CSE 486/586 Distributed Systems

Logical Time

Slides by: Steve Ko
Computer Sciences and Engineering
University at Buffalo

Last Time

- Clock skew does happen
- Cristian's algorithm
  - One server
  - Server-side timestamp with one-way delay estimate
- NTP (Network Time Protocol
  - Hierarchy of time servers
  - Estimates the offset between two clocks
  - Designed for the Internet
- Logical clocks stamp events, not times

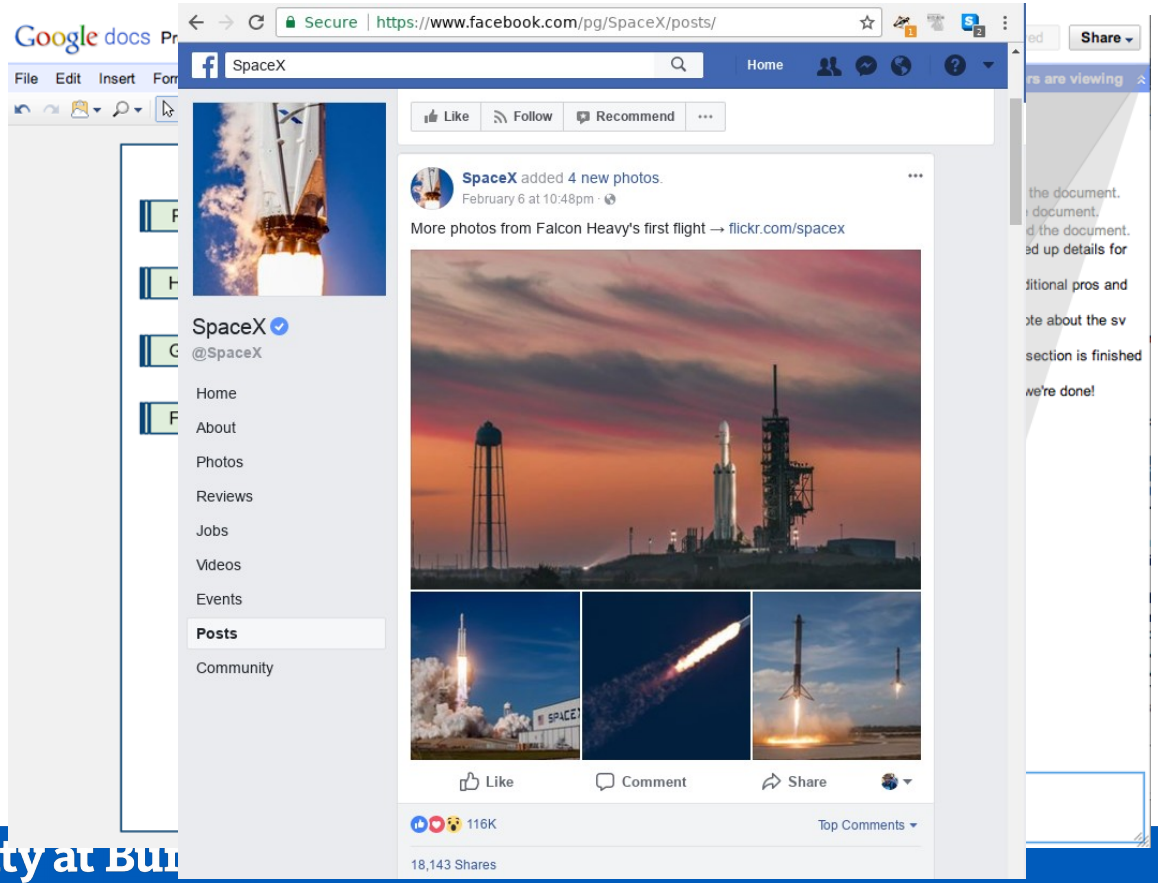
Logical clocks

- We cannot sync multiple clocks perfectly.
- Thus, if we want to order events happening at different processes (remember the ticket reservation example?), we cannot rely on physical clocks.
- Then came logical time.
  - First proposed by Leslie Lamport in the 70s [1]
  - Based on causality of events
  - Defined relative time, not absolute time
- Critical observation: time (ordering) only matters if two or more processes interact: *i.e.*, send/receive messages.

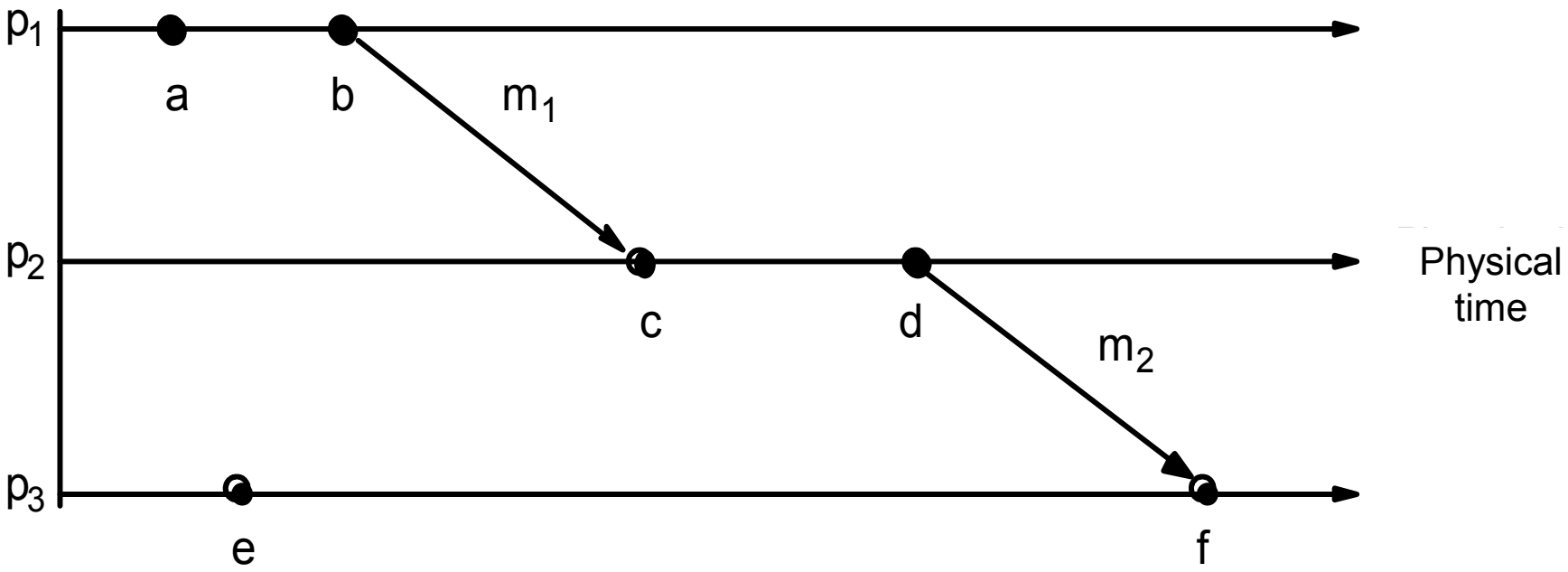
Time, Clocks, and the Ordering of Events in a Distributed System [1] is required reading.

Ordering Basics

- Why did we want to synchronize physical clocks?
- We actually need ordering of events.
- Arises in many different contexts…

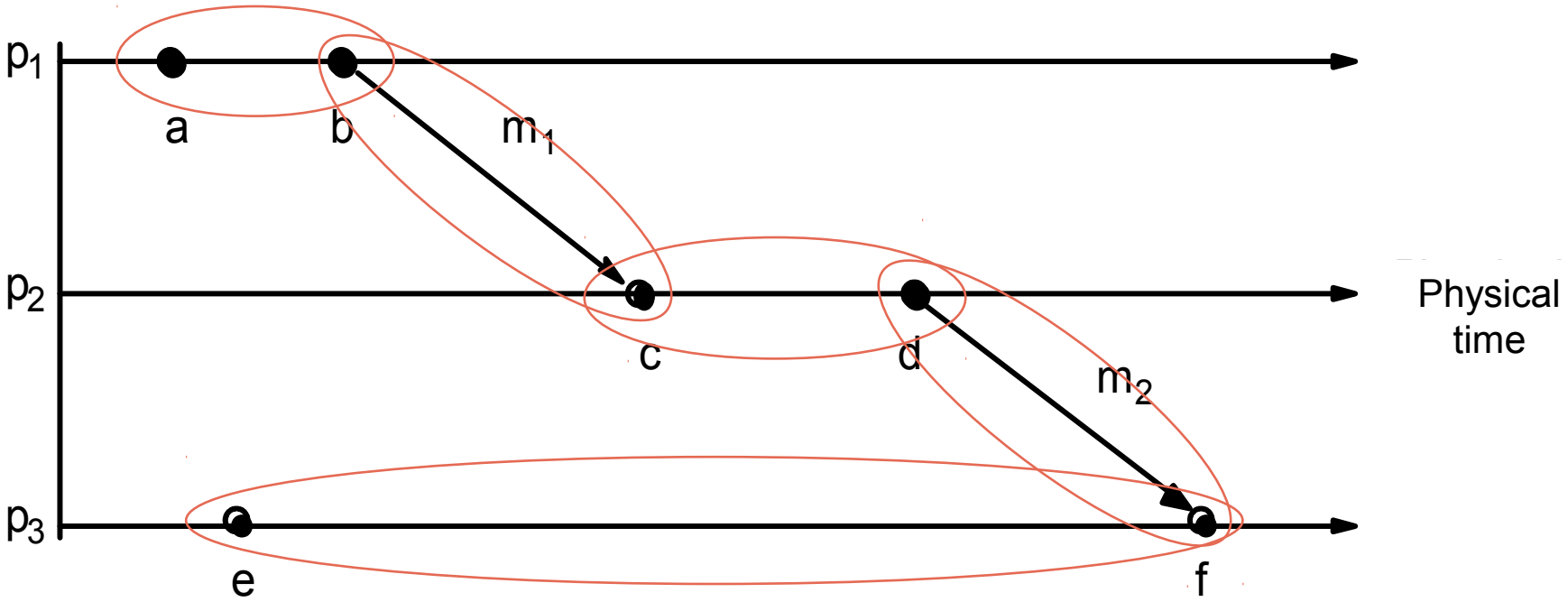


Abstract View



- Think of a program as a collection of actions: instructions, send, and receive events.
- This is what we will deal with most of the time.
  - This is the execution view of a distributed system.
- Ordering question: what do we ultimately want?
  - Determine the ordering of (any?) two events.

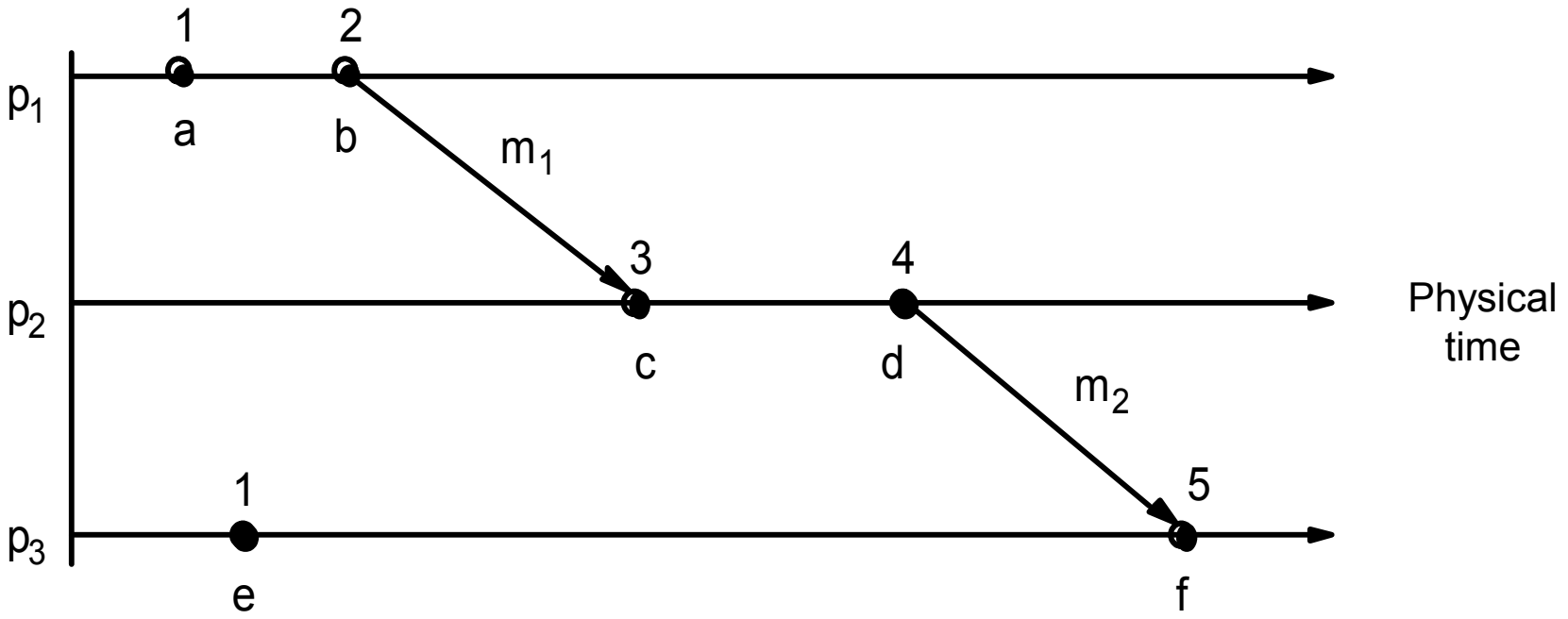
What Ordering?



- What would be ideal?
  - Perfect physical clock synchronization
- Without this, what is reliable?
  - Events in the same process
  - Send/receive events

Lamport Timestamps

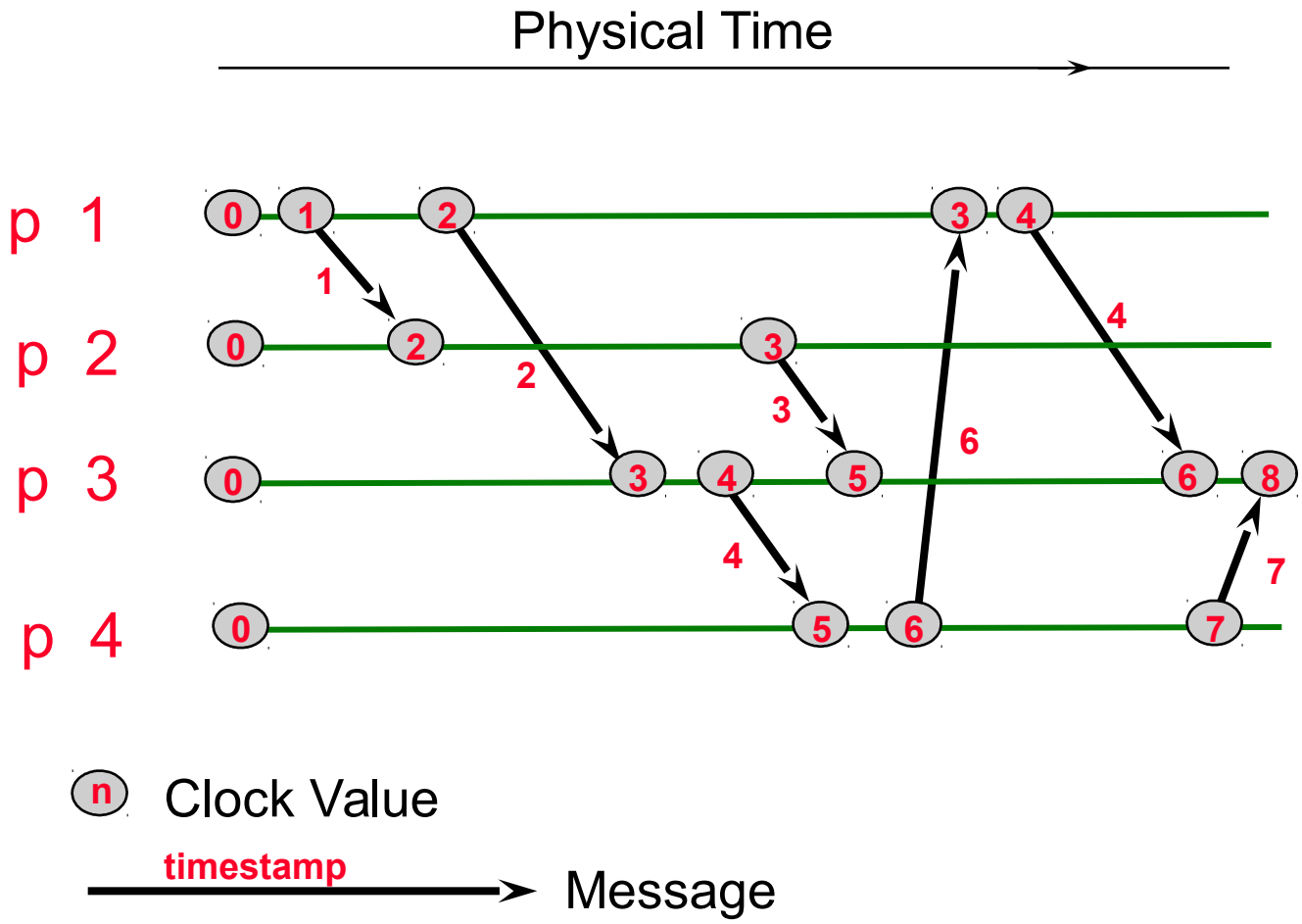
- Goal: take any two events, and determine their ordering.
- It uses a single number to do so.



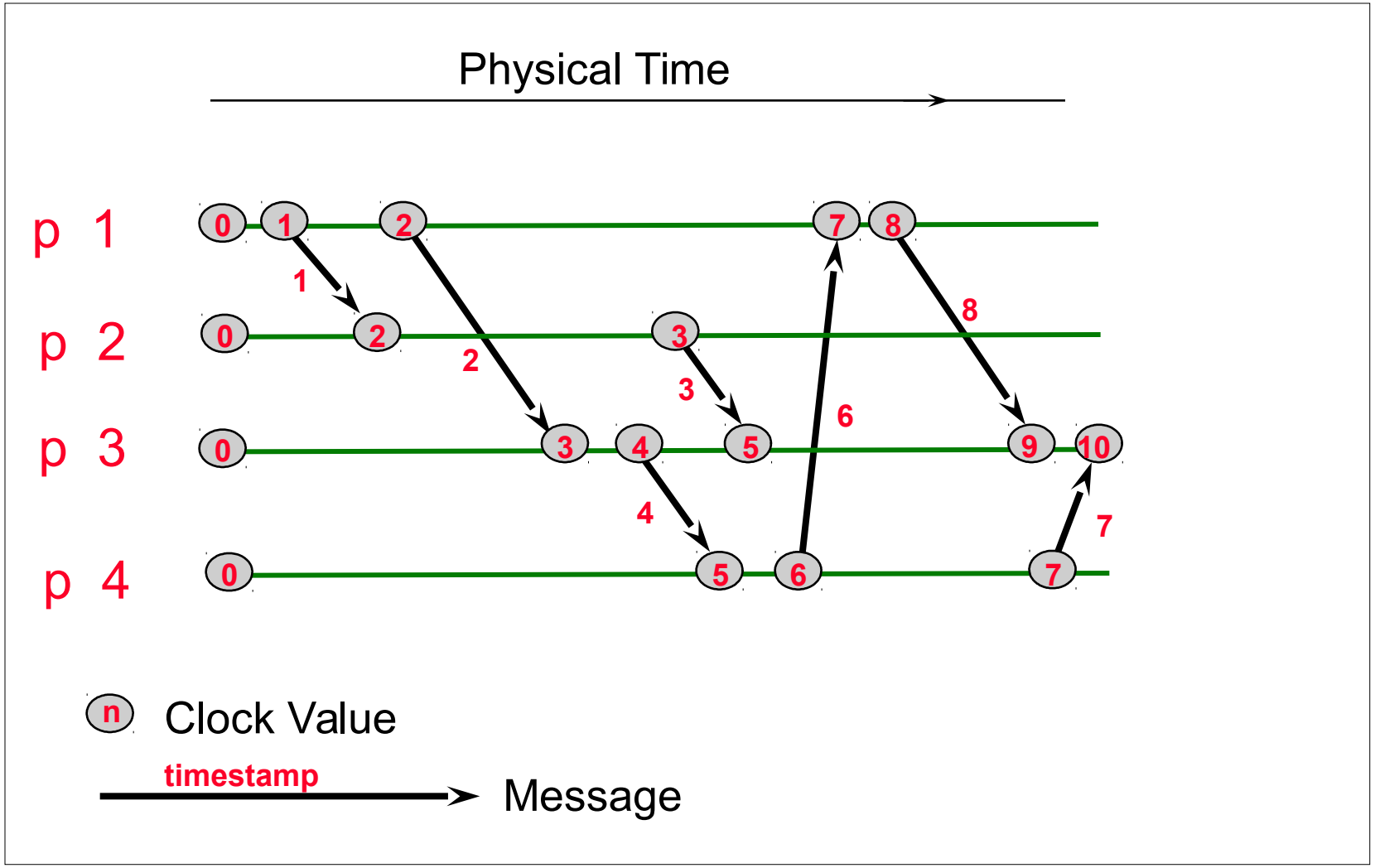
Logical Clocks

- Lamport's algorithm assigns logical timestamps:
  - All processes use a counter (clock) with initial value of zero
  - A process increments its counter when executing a send or an instruction.
  - The counter is assigned to the event as its timestamp.
  - A send event carries its timestamp in the message
  - On a receive event, the process counter is updated by max(local clock, message timestamp) + 1
- Defines a logical relation *happened-before* ($\rightarrow$) over events:
  - On the same process: $a \rightarrow b$, if $time(a) < time(b)$
  - If p_1 sends m to p_2: $send(m) \rightarrow receive(m)$
  - Transitive: If $a \rightarrow b$ *and* $b \rightarrow c$ then $a \rightarrow c$
  - Shows causality of events

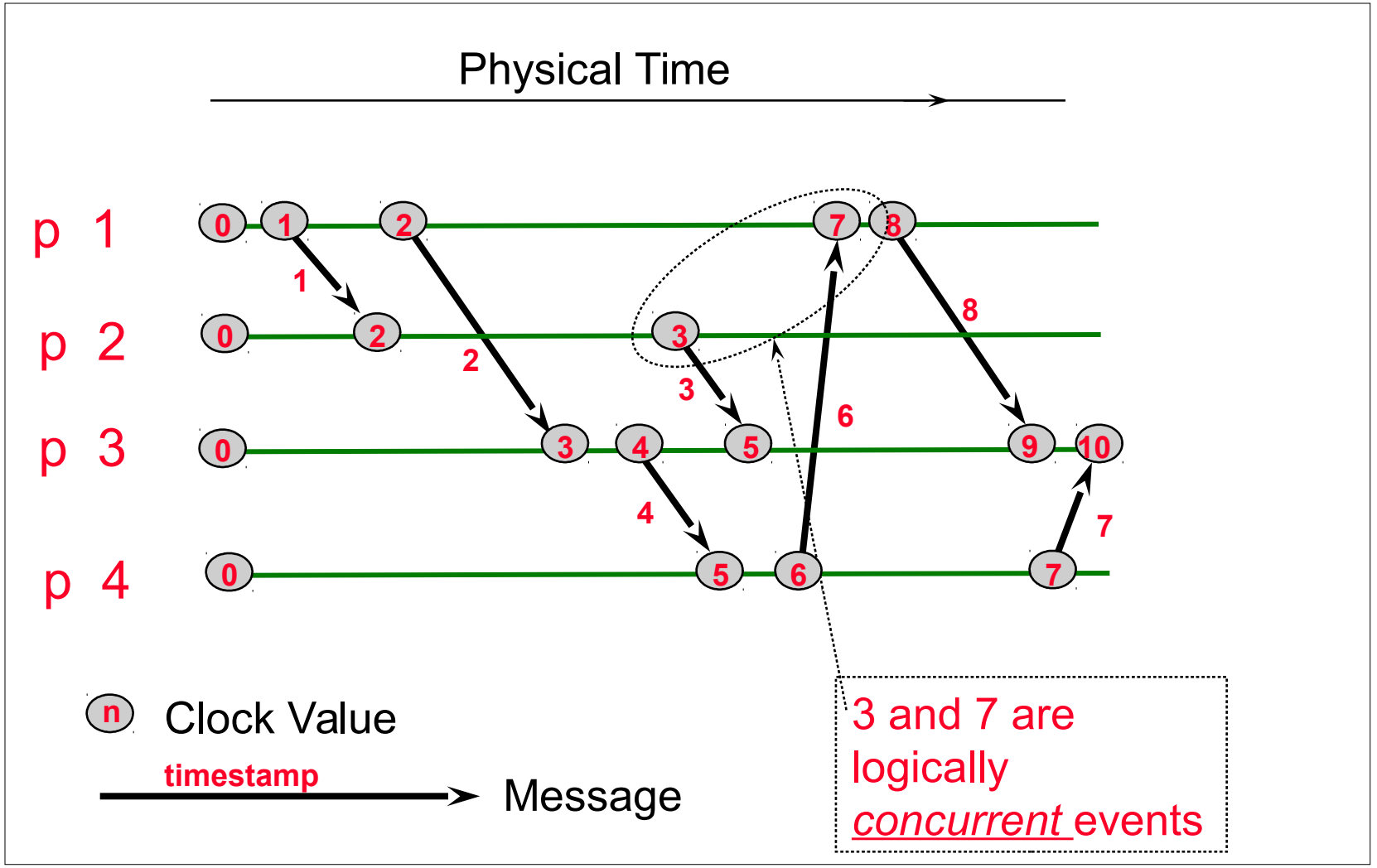
Find the Mistake: Lamport Logical Time



Corrected: Lamport Logical Time

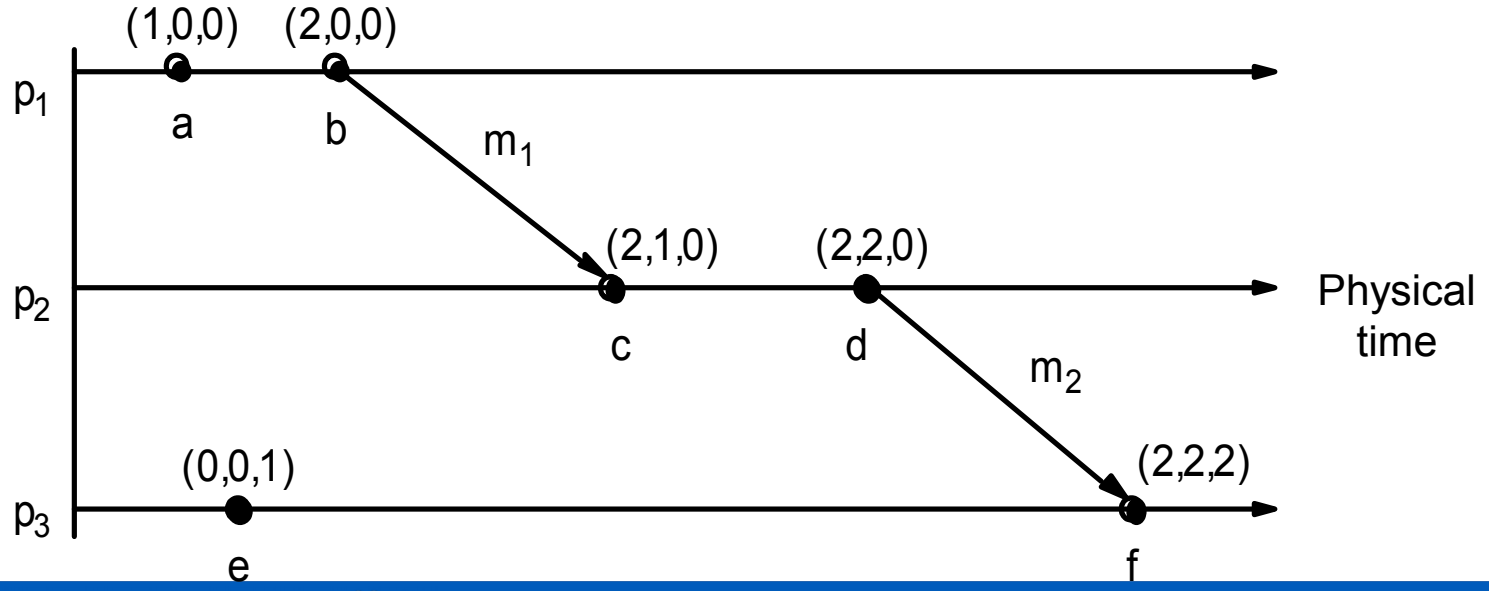


Lamport Logical Time Ambiguities



Vector Timestamps

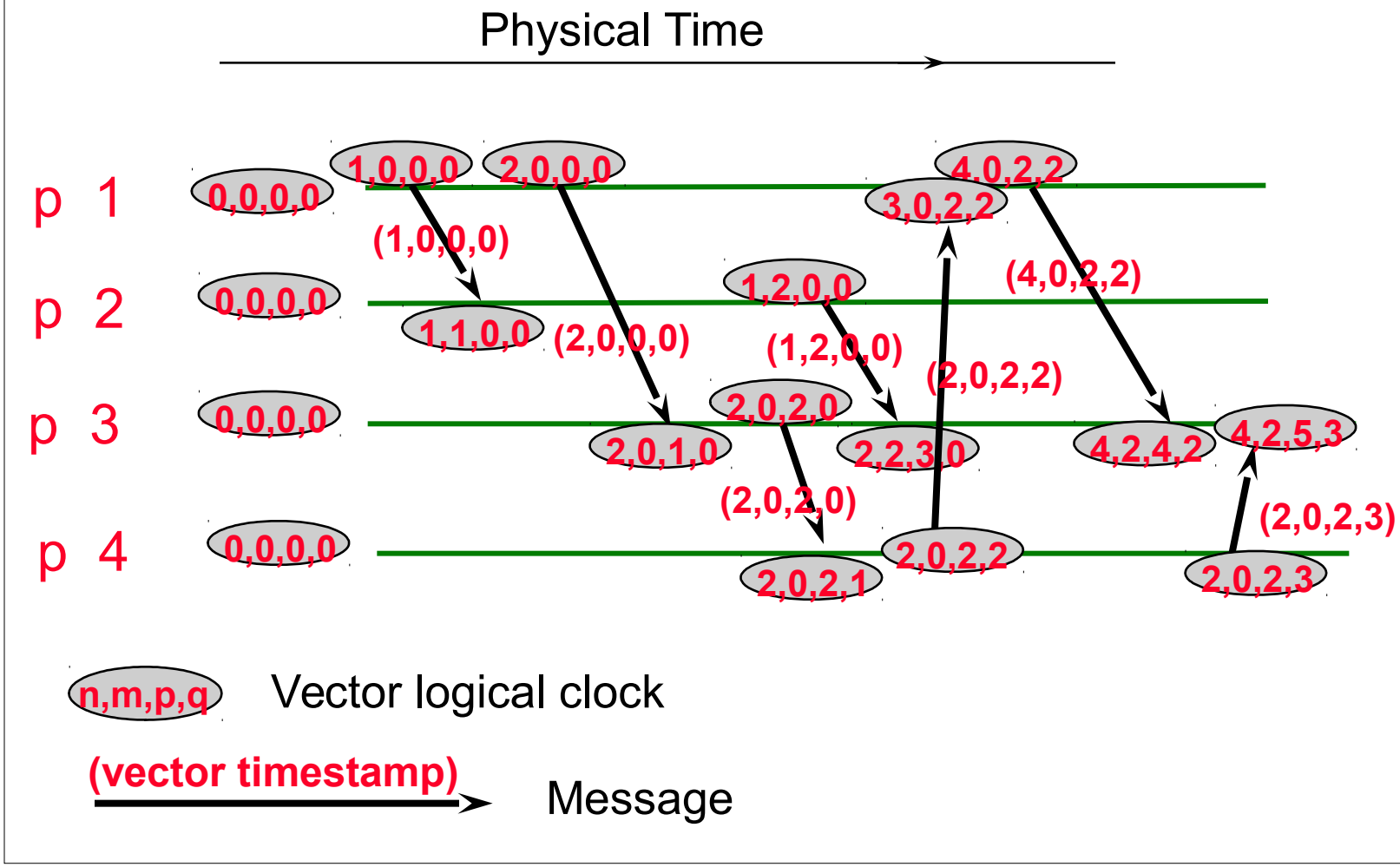
- With Lamport clock
  - $e \rightarrow f \Rightarrow$ timestamp(e) < timestamp(f), but
  - timestamp(e) < timestamp (f) $\not\Rightarrow$ $e \rightarrow f$
- Idea?
  - Each process keeps a separate clock & passes all around.
  - Each process learns about what happened in all others.



Vector Logical Clocks

- Vector Logical time:
  - All processes use a vector of counters (logical clocks), i^{th} element is the clock value for process i, initially all zero.
  - Each process i increments the i^{th} element of its vector upon an instruction or send event. Vector value is timestamp of the event.
  - A send event carries its vector timestamp
  - For a receive event, $V_{receiver}[j]$ =
    - $Max(V_{receiver}[j] , V_{message}[j])$, if j is not self,
    - $V_{receiver}[j] + 1$, otherwise
- Key point
  - You update your own clock. For all other clocks, rely on what other processes tell you and get the most up-to-date values.

Find a Mistake: Vector Logical Time



Comparing Vector Timestamps

- $VT_1 = VT_2$,
  - *iff* $VT_1[i] = VT_2[i]$, for all $i = 1, \ldots, n$
- $VT_1 <= VT_2$,
  - *iff* $VT_1[i] <= VT_2[i]$, for all $i = 1, \ldots, n$
- $VT_1 < VT_2$,
  - *iff* $VT_1 <= VT_2 \;\&\; \exists\, j\, (1 <= j <= n \;\&\; VT_1[j] < VT_2[j])$
- VT_1 is concurrent with VT_2
  - *iff* (not $VT_1 <= VT_2$ AND not $VT_2 <= VT_1$)

The Use of Logical Clocks

- Is a design decision
- NTP error bound
  - Local: a few ms
  - Wide-area: 10s of ms
- If your system doesn't care about this inaccuracy, then NTP should be fine.
- Logical clocks impose an arbitrary order over concurrent events anyway
  - Breaking ties: process IDs, etc.

Summary

- Relative order of events enough for practical purposes
  - Lamport's logical clocks
  - Vector clocks
- Next: How to take a global snapshot

References

[1] Time, Clocks, and the Ordering of Events in a Distributed System. Leslie Lamport. Communications of the ACM Vol 21 No 7. July 1978. **Required Reading.** https://www.microsoft.com/en-us/research/uploads/prod/2016/12/Time-Clocks-and-the-Ordering-of-Events-in-a-Distributed-System.pdf

[2] Textbook section 14.4. **Required Reading.**

Acknowledgements

- Slides by Steve Ko (used with permission) and lightly modified by Ethan Blanton.
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