Today: Fault Tolerance

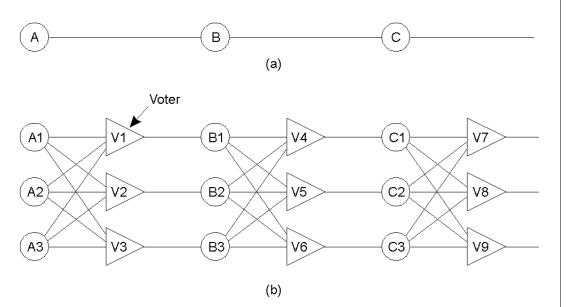
- Agreement in presence of faults
 - Two army problem
 - Byzantine generals problem
- Reliable communication
- Distributed commit
 - Two phase commit
 - Three phase commit
- Failure recovery
 - Checkpointing
 - Message logging



CS677: Distributed OS

Lecture 17, page 1

Failure Masking by Redundancy



Triple modular redundancy.



CS677: Distributed OS

Agreement in Faulty Systems

- How should processes agree on results of a computation?
- *K-fault tolerant*: system can survive k faults and yet function
- Assume processes fail silently
 - Need (k+1) redundancy to tolerant k faults
- Byzantine failures: processes run even if sick
 - Produce erroneous, random or malicious replies
 - Byzantine failures are most difficult to deal with
 - Need? Redundancy to handle Byzantine faults



CS677: Distributed OS

Lecture 17, page 3

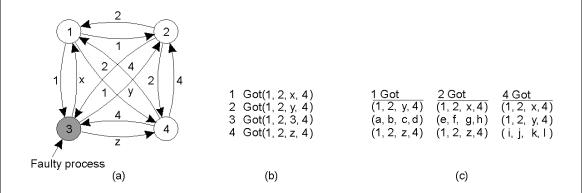
Byzantine Faults

- Simplified scenario: two perfect processes with unreliable channel
 - Need to reach agreement on a 1 bit message
- Two army problem: Two armies waiting to attack
 - Each army coordinates with a messenger
 - Messenger can be captured by the hostile army
 - Can generals reach agreement?
 - Property: Two perfect process can never reach agreement in presence of unreliable channel
- Byzantine generals problem: Can N generals reach agreement with a perfect channel?
 - M generals out of N may be traitors



CS677: Distributed OS

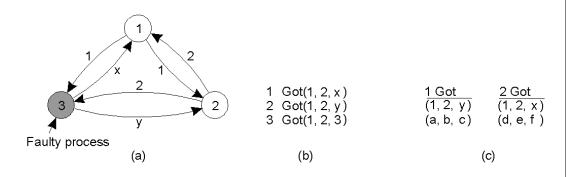
Byzantine Generals Problem



- Recursive algorithm by Lamport
- The Byzantine generals problem for 3 loyal generals and 1 traitor.
- a) The generals announce their troop strengths (in units of 1 kilosoldiers).
- b) The vectors that each general assembles based on (a)
- c) The vectors that each general receives in step 3.

Lecture 17, page 5

Byzantine Generals Problem Example



- The same as in previous slide, except now with 2 loyal generals and one traitor.
- Property: With m faulty processes, agreement is possible only if 2m+1 processes function correctly out of 3m+1 total processes. [Lamport 82]
 - Need more than two-thirds processes to function correctly

Byzantine Fault Tolerance

- Detecting a faulty process is easier
 - 2k+1 to detect k faults
- Reaching agreement is harder
 - Need 3k+1 processes (2/3rd majority needed to eliminate the faulty processes)
- Implications on real systems:
 - How many replicas?
 - Separating agreement from execution provides savings



CS677: Distributed OS

Lecture 17, page 7

Reaching Agreement

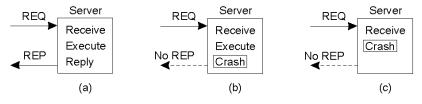
- If message delivery is unbounded,
 - No agreeement can be reached even if one process fails
 - Slow process indistinguishable from a faulty one
- BAR Fault Tolerance
 - Until now: nodes are byzantine or collaborative
 - New model: Byzantine, Altruistic and Rational
 - Rational nodes: report timeouts etc



CS677: Distributed OS

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



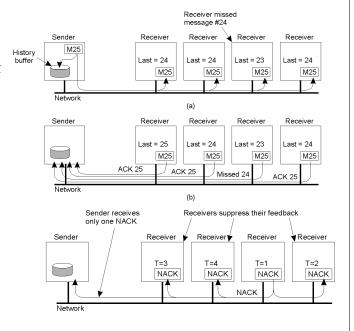


CS677: Distributed OS

Lecture 17, page 9

Reliable One-Many Communication

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

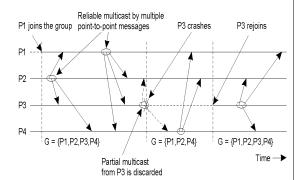




CS677: Distributed OS

Atomic Multicast

- •Atomic multicast: a guarantee that all process received the message or none at all
 - Replicated database example
 - Need to detect which updates have been missed by a faulty process
- •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)



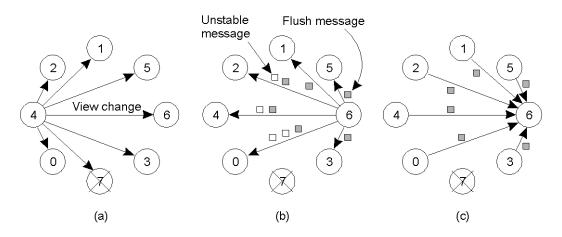
Virtually Synchronous Multicast



CS677: Distributed OS

Lecture 17, page 11

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



CS677: Distributed OS

Implementing Virtual Synchrony

Multicast	Basic Message Ordering	Total-Ordered Delivery?
Reliable multicast	None	No
FIFO multicast	FIFO-ordered delivery	No
Causal multicast	Causal-ordered delivery	No
Atomic multicast	None	Yes
FIFO atomic multicast	FIFO-ordered delivery	Yes
Causal atomic multicast	Causal-ordered delivery	Yes



Lecture 17, page 13

Distributed Commit

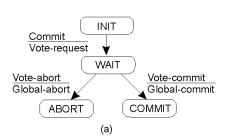
- Atomic multicast example of a more general problem
 - All processes in a group perform an operation or not at all
 - Examples:
 - Reliable multicast: Operation = delivery of a message
 - Distributed transaction: Operation = commit transaction
- Problem of distributed commit
 - All or nothing operations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

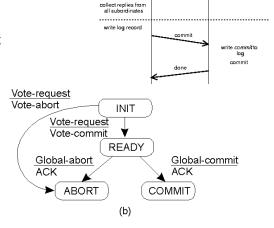


CS677: Distributed OS

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





write *prepare* to log



CS677: Distributed OS

Lecture 17, page 15

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



CS677: Distributed OS

Implementing 2PC

actions by participant:

```
write INIT to local log;
                                                   actions for handling decision requests: /
wait for VOTE_REQUEST from coordinator;
                                                   *executed by separate thread */
if timeout {
  write VOTE_ABORT to local log;
                                                   while true {
  exit:
                                                   wait until any incoming DECISION_REQUEST
if participant votes COMMIT {
                                                    is received; /* remain blocked */
  write VOTE_COMMIT to local log;
                                                      read most recently recorded STATE from the
  send VOTE COMMIT to coordinator;
                                                   local log:
  wait for DECISION from coordinator;
  if timeout {
                                                      if STATE == GLOBAL COMMIT
    multicast DECISION REQUEST to other participants:
                                                        send GLOBAL COMMIT to requesting
                                                             participant;
    wait until DECISION is received; /* remain blocked */
    write DECISION to local log;
                                                     else if STATE == INIT or STATE ==
                                                             GLOBAL ABORT
  if DECISION == GLOBAL_COMMIT
                                                        send GLOBAL ABORT to requesting
    write GLOBAL_COMMIT to local log;
                                                   participant;
  else if DECISION == GLOBAL_ABORT
                                                     else
    write GLOBAL_ABORT to local log;
                                                        skip; /* participant remains blocked */
  write VOTE ABORT to local log;
  send VOTE ABORT to coordinator;
```



CS677: Distributed OS

Lecture 17, page 17

Recovering from a Crash

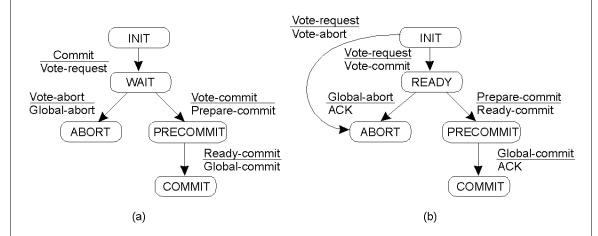
- If INIT: abort locally and inform coordinator
- If Ready, contact another process Q and examine Q's state

State of Q	Action by P	
COMMIT	Make transition to COMMIT	
ABORT	Make transition to ABORT	
INIT	Make transition to ABORT	
READY	Contact another participant	



CS677: Distributed OS

Three-Phase Commit



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



CS677: Distributed OS

Lecture 17, page 19

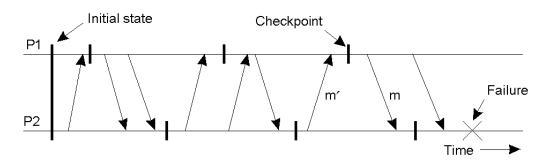
Recovery

- 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



CS677: Distributed OS

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.



CS677: Distributed OS

Lecture 17, page 21

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



CS677: Distributed OS

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



CS677: Distributed OS