CS 764: Topics in Database Management Systems

Lecture 13: Modern OCC

Xiangyao Yu

10/19/2022

Announcement

Guest lecture next Monday (Oct. 24) in **virtual mode** (zoom only)

Project Idea Pitch

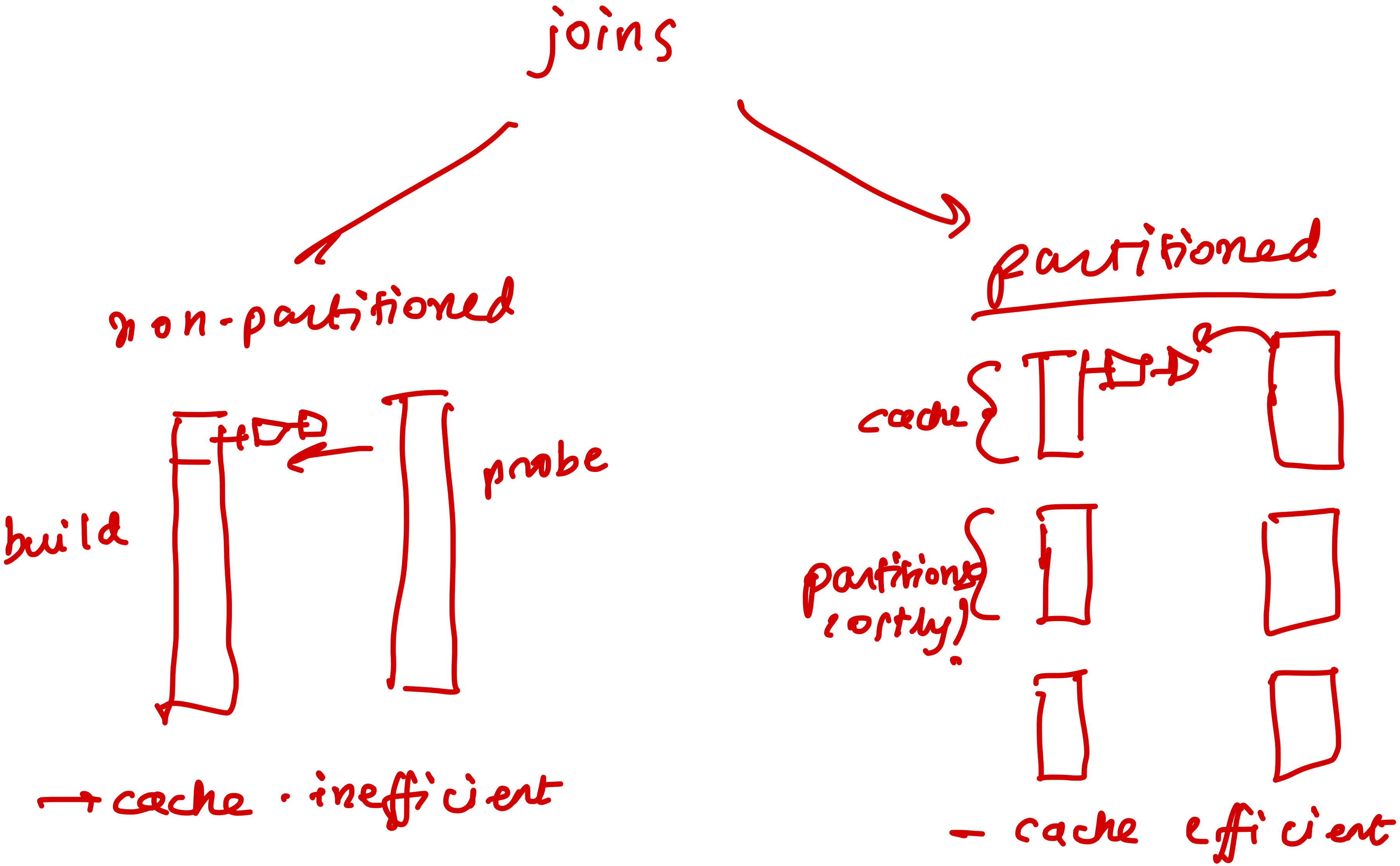
Problem Statement - Implement radix partitioned joins in a vectorized database engine.

Related work - Some key papers:

1. An Experimental Comparison of Thirteen Relational Equi-Joins in Main Memory [Schuh et al.]
2. Main-Memory Hash Joins on Multi-Core CPUs: Tuning to the Underlying Hardware [Balkesen et al.]
3. To Partition, or Not to Partition, That is the Join Question in a Real System [Bandle et al.]

Reach out to aaratik@cs.wisc.edu if interested!

Project Idea Pitch



Today's Paper: Modern OCC

Speedy Transactions in Multicore In-Memory Databases

Stephen Tu, Wenting Zheng, Eddie Kohler[†], Barbara Liskov, and Samuel Madden
MIT CSAIL and [†]Harvard University

Abstract

Silo is a new in-memory database that achieves excellent performance and scalability on modern multicore machines. Silo was designed from the ground up to use system memory and caches efficiently. For instance, it avoids all centralized contention points, including that of centralized transaction ID assignment. Silo's key contribution is a commit protocol based on optimistic concurrency control that provides serializability while avoiding *all* shared-memory writes for records that were only read. Though this might seem to complicate the enforcement of a serial order, correct logging and recovery is provided by linking periodically-updated *epochs* with the commit protocol. Silo provides the same guarantees as any serializable database without unnecessary scalability bottlenecks or much additional latency. Silo achieves almost 700,000 transactions per second on a standard TPC-C workload mix on a 32-core machine, as well as near-linear scalability. Considered per core, this is several times higher than previously reported results.

1 Introduction

Thanks to drastic increases in main memory sizes and processor core counts for server-class machines, modern high-end servers can have several terabytes of RAM and 80 or more cores. When used effectively, this is enough processing power and memory to handle data sets and computations that used to be spread across many disks and machines. However, harnassing this power is tricky; even single points of contention, like compare-and-swaps on a shared-memory word, can limit scalability.

This paper presents Silo, a new main-memory database that achieves excellent performance on multicore machines. We designed Silo from the ground up to use system memory and caches efficiently. We avoid all centralized contention points and make all synchronization scale with the data, allowing larger databases to support more concurrency.

Silo uses a Masstree-inspired tree structure for its underlying indexes. Masstree [23] is a fast concurrent B-tree-like structure optimized for multicore performance. But Masstree only supports non-serializable, single-key transactions, whereas any real database must support transactions that affect multiple keys and occur in some serial order. Our core result, the Silo commit protocol, is a minimal-contention serializable commit protocol that provides these properties.

Silo uses a variant of optimistic concurrency control (OCC) [18]. An OCC transaction tracks the records it reads and writes in thread-local storage. At commit time, after validating that no concurrent transaction's writes overlapped with its read set, the transaction installs all written records at once. If validation fails, the transaction aborts. This approach has several benefits for scalability. OCC writes to shared memory only at commit time, after the transaction's compute phase has completed; this short write period reduces contention. And thanks to the validation step, read-set records need not be locked. This matters because the memory writes required for read locks can induce contention [11].

Previous OCC implementations are not free of scaling bottlenecks, however, with a key reason being the requirement for tracking "anti-dependencies" (write-after-read conflicts). Consider a transaction t_1 that reads a record from the database, and a concurrent transaction t_2 that overwrites the value t_1 saw. A serializable system must order t_1 before t_2 even after a potential crash and recovery from persistent logs. To achieve this ordering, most systems require that t_1 communicate with t_2, such as by posting its read sets to shared memory or via a centrally-assigned, monotonically-increasing transaction ID [18, 19]. Some non-serializable systems can avoid this communication, but they suffer from anomalies like snapshot isolation's "write skew" [2].

Silo provides serializability while avoiding *all* shared-memory writes for read transactions. The commit protocol was carefully designed using memory fences to scalably produce results consistent with a serial order. This leaves the problem of correct recovery, which we solve using a form of *epoch-based group commit*. Time is divided into a series of short epochs. Even though transaction results always agree with a serial order, the system

SOSP'13, Nov. 3–6, 2013, Farmington, Pennsylvania, USA.
ACM 978-1-4503-2388-8/13/11.
http://dx.doi.org/10.1145/2517349.2522713

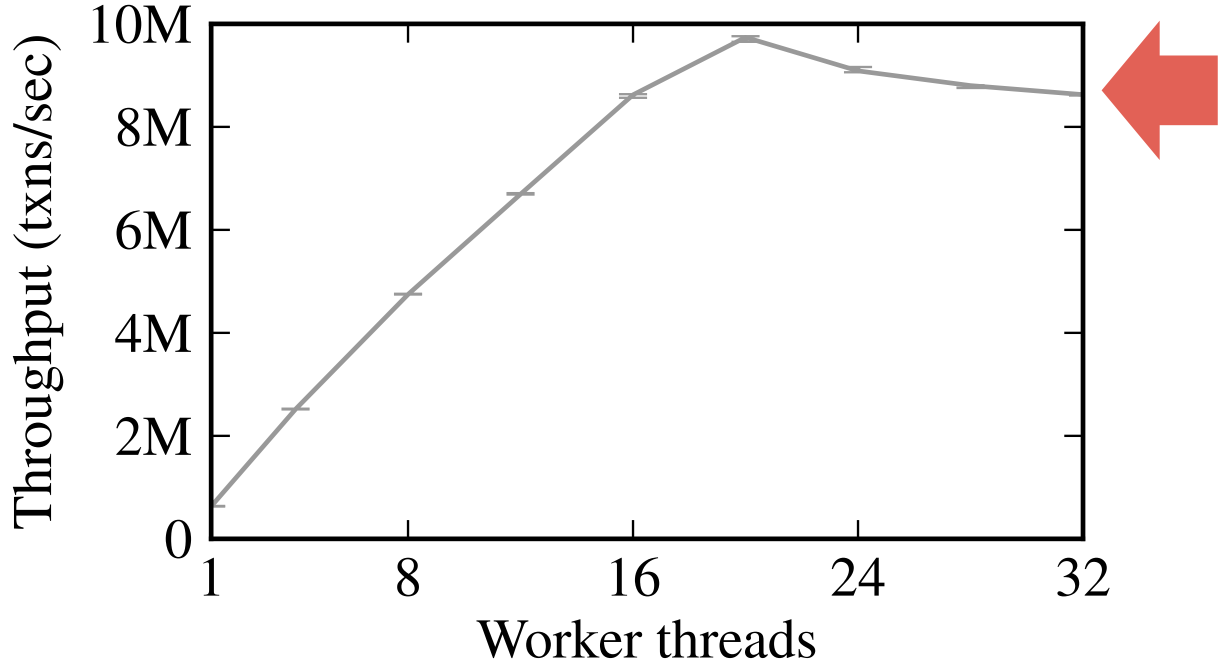
SOSP, 2013

Outline

- Multi-core scalability bottleneck
- Silo OCC protocol
  - Read phase
  - Validation phase
  - Write phase
- Discussion
  - Serializability proof sketch
  - Silo vs. OCC 1981
  - Phantom protection
- OCC vs. 2PL

Timestamp Allocation Bottleneck

`atomic_fetch_and_add(&lsn, size);`



Even a single atomic instruction can become a scalability bottleneck

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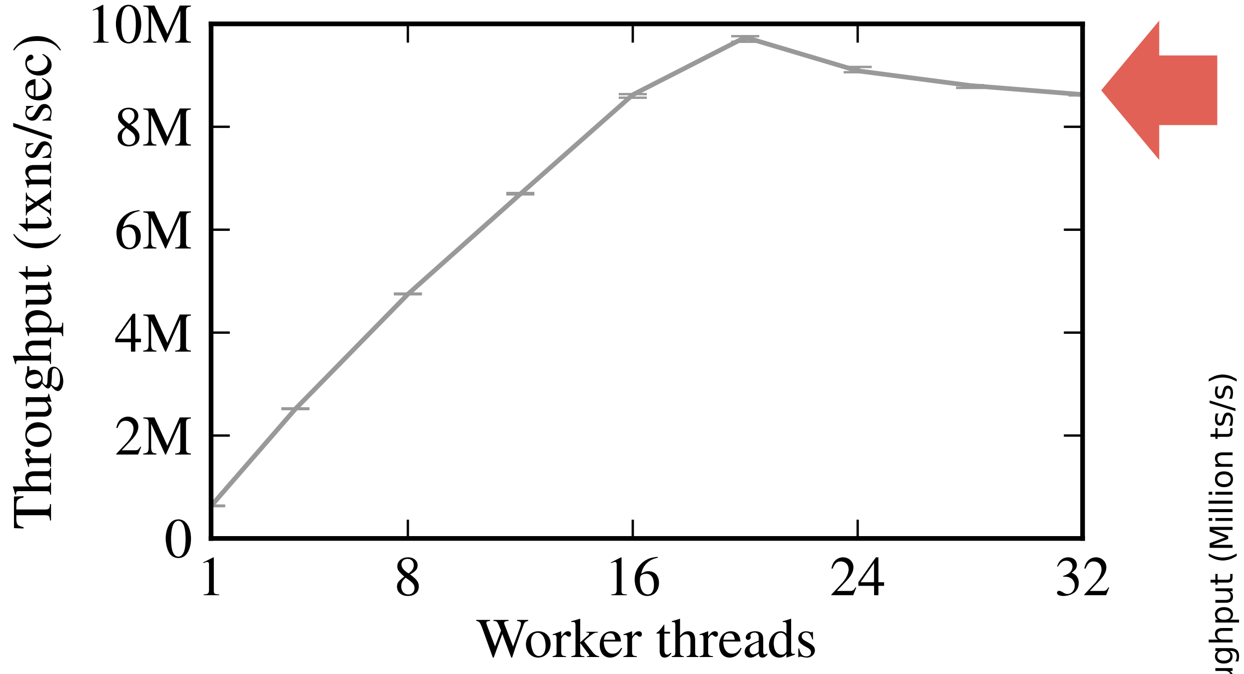

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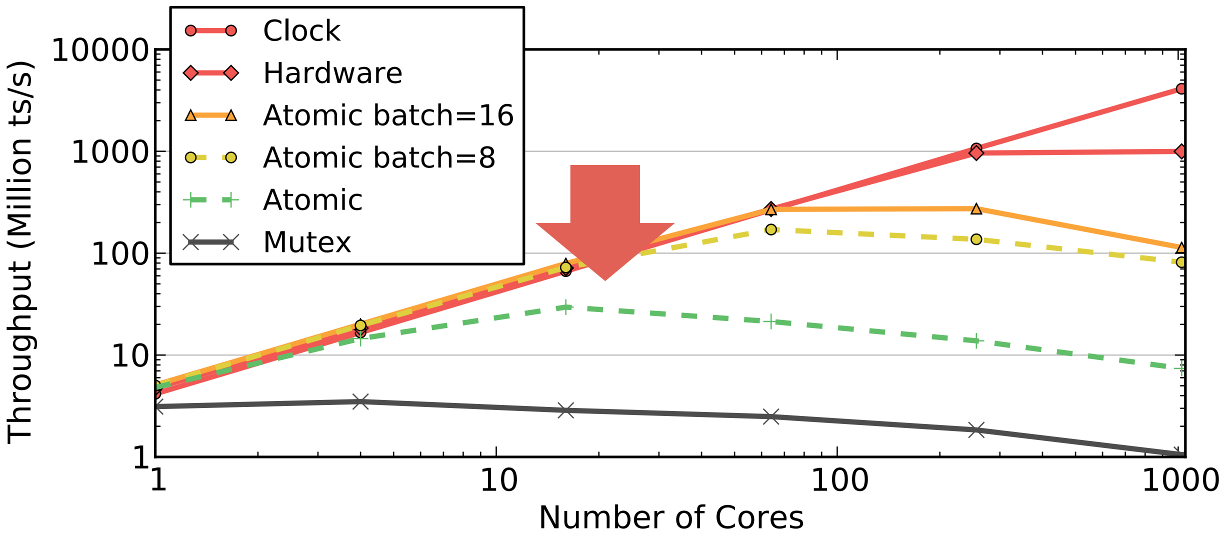
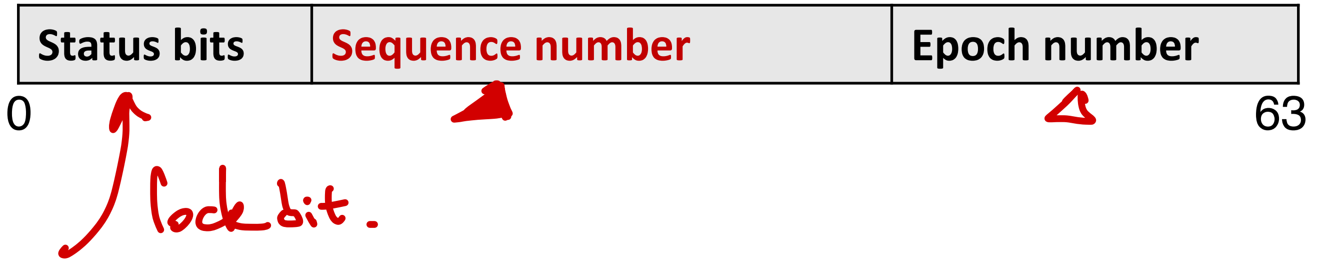


X. Yu et al. *Staring into the Abyss: An Evaluation of Concurrency Control with One Thousand Cores*, VLDB 2014

Silo Read Phase

Each tuple contains a 64-bit TID word



Silo Read Phase

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Status bits	Sequence number	Epoch number

0 … 63

Each read returns consistent **value** and **TID word**

- Method 1: Guard the read with a latch (i.e., a short lock)
- Method 2: Optimistic lock (Silo's approach)

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// read a record
do
    v1 = t.read_TID_word()
    RS[t.key].data = t.data
    v2 = t.read_TID_word()
while (v1 != v2 or v1.lock_bit == 1);
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```

```
// write a record
v1.lock_bit = 1
v1.update()
v1.update_seq_number()
v1.lock_bit = 0
```

Silo Validation Phase

Data: read set R, write set W, node set N,
global epoch number E

// Phase 1
for *record, new-value* **in** sorted(W) **do**
  lock(*record*);
compiler-fence();
$e \leftarrow E$; *// serialization point*
compiler-fence();

// Phase 2
for *record, read-tid* **in** R **do**
  if *record.tid* $\neq$ *read-tid* **or not** *record.latest*
    or (*record.locked* **and** *record* $\notin W$)
  then abort();
for *node, version* **in** N **do**
  if *node.version* $\neq$ *version* **then** abort();
commit-tid $\leftarrow$ generate-tid(R, W, e);

// Phase 3
for *record, new-value* **in** W **do**
  write(*record, new-value, commit-tid*);
  unlock(*record*);

Phase 1: Lock the write set

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Phase 1: Lock the write set

Q: Why need to sort write set?

Silo Validation Phase

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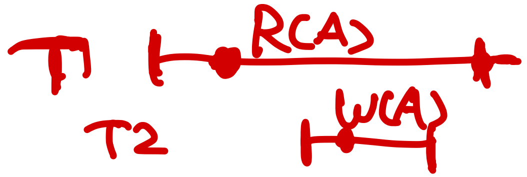
Phase 1: Lock the write set

Phase 2: Validate the read set

- Validation fails if (1) the tuple is modified since the earlier read or (2) the tuple is locked by another transaction

Silo Validation Phase

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Phase 1: Lock the write set

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- Validation fails if (1) the tuple is modified since the earlier read or (2) the tuple is locked by another transaction

Q: If a tuple is modified since a transaction's earlier read, can the transaction still be serializable?

Silo Validation Phase

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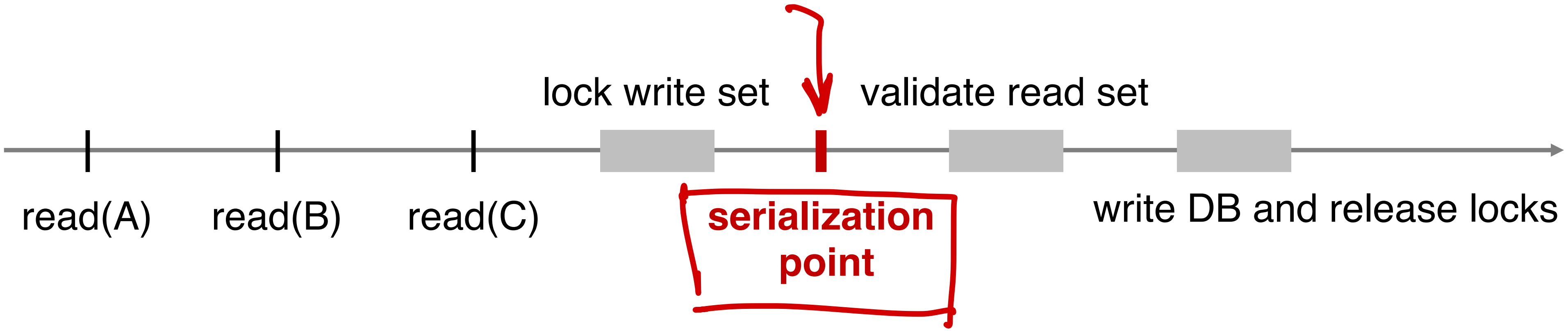
Phase 1: Lock the write set

Phase 2: Validate the read set

Phase 3: Write phase

Silo OCC is Serializable



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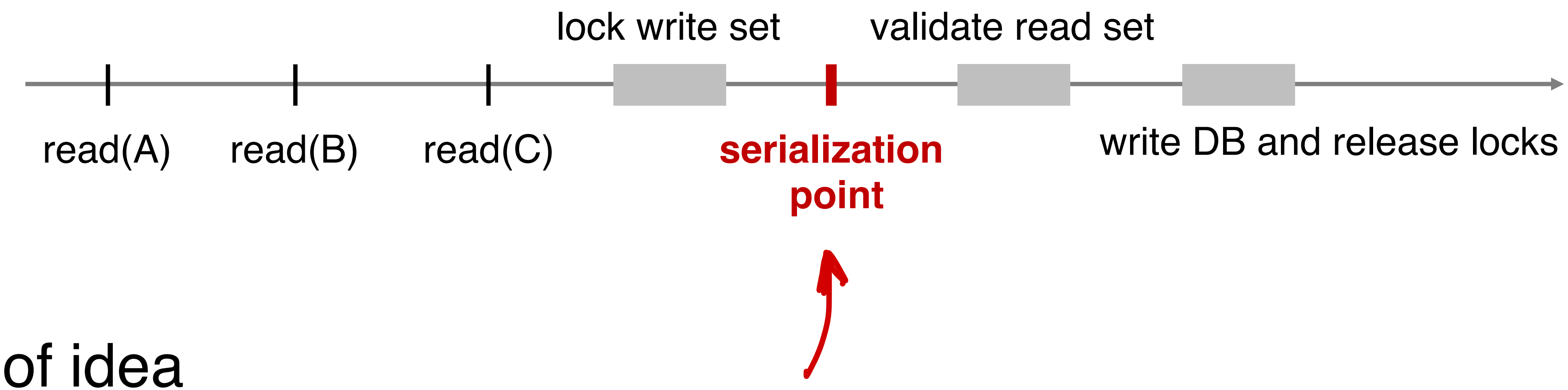

Proof idea

- The Silo schedule is equivalent to an idealized schedule where all reads and writes of a transaction occur at the serialization point
- (Same strategy can be used to prove that 2PL is serializable)

Silo vs. OCC 1981

Silo

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OCC 1981

```
tend = (
  ⟨finish tn := tnc;
   valid := true;
   for t from start tn + 1 to finish tn do
       if (write set of transaction with transaction number t intersects read set)
         then valid := false;
   if valid
       then ((write phase); tnc := tnc + 1; tn := tnc)⟩;
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- Silo locks tuples in write set; OCC'81 uses global critical sections
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Q: When is OCC 1981's validation better than Silo's validation?

Phantom Protection in 2PL

Gap locks

- A gap lock is a lock on a gap between index records, or a lock on the gap before the first or after the last index record (MySQL reference manual)

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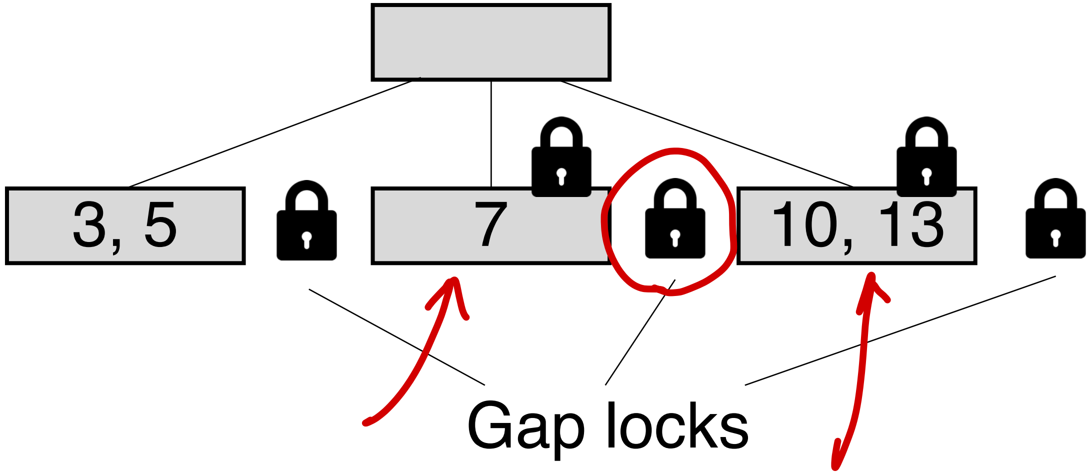

Phantom Protection in 2PL

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- Next key lock = index node lock + gap lock before the record

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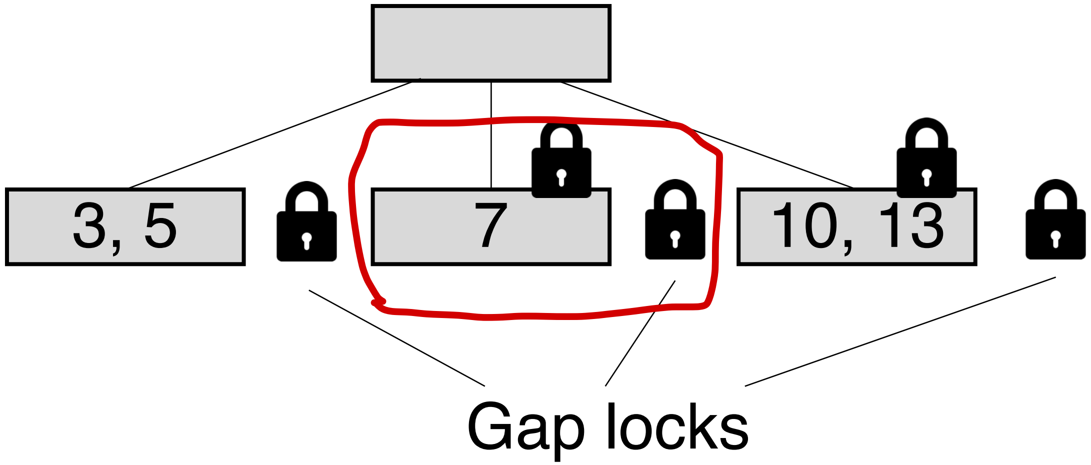

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Validate the versions of accessed index nodes

- May need to consider the *next* nodes as well

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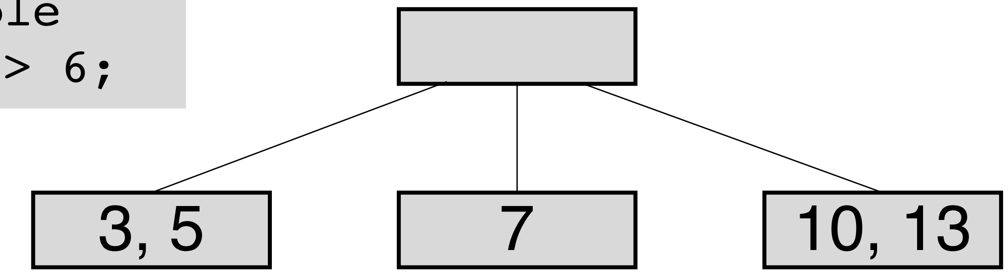

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Discussions

Epochs in Silo: A mechanism to enable parallel logging

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Granularity of locking: Support coarse-grained “locks” in Silo?

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Epochs in Silo: A mechanism to enable parallel logging

Granularity of locking: Support coarse-grained “locks” in Silo?

Priority and **preemption** of transactions?

Discussions

Epochs in Silo: A mechanism to enable parallel logging

Granularity of locking: Support coarse-grained “locks” in Silo?

Priority and **preemption** of transactions?

Opacity: Strict serializability for both committed and aborted transactions

- Achieve opacity in 2PL vs. OCC?

Polaris

Goal: add priority mechanism to Silo

Key idea: add minimum pessimism into the protocol

- Transactions with higher priority can block transactions with lower priority
- Transactions within the same priority level run Silo

Chenhao Ye, Wuh-Chwen Hwang, Keren Chen, Xiangyao Yu, *Polaris: Enabling Transaction Priority in Optimistic Concurrency Control*, **SIGMOD** 2023

Polaris

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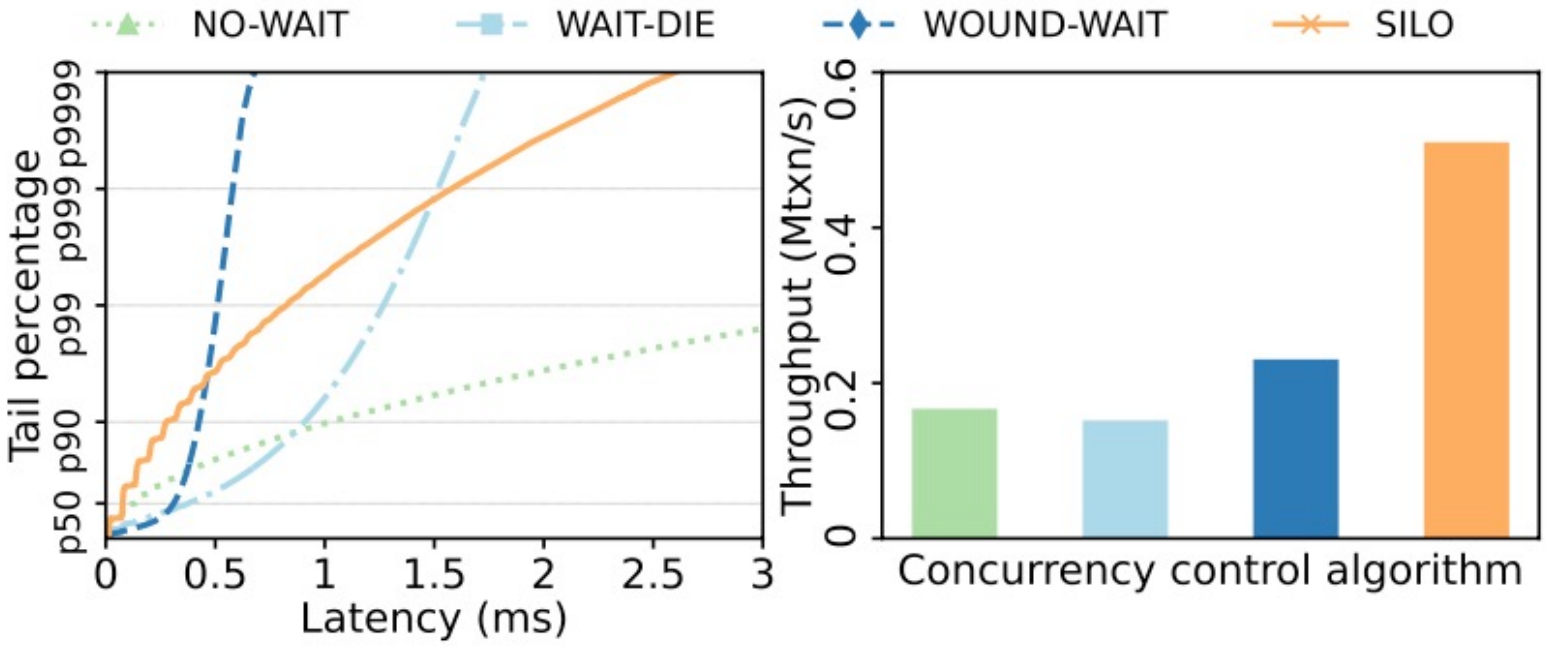
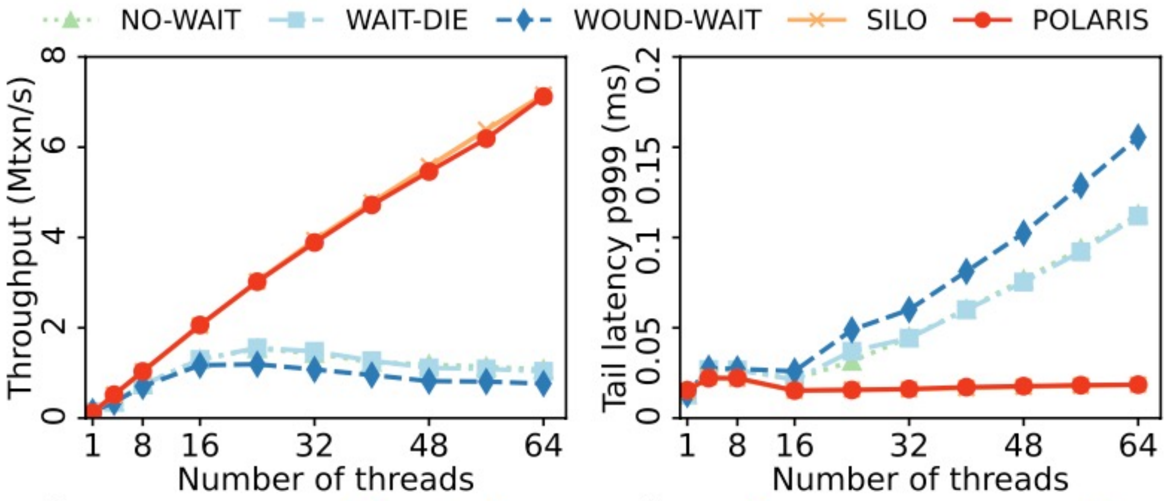


Polaris

Read only workload



Both Silo and Polaris achieve high throughput and low tail latency

Polaris

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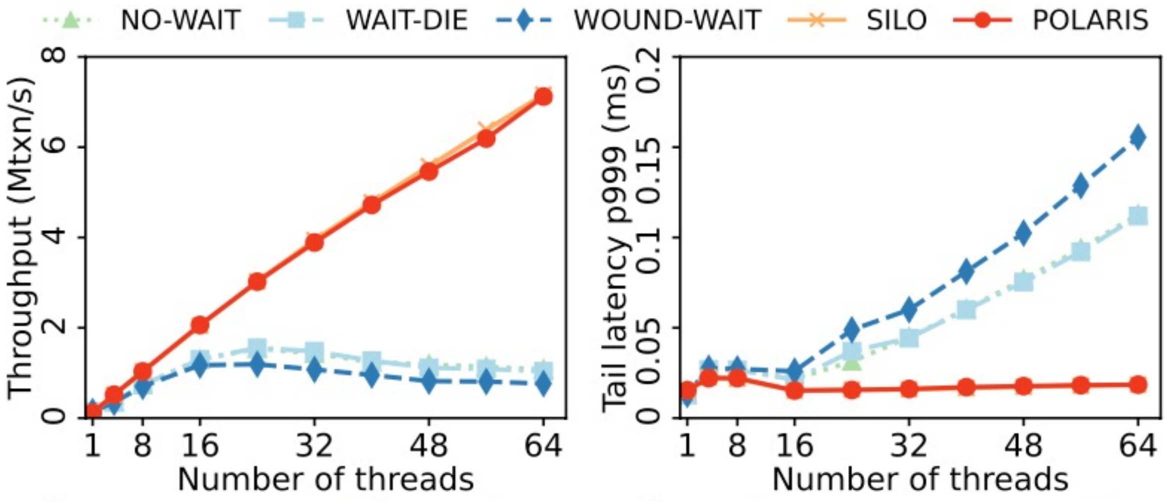

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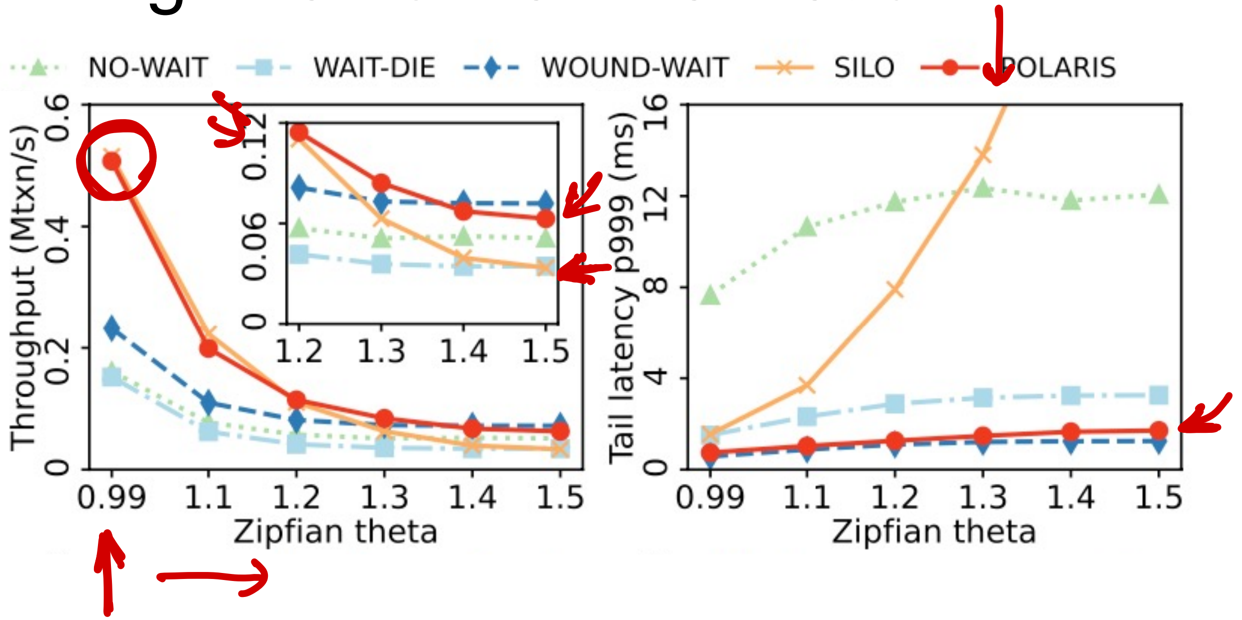
High-contention workload



Silo has decreased throughput and very high tail latency

- Some transactions experience repeated aborts

Polaris' performance approaches 2PL at high contention

Q/A – Modern OCC

Silo applicable only to in-memory database?

How to achieve durability for in-memory database?

Extend Silo to a partitioned distributed system?

Modern systems using this concurrency control mechanism?

Support interactive query besides on-shot?

Global epoch number becomes a contention point?

Next Lecture

Guest lecture next Monday (Oct. 24) in **virtual mode** (zoom only)

Submit a review for the guest lecture

- Deadline: **Oct. 28 (Friday), 11:59pm**
- Use the same format as a paper review

Submit review before next Wednesday

- Philip Lehman, S. Bing Yao, Efficient Locking for Concurrent Operations on B-Trees. ACM Transactions on Database Systems, 1981