Proposal of Transaction on RAMCloud

rev0.63

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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

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

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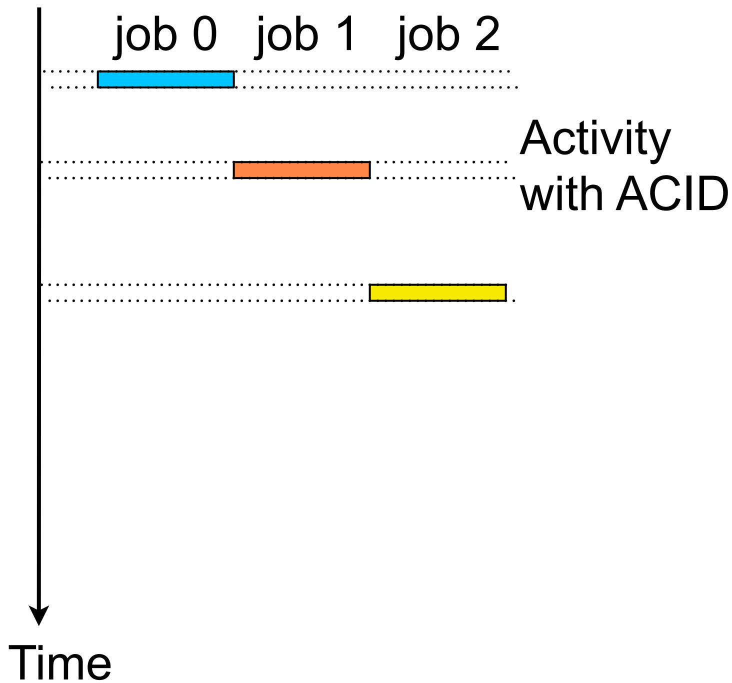
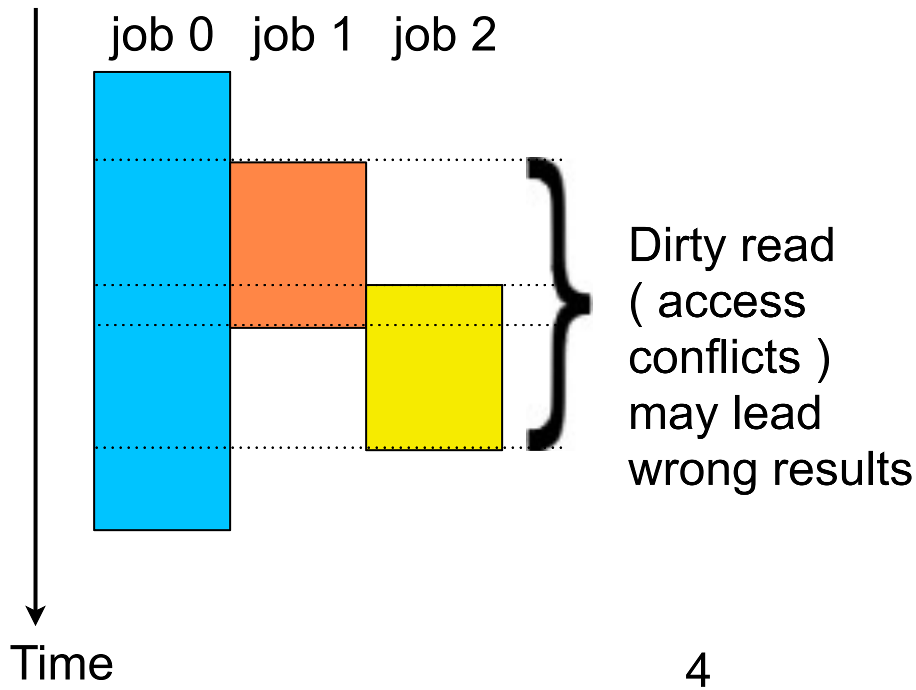
Issues in Parallel Execution

- 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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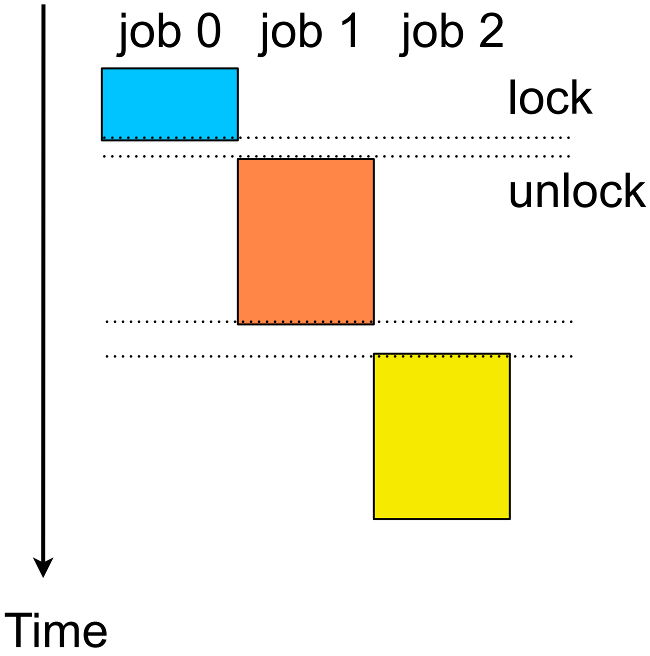
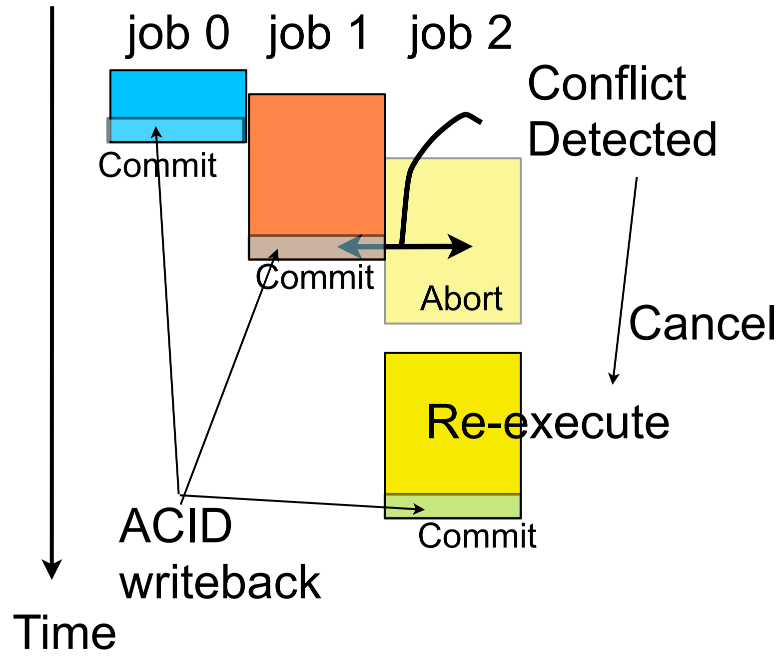
Conflict Solutions

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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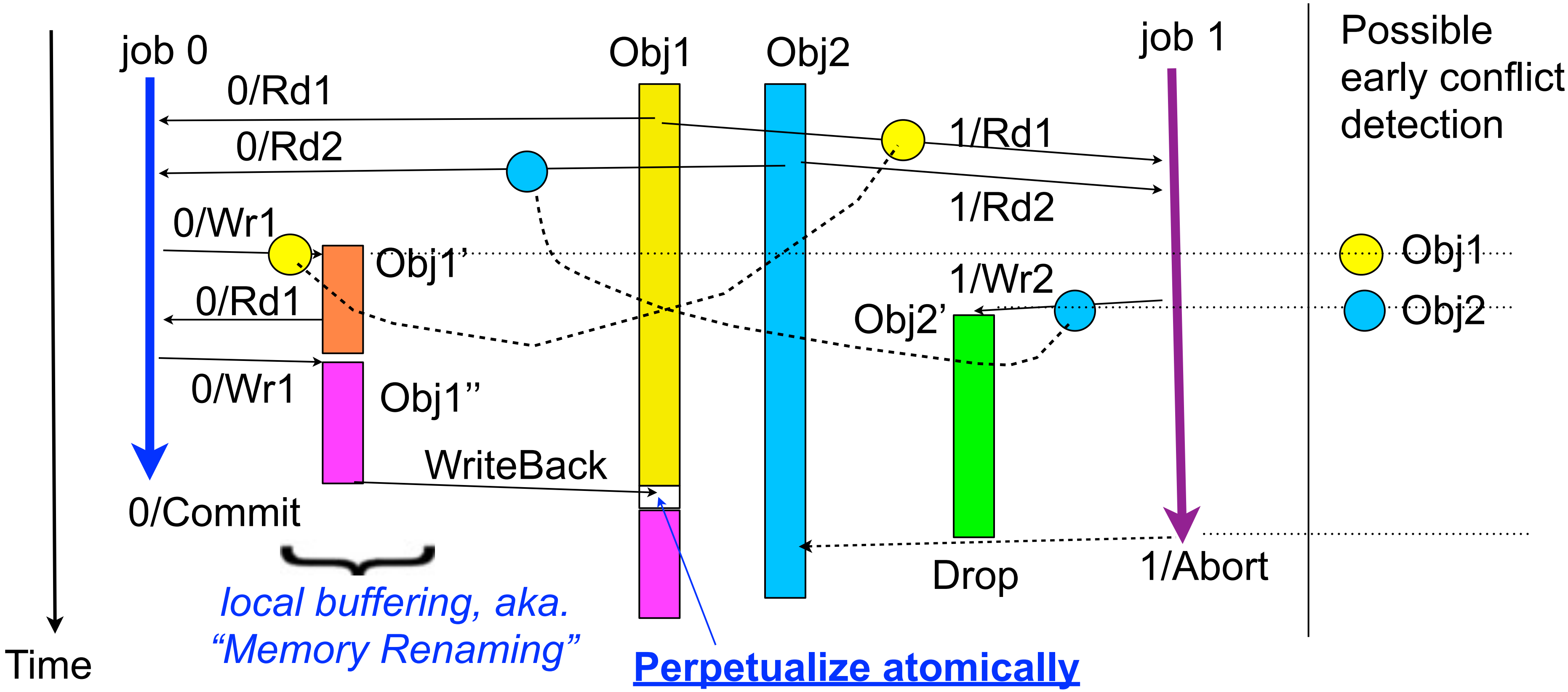
Optimistic Lock: General Solution

- 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 use pessimistic lock at user level
- Small probability of node failure during a transaction
  - Involve small number of different nodes in a transaction

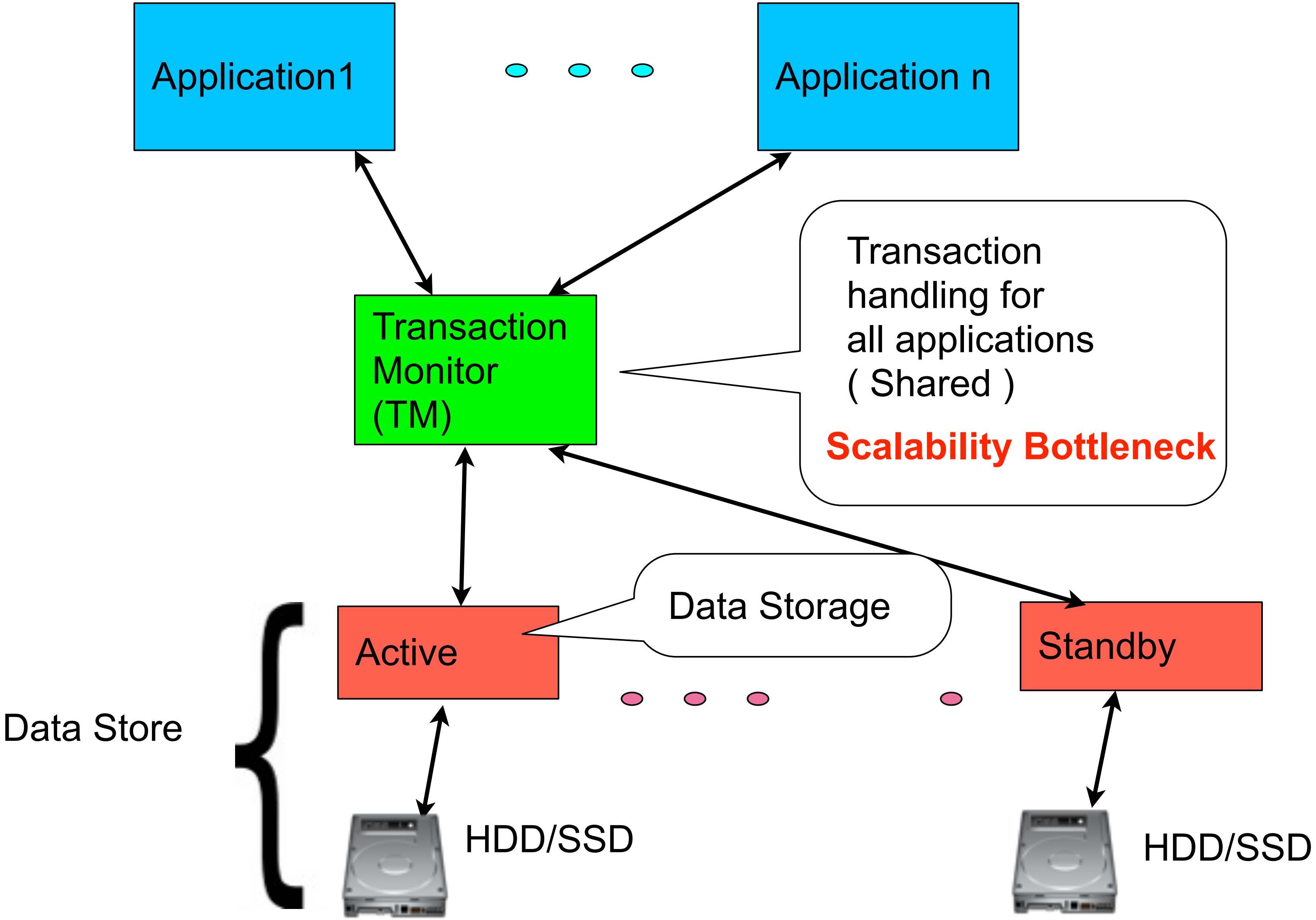
RAMCloud Specific)

- Faster crash recovery around 1 sec
  - Can yield to blocking algorithm to prevent corner cases
- A separate log on each master

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



Traditional Transaction: Sharding

- Distribute database into several servers for scalability

- Micro-Sharding: design SQL transaction in KVS

- Problems)
  - Not easy to design field in record
  - Not always possible to allocate independent shard

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 Added

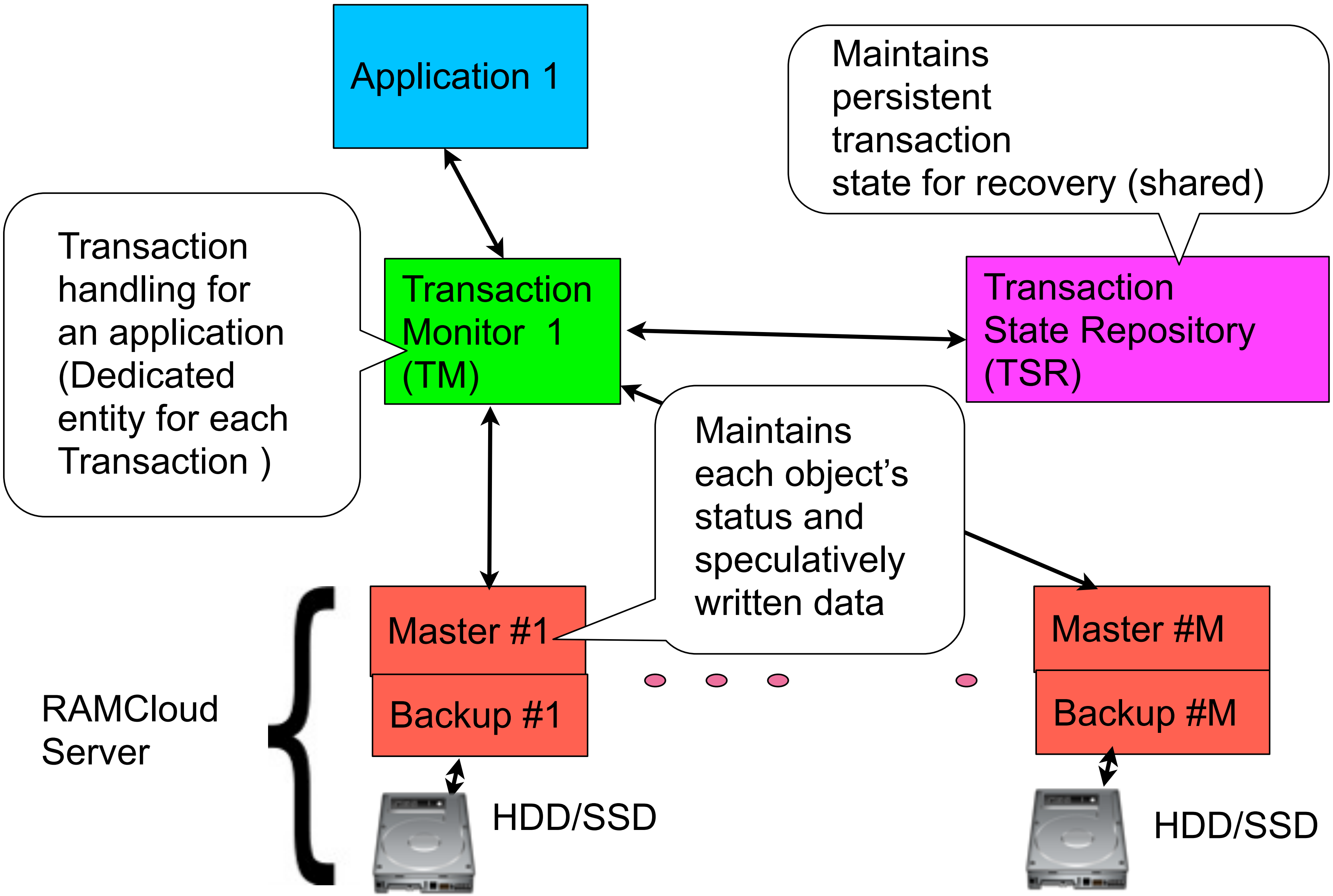
- User library manages transaction - distributed transaction monitor design
- Two phase commit
  - Compare and swap at commit time
- Recovery mechanism not included
  - Node failure detection
  - Checkpoint based recovery for node crash
  - Recovery coordinator for coordinator crash
- Conditional commit (two phase commit) only
  - Delay inquiry to all relevant nodes at commit time

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

Proposal: Summary

- 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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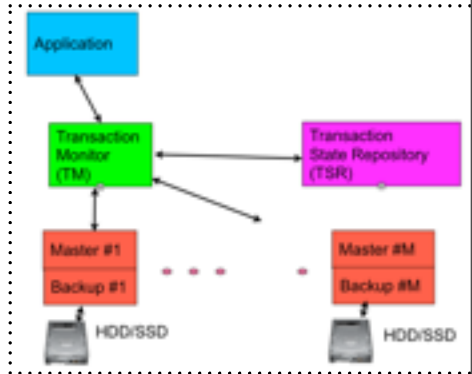
Components - Functions

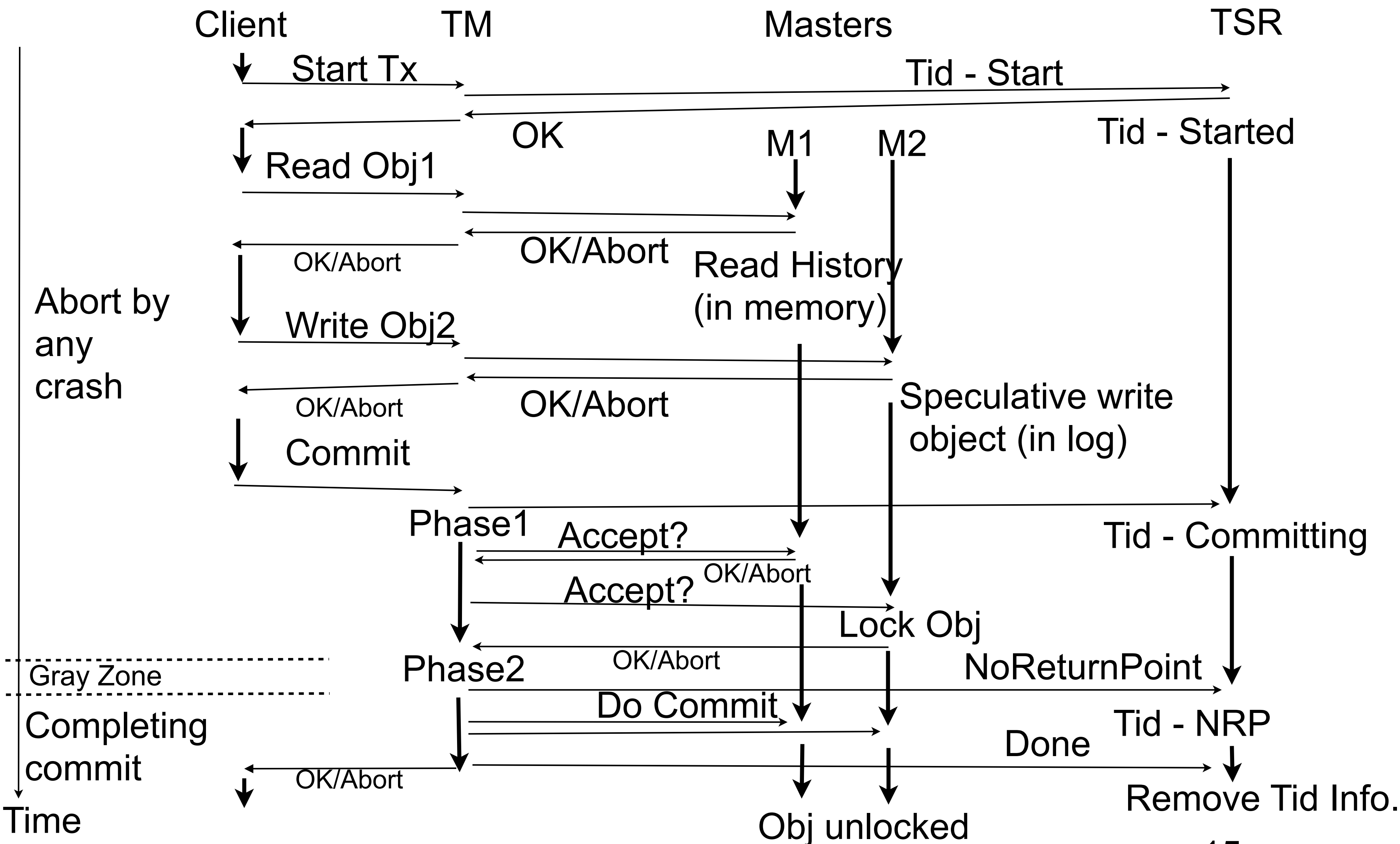


- If client application is restarted <u>immediately</u> (by coordinator, etc), TM can be implemented in client library.

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



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Detailed discussion: outline

1. Client API
2. Conflict Management
   i. Resolution at object access with transaction priority
   ii. TMid/Tid for unique global transaction order
   iii. Timeout to avoid deadlock
3. Commit - transition from non-blocking to blocking
   (Gray zone solution)
4. 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
5. Implementation Control / Data structure
6. Optimization
   i. Callback instead of piggyback
   ii. Separate key/state and data for objects in log

1. Client API

- 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-...(),
    We can make tx_read, tx_write by default using tid=0
    for non transactional operation.
- Commit Transaction
  - tx_commit(tid, &state);
  - tx_abort(tid, &state);
- Status
  - tx_status(tid, &state);   // return current transaction state

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 is given by coordinator at TM startup
- Tid
  - 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 needed, because Tid is just a priority to decide winner transaction at object access time.

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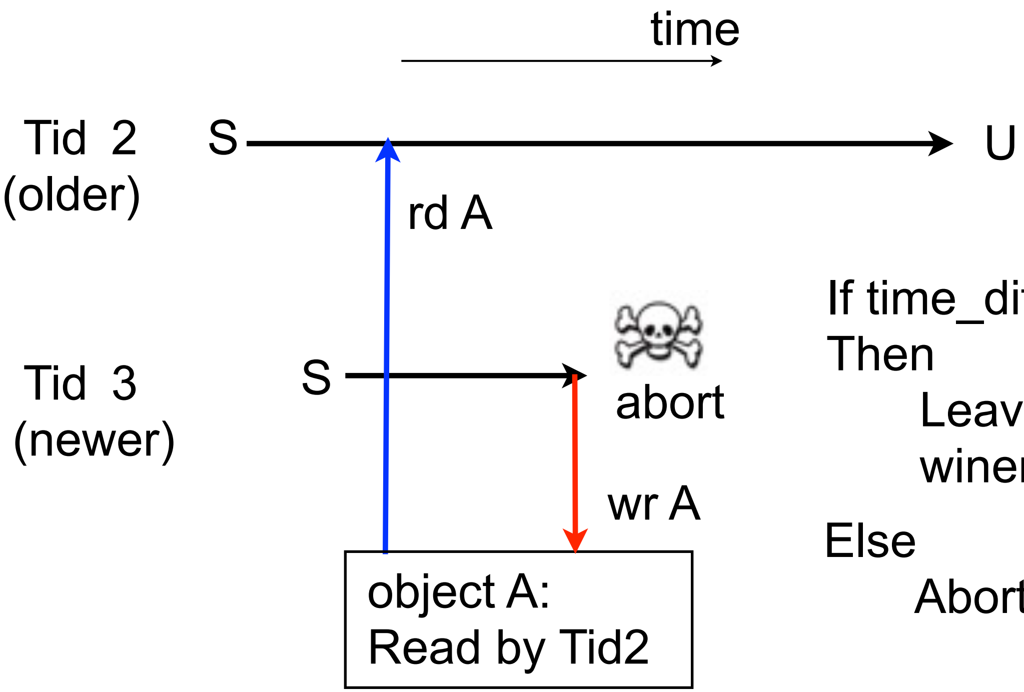
Conflict management at object access

- 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

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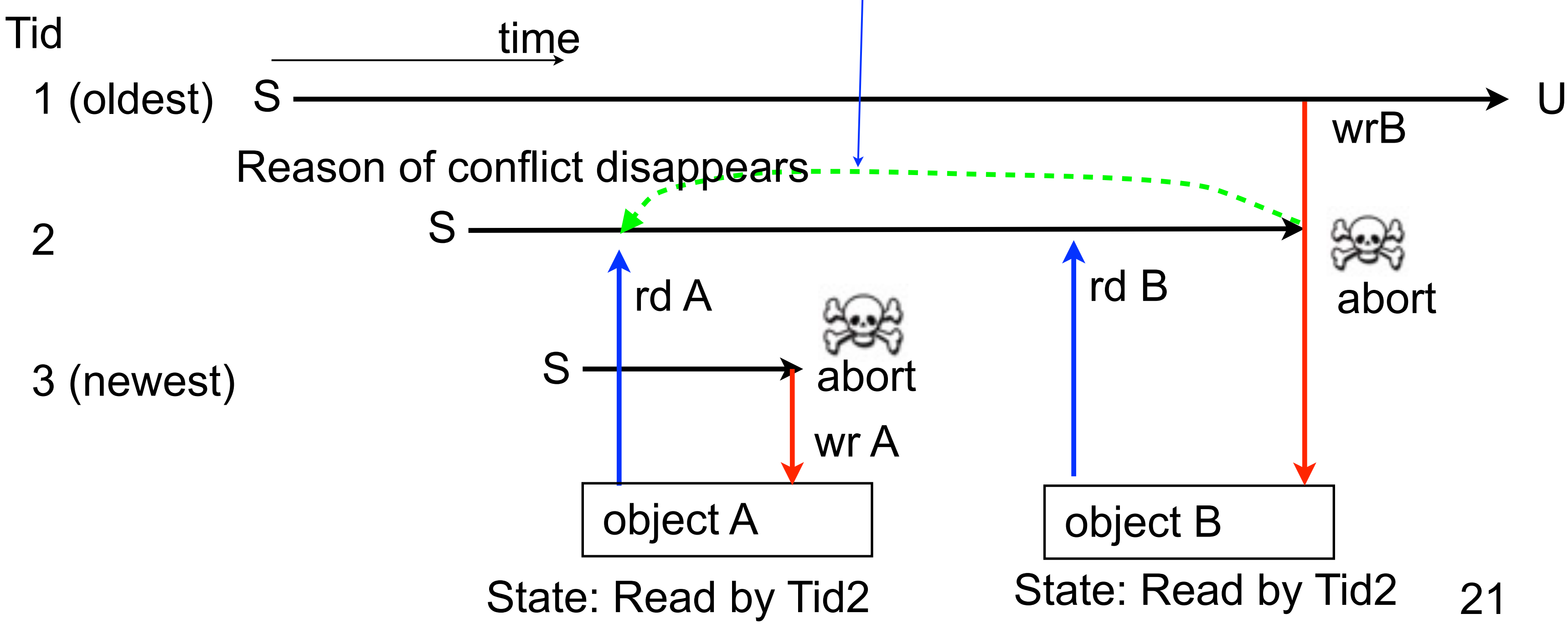
Issues - False abort/Status piggyback

- False Abort: <u>the conflict which aborted Tid3</u> 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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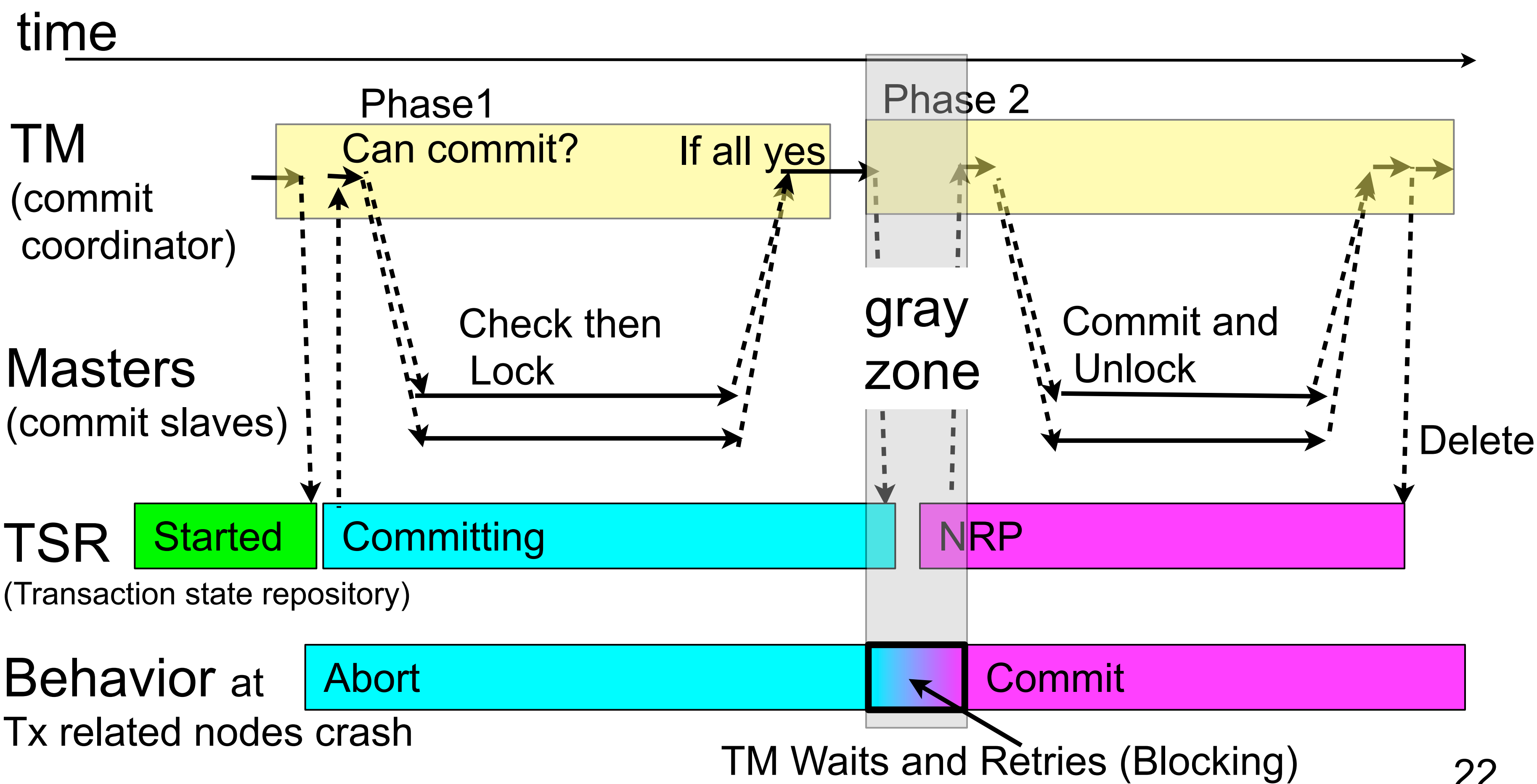
3. Commit - Two phase commit

- 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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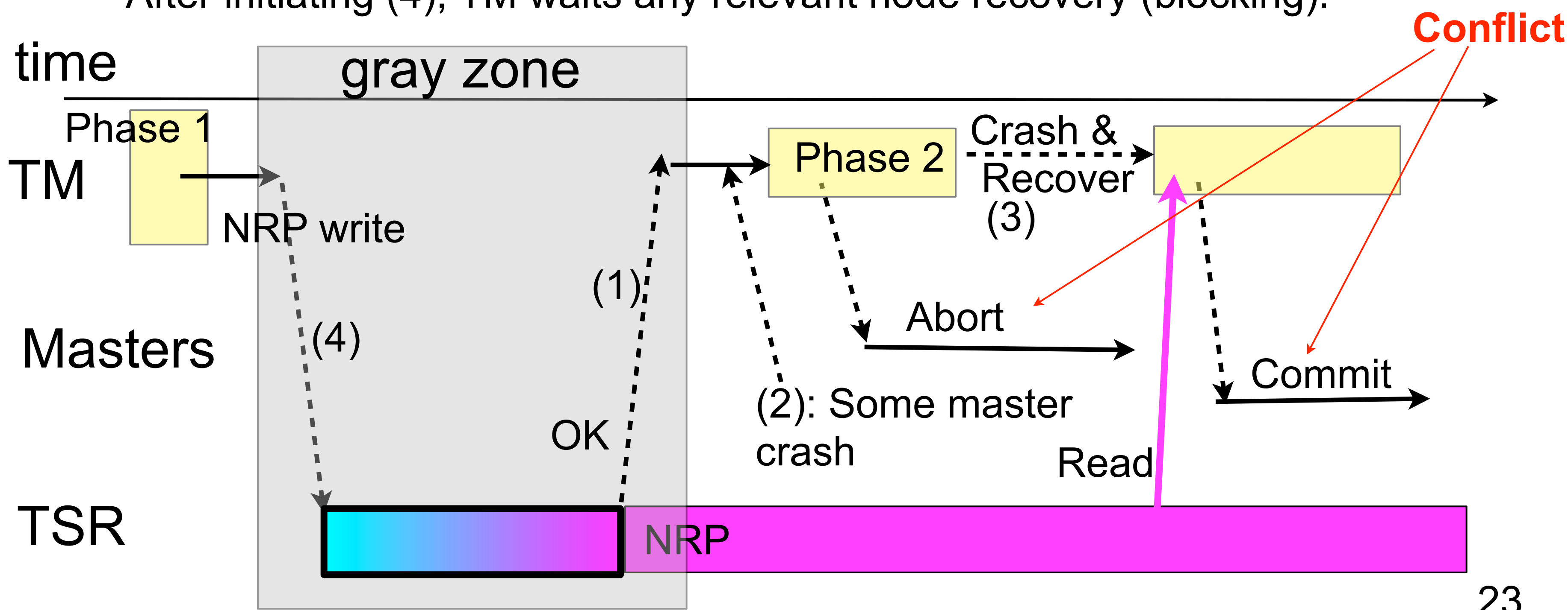
3. Commit - Racing conditions

- Racing condition: Note that abort and commit are unilateral
  - 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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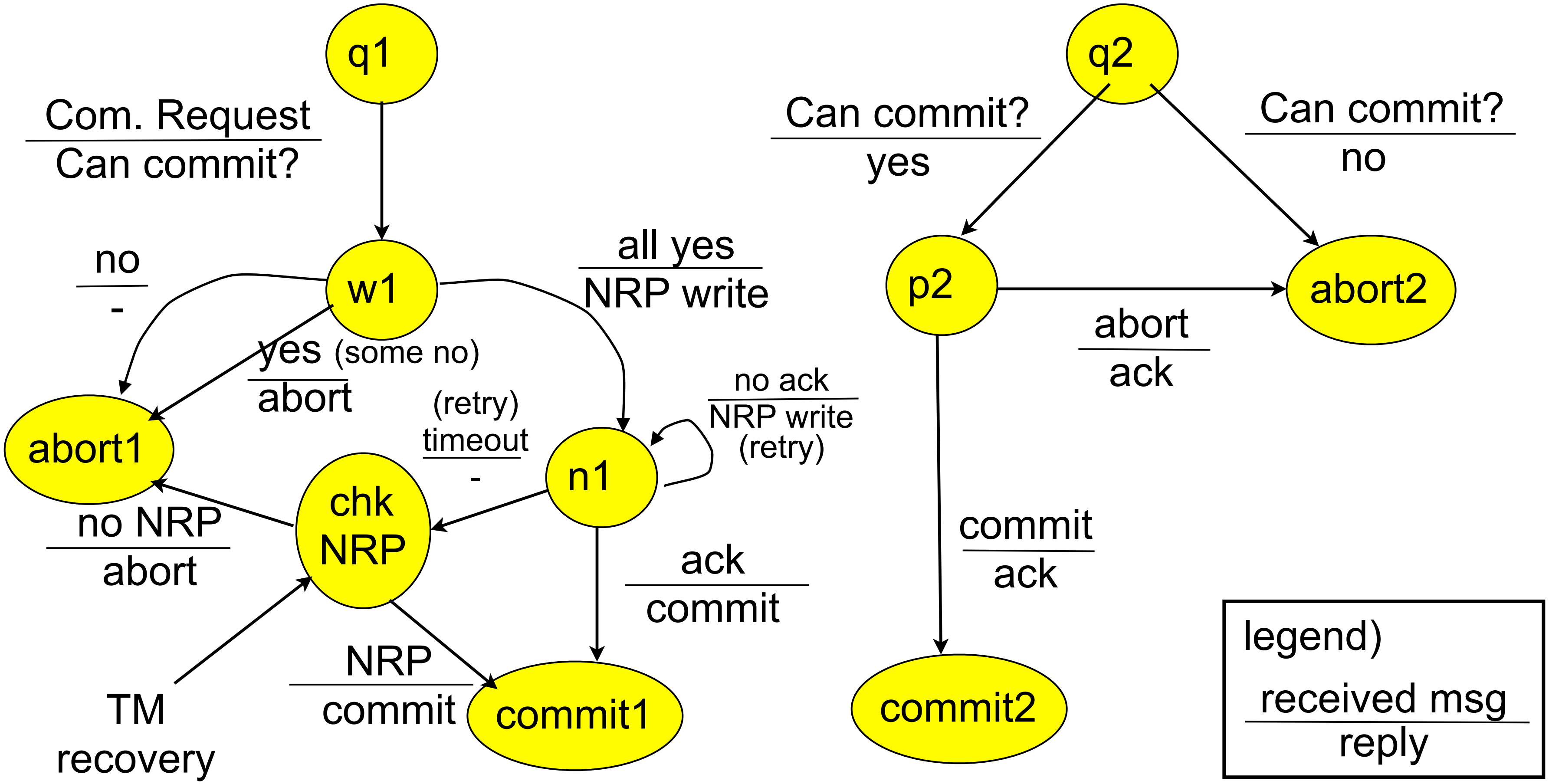
3. Commit - State Machine

TM (coordinating) Masters



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
    - Commits transaction if NRP is found. Otherwise abort transaction.
    - Fast restart required because other clients are blocked by accessing the locked objects
- Server crash
  - Reconstruct hash and object status in memory from log
- TSR crash
  - Recover 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 a location decision and lookup by coordinator
    - Cons) Extra access latency and network traffic by additional hop in data access.
  3. In a separate process/thread in a client node
    - Need another 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

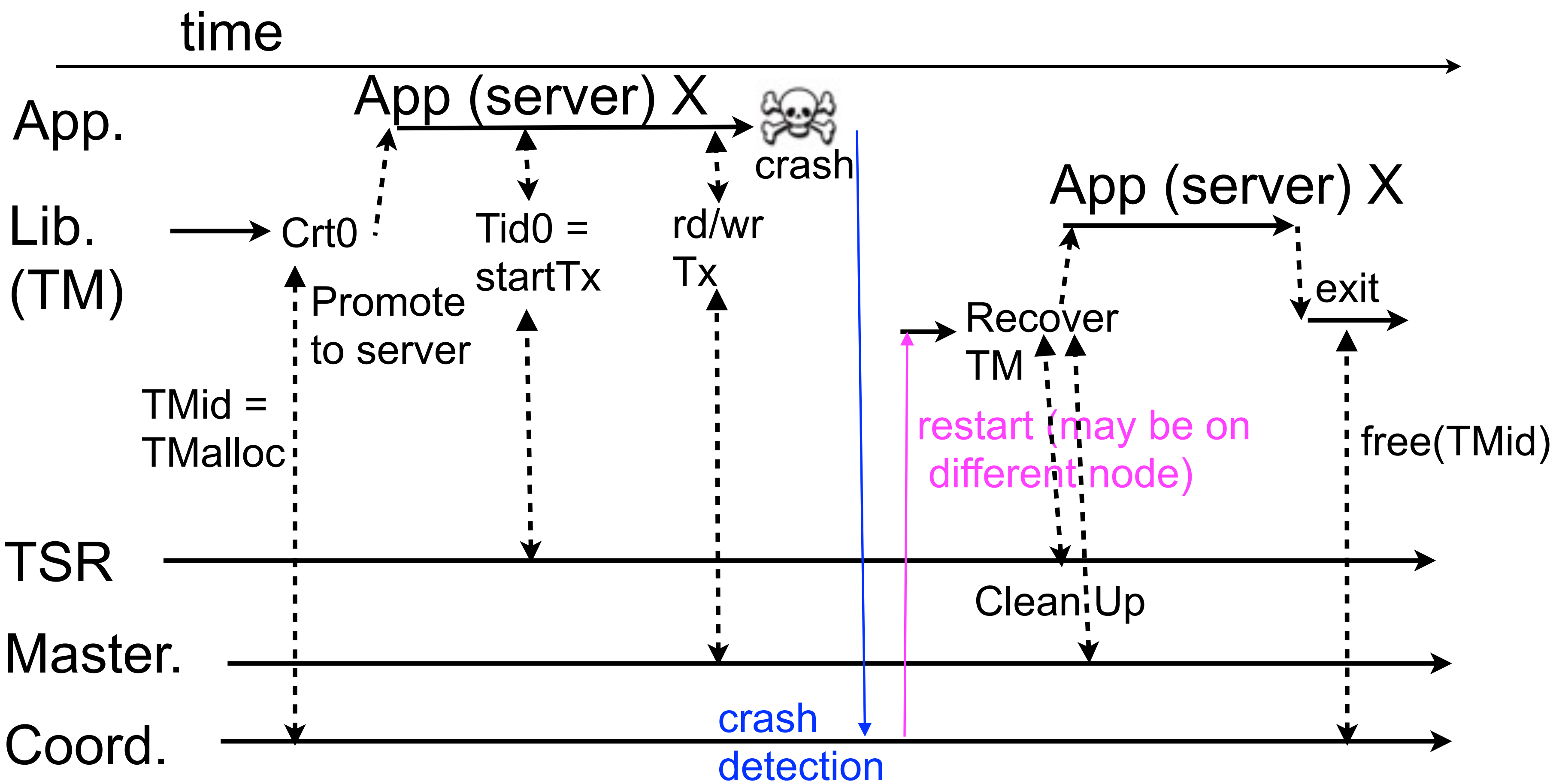
- TM as **client library**
  - Coordinator detects client failure and restarts
  - Naming issue: ‘It would better to call an application promote to server by requesting recovery to coordinator’.
- TMid given by coordinator
  - Generate: Tid = [TMid, TM’s local time]
  - Timed loosely correct TM’s local time

[a, b] denotes concatenation

- TSR as a specific table
  - (Key, Value) = (Tid, TransactionState)
  - How to find active transactions associated to a TMid?
    - Range query : [TMid, time min] to [TMid, time max]
    - Other object : (TMid, list_of_Tids)

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

To Be Done.

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Master Data Structure

To Be Done.

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