Fault Tolerance - Part II

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Based on slides by Maarten Van Steen

What is the Problem?

Two Generals' Problem

- Two generals need to be agree on time to attack to win.
- They communicate through messengers, who may be killed on their way.

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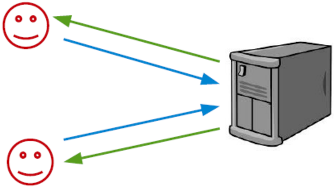

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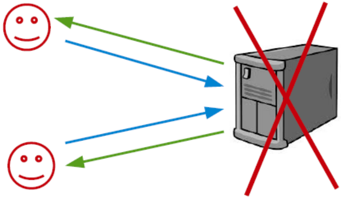

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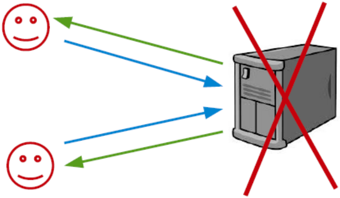
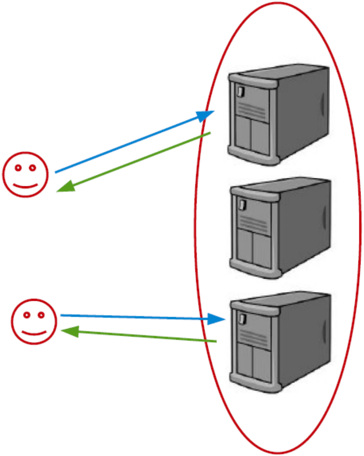


- The solution: replicate the server.

Replicated State Machine Problem (2/2)

- Make the server deterministic (state machine).
- Replicate the server.
- Ensure correct replicas step through the same sequence of state transitions (How?)



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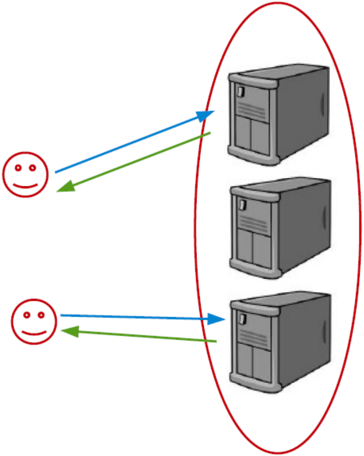

Distributed Commit

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- Concurrent processes and uncertainty of timing, order of events and inputs.
- Failure and recovery of machines/processors, of communication channels.

Distributed Commit

- Given a computation distributed across a process group, how can we ensure that either all processes commit to the final result, or none of them do (atomicity)?

- Possible solutions:
  - Two-Phase Commit (2PC)
  - Three-Phase Commit (3PC)

Two-Phase Commit (2PC)

Intuitive Example (1/3)

- You want to organize outing with 3 friends at 6pm Tuesday.
  - Go out only if all friends can make it.

Intuitive Example (2/3)

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  - Call each of them and ask if can do 6pm on Tuesday (voting phase)
  - If all can do Tuesday, call each friend back to ACK (commit)
  - If one cannot do Tuesday, call other three to cancel (abort)

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- That is exactly how 2PC works.

2PC Players

- Coordinator: the client who initiated the computation.
- Participants: the processes required to commit.

2PC (1/2)

- Phase 1a: the coordinator sends vote-request to participants.

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- Phase 1b: when a participant receives vote-request, it returns either vote-commit or vote-abort to coordinator.
    - If it sends vote-abort, it aborts its local computation.

2PC (2/2)

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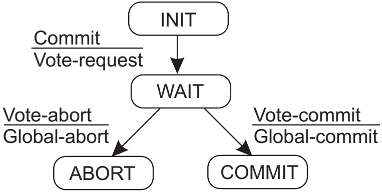
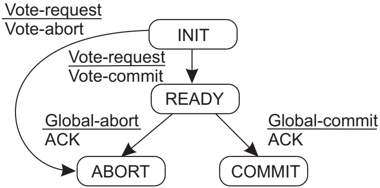
- Phase 2b: each participant waits for global-commit or global-abort and handles accordingly.

2PC States



(a)

Coordinator



(b)

Participant

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- Abort state: remove the workspace of results.
- Commit state: copying workspace to storage.

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- If all participants are in the READY state, the protocol blocks. Apparently, the coordinator is failing. Note: The protocol prescribes that we need the decision from the coordinator.

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- Essence of the problem is that a recovering participant cannot make a local decision: it depends on other (possibly failed) processes.

Three-Phase Commit (3PC)

3PC (1/3)

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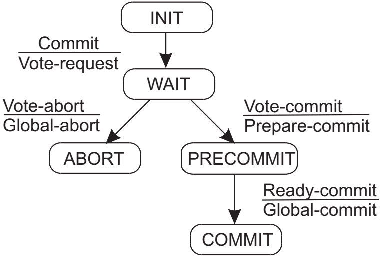
3PC (2/3)

- Phase 2a: the 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 waits for prepare-commit, or waits for global-abort after which it halts.

3PC (3/3)

- Phase 3a: the coordinator waits until all participants have sent ready-commit, and then sends global-commit to all.
- Phase 3b: each participant waits for global-commit.

3PC States



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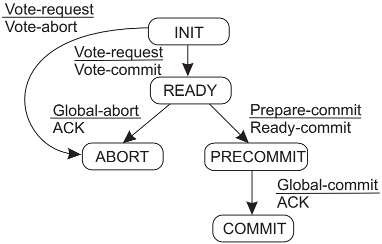

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- If a participant already made it to the PRE-COMMIT state, it can always safely commit (but is not allowed to do so for the sake of failing other processes).

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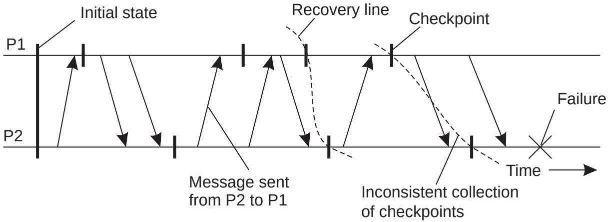
- Recovery in distributed systems is complicated by the fact that processes need to cooperate in identifying a consistent state from where to recover.

Checkpointing

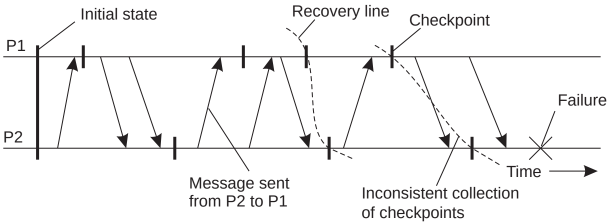
Consistent Recovery State

- Requirement: every message that has been received is also shown to have been sent in the state of the sender.



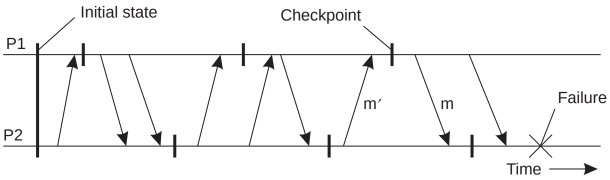
Consistent Recovery State

- Requirement: every message that has been received is also shown to have been sent in the state of the sender.
- Recovery line: assuming processes regularly checkpoint their state, the most recent consistent global checkpoint.



Cascaded rollback

- If checkpointing is done at the wrong instants, the recovery line may lie at system startup time ⇒ cascaded rollback



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- The dependency $INT[i](m) \rightarrow INT[j](n)$ is saved in a stable storage when taking checkpoint $CP[j](n)$.

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- If process P_i rolls back to $CP[i](m-1)$, P_j must roll back to $CP[j](n-1)$.
- How can P_j find out where to roll back to? we can build a dependency graph between checkpoints to discover the recovery line.

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  - When all checkpoints have been confirmed at the coordinator, it latter broadcasts a checkpoint done message to allow all processes to continue.

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- We assume a piecewise deterministic execution model:
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  - Each state interval starts with a nondeterministic event (e.g., message receipt).
  - Execution in a state interval is deterministic.

Message Logging and Consistency

- Example:
    - Process Q has just received and subsequently delivered messages m_1 and m_2.
    - Assume that m_2 is never logged.
    - After delivering m_1 and m_2, Q sends message m_3 to process R.
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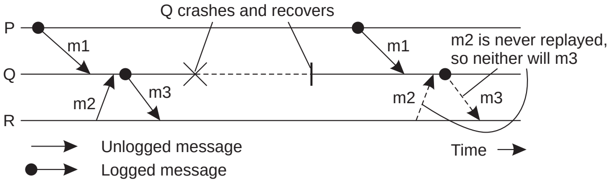

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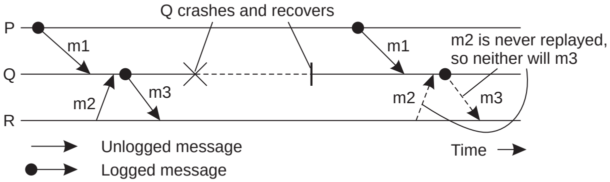
- Orphan process: a process that survives the crash of another process, but whose state is inconsistent with the crashed process after its recovery.



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- $DEP[m]$: the set of processes to which message m has been delivered, as well as any message that causally depends on delivery of m.
- $COPY[m]$: the set of processes that have a copy of $HDR[m]$ in their volatile memory.

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- Goal: no orphans, means that for each message m, $DEP[m] \subseteq COPY[m]$.

Message-Logging Schemes (3/4)

- Pessimistic protocol: for each unstable message m, there is at most one process dependent on m, that is $|DEP[m]| \leq 1$.

- Consequence: an unstable message in a pessimistic protocol must be made stable before sending a next message.

Message-Logging Schemes (4/4)

- Optimistic protocol: for each unstable message m, we ensure that if $COPY[m] \subseteq C$, then eventually also $DEP[m] \subseteq C$, where C denotes a set of processes that have been marked as faulty.

- Consequence: to guarantee that $DEP[m] \subseteq C$, we generally rollback each orphan process Q until $Q \notin DEP[m]$.

Summary

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- Distributed commit: 2PC and 3PC
- Recovery: checkpointing and message logging

Reading

- Chapter 8 of the Distributed Systems: Principles and Paradigms.

Questions?