CS514: Intermediate Course in Operating Systems

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Recap

- Our recipe for group communication:
  - Group membership
    - We solved this by building a fault-tolerant group membership service
    - Everyone who uses it sees the same group "views" in the same order
    - When it makes a mistake about a failure, we just terminate the unfortunate victim!
  - Fault-tolerant view-synchronous multicast
  - Ordering mechanisms

Ordering: The missing element

- Our fault-tolerant protocol was
  - FIFO ordered: messages *from a single sender* are delivered in the order they were sent, even if someone crashes
  - View synchronous: everyone receives a given message in the same group view
- This is the protocol we called **fbcast**

But we identified other options

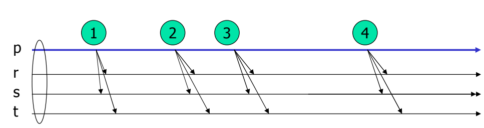
- **cbcast**: If cbcast(a)→cbcast(b), deliver a before b at common destinations
- **abcast:** Even if a and b are concurrent, deliver in some agreed order at common destinations
- **gbcast:** Deliver this message like a new group view: agreed order w.r.t. multicasts of all other flavors

Can we implement them?

- First look at cbcast
  - Recall that this property was "like" fbcast
  - The issue concerns the meaning of a "single sender"
    - With fbcast, a single sender is a single process
    - With cbcast, we think about a single causal thread of events that can span many processes
      - For example: p asks q to send a, then asks r to send b. So a→b but a happens at q and b happens at r!

Single updater

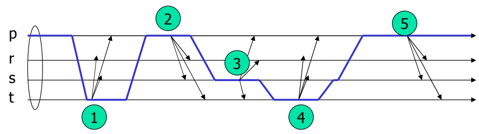
- If p is the only update source, the need is a bit like the TCP "fifo" ordering



- **fbcast** is a good choice for this case

Causally ordered updates

- Events occur on a "causal thread" but multicasts have different senders

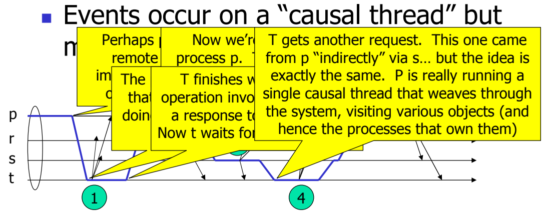


Reminder: Who needs it?

- The issue is that with Web Services and CORBA, you might not even "know" that you are invoking a remote object
- If it does a multicast for you, that event seems like something you did… but may have been issued by some other process
- If we use cbcast, messages will be delivered in the order they were sent

Causally ordered updates

- Events occur on a "causal thread" but m

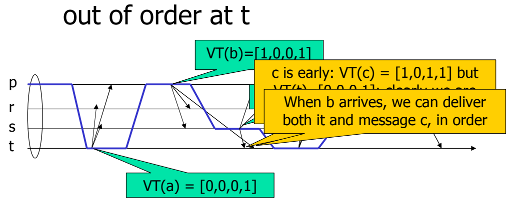


How to implement it?

- Within a single group, the easiest option is to include a vector timestamp in the header of the message
  - Only increment the VT when sending
  - Send these "labeled" messages with fbcast
- Delay a received message if a causally prior message hasn't been seen yet

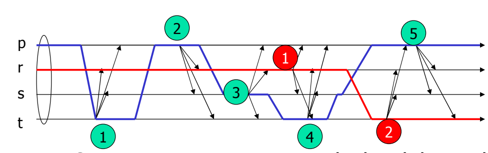
Causally ordered updates

- Example: messages from p and s arrive out of order at t



Causally ordered updates

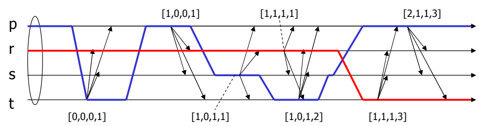
- This works even with multiple causal threads.



- Concurrent messages might be delivered to different receivers in different orders
  - Example: green 4 and red 1 are concurrent

Causally ordered updates

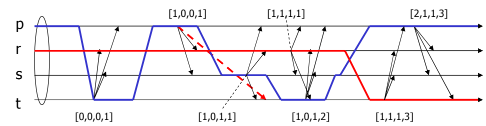
- Sorting based on vector timestamp



- In this run, everything can be delivered immediately on arrival

Causally ordered updates

- Suppose p's message [1,0,0,1] is "delayed"



- When t receives message [1,0,1,1], t can "see" that one message from p is late and can delay deliver of s's message until p's prior message arrives!

Other uses for cbcast?

- The protocol is very helpful in systems that use locking for synchronization
  - Gaining a lock gives some process mutual exclusion
  - Then it can send updates to the locked variable or replicated data
- Cbcast will maintain the update order

Cost of cbcast?

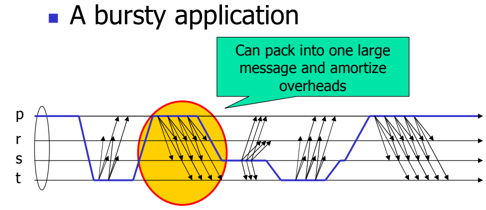
- This protocol is very cheap!
  - It requires one phase to get the data from the sender to the receiver
  - Receiver can deliver instantly
    - Same cost as an IP multicast or a set of UDP sends
  - Imposes a small header and a small garbage collection overhead
    - Nobody is likely to notice! And we can often omit or compress the header

Better and better

- Suppose some process sends a bunch of small updates using fbcast or cbcast
  - Pack them into a single bigger message
  - Benefit: message costs are dominated by the system call and almost unrelated to size, at least until we get big enough to require fragmentation!

Causally ordered updates

- A bursty application



Screaming performance!

- This type of packing can give incredible performance
  - Sender is able to send a small message, then "move on" to the next task (like sending a TCP message without waiting for it to get through)
  - Sender's "platform" packs them together
  - Receiver unpacks on arrival
- Can send *hundreds of thousands of asynchronous updates per second in this mode!*

Snapshots with cbcast

- Send two rounds of cbcast
  - Round 1: "Start a snapshot"
    - Receivers make a checkpoint
    - And they start recording incoming messages
    - Then say "OK"
  - Round 2: "Done"
    - They send back their checkpoints and logs
- Thought question: *why does this work?*

What about abcast?

- Abcast puts messages into a single agreed upon order even if two multicasts are sent concurrently
  - fbcast and cbcast can deliver messages in different orders at different receivers
  - Notice that this disordered delivery wouldn't matter in the cases we discussed!

Many options…

- Literature has at least a dozen abcast protocols, and some are causal too
- Easiest just uses a token
  - To send an abcast, either pass it to the token holder, or request the token
  - Token holder can increment a counter and put it in header of message
    - Only need the counter if token can move…
    - Delay a message until it can be delivered in order

What about gbcast?

- This is a *very* costly protocol
  - Must be ordered wrt all other event types, including fbcast, cbcast, abcast, view changes, other gbcasts
  - Used to change a security key or even modify the protocol stack at runtime
    - Like changing the engines on a jet while it is flying! Not a common event
- Implement with a fusion of flush protocol and abcast. Requires at least 2 phases

Life of a multicast

- The sender sends it…
- The protocol moves it to the right machines, deals with failures, puts it in order, finally delivers it
  - All of this is hidden from the real user
- Now the application "gets" the multicast and could send replies point-to-point

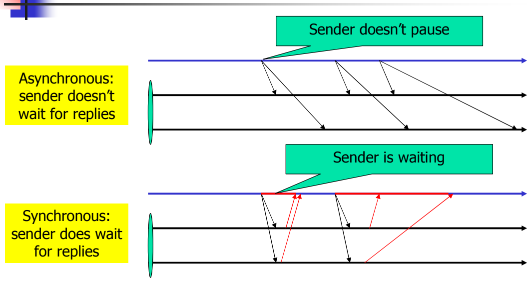
Should we ask for replies?

- Synchronous versus asynchronous
  - A "synchronous" operation is RPC-like
    - We need one or more replies from the processes that we invoke
  - An "asynchronous" operation is a multicast with no replies or feedback to the caller
    - I.e. "add flight AF 1981 to the list of active flights in sector D-9". No reply is needed

Should we ask for replies?

- Synchronous cases (one or more replies) won't batch messages
  - Exception: sender could be multithreaded
  - But this is sort of rare since hackers prefer not to work with concurrent threads unless they really have to
- Waiting for all replies is worst since slowest receiver limits the whole system
- So speed is greatly reduced…

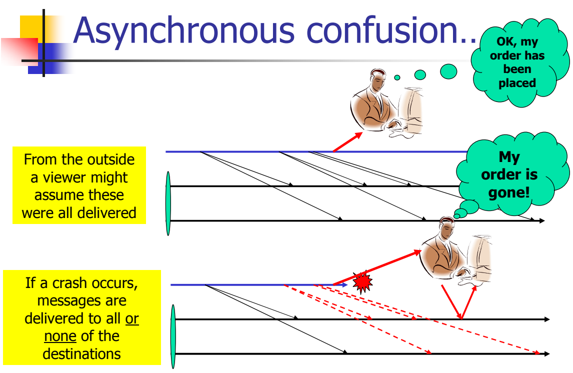
Life of a multicast



Asynchronous multicast: Pros and cons

- Asynchronous multicast allows higher speeds
  - The system can batch up multiple messages into one big message, as we saw earlier
  - And the sender won't be limited by the speed of the network and the recievers
- This makes asynchronous multicast very popular in real systems
- But the sender can get "way ahead" and this can cause confusion if it then fails
  - Multicasts still in the channels can be lost

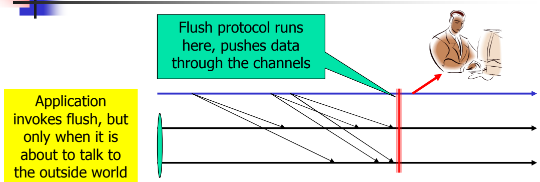
Asynchronous confusion…



Remedies for confusion

- Insight is that these red multicasts were unstable
  - If we **flush** the channels and wait until they have been delivered (become stable), the issue is eliminated
  - Users find this easy to understand because file systems work the same way
    - File I/O is asynchronous through the buffer pool… must use **fsync** to force writes to disk

Asynchronous confusion…



Limits to asynchrony

- At any rate, most systems *limit the number of asynchronous multicasts that are running simultaneously*
  - Issue is that otherwise, sender can get arbitrarily far ahead of receivers
  - A few messages is one thing… millions is another
  - So most systems allow a few asynchronous messages at a time, but then force new multicasts to wait for some old ones to finish
  - Very similar to TCP window idea

Picking between synchronous and asynchronous multicast

- With synchronous multicast we can "ask" the receivers to do something
  - Please search the telephone book
  - With k members at the time of reception, the group member i searches the i'th part of the book (dividing it into k parts)
  - Each reply has $1/k^{th}$ of the answer!
- But we need to wait for the answers
  - This is a shame if we didn't actually need answers

A range of synchrony levels

- A platform usually offers multiple options
  - Wait for k replies, for some specified $k \geq 0$. *Waiting for no replies: asynchronous*
  - Wait for "all" to reply
- When we say "all":
  - This means "one reply from each member in the view at the time of delivery"
  - If someone gets the message but then fails, obviously, we should stop waiting for a reply….

Recap

- We've got a range of ordered multicast primitives
  - Two (fbcast, cbcast) have low cost
  - Two (abcast, gbcast) are more ordered but more costly
- And we can use them asynchronously or synchronously
- Now touch some "esoteric" issues…

Orphaned messages

- With all of these protocols a failure can leave messages "orphaned"
  - E.g. $a \rightarrow b$, but after failure a has been completely lost and someone still has a copy of b (presumably delayed)
  - Similar issue can arise with abcast
- Modify flush protocol to discard such messages

Dynamic uniformity ("safe")

- Suppose that process p receives message a, delivers is, then fails
  - Application program may have done something, like "issue cash from the machine"
- Now system could "lose" a message after the failure
  - Nobody else will see this message

Dynamic uniformity ("safe")

- We say that a multicast is "safe" if a message delivered to any process will be delivered to *all* processes (unless they crash first)
- To guarantee this for every multicast is expensive
  - Requires two phase protocol
  - First make sure that everyone has a copy
  - Only then start to deliver copies
- This is quite slow!!!!!

Is this form of safety needed?

- Perhaps not:
  - Many actions only impact the "internal" state of a system
    - Like reports of load, updates to variables employed by algorithm, etc
    - Relatively few multicasts have external visibility
  - We only need dynamic uniformity when something will be visible *outside* the system

Is this form of safety needed?

- Moreover, can easily hack around issue
  - The same flush primitive we mentioned earlier can solve this problem
  - Just call it when you need to take an external action
- Seems unnecessary to provide such a costly property for every multicast when there is such a simple alternative

Communication from a client to a group

- Some communication occurs entirely within a group
- But other requests come from outside (from a "client")
- What issues does this raise?

Communication from a client to a group

- It turns out that we can implement client-to-group multicast fairly easily
  - Either hand the request off to a member, who does it for you. Involves a small delay
  - Or cache the membership and label the multicast with the view in which it was sent
    - Some trickiness when view is changing just at this moment… book explains how it can be handled… at worst, client has to retry
    - But multicast goes directly to the members… no delay

Wrapup

- We've seen how this stuff works
  - Hopefully, someone else will implement it for you and you'll use it via a library!
  - Spread and Ensemble are examples
- What are the pros and cons?
  - Pro: a powerful abstraction
  - Con: not trivial to understand or use

Arguments for "platform support"

- … sometimes, GCS is found in the O/S
  - In IBM Websphere, virtual synchrony is used in a replication package
  - In Microsoft Windows Clusters, group communication is employed within the cluster management technology
- But not often visible to end user
  - Considered a "dangerously powerful tool"

Take-aways?

- We can implement very high performance multicast
  - Virtual synchrony model
  - Incredible asynchronous throughput
  - Ordering matched to the needs of app.
- And many vendors have done so
- But developers aren't able to access these primitives (for now)