Lecture 10 – Process Groups, Causal Ordering

1. Questions from reviews
2. Overall model
    a. Small scale distributed system: air traffic control
        i. Radars sense where planes are, send out updates
        ii. Controllers make requests, send out their commands
        iii. Planes ask for commands
        iv. Note that radars + planes are “outside” – the system is really the controllers
    b. QUESTION: What are goals?
        i. Goal is fault tolerant computing
            1. Use replication for reliability
        ii. Goal is simple programming
            1. Programmer relies on library/service to handle things
        iii. Non goal: byzantine fault tolerance
            1. Rely on failure detector to mark failed nodes as dead
    c. USE:
        i. Used in DCE corba for dist object-oriented systems
        ii. Used in Microsoft cluster service for coordination
        iii. Used by stock exchange, French air-traffic control
        iv. Ultimately lost in the market to much larger scheme for database-oriented solutions
3. History of model
    a. Grew out of byzantine-fault tolerance work: the idea of replicated state machines, atomic delivery of messages
    b. Want to adapt to a practical setting – not just replicated, deterministic state machine, but any applications
    c. Want to make higher performance than atomic/total ordering
4. WHAT does the model include?
    a. Failure mode: halt (fail stop)
        i. Processes fail by halting
        ii. A failure detector service detects failures, sends out notification messages
    b. Process groups
        i. Names for groups (e.g. identifiers)
        ii. Memberships change over time
            1. Unlike byzantine generals…
    c. Reliable Multicast (called broadcast) to a group
        i. Can achieve “atomic broadcast” meaning all receive or none do
            1. Just like byzantine generals

        ii. Relaxed a bit: if one node receives a message then fails before sending anything else, order can be changed at other nodes
    d. Ordering model: virtual synchrony
        i. Ideal situation: clocks advance in lockstep on all nodes. Reality is clock skew, message delay, processing delays
            1. Everything has a total global order
        ii. Implement *virtual synchrony*, which has the same programming model as synchrony

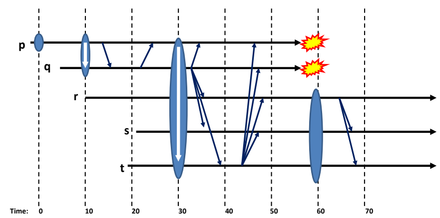


Fig. 6.1 Synchronous run.

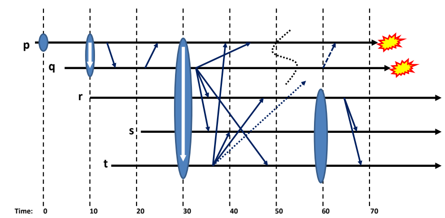


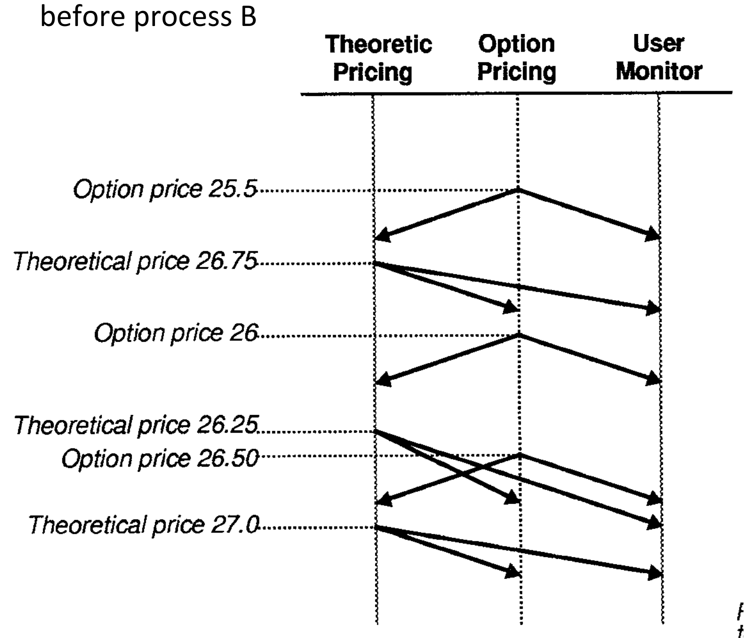
Fig. 6.2 Virtually synchronous run.

        iii.
            1. Difference: concurrent messages can overlap
5. Process groups
    a. QUESTION: what is the point?
        i. Naming: keep track of who is interested in an object
        ii. Membership: handle views of who is supposed to receive messages
        iii. Failure reporting: other members of a group learn of failed members
    b. USES:
        i. Diffusion groups: propagate information from leader to followers
        ii. Client server groups: clients talk to a group of servers
        iii.
    c. QUESTION: How are process groups maintained?
        i. GBCAST (Group broadcast) communicates membership changes
        ii. QUESTION: How should these be ordered with respect to normal application communication?
            1. A: want total order (like a distributed snapshot): app messages are either before membership change or afterwards
        iii. Basic model: failure detector service runs at every node
            1. When app detects possible failure (e.g. missed message), notifies failure detector
            2. Failure detector can then use GBCAST to make failure visible to all
    d. Protocol for updating view:
        i. Send "view extension message"
            1. On receipt, if no prior concurrent view extension, than ACK
            2. Else NACK, providing nodes from other view extension
        ii. On receipt of ACKs
            1. Send out commit making new view real
        iii. On receipt of a NACK, update extension and retry from beginning
        iv. If there are partial views from a failed extension

            1. If new primary has them, include failure of prior manager, includes in view (to prevent NACK)
            2. If has committed prior extension, some nodes may not have committed – includes in next view.
    e. QUESTION: How use process groups
        i. Keep track of coordination information (e.g. GFS masters in Google File System)
        ii. Different terminals used by different air traffic controllers
6. Multicast Primitives
    a. Key idea: virtual synchrony
        i. In real synchrony, can only send one message at a time (to get total order everywhere)
        ii. In virtual synchrony, can have concurrent independent operation, but ensure delivery is in correct order at the end
            1. Buffer messages at recipient until can be delivered in right order
        iii. SO: separate reception (message arrives) from delivery (give to application)
        iv.
    b. GBCAST: totally ordered with respect to other communication
        i. Messages from a failed process must be **delivered** before GBCAST of its failure
        ii. GBCASTS and other broadcasts with overlapping destinations must have same order
        iii. NOTE: this ordering requirement (ordered with everything) could be very expensive!
        iv. IMPLEMENTATION: deferred
    c. ABCAST: atomic broadcast
        i. Specify a destination label (scope of ordering) so you can have independent atomic broadcasts going on
            1. Want most flexibility possible in ordering
        ii. All ABCAST delivered to all destinations or none (Atomic)
            1. If delivered to one node & sender fails, receiver can resend
        iii. All ABCAST to same label are received in same order at all destinations
        iv. Prototype implementation: two phase delivery (like Lamport)
            1. Send msg to all receipiend
            2. Recipients mark **undelivered**, send back a priority (e.g. like a lamprt clock)
            3. Sender collects all acks, picks max priority and sends it back
            4. Receiver resorts queue, marks message **deliverable** and delivers message at head of queue
            5. NOTE: single queue undelivered and deliverable messages
            6. SHOW EXAMPLE
            7. NOTE: can have a separately delivery queue for each label
        v. Reliability:

1. If a node has an undelivered message and detects failure of sender, will resend as the new leader (guarantees eventual delivery if any recipient received it).

d. CBCAST: causal broadcast
    i. Specify set of destinations. (process group)
    ii. Ordering:
        1. Ensures happens-before delivery: if message sent by A to B and C, then B sends a message to C, then C receives message from A before message from B
        2. Uses "clabel" to express causality, like Vector or Lamport clocks
        3. QUESTION: Why?
            a. Suppose you have a file
                i. Process A multicasts "create file F"
                ii. Process B multicasts "append to file F"
            b. Causality ensures that all members get process A message before process B



        4.
        5. Notice: does not ensure total order (P1 sees broadcast in 4 and 5 an order different from P2 and P3)
        6. Example: doesn't provide total order,
        7. VISION: FIFO channels in point-to-point are helpful (e.g. tcp/ip)
            a. Ensure things come in the right order
                i. Buffer things that arrive out of order, resend if missed
            b. Want same property for multicast, but want most useful relaxed order (for performance)
    iii. Atomic delivery: to all or none of destination
    iv. Implementation (prototype – not real one used)

1. Have a queue of messages received, messages to be sent (in order) - BUF
2. Messages have full list of recipients on them
3. To send a message:
    a. Add to BUF, remove self (p) from destinations, deliver locally
4. When sending a message B,
    a. Create a **transfer packet** of all messages B' that happen before B and have remote destinations, sorted causally
    b. Send transfer packet to destination
    c. Send message B to destination
5. On receiving packet with messages B' and B at process q
    a. If any message B already delivered, than drop (as duplicate)
    b. If q is a destination (not just forwarding), then remove q from remaining destinations and deliver in order.
6. BASIC idea: when send a message that depends on a prior one to the same destination, include it.

v. REAL IMPLEMENTATION:
1. Include vector clock on all broadcasts to a process group
2. Delay delivery if message arrived out of order:
    a. Vector[sender] != vector[previous message from sender] +1
    b. Vector [anyone else] != vector[anyone else in last message]

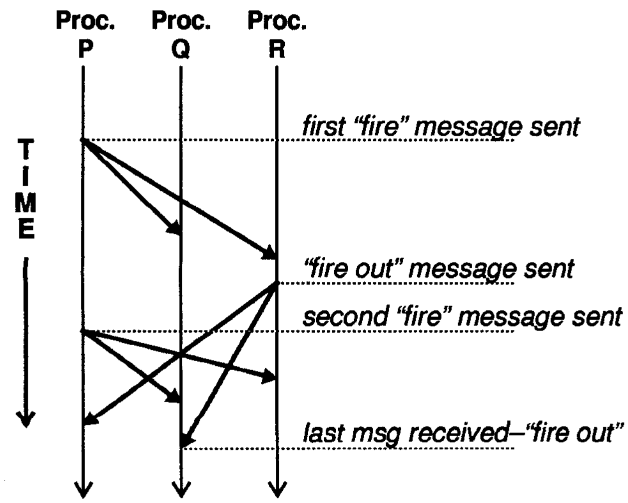
e. GBCAST implementation:
   i. Requirement: must be totally ordered with respect to failures, ABCAST, GBCAST
   ii. Failure:
      1. For failure of node F, Send message to everyone, ask them complete deliver of messages from F
         a. For CBCAST: Schedule delivery of messages from f
         b. For ABCAST: wait until all message from F become deliverable
   iii. Order W.R.T. ABCAST
      1. Treat it like an ABCAST across all labels – deliver when becomes the next message for all labels.
   iv. Order W.R.T CBCAST
      1. Treat like snapshot algorithm: make a queue of messages, and order them as before or after the GBCAST
         a. GBCAST sender P ask all recipients for a list of current pending messages
            i. Each recipient creates wait queue for messages instead of delivering them

            - ii. Send all messages in BUF to remaining destinations – so sent before failure
            - iii. Send a list IDLIST of all messages that have been delivered to P
         - b. P sends list of all messages received before GBCAST to all recipients as “before gbcast” messages
            - i. Received should have received it during forwarding step ii above and placed it on wait queue
            - ii. Can now deliver these
      2. Now deliver all before- messages on wait queue
      3. Then GBCAST
      4. Then re-allow ABCASTS
   - v. Simpler implementation of ABCAST
      1. Observation: CBCAST and ABCAST act the same if there is a single sender at a time
         - a. Grab a lock using CBCAST
      2. Use CBCAST to deliver message
         - a. No need to wait for replies from everyone
         - b. Can overlap
      3. Sends ordered by lock, so maintain total order needed by ABCAST
- f. Use of broadcast:
   - i. ABCAST,GBCAST: tend to be synchronous to do things like to do an RPC that updates common state
      1. Use it for performing totally ordered writes
   - ii. CBCAST: tends to by async: fire & forget
      1. E.g. read an object by “registering” a read lock with CBCAST and reading a local copy
      2. Can then read local copy & drop lock
      3. Is totally ordered before or after other ABCASTS
      4. Can use for a lock:
         - a. Broadcast to acquire lock, holder replies to oldest broadcast
         - b. Causality ensures lock arrives after any messages preceding lock release
         - c. Same idea as Lamport lock, but use causal broadcast instead of atomic

7. Objections
   - a. David Cheriton and Dale Skeen had a paper in SOSP’1993 saying causally & totally ordered communication is not very helpful:
      - i. Fundamental problem: causality is around communications, but doesn’t respect real ordering of program (e.g. database serializability), doesn’t handle stable updates to persistent data
         1. Their view: you have durable data and separate processes operating it (like a database)

2. Want consistent updates to stored data
3. CATOCS doesn't really do this.

ii. Does not recognize causality outside the system (e.g. between sensors/actuators in real world.)

1. Example: fire detected (broadcast), fire out (broadcast in response). Second fire detected (broadcast) could overlap – does not preserve causality when events are causally ordered externally
2. 

3. Problem: causality of second fire starting after first not respected

iii. Cannot group updates like a transaction

1. Suppose updating multiple objects – need to acquire a lock (like lamport clock paper)

iv. Cannot expose semantic orderings outside of messages

1. E.g. stock pricing: exposes causal order, but if that isn't the right order (e.g. A sends to B and C, B sends to C, A sends to C after B in stock pricing), then not enough

v. Inefficient

1. May need to buffer messages before delivery (e.g. ABCAST, CBCAST)

b. Responses from Birman

i. Focus on apps without durable state – they work well with a database—and more on command/control with short-term transient state

1. E.g. who is the leader now, who is holding locks right now
2. Tend not to have multi-object updates as in a database
3. Database apps interact indirectly through shared objects
   a. E.g. write/read file in file system, update/query data
4. Control apps interact directly
   a. Send message to processes telling them what to do.

ii. Most causality actually captured by communication

iii. Can do transactions with a CBCAST locks: get lock, then CBCAST updates asynchronously
iv. Inefficient: can condense down to a vector clock per message, not very big.
    1. Any kind of ordered delivery requires some buffering plus clocks
    2. E.g. windows for TCP/IP
    3. Question: can cost be small, can benefit outweigh cost?