CS5412: VIRTUAL SYNCHRONY

Lecture XIV

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Group Communication idea

- System supports a new abstraction (like an object)
  - A "group" consisting of a set of processes ("members") that join, leave and cooperate to replicate data or do parallel processing tasks
  - A group has a name (like a filename)
  - … and a state (the data that its members are maintaining)
    - The state will often be *replicated* so each member has a copy
    - Note that this is in contrast to Paxos where each member has a partial copy and we need to use a "learner algorithm" to extract the actual current state
    - Think of state much as you think of the value of a variable, except that a group could track many variables at once

Group communication Idea

- The members can send each other
  - Point-to-point messages
  - Multicasts that go from someone to *all* the members
- They can also do RPC style queries
  - Query a single member
  - Query the whole group, with all of them replying

- Example: The Isis^2 system

Isis^2 is a *library* for group communication

It Uses a Formal model

- Formal model permits us to achieve correctness
- Isis^2 is too complex to use formal methods as a development tool, but does facilitate debugging (model checking)
- Think of Isis^2 as a collection of modules, each with rigorously stated properties

It Reflects Sound Engineering

- Isis^2 implementation needs to be fast, lean, easy to use
- Developer must see it as easier to use Isis^2 than to build from scratch
- Seek great performance under "cloudy conditions"
- Forced to anticipate many styles of use

Isis^2 makes developer's life easier


```
Group g = new Group("myGroup");
g.ViewHandlers += delegate(View v) {
    Console.Title = "myGroup members: "+v.members;
};
g.Handlers[UPDATE] += delegate(string s, double v) {
    Values[s] = v;
};
g.Handlers[LOOKUP] += delegate(string s) {
    Reply(Values[s]);
};
g.Join();

g.Send(UPDATE, "Harry", 20.75);

List<double> resultlist = new List<double>;
nr = g.Query(LOOKUP, ALL, "Harry", EOL, resultlist);
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- First sets up group
- Join makes this entity a member. State transfer isn't shown
- Then can multicast, query. Runtime callbacks to the "delegates" as events arrive
- Easy to request security (g.SetSecure), persistence
- "Consistency" model dictates the ordering aseen for event upcalls and the assumptions user can make

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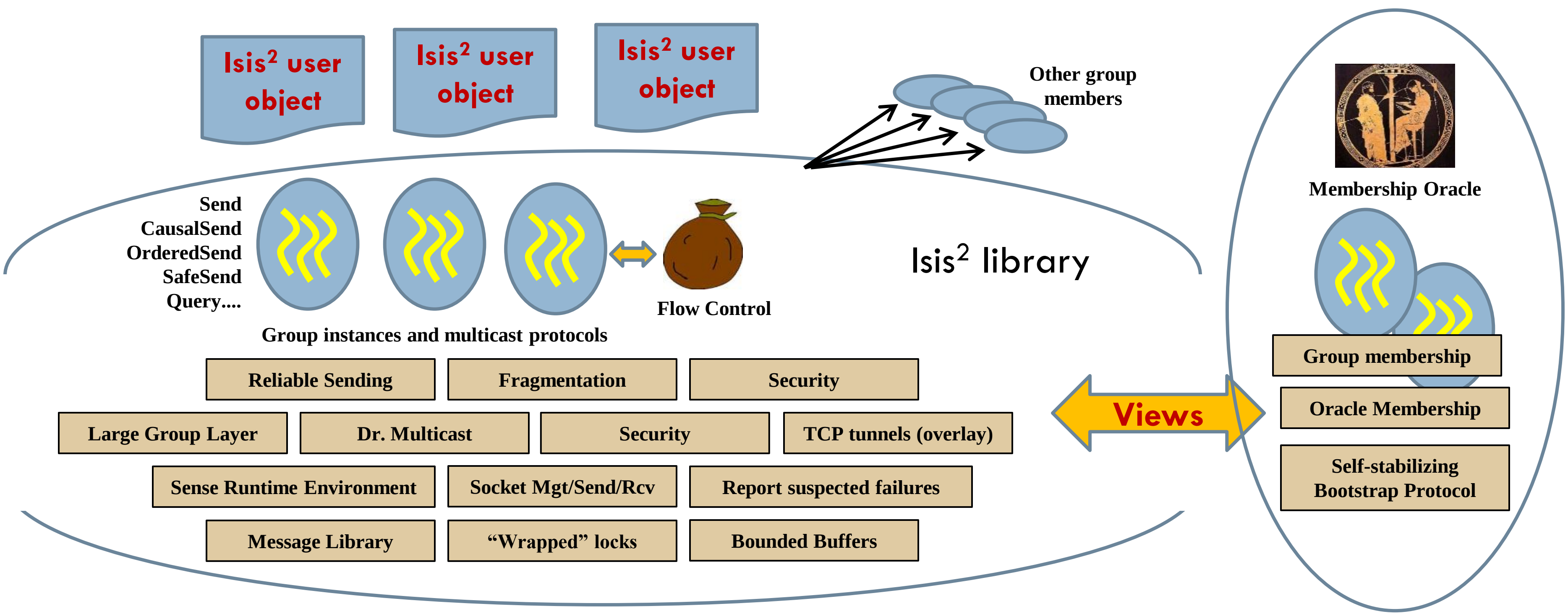
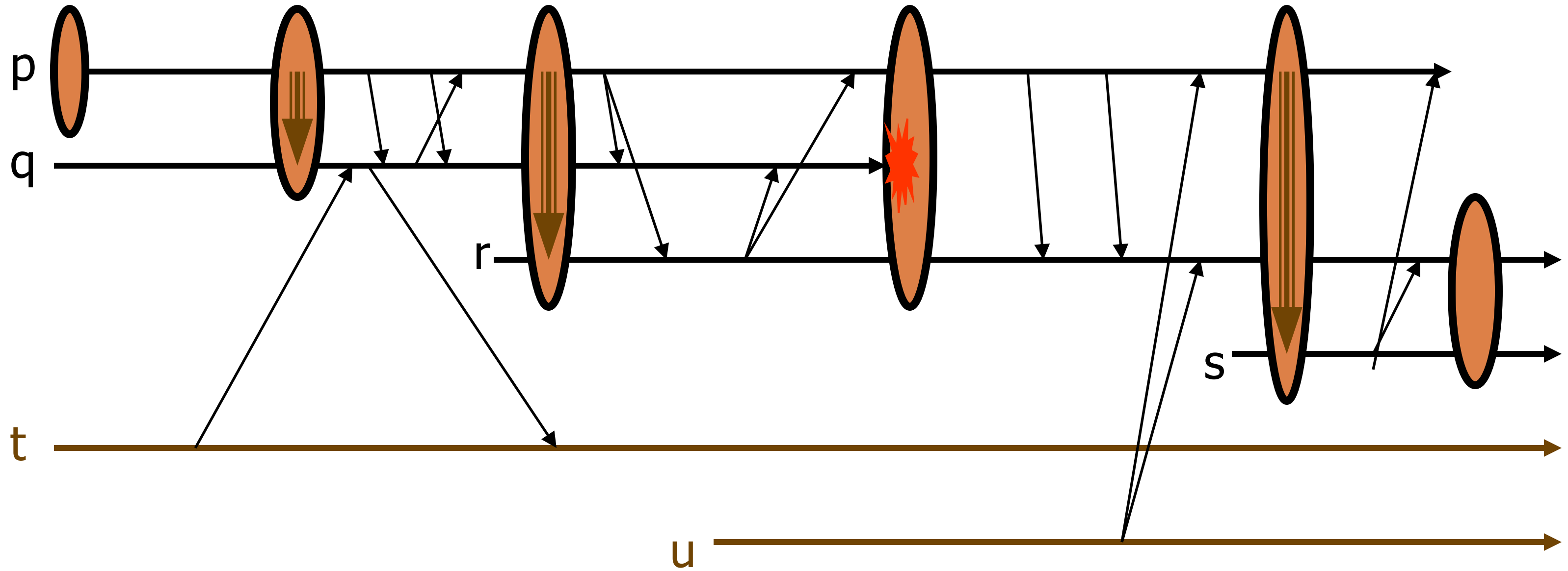
It takes a "community"

- A lot of complexity lurks behind those simple APIs
- Building one of your own would be hard
- Isis^2 took Ken 3 years to implement & debug



What goes on down there?



- Terminology: group create, view, join with state transfer, multicast, client-to-group communication
- This is the “dynamic” membership model: processes come & go

Concepts

- You build your program and link with Isis^2
- It starts the library (the new guy tracks down any active existing members)
- Then you can create and join groups, receive a "state transfer" to catch up, cooperate with others
- All kinds of events are reported via upcalls
  - New view: View object tells members what happened
  - Incoming message: data fields extracted and passed as values to your handler method

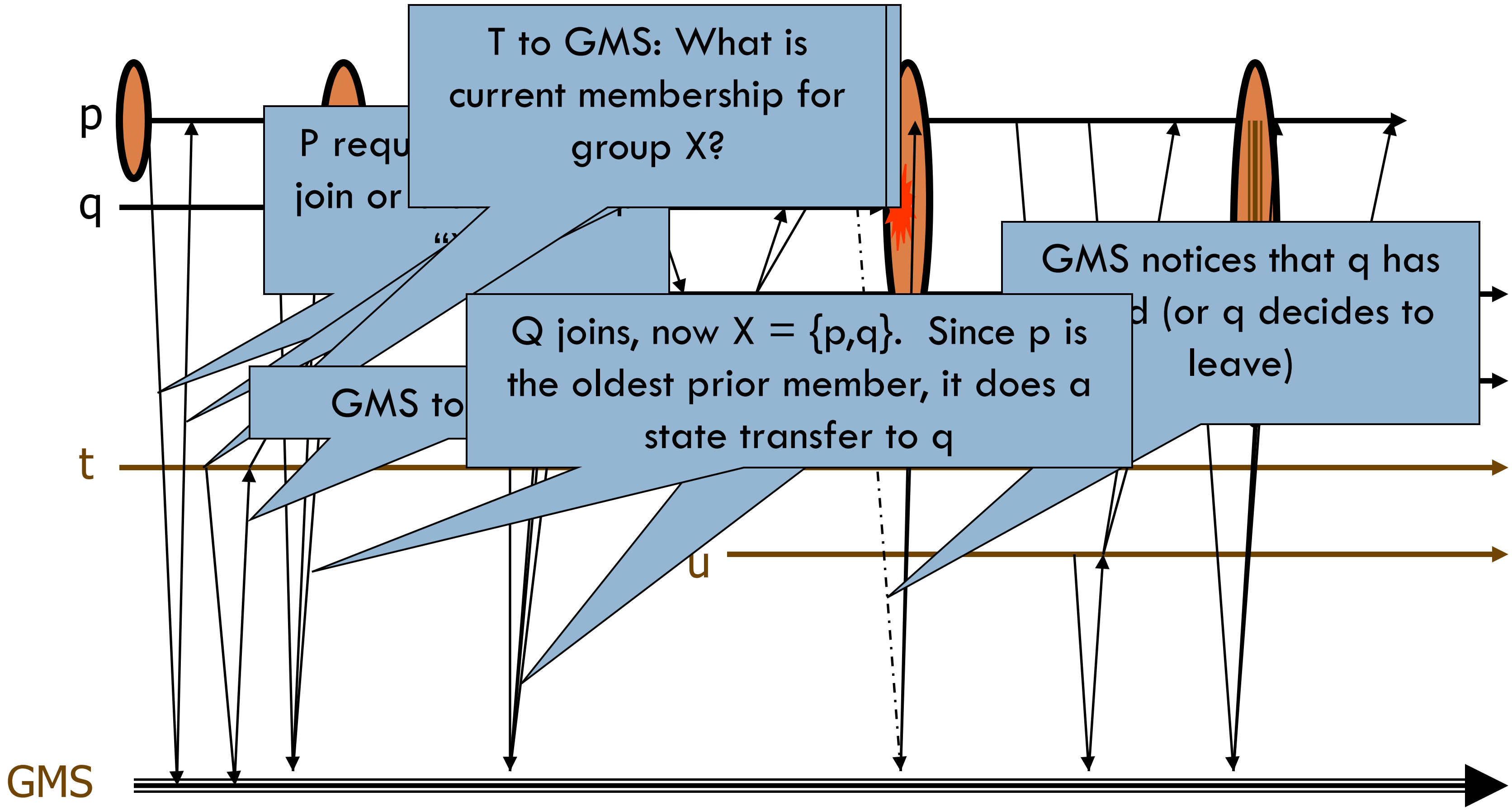
Recipe for a group communication system

- Back one pie shell
  - *Build a service that can track group membership and report "view changes"*
- Prepare 2 cups of basic pie filling
  - *Develop a simple fault-tolerant multicast protocol*
- Add flavoring of your choice
  - *Extend the multicast protocol to provide desired delivery ordering guarantees*
- Fill pie shell, chill, and serve
  - *Design an end-user "API" or "toolkit". Clients will "serve themselves", with various goals…*

Role of GMS

- We'll add a new system service to our distributed system, like the Internet DNS but with a new role
  - Its job is to track membership of groups
  - To join a group a process will ask the GMS
  - The GMS will also monitor members and can use this to drop them from a group
  - And it will report membership changes

Group picture… with GMS



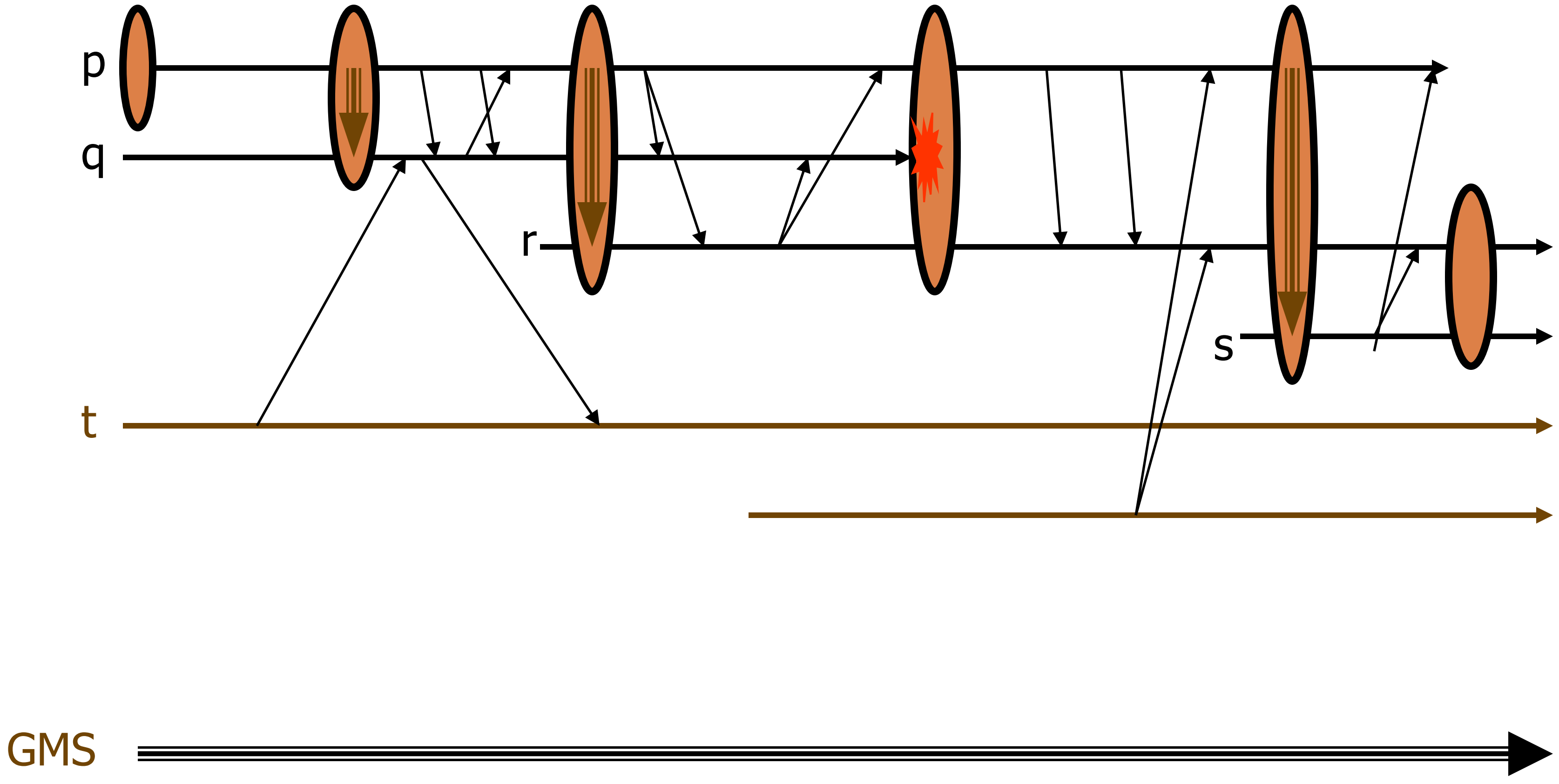
Group membership service

- Runs on some sensible place, like the first few machines that start up when you launch Isis[2]
- Takes as input:
  - Process "join" events
  - Process "leave" events
  - Apparent failures
- Output:
  - Membership views for group(s) to which those processes belong
  - Seen by the protocol "library" that the group members are using for communication support

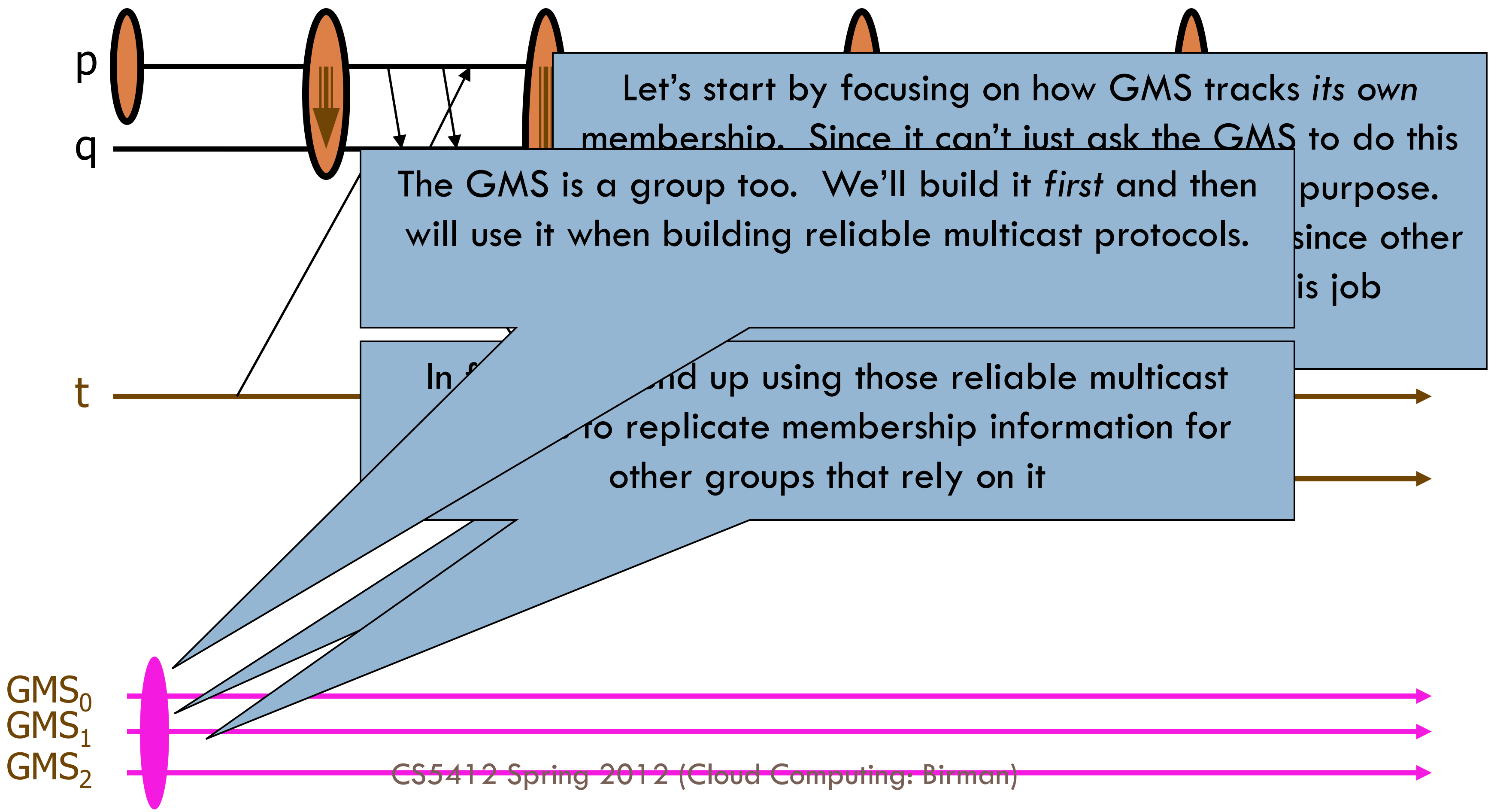
Issues?

- The service *itself* needs to be fault-tolerant
  - Otherwise our entire system could be crippled by a single failure!
- So we'll run two or three copies of it
  - Hence Group Membership Service (GMS) must run some form of protocol (GMP)

Group picture… with GMS



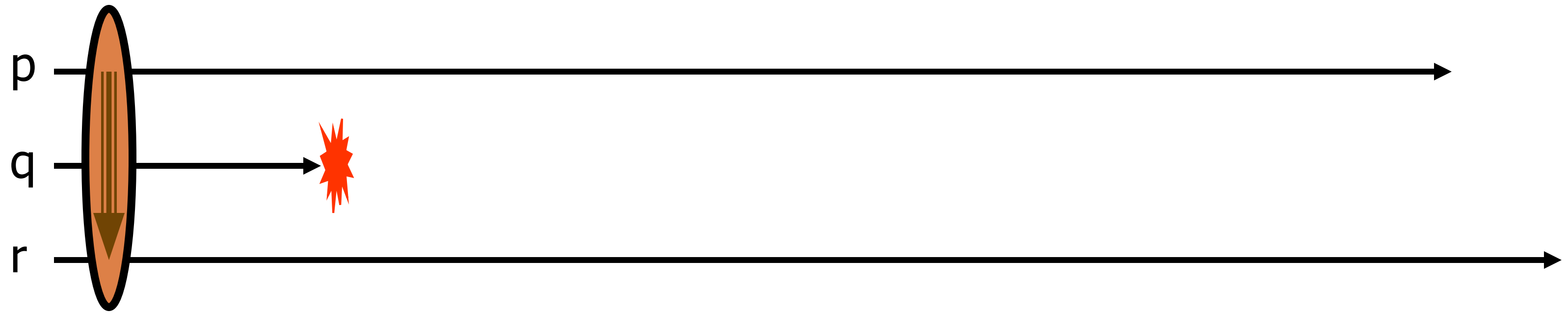
Group picture… with GMS



Approach

- Assume that GMS has members {p,q,r} at time t
- Designate the "oldest" of these as the protocol "leader"
  - To initiate a change in GMS membership, leader will run the GMP
  - Others can't run the GMP; they report events to the leader

GMP example



- Example:
  - Initially, GMS consists of {p,q,r}
  - Then q is believed to have crashed

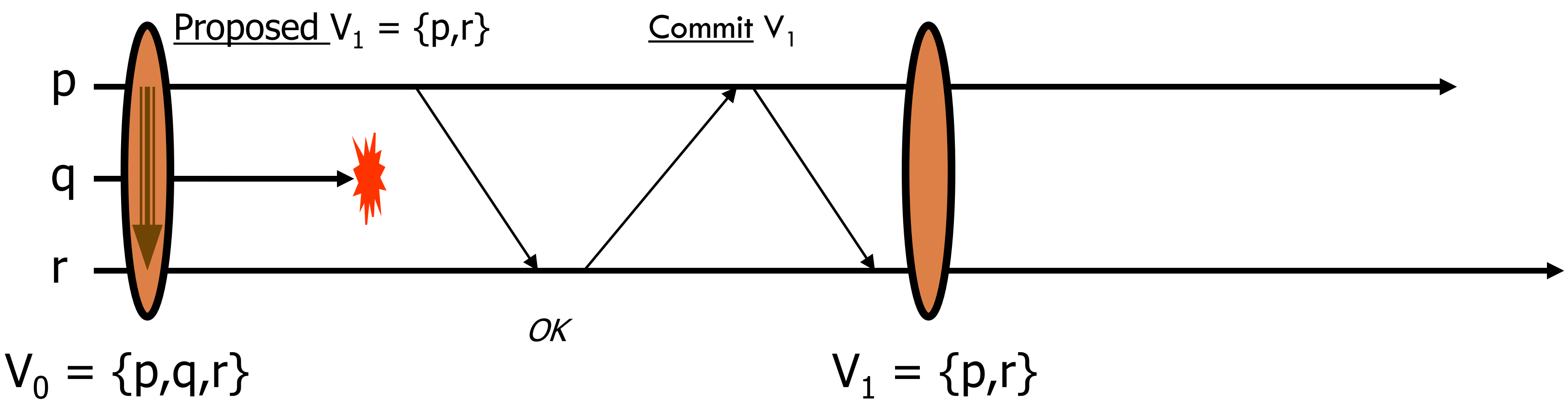
Failure detection: may make mistakes

- Recall that failures are hard to distinguish from network delay
  - So we accept risk of mistake
  - If p is running a protocol to exclude q because "q has failed", all processes that hear from p will cut channels to q
    - Avoids "messages from the dead"
  - q must rejoin to participate in GMS again

Basic GMP

- Someone reports that “q has failed”
- Leader (process p) runs a 2-phase commit protocol
  - Announces a “proposed new GMS view”
    - Excludes q, or might add some members who are joining, or could do both at once
  - Waits until a majority of members of current view have voted “ok”
  - Then commits the change

GMP example



- Proposes new view: {p,r} [-q]
- Needs majority consent: p itself, plus one more ("current" view had 3 members)
- Can add members at the same time

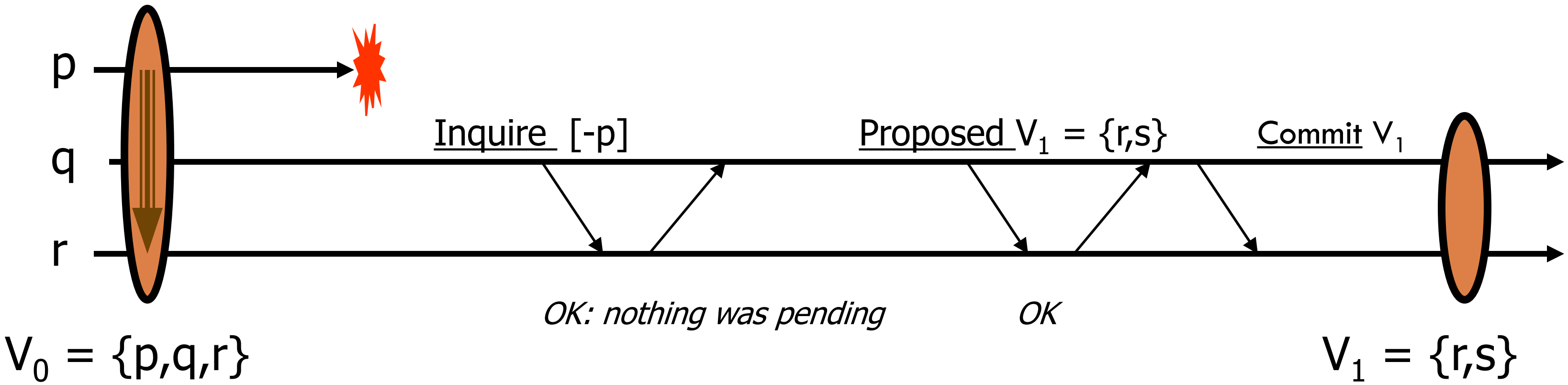
Special concerns?

- What if someone doesn't respond?
  - P can tolerate failures of a minority of members of the current view
    - New first-round "overlaps" its commit:
      - "Commit that q has left. Propose add s and drop r"
  - P must wait if it can't contact a majority
    - Avoids risk of partitioning

What if leader fails?

- Here we do a 3-phase protocol
  - New leader identifies itself based on age ranking (oldest surviving process)
  - It runs an inquiry phase
    - "The adored leader has died. Did he say anything to you before passing away?"
    - Note that this causes participants to cut connections to the adored previous leader
  - Then run normal 2-phase protocol but "terminate" any interrupted view changes leader had initiated

GMP example



- New leader first sends an inquiry
- Then proposes new view: {r,s} [-p]
- Needs majority consent: q itself, plus one more ("current" view had 3 members)
- Again, can add members at the same time

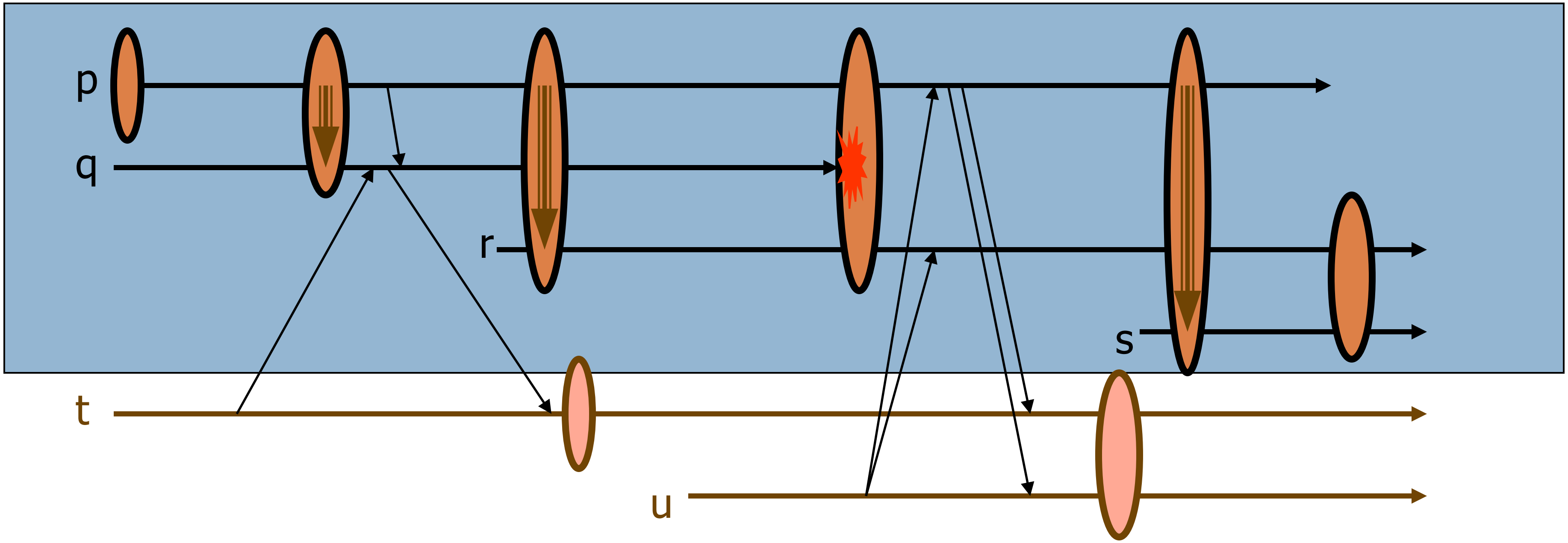
Properties of GMP

- We end up with a single service shared by the entire system
  - In fact every process can participate
  - But more often we just designate a few processes and they run the GMP
- Typically the GMS runs the GMP and also uses replicated data to track membership of *other* groups

Use of GMS

- A process t, not in the GMS, wants to join group "Upson309_status"
  - It sends a request to the GMS
  - GMS updates the "membership of group Upson309_status" to add t
  - Reports the new view to the current members of the group, and to t
  - Begins to monitor t's health

Processes t and u "using" a GMS



- The GMS contains p, q, r (and later, s)
- Processes t and u want to form some other group, but use the GMS to manage membership on their behalf

Relate to Paxos

- In fact we're doing something *very* similar to Paxos
  - The "slot number" is the "view number"
  - And the "ballot" is the current proposal for what the next view should be
  - With Paxos proposers can actually talk about multiple future slots/commands (concurrency parameter α)
  - With GMS, we do that too!
    - A single proposal can actually propose multiple changes
    - First [add X], then [drop Y and Z], then [add A, B and C]…
    - In order… eventually 2PC succeeds and they all commit

How does this differ from Paxos?

- Details are clearly <u>not</u> identical
- Runs with a well-defined leader; Paxos didn't need one (in Paxos we often prefer to have a leader but correctness is ensured with multiple coordinators)
- Very similar guarantees of ordering and durability
- Isis GMS protocol predates Paxos

We have our pie shell

- Now we've got a group membership service that reports identical views to all members, tracks health
- Can we build a reliable multicast?

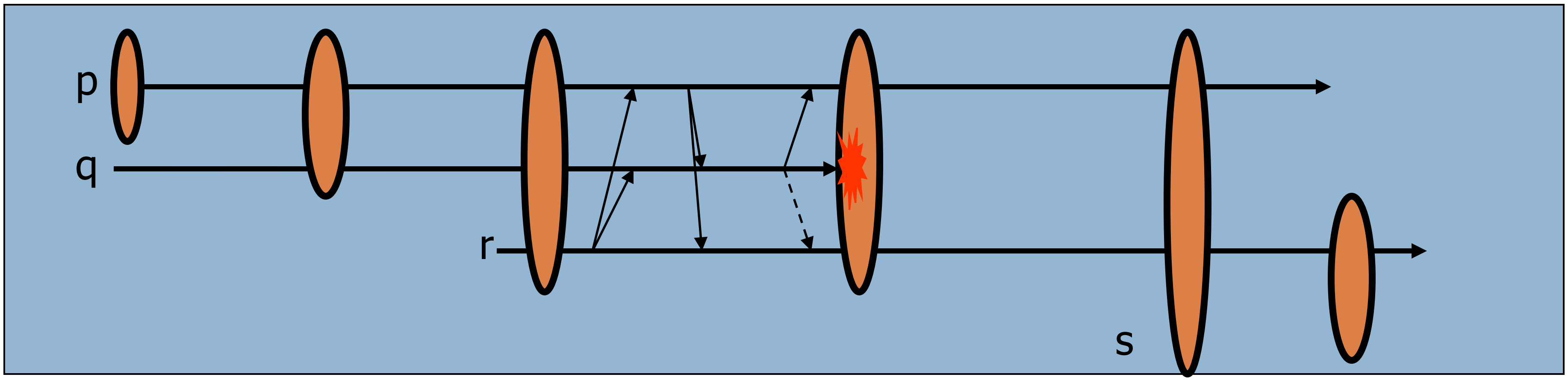
Unreliable multicast

- Suppose that to send a multicast, a process just uses an unreliable protocol
  - Perhaps IP multicast
  - Perhaps UDP point-to-point
  - Perhaps TCP
- … some messages might get dropped. If so it eventually finds out and resends them (various options for how to do it)

Concerns if sender crashes

- Perhaps it sent some message and only one process has seen it
- We would prefer to ensure that
  - All receivers, in "current view"
  - Receive any messages that any receiver receives (unless the sender and all receivers crash, erasing evidence…)

An interrupted multicast



- A message from q to r was “dropped”
- Since q has crashed, it won’t be resent

Terminating an interrupted multicast

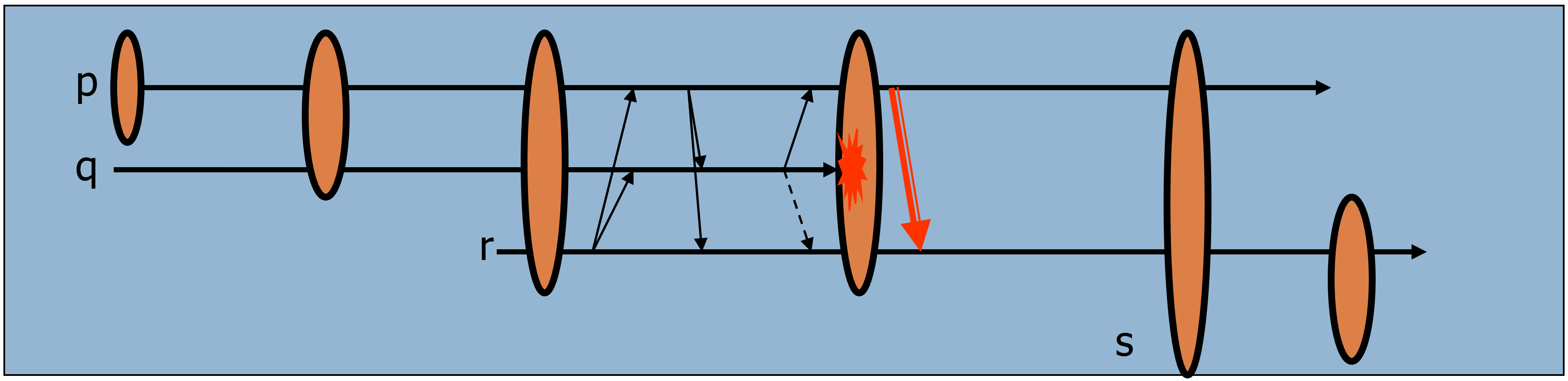
- We say that a message is *unstable* if some receiver has it but (perhaps) others don't
  - For example, q's message is unstable at process r
- If q fails we want to terminate unstable messages
  - Finish delivering them (without duplicate deliveries)
  - Masks the fact that the multicast wasn't reliable and that the leader crashed before finishing up

How to do this?

- Easy solution: all-to-all echo
  - When a new view is reported
  - All processes echo any unstable messages on all channels on which they haven't received a copy of those messages
- A flurry of $O(n^2)$ messages

- *Note: must do this for <u>all</u> messages, not just those from the failed process. This is because more failures could happen in future*

An interrupted multicast



- p had an unstable message, so it echoed it when it saw the new view

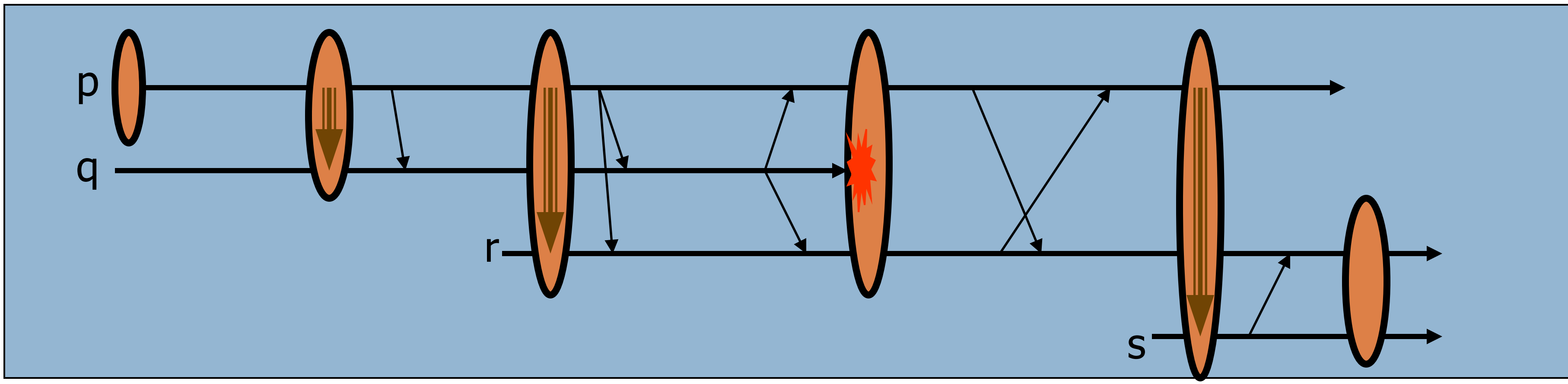
Event ordering

- We should *first* deliver the multicasts to the application layer and *then* report the new view
- This way all replicas see the same messages delivered "in" the same view
  - Some call this "view synchrony"

State transfer

- At the instant the new view is reported, a process already in the group makes a checkpoint
- Sends point-to-point to new member(s)
- It (they) initialize from the checkpoint

State transfer and reliable multicast



- After re-ordering, it looks like each multicast is reliably delivered <u>in the same view</u> at each receiver
- Note: if sender *and all receivers* fails, unstable message can be "erased" even after delivery to an application
  - This is a price we pay to gain higher speed

What about ordering?

- It is trivial to make our protocol FIFO wrt other messages from same sender
  - If we just number messages from each sender, they will "stay" in order
- Concurrent messages are unordered
  - If sent by different senders, messages can be delivered in different orders at different receivers
- This is the protocol called "fbcast"

What does this give us?

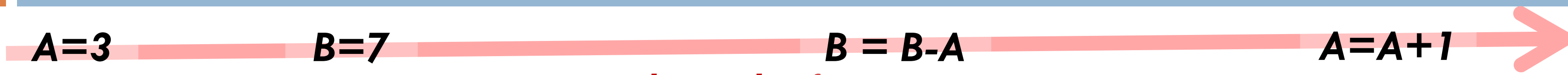
- A second way to implement state machine replication in which each member has a complete and correct state
  - Notice contrast with Paxos where to learn the state you need to run a decision process that reads Q_R copies
  - Isis^2 replica is just a local object and you use it like any other object (with locking to prevent concurrent update)
  - Paxos has replicated state but you need to read multiple process states to figure out the value
- This makes Isis^2 faster and cheaper

Does Isis^2 offer Paxos?

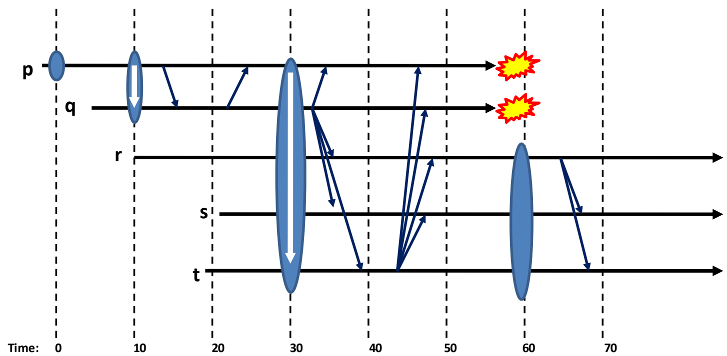
- Yes! Via the SafeSend API mentioned last time
  - SafeSend is a genuine Paxos implementation
  - But it does have some optimizations

- In normal Paxos we don't have a GMS
  - With a GMS the protocol simplifies slightly and we can relax the quorum rules
  - SafeSend includes these performance enhancements but they don't impact the correctness or properties of sol'n

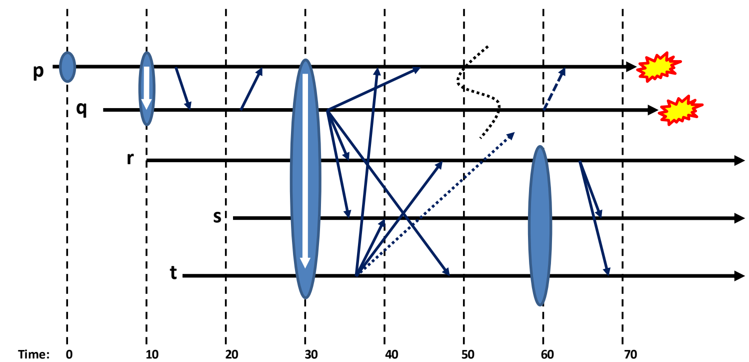
Consistency model: Virtual synchrony meets Paxos (and they live happily ever after…)



Non-replicated reference execution



Synchronous execution



Virtually synchronous execution

- **Virtual synchrony is a "consistency" model:**
  - ***Synchronous runs:*** ***indistinguishable from non-replicated object that saw the same updates (like Paxos)***
  - ***Virtually synchronous runs*** ***are indistinguishable from synchronous runs***

How about the “gotcha” from last time?

- Recall that just sticking Paxos in front of a set of file or database replicas is tempting, but a mistake
  - The protocol might “decide” something but this doesn’t mean the database has the updates
  - Surprisingly tricky to ensure that we apply them all
- Isis^2: apply update when multicast delivered
  - This is safe and correct: all replicas do same thing
  - But it does require a state transfer to add members: we need to make a new DB copy for each new member
  - Can we do better?

State transfer worry

- If my database is just a few Mbytes… just send it
- But in the cloud we often see databases with tens of Gbytes of content!
- Copying them will be a very costly undertaking

With SafeSend can do better

- Isis^2 has the "DiskLogger" mentioned last time
  - It deals with catching a database up if it was out of the group for a while and missed updates
  - Each update gets delivered at least once
  - DB must filter duplicates
- Another option is to build a fancier state transfer
  - E.g. get it almost caught up "offline"
  - Then do the last small delta of state as a final step

Summary

- Group communication offers a nice way to replicate an application
  - Replicated data (without the cost of quorums)
  - Coordinated and replicated processing of requests
  - Automatic leader election, member ranking
  - Automated failure handling, help getting external database caught up after a crash
  - Tools for security and other aspects that can be pretty hard to implement by hand