CSE 486/586 Distributed Systems
Logical Time

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Last Time

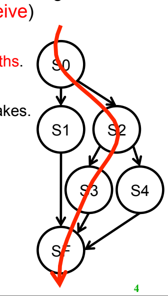
- Clock skews do happen
- Cristian's algorithm
  – One server
  – Server-side timestamp and one-way delay estimation
- NTP (Network Time Protocol)
  – Hierarchy of time servers
  – Estimates the actual offset between two clocks
  – Designed for the Internet

Then a Breakthrough…

- We cannot sync multiple clocks perfectly.
- Thus, if we want to order events happened 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 70's
  – 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.

Basics: State Machine

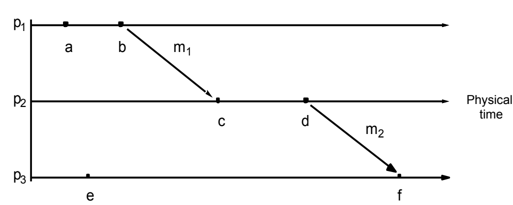
- State: a collection of values of variables
- Event: an occurrence of an action that changes the state, (i.e., instruction, send, and receive)
- As a program,
  – We can think of all possible execution paths.
- At runtime,
  – There's only one path that the program takes.
- Equally applicable to
  –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



Ordering Basics

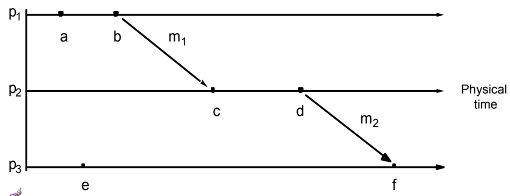
- Why did we want to synchronize physical clocks?
- What we need: Ordering of events.
- Arises in many different contexts…

Abstract View



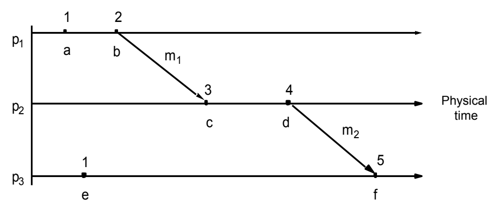
- Above is what we will deal with most of the time.
- Ordering question: what do we ultimately want?
  – Taking two events and determine which one happened before the other one.

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* (→) among events:
  - On the same process: *a → b*, if *time(a) < time(b)*
  - If p1 sends *m* to p2: *send(m) → receive(m)*
  - (Transitivity) If *a → b and b → c* then *a → c*
  - Shows causality of events

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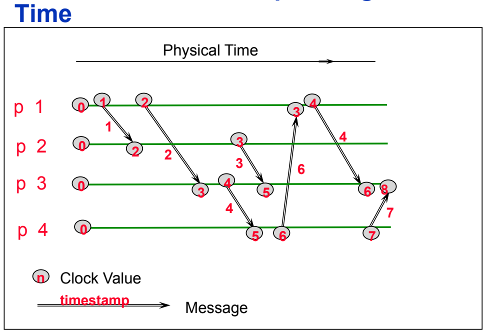
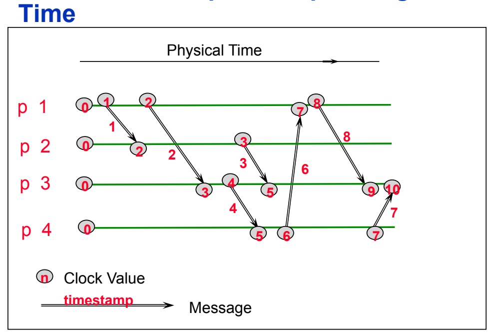
- PA2 is out. Two points:
  - Multicast: Just create 5 connections (5 sockets) and send a message 5 times through different connections.
  - ContentProvider: Don't call it directly. Don't share anything with the main activity. Consider it an almost separate app only accessible via ContentResolver.
- Please pay attention to your coding style.
- Please participate in our survey (not related to class, but still :-)
  - http://goo.gl/forms/nwFgf3niFW
  - We're designing a new photo storage/programming framework for mobile devices.

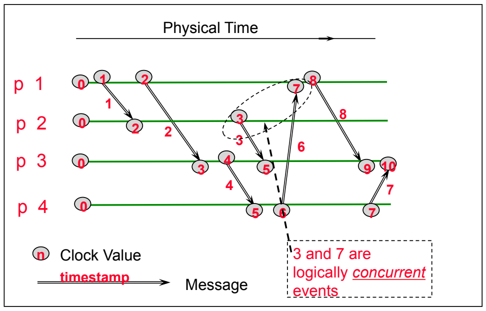
Find the Mistake: Lamport Logical Time



Corrected Example: Lamport Logical Time

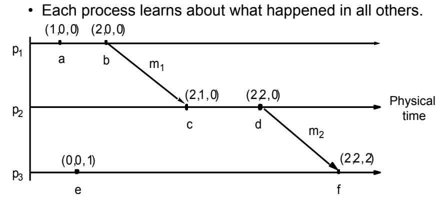


One Issue



Vector Timestamps

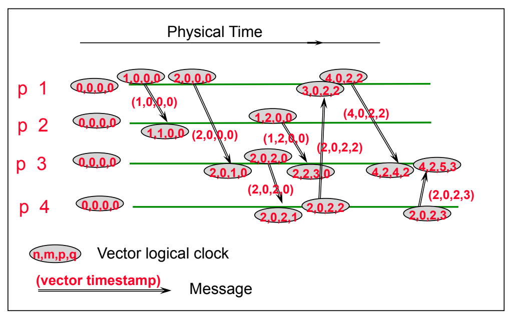
- With Lamport clock
  - e "happened-before" f ⇒ timestamp(e) < timestamp (f), but
  - timestamp(e) < timestamp (f) ⇏ e "happened-before" f
- Idea?
  - Each process keeps a separate clock & pass them around.
  - Each process learns about what happened in all others.



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
- 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, … , n
- $VT_1 <= VT_2$,
  - *iff* $VT_1[i] <= VT_2[i]$, for all i = 1, … , n
- $VT_1 < VT_2$,
  - *iff* $VT_1 <= VT_2$ & ∃ 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

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