Computer Science 425
Distributed Systems

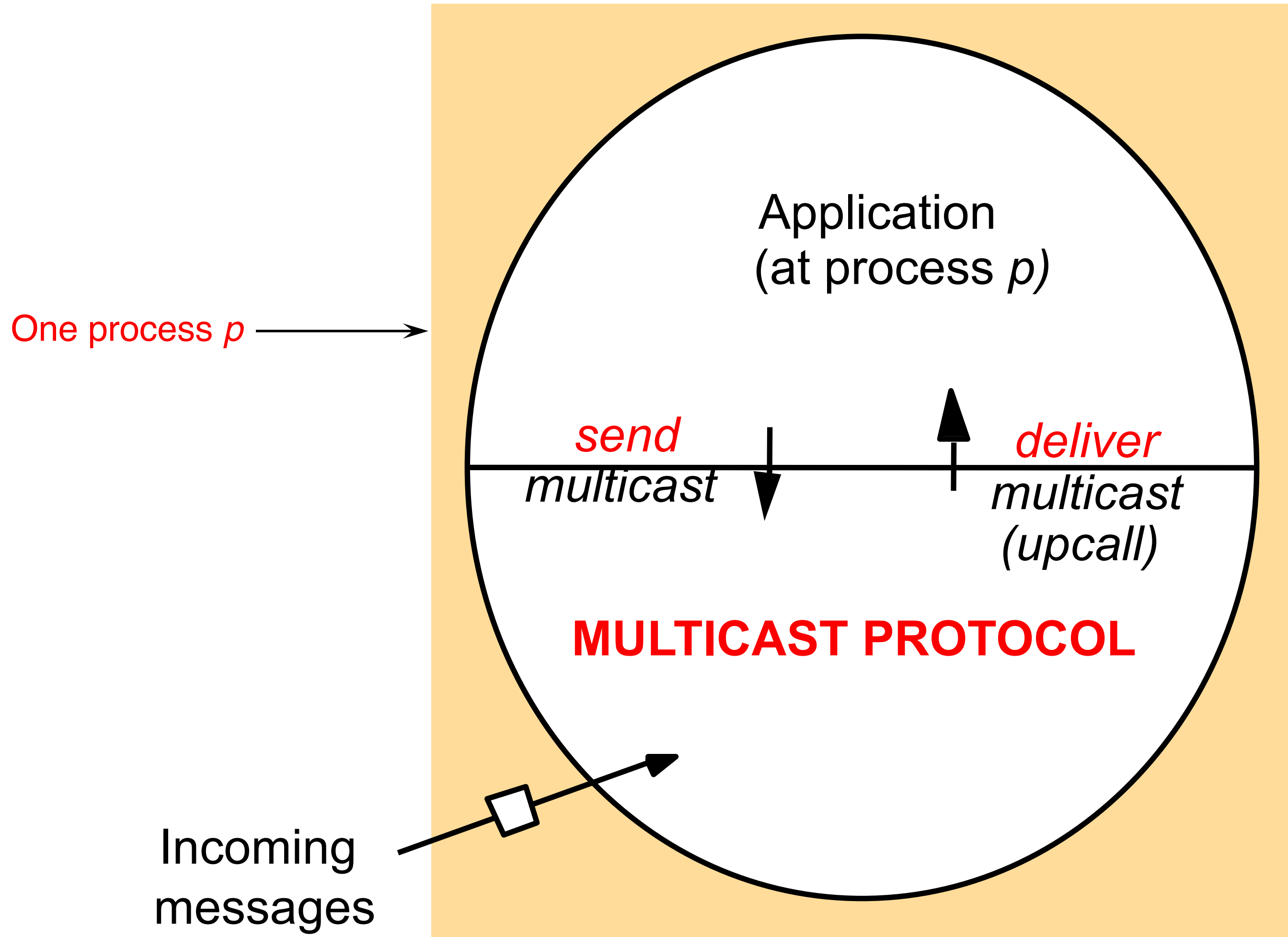
CS 425 / ECE 428

Multicast

Communication Modes in Distributed System

- **Unicast**
  - Messages are sent from exactly one process to one process.
  - *Best effort*: if a message is delivered it would be intact; no reliability guarantees.
  - *Reliable:* guarantees delivery of messages.
- **Broadcast**
  - Messages are sent from exactly one process to all processes on the network.
- **Multicast**
  - Messages broadcast within a group of processes.
  - A multicast message is sent from any one process to the group of processes on the network.
  - Reliable multicast can be implemented “above” (i.e., “using”) a reliable unicast.
    - This lecture!

What're we designing in this class



Basic Multicast (B-multicast)

- ***Let's assume the all processes know the group membership***
- ***A straightforward way to implement B-multicast is to use a reliable one-to-one send (unicast) operation:***
  - ***B-multicast(group g, message m):***

    for each process *p* in *g*, *send (p,m).*
  - **receive(m): *B-deliver(m)* at p.**
- **A "correct" process= a "non-faulty" process**
- **A basic multicast primitive guarantees a correct process will eventually deliver the message, as long as the sender (multicasting process) does not crash.**
  - ***Can we provide reliability even when the sender crashes (after it has sent the multicast)?***

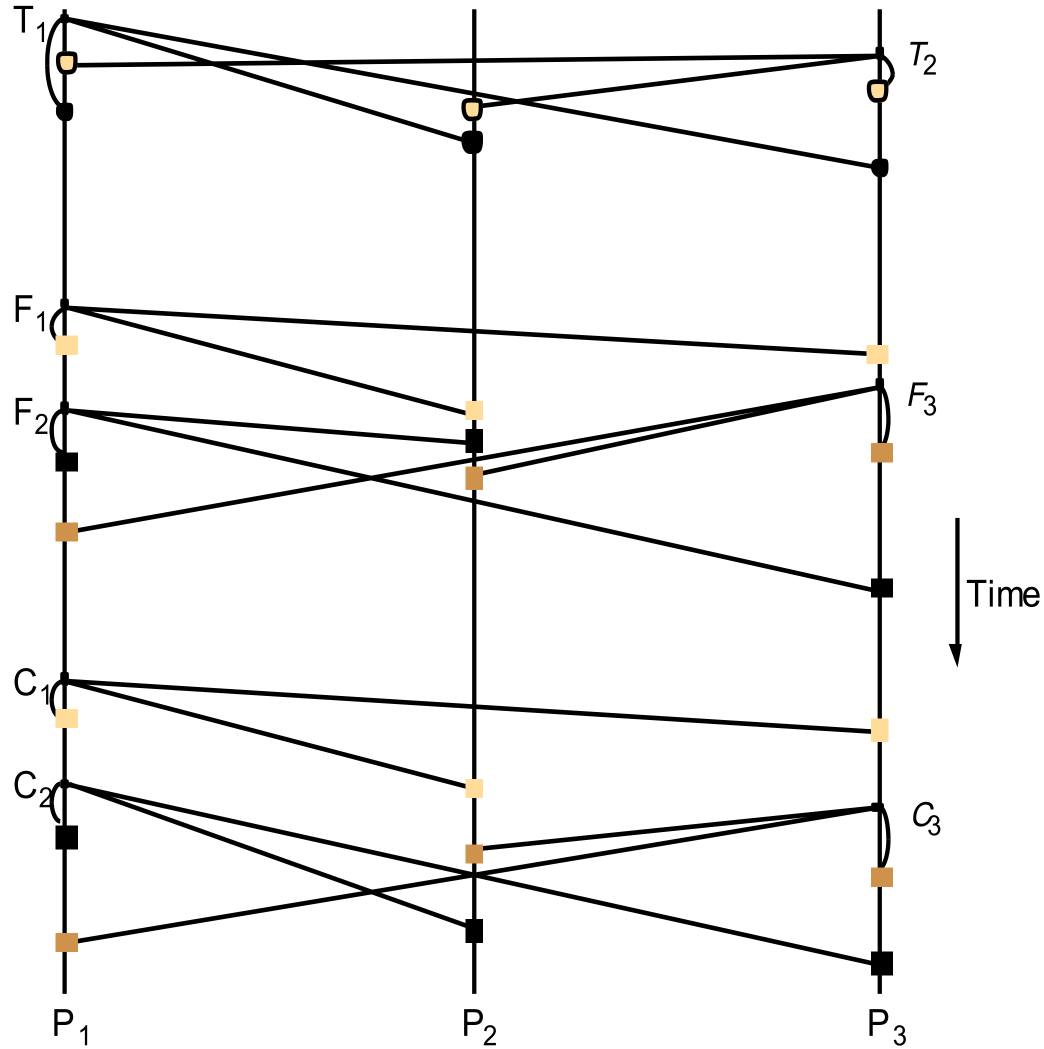
What about Multicast Ordering?

- ***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.**
- ***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

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



Display From Newsgroup

Newsgroup: *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)

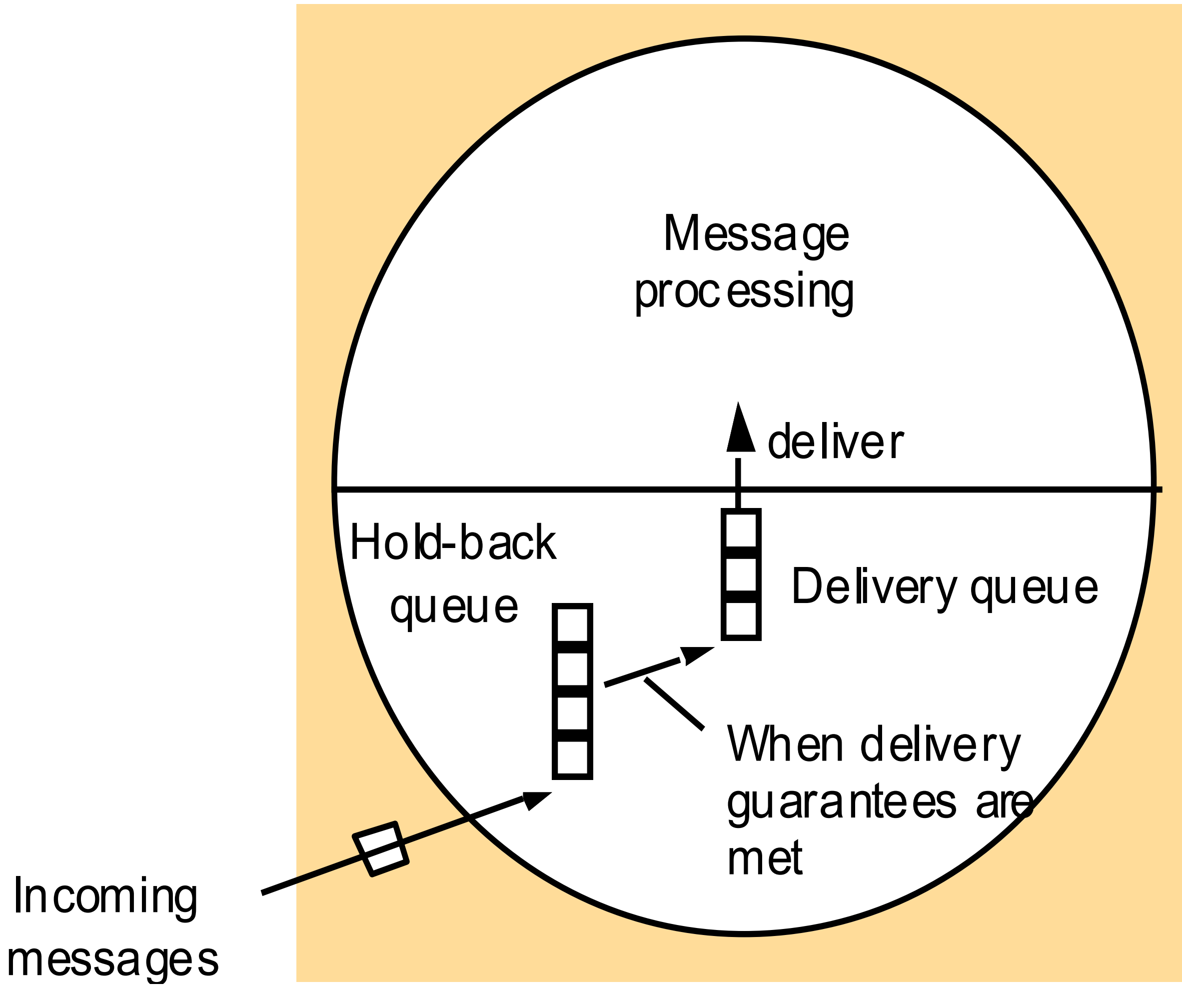
- Look at messages from each process in the order they were sent:
  - Each process keeps a sequence number for each other process (vector)
  - When a message is received,

If Message# is
- as expected (next sequence), accept
- higher than expected, buffer in a queue
- lower than expected, reject

Implementing FIFO Ordering

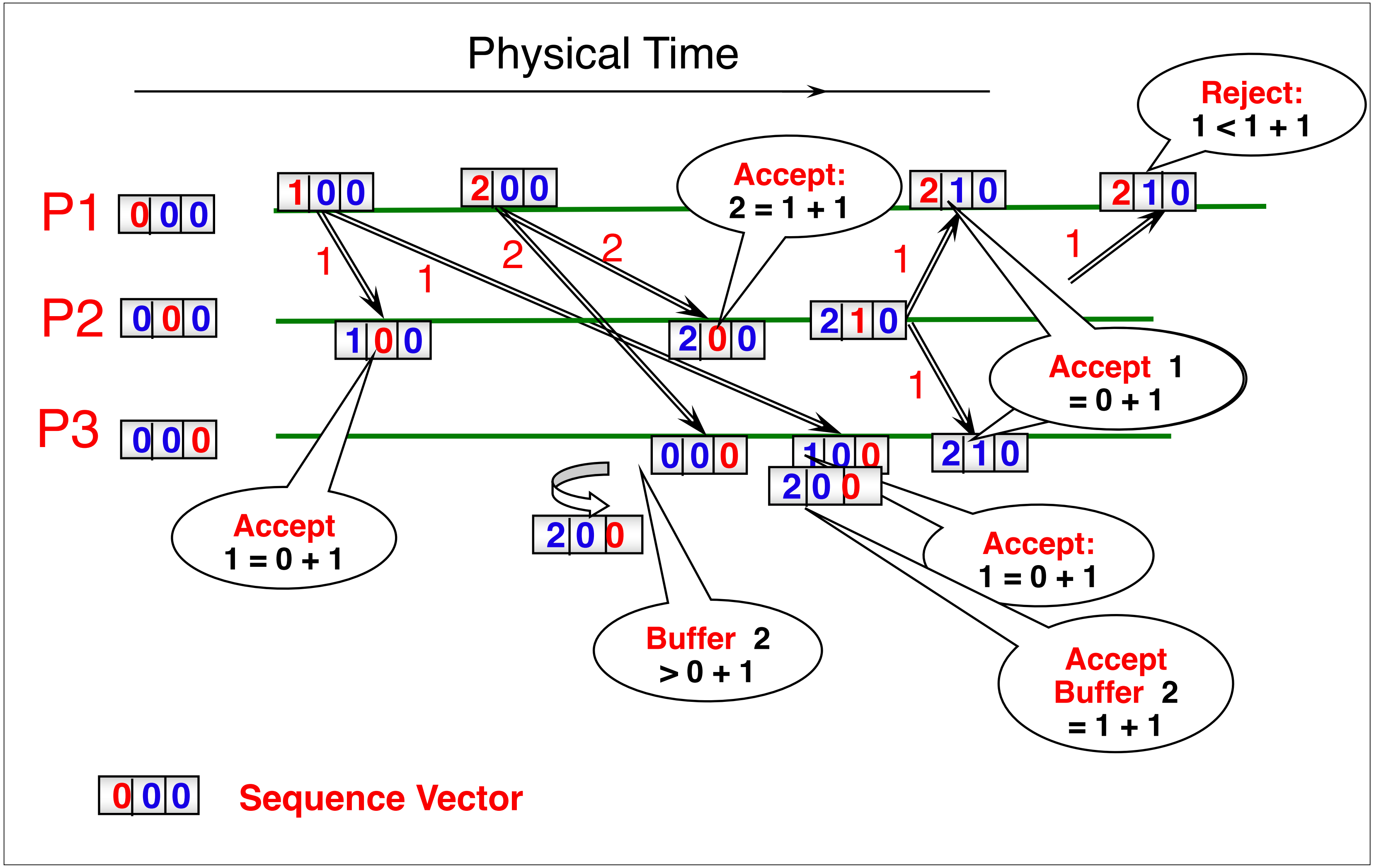
- S^p_g: the number of messages *p* has sent to *g*.
- R^q_g: the sequence number of the latest group-*g* message that *p* has delivered from *q* (maintained for all q at p)
- For *p* to FO-multicast *m* to *g*
  - *p increments S^p_g by 1.*
  - p "piggy-backs" the value *S^p_g onto the message.*
  - *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 $S = R^q_g+1$.*
  - *If $S < R^q_g+1$, reject m*

Hold-back Queue for Arrived Multicast Messages



Example: FIFO Multicast

*(do **NOT** confuse with vector timestamps)*
"Accept" = Deliver



Total Ordering Using a Sequencer

Sequencer = Leader process

1. Algorithm for group member p

On initialization: $r_g := 0$;

To TO-multicast message m to group g
   B-multicast$(g \cup \{sequencer(g)\}, <m, i>)$;

On B-deliver$(<m, i>)$ *with* $g = group(m)$
   Place $<m, i>$ in hold-back queue;

On B-deliver$(m_{order} = <\text{"order"}, i, S>)$ *with* $g = group(m_{order})$
   wait until $<m, i>$ in hold-back queue and $S = r_g$;
   TO-deliver m;   // (after deleting it from the hold-back queue)
   $r_g = S + 1$;

2. Algorithm for sequencer of g

On initialization: $s_g := 0$;

On B-deliver$(<m, i>)$ *with* $g = group(m)$
   B-multicast$(g, <\text{"order"}, i, s_g>)$;
   $s_g := s_g + 1$;

Causal Ordering using vector timestamps

Algorithm for group member p_i ($i = 1, 2..., N$)

On initialization

$V_i^g[j] := 0$ ($j = 1, 2..., N$);

The number of group-g messages from process j that have been seen at process i so far

To CO-multicast message m to group g

$V_i^g[i] := V_i^g[i] + 1$;

B-multicast(g, <V_i^g, m>);

On B-deliver(<V_j^g, m>) *from* p_j, *with* $g = group(m)$

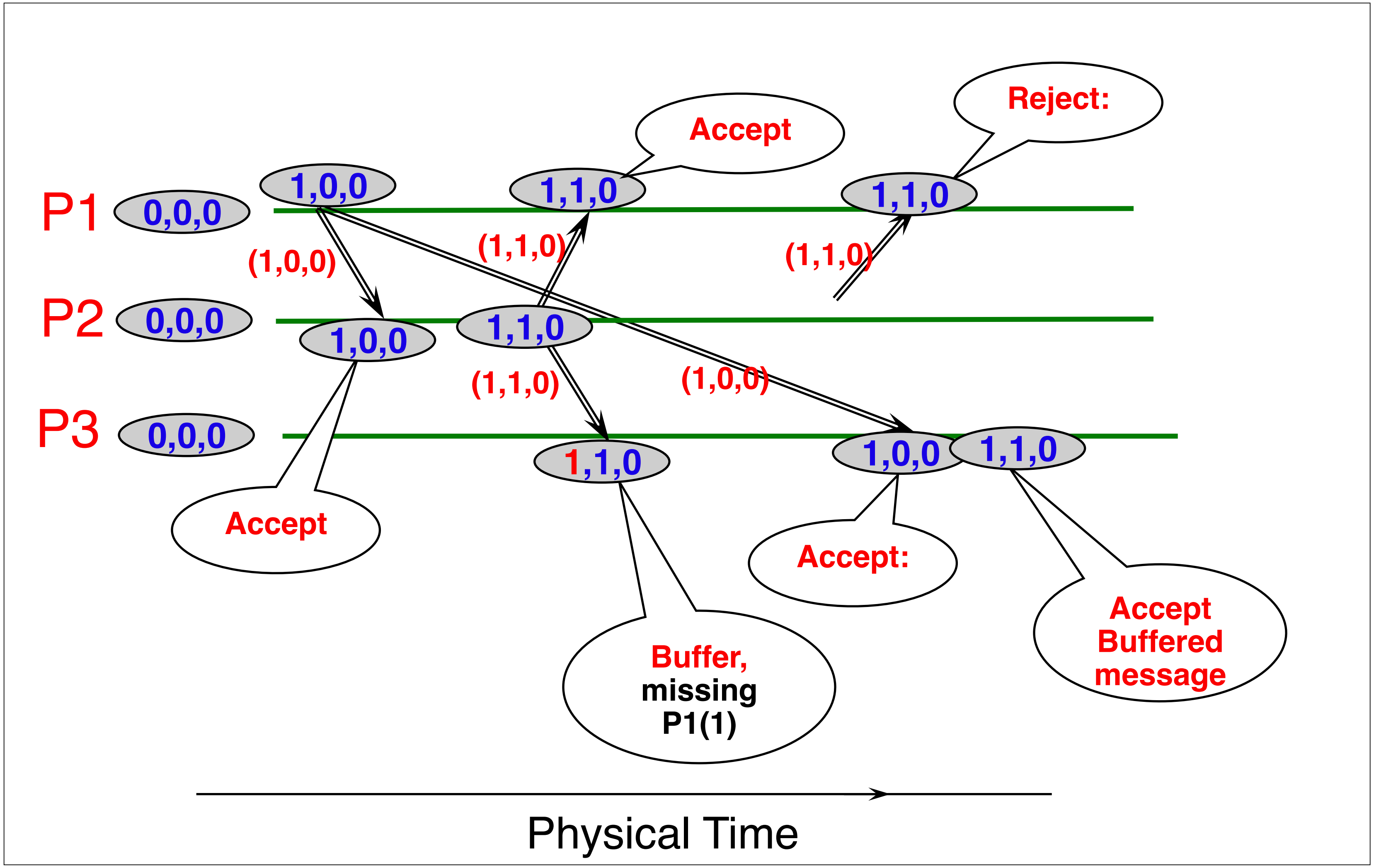
place <V_j^g, m> in hold-back queue;

wait until $V_j^g[j] = V_i^g[j] + 1$ and $V_j^g[k] \le V_i^g[k]$ ($k \ne j$);

CO-deliver m; // after removing it from the hold-back queue

$V_i^g[j] := V_i^g[j] + 1$;

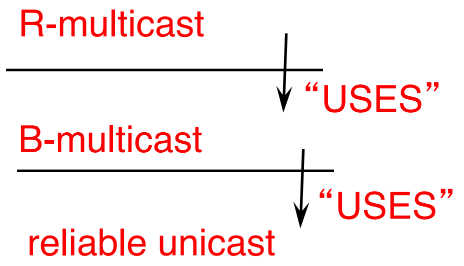
Example: Causal Ordering Multicast



Reliable Multicast

- ***Integrity***: A ***correct*** (i.e., non-faulty) process ***p*** ***delivers*** a message m at most once.
- ***Validity***: If a correct process multicasts (sends) message ***m***, then it will eventually deliver ***m*** itself.
  - Guarantees liveness to the sender.
- ***Agreement***: If some one correct process delivers message ***m***, then all other correct processes in ***group(m)*** will eventually deliver ***m***.
  - Property of "all or nothing."
  - Validity and agreement together ensure overall liveness: if some correct process multicasts a message m, then, all correct processes deliver m too.

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 a destination

On B-deliver(*m*) *at process q with g = group*(*m*)
    if ($m \notin$ *Received*)
    then
        Received := *Received* $\cup$ {*m*};
        if ($q \neq p$) *then B-multicast*(*g*, *m*); *end if*
        R-deliver m;
    end if

Reliable Multicast Algorithm (R-multicast)

On initialization
　Received := {};

For process p to R-multicast message m to group g
　B-multicast(*g*, *m*);　　// $p \in g$ is included as a destination

On B-deliver(*m*) *at process q with g* = *group*(*m*)
　if ($m \notin$ *Received*)　Integrity
　then
　　Received := *Received* $\cup$ {*m*};
　　if ($q \neq p$) *then B-multicast*(*g*, *m*); *end if*　Agreement
　　R-deliver m;　Integrity, Validity
　end if

if <u>some</u> correct process B-multicasts a message m, then, all correct processes R-deliver m too. If no correct process B-multicasts m, then no correct processes R-deliver m.

Summary

Multicast is operation of sending one message to multiple processes in a given group

- Reliable multicast algorithm built using unicast
- Ordering – FIFO, total, causal