Distributed Systems

08. State Machine Replication & Virtual Synchrony

Paul Krzyzanowski

Rutgers University

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Virtual Synchrony – State Machine Replication

State machine replication

- We want high scalability and high availability
  - Achieve via redundancy
- High availability means replicated functioning components will take place of ones that stop working
  - Active-passive: replicated components are standing by
  - Active-active: replicated components are working
- Model system as a sequence of states
  - Input to a specific state produces deterministic output and a transition to a new state
    - "State": replicated data or replicated computing
  - To ensure correct execution & high availability
    - Each process must see & process the same inputs in the same sequence
    - Obtain consensus at each state transition

State machine replication

- Replicas = group of machines = **process group**
  - Load balancing (queries can go to any replica)
  - Fault tolerance (OK if some dies; they all do the same thing)
- Important for replicas to remain consistent
  - Need to receive the same messages [usually] in the same order
- What if one of the replicas dies?
  - Then it does not get updates
  - When it comes up, it will be in a state prior to the updates
    - *Not good – getting new updates will put it in an inconsistent state*

Faults

- Faults may be
  - Fail-silent (fail-stop)
  - Byzantine (corrupted data)
- synchronous system vs. asynchronous system
  - Synchronous = system responds to a message in a bounded time
  - E.g., IP packet versus serial port transmission
  - We assume we have an asynchronous system

Agreement in faulty systems

Two army problem

- Good processors
- Asynchronous & unreliable communication lines
- Coordinated attack
- Infinite acknowledgement problem

Agreement in faulty systems

- It is impossible to achieve consensus with asynchronous faulty processes
  - There is no way to check whether a process failed or is alive but not communicating (or communicating quickly enough)
- We have to live with this
- We cannot reliably detect a failed process
- *But* we can propagate our knowledge that we think it failed
  - *Take it out of the group*

Group View

- Set of processes currently in the group
- A multicast message is associated with a *group view*
- Every process in the group should have the same view
- View change
  - When a process joins or leaves the group, the group view changes
  - View change
    - Multicast message announcing the joining or leaving of a process

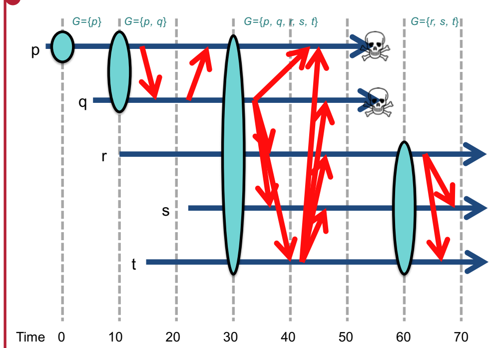
Virtual Synchrony

- What if a message is being multicast during a view change?
  - Two multicast messages in transit at the same time:
    - view change (*vc*)
    - message (*m*)

recall the distinction between **receiving** a message and **delivering** it to the application

- Need to guarantee
  - *m* is delivered to all processes in G before any process is delivered *vc*
  - OR *m* is not delivered to any process in G
- Reliable multicasts with this property are virtually synchronous
  - All multicasts must take place between view changes
  - A view change is a barrier

View Changes & Virtual Synchrony



Virtual Synchrony: implementation example

- Isis: fault-tolerant distributed system offering virtual synchrony
  - Achieves high update & membership event rates
  - Hundreds of thousands of events/second on commodity hardware as of 2009
- Virtual synchrony
  - Provides distributed consistency
  - Applications can create & join groups & send multicasts
  - Applications will see the same events in an equivalent order
  - Group members can update group state in a consistent, fault-tolerant manner
- Who uses it?
  - Isis: Microsoft's scalable cluster service, IBM's DCS system, CORBA
  - Similar models: Apache Zookeeper (configuration, synchronization, and naming service)

Implementation: Goals

- Message transmission is asynchronous
  - Machines may receive messages in different order
- Virtual synchrony
  - Preserve the illusion that events happen in the same order
    - Hold back & deliver to the application in a consistent order.
  - Uses TCP → reliable point-to-point message delivery
  - Multicasting is implemented by sending a message to each group member
  - No guarantee that ALL group members receive the message
    - The sender may fail before transmission ends

Implementation: Group Management

- Group Membership Service (GMS)
  - Failure detection service
  - If a process *p* reports a process *q* as faulty
    - GMS reports this to every process with a connection to q
    - q is taken out of the process group and would need to re-join
  - Imposes a consistent picture on membership

Implementation: State Transfer

- When a new member joins a group
  - It will need to import the current state of the group
  - **State transfer**:
    - Contact an existing member to request a state transfer
    - Initialize the replica to that checkpoint state
    - A state transfer is treated as an instantaneous event
- Problem
  - Guarantee that all messages sent to view G_i are delivered to all non-faulty processes in G_i before the next view change (G_{i+1})

Implementation: Receiving all messages

- Make sure each process in G_i has received all messages that were sent to G_i
  - A sender may have failed
    → there may be processes that will not receive a message *m*
  - These processes should get *m* from somewhere else
- Let every process hold *m* until it knows that *all* members of G_i received it
  - Once all members received it, m is **stable**
  - Only stable messages can get delivered to applications
  - Select an arbitrary process in G_i and request it to send *m* to all other processes
    - Delivery within the group is reliable, so this ensures that the message is stable

View change: $G_i \rightarrow G_{i+1}$

- Some process *P* receives a *view change* message
  - It detected a failure or received a request from a process wanting to join or leave the group
  - *P* forwards a copy of any unstable messages to every process in G_{i+1}
  - It then marks the message as stable
  - *P* indicates it no longer has any unstable messages
  - It is ready to transition to view G_{i+1} as soon as other processes are ready
  - *P* multicasts a **flush** message for G_{i+1}
  - Waits to receive a **flush** message for G_{i+1} from every other process
  - Then switches to the new view G_{i+1}

View change: $G_i \rightarrow G_{i+1}$

- Some process *Q*, still operating in view G_i, receives a message *m*
  - If it has already received message *m*, it discards it as a duplicate
  - Delivers *m* (using message ordering constraints as necessary)
- When *Q* receives a view change message, it will
  - Forward any of its unstable messages to the group
  - Multicast a **flush** message for G_{i+1}
  - Waits to receive a *flush* message for G_{i+1} from every other process
  - Then switches to the new view G_{i+1}

View change summary

- Every process will
  - Send any unstable messages to all group members
  - Process received messages that are not duplicates
  - Send a flush message to the group
  - Receive a flush message from the entire group

The end