Fault Tolerance

Atomic Commitment

Pedro F. Souto (`pfs@fe.up.pt`)

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Atomic Commitment: Informal

Problem How to ensure that a set of operations executed in different processors?

- either are **all** executed (**all committed**)
- or **none** of them is executed (**all aborted**)

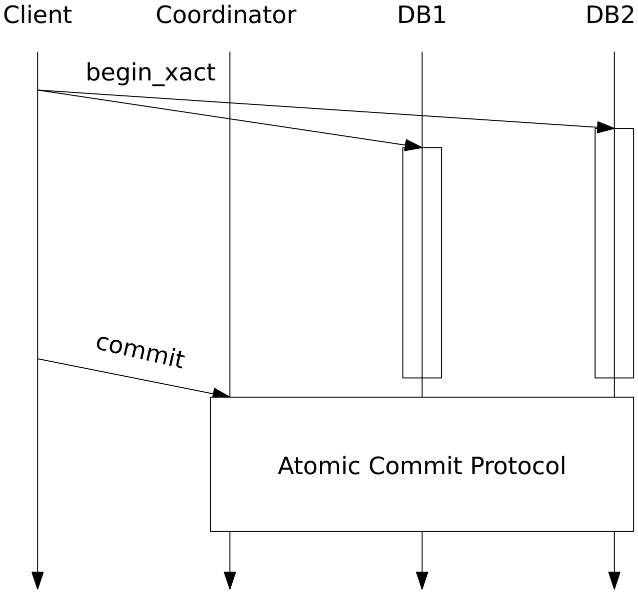
Observation The origin of this problem is distributed databases, i.e. distributed transactions:

- A transaction comprises operations (sub-transactions) in different DBs
- A transaction must be **atomic** (and also CID)

Observation AC is useful:

- Not only when processes may fail
- But also when the operations may not be performed because of some reason other than the failure of the process that execute them
  - E.g., because of a deadlock in one of the sub-transactions

Distributed transactions and Atomic Commit



Transaction's ACID[1] Properties (Reminder)

A **tomicity:** either all operations of a transaction are executed or none of them

C **onsistency:** a transaction transforms a consistent state into another consistent state

I **solation:** the effects of a transaction are as if no other transactions executed concurrently

D **urability:** the effects of a transaction that commits are permanent

[1] Coined by T. Häerder and A. Reuter in 1983

Transaction's Consistency Contract (R. Guerraoui)

System

- Atomicity
- Isolation
- Durability

Programmer

- Consistency (local)

Consistency (global)

Atomic Commitment: Formal

Def. Consider a set of n processes such that:

1. Each process has to decide one of two values: **commit**/**abort**
2. Each process shall vote/propose one of these two values
3. The value decided by each process must satisfy the following assertions:

   AC1 All processes that decide, must decide the same value

   AC2 The decision of a process is final (it cannot be changed)

   AC3 If some process decides **commit**, then all processes must have voted commit

   AC4 If all processes voted **commit** and there are no failures, then all processes must decide commit

   AC5 For any execution containing only failures that the algorithm is designed to tolerate. At any point in this execution, if all existing failures are repaired and no new failures occur for sufficiently long, then all processes eventually reach a decision

Two-Phase Commit: A solution for AC (1/10)

Assumptions Processes may fail by crashing and recover

- Each process has storage whose content survives a crash

Outline The protocol has two kinds of processors:

Coordinator there is only one coordinator process, at any time instant

Participant every process that performs an operation is a participant

- The coordinator may also be a participant, in which case it will have to perform both the coordinator-side and the participant-side of the protocol

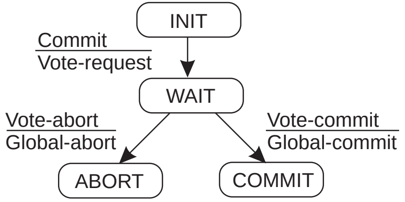
Two-Phase Commit: Basic Protocol (2/10)

Outline The protocol has two phases:

- **Phase 1** Upon request from the application:
  - **Coordinator** sends a VOTE-REQUEST to each participant and waits for their reply
  - **Participant** upon receiving a VOTE-REQUEST each process sends its vote, either VOTE-COMMIT/YES or VOTE-ABORT/NO
- **Phase 2** Once the coordinator determines that is time to decide
  - **Coordinator** decides/sends:
    - **GLOBAL-COMMIT** if it received a VOTE-COMMIT/YES from all participants
    - **GLOBAL-ABORT** otherwise
  - **Participant** decides according to the message received from the coordinator

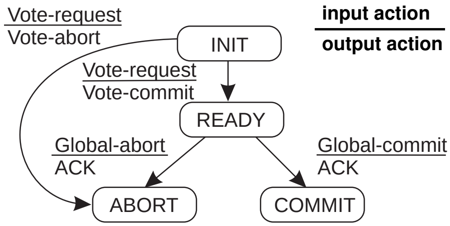
Two-Phase Commit: Simplified State Machine (3/10)

State Machines



(a)

Coordinator

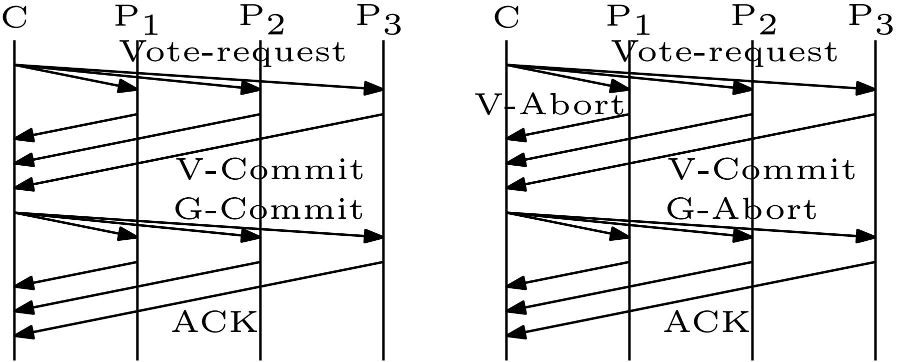


(b)

Participant

Two-Phase Commit: Fault-free Execution (4/10)

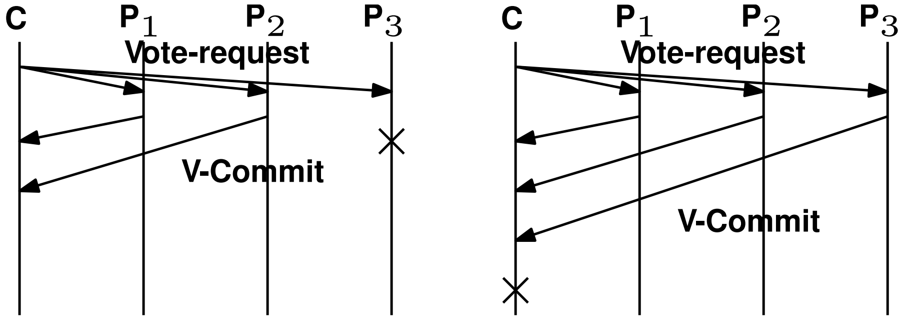
Possible Executions



- In the absence of faults, the protocol is straightforward

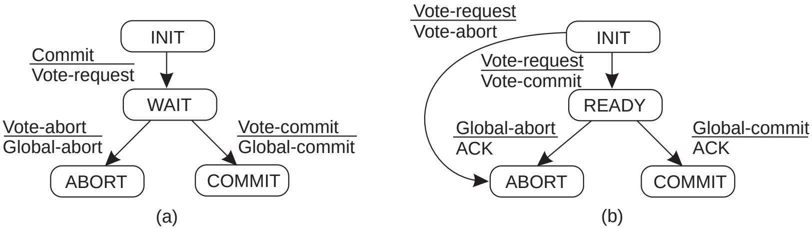
Two-Phase Commit: Faulty Executions (5/10)

Possible Executions with Faults



- We need to specify what to do in the case of failure
  - In practice, we use **timeouts** to detect failure

Two-Phase Commit: Timeouts (6/10)



Timeout Actions Actions taken by a process upon a timeout

- **Coordinator** Waits for messages only in the WAIT state
  - Decides ABORT and sends a GLOBAL-ABORT to participants
- **Participants** Waits for messages both in:
  - **INIT** Decide ABORT and move to corresponding state
  - **READY** Must execute a **termination protocol** to find out the outcome.

Two-Phase Commit: Termination Protocol (7/10)

Participant must communicate with the other participants to find out the outcome

If some participant has voted VOTE-ABORT ...

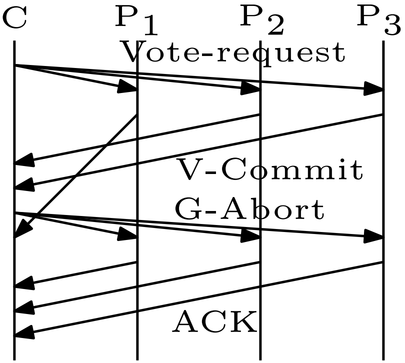
If some participant knows the decision ...

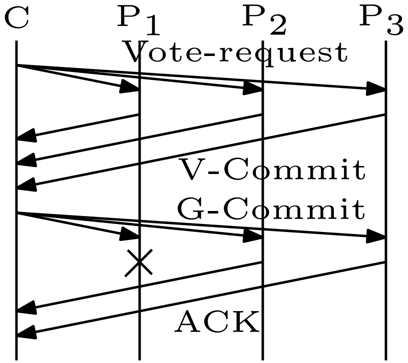
Otherwise

- Process must wait until it learns the coordinator's decision
  - May continue probing both the coordinator and other participants

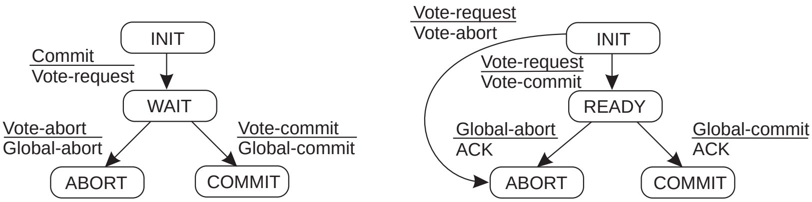
Two-Phase Commit: Execution with Faults (8/10)

Possible Executions with Faults





Two-Phase Commit: Recovery (9/10)



(a) (b)

Recovery Actions Actions taken by a process upon recovery from a crash

- Assumes that each process keeps in stable storage the state of the 2PC protocol
- If process has not decided yet then
  - If crashed while waiting for a message, take the corresponding timeout action
    - Including the execution of a termination protocol, if a participant failed in the READY state
  - Otherwise (coordinator in the INIT state) decide ABORT

Two-Phase Commit: Recovery (10/10)

- To allow recovery, processes must write the state of the protocol as entries to a **log in stable storage**
  - The write of the entry should be performed before or after sending the corresponding messages?
  - In addition to the state of the protocol, the log may be used to store application data
- The 2-phase commit protocol satisfies assertions AC1-AC5, even in the presence:
  - non-byzantine node failures
  - communication faults, including partitions
- The main problem with this protocol is that it may require **participants** to block (wait longer than a communication timeout)
  - This problem can be made less likely by using the three-phase commit protocol

Atomic Commit: Independent Recovery and Blocking

Impossibility of independent recovery there is no AC protocol that always allows local recovery, i.e. without communication with other processes

- If a process is uncertain when it fails, ...

Non-blocking impossibility there is no AC protocol that never blocks in the presence of either:

Communication failures

- If a participant becomes isolated when it is in uncertain state ...

Failures on all other processes

2 Phase-Commit may block even when there is no failure on all sites:

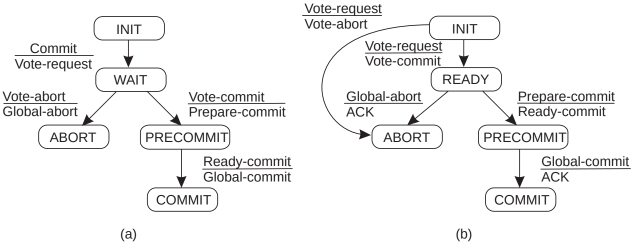
Can we do better?

Assuming:

1. Communication is reliable
2. Process failure can be reliably detected

Three-Phase Commit (1/2)

- Adds a phase between the 2 phases of the 2PC protocol, in which the coordinator reveals its intention to COMMIT



Coordinator　　　　　Participant

- The PRECOMMIT states ensure the **non-blocking** condition:
  - No process can commit while another process is in an uncertain state (INIT, WAIT, READY), i.e. can decide either way

    Note a process in the PRE-COMMIT state is not uncertain:
    - It will decide **commit**, unless the coordinator fails
- It can be shown that this condition is necessary and sufficient to prevent blocking **unless ...**

Three-Phase Commit (2/2)

All processes fail

There is no majority

- If a majority is able to communicate:
  - If a majority of the participants are in the READY state, they can decide ABORT
  - If a majority of the participants are in the PRECOMMIT state, they can decide PRECOMMIT
- Because two majorities must overlap, no different decisions can be made
  - Note that a process in the PRECOMMIT state may still ABORT, but only if the coordinator fails
- If there is no majority (as a result of network partition, e.g.) processes may block

Need appropriate timeout/termination/recovery actions

- Anyway, virtually all systems implement 2PC, not 3PC

What if communication is not reliable?

- I.e., communication failures are not masked by retransmissions?

Stable Storage (1/2)

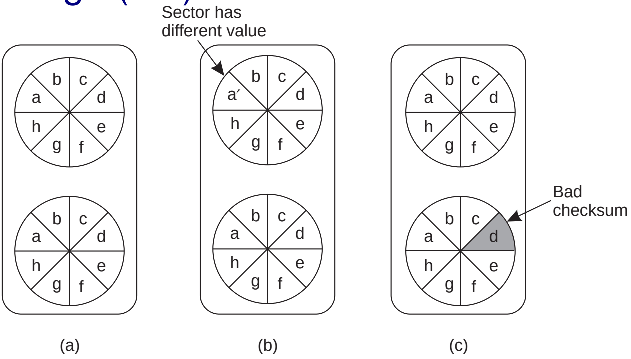
Problem

- Many protocols like 2PC assume that the state of processes, or at least some part of it, survives the failure of the process
- Usually, this means to store the state on disk
- How do you ensure that the data survives disk failures?

Solution: Stable Storage

- Use two identical disks
- Writing a block requires writing first in disk 1 and then in disk 2
- Upon reading a block, try disk 1 first, unless its **checksum** is not valid

Stable Storage (2/2)



Recovery after a crash

- If the checksum of disk 1 is valid, and the two blocks are different, copy block from disk 1 to disk 2
- If the checksum of disk 1 is not valid, use the block on disk 2, if its checksum is valid
- If the checksums of both disks are not valid, then **data has been lost**, i.e. we have a **catastrophic-failure**

Further Reading

- Chapter 8, Tanenbaum and van Steen, *Distributed Systems*, 2nd Ed.
  - Section 8.5: Distributed Commit
  - Paragraph 8.6.1: Stable Storage
- P. Bernstein, V. Hadzilacos and N. Goodman, *Distributed Recovery*, Chp. 7 of *Concurrency Control and Recovery in Database Systems*, Addison-Wesley, 1987