# Distributed Systems

## ECE428

## Lecture 8

*Adopted from Spring 2021*

# Today's agenda

- Multicast
  - Chapter 15.4
- Goal: reason about desirable properties for message delivery among a group of processes.

# 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($g$,$m$) $\rightarrow$ multicast($g$,$m'$) then any correct process that delivers $m'$ will have already delivered $m$.
  - Note that $\rightarrow$ counts multicast messages delivered to the application, rather than all network messages.
- Total ordering
  - Yet to discuss.

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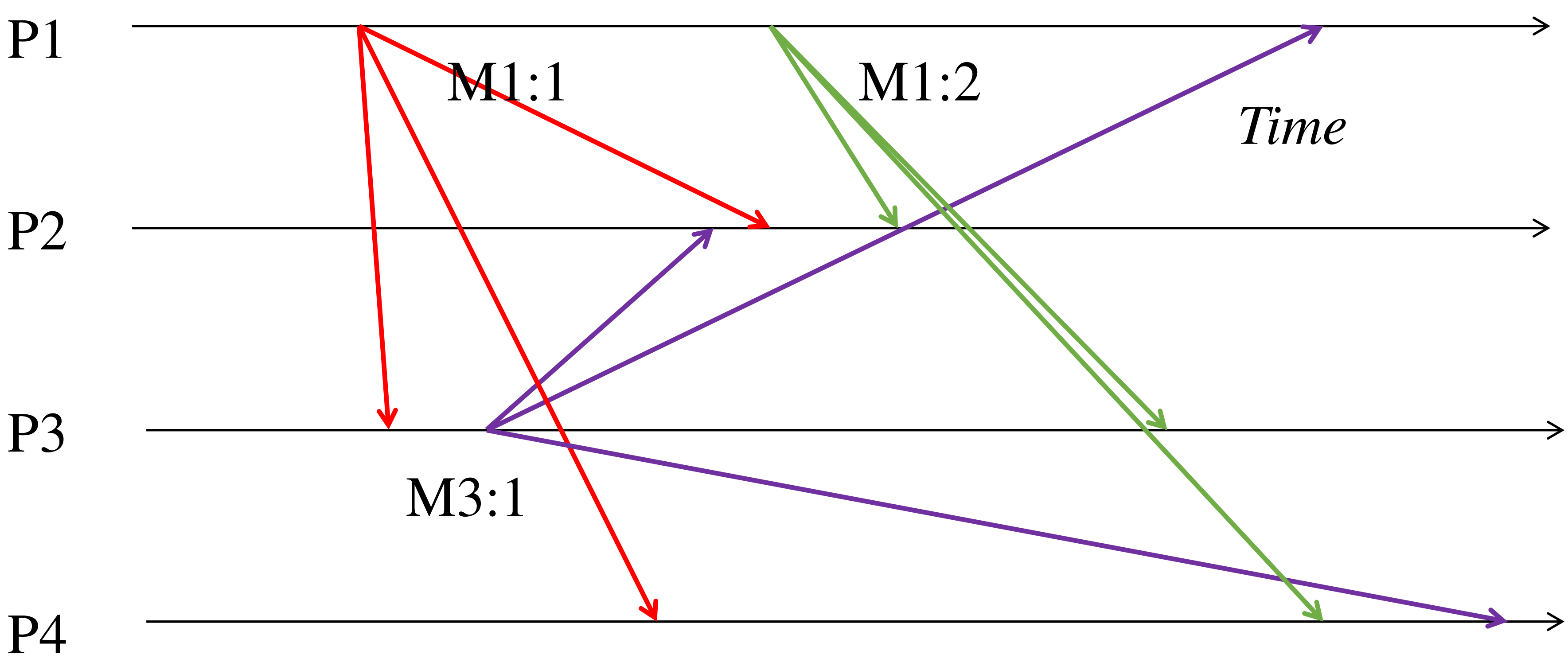
# Where is causal ordering useful?

- Group = set of your friends on a social network.
- A friend sees your message *m*, and she posts a response (comment) *m'* to it.
    - If friends receive *m'* before *m*, it wouldn't make sense
    - But if two friends post messages m" and n" concurrently, then they can be seen in any order at receivers.
- A variety of systems implement causal ordering:
    - social networks, bulletin boards, comments on websites, etc.

# Causal vs FIFO

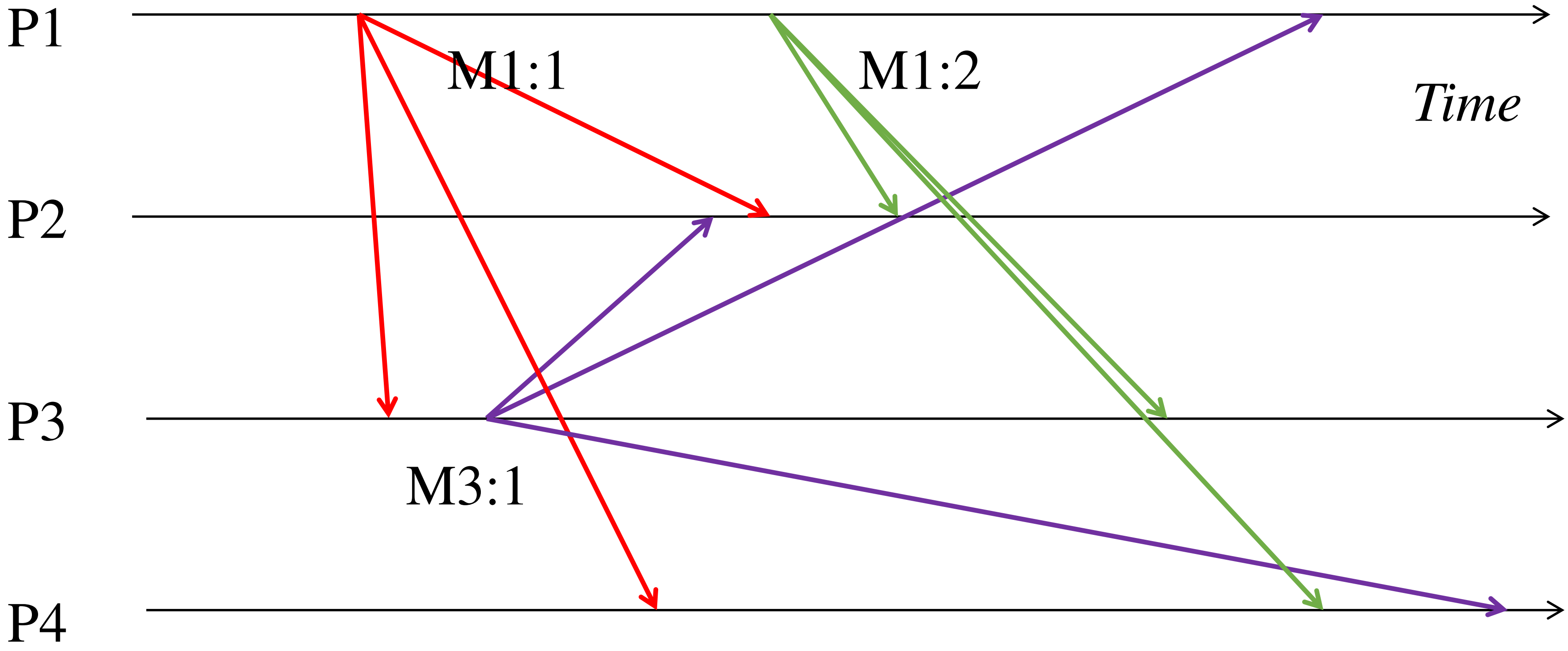
- Causal Ordering => FIFO Ordering
- Why?
  - If two multicasts M and M’ are sent by the same process P, and M was sent before M’, then M $\rightarrow$ M’.
  - Then a multicast protocol that implements causal ordering will obey FIFO ordering since M $\rightarrow$ M’.
- Reverse is not true! FIFO ordering does not imply causal ordering.

# Example




Does this satisfy FIFO order?

# Example

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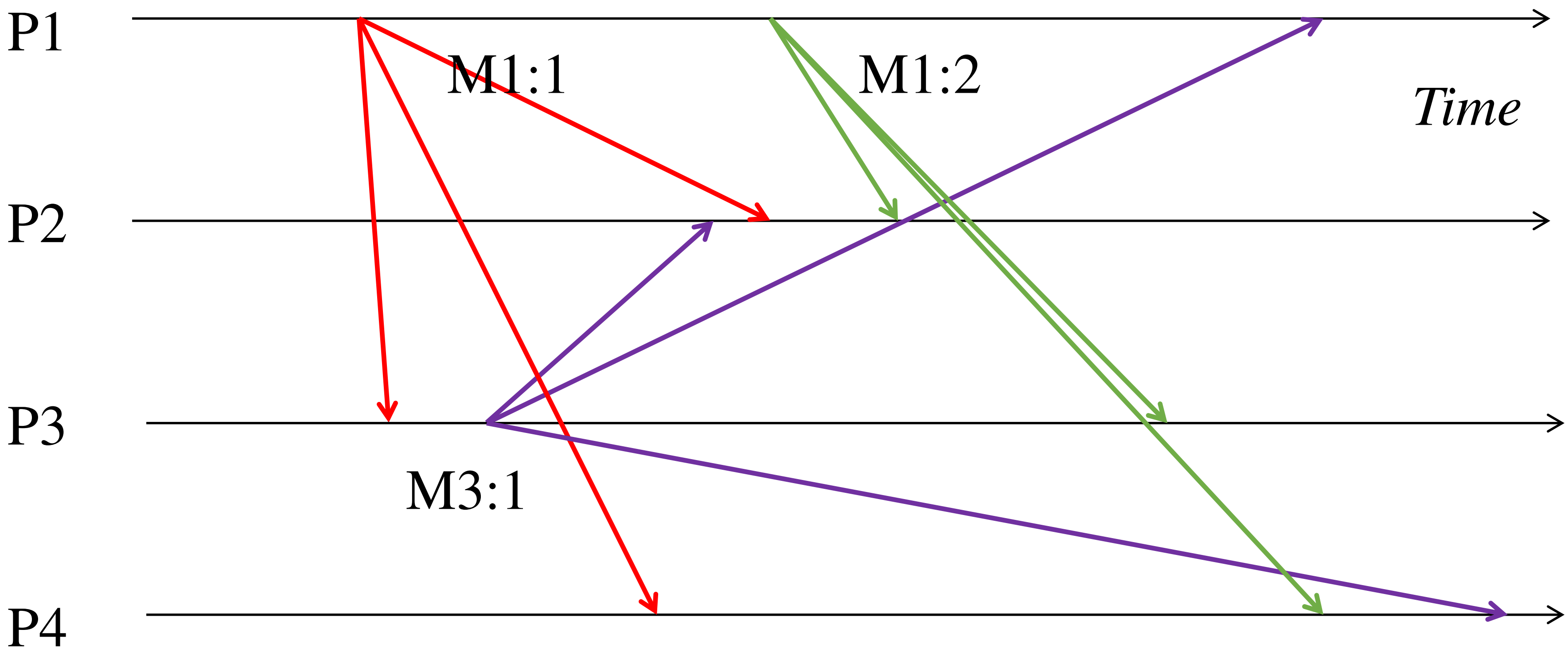


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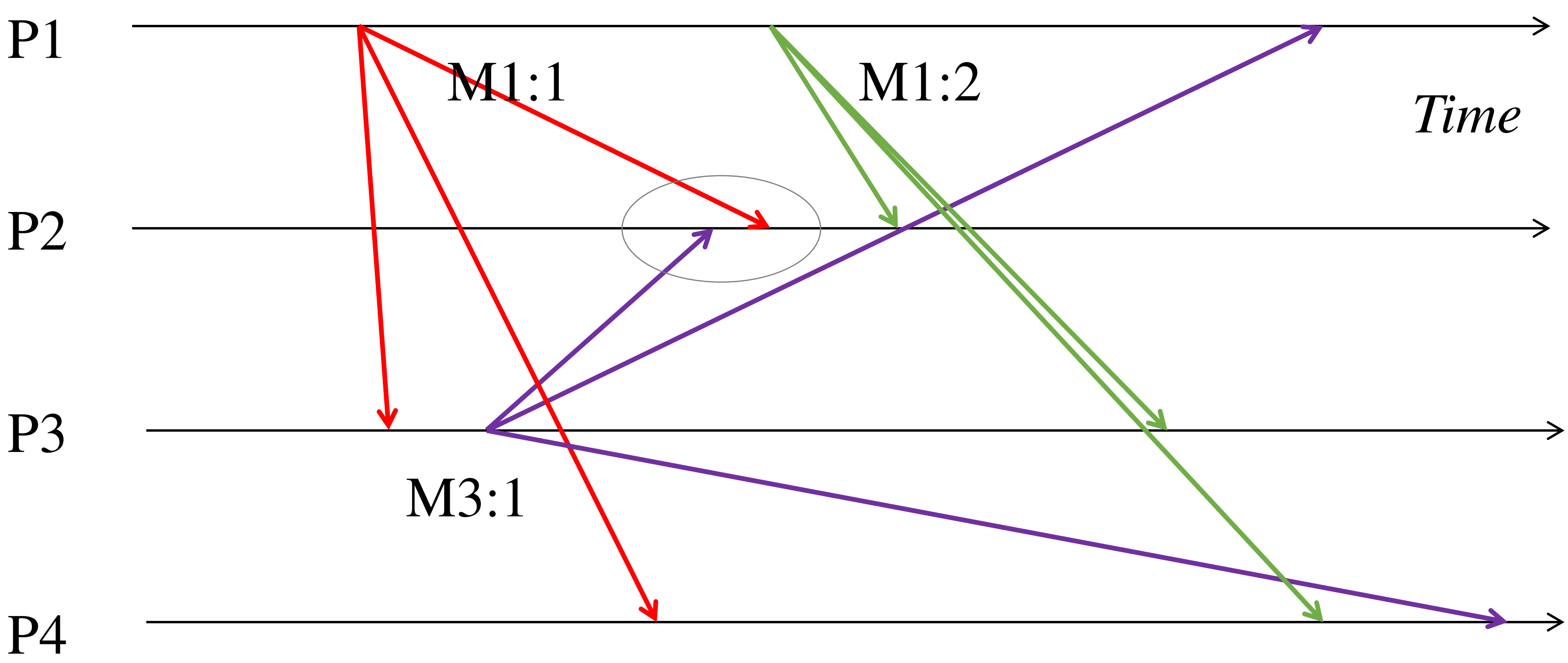
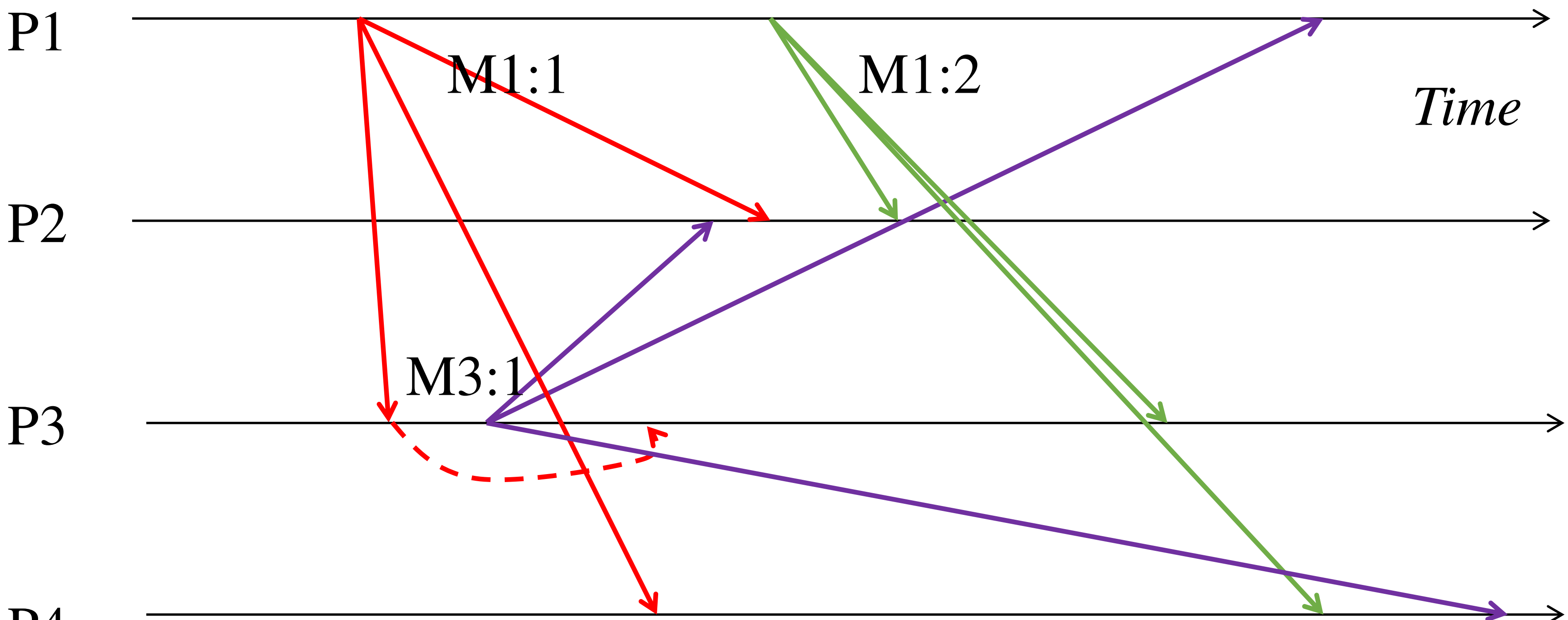


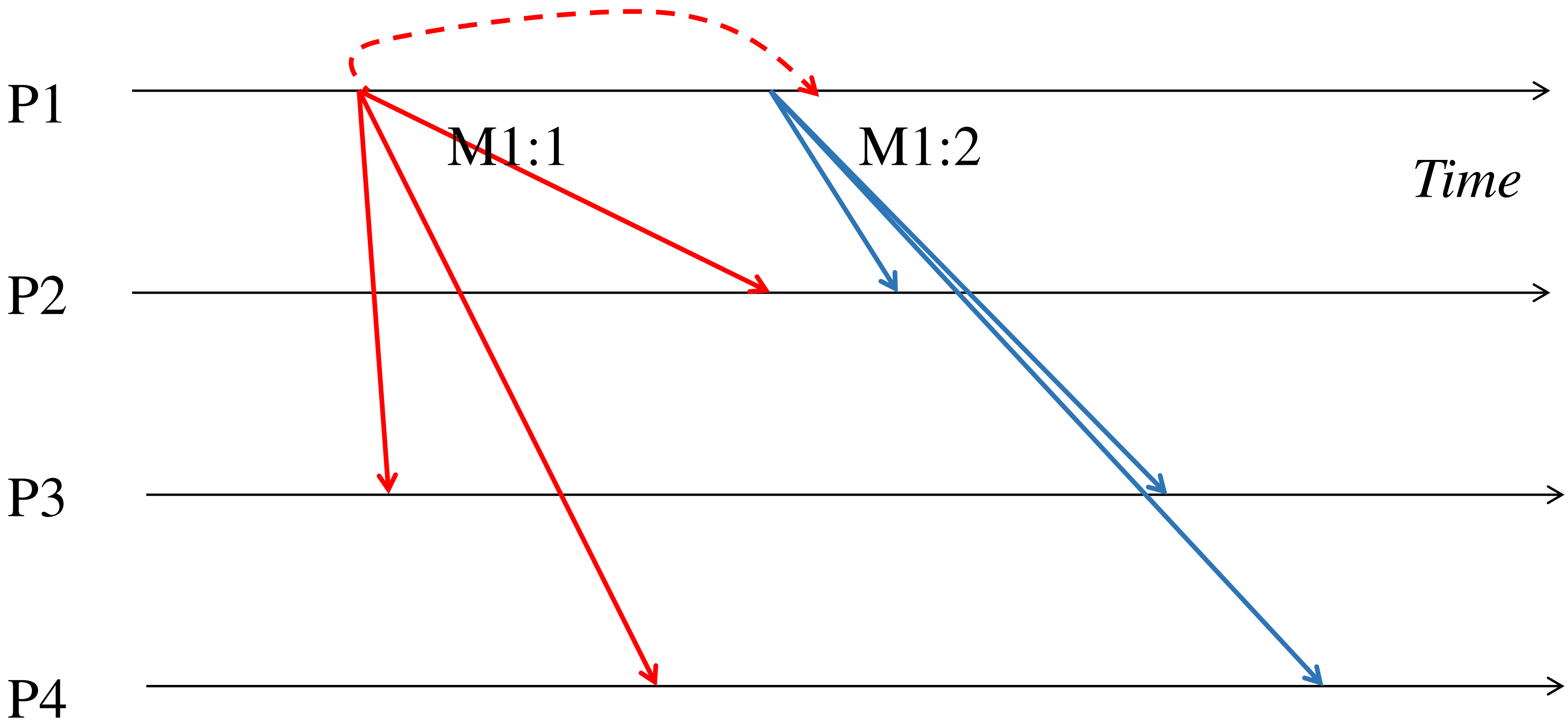

Does this satisfy causal order?
No

# Example



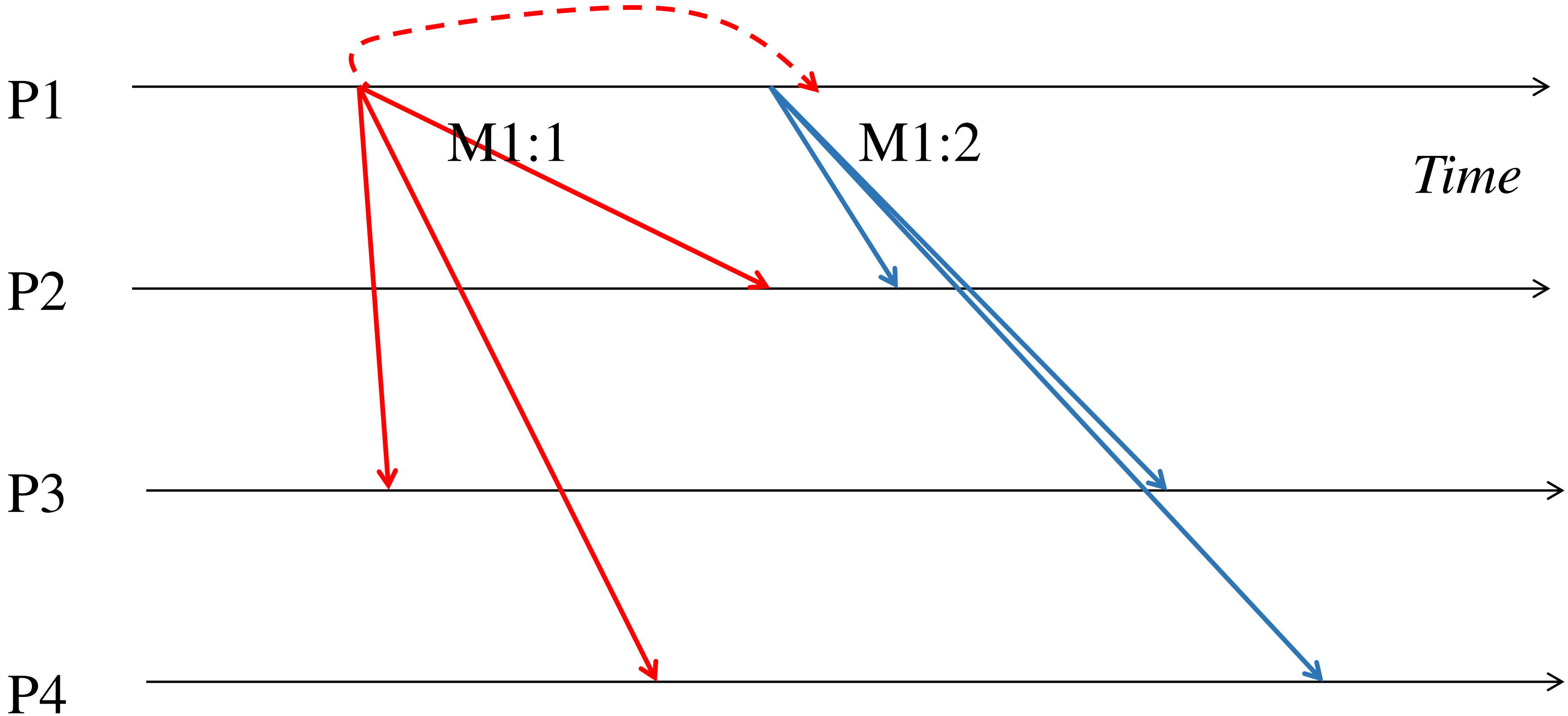

M1:1 is delivered at P3 after M3:1's multicast.
Does this satisfy causal order?
Yes

# Example




Does this satisfy causal order?
No

# Example




Does this satisfy FIFO order?
No

# Recap: Ordered Multicast

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  - 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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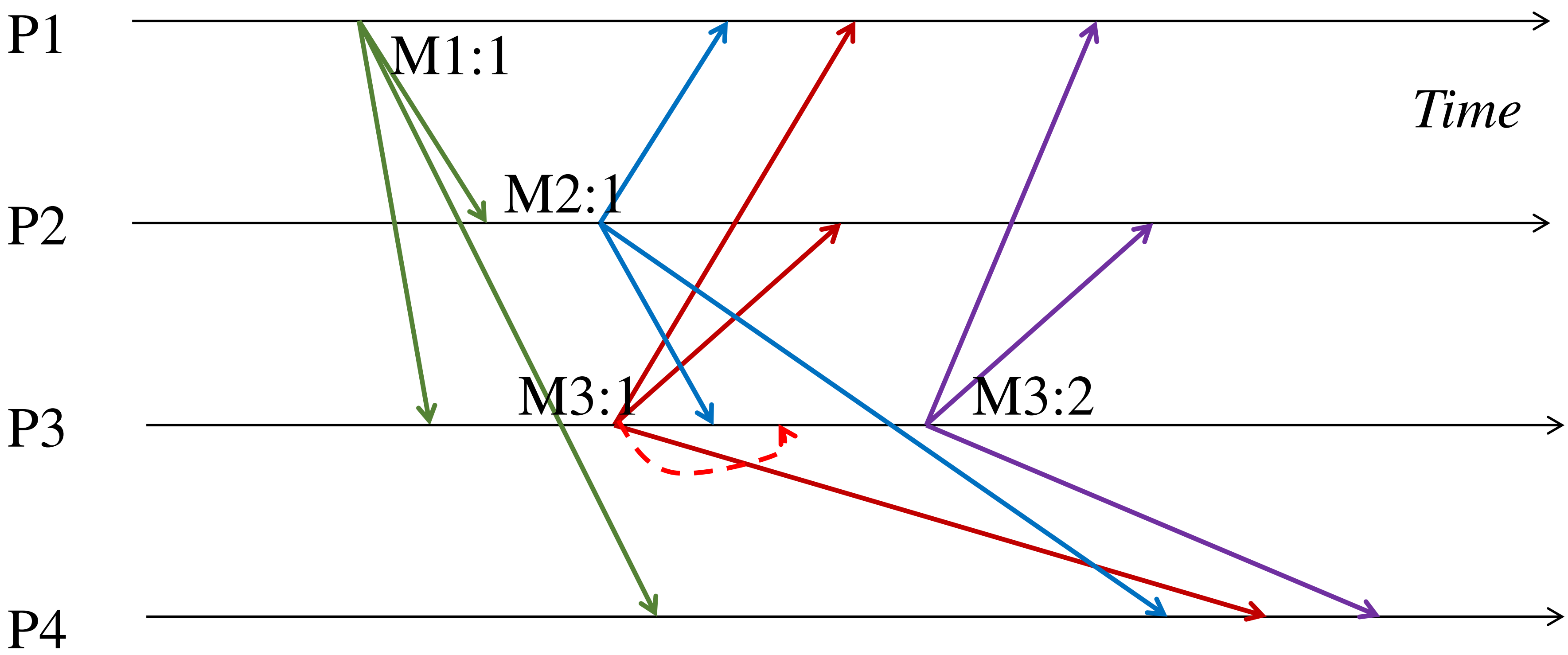
- Total ordering

# Total Order

- Ensures all processes deliver all multicasts in the same order.
- Unlike FIFO and causal, this does not pay attention to order of multicast sending.
- Formally
    - If a correct process delivers message *m* before *m'* (independent of sending order), then any other correct process that delivers *m'* will have already delivered *m*.

# Total Order: Example




The order of receipt of multicasts is the same at all processes.
M1:1, then M2:1, then M3:1, then M3:2
*May need to delay delivery of some messages.*

# Causal vs Total

- Total ordering does not imply causal ordering.
- Causal ordering does not imply total ordering.

# Hybrid variants

- We can have hybrid ordering protocols:
  - Causal-total hybrid protocol satisfies both Causal and total orders.

# 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'*, then any other correct process that delivers *m'* will have already delivered *m*.

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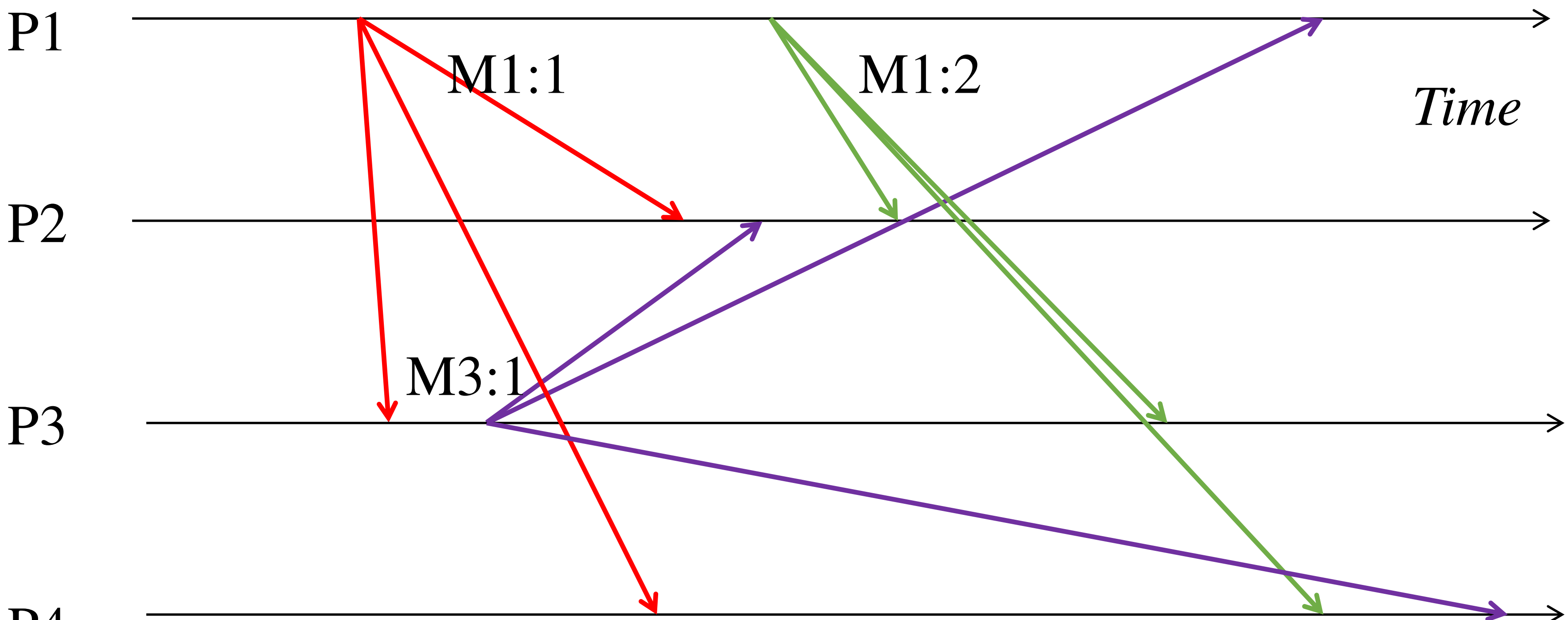
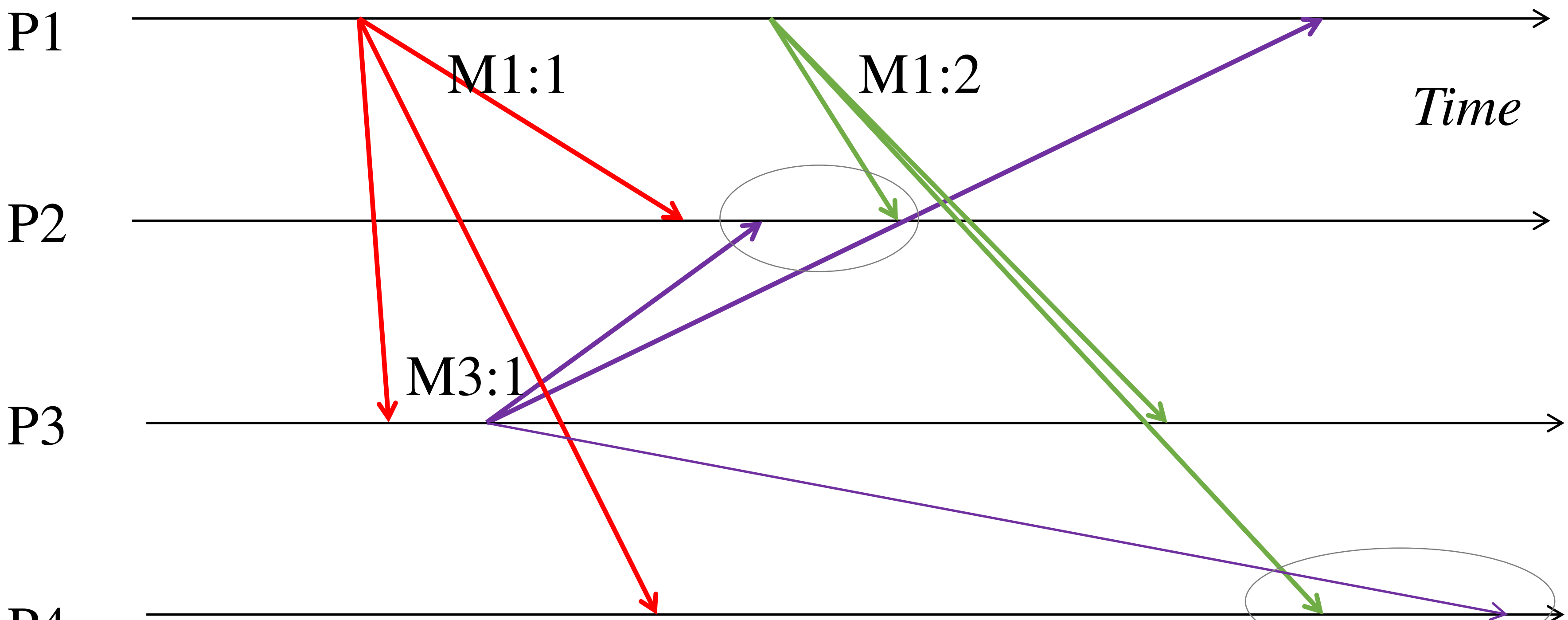



Does this satisfy causal (and FIFO) order?

Yes

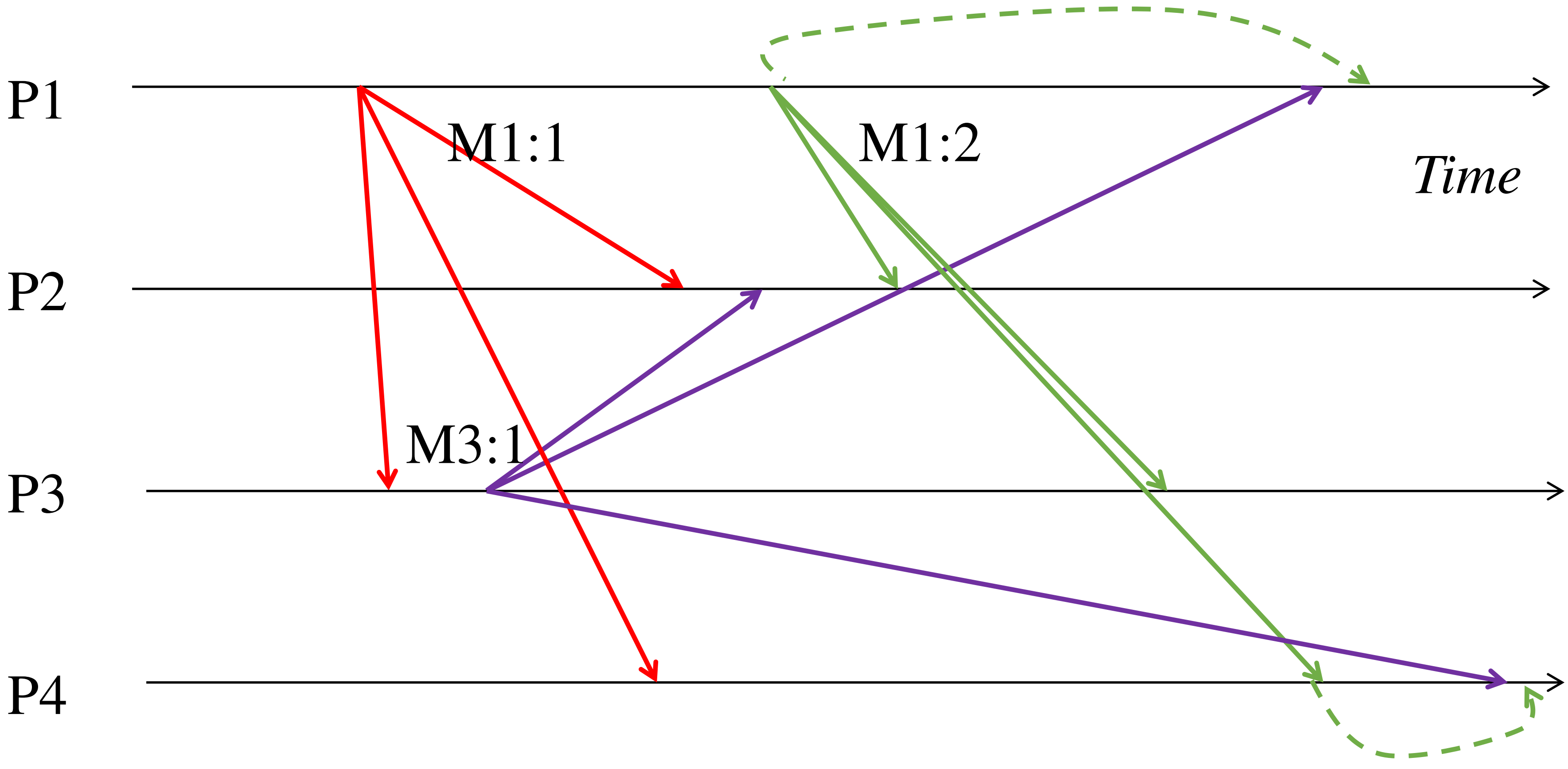
# Example




Does this satisfy total order?

No

# Example




Does this satisfy total order?

Yes

# Next Question

*How do we implement ordered multicast?*

# Ordered Multicast

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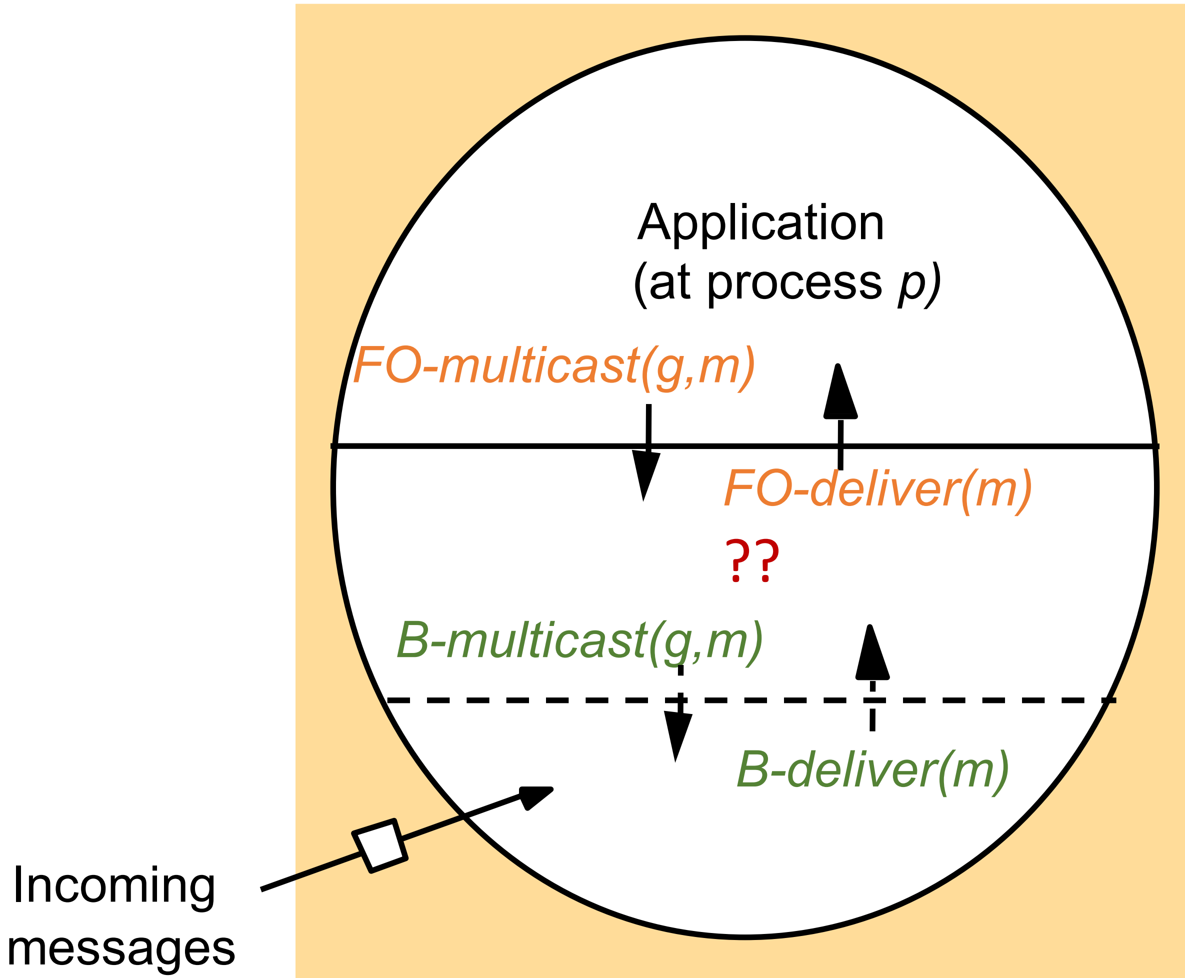
# Implementing FIFO order multicast



# 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 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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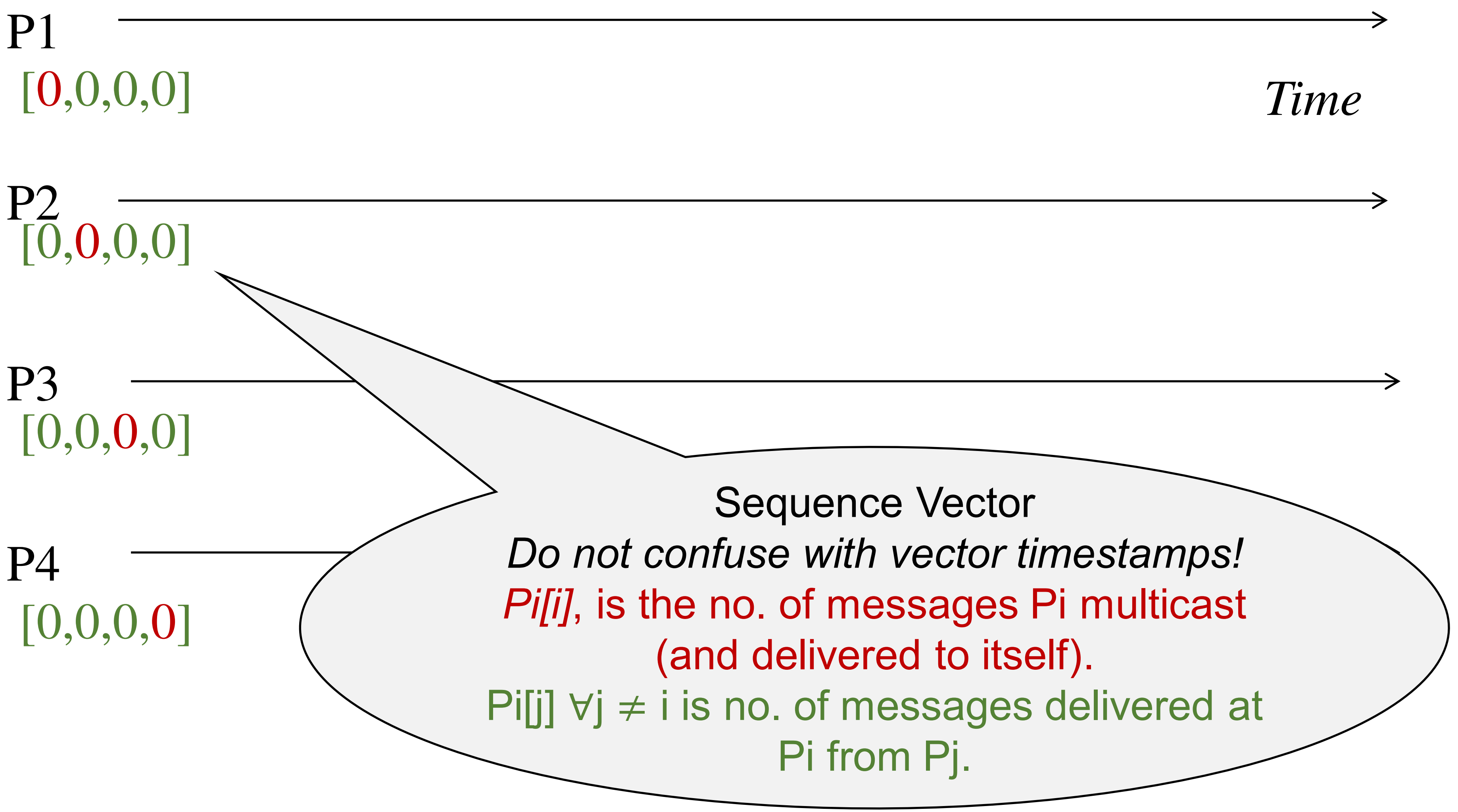

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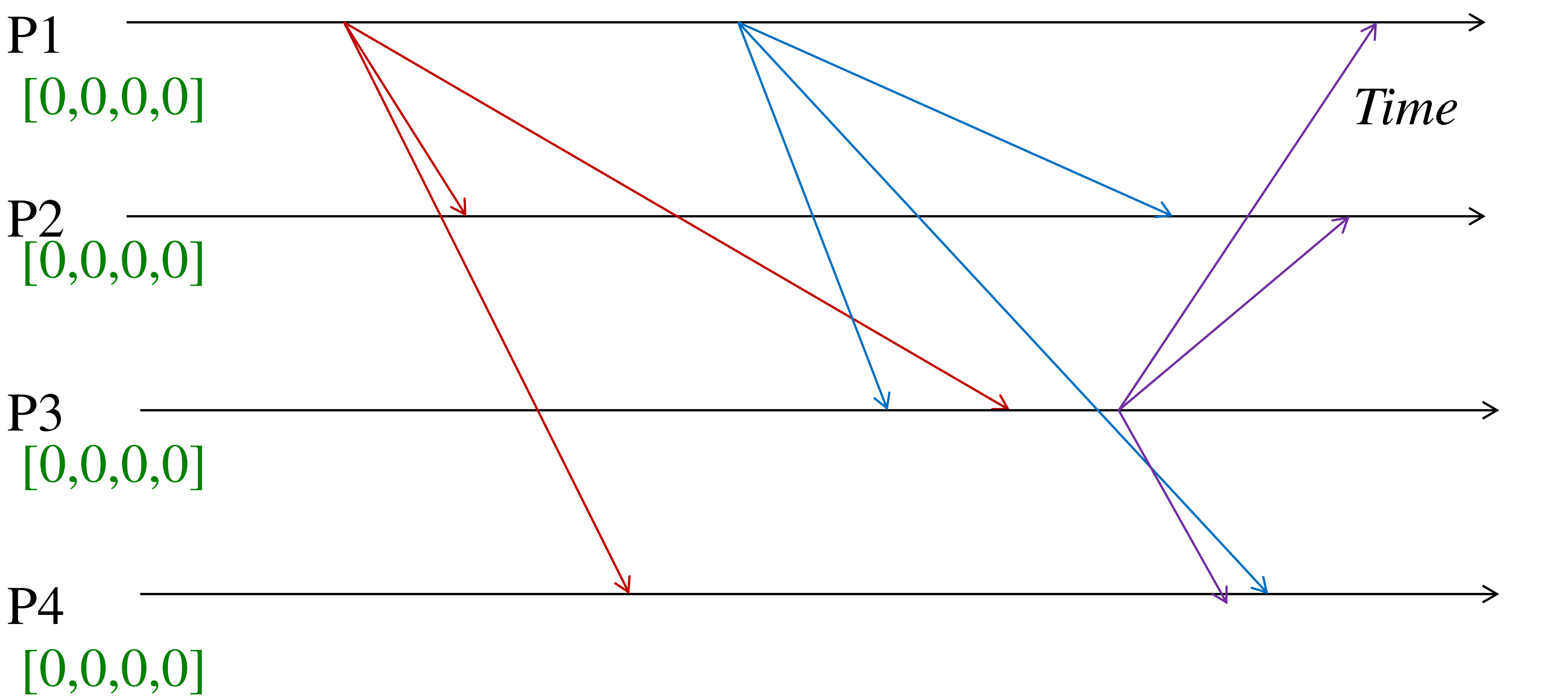
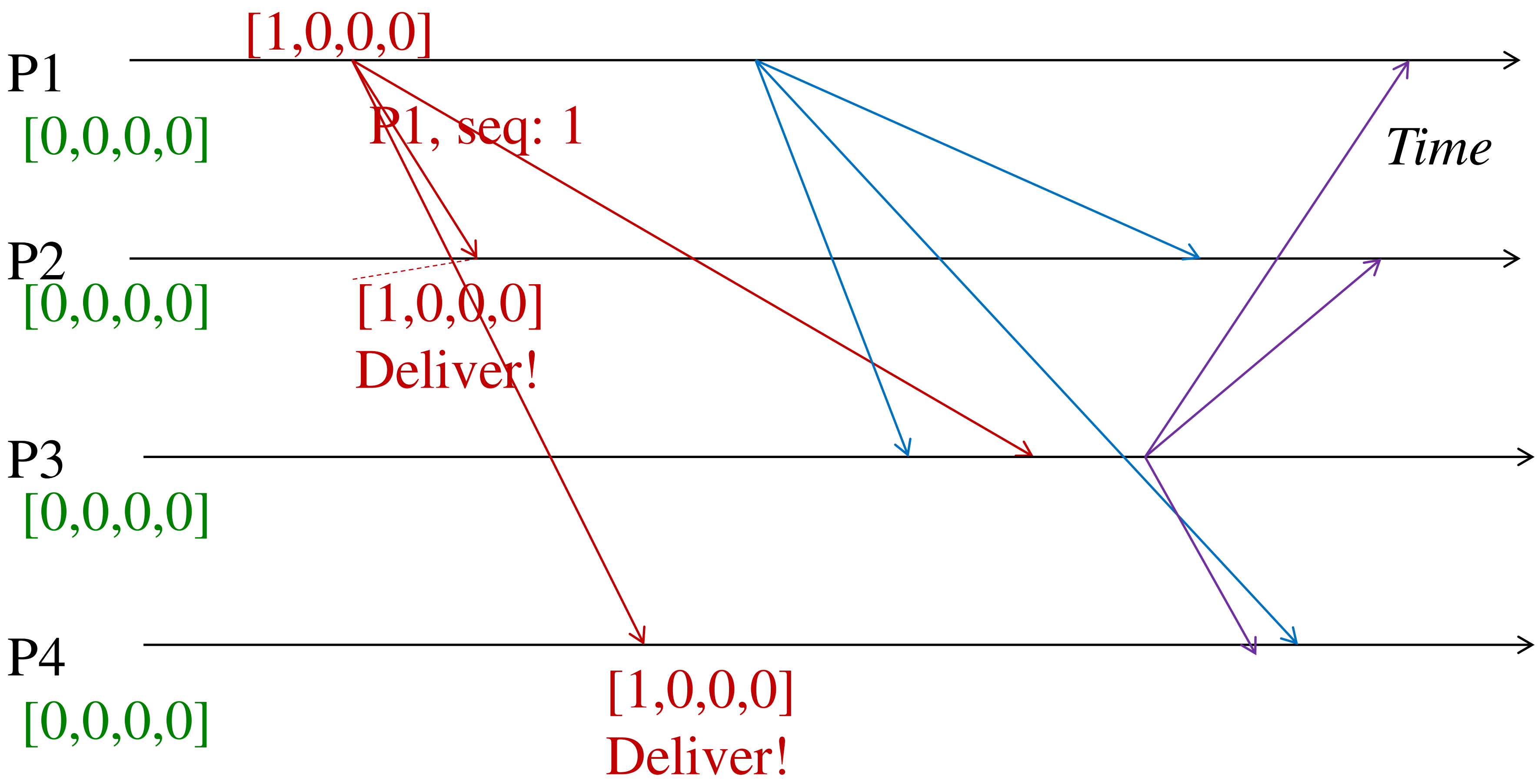



Self-deliveries omitted for simplicity.

# FIFO order multicast execution



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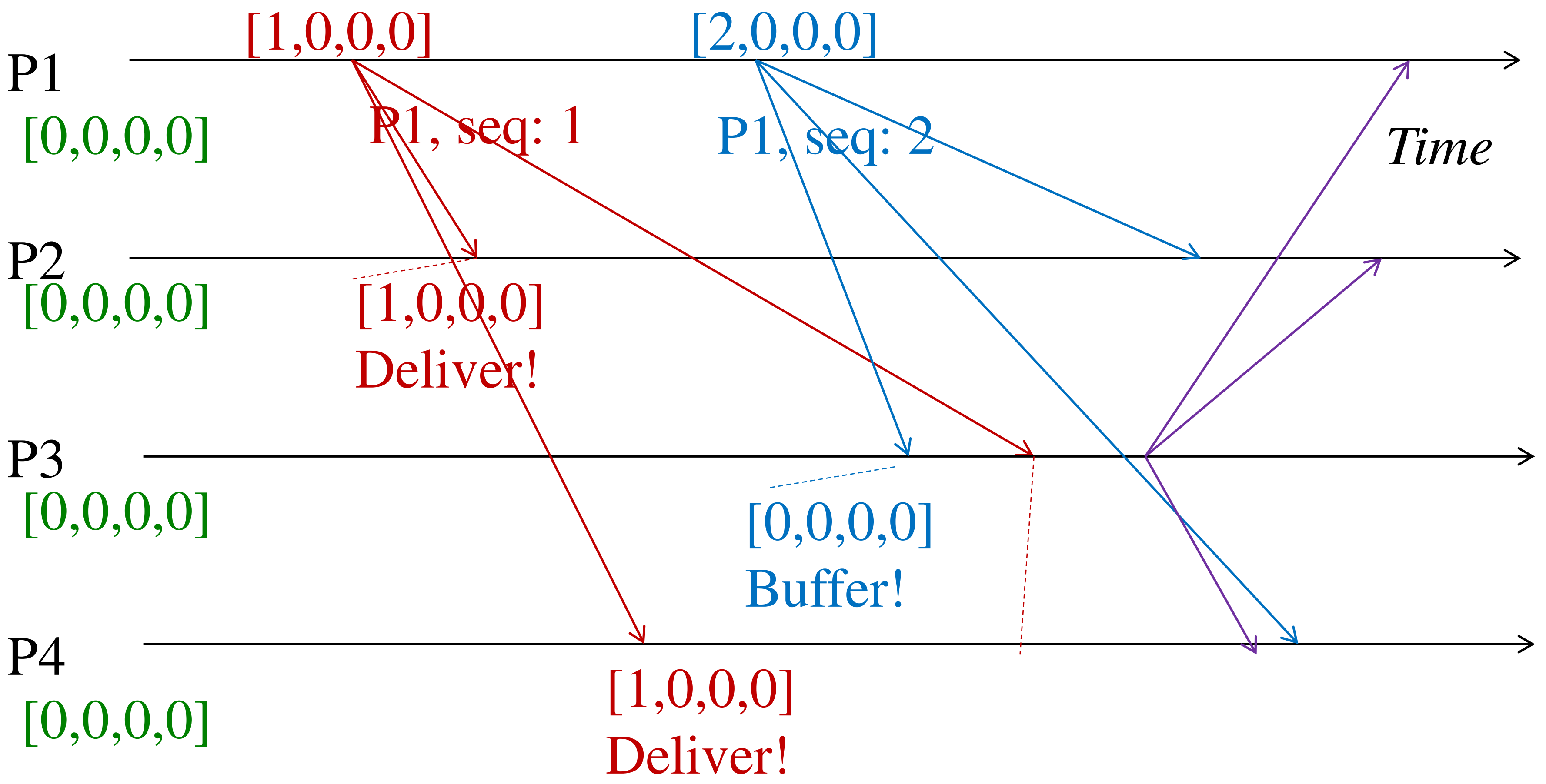

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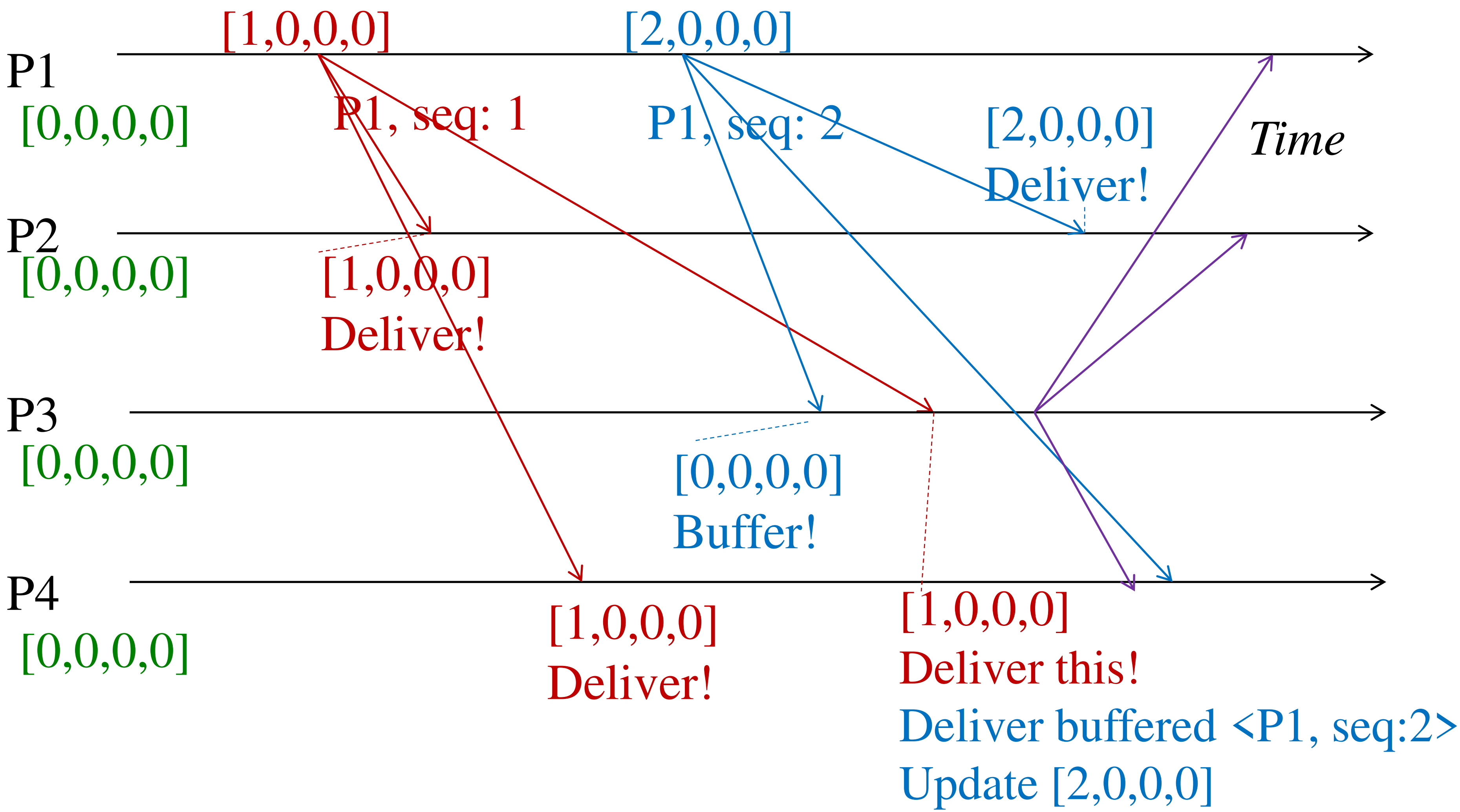

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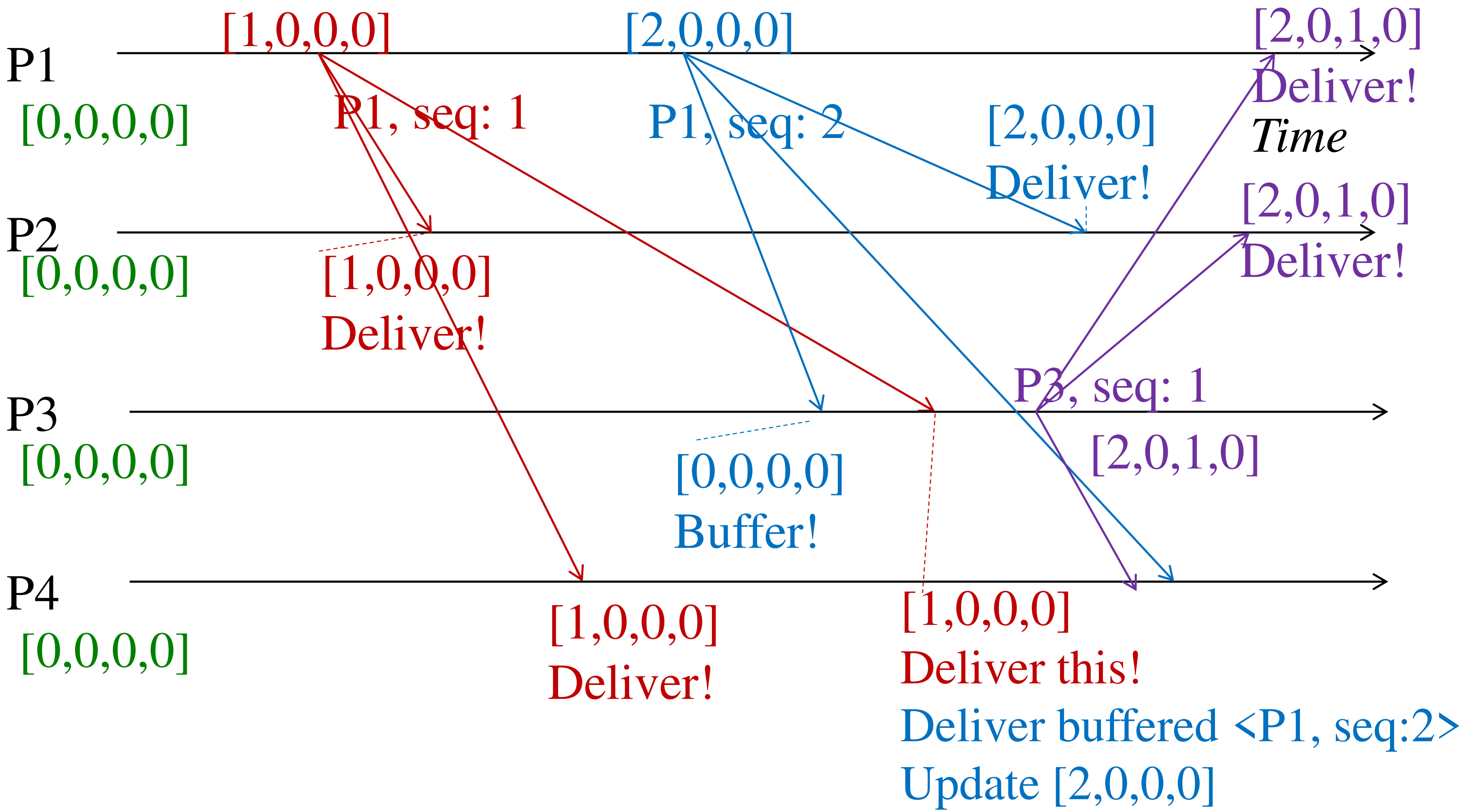

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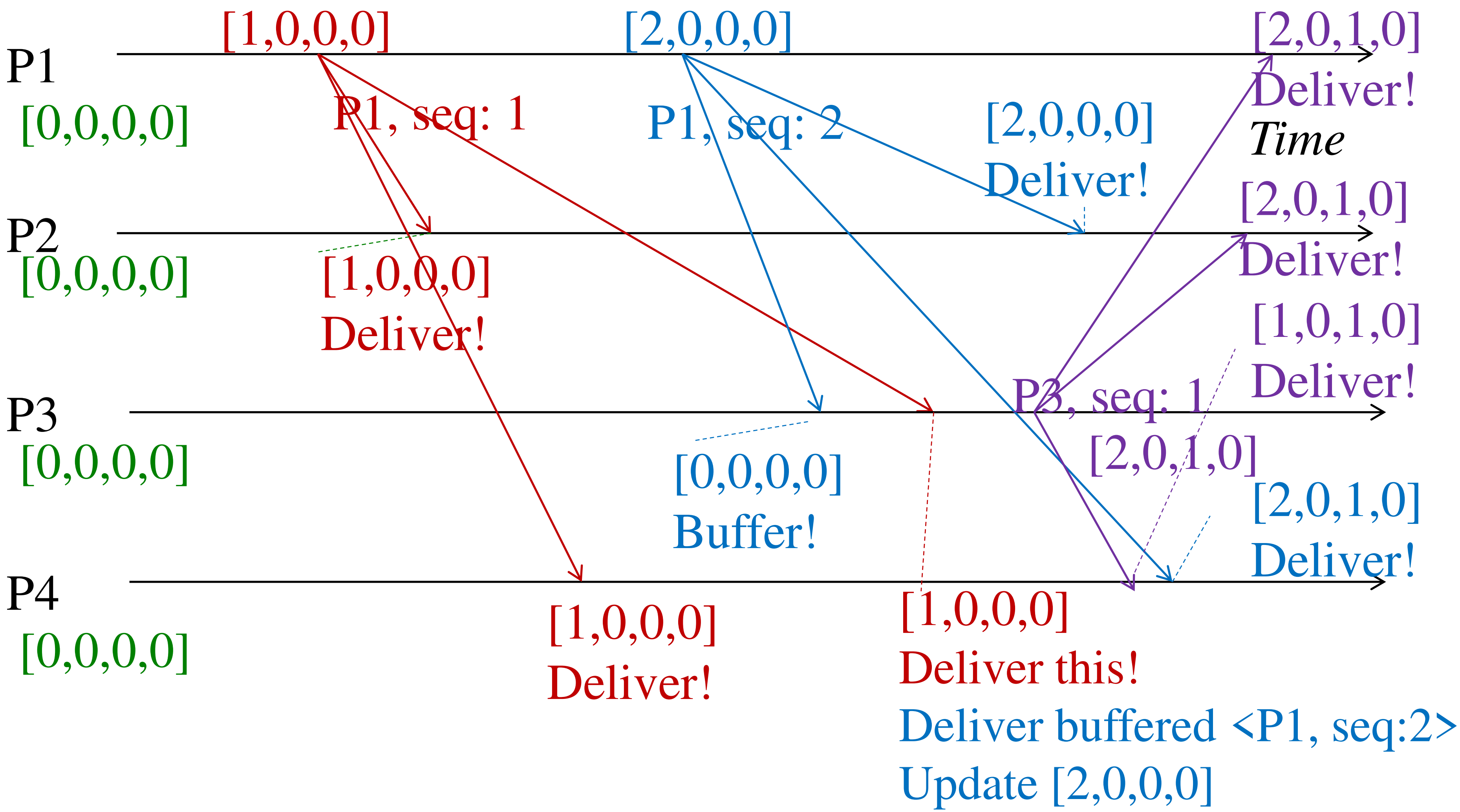

# Implementing FIFO order multicast

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

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  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

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# 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.
- *C*ausal ordering: If multicast(*g*,*m*) → multicast(*g*,*m'*) then any correct process that delivers *m'* will have already delivered *m*.
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- Total ordering: If a correct process delivers message *m* before *m'* 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)

# Sequencer based total ordering

- Special process elected as leader or sequencer.
- TO-multicast(g,m) at P*i*:
  - B-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*, 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

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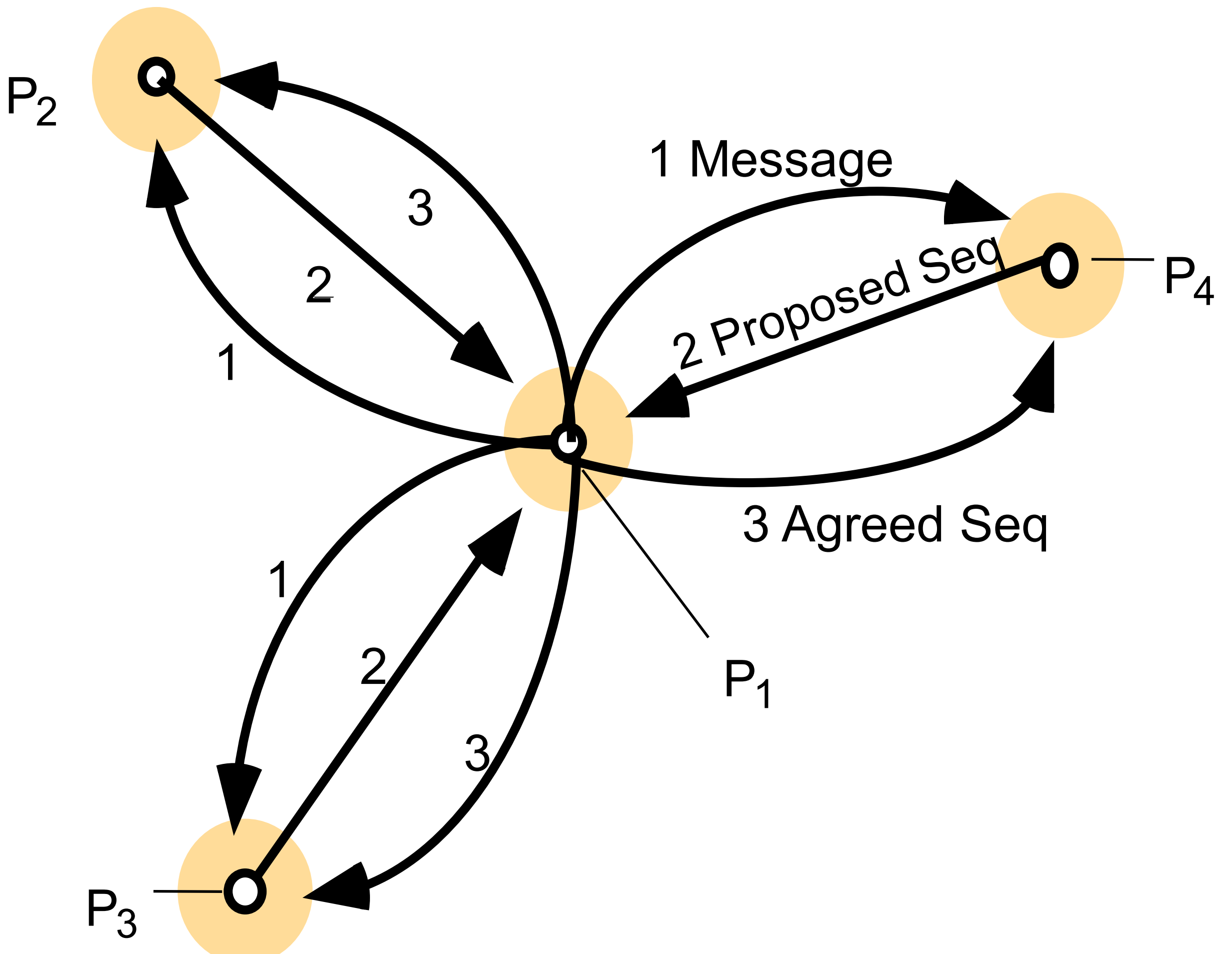
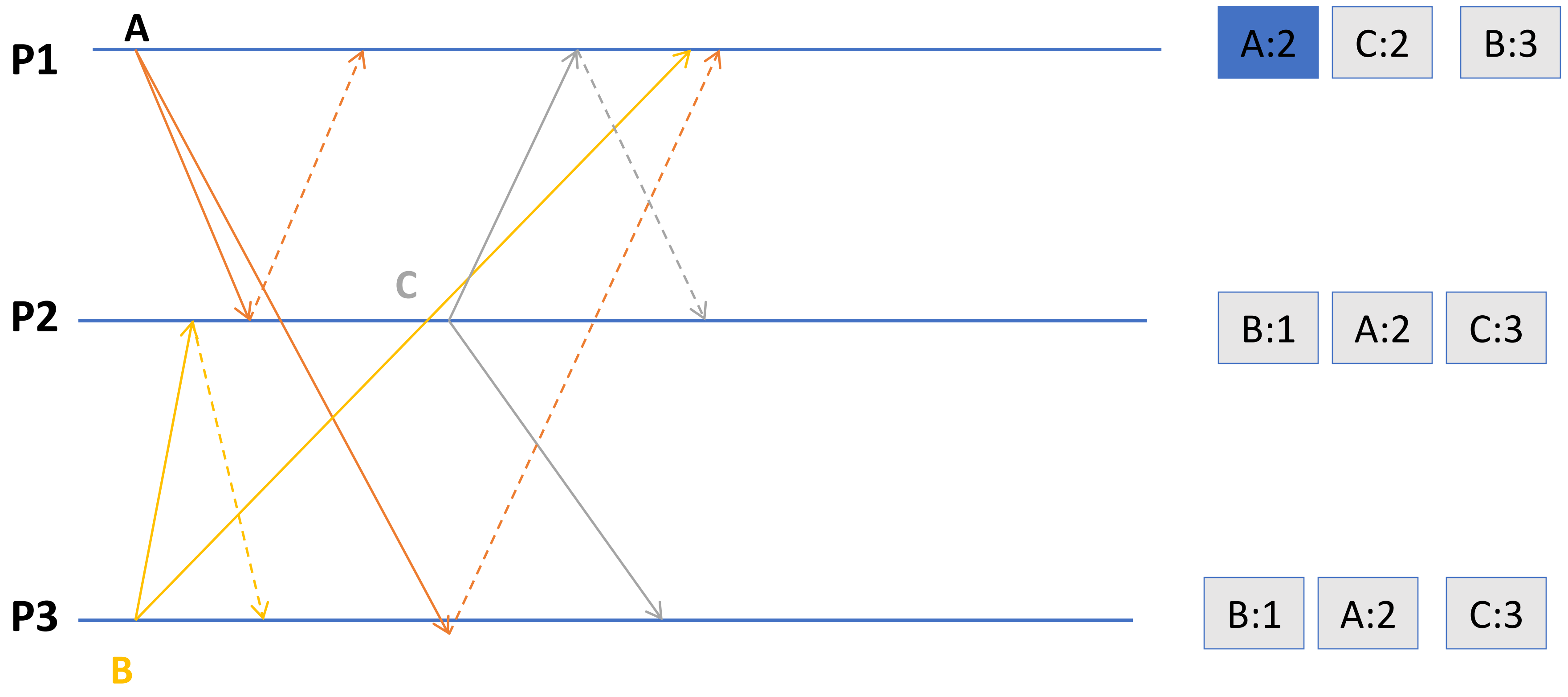
# ISIS algorithm for total ordering



# 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 id with agreed priority
  - maximum of all proposed priorities
- Upon receiving agreed (final) priority for a message 'm'
  - Update m's priority to final, accordingly reorder messages in queue.
  - mark the message m as deliverable.
  - deliver any deliverable messages at front of priority queue.

# Example: ISIS algorithm



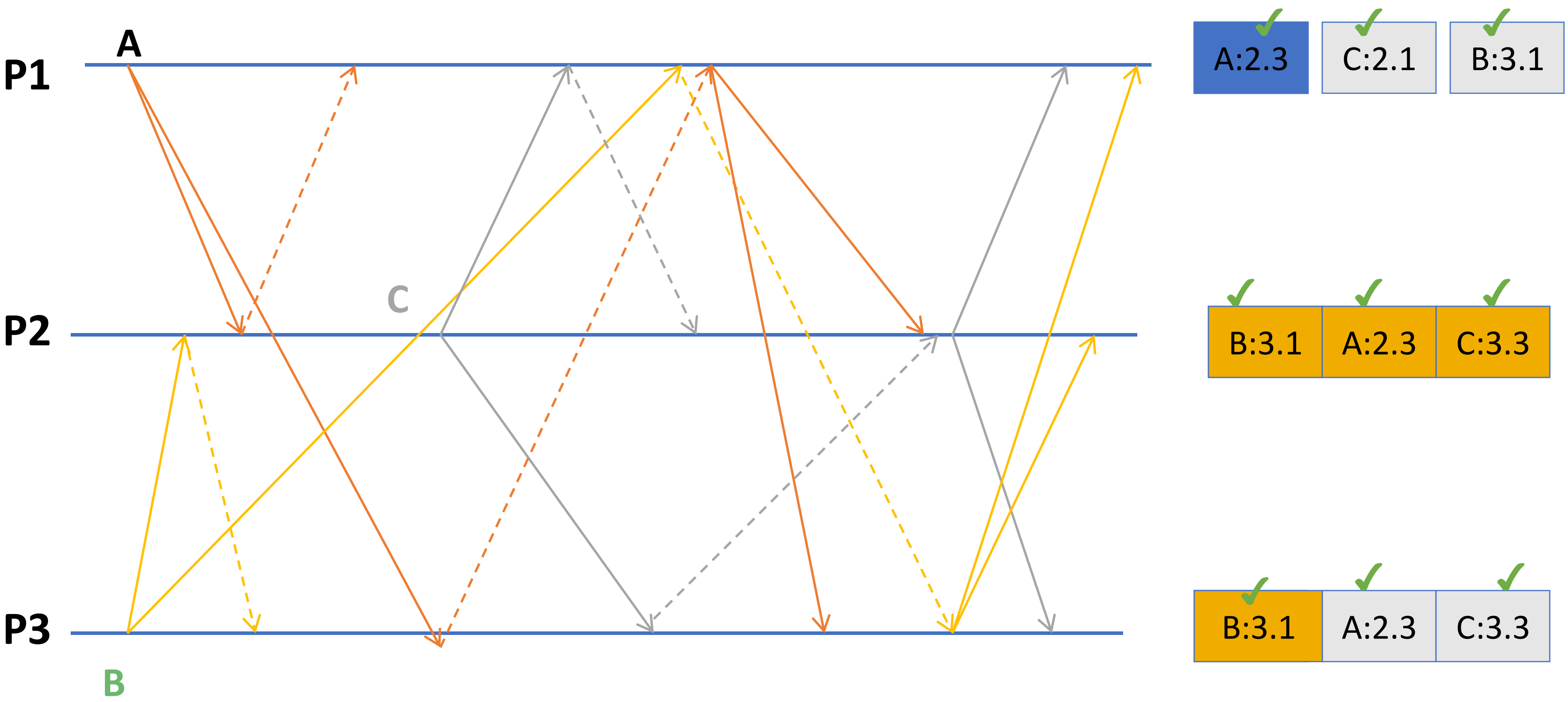
# How do we break ties?

- 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



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# To be continued in next class

- Proof of total-ordering with ISIS.
- Implementation of causal order multicast.

# Summary

- Multicast is an important communication mode in distributed systems.
- Applications may have different requirements:
  - Reliability
  - Ordering: FIFO, Causal, Total
  - Combinations of the above.