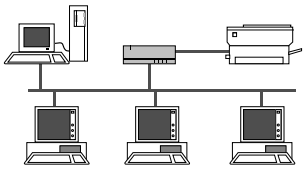


Distributed Systems
600.437

Distributed Transactions

Department of Computer Science
The Johns Hopkins University

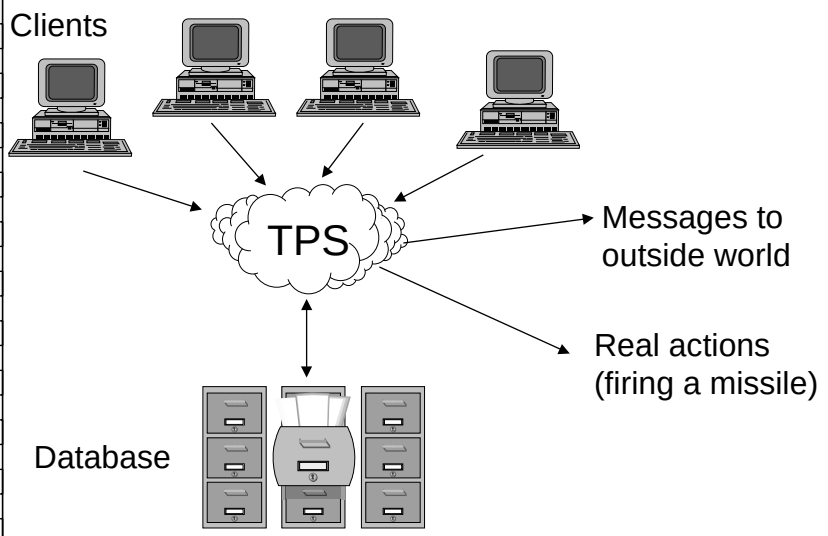
Distributed Transactions

Lecture 8

Further reading:
Concurrency Control and Recovery in Database Systems
P. A. Bernstein, V. Hadzilacos, and N. Goodman,
Addison Wesley. 1987.

Transaction Processing: Concepts and Techniques
Jim Gray & Andreas Reuter,
Morgan Kaufmann Publishers, 1993.

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.

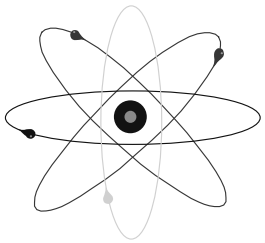
Atomicity

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 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.

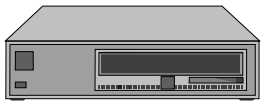
Isolation

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.

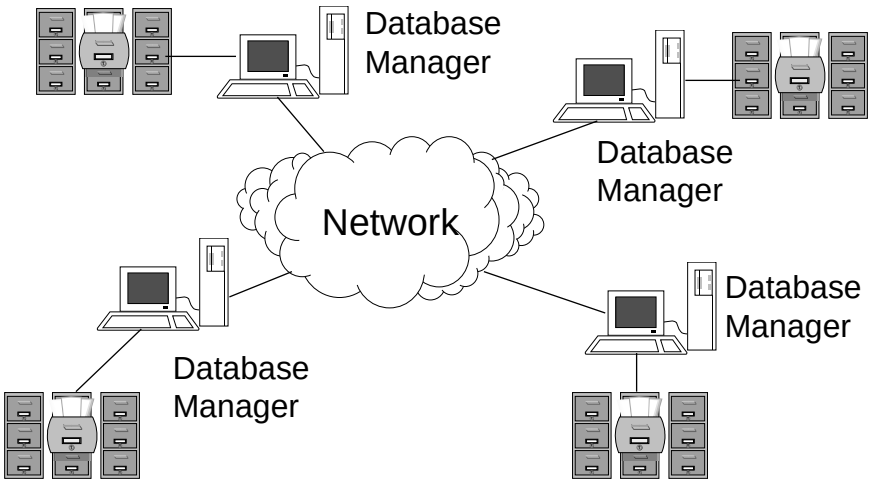
Durability

- 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 is, sometimes, impossible).

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.

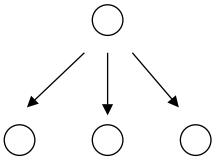
Atomic Commitment Protocol

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 voted to commit.
- If there are no failures and all the DMs voted 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.

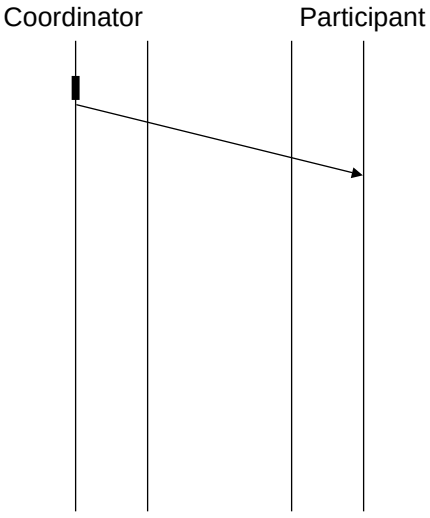
Two Phase Commit

Send “prepare to commit”



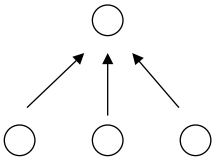
Forced disk write

Lazy disk write

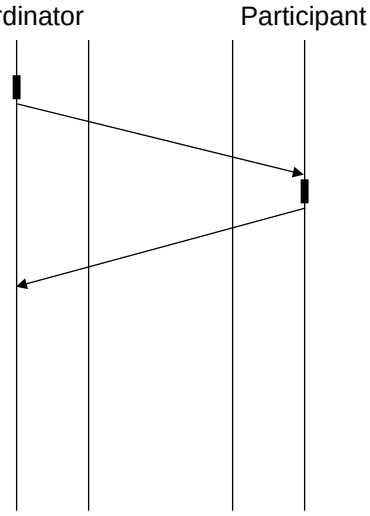


Two Phase Commit

Return vote (ready or abort)

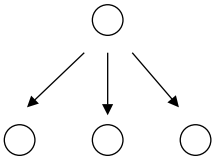


- Forced disk write
- Lazy disk write

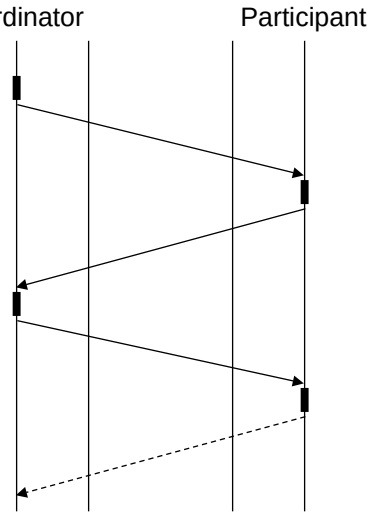


Two Phase Commit

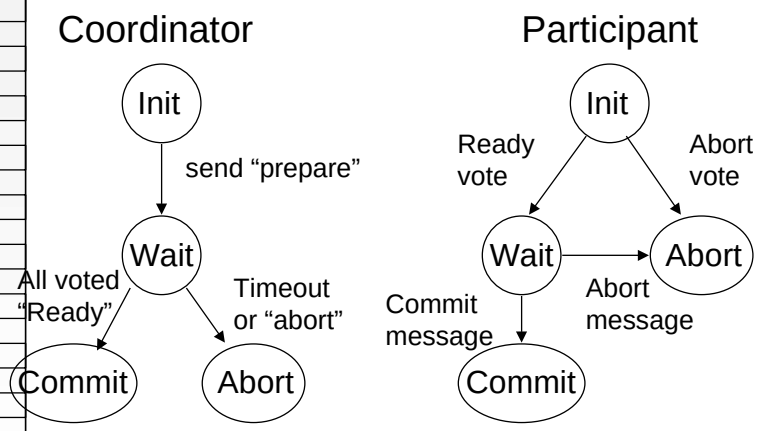
Send decision (commit or abort)



- Forced write
- Lazy write

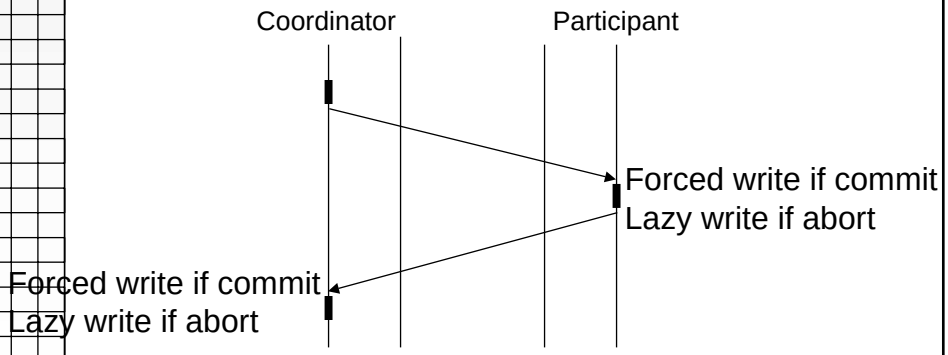


State Diagram for 2PC



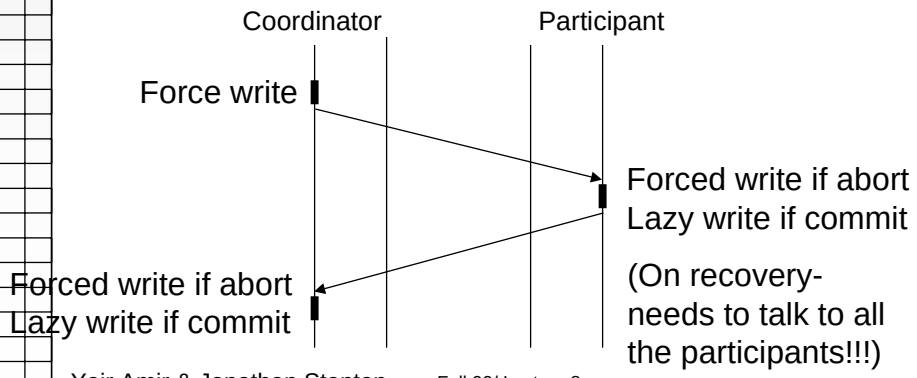
Presumed Abort 2PC

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

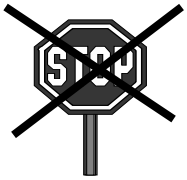


Presumed Commit 2PC

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



Non Blocking ACPs



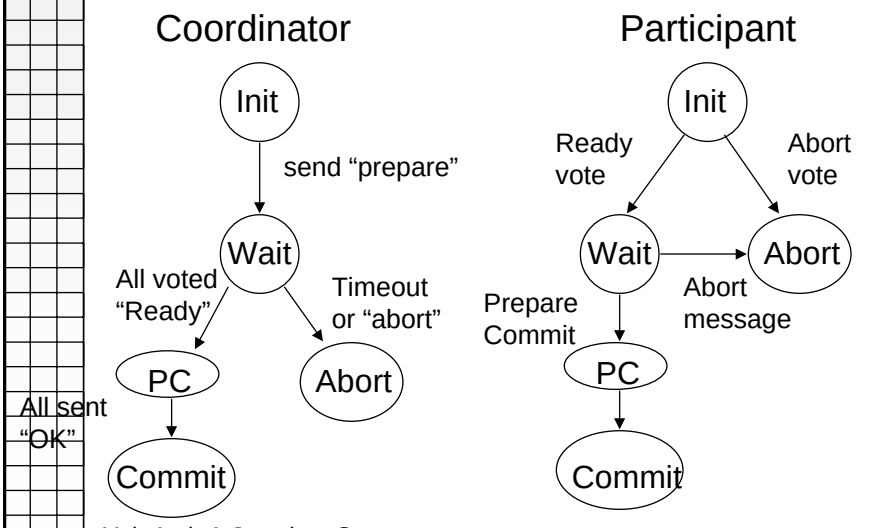
- An ACP is called **blocking** if the occurrence of some failures forces the DMs to wait until failures are repaired before terminating the transaction.
- When a transaction is blocked at the DM, its locks cannot be released. This may lead to system blocking.
- **Every protocol that tolerates network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

3PC State Diagram (no faults)

Skeen - 1982.



Decision Rule for Recovery

Collected States:

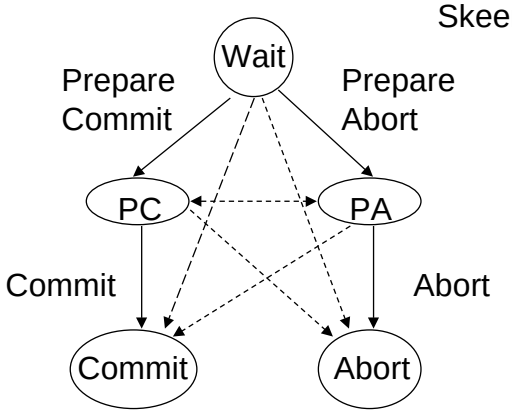
- If at least one DM aborted - decide to **abort**.
- If at least one DM committed - decide to **commit**.
- Otherwise if at least one DM in Pre-Commit and a quorum of DMs in (Pre-Commit and Wait) - move to Pre-Commit and send “prepare commit”.
- Otherwise if there is a quorum of DMs in (Wait and Pre-Abort)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

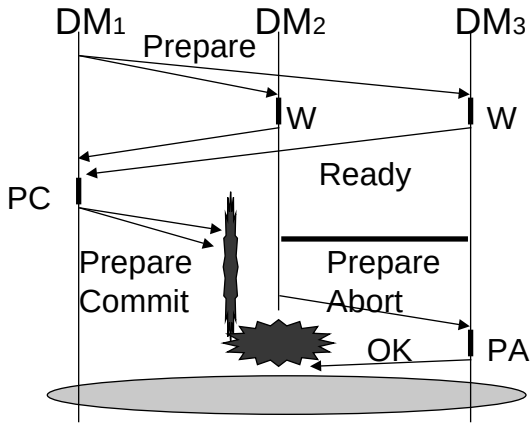
3PC Recovery State Diagram

Skeen - 1982.



3PC Can Block a Quorum

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



DM1 & DM3 are blocked.

Enhanced 3PC Highlights

E3PC: Keidar & Dolev - 1995.

- 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.

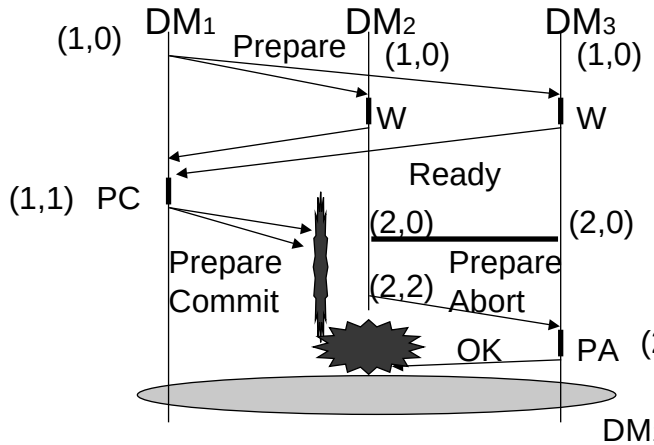
- If at least one DM aborted - decide **abort**.
- If at least one DM committed - decide **commit**.
- If IMAC and there is a quorum - move to Prepare-Commit.
- If not IMAC and there is a quorum - move to Prepare-Abort.
- Otherwise (i.e. no quorum) - Block

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.
  - move to the calculated state and multicast 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 Does Not Block a Quorum

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



Summary

- Basic approach: Two Phase Commit:
  - works.
  - pays in forced disk writes.
  - vulnerable to coordinator failure at certain times.
- 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:
  - works.
  - pays in forced disk writes.
  - vulnerable to coordinator failure at certain times.
- Three Phase Commit:
  - pays even more in forced disk writes.
  - most of the time solves the vunlerability problem of 2PC when quorum exists.
- Enhanced Three Phase Commit:
  - Costs exactly as 3PC, but with better logic.
  - Always solves the vulnerability problem of 2PC when quorum exists.