Sonata: Multi-Database Transactions Made Fast and Serializable

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[2] New York University

Transaction Abstraction

- **Transactions are an important programming abstraction.**
  - Ensures correctness in the presence of concurrent operation and failures.

Large-Scale Applications

ebay Booking.com amazon HSBC CHASE

Safeguarding Critical Business Logic

Transactional Databases

PolarDB Google Cloud Spanner Amazon Aurora PostgreSQL Microsoft SQL Server

Transaction Processing

Transaction Logic

Checking $50

Savings $50

T1: withdraw(Checking, $100)

```
Begin Transaction
total := s_bal + c_bal
if total >= 100:
  c_bal -= 100
Commit Transaction
```

T2: withdraw(Savings, $100)

```
Begin Transaction
total := c_bal + s_bal
if total >= 100:
  s_bal -= 100
Commit Transaction
```

Transaction Processing

Transaction Logic → **Submit** → **Transactional Database**

Checking: $50 Savings: $50

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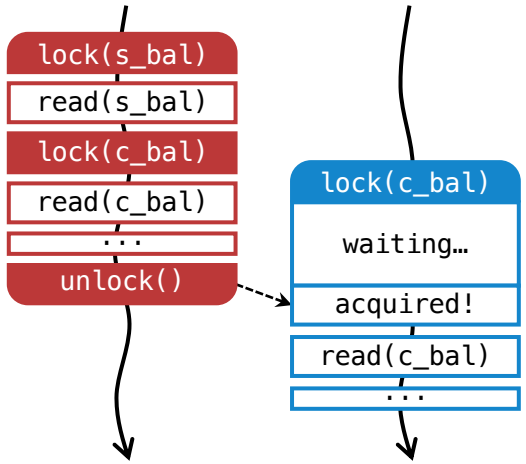
Concurrent Execution

(e.g., via two-phase locking)



Transaction Processing

Transaction Logic → Submit → **Transactional Database** → Return → **Correct Result**

Checking	Savings
$50	$50

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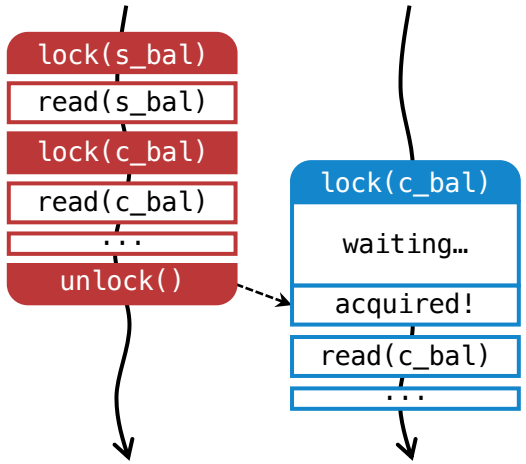
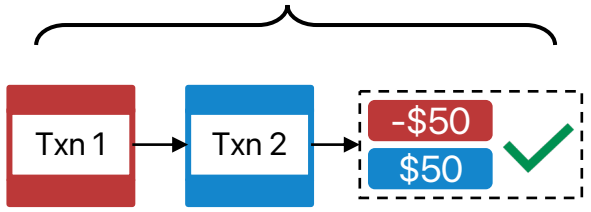


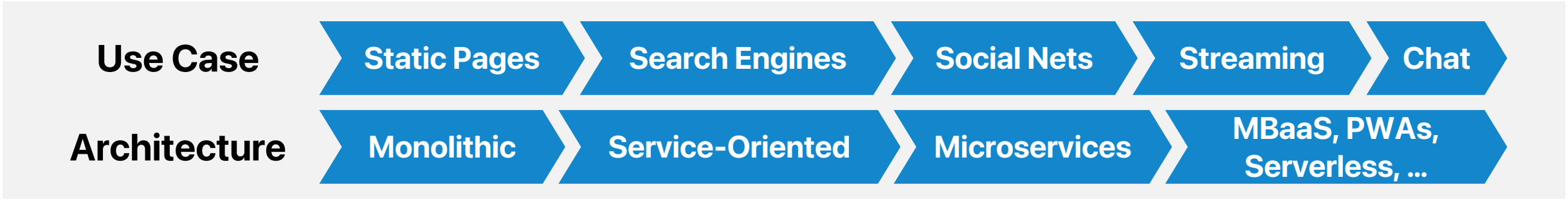
ACID Properties



Isolation: Serializable Execution

Atomicity Consistency Durability

Today: Evolving Applications



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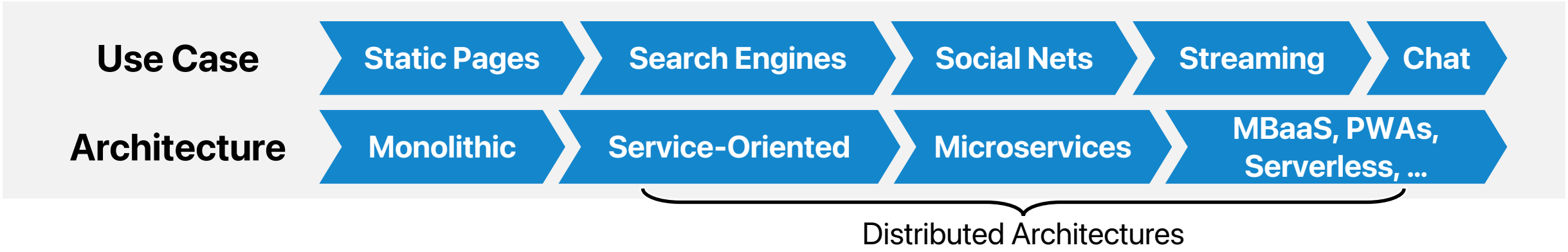
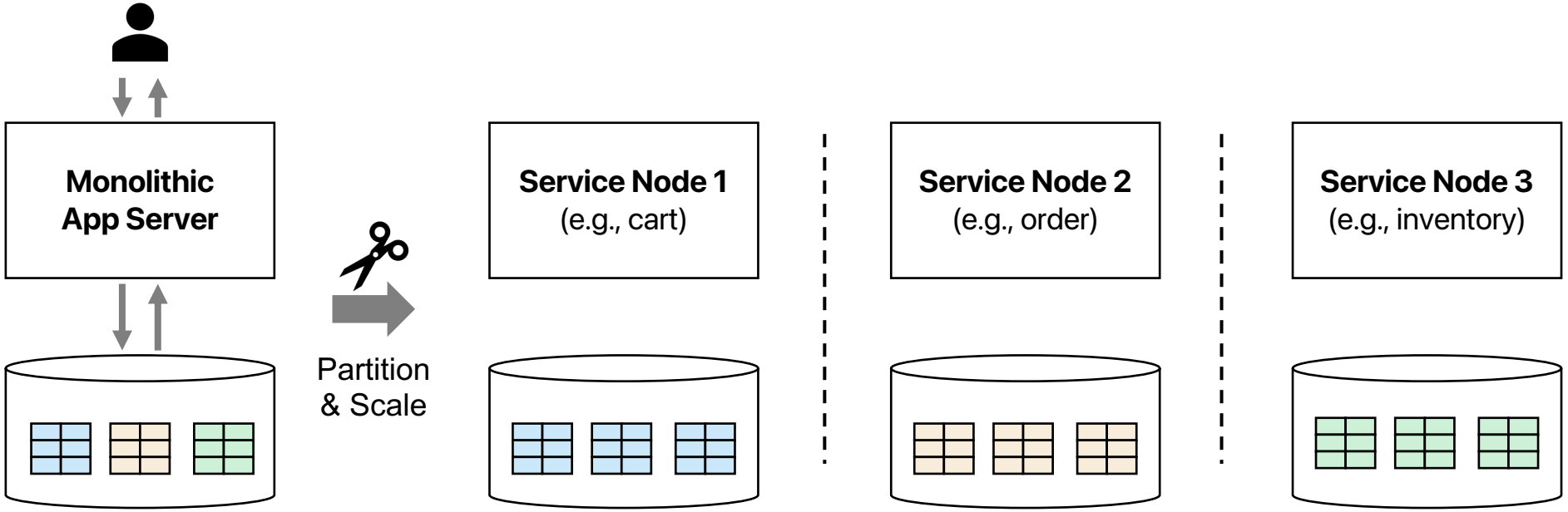


Today: Evolving Applications

Use Case	Static Pages	Search Engines	Social Nets	Streaming	Chat
Architecture	Monolithic	Service-Oriented	Microservices	MBaaS, PWAs, Serverless, …	

Distributed Architectures



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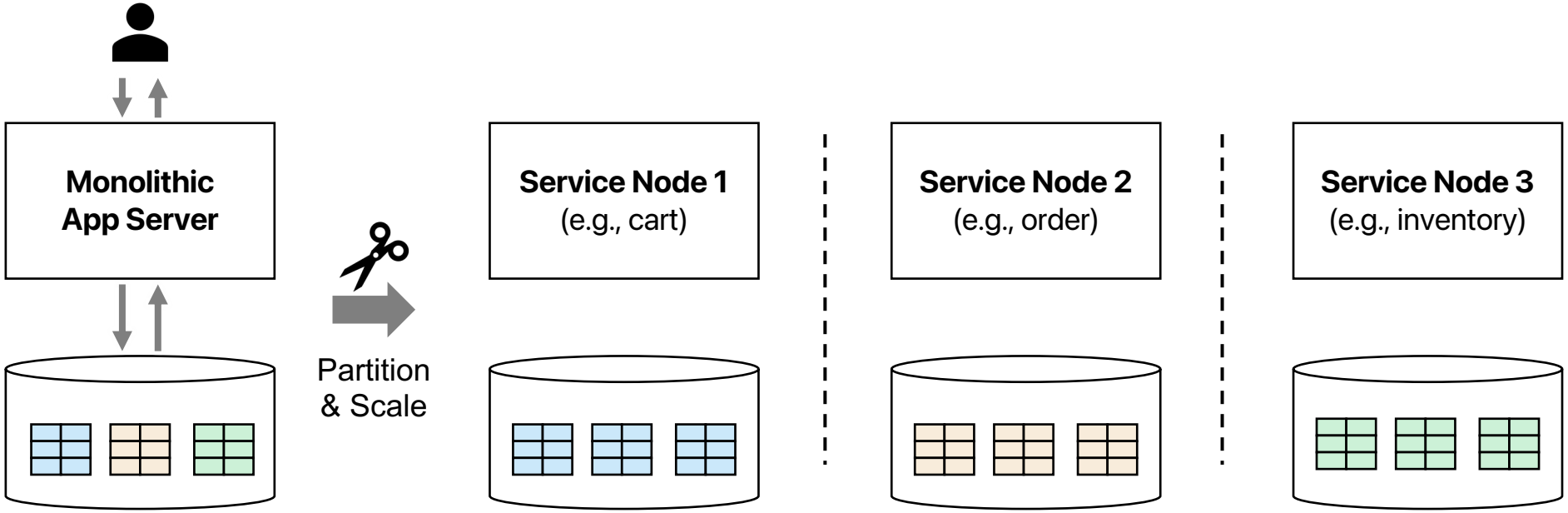
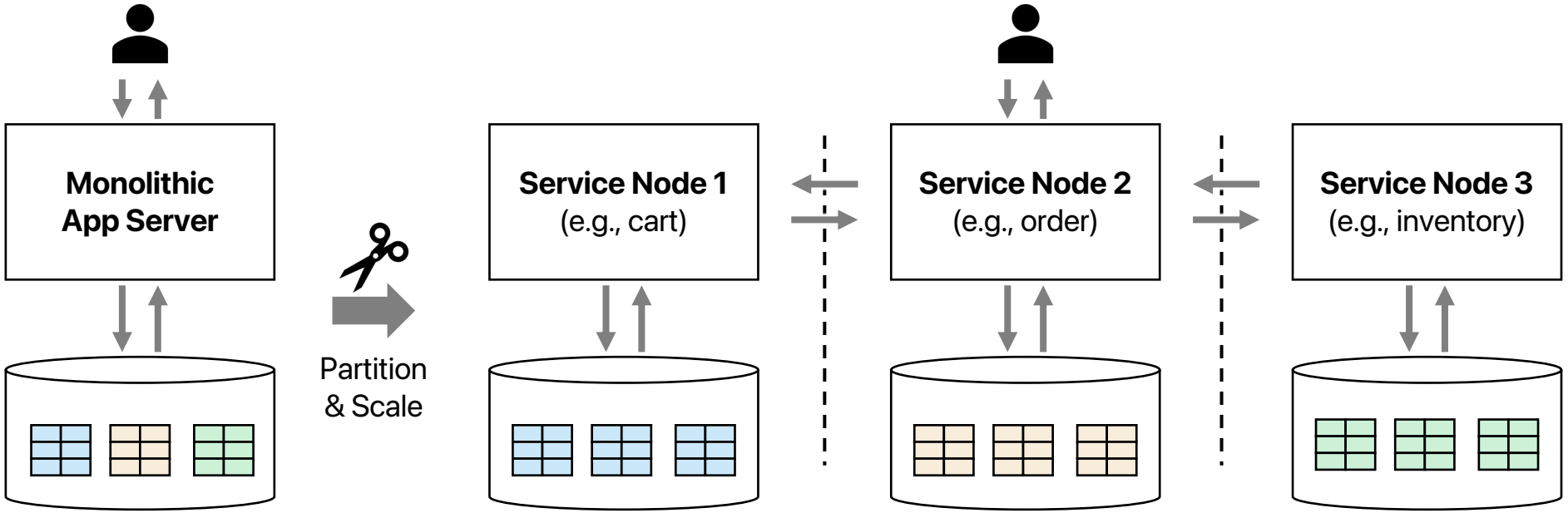


Better scalability in applications' development, deployment, and maintenance

Today: Multi-Database Transactions



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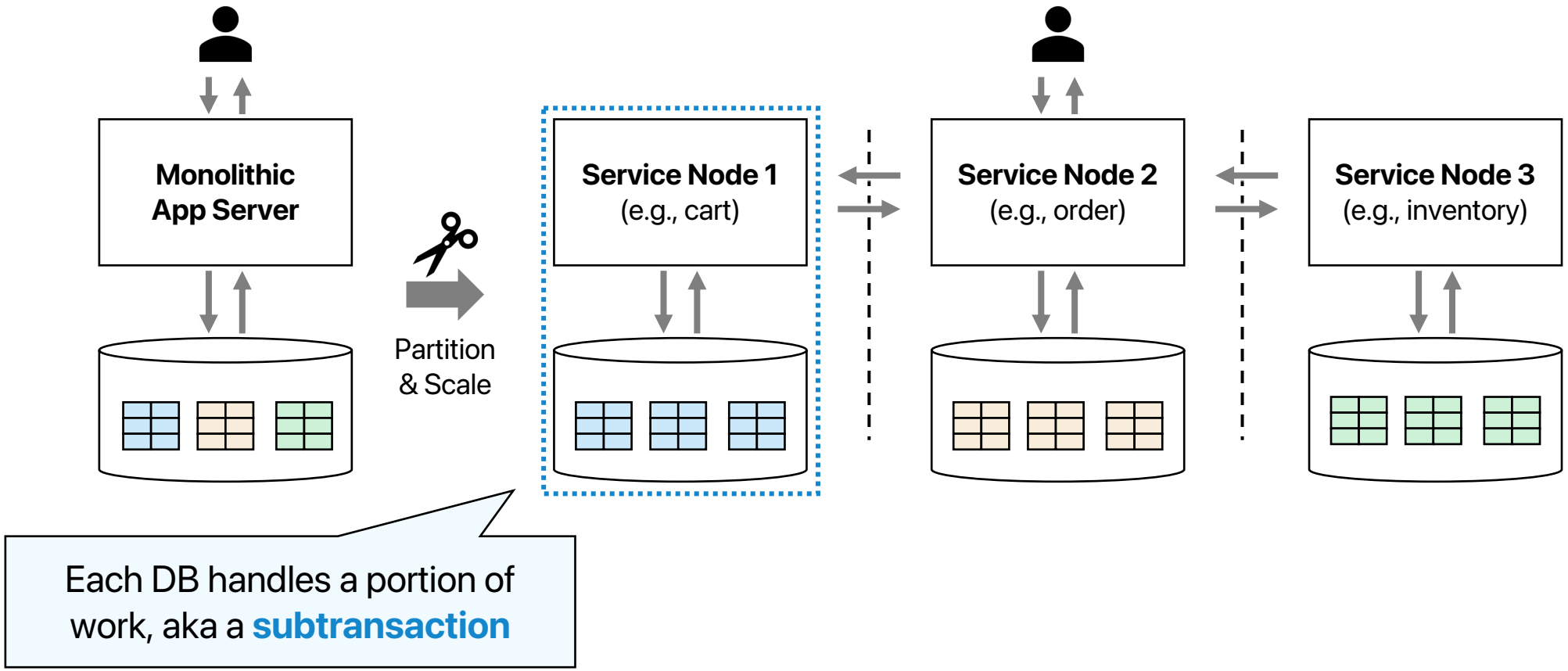

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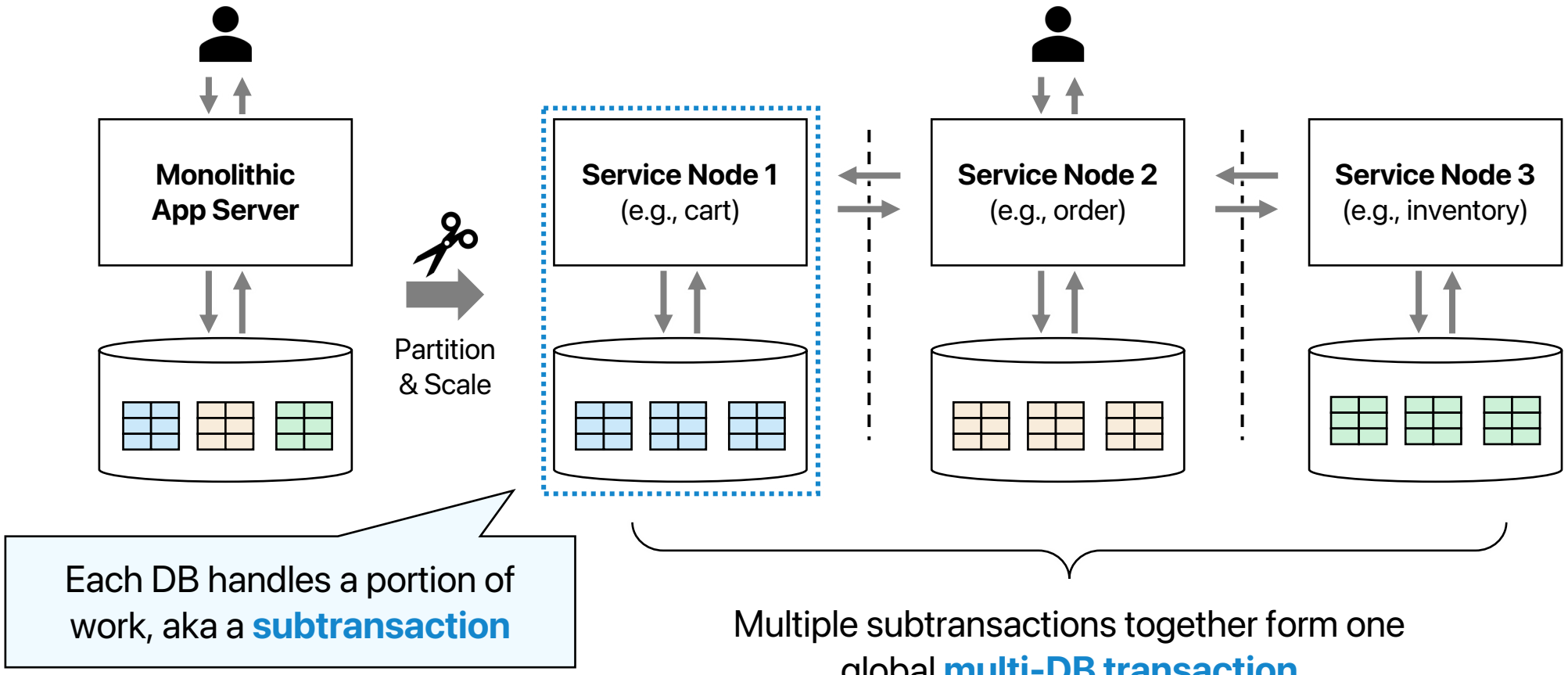

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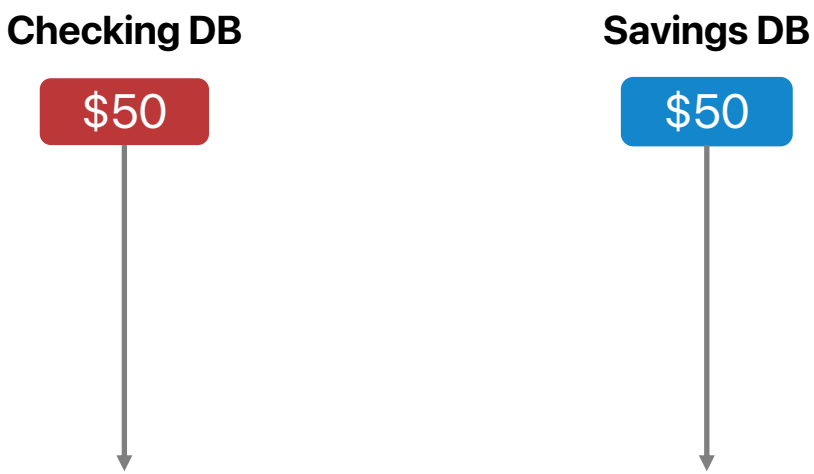

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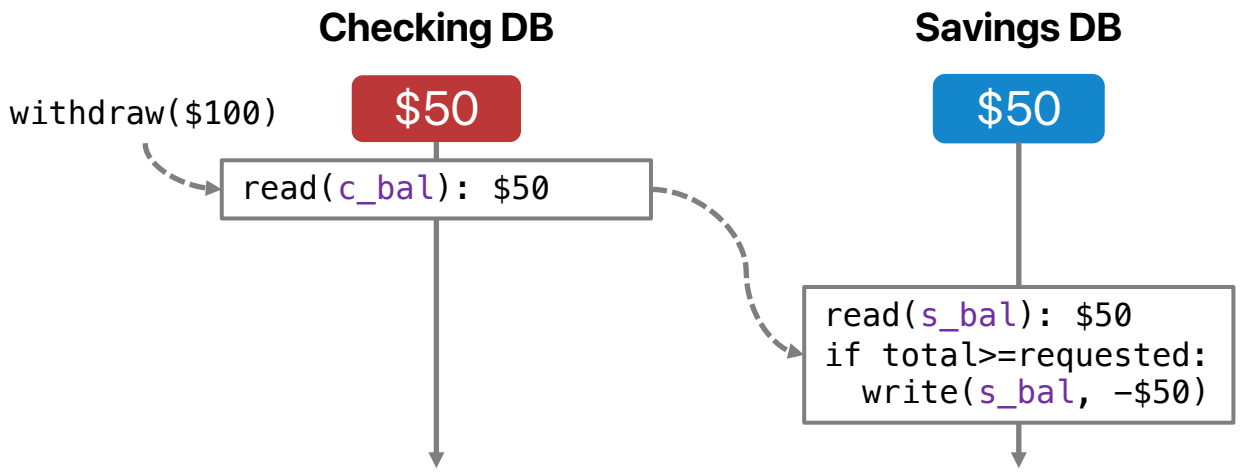

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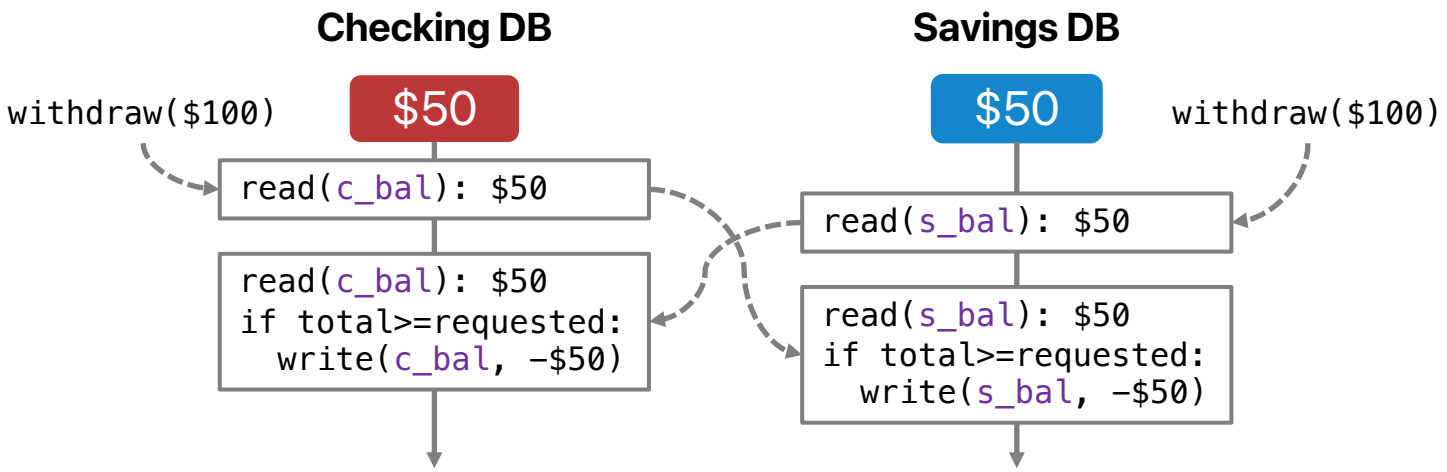

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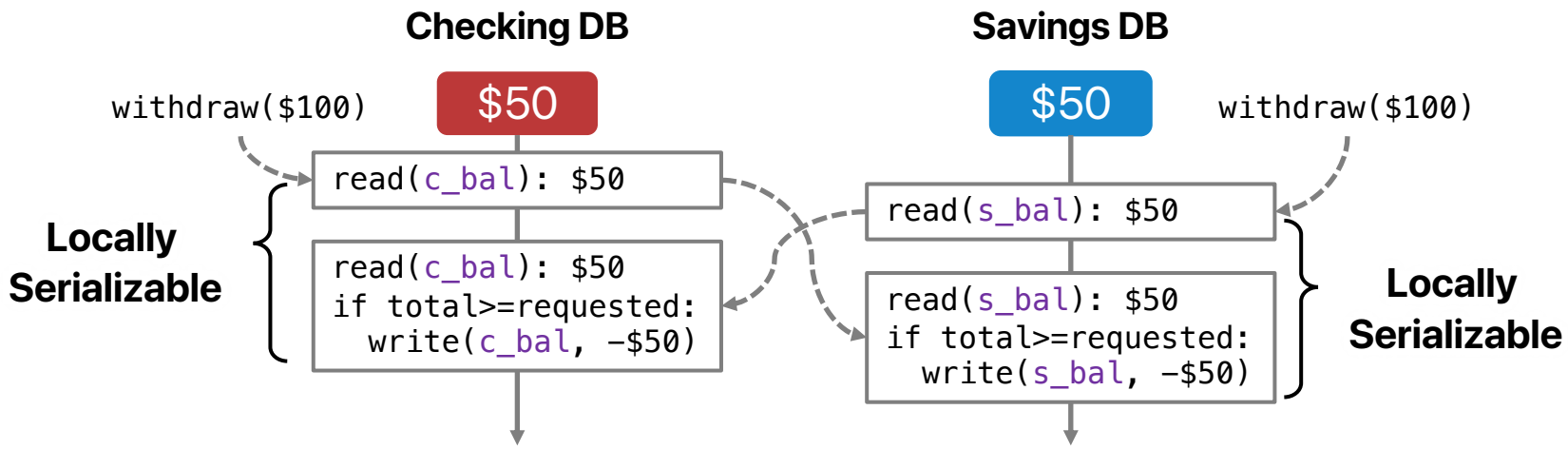

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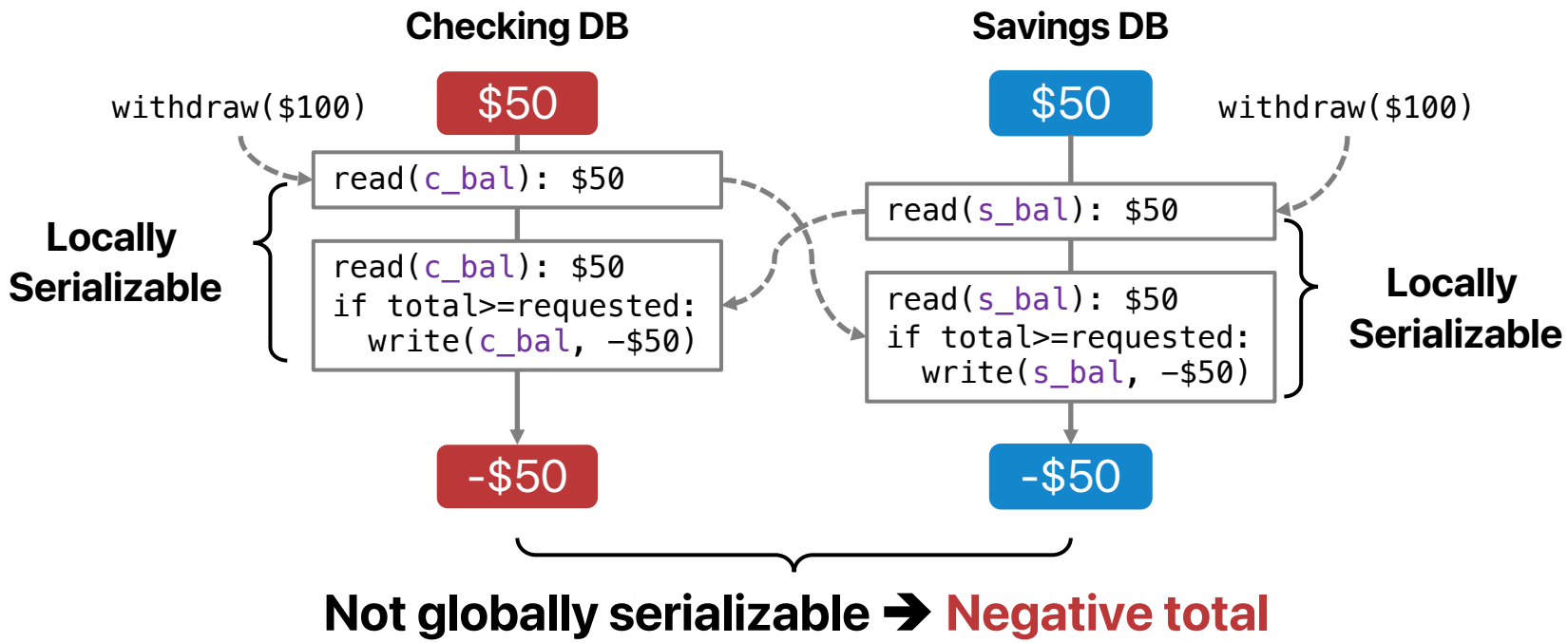
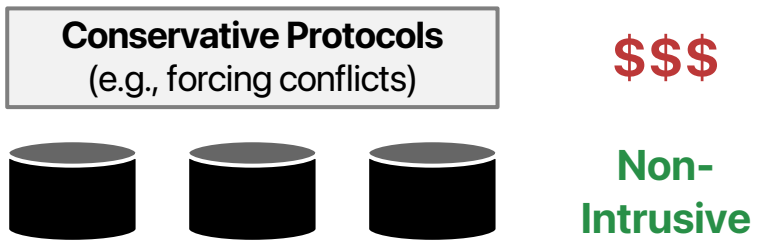


State-of-the-Art Approaches

Earlier Work [ICDE '91]*

Local DBs as serializable black boxes

- Force conflicts between subtransactions.
- **Large overhead** due to limited parallelism (>20-fold degradation)



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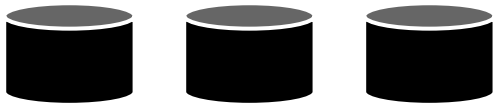
Conservative Protocols
(e.g., forcing conflicts)



$$$

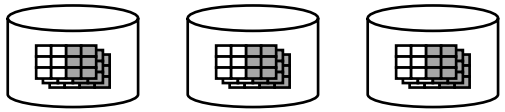
Non-Intrusive

Recent Work [VLDB '23]**

Local DBs as non-transactional stores

- Full concurrency control in middleware.
- **Still large overhead** as DB transaction mechanisms are exercised still.
- **Intrusive changes** to for additional CC metadata.

Fully App-Level Protocols
(e.g., app-level OCC)



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Intrusive Metadata

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** Yamada et al. 2023. ScalarDB: Universal Transaction Manager for Polystores. VLDB '23.

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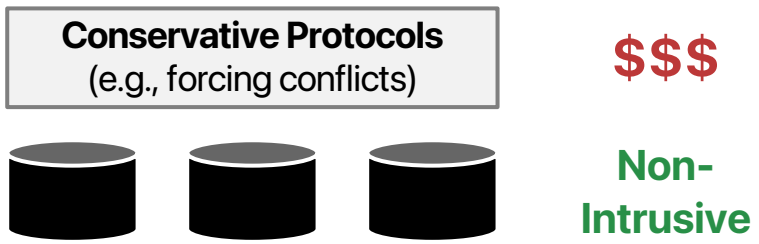

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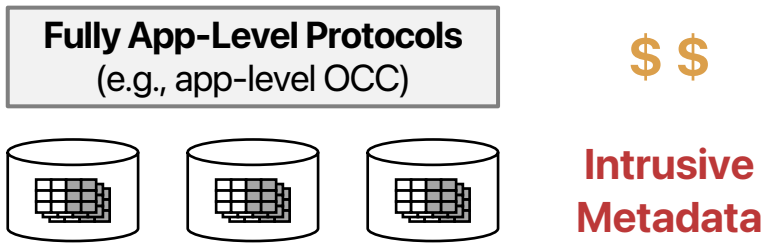

Can we achieve high performance without intrusive changes?

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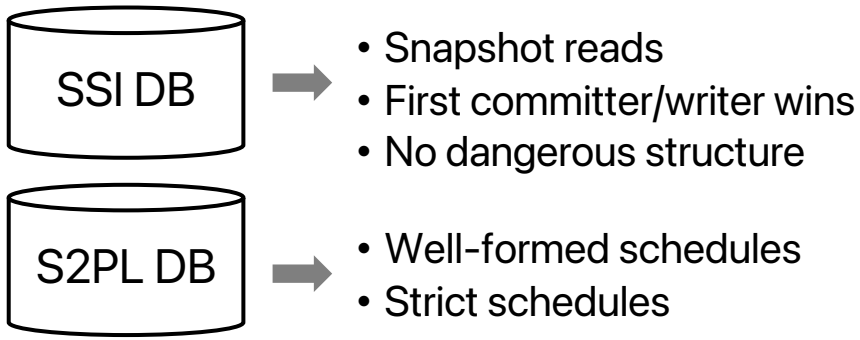
Our Gray-Box Approach

- **Observation: Dominant CC families in mainstream DBs, SSI & S2PL, offer useful common properties.**



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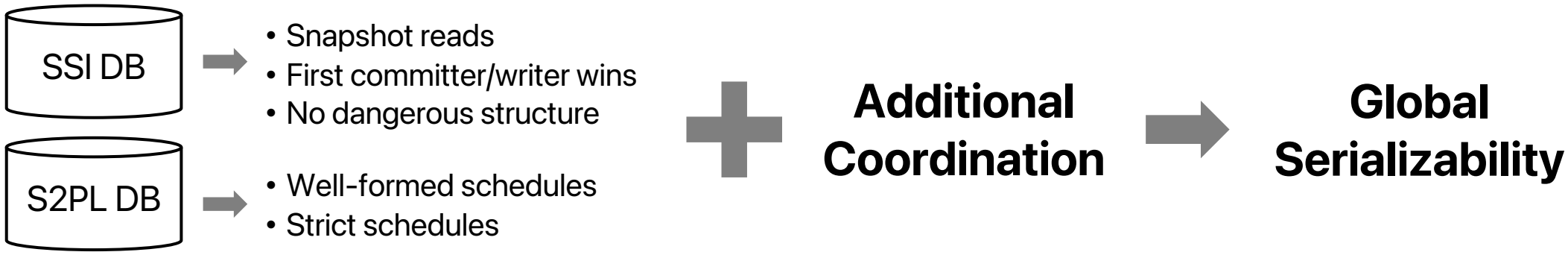
- **Basic Idea: Reuse such properties & add necessary coordination.**



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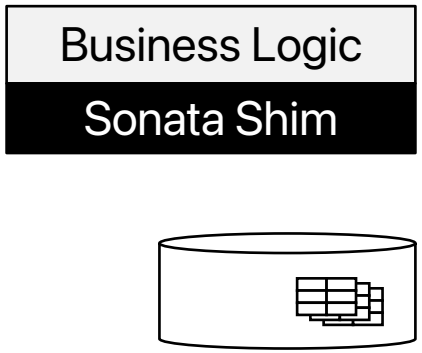
The theory of commitment ordering (CO) [VLDB '92] enables a locally enforceable condition, allowing lightweight coordination.

*Yoav Raz. 1992. The Principle of Commitment Ordering, or Guaranteeing Serializability in a Heterogeneous Environment of Multiple Autonomous Resource Mangers Using Atomic Commitment. VLDB '92.

Sonata Overview

- **Sonata works as application-level shims.**



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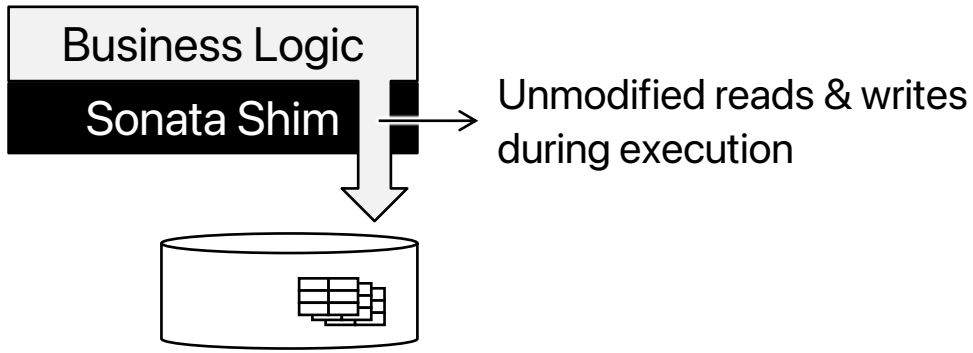

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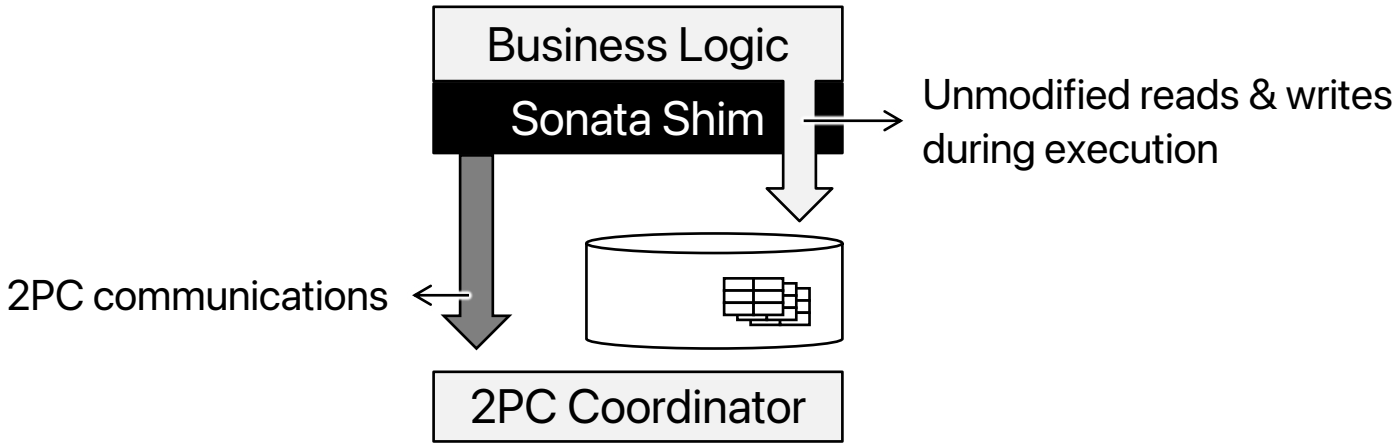

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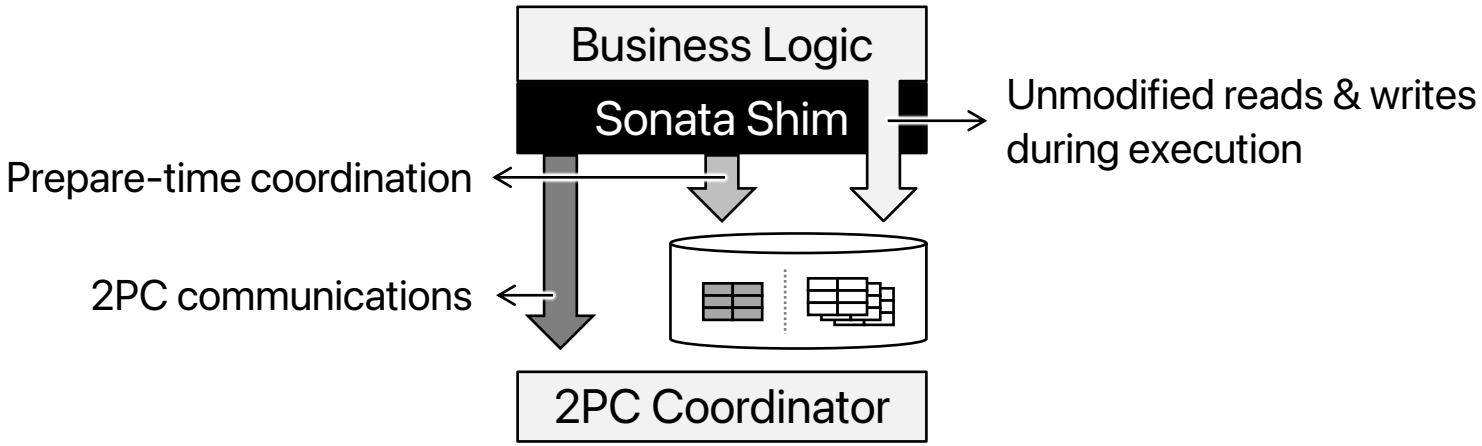

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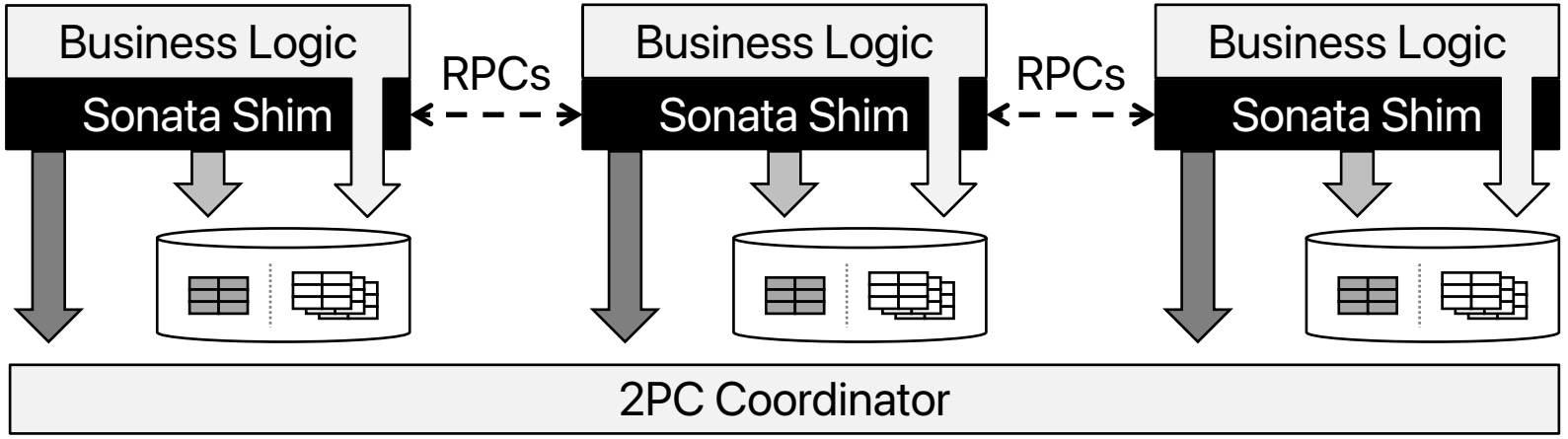
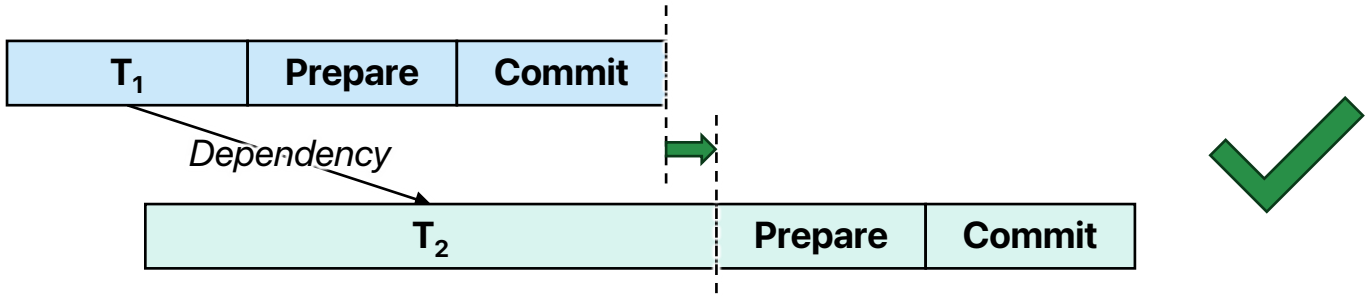


(Also works with single-server, multi-DB cases)

Global Serializability via Local Enforcement

- **The local condition** (derived from the CO theory):
  In a DB, if $T_1 \rightarrow T_2$, then T_1 commits before T_2 prepares.



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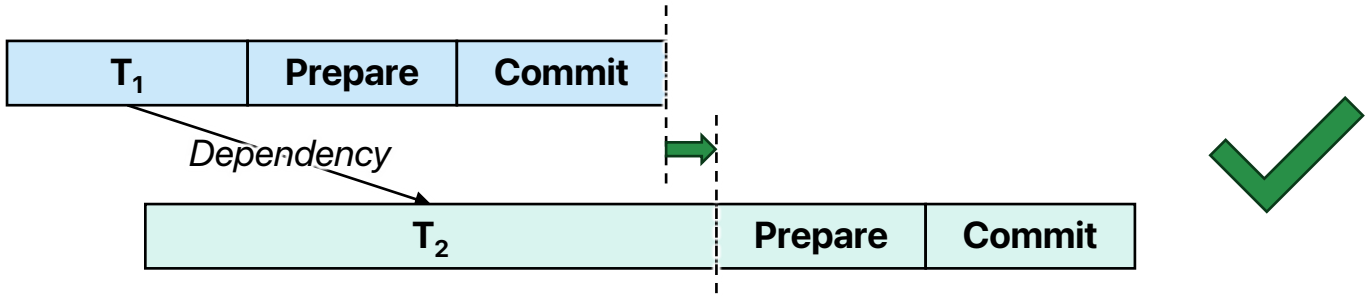

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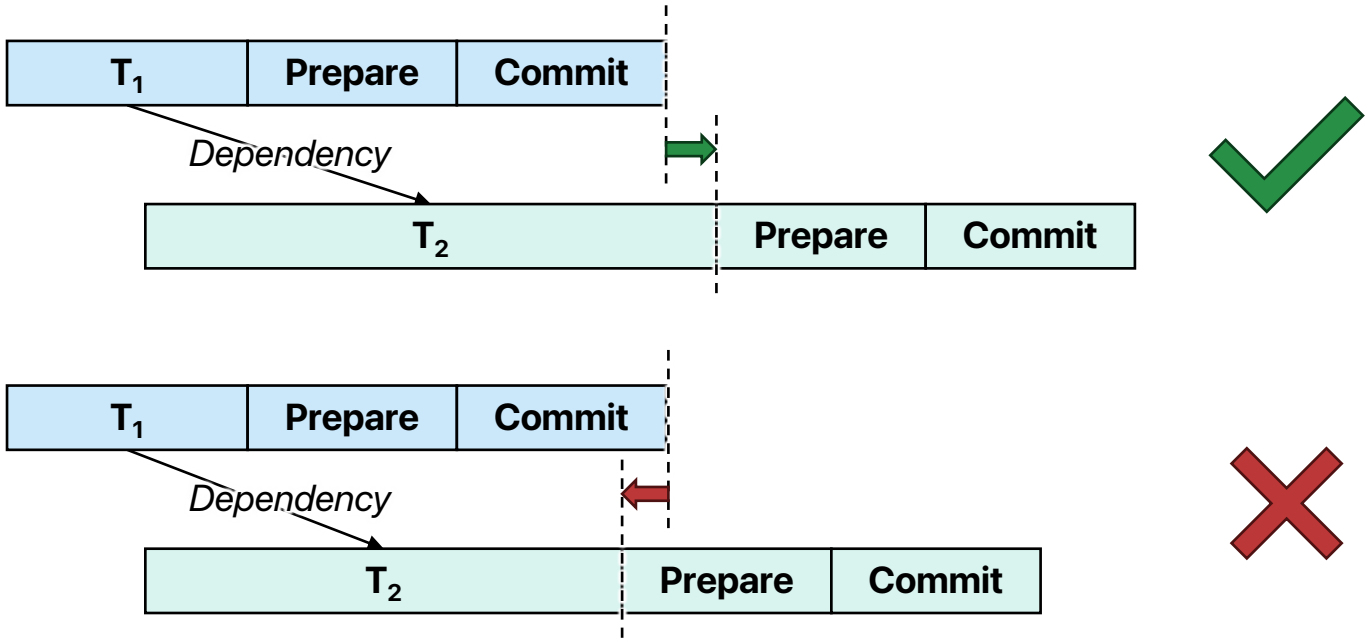
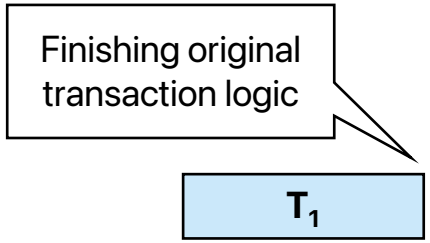


Enforcement in SSI DBs

- **For SSI DBs, we introduce helper transactions.**



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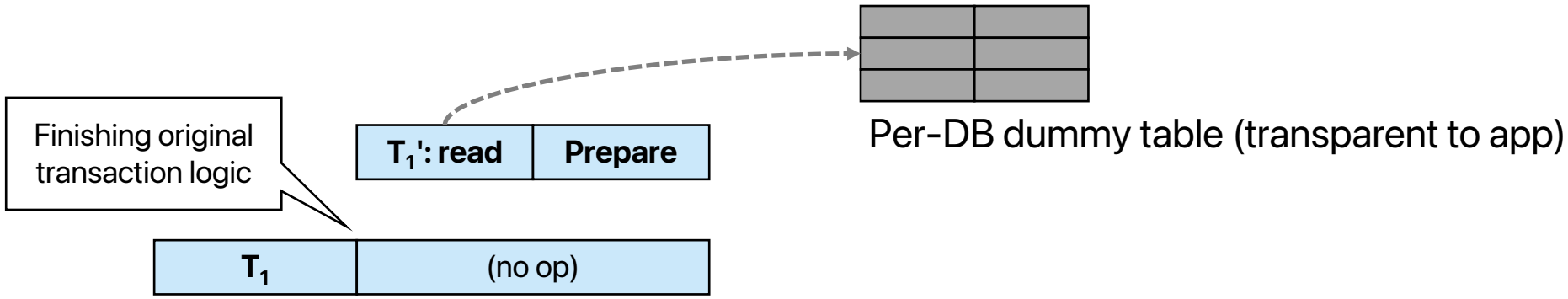

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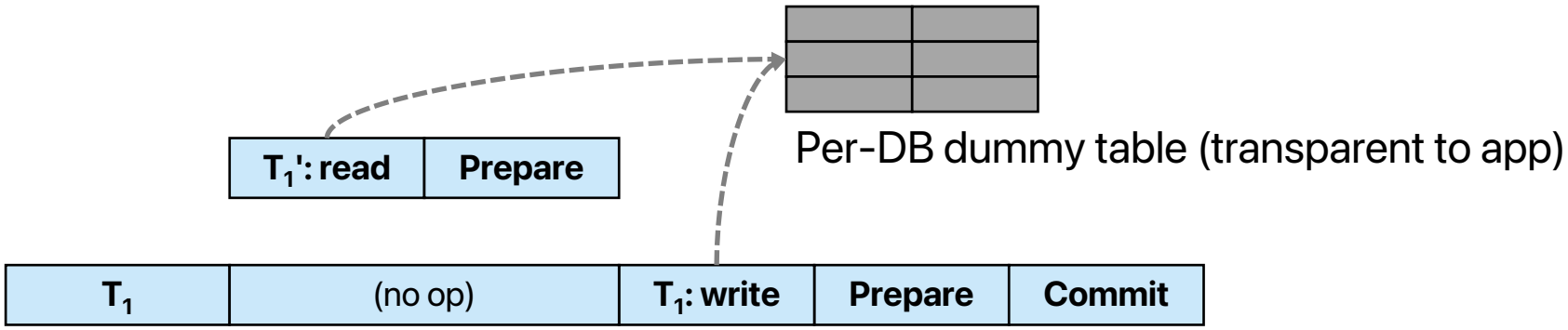

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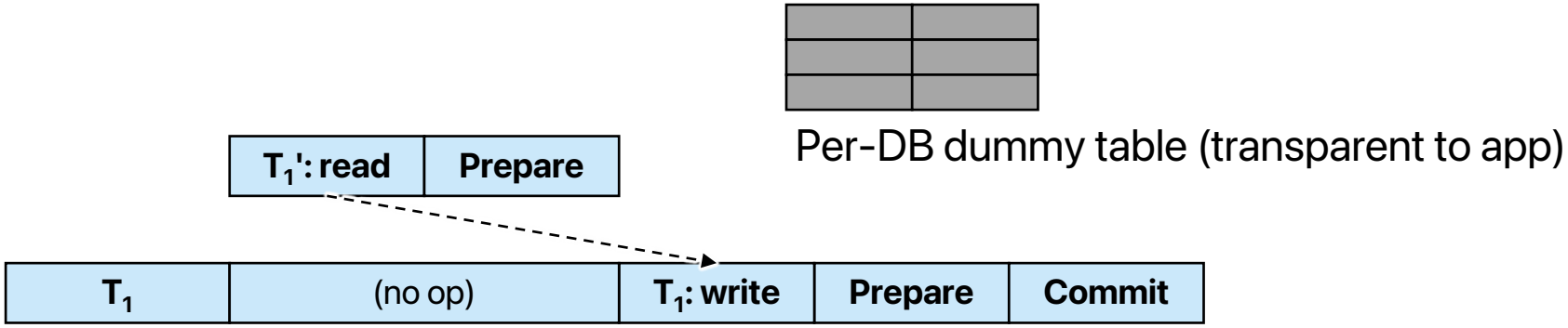

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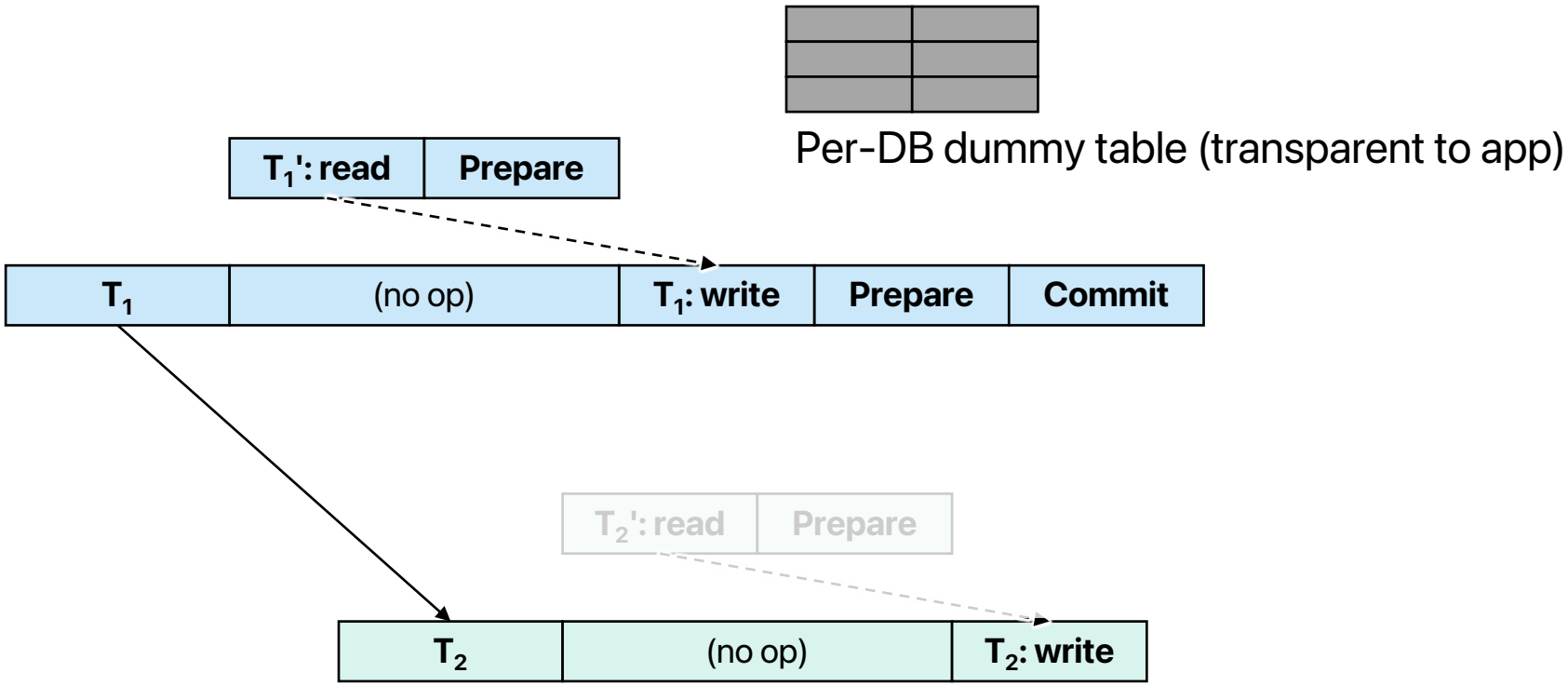

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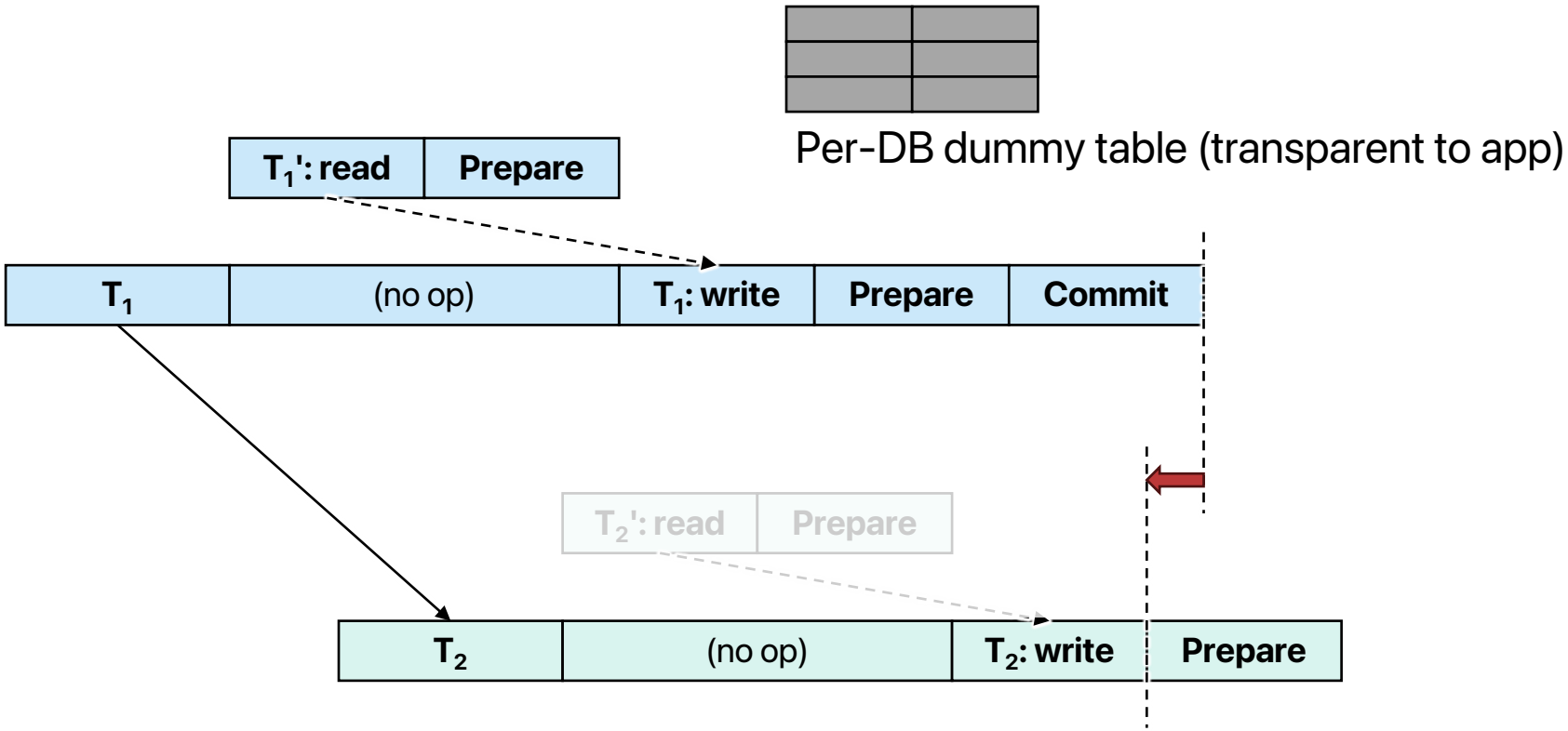

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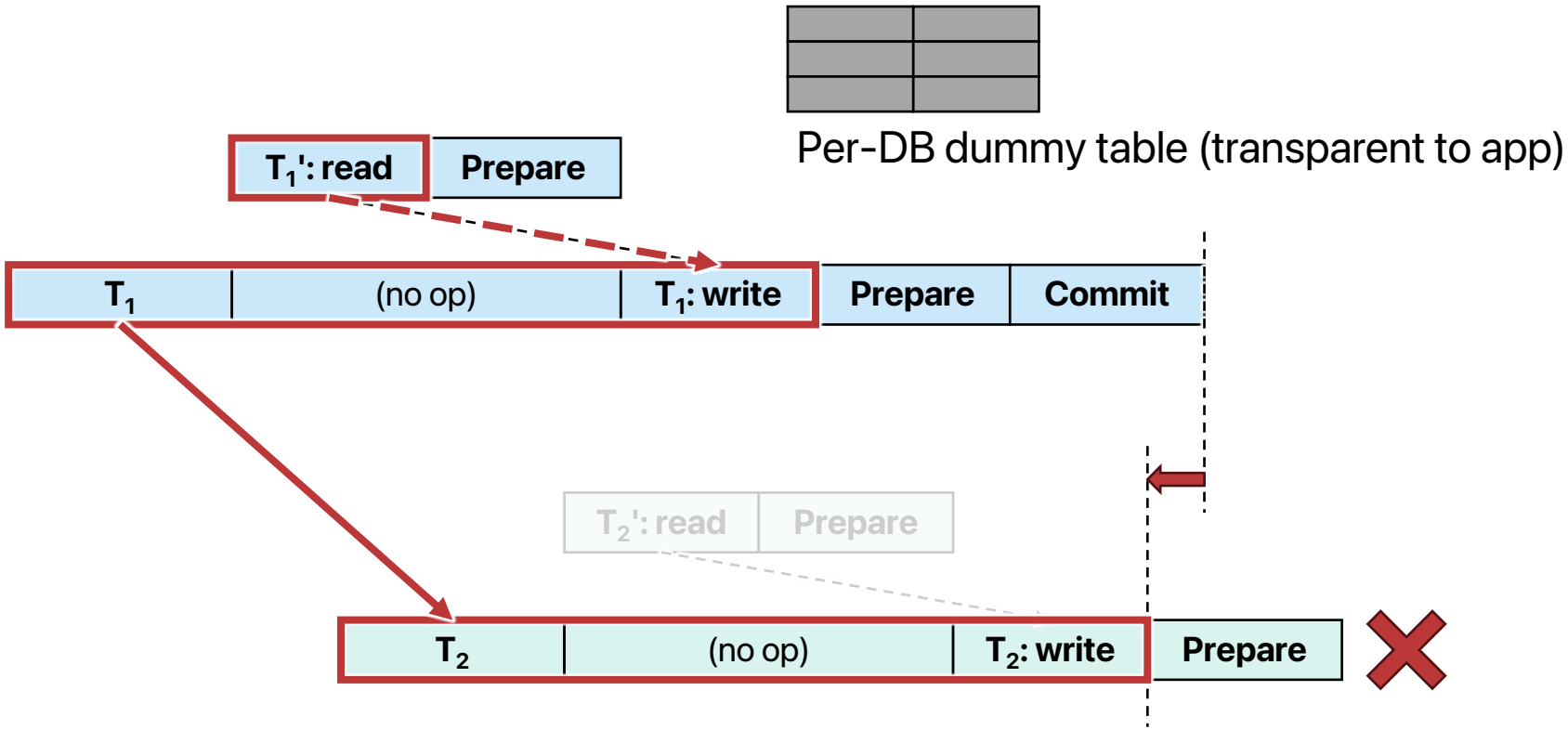

SSI dangerous structure!

T2 will be aborted → No violation

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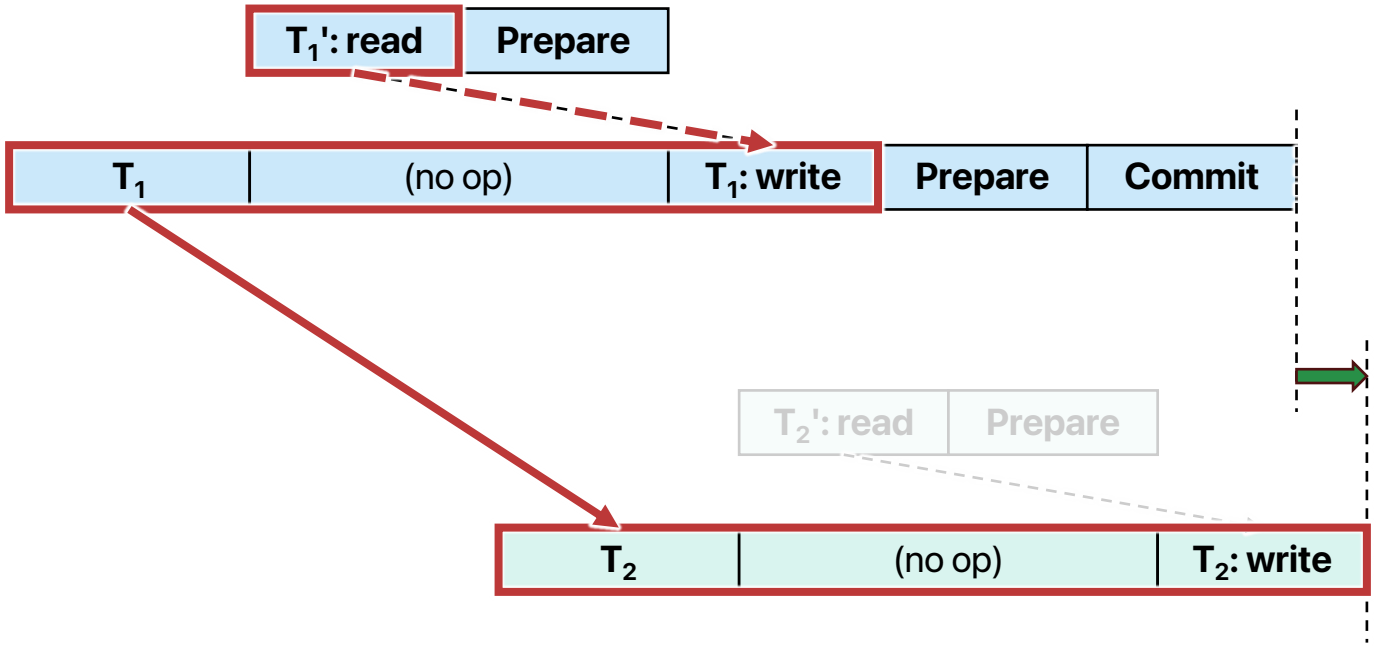

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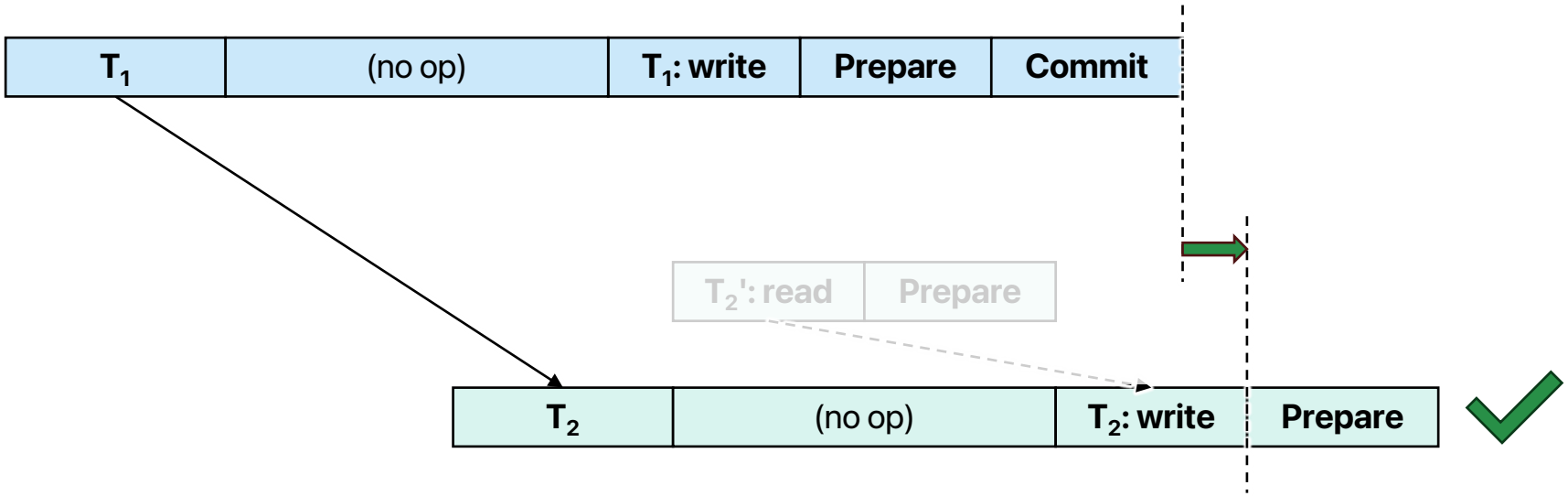

No SSI dangerous structure!

T2 won't be aborted → No false positive

Enforcement in S2PL DBs

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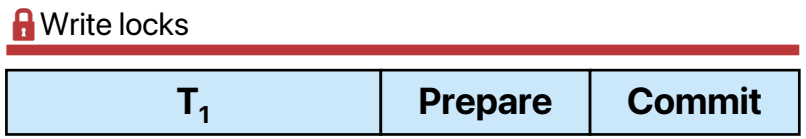

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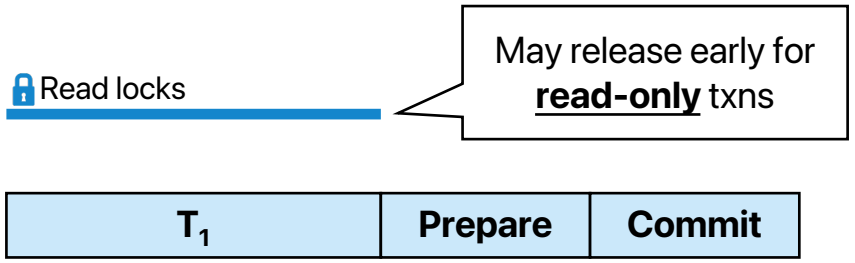

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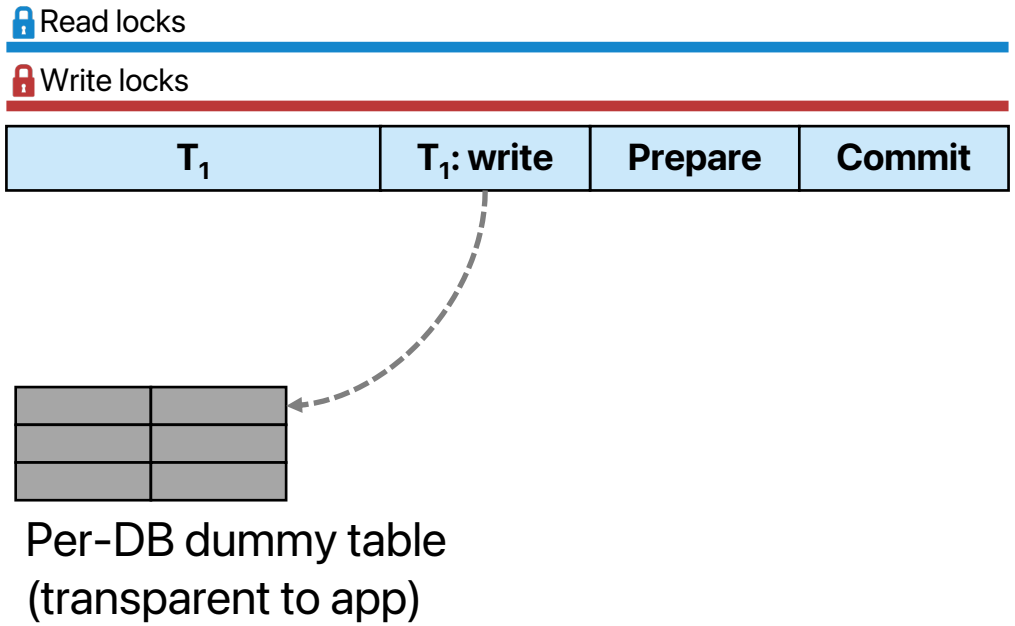

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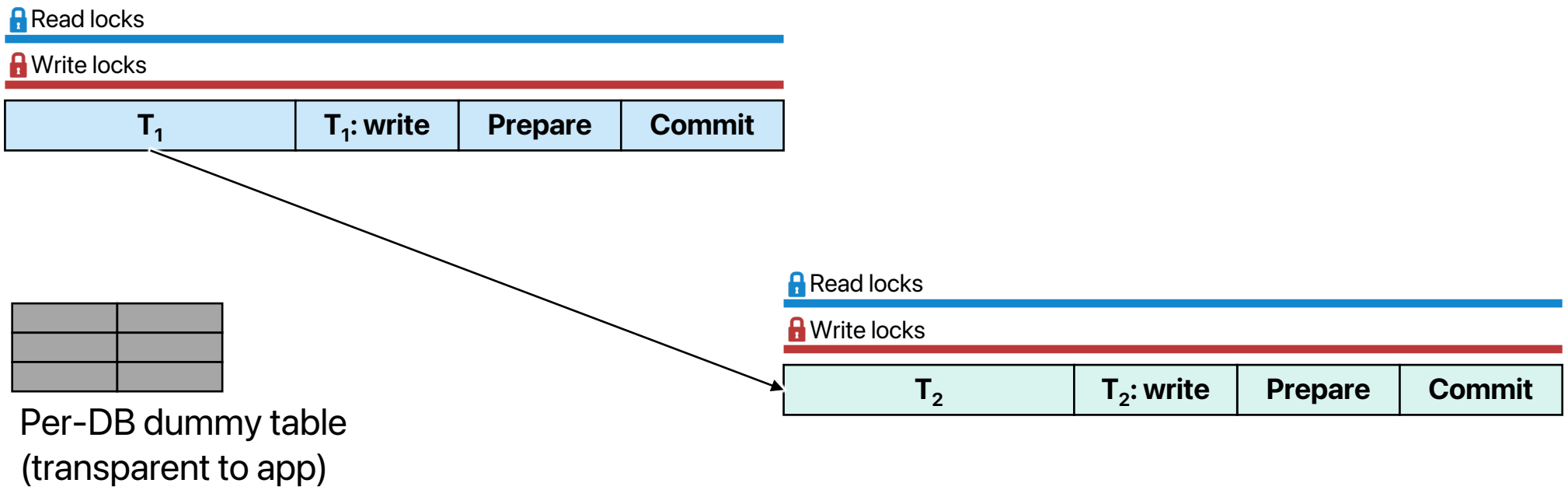

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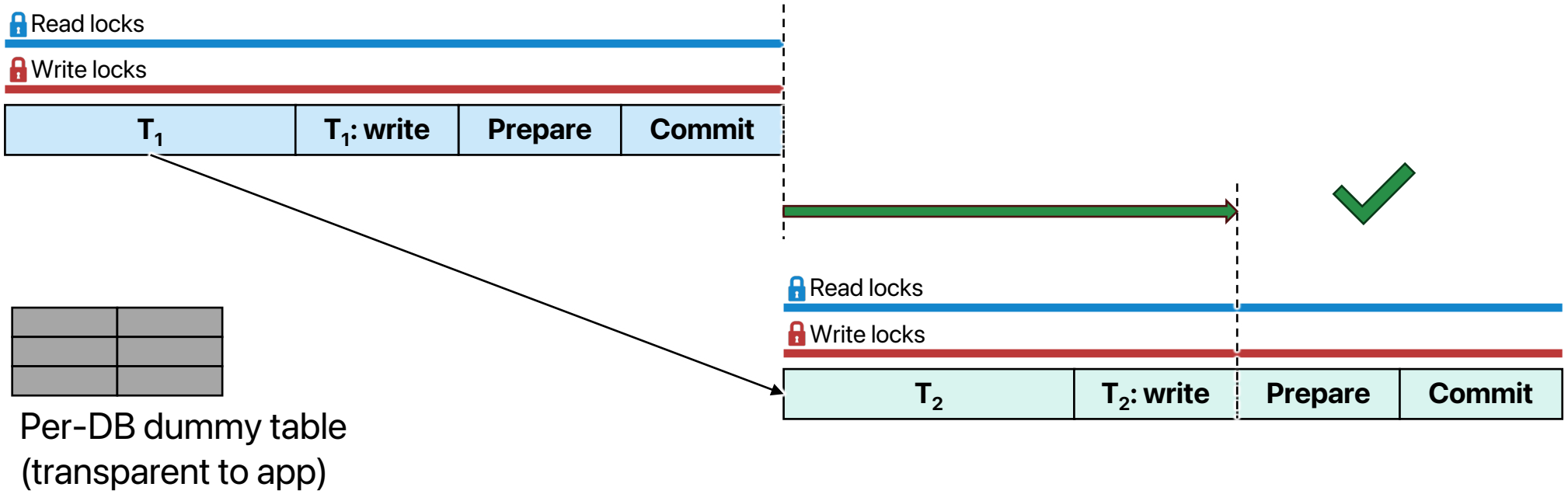

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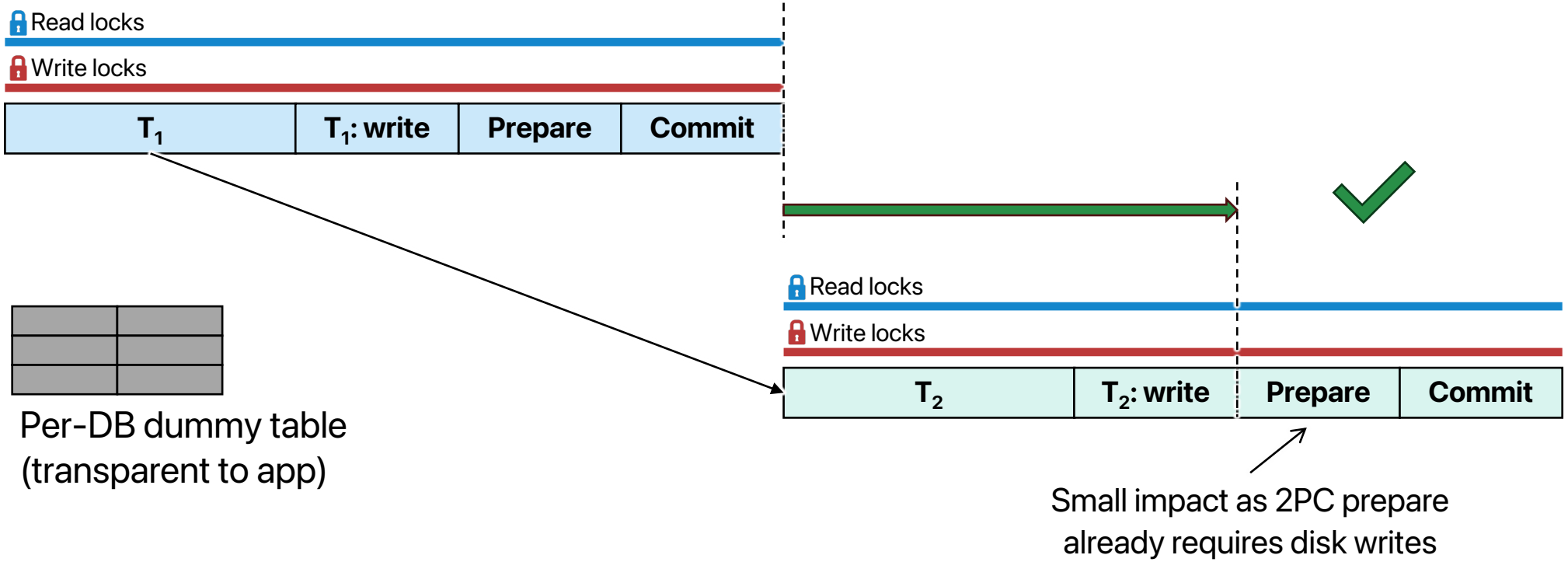

Correctness and False Positives

- **Sonata provably guarantees the local condition, thus global serializability.** (Sec. 4.1)
  - The proofs leverage lemmas from [TODS 05]*.

- **With PostgreSQL and MySQL, there's no false positive if the DB's conflict detection is accurate.** (Sec. 4.2)
  - The analysis depends on DB's implementation details.

* Fekete et al. 2005. Making snapshot isolation serializable. ACM TODS.

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Any RPC framework able to piggyback transaction ID strings
(We currently intercept HTTP requests)

Sonata Performance

- **We build a multi-DB TPC-C by partitioning by warehouses.**
  - Either PostgreSQL or MySQL as local DBs.
  - Global serializability: ScalarDB [VLDB '23] & Ticket [ICDE '91].

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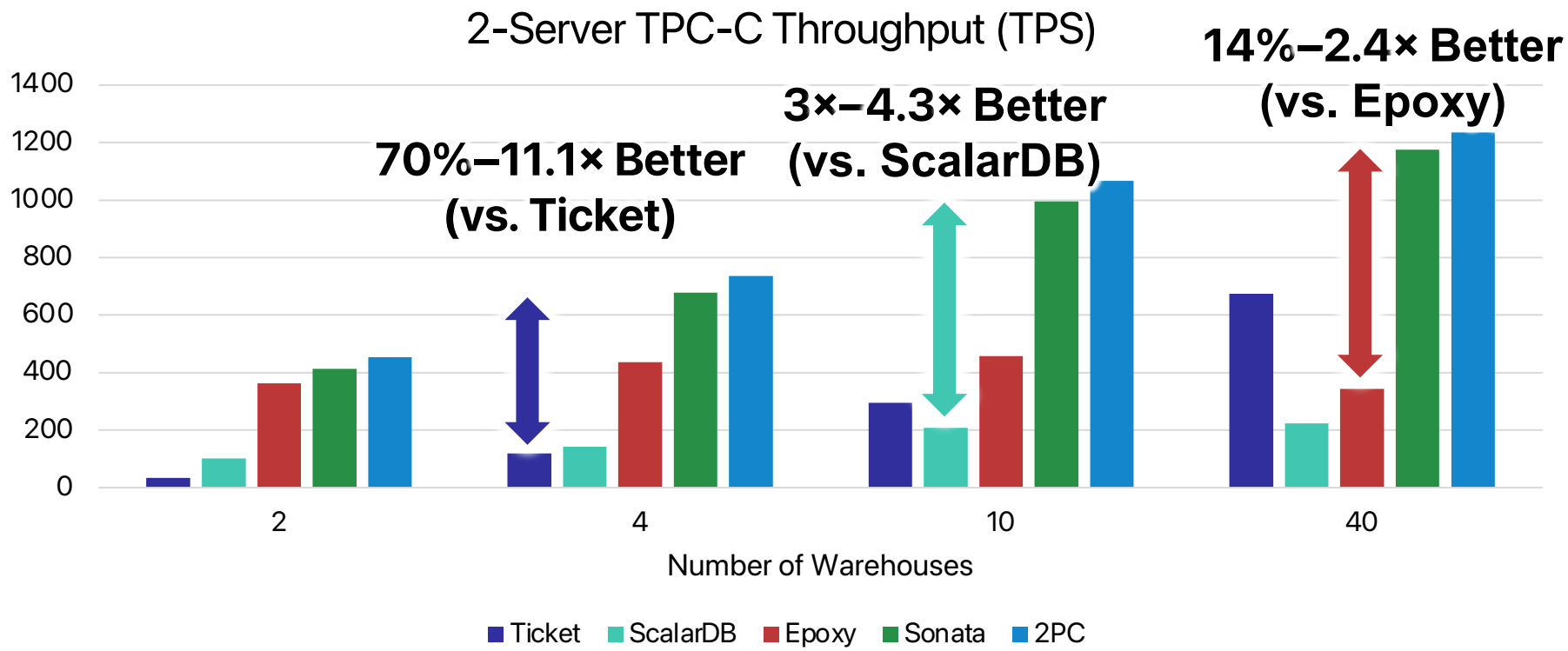

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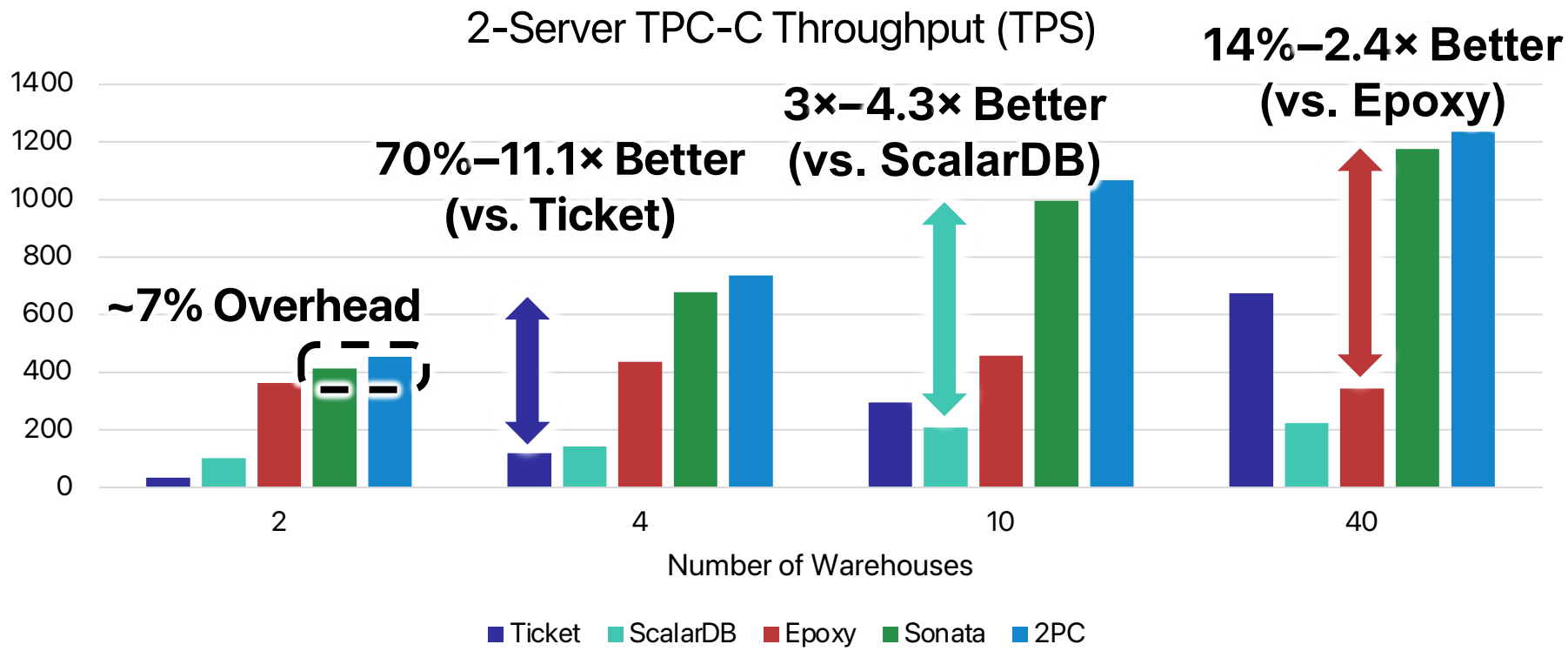

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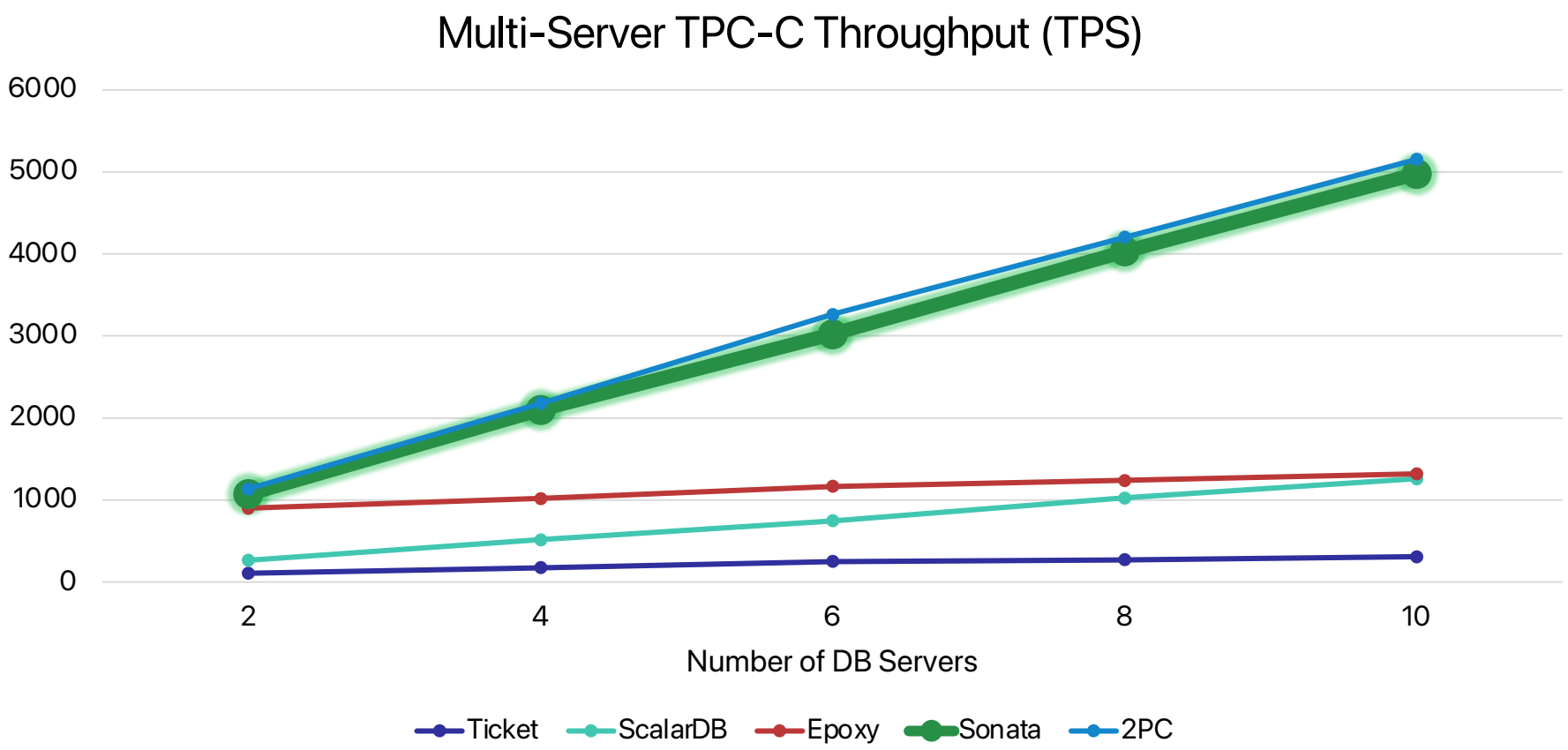
Sonata Performance

- **For scalability, at 10 nodes, Sonata (green) achieves 4.65× its 2-node throughput.**



Summary and Q/A

- **Sonata offers global serializability in an efficient, non-intrusive way.**
- **It reuses DB concurrency control to add lightweight coordination.**
- **It achieves up to 11.1× higher throughput than prior solutions.**

- **Check out our paper and code!**
  - Design details, optimizations, proofs, & more evaluation results.

Paper

Code