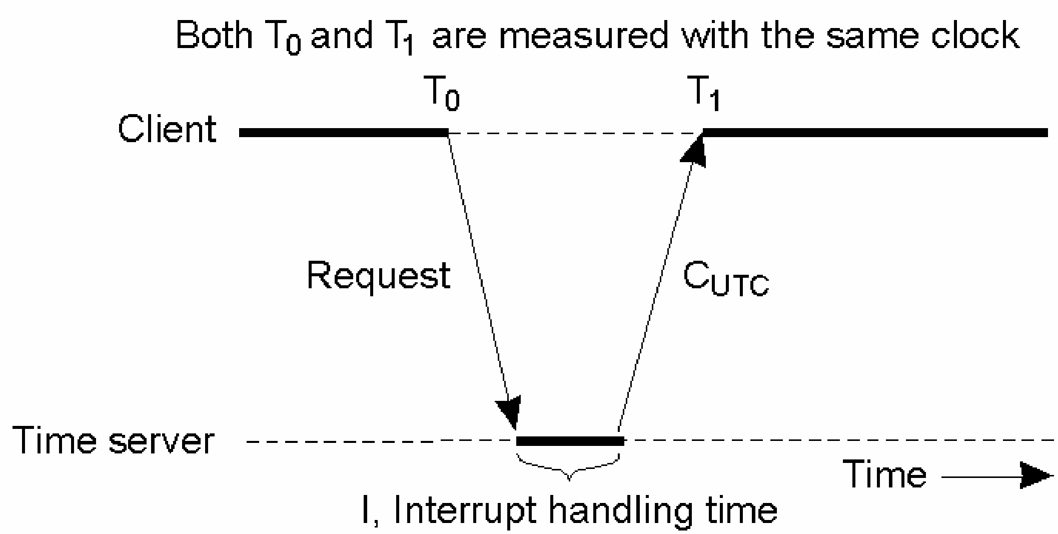
Absence of Global Clock

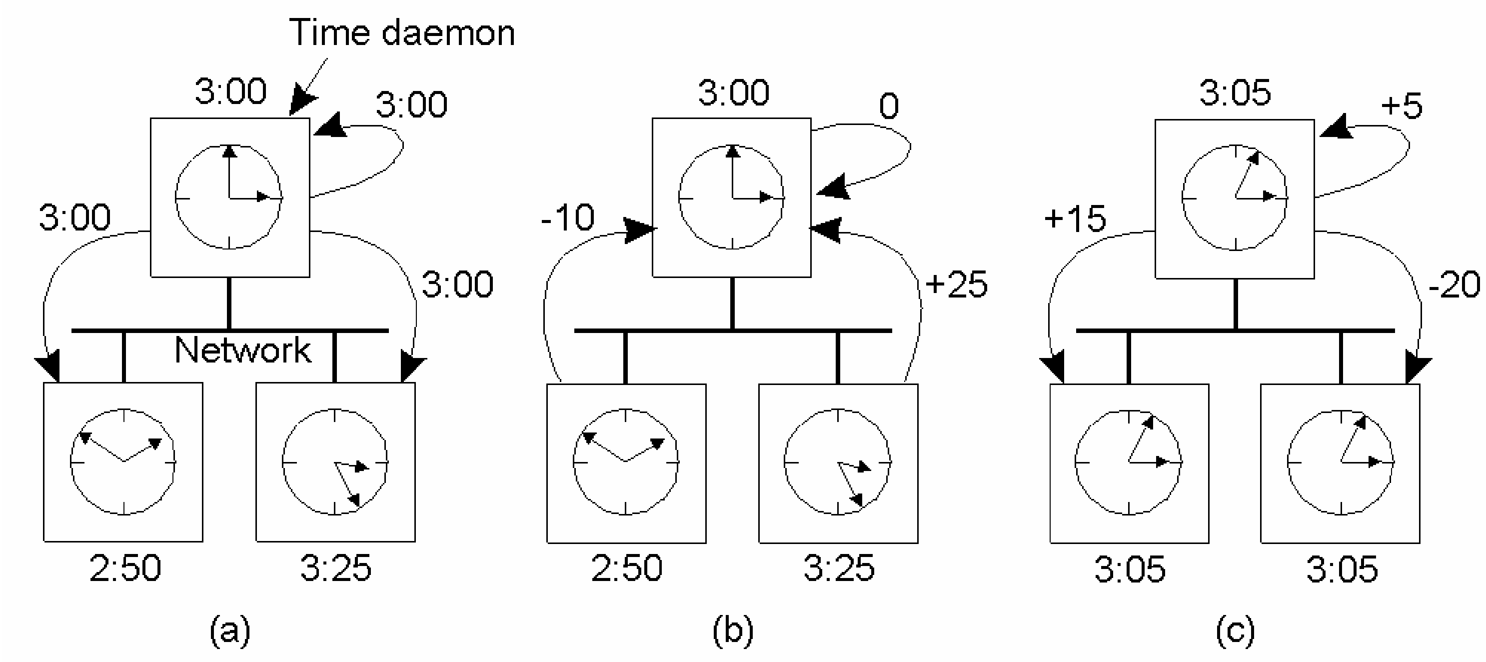
- Problem: synchronizing the activities of different part of the system (e.g. process scheduling)
- What about using a single shared clock?
  - two different processes can see the clock at different times due to unpredictable transmission delays
- What about using radio synchronized clocks?
  - Propagation delays are unpredictable
- Software approaches
  - Clock synchronization algorithms
  - Logical clocks

Cristian's Algorithm

- Basic idea: get the current time from a time server.
- Issues:
  - Error due to communication delay - can be estimated as $(T_1\text{-}T_2\text{-}I)/2$
  - Time correction on client must be gradual



The Berkeley Algorithm



a) The time daemon asks all the other machines for their clock values
b) The machines answer
c) The time daemon tells everyone how to adjust their clock

Logical clocks

- The need to order events in a distributed system has motivated schemes for “logical clocks”
- These artificial clocks provide some but not all of the functionality of a real global clock
- They build a clock abstraction based on underlying physical events of the system

"Happened before" relation: definitions

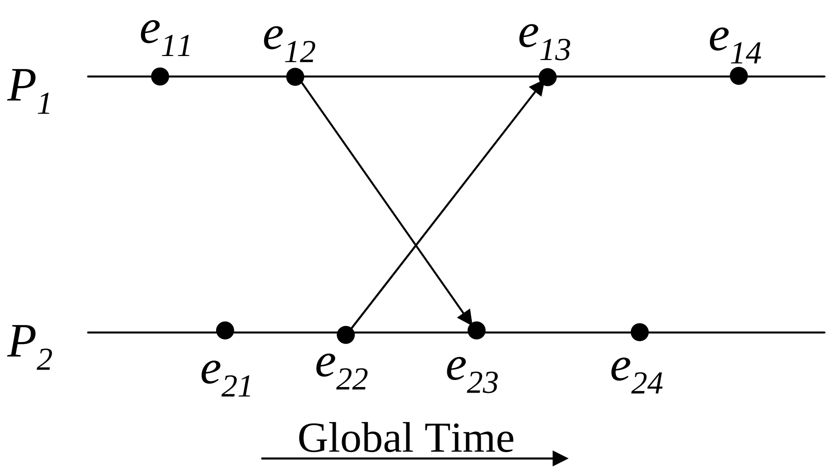
- "Happened before" relation ($\rightarrow$):
  - $a \rightarrow b$ if a and b are in the same process and a occurred before b
  - $a \rightarrow b$ if a is the event of sending a message and b is the event of receiving the same message by another process
  - if $a \rightarrow b$ and $b \rightarrow c$ then $a \rightarrow c$, i.e. the relation "$\rightarrow$" is transitive
- The *happened before* relation is a way of ordering events based on the behavior of the underlying computation

“Happened before” relation: definitions (2)

- Two distinct events a and b are said to be *concurrent* ($a \parallel b$) if and $a \not\rightarrow b$ $\quad$ $b \not\rightarrow a$
- For any two events in the system, either $a \rightarrow b$, $b \rightarrow a$ or $a \parallel b$
- Example:

$e_{11} \parallel e_{21}$

$e_{22} \rightarrow e_{13}$, $e_{13} \rightarrow e_{14}$
thus $e_{22} \rightarrow e_{14}$



Lamport's Logical Clocks: definitions

- A logical clock C_i at each process P_i is a function that assigns a number $C_i(a)$ to any event a, called *timestamp*
  - timestamps are monotonically increasing values
  - example: $C_i(a)$ could be implemented as a counter
- We want to build a logical clock $C(a)$ such that:

$$\text{if } a \rightarrow b \text{ then } C(a) < C(b)$$

Lamport's Logical Clocks: implementation

- If we want a logical clock $C(a)$ to satisfy:

$$\text{if } a \rightarrow b \text{ then } C(a) < C(b)$$

the following conditions must be met:

  - if a and b are in the same process and a occurred before b, then $C_i(a) < C_i(b)$
  - if a is the event of sending a message in process P_i and b is the event of receiving the same message by process P_j then $C_i(a) < C_j(b)$

Lamport's Logical Clocks: implementation (2)

- Two implementations rules that satisfy the previous correctness conditions are:
  - clock C_i is incremented by d at each event in process $P_{i:}$

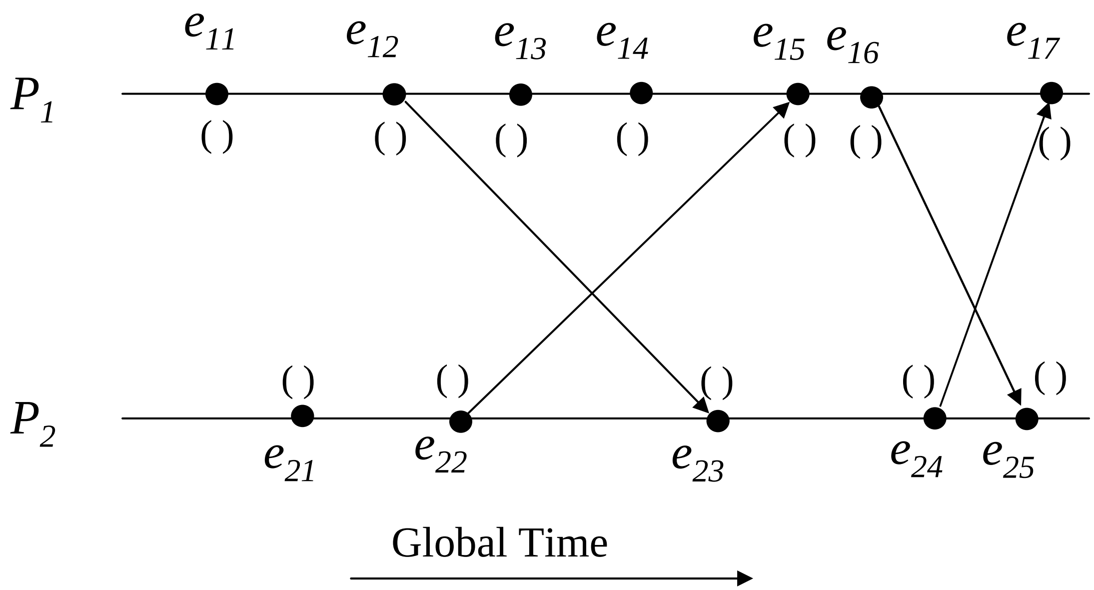
    $$C_i := C_i + d \qquad (d > 0)$$

  - if event a is the sending of a message m by process P_i, then
    - message m is assigned the timestamp $t_m = C_i(a)$ ($C_i(a)$ is obtained after applying previous rule).
    - Upon receiving message m, process P_j sets its clock to:

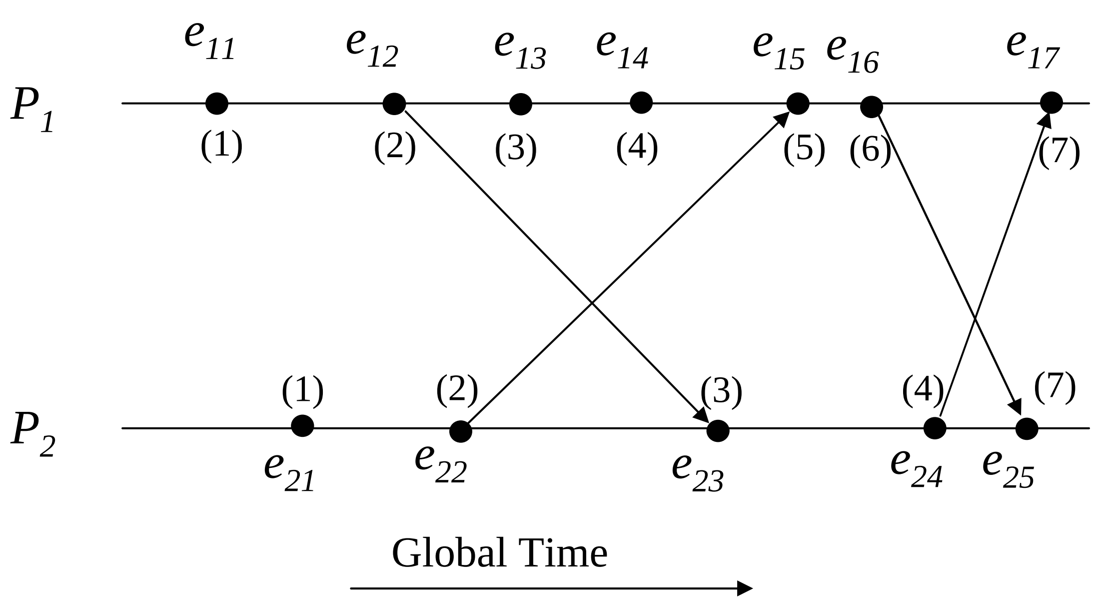
      $$C_j := \max(C_j\ , t_m + d) \qquad (d > 0)$$

Lamport's Logical Clocks: example

- Fill the blanks …



Lamport's Logical Clocks: example



Lamport's Clock limitations

- In Lamport's system of logical clocks if $a \rightarrow b$ then $C(a) < C(b)$
- However the opposite is not true
  - if $C(a) < C(b)$ is not necessarily true that $a \rightarrow b$ (see example)
  - the Vector Clocks version of Lamports' clock idea addresses this limitation

$C(e_{11}) < C(e_{22})$ and $e_{11} \rightarrow e_{22}$
but
$C(e_{11}) < C(e_{32})$ and $e_{11} \not\rightarrow e_{32}$