MDCC: Multi-Data Center Consistency

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Outline

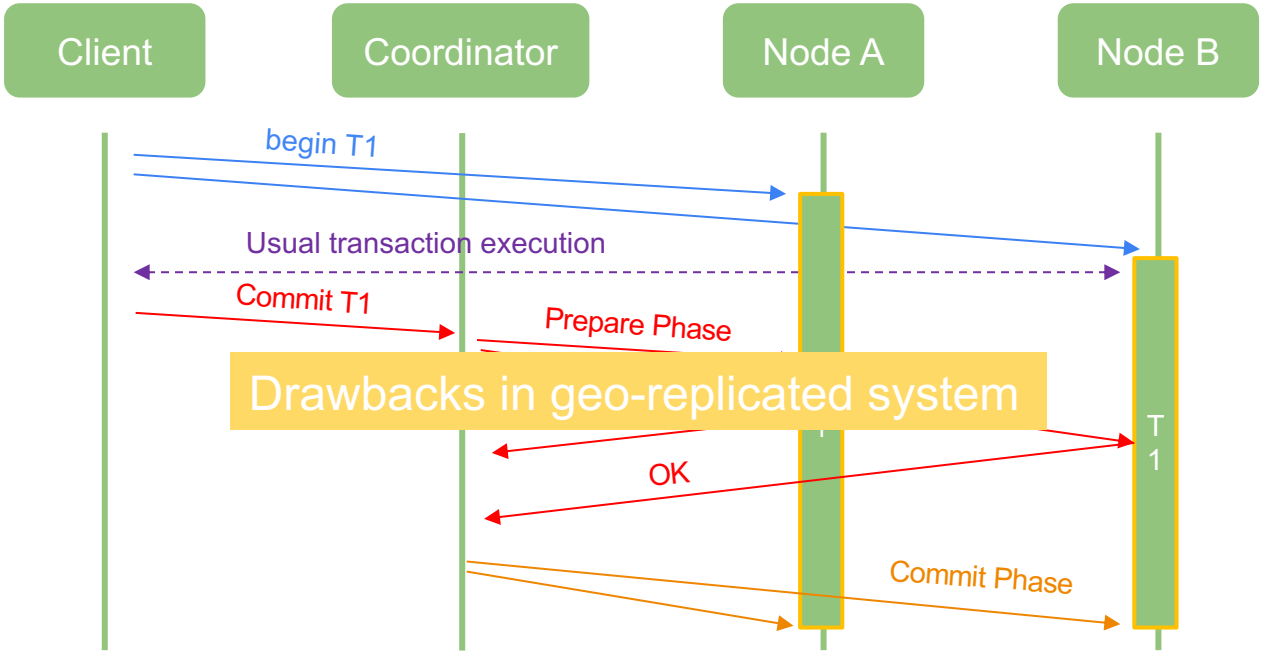
- **Introduction**
- **Classic Paxos**
- **MDCC**
  - Transaction Support
    - Multi-Paxos
  - Transactions Bypassing the Master
    - Fast Paxos
  - Commutative Updates
    - Generalized Paxos
- **Consistency Guarantees**
- **Evaluation**
- **Conclusion**

Introduction

- Databased Backed Application
  - Replicate data across multiple data centers
  - Keep replicas synchronized and consistent
- Geo-Replication
  - High network latency
  - Need to reduce the number of message round-trips

Background– 2 Phase Commit (2PC)

- Two Phases : Prepare Phase + Commit Phase



Background - Paxos

- Google Mega-store / Google Spanner / Paxos-CP
  - Based on Paxos
  - Scalability bottleneck

- Still rely on 2 phase commit
- Require 2 message rounds

MDCC (Multi-Data Center Consistency)

an optimistic commit protocol for geo-replicated transactions.

MDCC - Multi-Data Center Consistency

- Requires only 1 message round
- Strong consistency
- Low latency

Classic Paxos

Paxos Basics

What is Paxos?

Achieving consensus among replicas

Features of Paxos

- Tolerate failures
  - Lost, duplicated, re-ordered messages
- Not consider Byzantine problem

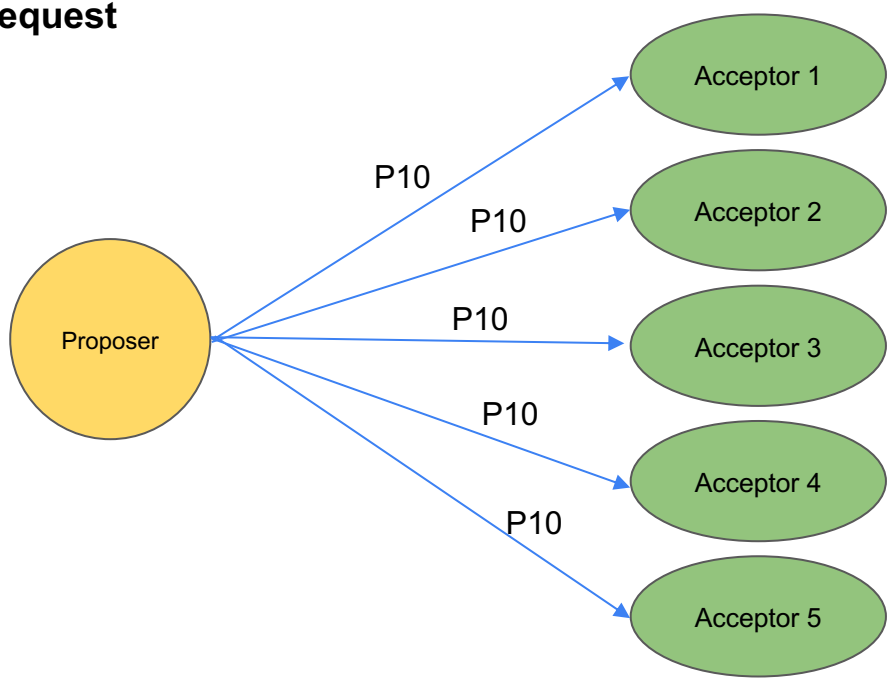
Paxos Basics

Paxos define four roles:

- Clients (app-servers)
- Proposers (masters)
- Acceptors (storage nodes)
- Learners (all nodes)

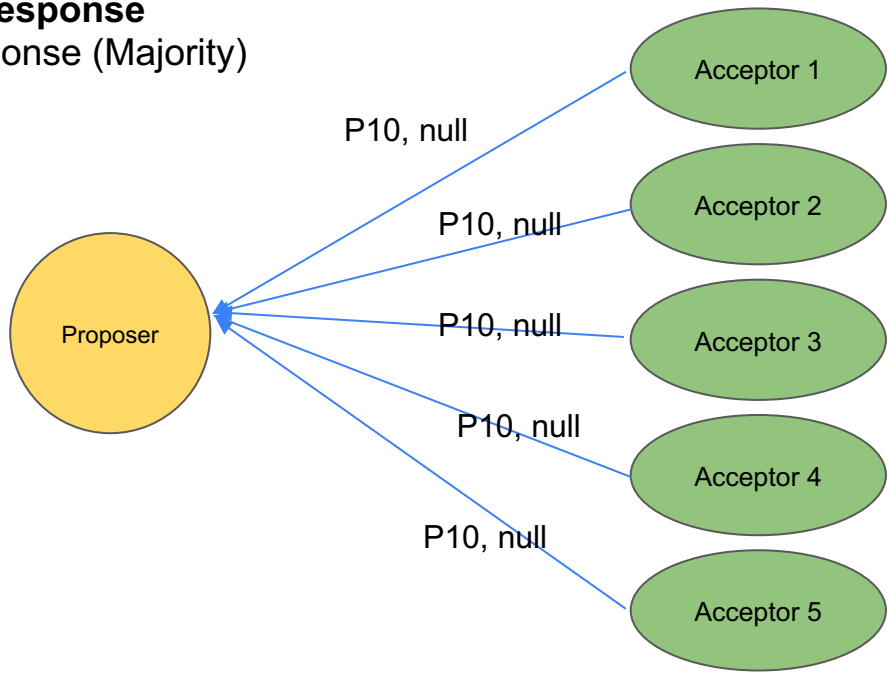
Classic Paxos - Prepare phase

Proposer sends prepare request



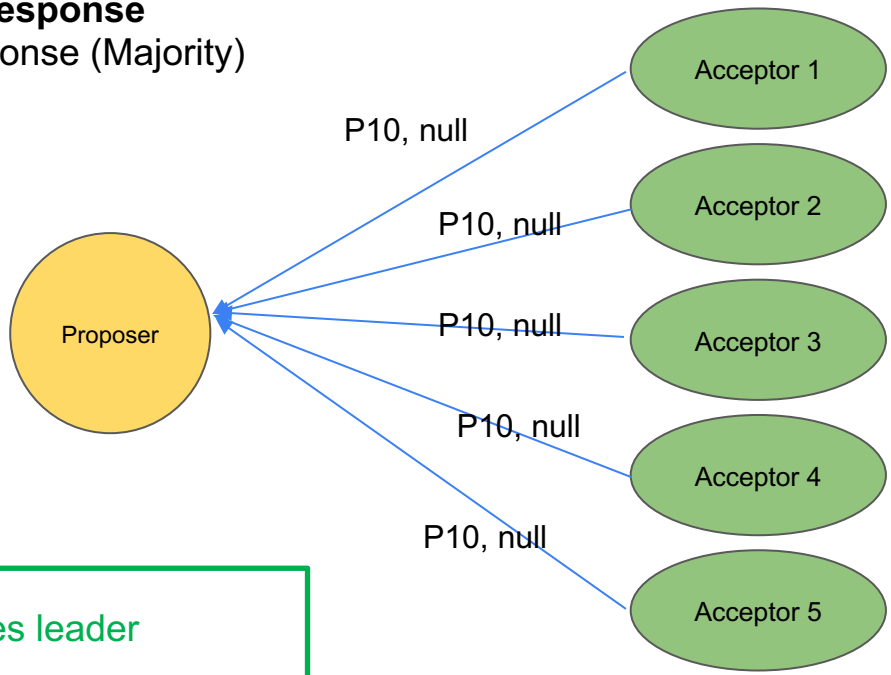
Classic Paxos - Prepare phase

Acceptors send prepare response
More than 3 Acceptors response (Majority)



Classic Paxos - Prepare phase

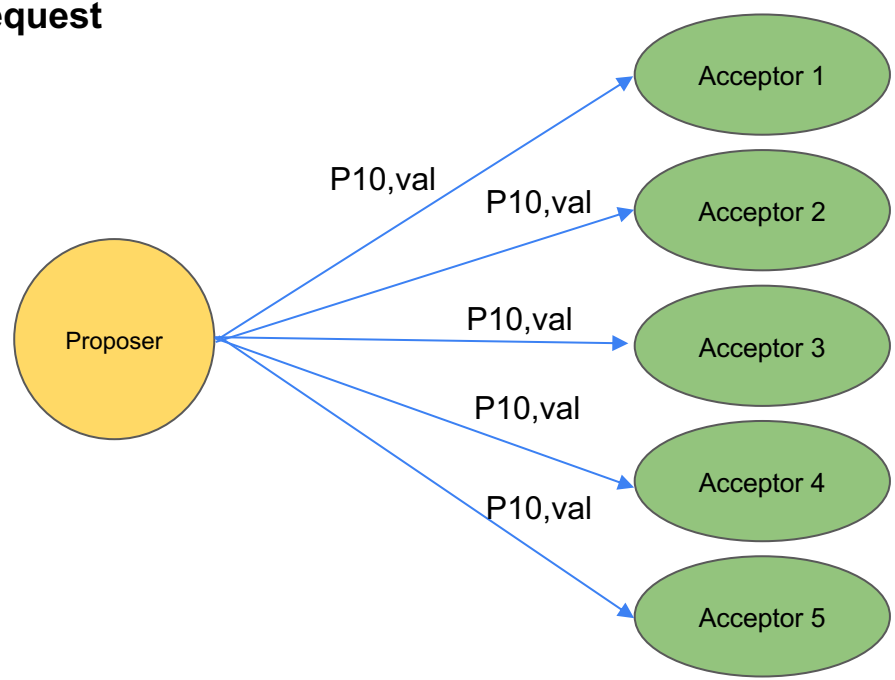
Acceptors send prepare response
More than 3 Acceptors response (Majority)



Proposer becomes leader

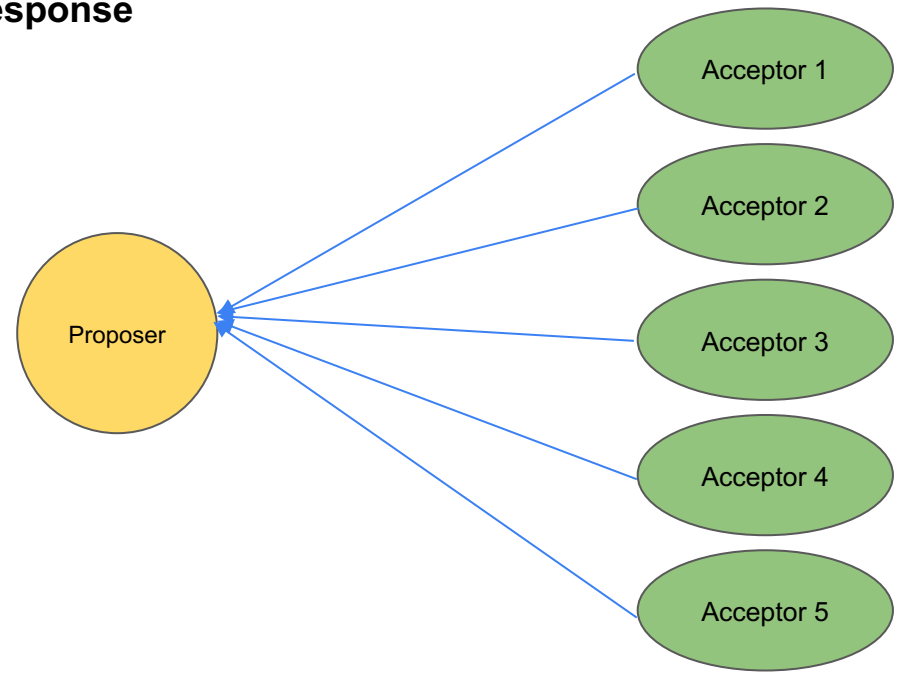
Classic Paxos - Accept phase

Proposer sends accept request



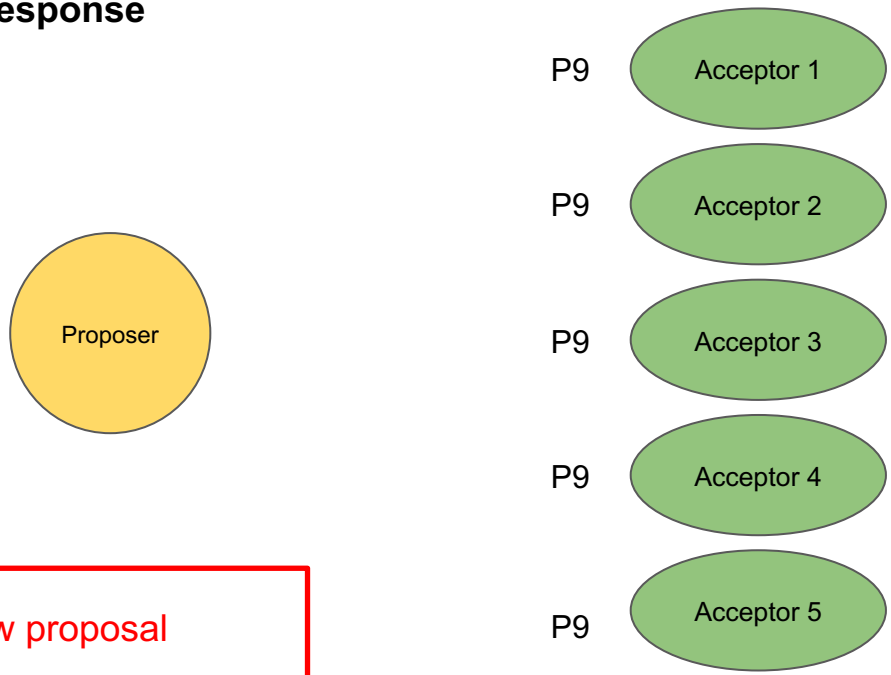
Classic Paxos - Accept phase

Acceptors send accept response



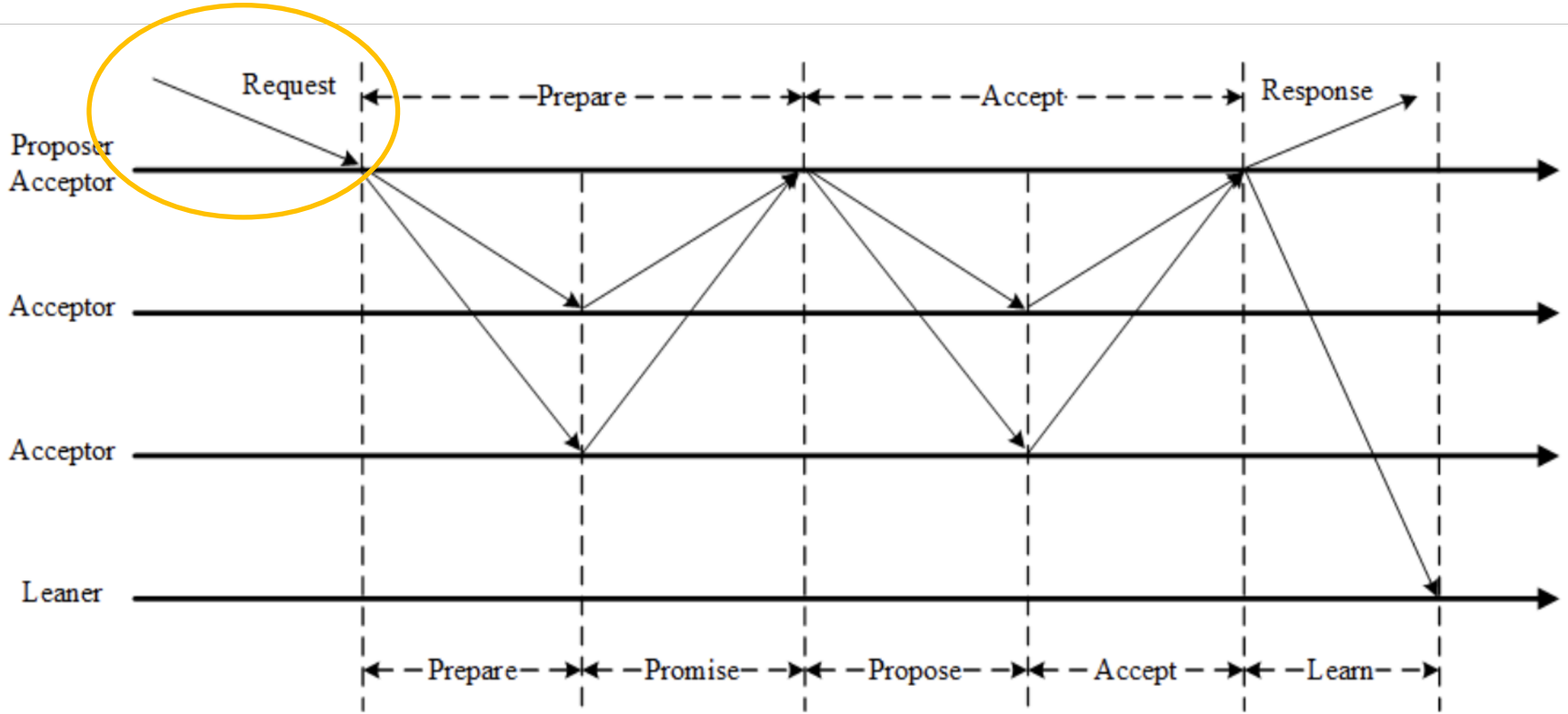
Classic Paxos - Prepare phase

Acceptors send prepare response



Time out! Send new proposal

Classic Paxos



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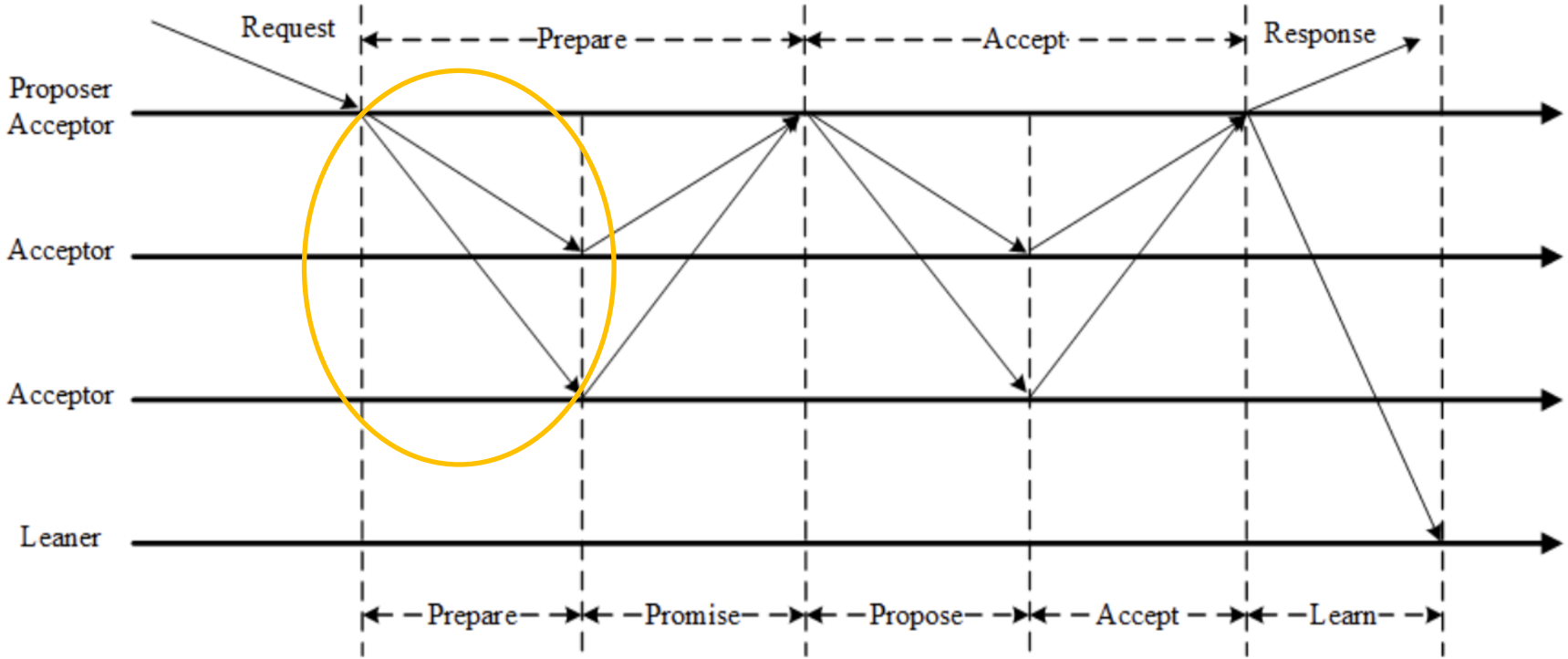

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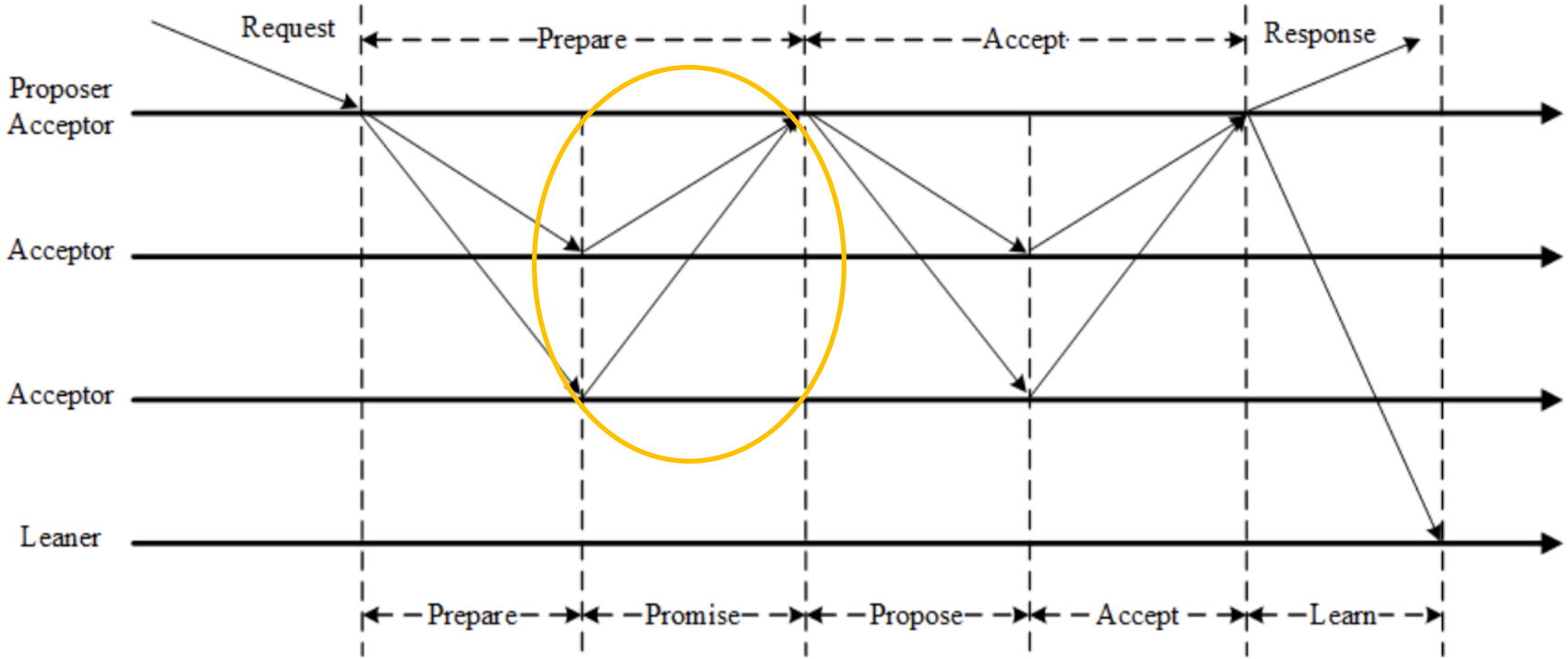
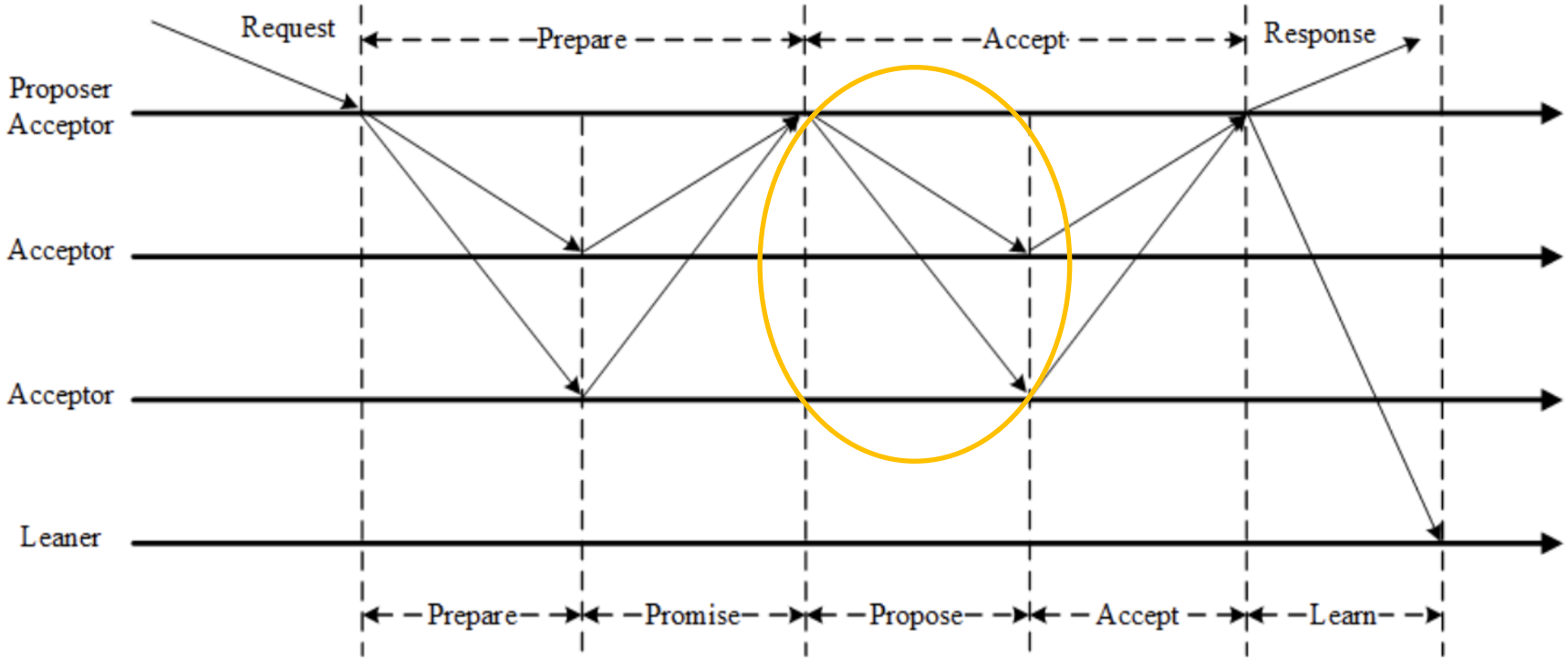
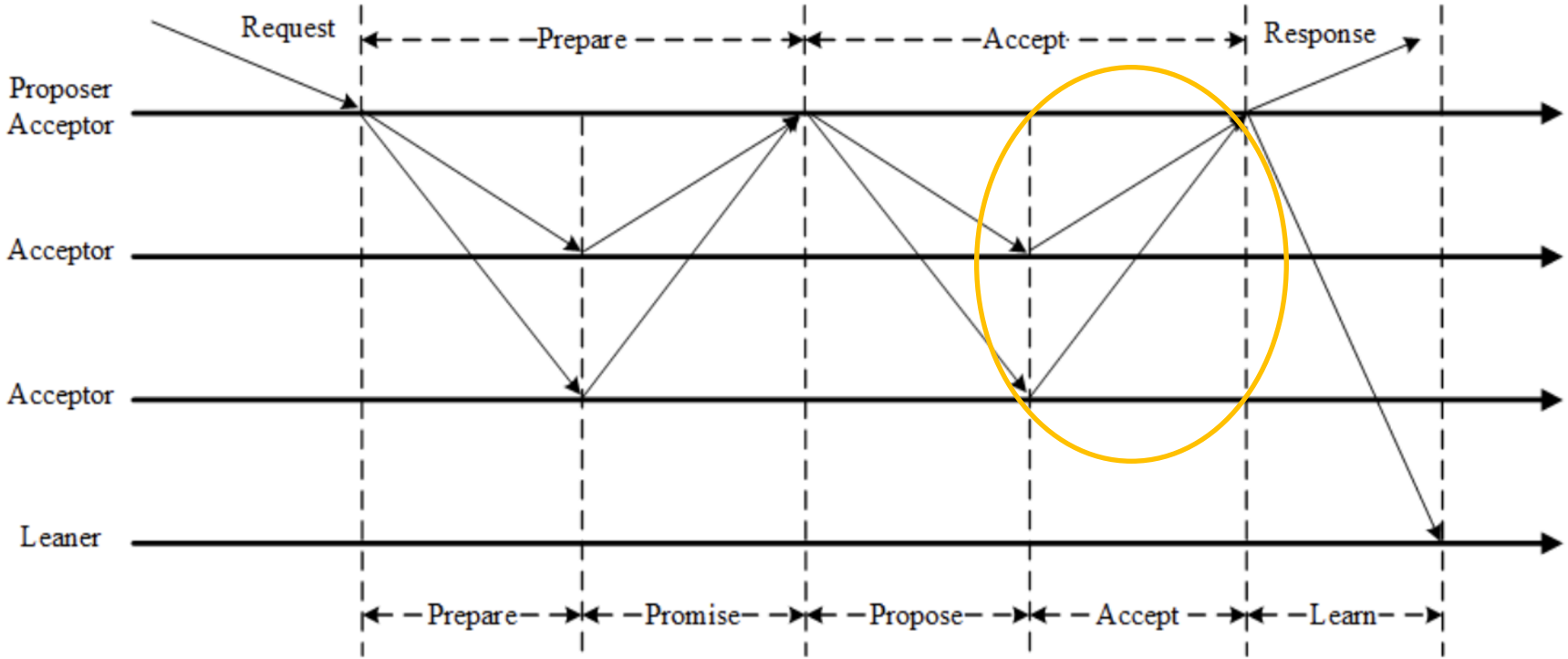


Classic Paxos



Classic Paxos



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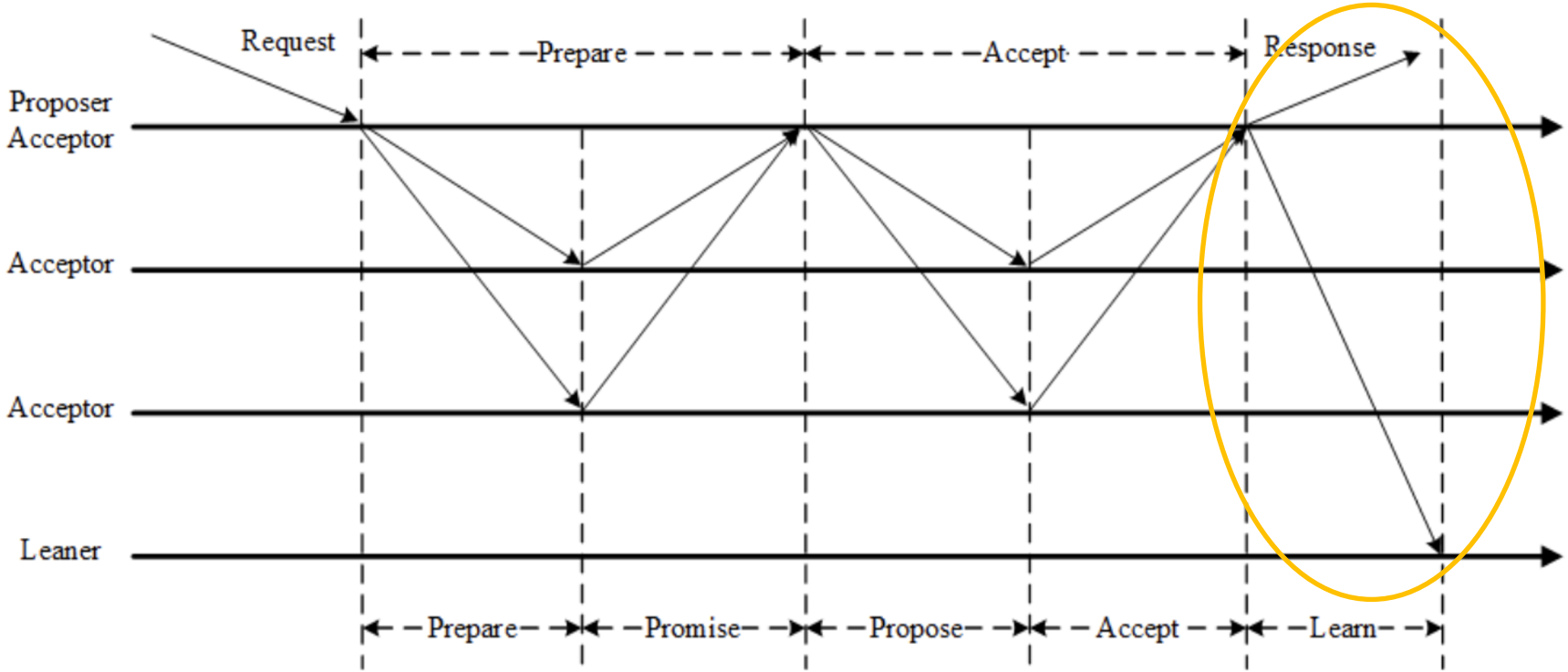
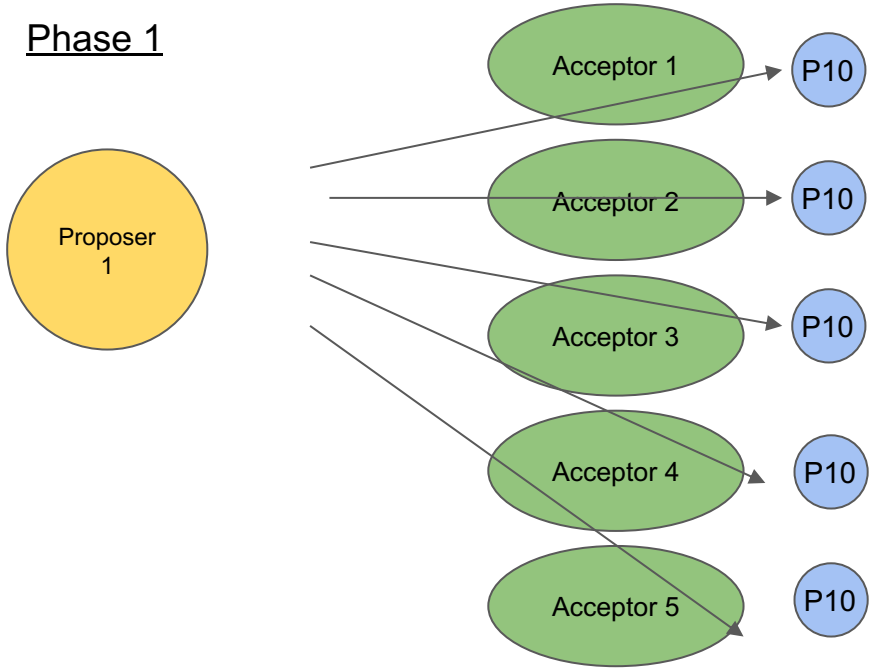


Multi-Paxos

Multi-Paxos

- Reserve Leadership
  - One Phase 1 of Classic Paxos
  - Write quickly with only Phase 2



No need in the future !

MDCC - Transactions Support

Transaction Support

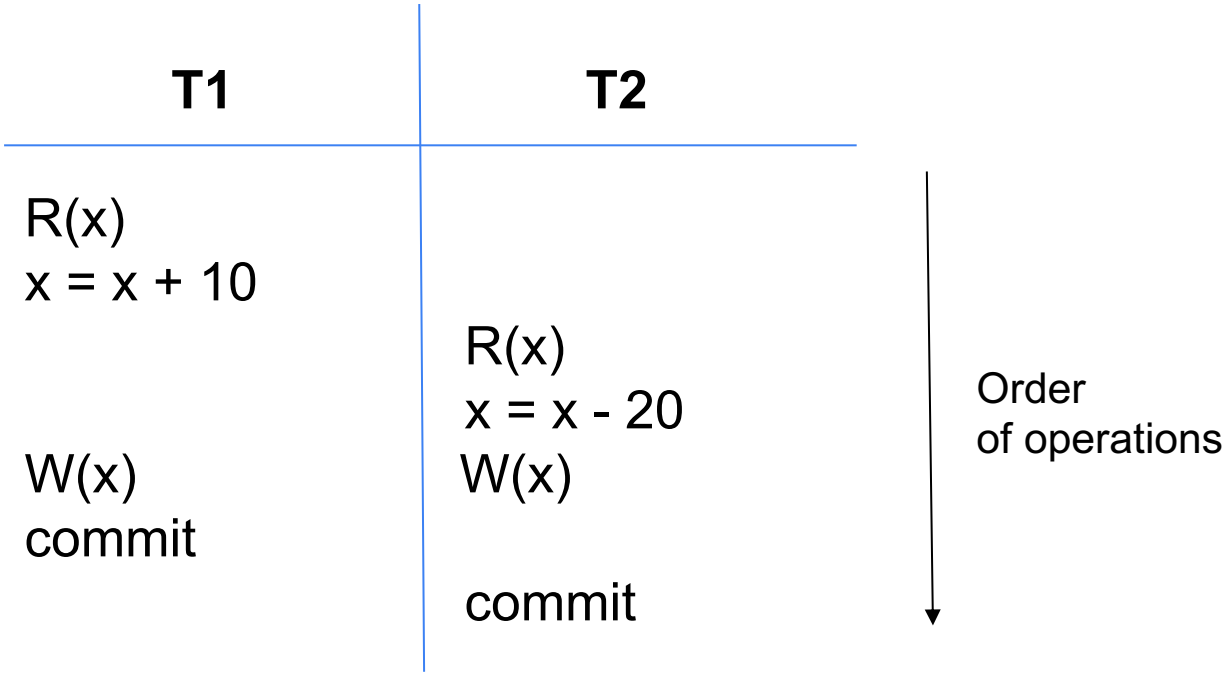
- Extension of Multi-Paxos supports multi-record transactions
  - Ensure **atomic durability**
  - Detect **write-write conflict**

- To guarantee consistency
  - Accept an ***option***
    - Not writing value directly
    - After committing transaction, notify storage nodes to execute options

Write – Write Conflict

Write-write conflict

Database x: 100



Write-write conflict

Database x: 100

T1		T2
R(x)	100	
x = x + 10		
		R(x)
		x = x - 20
W(x).		W(x)
commit		
		commit

Write-write conflict

Database x: 100

T1		T2
R(x)	100	
x = x + 10	110	
		R(x)
		x = x - 20
W(x)		W(x)
commit		
		commit

Write-write conflict

Database x: 100

T1		T2	
R(x)	100		
x = x + 10	110		
		R(x)	100
		x = x - 20	
W(x)		W(x)	
commit			
		commit	

Write-write conflict

Database x: 100

T1		T2	
R(x)	100		
x = x + 10	110		
		R(x)	100
		x = x - 20	80
W(x)		W(x)	
commit			
		commit	

Write-write conflict

Database x: 100

T1		T2	
R(x)	100		
x = x + 10	110		
		R(x)	100
		x = x - 20	80
W(x)	110	W(x)	80
commit			
		commit	

Write-write conflict

Database x: 110

T1		T2	
R(x)	100		
x = x + 10	110		
		R(x)	100
		x = x - 20	80
W(x)	110	W(x)	80
commit	110		
		commit	

Write-write conflict

Database x: 80

T1		T2	
R(x)	100		
x = x + 10	110		
		R(x)	100
		x = x - 20	80
W(x)	110	W(x)	80
commit	110		
		commit	80

Write-write conflict - Solution

Two Phase Lock

- Shared lock (Read lock)
  - read data items only
- Exclusive lock (Write lock)
  - read and write data items
  - owned by only one transaction at a time

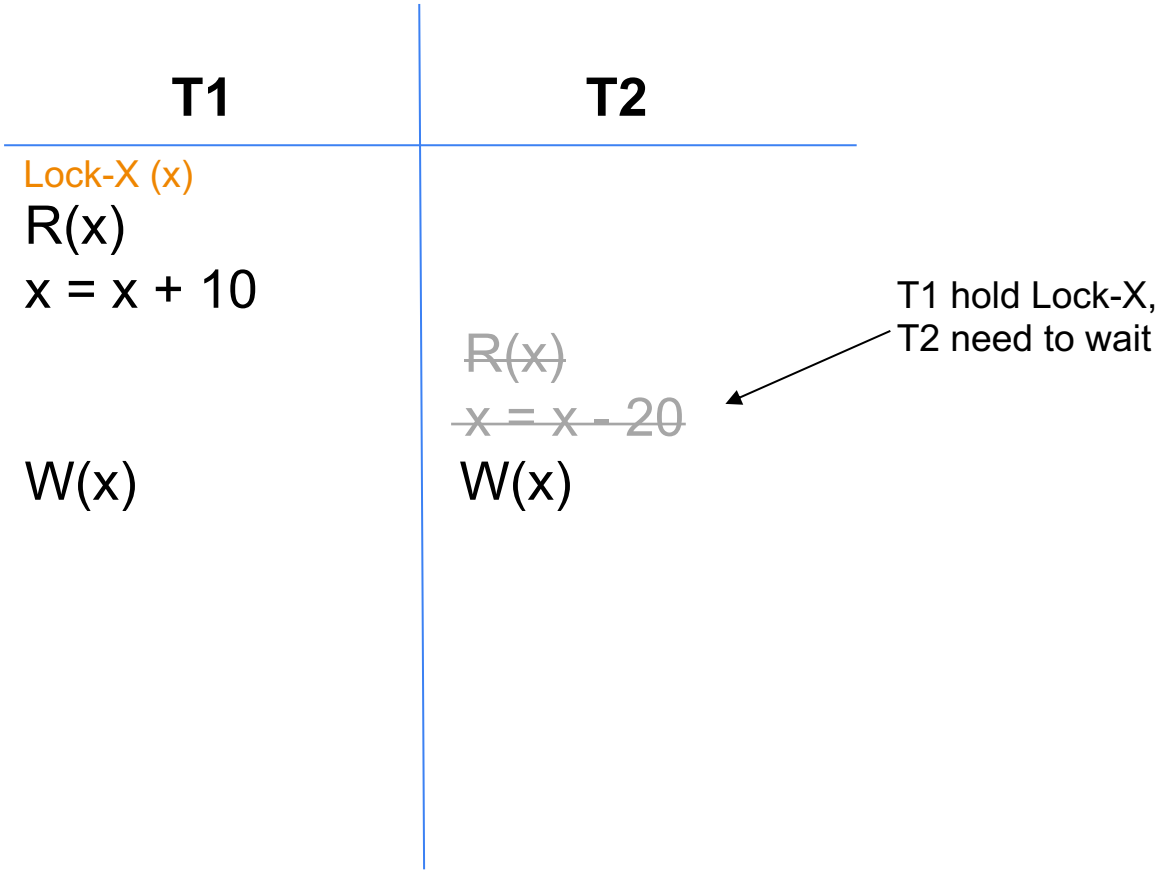
Write-write conflict - Solution

Database x: 100
T1: x = x + 10
T2: x = x - 20

T1	T2
Lock-X (x)	
R(x)	
x = x + 10	
	R(x)
	x = x - 20
W(x)	
	W(x)

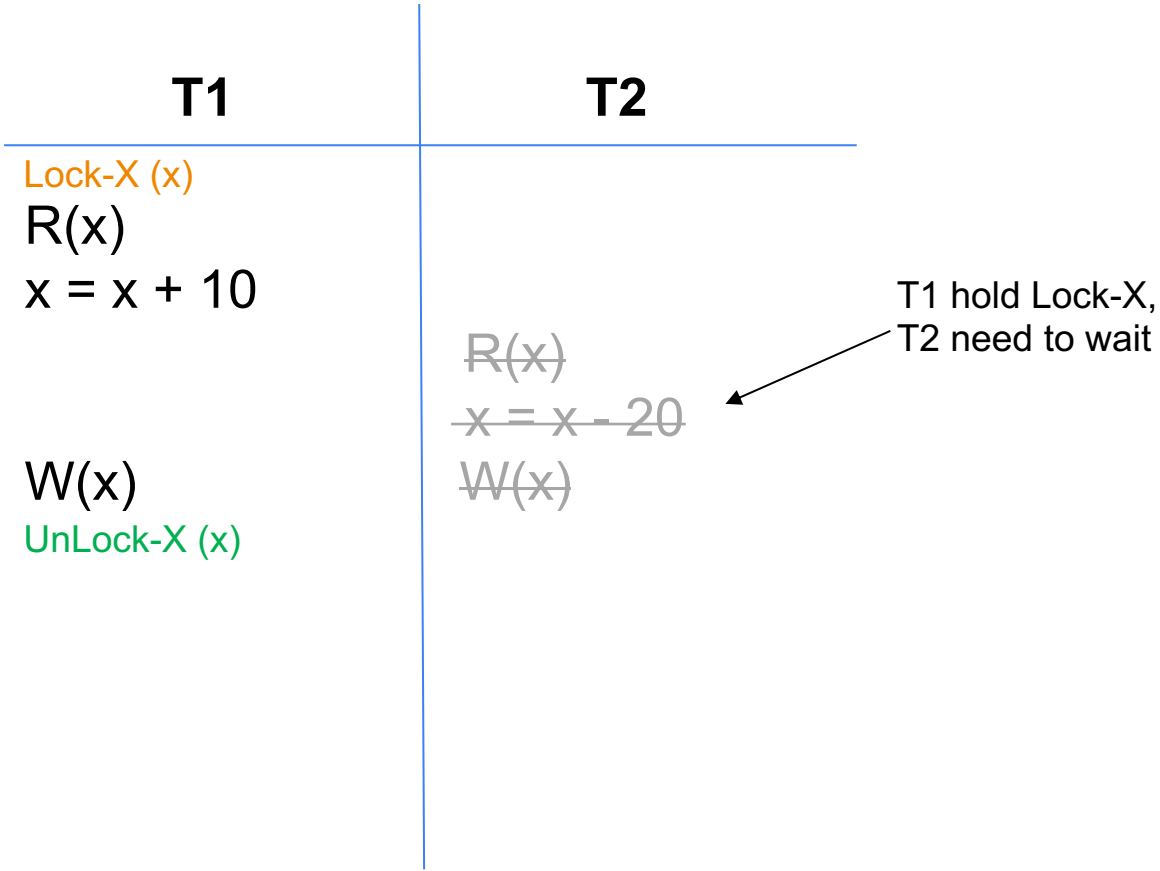
Write-write conflict

Database x: 100
T1: x = x + 10
T2: x = x - 20



Write-write conflict

Database x: **110**
T1: x = x + 10
T2: x = x - 20



Write-write conflict

Database x: ~~110~~ **90**
T1: x = x + 10
T2: x = x - 20

T1	T2
Lock-X (x)	
R(x)	
x = x + 10	
	~~R(x)~~
	~~x = x - 20~~
W(x)	~~W(x)~~
UnLock-X (x)	
	Lock-X (x)
	R(x)
	x = x - 20
	W(x)
	UnLock-X (x)

T1 hold Lock-X,
T2 need to wait

Deadlocks

Deadlocks

- Two Phase Lock might cause deadlocks

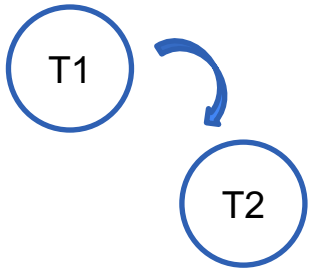
Deadlocks

T1	T2	T3
Lock-S(A)		
	Lock-X(B)	
		Lock-S(C)

Deadlocks

T1	T2	T3
Lock-S(A)		
	Lock-X(B)	
		Lock-S(C)
Lock-S(B)		

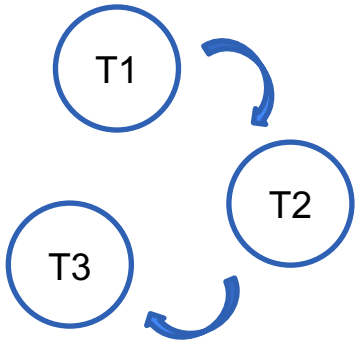
Wait-for-graph



Deadlocks

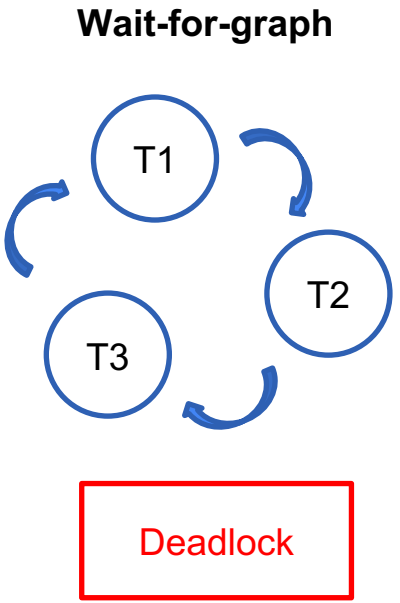
T1	T2	T3
Lock-S(A)		
	Lock-X(B)	
		Lock-S(C)
Lock-S(B)		
	Lock-X(C)	

Wait-for-graph



Deadlocks

T1	T2	T3
Lock-S(A)		
	Lock-X(B)	
		Lock-S(C)
Lock-S(B)		
	Lock-X(C)	
		Lock-X(A)



Deadlocks

- Two Phase Lock might cause deadlocks
- Deadlocks detection
  - Use Wait-for-graph
  - Abort one transaction to break cycle

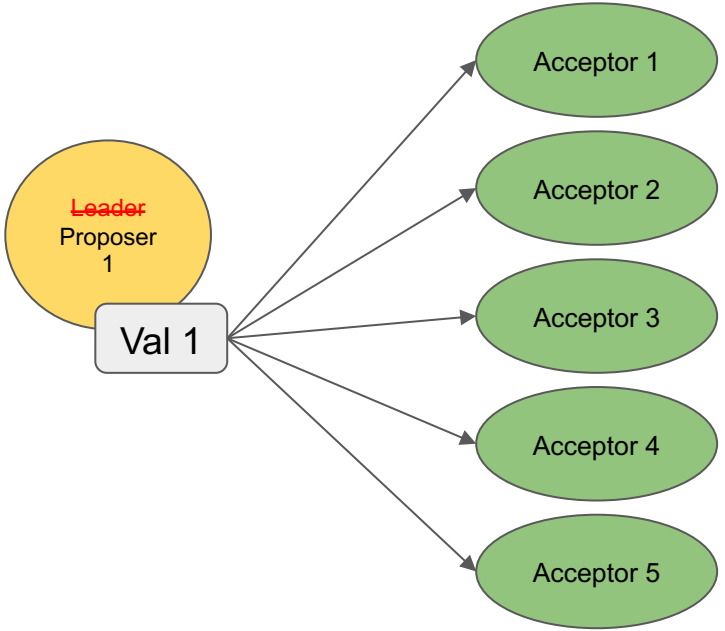
Protocol - Failure Scenarios

- Storage nodes failure
  - Solution: Be masked by the use of quorums
- Master failure
  - Solution
    - Be recovered by selecting new master
    - Trigger Phase 1 and Phase 2
- App-server failure
  - **Dangling transaction**
  - Solution
    - **Unique transaction-id**, **primary keys of write-set**, **log of learned options**
    - Reconstruct the node

Fast Paxos

Fast Paxos

- Does not require leadership
  - Any client / proposer can write values to the acceptors without becoming the leader
- Need larger quorum size
  - Classic : [N/2] responses
  - Fast : [2N/3] + 1 responses
  - For a value to be safely written
- Need more time to resolve conflicts



Fast Paxos – Resolve Conflicts

- Concurrent updates might cause collision
- Leader must step in to resolve conflicts
- 2 additional message rounds to resolve conflicts
- Need 3 message rounds

MDCC - Transactions Bypassing the Master

Protocol - MDCC use Fast Ballots Approach

1. All versions starts with a Fast Ballot number
2. This ballot number informs acceptors to accept next options from any Proposers
3. Clients can propose option **directly** to the acceptor.
4. Storage node accept the **first** proposed option

MDCC – Fast Policy

Fast Policy – Trade-offs

- Classic instances
  - Require 2 message rounds

- Fast instances
  - Require only 1 message round
  - Collision : will require another 2 message rounds

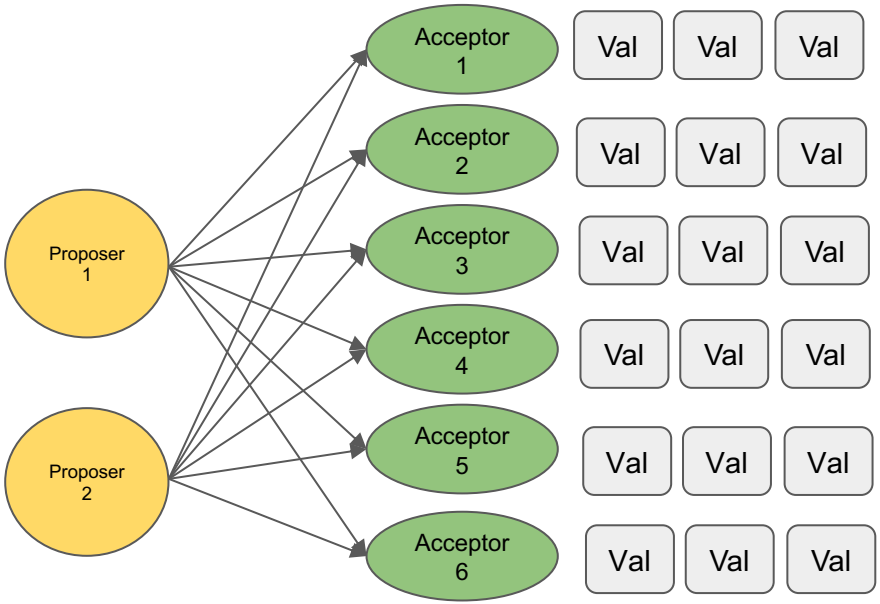
Fast Policy - Strategy

- Pre-set all instances to fast
- Detect a collision and set the next instances to classic.
- After resolving conflicts, go back to fast instance.

Generalized Paxos

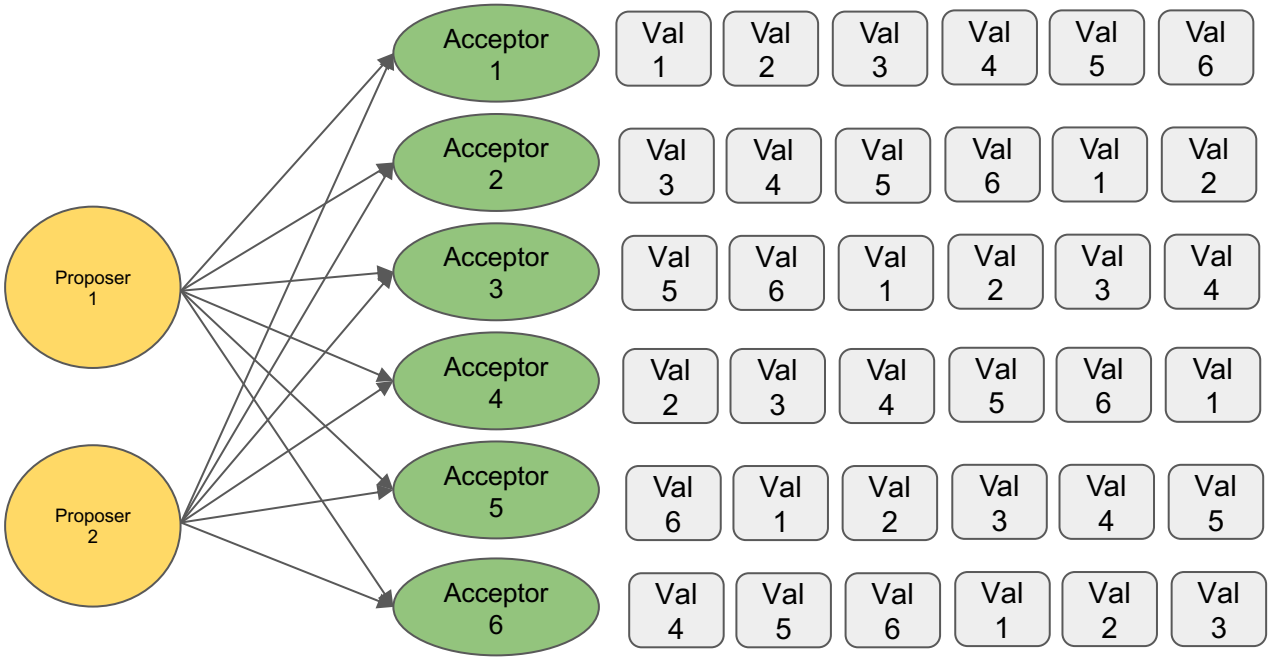
Generalized Paxos

- Combines Classic Paxos and Fast Paxos.
- Each round accepts a sequence of values.



Generalized Paxos

- **Compatibility of sequences** -> To detect conflicts.



Generalized Paxos - Example

- Proposed operations need to be commutative operations.

Commutativity Table

	Read(A)	Write(A)	Read(B)	Write(B)
Read(A)		✗		
Write(A)	✗	✗		
Read(B)				✗
Write(B)			✗	✗

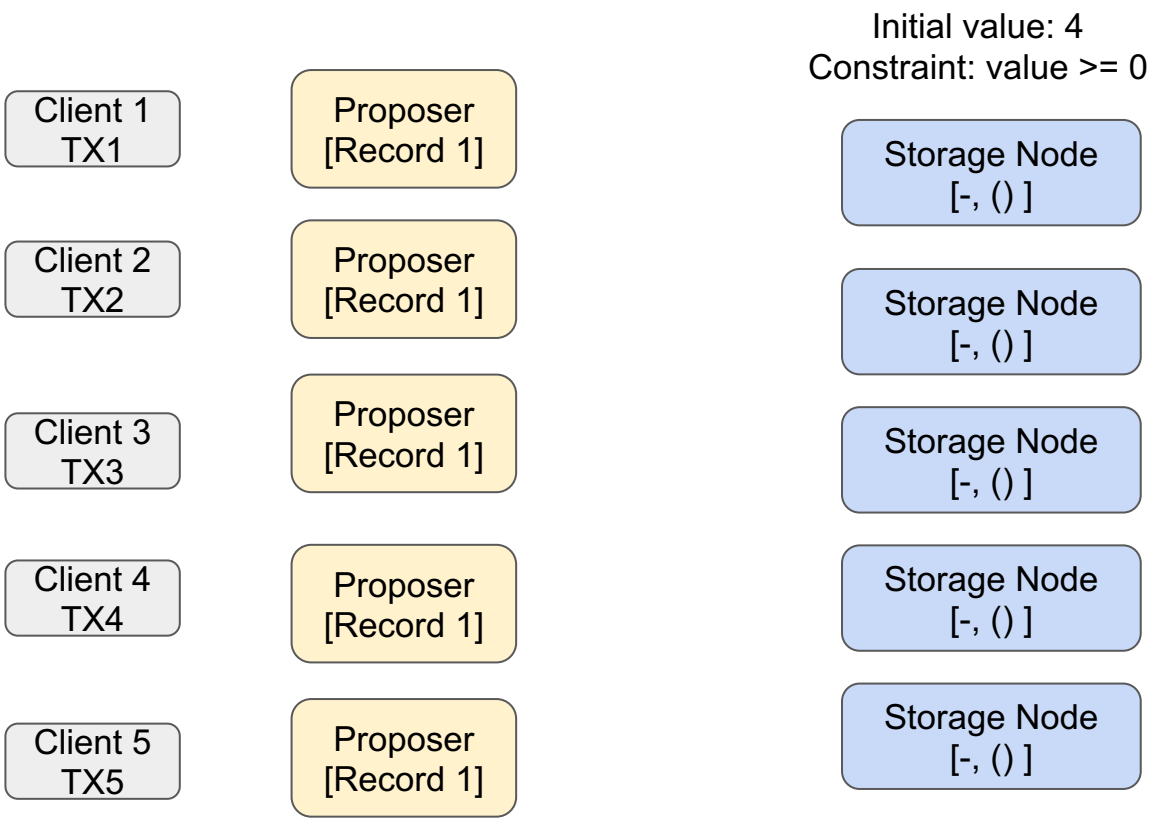
MDCC - Commutative Updates

MDCC - Commutative Updates

- MDCC usage of Generalized Paxos
  - Avoid conflicts for concurrent updates.
  - Sequence is only available for commutative operations.

- MDCC - New Demarcation Protocol
  - Use for commutative updates in MDCC
  - Deal with domain integrity constraints
    - EX: Constraint: value >= 0

General Demarcation Protocol



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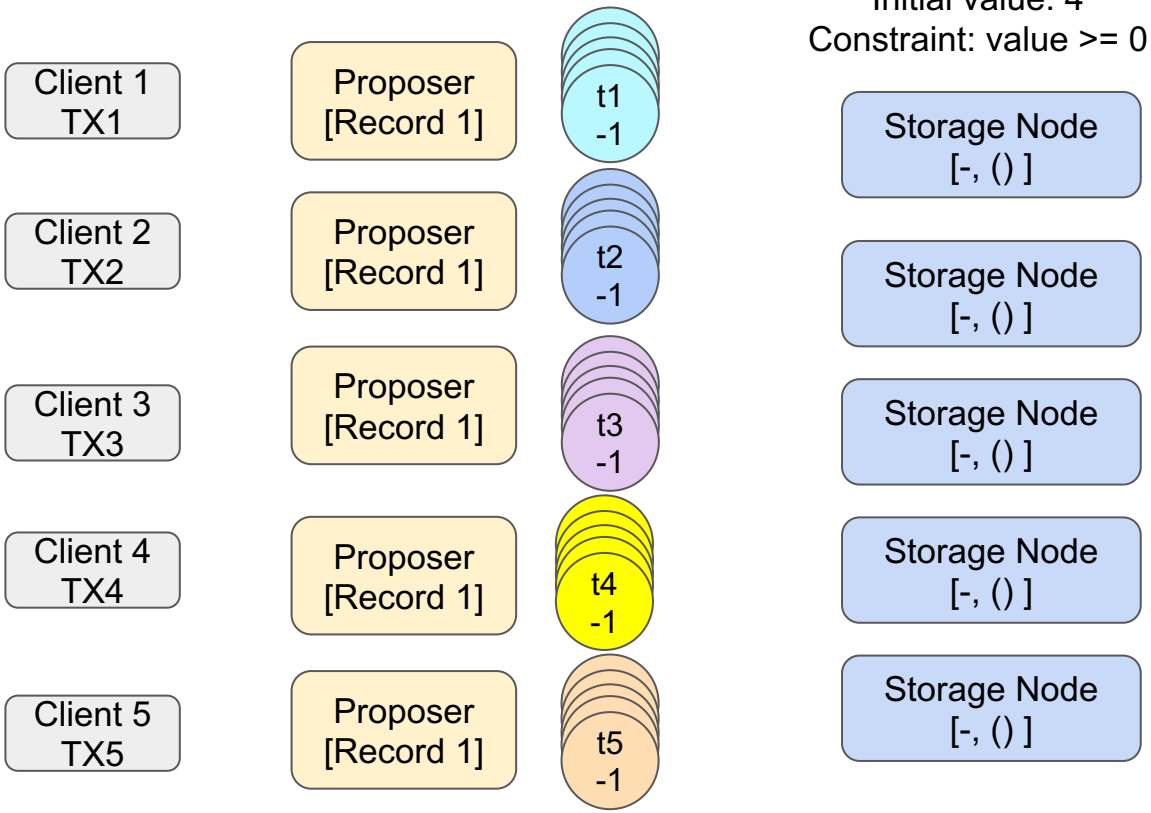

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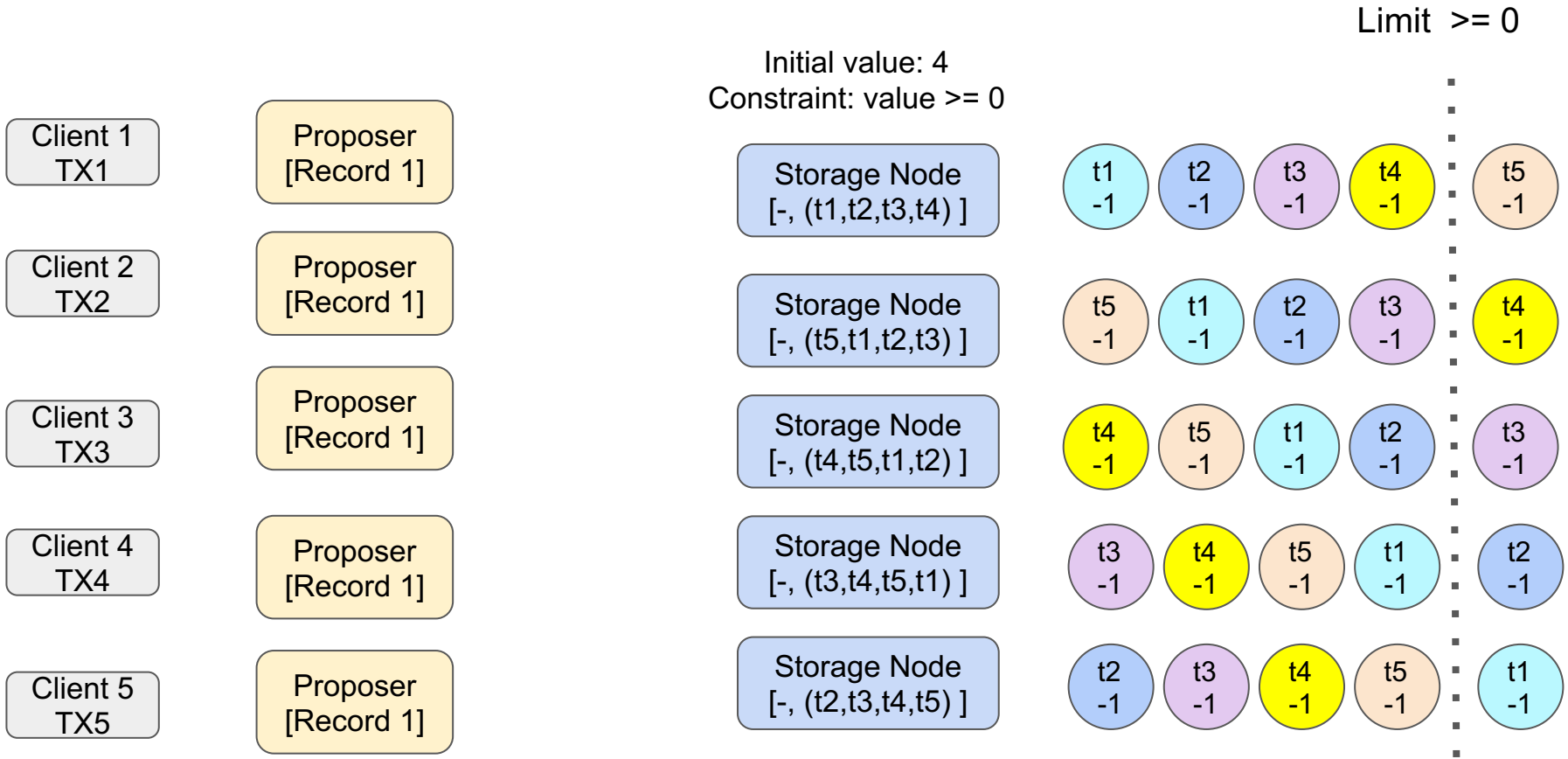

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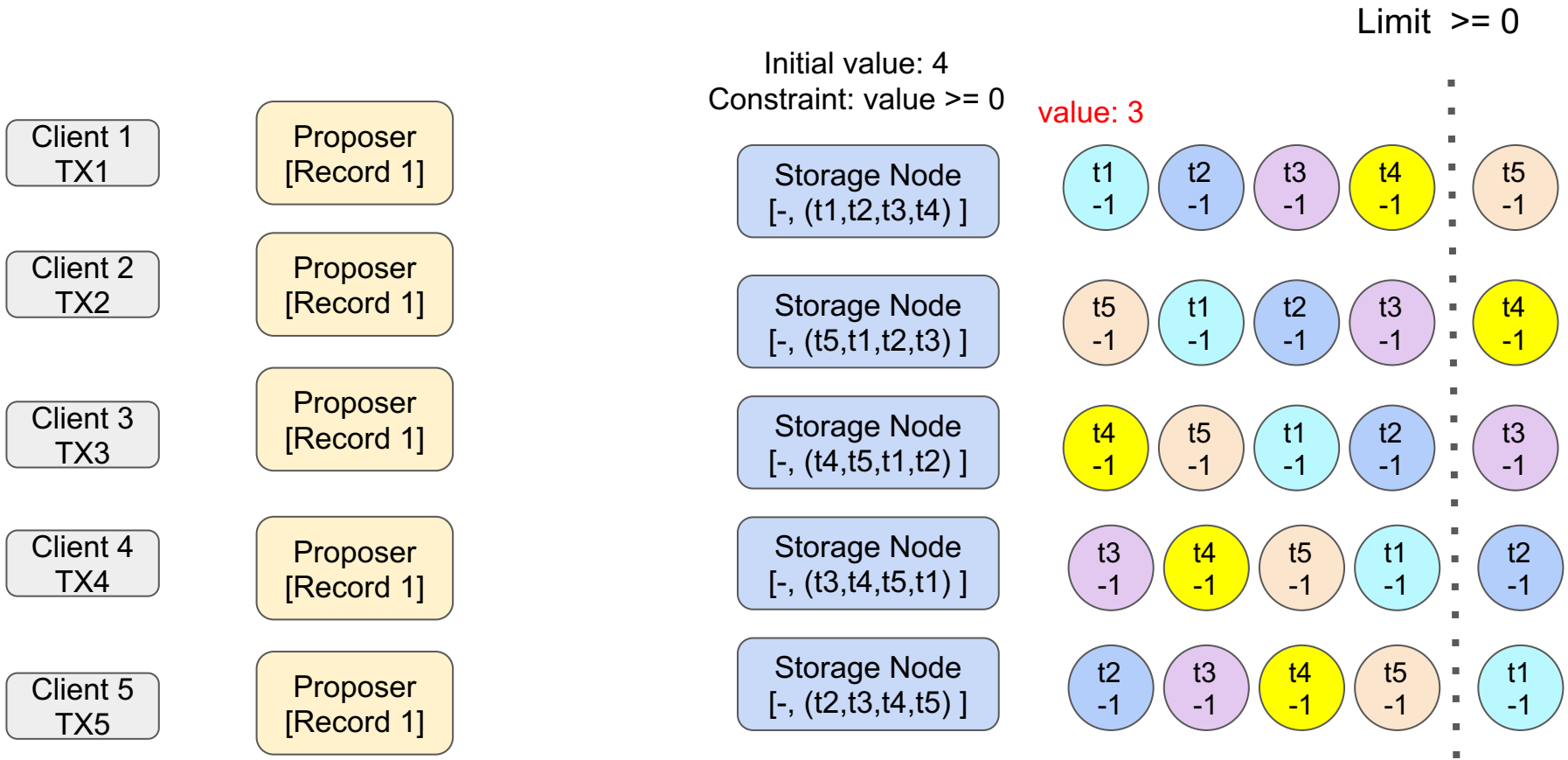

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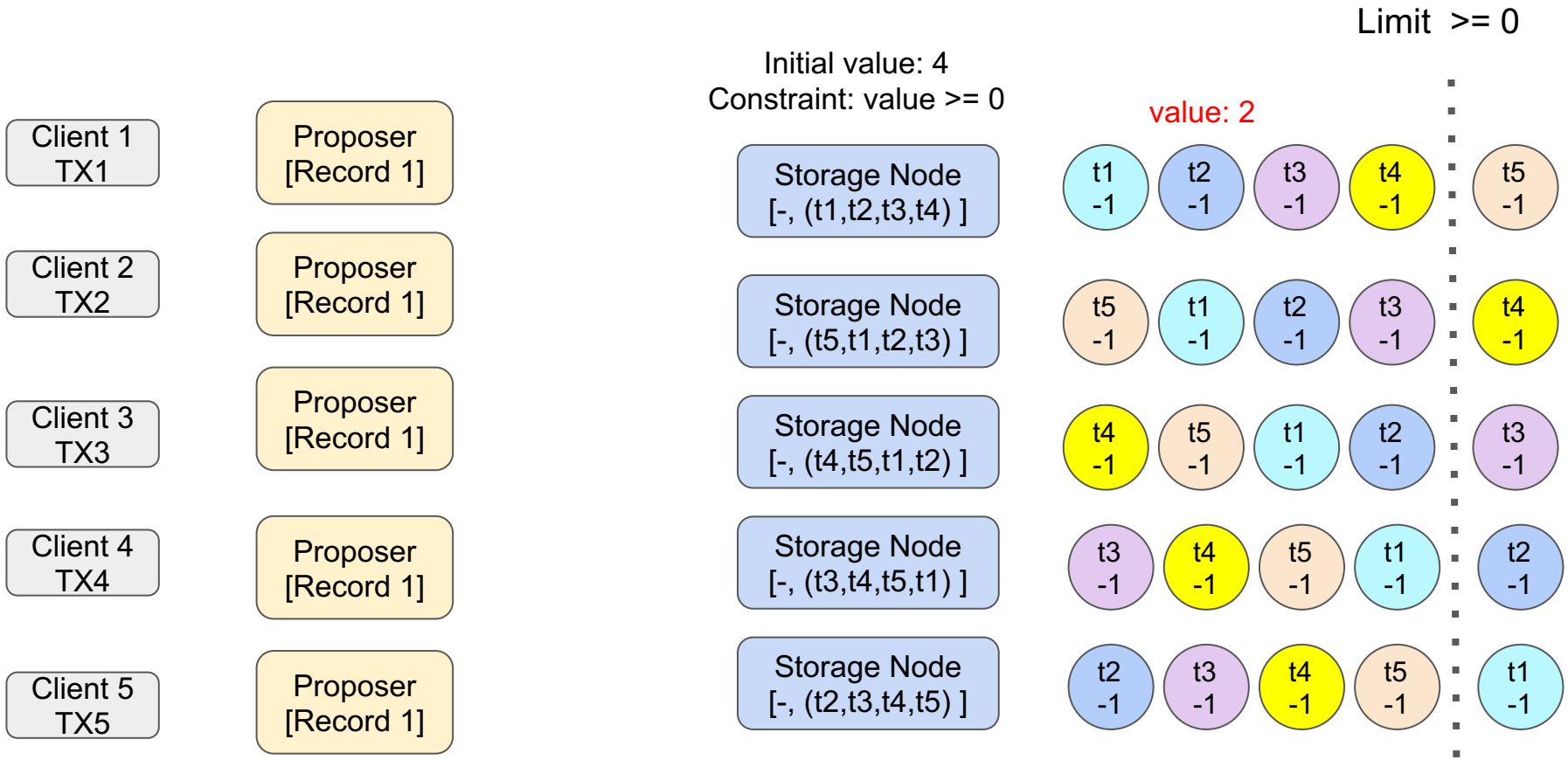

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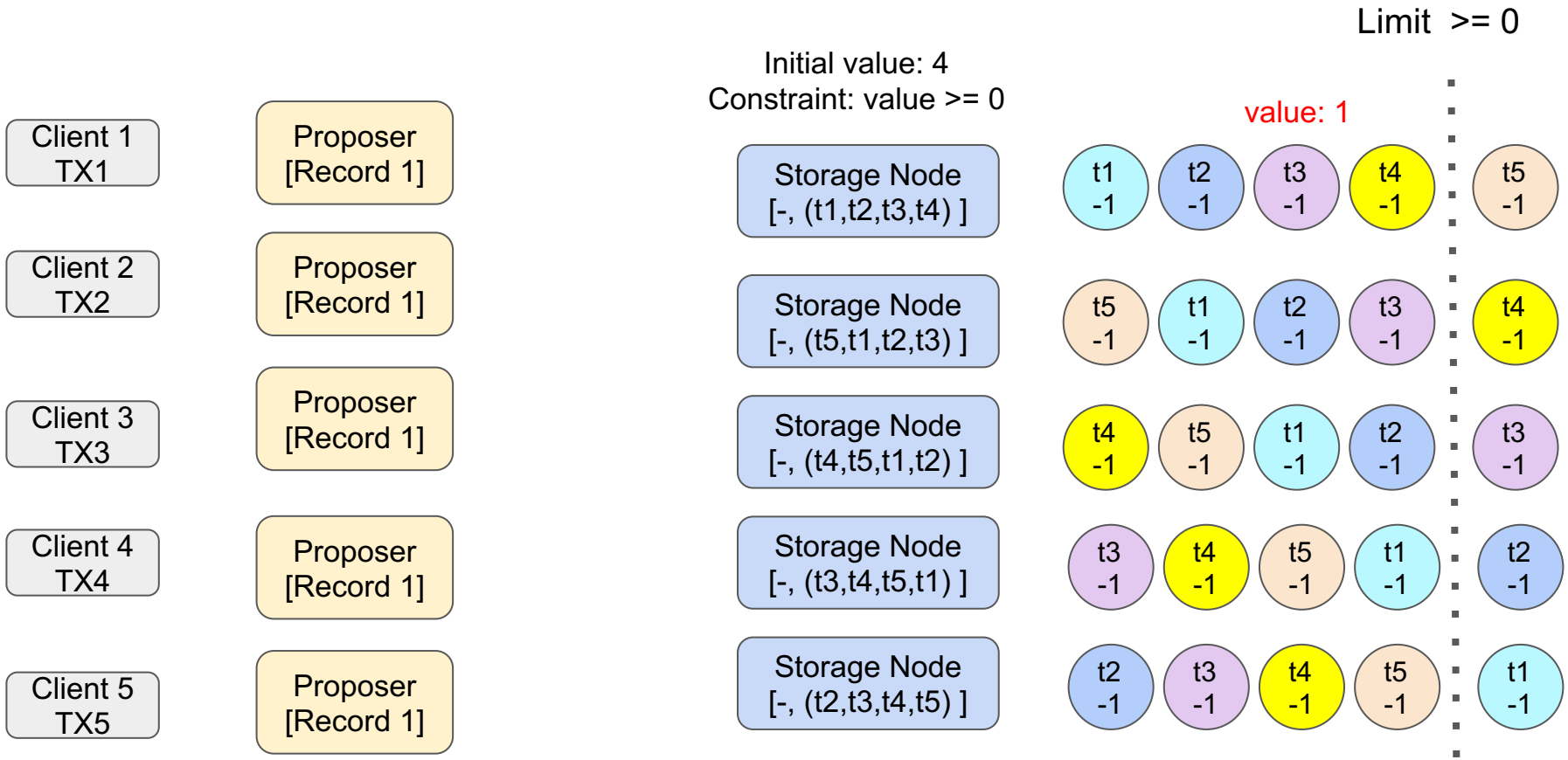

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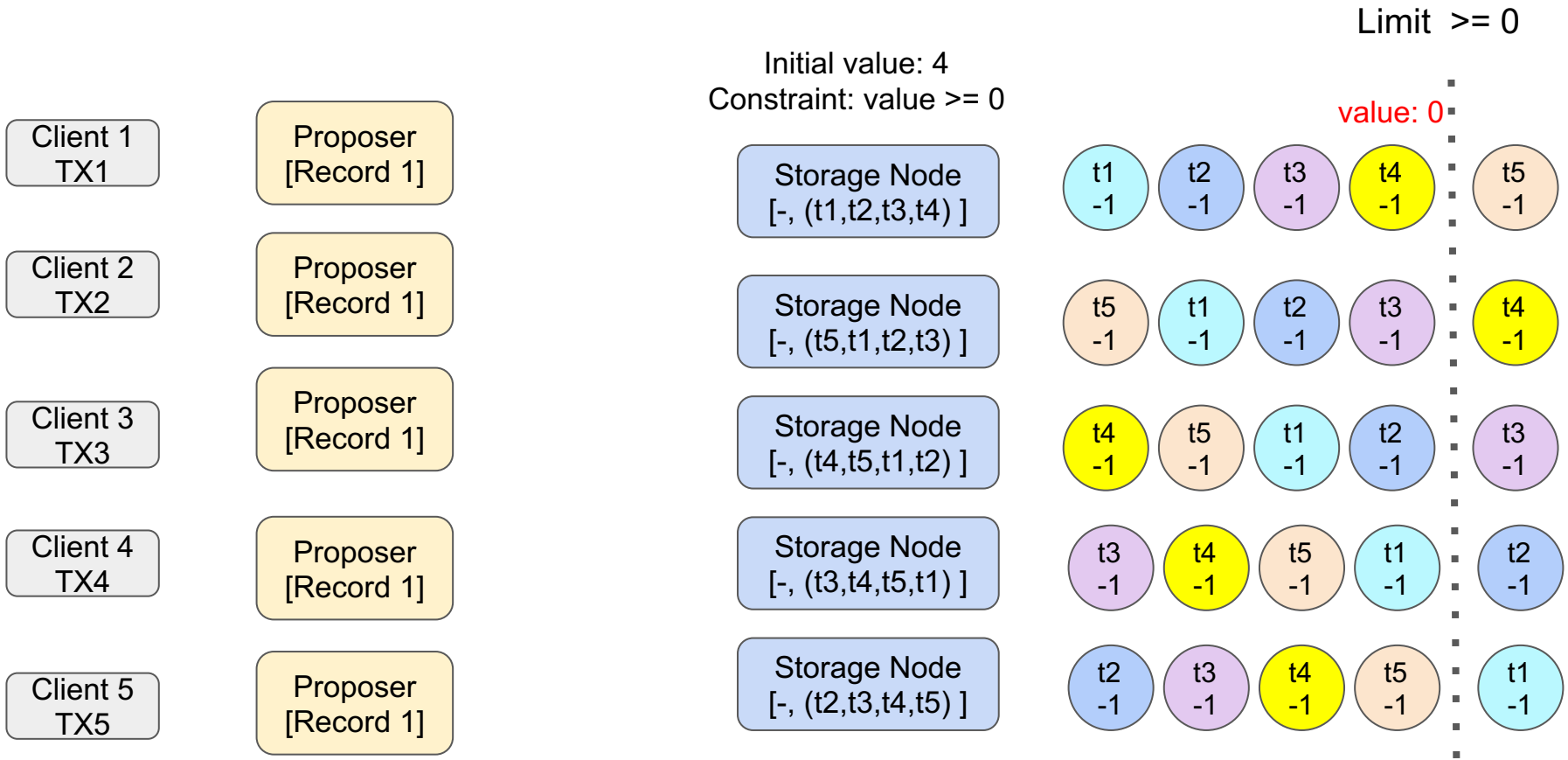

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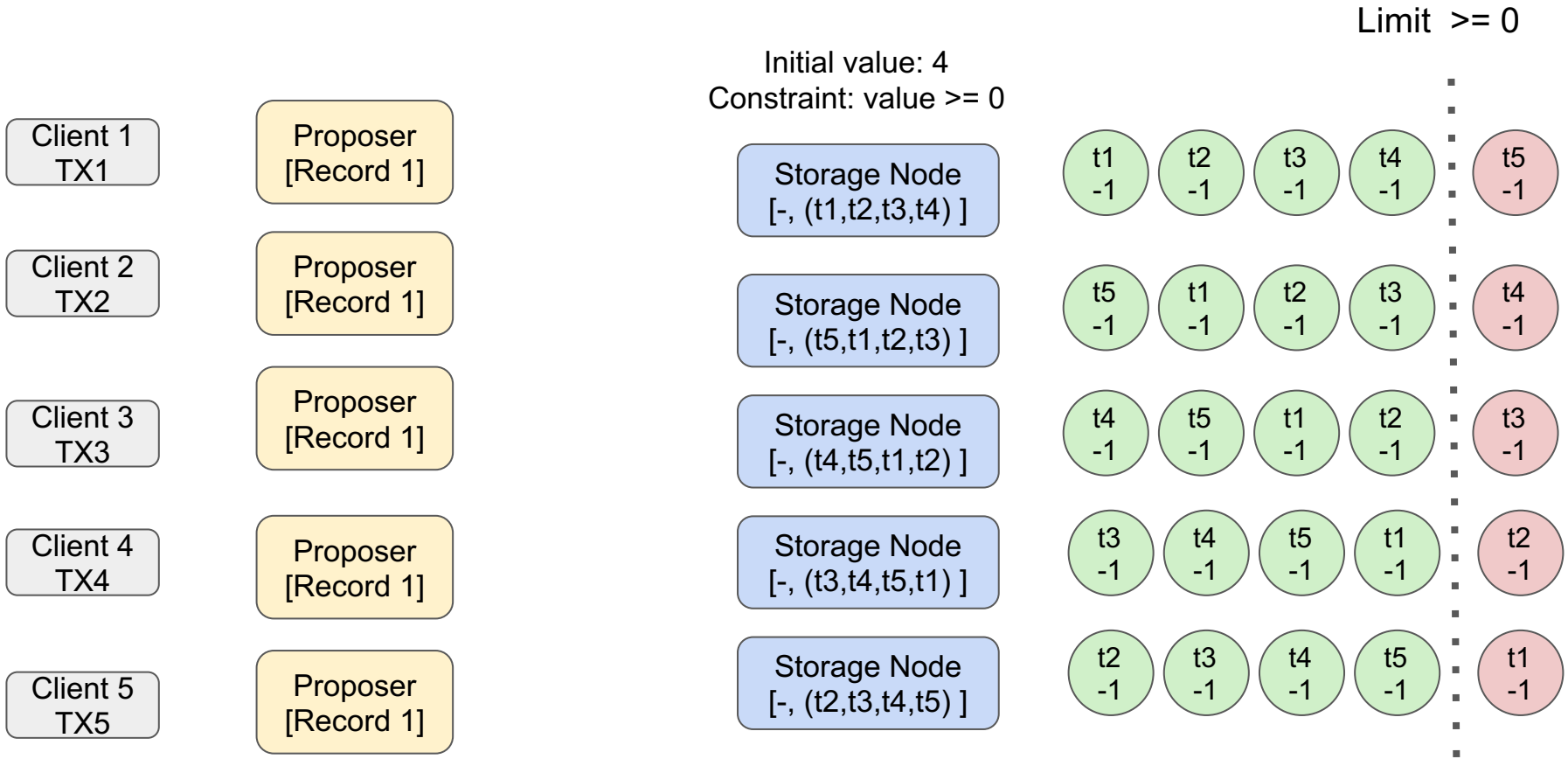

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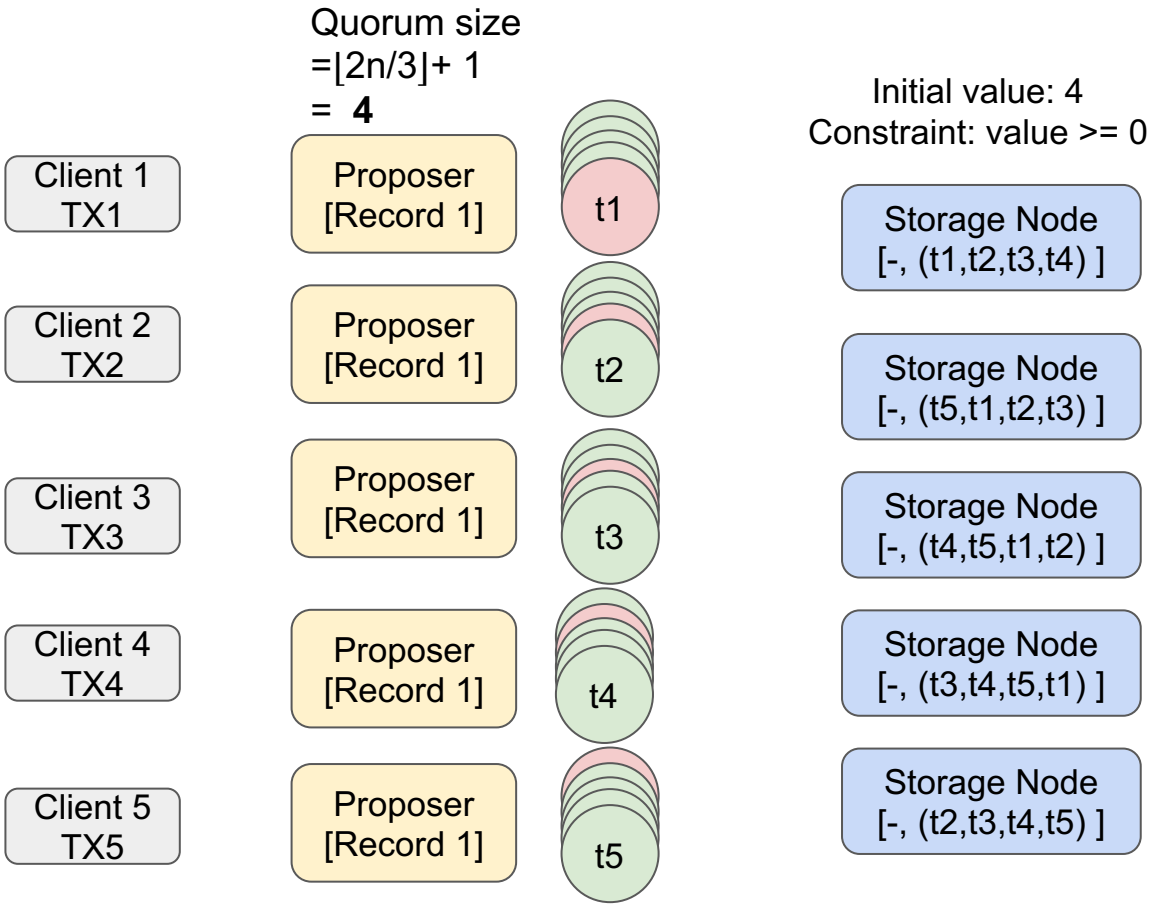

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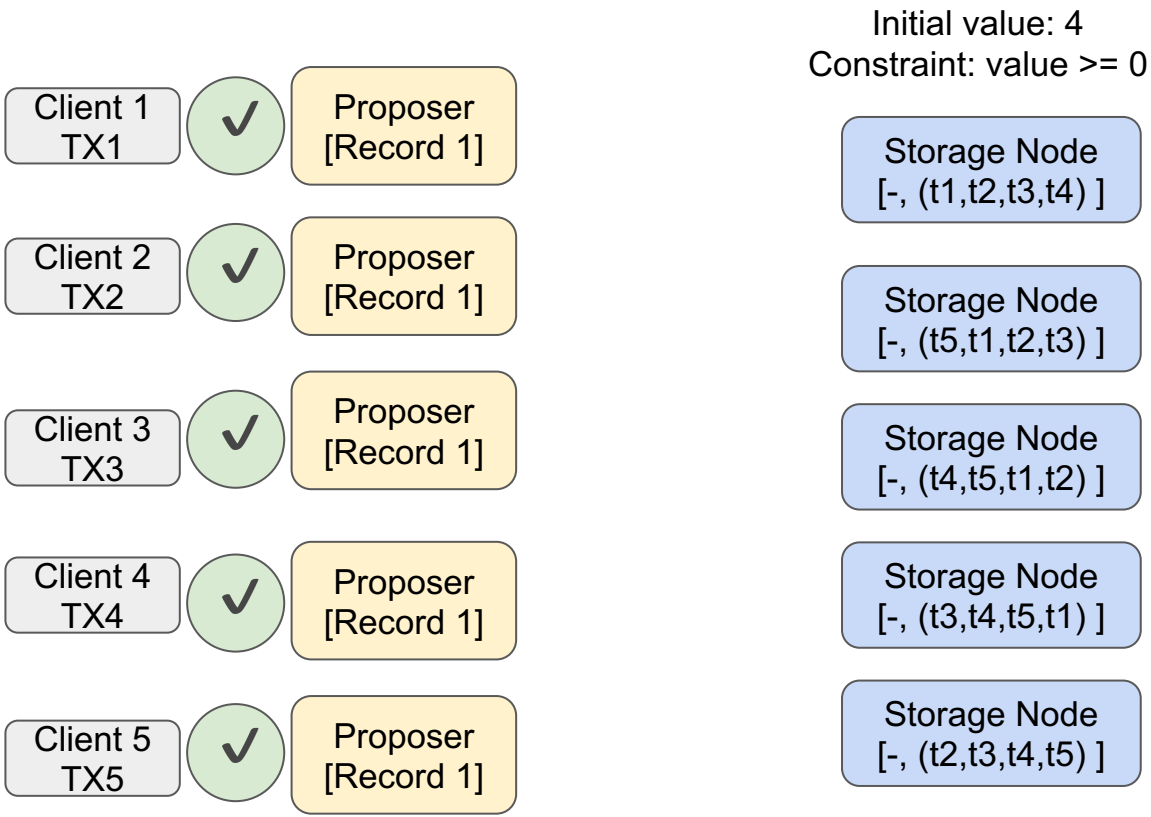
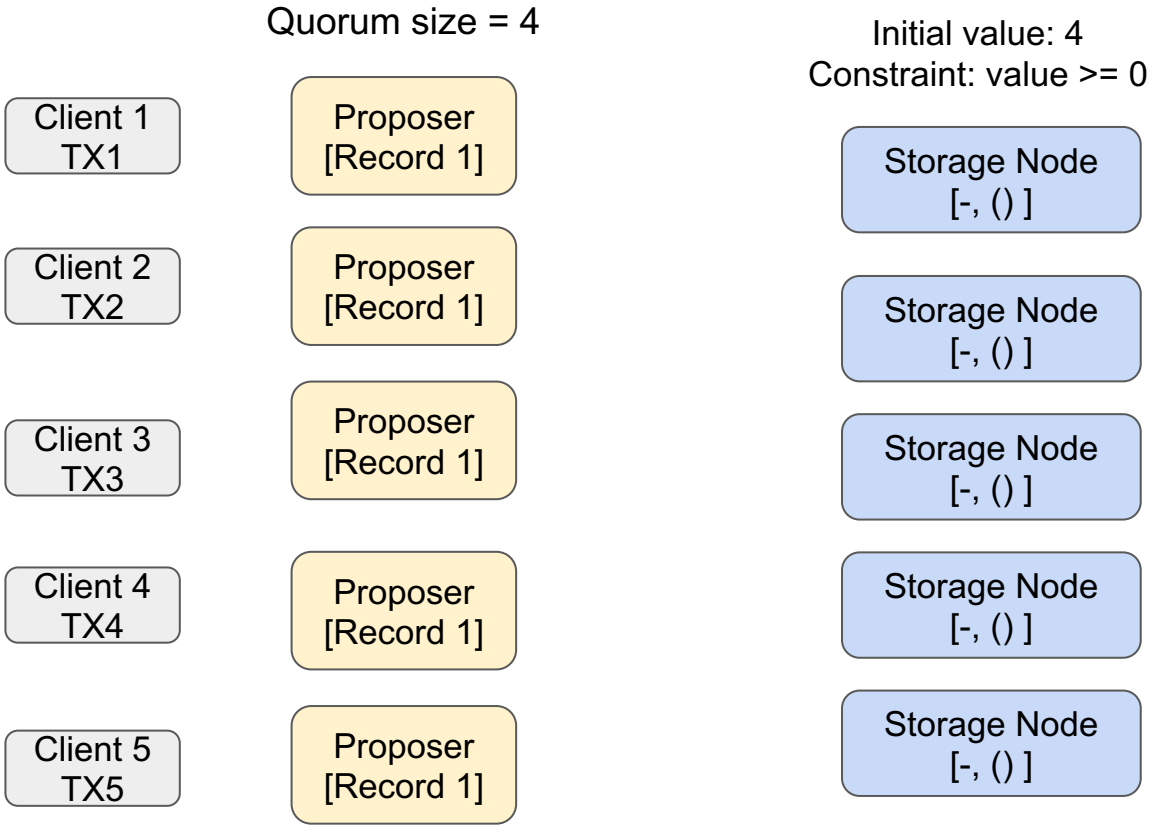


MDCC – New Demarcation Protocol



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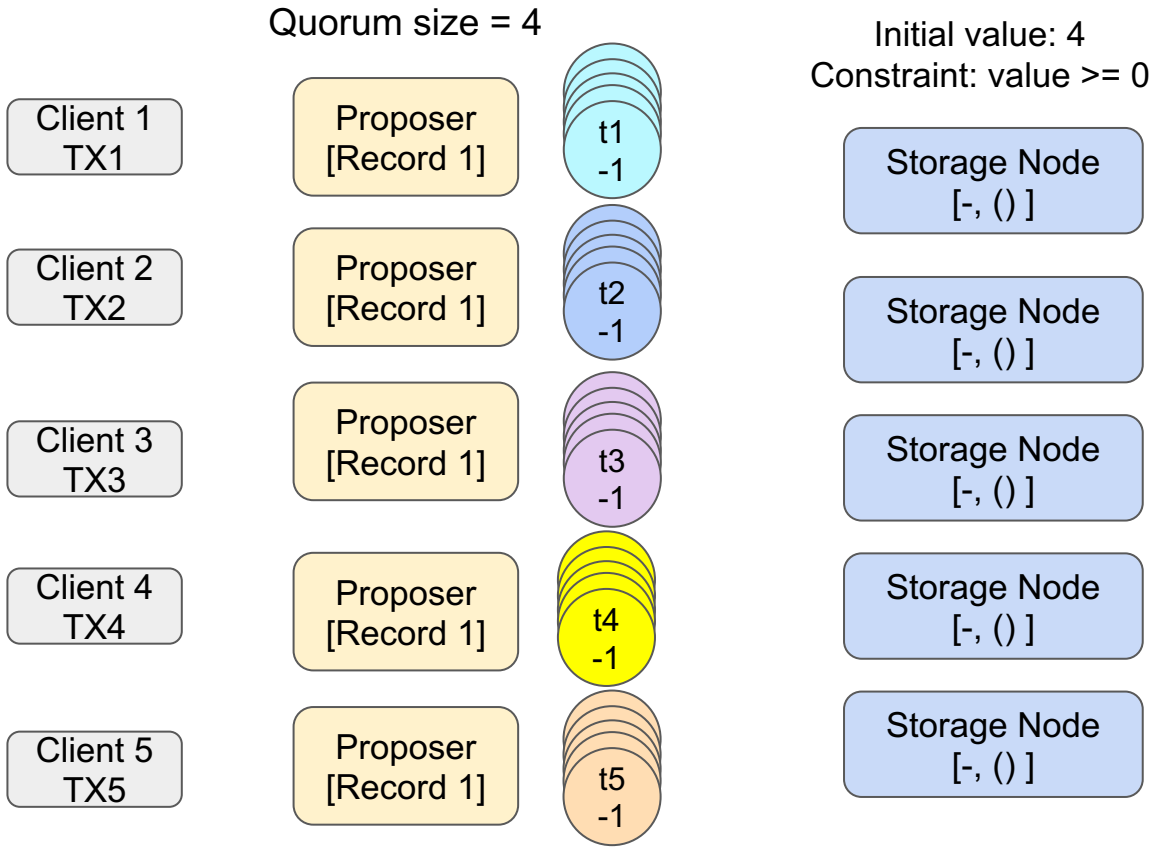

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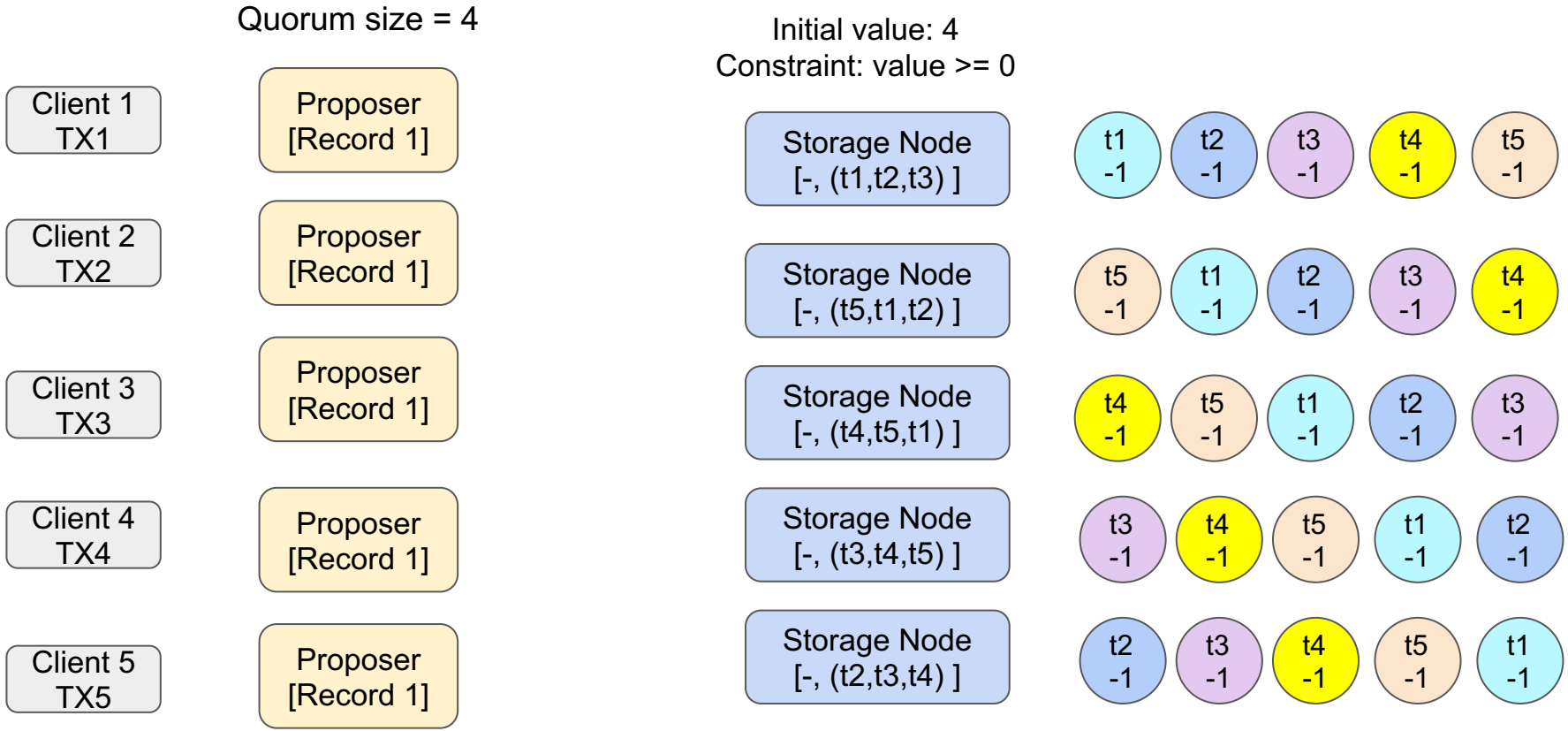
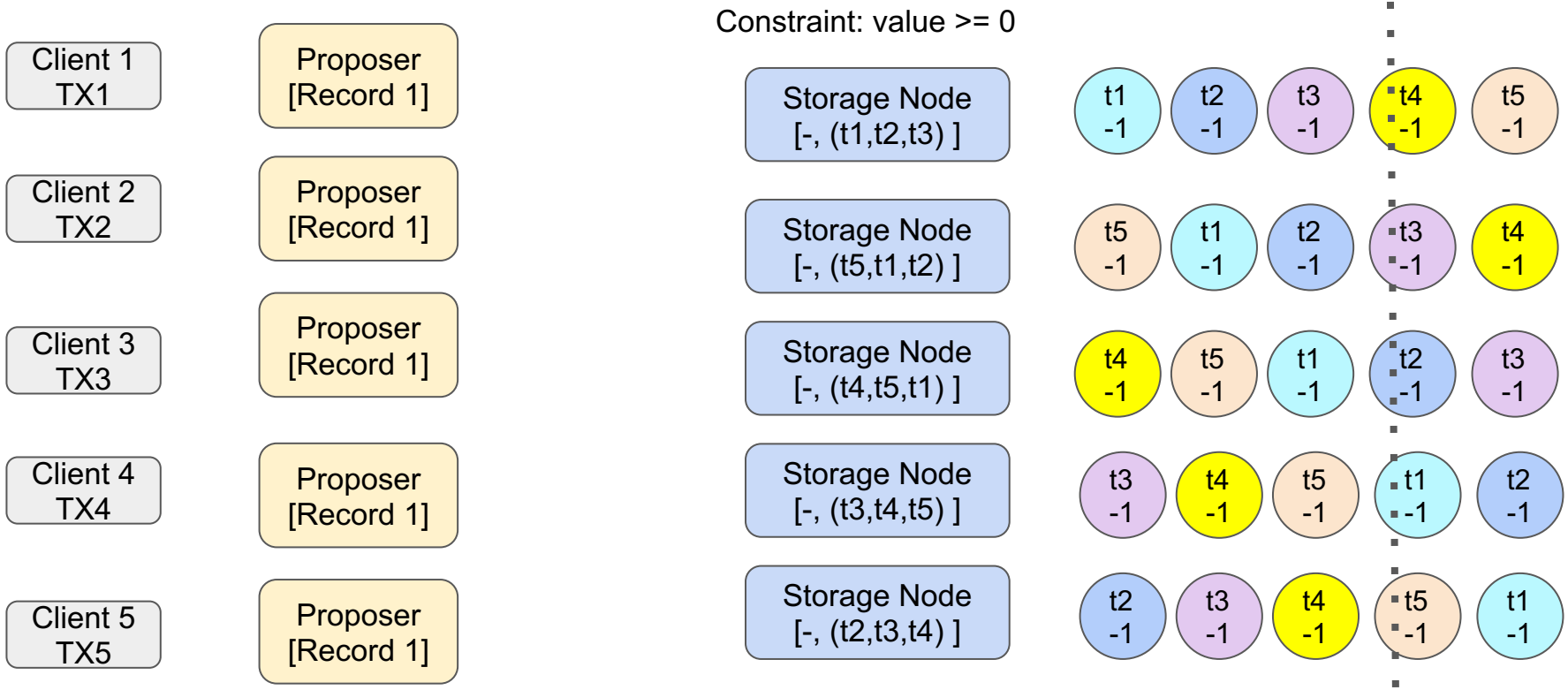


MDCC – New Demarcation Protocol

Limit >= (N-Q)/N
>= (5-4)/5
>= ⅕ = 0.8

Quorum size = 4

Initial value: 4
Constraint: value >= 0



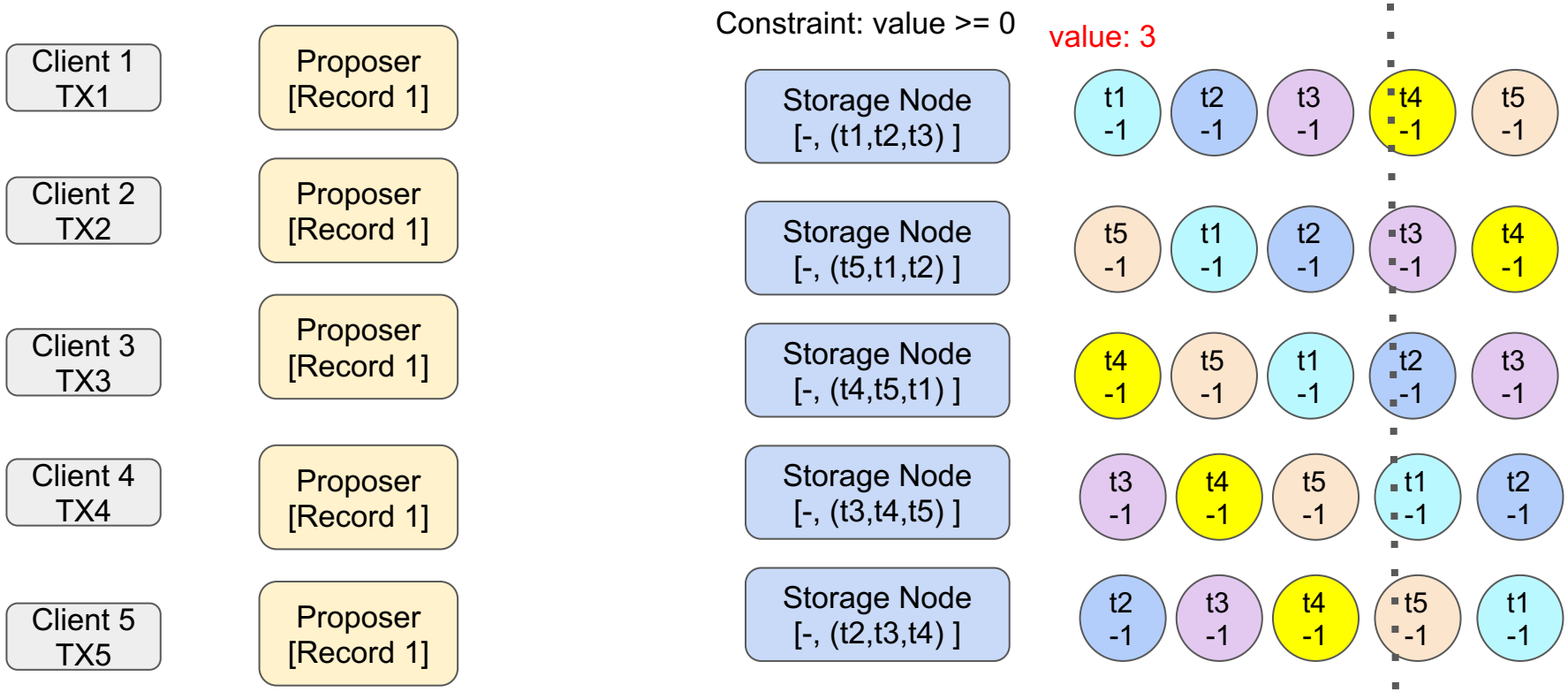
MDCC – New Demarcation Protocol

Limit >= (N-Q)/N
>= (5-4)/5
>= ⅕ = 0.8

Quorum size = 4

Initial value: 4
Constraint: value >= 0

value: 3



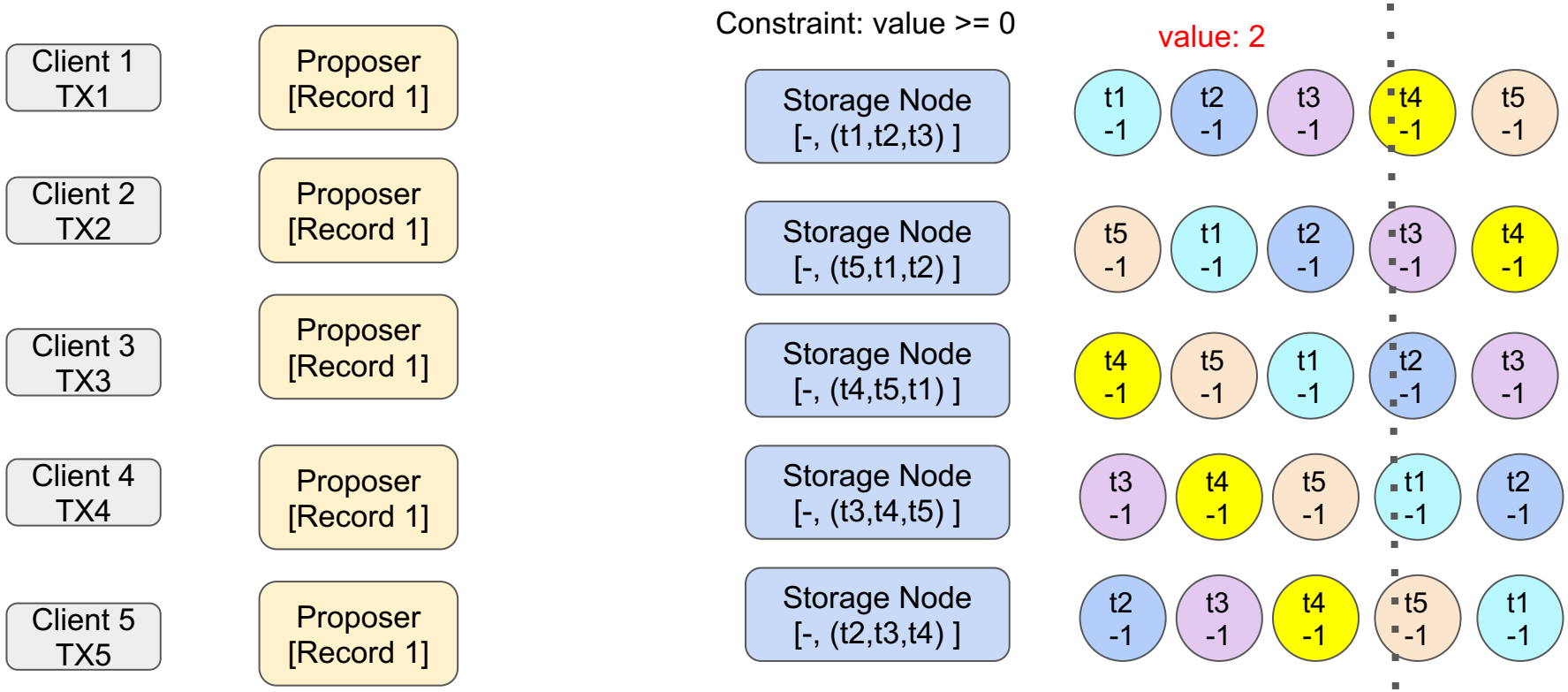
MDCC – New Demarcation Protocol

Limit >= (N-Q)/N
>= (5-4)/5
>= ⅕ = 0.8

Quorum size = 4

Initial value: 4
Constraint: value >= 0

value: 2



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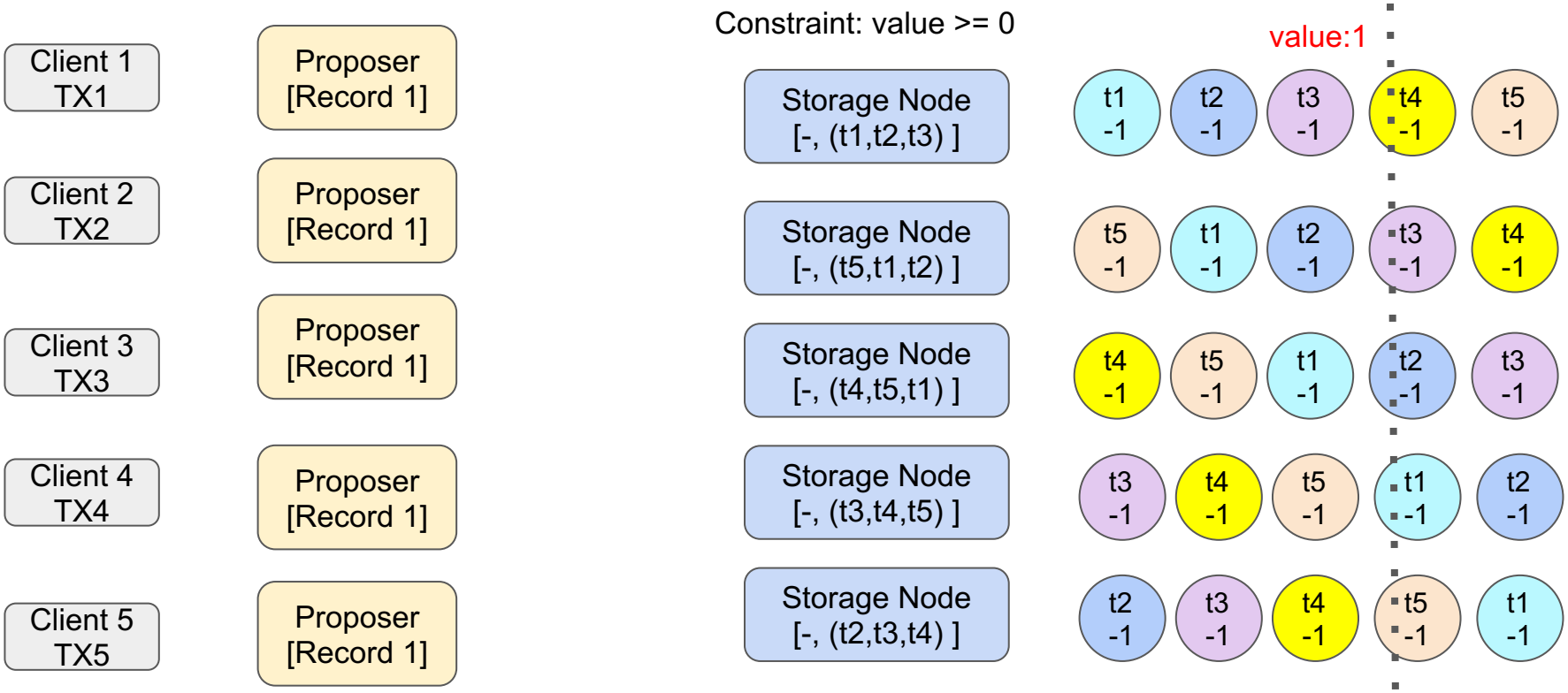

MDCC – New Demarcation Protocol

Limit >= (N-Q)/N
>= (5-4)/5
>= ⅕ = 0.8

Quorum size = 4

Initial value: 4
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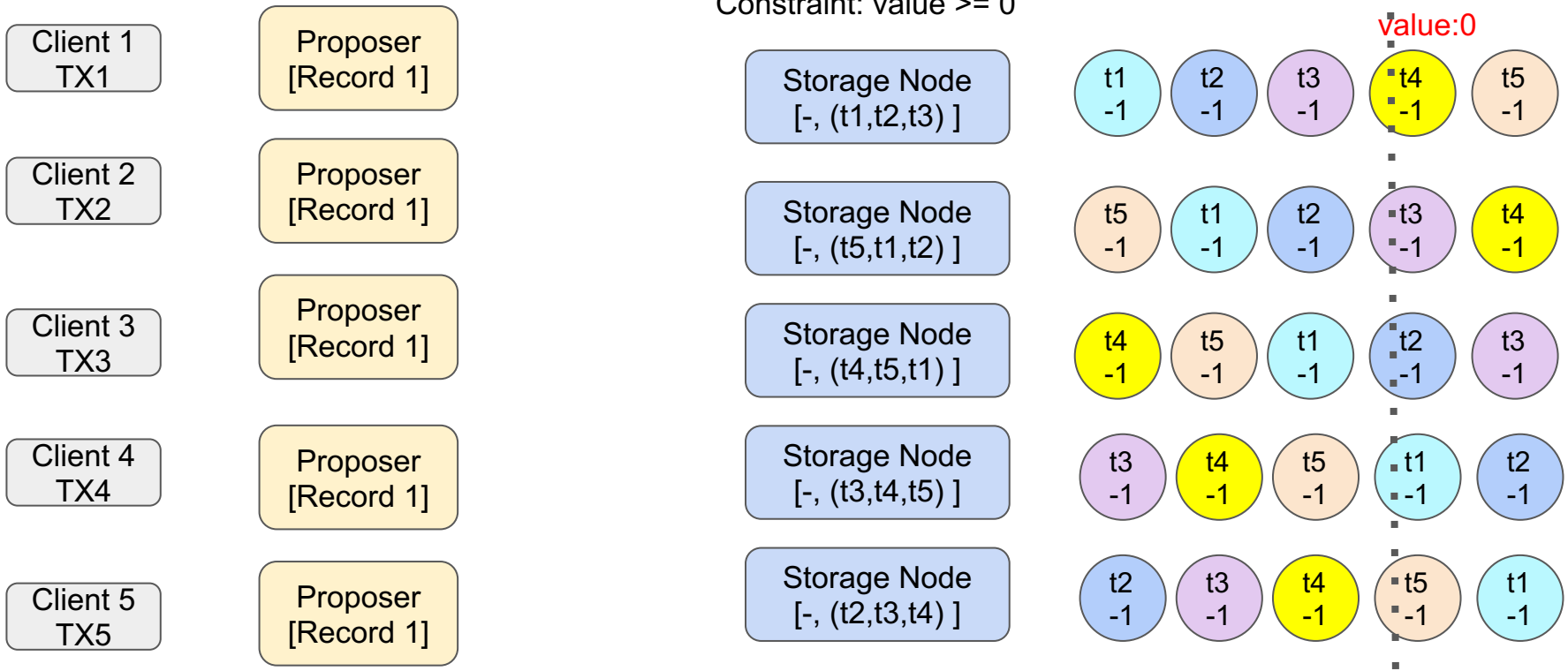

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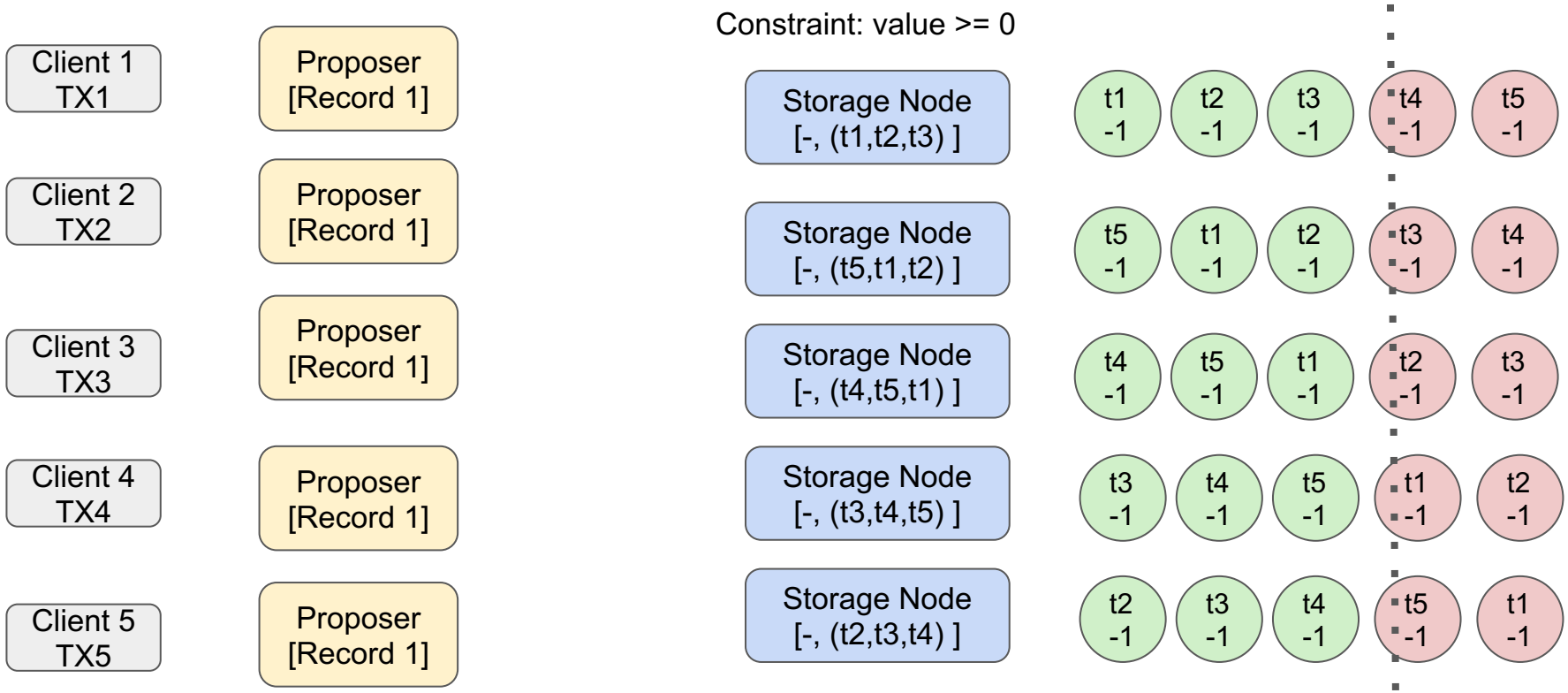

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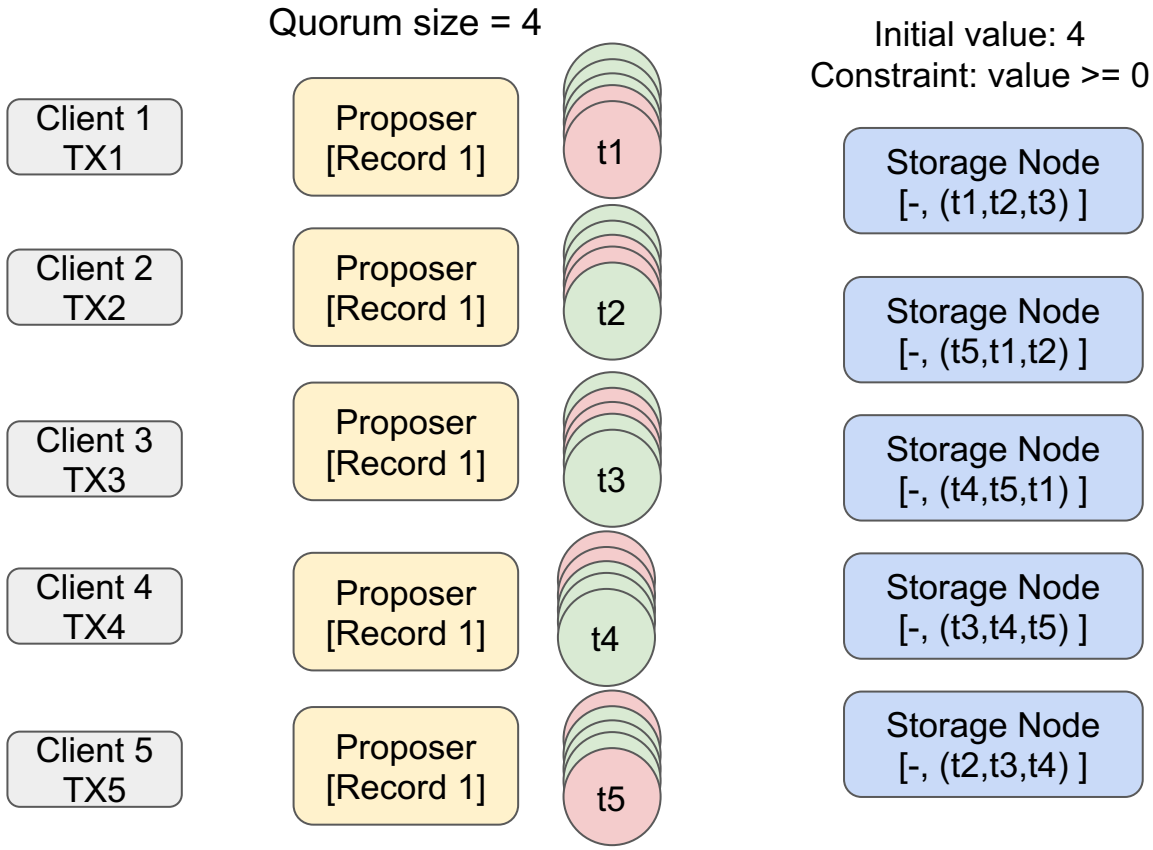

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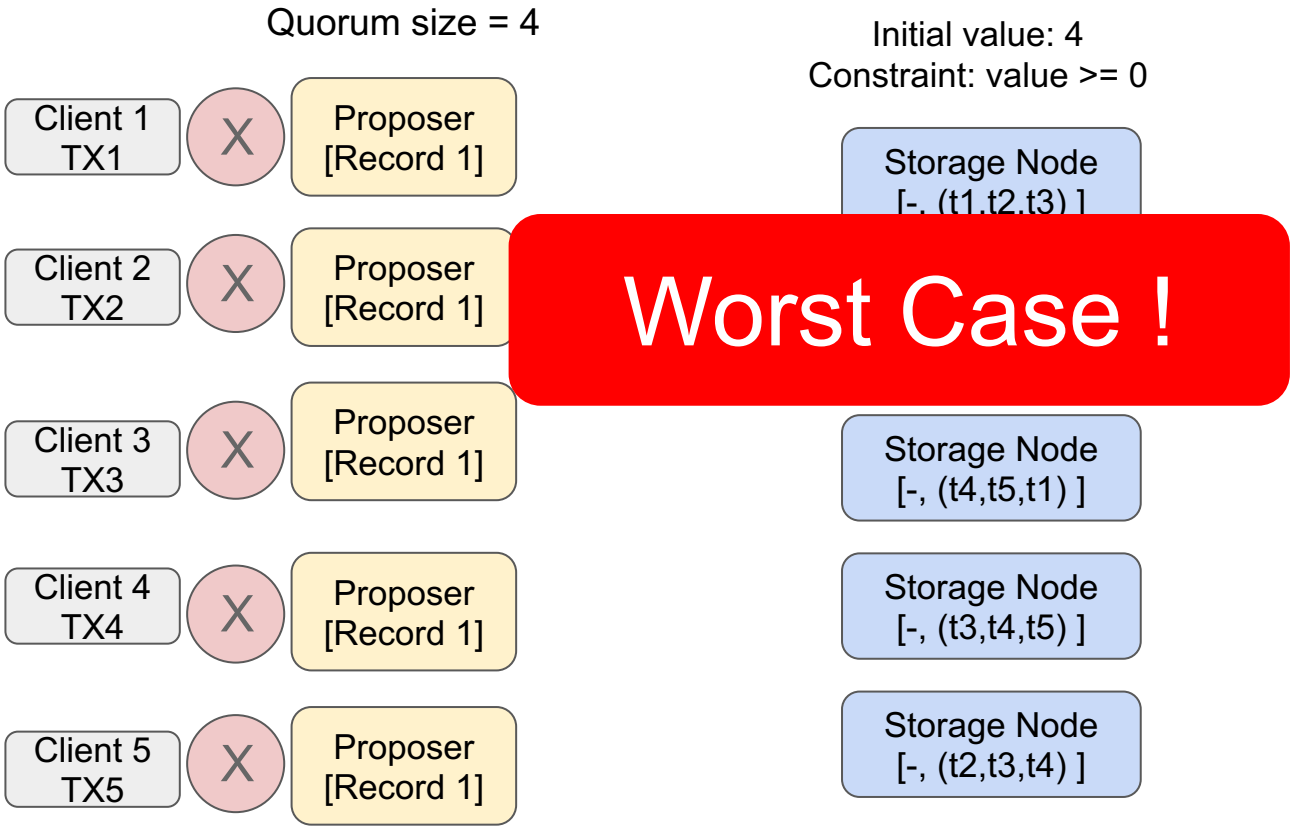

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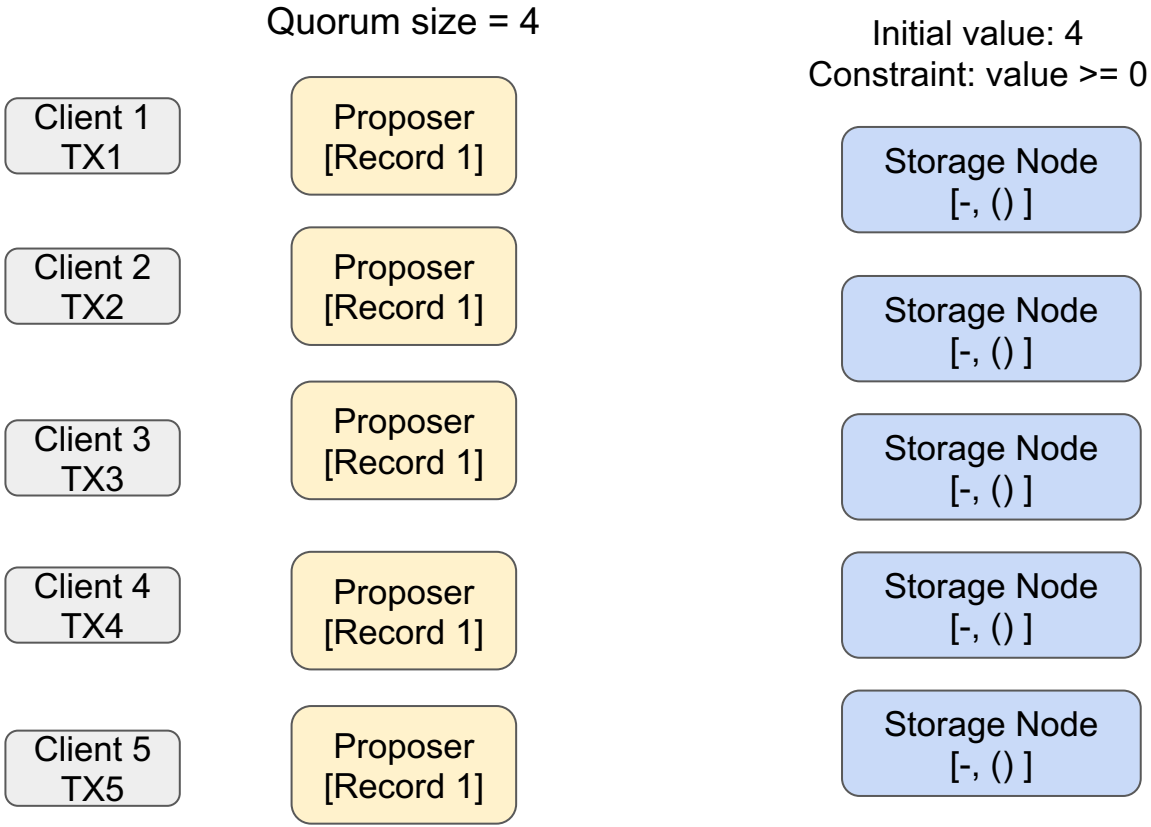

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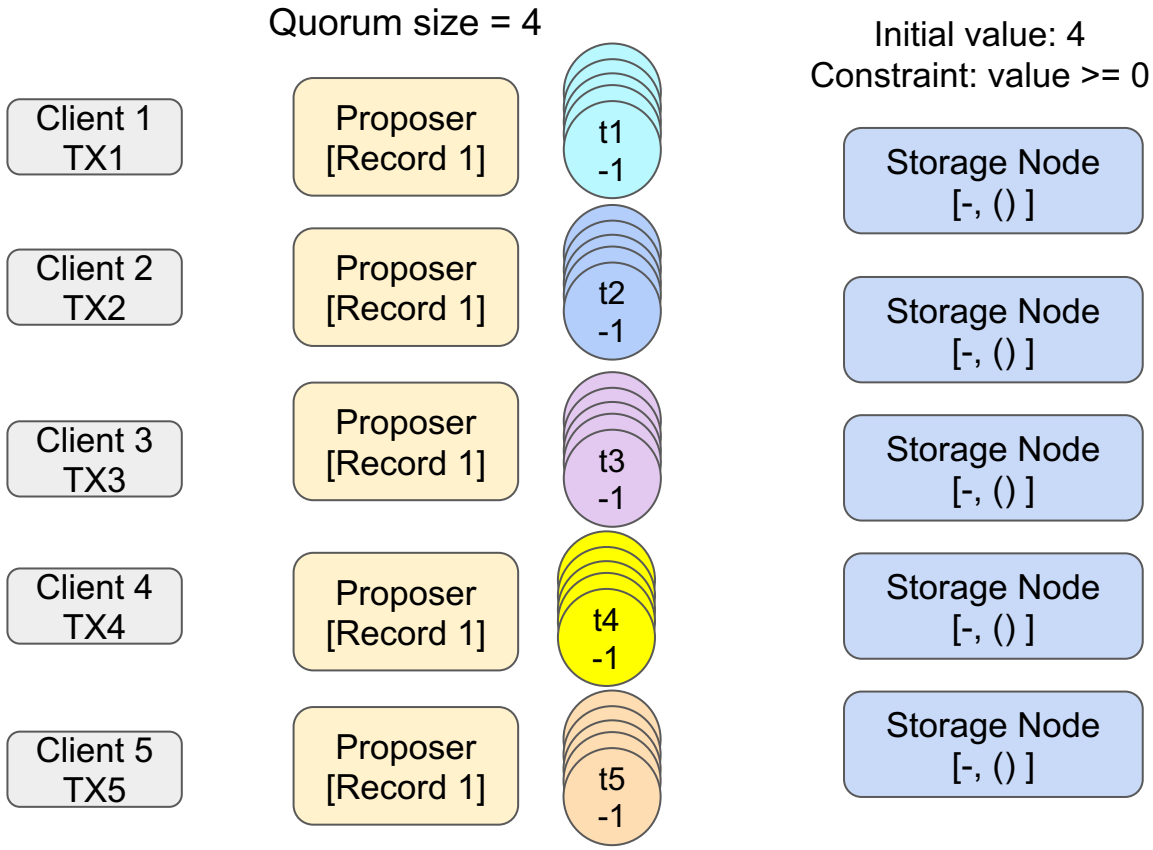

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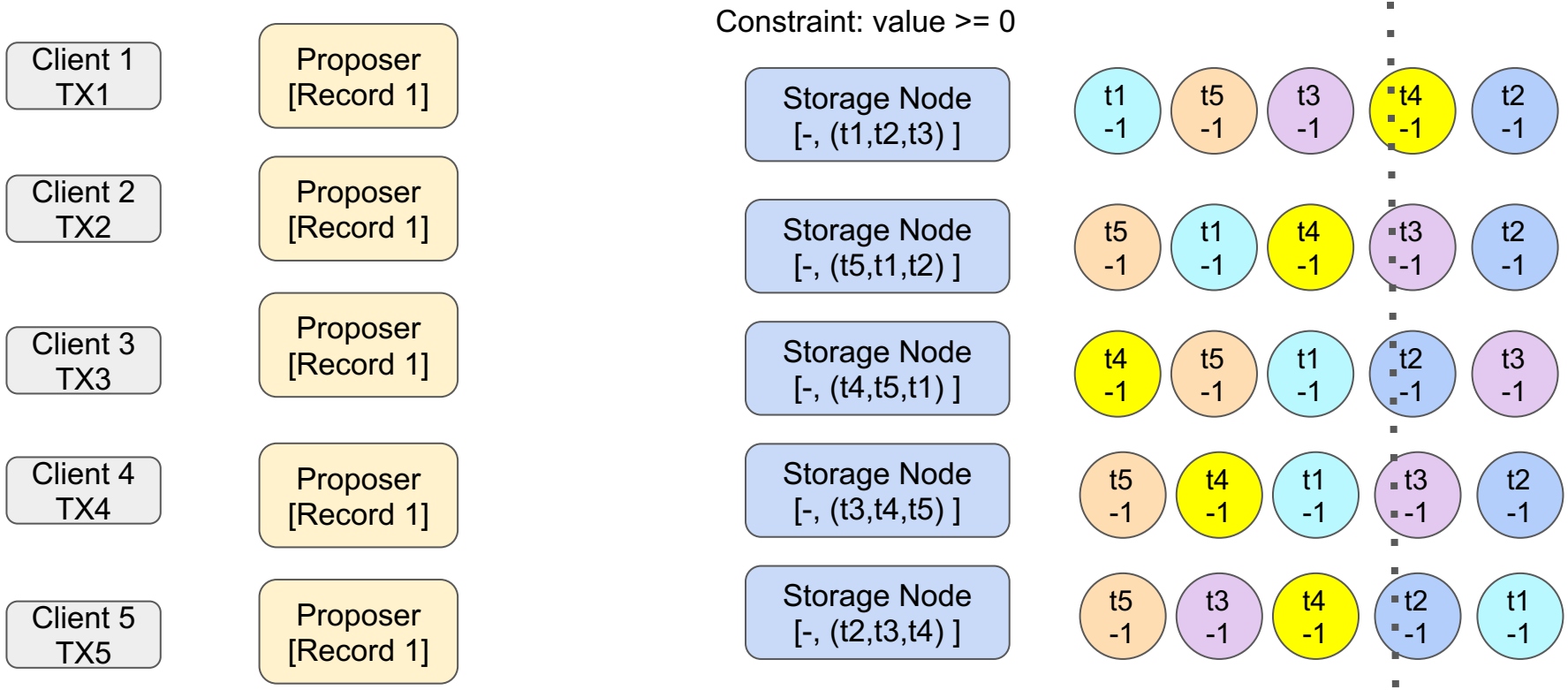

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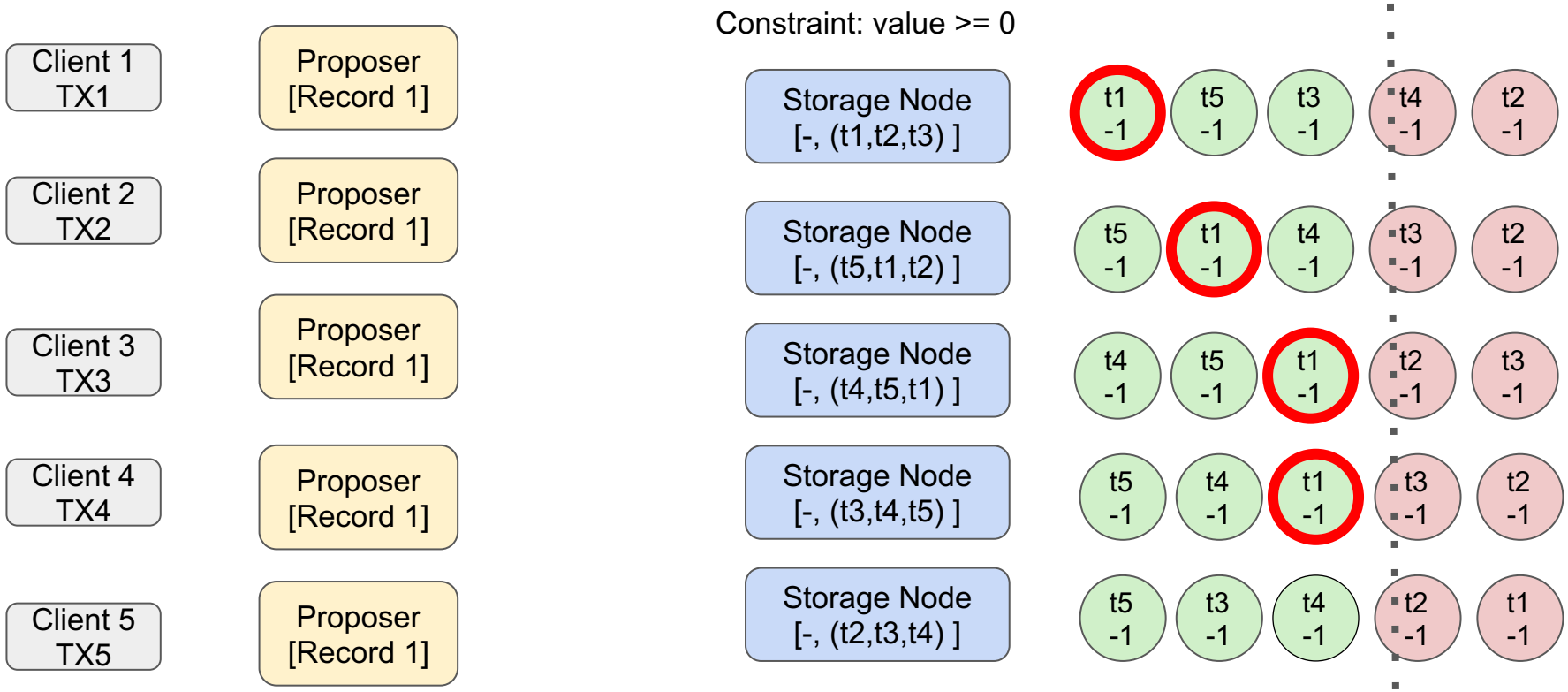

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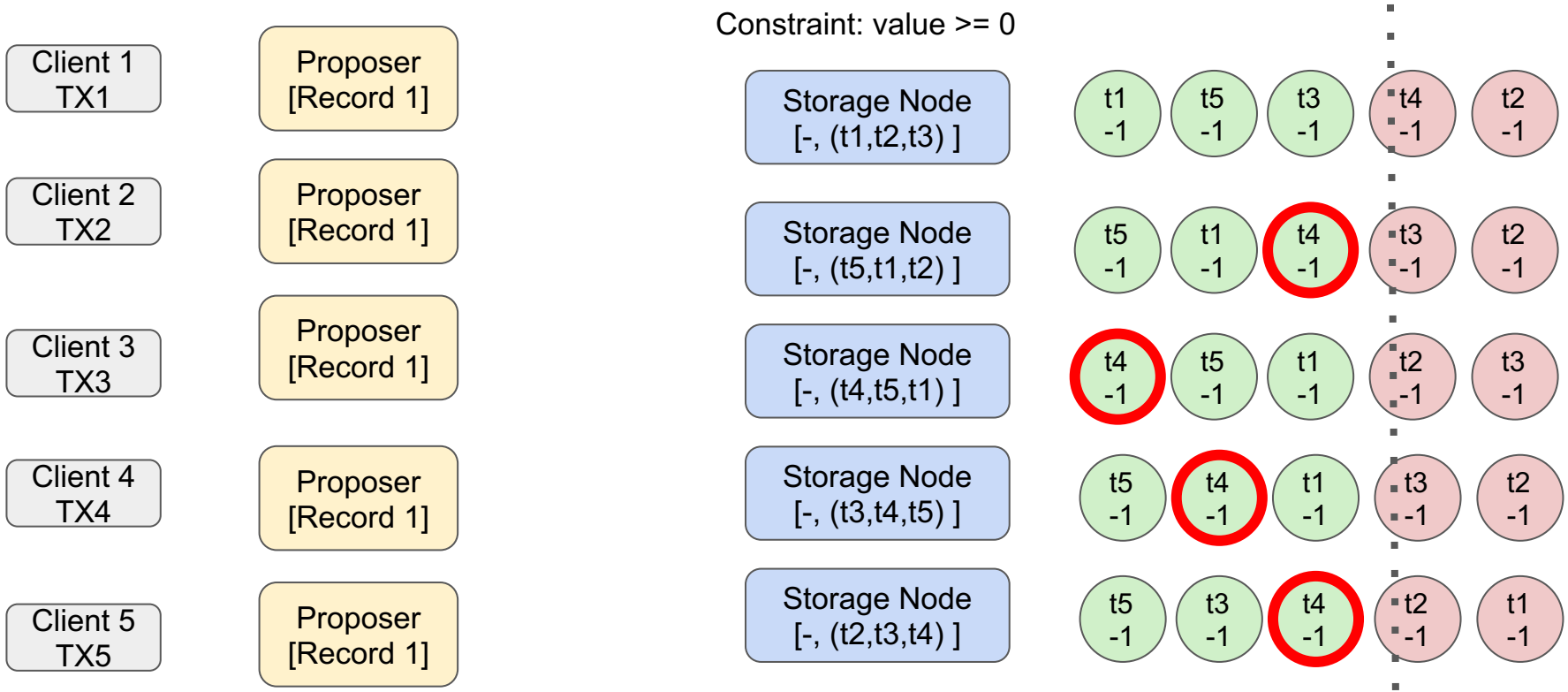

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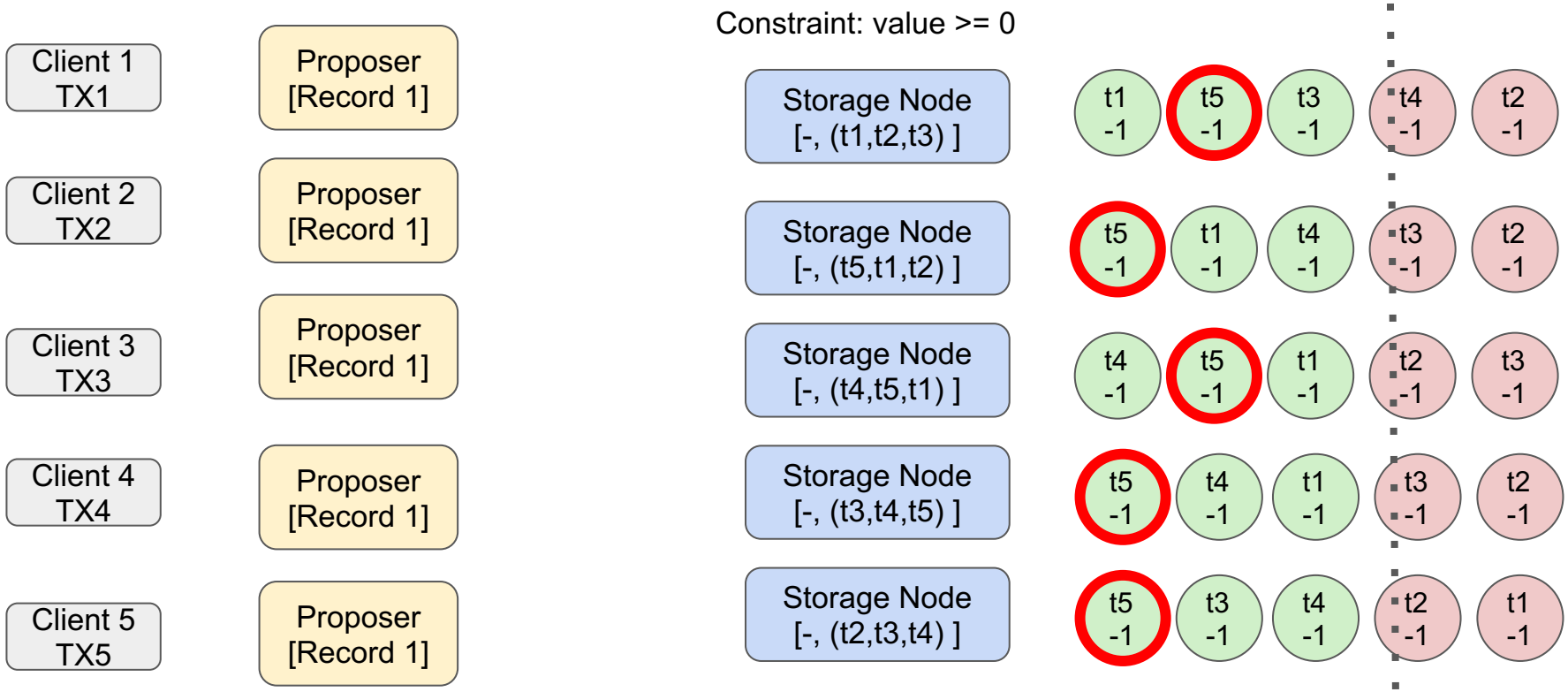

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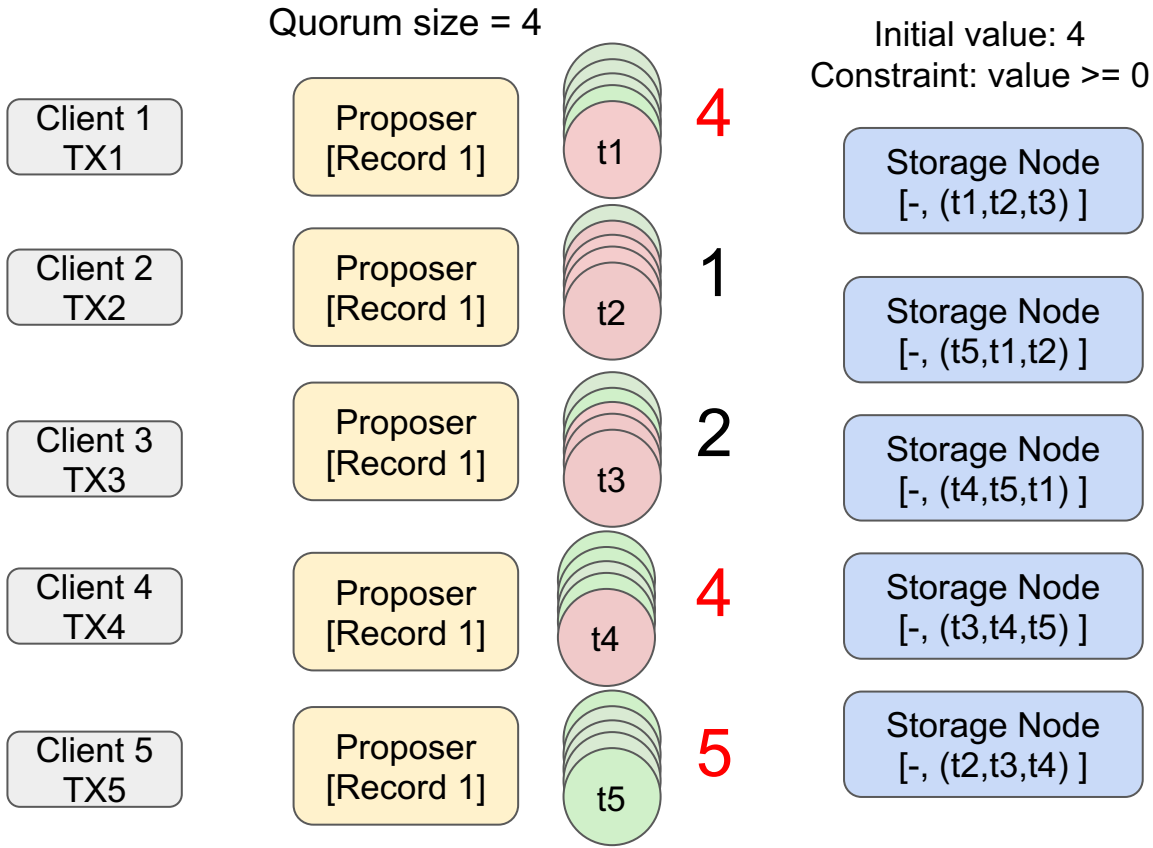

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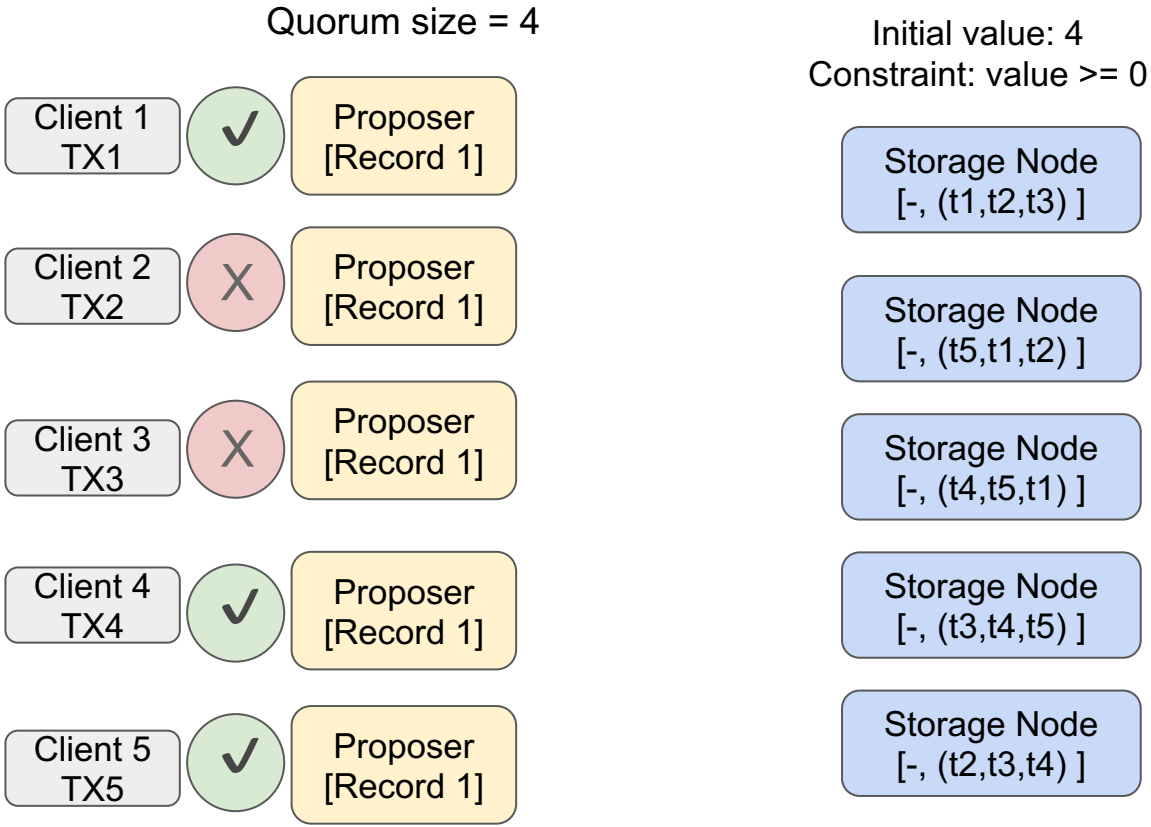


Consistency Guarantees

Consistency Guarantees

- Read Committed without Lost Updates
  - Lost update
    - Ex: T1 read data X
      T2 write data X
      T1 write data X (overwrite data X)
  - Only allow to read committed changes
  - Solve lost updates by **detecting write-write conflicts**

Consistency Guarantees

- Staleness
  - Stale data
  - Require reading from majority of nodes
  - Techniques from Megastore
    - **Pseudo-master storage node**
    - They are **part of the quorum** of phase1 and 2

Consistency Guarantees

- Atomic Visibility
  - Only atomic durability
  - To support atomic visibility
    - Two-phase locking
    - Snapshot isolation

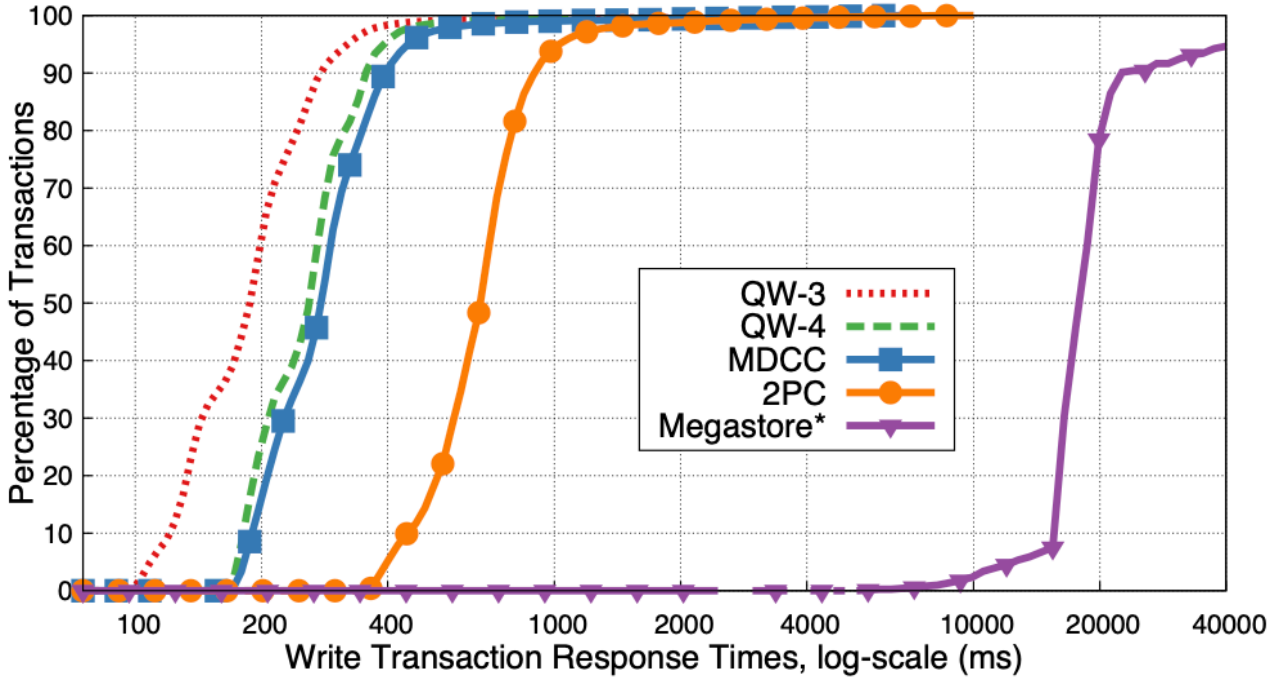
Evaluation

Evaluation

- TPC-W benchmark
  - for general performance
- Micro benchmark
  - for protocol investigation

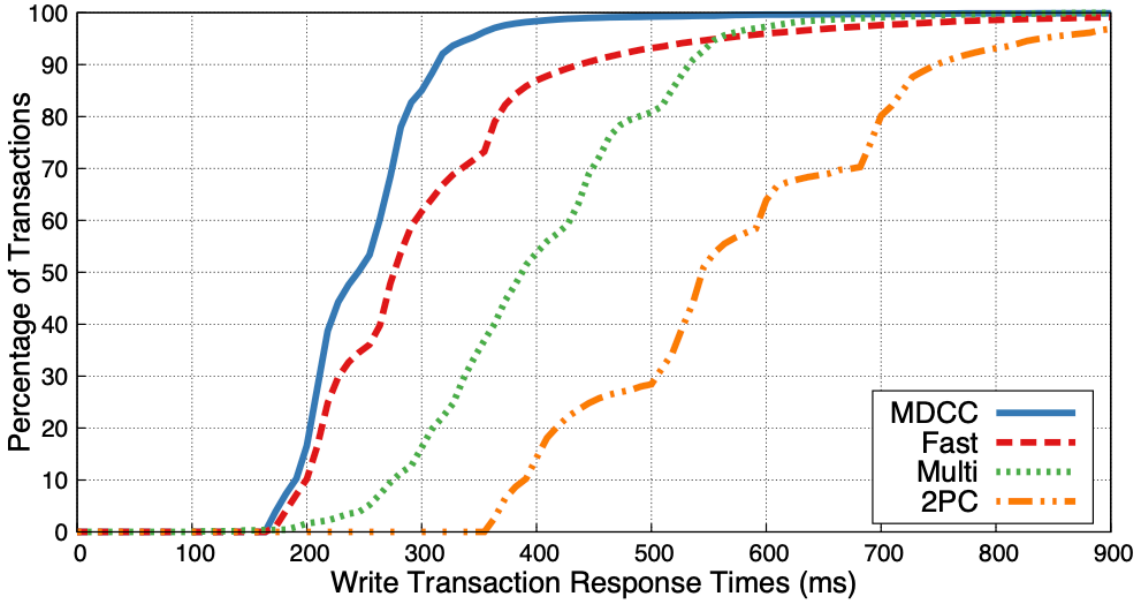
Evaluation

- TPC-W benchmark



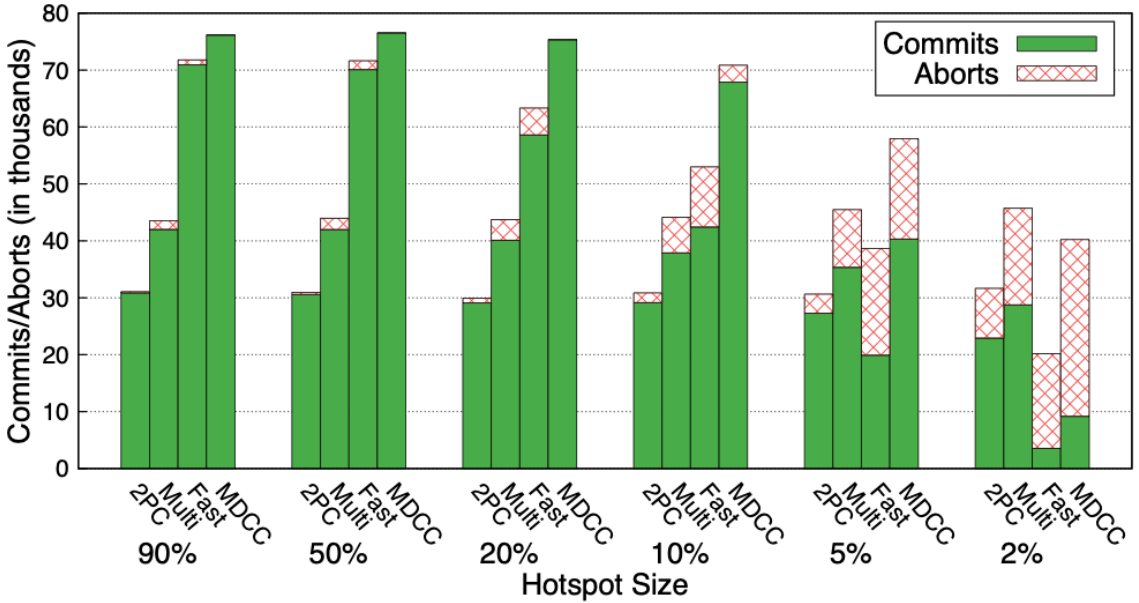
Evaluation

- Micro benchmark - write response times CDF



Evaluation

- Micro benchmark - varying conflict rate



Conclusion

- MDCC - Multi-Data Center Consistency
  - Optimization protocol
    - Conflicts are rare
    - Updates are commutative
  - Requires only 1 message round
  - Strong consistency
  - Low latency