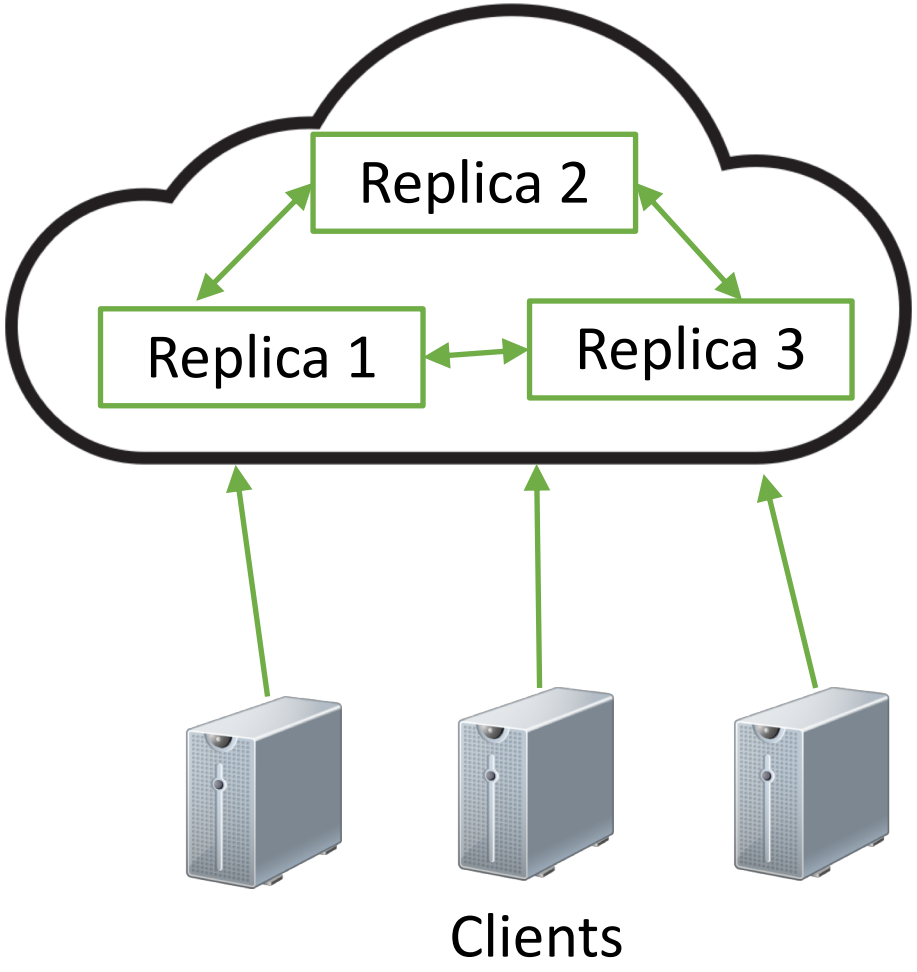
Week 2
Spyros Mastorakis

Outline

- Clocks
- Snapshots & Checkpointing

Why we need clocks?

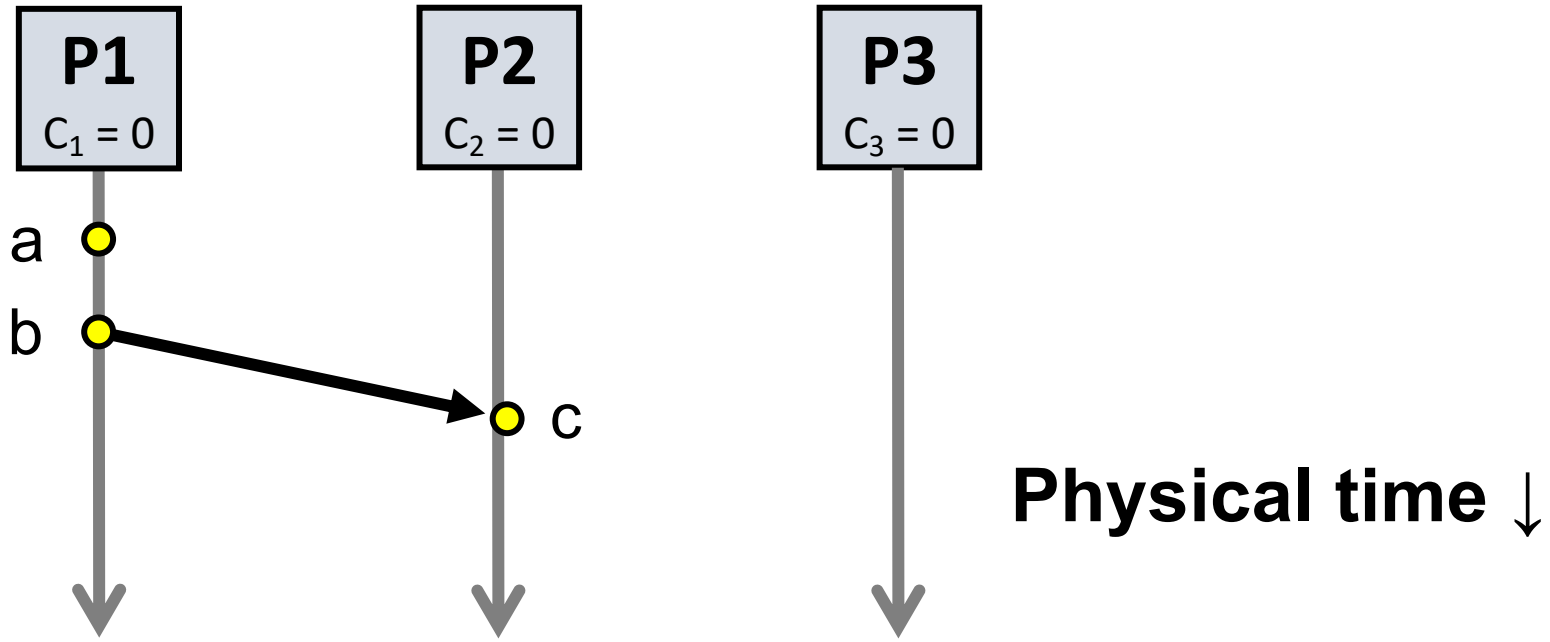


- Multiple replicas running a service
  - Give ”illusion” of consistent state to clients
- All replicas need to apply updates in the same order
  - Replicated state machine
- Need to come up with a relative order of events

Logical Clocks

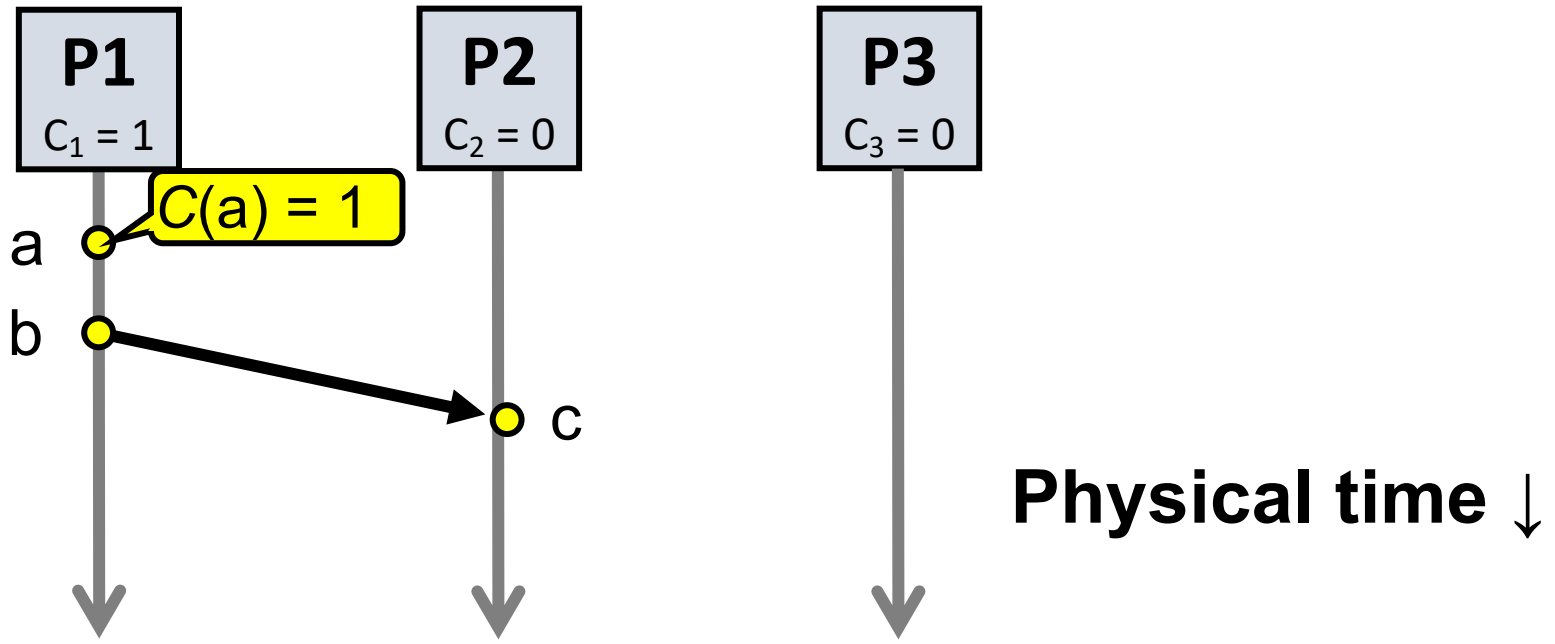
- Associate any event a with a clock time C(a)
- Clock condition: if a → b, then C(a) < C(b)
- Order events at all nodes based on clock time

The Lamport Clock algorithm



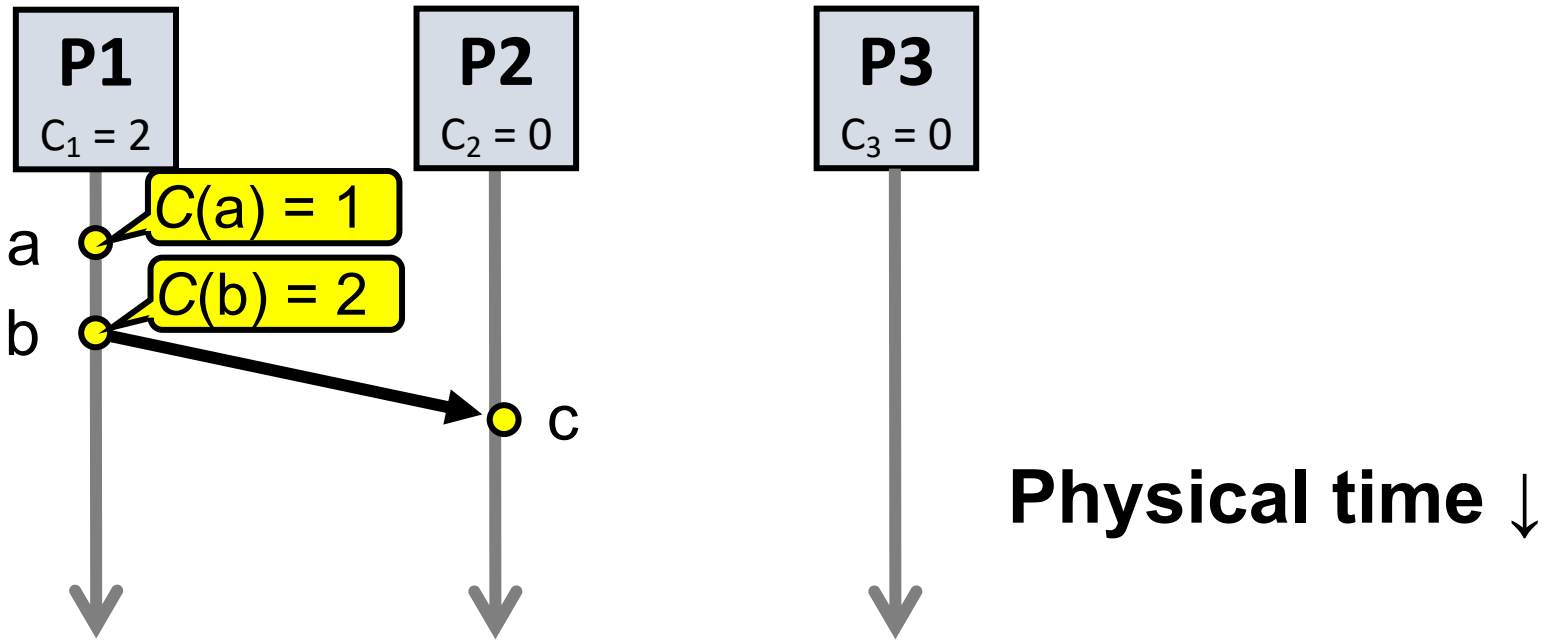
- Each process P_i maintains a local clock C_i
- All process clocks start at time 0

The Lamport Clock algorithm



1. Before executing an event, $C_i \leftarrow C_i + 1$

The Lamport Clock algorithm



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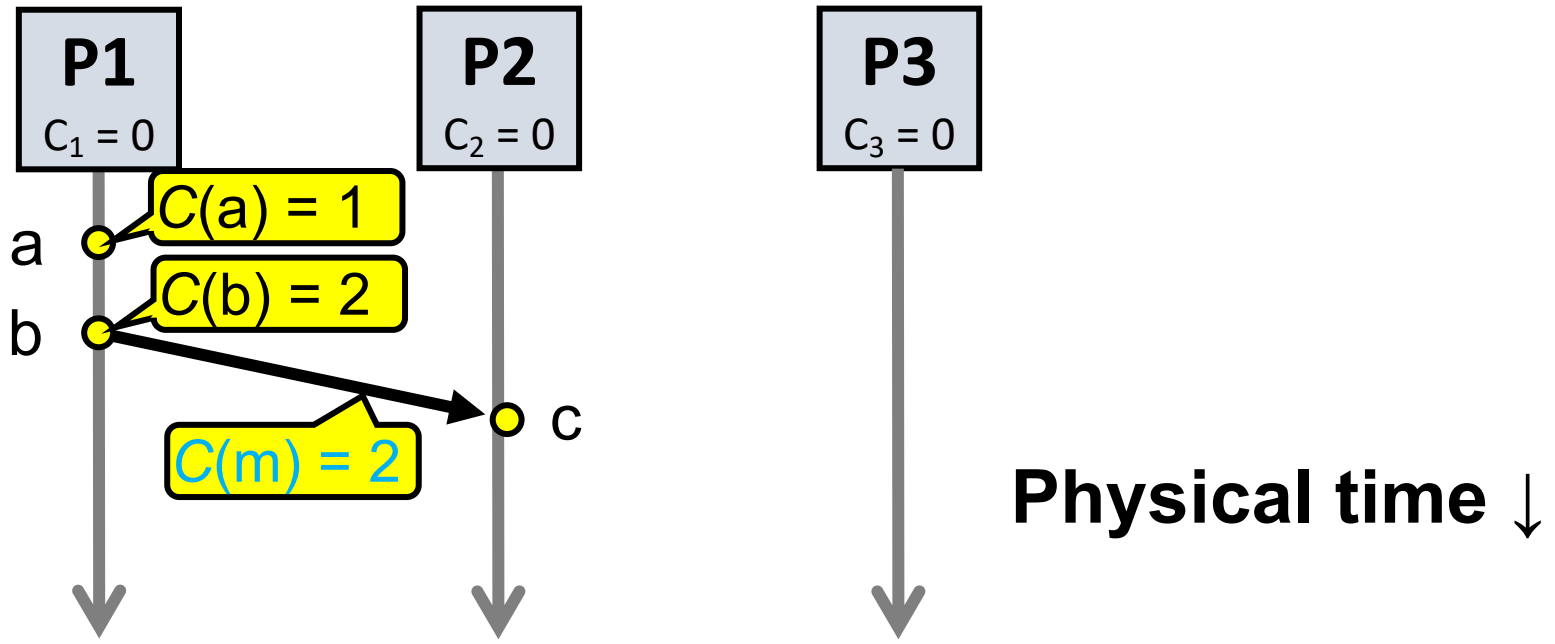
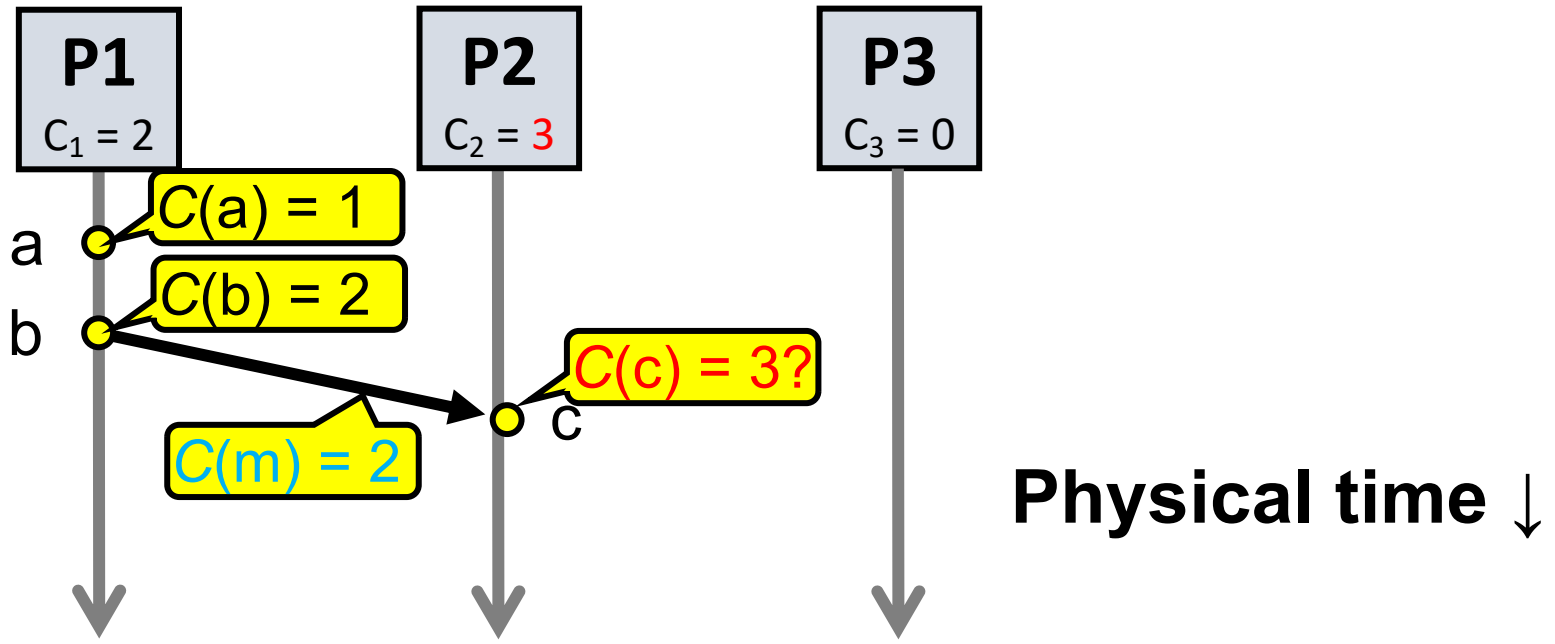


1. Before executing an event, $C_i \leftarrow C_i + 1$
2. Send the local clock in the message m

The Lamport Clock algorithm



1. Before executing an event, $C_i \leftarrow C_i + 1$
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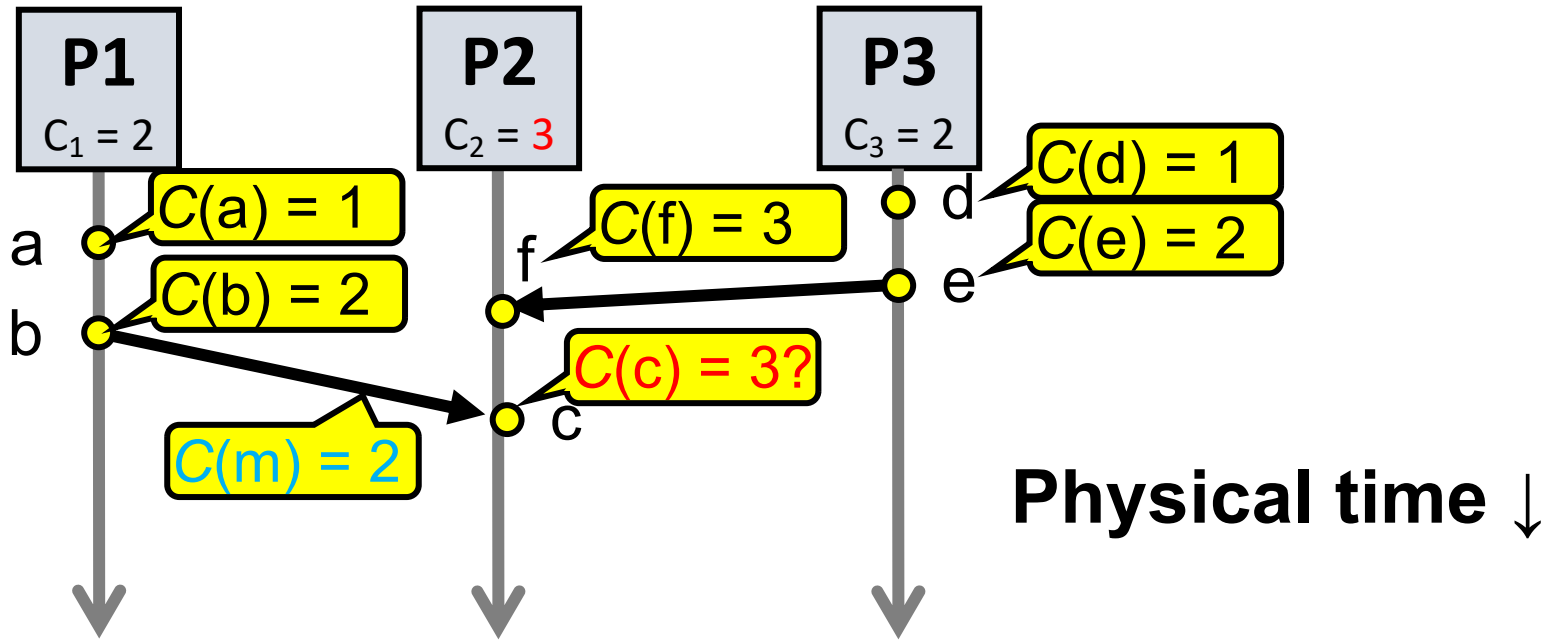
3. On process P_j receiving message m: what time should the receive event (C(m) + 1) use?

The Lamport Clock algorithm



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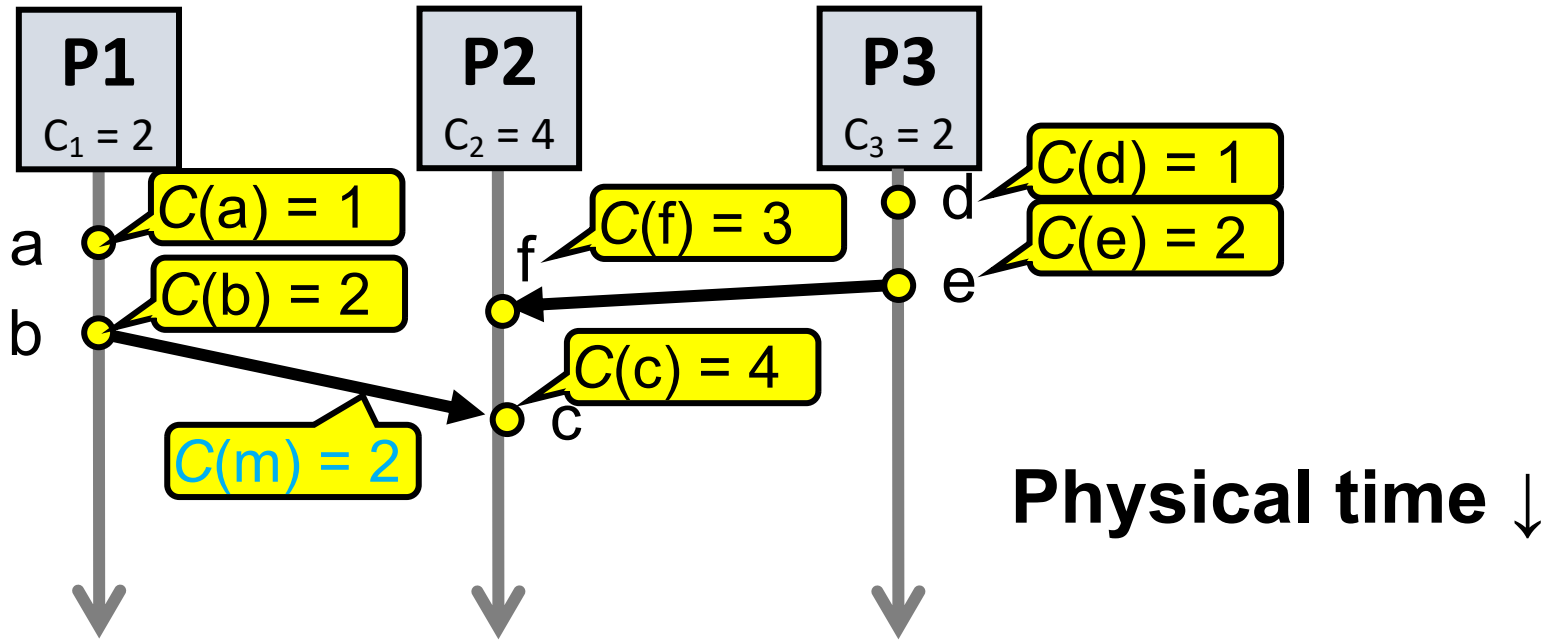
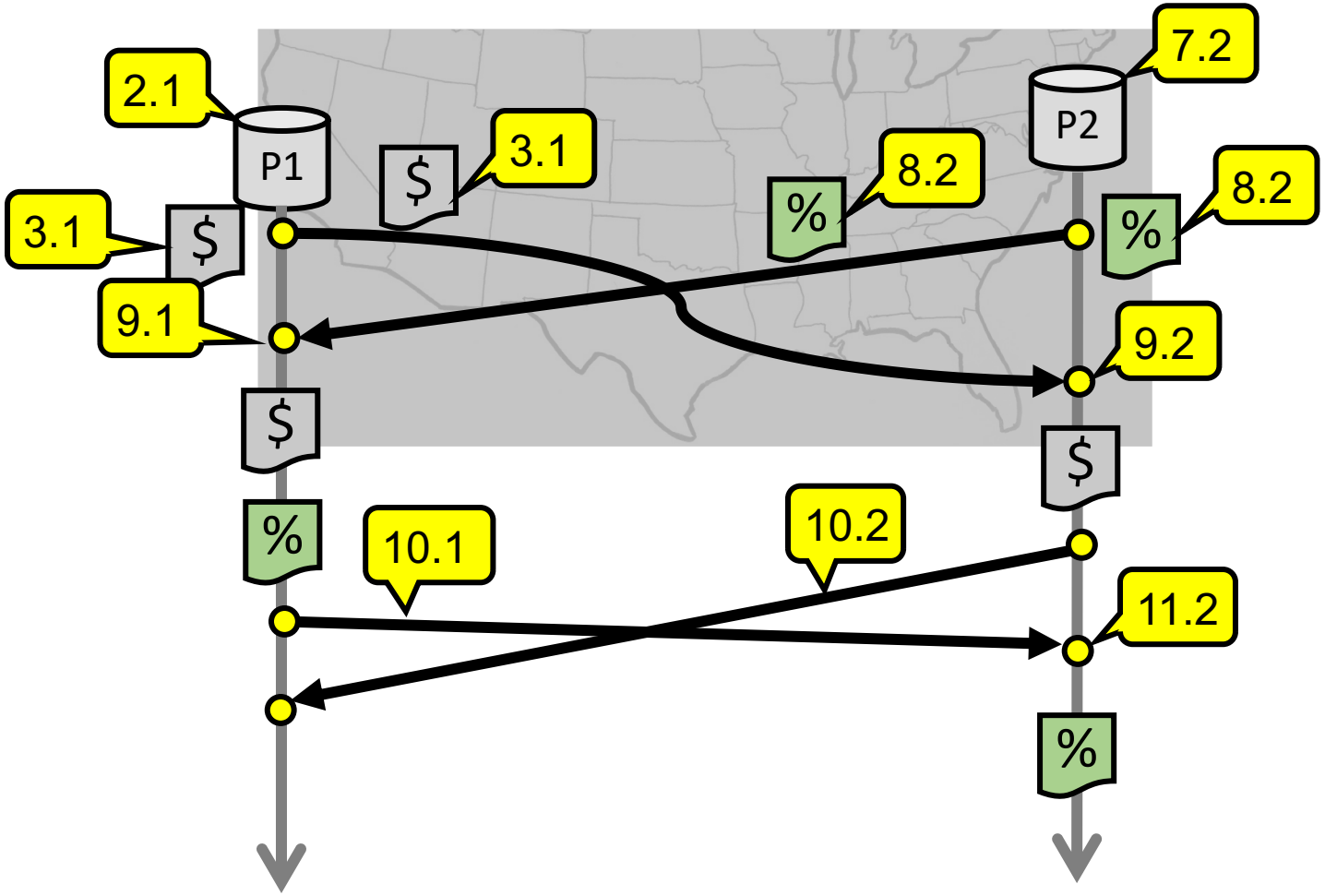


1. Before executing an event, $C_i \leftarrow C_i + 1$
2. Send the local clock in the message m
3. On process P_j receiving message m: set C_j and time of receive event to $1 + \max\{C_j, C(m)\}$

RSMs with Lamport Clocks

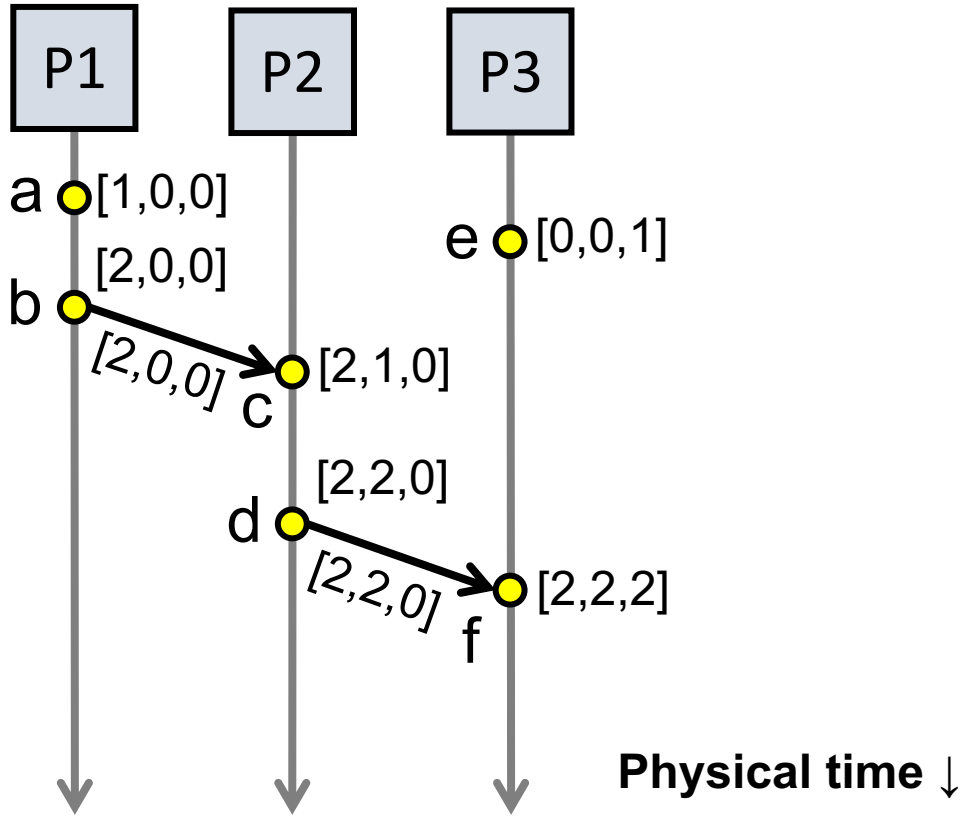
RSMs with Lamport Clocks

Assumption: network guarantees FIFO delivery



Vector clocks (VC)

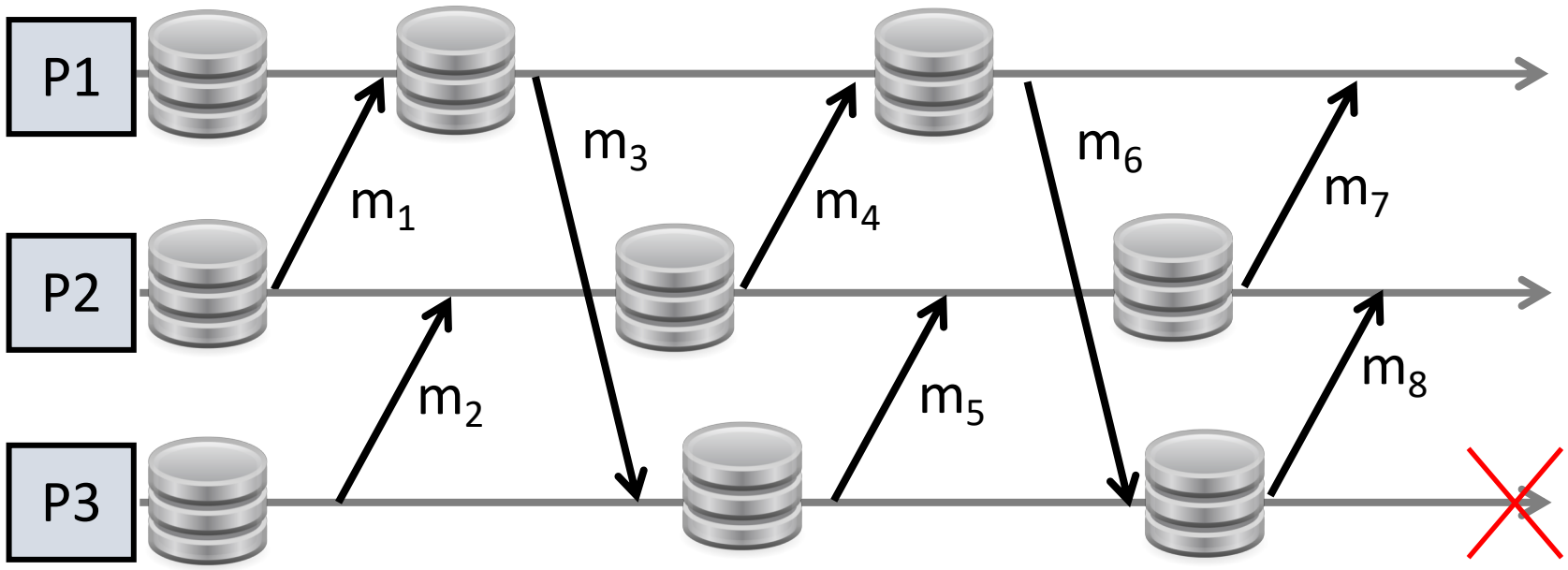
- Label each event e with a vector, V(e) = [c_1, c_2,…, c_n]
  - Number of components = number of processes



Replicated State Machines with Logical Clocks

- Any replica can execute an update only after confirming the clock on all other replicas is higher than the update's clock
- Implication: if any one replica is down, all other replicas are unable to make progress
  - Our RSM implementation (with logical clocks) only gives us a way to apply updates at replicas
- We assume crash failures: replicas can resume execution with saved state

Challenge in checkpointing



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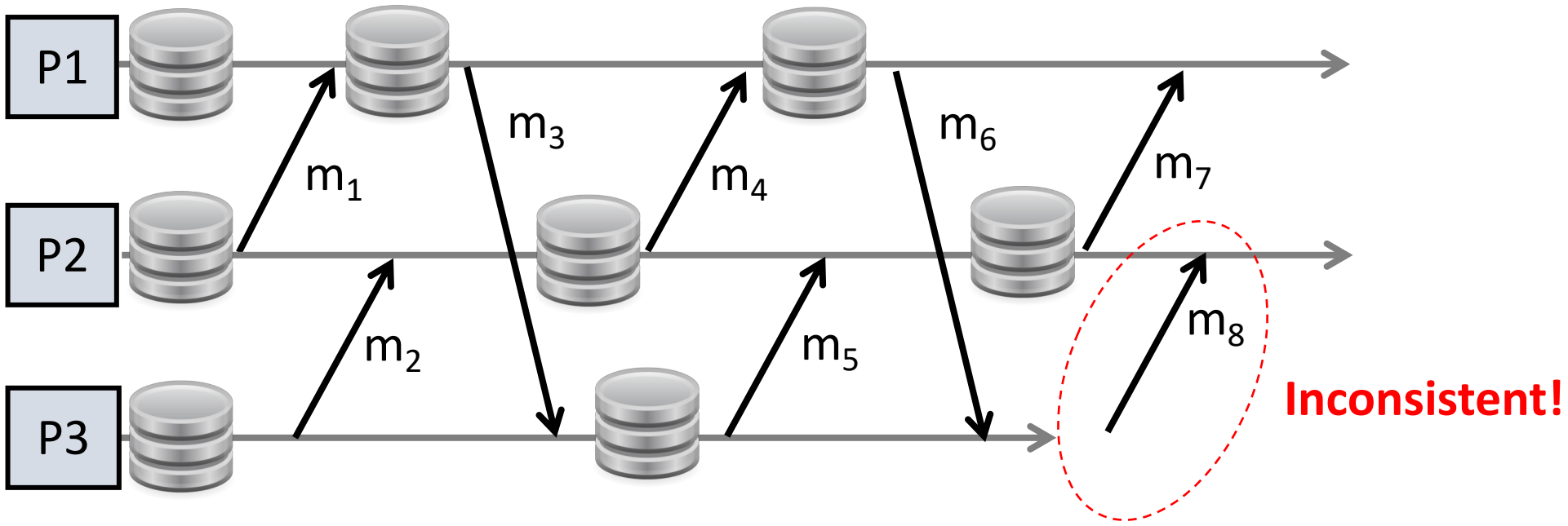

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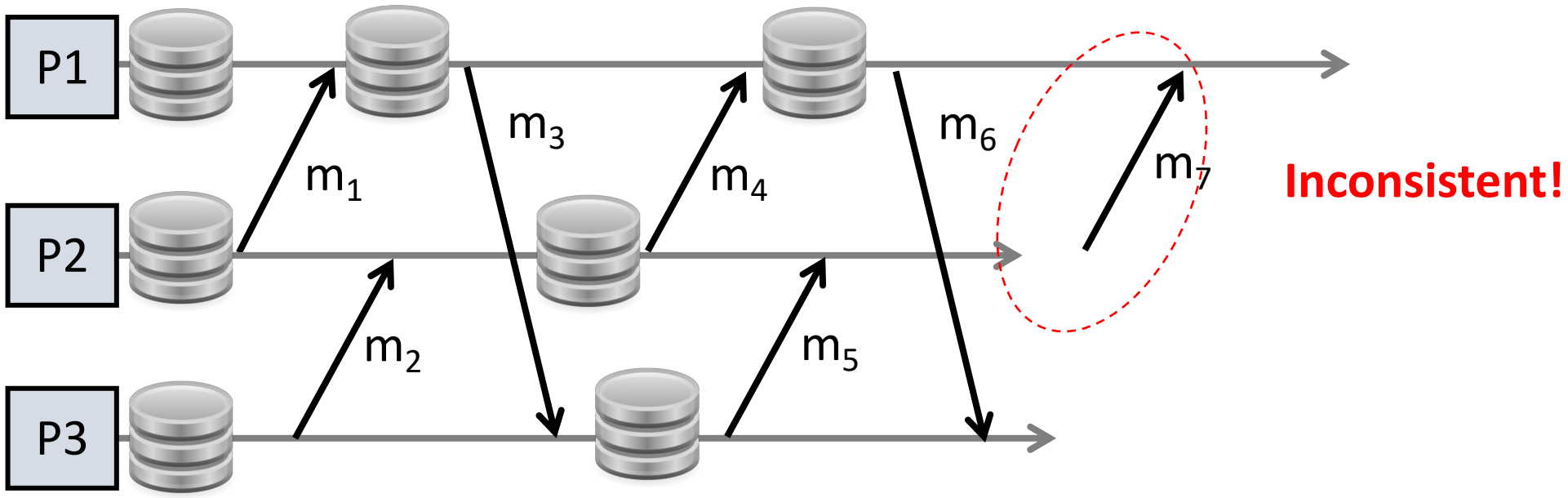

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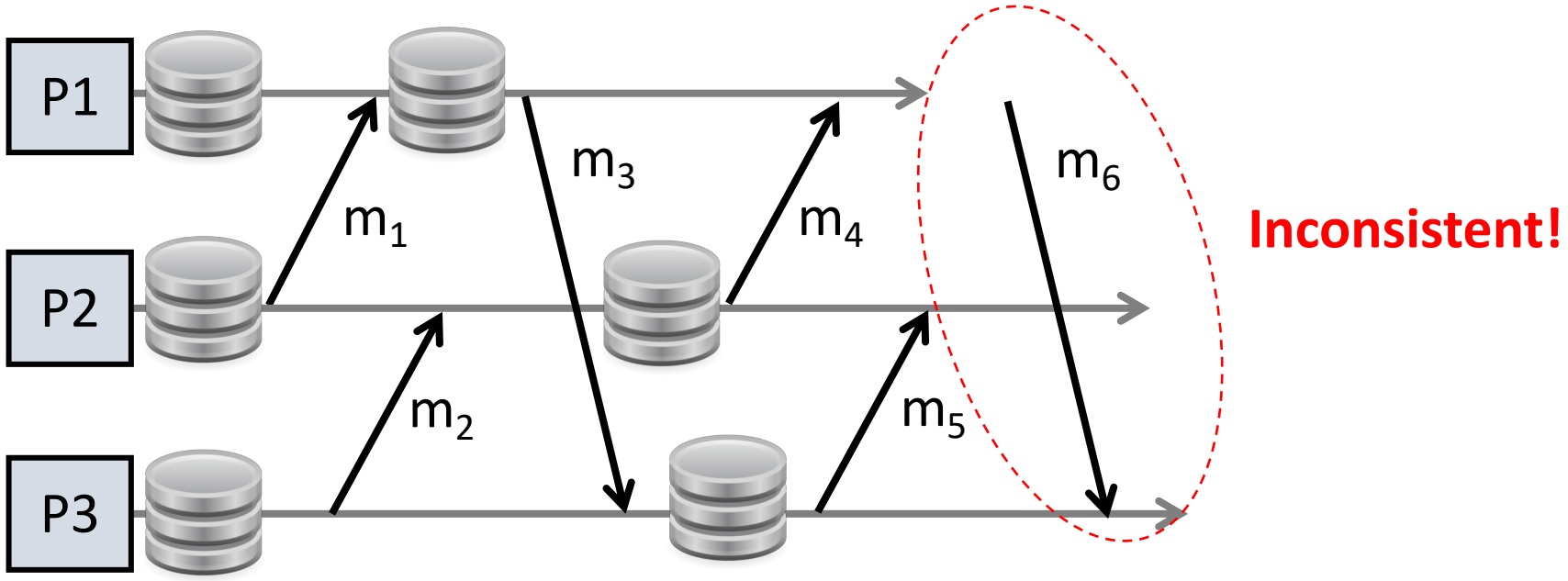

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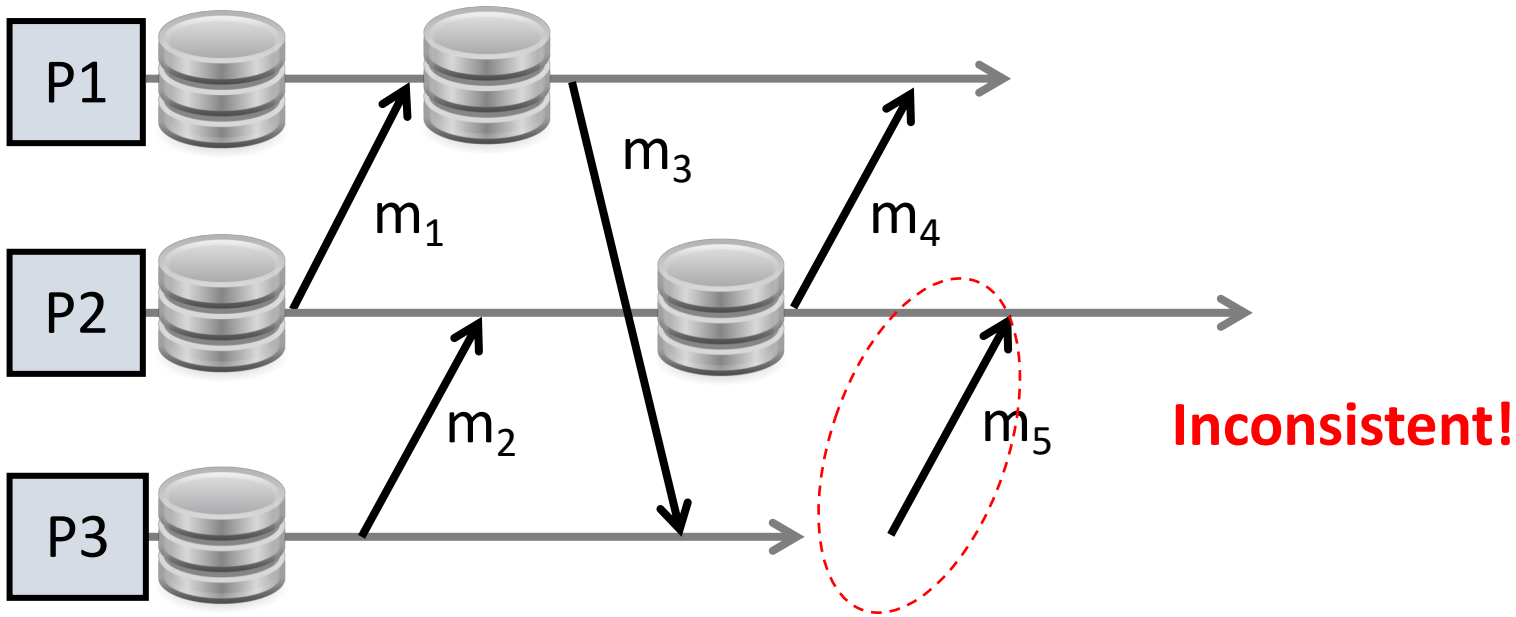

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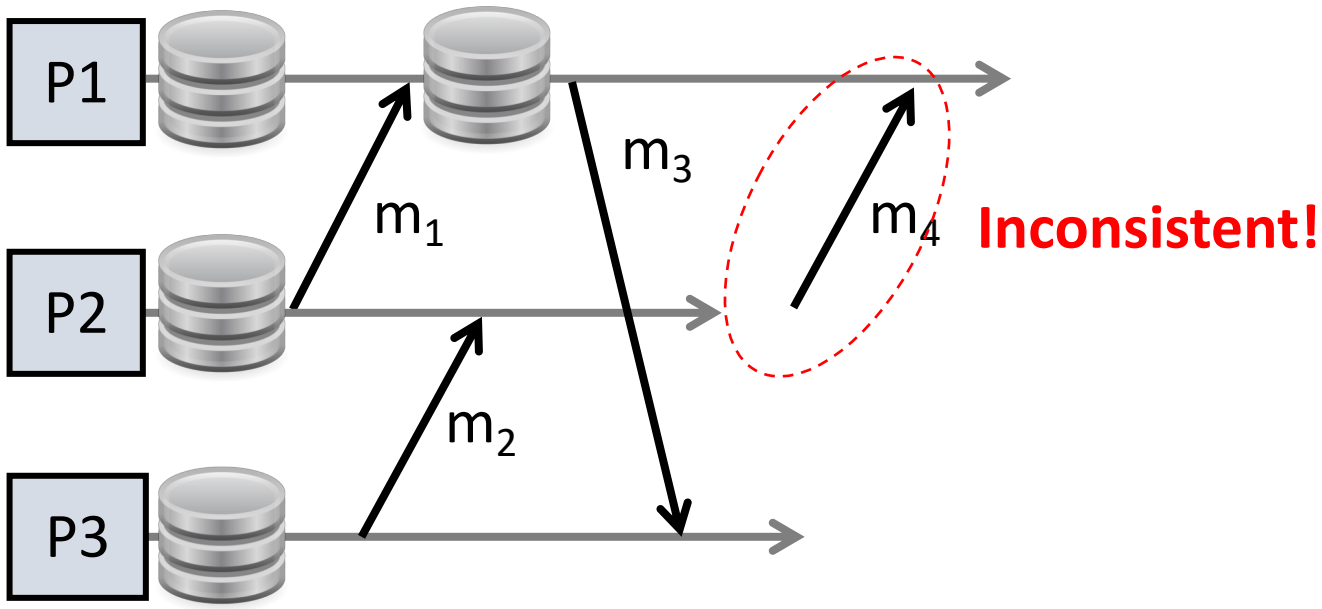

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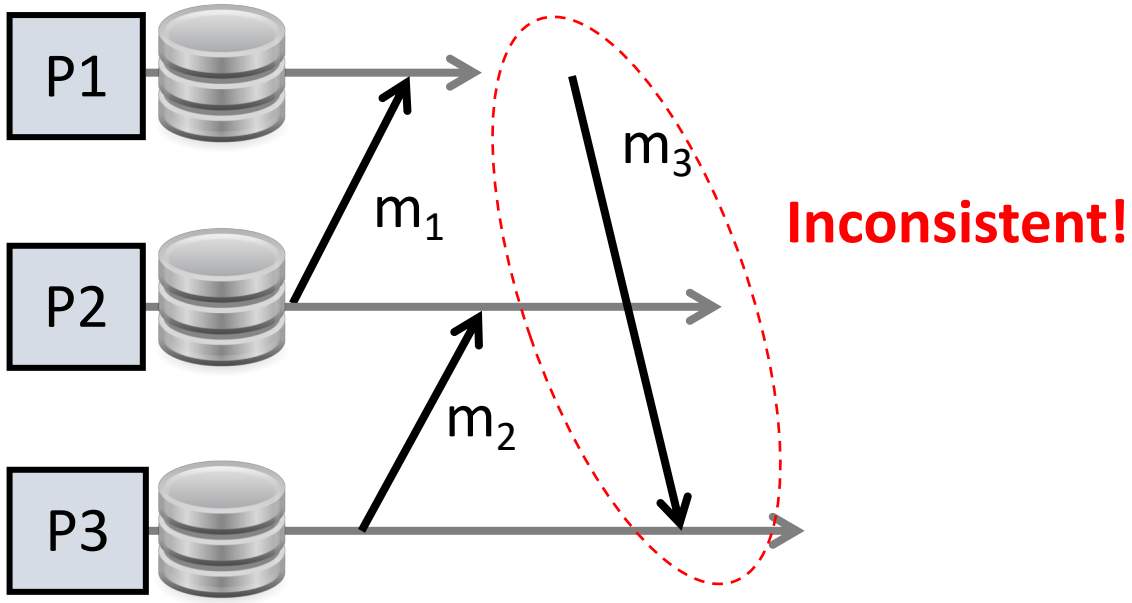

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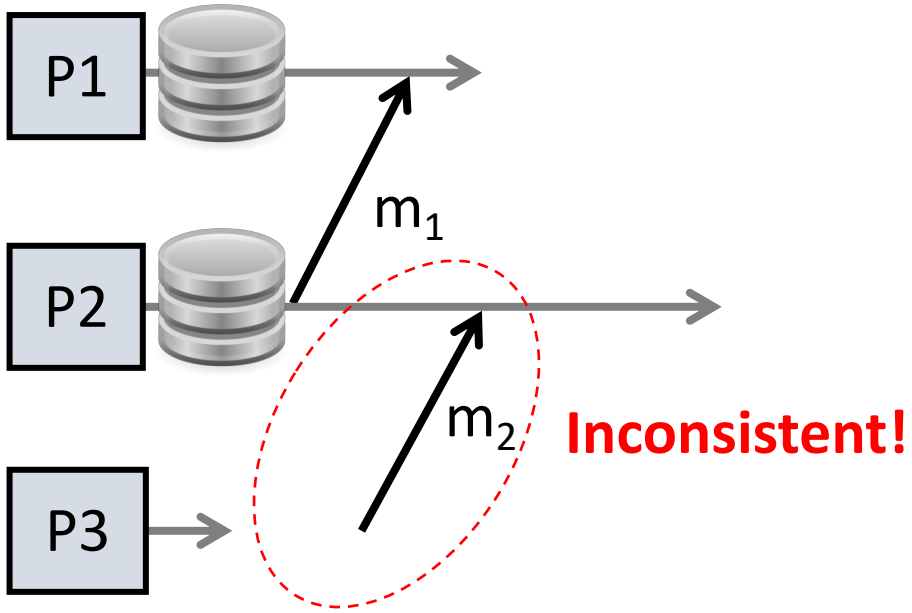

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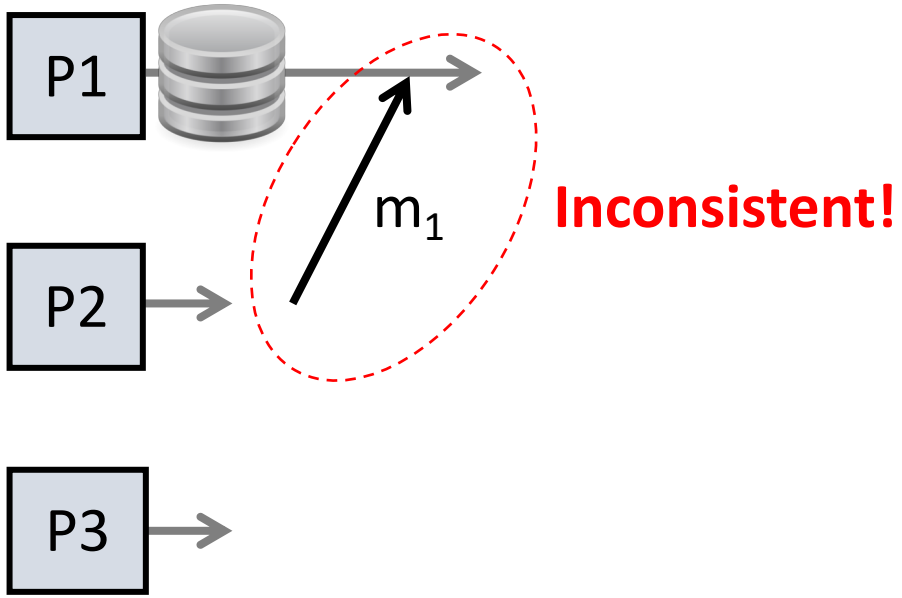

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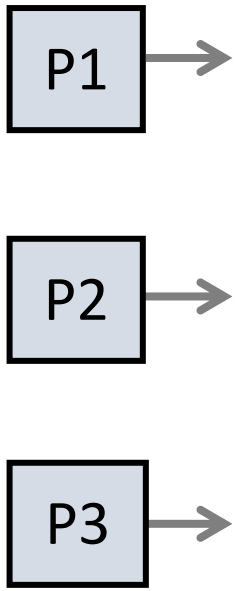
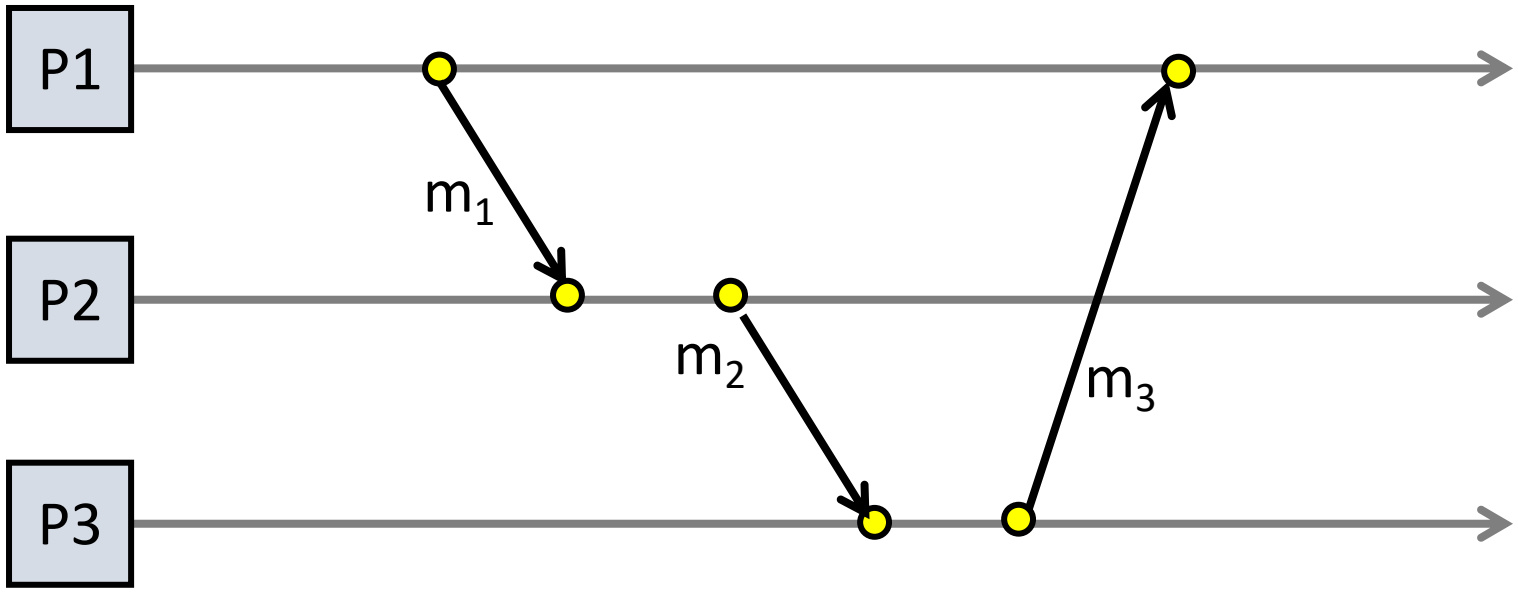


Domino effect!

Chandy-Lamport algorithm

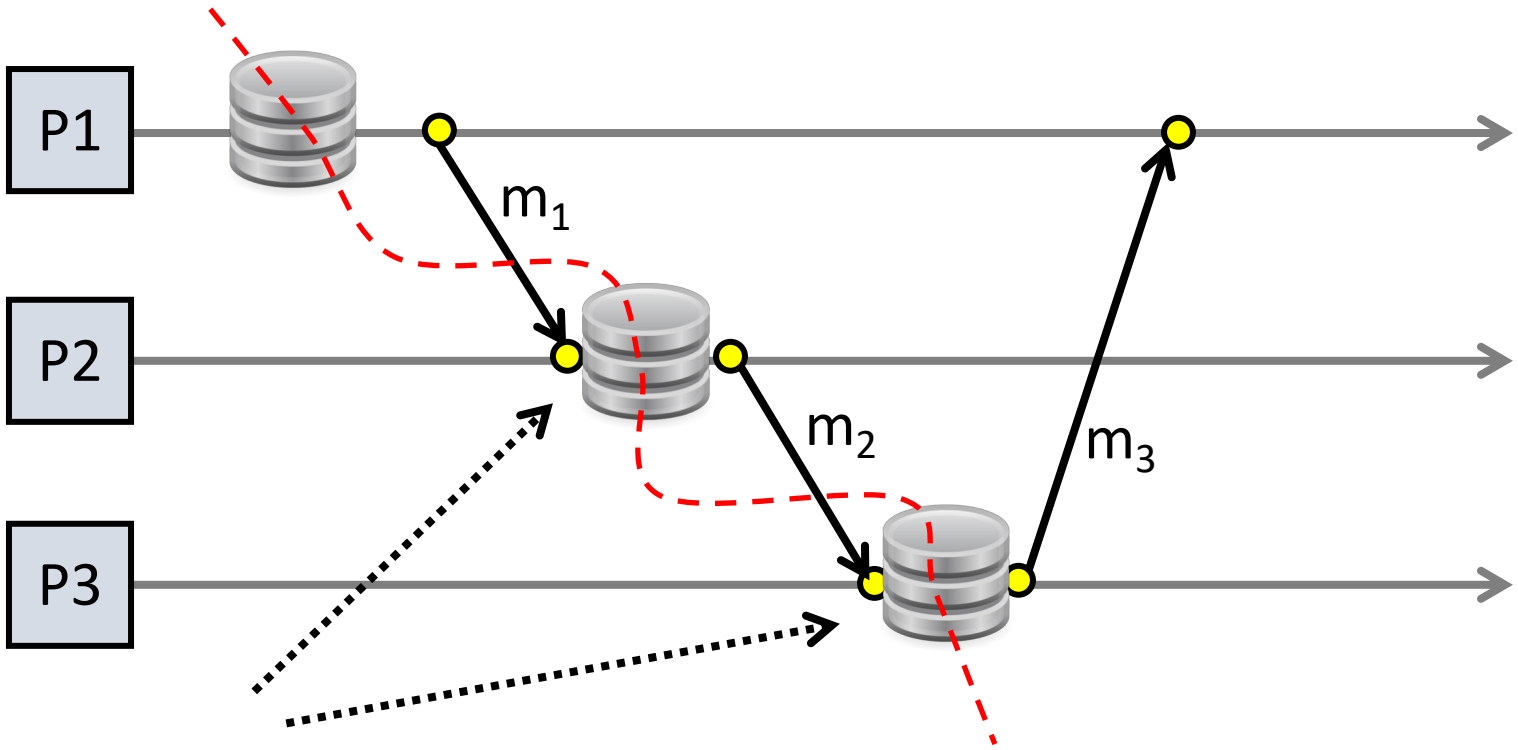
- Take a snapshot of a distributed system
- N processes in the system
  - Processes don’t fail while taking snapshot
  - Any process may initiate collection of snapshot
- One unidirectional channel/network in either direction between each pair of processes
  - All channels ensure FIFO delivery
  - Lossless and no duplication

Example: token ring



Rotate lock possession across processes in circle/ring order

Example: token ring (everybody has a token!)

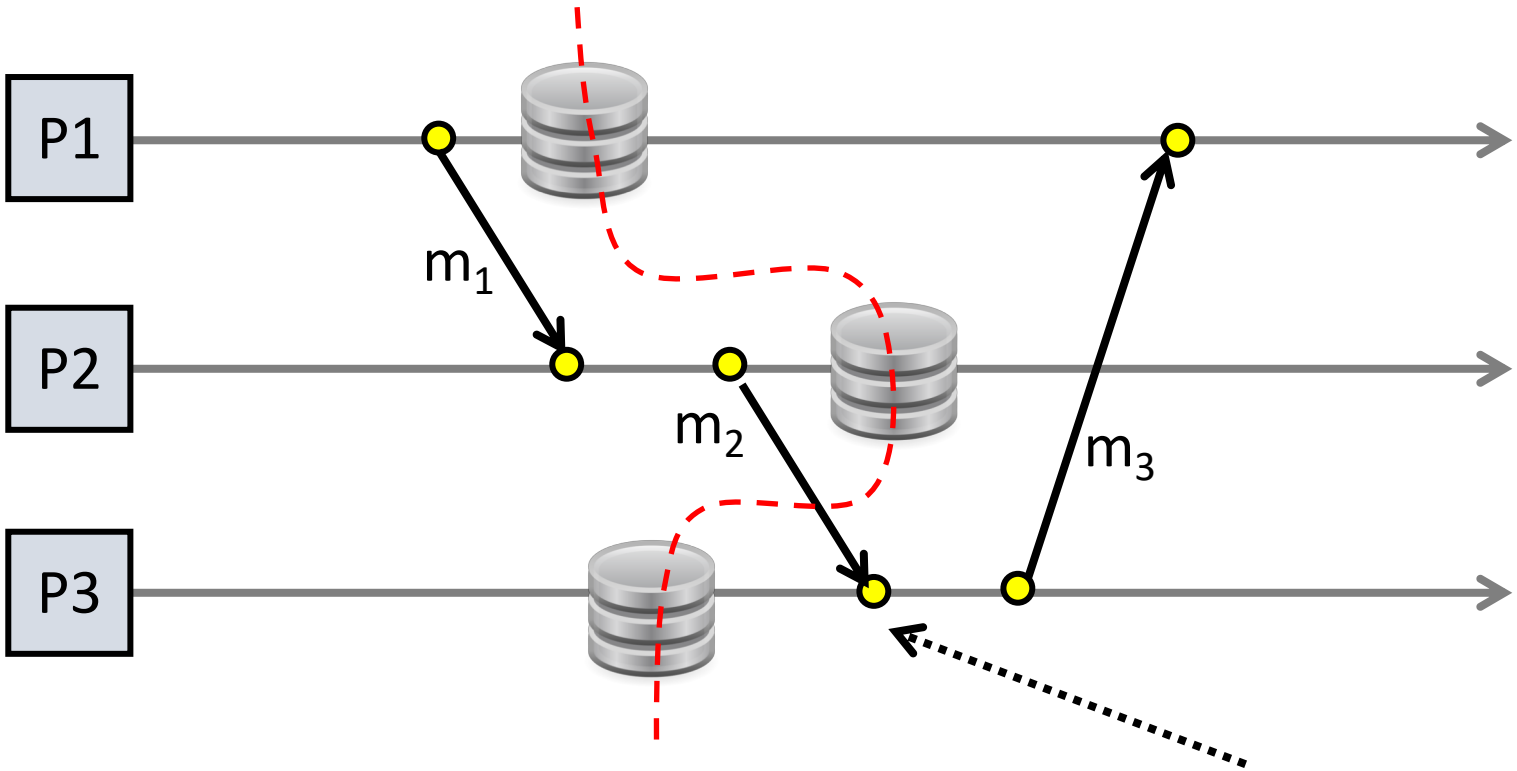


Global Snapshot

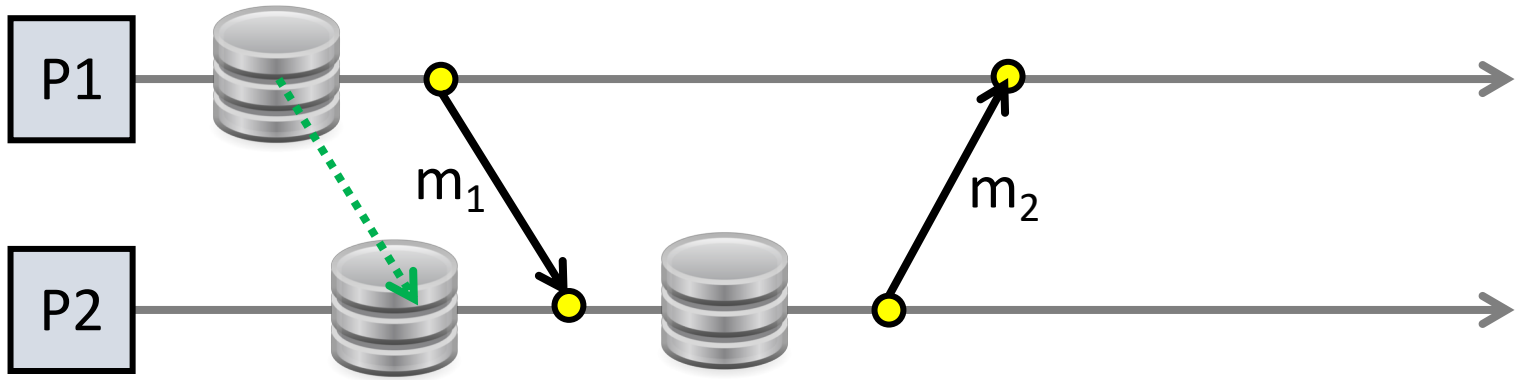
- Captured state must satisfy “happens before” principle
  - If event b is in the snapshot and a → b, then event a must also be in the snapshot

- ***Main challenge***: If a snapshot includes message receipt, it should also include sending it

Example: token ring (desired snapshot)



Chandy-Lamport snapshot



Solution: after taking checkpoint, send message to others informing them to also take checkpoints

- This message will arrive before any subsequent ones (FIFO)