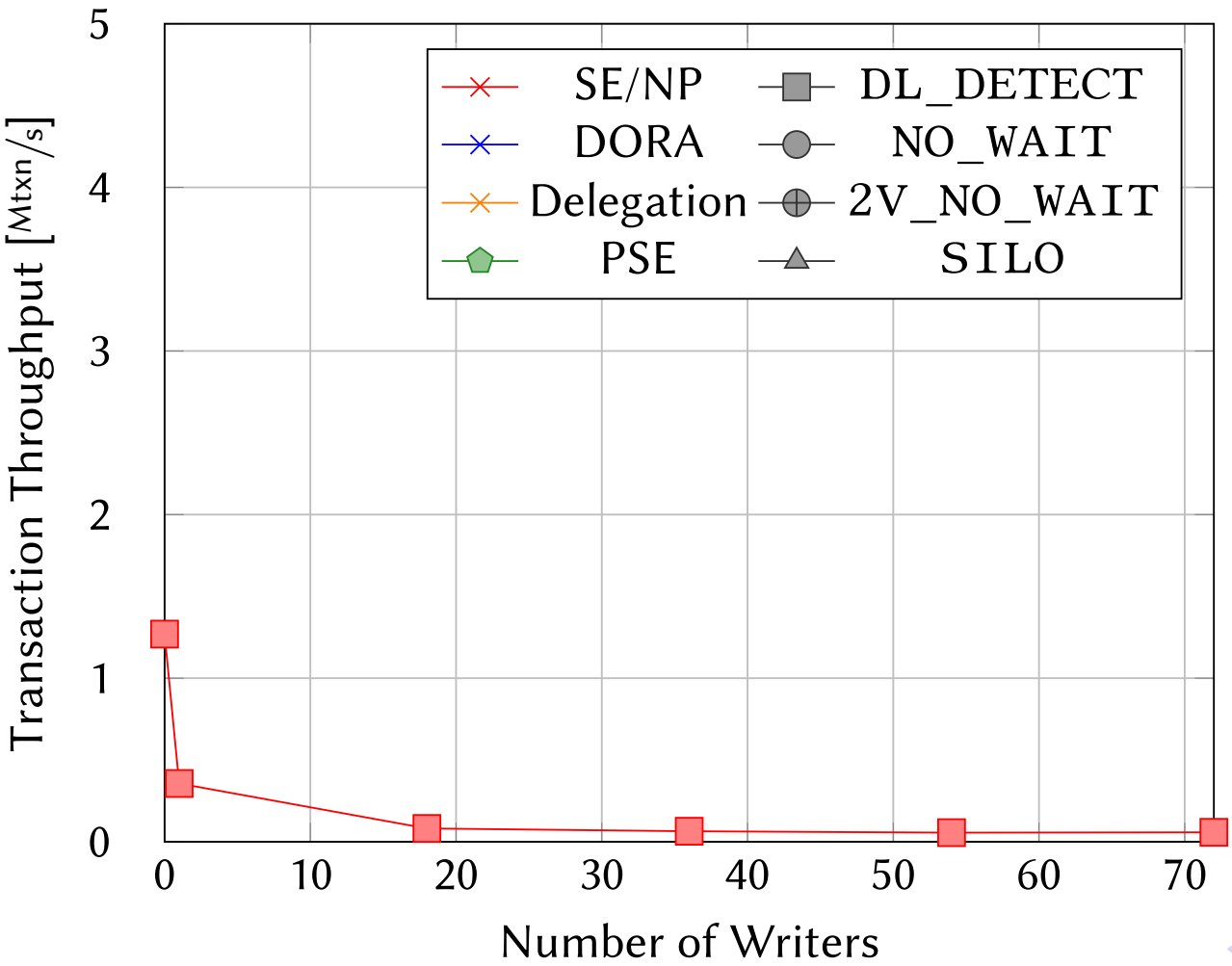
Observations

Mixed YCSB ($\Theta = 0.8$, 72 Threads)



Observations

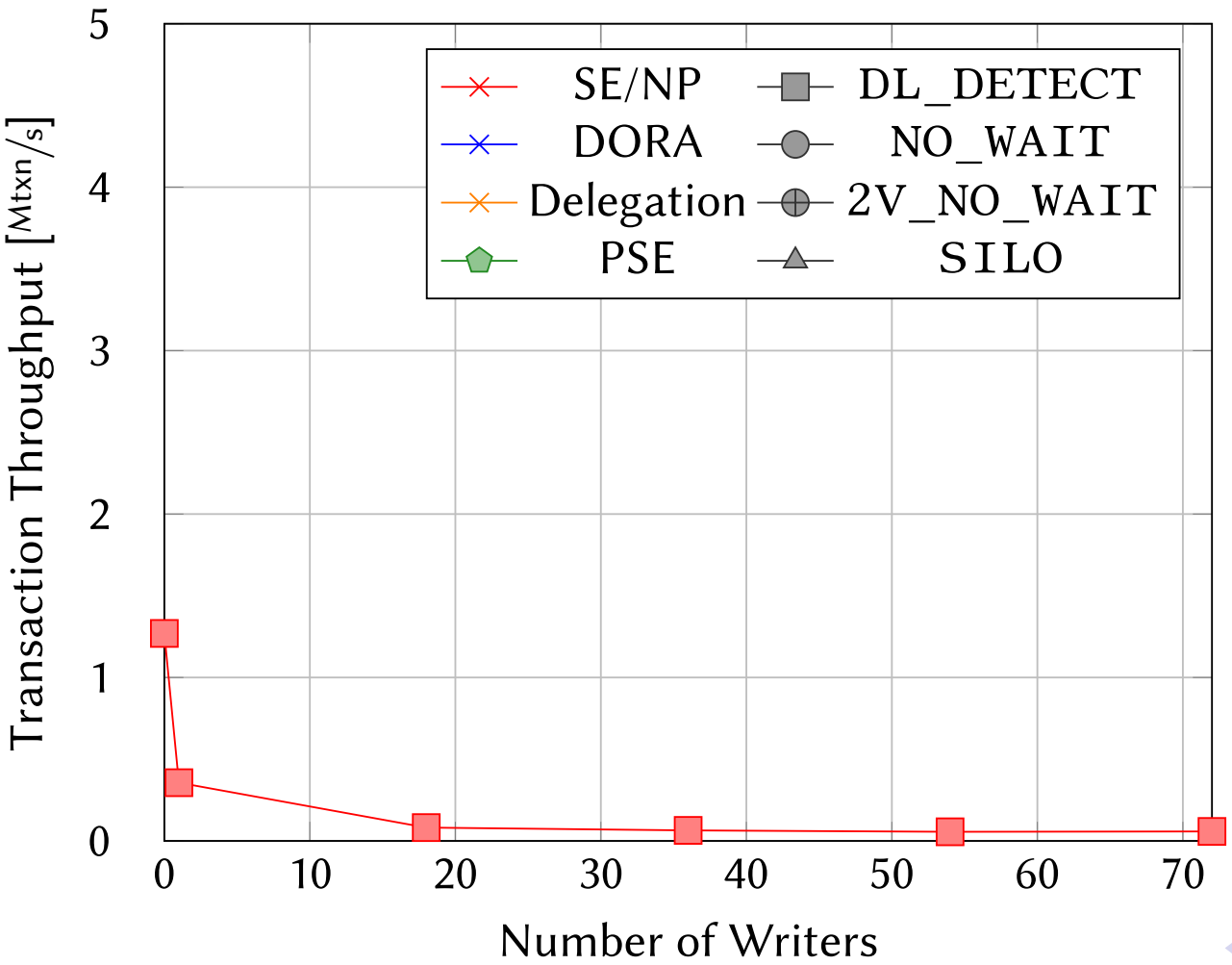
Mixed YCSB ($\Theta = 0.8$, 72 Threads)



Observations

- ■ suffers from latch contention for 72 reading threads

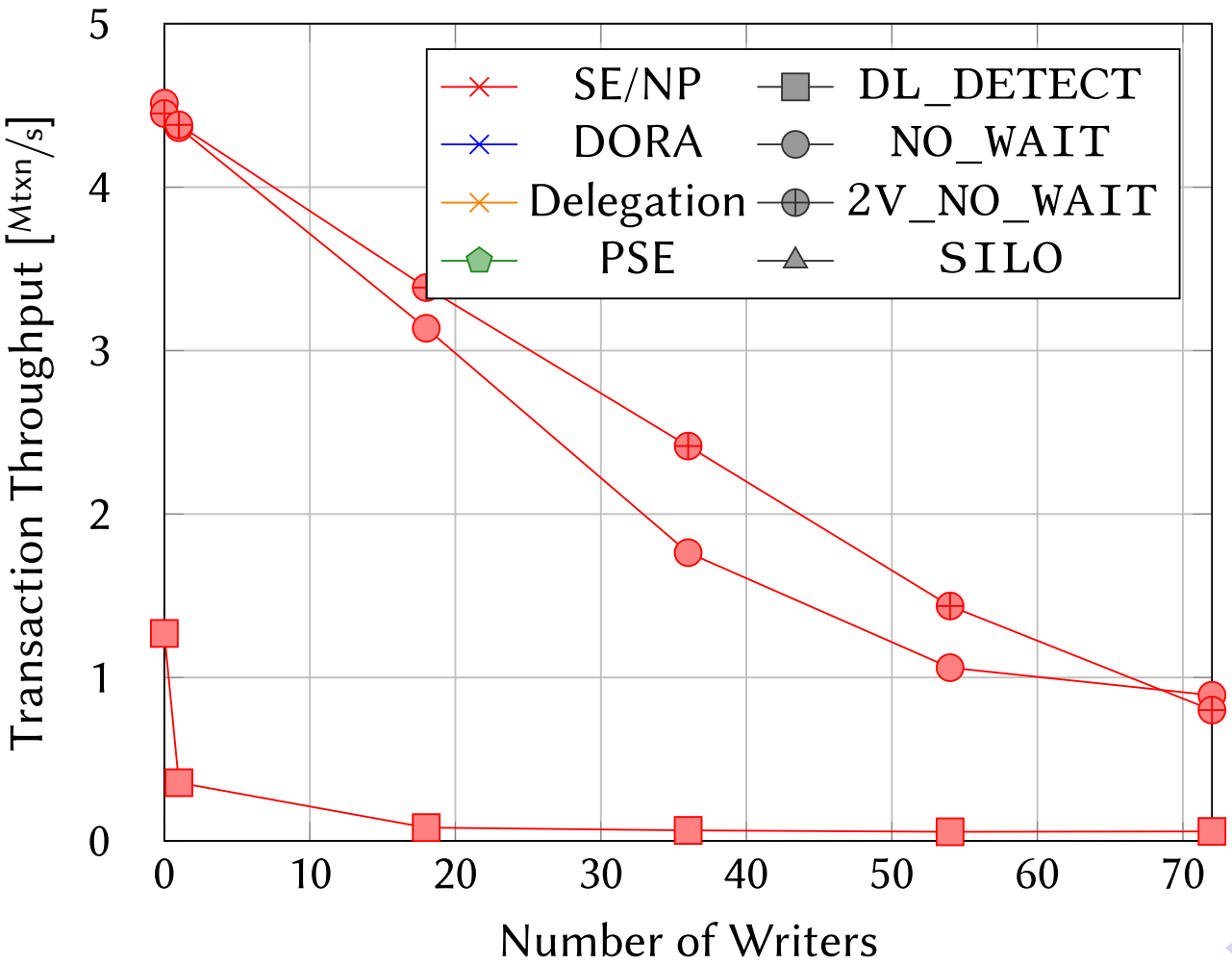
Mixed YCSB ($\Theta = 0.8$, 72 Threads)



Observations

- ■ suffers from latch contention for 72 reading threads
- ■ suffers from deadlocks for writing threads

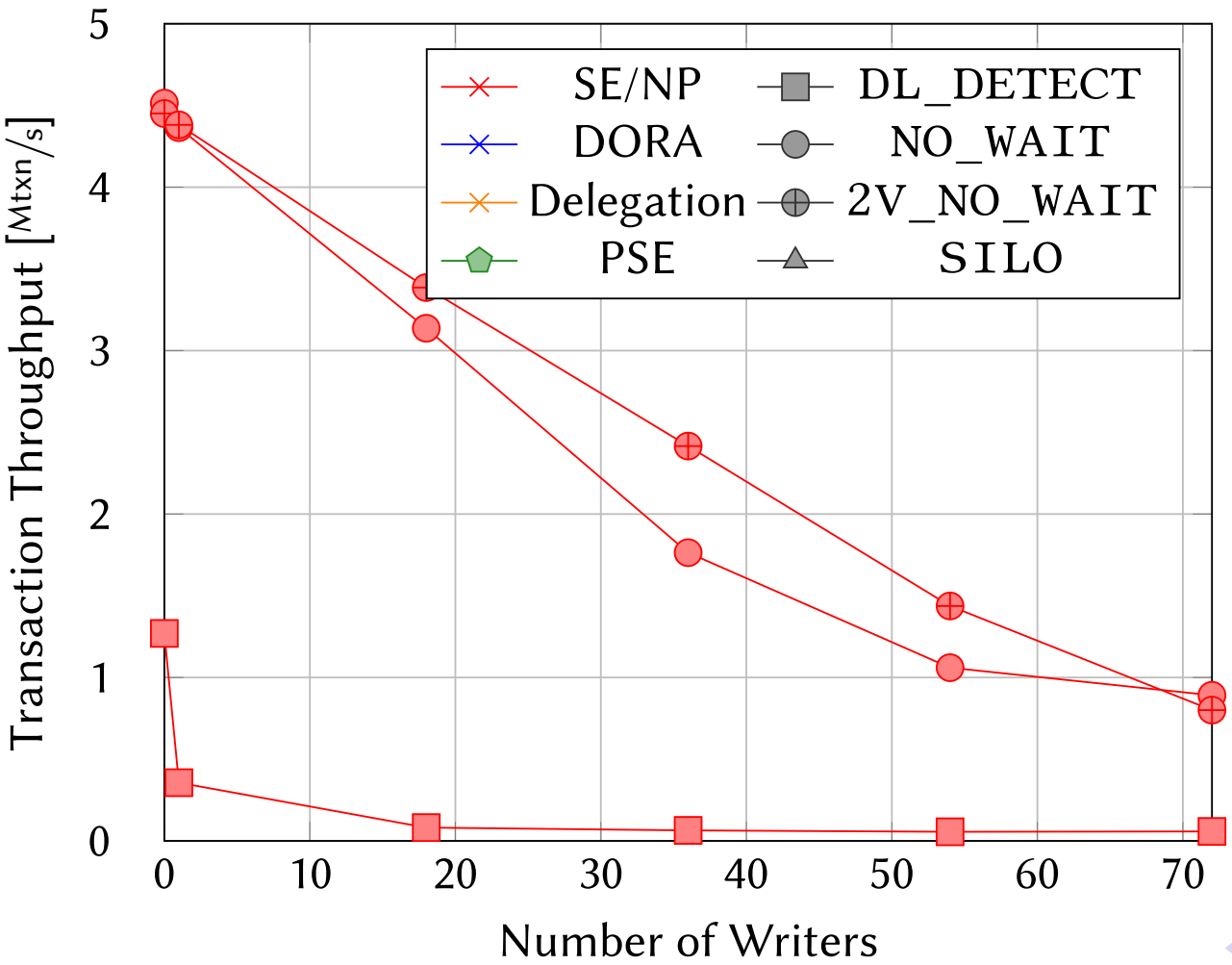
Mixed YCSB ($\Theta = 0.8$, 72 Threads)



Observations

- ■ suffers from latch contention for 72 reading threads
- ■ suffers from deadlocks for writing threads

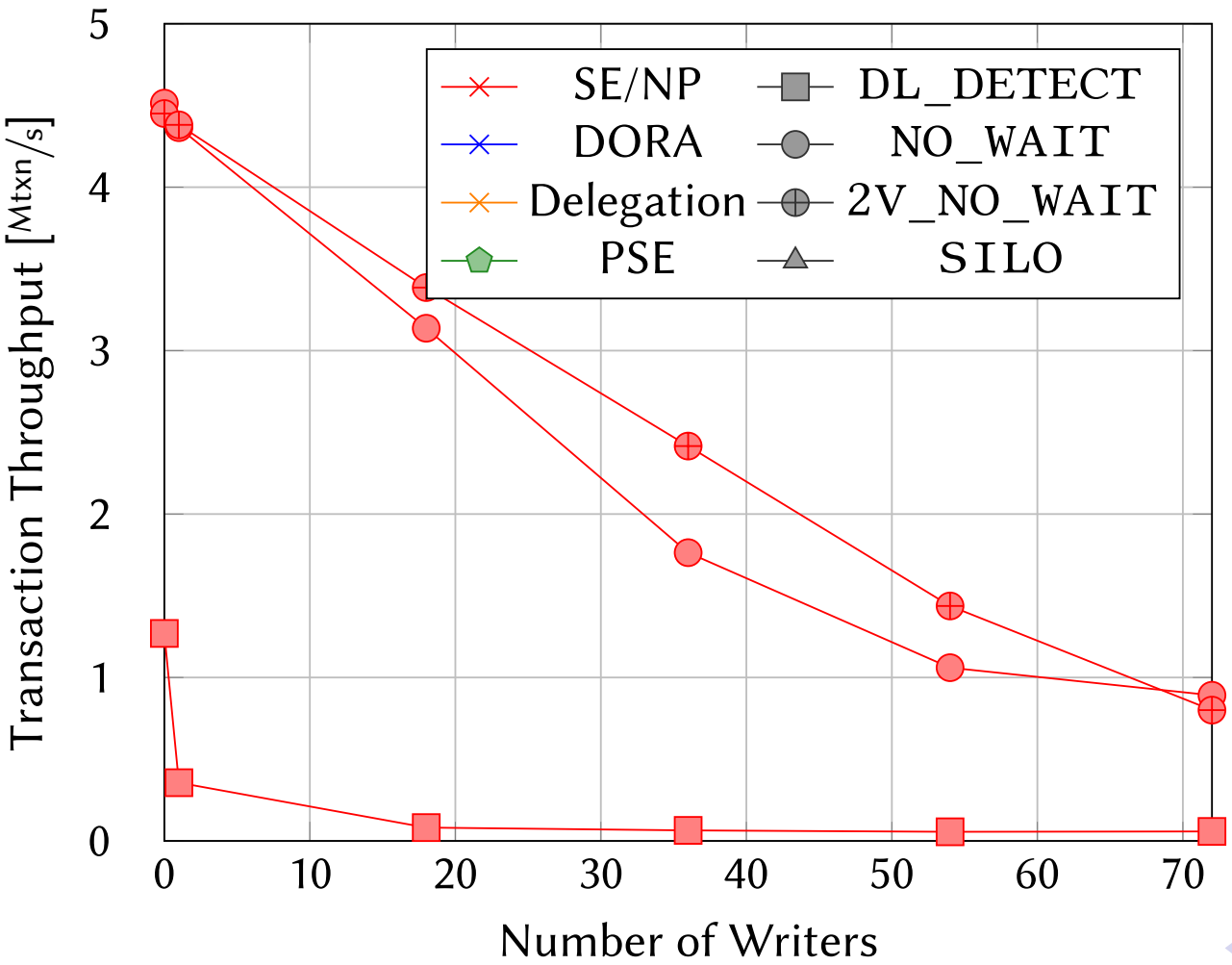
Mixed YCSB ($\Theta = 0.8$, 72 Threads)



Observations

- ■ suffers from latch contention for 72 reading threads
- ■ suffers from deadlocks for writing threads
- atomics of ● scale better than latches of ■

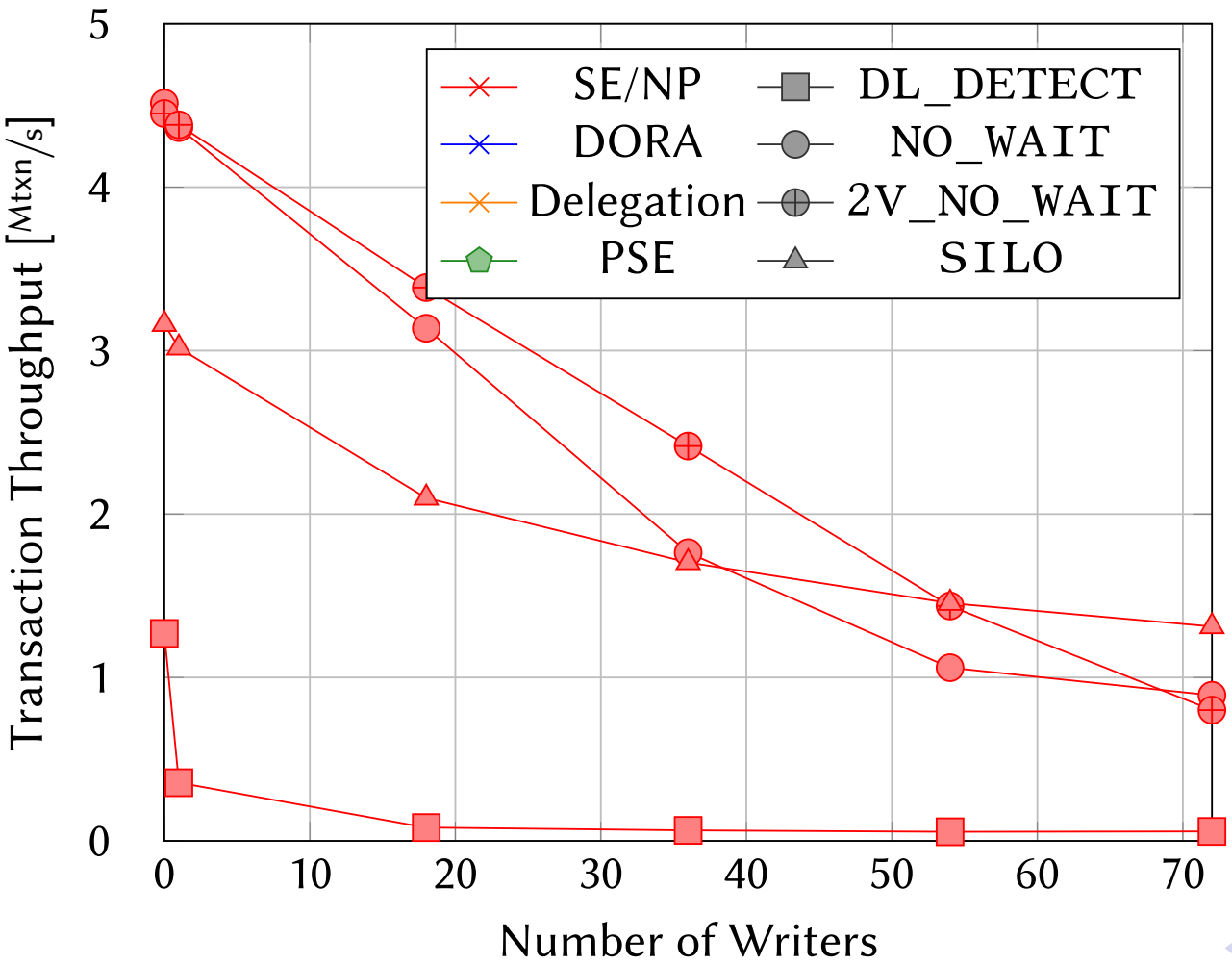
Mixed YCSB ($\Theta = 0.8$, 72 Threads)



Observations

- ■ suffers from latch contention for 72 reading threads
- ■ suffers from deadlocks for writing threads
- atomics of ● scale better than latches of ■
- multi-versioning of ⊕ improves concurrency for mixed workloads

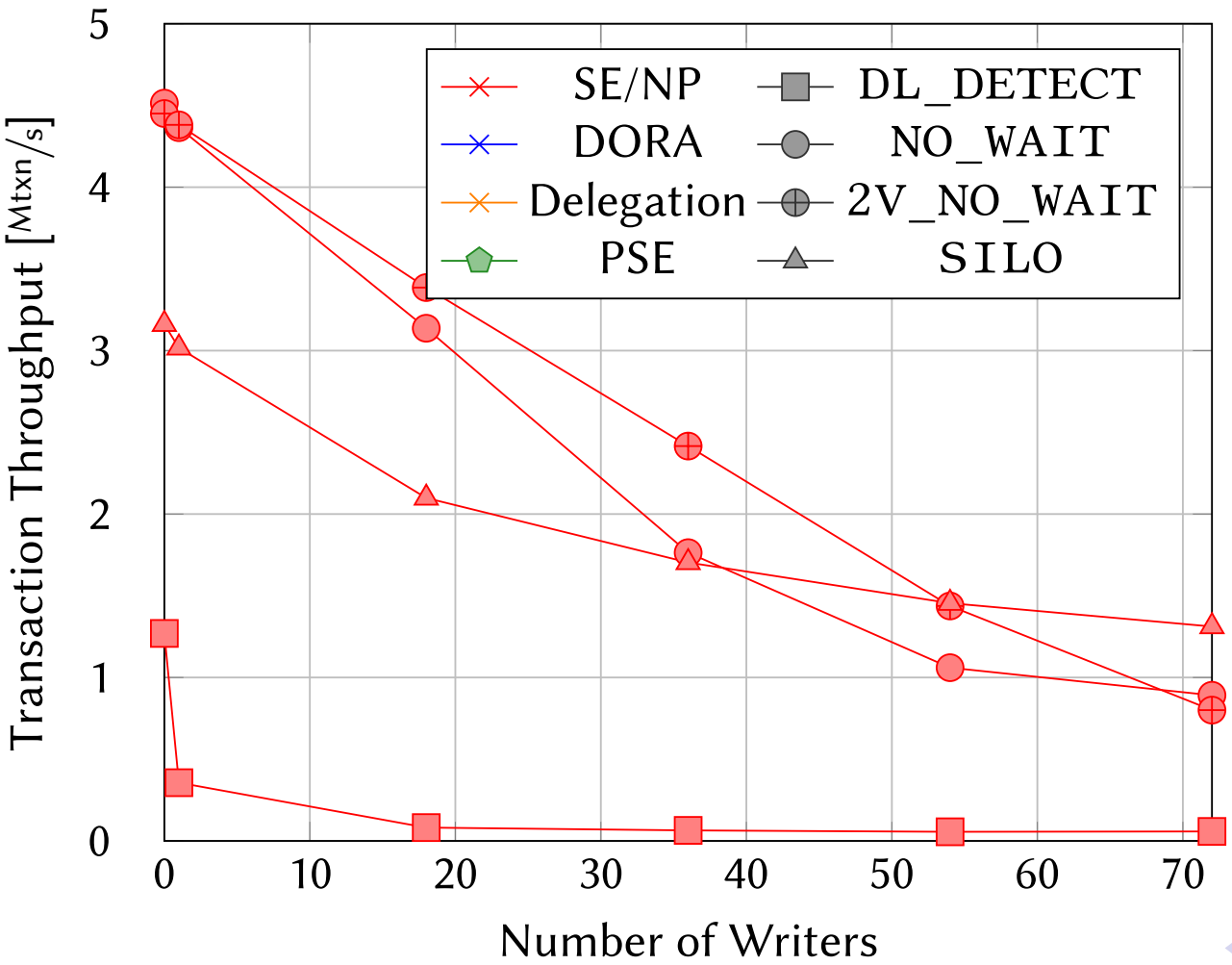
Mixed YCSB ($\Theta = 0.8$, 72 Threads)



Observations

- ■ suffers from latch contention for 72 reading threads
- ■ suffers from deadlocks for writing threads
- atomics of ● scale better than latches of ■
- multi-versioning of ⊕ improves concurrency for mixed workloads

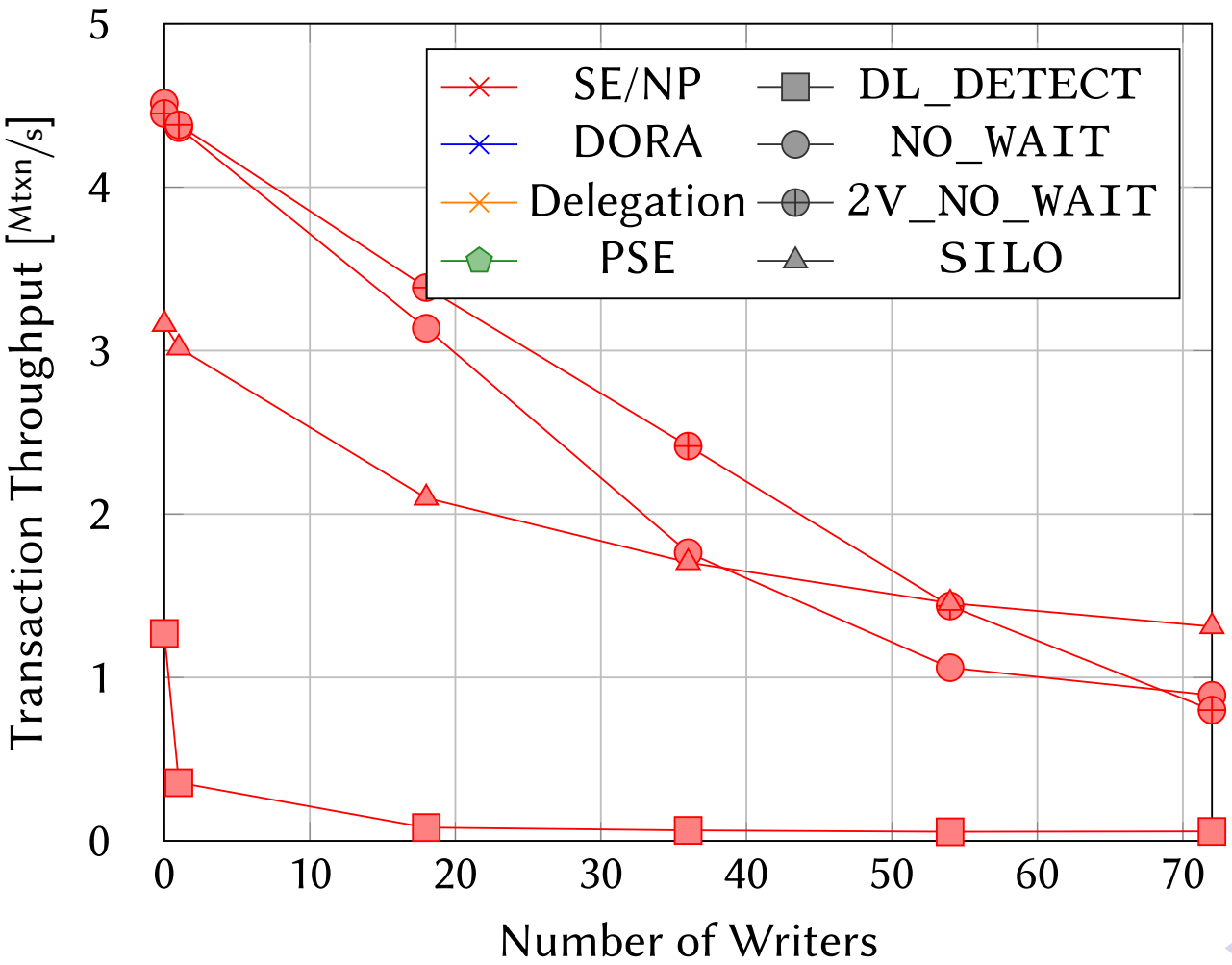
Mixed YCSB ($\Theta = 0.8$, 72 Threads)



Observations

- ■ suffers from deadlocks for writing threads
- atomics of ● scale better than latches of ■
- multi-versioning of ⊕ improves concurrency for mixed workloads
- ▲ lags behind ⊕ due to the overhead of copying read (large) records for validation

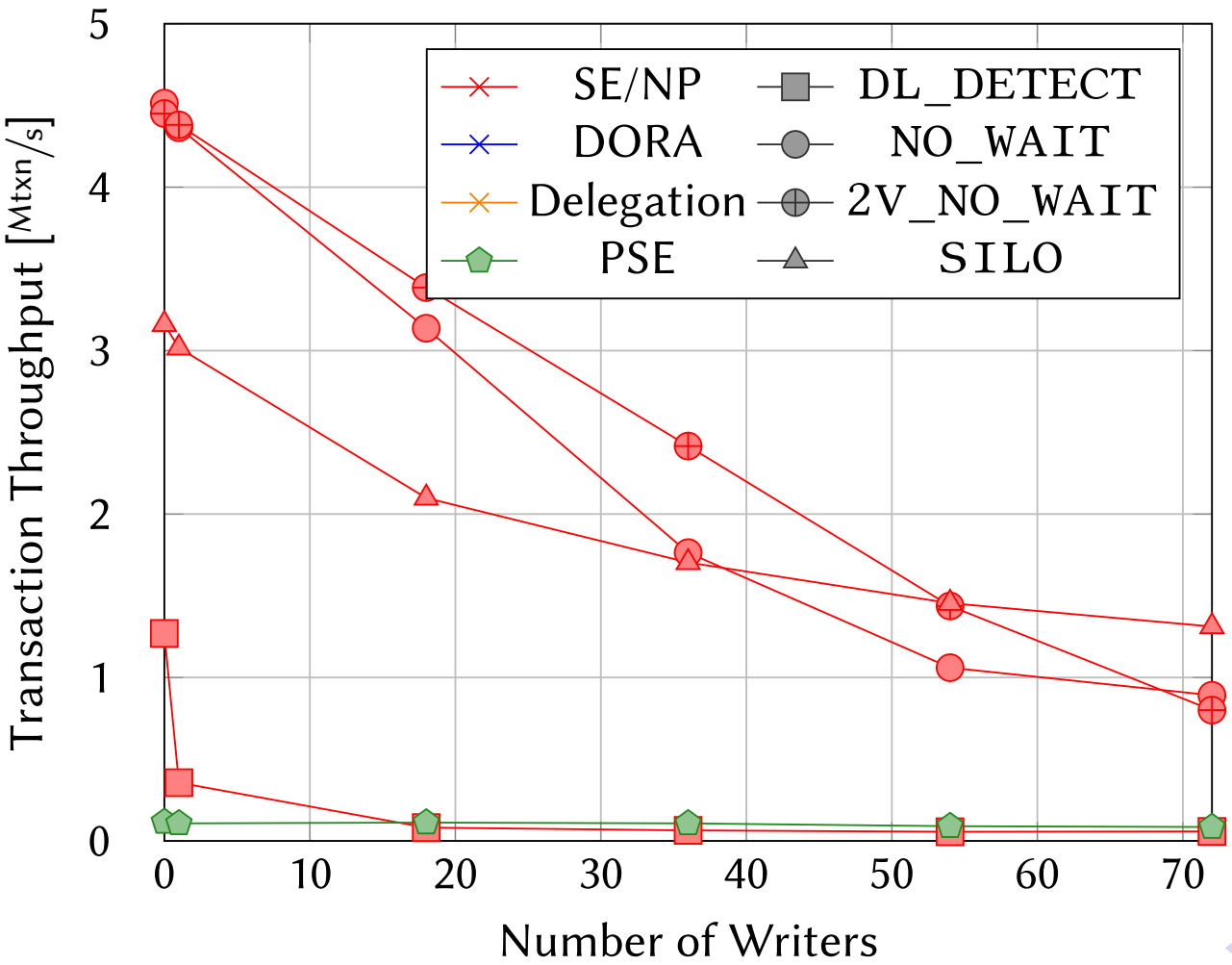
Mixed YCSB ($\Theta = 0.8$, 72 Threads)



Observations

- atomics of ● scale better than latches of ■
- multi-versioning of ⊕ improves concurrency for mixed workloads
- ▲ lags behind ⊕ due to the overhead of copying read (large) records for validation
- ▲ causes less aborts than ⊕ due its optimism for many writers

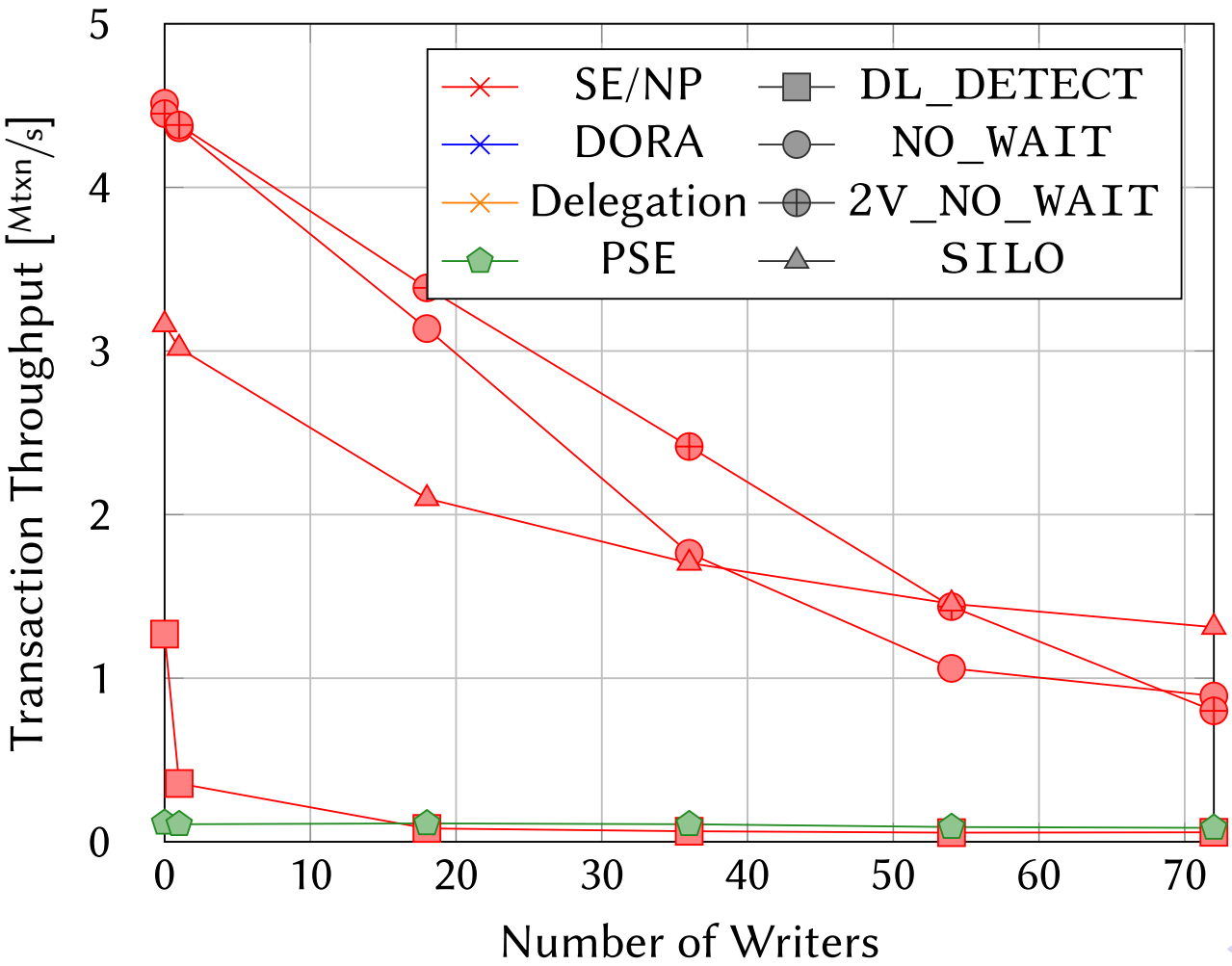
Mixed YCSB ($\Theta = 0.8$, 72 Threads)



Observations

- atomics of ● scale better than latches of ■
- multi-versioning of ⊕ improves concurrency for mixed workloads
- △ lags behind ⊕ due to the overhead of copying read (large) records for validation
- △ causes less aborts than ⊕ due its optimism for many writers

Mixed YCSB ($\Theta = 0.8$, 72 Threads)



Observations

- △ lags behind ⊕ due to the overhead of copying read (large) records for validation
- △ causes less aborts than ⊕ due its optimism for many writers
- ⬠ (and ✕/✕) does not scale well due to partition-unfriendly Zipfian access distribution

Conclusion I

- optimistic concurrency control scales better than pessimistic CC for most workloads
- optimistic CC suffers from large record sizes
- atomic operations scale better than latches
- partitioning makes latches scalable
- 2PL does not scale for mixed workloads
- partitioning DB architectures perform bad under partition-unfriendly workloads
- partitioning DB architectures perform bad under multi-sited transactions

Conclusion II

- the transaction throughput decreases by an order of magnitude for update-only instead of read-only workloads (PSE is insensitive to writes)
  $\rightarrow$ PSE scales best for update-intensive workloads
- PSE does not scale for read-intensive high-contention workloads with small hot sets

$\rightarrow$ None of the architectures or CC protocols outperform the others for any workload!

$\rightarrow$ Every architecture and CC protocol performs very bad for some specific workload!

Discussion of the Performance Evaluation

- read-only and update-only workload are not appropriate to evaluate concurrency control algorithms
- partition-unfriendly workloads are not appropriate to evaluate database architectures that use partitioning
- neither the microbenchmark nor YCSB are OLTP benchmarks

→ The authors did not properly analyze the combination of database architecture and concurrency control algorithm for OLTP workloads!

References I


Enterprise-Festplatten: 36 High-Performance-Festplatten im Vergleichstest. Oct. 2, 2013. URL: http://www.tomshardware.de/enterprise-hdd-sshd,testberichte-241390-6.html (visited on Feb. 8, 2017).


C. Mohan. "ARIES/KVL: A Key-Value Locking Method for Concurrency Control of Multiaction Transactions Operating on B-Tree Indexes". Aug. 1990.


Ippokratis Pandis et al. "Data-Oriented Transaction Execution". Sept. 2010.

References II


Igor Pavlov. *Intel Skylake.* URL: http://www.7-cpu.com/cpu/Skylake.html (visited on Jan. 19, 2017).


Danica Porobic et al. "OLTP on Hardware Islands". July 2012.


Seagates Speicherriese ist schnell und sehr sparsam. Aug. 16, 2016. URL: https://www.computerbase.de/2016-08/seagate-enterprise-capacity-3.5-hdd-10tb-test/3/#diagramm-zugriffszeiten-lesen-h2benchw-316 (visited on Feb. 8, 2017).


"Why SSDs Are Awesome - An SSD Primer". Aug. 2015.

Any Questions?