# Design and Evaluation of an Edge Concurrency Control Protocol for Distributed Graph Databases

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[2]Neo4j


# Graph Databases

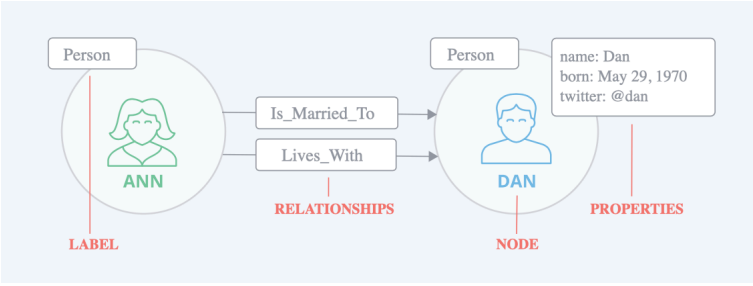


**Figure 1:** Labeled property graph[1]

[1] https://neo4j.com

# Graph Databases

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- **Use cases:** telecommunications, pharma, publishing, finance, social media

# Graph Database Popularity

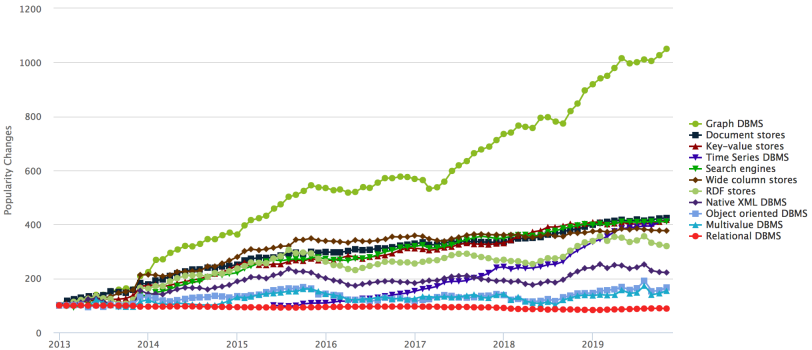


**Figure 2:** Database popularity by data model[2]

[1] https://db-engines.com/en/ranking_categories

# Distributed Graph Databases

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- Partition the graph across multiple machines in a cluster, with partitions replicated for fault-tolerance and availability
- Graph partitioning inevitably leads to **distributed edges**

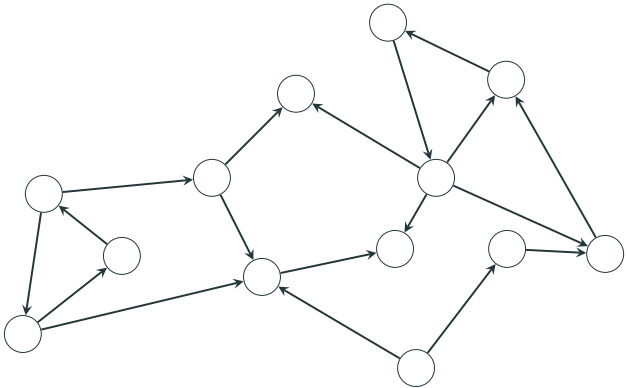

**Figure 3:** Connected graph

# Distributed Graph Databases: Partitioning

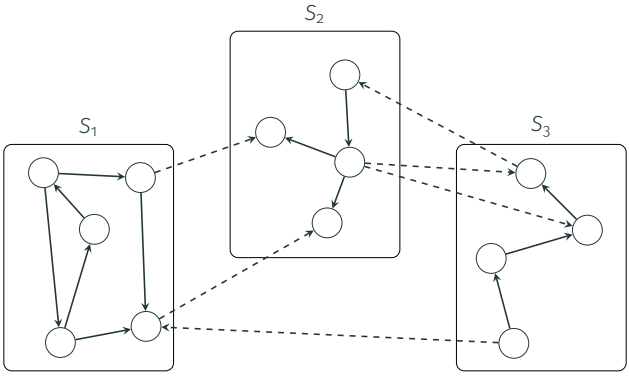


**Figure 4:** Graph partitioned across 3 servers

A logical edge is represented by 2 physical records


**Figure 5:** A reciprocal consistent edge

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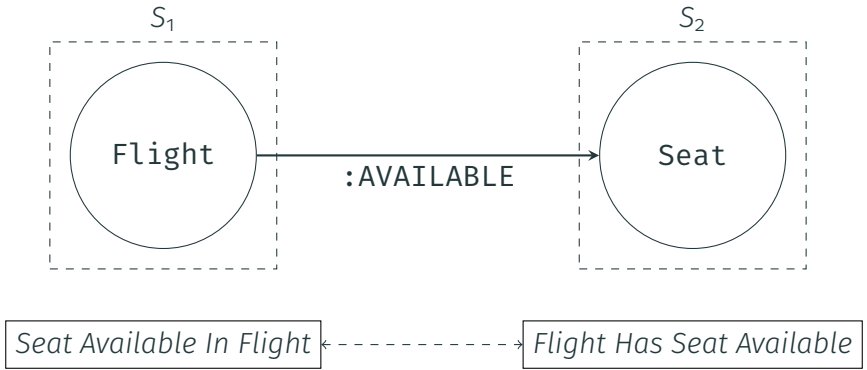


**Figure 5:** A reciprocal consistent edge

# Reciprocal Consistency Violation

Two concurrent transactions:

- Mr Red requests to book the seat, $T_R$
- Mr Blue requests to book the seat, $T_B$

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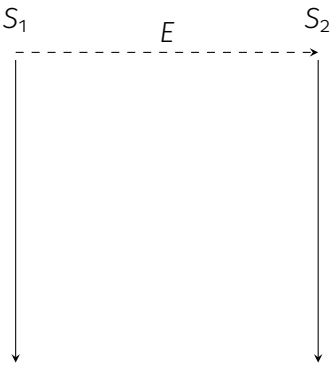


**Figure 6:** Concurrent transactions interleave and violate reciprocal consistency

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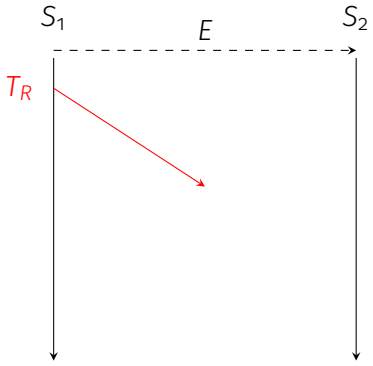


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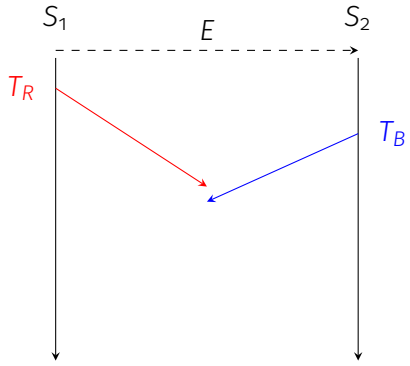


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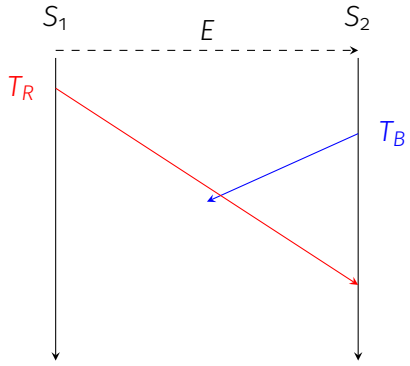


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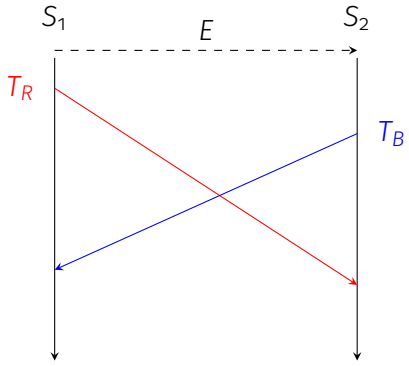


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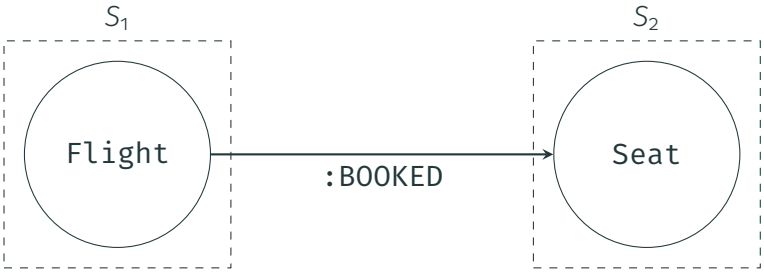


**Figure 7:** Reciprocal inconsistent distributed edge

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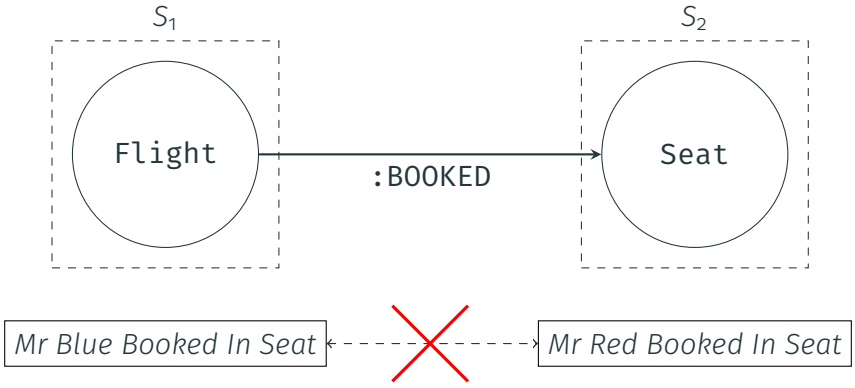


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# Distributed Edge Reciprocal Consistency

- Without concurrency control, distributed edges can become reciprocally inconsistent
  - A distributed edge's reciprocal information is separated by the network

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- Without concurrency control, distributed edges can become reciprocally inconsistent
  - A distributed edge's reciprocal information is separated by the network
- Reciprocal inconsistency is a source of corruption[3]
- No known concurrency control protocol exists specific to graph databases and maintaining reciprocal consistency

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# Our Solution: Collision Detection

- Carefully abort transaction(s)

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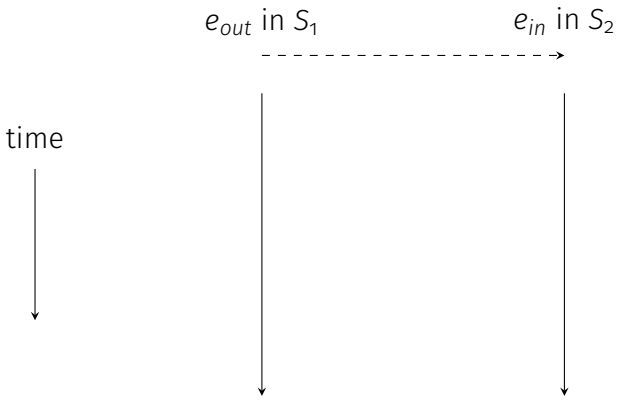
- When a transaction attempts to update a given record, it can identify all other transactions that have earlier updated that record provisionally

# Interference-free Update



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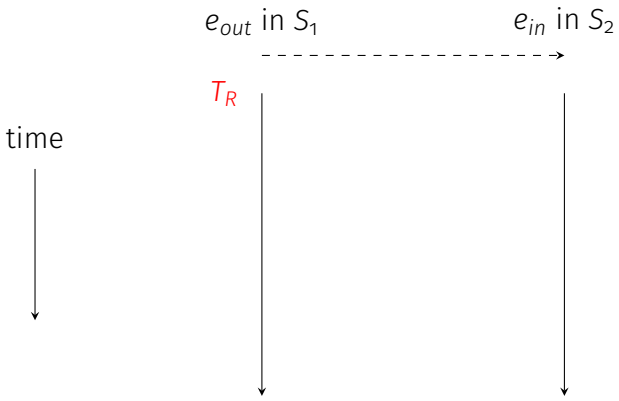

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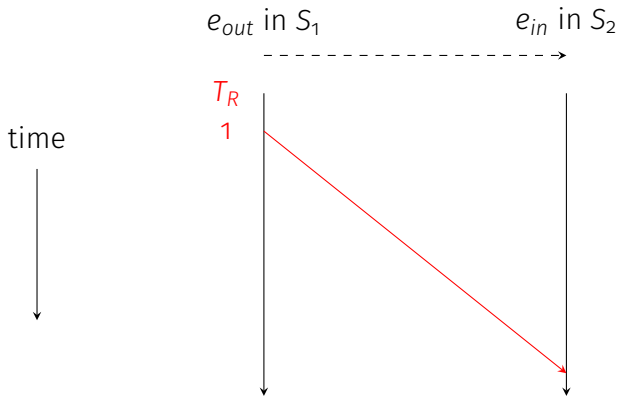

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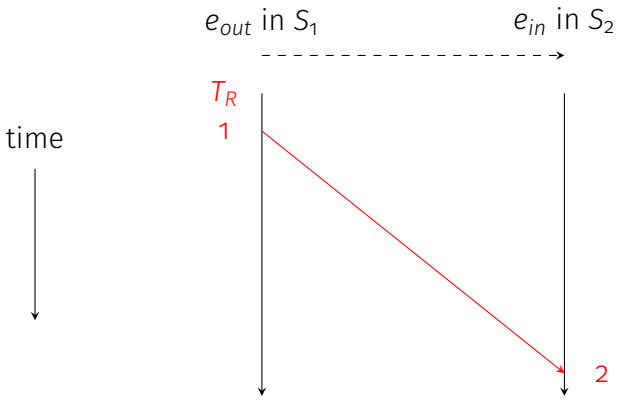

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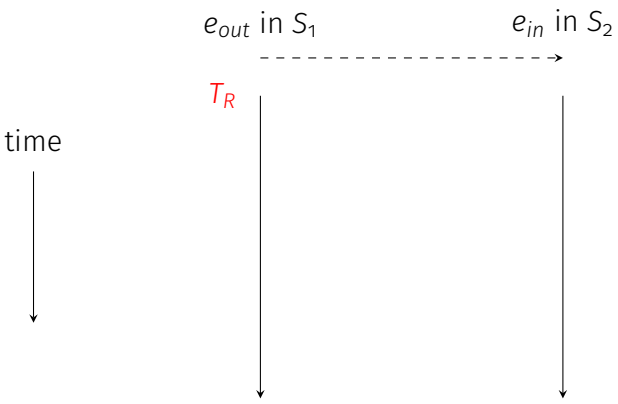

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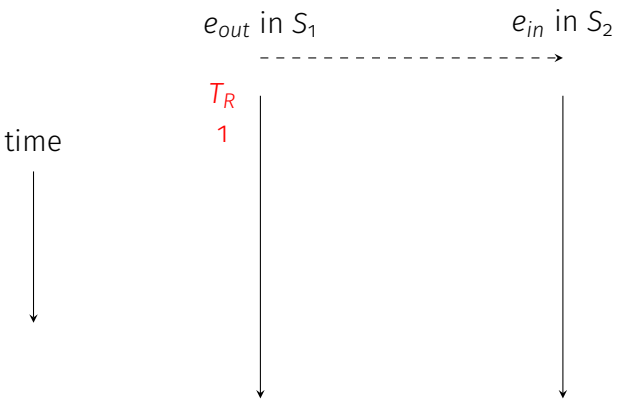

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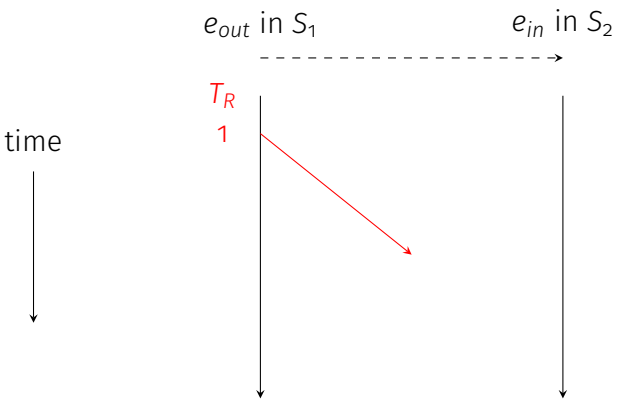

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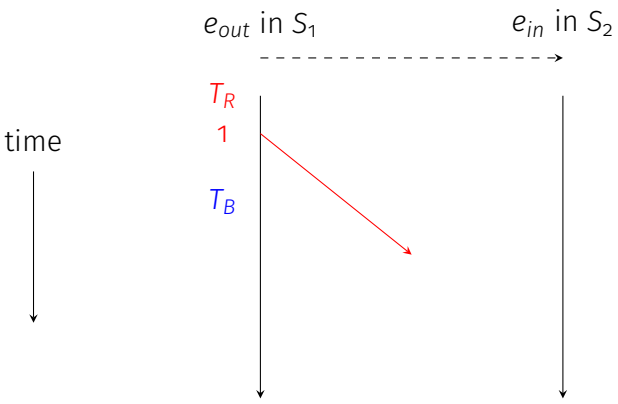

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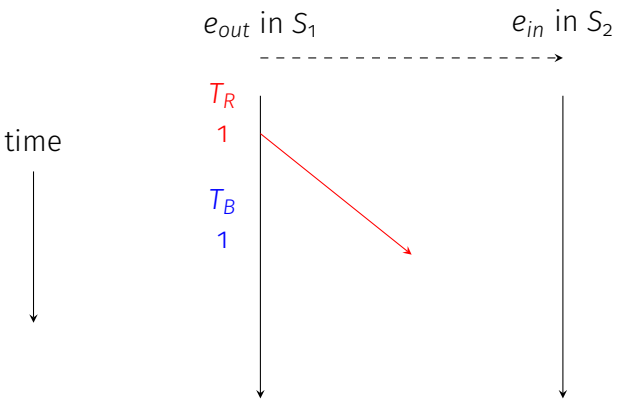

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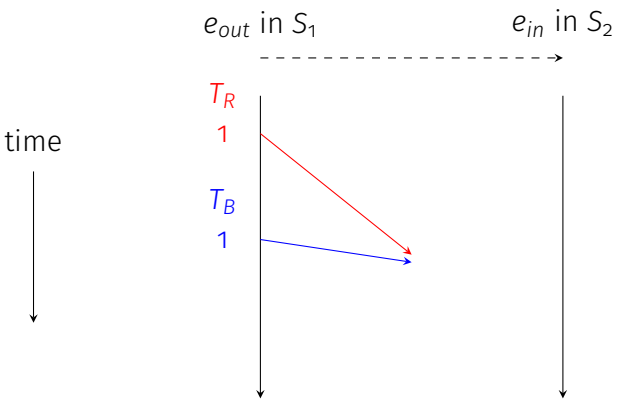

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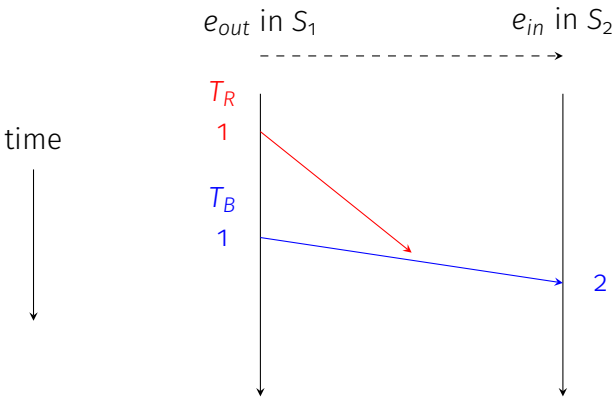

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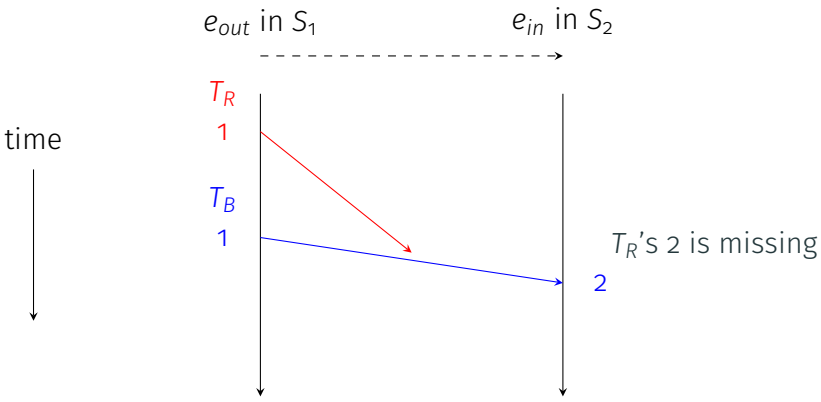

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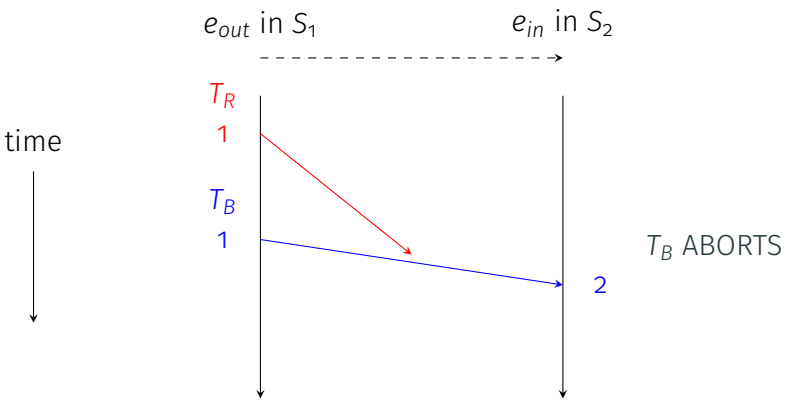

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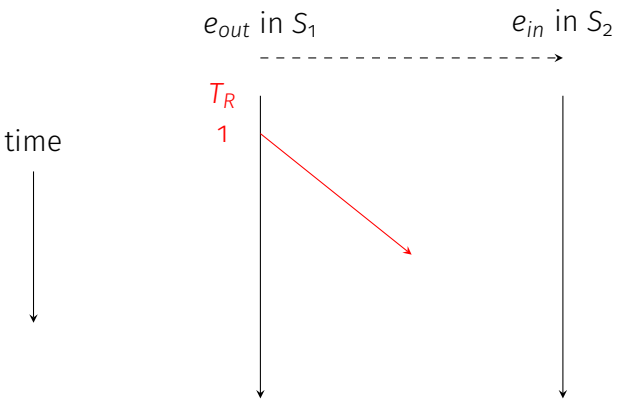

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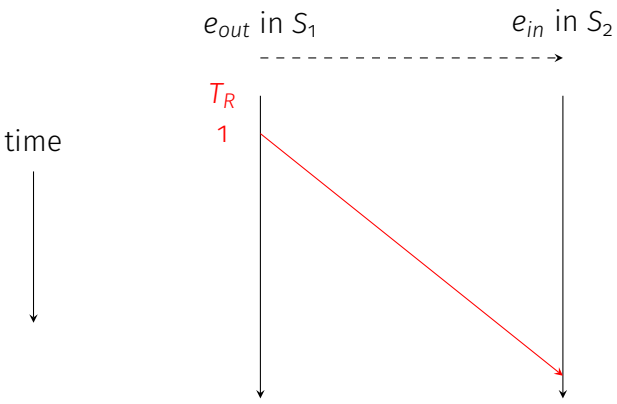

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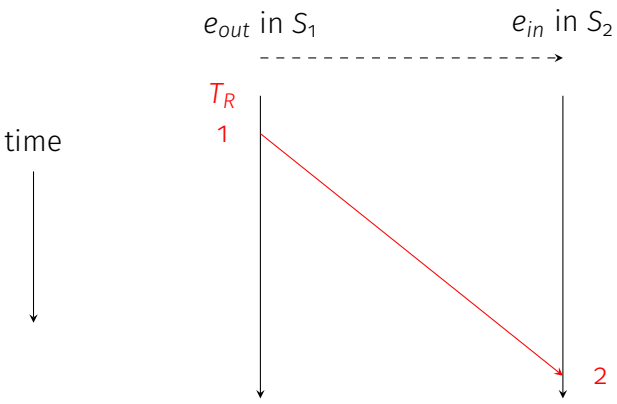

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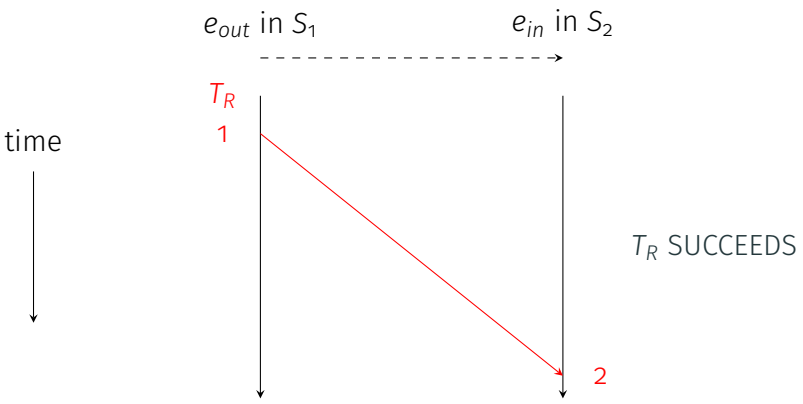

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- Consider 2 transactions that update 2 or more of the *same* distributed edges
- Each update is reciprocally consistent
- Then if $T_R$ updates before $T_B$ on a given edge then this order should be preserved across all edges

# Edge-Order Consistency Violation

Consider two edges,

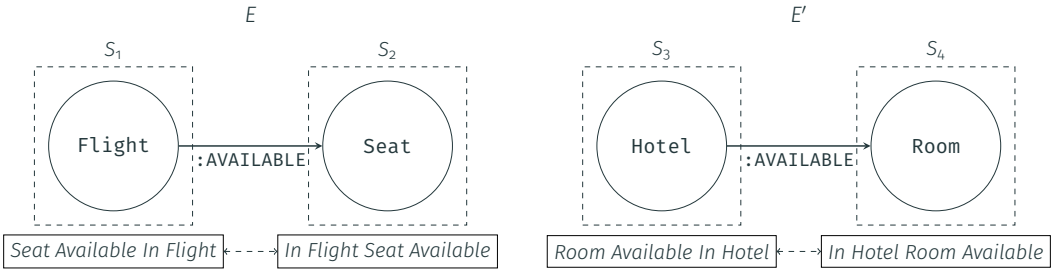


**Figure 8:** Two distributed edges

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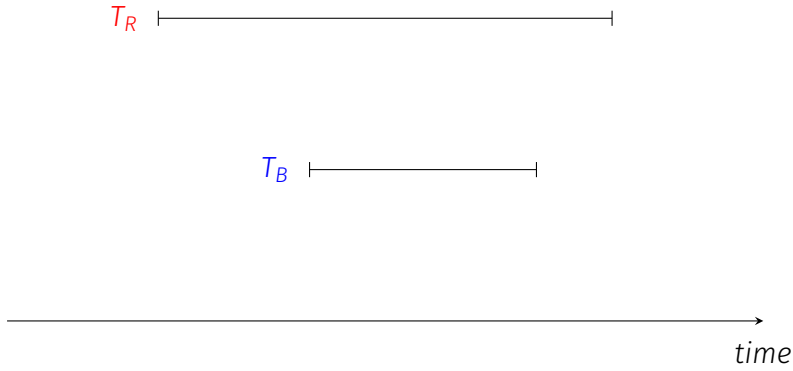
Two concurrent transactions by a travel agent:

- Requests to book room and seat for Mr Red, $T_R$
- Requests to book room and seat for Mr Blue, $T_B$

# Edge-Order Consistency Violation

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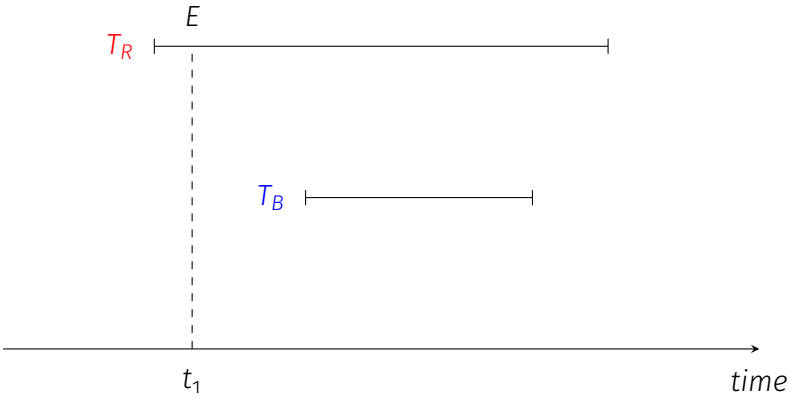


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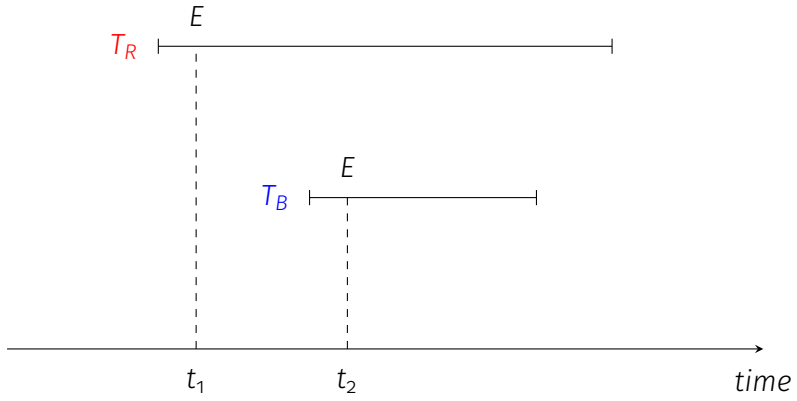


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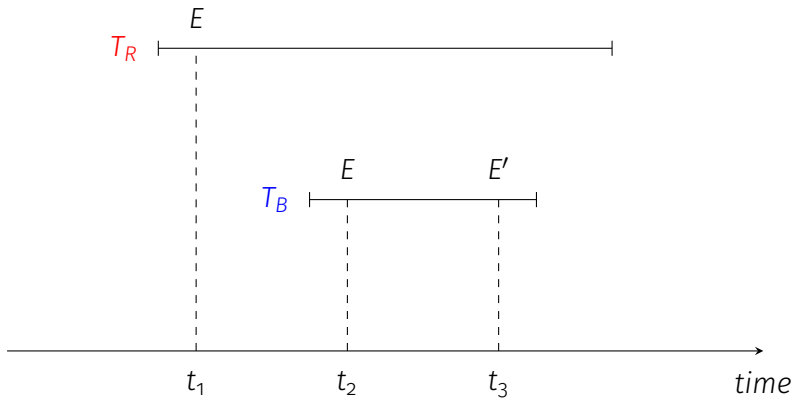


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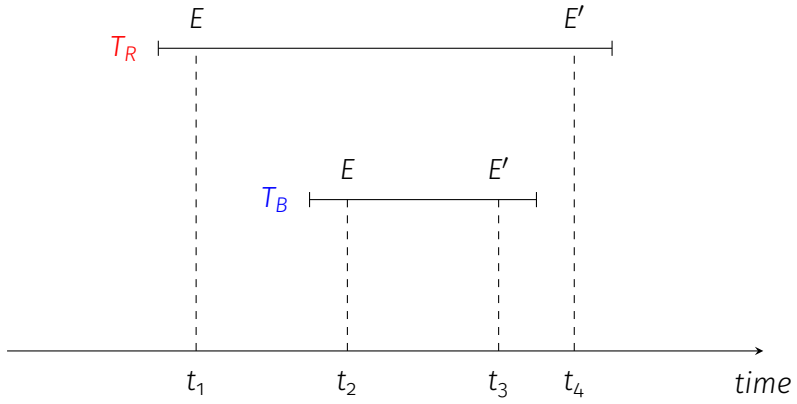


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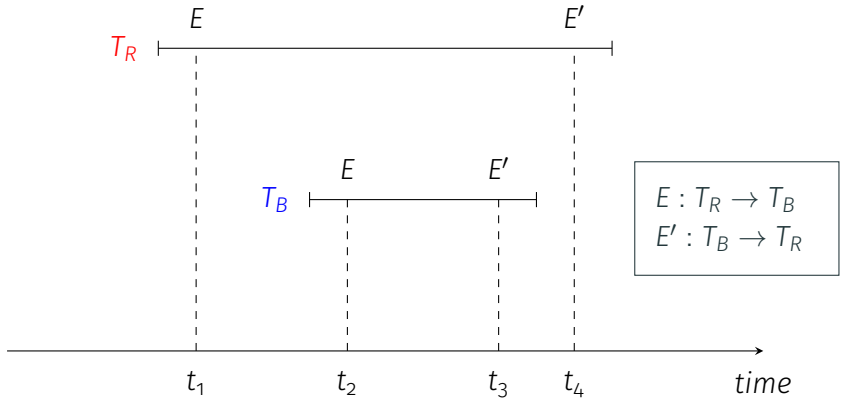


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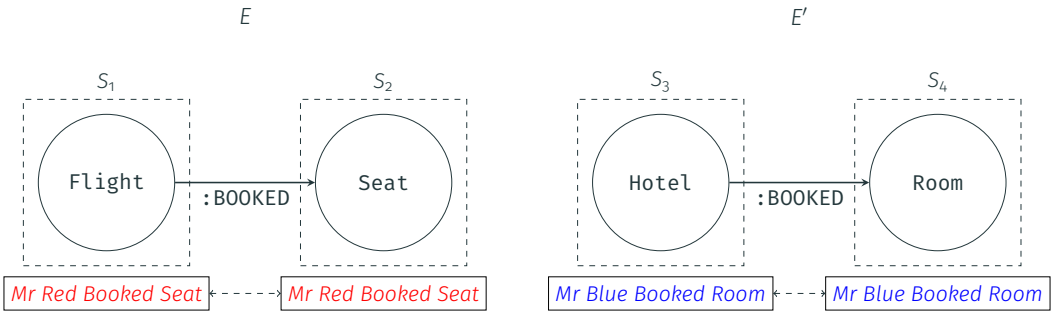


**Figure 10:** Edge-order consistency violation

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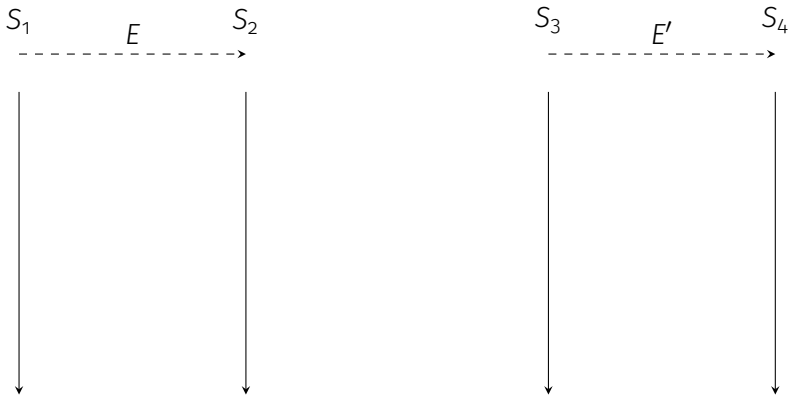
- Centralized arbiter maintains some global state
- Global state used to detect edge-order violations
- Offending transactions are aborted

# Order Arbitration

Rule: Collect predecessors after every successful update



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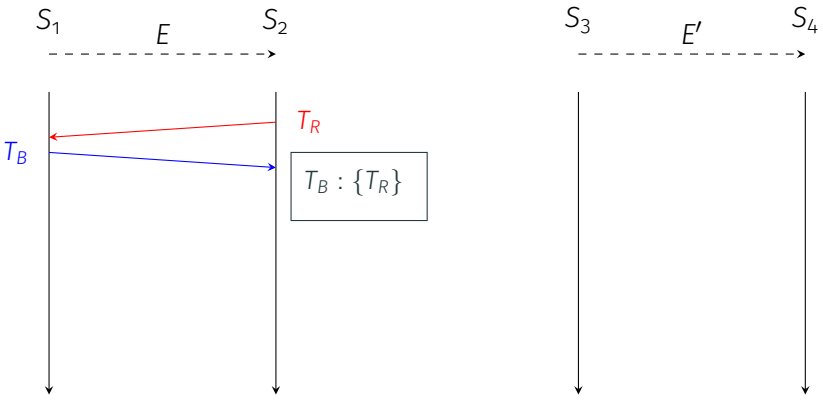

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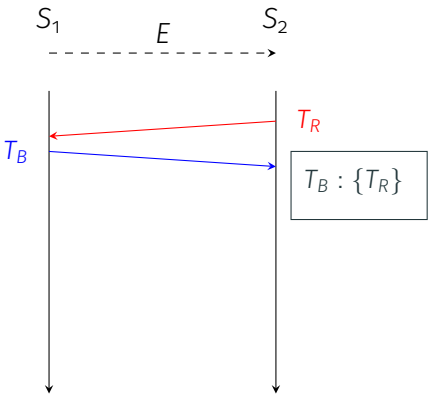


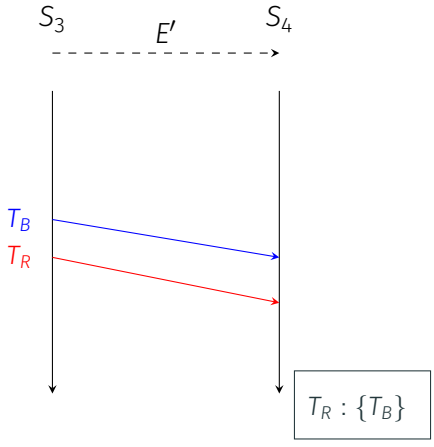

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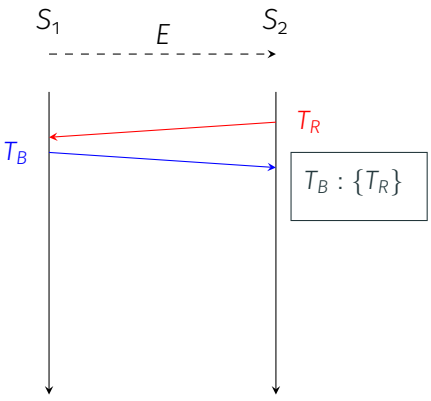


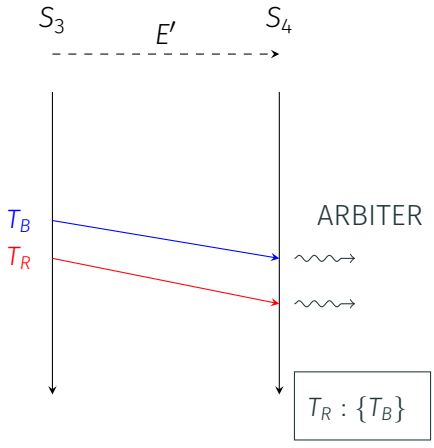

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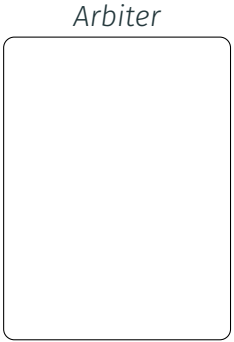

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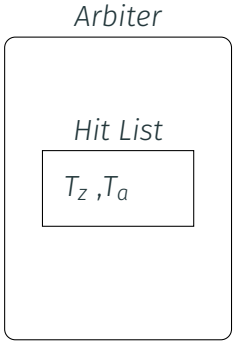

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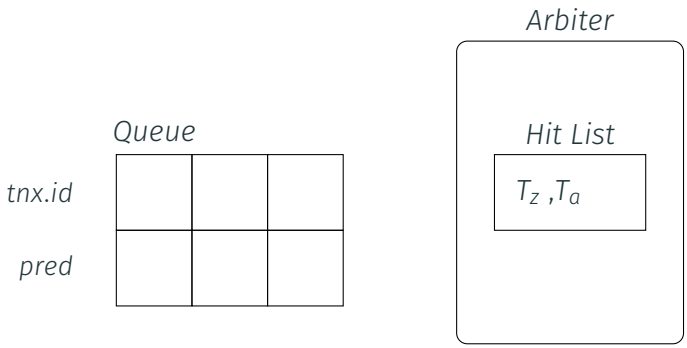

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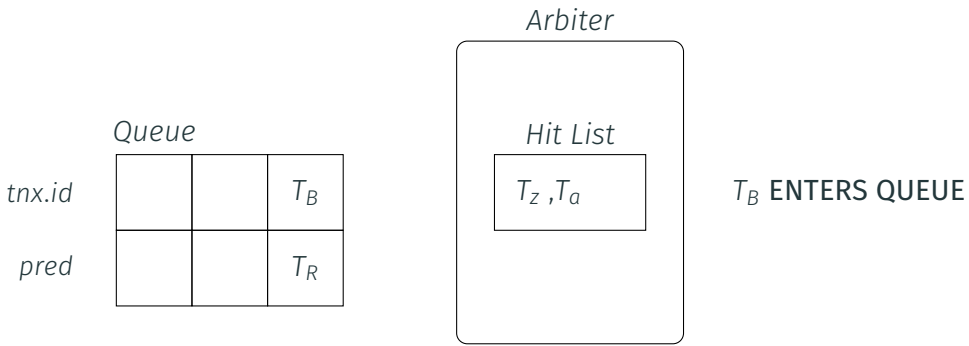

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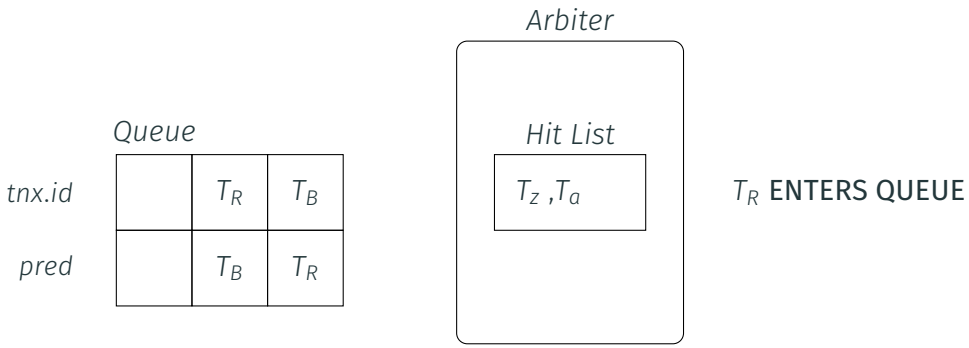

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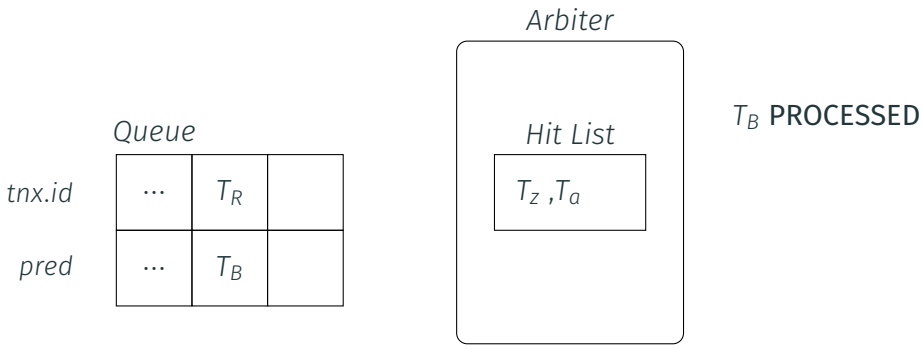

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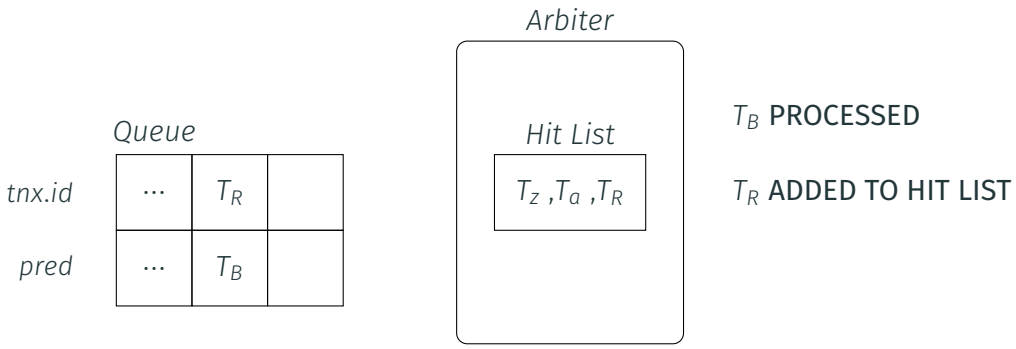

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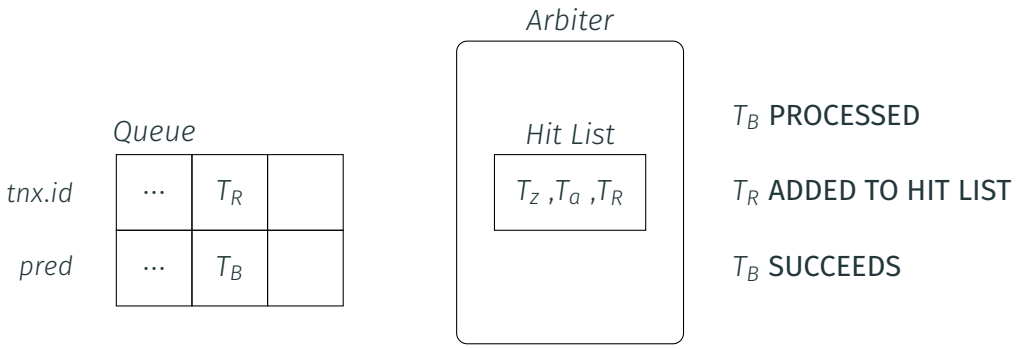

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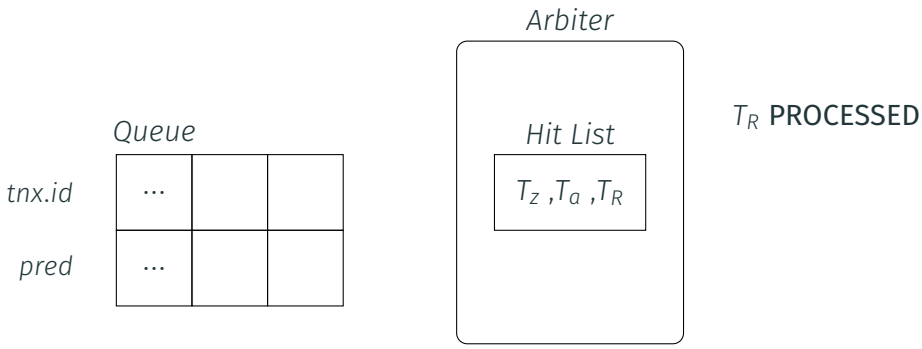

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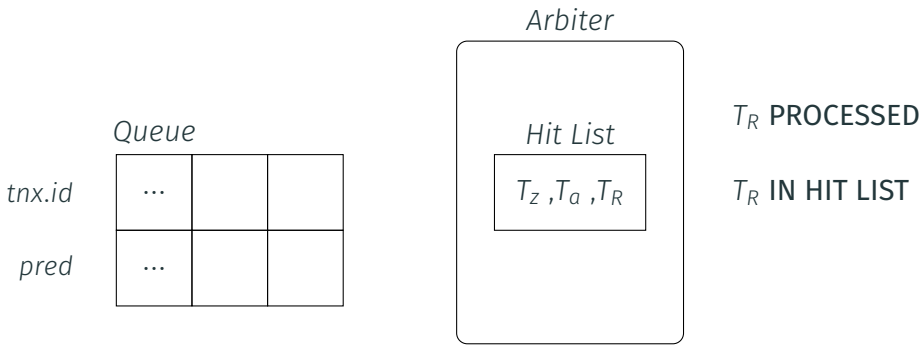

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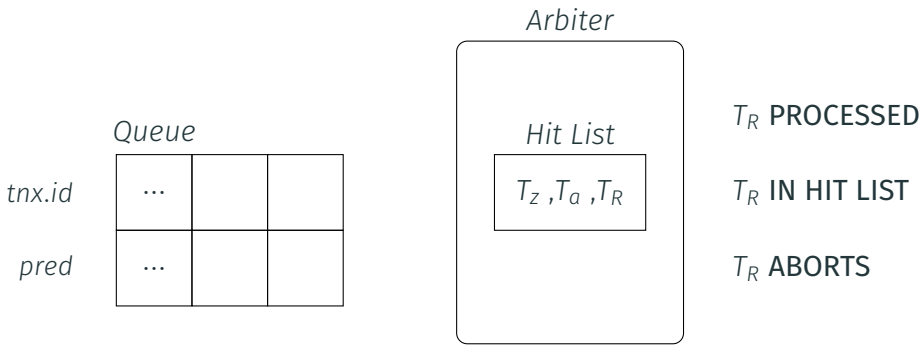

# Order Arbitration Protocol

If a transaction updates 1 or more distributed edges:

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- Else in hit list then abort

# Edge Concurrency Control Protocol Summary

1. Collision detection: enforces **reciprocal consistency** for distributed edges
2. Order arbitration: enforces **edge-order consistency** between transactions

# Performance Evaluation

Performance measures of interest:

- Average number of transactions that are aborted
- Load at the arbiter

# Evaluation Approach

1. Developed approximate model
2. Measure accuracy of model through simulation

# Parameters

- Database size
- Transaction arrival rate
- Average updates per transaction
- Average arbiter service time
- Average network delay

# Aborts per second ($R$) vs Database Size ($N$)

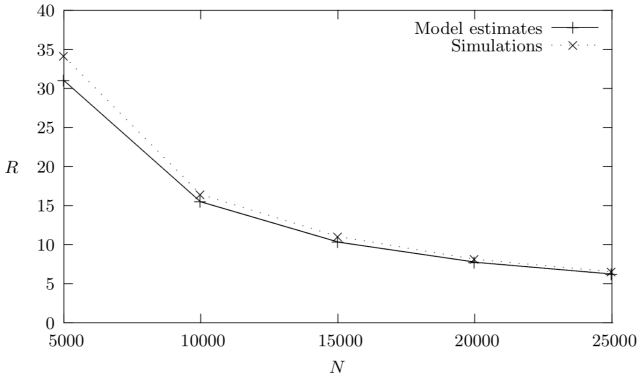


**Figure 11:** TPS = 1000, av updates/tnx = 5, av arbiter service time = 10*ms*, av network delay = 5*ms*

# Aborts per second ($R$) vs Transaction Arrival Rate ($\lambda$)

Arbiter queue unstable at $\sim$ 1500 TPS

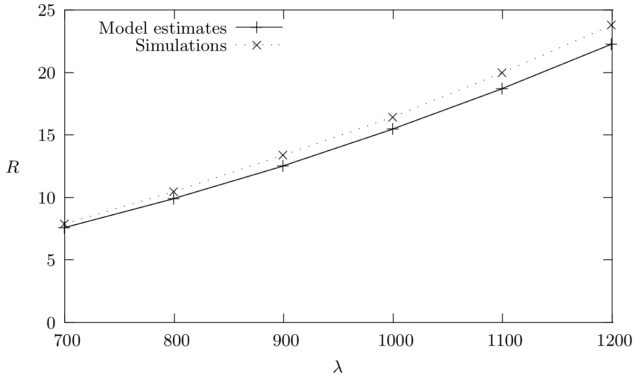


**Figure 12:** size = 10$K$, av updates/tnx = 5, av arbiter service time = 10$ms$, av network delay = 5$ms$

# Aborts per second ($R$) vs Transaction Arrival Rate ($\lambda$)

Arbiter queue unstable at $\sim$ 1100 TPS

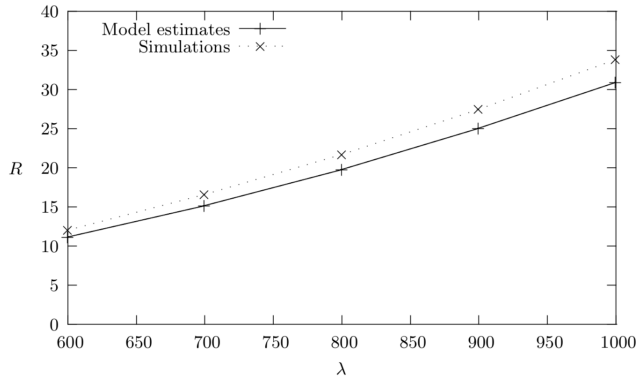


**Figure 13:** size $=$ 10$K$, av updates/tnx $=$ 5, av arbiter service time $=$ 10$ms$, av network delay $=$ 10$ms$

# Aborts per second ($R$) vs Transaction Arrival Rate ($\lambda$)

Arbiter queue unstable at $\sim$ 550 TPS

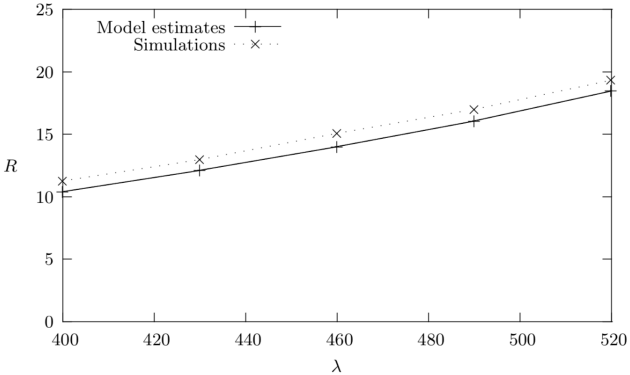


**Figure 14:** size = 10$K$, av updates/tnx = 10, av arbiter service time = 10$ms$, av network delay = 5$ms$

# Summary and Future Work

- Model accuracy similar to simulations under a variety of parameter settings

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- Between 1-4% transactions are aborted

# Summary and Future Work

- Model accuracy similar to simulations under a variety of parameter settings
- Between 1-4% transactions are aborted
- Improve accuracy of simulation

Thanks for listening!

Any Questions?

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