Distributed Systems

CS425/ECE428

02/14/2020

Today's agenda

- Multicast (contd.)
  - *Chapter 15.4*
  - Implementing ordered multicast.

- Acknowledgement:
  - Materials derived from Prof. Indy Gupta, Prof. Nitin Vaidya, and Prof. Nikita Borisov.

Logistics

- Midterm on March 2nd 7-9pm.
  - Please let us know of any conflicts by Monday.
- HW2 will be released tonight.
  - Due on Feb 27th.
- Still have people who do not have CampusWire access!
  - Please email the instructors and make sure you have access.

Recap: Multicast

- Useful communication mode in distributed systems:
  - Writing an object across replica servers.
  - Group messaging.
  - …..
- Basic multicast (B-multicast): unicast send to each process in the group.
  - Does not guarantee consistent message delivery if sender fails.
- Reliable multicast (R-mulicast):
  - Defined by three properties: *integrity, validity, agreement*.
  - If some correct process multicasts a message **m**, then all other correct processes deliver the **m** (exactly once).
  - When a process receives a message 'm' for the first time, it re-multicasts it again to other processes in the group.

Recap: 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*.
  - Note that → counts messages **delivered** to the application, rather than all network messages.
- **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*.

Multicast Ordering Example

Online bulletin board		
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		

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If we swap items 23 and 24, does that satisfy FIFO order?

Yes

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If we swap items 24 and 25, does that satisfy FIFO order?

Yes

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If we swap items 24 and 25, does that satisfy causal order?

No

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If we swap items 23 and 24 for one process displaying the bulletin and not for another, does that satisfy FIFO order?

Yes

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If we swap items 24 and 25 for all processes displaying the bulletin does that satisfy causal order?

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If we swap items 24 and 25 for all processes displaying the bulletin does that satisfy total order?

Yes

Next Question

How do we implement ordered multicast?

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.
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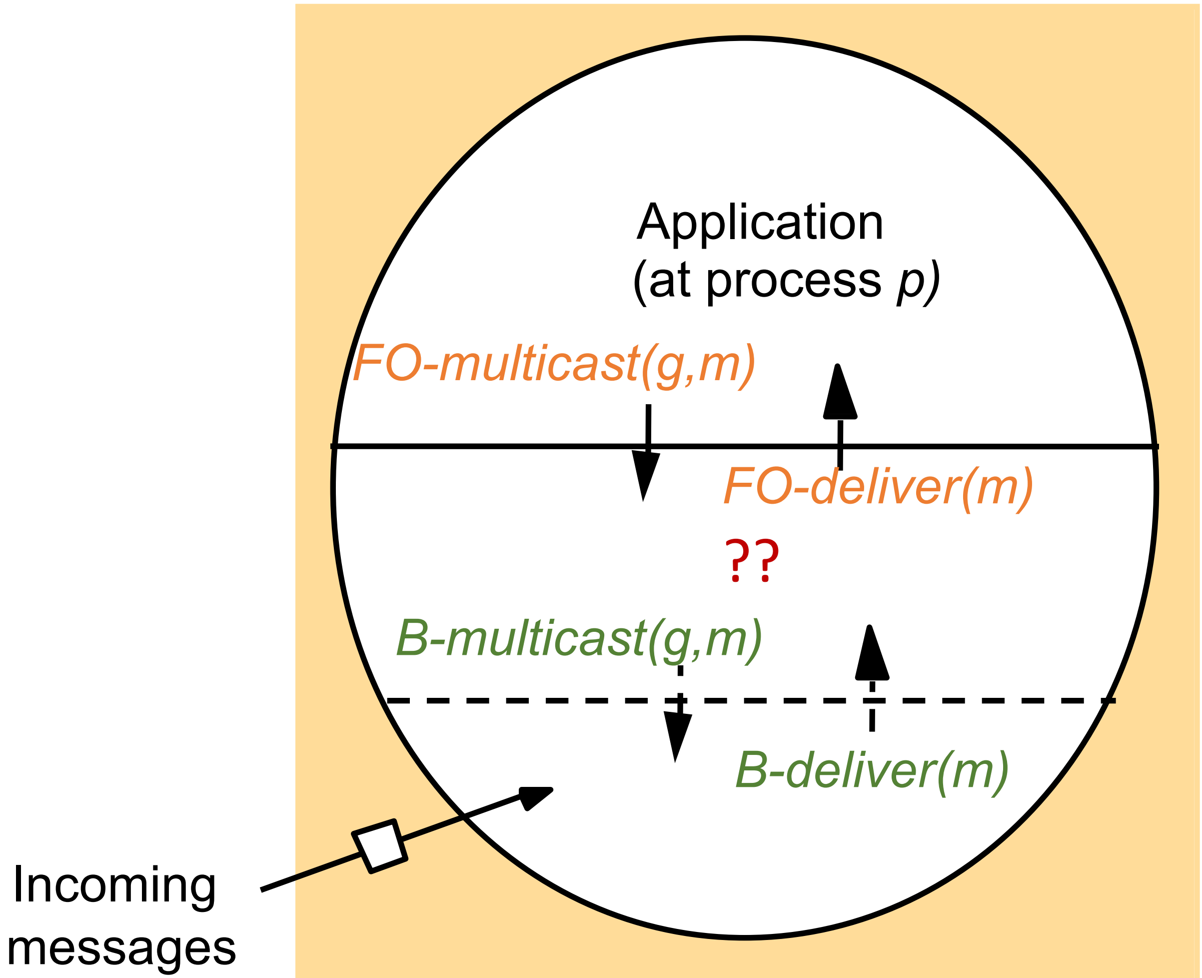
Implementing FIFO order multicast



Implementing FIFO order multicast

- Each receiver maintains a per-sender sequence number
  - Processes P*1* through P*N*
  - P*i* maintains a vector of sequence numbers P*i*[1…N] (initially all zeroes)
  - P*i*[*j*] is the latest sequence number P*i* has received from P*j*

Implementing FIFO order multicast

- On FO-multicast(g,m) at process P*j*:

  set P*j*[*j*] = P*j*[*j*] + 1

  piggyback P*j*[*j*] with m as its sequence number.

  B-multicast(g,{m, P*j*[*j*]})

- On B-deliver({m, S}) at Pi from Pj: *If Pi receives a multicast from Pj with sequence number S in message*

  if (S == P*i*[*j*] + 1) then

  FO-deliver(m) to application

  set P*i*[*j*] = P*i*[*j*] + 1

  else buffer this multicast until above condition is true

FIFO order multicast execution

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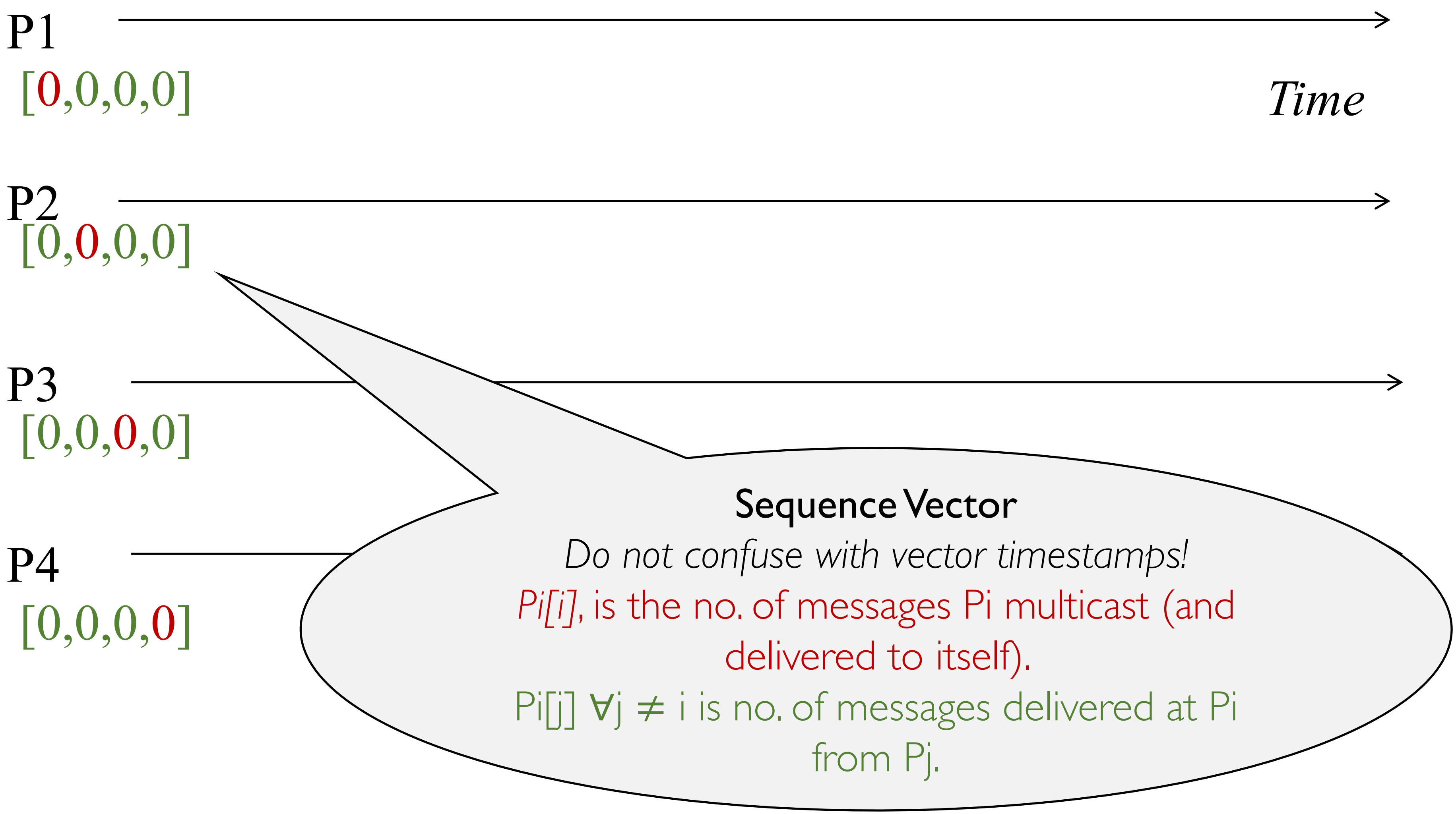

FIFO order multicast execution

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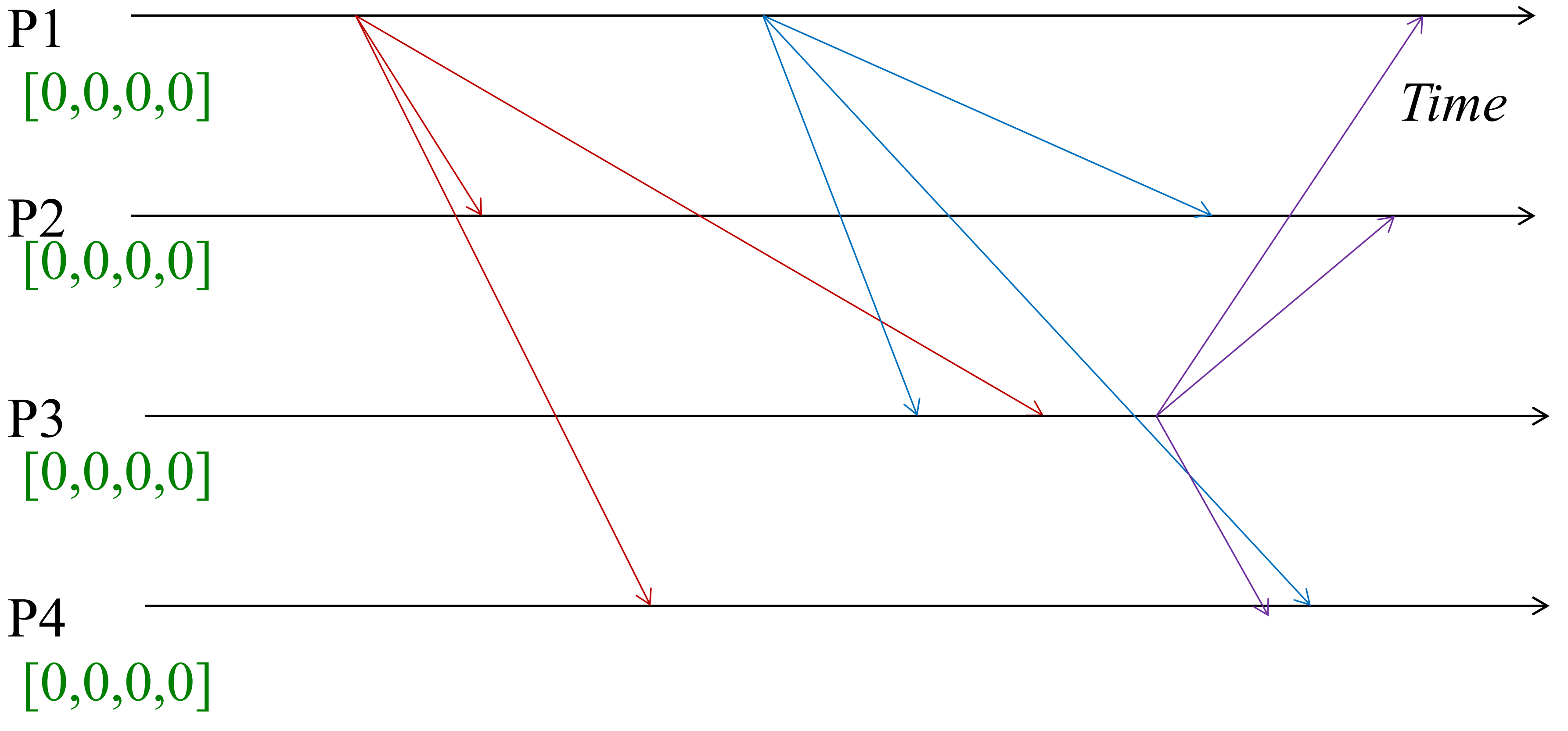
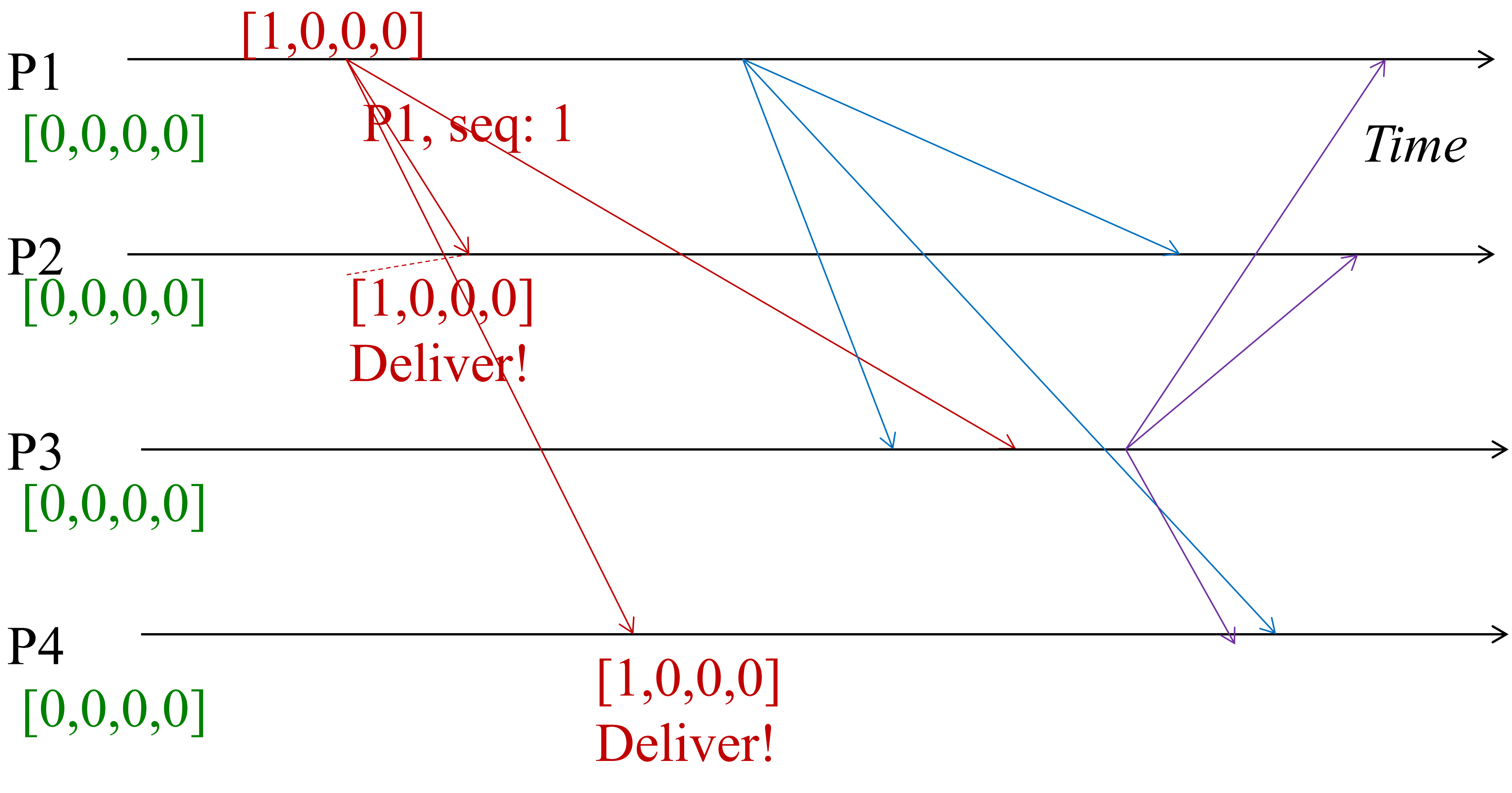


Self-deliveries omitted for simplicity.

FIFO order multicast execution



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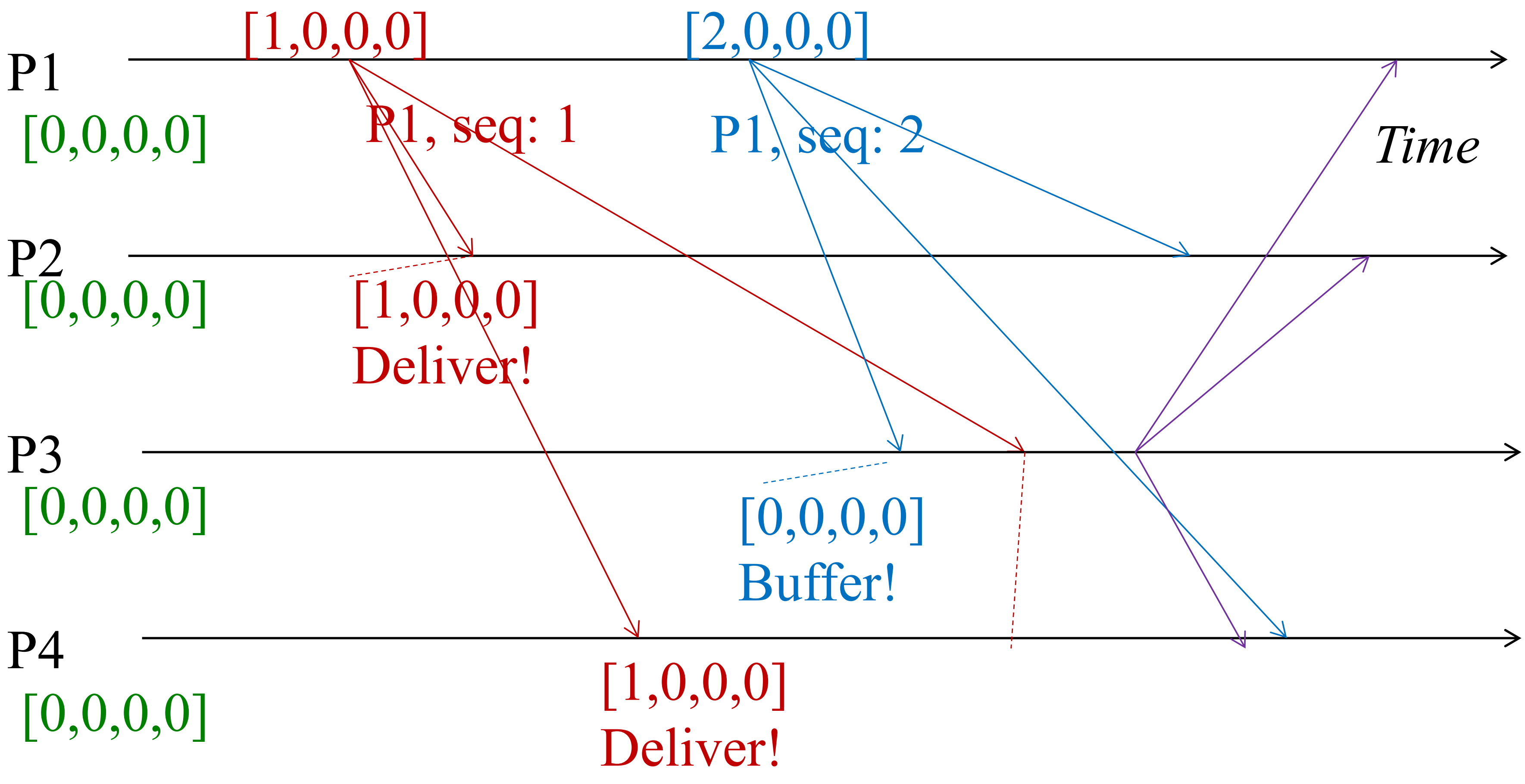

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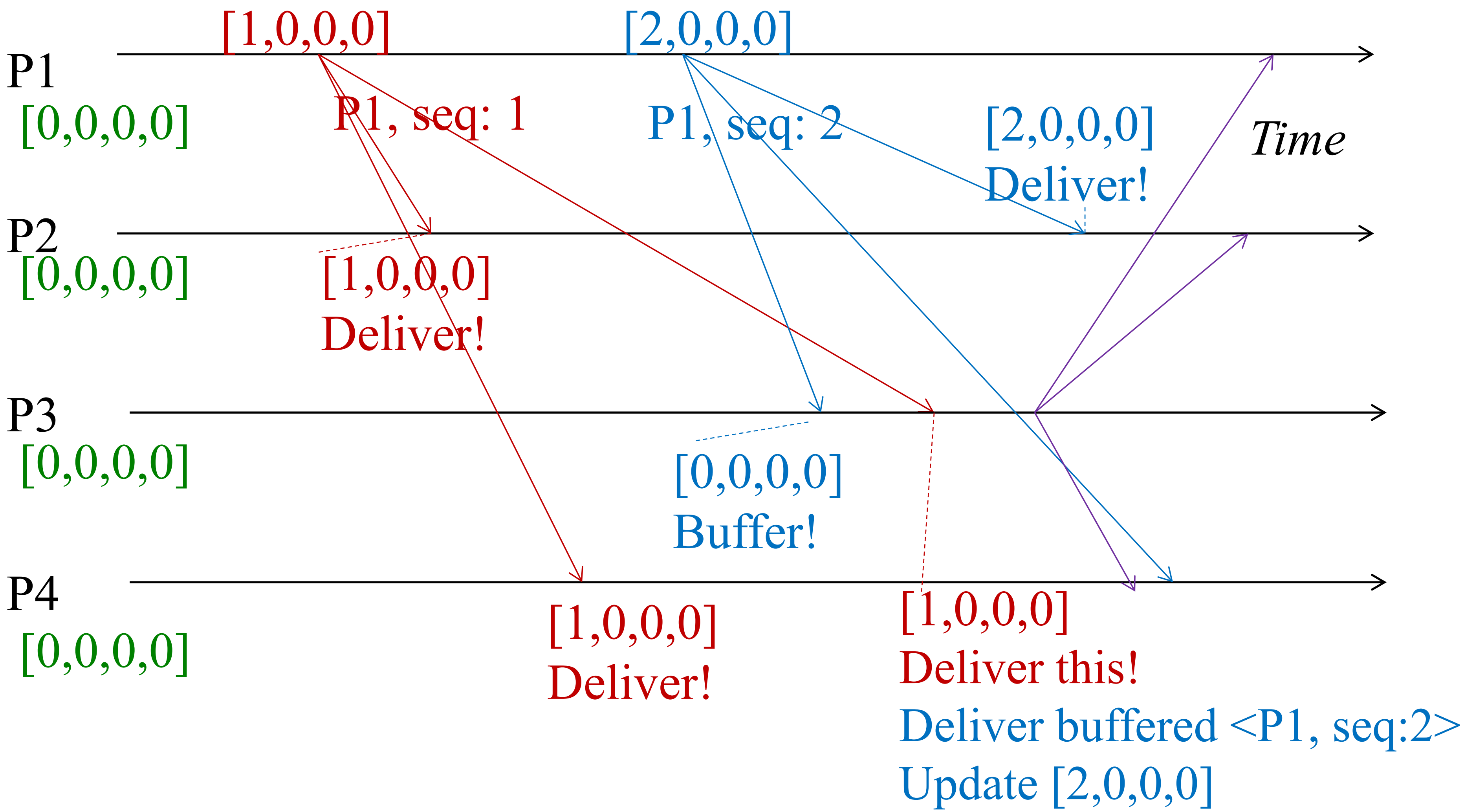

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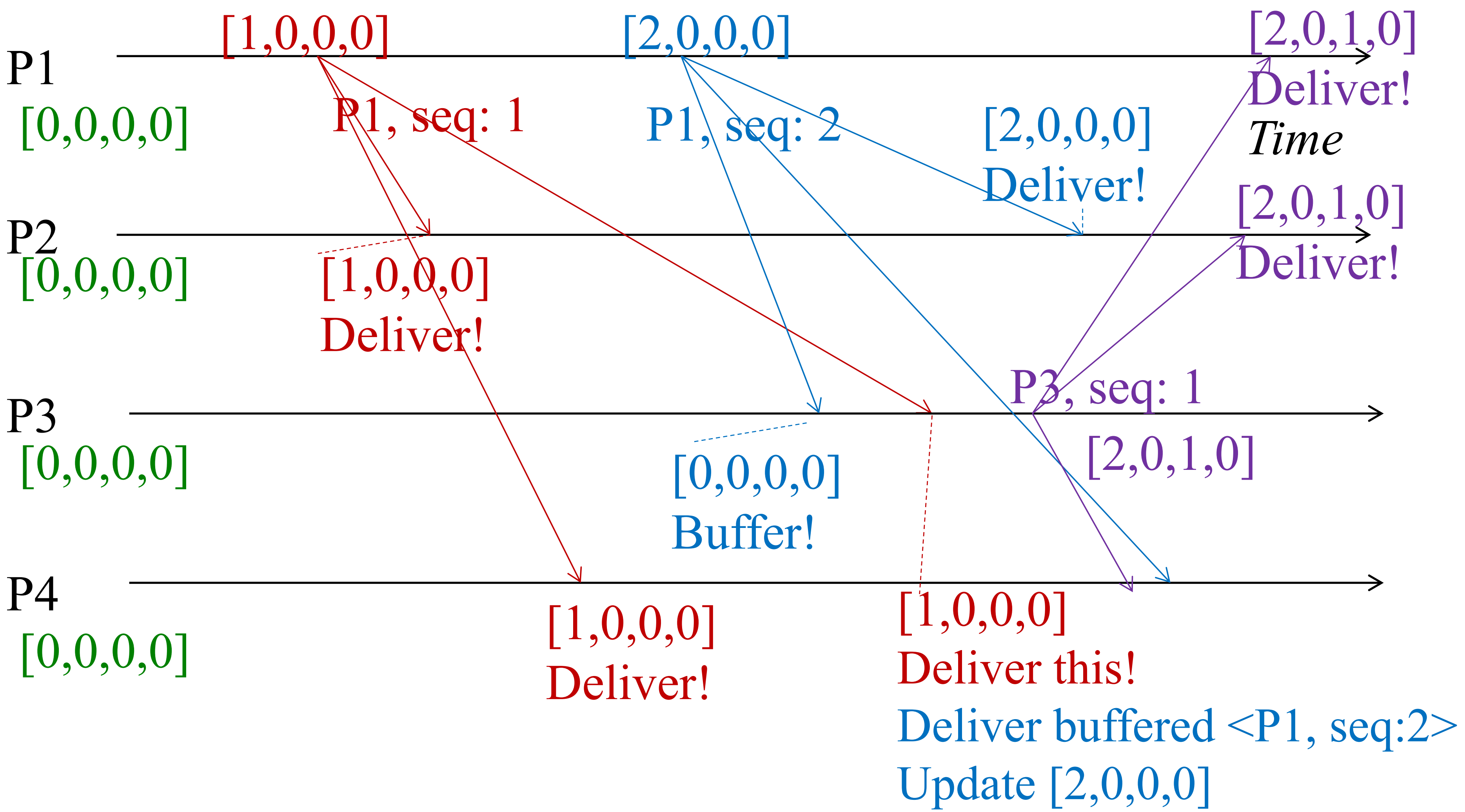

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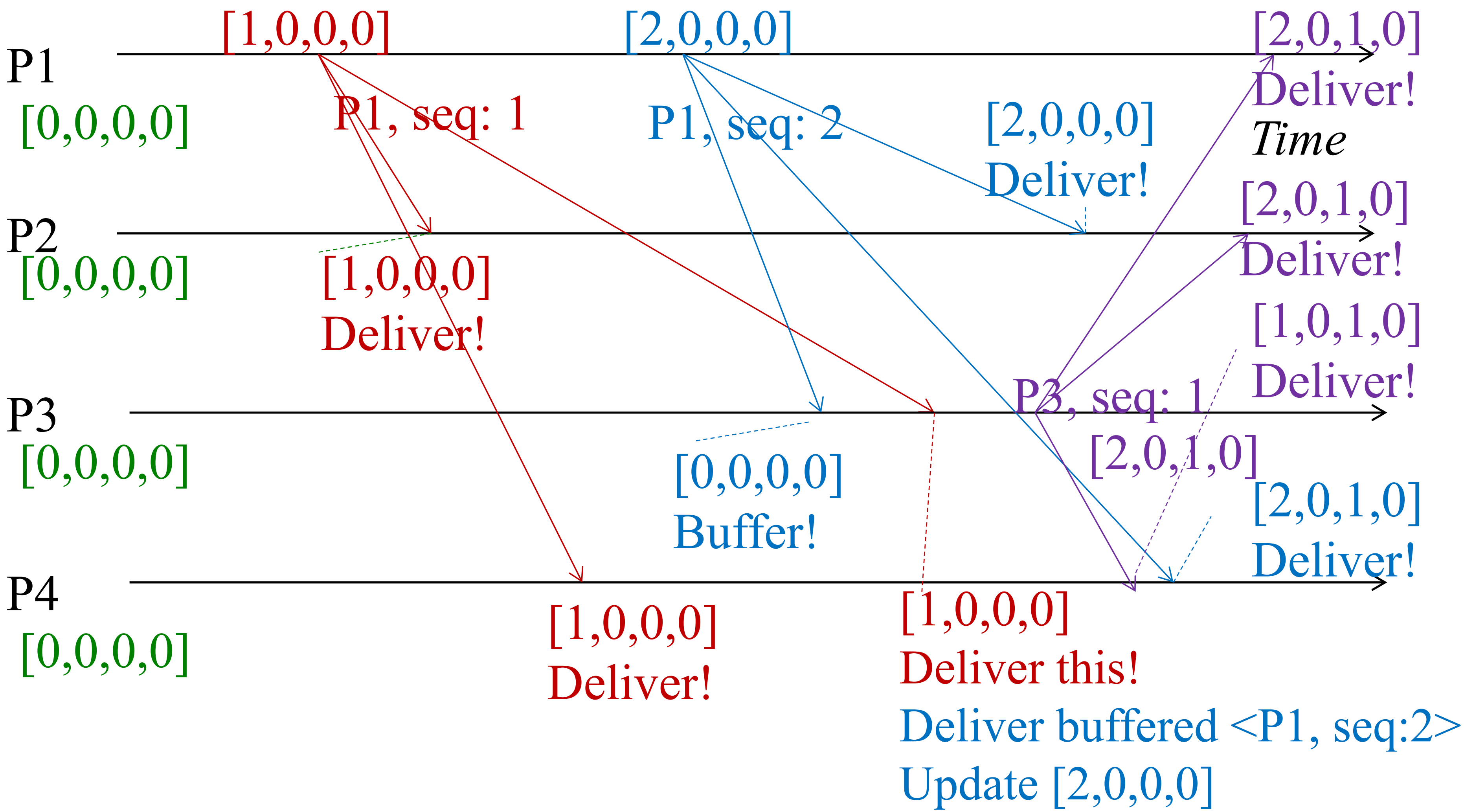

Implementing FIFO order multicast

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  B-multicast(g, {m, P*j*[*j*]})

- On B-deliver({m, S}) at Pi from Pj: *If Pi receives a multicast from Pj with sequence number S in message*

  if (S == P*i*[*j*] + 1) then

  FO-deliver(m) to application

  set P*i*[*j*] = P*i*[*j*] + 1

  else buffer this multicast until above condition is true

Implementing FIFO reliable multicast

- On FO-multicast(g,m) at process P*j*:

  set P*j*[*j*] = P*j*[*j*] + 1

  piggyback P*j*[*j*] with m as its sequence number.

  R-multicast(g,{m, P*j*[*j*]})

- On **R-deliver({m, S})** at Pi from Pj: *If Pi receives a multicast from Pj with sequence number S in message*

  if (S == P*i*[*j*] + 1) then

  FO-deliver(m) to application

  set P*i*[*j*] = P*i*[*j*] + 1

  else buffer this multicast until above condition is true

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*.
  - Note that → counts messages **delivered** to the application, rather than all network messages.
- **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*.

Implementing total order multicast

- Basic idea:
  - Same sequence number counter across different processes.
  - Instead of different sequence number counter for each process.

- Two types of approach
  - Using a centralized sequencer
  - A decentralized mechanism (ISIS)

Implementing total order multicast

- Basic idea:
  - Same sequence number counter across different processes.
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- Two types of approach
  - **Using a centralized sequencer**
  - A decentralized mechanism (ISIS)

Sequencer based total ordering

- Special process elected as leader or sequencer.
- TO-multicast(g,m) at P*i*:
  - Send multicast message m to group g *and the sequencer*
- Sequencer:
  - Maintains a global sequence number S (initially 0)
  - When a multicast message m is B-delivered to it:
    - sets S = S + 1, and B-multicast(g,{"order", m, S})
- Receive multicast at process P*i*:
  - P*i* maintains a local received global sequence number S*i* (initially 0)
  - On B-deliver(m) at P*i* from P*j*, it buffers it until both conditions satisfied
    1. B-deliver({"order", m, S}) at P*i* from sequencer, and
    2. S*i* + 1 = S
    - Then TO-deliver(m) to application and set S*i* = S*i* + 1

Implementing total order multicast

- Basic idea:
  - Same sequence number counter across different processes.
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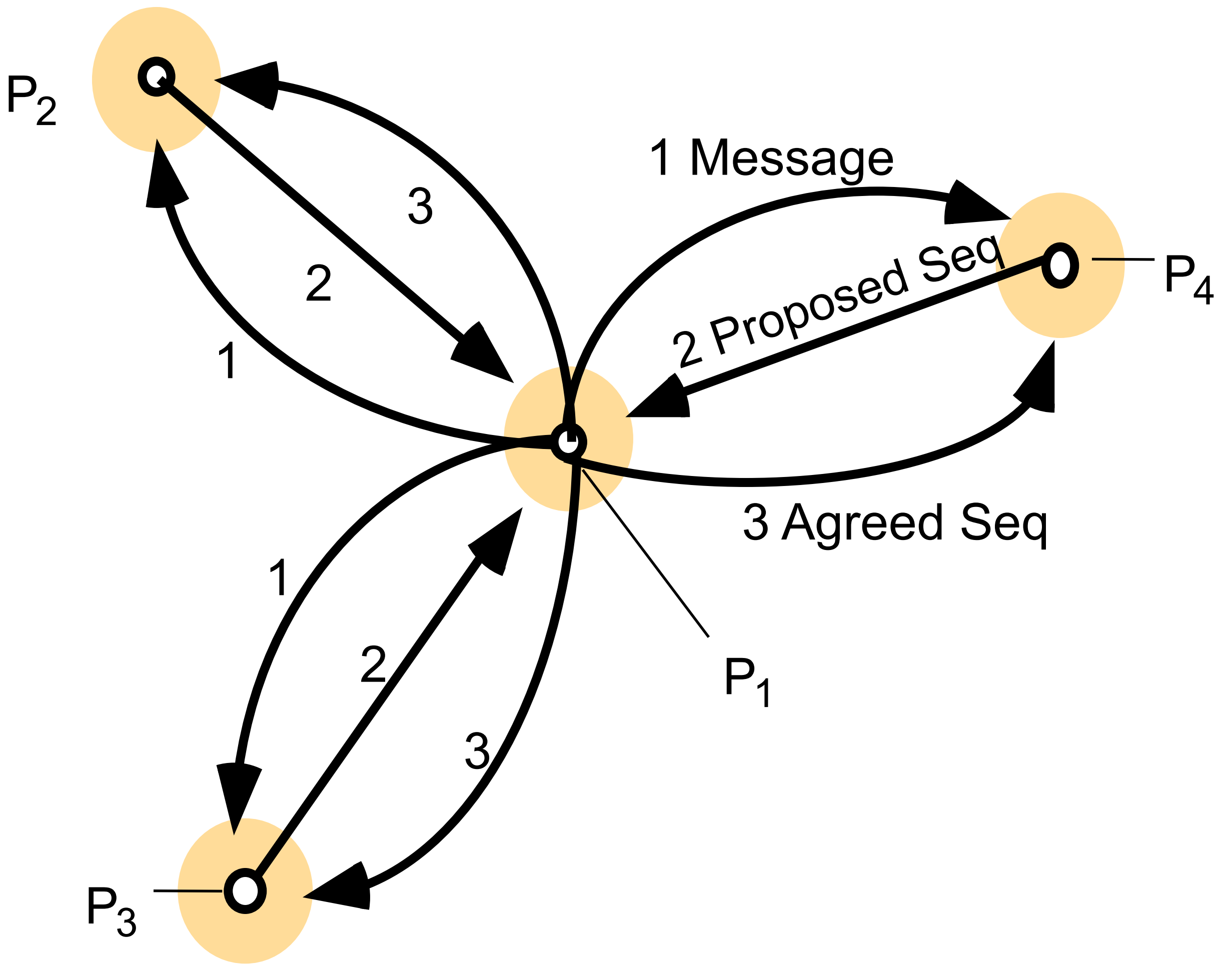
- Two types of approach
  - Using a centralized sequencer
  - **A decentralized mechanism (ISIS)**

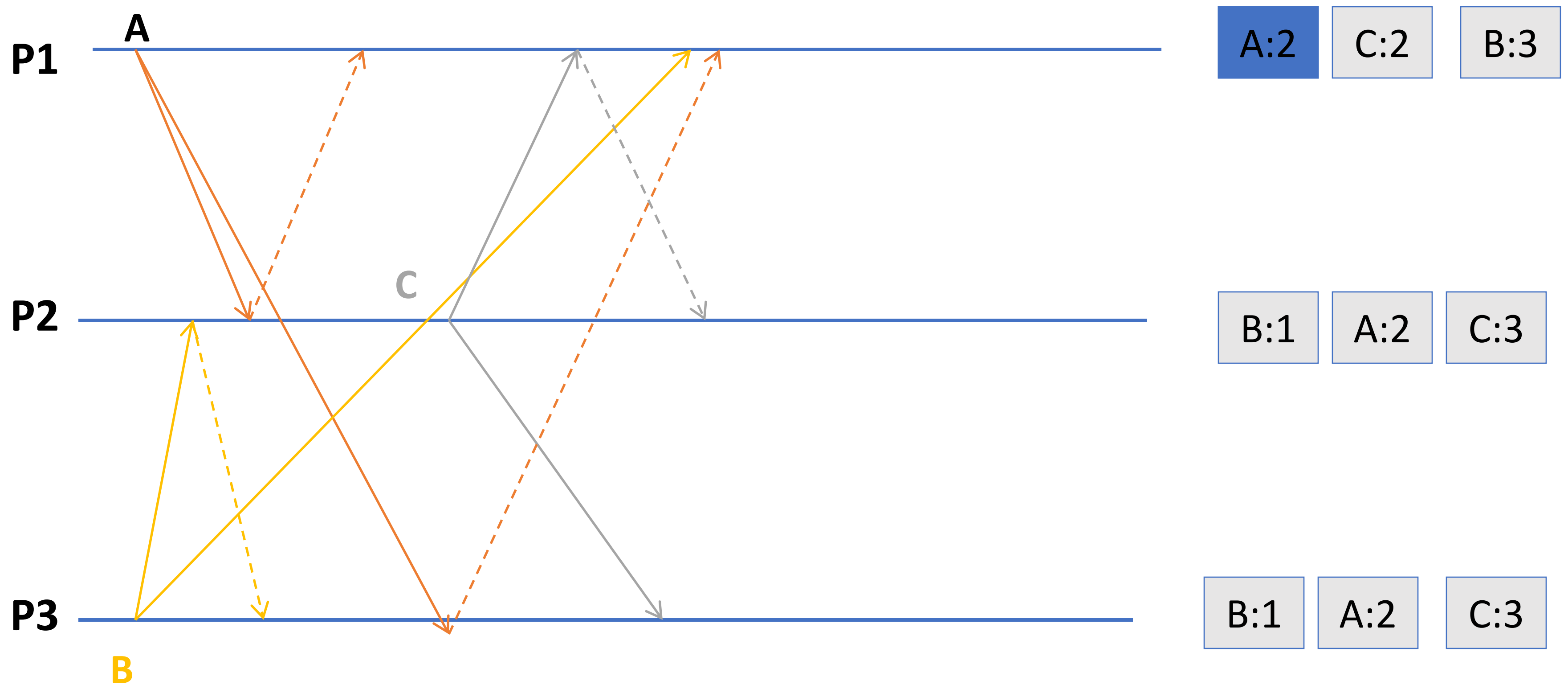
ISIS algorithm for total ordering



ISIS algorithm for total ordering

- Sender multicasts message to everyone.
- Receiving processes:
  - reply with *proposed* priority (sequence no.)
    - larger than all observed *agreed* priorities
    - larger than any previously proposed (by self) priority
  - store message in *priority queue*
    - ordered by priority (proposed or agreed)
  - mark message as undeliverable
- Sender chooses *agreed* priority, re-multicasts message with agreed priority
  - maximum of all proposed priorities
- Upon receiving agreed (final) priority
  - reorder messages based on final priority.
  - mark the message as deliverable.
  - deliver any deliverable messages at front of priority queue.

Example: ISIS algorithm



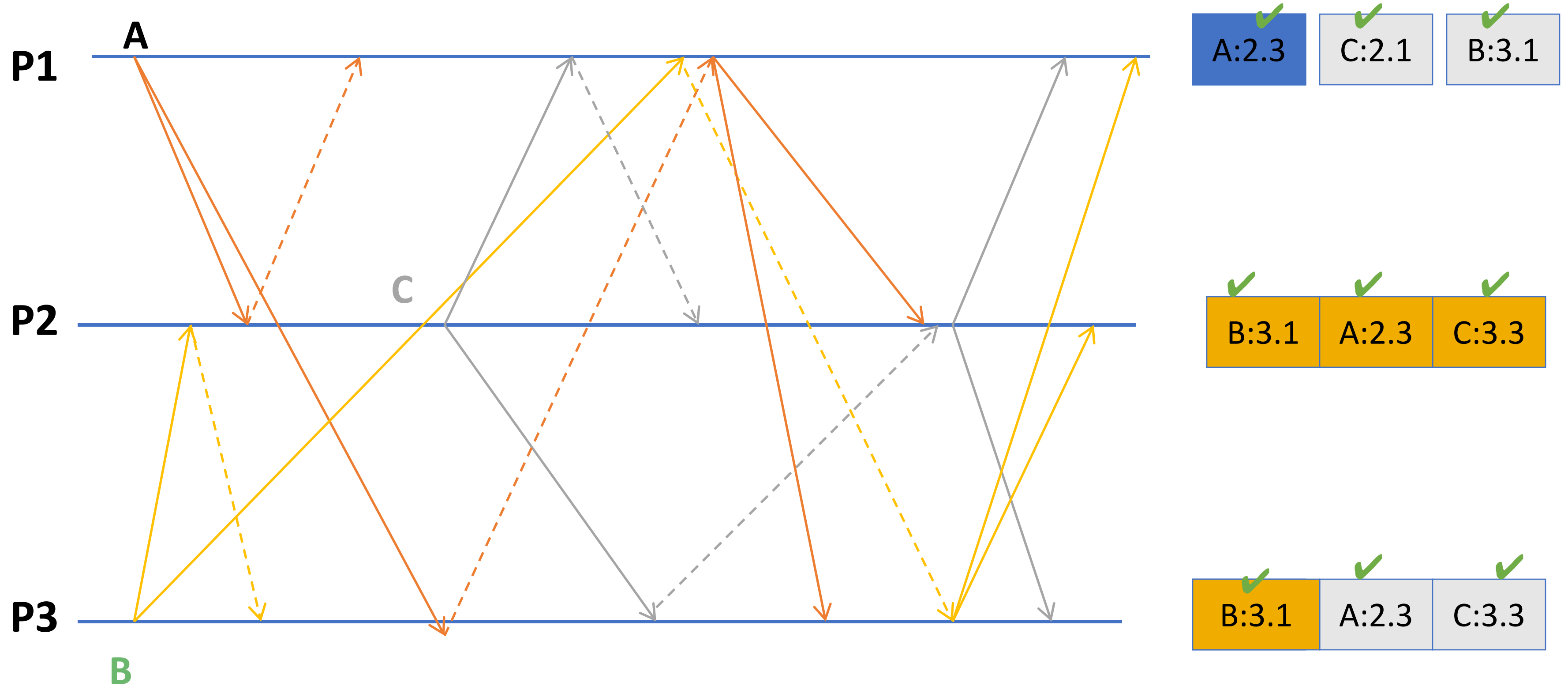
How do we break ties?

- Problem: priority queue requires unique priorities.

- Solution: add process # to suggested priority.
  - priority.(*id of the process that proposed the priority*)
  - i.e., 3.2 == process 2 proposed priority 3

- Compare on priority first, use process # to break ties.
  - 2.1 > 1.3
  - 3.2 > 3.1

Example: ISIS algorithm



Proof of total order with ISIS

- Consider two messages, m_1 and m_2, and two processes, p and p'.
- Suppose that p delivers m_1 before m_2.
- When *p* delivers m_1, it is at the head of the queue. m_2 is either:
  - Already in *p*'s queue, and deliverable, so
    - finalpriority(m_1) < finalpriority(m_2)
  - Already in *p*'s queue, and not deliverable, so
    - finalpriority(m_1) < proposedpriority(m_2) <= finalpriority(m_2)
  - Not yet in *p*'s queue:
    - same as above, since proposed priority > priority of any delivered message
- Suppose *p*' delivers m_2 before m_1, by the same argument:
  - finalpriority(m_2) < finalpriority(m_1)
  - Contradiction!

Ordered Multicast

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- 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*.

Implementing causal order multicast

- Similar to FIFO Multicast
  - What you send with a message differs.
  - Updating rules differ.

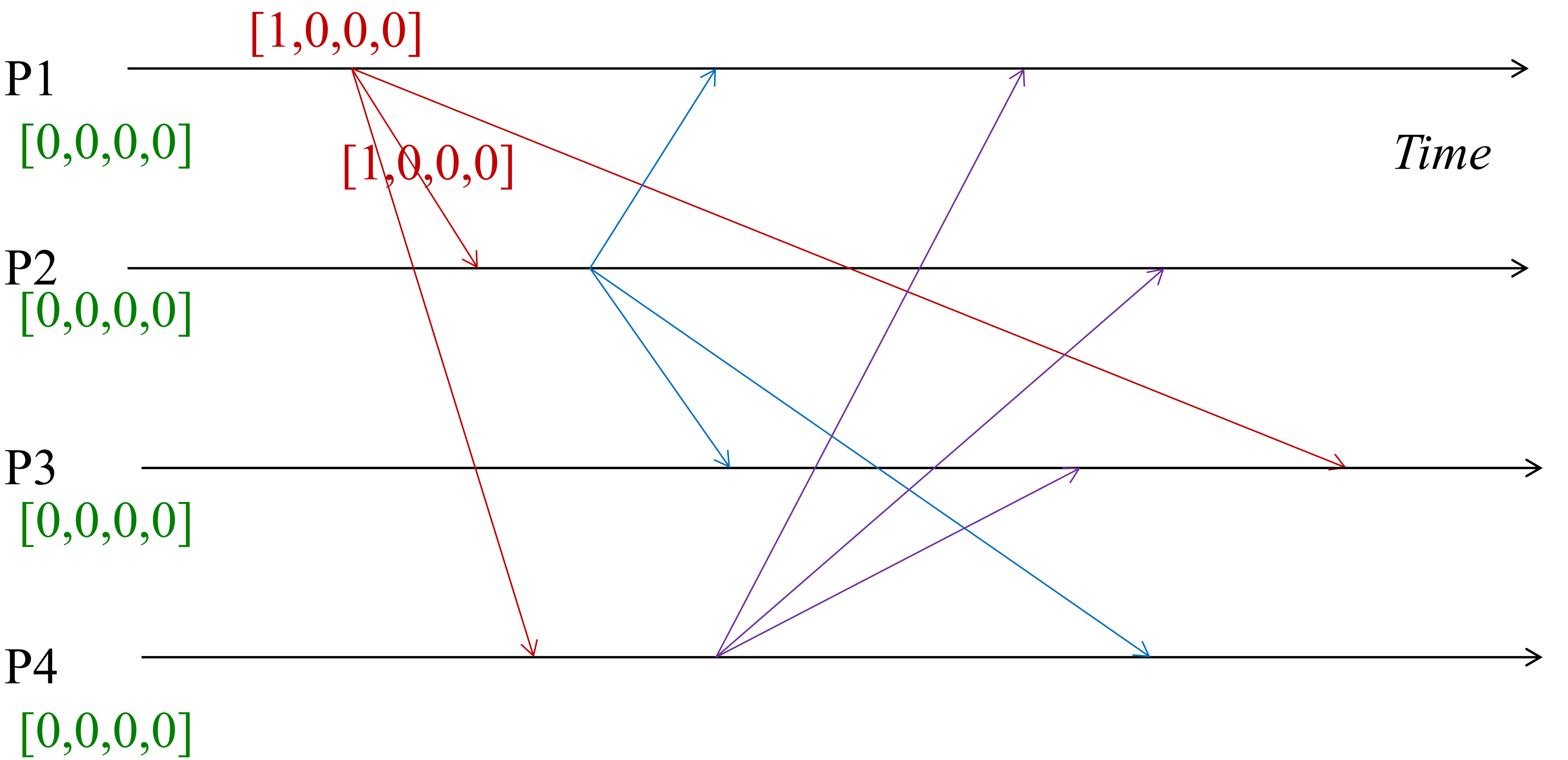
- Each receiver maintains a vector of per-sender sequence numbers (integers)
  - Processes P*1* through P*N*.
  - P*i* maintains a vector of sequence numbers P*i*[1…N] (initially all zeroes).
  - P*i*[*j*] is the latest sequence number P*i* has received from P*j*.

Implementing causal order multicast

- *CO-multicast(g,m) at Pj:*
  set $Pj[j] = Pj[j] + 1$
  piggyback entire vector Pj[1…N] with m as its sequence no.
  B-multicast(g,{m, *Pj[1…N]*})
- *On B-deliver({m, V[1..N]}) at Pi from Pj:* If Pi receives a multicast from Pj with sequence vector V[1…N], buffer it until both:
  1. This message is the next one P*i* is expecting from P*j*, i.e.,
     $V[j] = Pi[j] + 1$
  2. All multicasts, anywhere in the group, which happened-before m have been received at P*i*, i.e.,
     For all $k \neq j$: $V[k] \leq Pi[k]$

  When above two conditions satisfied,
  CO-deliver(m) and set $Pi[j] = V[j]$

Causal order multicast execution



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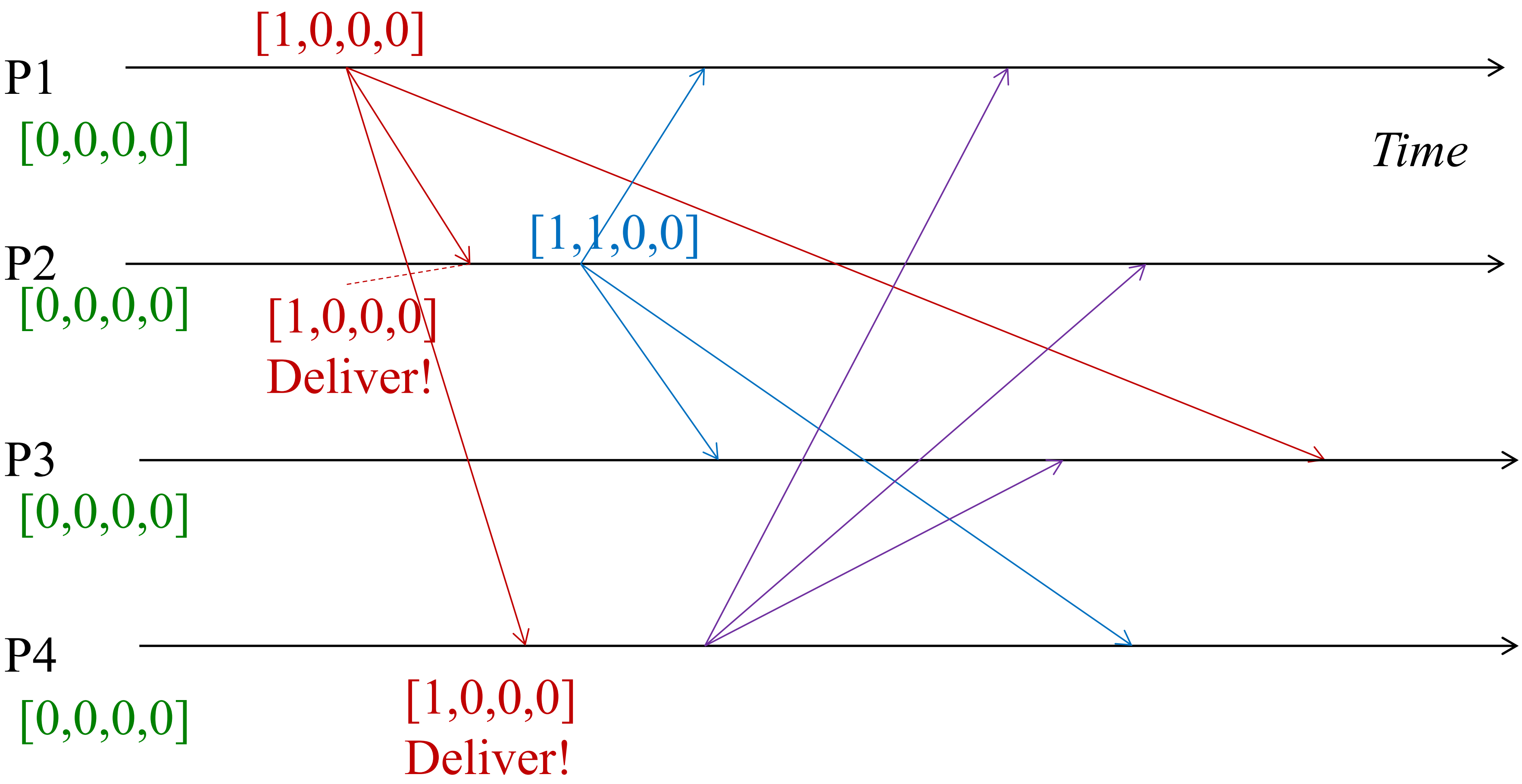

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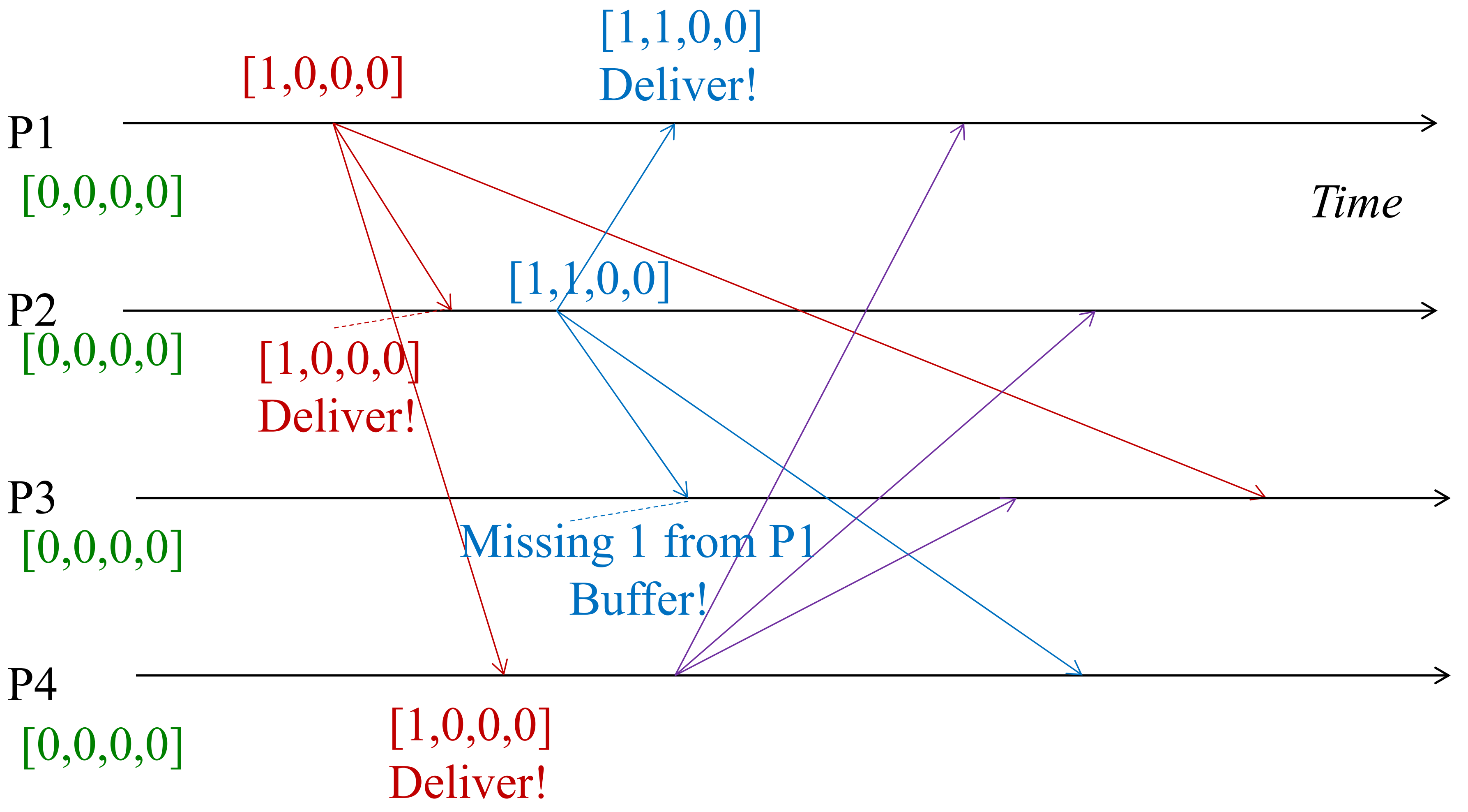

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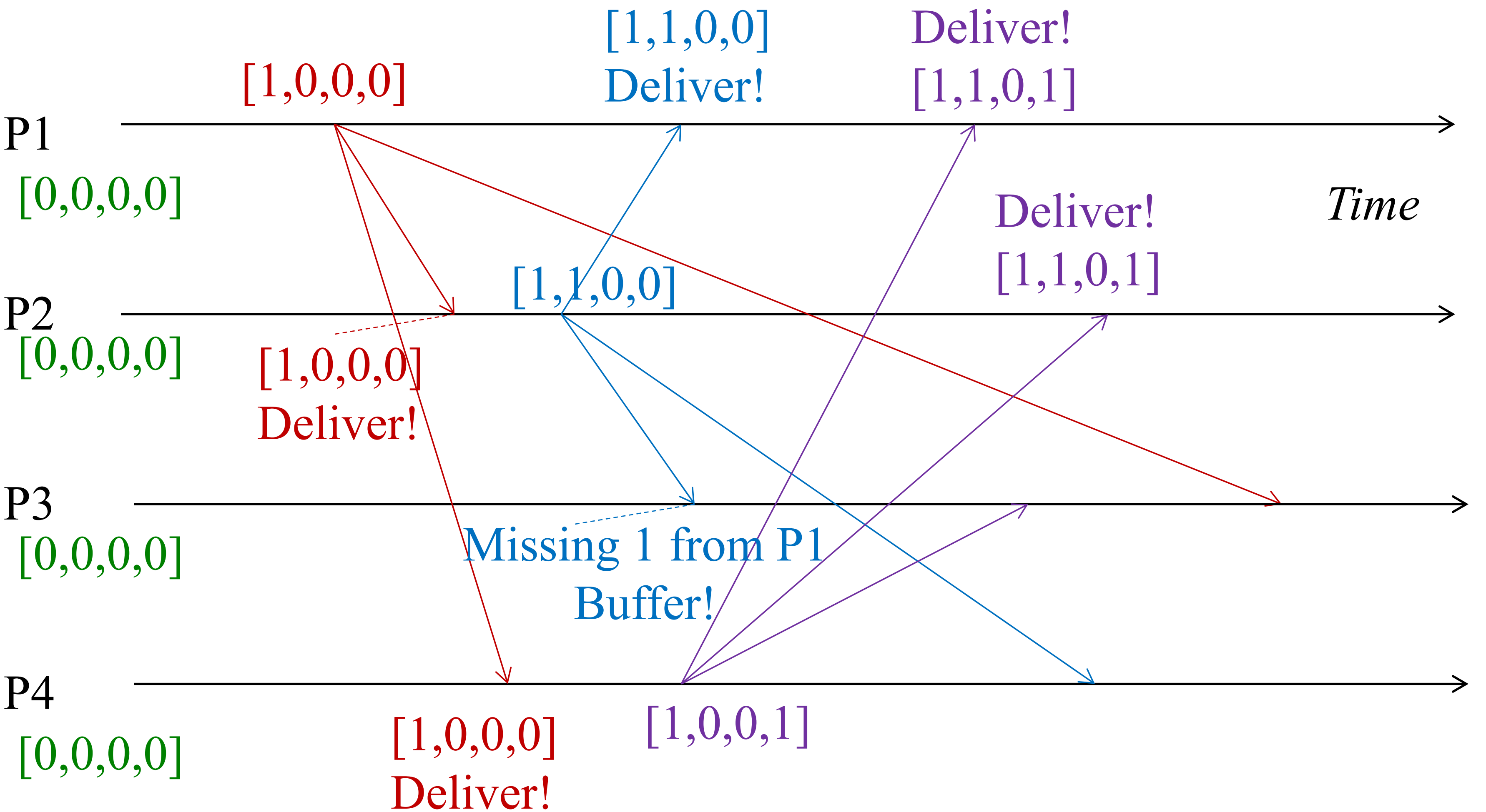

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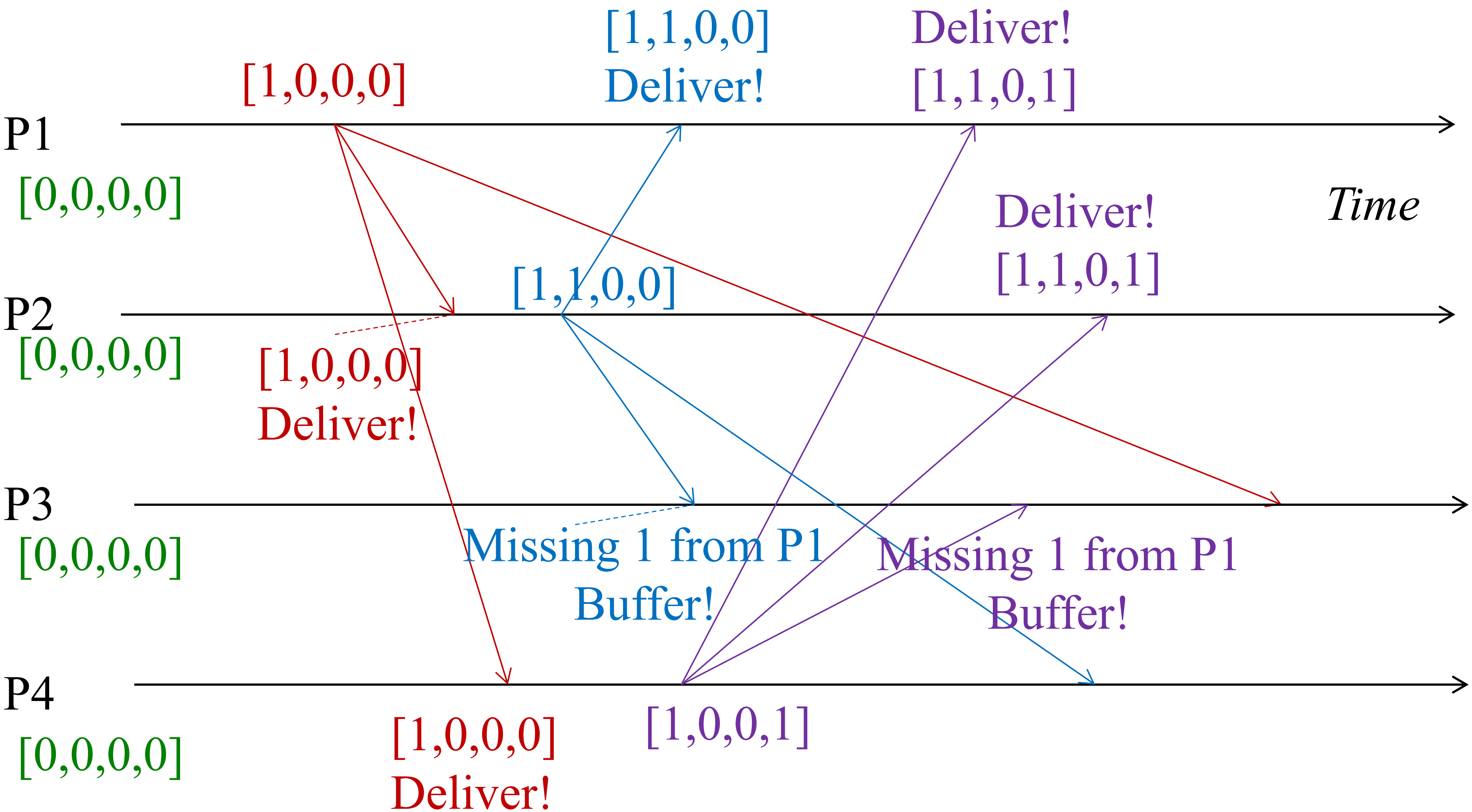

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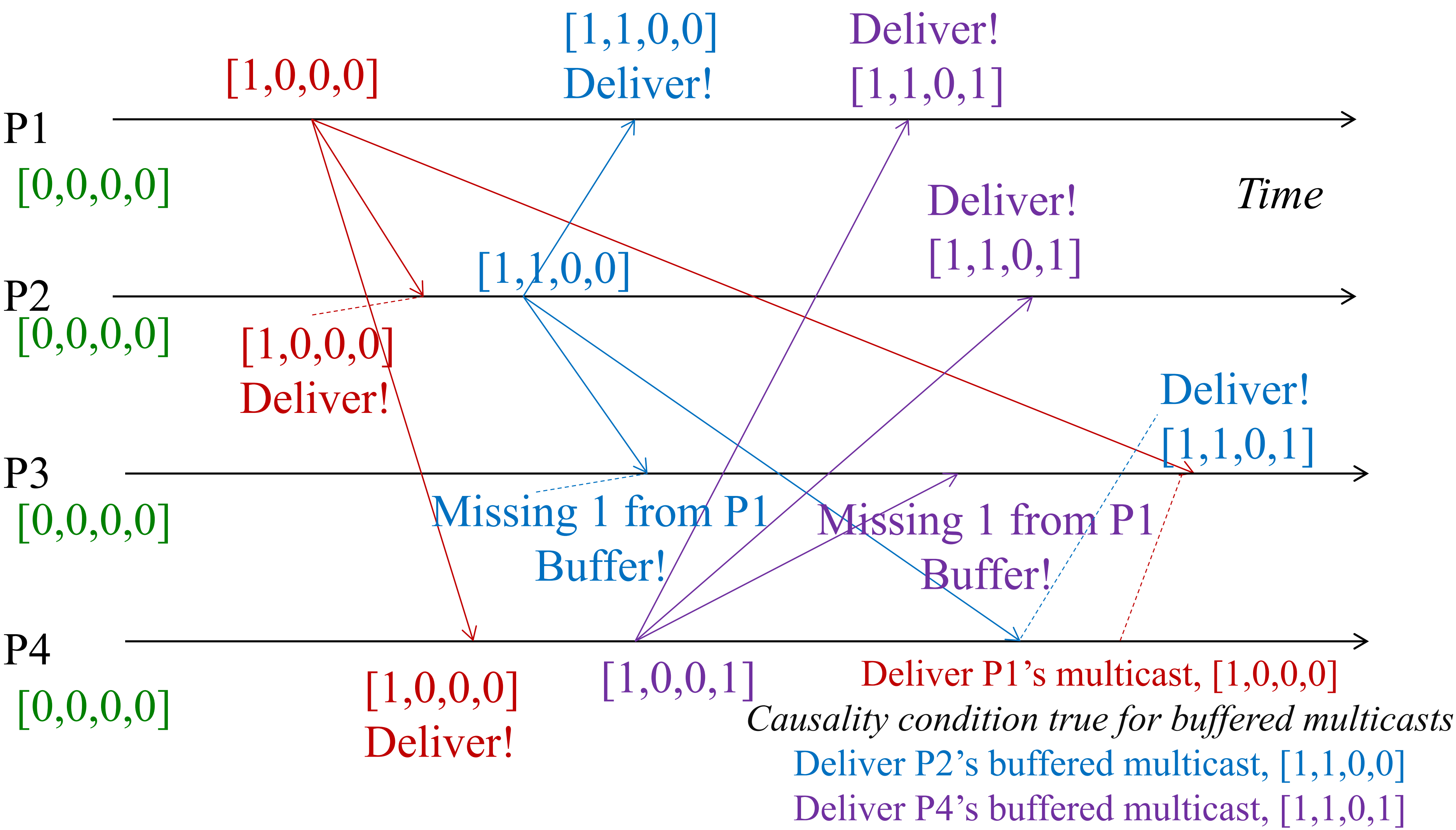

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Summary

- Multicast is an important communication mode in distributed systems.

- Applications may have different requirements:
  - Reliability
  - Ordering: FIFO, Causal, Total
  - Combinations of the above.