CSE 486/586 Distributed Systems
Logical Time

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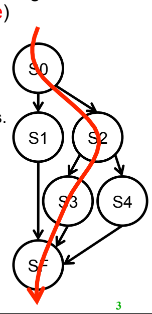
Last Time

- Clock skews do happen
- Cristian's algorithm
  - One server
  - Server-side timestamp and one-way delay estimation
- NTP (Network Time Protocol)
  - Hierarchy of time servers
  - Estimates the actual offset between two clocks
  - Designed for the Internet
- Logical time
  - For ordering events, relative time should suffice.
  - Will continue today

Basics: State Machine

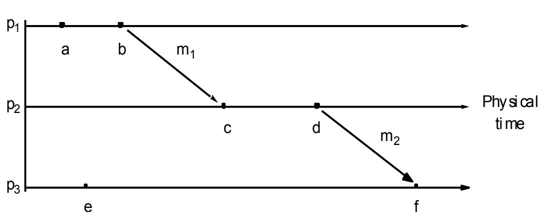
- State: a collection of values of variables
- Event: an occurrence of an action that changes the state, (i.e., instruction, send, and receive)
- As a program,
  - We can think of all possible execution paths.
- At runtime,
  - There's only one path that the program takes.
- Equally applicable to
  - A single process
  - A distributed set of processes



Ordering Basics

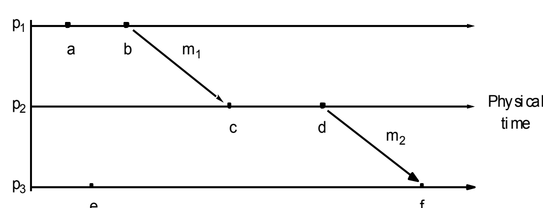
- Why did we want to synchronize physical clocks?
- What we need: Ordering of events.
- Arises in many different contexts…

Abstract View



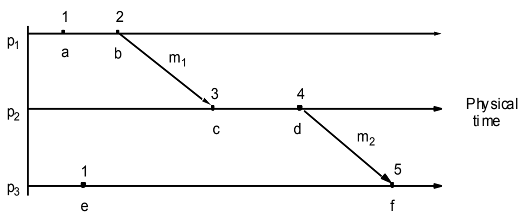
- Above is what we will deal with most of the time.
- Ordering question: what do we ultimately want?
  - Taking two events and determine which one happened before the other one.

What Ordering?



- Ideal?
  - Perfect physical clock synchronization
- Reliably?
  - Events in the same process
  - Send/receive events

Lamport Timestamps



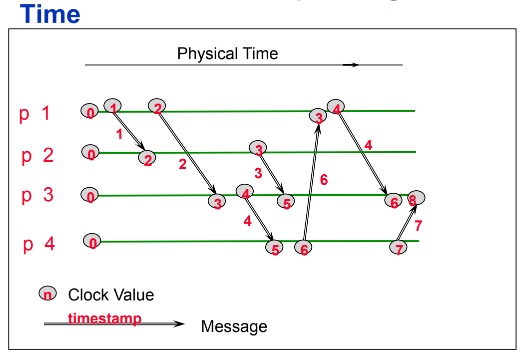
Logical Clocks

- Lamport algorithm assigns logical timestamps:
  - All processes use a counter (clock) with initial value of zero
  - A process increments its counter when a send or an instruction happens at it. The counter is assigned to the event as its timestamp.
  - A send (message) event carries its timestamp
  - For a receive (message) event the counter is updated by max(local clock, message timestamp) + 1
- Define a logical relation *happened-before* ($\rightarrow$) among events:
  - On the same process: $a \rightarrow b$, if $time(a) < time(b)$
  - If p1 sends *m* to p2: $send(m) \rightarrow receive(m)$
  - (Transitivity) If $a \rightarrow b$ and $b \rightarrow c$ then $a \rightarrow c$
  - Shows causality of events

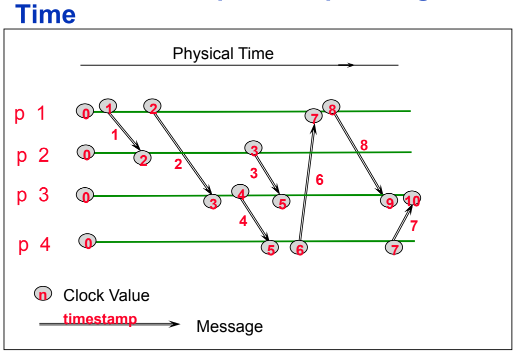
CSE 486/586 Administrivia

- PA2 will be out very soon.
  - Sorry for my delay; waiting on new TAs first.
- Please pay attention to your coding style.

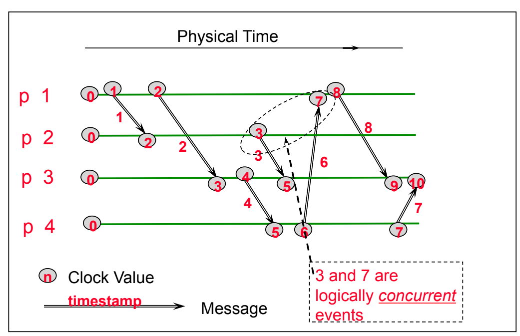
Find the Mistake: Lamport Logical Time



Corrected Example: Lamport Logical Time

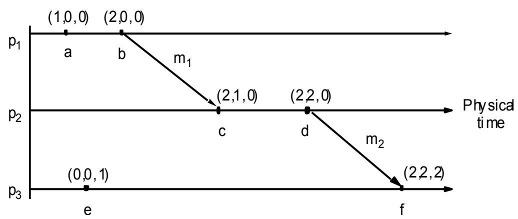


One Issue



Vector Timestamps

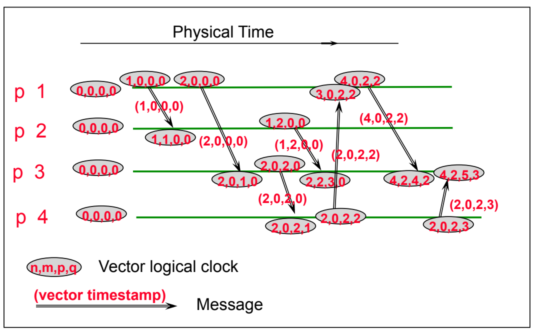
- With Lamport clock
  - e "happened-before" f $\Rightarrow$ timestamp(e) < timestamp (f), but
  - timestamp(e) < timestamp (f) $\not\Rightarrow$ e "happened-before" f
- Idea?



Vector Logical Clocks

- Vector Logical time addresses the issue:
  - 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(message) event carries its vector timestamp (counter vector)
  - For a receive(message) event, $V_{receiver}[j]$ =
    - Max($V_{receiver}[j]$, $V_{message}[j]$), if j is not self,
    - $V_{receiver}[j]$ + 1, otherwise

Find a Mistake: Vector Logical Time



Comparing Vector Timestamps

- $VT_1 = VT_2$,
  - *iff* $VT_1[i] = VT_2[i]$, for all i = 1, … , n
- $VT_1 <= VT_2$,
  - *iff* $VT_1[i] <= VT_2[i]$, for all i = 1, … , 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: 10's 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

Acknowledgements

- These slides contain material developed and copyrighted by Indranil Gupta at UIUC.