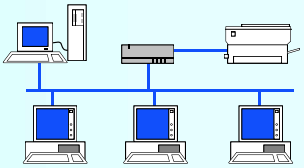


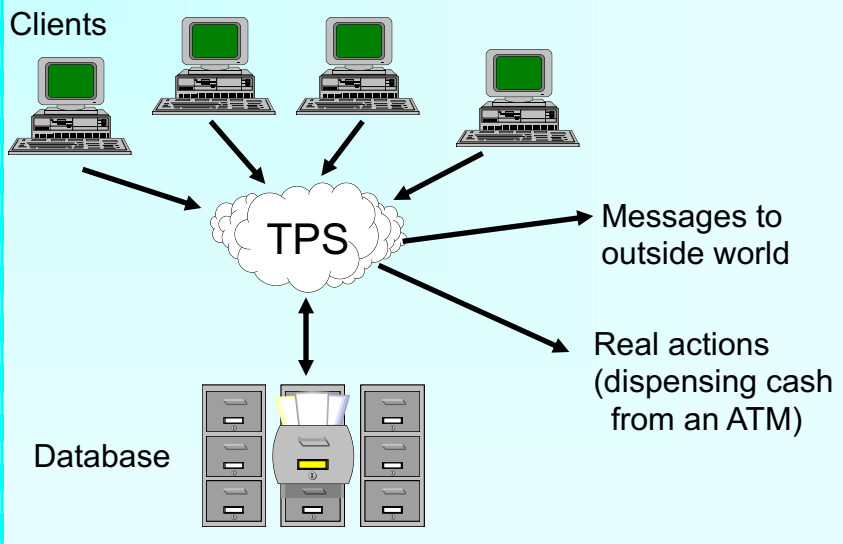
Distributed Systems
601.417
Distributed Transactions

Department of Computer Science
The Johns Hopkins University

Distributed Transactions

Lecture 6

Transaction Processing System



Basic Definition

Transaction - a collection of operations on the physical and abstract application state, with the following properties:

- **A**tomicity
- **C**onsistency
- **I**solation
- **D**urability

The **ACID** properties of a transaction

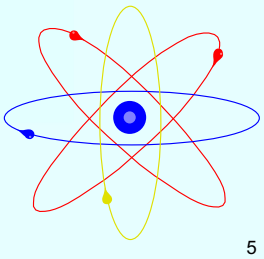
Atomicity

Changes to the state are atomic:

- A jump from the initial state to the result state without any **observable** intermediate state

- All or nothing (Commit / Abort) semantics

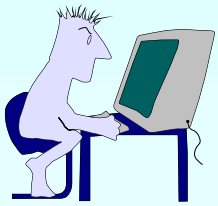
- Changes include:
  - Database changes
  - Messages to the outside world
  - Actions on transducers (testable / untestable)



Consistency

- The transaction is a correct transformation of the state

This means that the transaction is a correct program



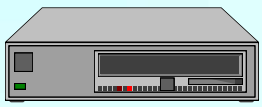
Isolation

Even though transactions execute concurrently, it appears to the **outside observer** as if they execute in some serial order

Isolation is required to guarantee consistent input, which is needed for a consistent program to provide consistent output

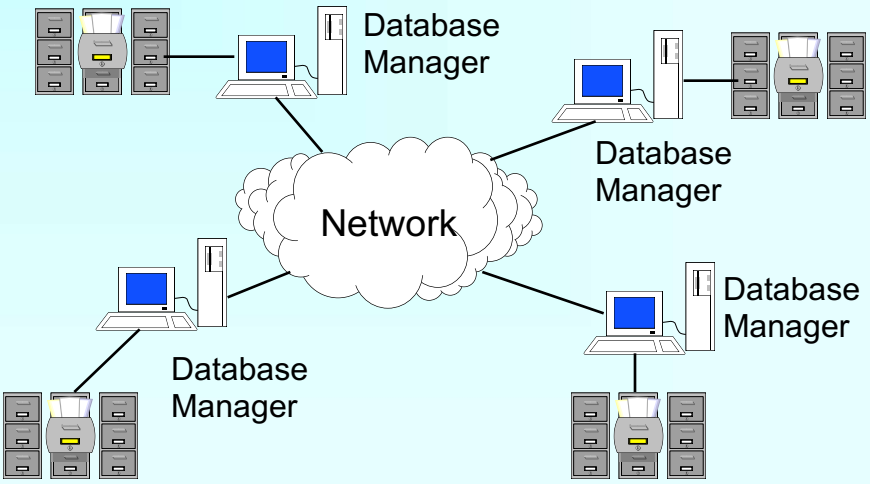
Durability

- Once a transaction completes successfully (commits), its changes to the state survive failures (what is the failure model ?)



- The only way to get rid of what a committed transaction has done is to execute a compensating transaction (which may be impossible sometimes)

A Distributed Database



A Distributed Transaction

- A distributed transaction is composed of several sub-transactions, each running on a different site
- Each database manager (DM) can decide to abort (the veto property)
- An Atomic Commitment Protocol (ACP) is run by each of the DMs to ensure that all the subtransactions are consistently committed or aborted

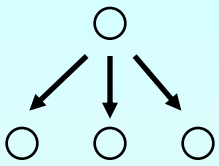
Atomic Commitment Protocol

A correct ACP guarantees that:

- All the DM that reach a decision, reach the same decision
- Decisions are not reversible
- A Commit decision can only be reached if **all** the DMs vote to commit (veto property)
- If there are no failures and all the DMs vote to commit, the decision will be Commit
- At any point, if all failures are repaired, and no new failures are introduced, then all the DMs eventually reach a decision

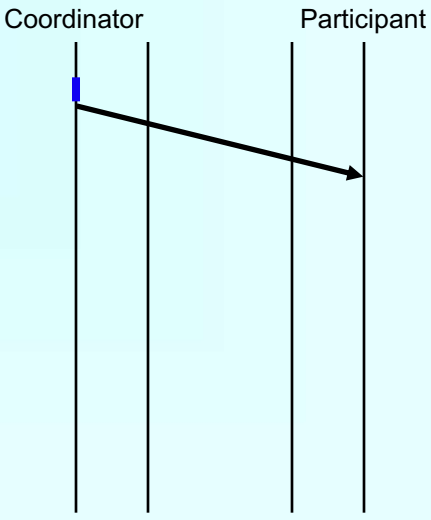
Two Phase Commit

Send "prepare to commit"



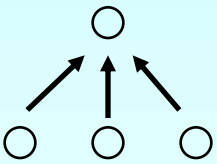
Forced disk write

Lazy disk write



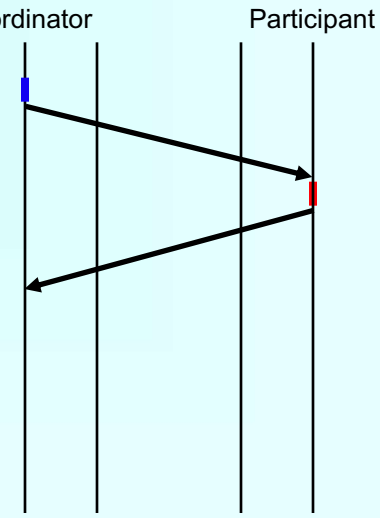
Two Phase Commit

Return vote (ready or abort)



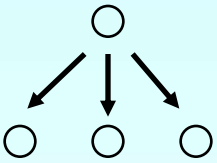
Forced disk write

Lazy disk write



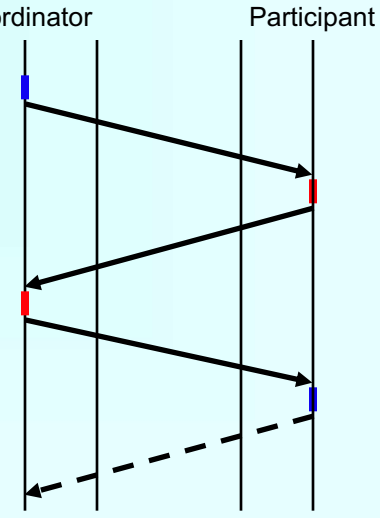
Two Phase Commit

Send decision (commit or abort)

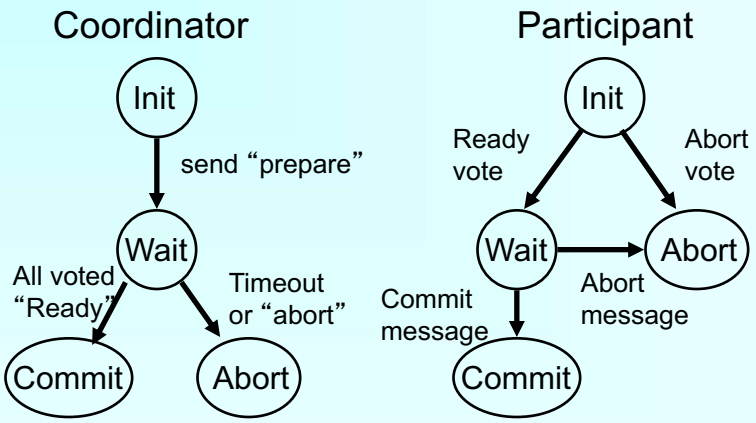


Forced write

Lazy write

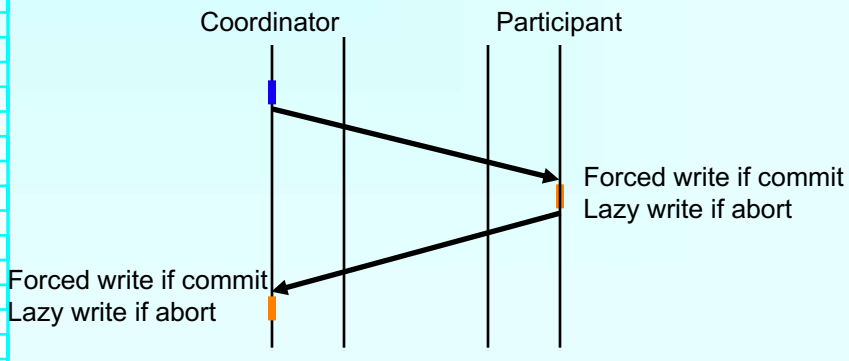


State Diagram for 2PC



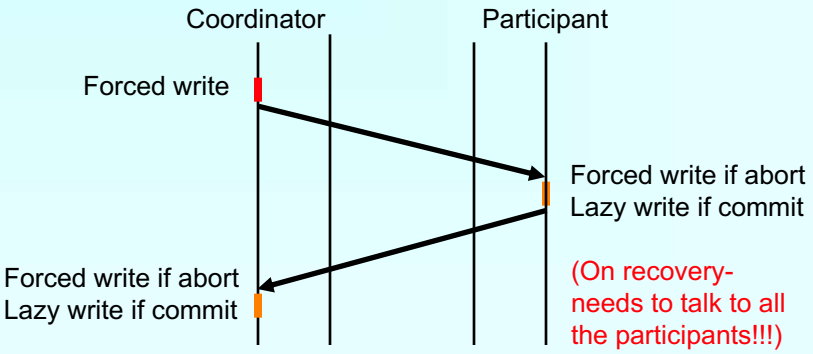
Presumed Abort 2PC

When the recovery mechanism has no information about a transaction, it presumes that the transaction has been **aborted**.



Presumed Commit 2PC

When the recovery mechanism has no information about a transaction, it presumes that the transaction has been **committed**.



Summary So Far

- Basic approach: Two Phase Commit:
  - It works
  - It pays in forced disk writes
  - It is vulnerable to coordinator failure
- Presumed Abort 2PC:
  - Saves forced disk writes by invoking lazy writes on abort
- Presumed Commit 2PC:
  - Saves forced disk writes by invoking lazy writes on commit but pays a price at recovery

Non Blocking ACPs

- An ACP is called **blocking** if the occurrence of some failures forces the DMs to wait until failures are repaired before terminating the transaction
- When a transaction is blocked at the DM, its locks cannot be released. This may lead to system-wide blocking
- What can we say about network partitions and blocking?

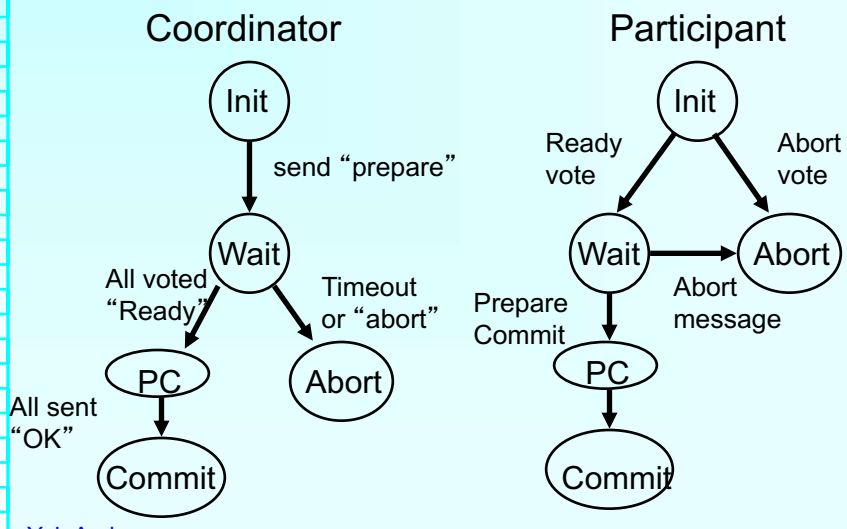
Non Blocking ACPs

- An ACP is called **blocking** if the occurrence of some failures forces the DMs to wait until failures are repaired before terminating the transaction
- When a transaction is blocked at the DM, its locks cannot be released. This may lead to system blocking
- **Every protocol that tolerates network partitions is bound to be blocking**

Quorum Based Protocols

- Every DM has to agree locally
- A majority of the DMs must agree to abort or commit after all the DMs agreed locally
- Simple majority can be generalized to weighted majority
- Majority can be generalized to a quorum
- Instead of one quorum, there can be an abort quorum and a commit quorum

3PC State Diagram (no faults)



3PC Decision Rule for Recovery

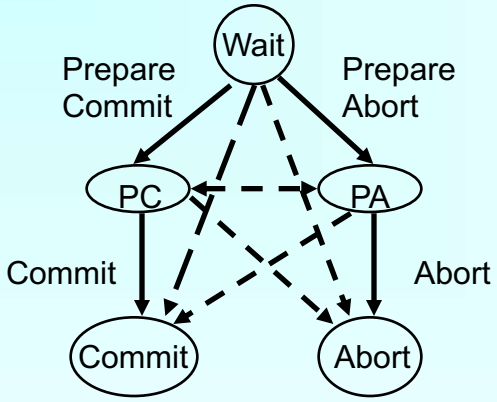
Collected States:

- If at least one DM aborted - decide to **abort**
- If at least one DM committed - decide to **commit**
- Otherwise if at least one DM in Pre-Commit and a quorum of DMs in (Pre-Commit and Wait) - move to Pre-Commit and send "prepare commit"
- Otherwise if there is a quorum of DMs in (Wait and Pre-Abort) move to Pre-Abort and send "prepare abort"
- Otherwise - Block

3PC Recovery Procedure

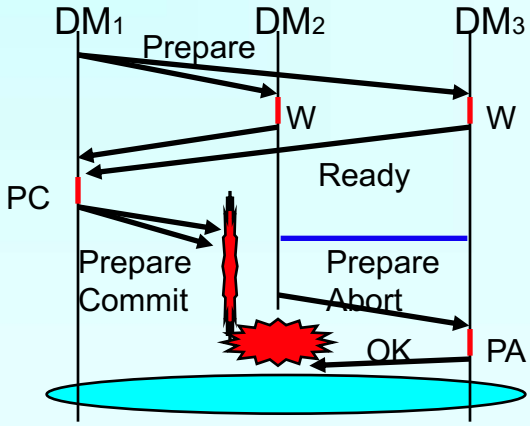
- Send state and id
- The new coordinator collects the states from all the connected DMs, it computes its next step according to the decision rule
- Upon receiving a Prepare-Commit/Prepare-abort, each DM sends an OK message
- Upon receiving an OK message from a **quorum,** the coordinator commits/aborts and sends the decision

3PC Recovery State Diagram



3PC Can Block a Quorum

- Simple majority, 3 DMs,
  smallest-id connected DM is the coordinator



DM1 & DM3 are blocked

Enhanced 3PC Highlights

E3PC:

- Uses identical state diagrams as 3PC
- Uses similar communication to 3PC (with different message contents)
- Maintains two additional counters:
  - Last_elected- the index of the last election this DM participated in
  - Last_attempt - the election number in the last attempt this DM made to commit or abort
- Uses a different decision rule and recover procedure

E3PC Decision Rule

IMAC : a predicate that is true iff all the connected members with max Last_attempt are in the PC state

Is Max Attempt Committable?

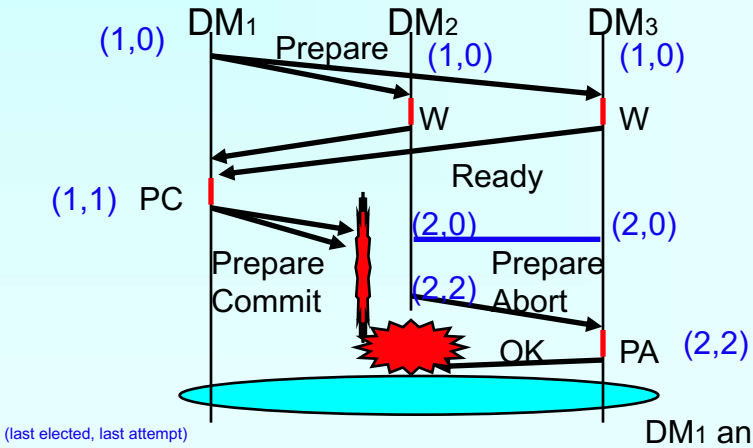
- If at least one DM aborted - decide **abort**
- If at least one DM committed - decide **commit**
- If IMAC and there is a quorum - move to Prepare-Commit
- If not IMAC and there is a quorum - move to Prepare-Abort
- Otherwise (i.e. no quorum) - Block

E3PC Recovery Procedure

- Elect a coordinator - send state and 2 counters
- Upon getting the Max_elected from the coordinator, set Last_elected = Max_elected+1
- If the coordinator decision is not to block
  - It sets Last_attempt = Last_elected
  - It moves to the calculated state & multicast a decision
- Upon receiving Prepare-Commit/Prepare-Abort, the DM:
  - Sets Last_attempt = Last_elected
  - Changes state to PC or PA and sends OK
- If a fault happens, restart the recovery procedure, otherwise termination is **guaranteed**

3EPC Never Blocks a Quorum

- Simple majority, 3 DMs,
  smallest connected DM is the coordinator



Summary

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  - It works
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  - It is vulnerable to coordinator failure
- Presumed Abort 2PC:
  - Saves forced disk writes by invoking lazy writes on abort
- Presumed Commit 2PC:
  - Saves forced disk writes by invoking lazy writes on commit but pays a price at recovery

Summary (cont.)

- Basic approach: Two Phase Commit:
  - It works
  - It pays in forced disk writes
  - It is vulnerable to coordinator failure
- Three Phase Commit:
  - It pays even more in messages & forced disk writes
  - Most of the time, it solves the vulnerability problem of 2PC when a quorum exists
- Enhanced Three Phase Commit:
  - It costs exactly as 3PC, but with a better logic
  - Always solves the vulnerability problem of 2PC when a quorum exists