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*

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Lehrgebiet Informationssysteme

Technische Universität Kaiserslautern

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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

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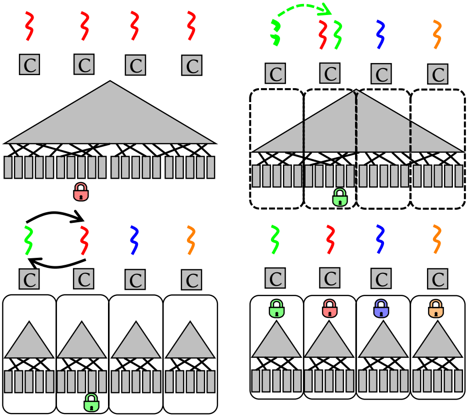
  - → Interleaved transaction execution to exploit abundant thread-level parallelism without violating the ACID properties!
  - → Interleaved operation execution to exploit intra-transaction parallelism!

→ physical & logical Synchronization

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

Section 2

Database Architectures



Shared Everything/ Non-Partitioned

Data-Oriented Transaction Execution (DORA)

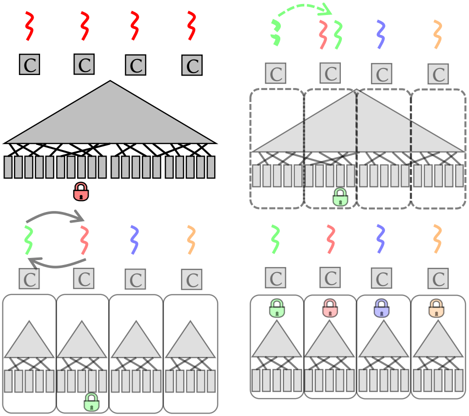
Delegation

Partitioned Serial Execution (PSE)

Subsection 1

Shared Everything/Non-Partitioned (SE/NP)

Shared Everything/Non-Partitioned



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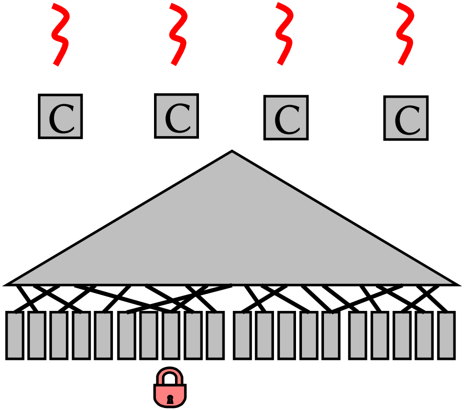

Properties of SE/NP

- ▶ 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

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- – 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
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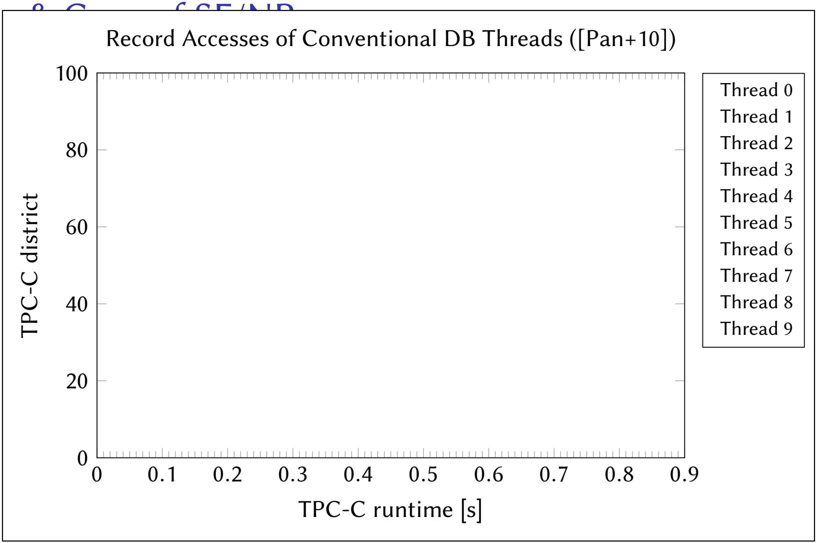
    - – each CPU may atomically write to any semaphore
      → hardware cache coherence overhead

Pro& Cons of SE/NP



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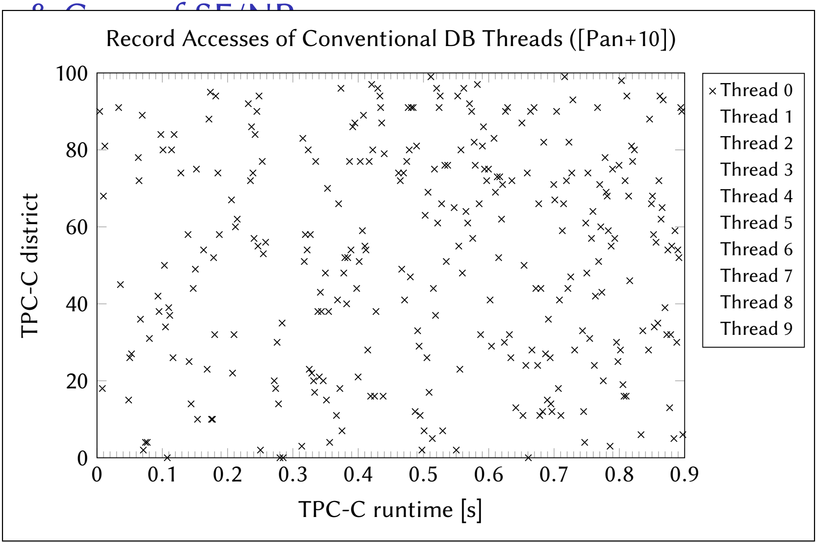
Record Accesses of Conventional DB Threads ([Pan+10])
TPC-C district
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
TPC-C runtime [s]
× Thread 0
Thread 1
Thread 2
Thread 3
Thread 4
Thread 5
Thread 6
Thread 7
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Thread 9

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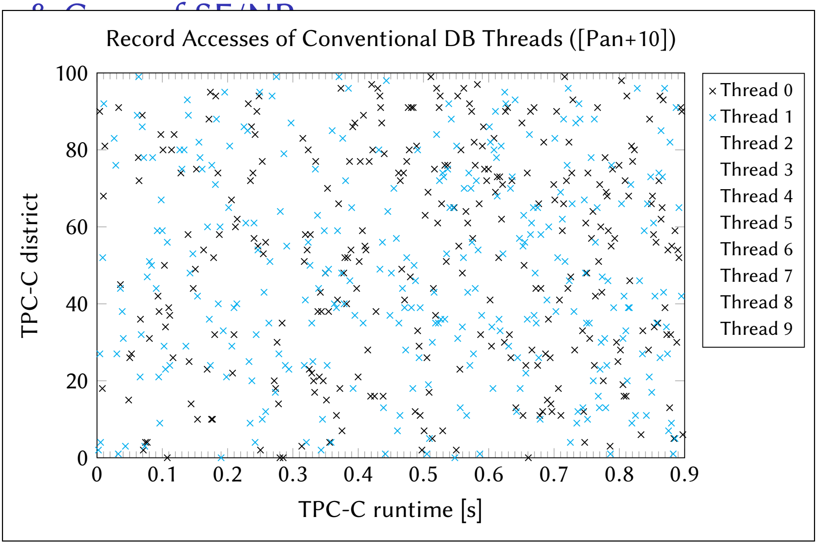
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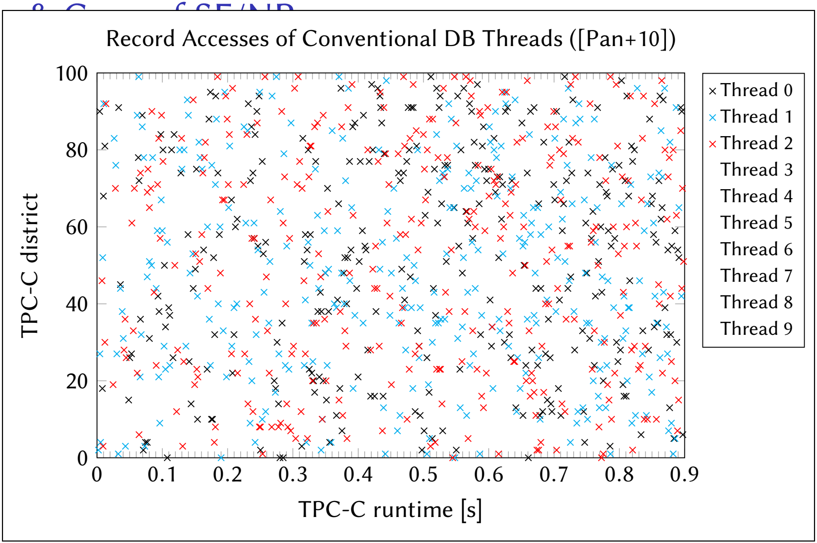
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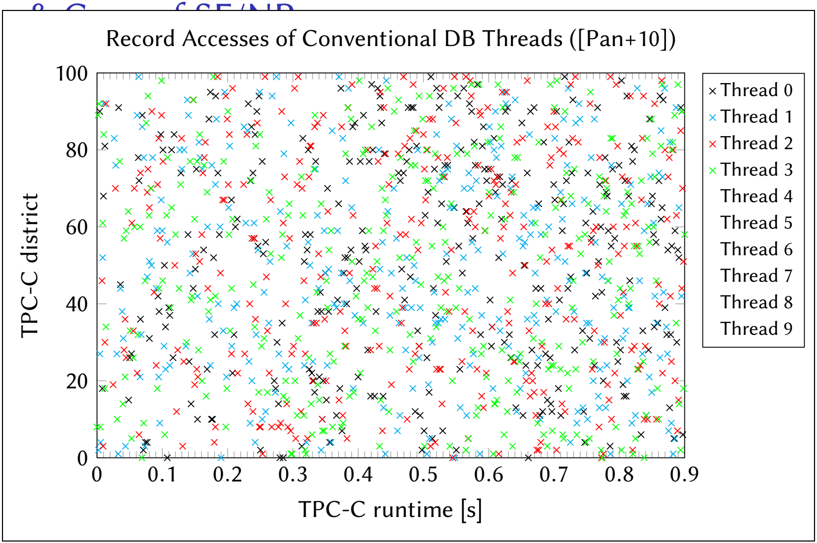
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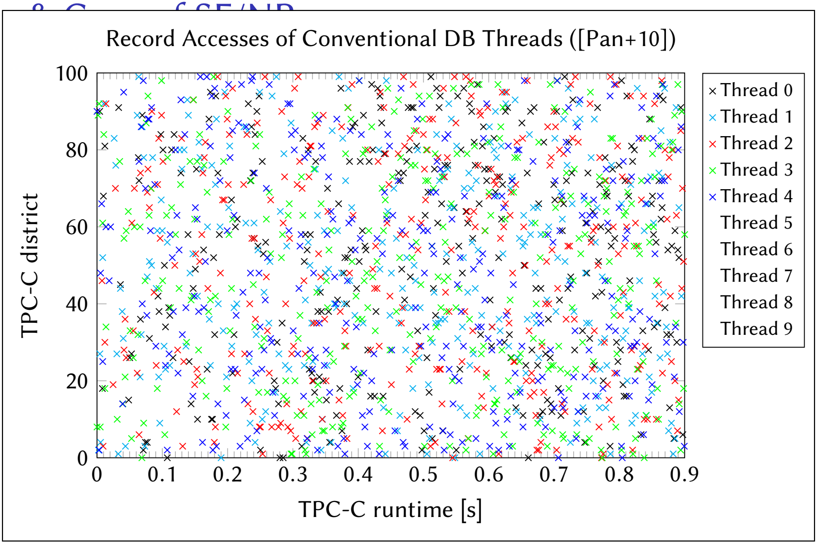
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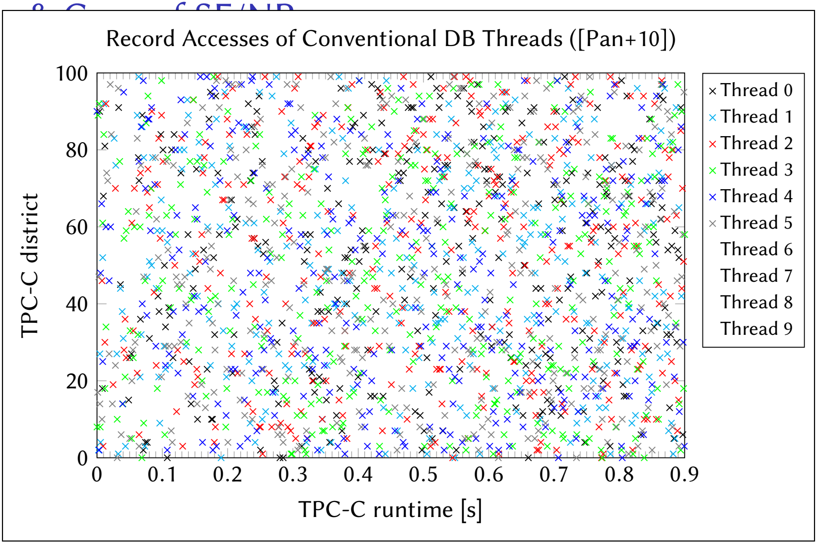
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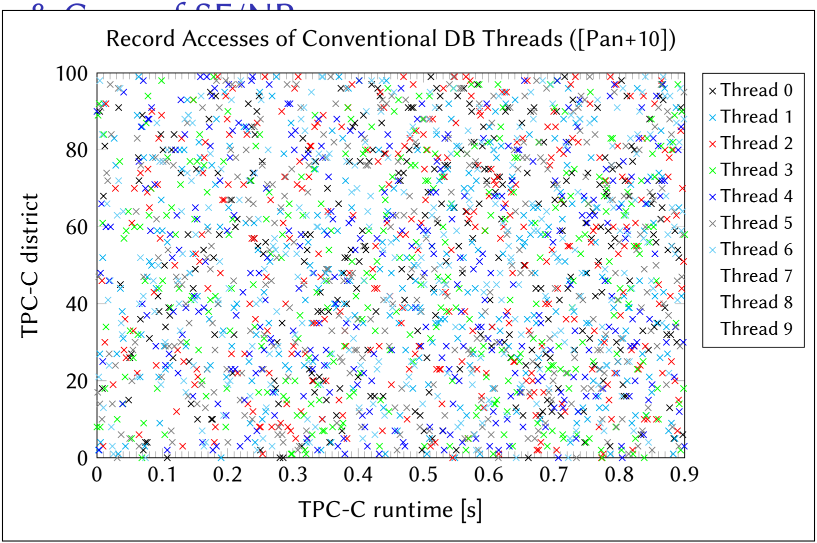
Pros & Cons of SE/NP



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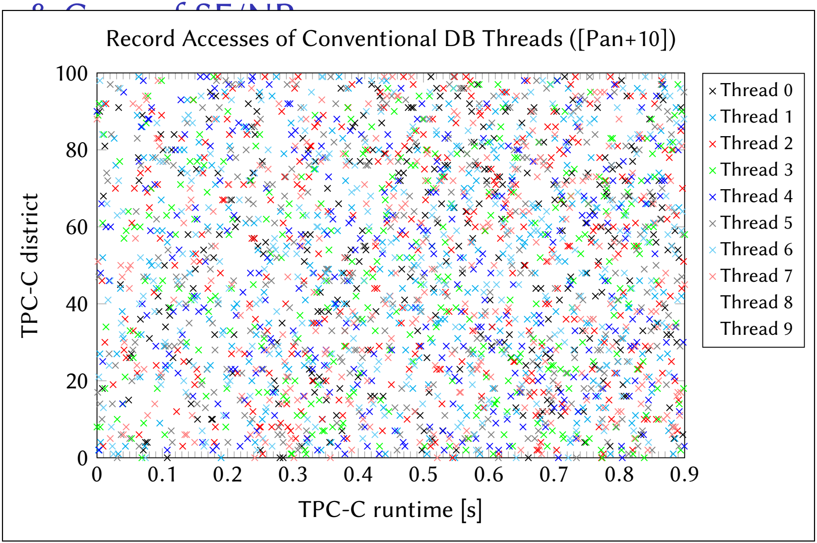

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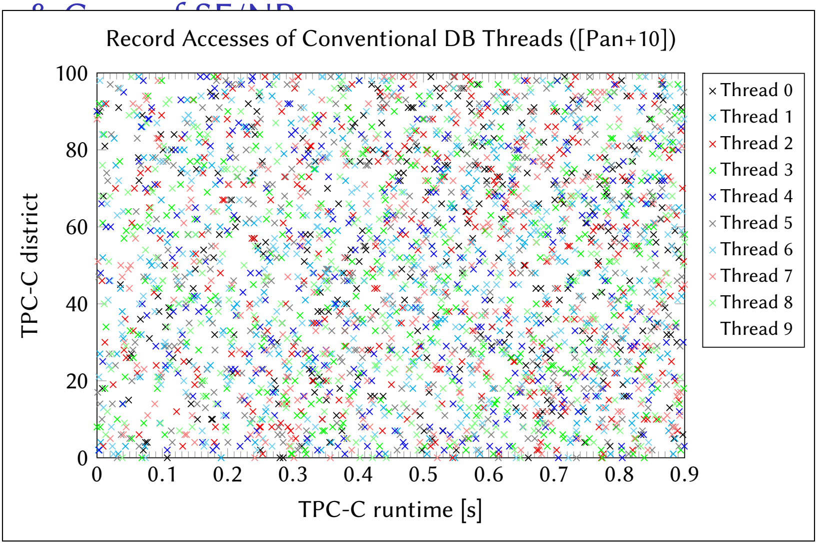

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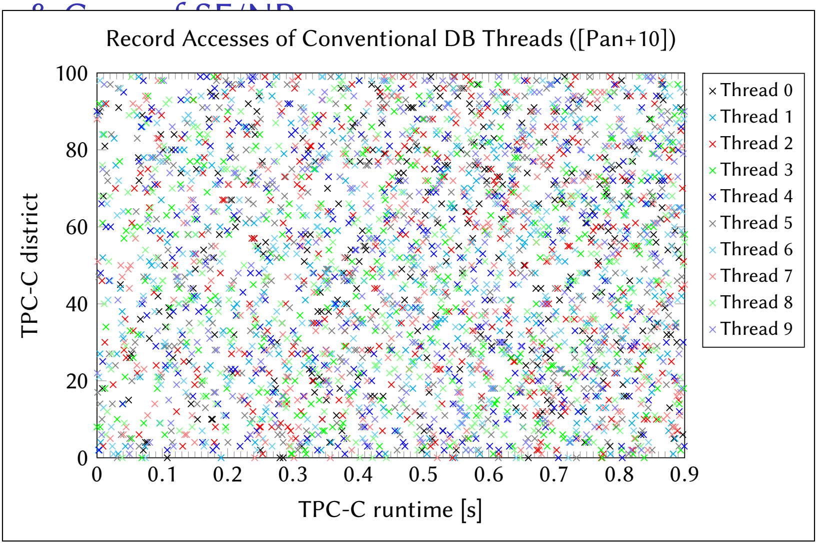

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    → hardware cache coherence overhead

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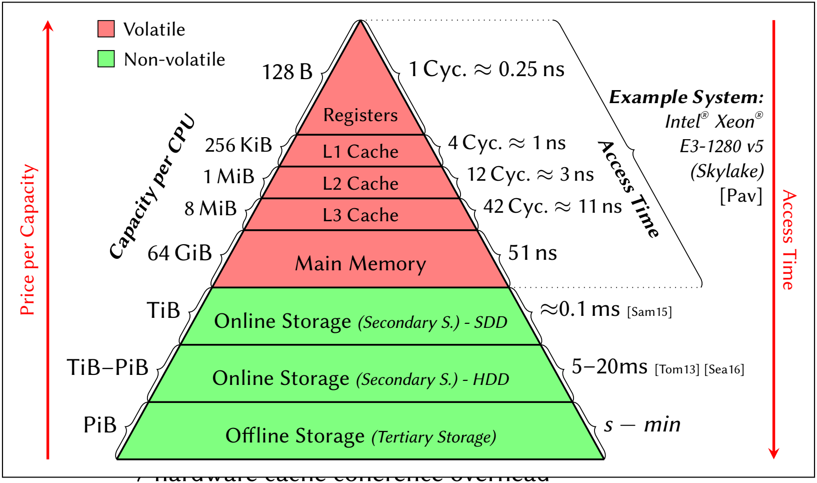

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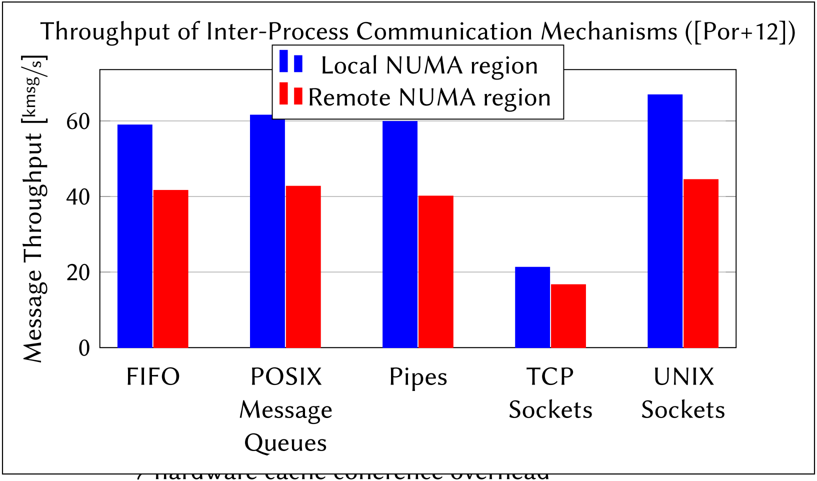

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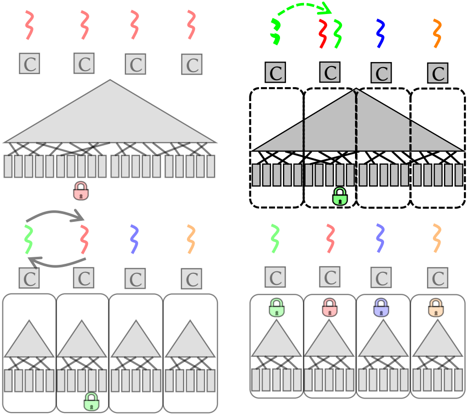
Subsection 2

Data-Oriented Transaction Execution (DORA)



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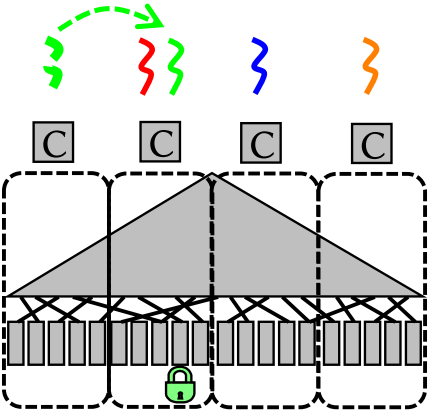


Properties of DORA

- 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, …

Thread 1

Fibers:	*idle*
Locks:	
Partition:	2 − 3, …

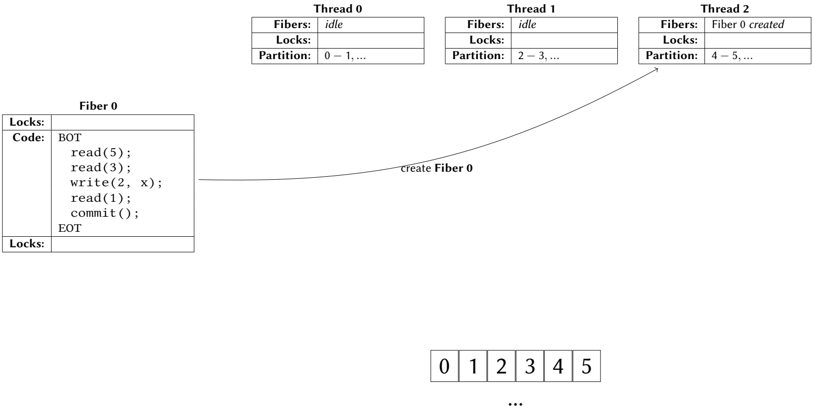
Thread 2

Fibers:	*idle*
Locks:	
Partition:	4 − 5, …

0	1	2	3	4	5

…

Interactive Example



Thread 0

Fibers:	*idle*
Locks:	
Partition:	0 — 1, ...

Thread 1

Fibers:	*idle*
Locks:	
Partition:	2 — 3, ...

Thread 2

Fibers:	Fiber 0 *created*
Locks:	
Partition:	4 — 5, ...

Fiber 0

Locks:	

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

Locks:	

create **Fiber 0**

0	1	2	3	4	5

...

Interactive Example

Thread 0

Fibers:	*idle*
Locks:	
Partition:	0 – 1, …

Thread 1

Fibers:	*idle*
Locks:	
Partition:	2 – 3, …

Thread 2

Fibers:	Fiber 0 *waiting*
Locks:	
Partition:	4 – 5, …

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, …

Thread 1

Fibers:	*idle*
Locks:	
Partition:	2 — 3, …

Thread 2

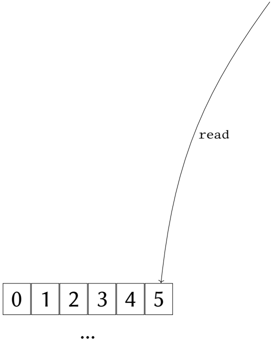
Fibers:	Fiber 0 *running*
Locks:	$(5, S)_0$
Partition:	4 — 5, …

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, …

Thread 1

Fibers:	Fiber 0 *suspended*
Locks:	
Partition:	2 — 3, …

Thread 2

Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	4 — 5, …

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:	

0	1	2	3	4	5

…

Interactive Example

Thread 0

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

Thread 1

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

Thread 2

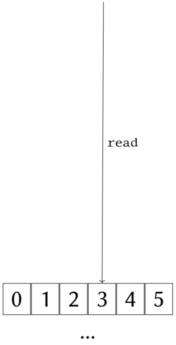
Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \dots$

Fiber 0

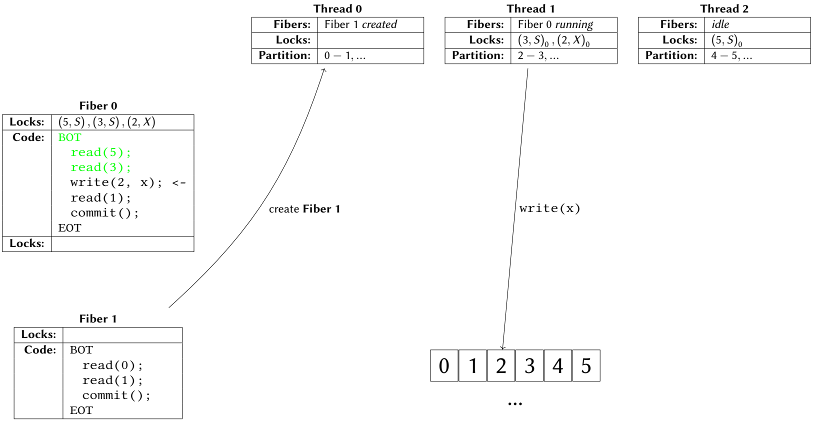
Locks:	$(5, S), (3, S)$

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

Locks:	



Interactive Example



Thread 0

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

Thread 1

Fibers:	Fiber 0 *running*
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 1 *waiting*
Locks:	
Partition:	0 — 1, ...

Thread 1

Fibers:	Fiber 0 *suspended*
Locks:	$(3, S)_0, (2, X)_0$
Partition:	2 — 3, ...

Thread 2

Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	4 — 5, ...

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

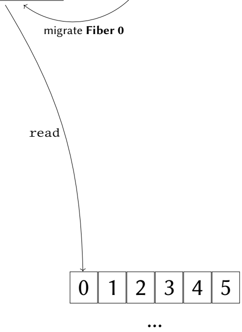
Fibers:	Fiber 1 *running* Fiber 0 *suspended*
Locks:	$(0, S)_1$
Partition:	0 − 1, ...

Thread 1

Fibers:	*idle*
Locks:	$(3, S)_0, (2, X)_0$
Partition:	2 − 3, ...

Thread 2

Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	4 − 5, ...



Fiber 0

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

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

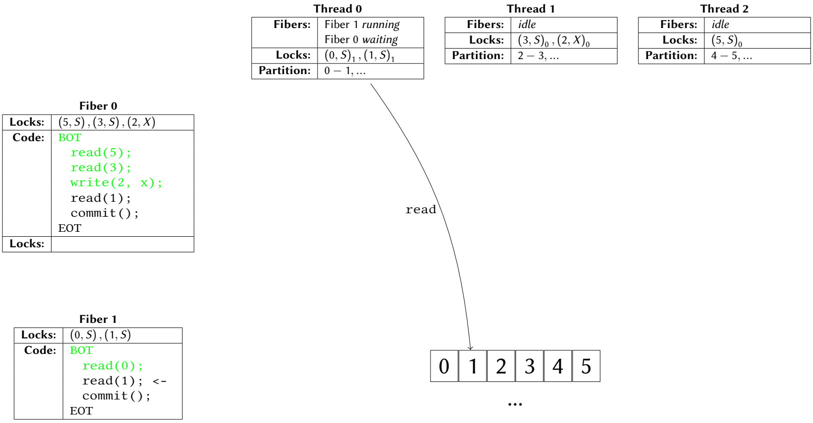
Locks:	

Fiber 1

Locks:	$(0, S)$

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

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

0	1	2	3	4	5

...

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

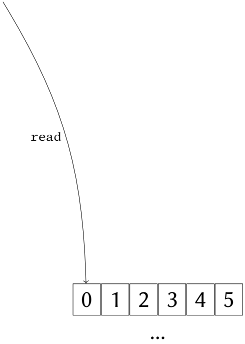
Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \ldots$

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

Thread 0

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

Thread 1

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

Thread 2

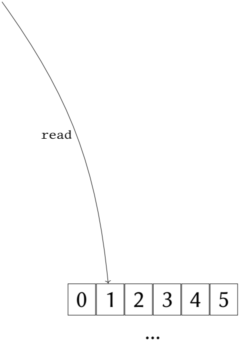
Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	$4 - 5, \ldots$

Fiber 0

Locks:	$(5, S), (3, S), (2, X),$ $(0, S), (1, S)$

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

Locks:	



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:	

0	1	2	3	4	5

...

Interactive Example

Thread 0

Fibers:	Fiber 0 *suspended*
Locks:	
Partition:	0 – 1, …

Thread 1

Fibers:	*idle*
Locks:	$(3, S)_0, (2, X)_0$
Partition:	2 – 3, …

Thread 2

Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	4 – 5, …

Fiber 0

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

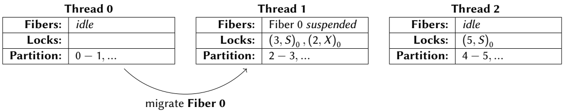
Code:	`BOT`
	`  read(5);`
	`  read(3);`
	`  write(2, x);`
	`  read(1);`
	`  commit(); <-`
	`EOT`

Locks:	

0	1	2	3	4	5

…

Interactive Example



Thread 0

Fibers:	*idle*
Locks:	
Partition:	0 — 1, …

Thread 1

Fibers:	Fiber 0 *suspended*
Locks:	$(3, S)_0, (2, X)_0$
Partition:	2 — 3, …

Thread 2

Fibers:	*idle*
Locks:	$(5, S)_0$
Partition:	4 — 5, …

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:	$0 - 1, \dots$

Thread 1

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

Thread 2

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

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 *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:	$(5, S)$

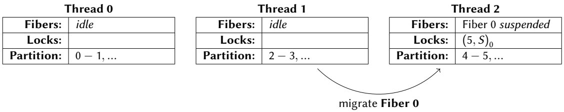
Code:	`BOT`
	`  read(5);`
	`  read(3);`
	`  write(2, x);`
	`  read(1);`
	`  commit(); <-`
	`EOT`

Locks:	

0	1	2	3	4	5

...

Interactive Example



Thread 0

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

Thread 1

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

Thread 2

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

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, …

Thread 1

Fibers:	*idle*
Locks:	
Partition:	2 — 3, …

Thread 2

Fibers:	Fiber 0 *committing*
Locks:	
Partition:	4 — 5, …

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, …

Thread 1

Fibers:	*idle*
Locks:	
Partition:	2 — 3, …

Thread 2

Fibers:	Fiber 0 *terminated*
Locks:	
Partition:	4 — 5, …

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:	$4 - 5, \ldots$

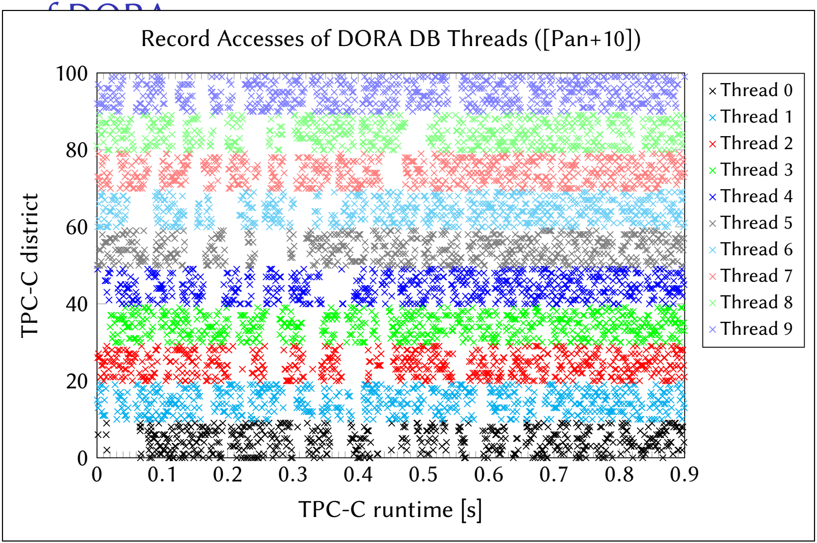
0	1	2	3	4	5

...

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 f DORA

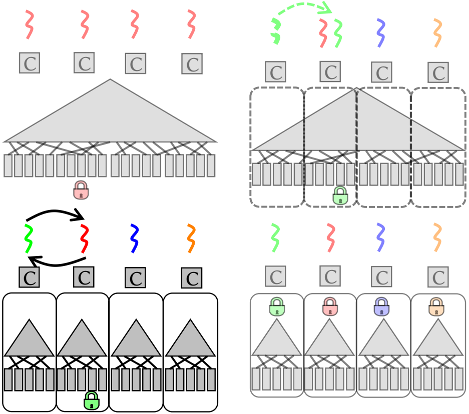

Record Accesses of DORA DB Threads ([Pan+10])
TPC-C district
100
80
60
40
20
0
TPC-C runtime [s]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
× Thread 0
× Thread 1
× Thread 2
× Thread 3
× Thread 4
× Thread 5
× Thread 6
× Thread 7
× Thread 8
× Thread 9

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
  → slower accesses with secondary index
- primary index is shared
  → centralized latching for inserts/deletes still required
  → some contention on the shared latch
- centralized deadlock detection still required (for DL_DETECT)

Subsection 3

Delegation



Shared Everything/Non-Partitioned

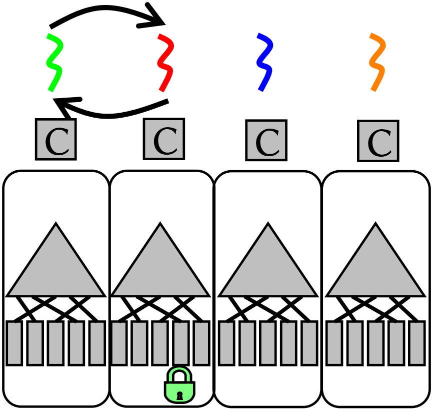
Data-Oriented Transaction Execution (DORA)

Delegation

Partitioned Serial Execution (PSE)

Subsection 3

Delegation



Properties of Delegation

- metadata (incl. locks) are physically partitioned

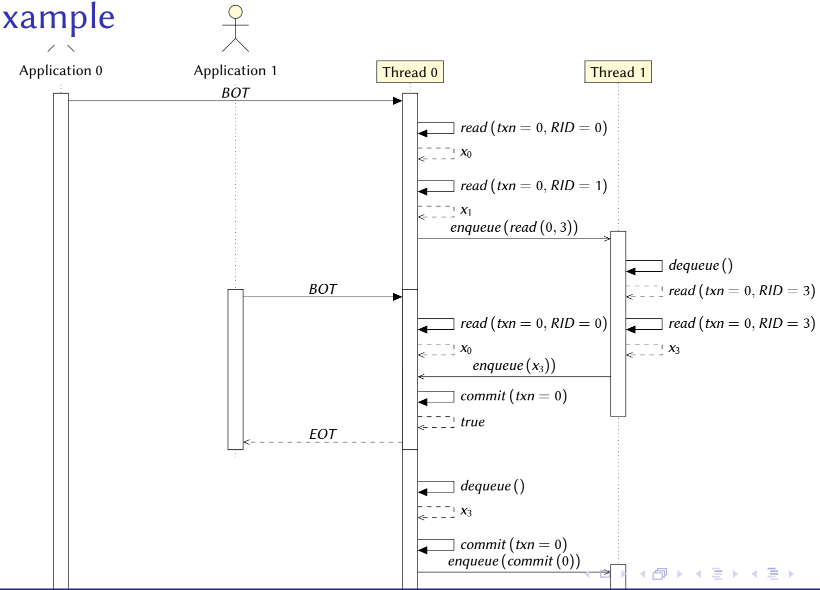
→ no physical synchronization (latches, atomics) required

- data and indices are physically partitioned

→ logical synchronization using a concurrency control protocol only locally required

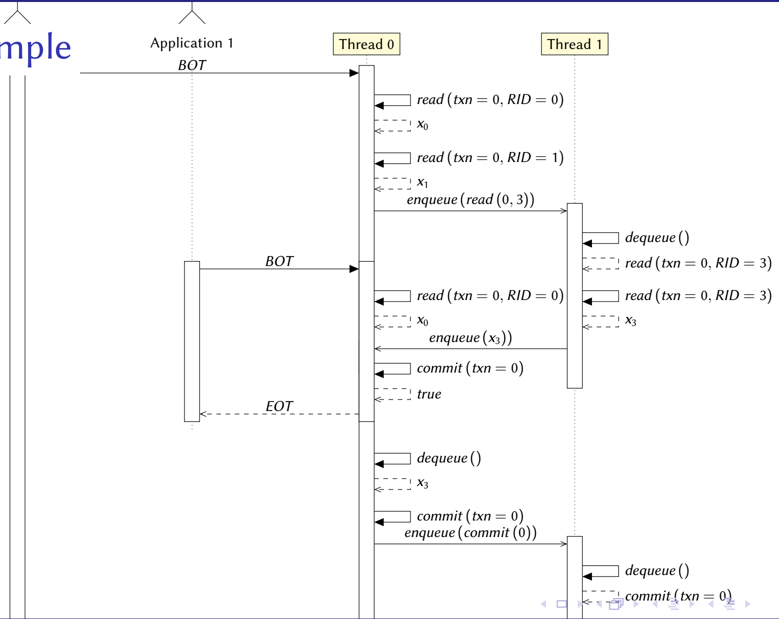
- transactions completely executed by one thread (ideally the one owning the majority of the records)
- thread accesses remote records by passing messages to the threads owning them
  - message passing implemented using shared variables
  - remote records are passed as pointers

Example



Application 0
Application 1
Thread 0
Thread 1
BOT
$read\,(txn = 0, RID = 0)$
x_0
$read\,(txn = 0, RID = 1)$
x_1
$enqueue\,(read\,(0, 3))$
$dequeue\,()$
$read\,(txn = 0, RID = 3)$
BOT
$read\,(txn = 0, RID = 0)$
$read\,(txn = 0, RID = 3)$
x_0
x_3
$enqueue\,(x_3))$
$commit\,(txn = 0)$
true
EOT
$dequeue\,()$
x_3
$commit\,(txn = 0)$
$enqueue\,(commit\,(0))$

Example



Application 1

Thread 0

Thread 1

BOT

$read\,(txn = 0, RID = 0)$

x_0

$read\,(txn = 0, RID = 1)$

x_1

$enqueue\,(read\,(0, 3))$

$dequeue\,()$

$read\,(txn = 0, RID = 3)$

BOT

$read\,(txn = 0, RID = 0)$

$read\,(txn = 0, RID = 3)$

x_0

x_3

$enqueue\,(x_3))$

$commit\,(txn = 0)$

true

EOT

$dequeue\,()$

x_3

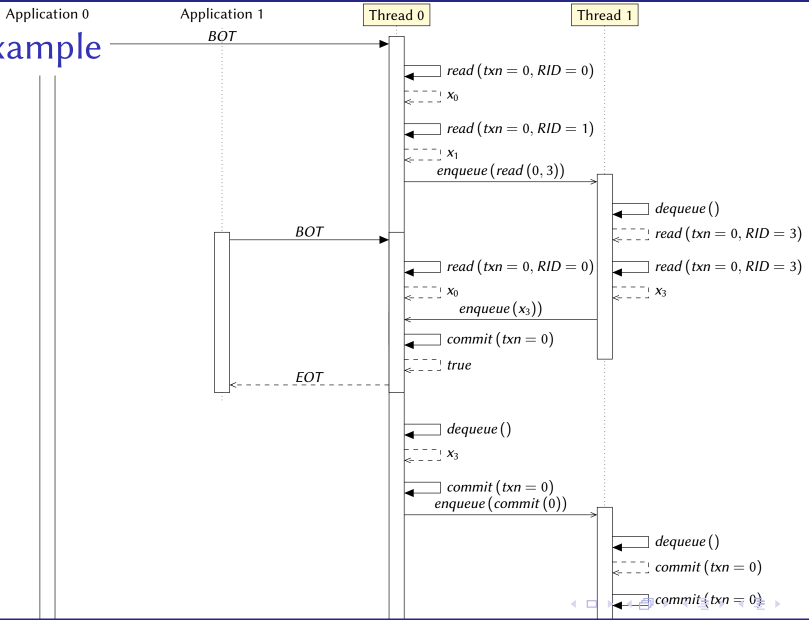
$commit\,(txn = 0)$

$enqueue\,(commit\,(0))$

$dequeue\,()$

$commit\,(txn = 0)$

Example



Application 0

Application 1

Thread 0

Thread 1

BOT

$read\left(txn = 0, RID = 0\right)$

x_0

$read\left(txn = 0, RID = 1\right)$

x_1

$enqueue\left(read\left(0, 3\right)\right)$

$dequeue\left(\right)$

BOT

$read\left(txn = 0, RID = 3\right)$

$read\left(txn = 0, RID = 0\right)$

$read\left(txn = 0, RID = 3\right)$

x_0

x_3

$enqueue\left(x_3\right))$

$commit\left(txn = 0\right)$

true

EOT

$dequeue\left(\right)$

x_3

$commit\left(txn = 0\right)$

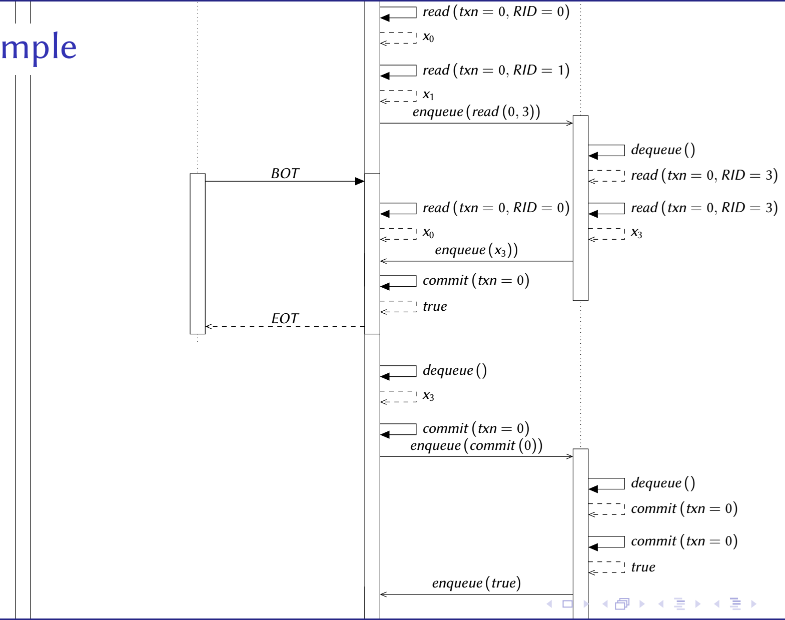
$enqueue\left(commit\left(0\right)\right)$

$dequeue\left(\right)$

$commit\left(txn = 0\right)$

$commit\left(txn = 0\right)$

Example



$read\,(txn = 0, RID = 0)$

x_0

$read\,(txn = 0, RID = 1)$

x_1

$enqueue\,(read\,(0, 3))$

$dequeue\,()$

BOT

$read\,(txn = 0, RID = 3)$

$read\,(txn = 0, RID = 0)$

$read\,(txn = 0, RID = 3)$

x_0

x_3

$enqueue\,(x_3))$

$commit\,(txn = 0)$

$true$

EOT

$dequeue\,()$

x_3

$commit\,(txn = 0)$

$enqueue\,(commit\,(0))$

$dequeue\,()$

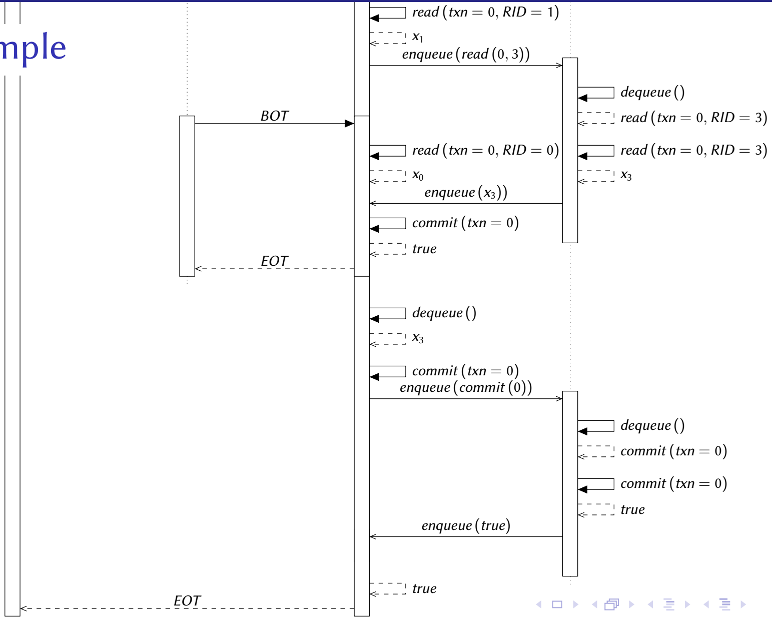
$commit\,(txn = 0)$

$commit\,(txn = 0)$

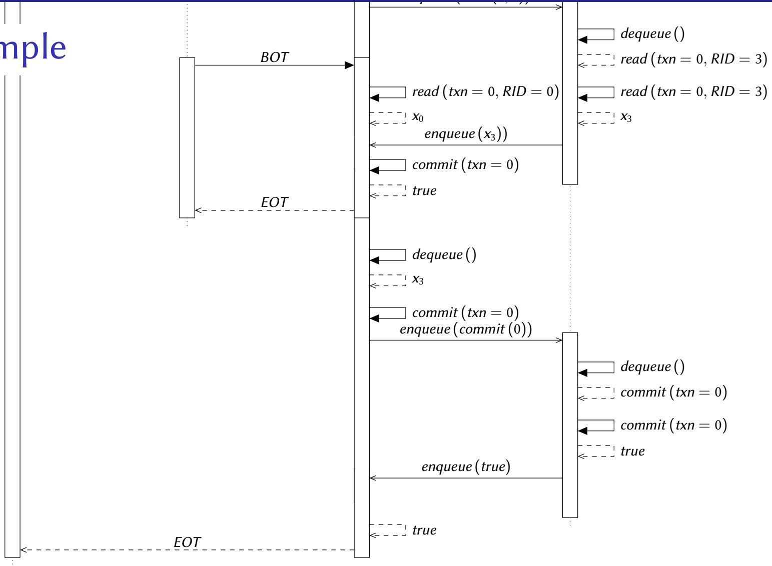
$true$

$enqueue\,(true)$

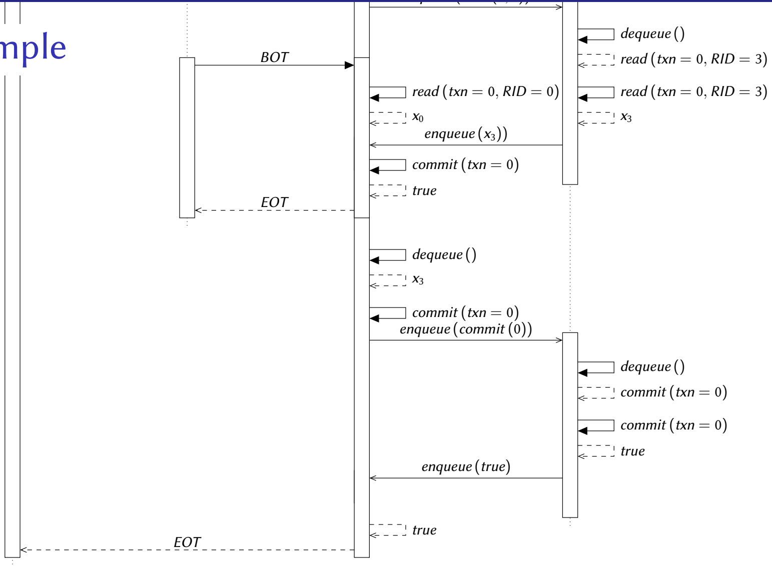
Example


$read\,(txn = 0, RID = 1)$
x_1
$enqueue\,(read\,(0, 3))$
$dequeue\,()$
$read\,(txn = 0, RID = 3)$
BOT
$read\,(txn = 0, RID = 0)$
$read\,(txn = 0, RID = 3)$
x_0
x_3
$enqueue\,(x_3))$
$commit\,(txn = 0)$
$true$
EOT
$dequeue\,()$
x_3
$commit\,(txn = 0)$
$enqueue\,(commit\,(0))$
$dequeue\,()$
$commit\,(txn = 0)$
$commit\,(txn = 0)$
$true$
$enqueue\,(true)$
$true$
EOT

Example


dequeue ()
BOT
read (txn = 0, RID = 3)
read (txn = 0, RID = 0)
read (txn = 0, RID = 3)
x_0
x_3
enqueue (x_3))
commit (txn = 0)
true
EOT
dequeue ()
x_3
commit (txn = 0)
enqueue (commit (0))
dequeue ()
commit (txn = 0)
commit (txn = 0)
true
enqueue (true)
true
EOT

Example


dequeue ()
read (txn = 0, RID = 3)
BOT
read (txn = 0, RID = 0)
read (txn = 0, RID = 3)
x0
x3
enqueue (x3))
commit (txn = 0)
true
EOT
dequeue ()
x3
commit (txn = 0)
enqueue (commit (0))
dequeue ()
commit (txn = 0)
commit (txn = 0)
true
enqueue (true)
true
EOT

Pros & Cons of Delegation

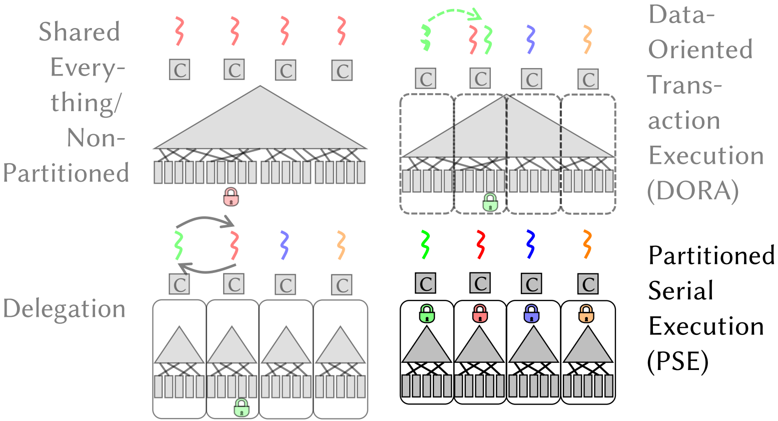
- + only multi-site transactions cause a thread to access unowned records
  - + each CPU cache usually only contains data of its partition
    → lower cache pollution
  - + each CPU usually only accesses data of its partitions
    → fewer data movement between NUMA regions
  - → No physical synchronization required!
- + message-passing required for multi-site transactions imposes only a low overhead

Pros & Cons of Delegation

- + only multi-site transactions cause a thread to access unowned records
  - + each CPU cache usually only contains data of its partition → lower cache pollution
  - + each CPU usually only accesses data of its partitions → fewer data movement between NUMA regions
  - → No physical synchronization required!
- + message-passing required for multi-site transactions imposes only a low overhead
- – partitioning required (e.g. manual selection of a partitioning strategy—*called routing rule*)
- – partitioning is sensitive to the workload
- – physical partitioning requires expensive repartitioning when the workload changes

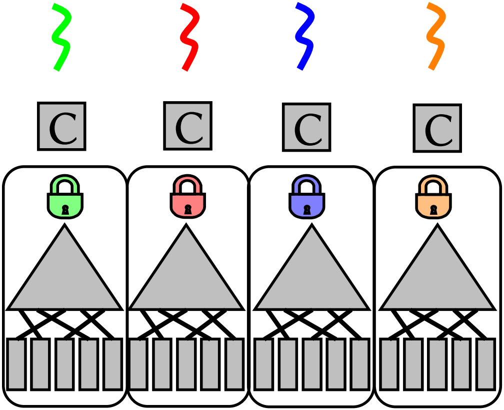
Subsection 4

Partitioned Serial Execution (PSE)


Shared Every-thing/ Non-Partitioned
Data-Oriented Trans-action Execution (DORA)
Delegation
Partitioned Serial Execution (PSE)
C

Subsection 4

Partitioned Serial Execution (PSE)



Properties of PSE

- data and associated metadata are physically partitioned
  → Shared-Nothing
- partition-level locking using latches (only exclusive mode)

→ No concurrency control algorithm required!

- single-site transactions run serially on the partition's thread (partition needs to be locked)
- multi-site transactions require upfront to lock of all relevant partitions/coordination between threads

Pros of PSE

+ only multi-site transactions cause a thread to access unowned records
  + each CPU cache usually only contains data of its partition
    → lower cache pollution
  + partition-lock is usually in the CPU cache
    → synchronization imposes minor overhead
  + each CPU usually only accesses data of its partitions
    → fewer data movement between NUMA regions

  → no physical synchronization beyond the partition-lock required

→ scales linearly for single-site transactions

Cons of PSE

- multi-site transactions require locking of all relevant partitions
  → decreases concurrency drastically
- partitioning required (e.g. manual selection of a partitioning strategy—*called routing rule*)
- partitioning is sensitive to the workload
- physical partitioning requires expensive repartitioning when the workload changes
- coordination of multi-site transactions required

Summary

Architecture				
SE/NP				
PSE				
Delegation				
DORA				

Summary

Architecture	**Process Management**			
	Parallelism			
SE/NP	Shared Memory			
PSE	Shared Nothing			
Delegation	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

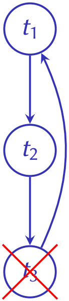
Architecture	Process Management		Transactional Storage Management	
	Parallelism	**Thread Assignment**	**Logical Synchronization**	
SE/NP	Shared Memory	thread-to-txn	CC Protocols	
PSE	Shared Nothing	thread-to-txn	Partition Lock	
Delegation	Message Passing	thread-to-txn	CC Protocols	
DORA	Shared Memory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

Summary

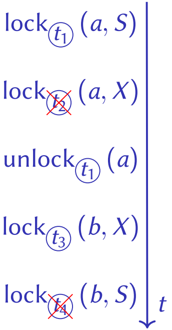
Architecture	Process Management		Transactional Storage Management	
	Parallelism	Thread Assignment	Logical Synchronization	Physical Synchronization
SE/NP	Shared Memory	thread-to-txn	CC Protocols	latch/atomics
PSE	Shared Nothing	thread-to-txn	Partition Lock	partition lock
Delegation	Message Passing	thread-to-txn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

Section 3

Concurrency Control Algorithms



DL_DETECT
(2PL)



$\text{lock}_{t_1}(a, S)$

$\text{lock}_{\cancel{t_2}}(a, X)$

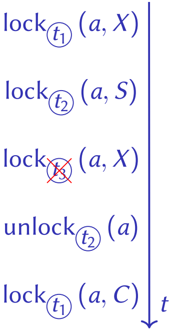
$\text{unlock}_{t_1}(a)$

$\text{lock}_{t_3}(b, X)$

$\text{lock}_{\cancel{t_4}}(b, S)$

t

NO_WAIT
(No-Waiting-2PL)



$\text{lock}_{t_1}(a, X)$

$\text{lock}_{t_2}(a, S)$

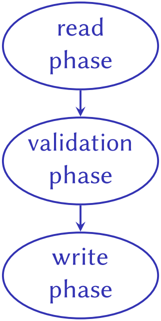
$\text{lock}_{\cancel{t_3}}(a, X)$

$\text{unlock}_{t_2}(a)$

$\text{lock}_{t_1}(a, C)$

t

2V_NO_WAIT
(Two-Version-2PL)



read phase

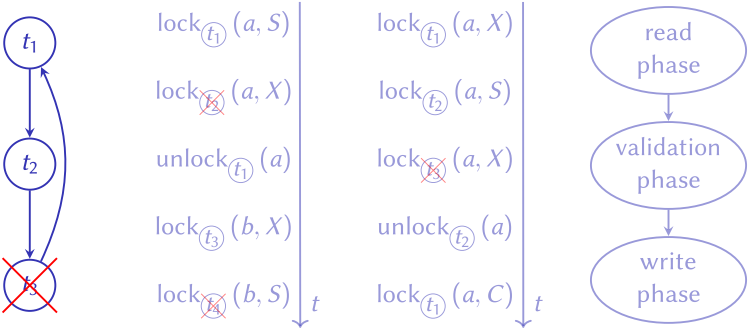
validation phase

write phase

SILO
(OCC)

Subsection 1

DL_DETECT (2PL)



$\text{lock}_{t_1}(a, S)$

$\text{lock}_{\cancel{t_2}}(a, X)$

$\text{unlock}_{t_1}(a)$

$\text{lock}_{t_3}(b, X)$

$\text{lock}_{\cancel{t_4}}(b, S)$

t

$\text{lock}_{t_1}(a, X)$

$\text{lock}_{t_2}(a, S)$

$\text{lock}_{\cancel{t_3}}(a, X)$

$\text{unlock}_{t_2}(a)$

$\text{lock}_{t_1}(a, C)$

t

read phase

validation phase

write phase

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
  $\rightarrow$ 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
  $\rightarrow$ 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		

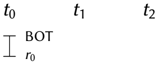
Locks:

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:



Locks:

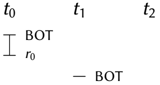
Record 0		Record 1		Record 2	
Current Mode:	S (1)	Current Mode:	NL	Current Mode:	NL
Waiters:		Waiters:		Waiters:	
Data:	x_0	Data:	x_1	Data:	x_2

···

Wait-for Graph:

Interactive Example

Transactions:


t_0 t_1 t_2

BOT
r_0

BOT

Locks:

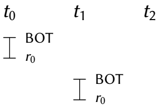
Record 0		Record 1		Record 2	
Current Mode:	S (1)	Current Mode:	NL	Current Mode:	NL
Waiters:		Waiters:		Waiters:	
Data:	x_0	Data:	x_1	Data:	x_2

…

Wait-for Graph:

Interactive Example

Transactions:


t_0 t_1 t_2

BOT
r_0

BOT
r_0

Locks:

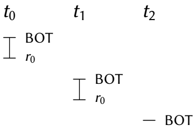
Record 0		Record 1		Record 2	
Current Mode:	S (2)	Current Mode:	NL	Current Mode:	NL
Waiters:		Waiters:		Waiters:	
Data:	x_0	Data:	x_1	Data:	x_2

…

Wait-for Graph:

Interactive Example

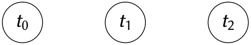
Transactions:



Locks:

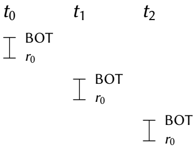
Record 0		Record 1		Record 2		…
Current Mode:	S (2)	Current Mode:	NL	Current Mode:	NL	
Waiters:		Waiters:		Waiters:		
Data:	x_0	Data:	x_1	Data:	x_2	

Wait-for Graph:



Interactive Example

Transactions:


t_0 t_1 t_2

BOT
r_0

BOT
r_0

BOT
r_0

Locks:

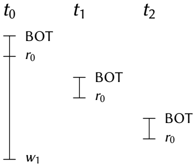
Record 0		**Record 1**		**Record 2**	
Current Mode:	S (3)	Current Mode:	NL	Current Mode:	NL
Waiters:		Waiters:		Waiters:	
Data:	x_0	Data:	x_1	Data:	x_2

…

Wait-for Graph:

Interactive Example

Transactions:

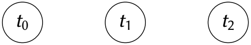


Locks:

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

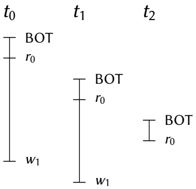
…

Wait-for Graph:



Interactive Example

Transactions:

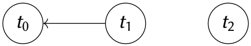


Locks:

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

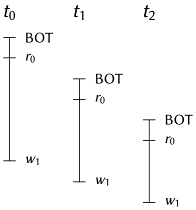
…

Wait-for Graph:



Interactive Example

Transactions:



Locks:

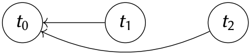
Record 0	
Current Mode:	S (3)
Waiters:	
Data:	x_0

Record 1	
Current Mode:	X (t_0)
Waiters:	(X, t_1) (X, t_2)
Data:	x_1'

Record 2	
Current Mode:	NL
Waiters:	
Data:	x_2

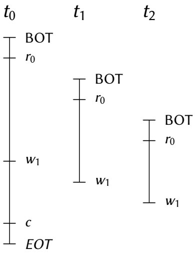
…

Wait-for Graph:



Interactive Example

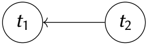
Transactions:



Locks:

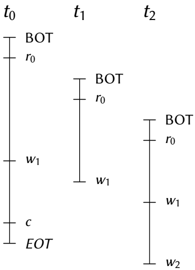
Record 0		Record 1		Record 2		…
Current Mode:	S (2)	Current Mode:	X (t_1)	Current Mode:	NL	
Waiters:		Waiters:	(X, t_2)	Waiters:		
Data:	x_0	Data:	x_1'	Data:	x_2	

Wait-for Graph:



Interactive Example

Transactions:

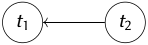


Locks:

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

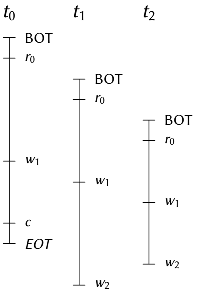
⋯

Wait-for Graph:



Interactive Example

Transactions:

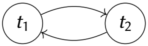


Locks:

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'

⋯

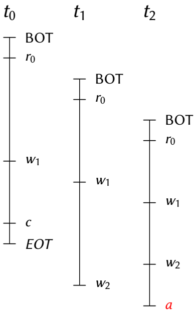
Wait-for Graph:



Cycle → Deadlock → Rollback a blocked Transaction

Interactive Example

Transactions:



Locks:

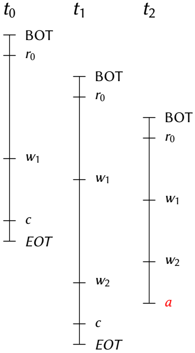
Record 0		**Record 1**		**Record 2**	
Current Mode:	S (1)	Current Mode:	X (t_1)	Current Mode:	X (t_1)
Waiters:		Waiters:		Waiters:	
Data:	x_0	Data:	x_1''	Data:	x_2

…

Wait-for Graph:

Interactive Example

Transactions:



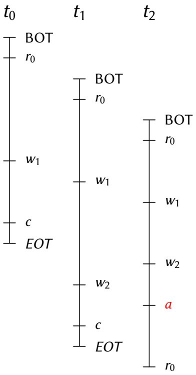
Locks:

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:



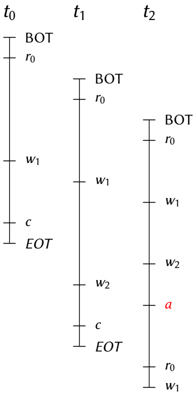
Locks:

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:



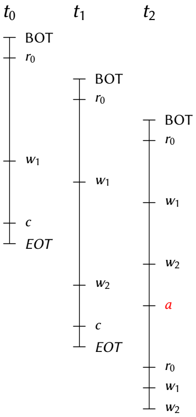
Locks:

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:

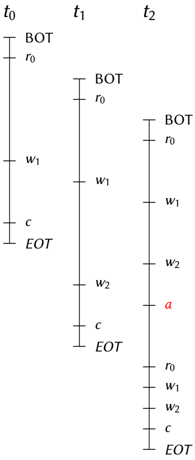
Record 0		**Record 1**		**Record 2**	
Current Mode:	S (1)	Current Mode:	X (t_2)	Current Mode:	X (t_2)
Waiters:		Waiters:		Waiters:	
Data:	x_0	Data:	x_1'''	Data:	x_2''

$\cdots$

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)

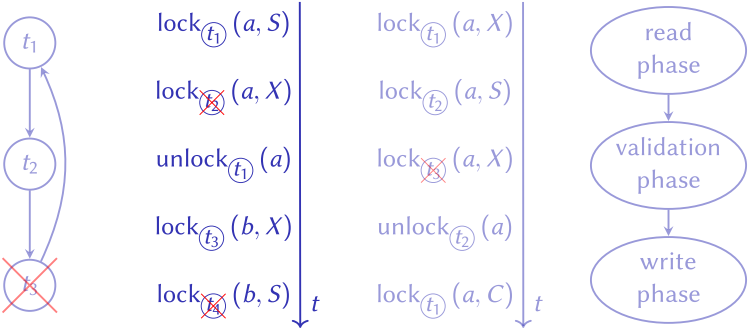
+ aborts only after deadlocks

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
  → done offline → transactions deadlocked for a while
– aborts happen
  → work done before needs to be repeated
– queue of waiters requires latching
  → limits scalability
– even writes need to acquire latches and wait

Subsection 2

NO_WAIT (No-Waiting-2PL)



DL_DETECT (2PL)

$\text{lock}_{t_1}(a, S)$

$\text{lock}_{\cancel{t_2}}(a, X)$

$\text{unlock}_{t_1}(a)$

$\text{lock}_{t_3}(b, X)$

$\text{lock}_{\cancel{t_4}}(b, S)$

NO_WAIT (No-Waiting-2PL)

$\text{lock}_{t_1}(a, X)$

$\text{lock}_{t_2}(a, S)$

$\text{lock}_{\cancel{t_3}}(a, X)$

$\text{unlock}_{t_2}(a)$

$\text{lock}_{t_1}(a, C)$

2V_NO_WAIT (Two-Version-2PL)

read phase

validation phase

write phase

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

⋯

Interactive Example

Transactions:

t_0 t_1 t_2

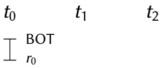
— BOT

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:

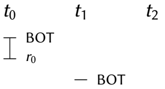


Locks:

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:

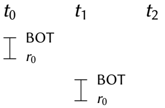


Locks:

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:



t_0 t_1 t_2

BOT
r_0

BOT
r_0

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:

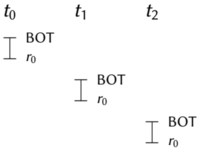
t_0	t_1	t_2
BOT r_0		
	BOT r_0	
		BOT

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:

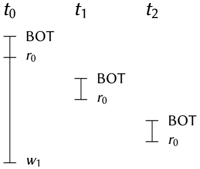


Locks:

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:

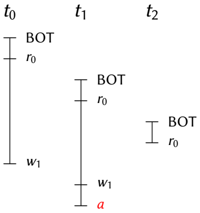


Locks:

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:

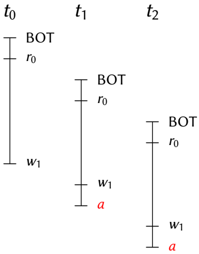


Locks:

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:



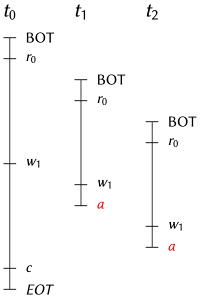
Locks:

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:



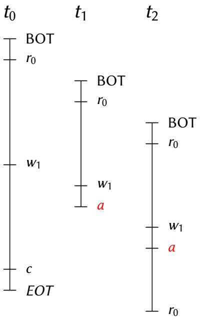
Locks:

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:



t_0: BOT, r_0, w_1, c, EOT

t_1: BOT, r_0, w_1, a

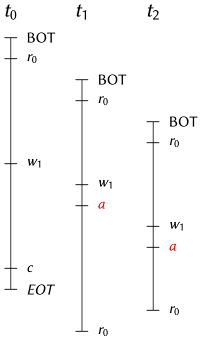
t_2: BOT, r_0, w_1, a, r_0

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:

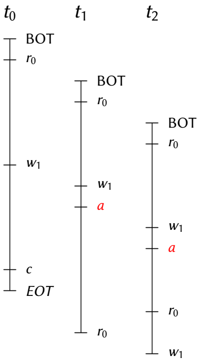


Locks:

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

Interactive Example

Transactions:

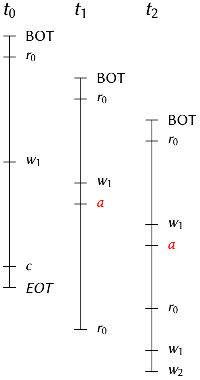


Locks:

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:

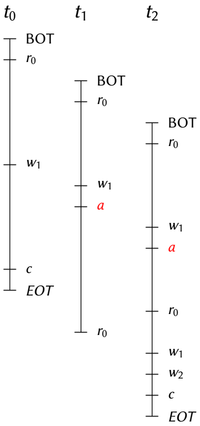


Locks:

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:



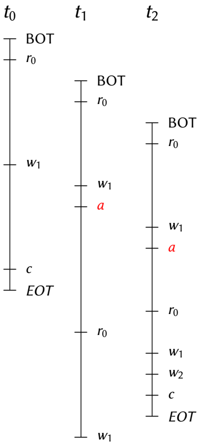
Locks:

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:



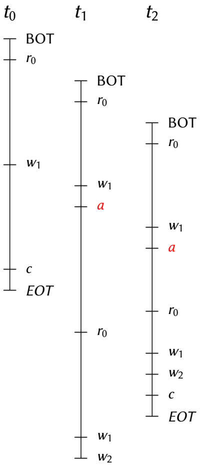
Locks:

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:



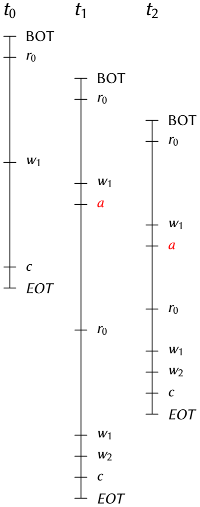
Locks:

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
  → scales better than latches
- + no need to expensively calculate and analysis a wait-for graph

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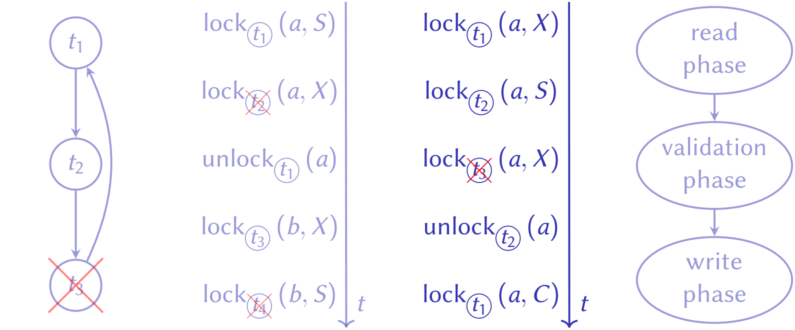
- + deadlocks are impossible
- + locks can be implemented using a semaphore and atomics
  → scales better than latches
- + no need to expensively calculate and analysis a wait-for graph
- – many lock conflicts for update-intensive high-contention workloads
  → many aborts → work done before needs to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

Subsection 3

2V_NO_WAIT (Two-Version-2PL)


t_1
t_2
$\cancel{t_3}$
$\text{lock}_{t_1}(a, S)$
$\text{lock}_{\cancel{t_2}}(a, X)$
$\text{unlock}_{t_1}(a)$
$\text{lock}_{t_3}(b, X)$
$\text{lock}_{\cancel{t_4}}(b, S)$
t
$\text{lock}_{t_1}(a, X)$
$\text{lock}_{t_2}(a, S)$
$\text{lock}_{\cancel{t_3}}(a, X)$
$\text{unlock}_{t_2}(a)$
$\text{lock}_{t_1}(a, C)$
t
read phase
validation phase
write phase

DL_DETECT (2PL)

NO_WAIT (No-Waiting-2PL)

2V_NO_WAIT (Two-Version-2PL)

SILO (OCC)

Properties of 2V_NO_WAIT (Two-Version-2PL) I

- multiversion pessimistic concurrency control protocol
- 3 phases: read, certify, write/commit
- transactions lock records before reading (shared mode *S*), privately updating (exclusive mode *X*) or certifying/globally updating (certify mode *C*) them
- updates happen first on a private copy
  → committed copy can still be read by other transactions
- before committing writes (replace original record with private copy) the absence of relevant conflicts needs to be certified (certification step)

Properties of 2V_NO_WAIT (Two-Version-2PL) II

- t_0 tries to acquire lock held by t_1 in compatible mode
  → 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
  → t_0 aborts

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

Protocol I

read r_i

C acquired r_i gets certified or committed by another transaction

- abort this transaction

C not acquired other threads might read r_i or privately update r_i

- acquire r_i's lock in S mode
- read global (committed) value of r_i

update r_i

W acquired r_i gets (privately or globally) updated by another transaction → there are already two versions

- abort this transaction

W not acquired other threads at most read r_i

- acquire r_i's lock in X mode
- create local copy of global (committed) value of r_i
- update local copy of r_i

Protocol II

certify r_i *(only if r_i was updated)*

S acquired r_i's global (committed) value gets read by other transaction
→ globally updating r_i would cause non-repeatable reads

- abort this transaction

S not acquired other threads at most read r_i

- acquire r_i's lock in C mode

commit

- *(only if r_i was updated)* replace global r_i with updated local version
- release the locks held on r_i

Pros & Cons 2V_NO_WAIT (Two-Version-2PL)

+ deadlocks are impossible
+ transactions can read while a transaction updates a record
+ locks can be implemented using a semaphore and a flag updated with atomic instructions
  → scales better than latches
+ no need to expensively calculate and analysis a wait-for graph

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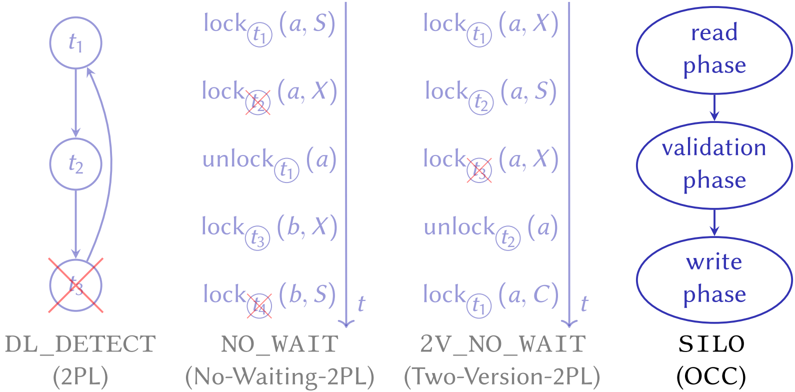
+ locks can be implemented using a semaphore and a flag updated with atomic instructions
  → scales better than latches
+ no need to expensively calculate and analysis a wait-for graph
– update-intensive high-contention workloads result in many lock conflicts
  → many aborts → work done before needs to be repeated
– locks still prevent concurrency too often (e.g. blind writes)
– additional steps for updates required:
  - create private copy of updated record (expensive but scalable)
  - certify update (cheap)

Subsection 4

SILO (OCC)



$\text{lock}_{t_1}(a, S)$
$\text{lock}_{t_2}(a, X)$
$\text{unlock}_{t_1}(a)$
$\text{lock}_{t_3}(b, X)$
$\text{lock}_{t_4}(b, S)$

$\text{lock}_{t_1}(a, X)$
$\text{lock}_{t_2}(a, S)$
$\text{lock}_{t_3}(a, X)$
$\text{unlock}_{t_2}(a)$
$\text{lock}_{t_1}(a, C)$

read phase
validation phase
write phase

DL_DETECT (2PL)

NO_WAIT (No-Waiting-2PL)

2V_NO_WAIT (Two-Version-2PL)

SILO (OCC)

Properties of SILO (OCC) I

- optimistic concurrency control protocol
- 3 phases: read, validate, write/commit
- each record contains the transaction ID (global ordered number based on epochs) from the last update
- transactions perform reads and local writes during the read phase without acquiring locks

Properties of SILO (OCC) II

- read and write sets (records read and written by the transaction) are recorded locally
- read and write sets used to validate absence of relevant conflicts
- commit requires three phases: locking of updated records, verification of read set (based on TIDs), execute global writes
- deletes invalidate records using updates
  → garbage collection required
- records for inserts created before validation to provide locks

Pros & Cons SILO (OCC)

- + deadlocks are impossible (locks acquired only in last phase → global order can be used)
- + transactions can concurrently read and write
- + only actual conflicts cause aborts (optimism)

Pros & Cons SILO (OCC)

- + deadlocks are impossible (locks acquired only in last phase → global order can be used)
- + transactions can concurrently read and write
- + only actual conflicts cause aborts (optimism)
- – update-intensive high-contention workloads result in many invalid reads
  → many aborts → work done before needs to be repeated
- – globally sorted transaction IDs need to be generated (epochs make that cheap)
- – additional steps for updating transactions required:
  - ▶ write and read sets locally (expensive but scalable)
  - ▶ validate reads

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

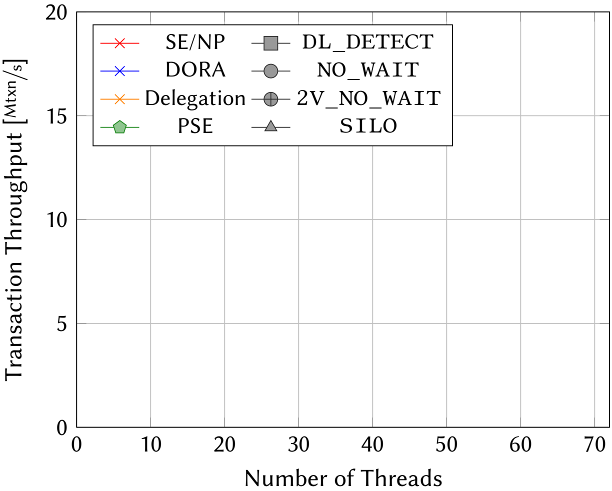
Microbenchmark

- 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)

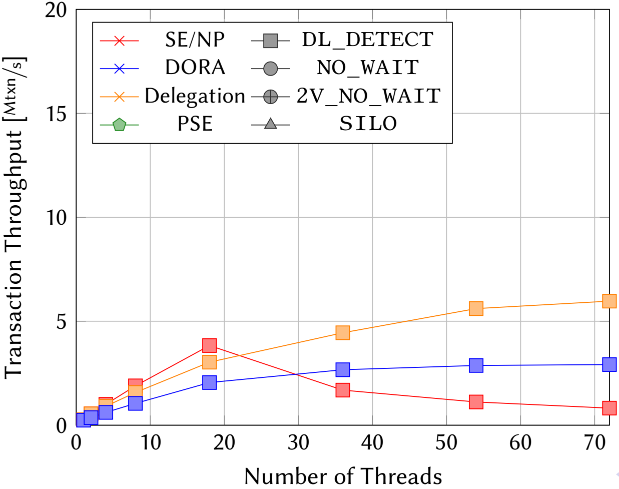
- 20 GB database
- 20 000 000 records
- Txn: reads/updates 16 records following Zipfian distribution according to parameter Θ

Read-Only Microbenchmark



Observations

Read-Only Microbenchmark



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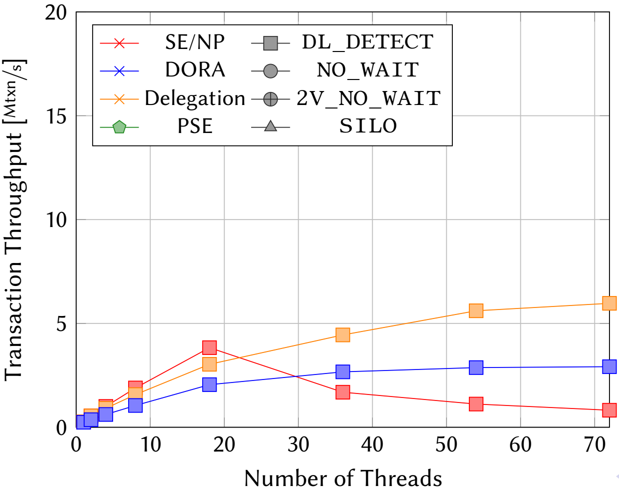
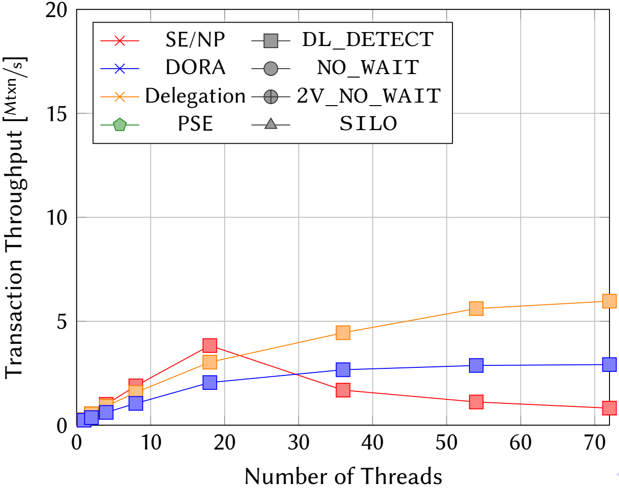
Read-Only Microbenchmark



Observations

- ×/× suffer from remote data access overhead

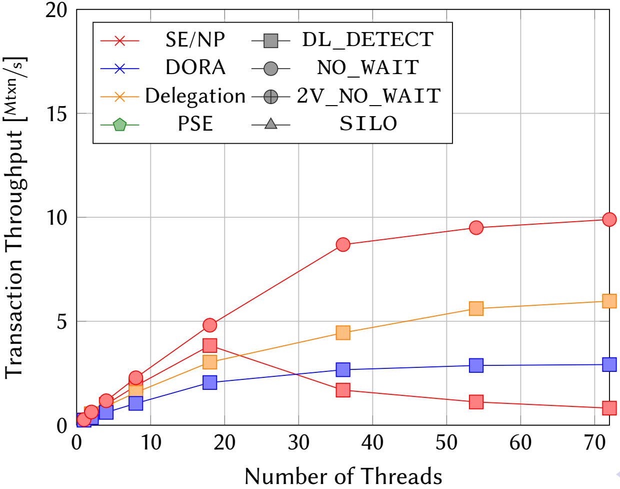
Read-Only Microbenchmark



Observations

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

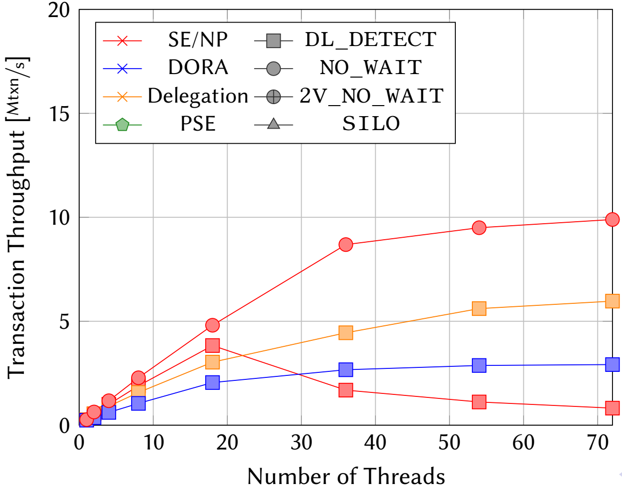
Read-Only Microbenchmark



Observations

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

Read-Only Microbenchmark



Observations

- ×/× suffer from remote data access overhead
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- atomics of ● outperform latches of ■

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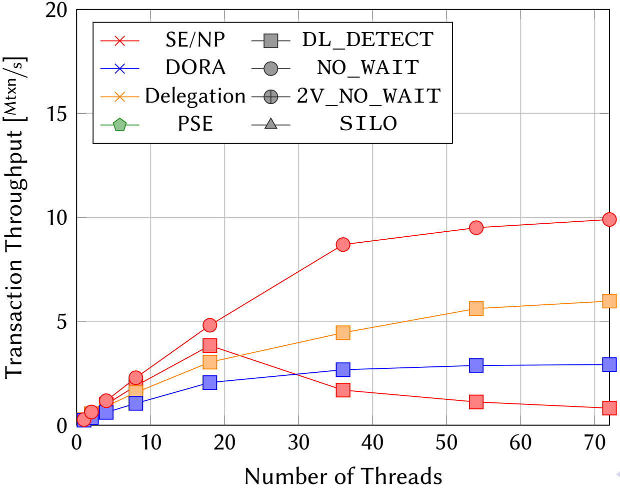
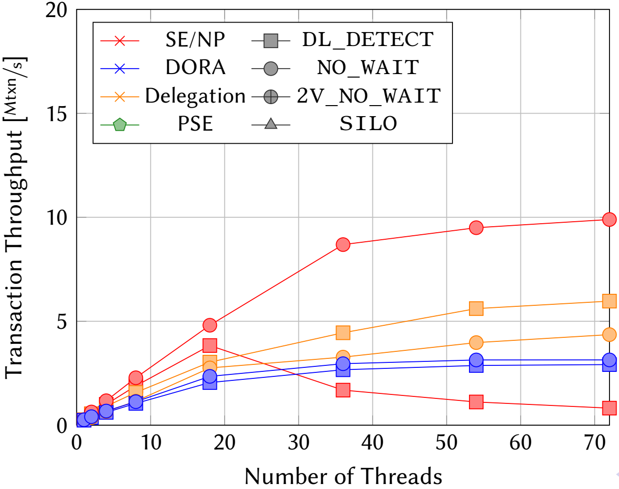


Observations

- ✕/✕ 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



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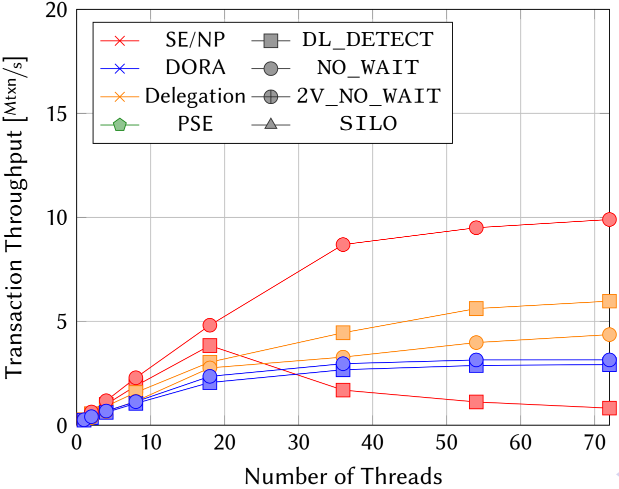

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- × suffers from latch contention on locks
- atomics of ● outperform latches of ■
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- ×/× suffer more from remote data accesses than × suffers from cache coherence

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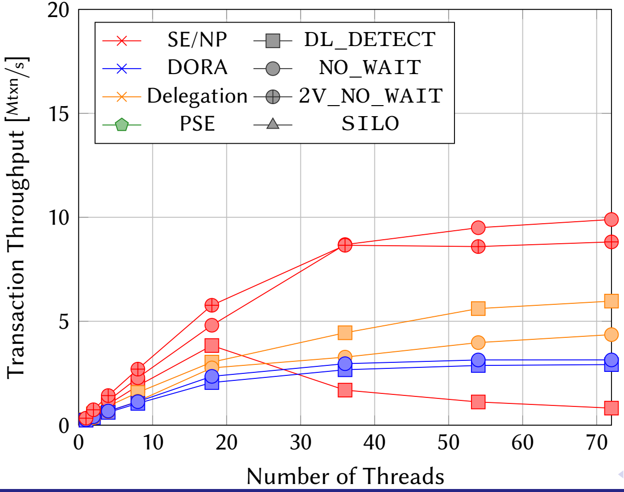

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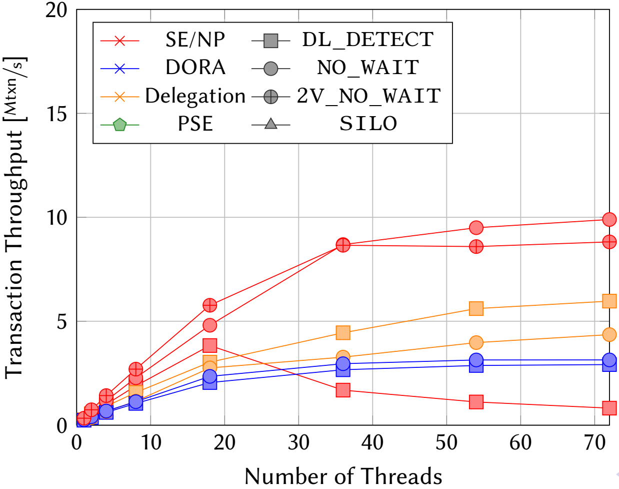

Observations

- atomics of ● outperform latches of ■
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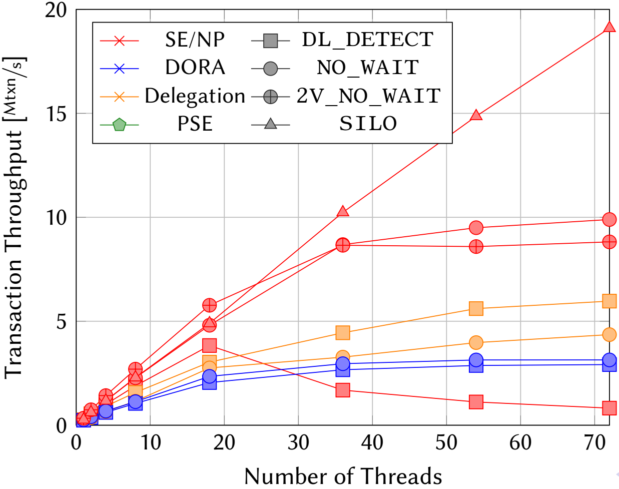
- ×/× suffer more from remote data accesses than × suffers from cache coherence
- ⊕ and ● perform identical for read-only

Read-Only Microbenchmark



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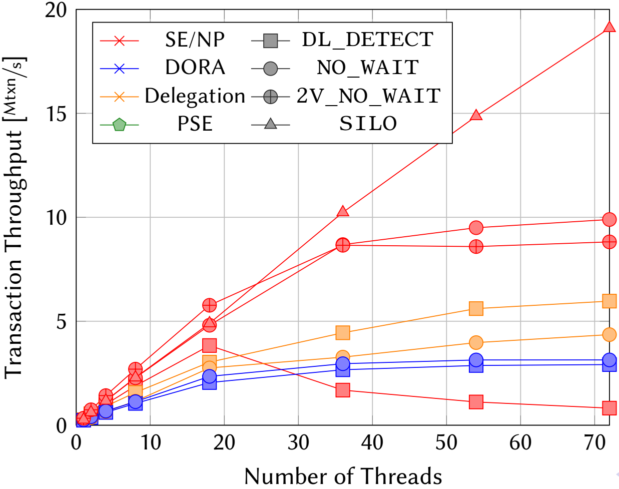
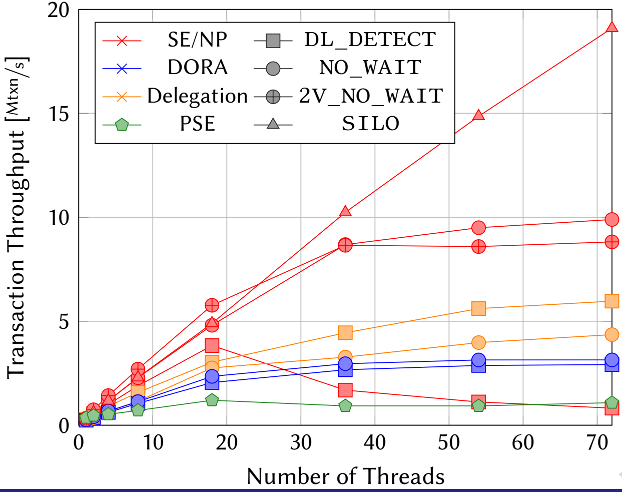


Observations

- 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

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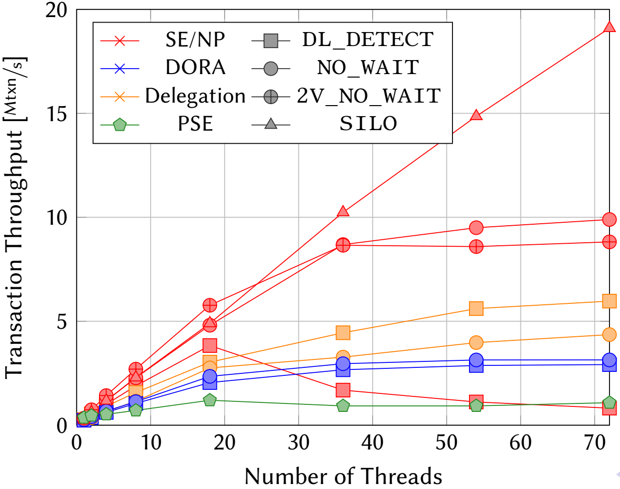
- ⊕ and ● perform identical for read-only
- ▲ behaves identical for × and × for read-only

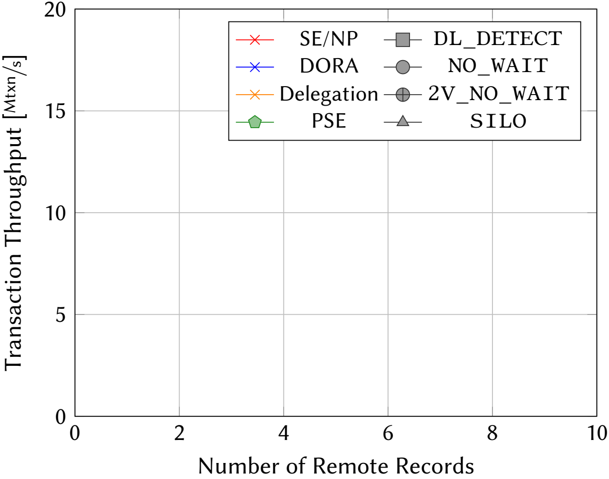
Read-Only Microbenchmark



Observations

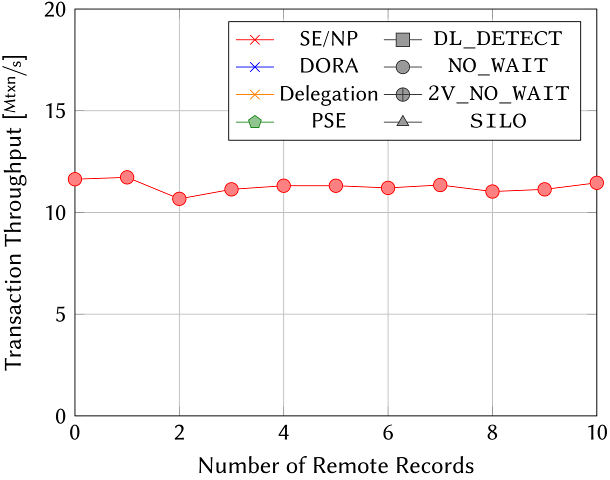
- ×/× suffer more from remote data accesses than × suffers from cache coherence
- ⊕ and ● perform identical for read-only
- △ behaves identical for × and × for read-only
- coarse-grained partition locking of ⬠ does not scale due to multi-site workload

Multi-Site Read-Only Microbenchmark



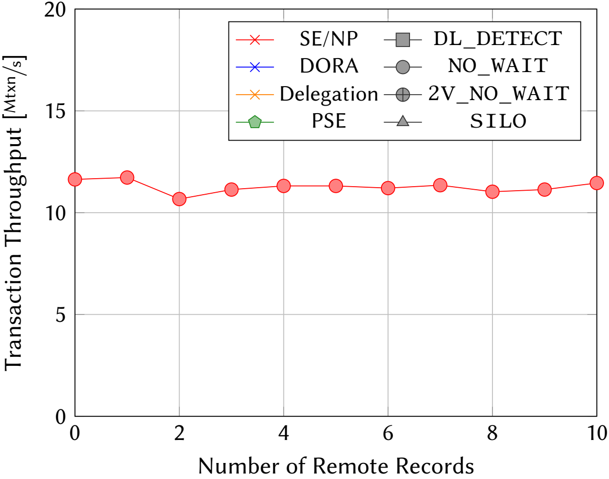
Observations

Multi-Site Read-Only Microbenchmark



Observations

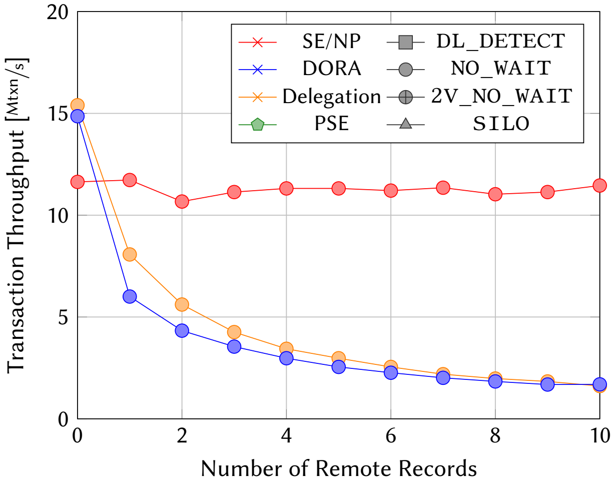
Multi-Site Read-Only Microbenchmark



Observations

- × does not know remote records

Multi-Site Read-Only Microbenchmark



Observations

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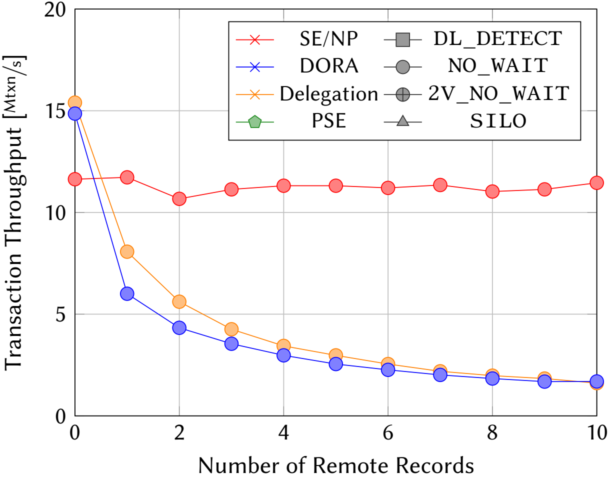
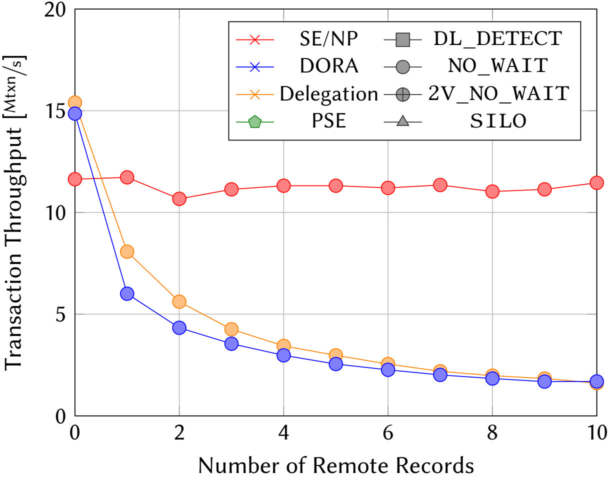


Observations

- × does not know remote records
- ×/× outperform × for 0 remote records due to lower cache coherence activity

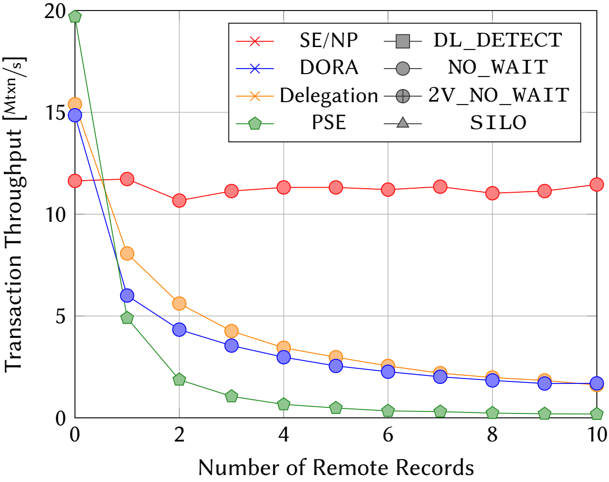
Multi-Site Read-Only Microbenchmark



Observations

- × does not know remote records
- ×/× outperform × for 0 remote records due to lower cache coherence activity
- ×/× suffer from remote data access overhead for $>$ 0 remote records

Multi-Site Read-Only Microbenchmark



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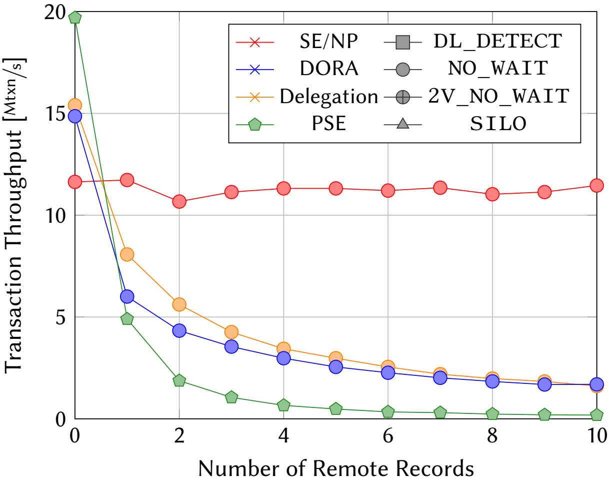
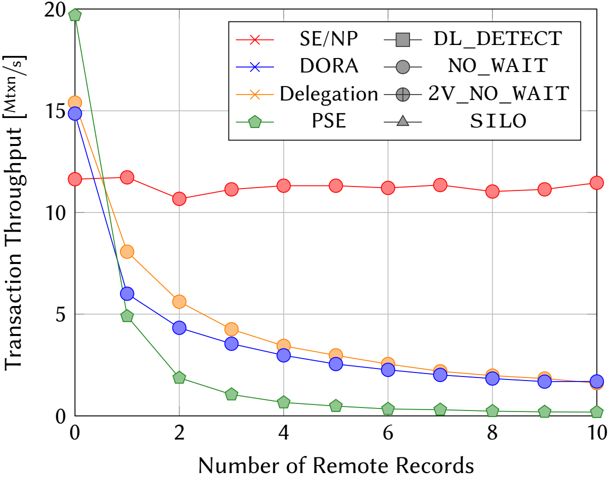


Observations

- ×/× outperform × for 0 remote records due to lower cache coherence activity
- ×/× suffer from remote data access overhead for $>$ 0 remote records
- coarse-grained partition locking of ⬟ imposes nearly no overhead for suitable partitioning

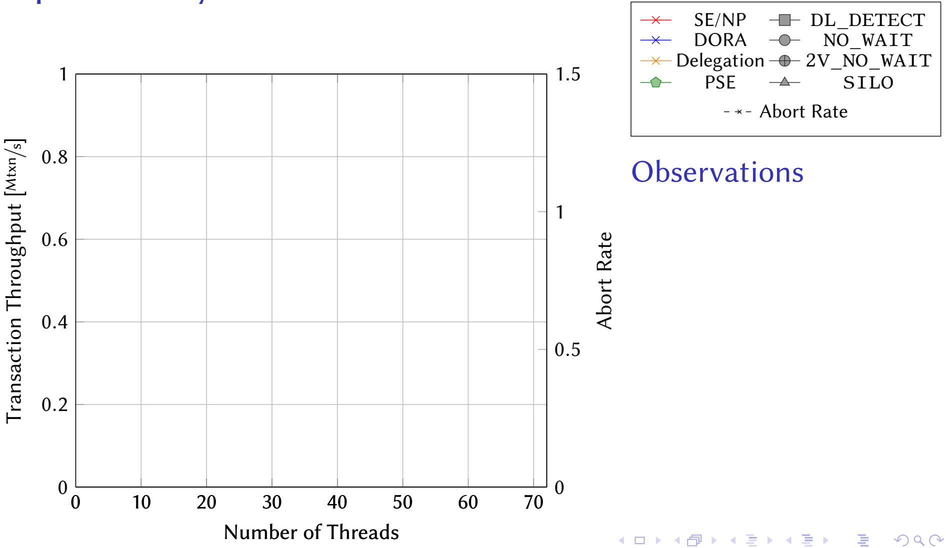
Multi-Site Read-Only Microbenchmark



Observations

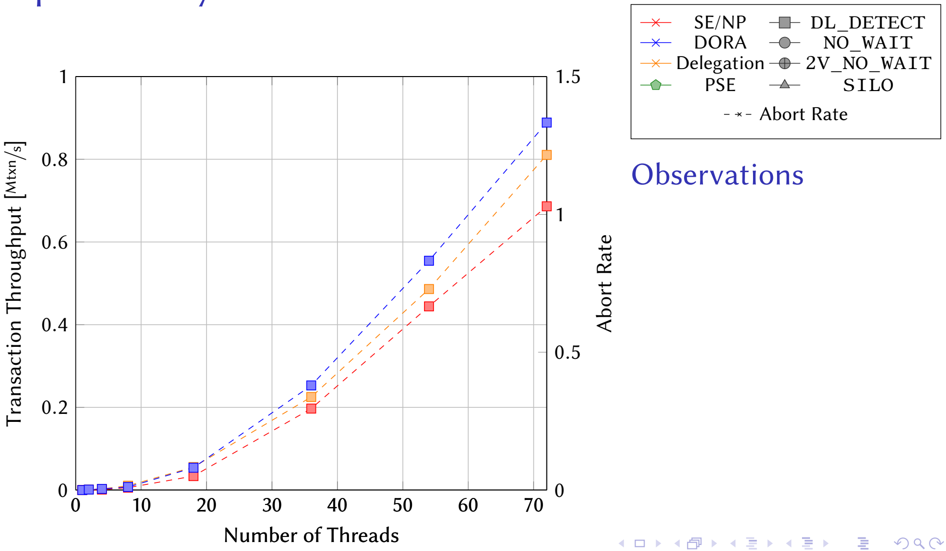
- ×/× suffer from remote data access overhead for $>$ 0 remote records
- coarse-grained partition locking of ⬠ imposes nearly no overhead for suitable partitioning
- coarse-grained partition locking of ⬠ limits the concurrency drastically for $>$ 0 remote records

Update-Only Microbenchmark



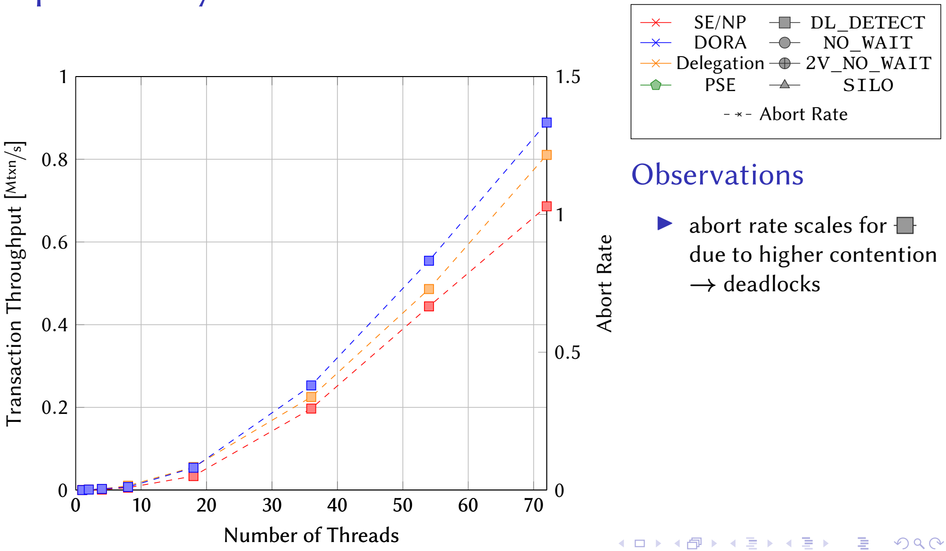
Observations

Update-Only Microbenchmark



Observations

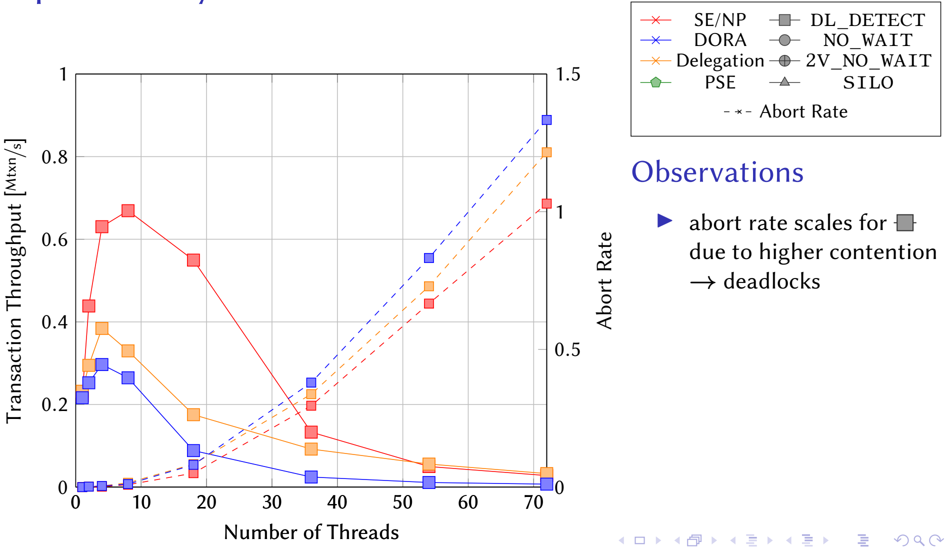
Update-Only Microbenchmark



Observations

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

Update-Only Microbenchmark



Observations

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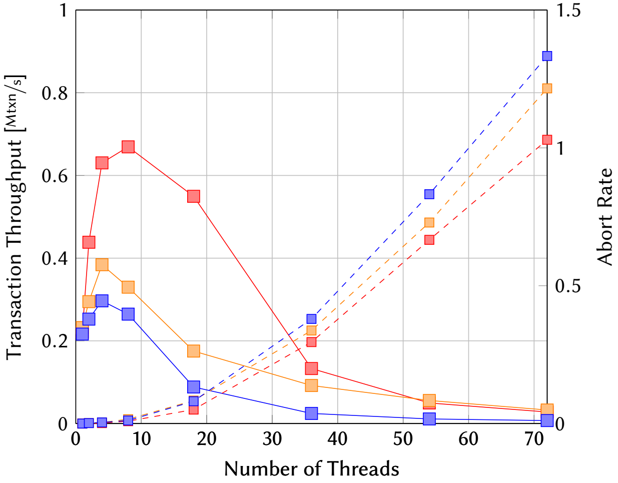
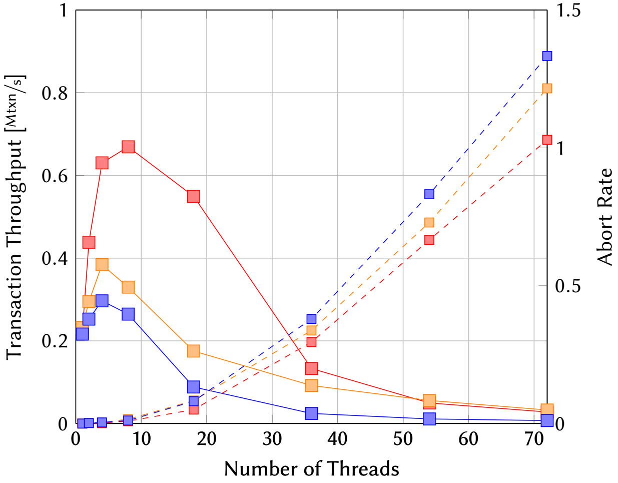
Update-Only Microbenchmark



Observations

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

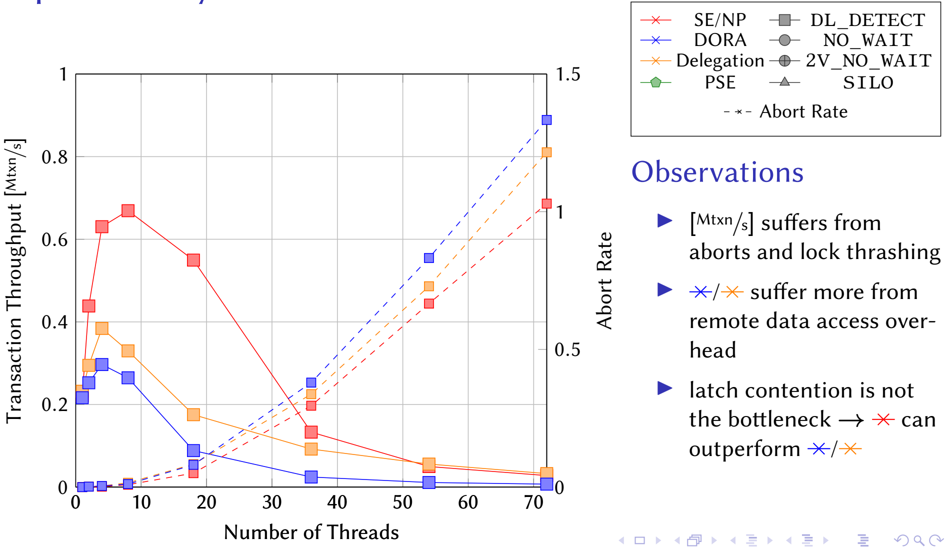
Update-Only Microbenchmark



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

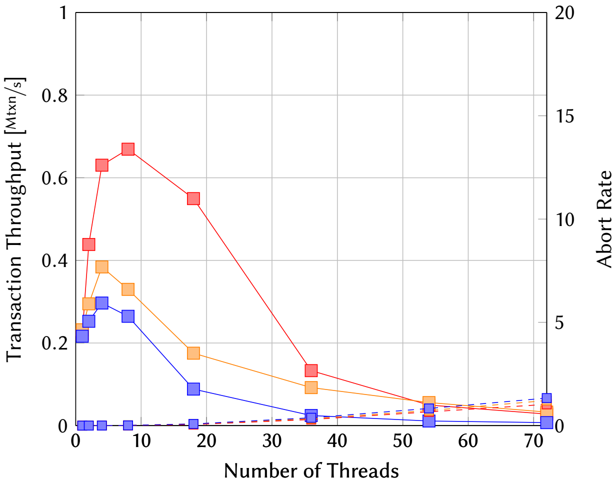
Update-Only Microbenchmark



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

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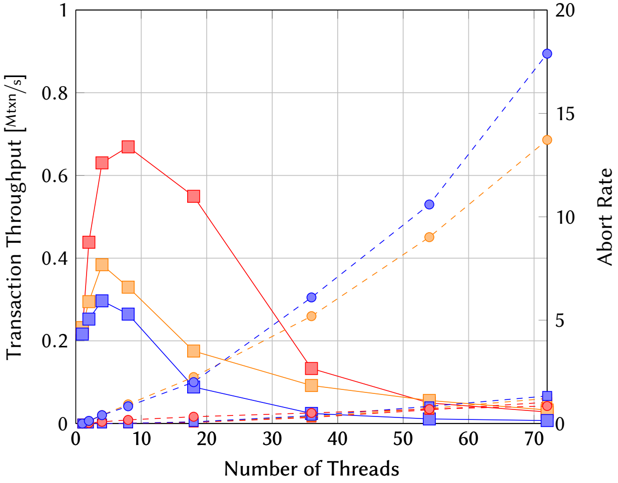
Update-Only Microbenchmark



Observations

- [Mtxn/s] suffers from aborts and lock thrashing
- ×/× suffer more from remote data access overhead
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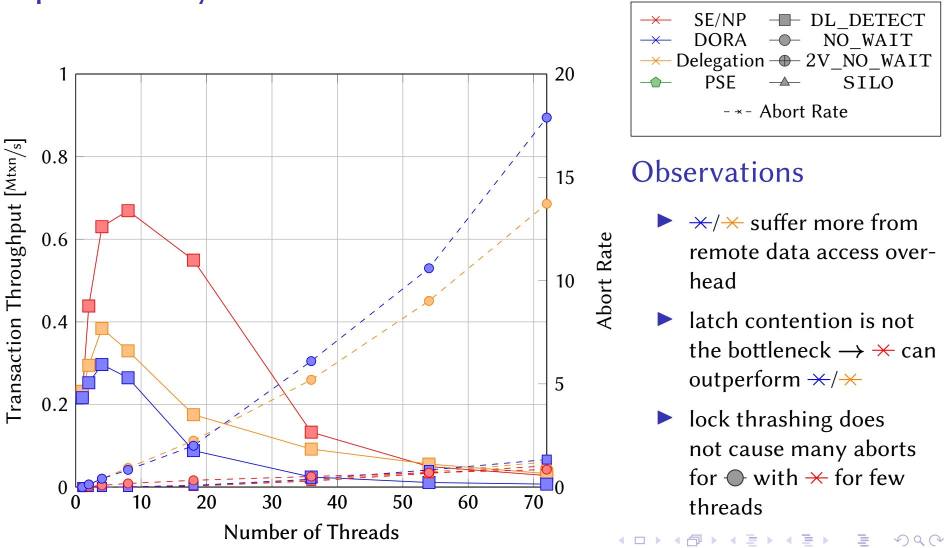
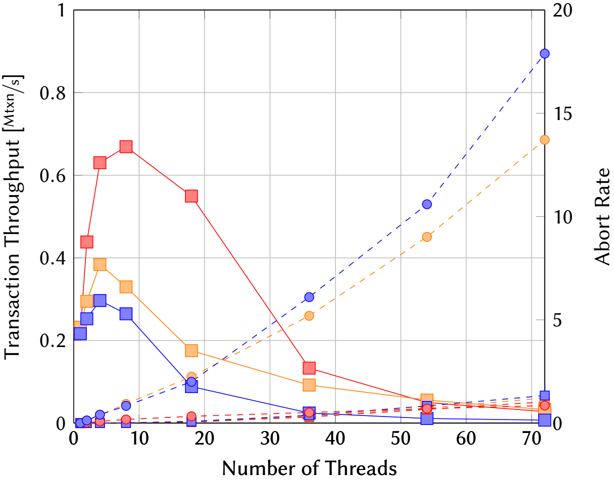
Update-Only Microbenchmark



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

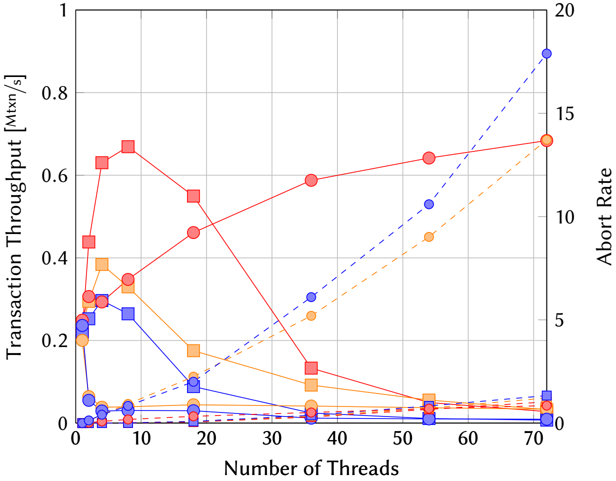
Update-Only Microbenchmark



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

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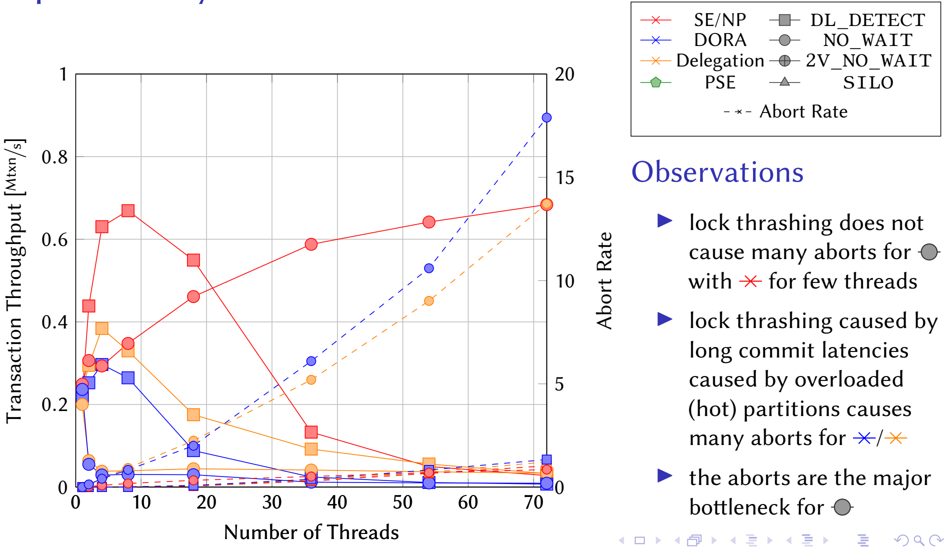
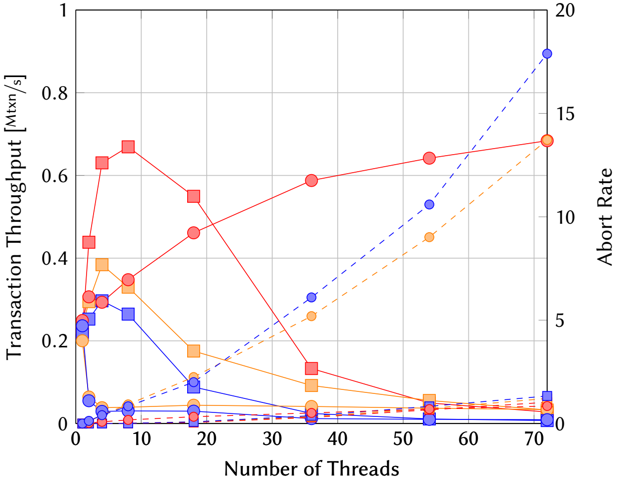
Update-Only Microbenchmark



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 ●

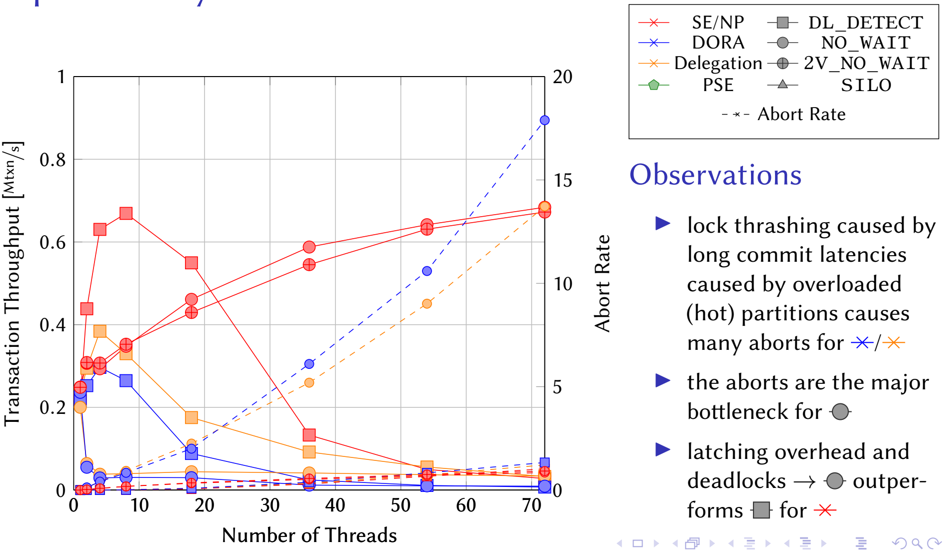
Update-Only Microbenchmark



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

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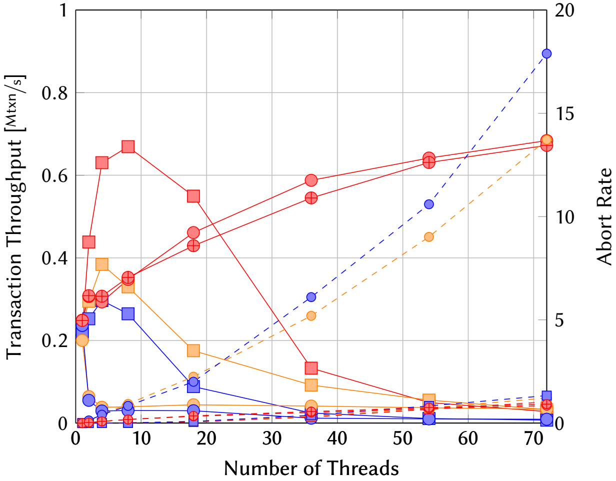
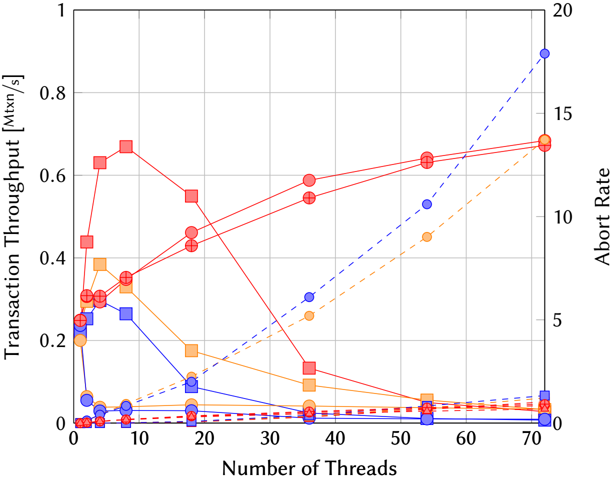


Observations

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

Update-Only Microbenchmark



Observations

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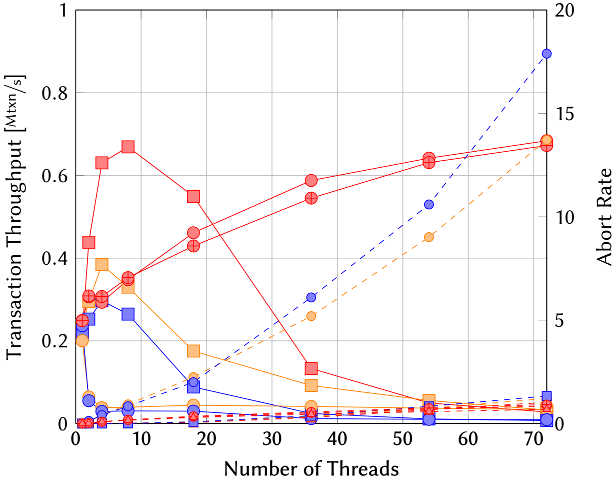
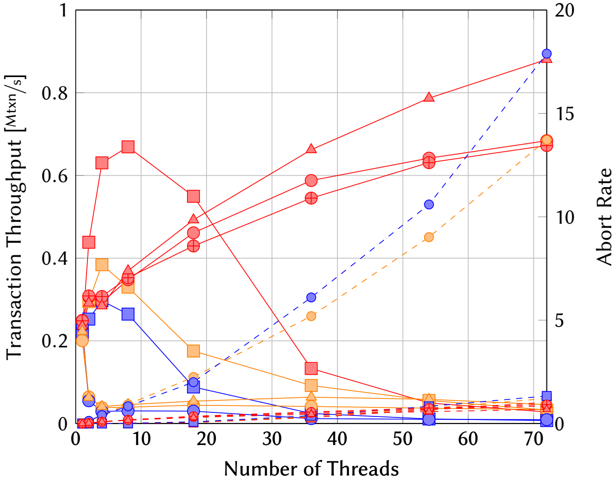
Update-Only Microbenchmark



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



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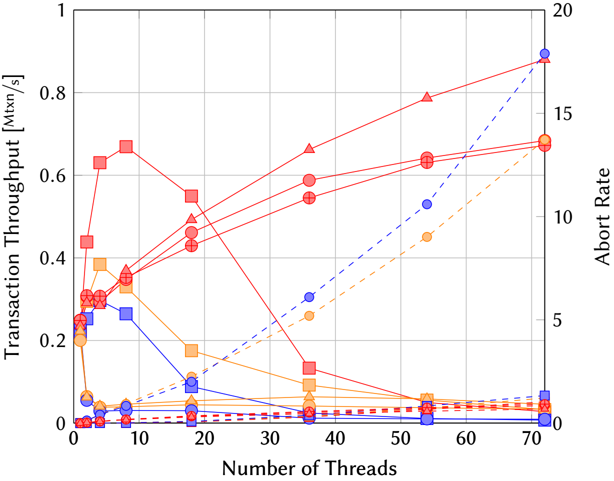
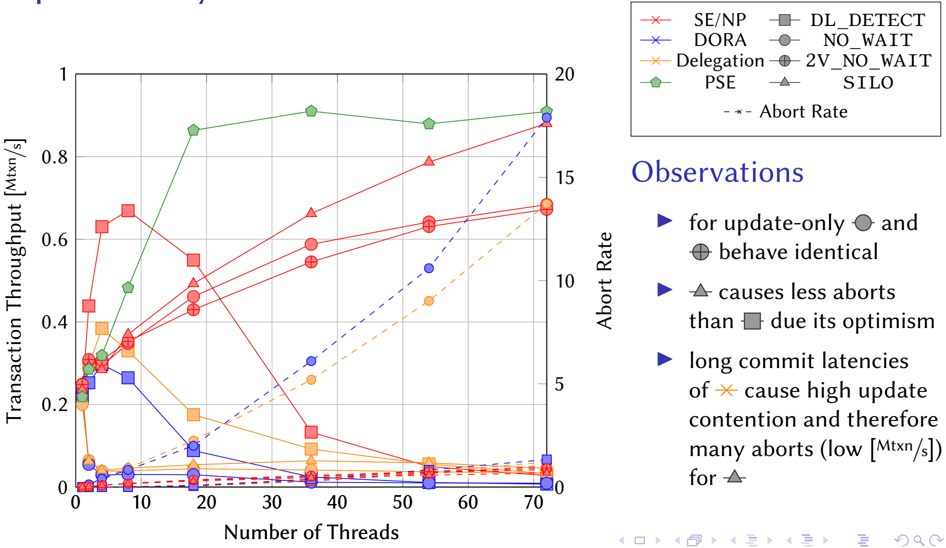
Update-Only Microbenchmark



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



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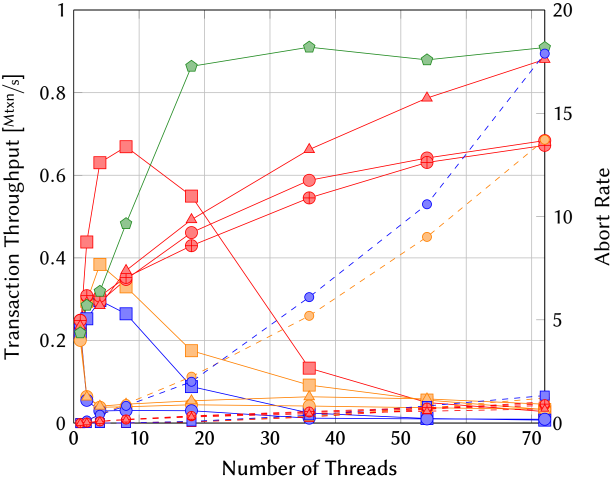
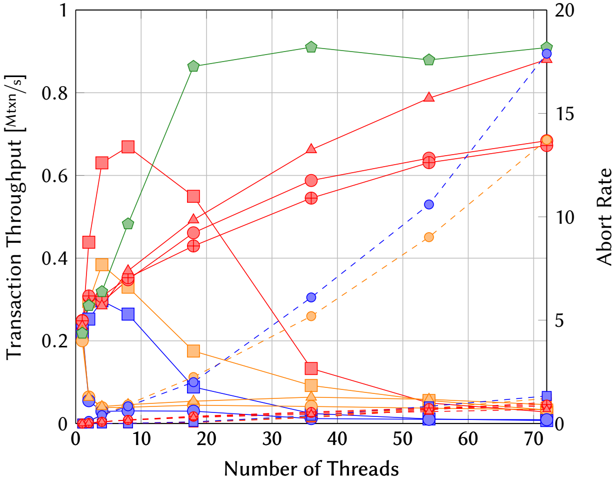
Update-Only Microbenchmark



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

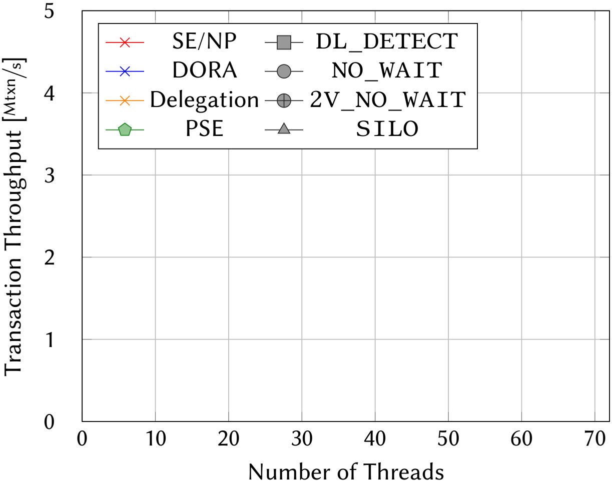
Update-Only Microbenchmark



Observations

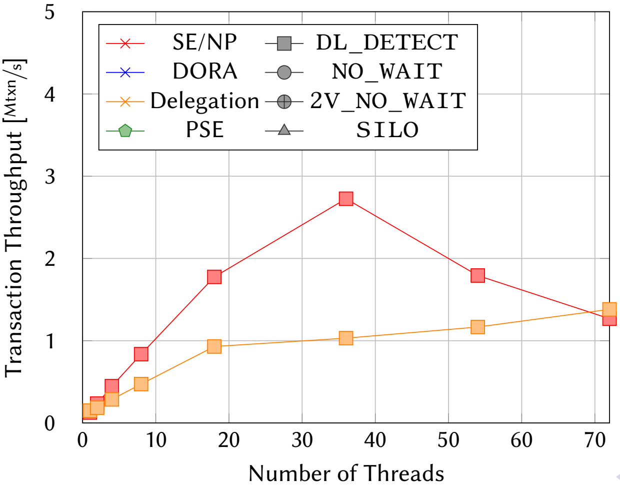
- coarse-grained partition locking of ⬟ is identical for read and update
- ⬟ scales according to the number of hot records (each transaction locks 2 of 16 (hot) partitions)

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



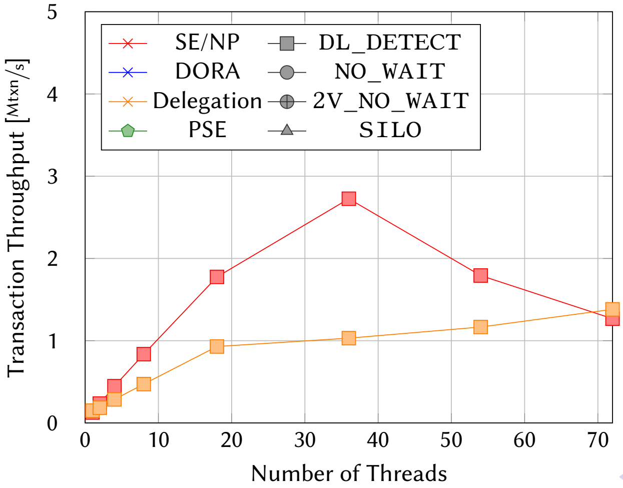
Observations

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



Observations

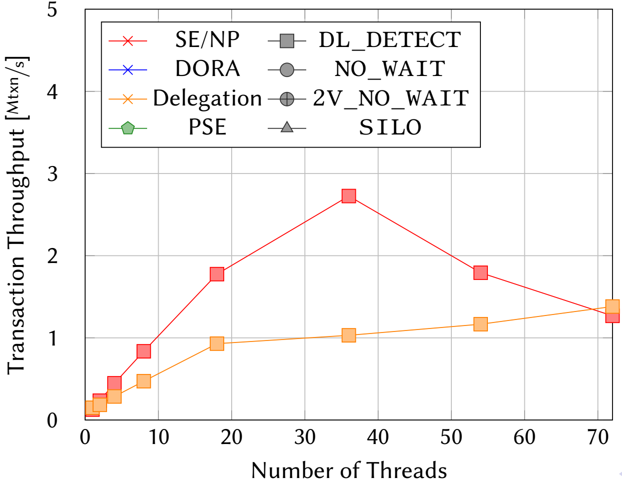
Read-Only YCSB ($\Theta = 0.8$)



Observations

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

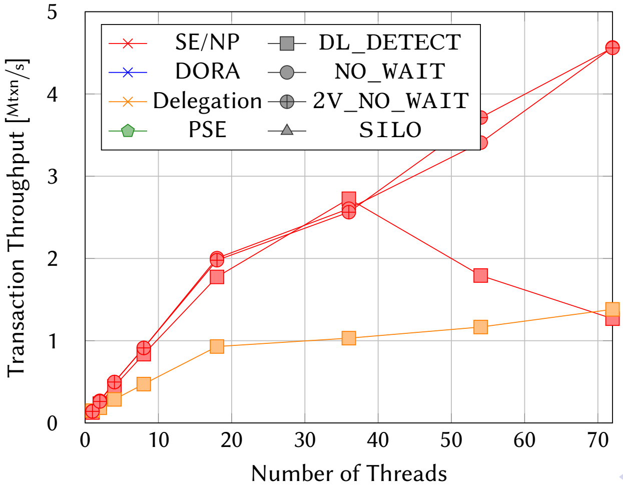
Read-Only YCSB ($\Theta = 0.8$)



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 ($\Theta = 0.8$)



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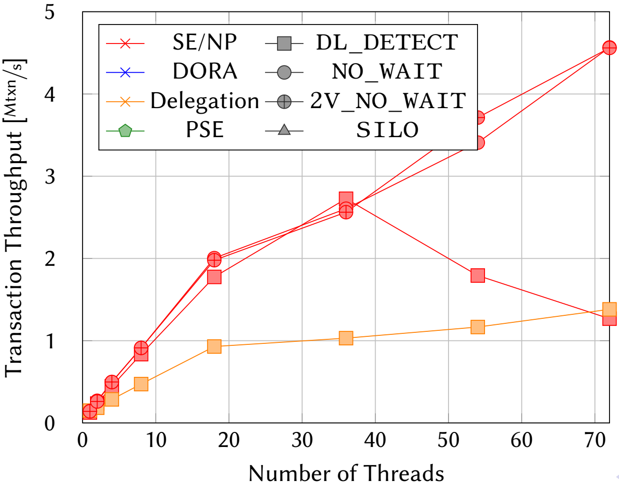

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- atomics of ● scale better than latches of ■

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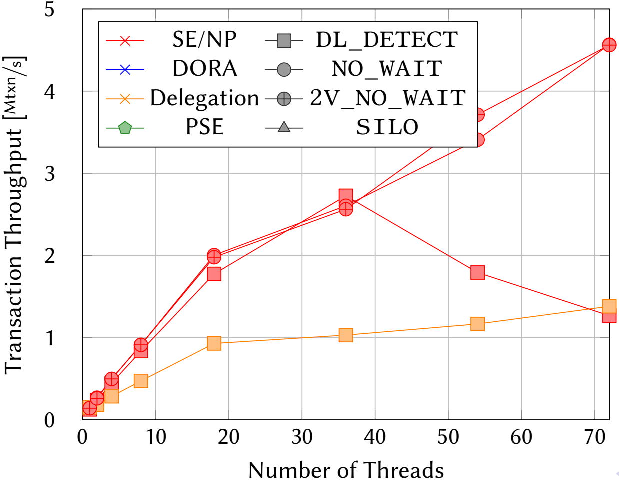

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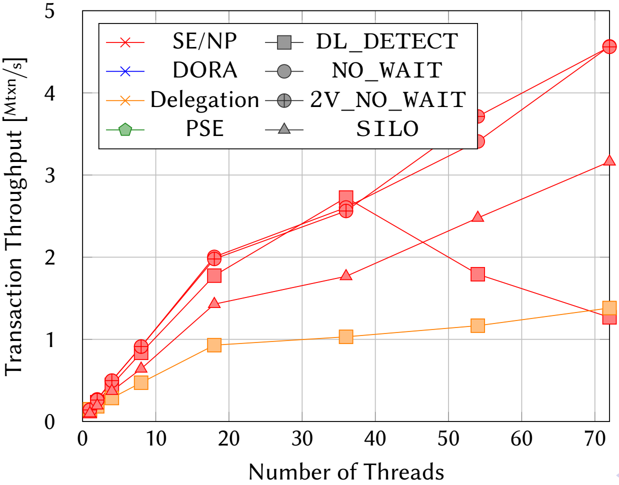

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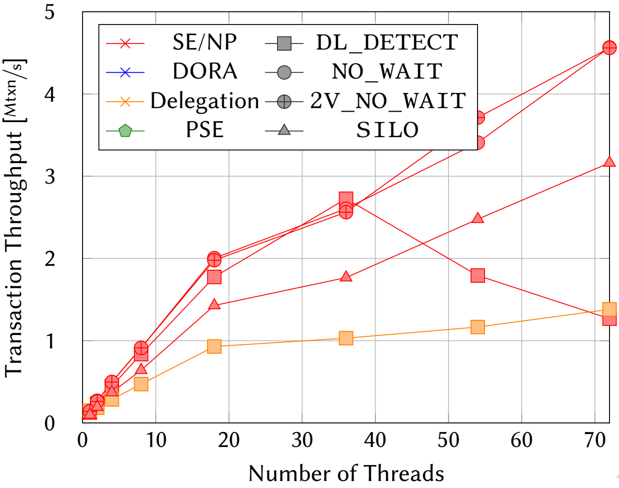

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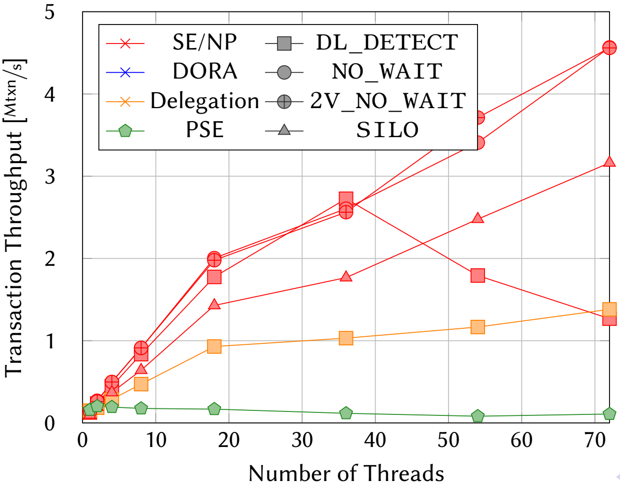

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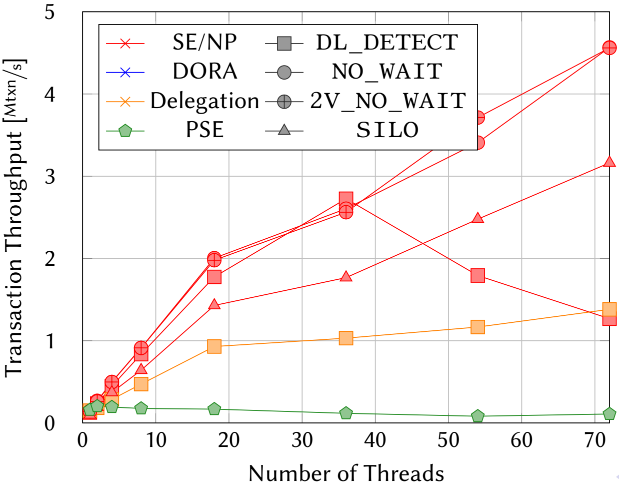

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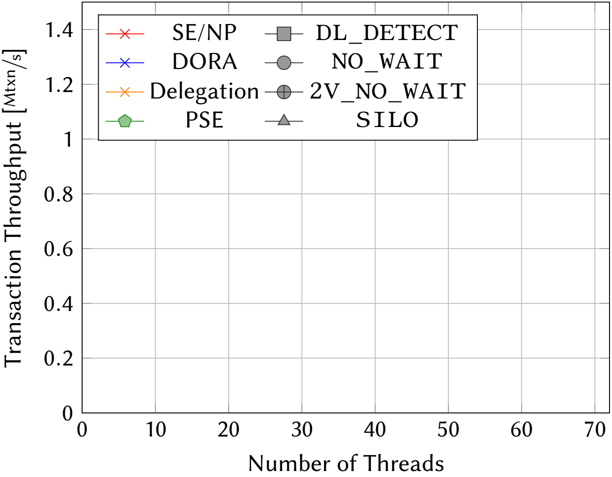
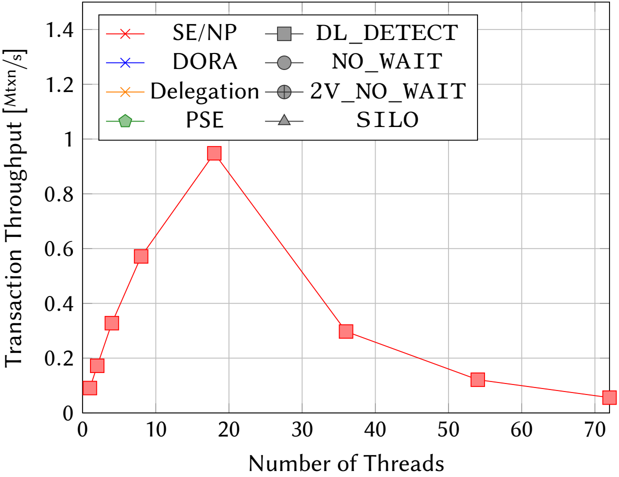


Observations

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



Observations

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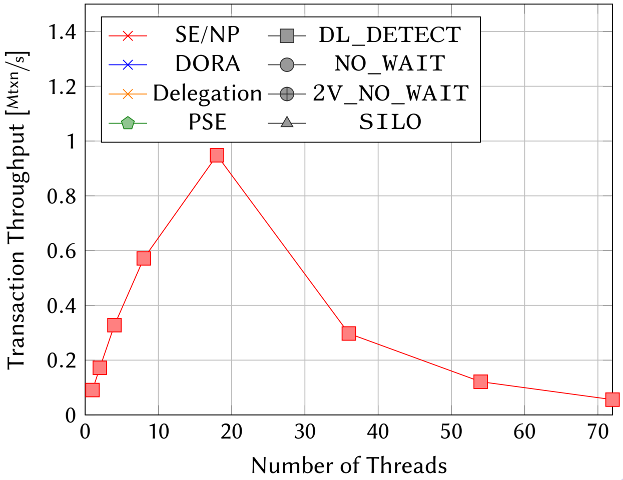
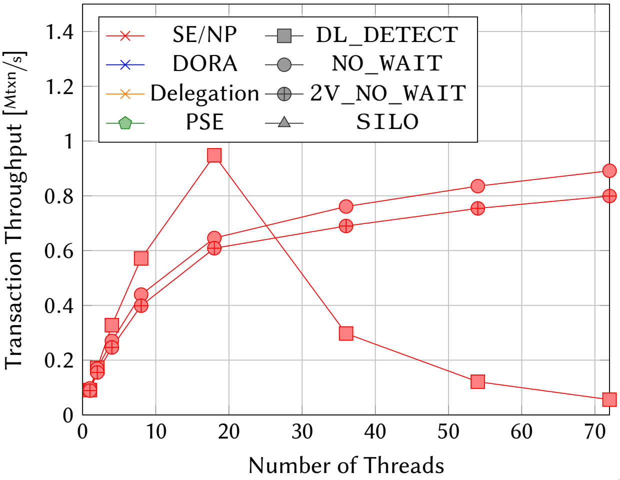


Observations

- ■ suffers from deadlocks for many threads

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



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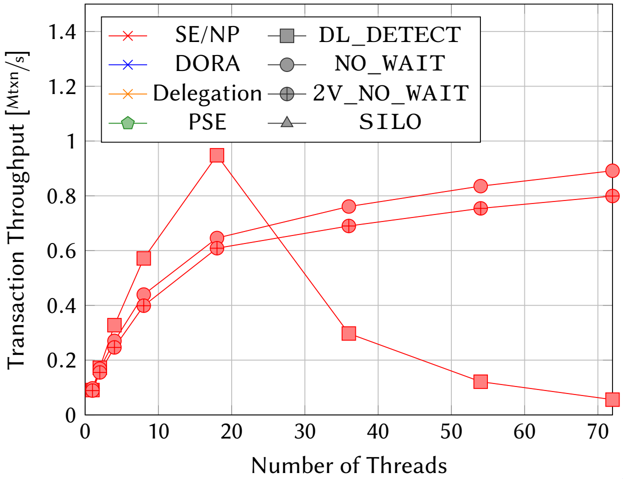
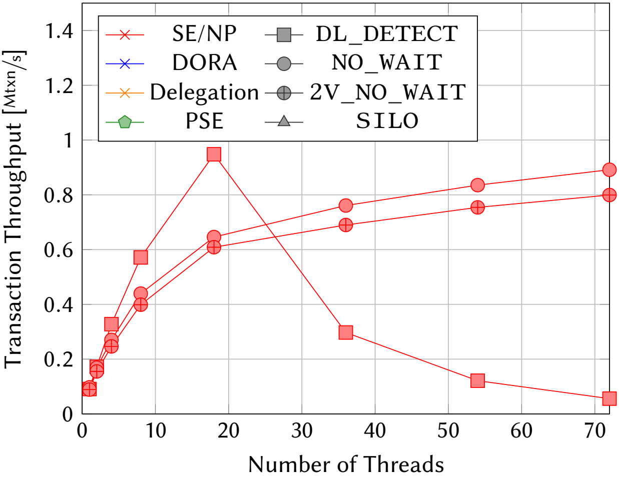


Observations

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

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



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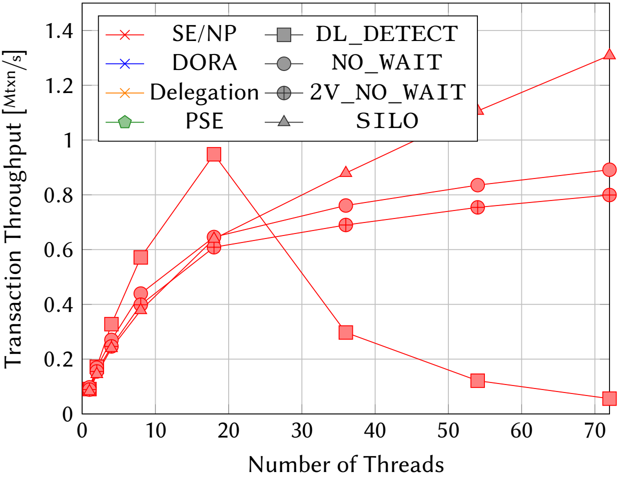

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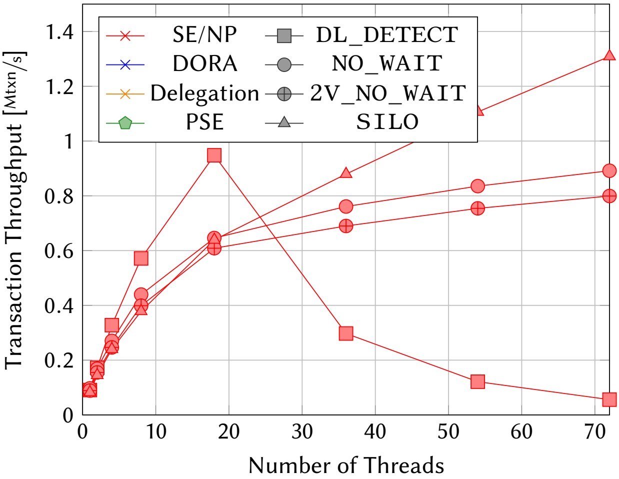

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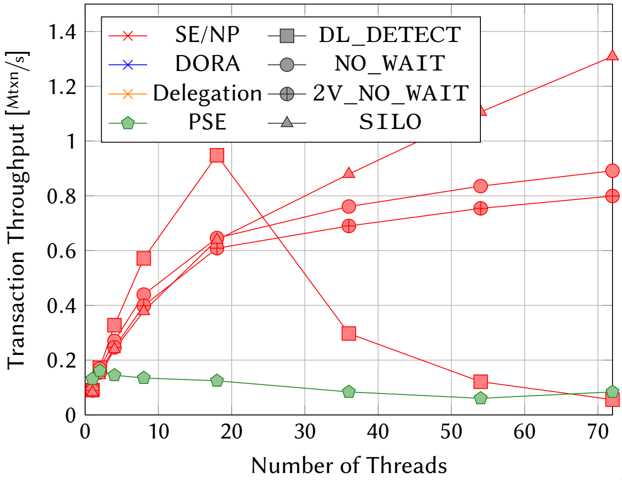
- ▲ causes less aborts than ● due its optimism → higher [$^{\mathrm{Mtxn}}/_{\mathrm{s}}$]

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



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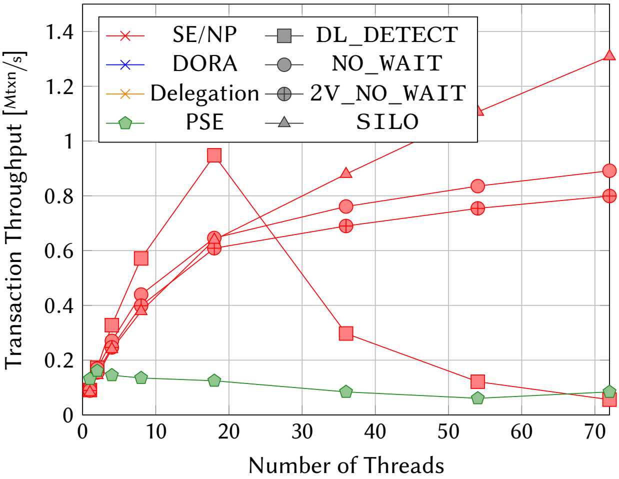

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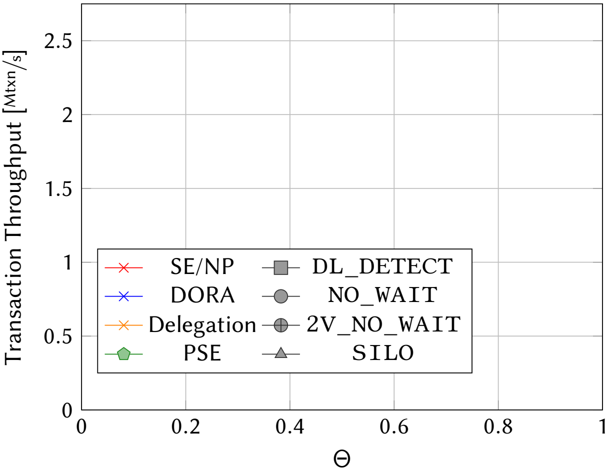
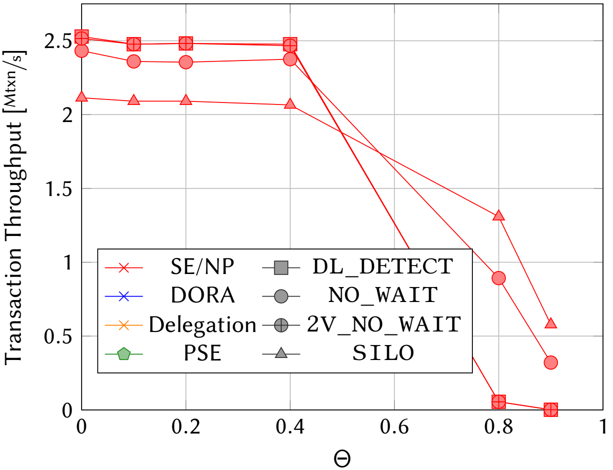
- ⬟ (and ×/×) does not scale well due to partition-unfriendly Zipfian access distribution

Update-Only YCSB (72 Threads)



Observations

Update-Only YCSB (72 Threads)



Observations

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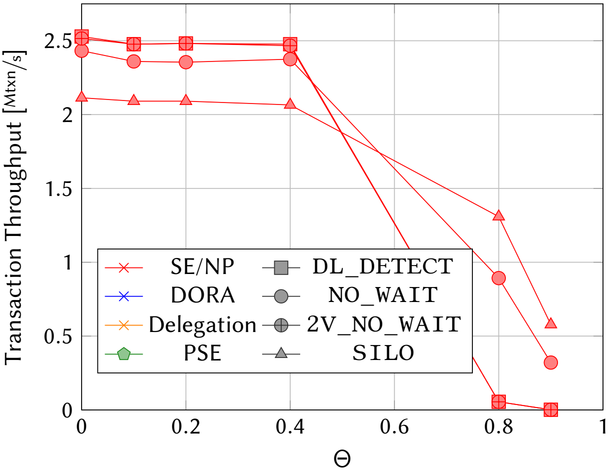
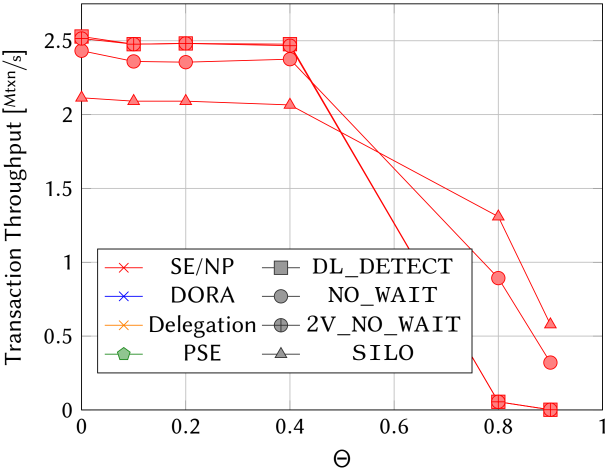


Observations

- for $\Theta \leq 0.4$ the contention is very low → high concurrency possible

Update-Only YCSB (72 Threads)



Observations

- for Θ ≤ 0.4 the contention is very low → high concurrency possible
- copying records imposes an overhead to ⊕/▲

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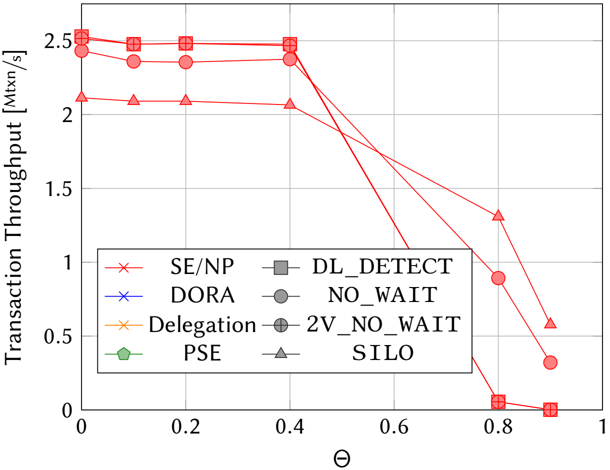

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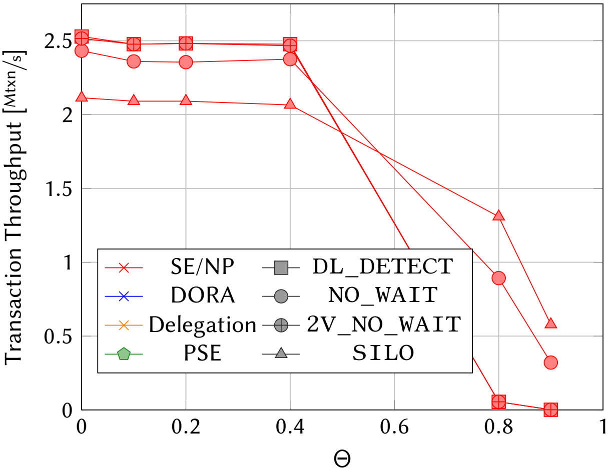

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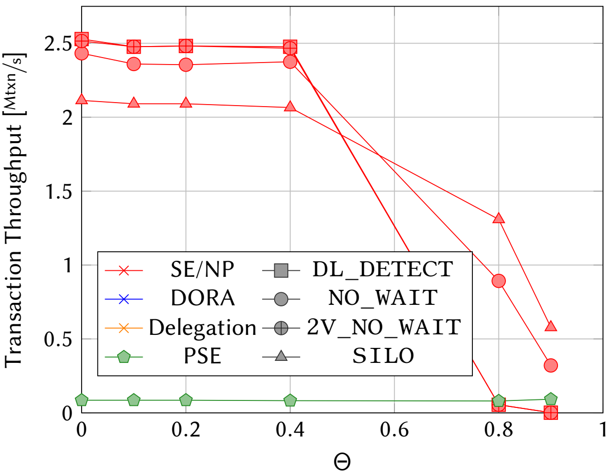
Update-Only YCSB (72 Threads)



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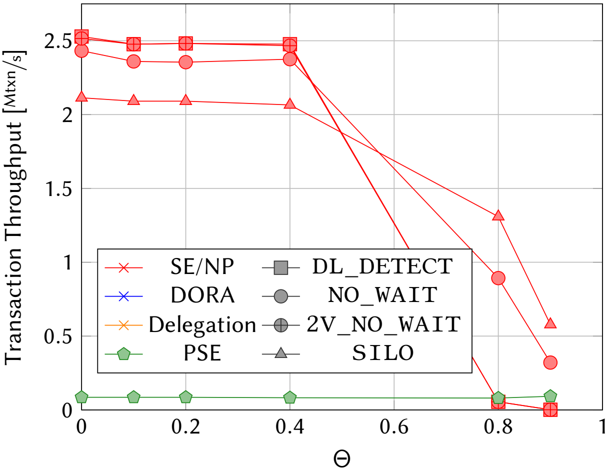
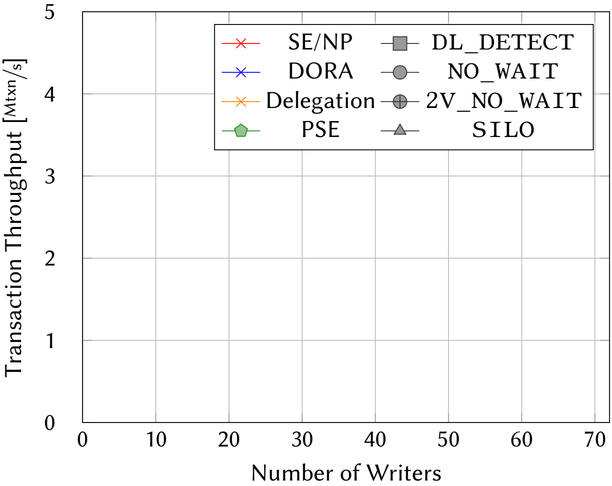
Update-Only YCSB (72 Threads)



Observations

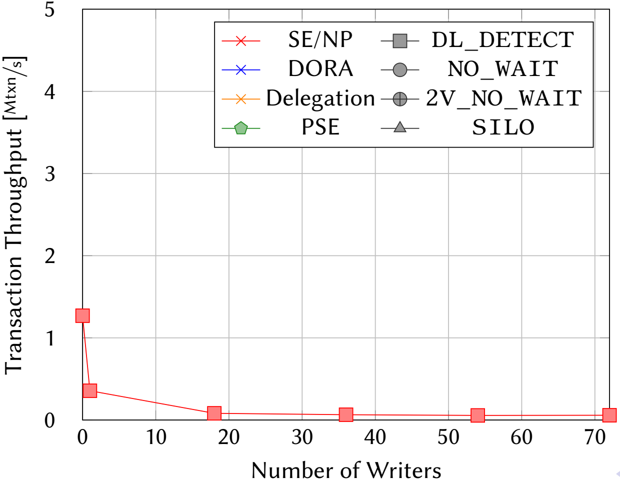
- copying records imposes an overhead to ⊕/▲
- atomics of ● scale better than latches of ■
- ▲ causes less aborts than ● due its optimism → higher [Mtxn/s]
- ⬟ does not scale well due to partition-unfriendly Zipfian access distribution

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



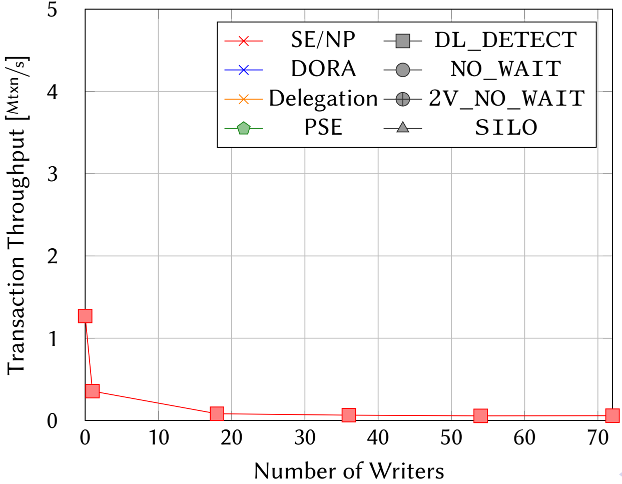
Observations

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



Observations

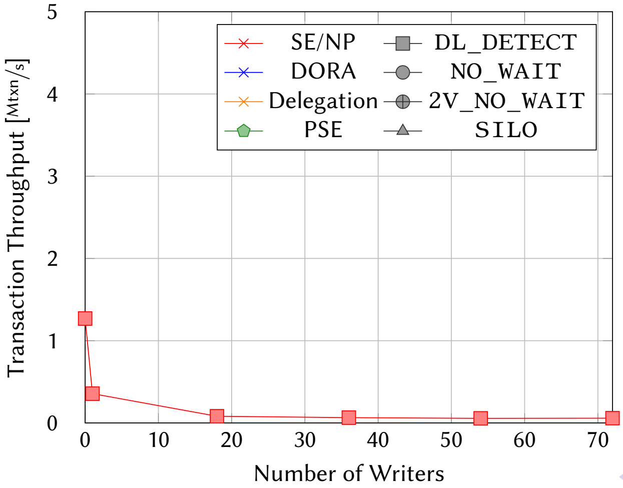
Mixed YCSB (Θ = 0.8, 72 Threads)



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

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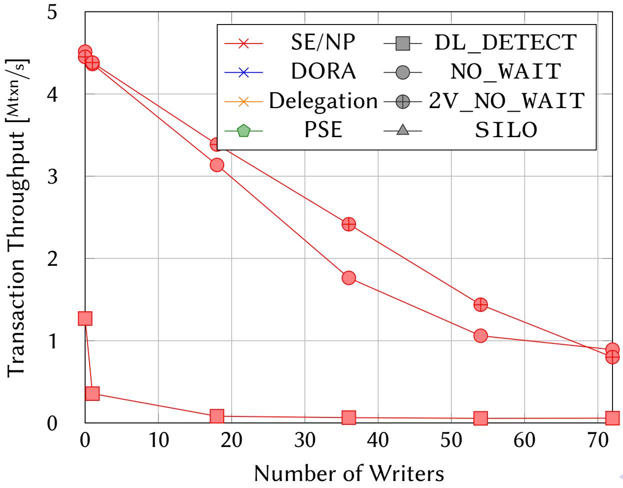

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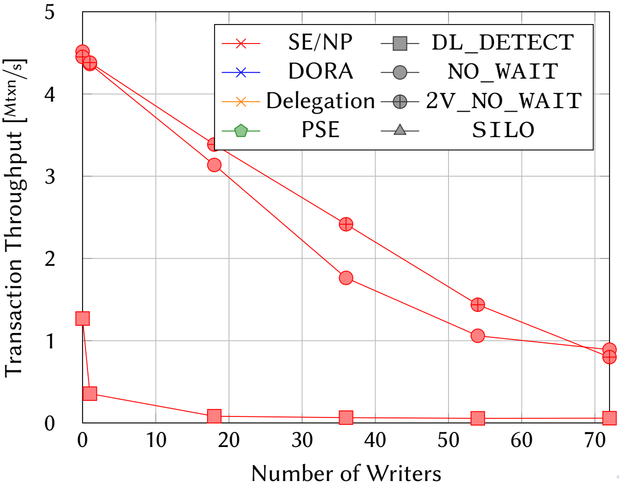

Observations

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- atomics of ● scale better than latches of ■

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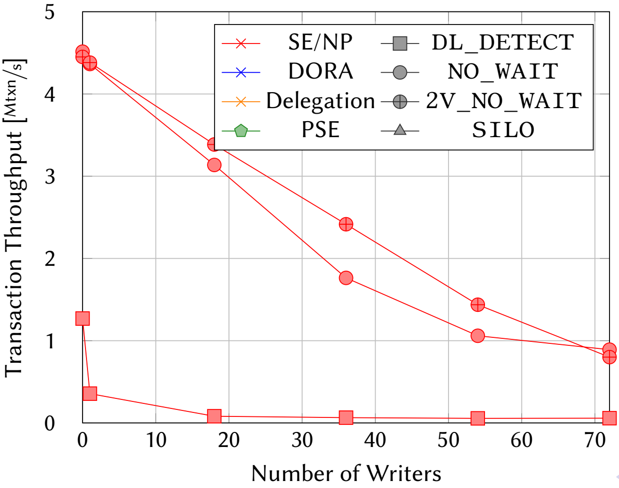

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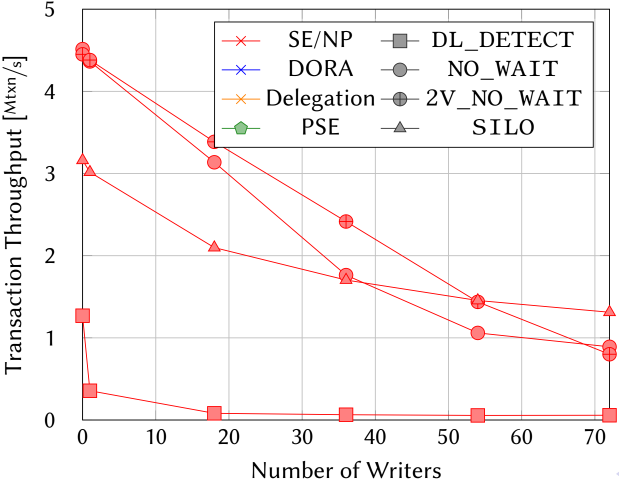

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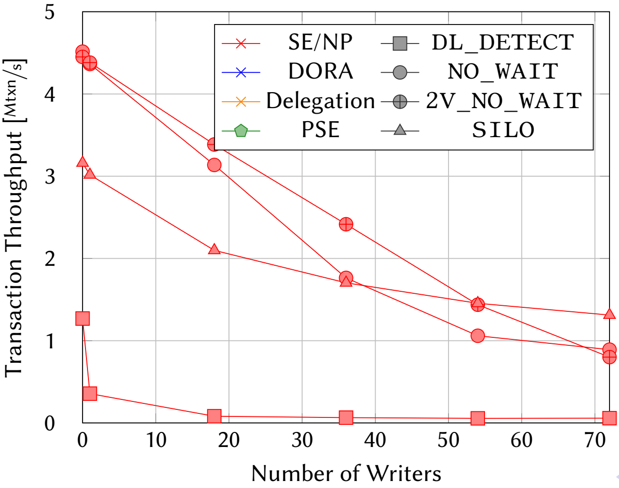
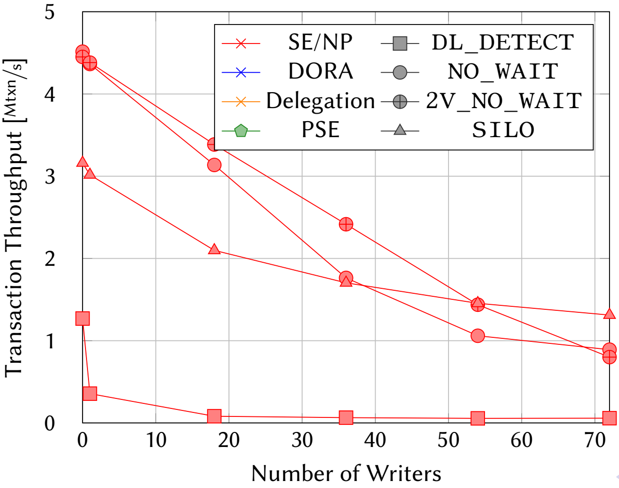


Observations

- ■ 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)



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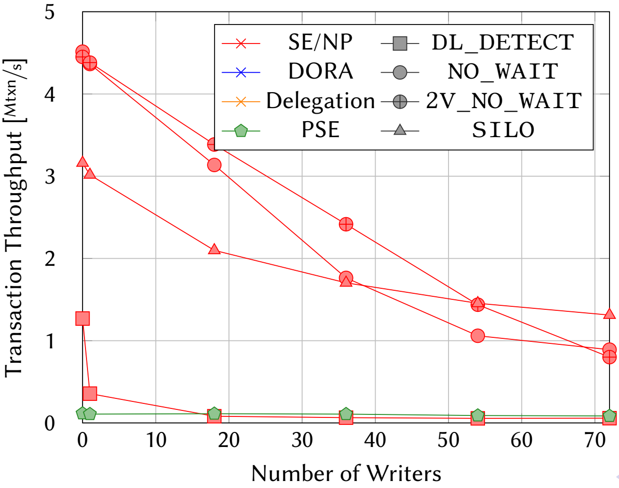
Mixed YCSB ($\Theta = 0.8$, 72 Threads)



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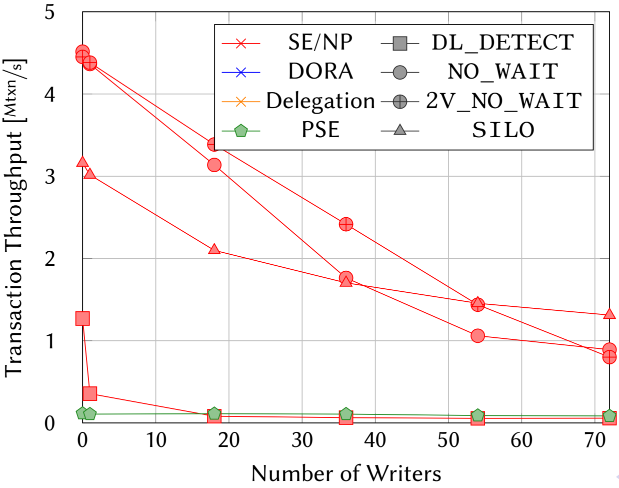

Observations

- △ 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)
  → PSE scales best for update-intensive workloads
- PSE does not scale for read-intensive high-contention workloads with small hot sets

→ None of the architectures or CC protocols outperform the others for any workload!

→ 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?