

1. For each of the following scenarios for the 2PC Protocol, explain why the log writes need to be forced or need not be forced.
 - (a) The coordinator needs to forced write a commit log record if the global decision is to commit.
 - (b) The coordinator does not need to forced write an abort log record if the global decision is to abort.
 - (c) A participant needs to forced write a ready log record before sending its vote.
 - (d) A participant needs to forced write a commit/abort log record if it has voted to commit.
 - (e) A participant does not need to forced write an abort log record if it has voted to abort.

Solution:

- (a) Consider the scenario where the coordinator simply non-forced writes the commit log record and sends out all the Global-commit messages. Suppose that the coordinator crashes after all the participants have advanced to the COMMIT state but before its commit log record has been flushed to disk. Thus, the coordinator would recover in the WAIT state (its last log record on the disk is *begin_commit*) and abort the transaction resulting in an inconsistent decision. To avoid such inconsistencies, the coordinator needs to forced write its commit log record if the global decision is to commit.
- (b) Consider the scenario where the global decision is to abort and the coordinator simply non-forced writes the abort log record and sends out the Global-abort message to all participants who have voted to commit. Suppose that the coordinator crashes before its abort log record has been flushed to disk. The coordinator would recover in the WAIT state (its last log record on the disk is *begin_commit*). Subsequently, the coordinator would timeout in the WAIT state and decide to globally abort the transaction. This decision is consistent with its previous global-abort decision. Thus, it is not necessary for the coordinator to forced-write abort log records.
- (c) Consider the scenario where a participant P is voting to commit and P simply non-forced writes the ready log record. Suppose that P crashes before its ready log record has been flushed to disk. P would recover in the INITIAL state and decide to unilaterally abort the transaction. This decision will be inconsistent if the global decision was to commit. Thus, it is necessary for a participant to forced-write its ready log record.
- (d) Consider the scenario where a participant P has received the global-commit/abort message and P simply non-forced writes its commit/abort log record and sends an ACK message to the coordinator. Suppose that P crashes before its commit/abort log record has been flushed to disk. Thus, P would recover in the READY state (its last log record on the disk is *ready*) and send a vote-commit message to the coordinator. If the coordinator has received ACK messages from all the participants, it is possible that the coordinator no longer has any information about the status of the completed transaction and is therefore unable to inform P about the global decision for the transaction. To avoid such situations, a participant that has voted to commit needs to forced write its commit/abort log record.
- (e) Consider the scenario where a participant P has voted to abort and P simply non-forced writes the abort log record. Suppose that P crashes before its abort log record has been flushed to disk. P would recover in the INITIAL state and decide to unilaterally abort the transaction. This decision is consistent with the global decision to abort the transaction. Thus, it is not necessary for a participant that has voted abort to forced-write its abort log record.

2. In the 2PC Protocol, in the absence of site failures, if a participant is in the READY state, what are the possible states for another participant?

Solution: The following are the possible state configurations of other participants:

- {Initial}
- {Ready}
- {Abort}
- {Commit}
- {Initial, Ready}
- {Initial, Abort}
- {Ready, Abort}
- {Ready, Commit}
- {Initial, Ready, Abort}

3. Answer each of the following questions for the 3PC-1 Protocol in the absence of site and communication failures:

- (a) If a participant is in the READY state, what are the possible states for another participant?
- (b) If a participant is in the PRECOMMIT state, what are the possible states for another participant?

Solution: The following are the possible state configurations of other participants:

- (a)
 - {Initial}
 - {Ready}
 - {Abort}
 - {Precommit}
 - {Initial, Ready}
 - {Initial, Abort}
 - {Ready, Abort}
 - {Ready, Precommit}
 - {Initial, Ready, Abort}
- (b)
 - {Ready}
 - {Precommit}
 - {Commit}
 - {Ready, Precommit}
 - {Precommit, Commit}

4. Consider the **Termination Protocol 1** for 3PC-1.

1. Participants elect a new coordinator C'
2. C' sends a State-request message to participants
3. Each participant responds to C' about its current state
4. C' terminates the transaction as follows:
 - (a) If there is some TM in COMMIT state, then C' sends “Global-commit” to all participants
 - (b) Else if no TM is in PRECOMMIT state, then C' sends “Global-abort” to all participants
 - (c) Otherwise, C' sends “Prepare-to-commit” to participants in READY state. After receiving “Ready-to-commit” from these participants, C' sends “Global-commit” to all participants

Suppose that we modify the above protocol by changing step 4(c) to the following:

- (4c) Otherwise, C' sends “Global-commit” to all participants. Any participant that receives “Global-commit” will transit to the COMMIT state and commit the transaction.

Explain with a scenario why the modified termination protocol could produce inconsistent transaction outcomes in the absence of communication failure.

Solution: Consider the scenario where the failure of the coordinator has been detected and $\{W, X, Y, Z\}$ is the set of operational participants, where W and X are in PRECOMMIT state and Y and Z are in READY state. Following the modified protocol, assume that W is elected to be the new coordinator. Suppose that after X has received the “Global-commit” and advanced to COMMIT state, both W and X fail, and both Y and Z did not receive the “Global-commit” message. Thus, both Y and Z remain in READY state. Consequently, a new coordinator will be elected among $\{Y, Z\}$ and the new global decision will be to abort, which is inconsistent with the previous commit decision.

5. In 3PC-1, a participant that has recovered from an earlier failure is not permitted to participate in the Termination Protocol 1. Explain with an example how inconsistent transaction outcomes could arise if this restriction is not imposed. Assume that there is no total site failure and no communication failure.

Solution: Consider a transaction execution with coordinator C and four participants P_1 , P_2 , P_3 , and P_4 where all the participants have voted to commit.

Suppose that after P_1 has received “Prepare-to-commit” and advanced to PRECOMMIT state, both C and P_1 fail. The participants P_2 , P_3 , and P_4 did not receive the “Prepare-to-commit” message and remain in the READY state. During the execution of the termination protocol, P_2 is elected to be the new coordinator. Suppose that after P_2 has sent “Global-abort” to P_3 and P_3 has advanced to ABORT state, both P_2 and P_3 fail. If P_1 has now recovered and it is allowed to participate in the next round of coordinator election together with P_4 , the global decision would be to commit which is inconsistent with the earlier abort decision.

6. Describe a scenario using 3PC-1 where the global decision is to abort even though a participant is in the PRECOMMIT state. Assume that there is no total site failure and no communication failure.

Solution: Consider the scenario where all the participants voted to commit during the voting phase. After sending “Prepare-to-commit” to participant P_1 , the coordinator fails. Assume that the remaining participants did not receive the “Prepare-to-commit” message. Thus, except for P_1 which is in PRECOMMIT state, all the other participants are in READY state. Suppose P_1

fails before the start of the new coordinator election. During the execution of the termination protocol, the global decision will be to abort since all the operational participants are in READY state. Upon recovery, P_1 will also abort after finding out the global decision from another participant. Thus, it is possible for the global decision to be abort even if some participant is in the PRECOMMIT state.