# Preserving Reciprocal Consistency in Distributed Graph Databases

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April 27, 2020

[1]Newcastle University

[2]Neo4j

# Graph Databases

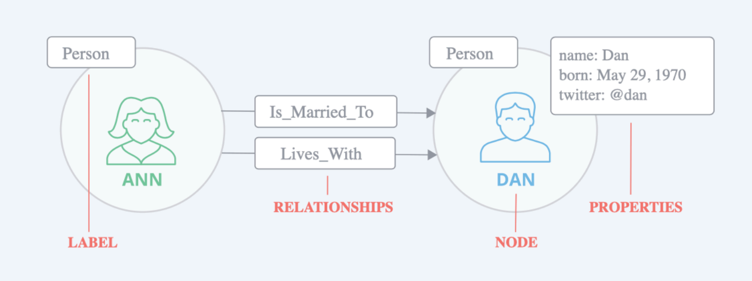

**Figure 1:** Labeled property graph[1]

[1] `https://neo4j.com`

# Graph Databases

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

# Graph Database Popularity

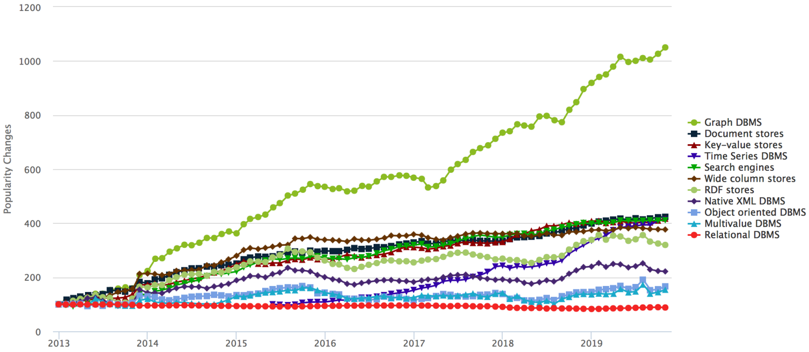

**Figure 2:** Database popularity by data model[2]

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

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- Graph partitioning inevitably leads to **distributed edges**

# Distributed Graph Databases: Partitioning

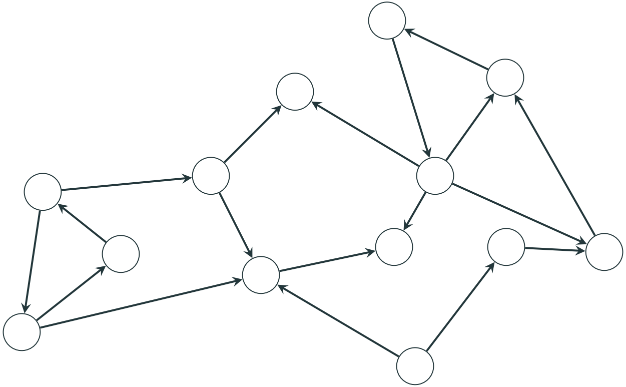


Figure 3: Connected graph

# Distributed Graph Databases: Partitioning

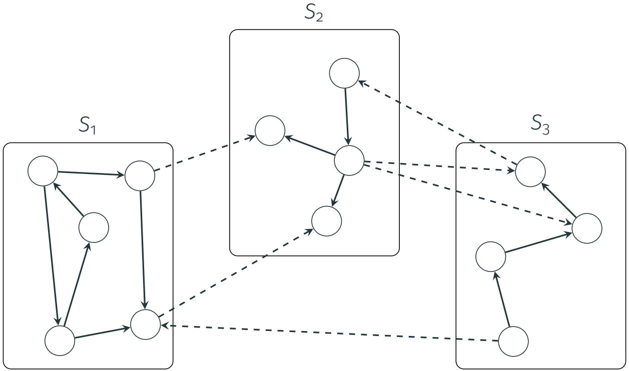
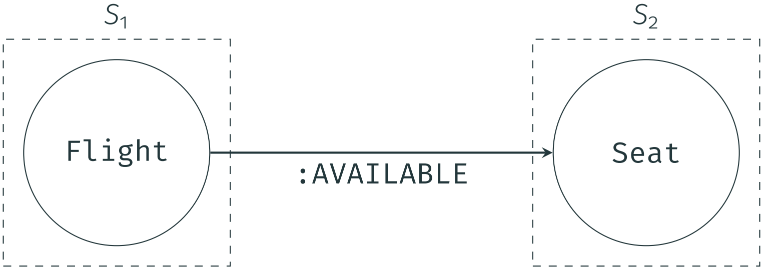


**Figure 4:** Graph partitioned across 3 servers

# Reciprocal Consistency

A logical edge is represented by 2 physical records



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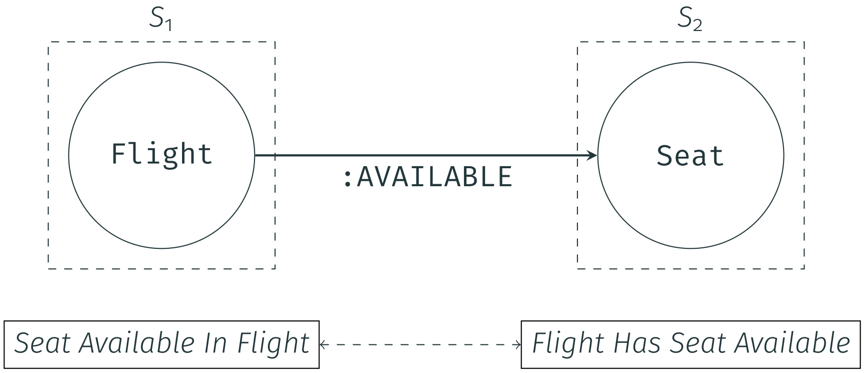

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# Reciprocal Consistency Violation

Two concurrent transactions:

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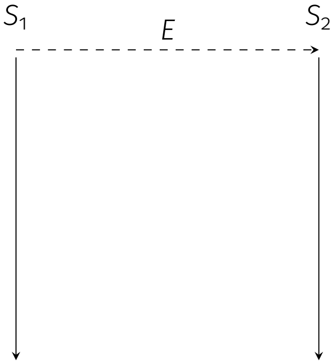

**Figure 6:** Concurrent transactions interleave and violate reciprocal consistency

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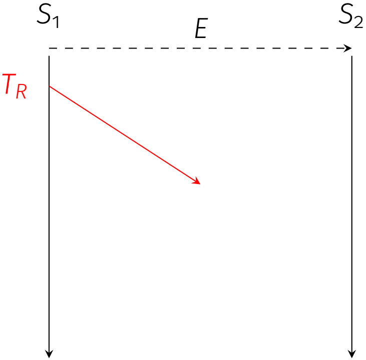

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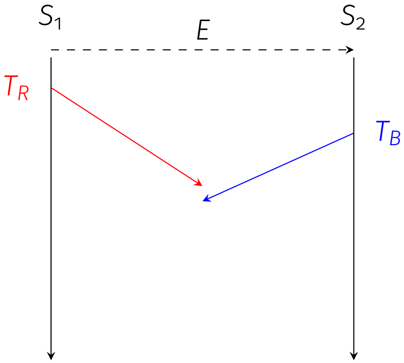

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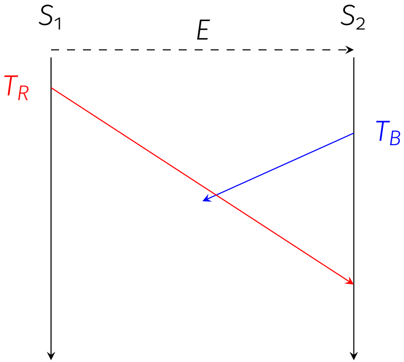

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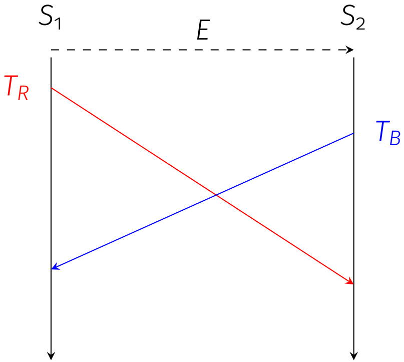

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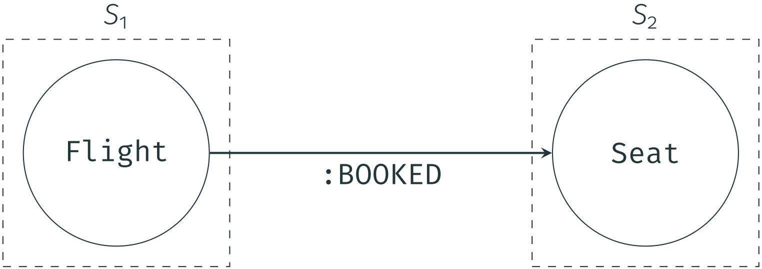

**Figure 7:** Reciprocal inconsistent distributed edge

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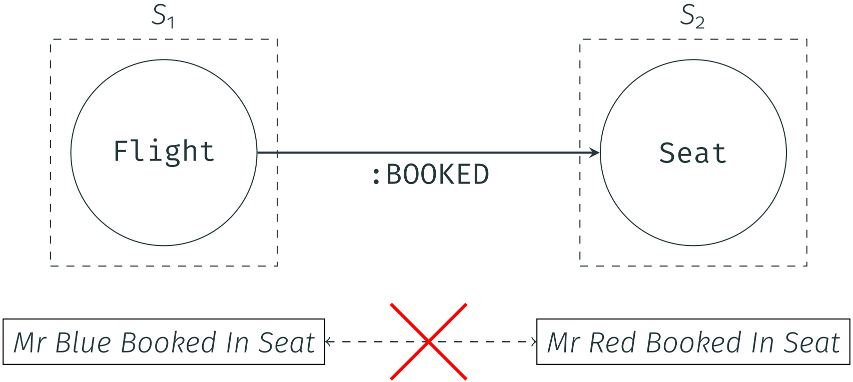

**Figure 7:** Reciprocal inconsistent distributed edge

# Distributed Edge Reciprocal Consistency

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

[3] Ezhilchelvan, P. et al, *On the degradation of distributed graph databases with eventual consistency*. European Performance Engineering Workshop 2018.

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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

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- Carefully abort transaction(s)
- No centralized control or synchronized clock
- Permits interleavings that preserve reciprocal consistency

# Collision Detection General Rules

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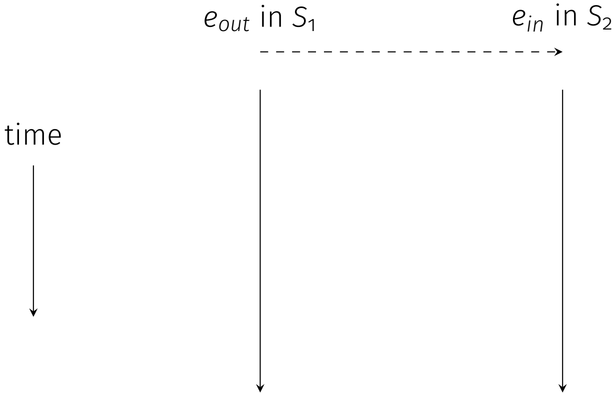
- Transactions distinguish between their first and second updates using labels
- When a transaction attempts to update a given record, it can identify all other transactions that have earlier updated that record provisionally

# Interference-free Update



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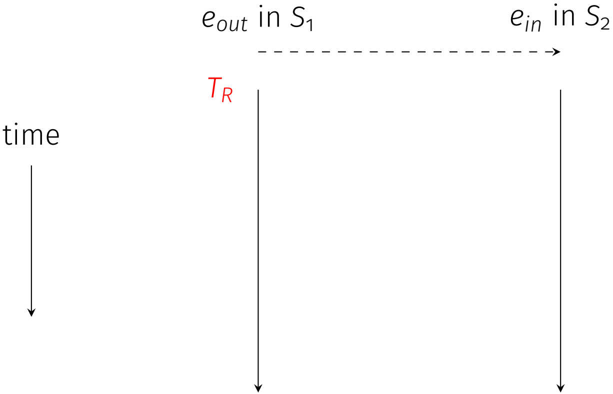

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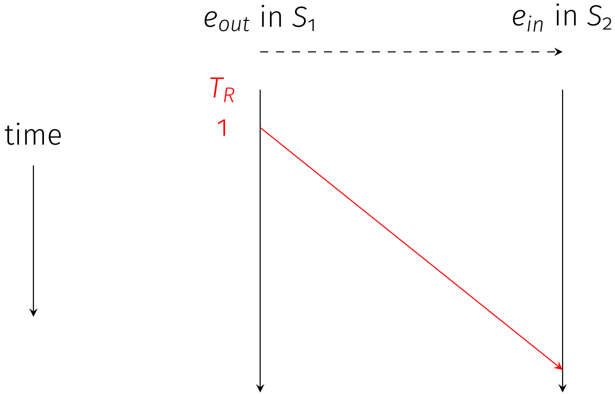

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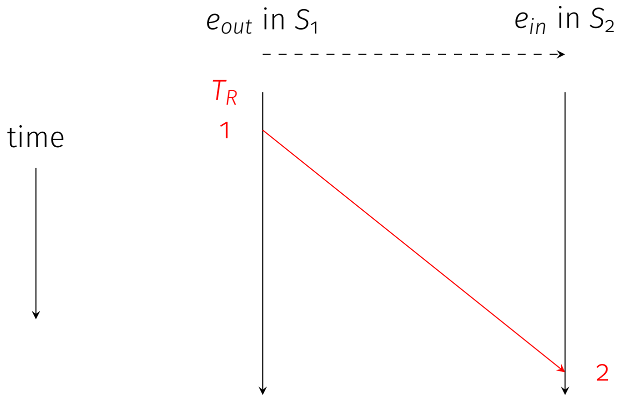

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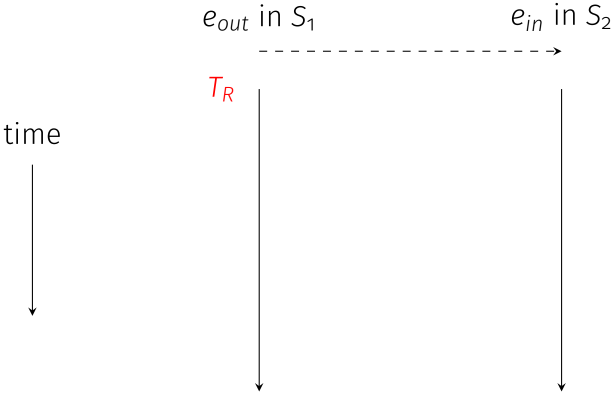

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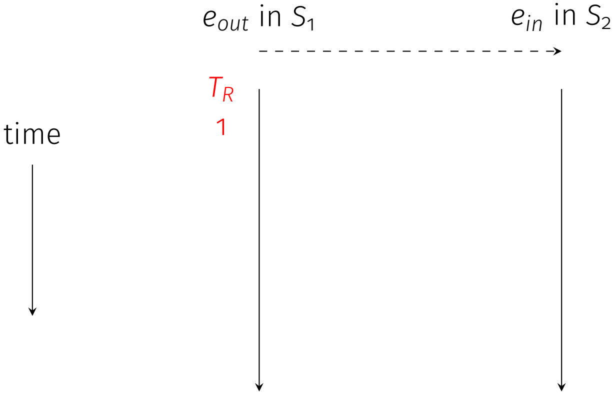

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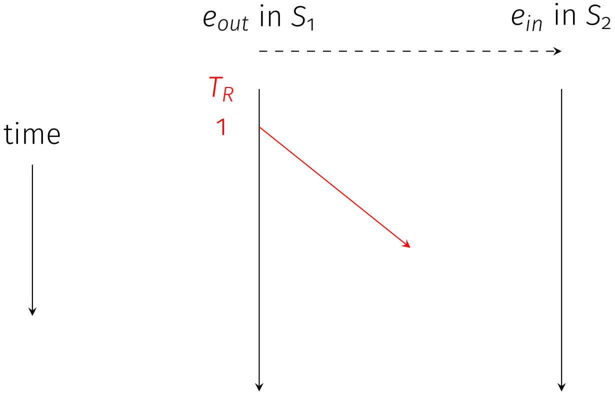

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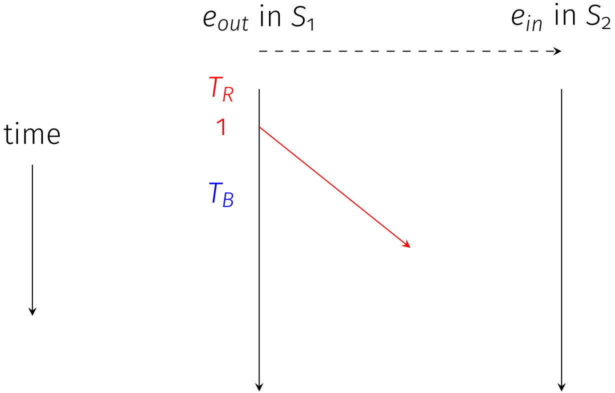

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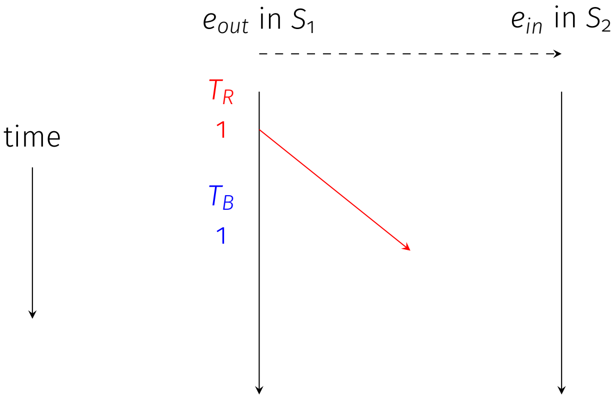

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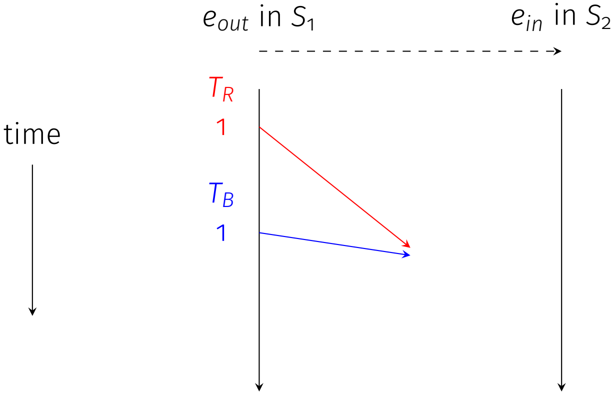

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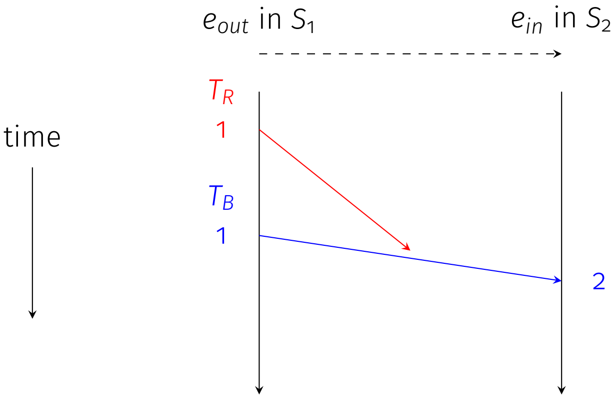

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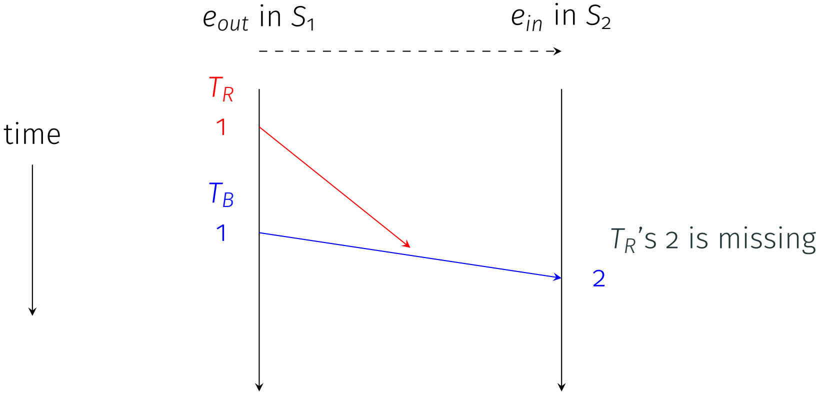

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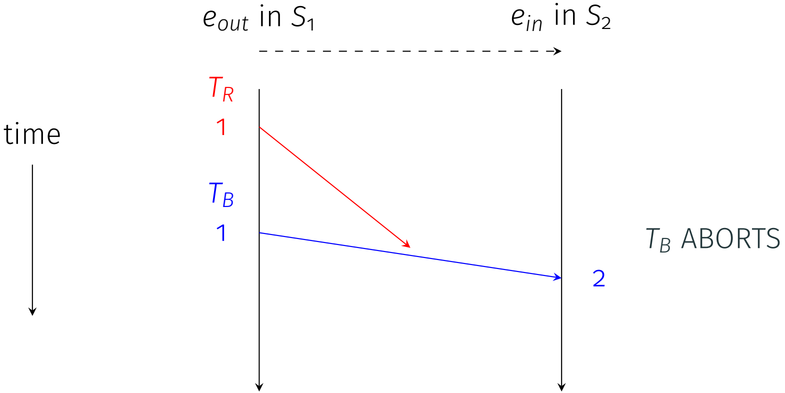

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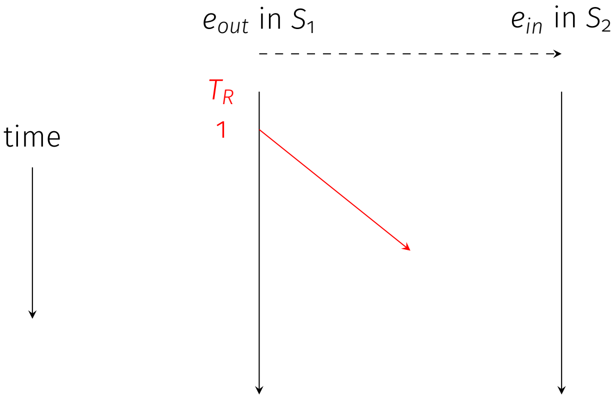

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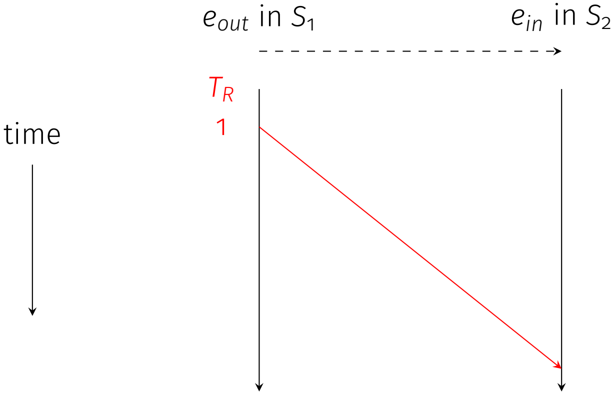

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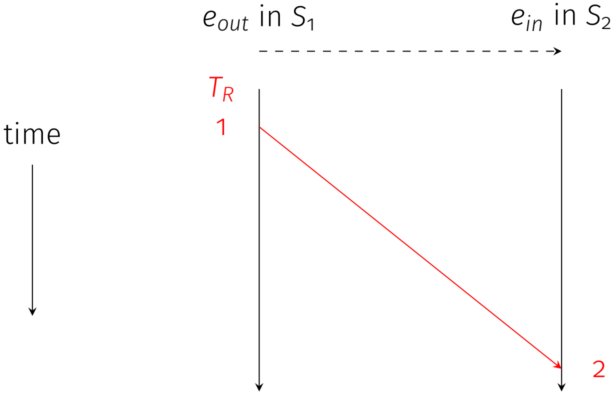

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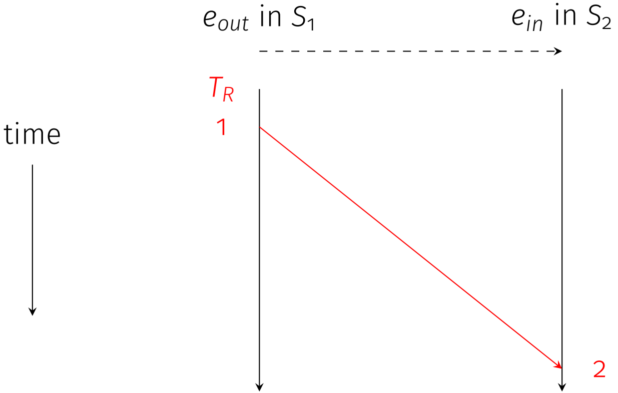

$T_R$ SUCCEEDS

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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,

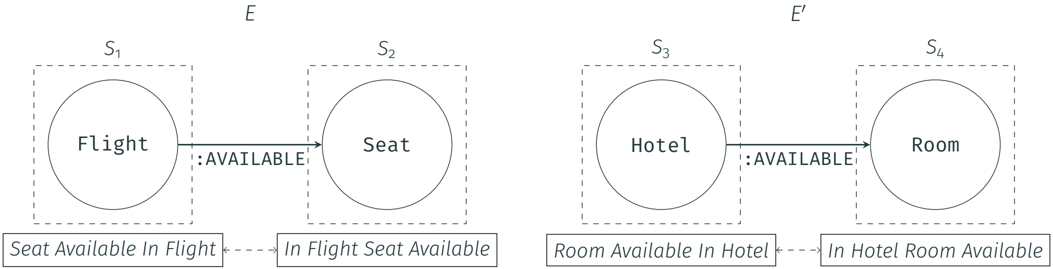

**Figure 8:** Two distributed edges

# Edge-Order Consistency Violation

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

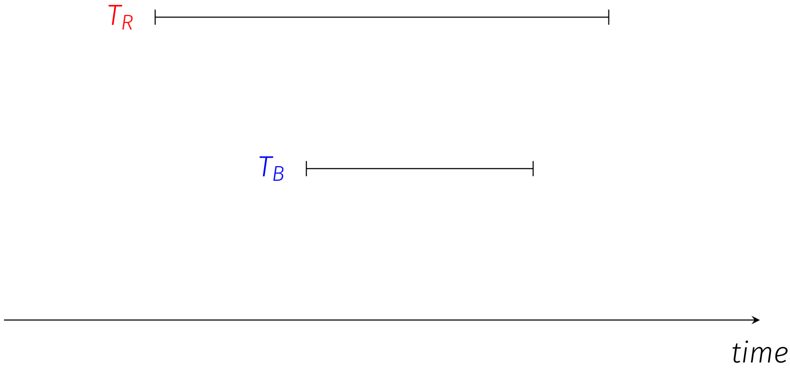

**Figure 9:** Edge-order consistency violation

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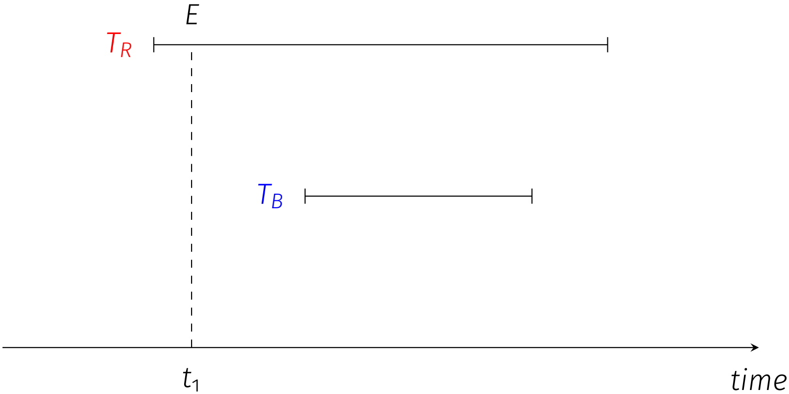

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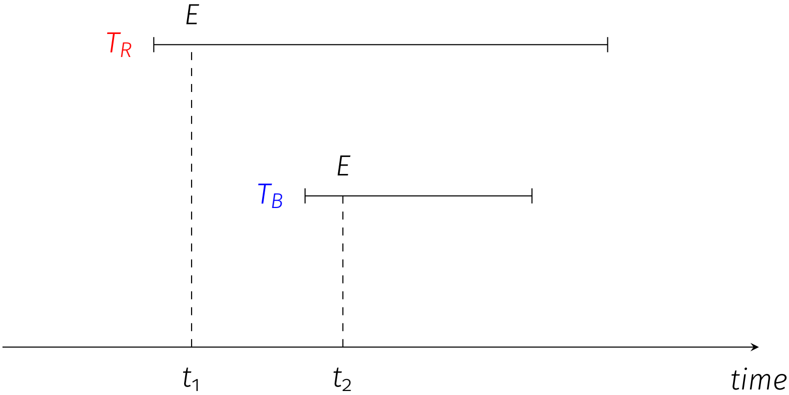

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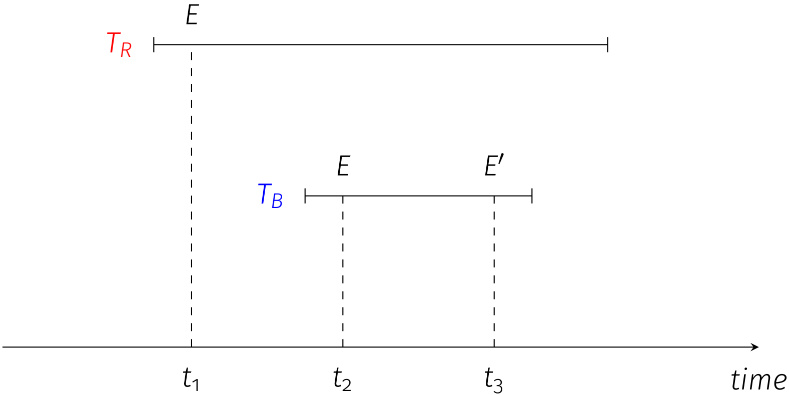

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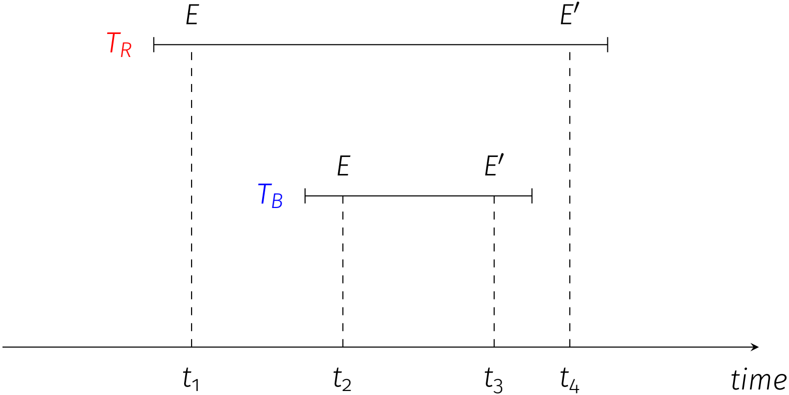

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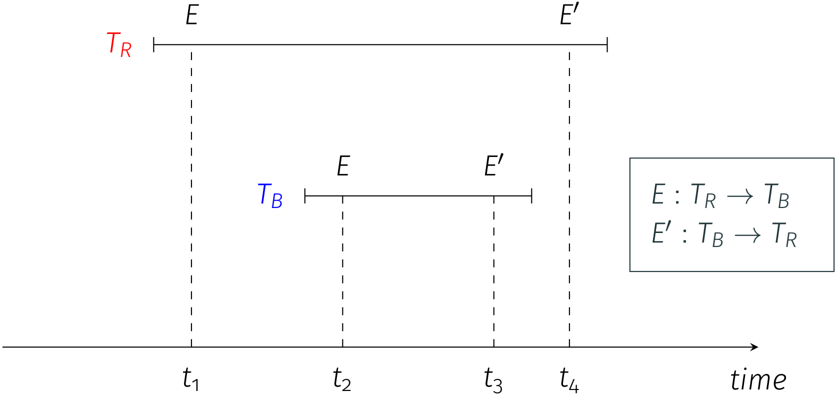

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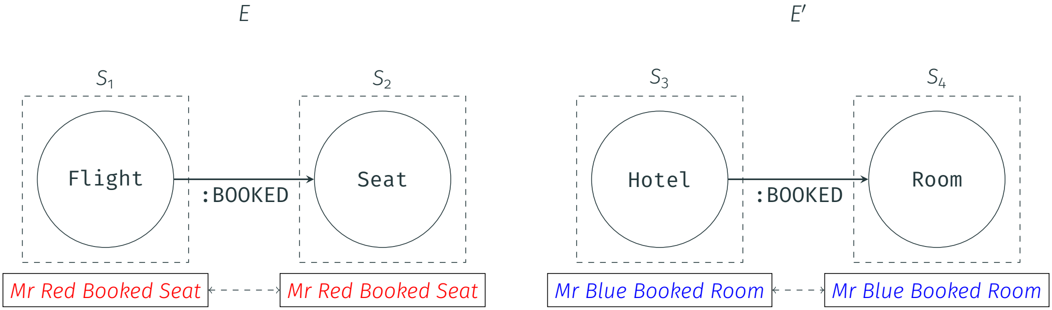

**Figure 10:** Edge-order consistency violation

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- Transactions collect predecessors from each update

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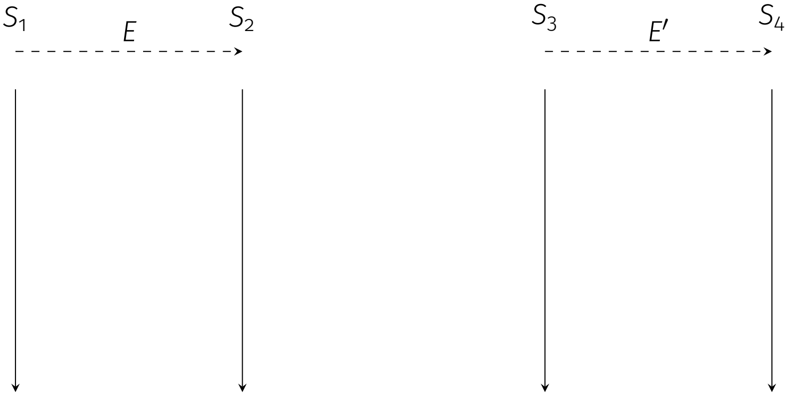
- Transactions collect predecessors from each update
- Centralized arbiter maintains some global state
- Global state used to detect edge-order violations
- Offending transactions are aborted

# Order Arbitration

Rule: Collect predecessors after every successful update



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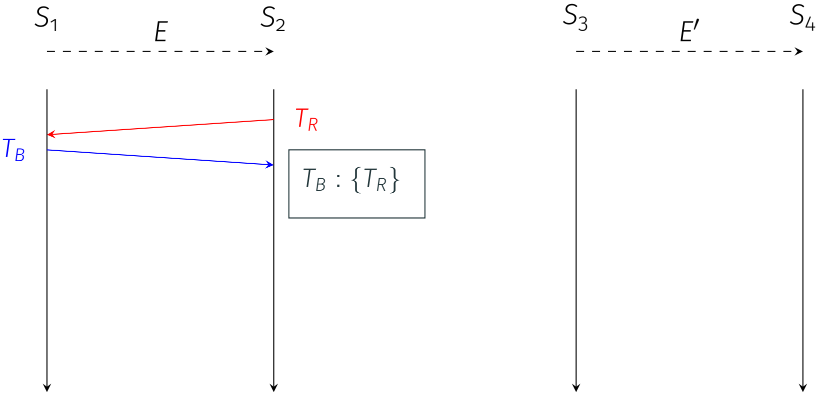

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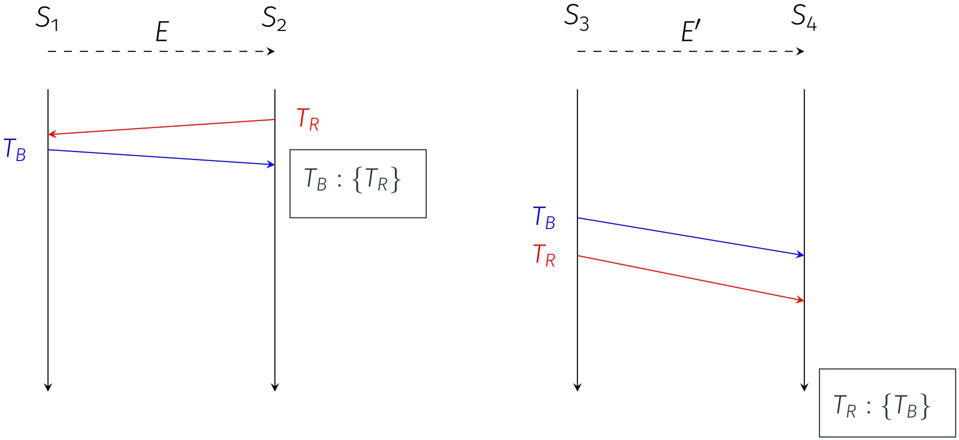

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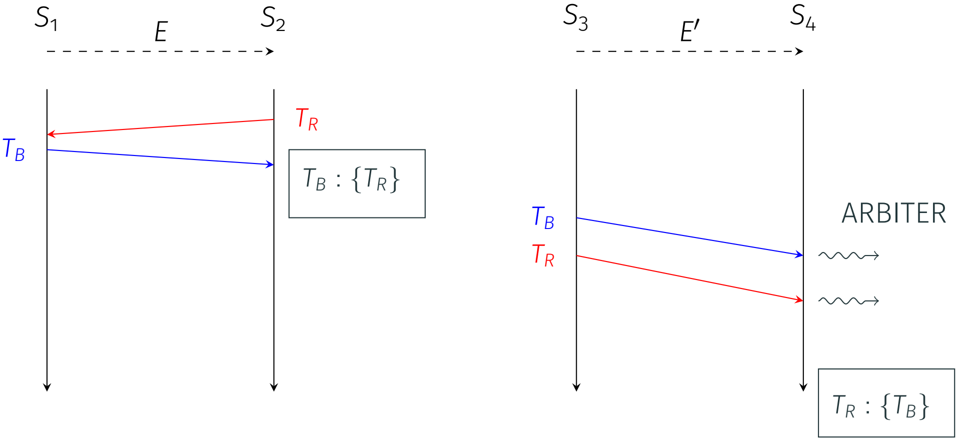

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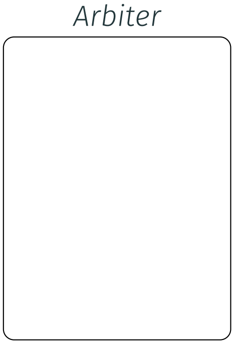
Rule: If transaction exists in hit list, abort. Else, merge predecessors into hit list



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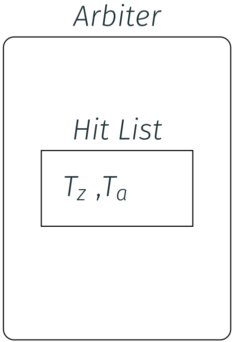

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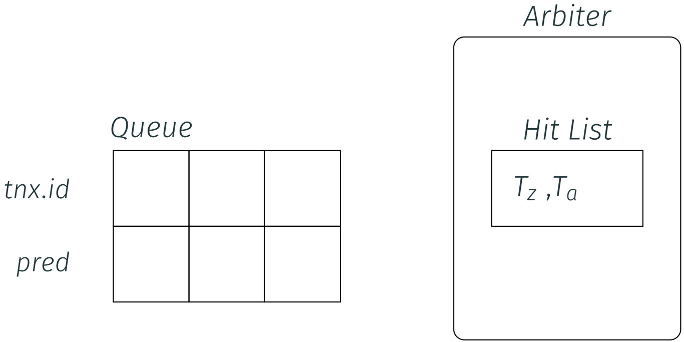

*Arbiter*

*Queue*

*tnx.id*

*pred*

*Hit List*

$T_z$ ,$T_a$

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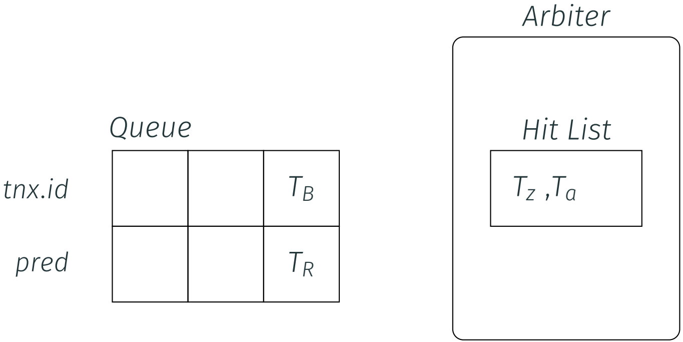

*Queue*

| | | | |
|---|---|---|---|
| *tnx.id* | | | $T_B$ |
| *pred* | | | $T_R$ |

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$T_B$ ENTERS QUEUE

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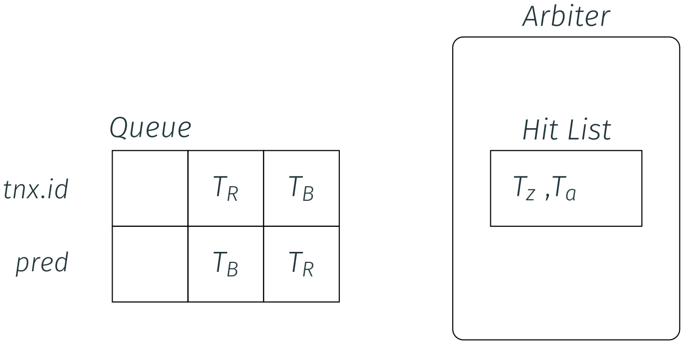

Queue

| | | | |
|---|---|---|---|
| *tnx.id* | | $T_R$ | $T_B$ |
| *pred* | | $T_B$ | $T_R$ |

$T_R$ ENTERS QUEUE

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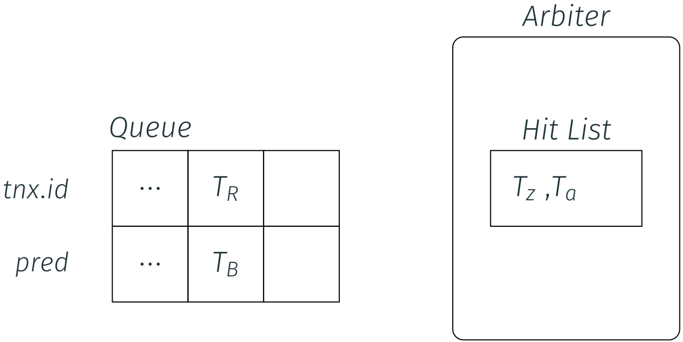

*Queue*

| | | | |
|---|---|---|---|
| *tnx.id* | $\cdots$ | $T_R$ | |
| *pred* | $\cdots$ | $T_B$ | |

$T_B$ PROCESSED

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*Queue*

| | | | |
|---|---|---|---|
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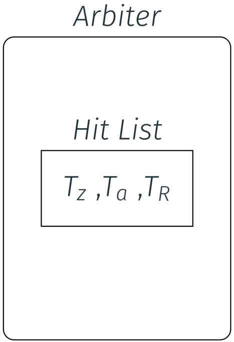

$T_B$ PROCESSED

$T_R$ ADDED TO HIT LIST

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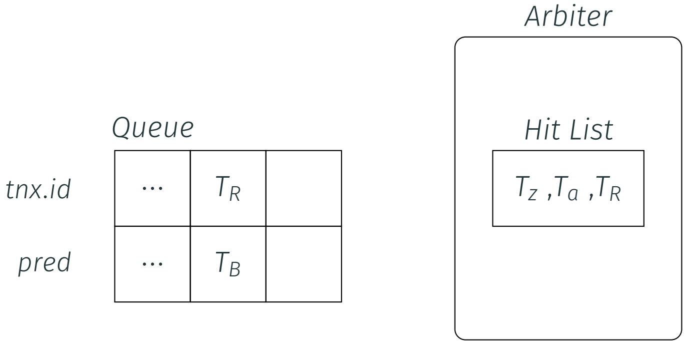


| | | | |
|---|---|---|---|
| *tnx.id* | … | $T_R$ | |
| *pred* | … | $T_B$ | |

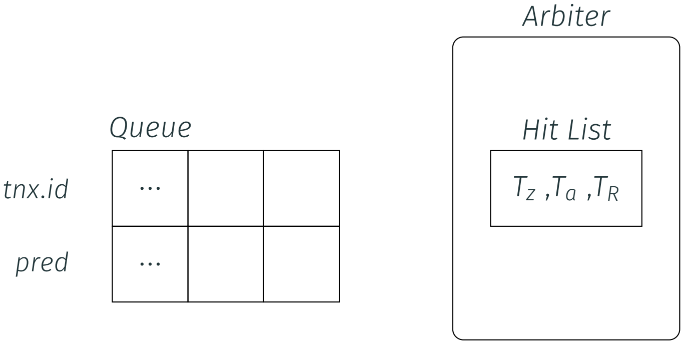
$T_B$ PROCESSED

$T_R$ ADDED TO HIT LIST

$T_B$ SUCCEEDS

# Order Arbitration

Rule: If transaction exists in hit list, abort. Else, merge predecessors into hit list



$T_R$ PROCESSED

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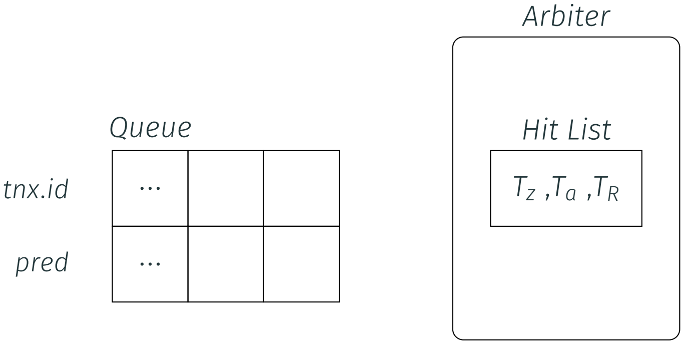

*Queue*

| | | | |
|---|---|---|---|
| *tnx.id* | ··· | | |
| *pred* | ··· | | |

*Arbiter*

*Hit List*

$T_z$ ,$T_a$ ,$T_R$

$T_R$ PROCESSED

$T_R$ IN HIT LIST

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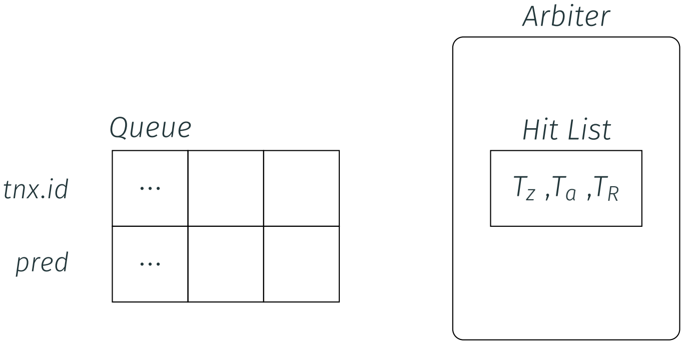

*Queue*

| | | | |
|---|---|---|---|
| *tnx.id* | $\cdots$ | | |
| *pred* | $\cdots$ | | |

$T_R$ PROCESSED

$T_R$ IN HIT LIST

$T_R$ ABORTS

# Order Arbitration Protocol

If a transaction updates 1 or more distributed edges:

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- If not in hit list then proceed and enter predecessors into the hit list
- 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 ($N$)

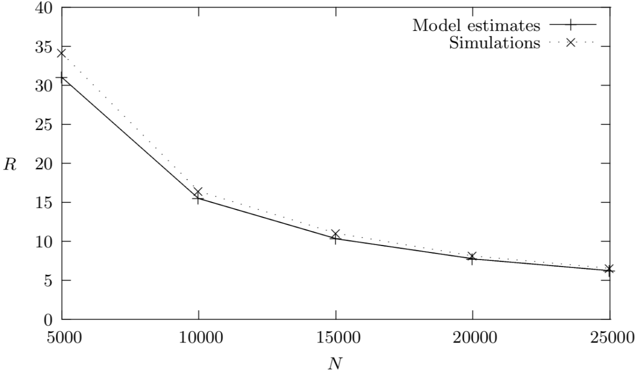

**Figure 11:** TPS $= 1000$, av updates/tnx $= 5$, av arbiter service time $= 10ms$, av network delay $= 5ms$

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

Arbiter queue unstable at $\sim$ 1500 TPS

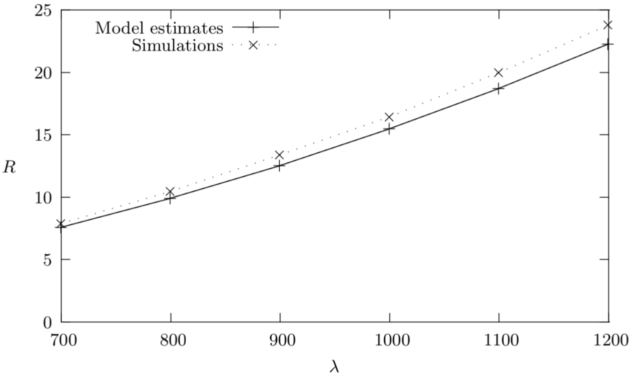

Figure 12: size $= 10K$, av updates/tnx $= 5$, av arbiter service time $= 10ms$, av network delay $= 5ms$

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

Arbiter queue unstable at $\sim$ 1100 TPS

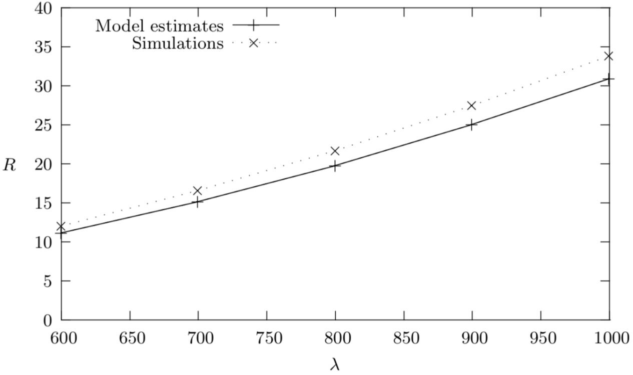

**Figure 13:** size $= 10K$, av updates/tnx $= 5$, av arbiter service time $= 10ms$, av network delay $= 10ms$

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

Arbiter queue unstable at $\sim$ 550 TPS

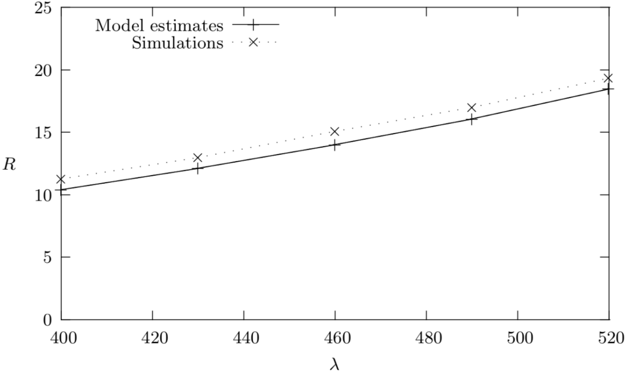

**Figure 14:** size $=$ 10$K$, av updates/tnx $=$ 10, av arbiter service time $=$ 10$ms$, av network delay $=$ 5$ms$

# Summary and Future Work

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

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# 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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