Outline

- Introduction & architectural issues
- Data distribution
- Distributed query processing
- Distributed query optimization
- Distributed transactions & concurrency control
- Distributed reliability
  - Logging
  - Distributed commit protocols
- Data replication
- Parallel database systems
- Database integration & querying
- Peer-to-Peer data management
- Stream data management
- MapReduce-based distributed data management

Reliability

Problem:

How to maintain

atomicity

durability

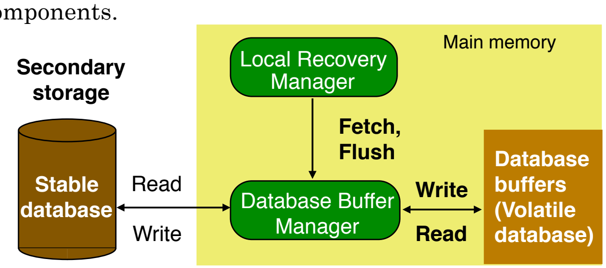
properties of transactions

Types of Failures

- Transaction failures
  - Transaction aborts (unilaterally or due to deadlock)
  - Avg. 3% of transactions abort abnormally
- System (site) failures
  - Failure of processor, main memory, power supply, …
  - Main memory contents are lost, but secondary storage contents are safe
  - Partial vs. total failure
- Media failures
  - Failure of secondary storage devices such that the stored data is lost
  - Head crash/controller failure (?)
- Communication failures
  - Lost/undeliverable messages
  - Network partitioning

Local Recovery Management – Architecture

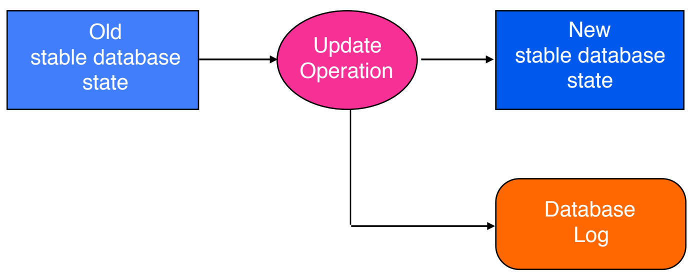
- Volatile storage
  - Consists of the main memory of the computer system (RAM).
- Stable storage
  - Resilient to failures and loses its contents only in the presence of media failures (e.g., head crashes on disks).
  - Implemented via a combination of hardware (non-volatile storage) and software (stable-write, stable-read, clean-up) components.



Recovery Information

Database Log

Every action of a transaction must not only perform the action, but must also write a *log* record to an append-only file.



Logging

The log contains information used by the recovery process to restore the consistency of a system. This information may include

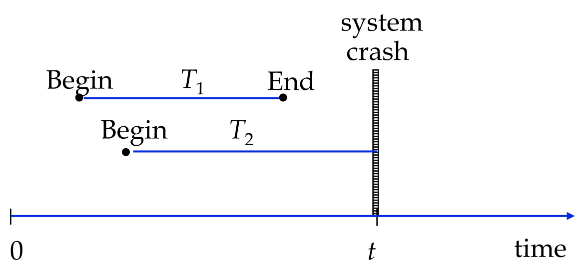
- transaction identifier
- type of operation (action)
- items accessed by the transaction to perform the action
- old value (state) of item (before image)
- new value (state) of item (after image)

…

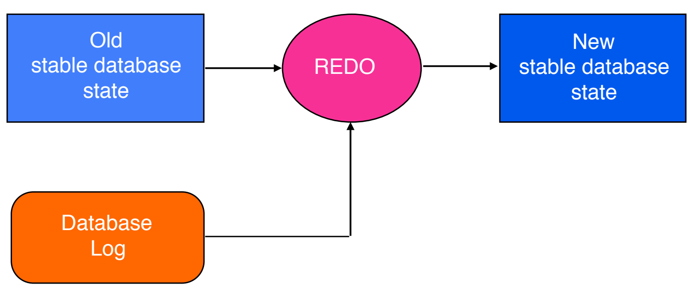
Why Logging?

Upon recovery:

- all of T_1's effects should be reflected in the database (REDO if necessary due to a failure)
- none of T_2's effects should be reflected in the database (UNDO if necessary)

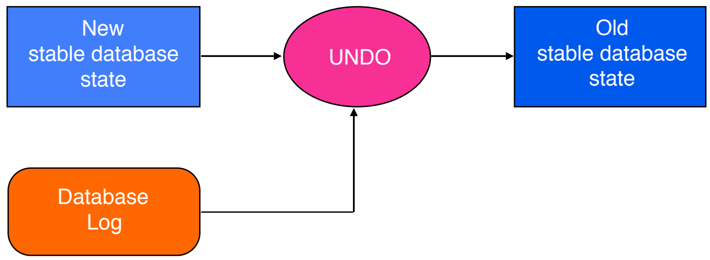


REDO Protocol



- REDO'ing an action means performing it again.
- The REDO operation uses the log information and performs the action that might have been done before, or not done due to failures.
- The REDO operation generates the new image.

UNDO Protocol



- UNDO'ing an action means to restore the object to its before image.
- The UNDO operation uses the log information and restores the old value of the object.

When to Write Log Records Into Stable Store

Assume a transaction *T* updates a page *P*

- Fortunate case
  - System writes *P* in stable database
  - System updates stable log for this update
  - SYSTEM FAILURE OCCURS!... (before *T* commits)

  We can recover (undo) by restoring *P* to its old state by using the log
- Unfortunate case
  - System writes *P* in stable database
  - SYSTEM FAILURE OCCURS!... (before stable log is updated)

  We cannot recover from this failure because there is no log record to restore the old value.
- Solution: Write-Ahead Log (WAL) protocol

Write–Ahead Log Protocol

- Notice:
  - If a system crashes before a transaction is committed, then all the operations must be undone. Only need the before images (*undo portion* of the log).
  - Once a transaction is committed, some of its actions might have to be redone. Need the after images (*redo portion* of the log).
- WAL protocol :
  1. Before a stable database is updated, the undo portion of the log should be written to the stable log
  2. When a transaction commits, the redo portion of the log must be written to stable log prior to the updating of the stable database.

Distributed Reliability Protocols

- Commit protocols
  - How to execute commit command for distributed transactions.
  - Issue: how to ensure atomicity and durability?
- Termination protocols
  - If a failure occurs, how can the remaining operational sites deal with it.
  - *Non-blocking* : the occurrence of failures should not force the sites to wait until the failure is repaired to terminate the transaction.
- Recovery protocols
  - When a failure occurs, how do the sites where the failure occurred deal with it.
  - *Independent* : a failed site can determine the outcome of a transaction without having to obtain remote information.
- Independent recovery ⇒ non-blocking termination

Two-Phase Commit (2PC)

Phase 1 : The coordinator gets the participants ready to write the results into the database

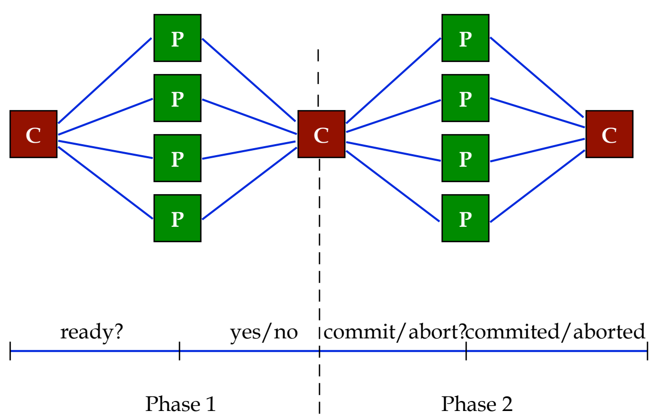
Phase 2 : Everybody writes the results into the database

- **Coordinator** :The process at the site where the transaction originates and which controls the execution
- **Participant** :The process at the other sites that participate in executing the transaction

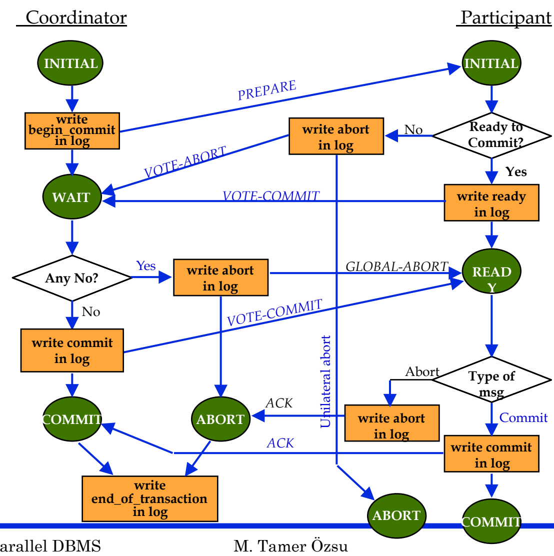
Global Commit Rule:

1. The coordinator aborts a transaction if and only if at least one participant votes to abort it.
2. The coordinator commits a transaction if and only if all of the participants vote to commit it.

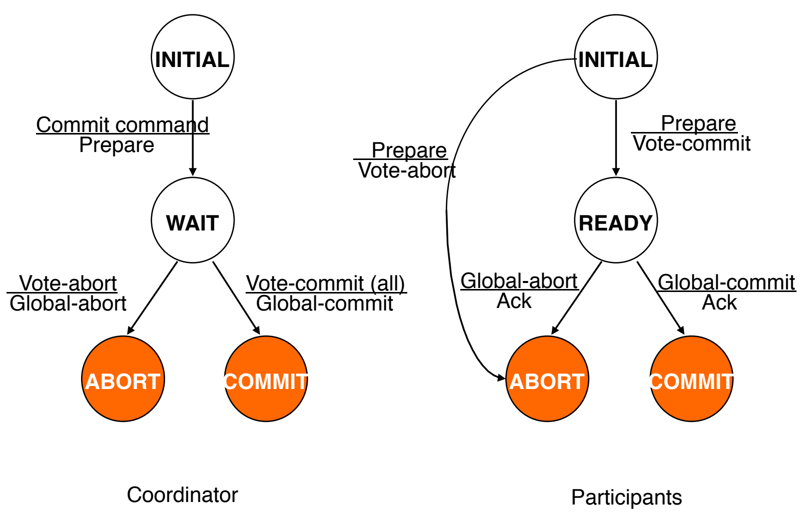
Centralized 2PC



2PC Protocol Actions

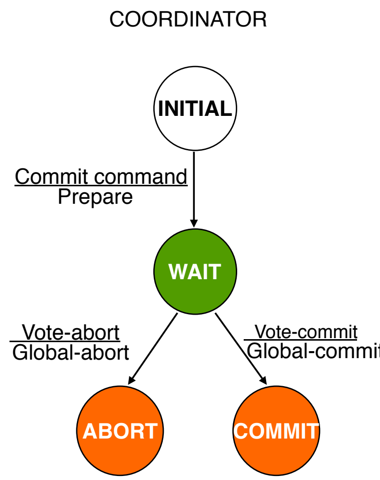


State Transitions in 2PC



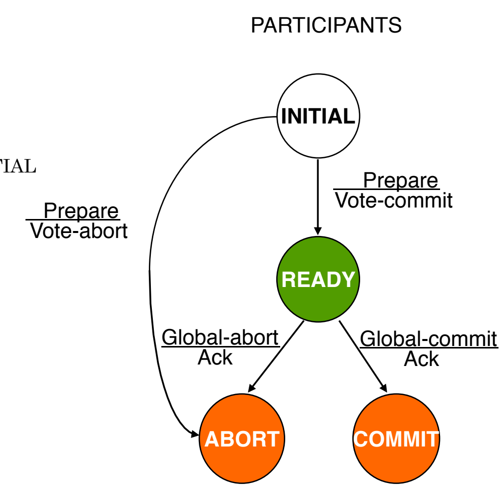
Site Failures - 2PC Termination

- Timeout in INITIAL
  - Who cares
- Timeout in WAIT
  - Cannot unilaterally commit
  - Can unilaterally abort
- Timeout in ABORT or COMMIT
  - Stay blocked and wait for the acks



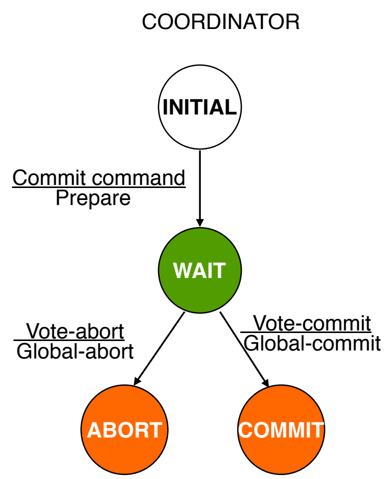
Site Failures - 2PC Termination

- Timeout in INITIAL
  - Coordinator must have failed in INITIAL state
  - Unilaterally abort
- Timeout in READY
  - Stay blocked



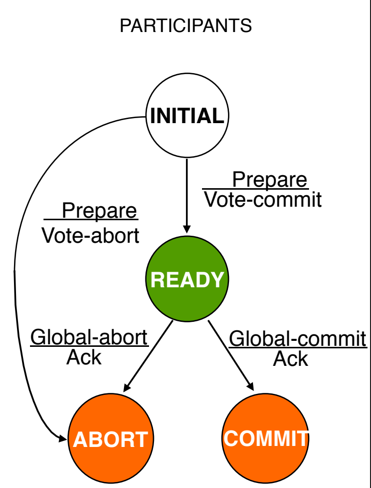
Site Failures - 2PC Recovery

- Failure in INITIAL
  - Start the commit process upon recovery
- Failure in WAIT
  - Restart the commit process upon recovery
- Failure in ABORT or COMMIT
  - Nothing special if all the acks have been received
  - Otherwise the termination protocol is involved



Site Failures - 2PC Recovery

- Failure in INITIAL
  - Unilaterally abort upon recovery
- Failure in READY
  - The coordinator has been informed about the local decision
  - Treat as timeout in READY state and invoke the termination protocol
- Failure in ABORT or COMMIT
  - Nothing special needs to be done



Problem With 2PC

- Blocking
  - Ready implies that the participant waits for the coordinator
  - If coordinator fails, site is blocked until recovery
  - Blocking reduces availability
- Independent recovery is not possible
- However, it is known that:
  - Independent recovery protocols exist only for single site failures; no independent recovery protocol exists which is resilient to multiple-site failures.
- So we search for these protocols – 3PC

Network Partitioning

- Simple partitioning
  - Only two partitions
- Multiple partitioning
  - More than two partitions
- Formal bounds:
  - There exists no non-blocking protocol that is resilient to a network partition if messages are lost when partition occurs.
  - There exist non-blocking protocols which are resilient to a single network partition if all undeliverable messages are returned to sender.
  - There exists no non-blocking protocol which is resilient to a multiple partition.

Independent Recovery Protocols for Network Partitioning

- No general solution possible
  - allow one group to terminate while the other is blocked
  - improve availability
- How to determine which group to proceed?
  - The group with a majority
- How does a group know if it has majority?
  - Centralized
    - Whichever partitions contains the central site should terminate the transaction
  - Voting-based (quorum)

Quorum Protocols

- The network partitioning problem is handled by the commit protocol.
- Every site is assigned a vote V_i.
- Total number of votes in the system V
- Abort quorum V_a, commit quorum V_c
  - $V_a + V_c > V$ where $0 \leq V_a , V_c \leq V$
  - Before a transaction commits, it must obtain a commit quorum V_c
  - Before a transaction aborts, it must obtain an abort quorum V_a