

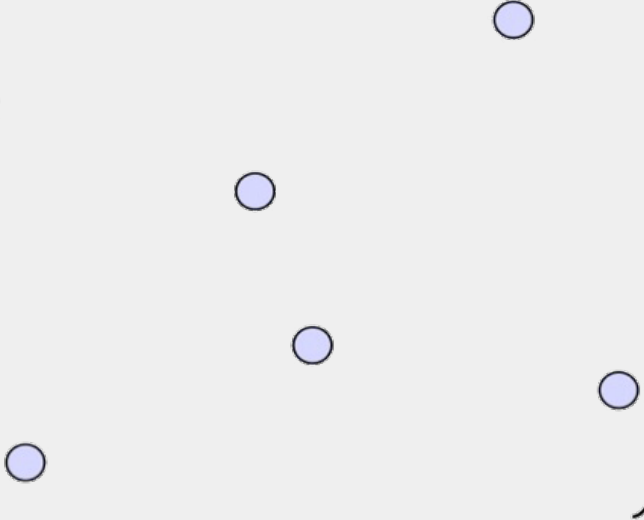
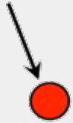
CS 425 / ECE 428
Distributed Systems
Fall 2022

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Lecture 16: Multicast

Multicast Problem

Node with a piece of information
to be communicated to everyone



Distributed Group
of "Nodes" =
Processes at
Internet-based host

Other Communication Forms

- **Multicast** → message sent to a group of processes
- **Broadcast** → message sent to all processes (anywhere)
- **Unicast** → message sent from one sender process to one receiver process

Who Uses Multicast?

- A widely-used abstraction by almost all cloud systems
- Storage systems like Cassandra or a database
 - Replica servers for a key: Writes/reads to the key are multicast within the replica group
 - All servers: membership information (e.g., heartbeats) is multicast across all servers in cluster
- Online scoreboards (ESPN, French Open, FIFA World Cup)
 - Multicast to group of clients interested in the scores
- Stock Exchanges
 - Group is the set of broker computers
 - Groups of computers for High frequency Trading
- Air traffic control system
 - All controllers need to receive the same updates in the same order

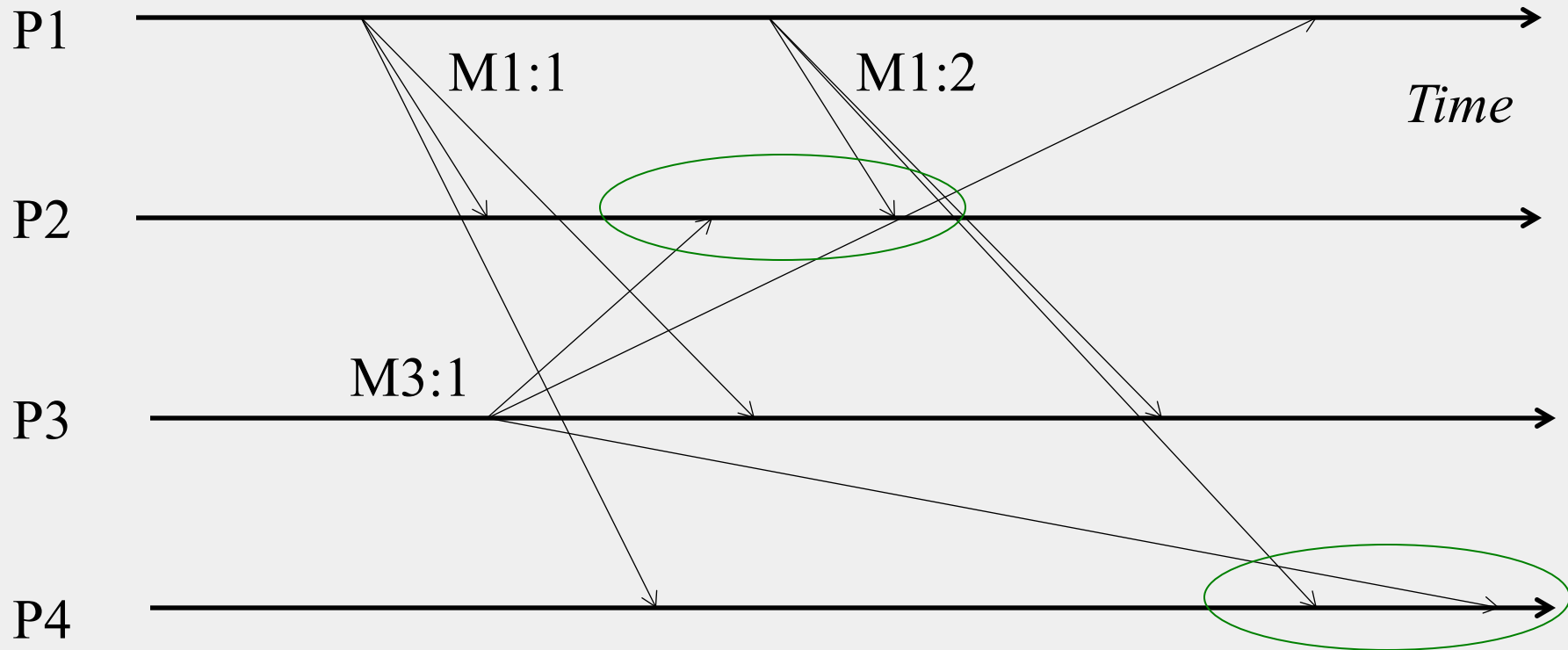
Multicast Ordering

- Determines the meaning of “same order” of multicast delivery at different processes in the group
- Three popular flavors implemented by several multicast protocols
 1. FIFO ordering
 2. Causal ordering
 3. Total ordering

1. FIFO ordering

- Multicasts from each sender are received in the order they are sent, at all receivers
- Don't worry about multicasts from different senders
- More formally
 - *If a correct process issues (sends) $\text{multicast}(g,m)$ to group g and then $\text{multicast}(g,m')$, then every correct process that delivers m' would already have delivered m .*

FIFO Ordering: Example



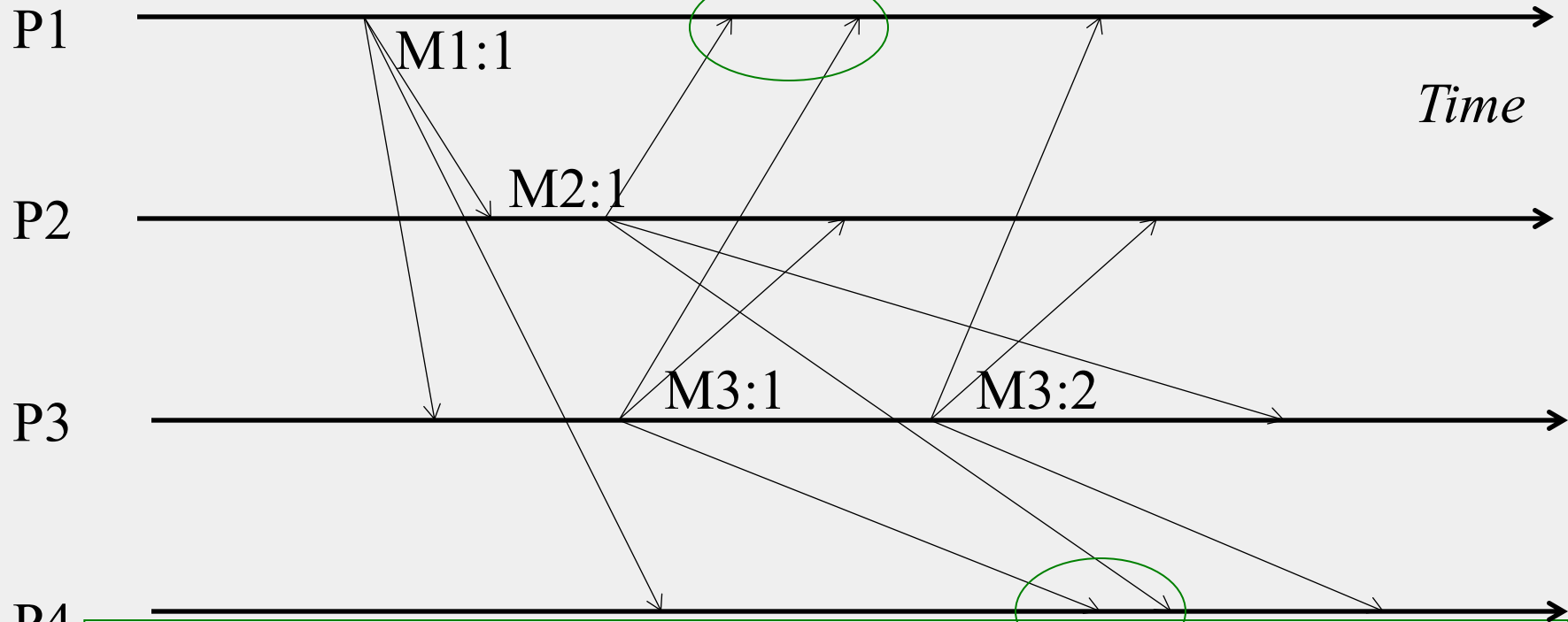
M1:1 and M1:2 should be received in that order at each receiver

Order of delivery of M3:1 and M1:2 could be different at different receivers

2. Causal Ordering

- Multicasts whose send events are causally related, must be received in the same causality-obeying order at all receivers
- Formally
 - *If $\text{multicast}(g,m) \rightarrow \text{multicast}(g,m')$ then any correct process that delivers m' would already have delivered m .*
 - (\rightarrow is Lamport's happens-before)

Causal Ordering: Example



M3:1 \rightarrow M3:2, and so should be received in that order at each receiver

M1:1 \rightarrow M3:1, and so should be received in that order at each receiver

M3:1 and M2:1 are concurrent and thus ok to be received in different orders at different receivers

Causal vs. FIFO

- Causal Ordering \Rightarrow 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.

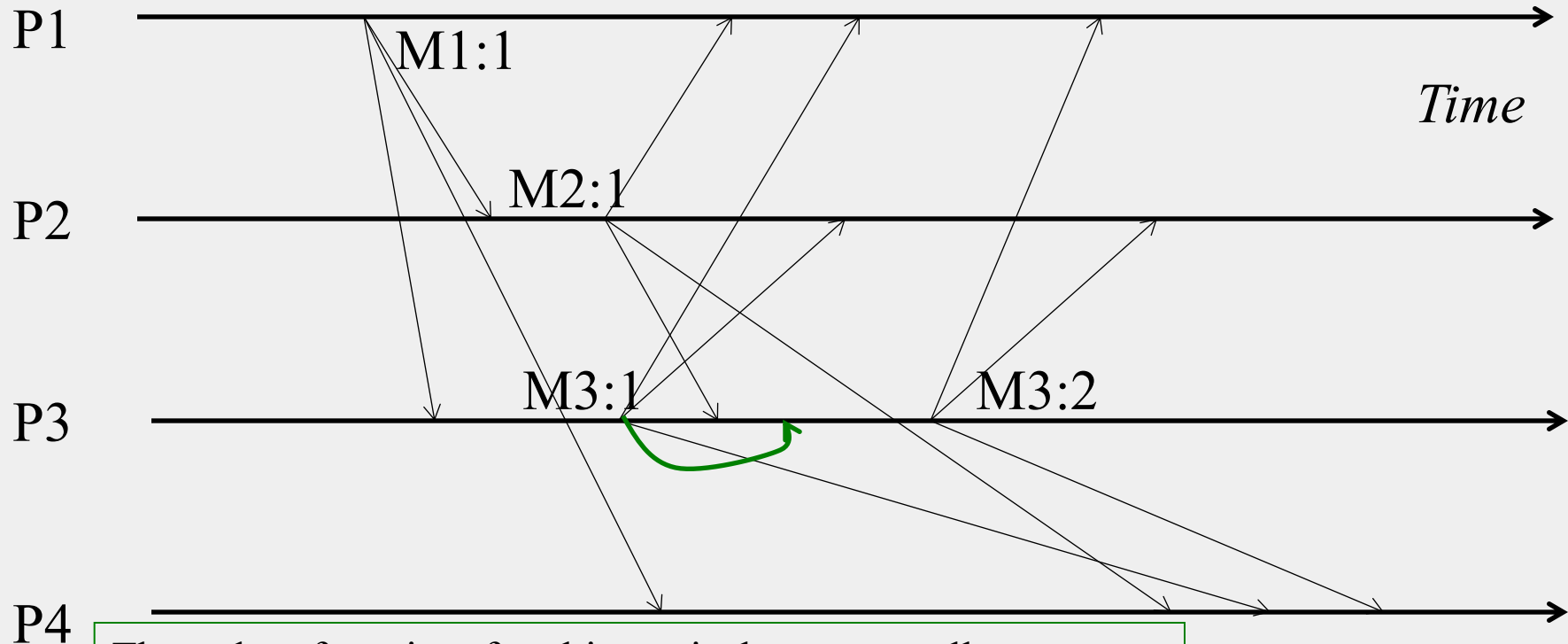
Why Causal at All?

- 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.

3. Total Ordering

- Also known as “Atomic Broadcast”
- Unlike FIFO and causal, this does not pay attention to order of multicast sending
- Ensures all receivers receive all multicasts in the same order
- Formally
 - *If a correct process P delivers message m before m' (independent of the senders), then any other correct process P' that delivers m' would already have delivered m .*

Total Ordering: 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

Hybrid Variants

- Since FIFO/Causal are orthogonal to Total, can have hybrid ordering protocols too
 - FIFO-total hybrid protocol satisfies both FIFO and total orders
 - Causal-total hybrid protocol satisfies both Causal and total orders

Implementation?

- That was *what* ordering is
- But *how* do we implement each of these orderings?

FIFO Multicast: Data Structures

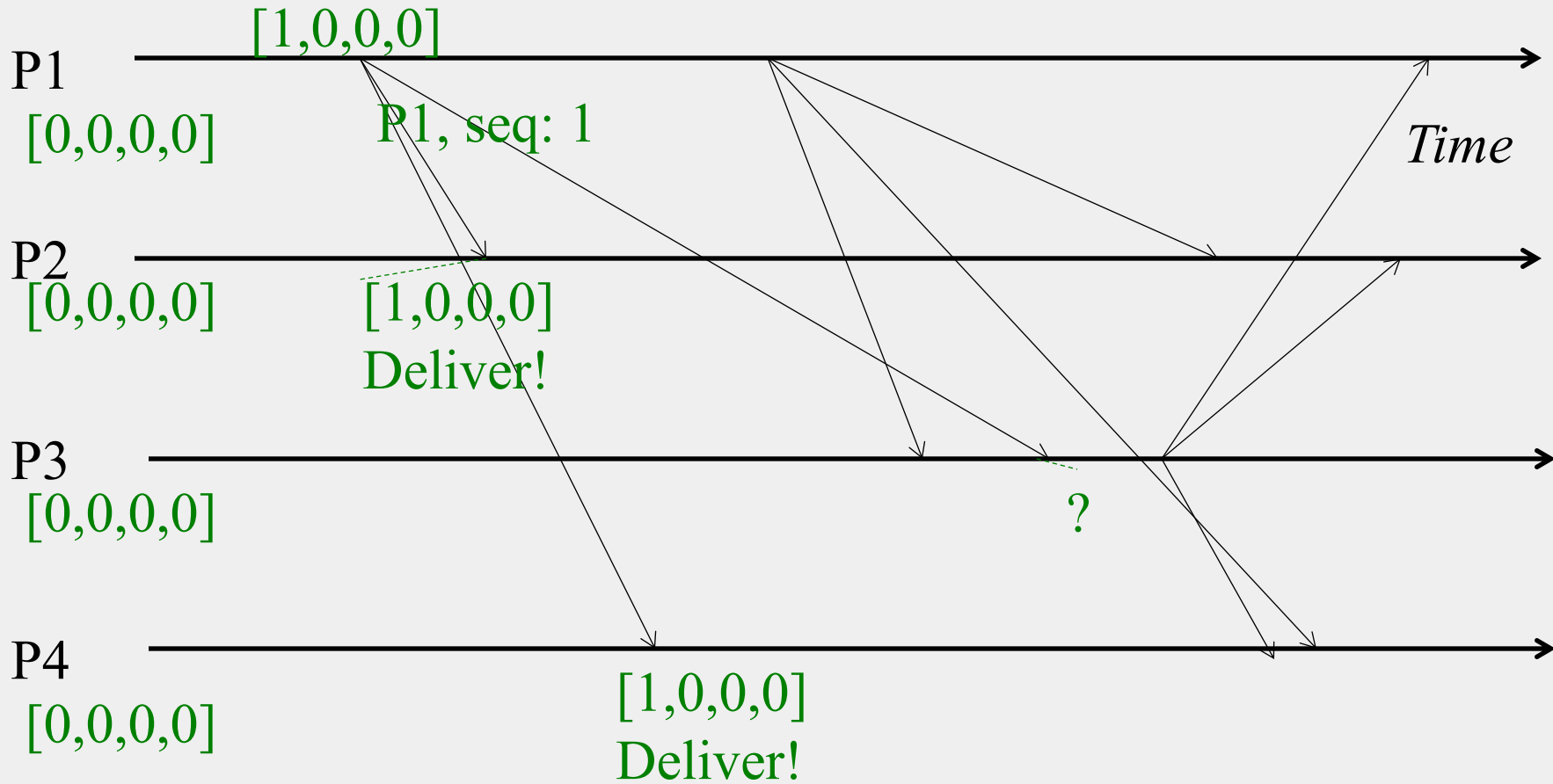
- Each receiver maintains a per-sender sequence number (integers)
 - Processes P_1 through P_N
 - P_i maintains a vector of sequence numbers $P_i[1 \dots N]$ (initially all zeroes)
 - $P_i[j]$ is the latest sequence number P_i has received from P_j

FIFO Multicast: Updating Rules

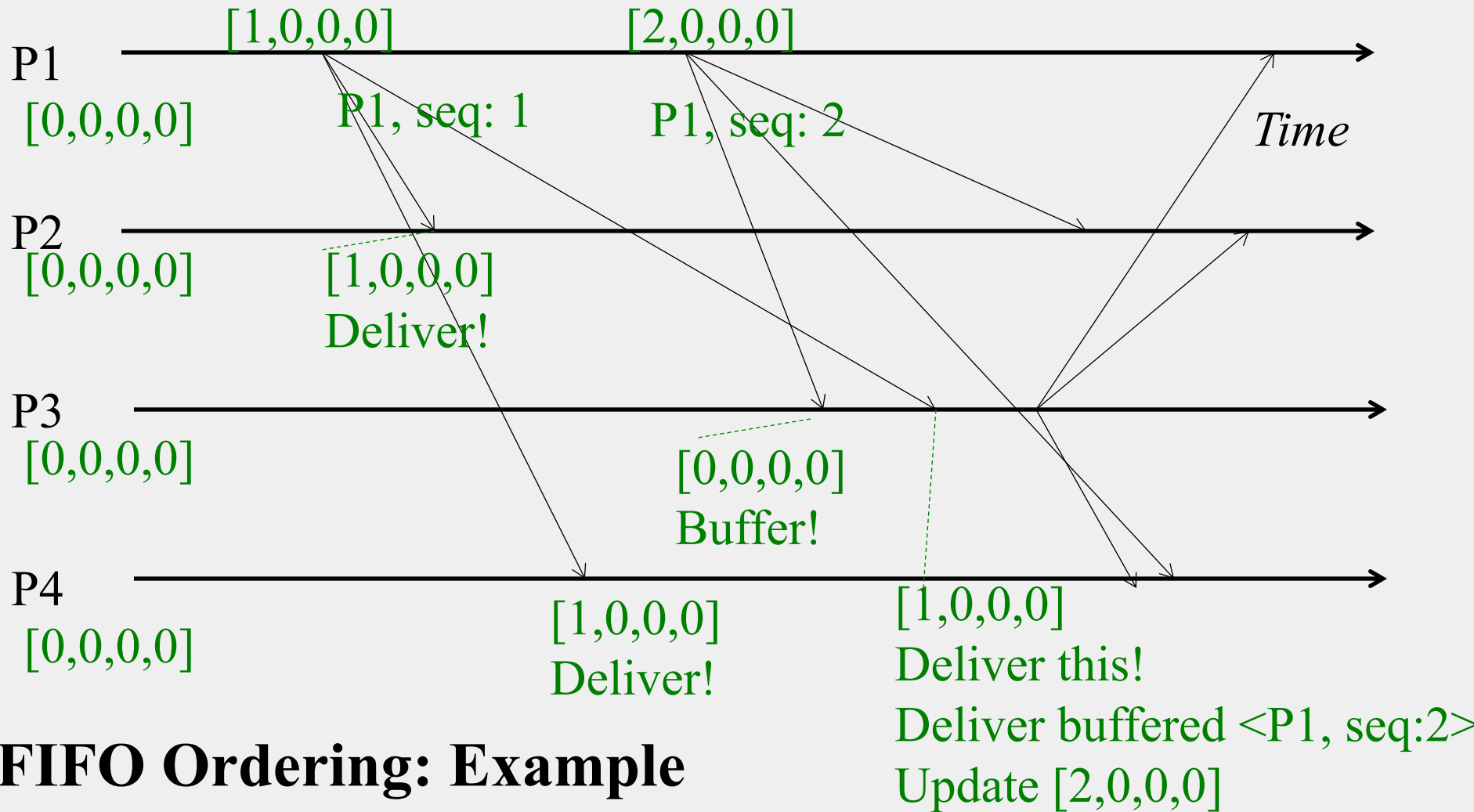
- Send multicast at process P_j :
 - Set $P_j[j] = P_j[j] + 1$
 - Include new $P_j[j]$ in multicast message as its sequence number
- Receive multicast: If P_i receives a multicast from P_j with sequence number S in message
 - if ($S == P_i[j] + 1$) then
 - deliver message to application
 - Set $P_i[j] = P_i[j] + 1$
 - else buffer this multicast until above condition is true

FIFO Ordering: Example

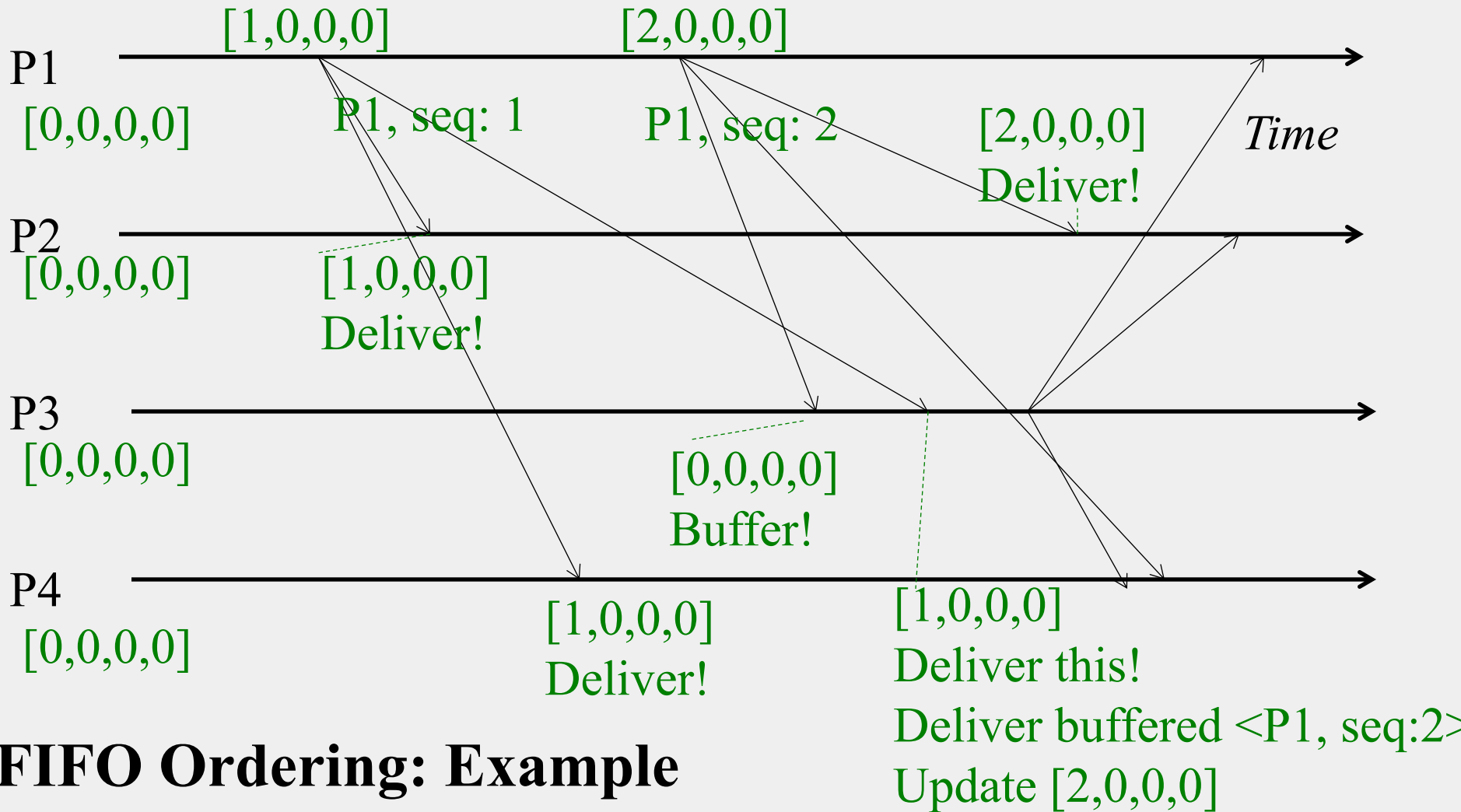


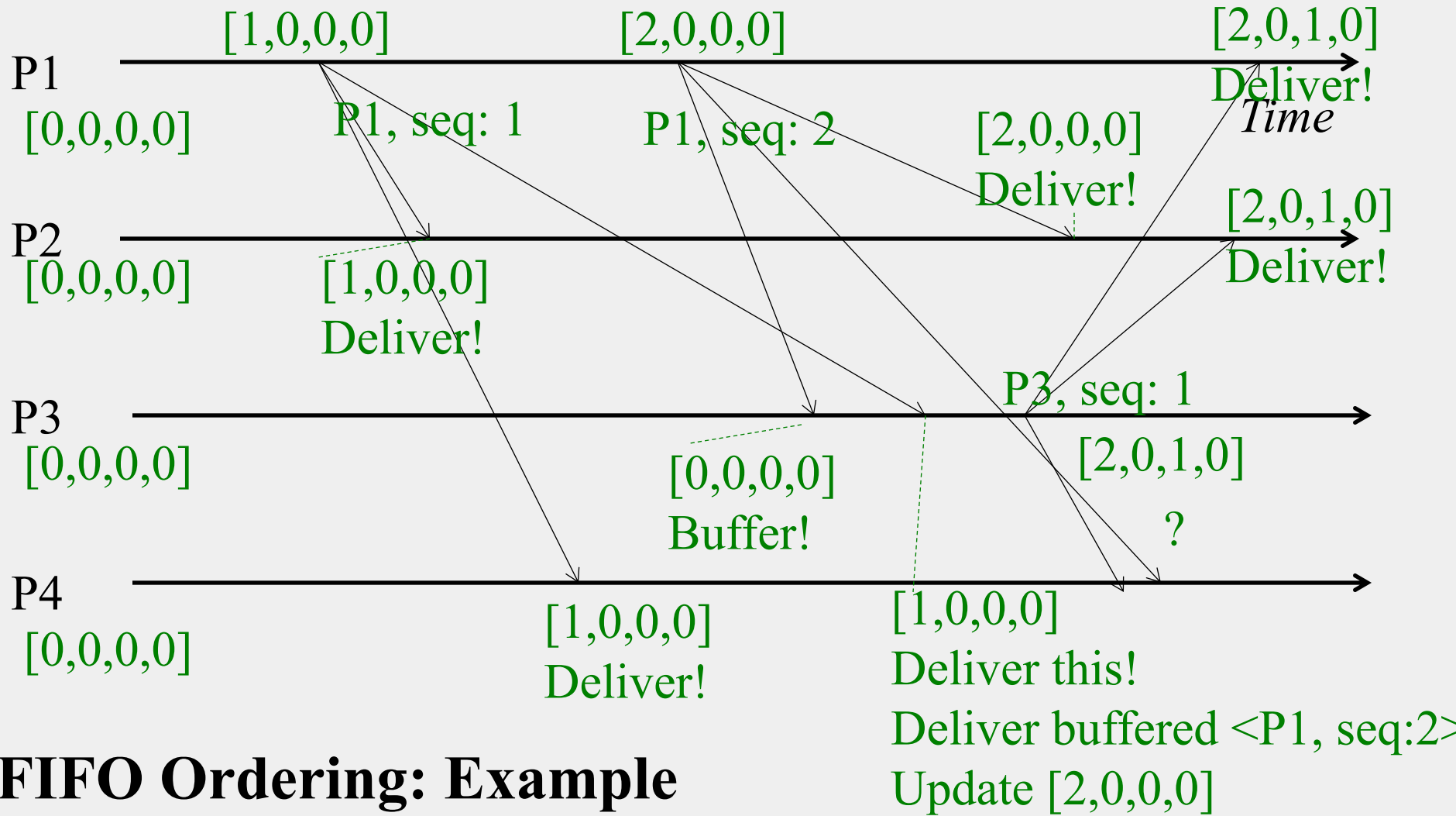


FIFO Ordering: Example

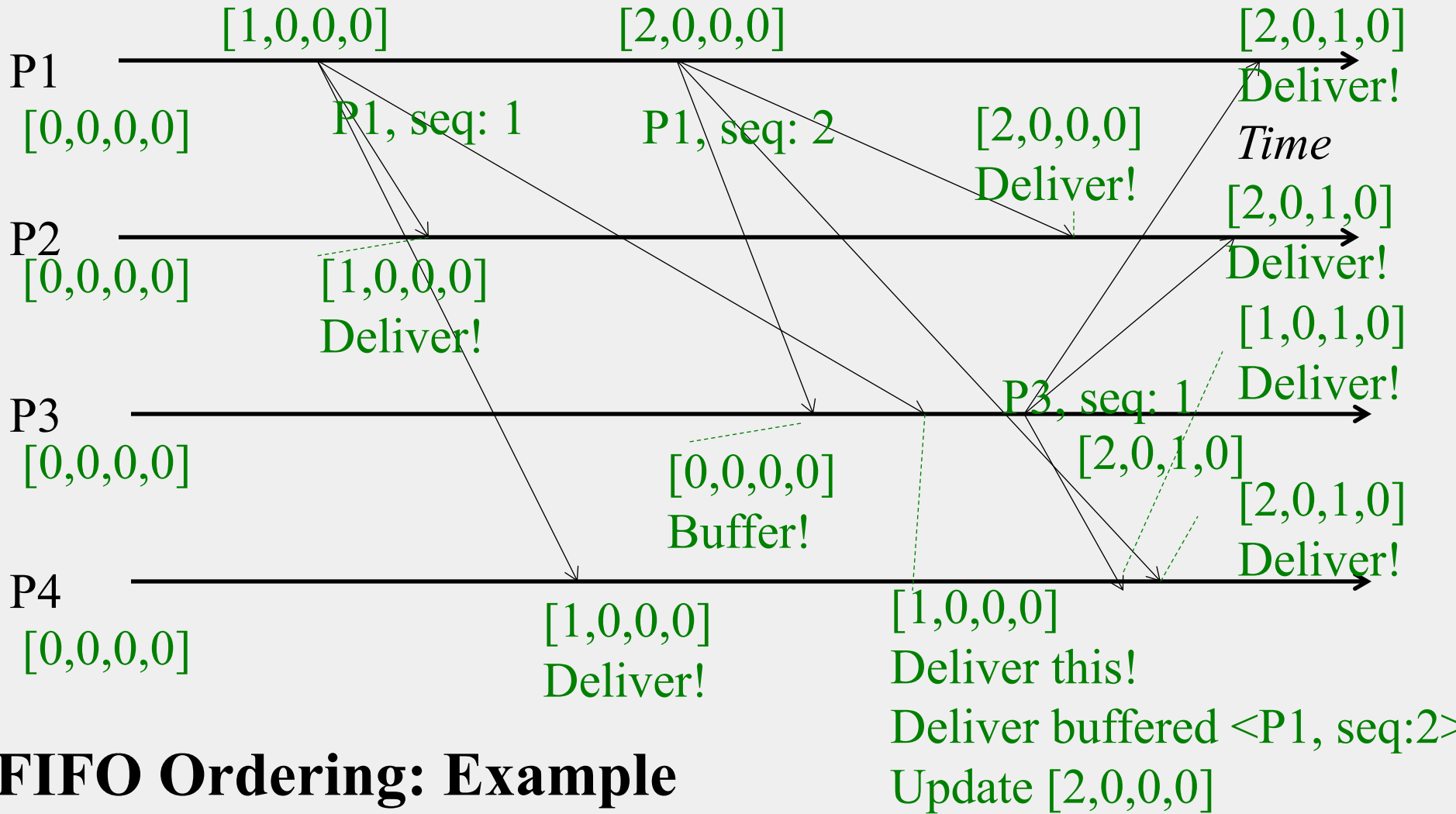


FIFO Ordering: Example





FIFO Ordering: Example



Total Ordering

- Ensures all receivers receive all multicasts in the same order
- Formally
 - *If a correct process P delivers message m before m' (independent of the senders), then any other correct process P' that delivers m' would already have delivered m .*

Sequencer-based Approach

- Special process elected as leader or sequencer
- Send multicast at process P_i :
 - Send multicast message M to group and sequencer
- Sequencer:
 - Maintains a global sequence number S (initially 0)
 - When it receives a multicast message M , it sets $S = S + 1$, and multicasts $\langle M, S \rangle$
- Receive multicast at process P_i :
 - P_i maintains a local received global sequence number S_i (initially 0)
 - If P_i receives a multicast M from P_j , it buffers it until it both
 1. P_i receives $\langle M, S(M) \rangle$ from sequencer, and
 2. $S_i + 1 = S(M)$
 - Then deliver message M to application and set $S_i = S_i + 1$

Causal Ordering

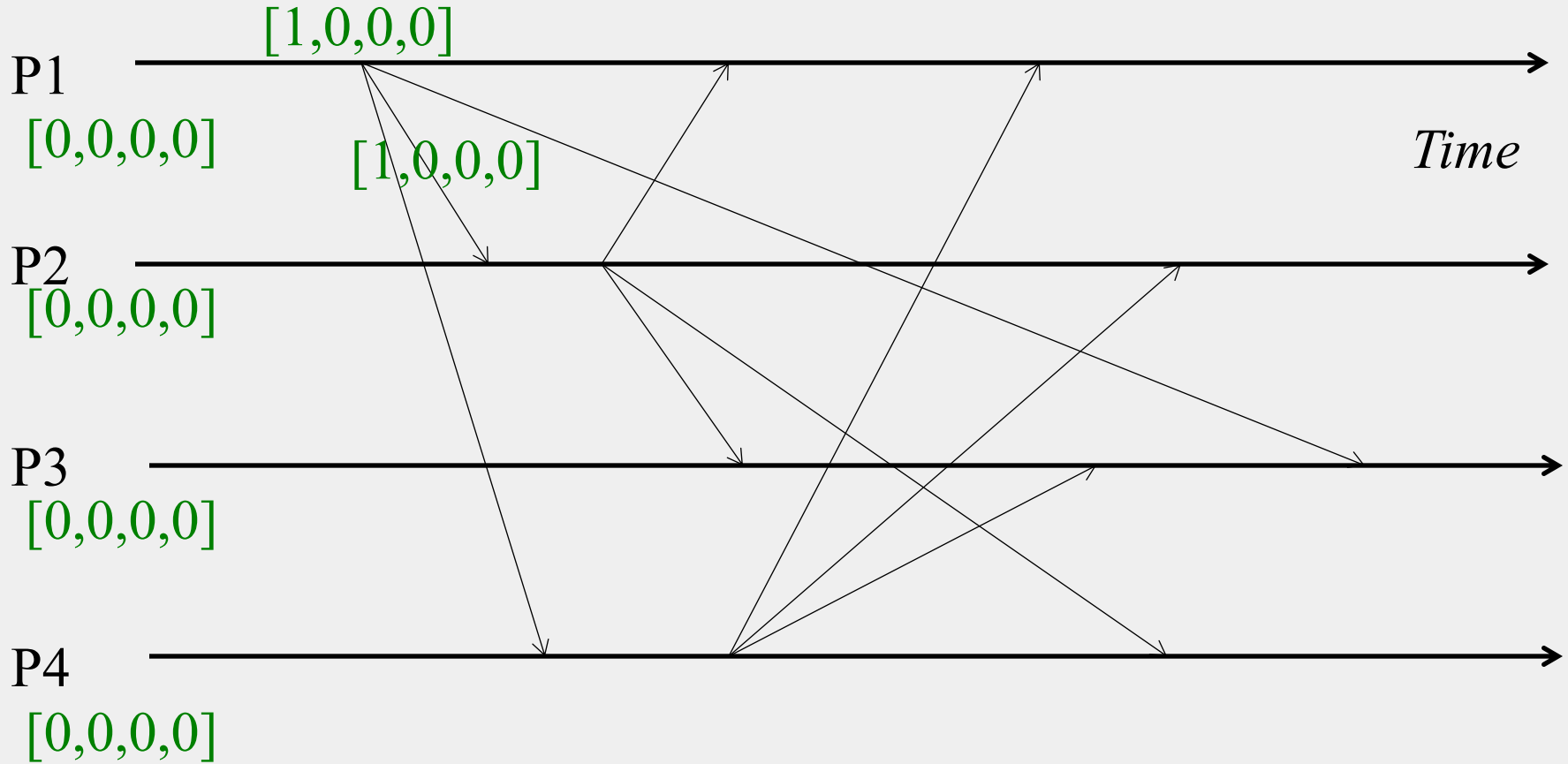
- Multicasts whose send events are causally related, must be received in the same causality-obeying order at all receivers
- Formally
 - *If $\text{multicast}(g,m) \rightarrow \text{multicast}(g,m')$ then any correct process that delivers m' would already have delivered m .*
 - *(\rightarrow is Lamport's happens-before)*

Causal Multicast: Datastructures

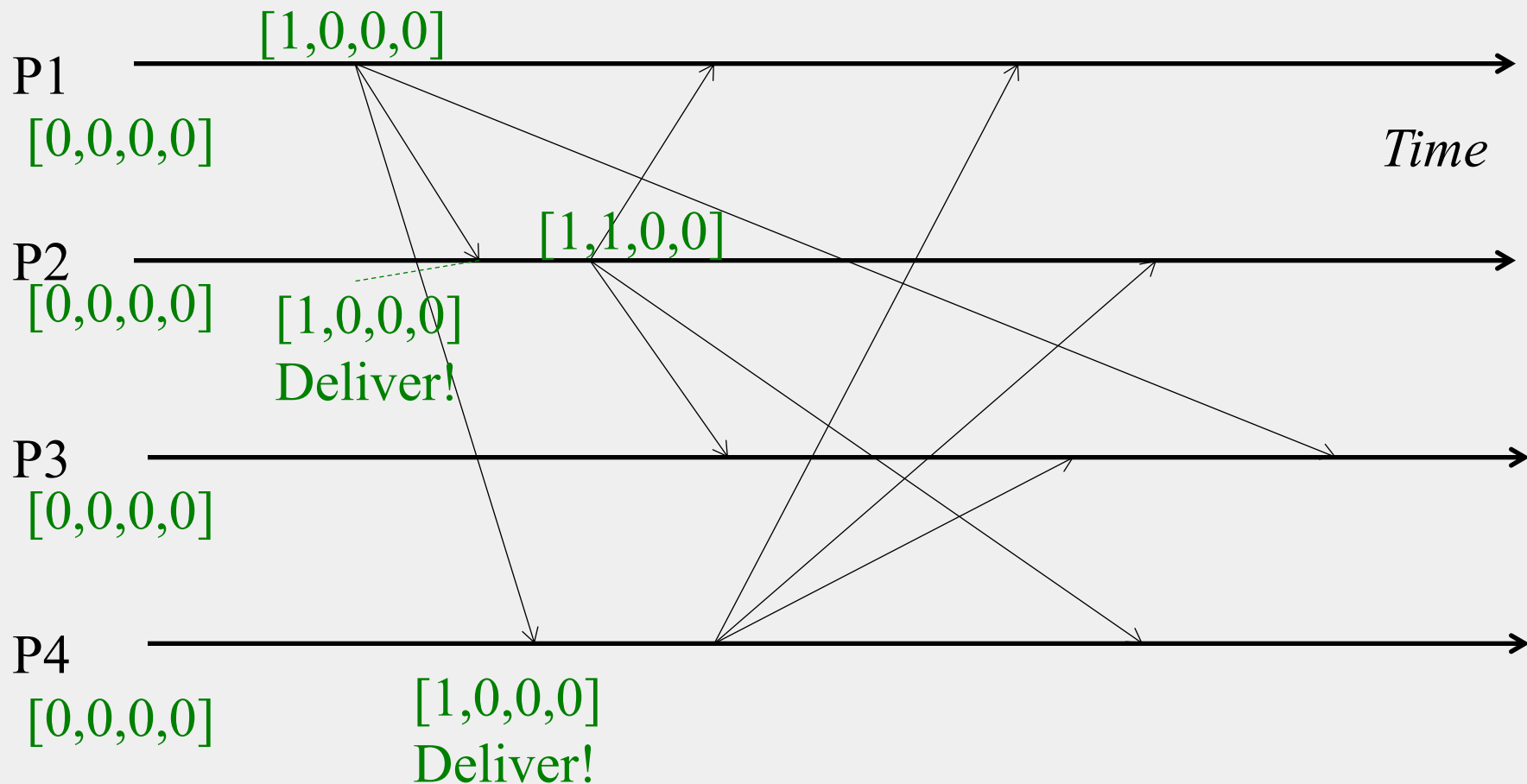
- Each receiver maintains a vector of per-sender sequence numbers (integers)
 - Similar to FIFO Multicast, but updating rules are different
 - Processes P_1 through P_N
 - P_i maintains a vector $P_i[1 \dots N]$ (initially all zeroes)
 - $P_i[j]$ is the latest sequence number P_i has received from P_j

Causal Multicast: Updating Rules

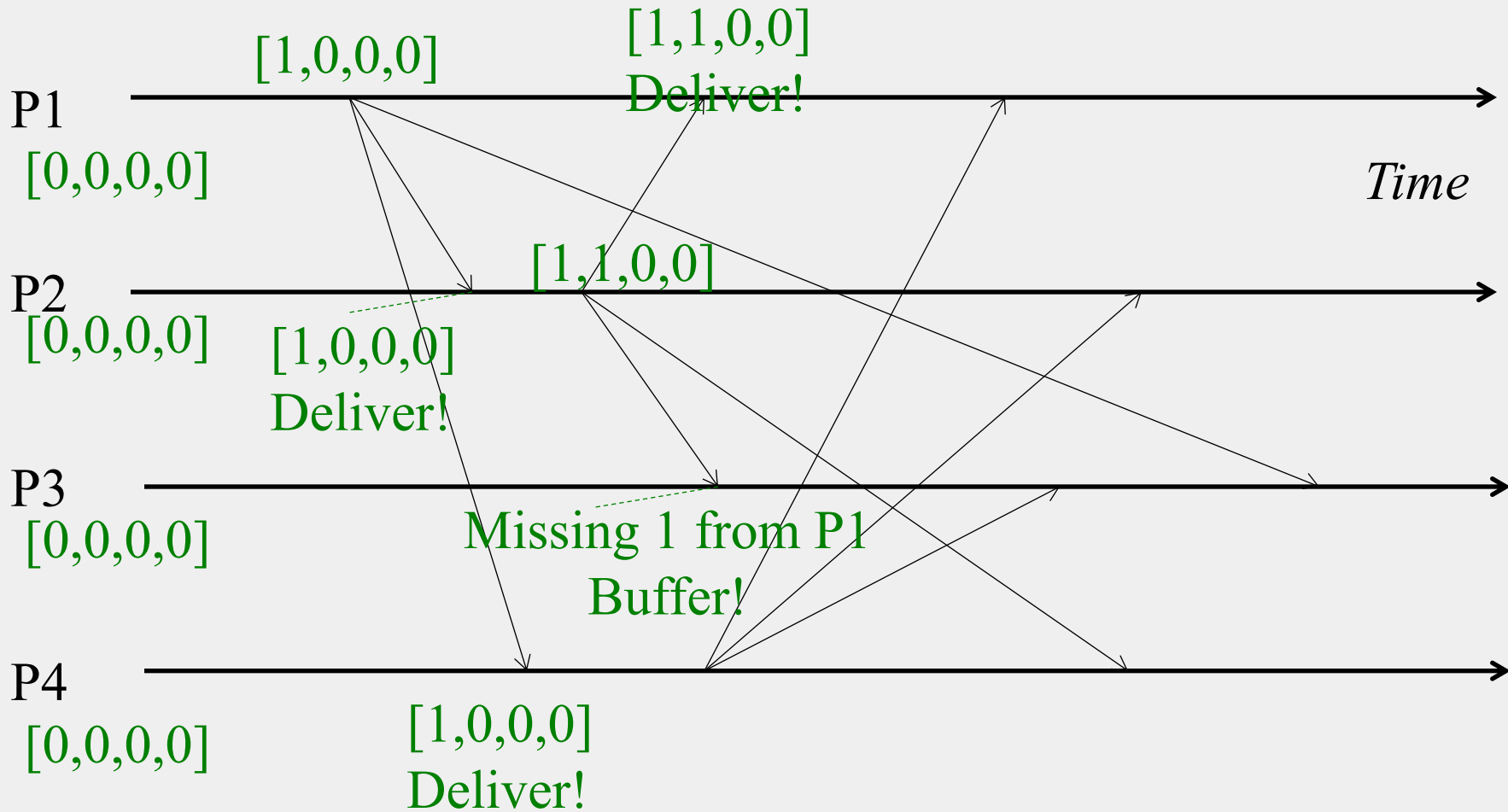
- Send multicast at process P_j :
 - Set $P_j[j] = P_j[j] + 1$
 - Include new entire vector $P_j[1..N]$ in multicast message as its sequence number
- Receive multicast: If P_i receives a multicast from P_j with vector $M[1..N]$ ($= P_j[1..N]$) in message, buffer it until both:
 1. This message is the next one P_i is expecting from P_j , i.e.,
 - $M[j] = P_i[j] + 1$
 2. All multicasts, anywhere in the group, which happened-before M have been received at P_i , i.e.,
 - For all $k \neq j$: $M[k] \leq P_i[k]$
 - i.e., *Receiver satisfies causality*
 3. When above two conditions satisfied, deliver M to application and set $P_i[j] = M[j]$



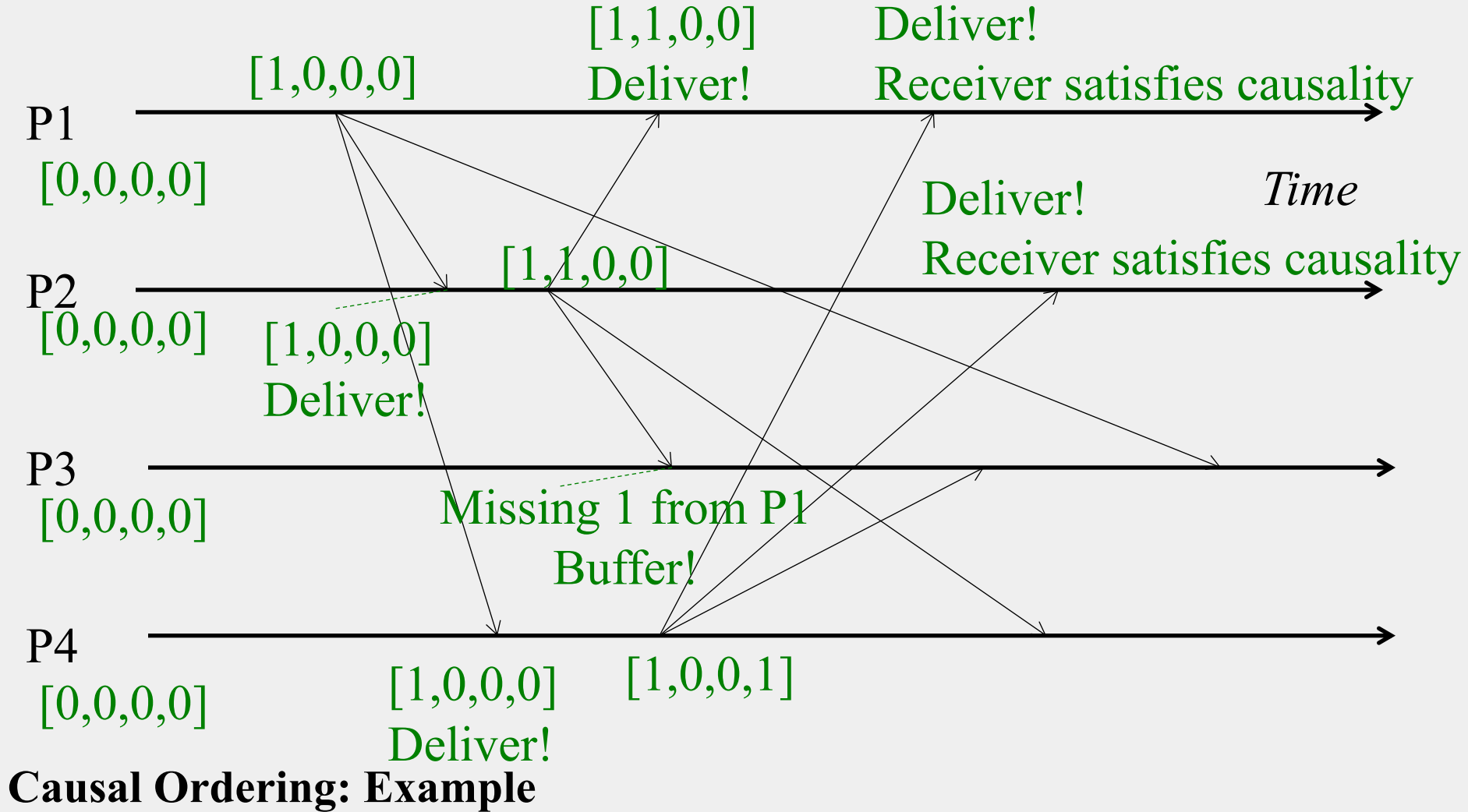
Causal Ordering: Example



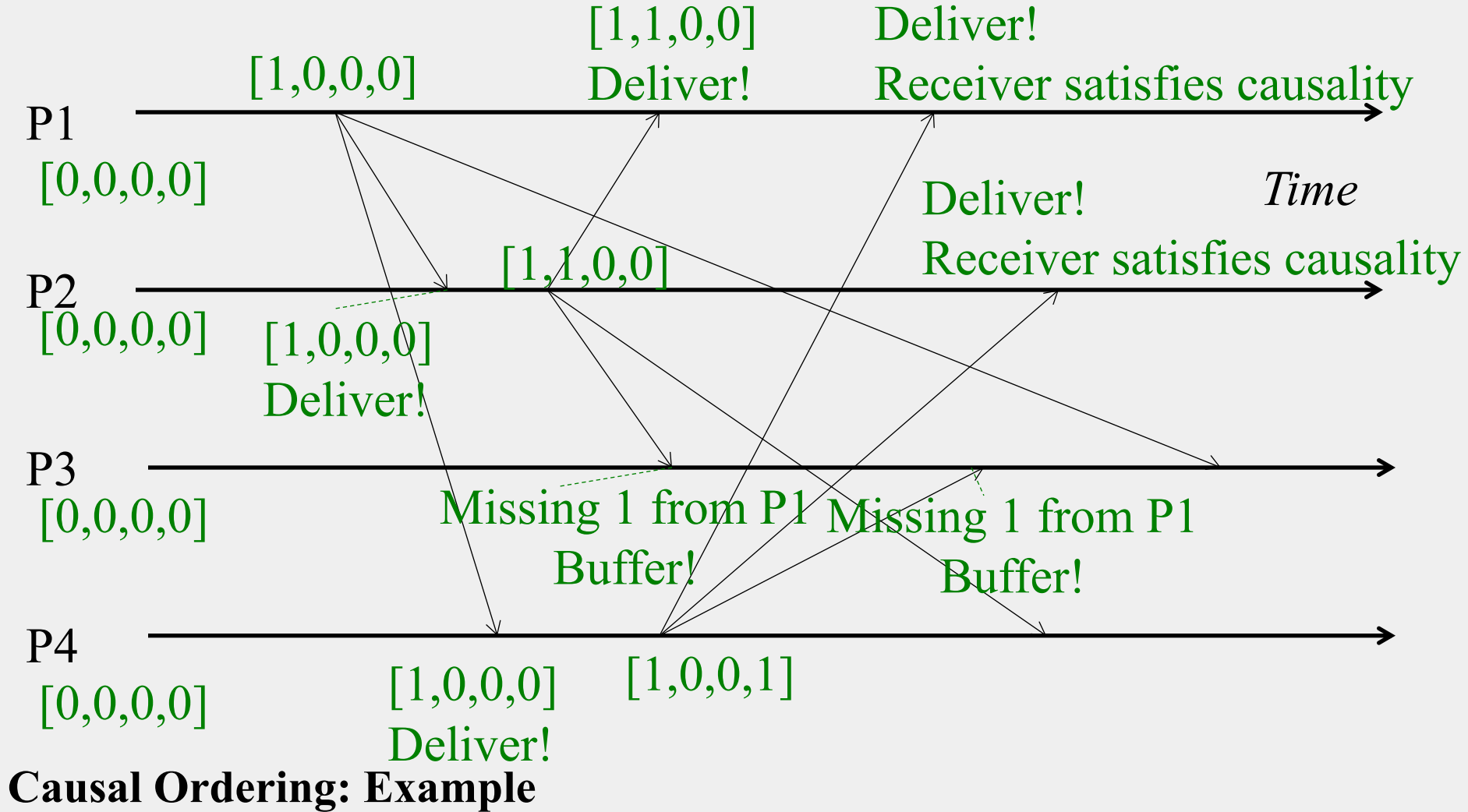
Causal Ordering: Example

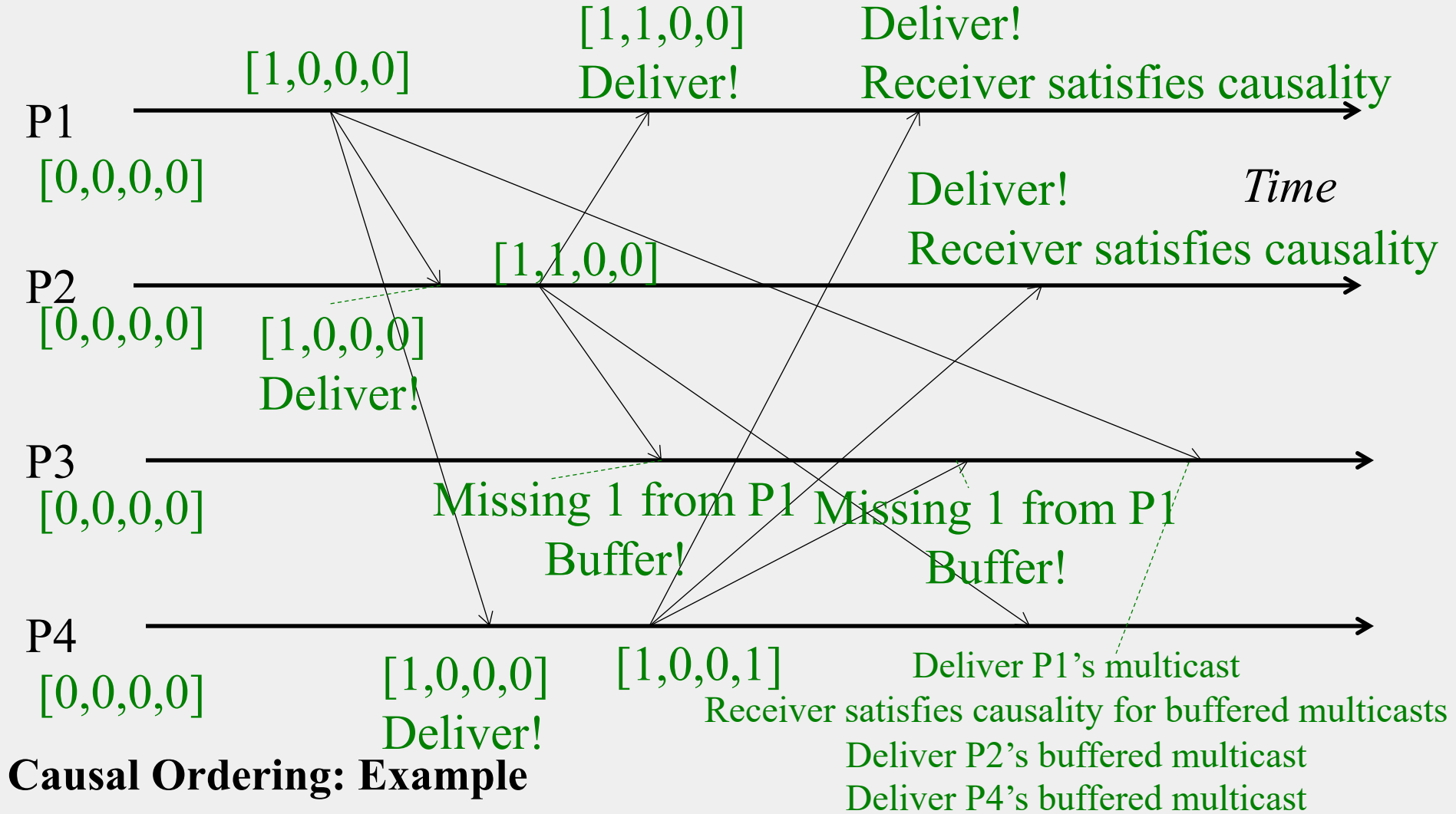


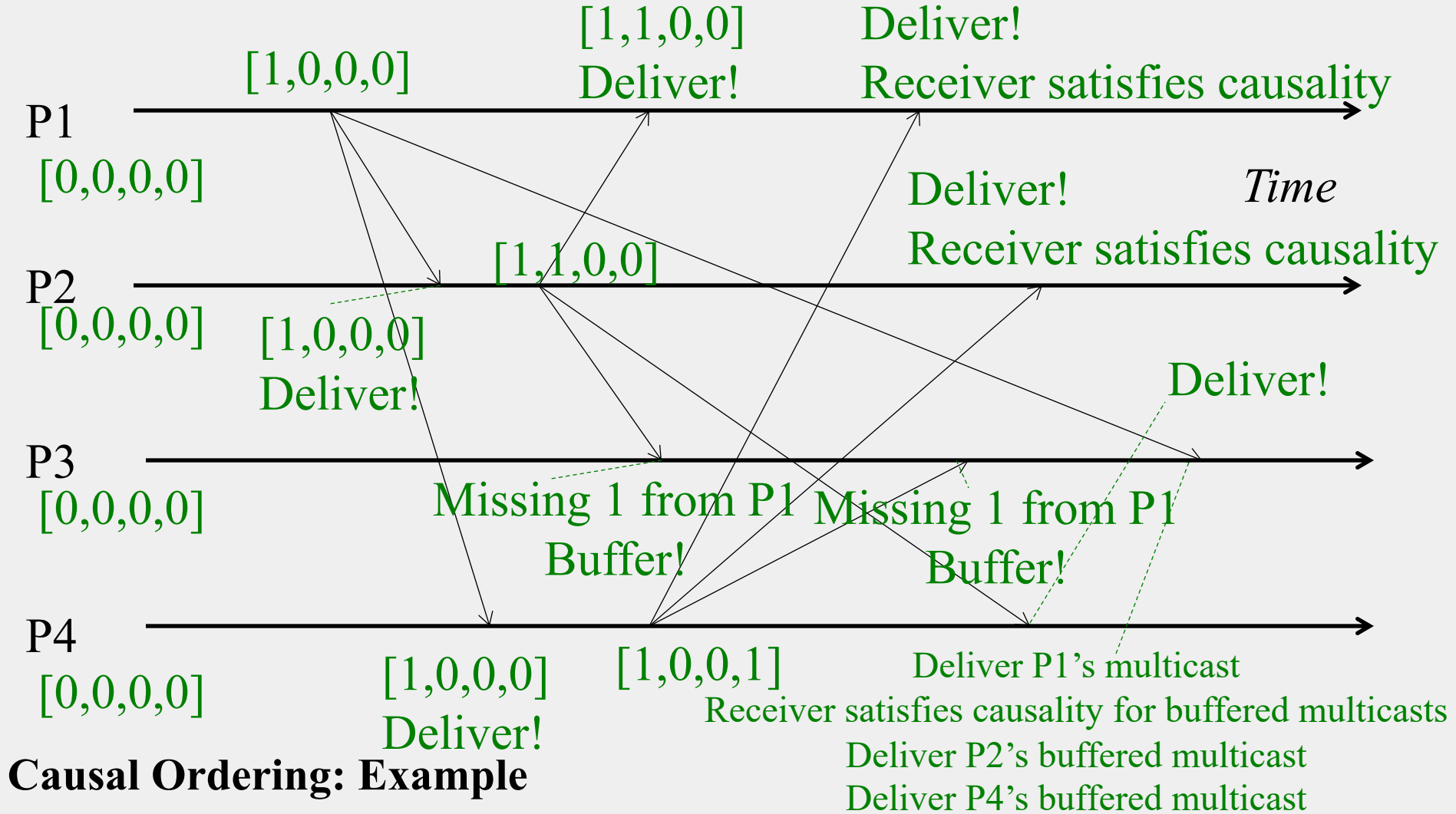
Causal Ordering: Example



Causal Ordering: Example







Summary: Multicast Ordering

- Ordering of multicasts affects correctness of distributed systems using multicasts
- Three popular ways of implementing ordering
 - FIFO, Causal, Total
- And their implementations
- What about reliability of multicasts?
- What about failures?

Reliable Multicast

- Reliable multicast loosely says that every process in the group receives all multicasts
 - Reliability is orthogonal to ordering
 - Can implement Reliable-FIFO, or Reliable-Causal, or Reliable-Total, or Reliable-Hybrid protocols
- What about process failures?
- Definition becomes vague

Reliable Multicast (under failures)

- Need all *correct* (i.e., non-faulty) processes to receive the same set of multicasts as all other correct processes
 - Faulty processes stop anyway, so we won't worry about them

Implementing Reliable Multicast

- Let's assume we have reliable unicast (e.g., TCP) available to us
- First-cut: Sender process (of each multicast M) sequentially sends a reliable unicast message to all group recipients
- First-cut protocol does not satisfy reliability
 - If sender fails, some correct processes might receive multicast M, while other correct processes might not receive M

REALLY Implementing Reliable Multicast

- Trick: Have receivers help the sender
 1. Sender process (of each multicast M) sequentially sends a reliable unicast message to all group recipients
 2. When a receiver receives multicast M, it also sequentially sends M to all the group's processes

Analysis

- Not the most efficient multicast protocol, but reliable
- Proof is by contradiction
- Assume two correct processes P_i and P_j are so that P_i received a multicast M and P_j did not receive that multicast M
 - Then P_i would have sequentially sent the multicast M to all group members, including P_j , and P_j would have received M
 - A contradiction
 - Hence our initial assumption must be false
 - Hence protocol preserves reliability

Virtual Synchrony or View Synchrony

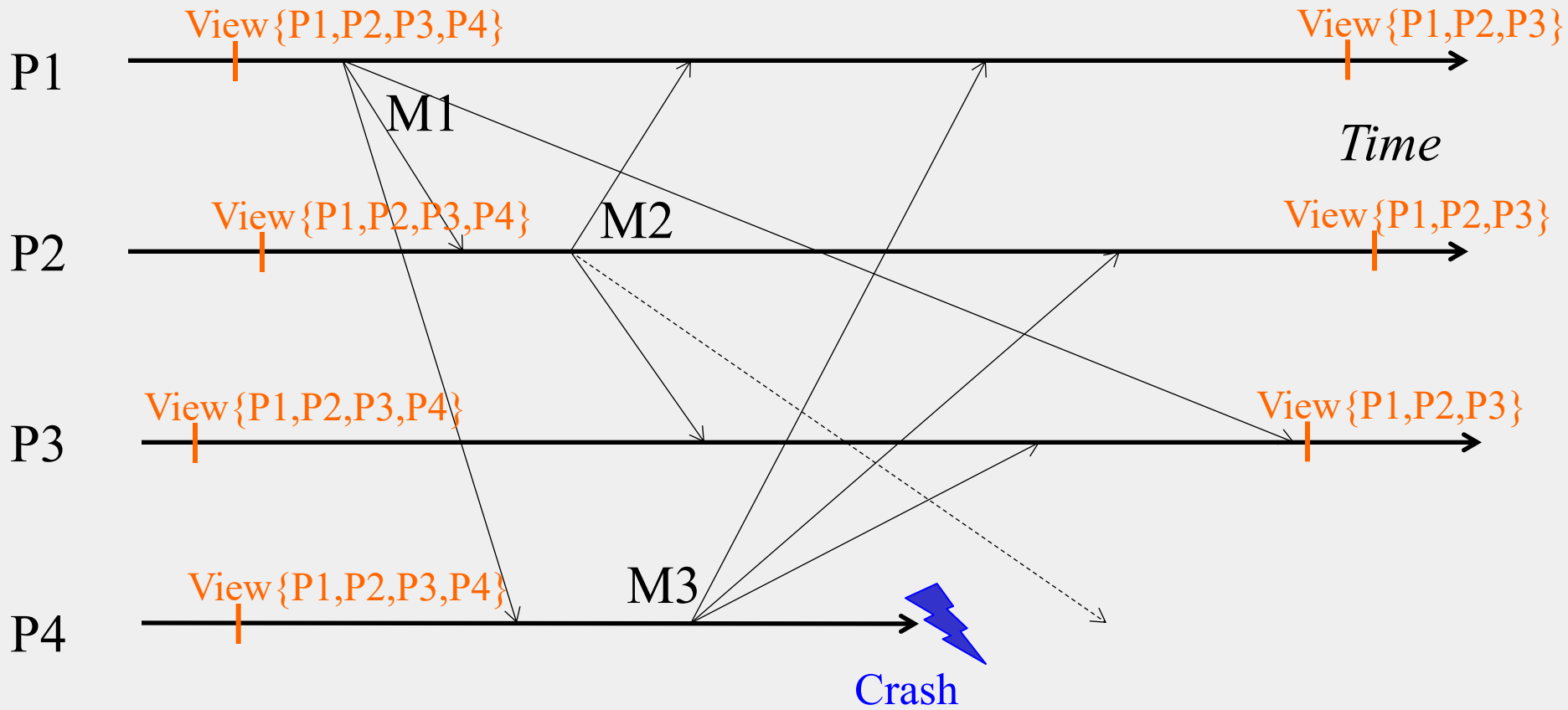
- Attempts to preserve multicast ordering and reliability in spite of failures
- Combines a membership protocol with a multicast protocol
- Systems that implemented it (like Isis Systems) have been used in NYSE, French Air Traffic Control System, Swiss Stock Exchange

Views

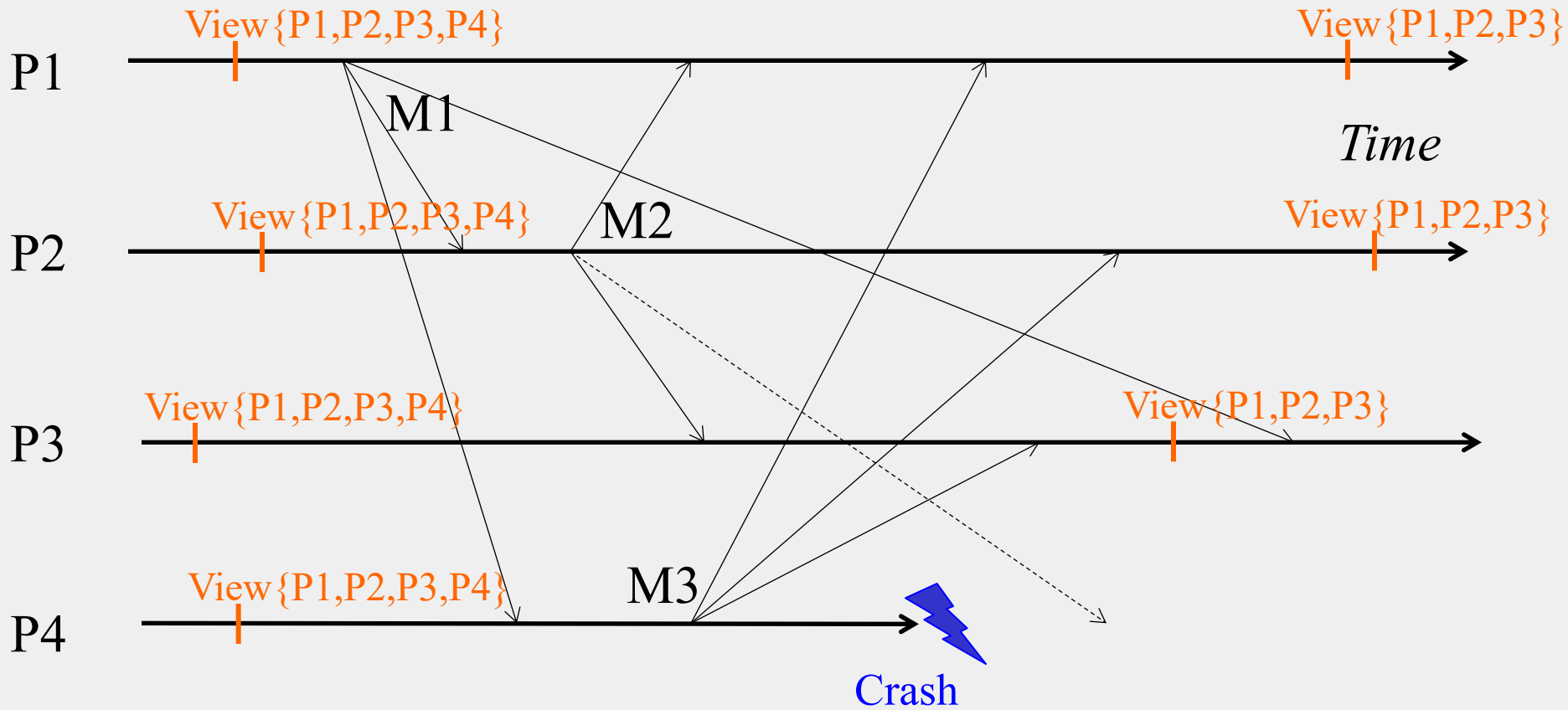
- Each process maintains a membership list
- The membership list is called a *View*
- An update to the membership list is called a *View Change*
 - Process join, leave, or failure
- Virtual synchrony guarantees that all **view changes are delivered in the same order at all correct processes**
 - If a correct P1 process receives views, say {P1}, {P1, P2, P3}, {P1, P2}, {P1, P2, P4} then
 - Any other correct process receives the *same sequence* of view changes (after it joins the group)
 - P2 receives views {P1, P2, P3}, {P1, P2}, {P1, P2, P4}
- Views may be delivered at different physical times at processes, but they are delivered in the same order

VSync Multicasts

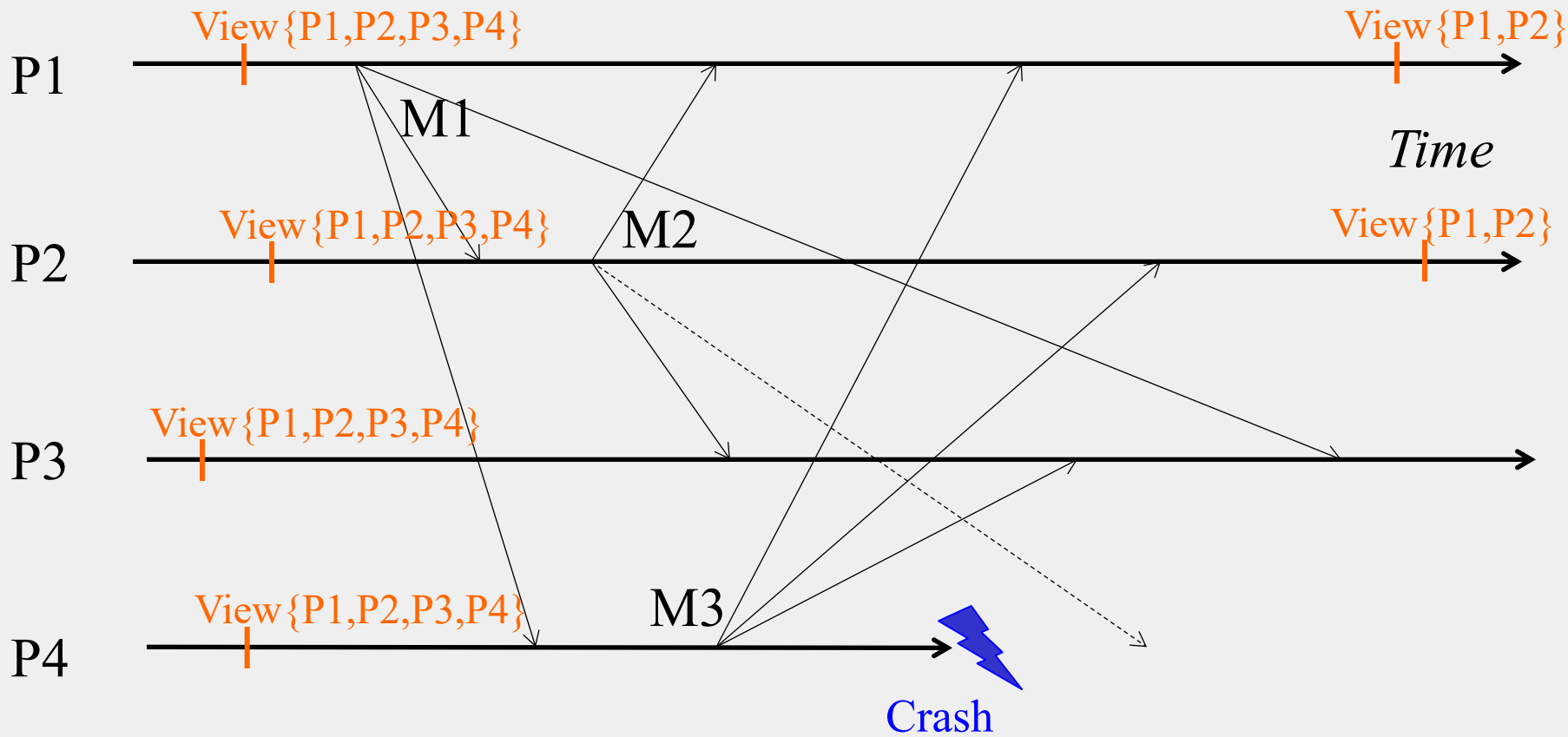
- A multicast M is said to be “delivered in a view V at process P_i ” if
 - P_i receives view V , and then sometime before P_i receives the next view it delivers multicast M
- Virtual synchrony ensures that
 1. **The set of multicasts delivered in a given view is the same set at all correct processes that were in that view**
 - *What happens in a View, stays in that View*
 2. The sender of the multicast message (and the send event) also belongs to that view
 3. If a process P_i does not deliver a multicast M in view V while other processes in the view V delivered M in V , then P_i will be *forcibly removed* from the next view delivered after V at the other processes



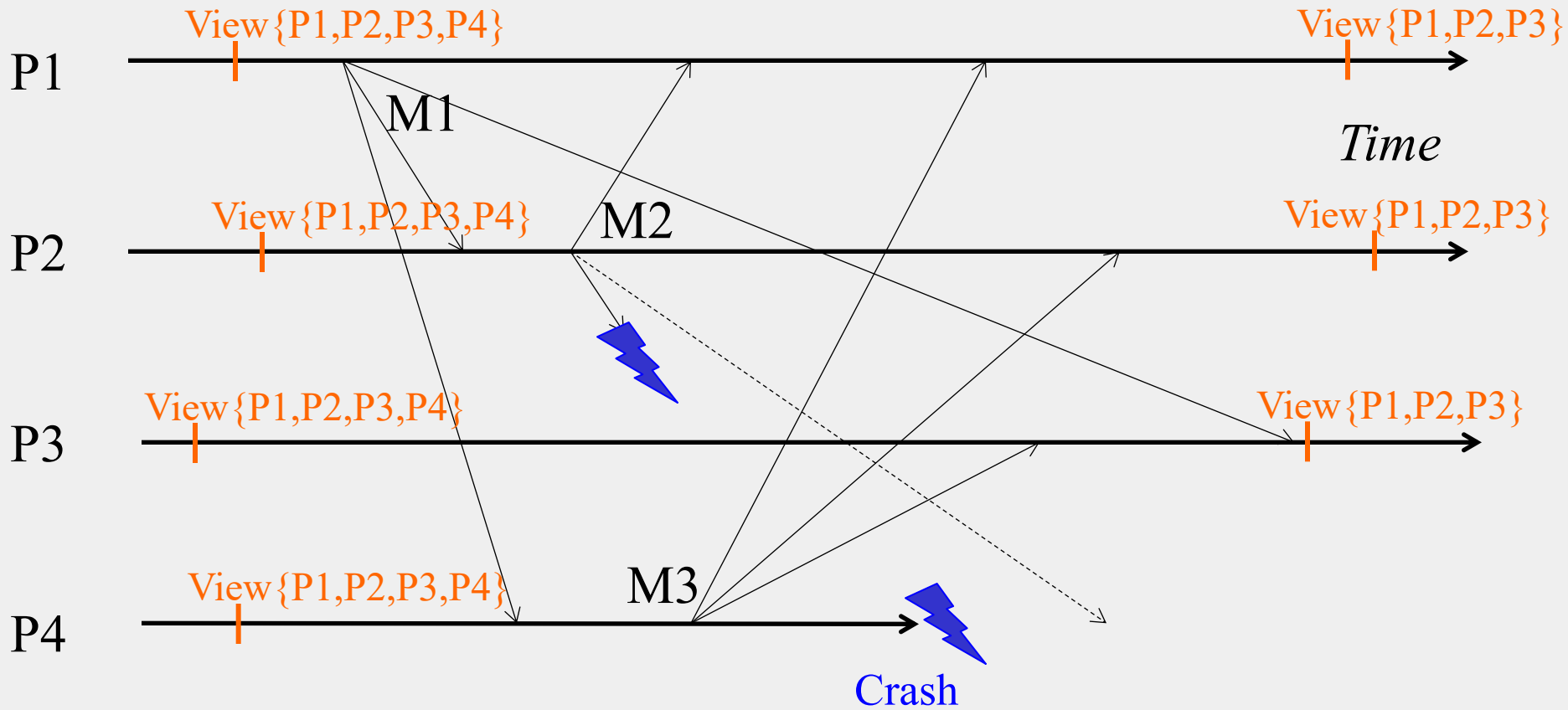
Satisfies virtual synchrony



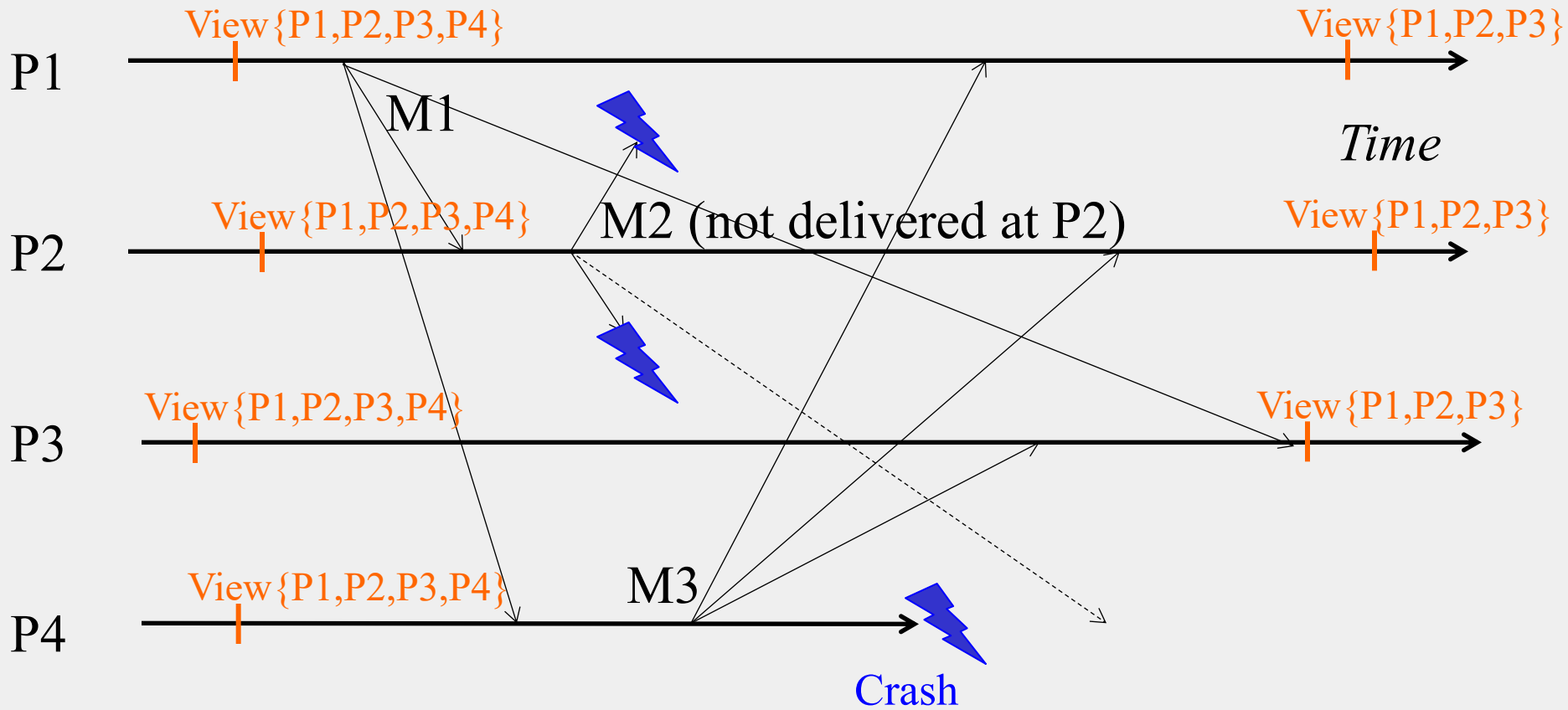
Does not satisfy virtual synchrony



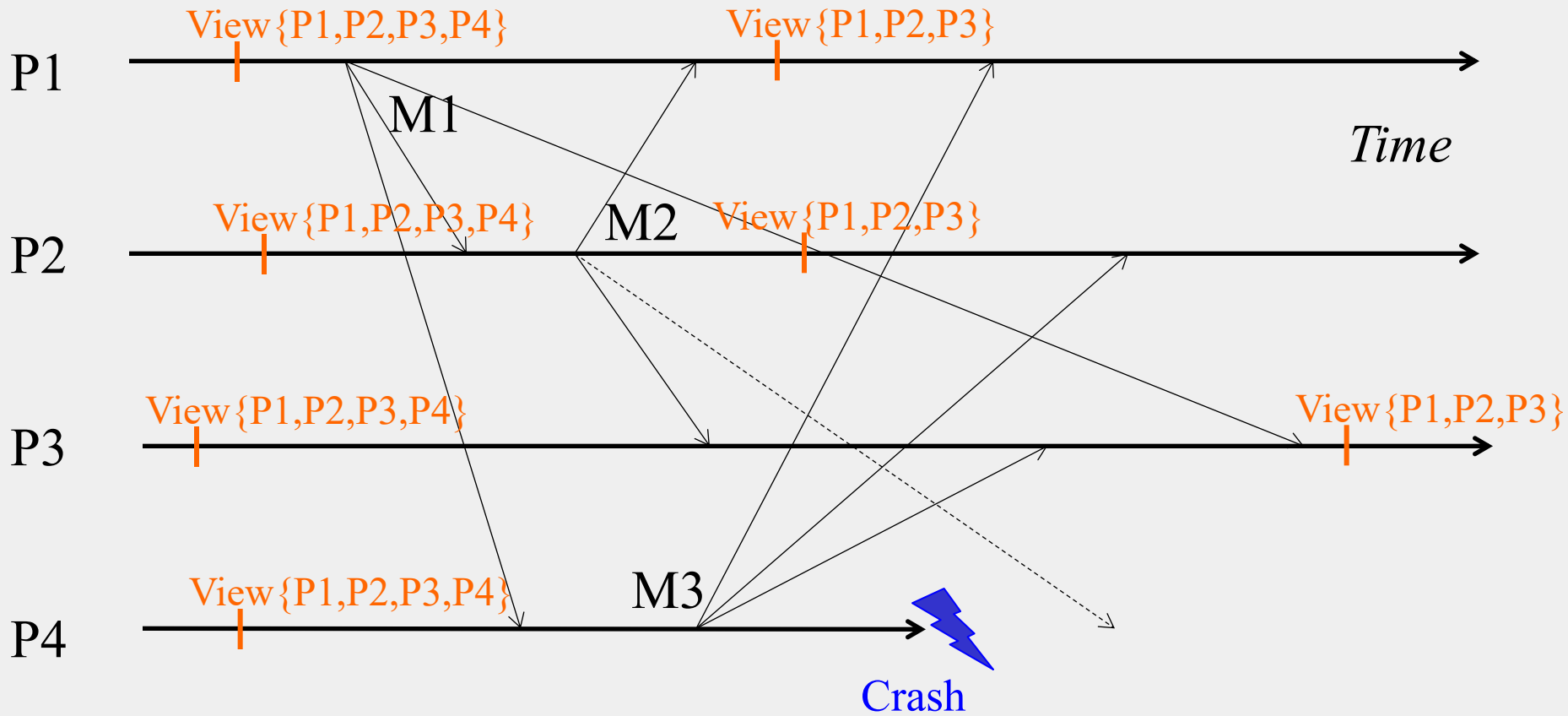
Satisfies virtual synchrony



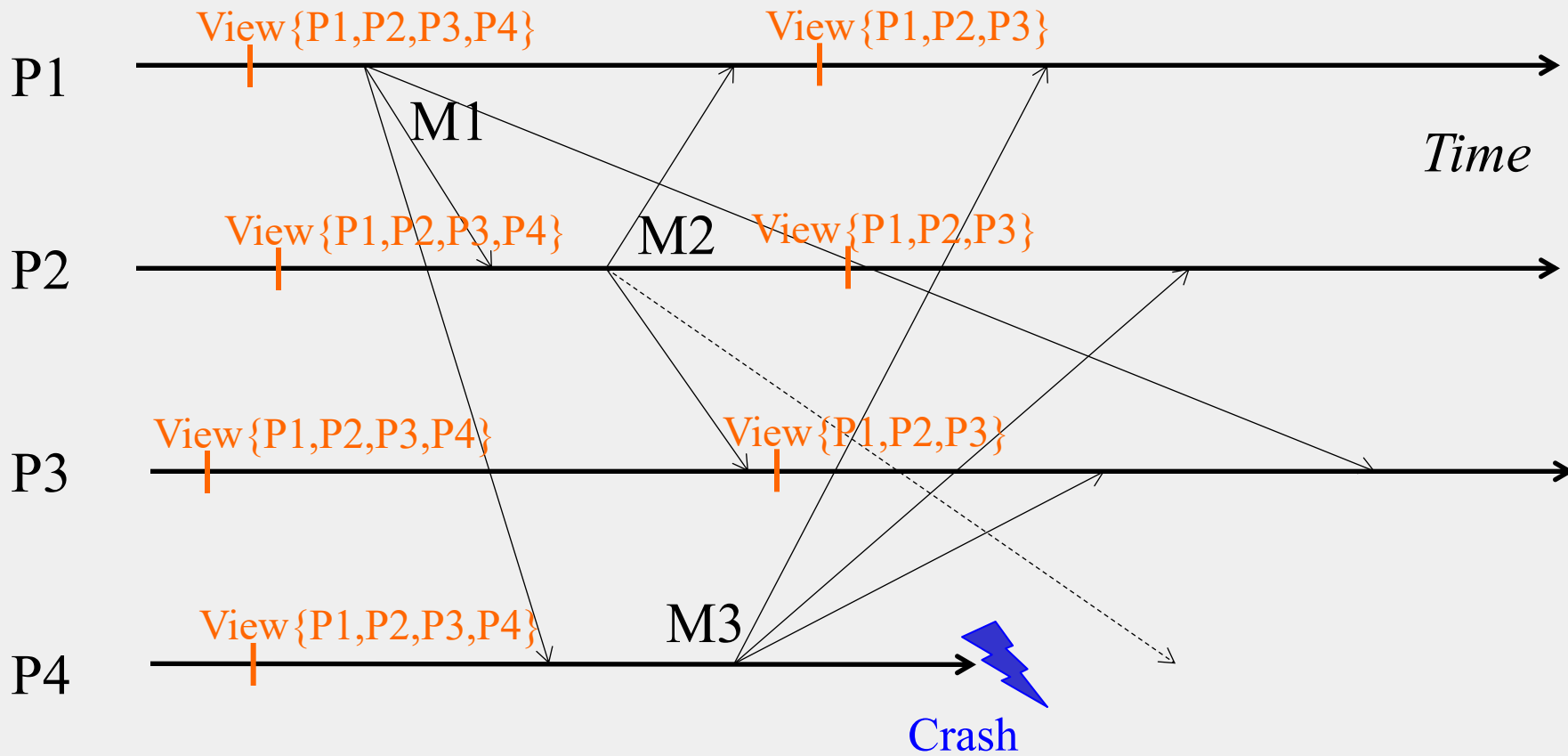
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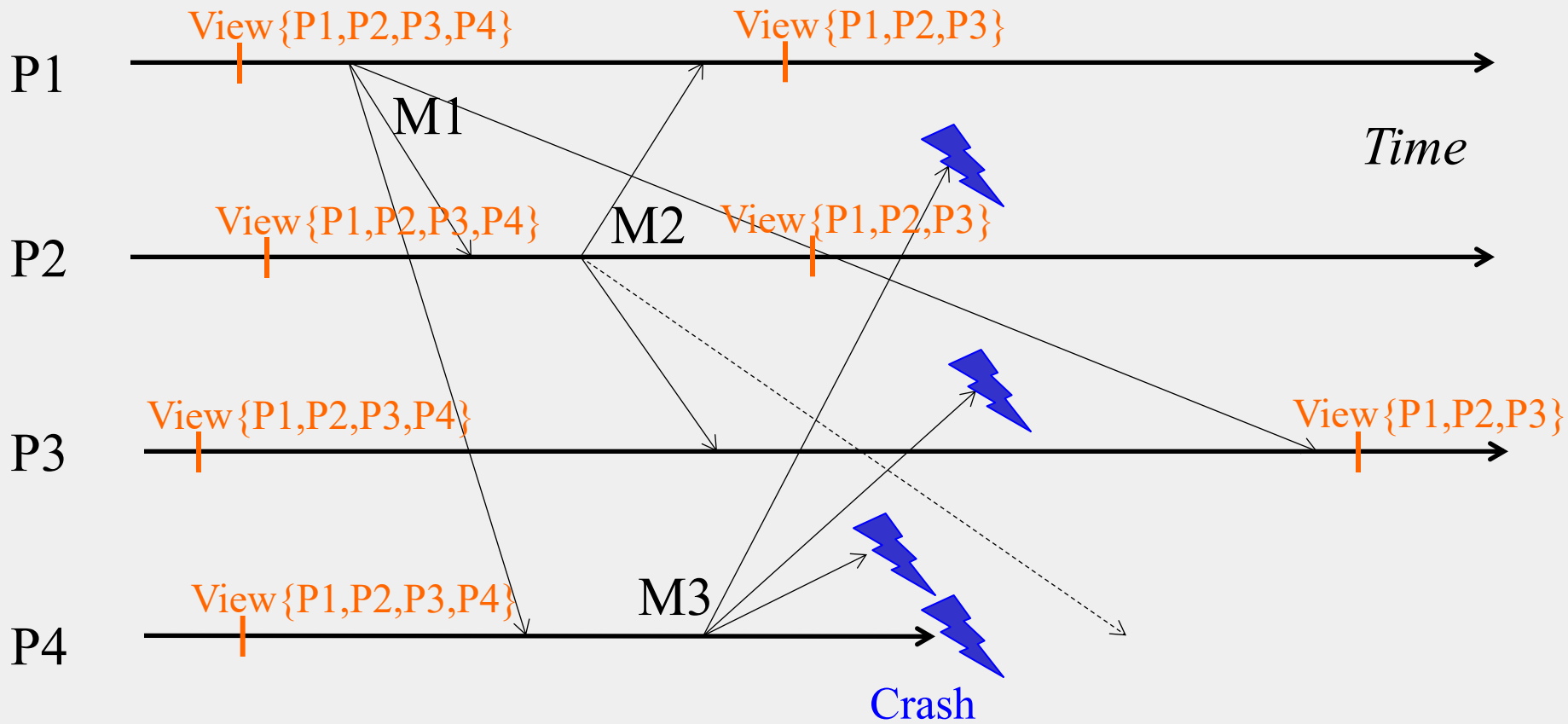
Satisfies virtual synchrony



Does not satisfy virtual synchrony



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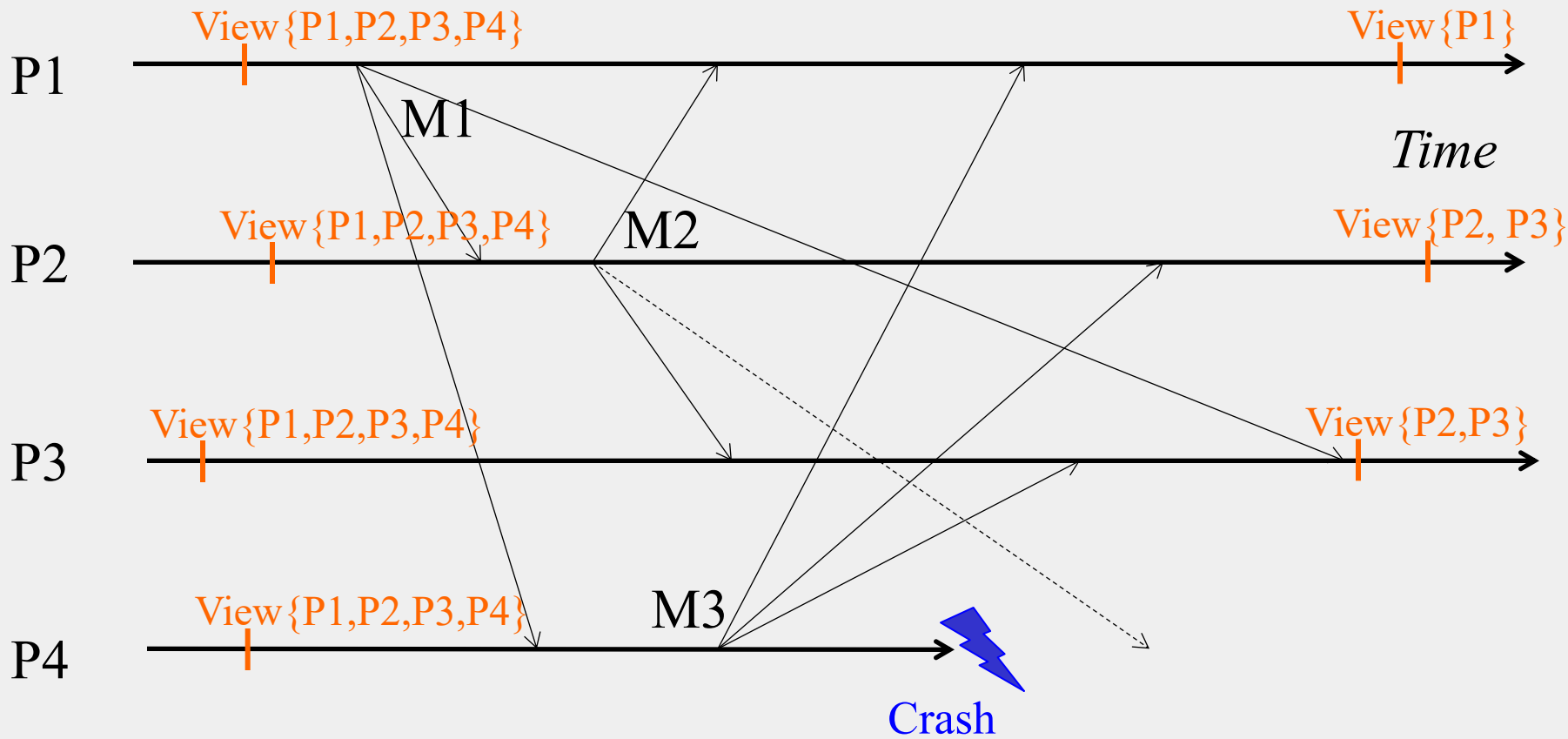
Satisfies virtual synchrony

What about Multicast Ordering?

- Again, orthogonal to virtual synchrony
- The set of multicasts delivered in a view can be ordered either
 - FIFO
 - Or Causally
 - Or Totally
 - Or using a hybrid scheme

About that name

- Called “virtual synchrony” since in spite of running on an asynchronous network, it gives the appearance of a synchronous network underneath that obeys the same ordering at all processes
- So can this virtually synchronous system be used to implement consensus?
- No! VSync groups susceptible to partitioning
 - E.g., due to inaccurate failure detections



Partitioning in View synchronous systems

Summary

- Multicast an important building block for cloud computing systems
- Depending on application need, can implement
 - Ordering
 - Reliability
 - Virtual synchrony

Announcements

- HW3, MP3 released. Start now!
- Midterms handed back Wed 10/12.
- Deadline for regrades: 10/19