9. Reliability

Aspects and Definitions

- A measure of success with which a system conforms to some authoritative specification of its behavior.
- Probability that the system does not experience failures within a given period.
- Typically used to describe systems that cannot be repaired or where the continuous operation of the system is critical.
- In transactional context: How to maintain *Atomicity* and *Durability*

Crash and crash recovery

- By *crash* all kinds of failures are denoted that bring down a server and cause all data in volatile memory to be lost (*soft crash*), but leave all data on stable secondary storage intact, i.e. not a (*hard crash*).
- A *crash recovery* algorithm restarts the server and brings its permanent data back to its most recent, consistent state

During crash recovery after a system failure, a server and its data are unavailable to clients. Goal: minimize recovery time

Recovery performance and system availability

MTBF: *mean time between failure*

MTTR: *mean time to repair*

Availability: probability for a server to be ready to serve:

$$\frac{MTBF}{MTBF + MTTR}$$

Examples

- Server fails once a month and takes 2 hours to recover: availability of 99.7%, downtime of 26 h a year.
- Server fails once every 48 h and takes 30 sec to recover: availability of 99.98%, downtime of 105 min a year.

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Local Reliablity Protocols

ARIES:

- Write-ahead Logging
- Repeating History on Crash

Distributed Reliability Protocols

- Commit Protocols
  - How to execute commit command for distributed transactions?
  - 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 it occurred deal with it?
  - *Independent*: a failed site can determine the outcome of a transaction without having to obtain remote information.

$\Longrightarrow$ Independent recovery $\rightarrow$ Non-blocking termination

9.1. Commit coordination

The coordination problem during the commit-phase.

Given a computation defined by a set of subtransactions each running at a seperate server. How can we ensure that either all subtransactions commit to the final result, or none of them do (atomicity)? To reach a unique decision among the subtransactions, a *coordinator* process is initiated running at one of the involved servers.

- A subtransaction may be aborted even after having reached the end because of some faulty other subtransaction.
- Therefore, during its commit-phase each subtransaction must figure out whether it and all the others will finish their commit-phase successfully.
- If this is not possible, all subtransaction have to be aborted.
- Reaching a global commit must be achieved by passing messages.

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2-Phase-Commit Protocol

how it works

- The client who inititated the computation acts as coordinator; processes required to commit are the participants.
- Phase 1a: Coordinator sends *vote-request* to participants.
- Phase 1b: When participant receives *vote-request* it returns either *vote-commit* or *vote-abort* to coordinator. If it sends *vote-abort*, it aborts its local computation. If it sends *vote-commit*, it writes its state to disk
- Phase 2a: Coordinator collects all votes; if all are *vote-commit*, it sends *global-commit* to all participants, otherwise it sends *global-abort*.
- Phase 2b: Each participant waits for *global-commit* or *global-abort* and reacts accordingly - discarding the result or making it permanent.

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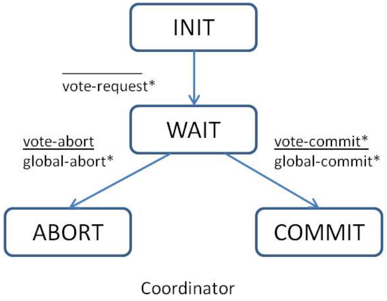

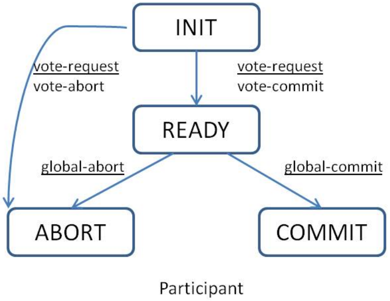

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State transitions during 2PC.

Distributed Transaction Log: DT log at each site

DT log maintenance

(1) When the coordinator sends *vote-request*, it writes a *start-2PC* record in the DT log. This record contains the identities of the participants, and may be written before or after sending the messages.

(2) If a participant replies *vote-commit*, it writes a *vote-commit* record in the DT log, before sending *vote-commit* to the coordinator. This record contains the name of the coordinator and a list of the other participants. If the participant votes no, it writes an *abort* record either before or after the participant sends *vote-abort* to the coordinator.

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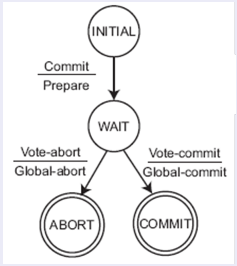
Termination Protocol: Coordinator Timeouts

- Timeout @ WAIT
  - Can not unilaterally commit.
  - Can abort and send Global-abort, since no global commit has been made
- Timeout @ ABORT / COMMIT
  - Repeatedly send Global-abort / Global-commit to the unresponsive participants.
  - **Stay blocked and wait for their ACK messages**.

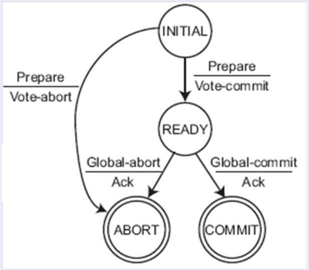
Coordinator



Termination Protocol: Participant Timeouts

- Timeout @ INITIAL
  - Coordinator must have failed at INITIAL.
  - Can abort.
  - If Prepare arrives later, can either Vote-abort or ignore it (i.e., let the coordinator timeout @WAIT).
- Timeout @ READY
  - Can not unilaterally commit or change its decision to an abort.
  - **Stay blocked**.

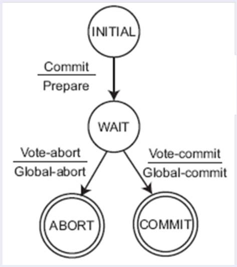
Participants



Recovery Protocol: Coordinator Failures

- Failure @ INITIAL
  - Start the commit process upon recovery.
- Failure @ WAIT
  - Restart the commit process upon recovery.
- Failure @ ABORT / COMMIT
  - If all ACKs have been received, nothing to do.
  - Else, invoke the termination protocol.

Coordinator



Recovery Protocol: Participant Failures

- Failure @ INITIAL
  - Abort upon recovery.
- Timeout @ READY
  - The coordinator has already been informed about the local decision.
  - Treat as Timeout @ READY and invoke the termination protocol.
- Timeout @ ABORT/COMMIT
  - Nothing to do

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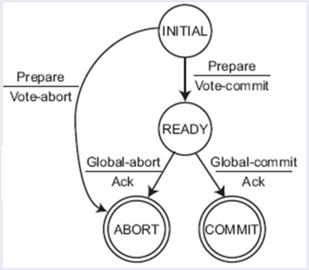

Recovery Protocol at Log Level

- If the DT log contains a *start-2PC* record, then S was the host of the coordinator. If it also contains a *commit* or *abort* record, then the coordinator had decided before the failure and it can resend its decision. If neither record is found, the coordinator can now unilaterally decide Abort by inserting an *abort* record in the DT log.
- If the DT log doesn't contain a *start-2PC* record, then S was the host of a participant. There are three cases to consider:
  (1) The DT log contains a *commit* or *abort* record. Then the participant had reached its decision before the failure.
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DT log garbage collection

- A site cannot delete log records of a transaction T from its DT log before its recovery manager has processed Commit or Abort.
- The coordinator should not delete the records of transaction T from its DT log until it has received messages indicating that Commit or Abort has been processed at all other sites where T executed. To this end participants may send a final *ACK*-message when moving in their commit-state.

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2-Phase-Commit Variants

decentralized 2PC

- Phase 1: Coordinator sends, depending on its vote, *vote-commit* or *vote-abort* to all participants.
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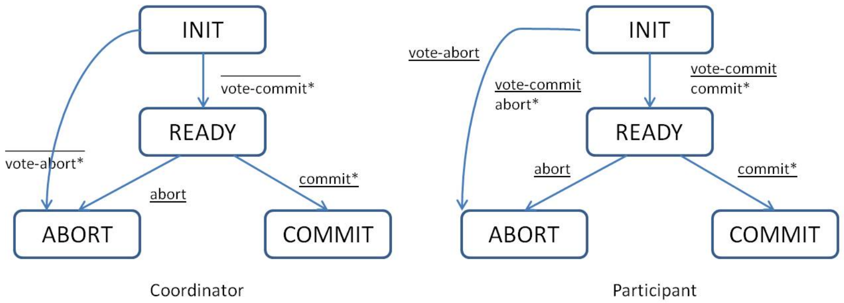

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State transitions during decentralized 2PC.

linear 2PC

All processes are linearly ordered, w.l.o.g. $P_0, P_1, P_2, \ldots, P_n$, where P_0 is the coordinator. Communication is possible between neighbors.

(S1) When the protocol starts, P_0 sends message *vote-request* to its right neighbor.

(S2) If process P_i, $1 \leq i < n$, receives a message from its left neighbor:

- (1) If message is *vote-request*, then
  - (i) if its own vote is commit, it sends *vote-request* to its right neighbor.
  - (ii) otherwise, it sends *abort* to its left and right neighbors and aborts.
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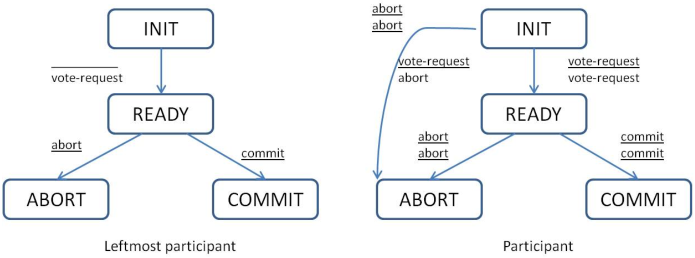
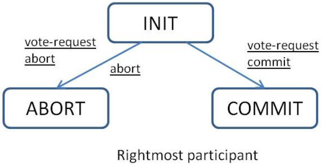
- (1) If message is *vote-request*, then
  - (i) if its own vote is commit, it sends *commit* to its left neighbor and commit.
  - (ii) if its own vote is abort, it sends *abort* to its left neighbor and aborts.
- (2) If message is *abort*, then it aborts.

(S5) If process P_0 receives message *commit* from its right neighbor, it commits; if it receives message *abort*, it aborts.





Notation: $\frac{\textit{message received}}{\textit{message sent}}$

State transitions during linear 2PC.

Comparison

Message Complexity: How many messages are exchanged to reach a decision?
Time Complexity: How long does it take to reach the decision? As several messages can be send in parallel, the number of message exchange *rounds* is counted.

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centralized 2PC	$3n$	3
decentralized 2PC		
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Under which assumptions does 2PC work correctly, i.e. will not block?

Possible failures

Assumption: A site is either working correctly (is *operational*) or not working at all (is *down*).[1]

- partial site failure:

  Some sites are operational, some sites are down.

- total site failure:

  All sites are down.

- communication failure:

  Some site A is not able to communicate with some site B, even though none of them is down. This may be due to broken communication links or site failures.

2PC may be blocking even in case of only partial failures. $\Longrightarrow$ 3PC

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3-Phase-Commit Protocol

In contrast to 2PC, 3PC tolerates partial failures by guaranteeing the property NB

- The period between the moment a process votes `Yes` for commit and the moment it has received sufficient information to know the decision is called *uncertainty period*. During its uncertainty period a process is called *uncertain*.

NB: If any operational process is uncertain, then no process (whether operational or failed) can have decided to commit.

- As a consequence, if the operational sites discover, that they all are uncertain, they can decide to abort, as the other failed process cannot have decided commit before.
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3-phase commit (3PC) protocol

- Phase 1a: Coordinator sends *vote-request* to participants.
- Phase 1b: When participant receives *vote-request* it returns either *vote-commit* or *vote-abort* to coordinator. If it sends *vote-abort*, it aborts its local computation.
- Phase 2a: Coordinator collects all votes; if all are *vote-commit*, it sends *prepare-commit* to all participants, otherwise it sends *global-abort*, and halts.
- Phase 2b: Each participant that voted *vote-commit* waits for *prepare-commit*, or waits for *global-abort* after which it halts. If *prepare-commit* is received, the process replies *ready-commit* and therefore the coordinator knows that this process is no longer uncertain.
- Phase 3a: (Prepare to commit) Coordinator waits until all participants have sent *ready-commit*, and then sends *global-commit* to all.
- Phase 3b: (Prepare to commit) Participant waits for *global-commit* and then commits. It knows that no other process is uncertain and thus commits without violating NB.

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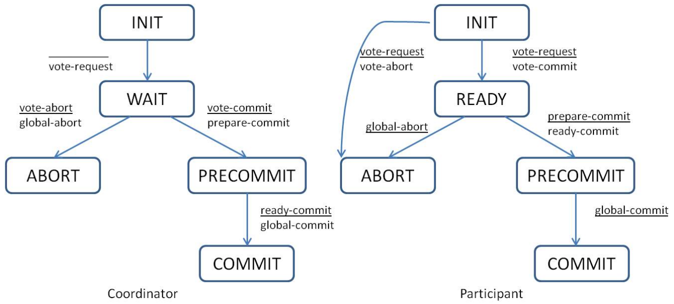


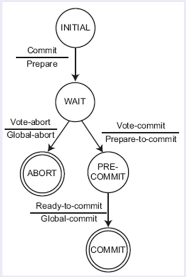
Notation: $\frac{\textit{message received}}{\textit{message sent}}$

State transitions during 3PC.

Termination Protocol: Coordinator Timeouts

- Timeout @ PRECOMMIT
  - Participants must be at least in READY.
  - Move all the participants to PRECOMMIT.
  - Globally commit
- Timeout @ ABORT / COMMIT
  - Ignore and treat as completed
  - Participants are either at PRECOMMIT or READY and they can continue to termination.

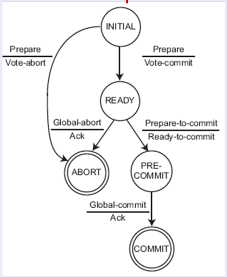
Coordinator



Termination Protocol: Participant Timeouts

- Timeout @ INITIAL
  - Coordinator must have failed at INITIAL.
  - Can abort.
  - If Prepare arrives later, can either Vote-abort or ignore it (i.e., let the coordinator timeout @WAIT).
- Timeout @ READY
  - Voted to commit, but does not know the coordinator's global decision.
  - Elect a new coordinator and terminate using a special protocol.
- Timeout @ PRECOMMIT
  - Same as Timeout @ READY

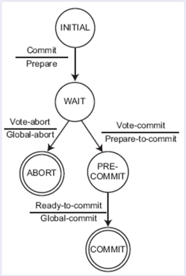
Participants



Recovery Protocol: Coordinator Failures

- Failure @ INITIAL
  - Start the commit process upon recovery.
- Failure @ WAIT
  - The participants may have elected a new coordinator and terminated.
  - Ask around for the fate of the transaction
- Failure @ PRECOMMIT
  - Ask around for the fate of the transaction
- Failure @ ABORT / COMMIT
  - If all ACKs have been received, nothing to do.
  - Else, invoke the termination protocol.

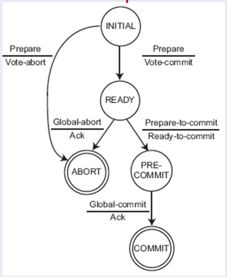
Coordinator



Recovery Protocol: Participant Failures

- Failure @ INITIAL
  - Abort upon recovery.
- Timeout @ READY
  - The coordinator has already been informed about the local decision.
  - Upon Recovery, ask around
- Timeout @ PRECOMMIT
  - Ask around how the others have terminated the transaction
- Timeout @ ABORT/COMMIT
  - Nothing to do

Participants



To proof correctness and termination of 3PC is difficult. Let's look at one case to demonstrate what could happen.

If a participant P times out in state PRECOMMIT, why can't it ignore the timeout and simply decide for commit?

- The coordinator may have failed after having sent a *prepare-commit*-messsage to P but before sending it to some other Q.
- Thus P times out outside its uncertainty period while Q will time out inside its uncertainty period.
- Thus, committing of P would violate NB.
- Therefore, before committing, P must assure, that all operational participants have received a *prepare-commit*-messsage and therefore moved outside their uncertainty period.
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Termination rules

By applying an election protocol among all operational processes determin a new coordinator.

(1) If some process is Aborted, the coordinator decides Abort, sends ABORT messages to all participants, and stops.

(2) If some process is Committed[2], the coordinator decides Commit, sends COMMIT messages to all participants, and stops.

(3) If all processes that reported their state are Uncertain, the coordinator decides Abort, sends ABORT messages to all participants, and stops.

(4) If some process is Committable but none is Committed, the coordinator first sends PRE-COMMIT messages to all processes that reported Uncertain, and waits for acknowledgments from these processes. After having received these acknowledgments the coordinator decides Commit, sends COMMIT messages to all processes, and stops.

Processes may fail during the termination protocol! The protocol then has to be repeated - either it will be finished by some coordinator or all processes will fail.

[2] This may have happened in a previous round of the termination protocol.