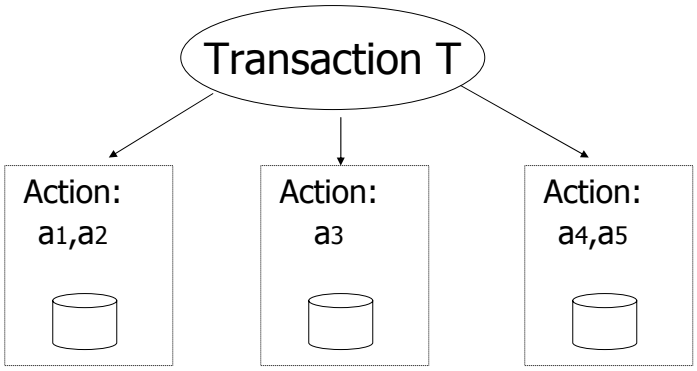
Distributed Commit

Distributed Recovery Control

- DDBMS is highly dependent on ability of all sites to be able to communicate reliably with one another.
- Sites may fail
- Communication failures can result in network becoming split into two or more partitions.

Distributed commit problem



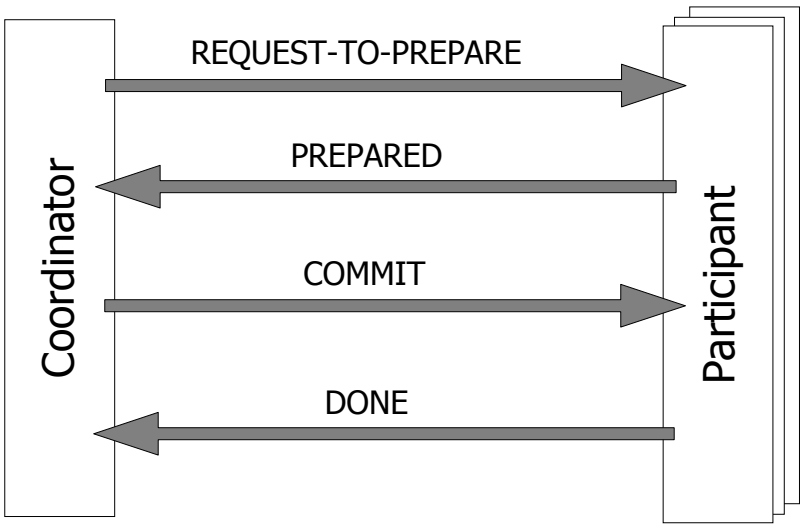
Commit must be atomic

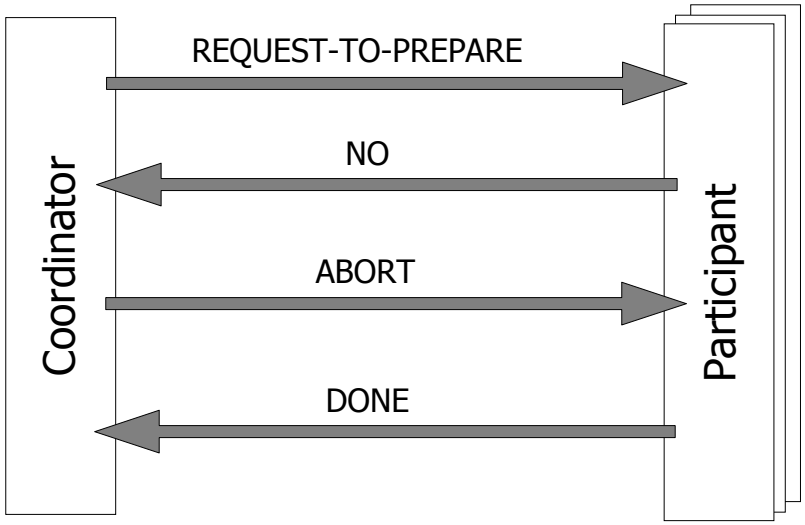
Two-Phase Commit (2PC)

- Two phases: a *voting phase* and a *decision phase*.
- Coordinator asks all participants whether they are prepared to commit transaction.
  - If **one** participant votes abort, or fails to respond within a timeout period, coordinator instructs all participants to abort transaction.
  - If **all** vote commit, coordinator instructs all participants to commit.
  - Once voted, **cannot** change the vote.
- All participants must adopt global decision.

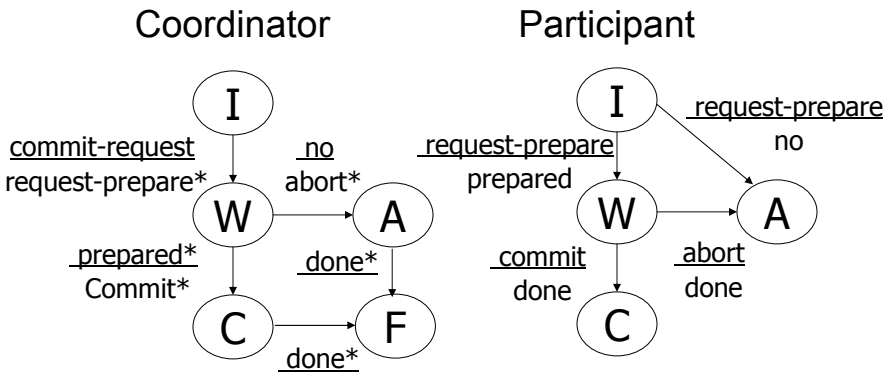
Two-Phase Commit (2PC)

- If participant votes abort, free to abort transaction immediately (**unilateral abort**)
- If participant votes commit, must wait for coordinator to broadcast global-commit or global-abort message.
- Protocol assumes each site has its own local log and can rollback or commit transaction reliably.
- If participant fails to vote, abort is assumed.
- If participant gets no vote instruction from coordinator, can abort.





Centralized two-phase commit



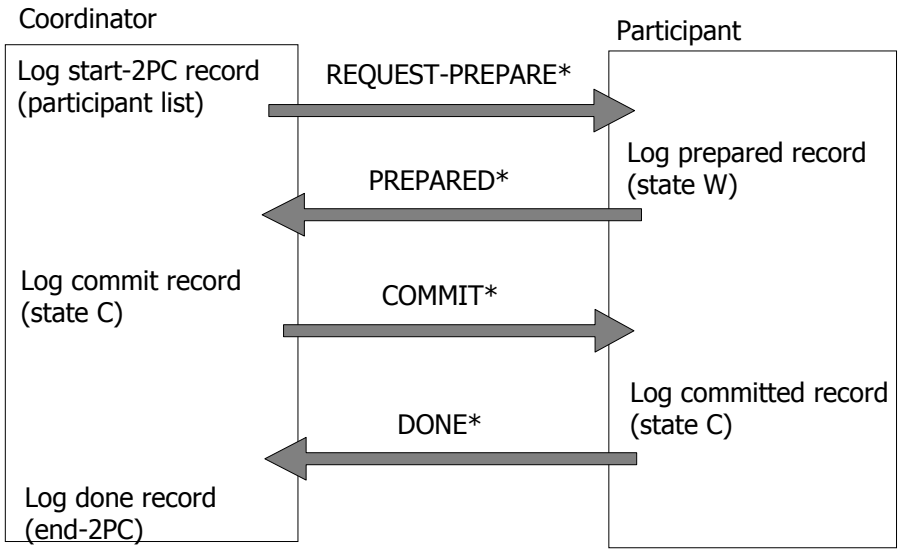
- Notation: Incoming message
  Outgoing message
  (* = everyone)
- When participant enters "W" state:
  - it must have acquired all resources
  - it can only abort or commit if so instructed by a coordinator
- Coordinator only enters "C" state if all participants are in "W", i.e., it is certain that all will eventually commit
- After coordinator receives DONE message, it can forget about the transaction (clean up control structures).

Handling failures

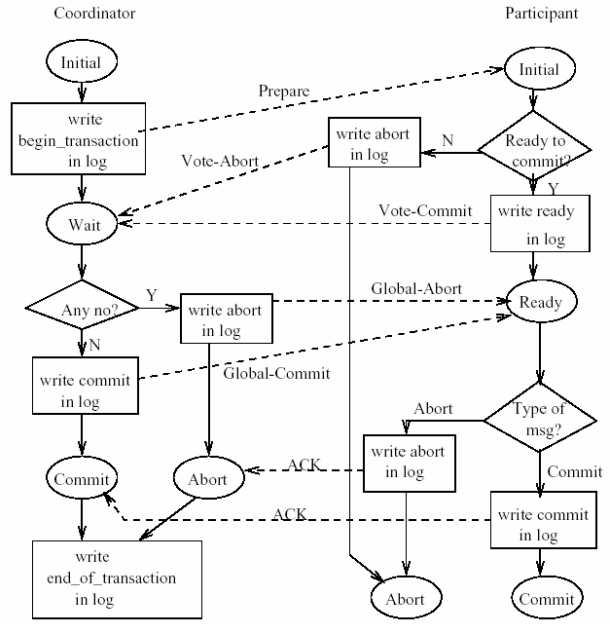
- Types of failures
  - Node failure
  - Timeout waiting for expected message
  - Communication failure???

Handling node failures

- Coordinator and participant logs are used to reconstruct state before failure
- State transitions must be logged



2PC Protocol Actions



Handling Failures

- Termination protocols
  - How operational nodes react
- Recovery protocols
  - How failed nodes behave

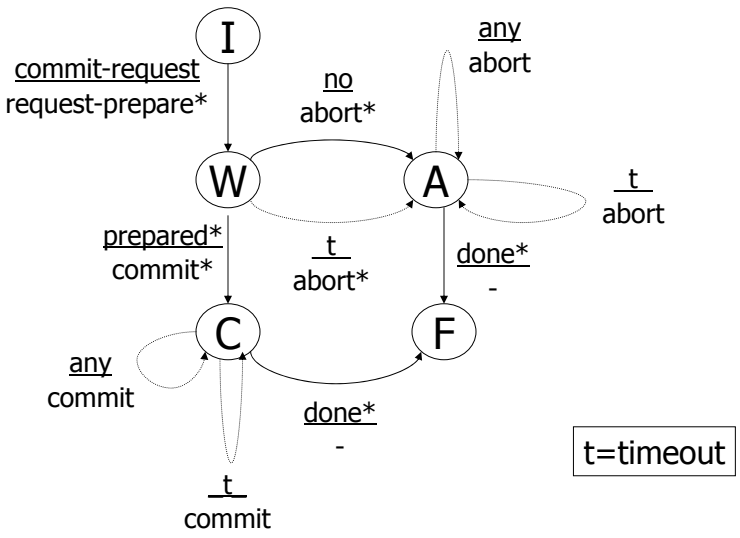
Termination Protocols

- Invoked whenever a coordinator or participant fails to receive an expected message and times out.

Coordinator

- Timeout in WAITING state
  - Globally abort the transaction.
- Timeout in COMMIT/ABORT state
  - Send global decision again to sites that have not acknowledged.

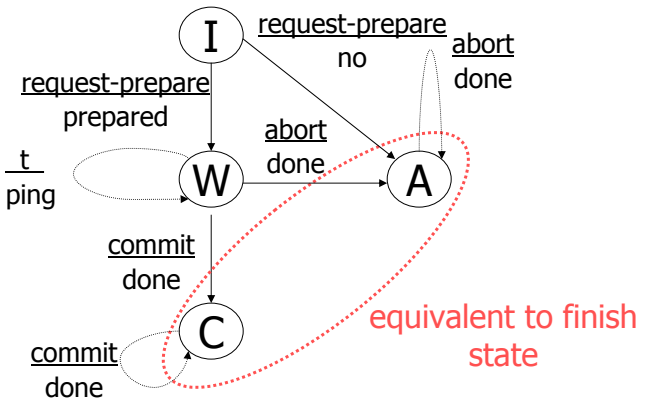
Coordinator



Termination Protocols - Participant

- Simplest termination protocol is to leave participant blocked until communication with the coordinator is re-established. Alternatively:
- Timeout in INITIAL state
  - Unilaterally abort the transaction.
- Timeout in the WAITING state
  - Without more information, participant blocked.
  - Could resend vote to coordinator, and wait
  - Could get decision from another participant
  - Cannot unilaterally abort

Participant



Recovery Protocols

- Action to be taken by operational site in event of failure. Depends on what stage coordinator or participant had reached.

Coordinator Failure

- Failure in INITIAL state
  - Recovery starts the commit procedure.
- Failure in WAITING state
  - Recovery restarts the commit procedure.

2PC - Coordinator Failure

- Failure in COMMIT/ABORT state
  - On restart, if coordinator has received all acknowledgements, it can complete successfully. Otherwise, has to initiate termination protocol discussed above.

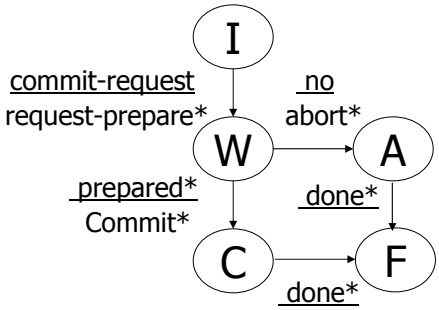
Failure scenarios

Coordinator

Start-2PC record
(participant list)

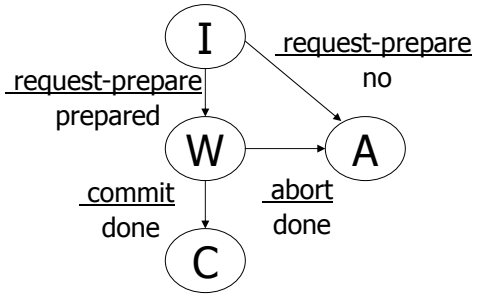
Commit/Abort record
(state C/A)

Done record



2PC - Participant Failure

- Objective to ensure that participant on restart performs same action as all other participants and that this restart can be performed independently.
- Failure in INITIAL state
  - Unilaterally abort the transaction.
- Failure in WAITING state
  - Recovery via termination protocol above.
- Failure in ABORT/COMMIT states
  - On restart, no further action is necessary.



Participant

Prepared record
(state W)

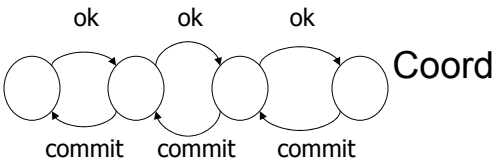
Commit/Abort record
(state C)

Complexity analysis

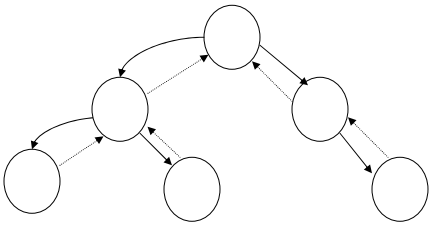
- Count number of messages, rounds
  - N participants
- Centralized 2PC
  - Ignore DONE messages
  - If there are no failures:

Variants of 2PC

- Linear

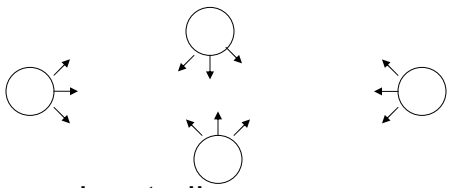


- Hierarchical



Variants of 2PC

- Distributed



  - Nodes broadcast all messages
  - Every node knows when to commit

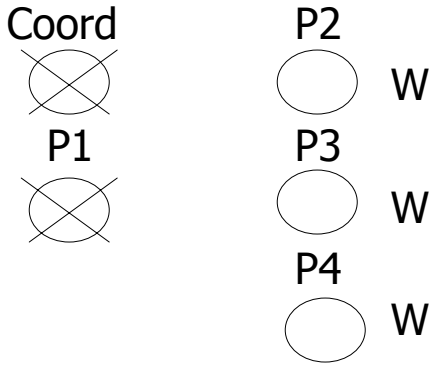
Exercise

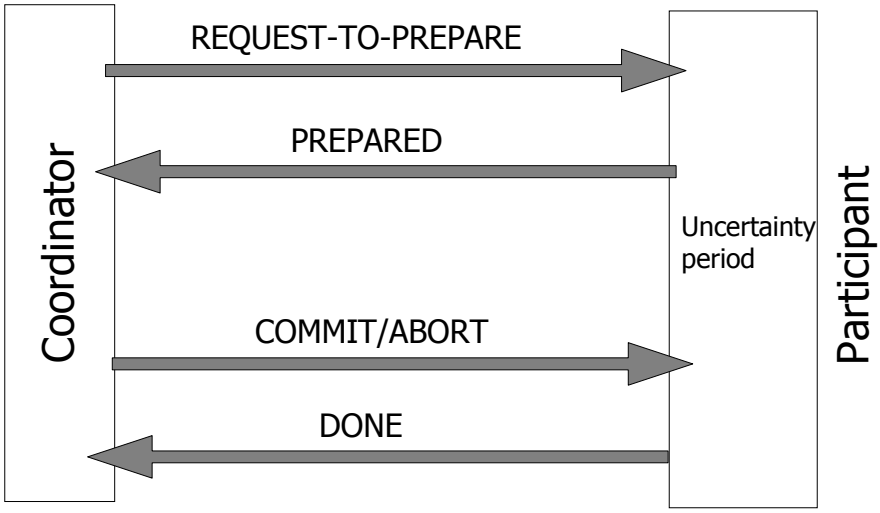
- Compare 2PC variants in terms of
  - Number of rounds
  - Number of messages

2PC is a blocking protocol. Is there a non-blocking protocol?

Three-Phase Commit

Sample scenario:





3PC Principle

- Ensures the following non-blocking property:
  - If ANY operational site is in the "uncertain" state, NO site (operational or failed) could have decided to commit
    - If all operational sites are uncertain, then they can simply decide **abort**, *i.e.*, they don't have to block for other sites to become operational.
- **Main Idea:**
  - Send (with ack) a PRE-COMMIT to all participants before sending COMMIT.
  - This ensures that decision is **commit** only if all sites have first received PRE-COMMIT (and are not uncertain).
- Reminder: Assume reliable network

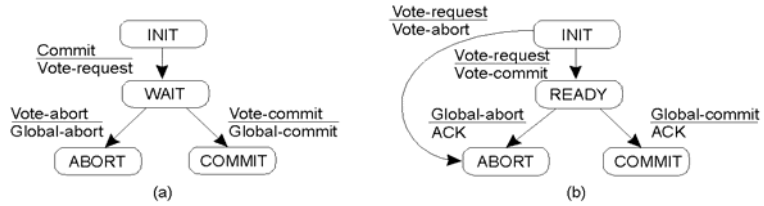
Basic 3PC Protocol

- **Phase 1:**
  - The coordinator sends VOTE_REQ to all participants.
  - When a participant receives VOTE_REQ, it responds with YES or NO, depending on its vote. If a participant votes NO, it decides **abort** and stops.
- **Phase 2:**
  - The coordinator collects all votes. If any vote was NO, then the coordinator decides **abort**, sends ABORT to all participants that voted YES, and stops. Otherwise, the coordinator sends PRE_COMMIT messages to all participants.
  - A participant that votes YES waits for a PRE_COMMIT or ABORT message from the coordinator. If it receives a PRE_COMMIT, then it responds with an ACK message.

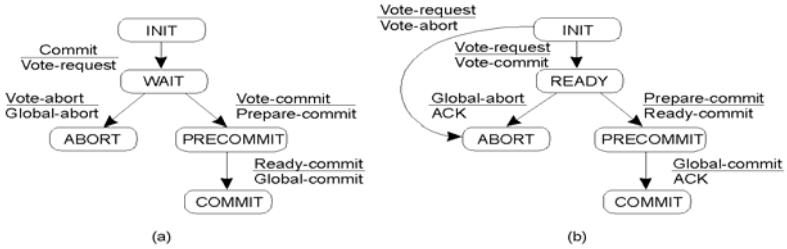
Basic 3PC Protocol

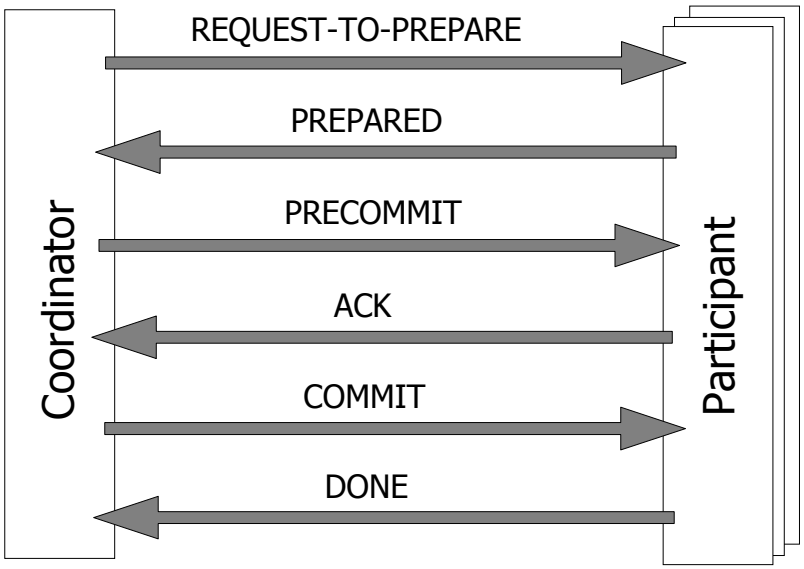
- **Phase 3:**
  - The coordinator collects the ACKs. When they have all been received, it decides **commit**, sends COMMITs to all participants, and stops.
  - A participant waits for a COMMIT from the coordinator. When it receives that message, it decides **commit** and stops.

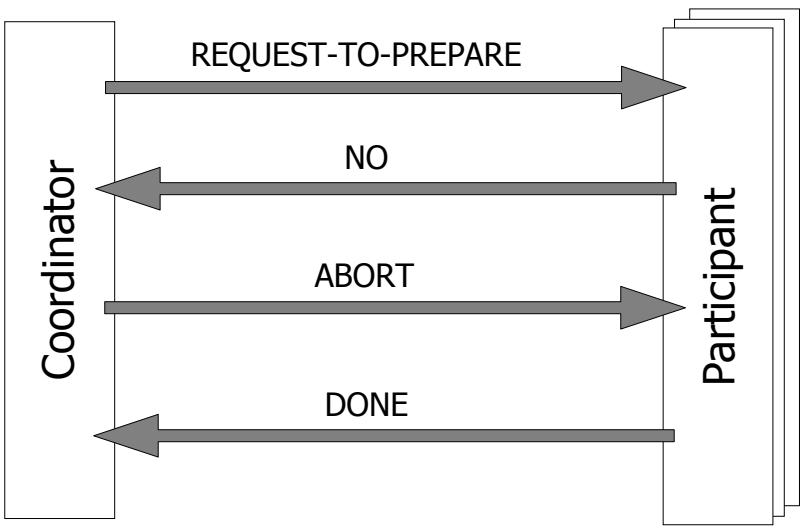
- 2PC FSM

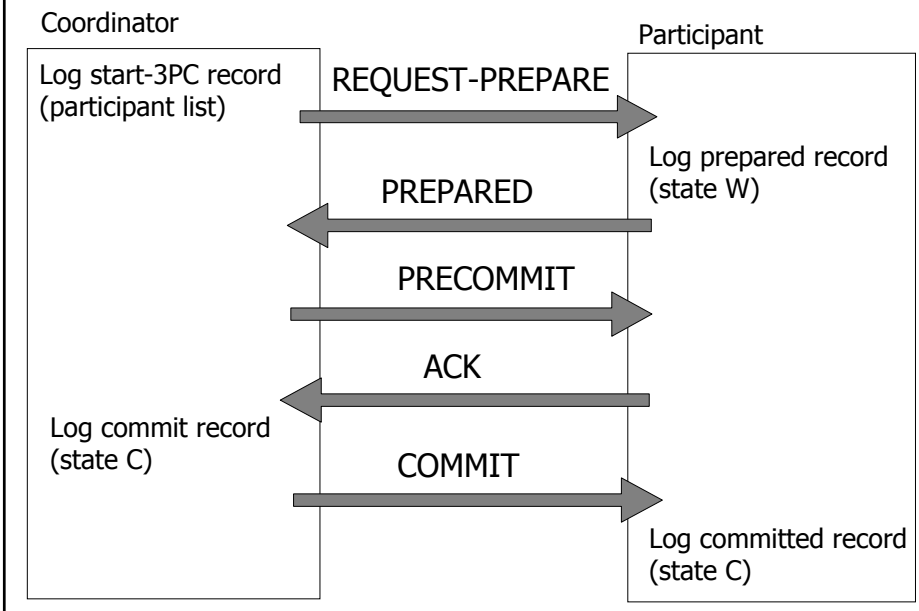


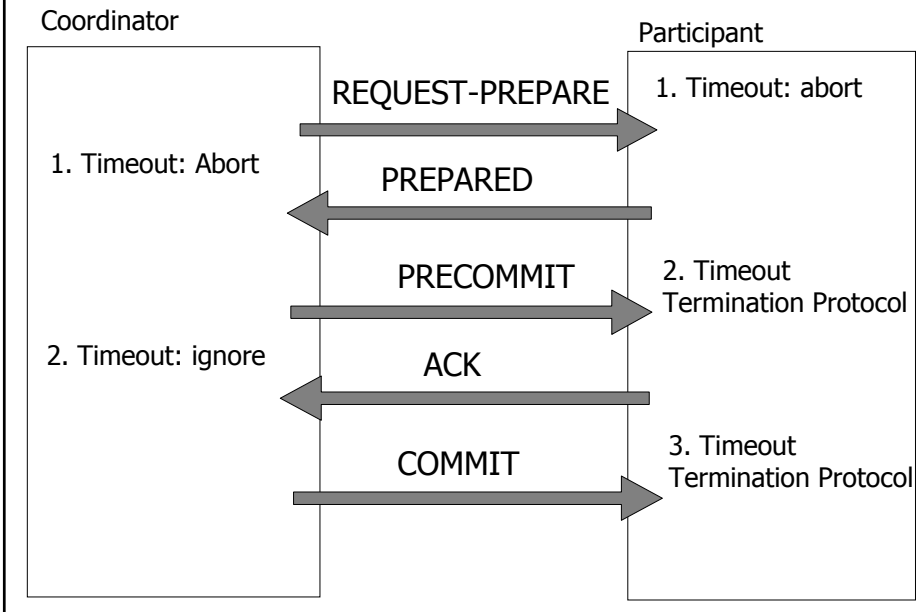
- Introduction of another Phase




REQUEST-TO-PREPARE
PREPARED
PRECOMMIT
ACK
COMMIT
DONE
Coordinator
Participant


REQUEST-TO-PREPARE
NO
ABORT
DONE
Coordinator
Participant


Coordinator
Participant
Log start-3PC record
(participant list)
REQUEST-PREPARE
Log prepared record
(state W)
PREPARED
PRECOMMIT
ACK
Log commit record
(state C)
COMMIT
Log committed record
(state C)


Coordinator
Participant
REQUEST-PREPARE
1. Timeout: abort
1. Timeout: Abort
PREPARED
PRECOMMIT
2. Timeout
Termination Protocol
2. Timeout: ignore
ACK
COMMIT
3. Timeout
Termination Protocol

Time-out Actions

- If the coordinator does not receive a vote, it decides **abort**, sends ABORT message to YES voters, and stops.
- If the coordinator times-out waiting for an ACK (it knows that the participant is at least ready), then it simply proceeds to send commit.
  - When the process that owes the ACK recovers, it is responsible for finding out the decision.
- In commit state? Ignore

Time-out Actions

- If a participant does not receive a VOTE_REQ, it decides **abort** and stops.
- If timeout occurs while a participant is waiting for COMMIT, ABORT, or PRE_COMMIT from coordinator, a new **Termination Protocol** is used.
  - Process **states**, defined next, are used in the Termination Protocol.

Site categories

- Three categories
  - Operational
    - Process has been up since start of 3PC
  - Failed
    - Process has halted since start of 3PC, or is recovering
  - Recovered
    - Process that failed and has completed recovery

Site States

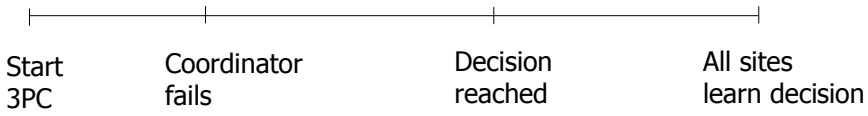
- **Aborted:** The process has not voted, has voted NO, or has received an ABORT.
- **Uncertain:** The process is in its uncertainty period.
- **Committable:** The process has received PRE_COMMIT but not COMMIT.
  - **Note:** PRE_COMMITs are not logged. So, if a process that is committable fails, it will think it is uncertain when it recovers.
- **Committed:** The process has received COMMIT.

Coexistence of States

	Aborted	Uncertain	Committable	Committed
Aborted	Y	Y	N	N
Uncertain	Y	Y	Y	N
Committable	N	Y	Y	Y
Committed	N	N	Y	Y

For example, it's impossible for one process to be Aborted and another Committable.

Termination Protocol

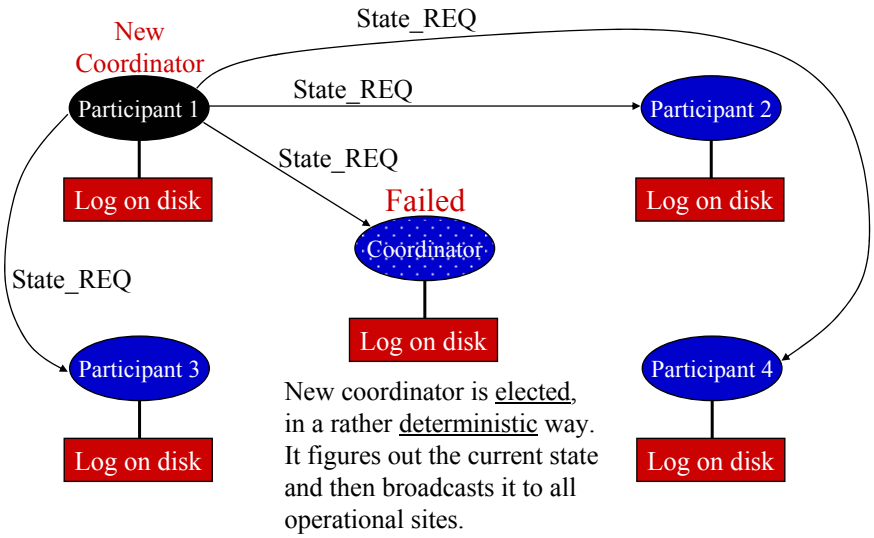


- Only operational sites participate in termination protocol.
- Recovered sites wait until decision is reached and then learn decision

Termination Protocol

- Elect new coordinator
  - Use Election Protocol (coming soon...)
- New coordinator sends STATE-REQUEST to participants
- Makes decision using termination rules
- Communicates to participants

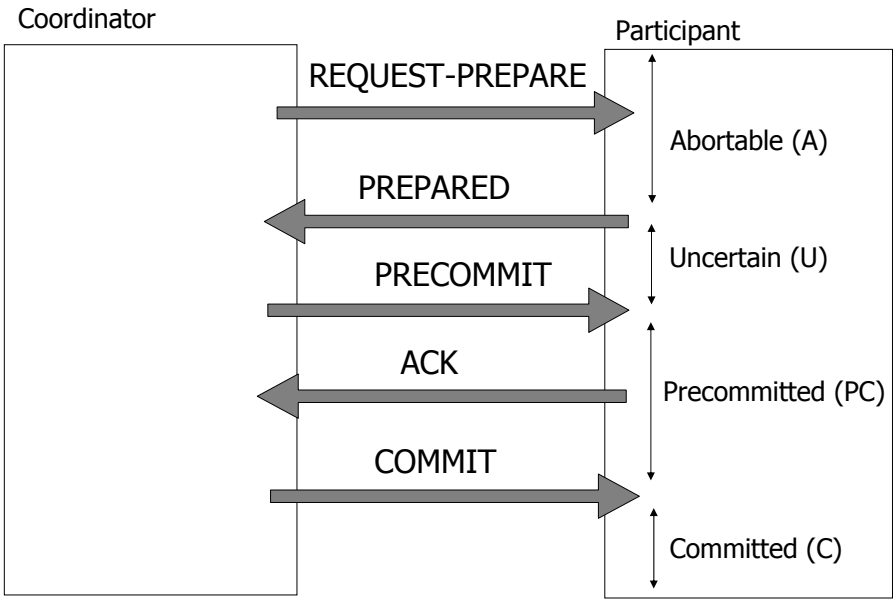
Termination Protocol

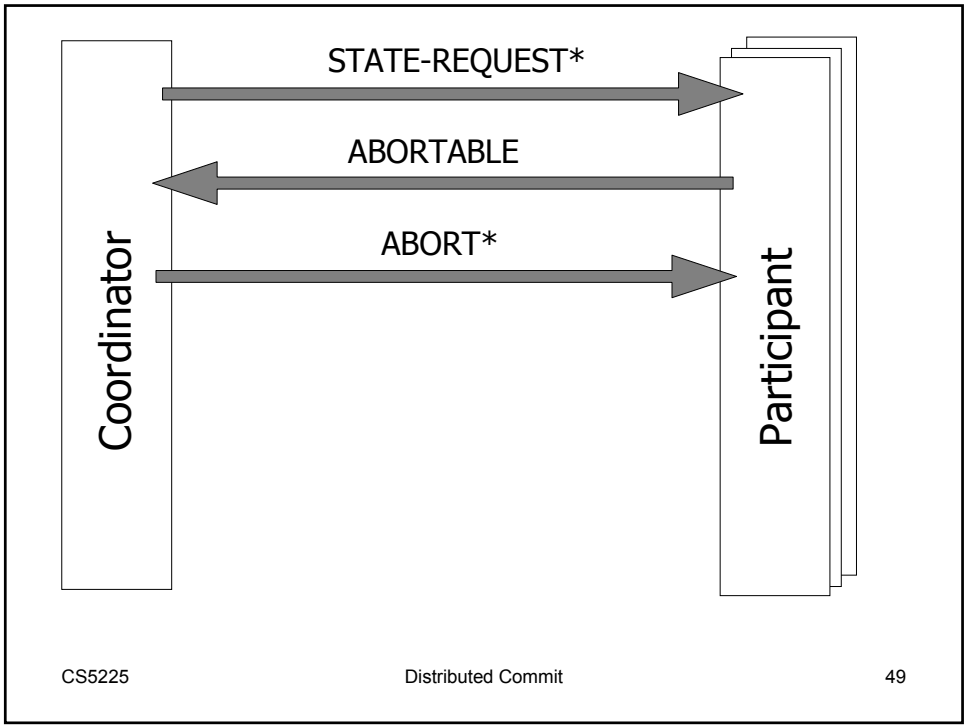


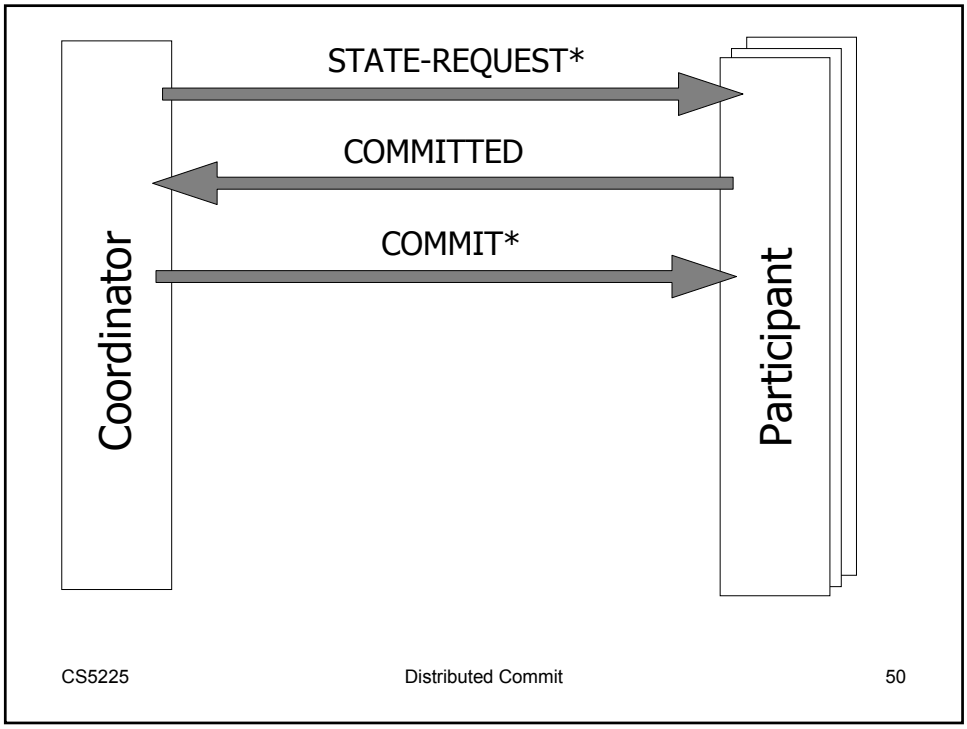
New coordinator is elected, in a rather deterministic way. It figures out the current state and then broadcasts it to all operational sites.

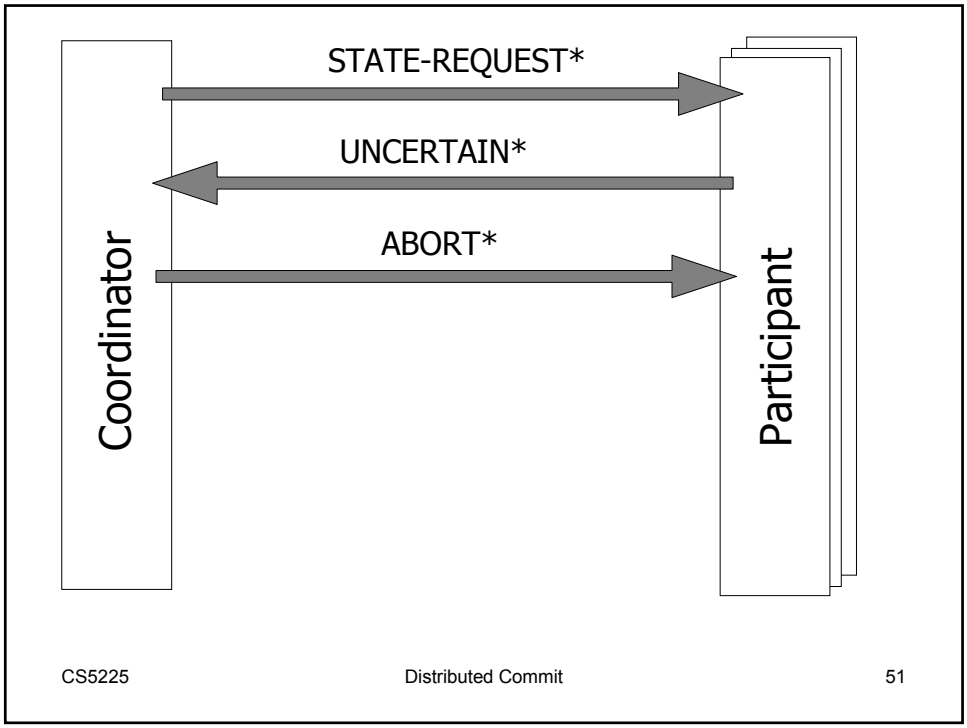
Termination Protocol

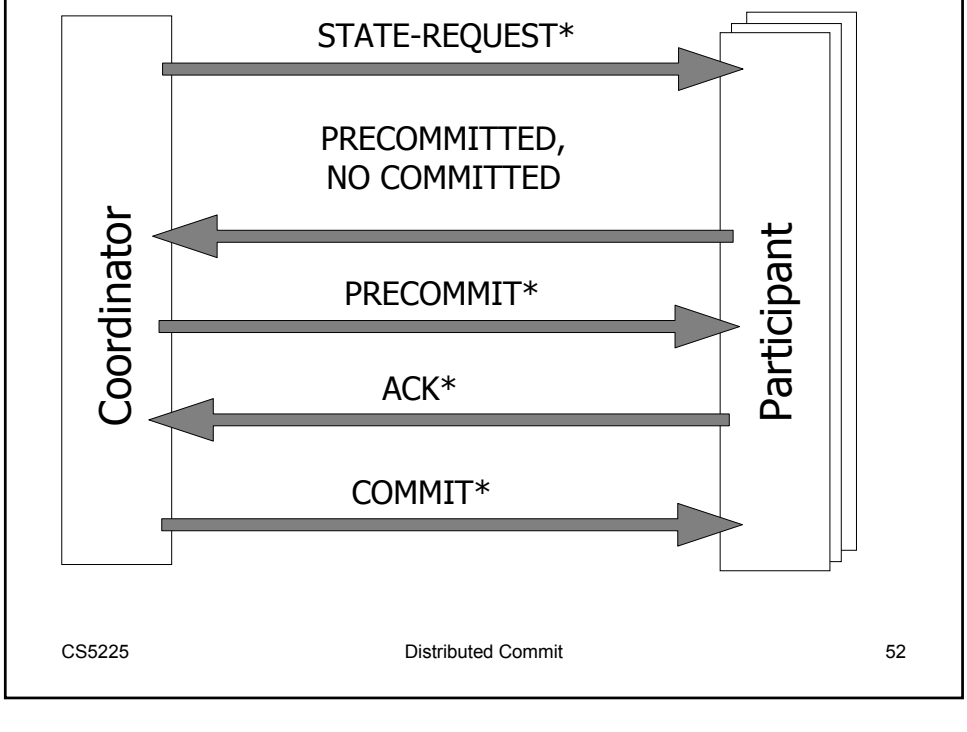
- *Elected* coordinator collects states and proceeds:
  - **TR1:** If some sites aborted, then the coordinator decides **abort**, sends ABORT, and stops.
  - **TR2:** If some sites are committed, then the coordinator decides **commit**, sends COMMIT, and stops.
  - **TR3:** If all sites report their state as uncertain, then the coordinator decides **abort** and informs participants.
  - **TR4:** If some sites are committable but none is committed, then the coordinator sends PRE_COMMIT to uncertain processes, and waits for ACK before sending COMMIT messages.




STATE-REQUEST*
ABORTABLE
ABORT*
Coordinator
Participant


STATE-REQUEST*
COMMITTED
COMMIT*
Coordinator
Participant


STATE-REQUEST*
UNCERTAIN*
ABORT*
Coordinator
Participant


STATE-REQUEST*
PRECOMMITTED,
NO COMMITTED
PRECOMMIT*
ACK*
COMMIT*
Coordinator
Participant

Failures during Termination Protocol

- Participant failures
  - Detected by coordinator timeout
  - Coordinator ignores failed sites
- Coordinator failure
  - Some site times out
  - Initiates election protocol to elect new coordinator. So, there will be *another* invocation of the TP.
    - If there are many failures, many invocations may be needed.

Failures during Termination Protocol

- Recovered sites do not participate in termination protocol
- Two possible outcomes
  - All sites fail (Total Failure)
  - Some coordinator reaches decision

Recovered Sites (Partial Failure)

- If participant has decided or has *not* voted YES, it can decide easily.
- If it voted YES but did not **commit** or **abort** (in log), then it asks other participants for the decision.
- Assuming that only partial site failures occur, either the decision has been made or is being made (**non-blocking**). So, *p* will eventually receive a message with the decision.
- Log entries are the same as in 2PC.
- But unlike 2PC, recovering uncertain sites do not have to invoke the Termination Protocol (unless there is a total site failure — see next).

Total Failures

- In case of **total failure**, the recovering site *p* must wait (block) until the last site to fail is up or a decided site recovers.
- **Note:** The last site to fail may have reached a decision (**commit** or **abort**) that no other operational site knows about.
- If operational site *q* has decided, it simply communicates its decision to *p*. If this doesn't happen, the Termination Protocol will be invoked. All recovering sites will therefore reach a consistent decision.

Election Protocol

- Total ordering of processes
  - Coordinator = 0, participants 1,...,n
- At any time, elect "smallest" operational site coordinator

Note: 3PC unsafe with communication failures!

Is there a non-blocking protocol?

Theorem:

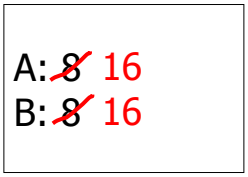
If communications failures or total site failures (i.e., all sites fail) are possible, then every atomic commit protocol can cause participants to become blocked.

Conclusion

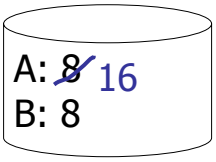
- 2PC is practical and widely used.
- These schemes strongly exploit
  - the fact that time-outs are sufficiently long,
  - the fact that logs are stable, and
  - the fact that **abort** is a suitable default decision in many cases where the decision isn't obvious.

T1: Read (A,t); t ← t×2
Write (A,t);
Read (B,t); t ← t×2
Write (B,t);
Output (A);
Output (B);

failure!



memory



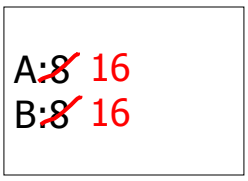
disk

Need atomicity: execute all actions of a transaction or none at all

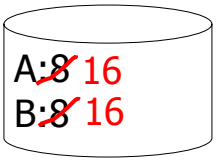
One Solution: Undo logging (Immediate modification)

T1: Read (A,t); t ← t×2
Write (A,t);
Read (B,t); t ← t×2
Write (B,t);
Output (A);
Output (B);

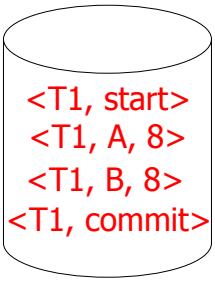
A=B



memory



disk



log