CS 425 / ECE 428
Distributed Systems
Fall 2019

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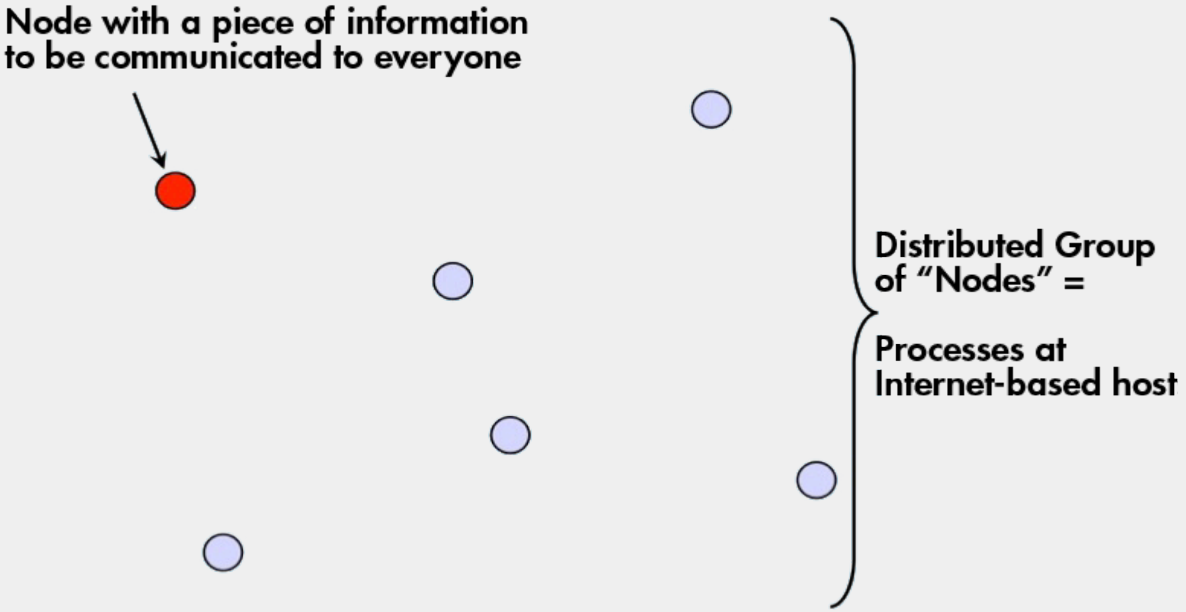
Lecture 16: Multicast

Multicast Problem



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

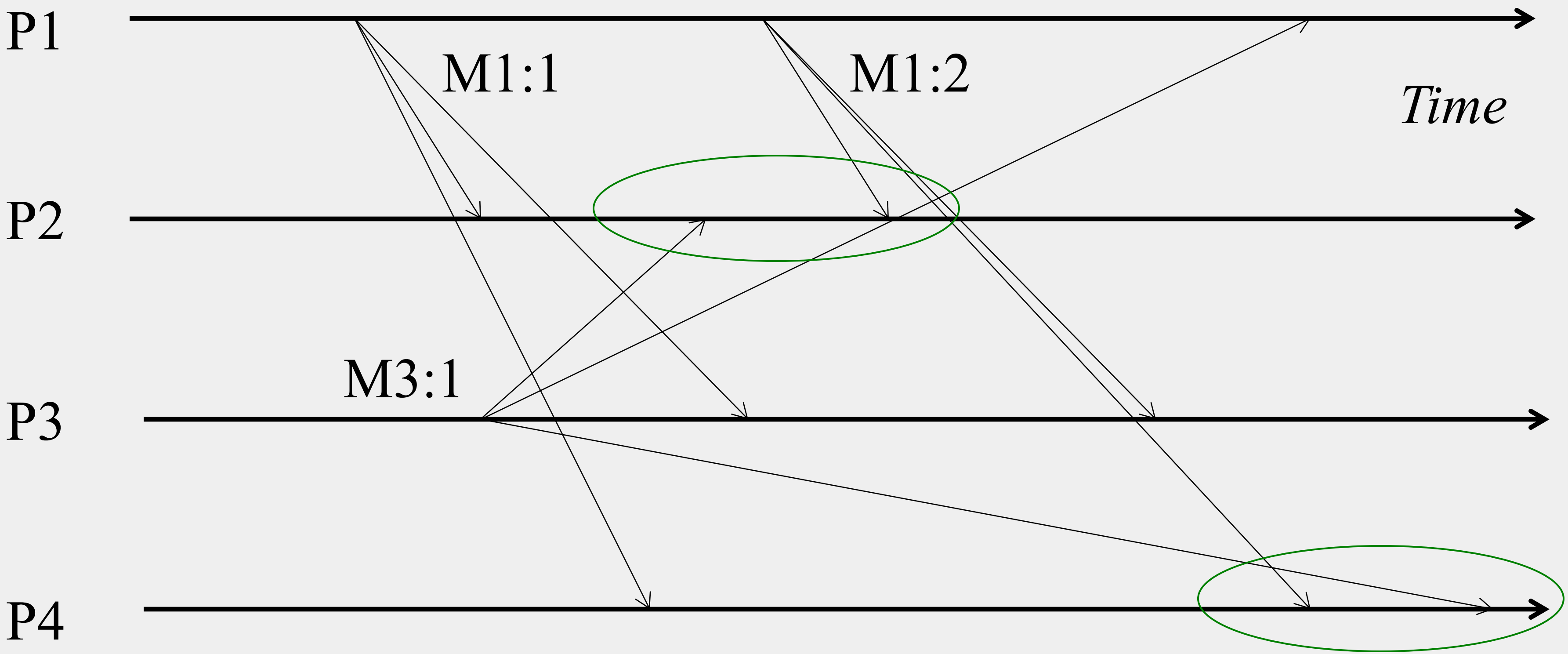
  by several multicast protocols

  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) multicast(g,m) to group g and then multicast(g,m'), then every correct process that delivers m' would already have delivered m.*

FIFO Ordering: Example



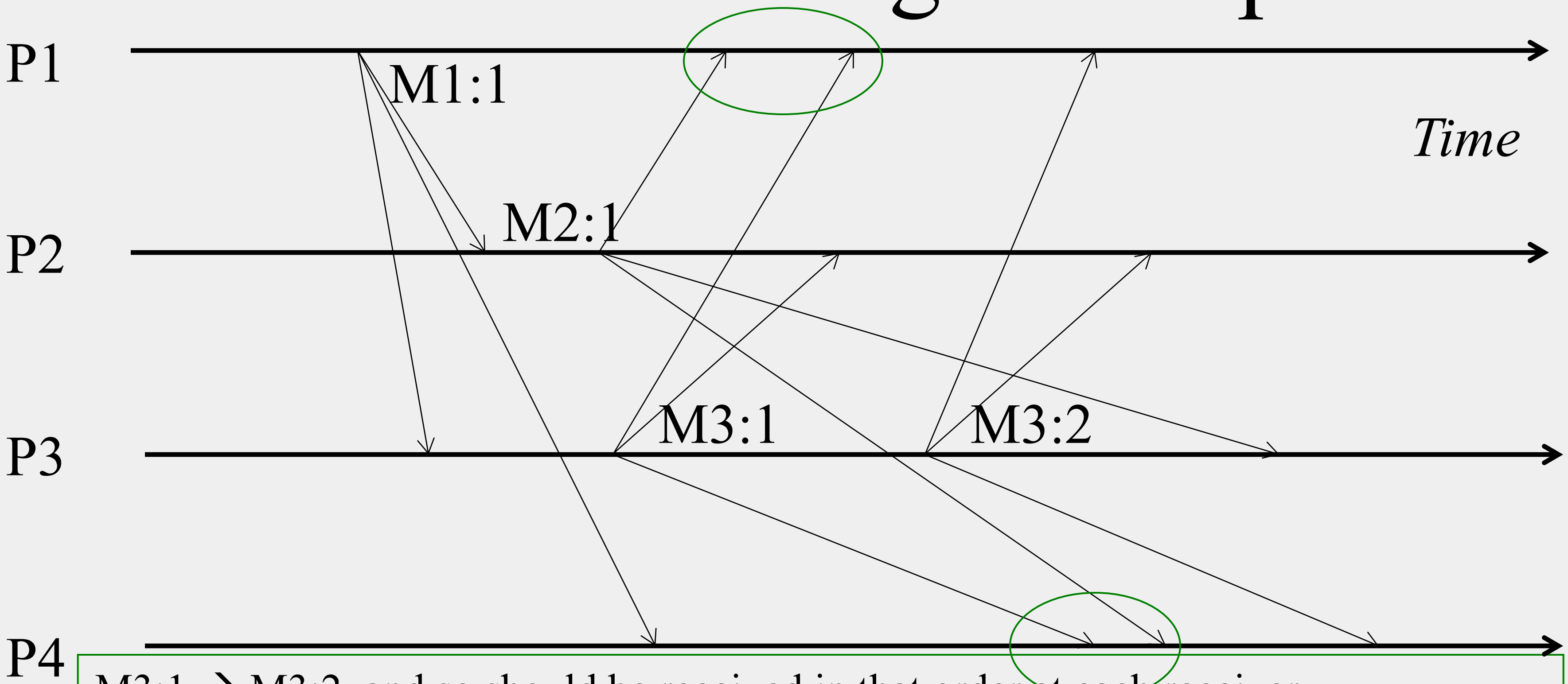
M1:1 and M1:2 should be received in that order at each receiver

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 multicast(g,m) → multicast(g,m′) then any correct process that delivers m′ would already have delivered m.*
  - *(→ is Lamport's happens-before)*

Causal Ordering: Example



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

M1:1 → 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 => FIFO Ordering
- Why?
  - If two multicasts M and M’ are sent by the same process P, and M was sent before M’, then M → M’
  - Then a multicast protocol that implements causal ordering will obey FIFO ordering since M → M’
- Reverse is not true! FIFO ordering does not imply causal ordering.

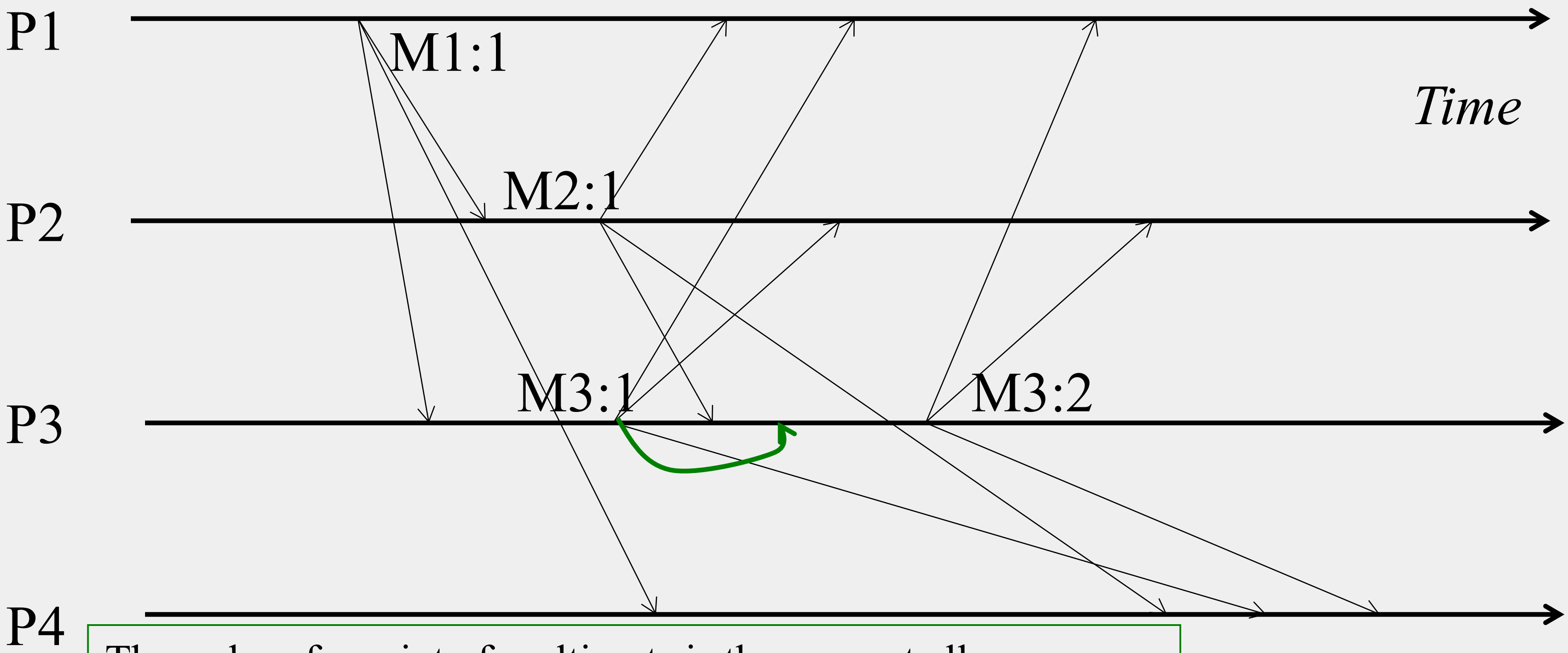
Why Causal at All?

- 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?

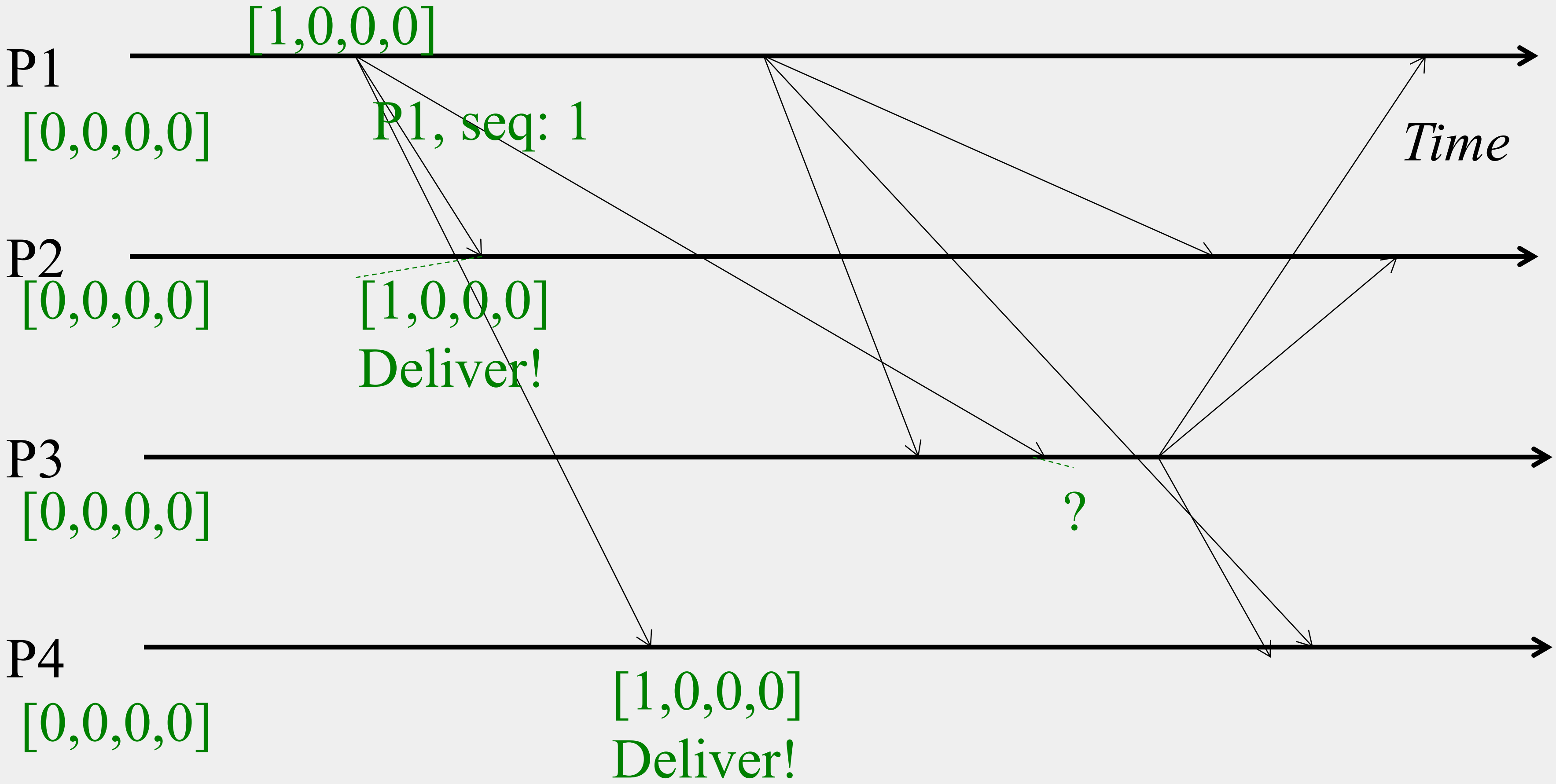
FIFO Multicast: Data Structures

- 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…N] (initially all zeroes)
  - P*i*[*j*] is the latest sequence number P*i* has received from P*j*

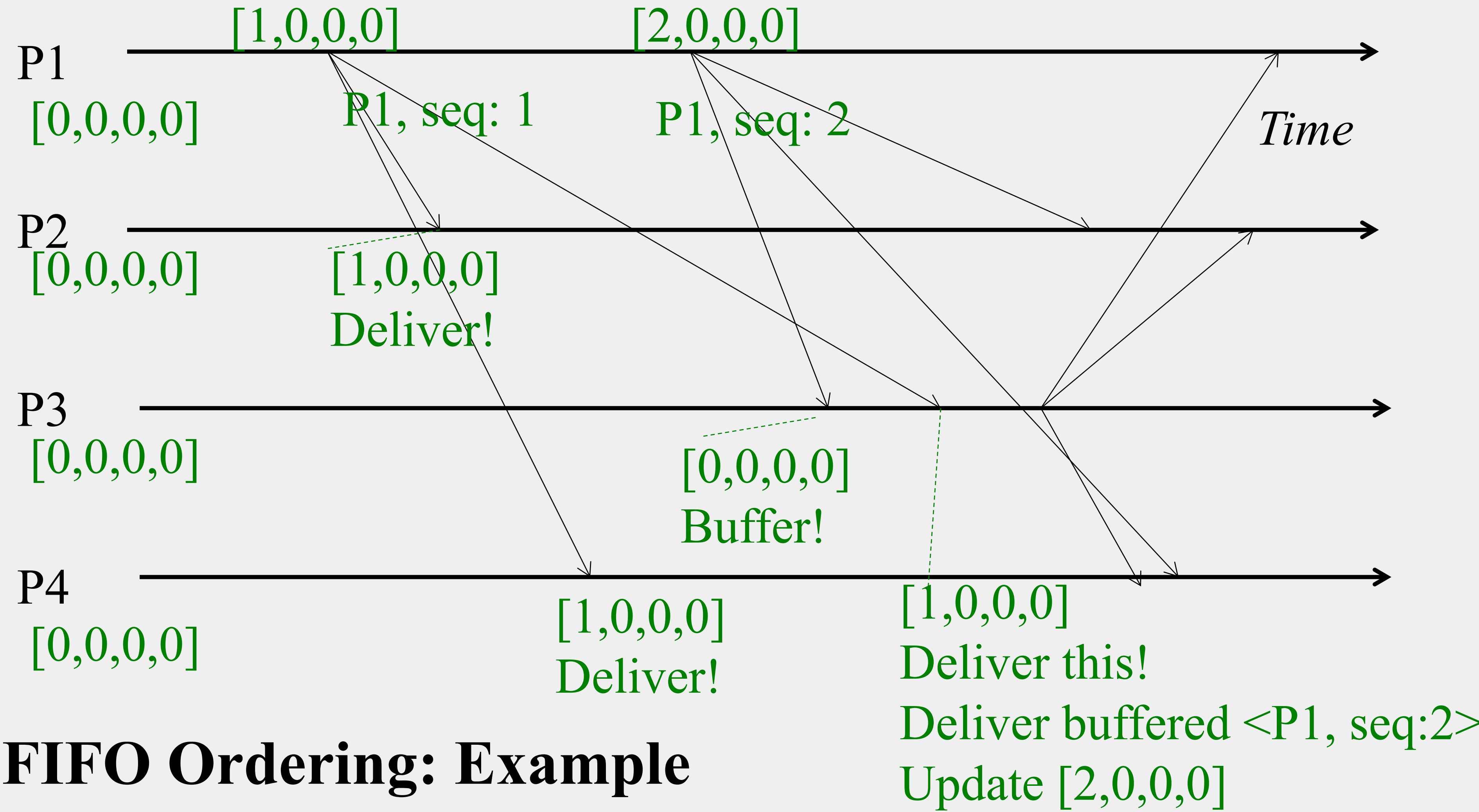
FIFO Multicast: Updating Rules

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

FIFO Ordering: Example



FIFO Ordering: Example



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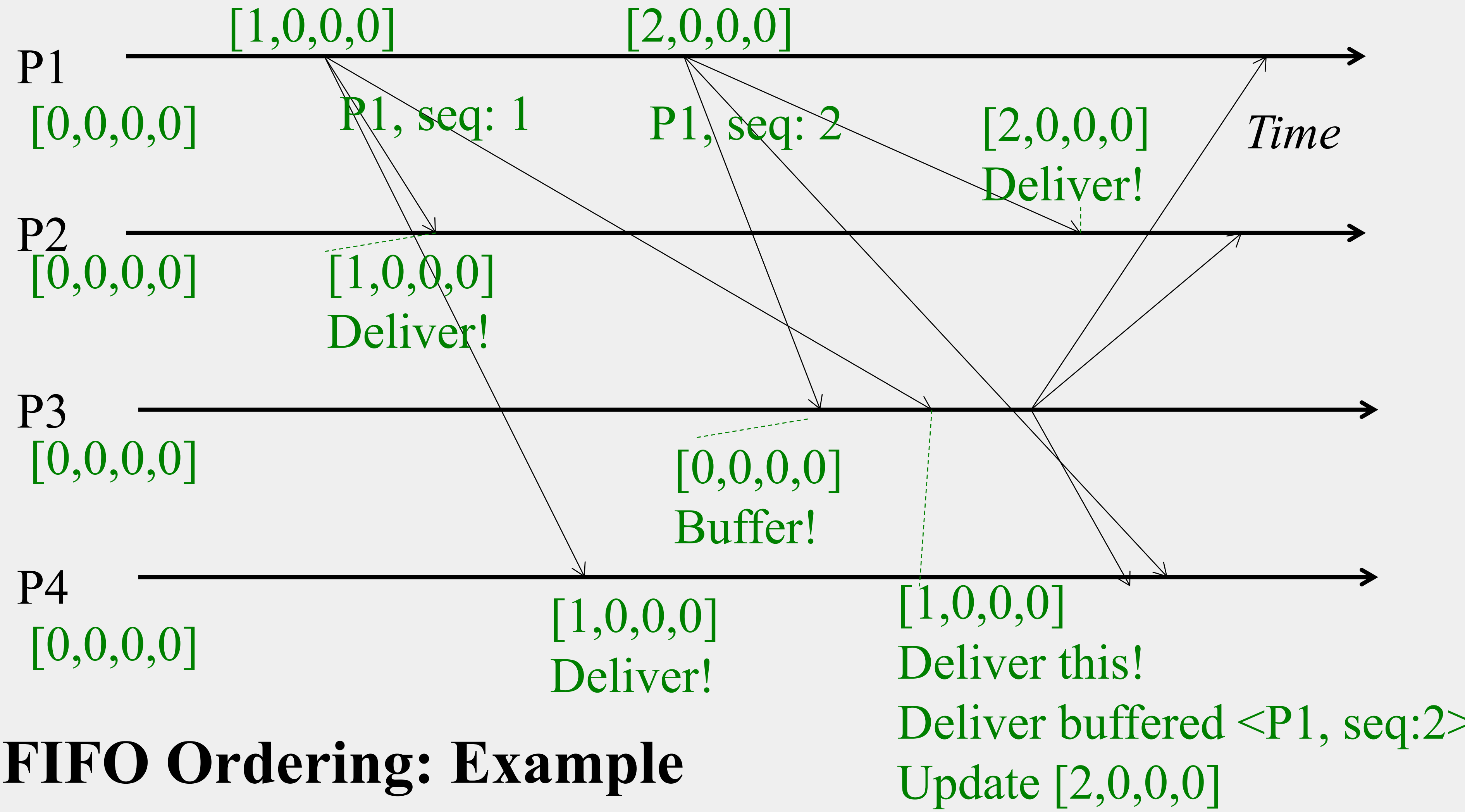

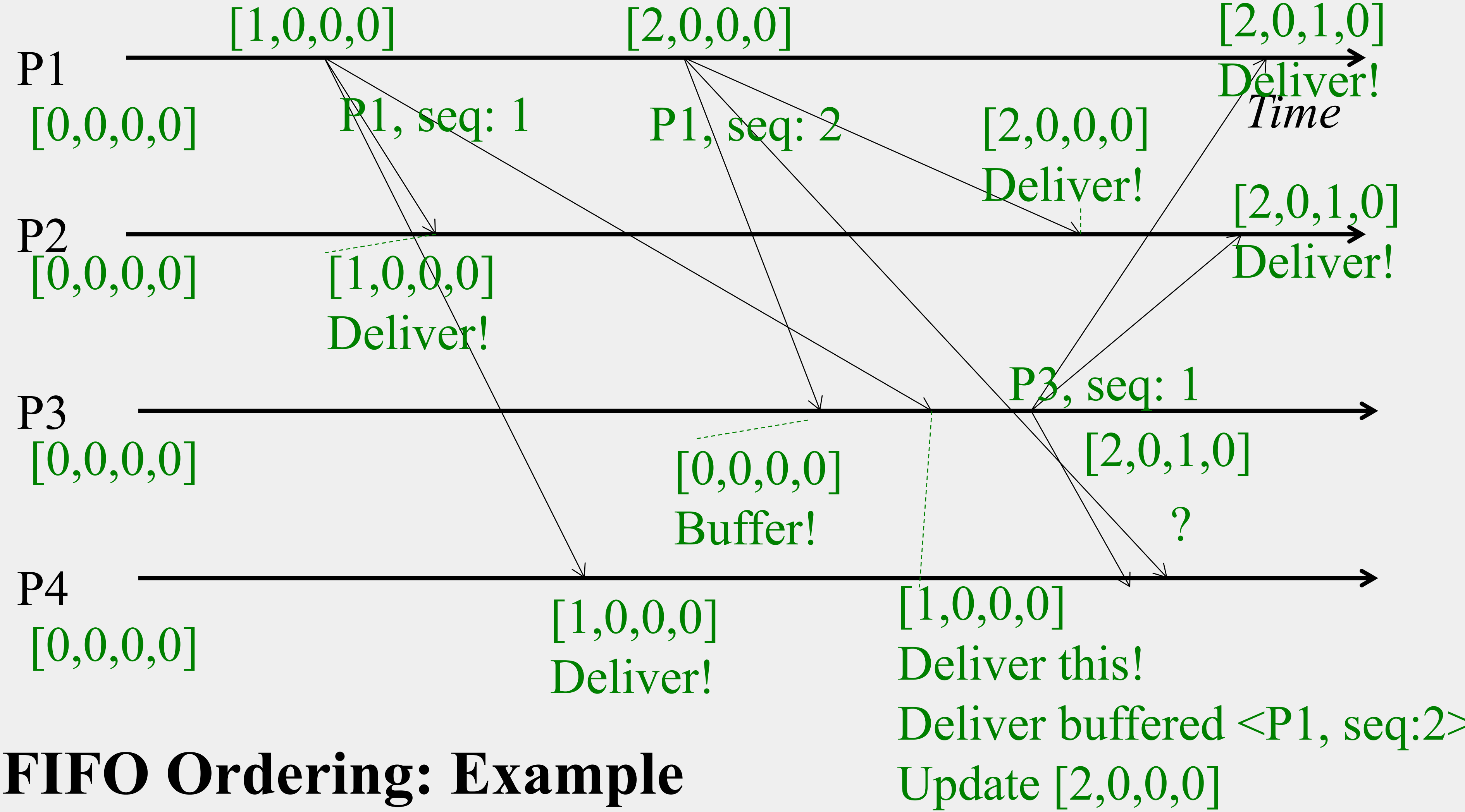

FIFO Ordering: Example

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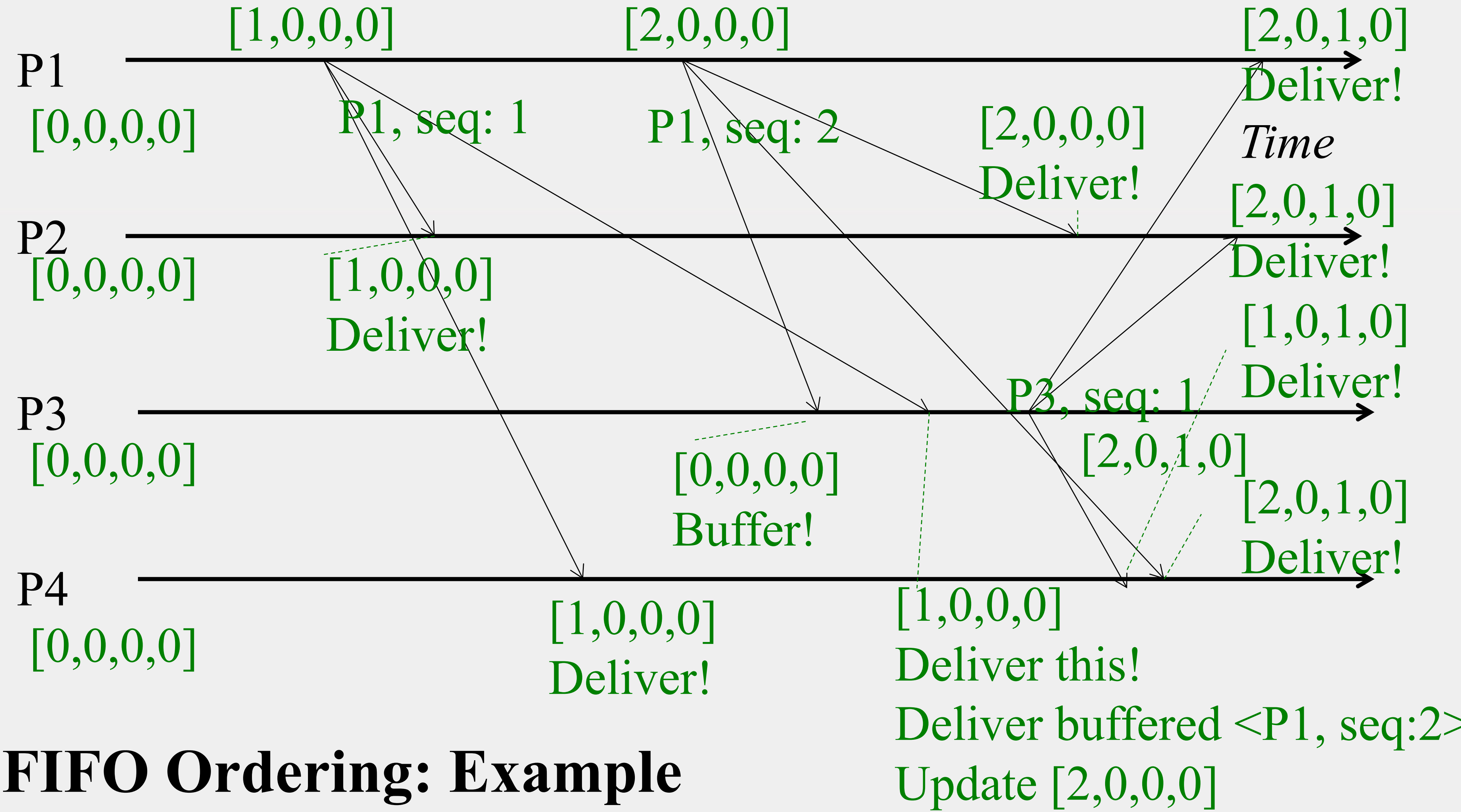


Total Ordering

- 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 Pi:
  - 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 <M, S>
- Receive multicast at process Pi:
  - Pi maintains a local received global sequence number Si (initially 0)
  - If Pi receives a multicast M from Pj, it buffers it until it both
    1. Pi receives <M, S(M)> from sequencer, and
    2. Si + 1 = S(M)
    - Then deliver it message to application and set Si = Si + 1

Causal Ordering

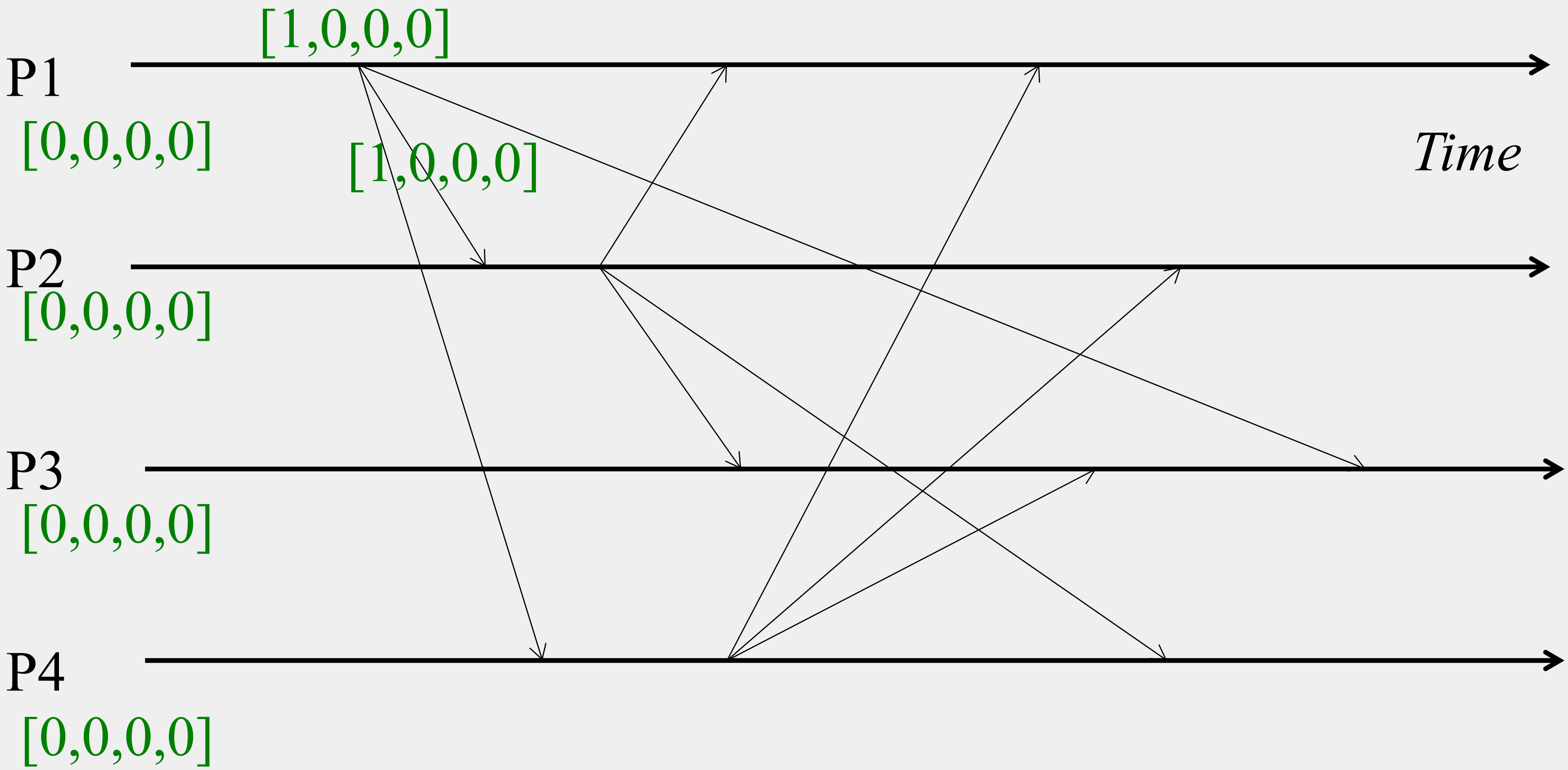
- Multicasts whose send events are causally related, must be received in the same causality-obeying order at all receivers
- Formally
  - *If multicast(g,m) → multicast(g,m′) then any correct process that delivers m′ would already have delivered m.*
  - *(→ is Lamport's happens-before)*

Causal Multicast: Datastructures

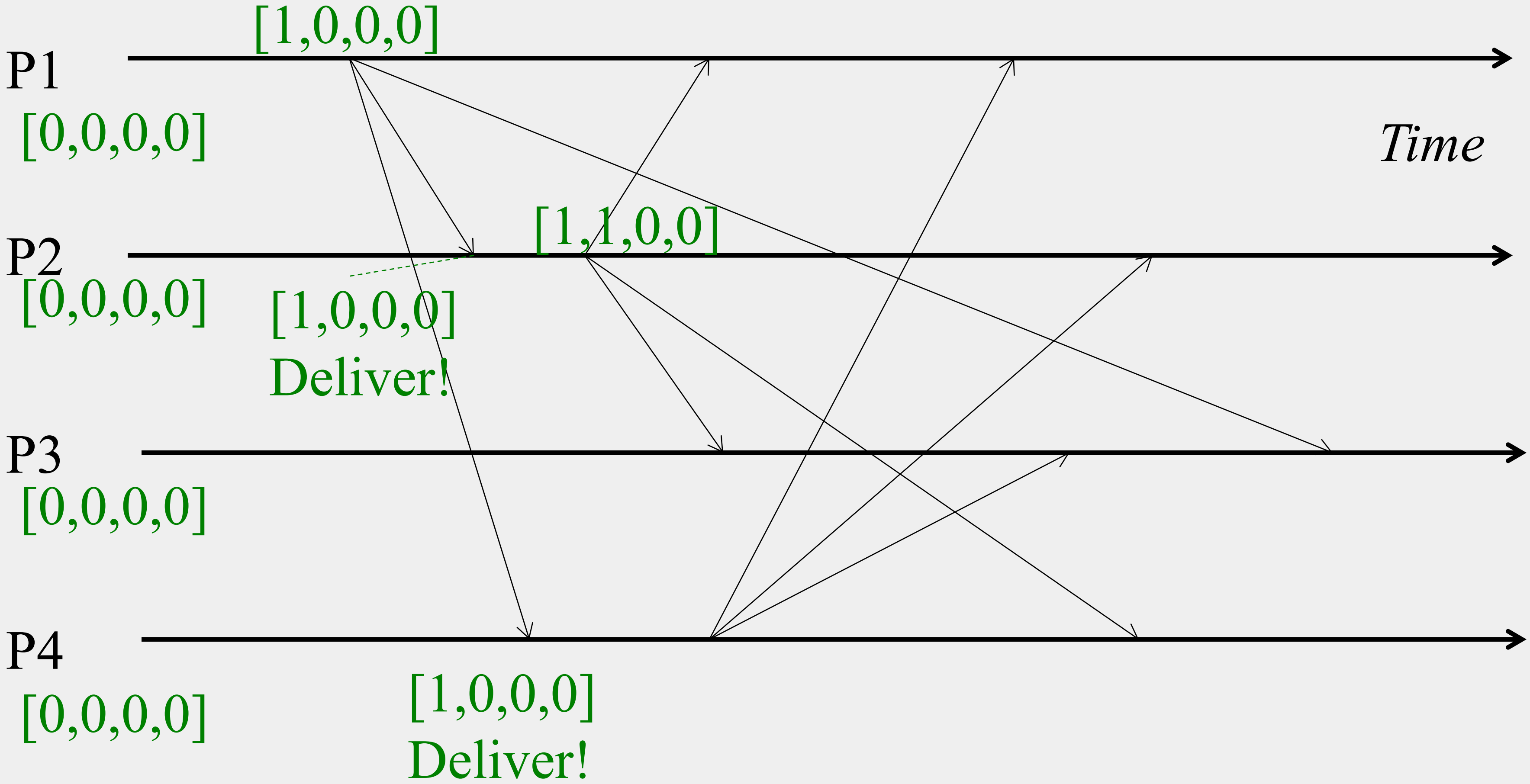
- Each receiver maintains a vector of per-sender sequence numbers (integers)
  - Similar to FIFO Multicast, but updating rules are different
  - Processes P*1* through P*N*
  - P*i* maintains a vector P*i*[1…N] (initially all zeroes)
  - P*i*[*j*] is the latest sequence number P*i* has received from P*j*

Causal Multicast: Updating Rules

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



Causal Ordering: Example



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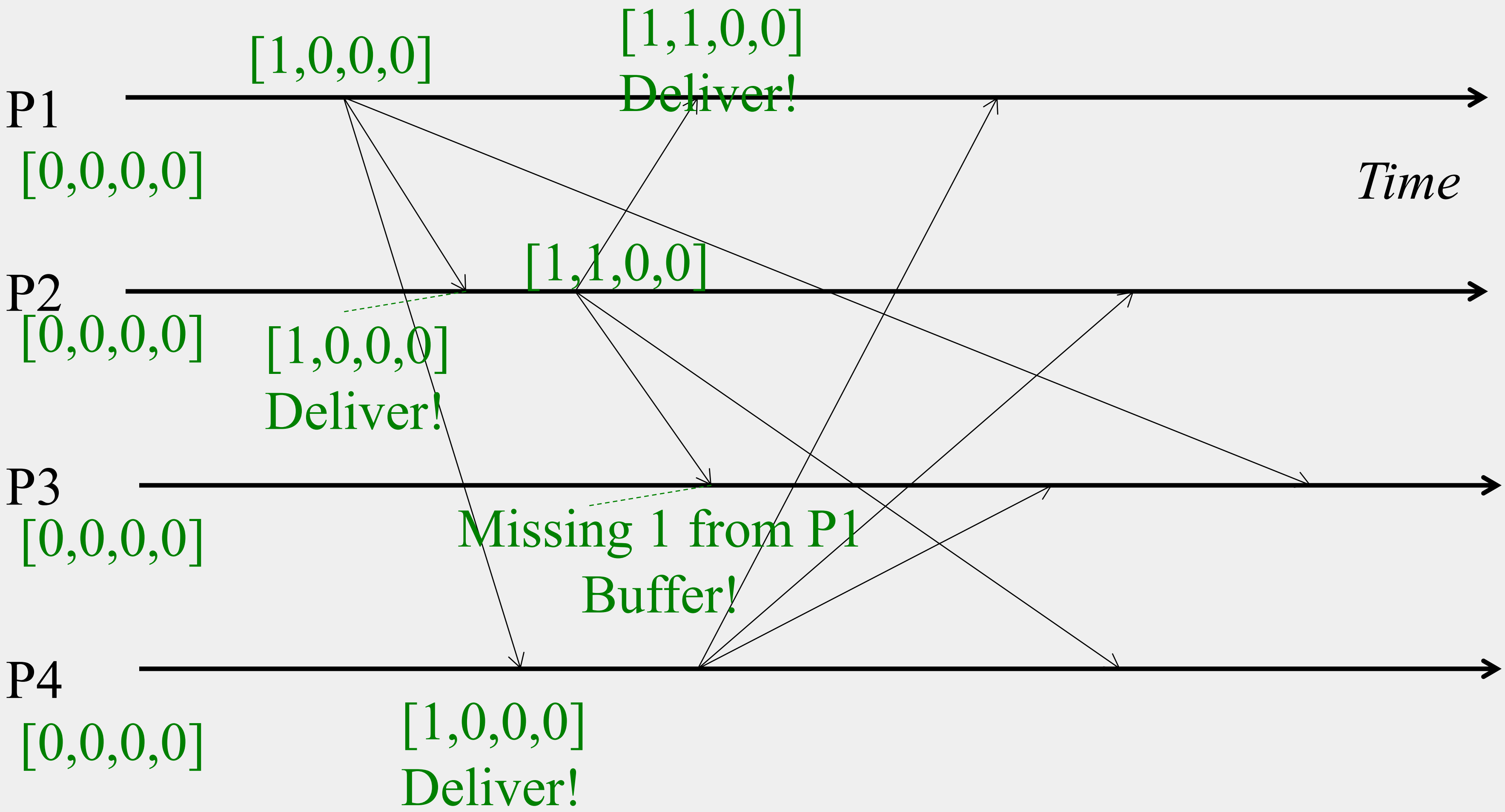

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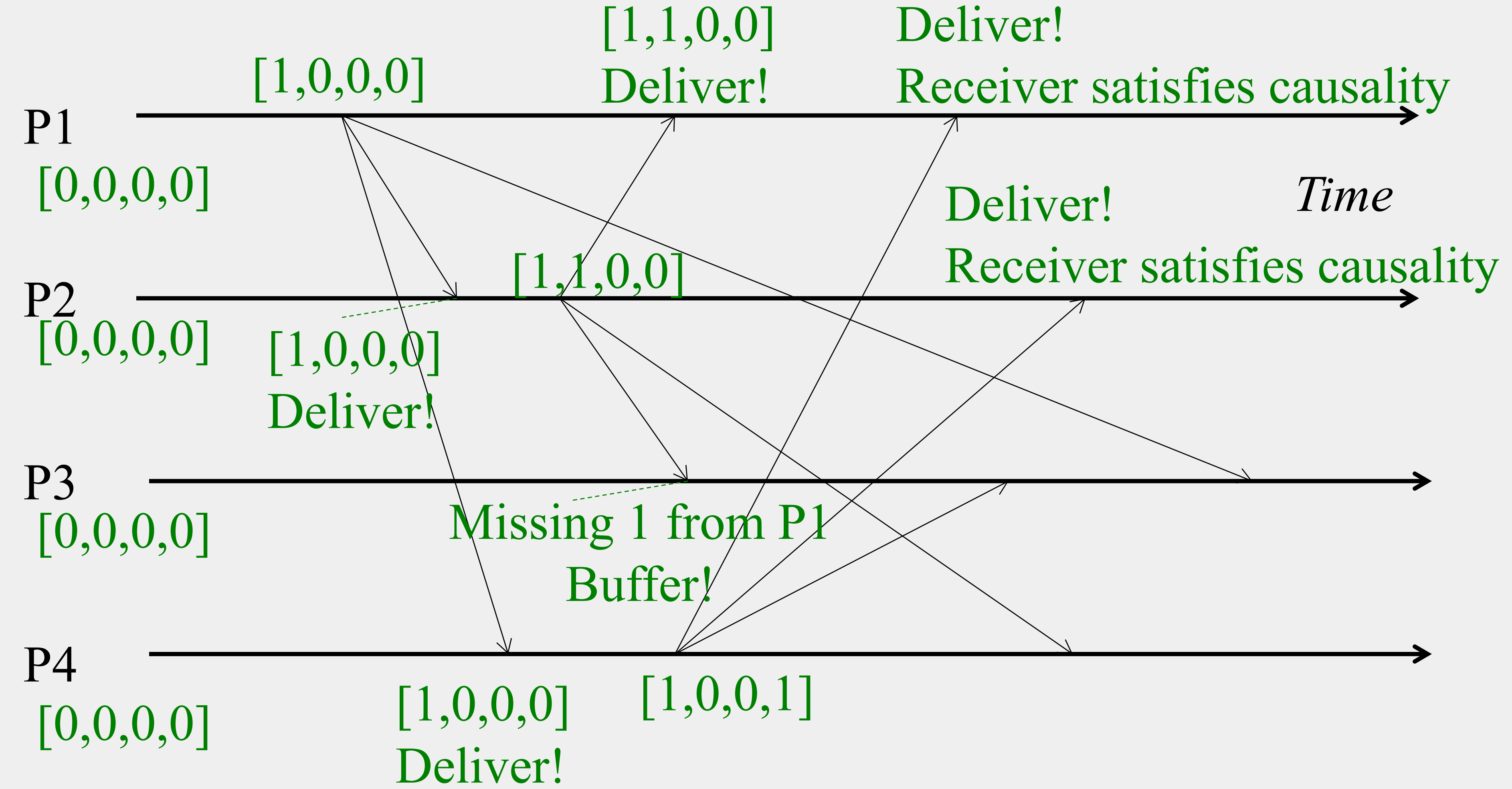

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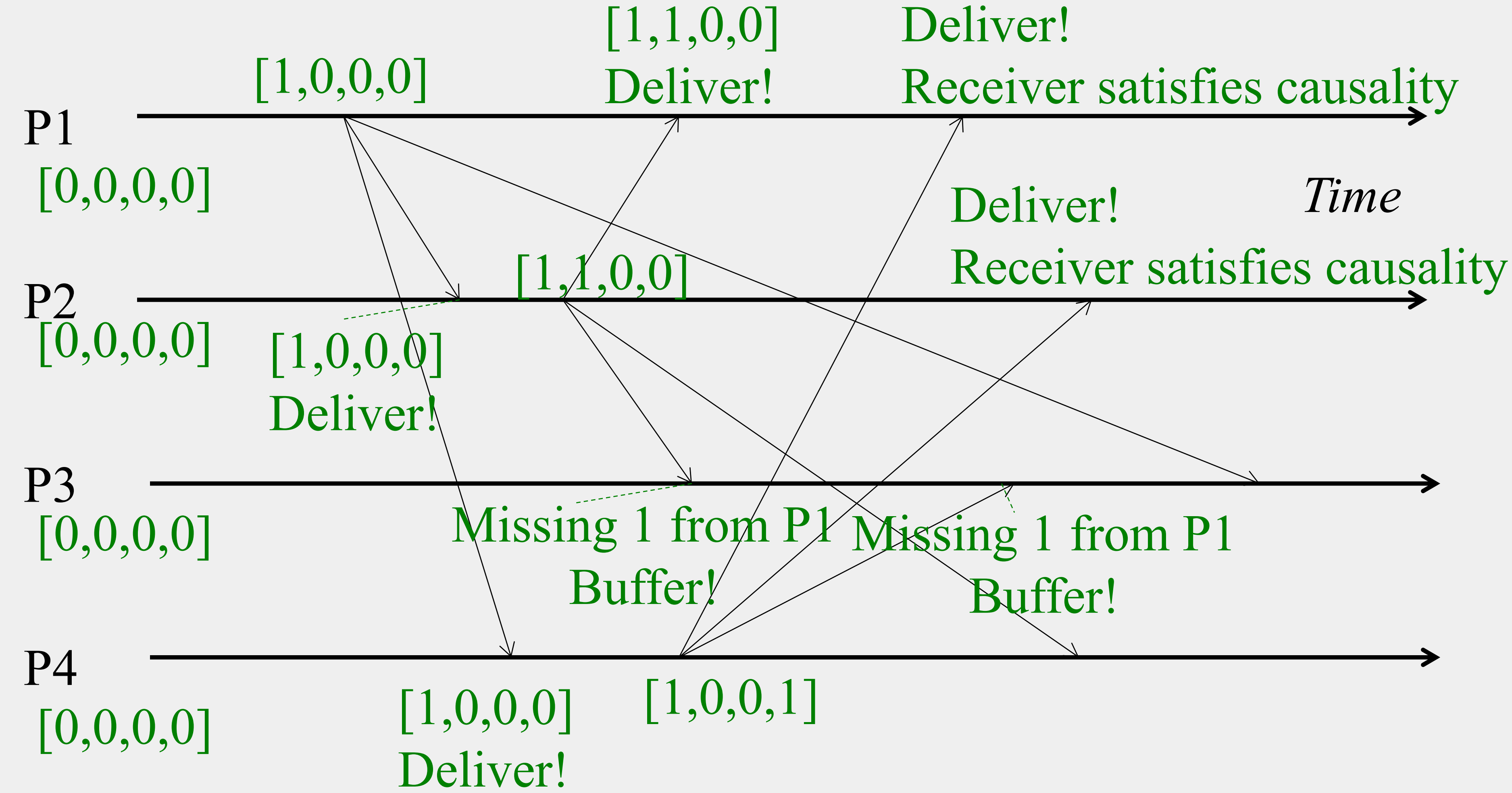

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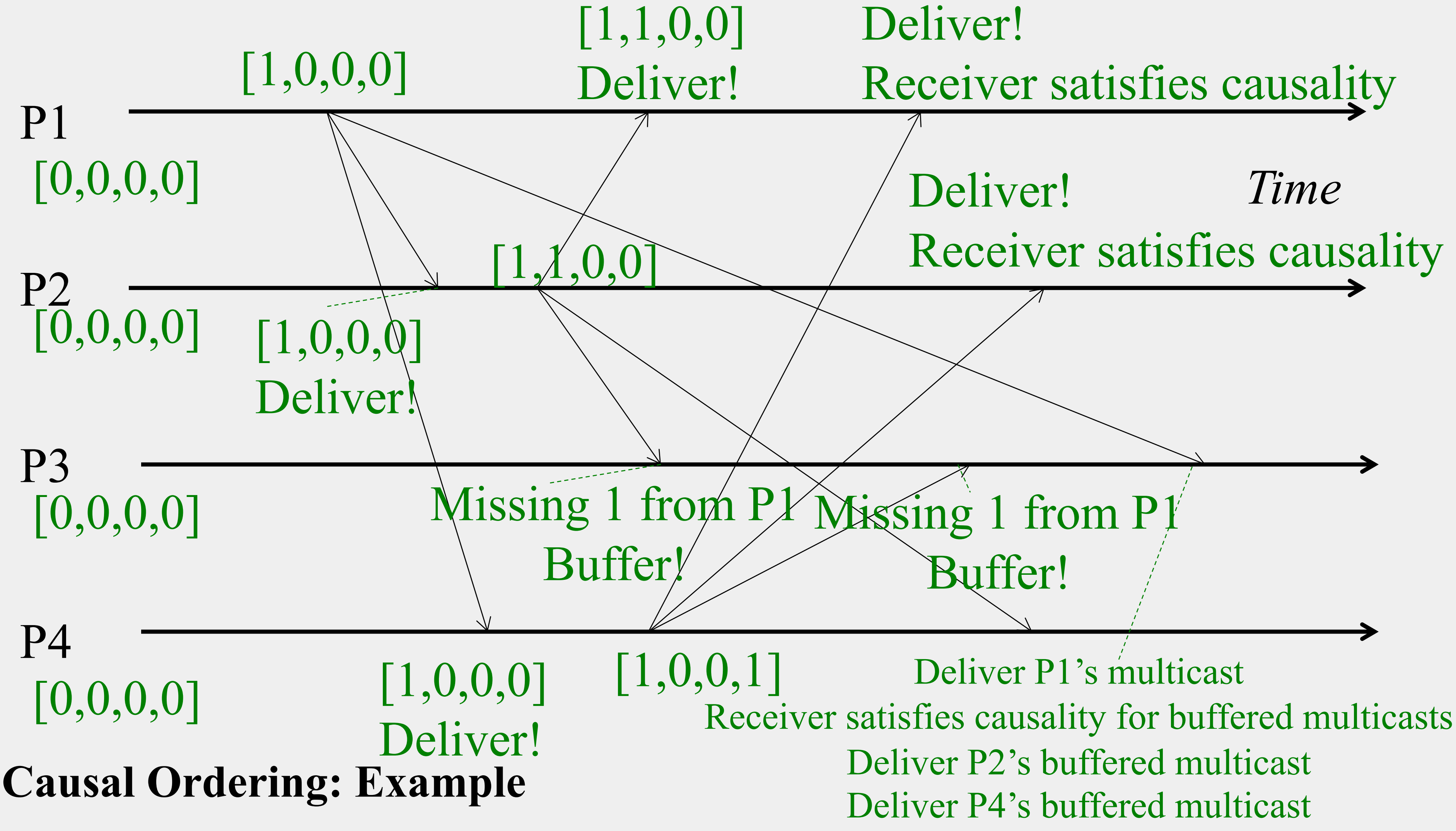

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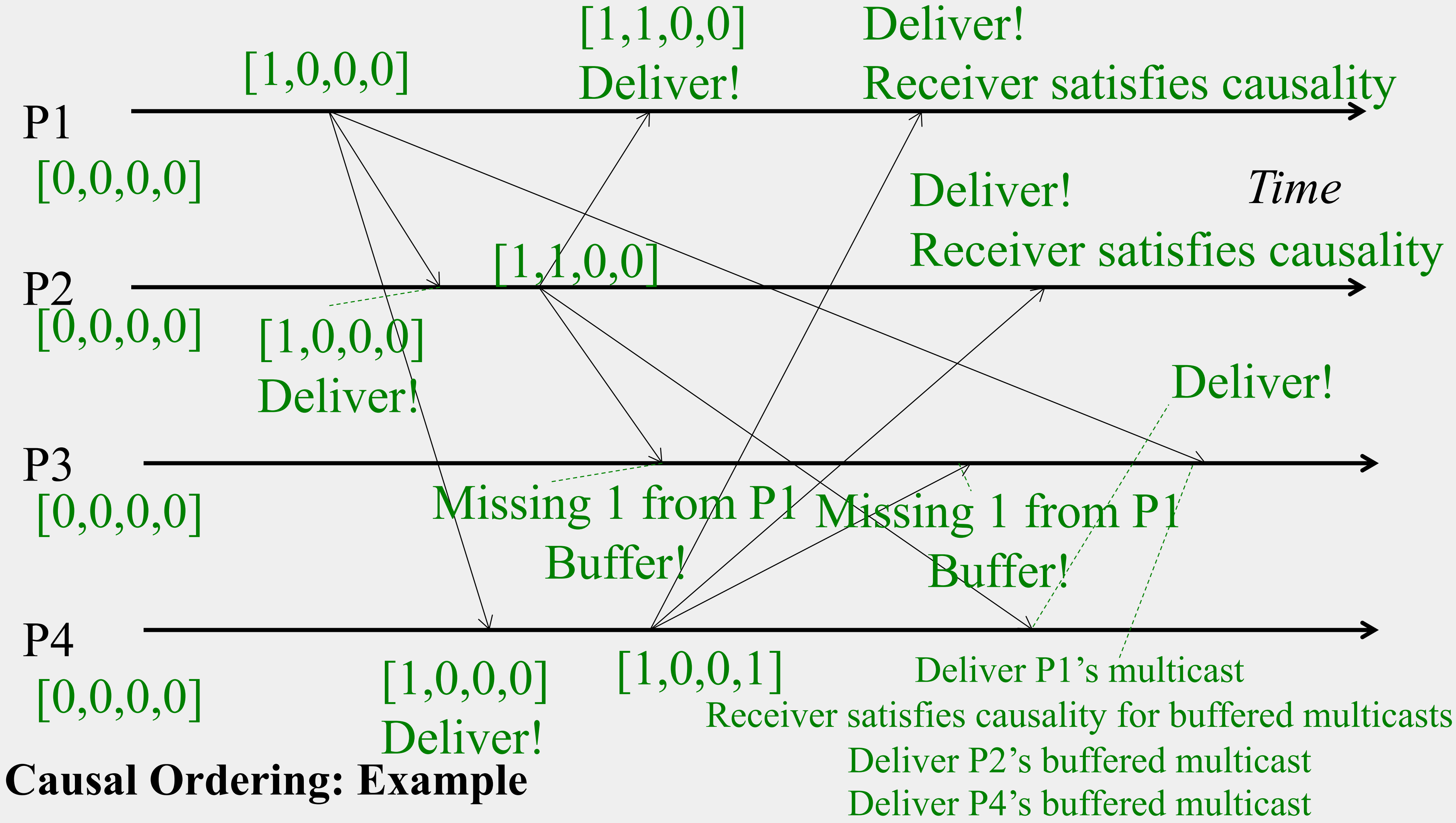


Causal Ordering: Example

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

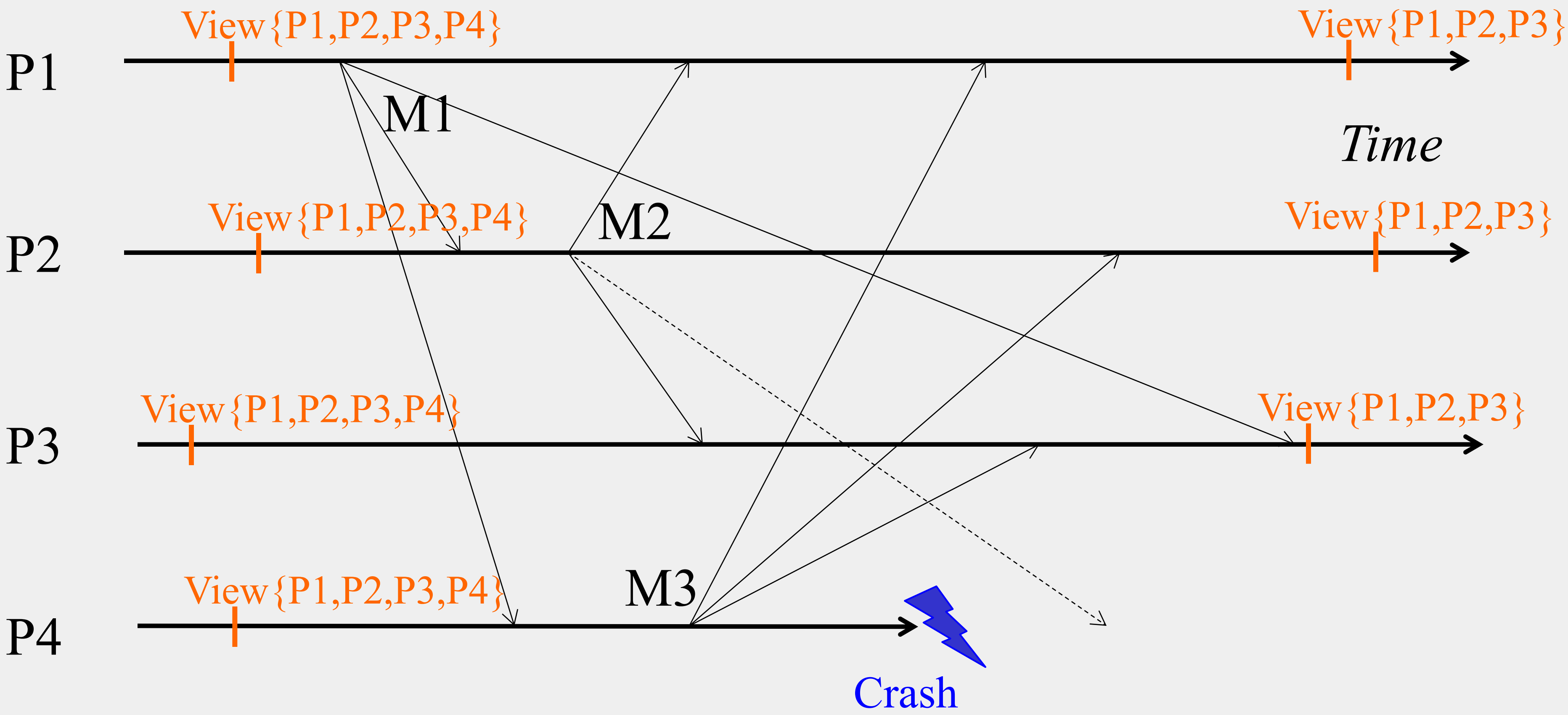
- Attempts to preserve multicast ordering and reliability in spite of failures
- Combines a membership protocol with a multicast protocol
- Systems that implemented it (like Isis Systems) have been used in NYSE, French Air Traffic Control System, Swiss Stock Exchange

Views

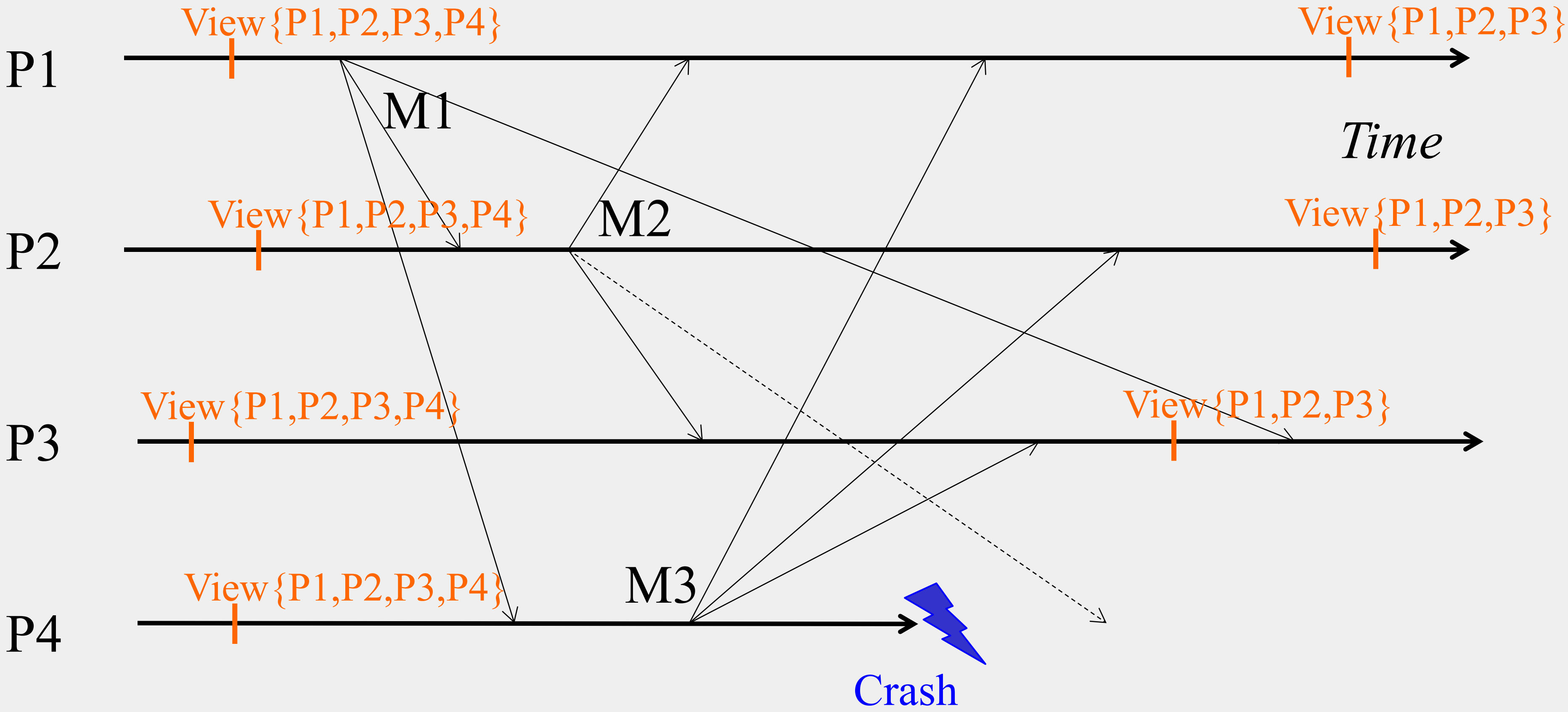
- Each process maintains a membership list
- The membership list is called a *View*
- An update to the membership list is called a *View Change*
  - Process join, leave, or failure
- Virtual synchrony guarantees that all **view changes are delivered in the same order at all correct processes**
  - If 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

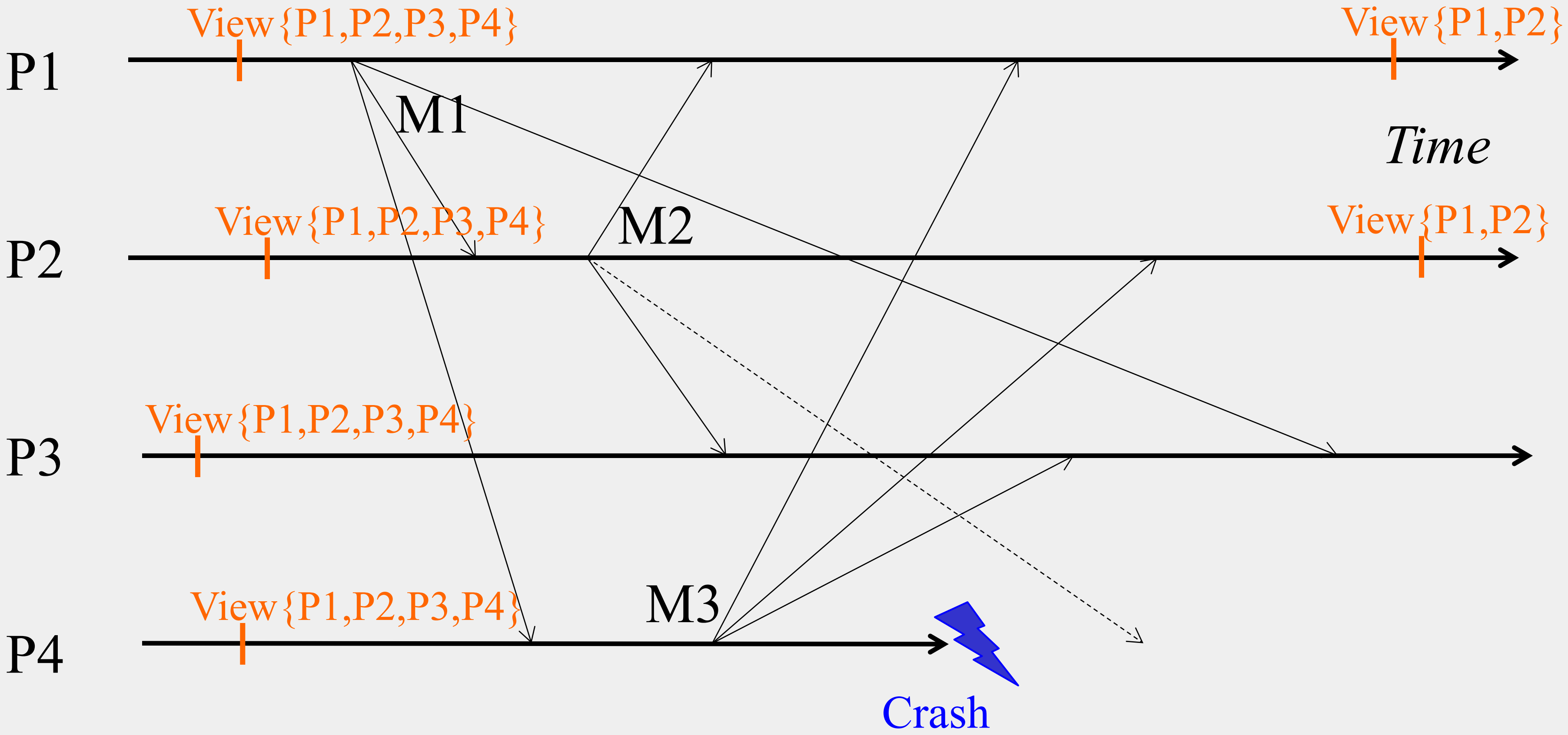
- A multicast M is said to be "delivered in a view V at process P*i*" if
  - P*i* receives view V, and then sometime before P*i* receives the next view it delivers multicast M
- Virtual synchrony ensures that
  1. **The set of multicasts delivered in a given view is the same set at all correct processes that were in that view**
     - *What happens in a View, stays in that View*
  2. The sender of the multicast message 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



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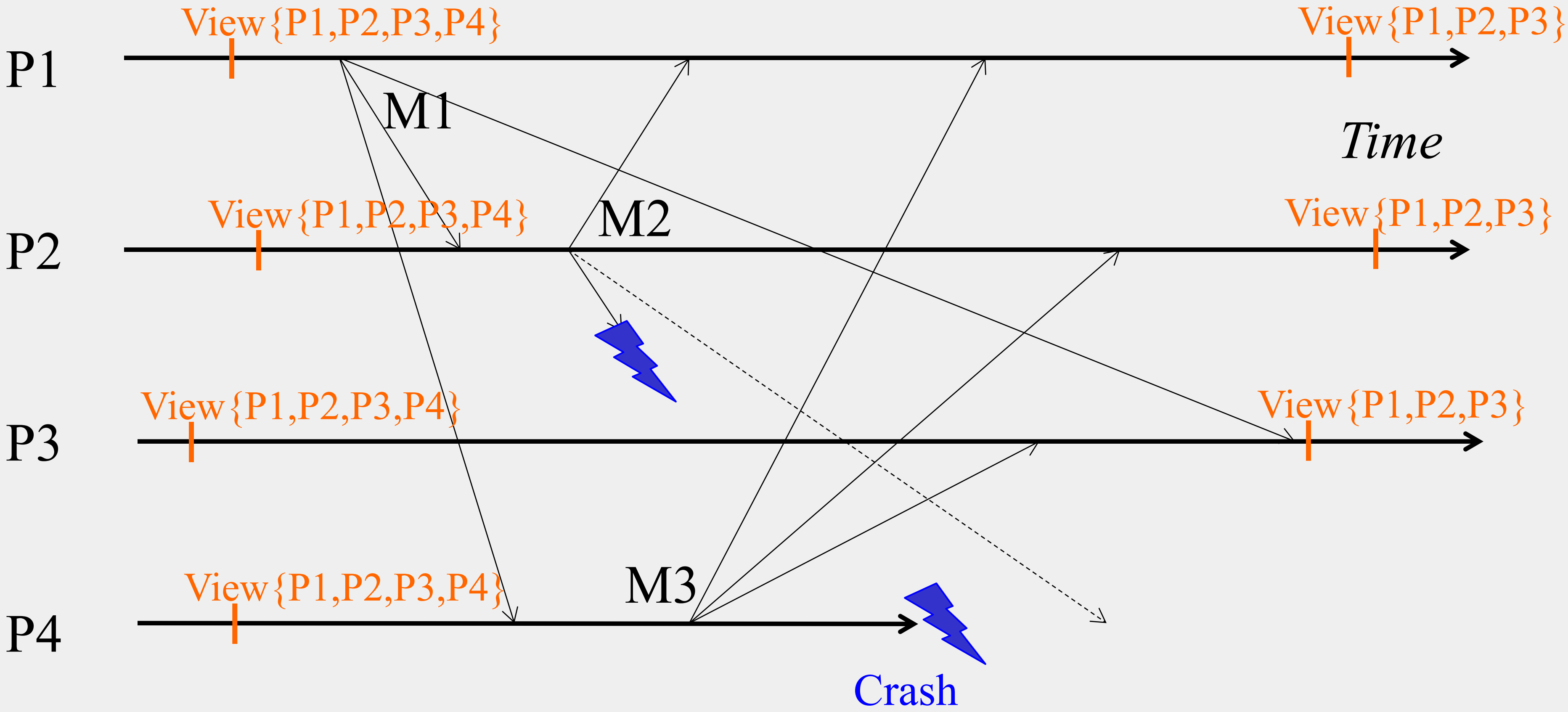

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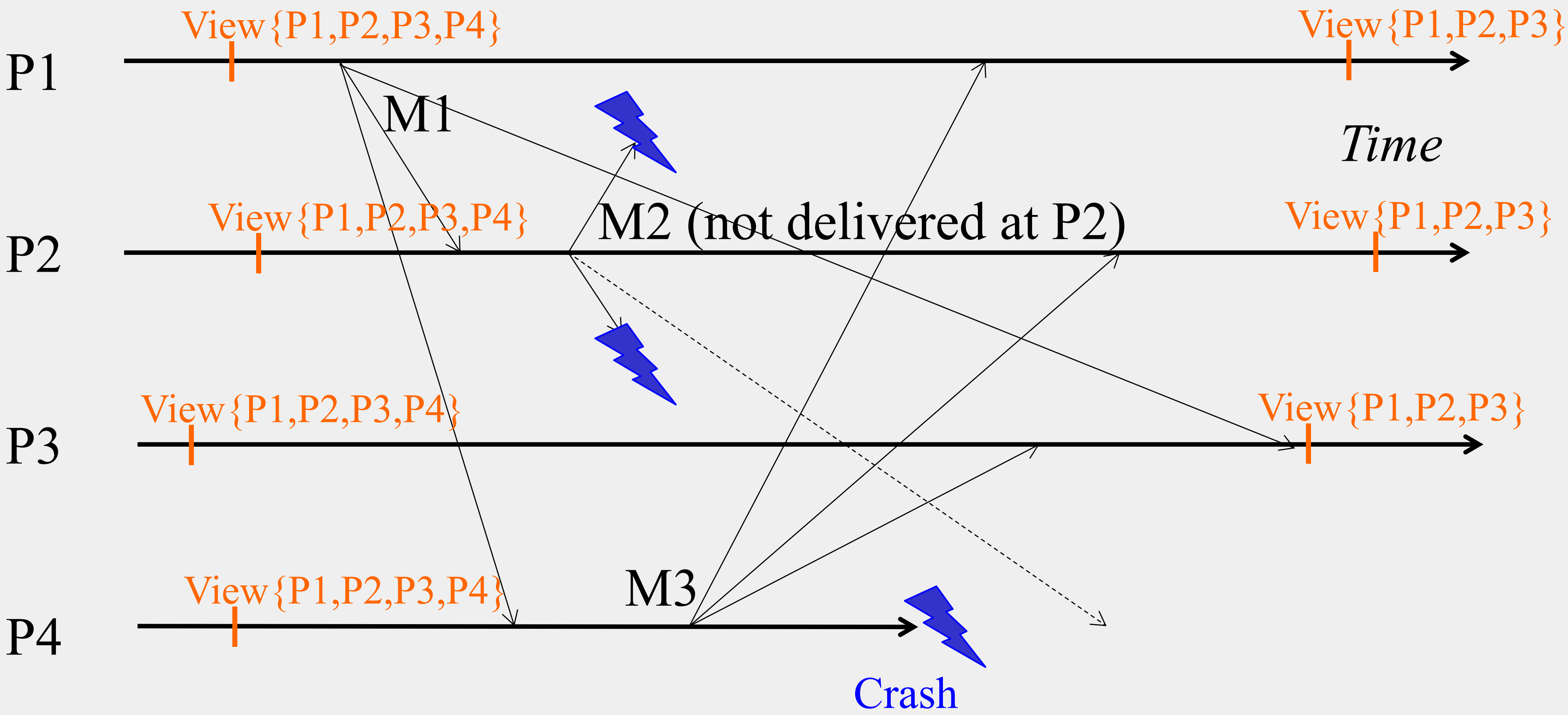

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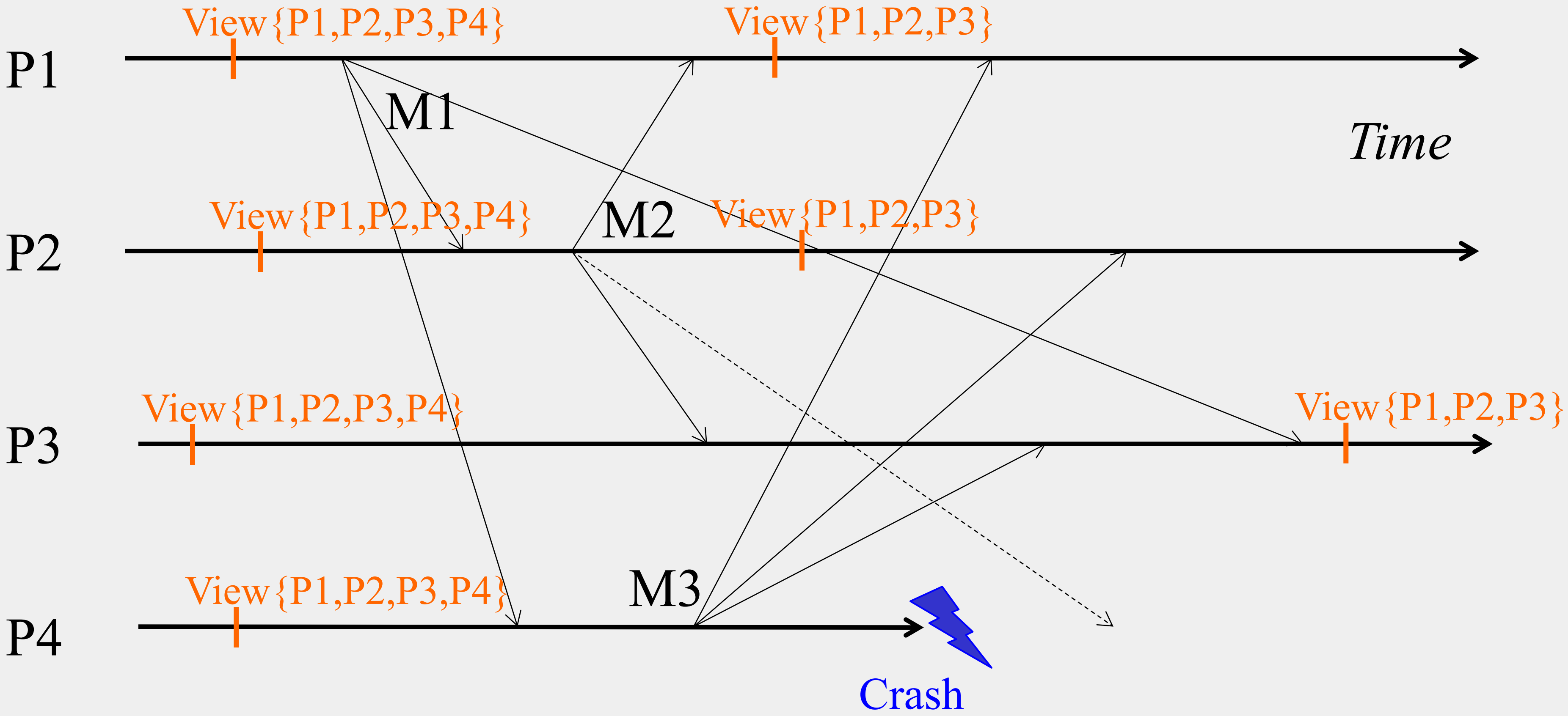

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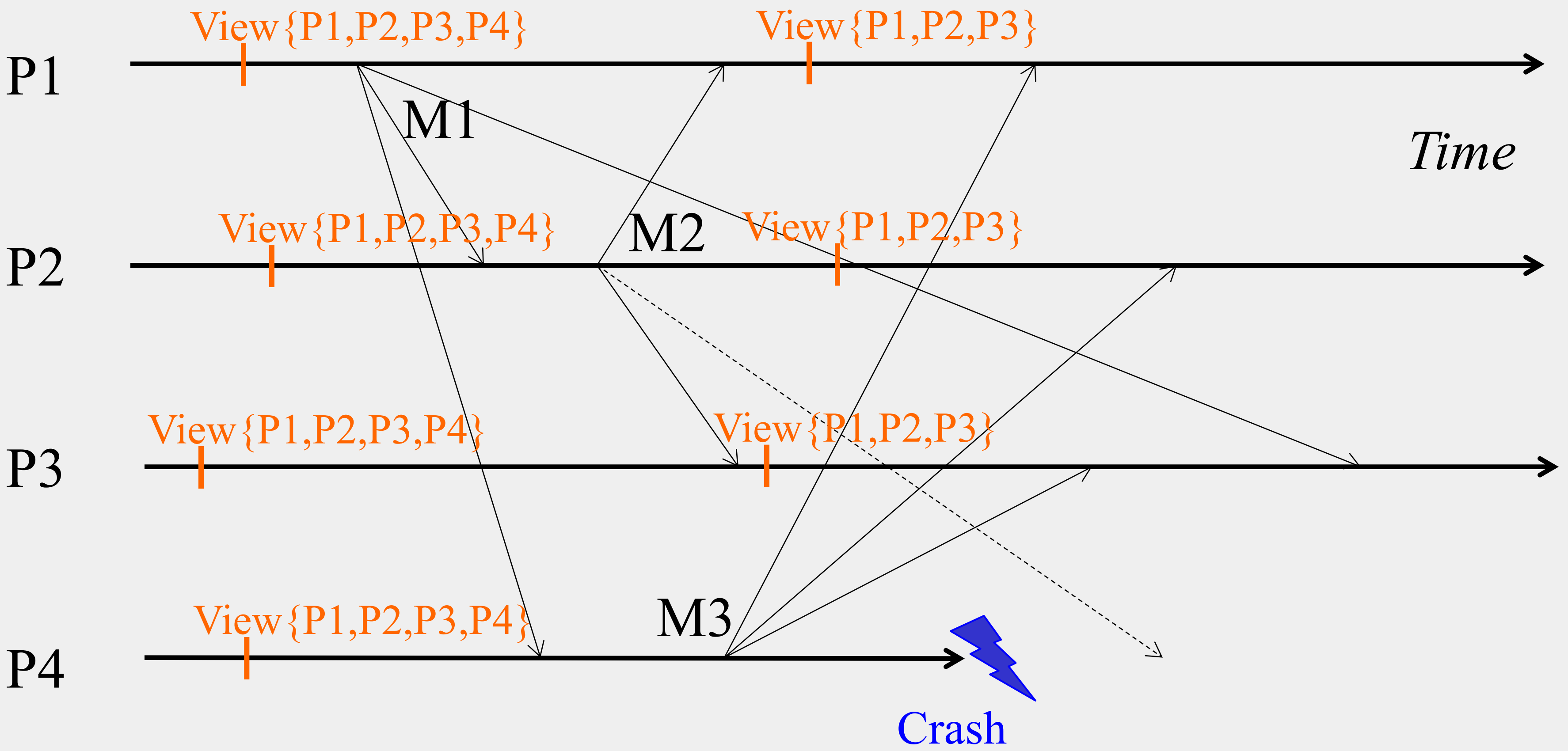

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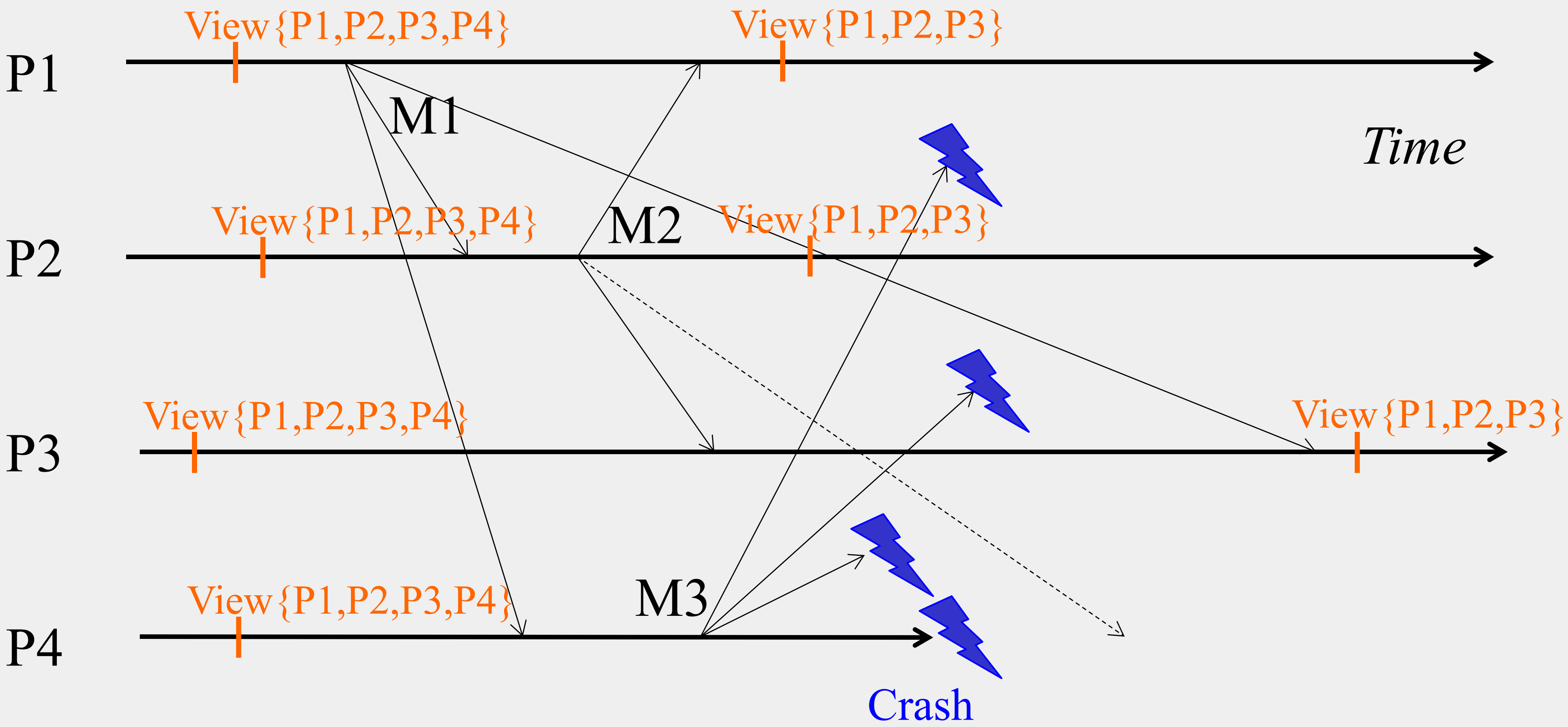


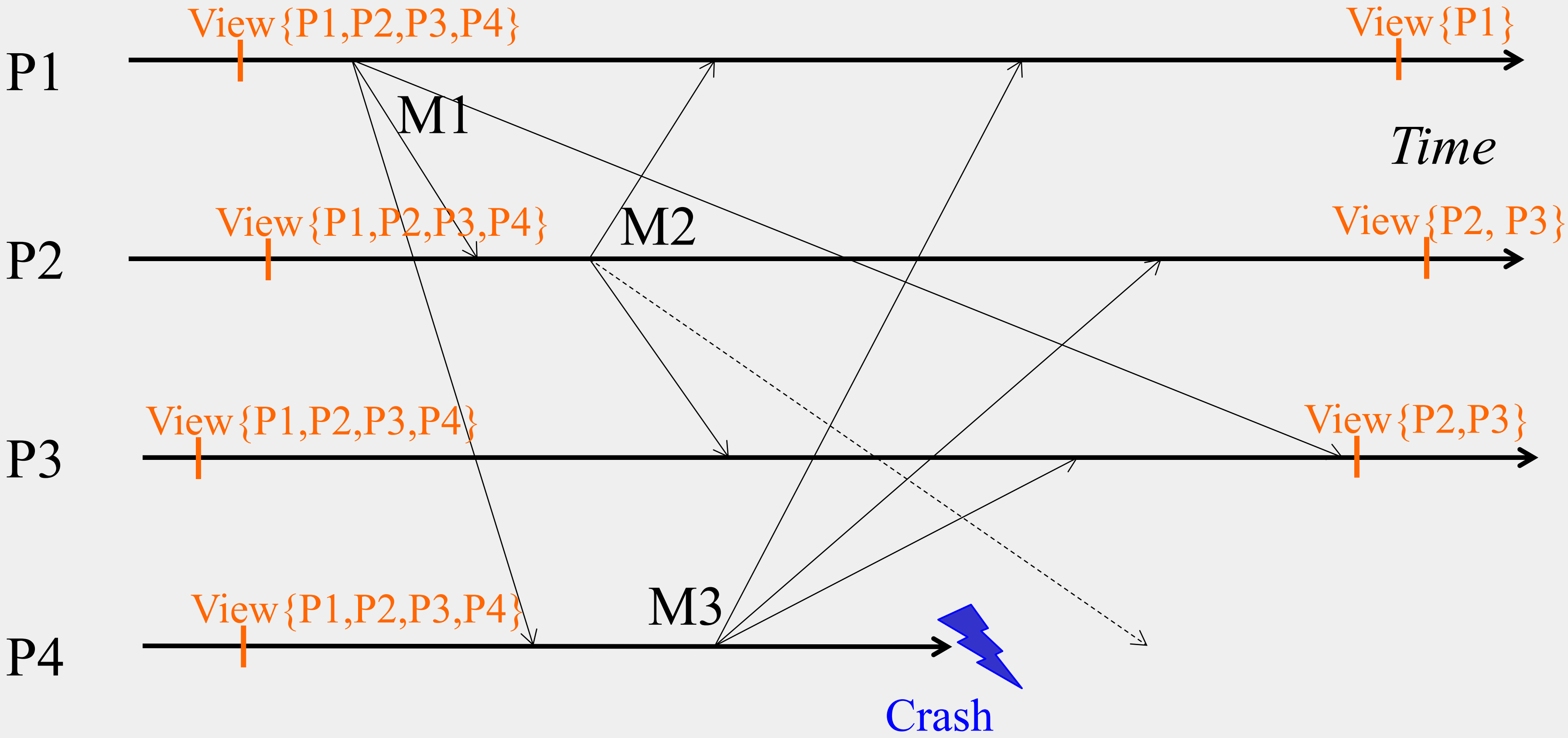
Satisfies virtual synchrony

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
- Midterm Solutions – soon
- MP Reports – handed back now
- Midterm Grading – handed back now

Midterm Statistics (Fall 2019)

		Min	Mean	Median	Std	Max
Undergrad	3cr	35.00	76.10	76.00	12.29	97.00
	4cr	44.50	79.34	82.50	12.92	100.00
Grad (On-Campus)	3cr	68.00	84.79	87.50	8.54	98.00
	4cr	32.00	83.35	87.00	11.70	99.00
MCS-DS	-	30.00	71.93	72.00	14.22	100.00

Collect your Midterms

- **After collecting, please leave immediately (make way for others).** Regrades and questions can be asked in TA Office Hours.
- Midterms: 4 piles, by last name
- In front of room: A-H (your left), I-N (your right)
- Outside of classroom: P-S, T-Z