CSE 486/586 Distributed Systems
Reliable Multicast --- 1

Steve Ko
Computer Sciences and Engineering
University at Buffalo

Last Time

- Global states
  - A union of all process states
  - Consistent global state vs. inconsistent global state
- The “snapshot” algorithm
  - Take a snapshot of the local state
  - Broadcast a “marker” msg to tell other processes to record
  - Start recording all msgs coming in for each channel until receiving a “marker”
  - Outcome: a consistent global state

Today's Question

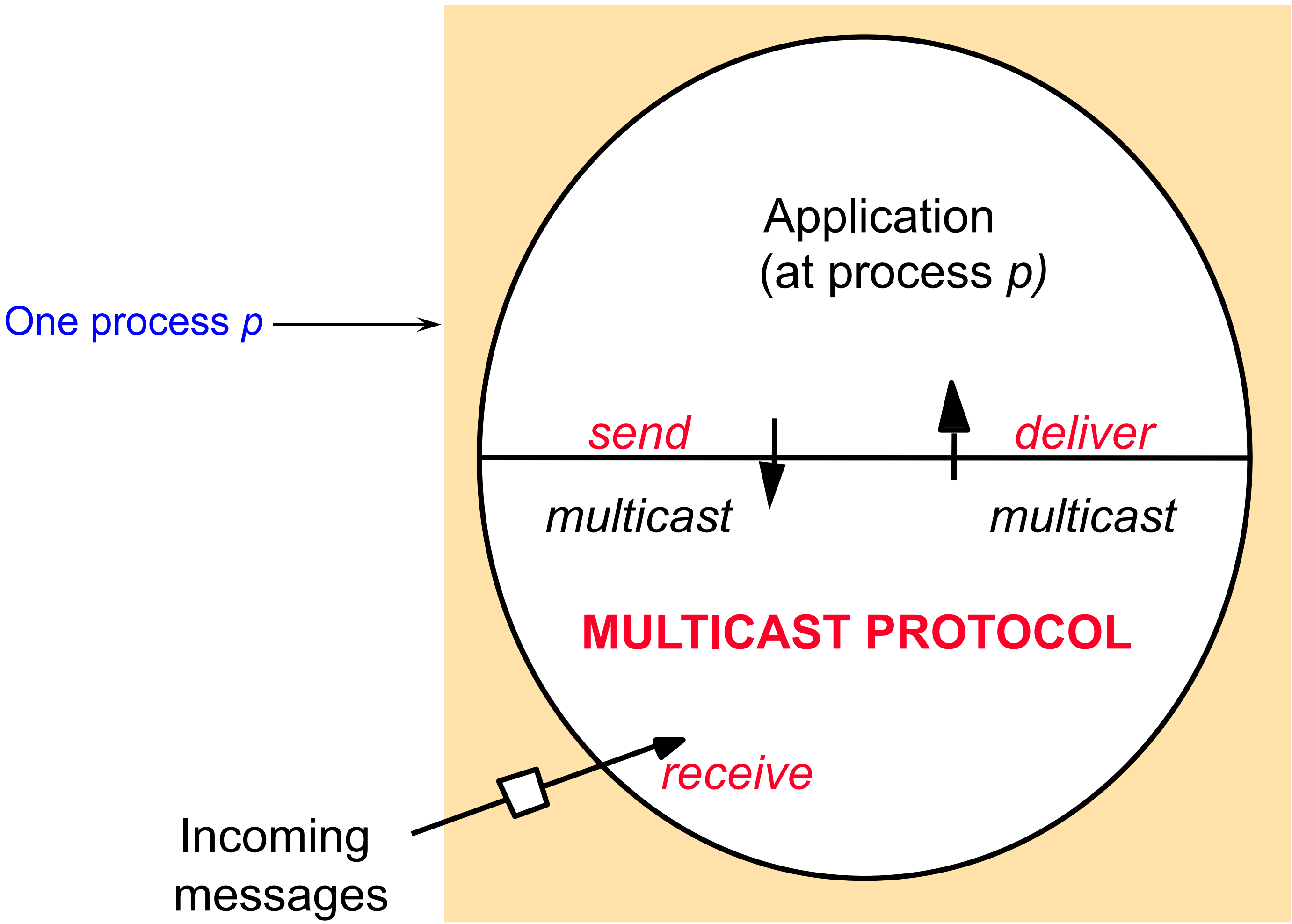
- How do a group of processes communicate?
- Unicast (best effort or reliable)
  - One-to-one: Message from process *p* to process *q*.
  - *Best effort*: message *may* be delivered, but will be intact
  - *Reliable:* message *will* be delivered
- Broadcast
  - One-to-all: Message from process *p* to *all* processes
  - Impractical for large networks
- Multicast
  - One-to-many: "Local" broadcast within a group *g* of processes
- What are the issues?
  - Processes crash (we assume crash-stop)
  - Messages get delayed

Why: Examples

Why: Examples

- Akamai's Configuration Management System (called ACMS)
  - A core group of 3-5 servers.
  - Continuously multicast to each other the latest updates.
  - After an update is reliably multicast within this group, it is then sent out to all the (1000s of) servers Akamai has all over the world.
- Air Traffic Control System
  - Commands by one ATC need to be ordered (and reliable) multicast out to other ATC's.
- Newsgroup servers
  - Multicast to each other in a reliable and ordered manner.

The Interface



What: Properties to Consider

- Liveness: guarantee that something good will happen eventually
  - For the initial state, there is a reachable state where the predicate becomes true.
  - “Guarantee of termination” is a liveness property
- Safety: guarantee that something bad will never happen
  - For any state reachable from the initial state, the predicate is false.
  - Deadlock avoidance algorithms provide safety
- Liveness and safety are used in many other CS contexts.

Basic Multicast (B-multicast)

- A straightforward way to implement B-multicast is to use a reliable one-to-one send (unicast) operation:
  - B-multicast(*g*,*m*): for each process *p* in *g*, send(*p*,*m*).
  - receive(*m*): B-deliver(*m*) at *p*.

- Guarantees?
  - All processes in *g* eventually receive every multicast message…
  - … as long as the sender doesn't crash
  - This guarantee is not so good.
- What guarantees do we want (once again)?

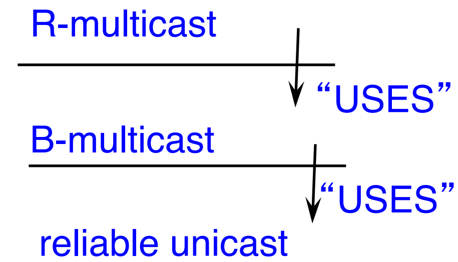
What: Reliable Multicast Goals

- Integrity: A correct (i.e., non-faulty) process *p* delivers a message *m* at most once.
  - "Non-faulty": doesn't deviate from the protocol & alive
- Agreement: If a correct process delivers message *m*, then all the other correct processes in group(*m*) will eventually deliver *m*.
  - Property of "all or nothing."
- Validity: If a correct process multicasts (sends) message *m*, then it will eventually deliver *m* itself.
  - Guarantees liveness to the sender.
- Validity and agreement together ensure overall liveness: if some correct process multicasts a message m, then, all correct processes deliver m too.

Reliable Multicast Overview

- Keep a history of messages for at-most-once delivery
- Everyone repeats multicast upon a receipt of a message.
  - Why? For agreement & validity.
  - Even if the sender crashes, as long as there is one process that receives, since it's going to repeat.

Reliable R-Multicast Algorithm



On initialization

    Received := {};

For process p to R-multicast message m to group g

    B-multicast(g,m);

    ($p \in g$ is included as destination)

On B-deliver(m) *at process q with g = group(m)*

    if ($m \notin$ *Received*):

        Received := *Received* ∪ *{m}*;

        if ($q \neq p$):

            B-multicast(g,m);

        R-deliver(m)

Reliable R-Multicast Algorithm

On initialization

```
        Received := {};
```

For process p to R-multicast message m to group g

```
        B-multicast(g,m);
```

($p \in g$ is included as destination)

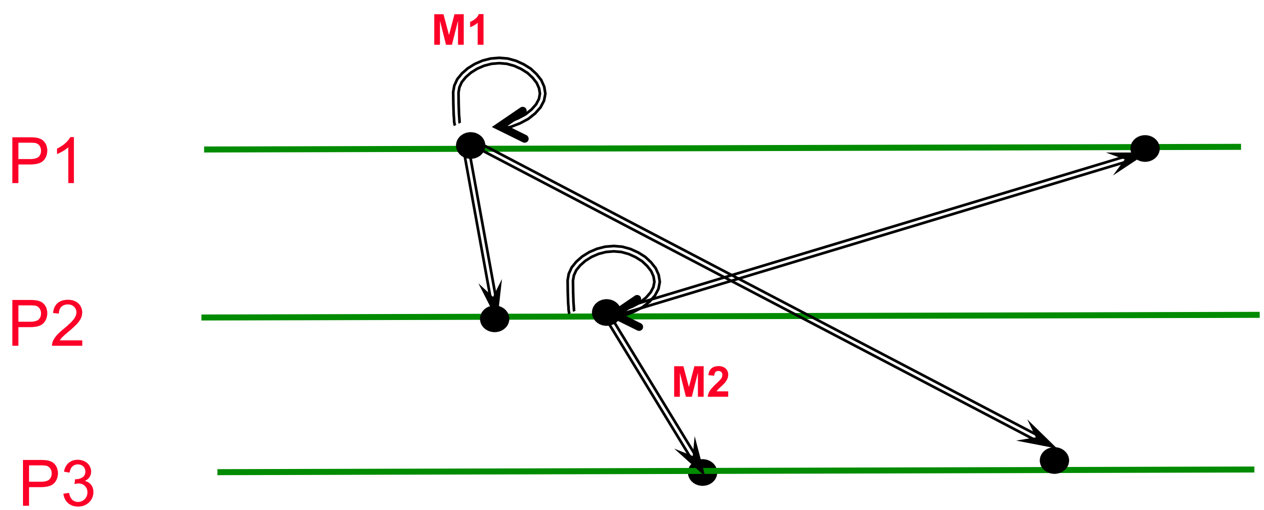
On `B-deliver(m)` *at process q with g = group(m)*

```
        if (m ∉ Received):  Integrity
                Received := Received ∪ {m};
                if (q ≠ p):
                        B-multicast(g,m);  Agreement
                R-deliver(m)  Validity
```

CSE 486/586 Administrivia

- PA1 grading is going on.
- Please ask questions and give feedback during my office hours.
  - Help us help you!

Ordered Multicast Problem



- Each process delivers received messages independently. What is the order of delivery for each process if they deliver as soon as they receive?
- The question is, what ordering does each process use?
- Three meaningful types of ordering
  - FIFO, Causal, Total

FIFO Ordering

- Preserving the process order
- The message delivery order at each process should preserve the message sending order from every process. But each process can deliver in a different order.
- For example,
  - P1: m0, m1, m2
  - P2: m3, m4, m5
  - P3: m6, m7, m8

- FIFO?
  - P1: m0, m3, m6, m1, m4, m7, m2, m5, m8
  - P2: m0, m4, m6, m1, m3, m7, m2, m5, m8
  - P3: m6, m7, m8, m0, m1, m2, m3, m4, m5

Causal Ordering

- Preserving the happened-before relations
- The message delivery order at each process should preserve the happened-before relations across all processes. But each process can deliver in a different order.
- For example,
  - P1: m0, m1, m2
  - P2: m3, m4, m5
  - P3: m6, m7, m8
  - Cross-process happened-before: m0 → m4, m5 → m8

- Causal?
  - P1: m0, m3, m6, m1, m4, m7, m2, m5, m8
  - P2: m0, m4, m1, m7, m3, m6, m2, m5, m8
  - P3: m0, m1, m2, m3, m4, m5, m6, m7, m8

Total Ordering

- Every process delivers all messages in the same order.
- For example,
  - P1: m0, m1, m2
  - P2: m3, m4, m5
  - P3: m6, m7, m8
- Total?
  - P1: m7, m1, m2, m4, m5, m3, m6, m0, m8
  - P2: m7, m1, m2, m4, m5, m3, m6, m0, m8
  - P3: m7, m1, m2, m4, m5, m3, m6, m0, m8
- Total?
  - P1: m7, m1, m2, m4, m5, m3, m6, m0, m8
  - P2: m7, m2, m1, m4, m5, m3, m6, m0, m8
  - P3: m7, m1, m2, m4, m5, m3, m6, m8, m0

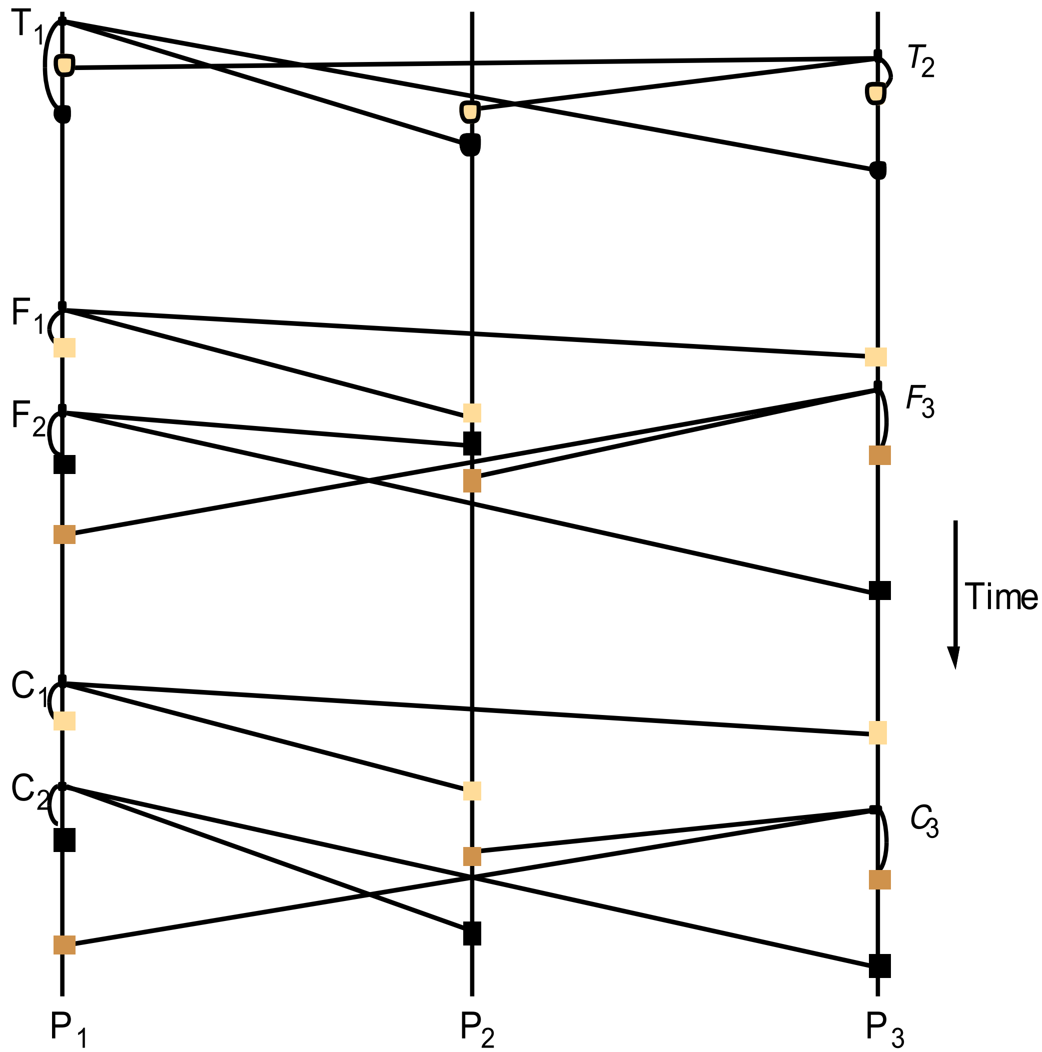
Ordered Multicast

- FIFO ordering: If a correct process issues multicast(*g*,*m*) and then multicast(*g*,*m'*), then every correct process that delivers *m'* will have already delivered m.
- Causal ordering: If multicast(*g*,*m*) → multicast(*g*,*m'*) then any correct process that delivers *m'* will have already delivered *m*.
  - Typically, → defined in terms of multicast communication only
- Total ordering: If a correct process delivers message *m* before *m'* (independent of the senders), then any other correct process that delivers *m'* will have already delivered *m*.

Total, FIFO and Causal Ordering

- Totally ordered messages T_1 and T_2.
- FIFO-related messages F_1 and F_2.
- Causally related messages C_1 and C_3

- Total ordering does not imply causal ordering.
- Causal ordering implies FIFO ordering
- Causal ordering does not imply total ordering.
- Hybrid mode: causal-total ordering, FIFO-total ordering.



Display From Bulletin Board Program

Bulletin board: *os.interesting*		
Item	From	Subject
23	A.Hanlon	Mach
24	G.Joseph	Microkernels
25	A.Hanlon	Re: Microkernels
26	T.L'Heureux	RPC performance
27	M.Walker	Re: Mach
end		

What is the most appropriate ordering for this application?

(a) FIFO (b) causal (c) total

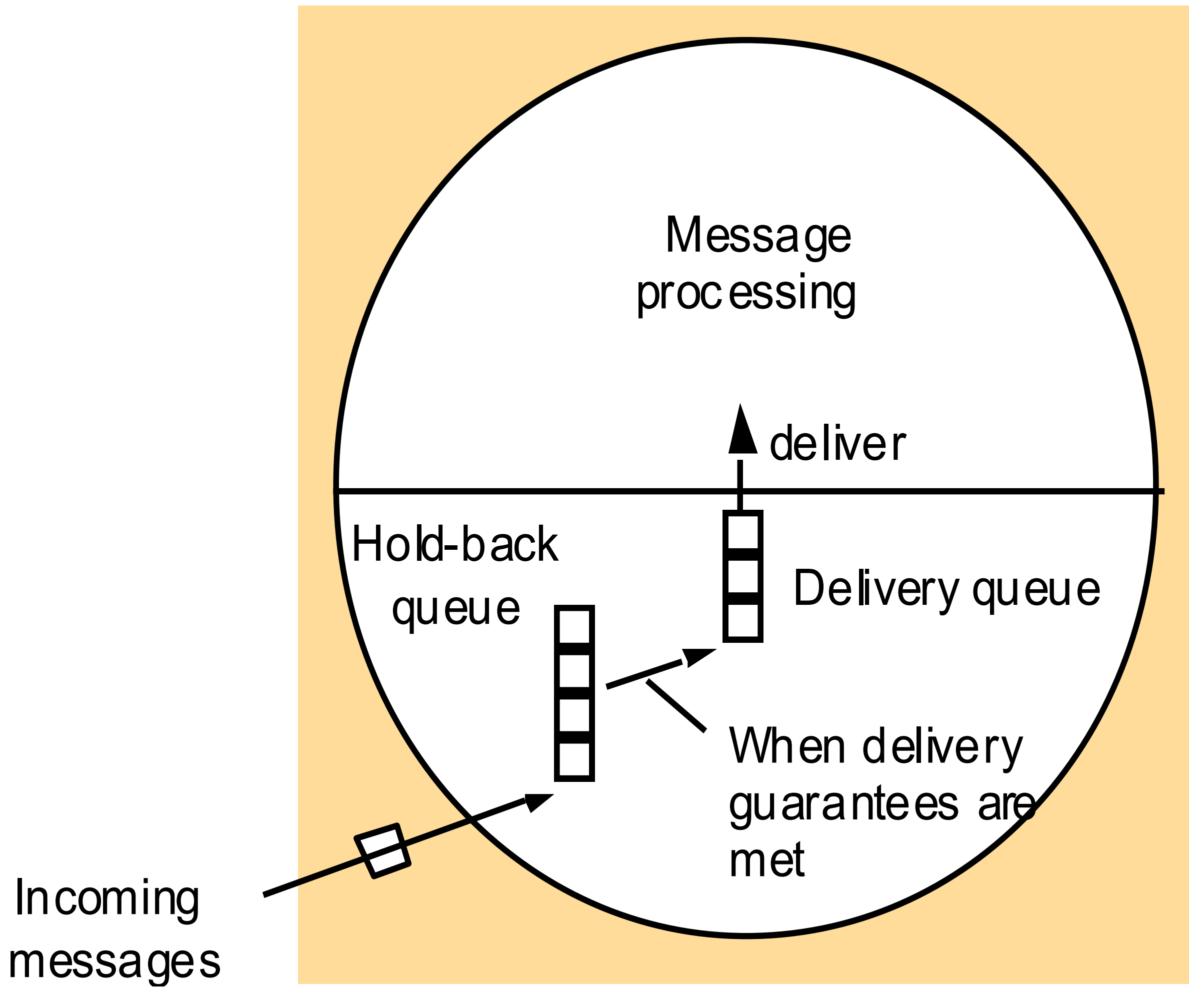
Providing Ordering Guarantees (FIFO)

- Look at messages from each process in the order they were sent:
  - Each process keeps a sequence number for each of the other processes.
  - When a message is received, if message # is:
    - » as expected (next sequence), accept
    - » higher than expected, buffer in a queue
    - » lower than expected, reject

Implementing FIFO Ordering

- S^p_g: the number of messages *p* has sent to *g*.
- R^q_g: the sequence number of the latest group-*g* message *p* has delivered from *q*.
- For *p* to FO-multicast *m* to *g*
  - *p* increments S^p_g by 1.
  - *p* "piggy-backs" the value S^p_g onto the message.
  - *p* B-multicasts *m* to *g*.
- At process *p*, Upon receipt of *m* from *q* with sequence number *S*:
  - *p* checks whether $S = R^q_g + 1$. If so, *p* FO-delivers m and increments R^q_g
  - If $S > R^q_g + 1$, *p* places the message in the hold-back queue until the intervening messages have been delivered and $S = R^q_g + 1$.

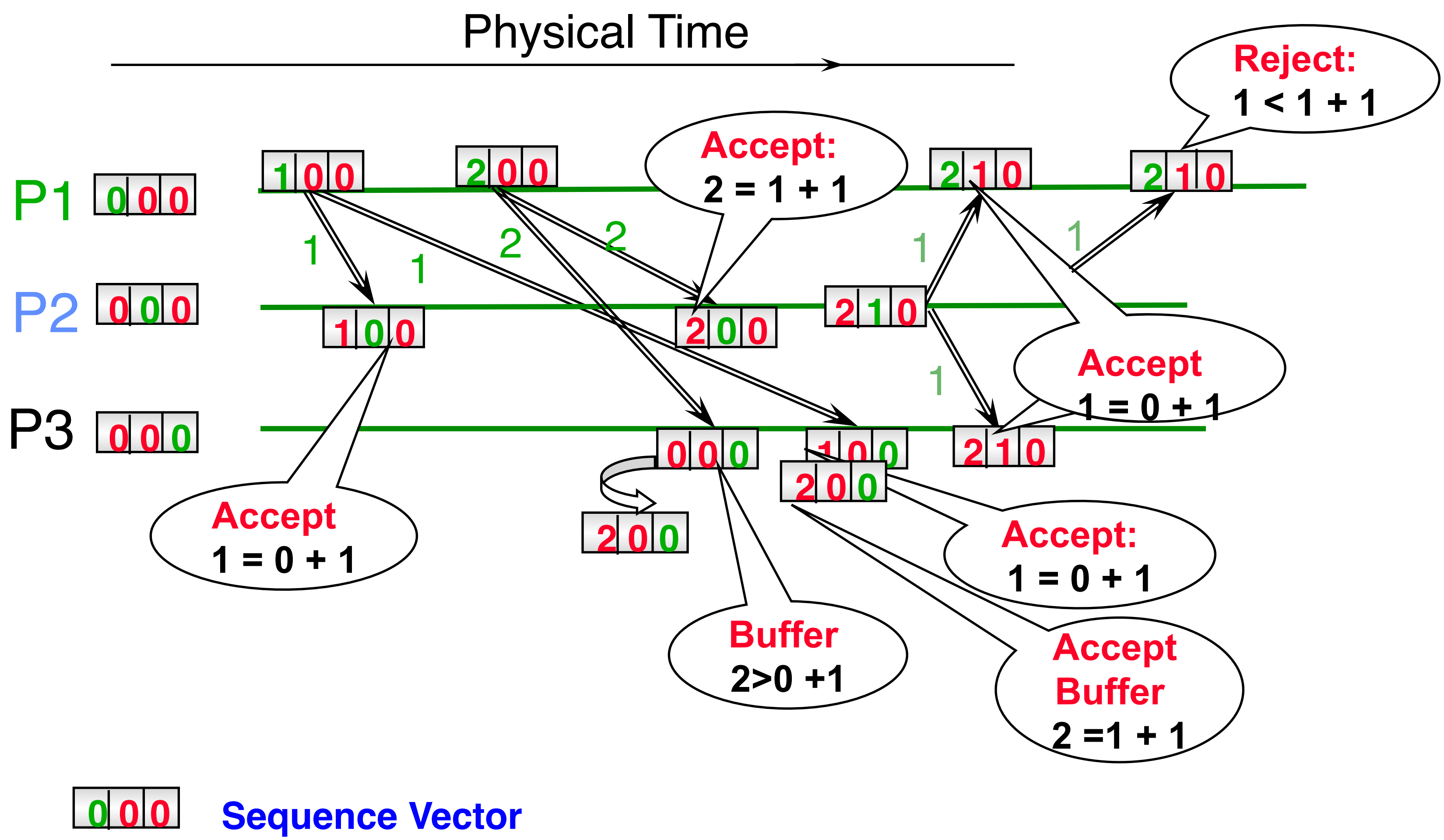
Hold-back Queue for Arrived Multicast Messages



Example: FIFO Multicast

*(do **NOT** be confused with vector timestamps)*

"Accept" = Deliver



Summary

- Reliable Multicast
  - Reliability
  - Ordering
  - R-multicast
- Ordered Multicast
  - FIFO ordering
  - Total ordering
  - Causal ordering
- Next: continue on multicast

Acknowledgements

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