CSci 5105

Introduction to Distributed Systems

Synchronization

Last Time

- Naming
- Fundamentals: binding, resolution, naming vs. directory service

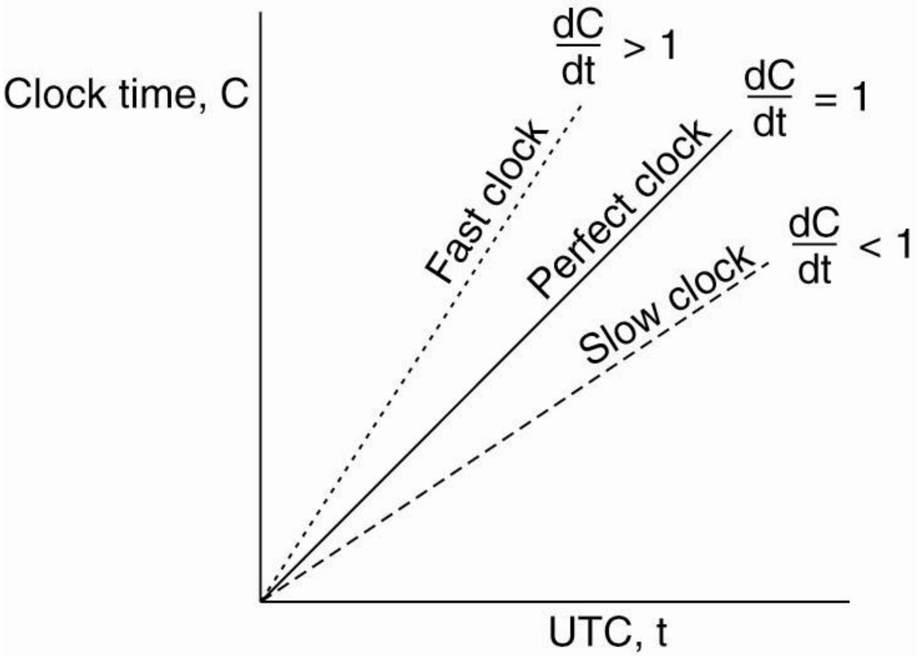
Time

- Why is time important in computer systems?

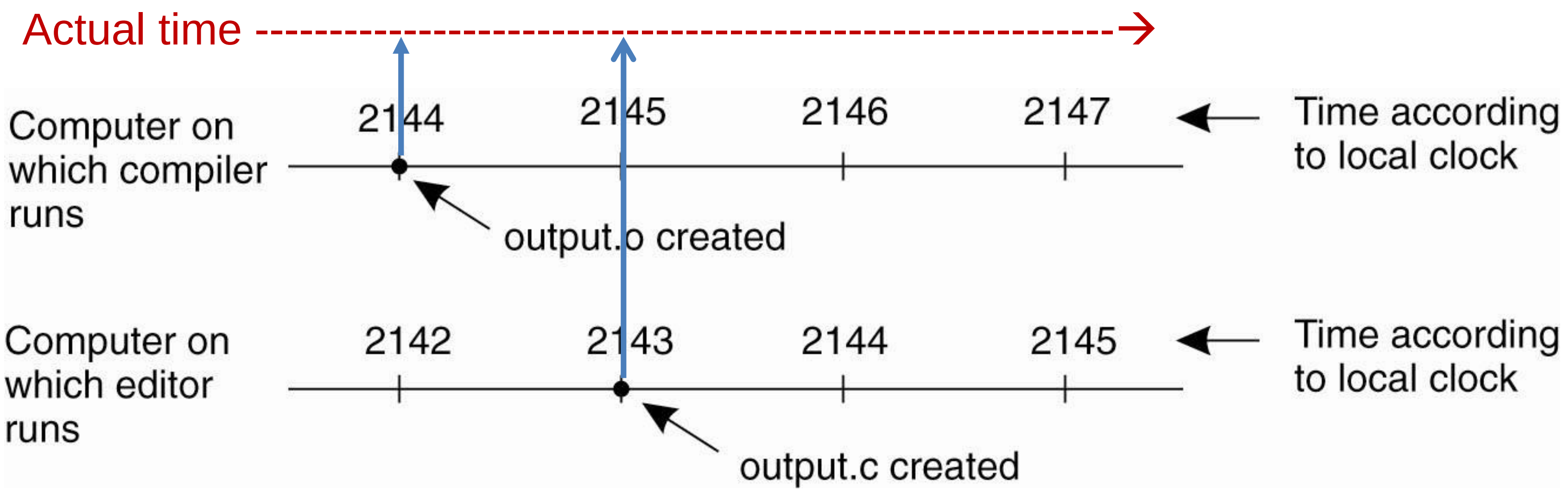
- Why is it hard in Distributed Systems?

Clock Synchronization Problem

- Clocks tick at different rate, skew.
- Interrupt fires every K msec; clock updates in a register
  - may fire K’



Clock Synchronization Example



- Makefile example
- What happens?

Solution Options

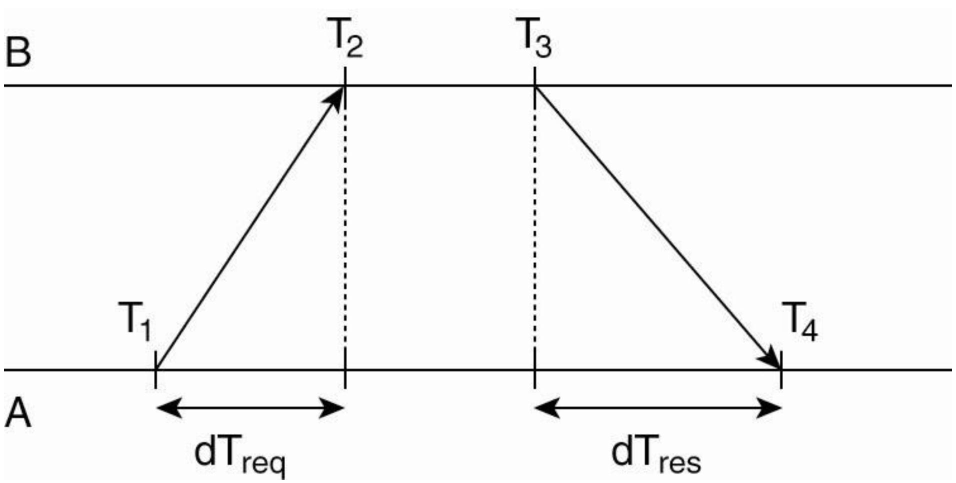
- Everyone's clock may be different
- Want notion of a single time
- Two options:

Global time: Network Time Protocol

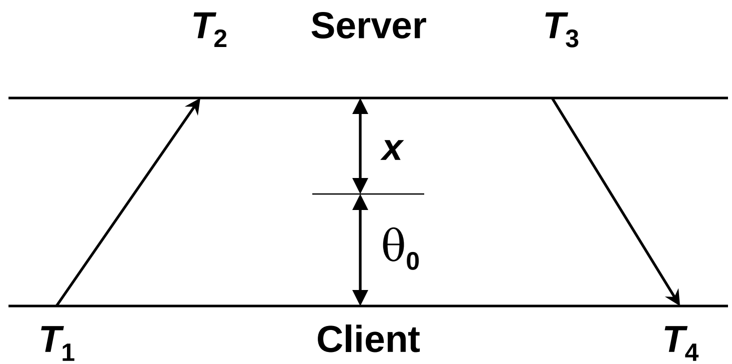
- **Time Server B has correct time**
- All other serves get in synch with it
- Server A must take what into account?
  - Delay

    λ = [(T2-T1)+(T4-T3)]/2 (one-way delay)

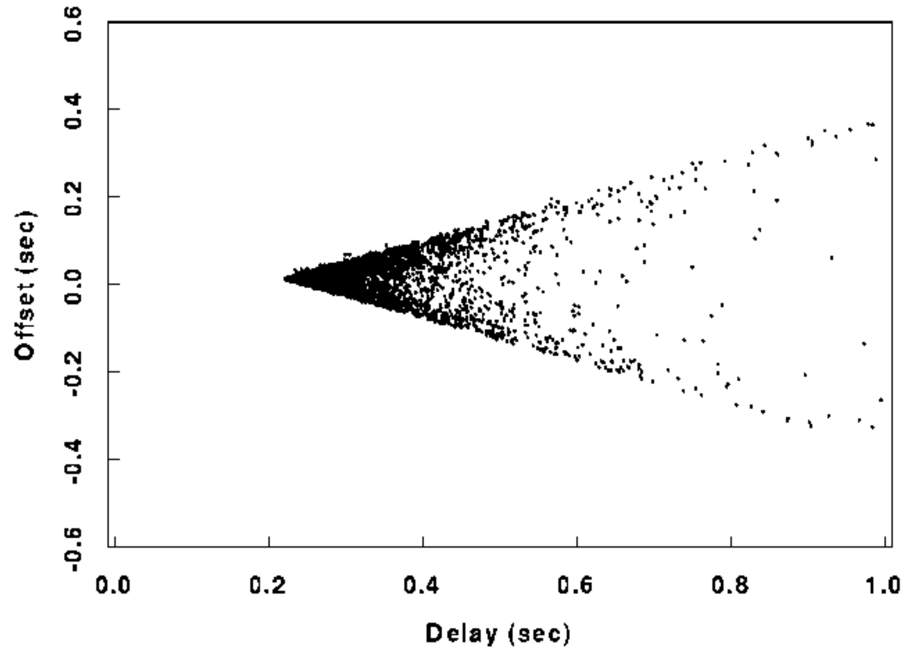
    θ = [(T2-T1) + (T3-T4)]/2 (offset)



NTP clock filter algorithm



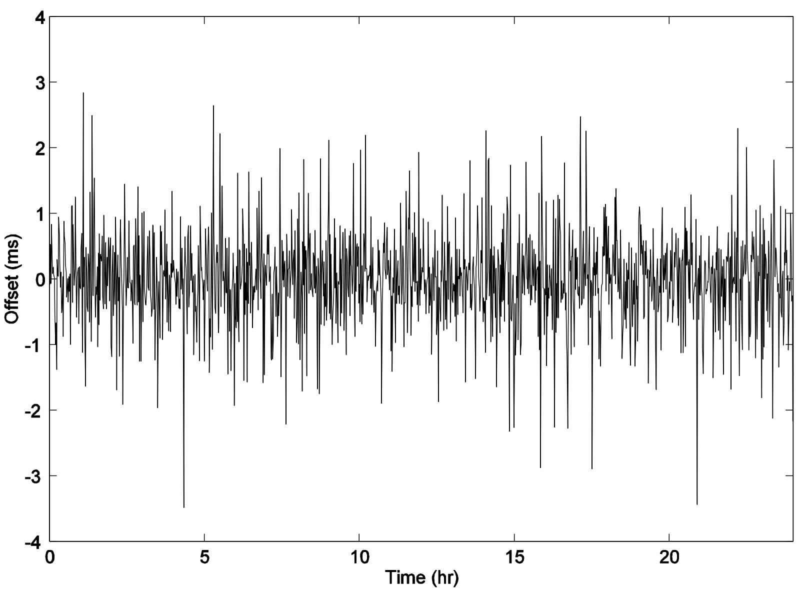
$$\theta = \tfrac{1}{2}[(T_2 - T_1) + (T_3 - T_4)]$$
$$\delta = (T_4 - T_1) - (T_3 - T_2)$$

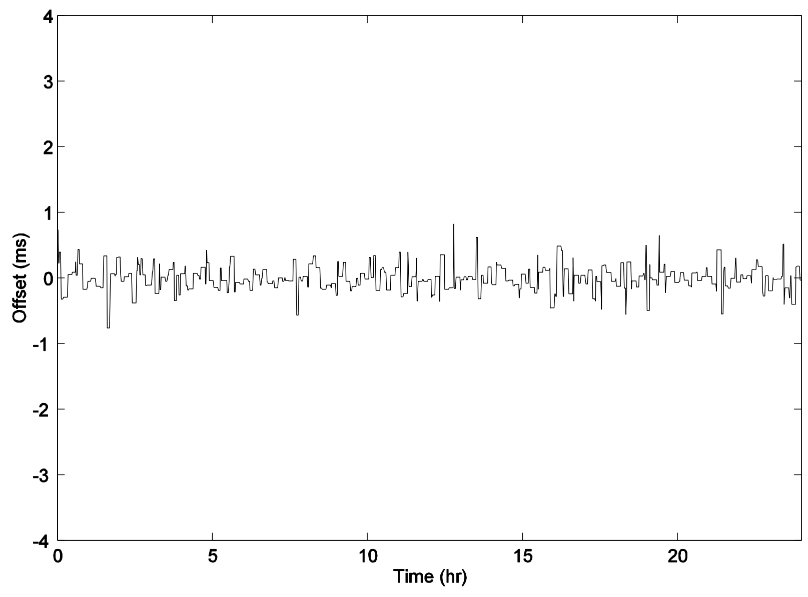


- The most accurate offset θ_0 is measured at the lowest delay δ_0 (apex of the wedge scattergram)
- The δ_0 is estimated as the minimum of the last eight delay measurements and (θ_0 , δ_0) becomes the peer update

NTP in practice

- Benefit of filtering algorithm
- Error: 724 μs down to 192 μs



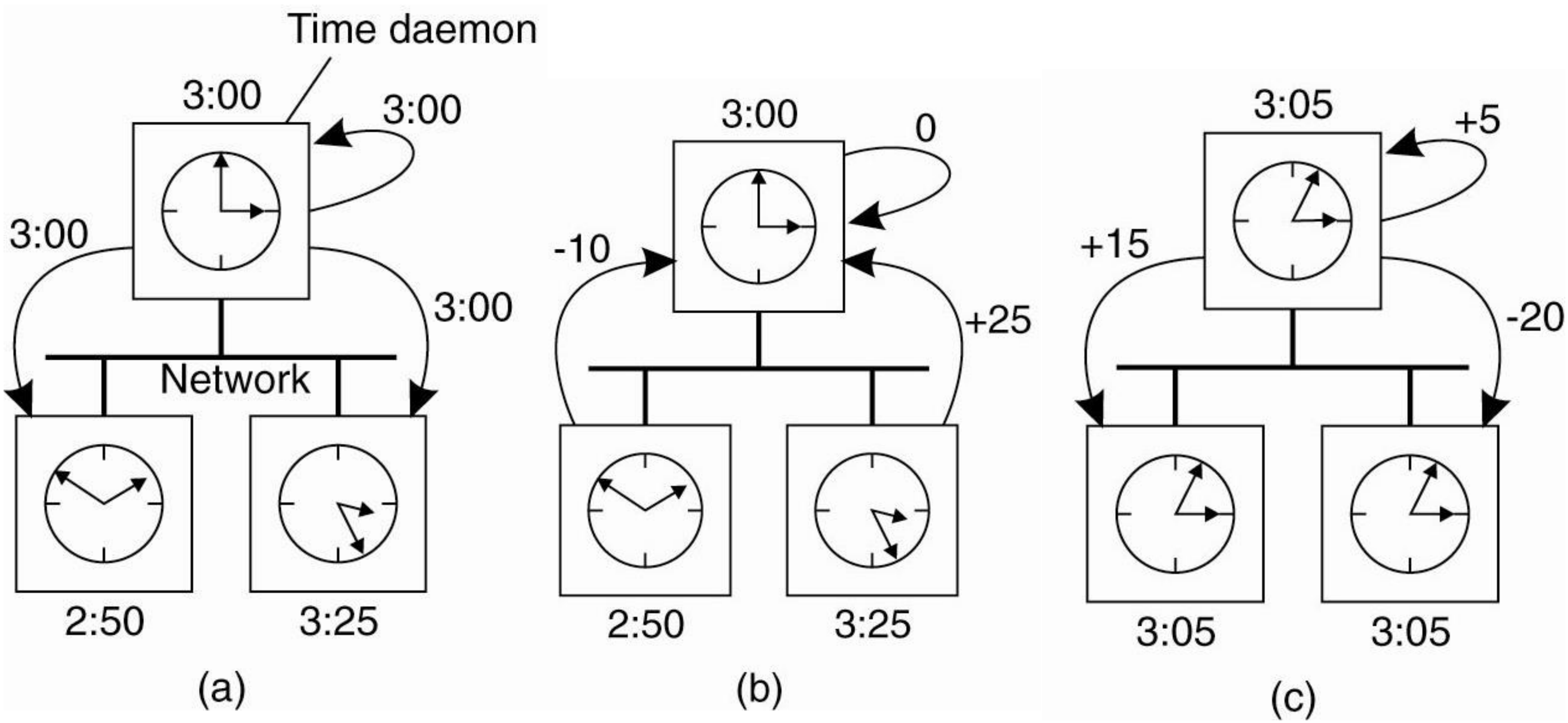


NTP

- Challenge: if A was faster than B
  - A would have to set its clock backward
  - Set clock backward and compile .c file!

- Slowly adjust its clock backward
- 1 interrupt every 10 msec
  - \+ 9 msec to clock

The Berkeley Algorithm



No accurate global clock: select time daemon which computes average (ignoring delay: could add back in);
change physical clock value

Do we need global (real) time stamps?

- Real clocks are hard to keep in synchrony
- Absolutely needed for real-time
- Maybe we can live with something weaker …
- Makefile:
  - output.c (logical time L)
  - output.o (logical time L')
  - L' > L

Lamport's Logical Clocks

- The "happens-before" relation $\rightarrow$ can be observed directly in two situations:
- If *a* and *b* are events in the same process, and *a* occurs before *b*, then $a \rightarrow b$ is true.
- If a is the event of a message being sent by one process, and *b* is the event of the message being received by another process, then $a \rightarrow b$

Causal Ordering

- The ordering of events is really a partial ordering
  - Transitive $a \rightarrow b$ and $b \rightarrow c$ then $a \rightarrow c$
  - Anti-symm $a! \rightarrow b$ and $b! \rightarrow a$ then a, b concurrent
  - Reflexive $a \rightarrow a$

Total

all a,b: either $a \rightarrow b$ *or* $b \rightarrow a$

Example

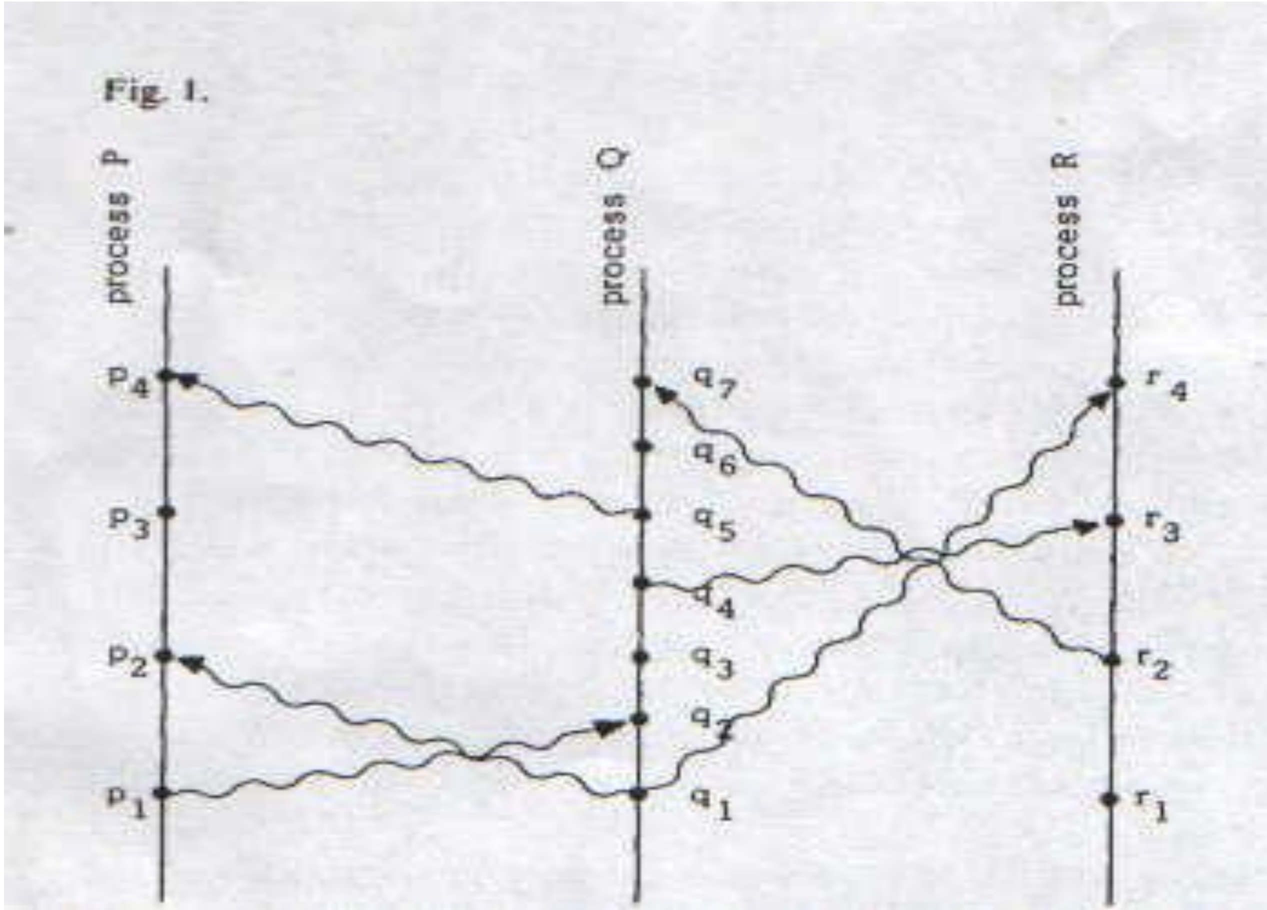
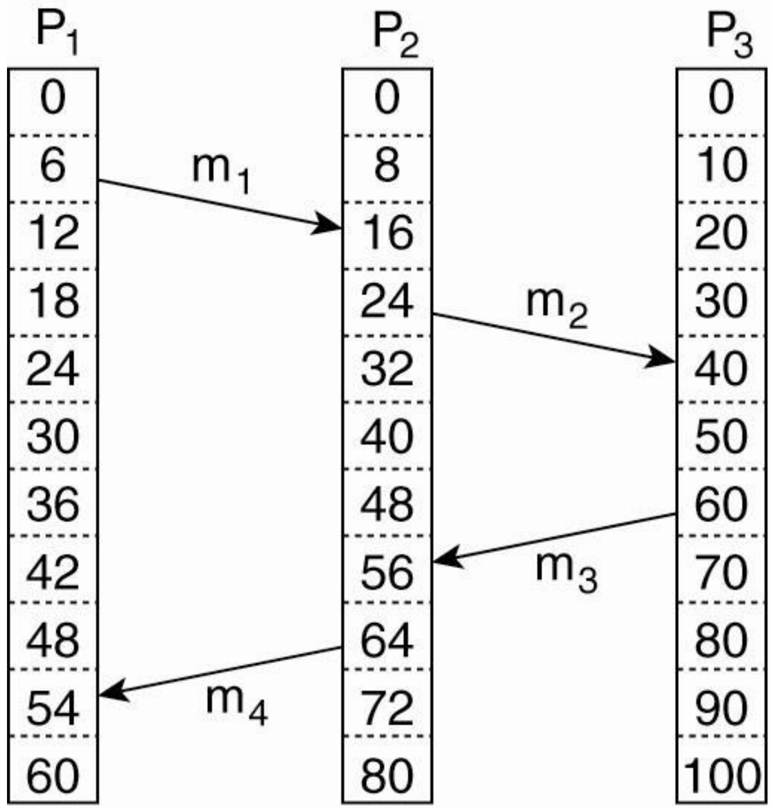


Fig. 1.
process P
process Q
process R
p_4
p_3
p_2
p_1
q_7
q_6
q_5
q_4
q_3
q_2
q_1
r_4
r_3
r_2
r_1

Example



Problem?

Quantifying Logical Clocks

- Assign clock values (#s) to events
- If $a \rightarrow b$
  - C(a) < C(b) for all events a, b

- Note: Says nothing about order of other events

Time Progression

Computing C_i for process P_i

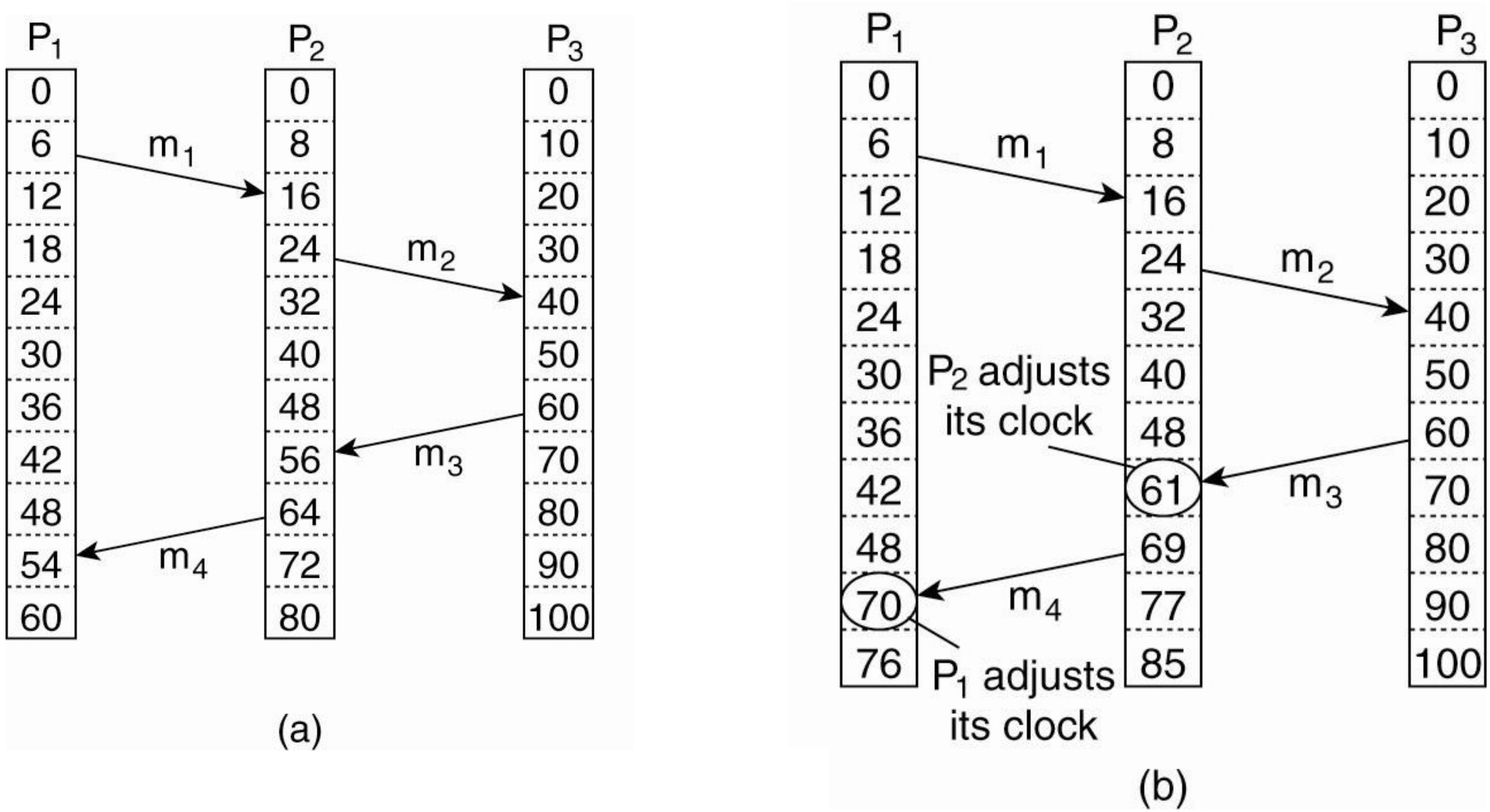
1. Before executing an event P_i sets $C_i \leftarrow C_i + 1$

2. When process P_i sends a message m to P_j, it sets *m*'s timestamp *ts (m)* equal to C_i

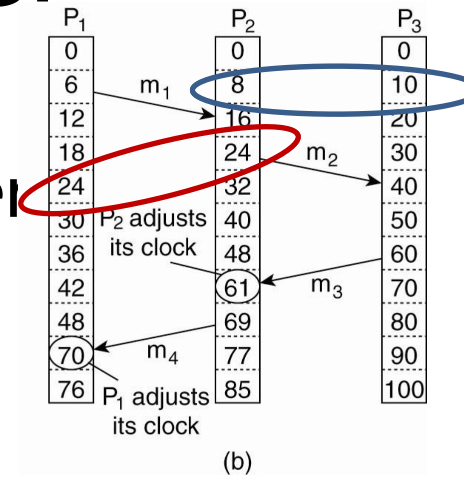
3. Upon the receipt of a message *m*, process P_j adjusts its own local counter:

$$C_j \leftarrow \max\{C_j\ ,\ ts\ (m)\}$$

Lamport's Logical Clocks



Partial vs. Total Order



- Basic lamport clocks give a partial order
  - Many events happen “concurrently”
  - C(a) < C(b) does not imply *a→b !*
- But sometimes a total order is more convenient
  - e.g., commit operations to a database
  - deposit, withdrawl
- Tie-breakers: concatenate unique PID (p1>p2>…)
  - E.g. C(a, P1) < C(b, P2) does imply *a→b*

Lamport Clocks

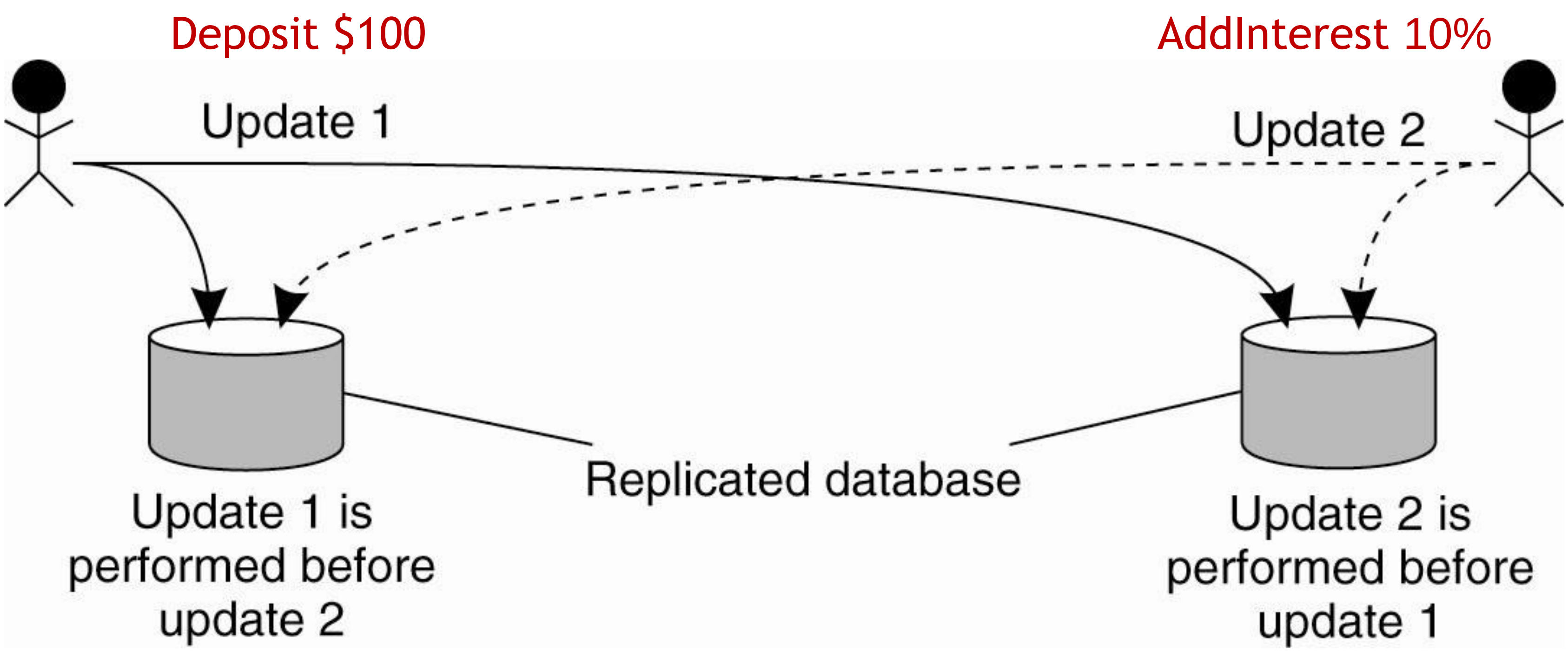
- Cannot solve total order
  - For any two events, a->b or b->a

- BUT can guarantee something weaker

  Everyone acts on messages in the same order

Using Lamport Clocks : Totally Ordered Multicasting

- Problem?

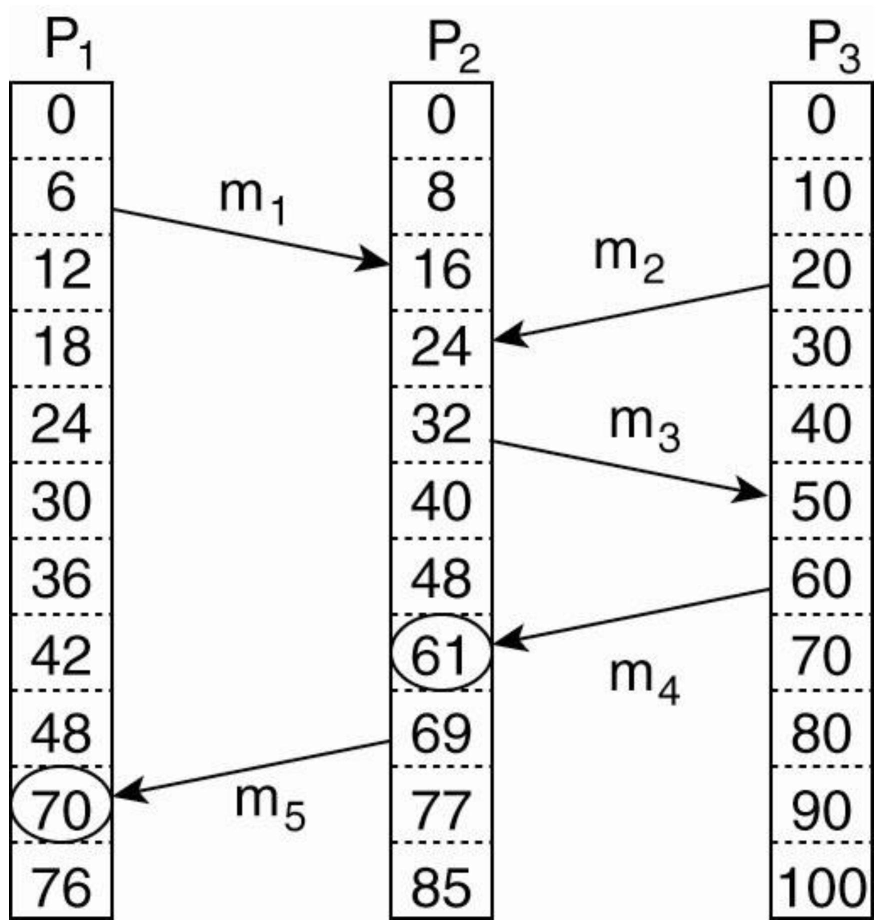


Can solve …

- Multicast acknowledgement
- Order events in the queue
- Execute event at top of queue in time order
  - Only if received acknowledgement to the event

Vector Clocks

Want C(b) < C(a) => a← b (and vice-versa)



Vector Clocks

Vector clocks are constructed by letting each process P_i maintain a vector VC_i with the following two properties:

1. $VC_i[i]$ is the number of events that have occurred so far at P_i. In other words, $VC_i[i]$ is the local logical clock at process P_i

2. If $VC_i[j] = k$ then P_i knows that k events have occurred at P_j. It is thus P_i's ~ knowledge of the local time at P_j

Multicast Using Vector Clocks

1. Before executing an event P_i executes $VC_i\,[i] \leftarrow VC_i[i] + 1$

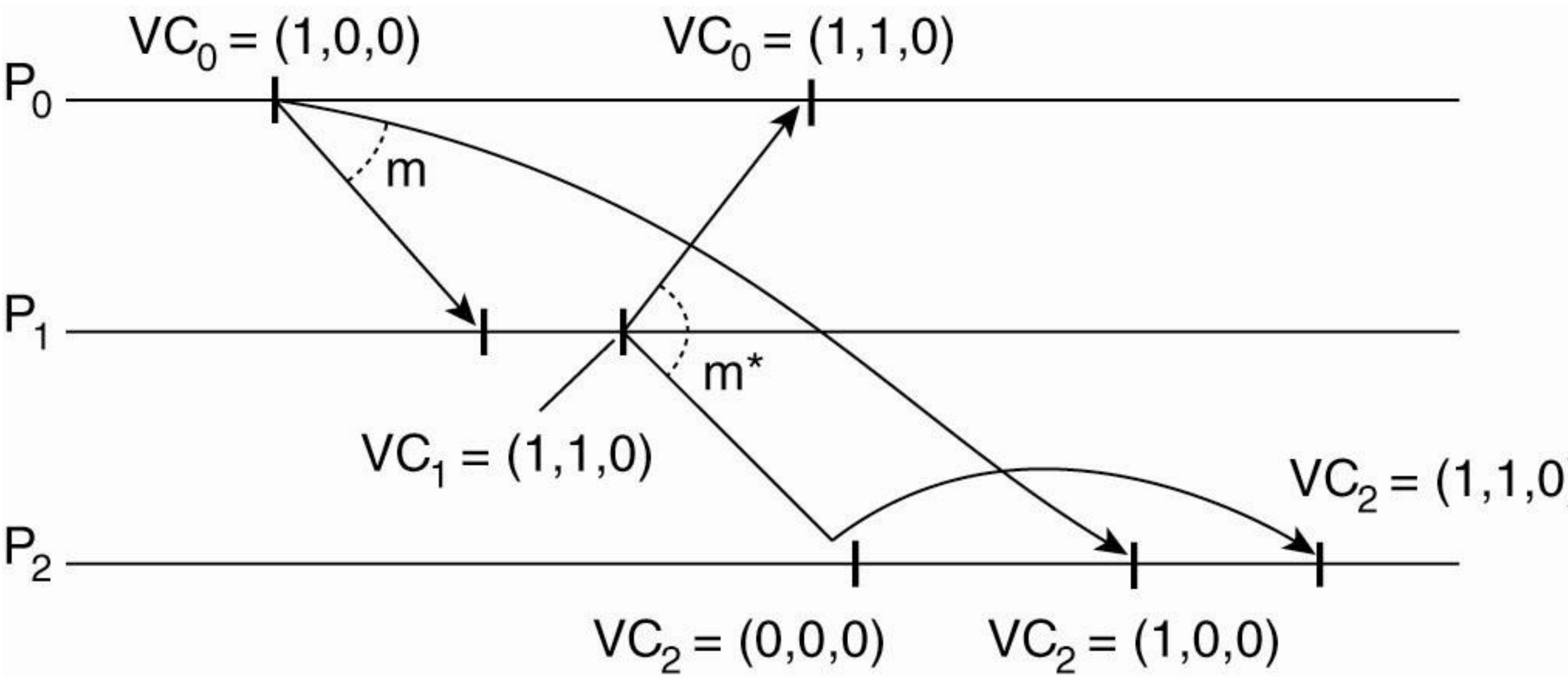
2. When process P_i sends a message m to P_j, it sets *m*'s (vector) timestamp ts (m) equal to VC_i

3. Upon the receipt of a message m, process P_j adjusts its own vector by setting $VC_j[i] \leftarrow \max\{VC_j[i], ts(m)[i]\}$ for each i

4. If message is out-of-order, queue m !

   there exists a k, k!=i, for which $VC_j[k]$!= m[k]

Enforcement



Next Time

Next topic: Mutual Exclusion

Read Chapter 6 TVS