CSE 515 — Winter 2004

Fault tolerance in Distributed Systems

Class 10

Distributed Fault-tolerance: How to get it

1. Failure Detection
2. Membership
3. Communication
4. Replication management
5. Resilience
6. Recovery

Membership

- A Process Group: a set of participants cooperating towards some common goal
  - Membership of the group changes over time as participants fail and recover
  - *membership service* keeps track of current membership, and informs members of the current
  - *group view*: the subset of the members that is available.
- Membership can also change deliberately
  - response to environmental or service requirements

What is the "correct" Group View?

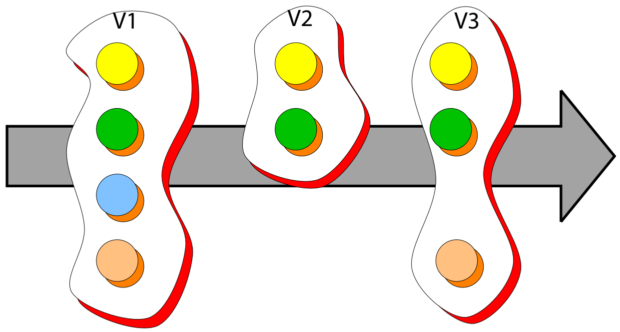
- Members' views must necessarily lag reality
  - What happens if a participant repeatedly leaves and rejoins the group?
- Working definition of correctness:
  - if membership doesn't change, and links don't fail, then all members eventually see the same view
- Membership service should be
  - consistent
  - accurate

Membership Service

- What happens if failure detection is:
  - inaccurate?
  - incomplete?
- Notification of changes in membership
  - should arrive everywhere in the same order
  - should be synchronized with respect to the other traffic seen by the group.

Linear Membership Service

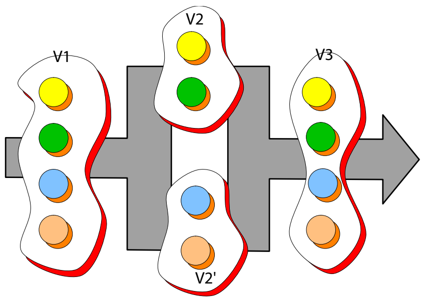
- Views are totally ordered
  - system moves from one view to another with every participant in agreement as to the order



- What happens when a partition occurs?
  1. allow participants in the primary partition to proceed, while others are blocked. They can proceed only when the partition is healed.
  2. Force the non-primary participants to crash. They can be recovered and join the system later
- In both cases, the service is degraded.

Partial Membership Service

- Keep delivering (inconsistent) views in both partitions.
  - When partition is healed, state is reconciled.
- No total order on views.
  - Strong partial order: concurrent views don't intersect



Communication

Reliable delivery in the presence of faults in the channel:

- Omission, timing and value faults

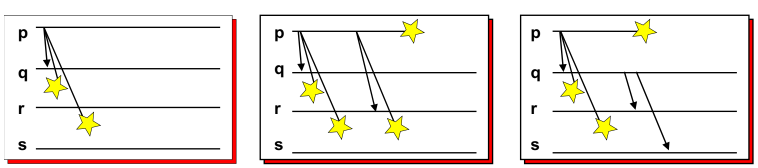
Reliable Delivery

- Mask the fault, by using multiple networks (spatial redundancy)
- Mask the fault, by send multiple copies of a message (temporal redundancy)
  - duplicates discarded at recipient
- Detect and recover (ack and retransmit)
  - acks may be +ve or −ve
- *When* should one mask rather than detect & recover?

Sender Failures in Multicast

- Software multicast: sender might send to some recipients, and then fail.
- Hardware multicast:?

Levels of reliability:



(a) Unreliable (b) Best Effort (c) Reliable

Implementing Reliable Multicast

Error Masking and Error Recover

- Masking: all participants re-multicast every message they receive
- Recovery: save messages, and retransmit if the sender is seen to have failed
  - a *stable* message is one that has been received by all recipient
  - stability tracking protocol: when a msg is stable everywhere, it can be deleted from the stash
- All dependent on failure detection

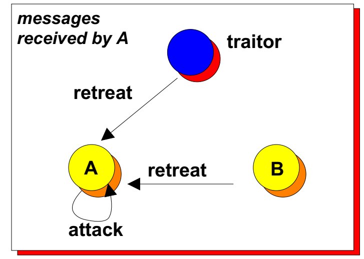
What about Assertion Faults?

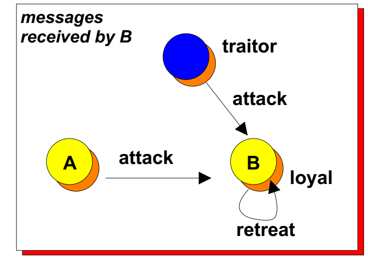
1. Convert assertion faults into omission faults by using CRCs, signatures, etc.
   – deals with faults in the channel but not in the sender.
2. Achieve consensus amongst the multiple recipients of a multicast message.

Byzantine Agreement

(Why is this in the section on communication?)

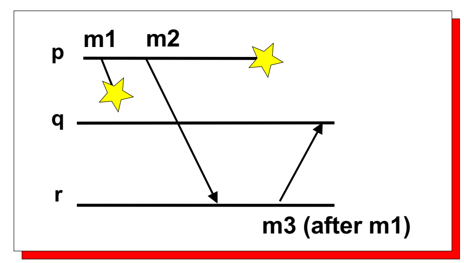
- In the Byzantine Generals problem, some of the participants may be traitors (fail)





- Agreement requires 3*f* + 1 participants to tolerate *f* Byzantine faults
  – even if the channel is perfect (no messenger is captured)
  – tolerating *f* faults requires *f*+1 rounds of messages

Causal Order despite Communication Failure



- m3 can never be delivered at q
- m2 should never become deliverable
  – not enough copies of m1 in the system

Totally-Ordered Multicast

- Securing total order is equivalent to securing consensus
  - particpants have to agree on the delivery order!

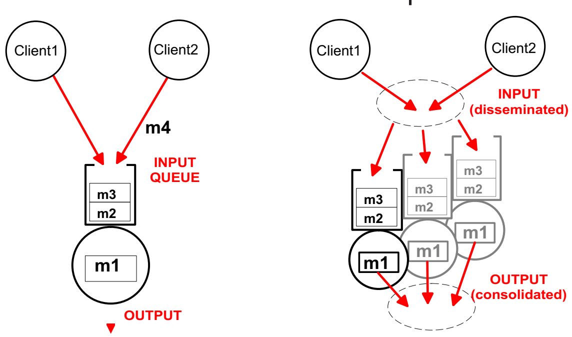
Replication Management

Replication is spatial redundancy

- Assume:
  - network does not partition
  - fail-stop: process failures are all crashes
  - all processes are *deterministic* state machines

Active replication

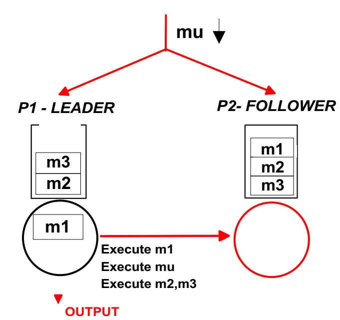
- use atomic multicast to distribute system events (atomic = reliable + totally-ordered)
- run the same state machine in *n* places



(a) *(b)*

Semi-Active Replication

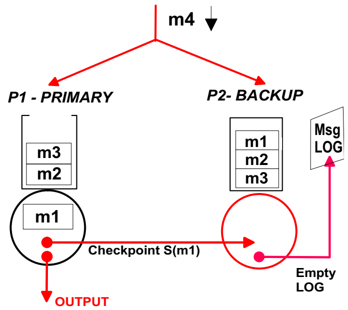
- What if the programs are non-deterministic?
- Use leader-follower architecture:
  - *leader* makes all non-deterministic choices, and disseminated the results to the *followers*.
  - not necessary to use atomic multicast, since execution order can be disseminated too; reliable multicast will do



Other Options

Passive Replication

- replicas log commands, but don't execute them
  - what if processes are non-deterministic …



Lazy Replication

- Ladin's gossip algorithm
- Causal order

What about Partitions?

Weighted Voting

- Any set of participants with a majority of the votes can proceed
  - w = write quorum, r = read quorum, n = nr of *votes*
  - require $2w > n$ and $r + w > n$
- Did you spot the deliberate error?
  - $n = 7$, $r = w = 4$
  - 4 nodes …

Coteries

- A set *Q* of sets, such that each *quorum* in *Q* overlaps with every other *quorum*
  - Q = {{a, b}, {b, c}, {a, c}} is a coterie of {a, b, c, d}
  - Weighted voting majorities are a special case

Resilience

So: we have value redundancy

- What do we do with the multiple (possibly conflicting) values?
- Consumers should reach agreement!
- Sometimes, the inputs are not *exactly* the same:
  - clock synchronization
  - readings from replicated thermometers

Recovery

After and un-masked, detected failure!

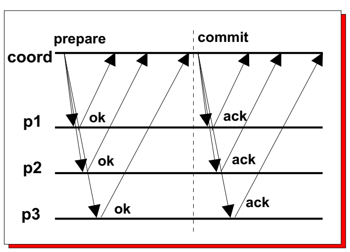
- Recover state from *stable storage*
  - not necessarily disks
- Checkpointing
  - Coordinated at all participants (like consistent cut protocol)
  - Uncoordinated (may cause multiple rollbacks: the *domino effect*)

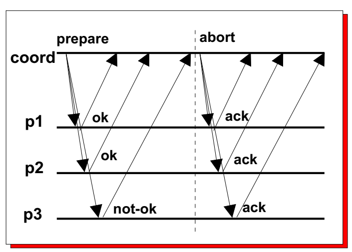
Logging

- Conceptually similar to checkpointing
  - replaying the log requires that processes are deterministic
  - logging may be pessimistic or optimistic
    - optimistic logging might require roll-back
  - If system is non-deterministic, all non-deterministic choices must be logged too.

Atomic Commitment

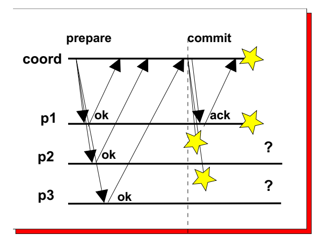
- 2PC is the most common protocol





- *If* a transaction comits, its effects are durable.

- 2PC can block



  - coordinator can fail between *prepare* and *commit/abort*
  - other participants are blocked waiting for decision.
- 3PC is non blocking so long as a majority of the procecsses are correct.

State Transfers

A failed replica must be recovered and re-integrated into the system

- Normally application dependent, since we wish to minimize the network traffic
- The state to be transferred is a moving taget!
  - We must ensure that state is transferred faster than it is changed

- Totally ordered broadcast can be used to mark the instant at which a replica rejoins