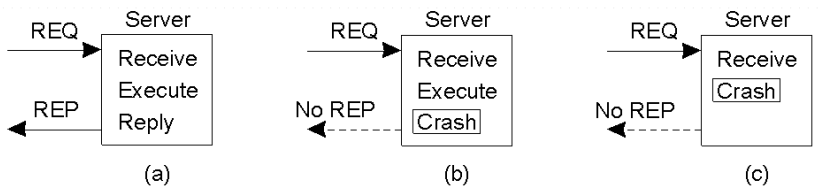
Today: Fault Tolerance

- Reliable communication
- Distributed commit
  - Two phase commit
  - Three phase commit
- Failure recovery
  - Checkpointing
  - Message logging

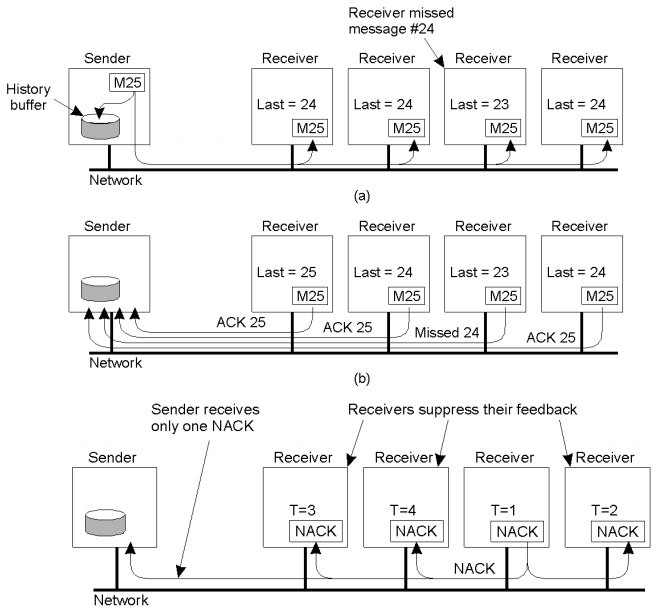
Reliable One-One Communication

- Issues were discussed in Lecture 3
  - Use reliable transport protocols (TCP) or handle at the application layer
- RPC semantics in the presence of failures
- Possibilities
  - Client unable to locate server
  - Lost request messages
  - Server crashes after receiving request
  - Lost reply messages
  - Client crashes after sending request



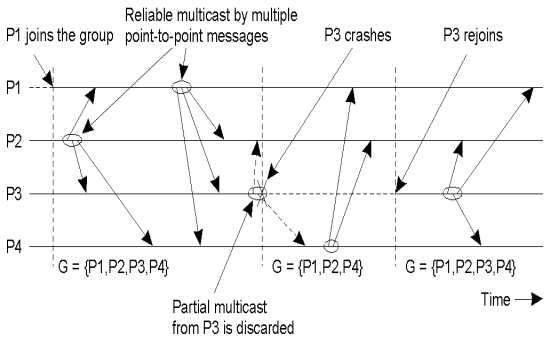
Reliable One-Many Communication

- Reliable multicast
  - Lost messages => need tc retransmit
- Possibilities
  - ACK-based schemes
    - Sender can become bottleneck
  - NACK-based schemes



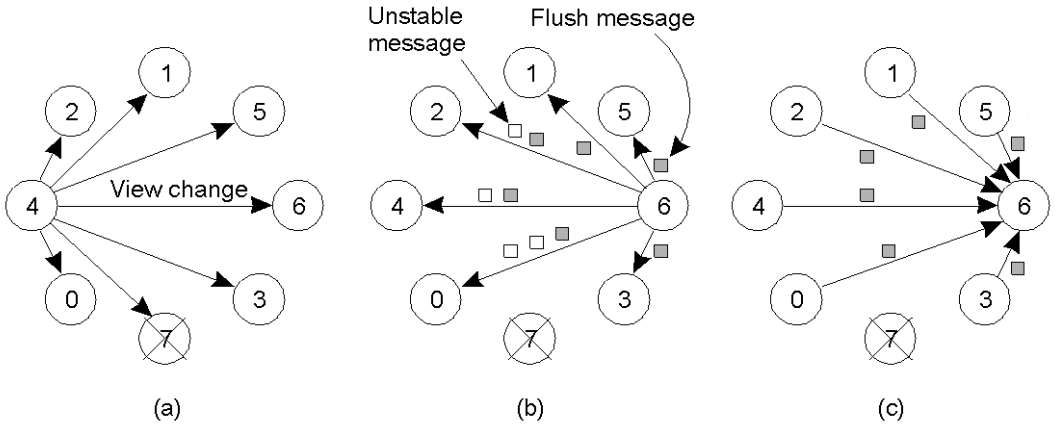
Atomic Multicast

- Atomic multicast: a guarantee that all process received the message or none at all
  - Replicated database example
- Problem: how to handle process crashes?
- Solution: *group view*
  - Each message is uniquely associated with a group of processes
    - View of the process group when message was sent
    - All processes in the group should have the same view (and agree on it)



Virtually Synchronous Multicast

Implementing Virtual Synchrony in Isis



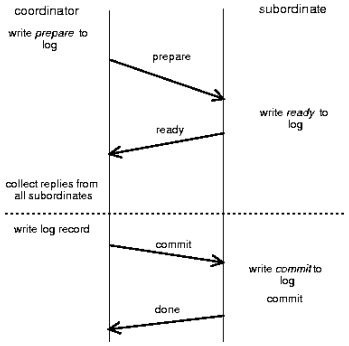
a) Process 4 notices that process 7 has crashed, sends a view change
b) Process 6 sends out all its unstable messages, followed by a flush message
c) Process 6 installs the new view when it has received a flush message from everyone else

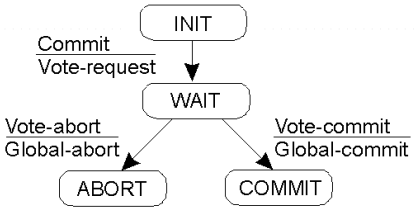
Distributed Commit

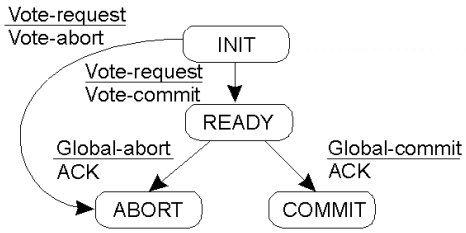
- Atomic multicast example of a more general problem
  - All processes in a group perform an operation or not at all
  - Examples:
    - Reliable multicast: Operation = delivery of a message
    - Distributed transaction: Operation = commit transaction
- Problem of distributed commit
  - All or nothing operations in a group of processes
- Possible approaches
  - Two phase commit (2PC) [Gray 1978]
  - Three phase commit

Two Phase Commit

- Coordinator process coordinates the operation
- Involves two phases
  - Voting phase: processes vote on whether to commit
  - Decision phase: actually commit or abort







Implementing Two-Phase Commit

actions by coordinator:

```
while START _2PC to local log;
multicast VOTE_REQUEST to all participants;
while not all votes have been collected {
   wait for any incoming vote;
   if timeout {
      while GLOBAL_ABORT to local log;
      multicast  GLOBAL_ABORT to all participants;
      exit;
   }
   record vote;
}
if all participants sent VOTE_COMMIT and coordinator votes COMMIT{
   write GLOBAL_COMMIT to local log;
   multicast GLOBAL_COMMIT to all participants;
} else {
   write GLOBAL_ABORT  to local log;
   multicast GLOBAL_ABORT to all participants;
}
```

- Outline of the steps taken by the coordinator in a two phase commit protocol

Implementing 2PC

actions by participant:

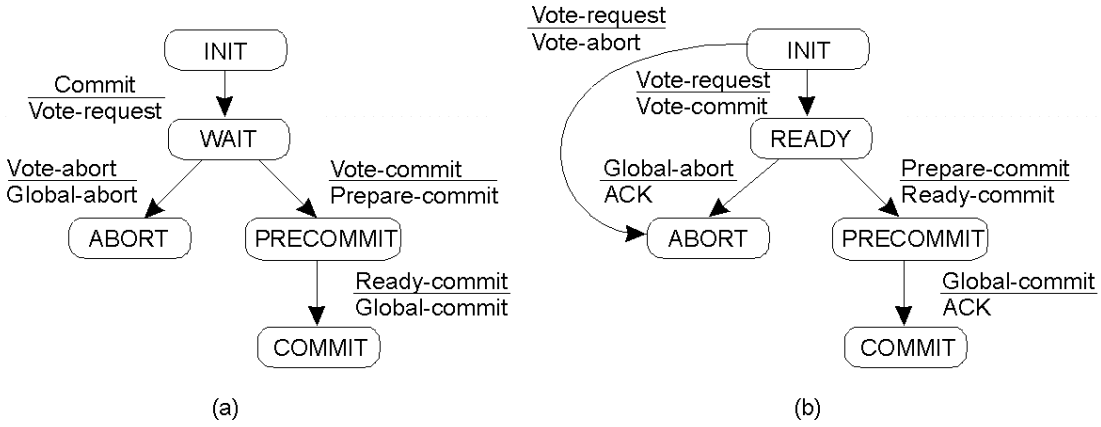
```
write INIT to local log;
wait for VOTE_REQUEST from coordinator;
if timeout {
   write VOTE_ABORT to local log;
   exit;
}
if participant votes COMMIT {
   write VOTE_COMMIT to local log;
   send VOTE_COMMIT to coordinator;
   wait for DECISION from coordinator;
   if timeout {
      multicast DECISION_REQUEST to other
participants;
      wait until DECISION is received; /* remain blocked */
      write DECISION to local log;
   }
   if DECISION == GLOBAL_COMMIT
      write GLOBAL_COMMIT to local log;
   else if DECISION == GLOBAL_ABORT
      write GLOBAL_ABORT to local log;
} else {
   write VOTE_ABORT to local log;
   send  VOTE ABORT to coordinator;
}
```

actions for handling decision requests:

```
/*executed by separate thread */

while true {
  wait until any incoming DECISION_REQUEST
is received; /* remain blocked */
   read most recently recorded STATE from the
local log;
   if STATE == GLOBAL_COMMIT
      send GLOBAL_COMMIT to requesting
            participant;
   else if STATE == INIT or STATE ==
GLOBAL_ABORT
      send GLOBAL_ABORT to requesting
participant;
   else
      skip;  /* participant remains blocked */
```


Three-Phase Commit

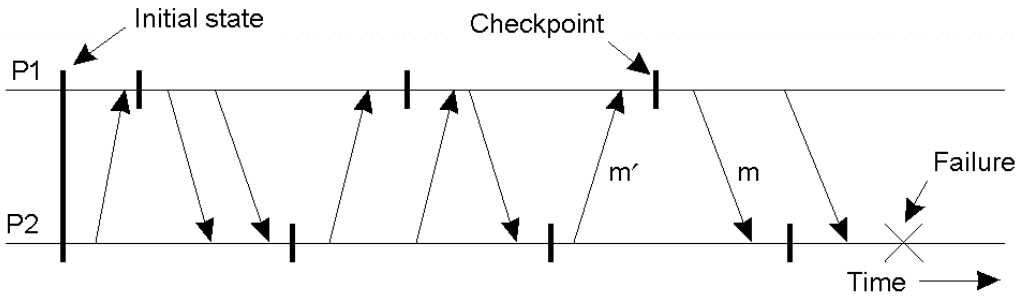


Two phase commit: problem if coordinator crashes (processes block)
Three phase commit: variant of 2PC that avoids blocking

Recovery

- Techniques thus far allow failure handling
- Recovery: operations that must be performed after a failure to recover to a correct state
- Techniques:
  - Checkpointing:
    - Periodically checkpoint state
    - Upon a crash roll back to a previous checkpoint with a *consistent state*

Independent Checkpointing



- Each processes periodically checkpoints independently of other processes
- Upon a failure, work backwards to locate a consistent cut
- Problem: if most recent checkpoints form inconsistenct cut, will need to keep rolling back until a consistent cut is found
- Cascading rollbacks can lead to a domino effect.

Coordinated Checkpointing

- Take a distributed snapshot [discussed in Lec 11]
- Upon a failure, roll back to the latest snapshot
  - All process restart from the latest snapshot

Message Logging

- Checkpointing is expensive
  - All processes restart from previous consistent cut
  - Taking a snapshot is expensive
  - Infrequent snapshots => all computations after previous snapshot will need to be redone [wasteful]
- Combine checkpointing (expensive) with message logging (cheap)
  - Take infrequent checkpoints
  - Log all messages between checkpoints to local stable storage
  - To recover: simply replay messages from previous checkpoint
    - Avoids recomputations from previous checkpoint