Proposal of Transaction on RAMCloud

rev0.64

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Problem Statement

- Introduce ”**Transaction**” to RAMCloud
- What is ”**Transaction**” ?
  - Wikipedia ‘Database Transaction’:
    - To provide **reliable units of work** that allow correct recovery from failures and **keep a database consistent** even in cases of system failure, when execution stops (completely or partially) and many operations upon a database remain uncompleted, with unclear status.
    - To provide **isolation** between programs accessing a database **concurrently**. If this isolation is not provided, the program's outcome are possibly erroneous.
  - User declares a partial sequence of data (object) access as “**a Transaction**”, to which RAMCloud provides ‘Database Transaction’ feature.

Characteristics of a Transaction

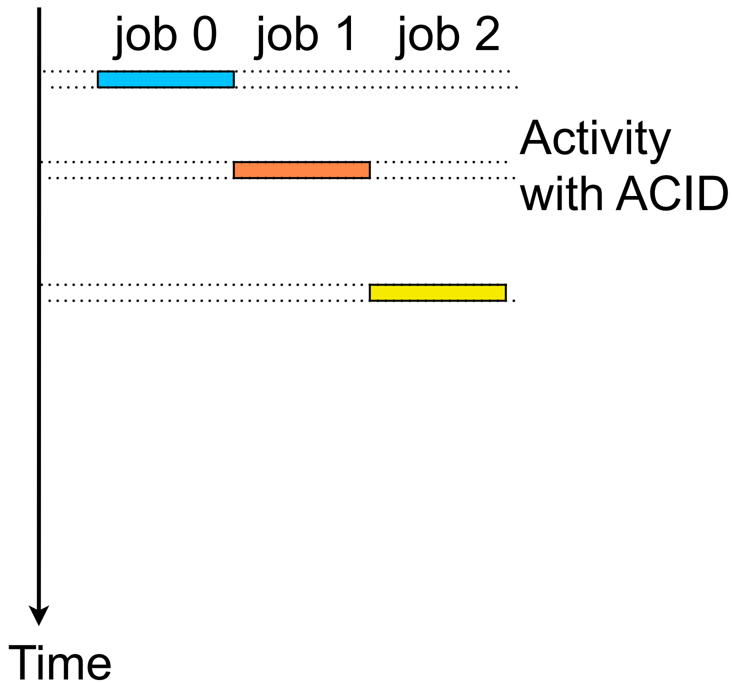
1. Duration varies from short to long: 0.1ms to 100ms
2. Very small chance of conflict to other transactions
3. Too many conflicts are data/control design issue

Example	Duration	Chance of Conflict
Analytic (Data analysis)	min. to hours	none after start
Ticket or seat reservation	to a few sec	small
Banking	to a few sec	small, at money transfer
Online shopping	to a few sec	small, can split to many independent
Stock trading	1 to 100ms	small or medium
SNS	100 to 1000 ms	small
Other web services	100 to 1000 ms	small

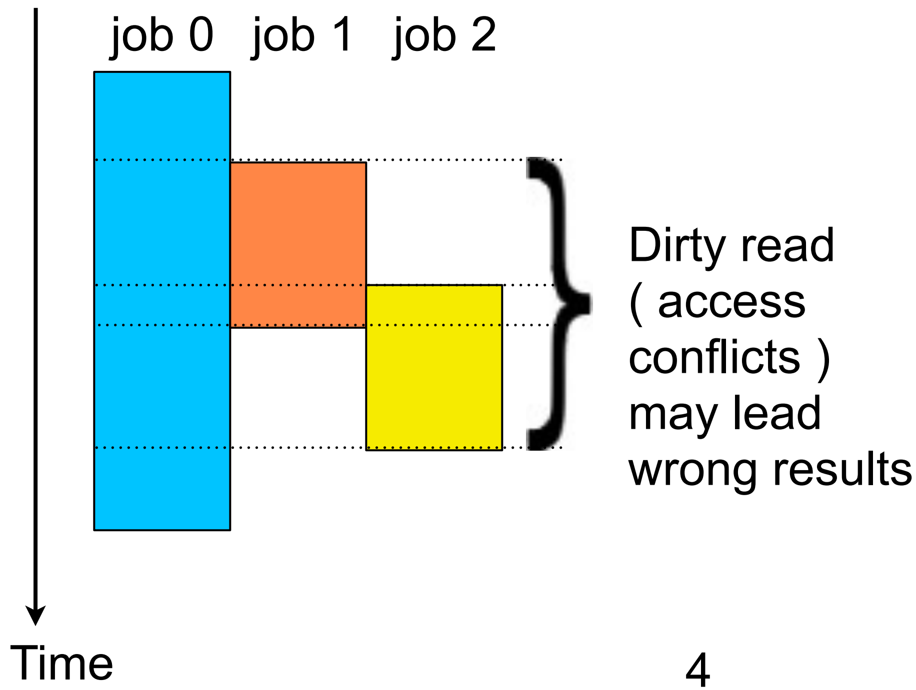
Issues in Parallel Execution

- Resource access conflict occurs in parallel execution
- Requirement to avoid the problem
  - ACID: (atomicity, consistency, isolation, durability)
  - CAP Theorem: (Can relax partition tolerance) - discuss later

Ideal Parallel Execution)



Reality)



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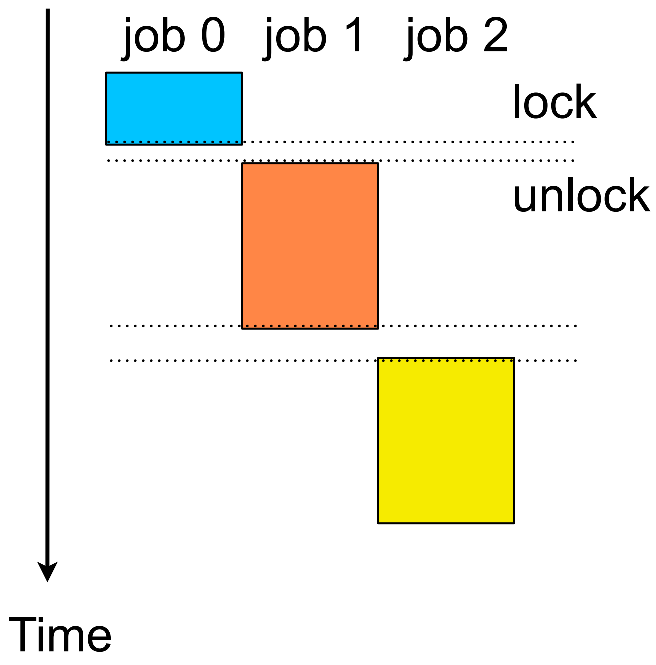
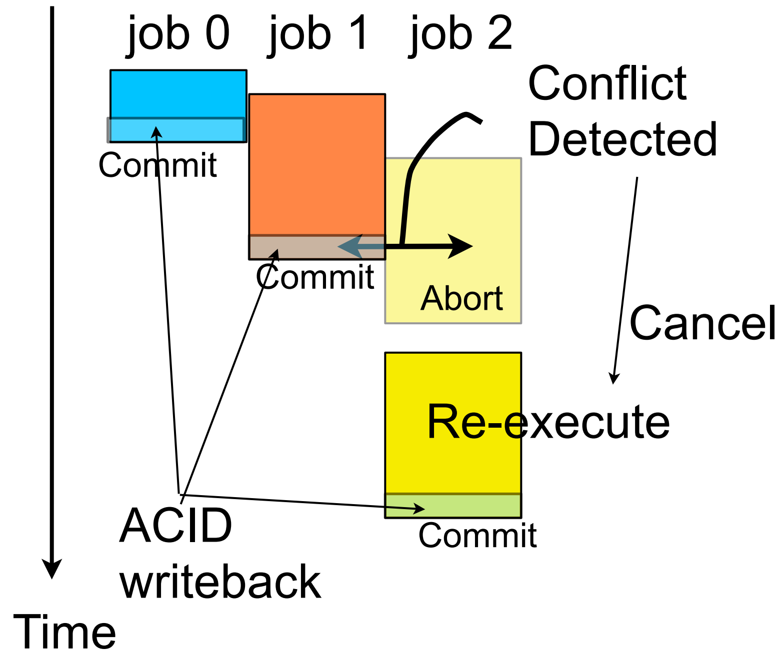
Conflict Solutions

Pessimistic Lock)



Text

Optimistic Lock)



Pros & Cons)
- Lower parallelism with giant locks
- Dead lock prone with fine locks
- Need releasing lock with node crash

Pros & Cons)
- Need conflict detection logic
- Lower Performance loss by frequent conflicts
- Alternatives in abort detection

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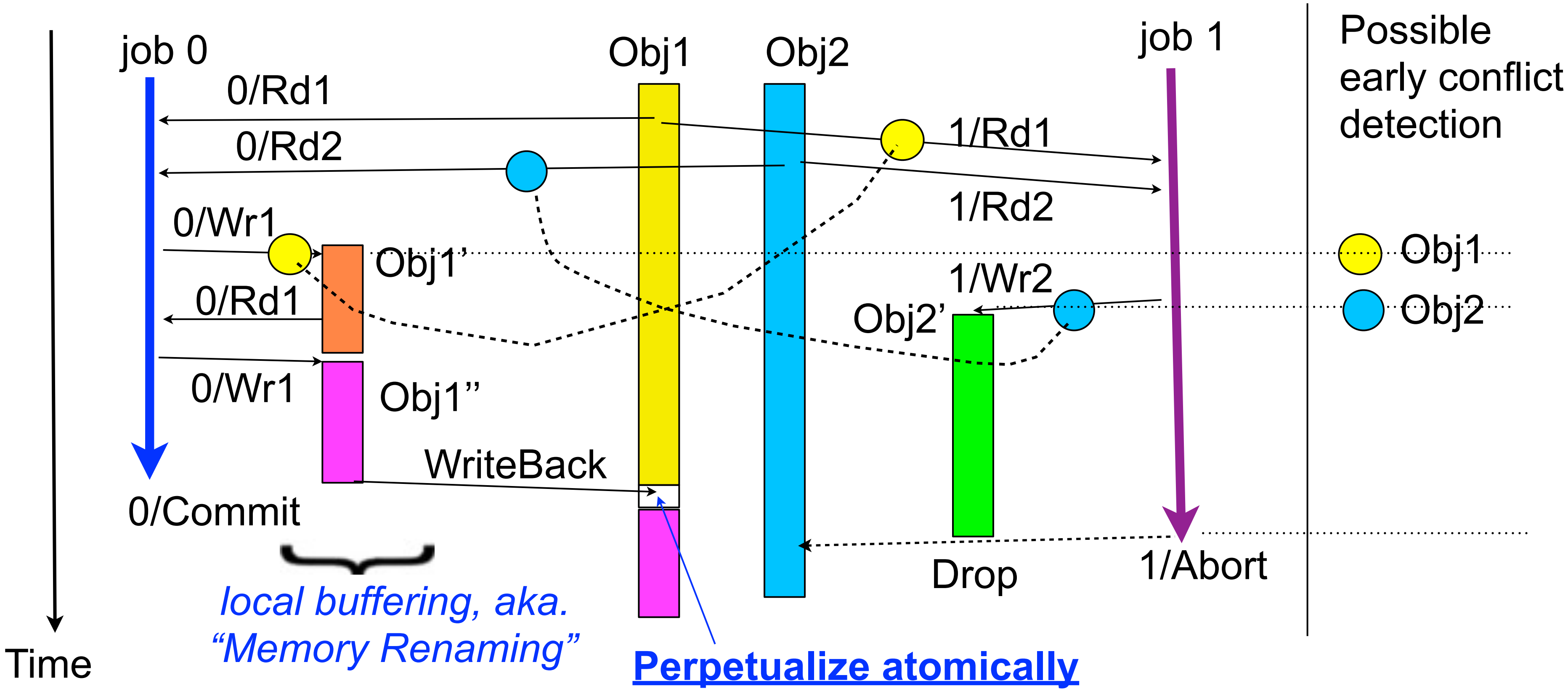
Optimistic Lock: General Solution

- Conflict detection of true dependencies: RAW (Read after Write)
- Renaming false dependencies : WAR, WAR
  - Common technique in parallel execution such as Speculative MT, Transactional Mem., RDBM



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Assumptions and Strategies

Application Specific)

- Transaction life varies between **short to long**
  - Try early conflict detection avoiding livelock
- **Small probability** of conflicts
  - Use optimistic lock based design
  - Otherwise create pessimistic lock at user level
- Well designed application shares appropriate amounts of data in a transaction
  - Involve small number of nodes to **reduce probability of relevant node crash** for a transaction

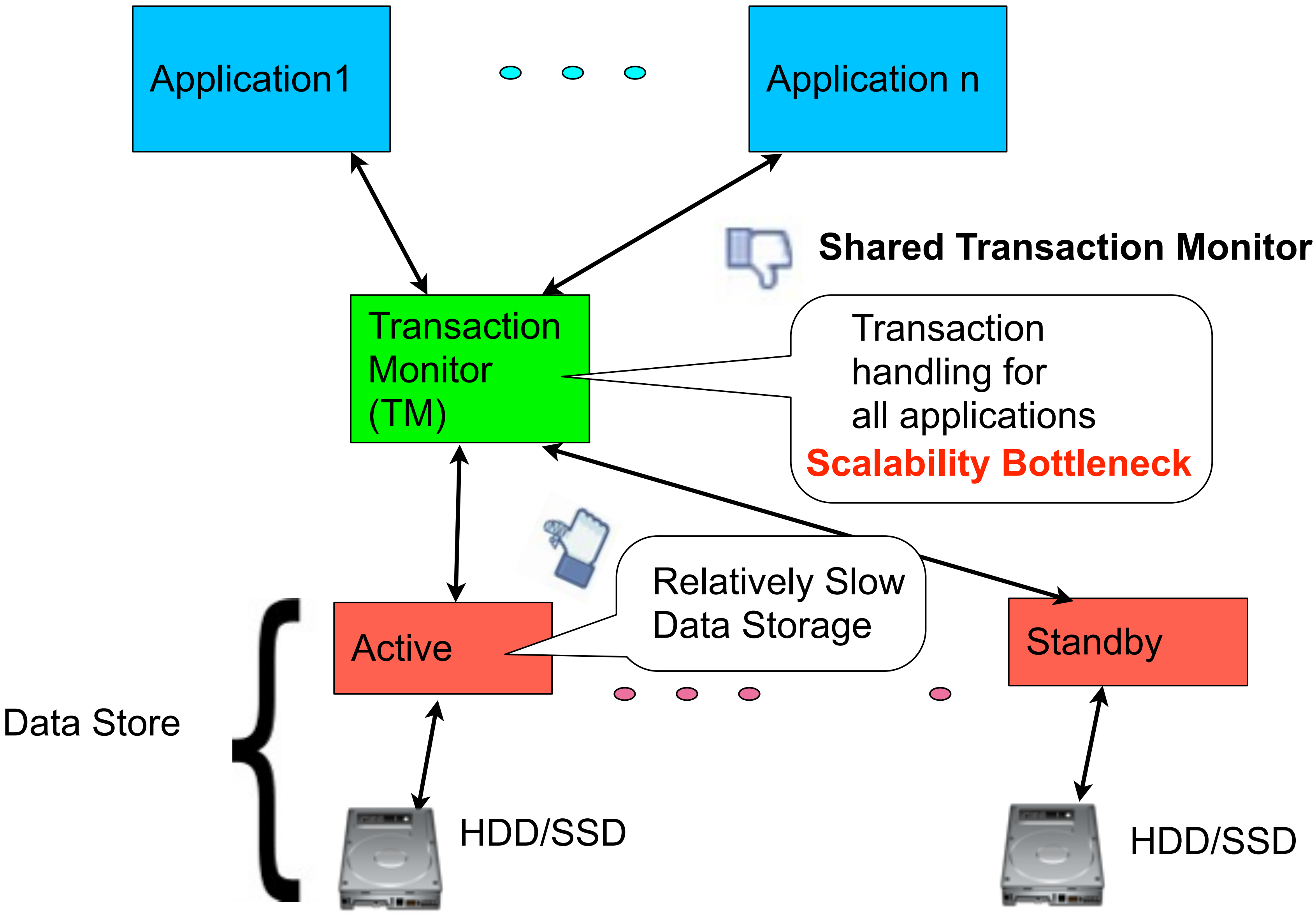
RAMCloud Specific)

- Faster crash recovery around 1 sec
  - Can yield to **blocking algorithm** without corner cases
- **A separate log** on each master - advantage of **scalability**

Note)

- CAP Theorem
  - Means: Consistency, Availability, Partition-tolerance
  - RAMCloud natively does not have partition tolerance, only the partition where coordinator exists works.
- Multiphase Commit
  - If we can allow waiting for node recovery, two phase commit works.
  - Since the blockage is not realistic, couple of non-blocking commit algorithm have been introduced:
    - Consensus (Paxos, Raft): Always live majority hides node crash
    - Multiphase Commit - prevent commit blockage
      - Quorum Commit: Majority side works during partitioning
      - Three phase commit - still it is not easy to detect failure mode.
      - Paxos commit, etc

Traditional Transaction System



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Traditional Transaction: Sharding

- Distribute database into several servers for scalability

- Micro-Sharding: implement SQL's transaction on KVS by confining a transaction related fields in a single row.

Problems)

- Need a good design of fields in record
- Not always possible to allocate independent sharding

To Be Added

Ref: Microsharding: Mapping Relational Workloads on Key-Value Stores, Junichi Tatemura, Hakan Hacigumus, et. al., NEC Lab. America

Traditional Transaction: Sinfonia

To Be Reviewed

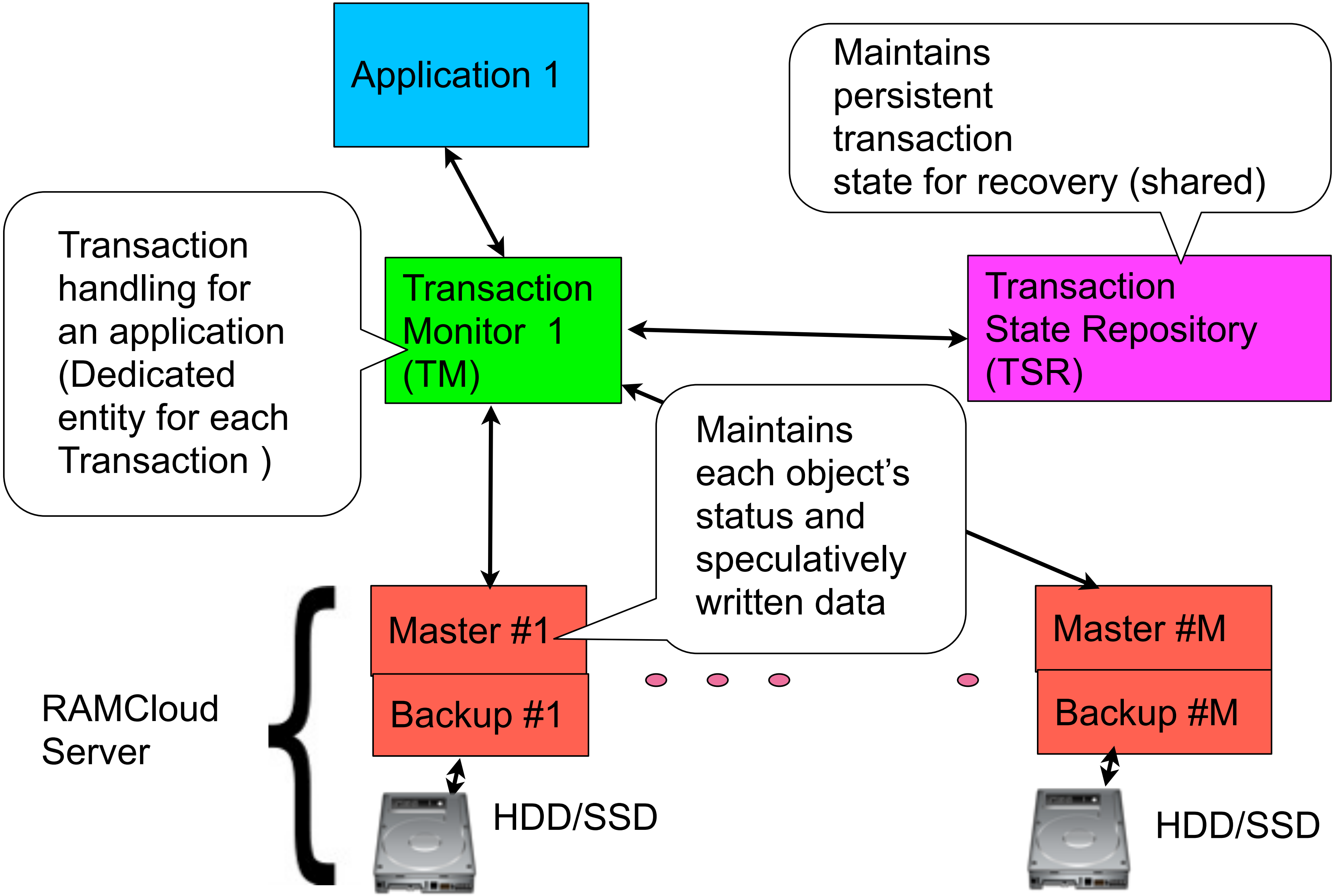
- Distributed design: user library manages transaction - distributed transaction monitor
- Light: memory based, so that fail detection and abort
  - Memory node recovery with redo-log
- Abundant APIs - transaction can be declarative, and natively simple
- Two phase commit
  - Compare and conditional store at commit time
- Trans. coordinator recovery mechanism not included
  - Node failure detection
  - Recovery coordinator for coordinator crash

Ref: Sinfonia: A New Paradigm of r Building Scalable Distributed Systems, Macros K. Aguilera (HP Lab.), et. al. , SOSP, Oct. 07

Proposal: Key Idea

- Distributed TM (transaction monitor) for **scalability**
  - Library based design for **low latency**
- **Integrated crash recovery**
  - triggered by RAMCloud coordinator which is always available by consensus algorithm
- Taking advantage of **distributed log** in RAMCloud master
  - Natively all the checkpoints are available and durable
- **Natural** transaction API
  - No need to design database field or a set of query **without exposing**:
    - Node crash/recovery
    - Data structure such as log, checkpoint

Proposal: Components



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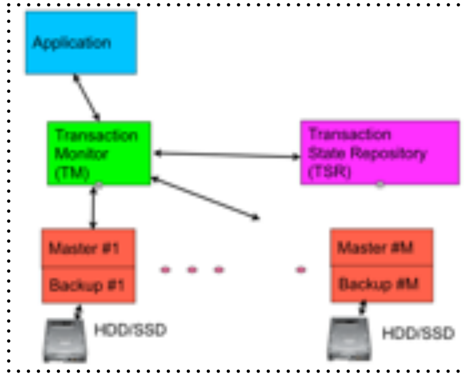
Components - Functions

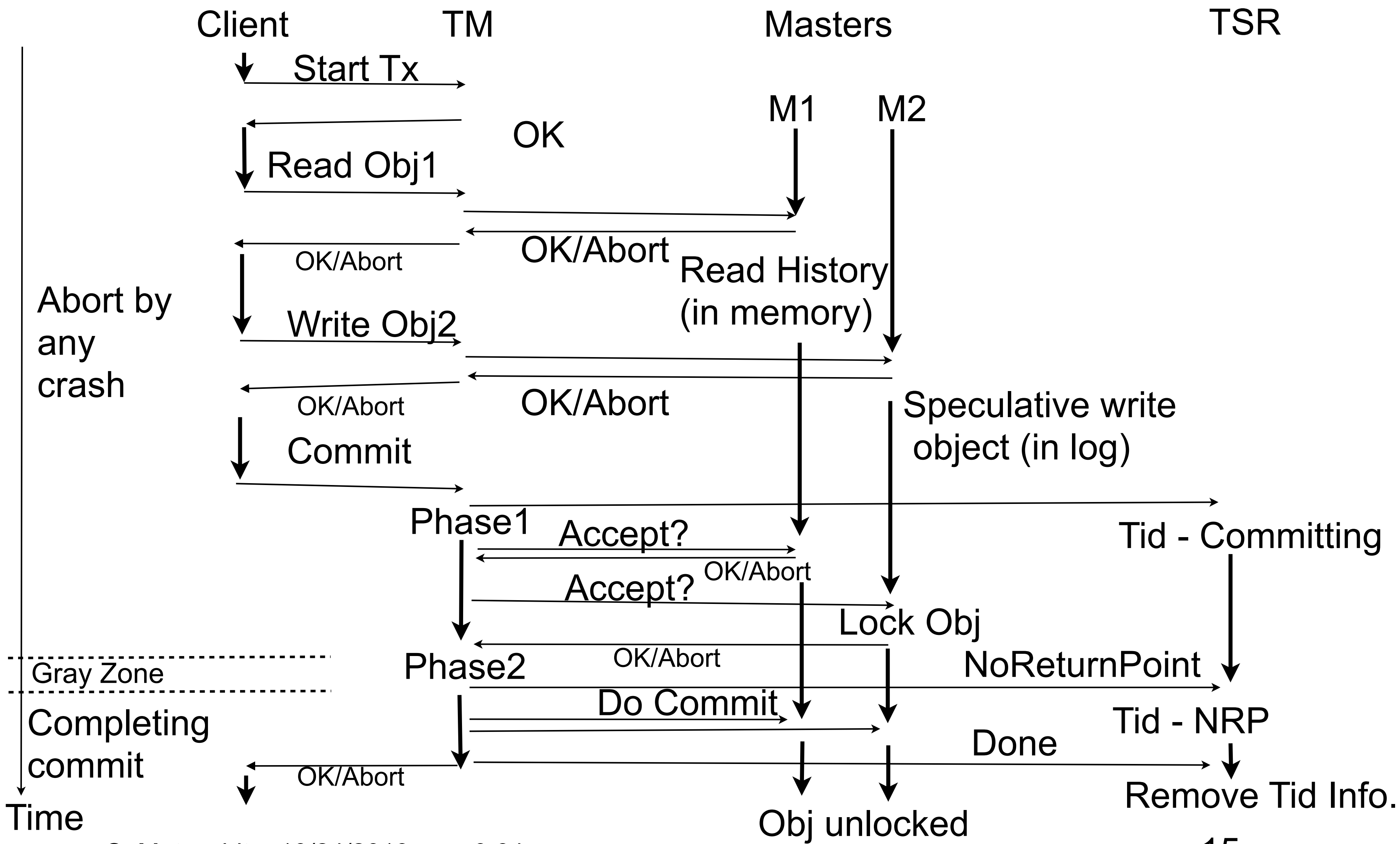


- If client application is restarted <u>immediately</u> (by coordinator, etc), TM can be implemented in client library.

Functions	TM:Trans. Monitor	TSR:Trans. State Repo.	Master	Coordinator
Normal Op.	Generate unique Transaction ID. Keep track objects states. 2phase commit coordination.	Store global status of a transaction persistently	Keep object s' status and temporal data, return appropriate data	Maintain crash information and TM identifier.
At Recovery	Continue 2phase commit (**<u>resource unlock</u>**)	TM accesses the transaction status	Respond TM to complete commit/abort	Restart TM, or notice TM crashed node.
Possible location	Client library, Client node, or Master	Master node as a normal table.	Master node	Coordinator

Basic Flow: Life of a Transaction

- Define Transaction priority uniquely with Tid: Transaction ID



Outline of Detailed Discussion

1. Client API
2. State transition of transaction and objects
3. Conflict Management
   i. Resolution at object access with transaction priority
   ii. TMid/Tid for unique global transaction order
   iii. Timeout to avoid deadlock
4. Commit - transition from non-blocking to blocking
5. Recovery
   i. Cleaning up by abort or completing commit
   ii. TM implementation
      service process or library - depends on client recovery
   iii. TSR implementation - in a normal table
6. Implementation Control / Data structure
7. Optimization
   i. Callback instead of piggyback
   ii. Separate key/state and data for objects in log

1. Client API - Simple,Minimum

- Start Transaction
  - tx_start(&tid); // return new tid
- Object Access
  - tx_read(tid, tableId, key, &buf, &state...);
  - tx_write (tid, tableId, key, &buf, &state...);
  - tx_remove(), tx_multi-...(),
  - ▸ Can define tid=0 as non-transactional operation
  - ▸ Still need compare & swap for multi-threading app?
- Commit & Status of Transaction
  - tx_commit(tid, &state);
  - tx_abort(tid, &state);
  - tx_status(tid, &state);

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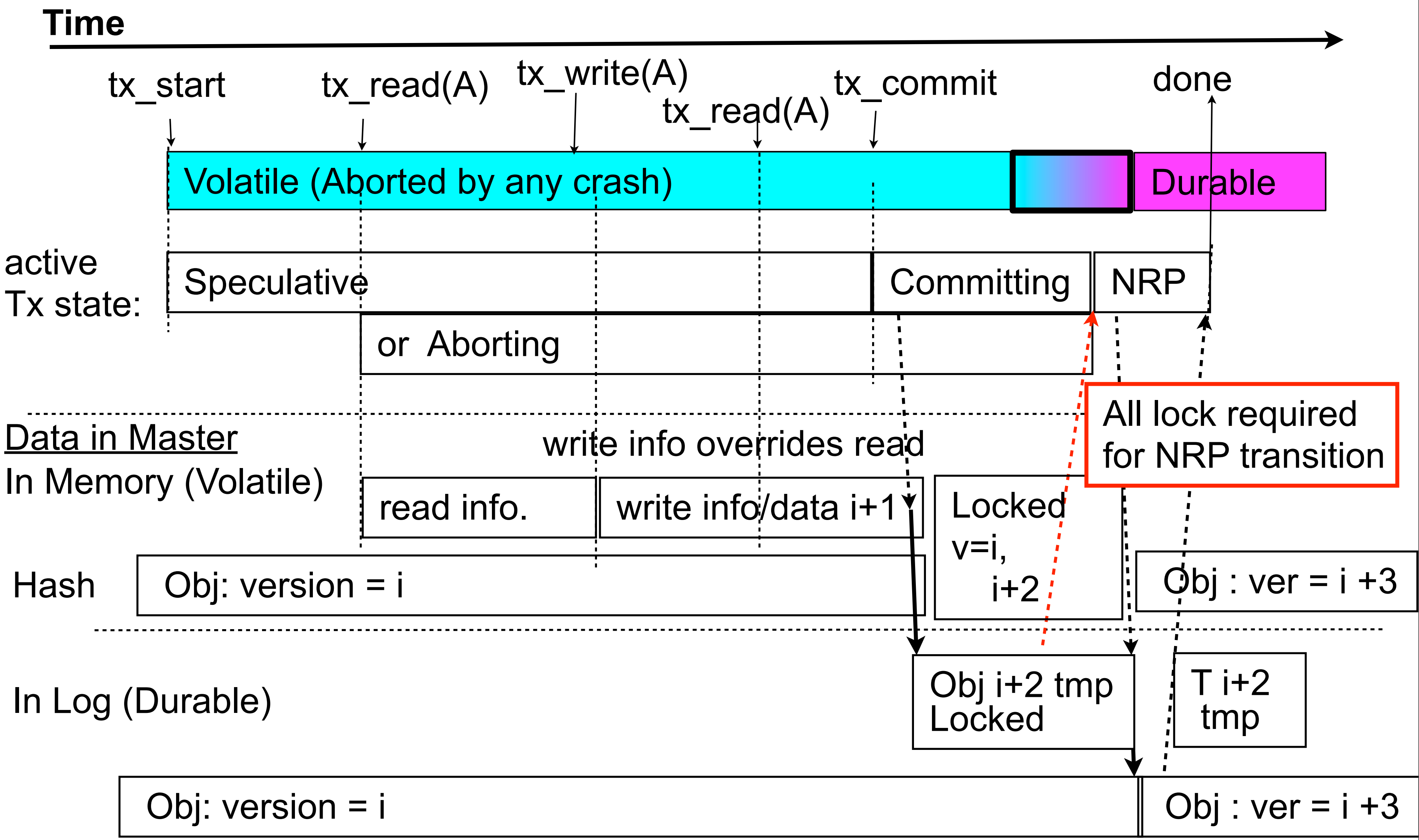
2. Transaction States

Detail

- Assume a transaction accesses single object 'A' for simplicity



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2. New Object Type

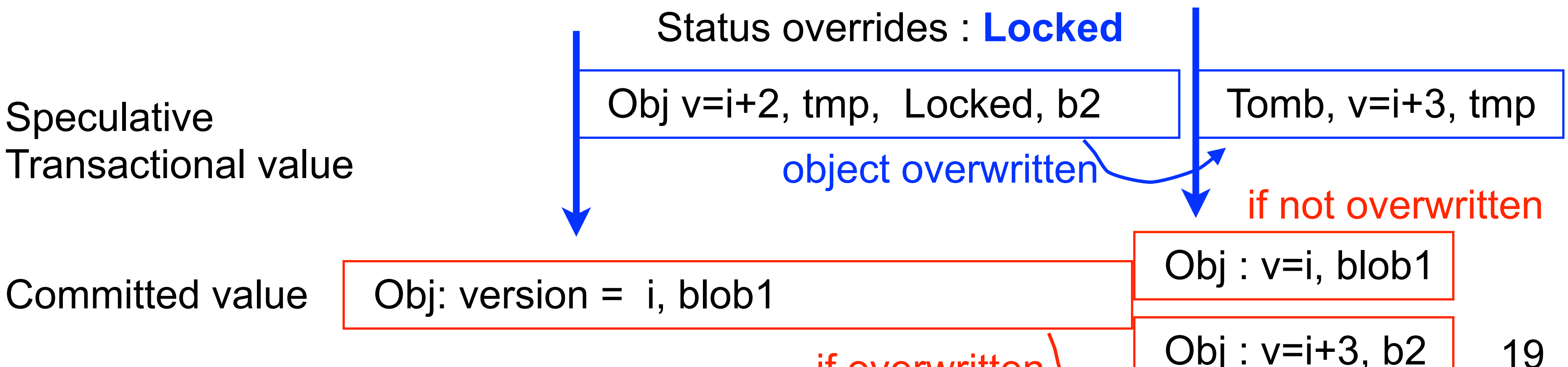
- How to declare locked object in log?

✓ 1. Define version grouping, let status override other groups

2. Define multi-data object containing both v=i, i+2

Note) 2 is simple but max object size becomes multiple

- Grouping object by group field
    - Compare version within the same group
  - Define temporal object as group=tmp
    - Object(key, ver, group=tmp, tid, status=locked, blob)
      Tomb(key, ver+1, group=tmp, tid)



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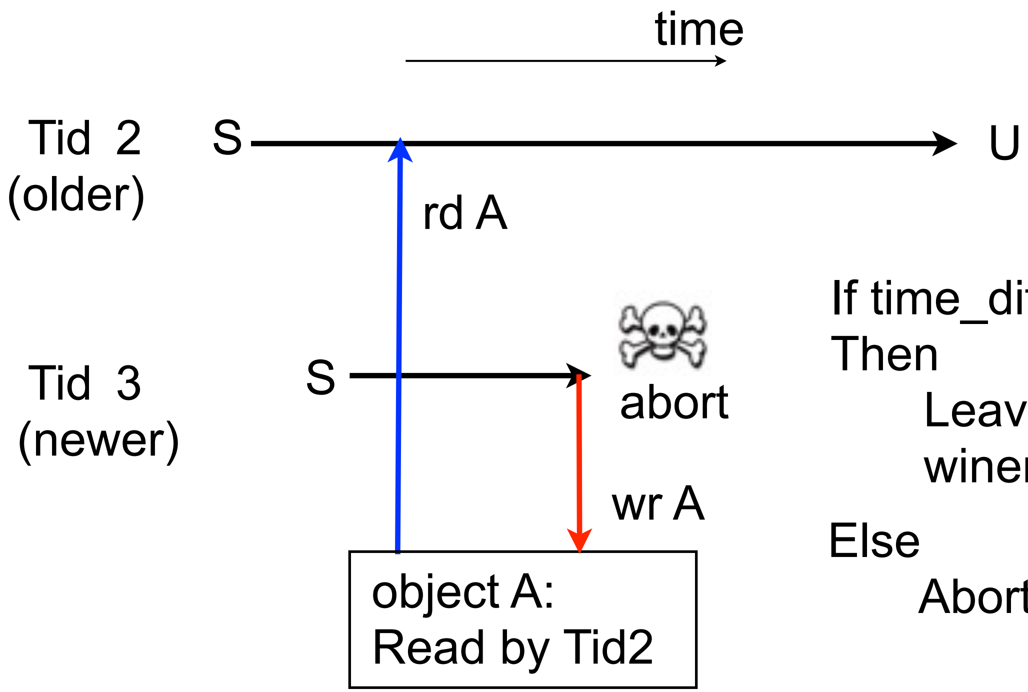
3. Conflict management at object access

- Compares Tid in Master. Abort newer Tid immediately.
  (Traditional technique in DBMS)
- Timeout to avoid deadlock by incorrect code or client crash, which freezes the oldest transaction.

Notation)
S: Started
A: Aborted
U: Uncommitted
(Speculatively running)



If time_difference(Tid3, Tid2) > Tout
Then
Leaves both alive and decides winer at commit time.

Else
Abort transaction with newer Tid

2. Truth Table of Conflicts Management

- Older transaction id wins at data access
- Provides only shared reads: can detect Read/Read conflict with dummy write: Rd (Obj1) with Wr(Dummy1)

Tid 1 (Older) < Tid 2 (Younger)

operation mode	Tid 1	Tid 2	winner
mode1	read	read	both
~~mode2~~ Not Supported		~~read~~	~~Tid 1~~
both modes	read	write	Tid 1
both modes	write	read	Tid 1
both modes	write	write	Tid 1

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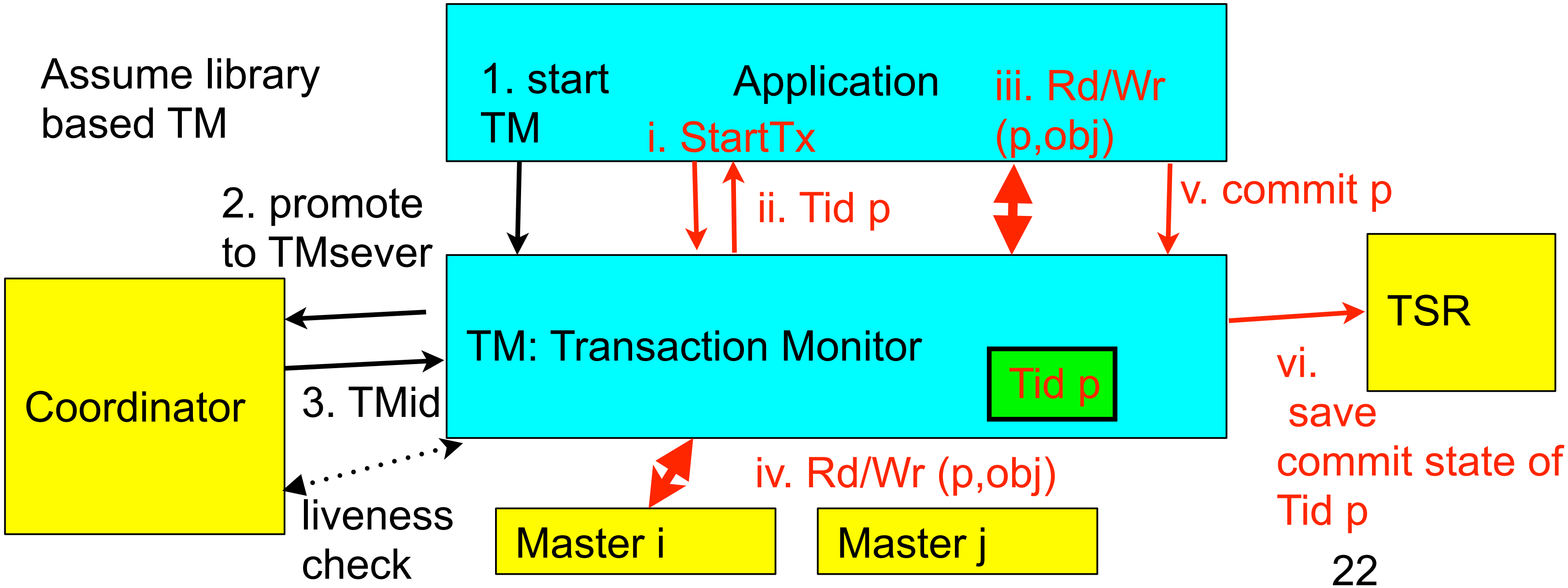
Tid, TMid

- TMid (TM identifier) is given by coordinator at TM startup
- Tid (Transaction identifier)
    - Define Tid = [TMid, TM-localtime] at a transaction generation // note: [a, b] = concatenation of ‘a’ and ‘b’
    - Compare TMid only when local time is the same
    - Preciseness is not required, because Tid is just a priority to decide a winner transaction at object access time.

Assume library based TM



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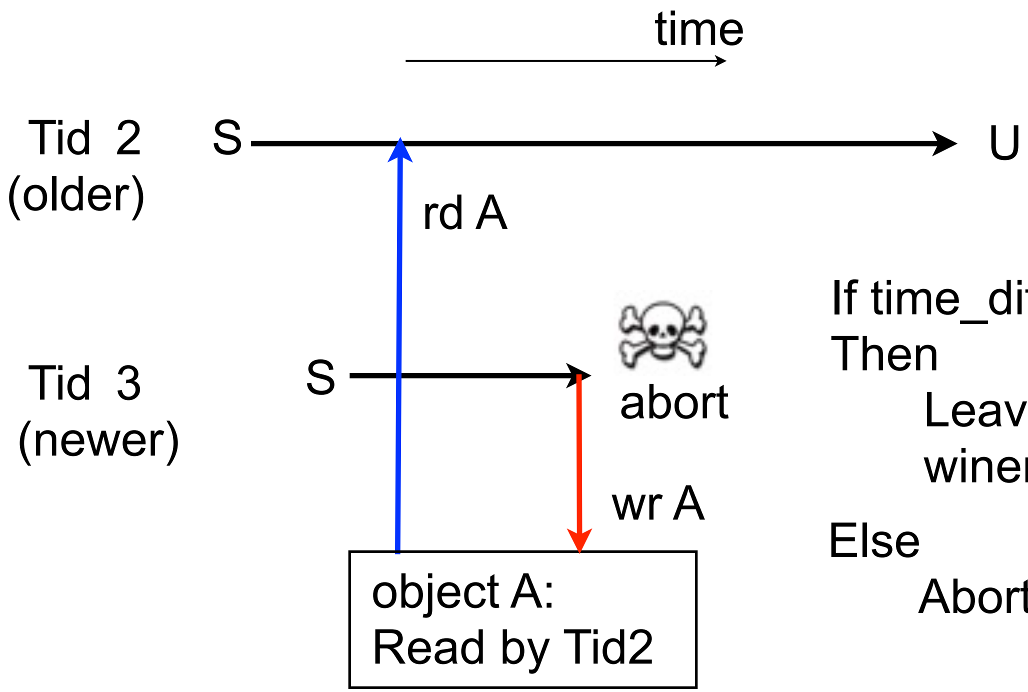

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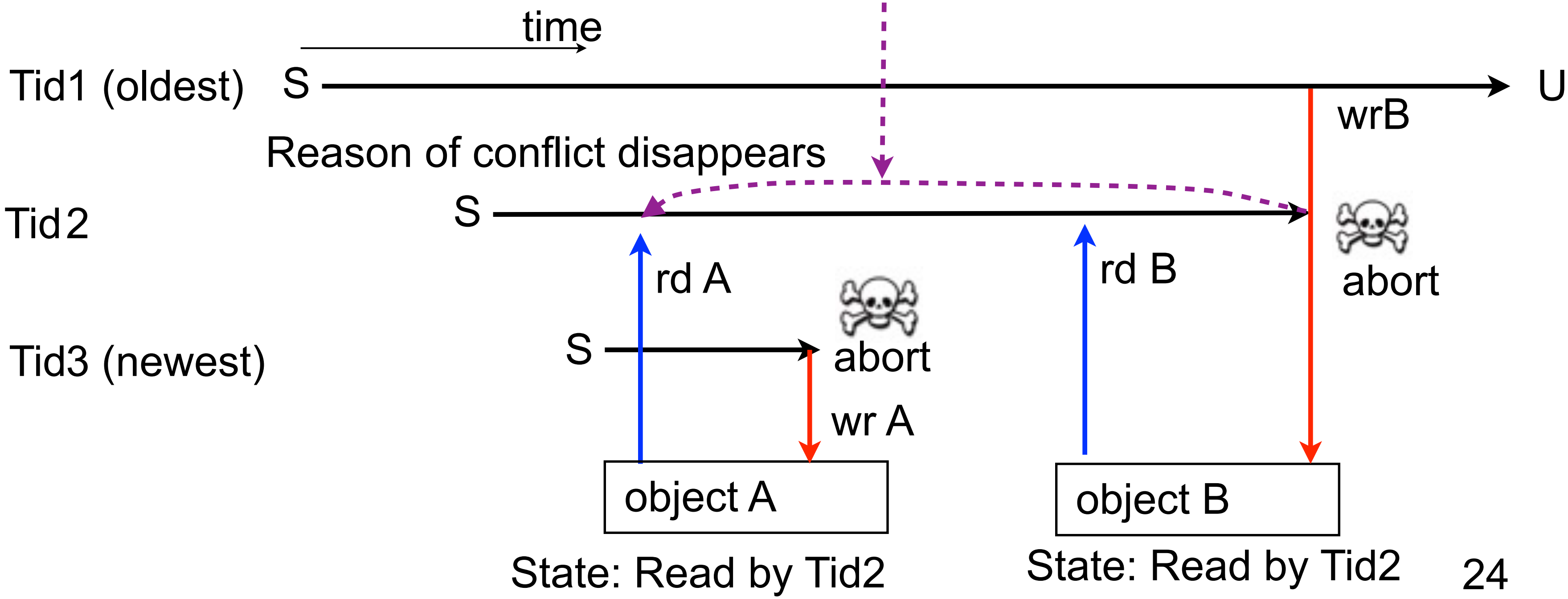
Issues - False abort/Status piggyback

- False Abort: the conflict which aborted Tid3 disappears when Tid2 is aborted later.
  - Chain reaction of false abort may occur
  - Leave it because provability of false abort is small.
- Abort notified as status return (piggyback).
  - Tid2 is not aborted by Tid1-write, but by some request in the future (Needs callback to optimize)



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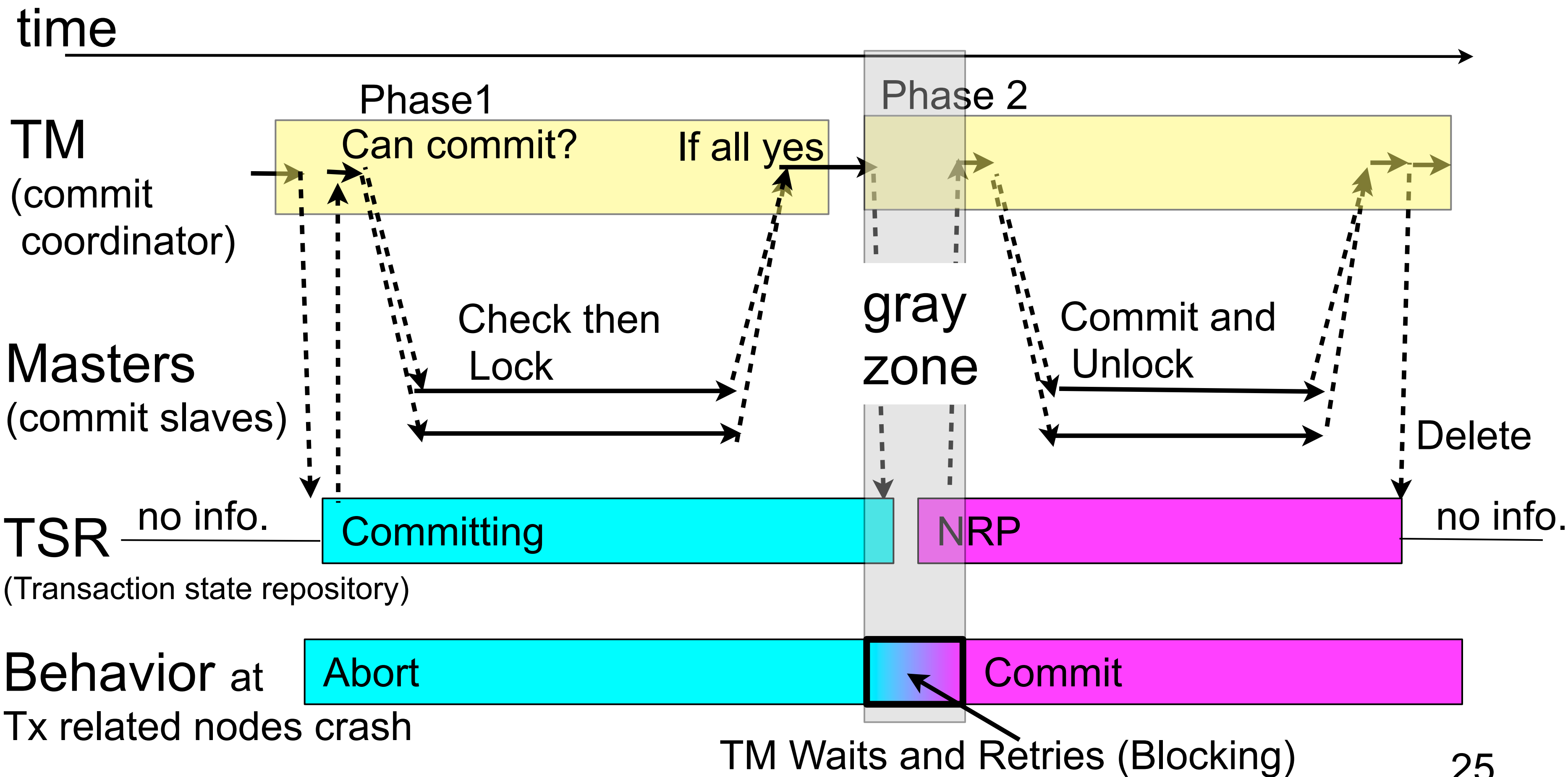
3. Commit - Two phase commit

- TM coordinates commit operation
- Save durable state in TSR
  - Committing: unlock object by abort (optimization)
  - NRP: no-return-point for durable transition to commit



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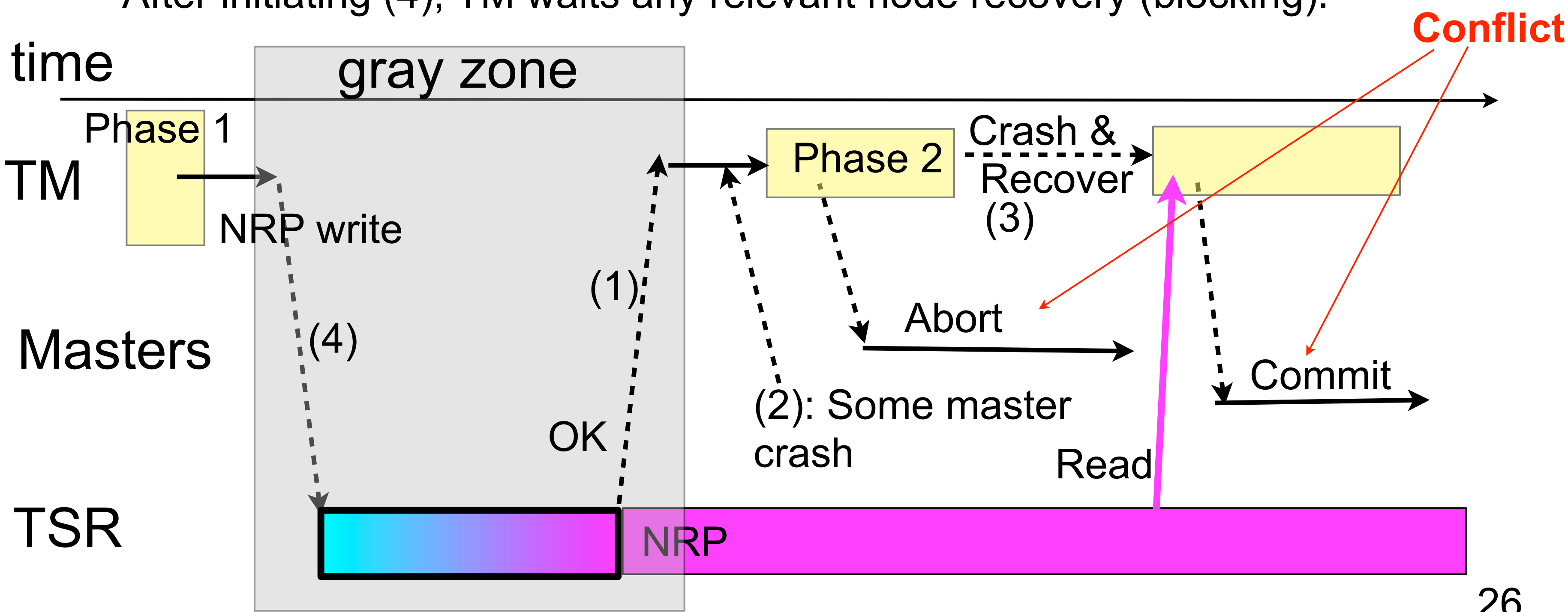
3. Commit - Racing conditions

- Racing condition: Note that <u>abort and commit are unilateral</u>
  - After NRP is written, TM start aborting in Phase2 due to (1) 'OK' loss or (2) relevant node crash
  - Then TM crashes. The recovered TM reads NRP then starts commit.
  - (1) cannot be distinguished from (4) lost NRP req
- Solution
  - NRP is idempotent: TM retries (4) and waits (1)
  - If TM failed retry, TM reads TSR after enough timeout to decide behavior.
  - After initiating (4), TM waits any relevant node recovery (blocking).



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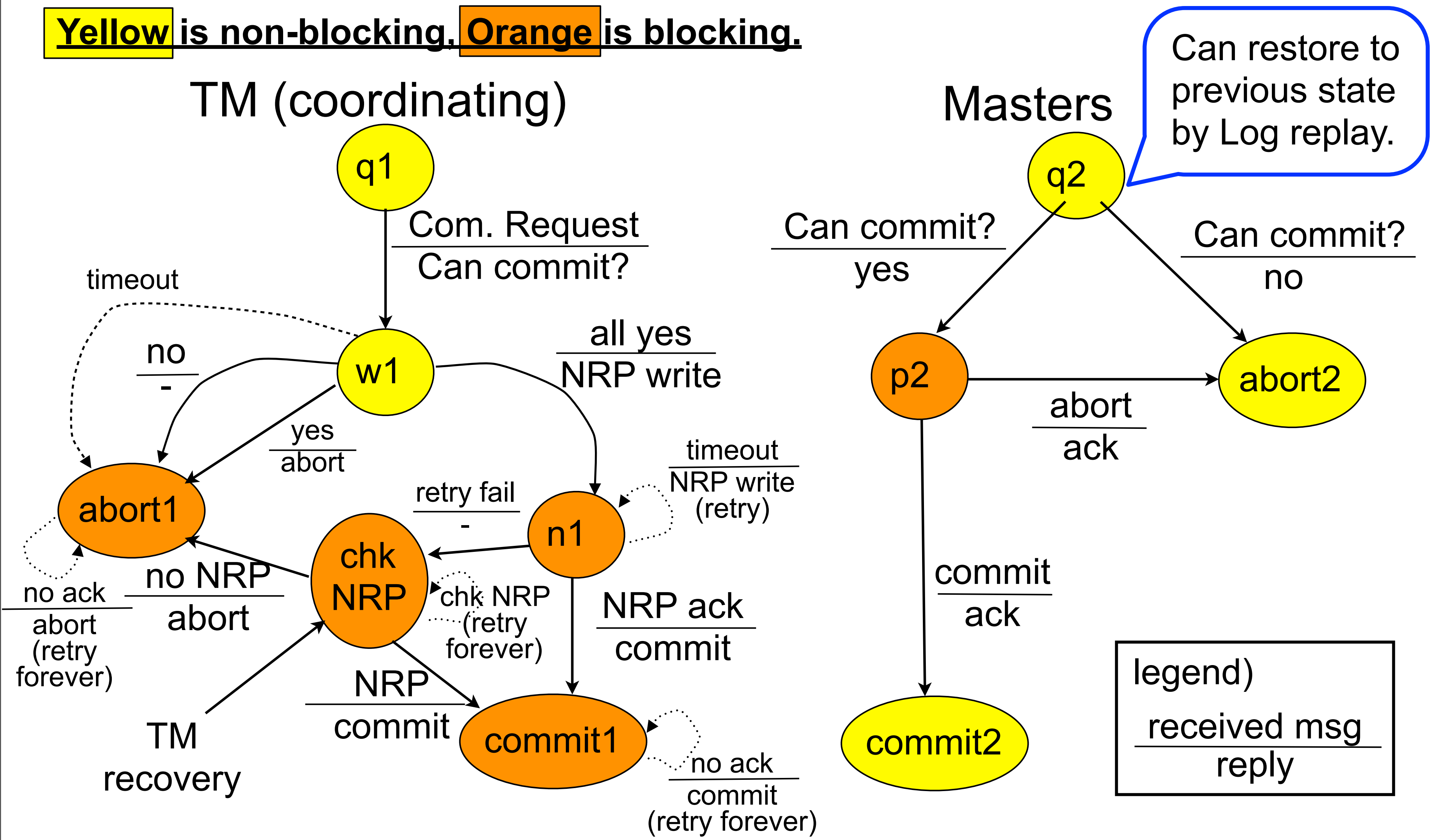
3. Commit - State Machine with Failure

Yellow is non-blocking. Orange is blocking.



Ref: A Formal Model of Crash Recovery in a Distributed System, Dale Skeen and Michael Stonebraker, 1983

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4. Crash Recovery - Clean up

- TM crash
  - Completes commit/abort transactions for the TM
    - Commits transactions whose NRPs are found in TSR
    - Otherwise aborts transactions which belong to the TMid
    - Fast cleanup required to prevent other clients' blockage by accessing locked objects
- Server crash
  - Reconstruct hash and object status in memory from log
- TSR crash
  - Recover commit status of transactions

5. Implementation Alternatives

- TM - item 1 seems simplest and good for performance.
  1. ✓ In client library such as crt0.
     - Pros) Application (Tire2, Tire3) needs to be recovered to continue web service anyway
     - Cons) Need client recovery mechanism by coordinator
  2. In a master
     - Need TM locator
     - Cons) Extra access latency and network traffic by additional hop for data access
  3. In a separate process/thread in a client node
     - Need recovery mechanism
     - Cons) Extra latency by process communication and dispatch
- TSR
  - In a master with defining a table and save transaction state as a normal object.

5. Implementation Proposal

- Implement TM in **client library**
  - Coordinator detects client failure and restarts
  - Naming issue: 'Once the liveness check/recovery is managed by coordinator, it should be called 'server' - not a client anymore'.
- TMid given by coordinator
- TM generates Tid = [TMid, TM's local time]

[a, b] denotes concatenation

- TSR as a specific table
  - List of status: (Key, Value) = (TMid, list_of{ (Tid, TransactionStatus) })
    - Can find both a Tid and all the Tids with TMid.
    - Simple enough since one commit operation is underway for a TM normally.

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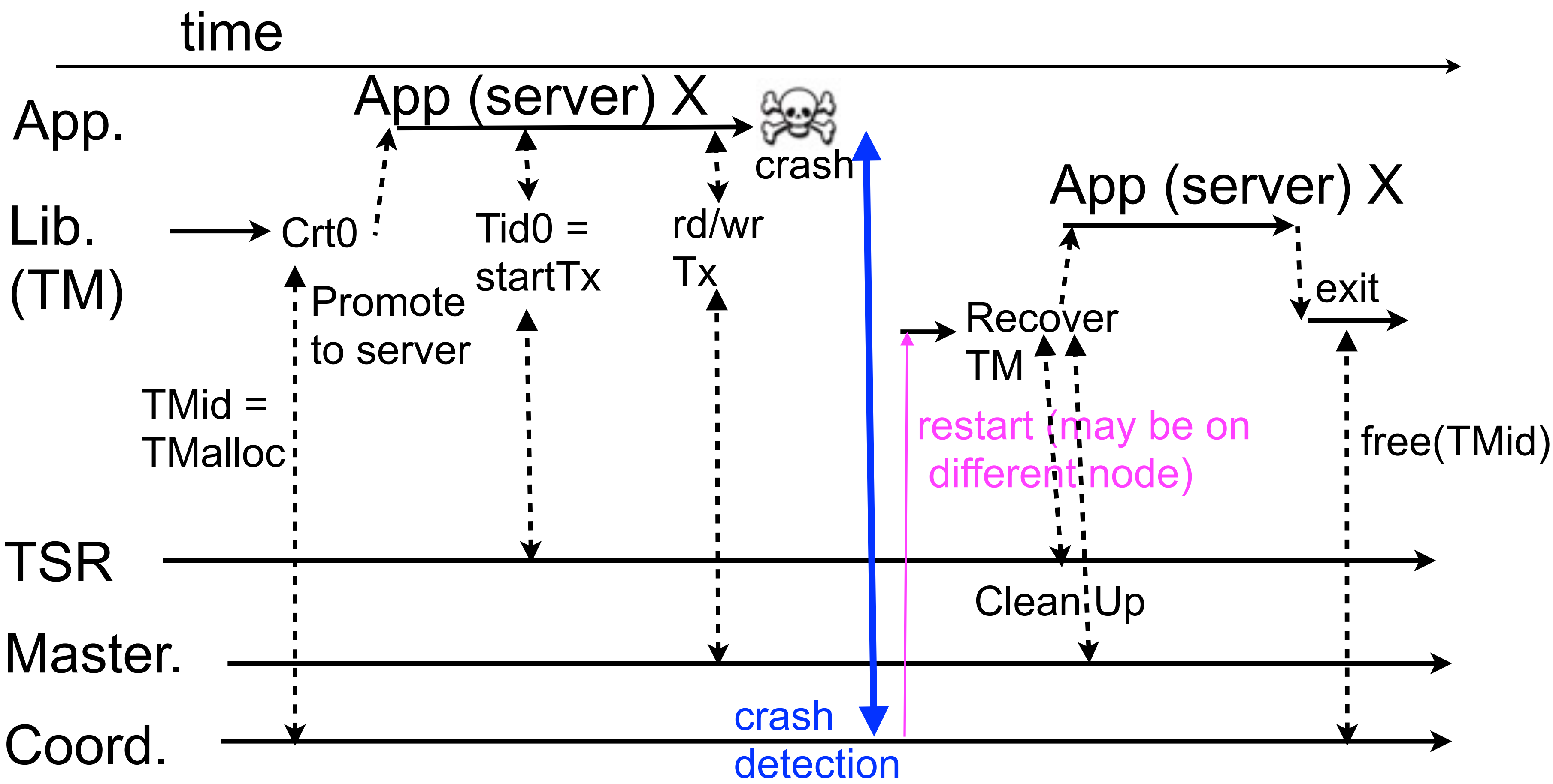
5. Implement TM in Client Library

- Crt0 contacts coordinator to get TMid and register application info. for recovery.
- User can modify transaction algorithm by modifying library.



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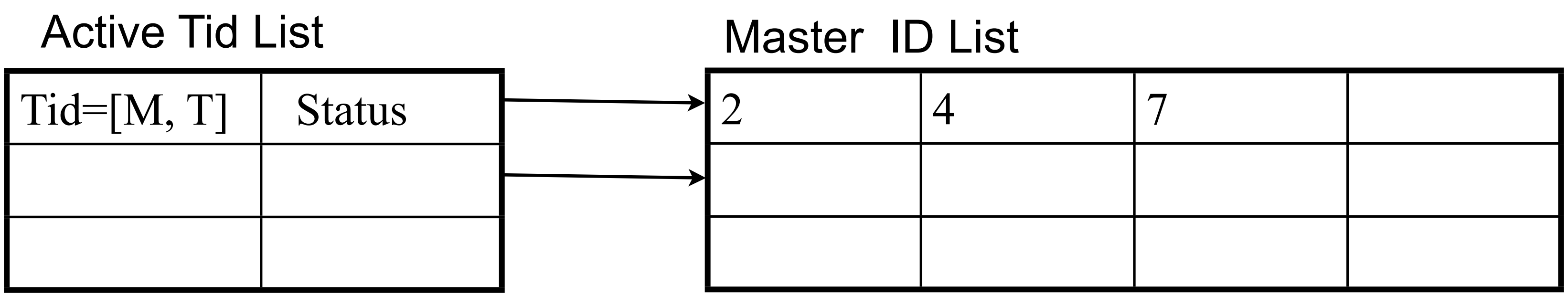
5. TM Data Structure

- All data in memory which consist:
  - Status: Speculative/Committing/NRP/Aborting
  - Master IDs: masters accessed by each transaction
  - After TM crash, states for Tids recovered from TSR:
    - State: NRP/Else
  - Finalize Commit if NRP / Abort otherwise

    by broadcasting a request for a TMid to all masters

    // TM crash probability is small and request size

    // is small. (no optimization so far)



5. TM Control

Status for each Tid: Speculative/Committing/NRP/Aborting

To Be Done.

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Master Data Structure

Simple example

- Volatile data forgot by crash: hash, array -- any improvement using log structure? memory management?

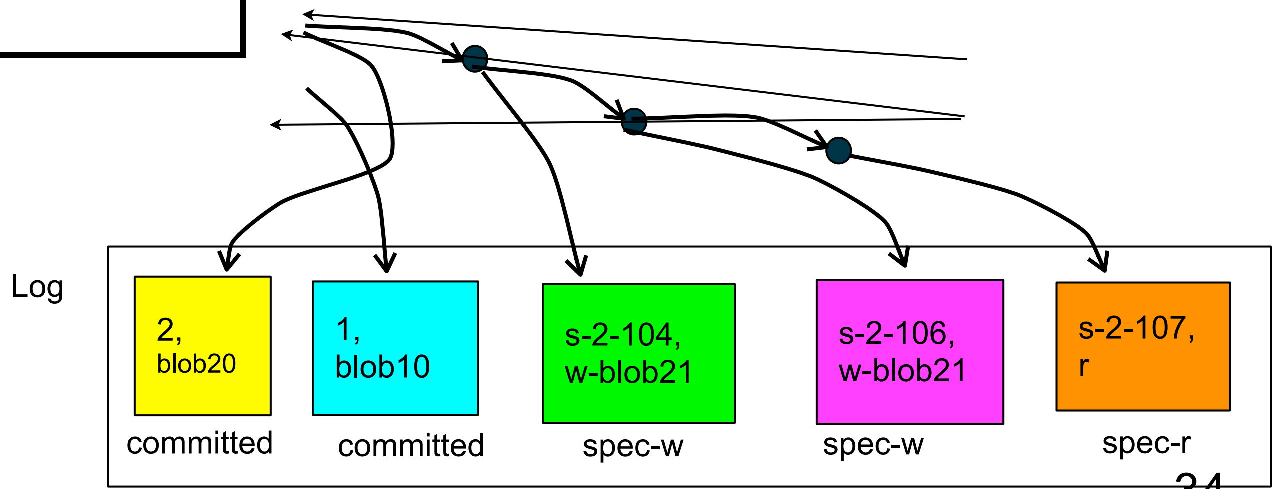
To Be Done.

Tid Hash

T1 = [1, 60 ms]
T2 = [1, 85 ms]
T5 = [3, 85 ms]

Key hash

2
1
12



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Master Control

To Be Done.

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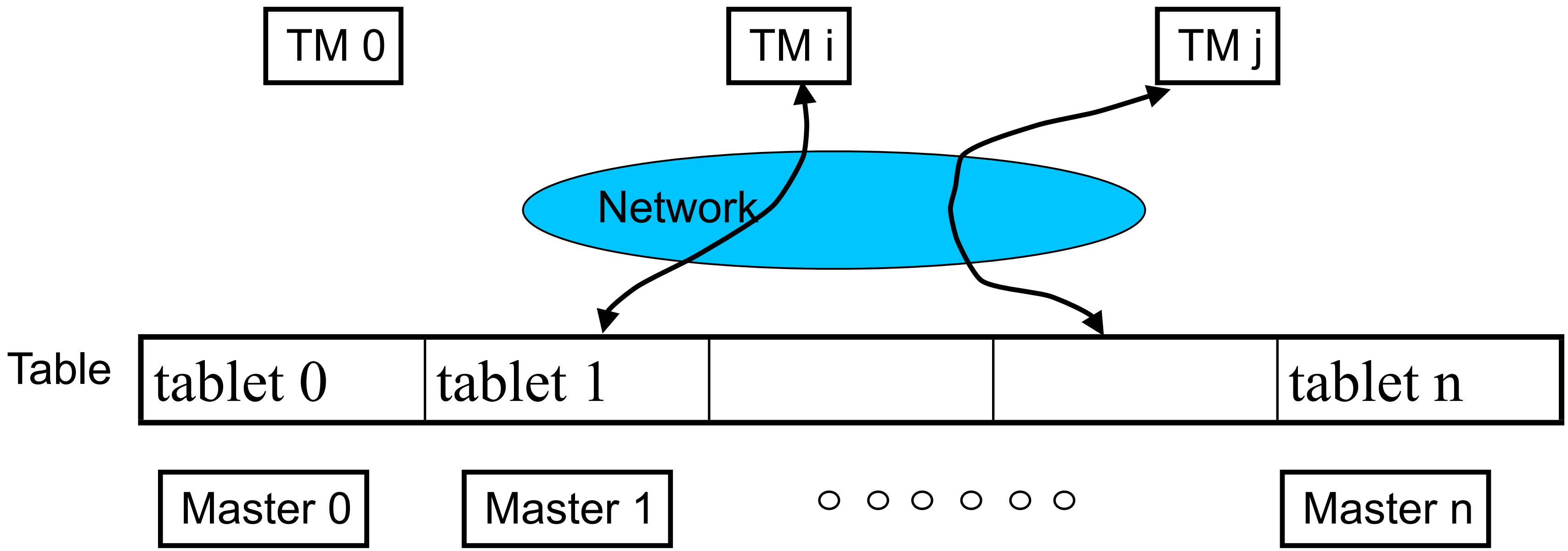
TSR Data Structure

- TSR as a specific table:
  (Key, Value) = (TMid, list_of{ (Tid, TransactionStatus) })
- Distribute access by a hash of the Key
- Durable and available



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