Distributed Systems
COMP 212

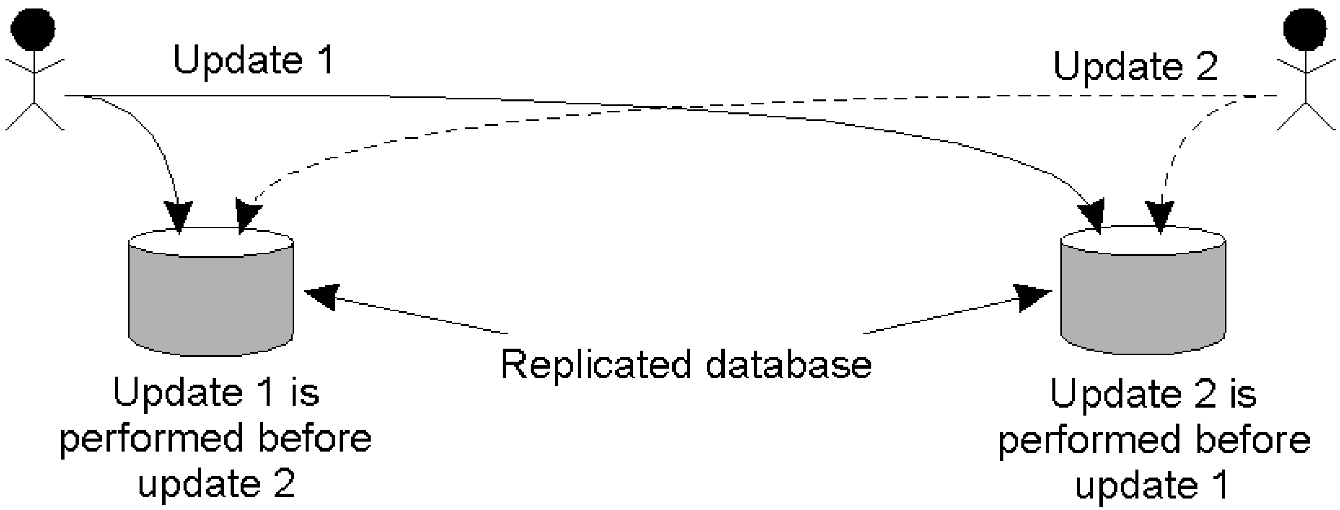
Lecture 18

Othon Michail

UNIVERSITY OF LIVERPOOL

Synchronisation

What Can Go Wrong



- Updating a replicated database: Customer (update 1) adds £100 to an account, bank employee (update 2) adds 1% interest to the same account
- Clock reading might be different for different computers!
- Inconsistent state

Possible Solutions

- Include the time of every update in the update message
  - Clock synchronisation
- Order events in the network
  - Logical clock
- Transactions

Computer Clock

- We need to measure time accurately:
  - to know the time an event occurred at a computer
- Algorithms for clock synchronisation are useful for
  - concurrency control based on timestamp ordering
  - authenticity of requests e.g. in Kerberos
- Each computer in a DS has its own internal clock
- Even if clocks on all computers in a DS are set to the same time, their clocks will eventually vary quite significantly unless corrections are applied

Synchronisation based on “Actual Time”

- Note: time is really easy on a uniprocessor system
- Achieving agreement on time in a DS is not trivial
- Question: is it even possible to synchronise all the clocks in a Distributed System?
- With multiple computers, due to clock skew, different machines do not in general have the same value for the current time
- But, how do we measure time?

How Do We Measure Time?

- Turns out that we have only been measuring time accurately with a “global” atomic clock since *Jan. 1st, 1958* (the “beginning of time”)

- Refer to the textbook for all the details – it’s quite a story

- Bottom Line: measuring time is not as easy as one might think it should be

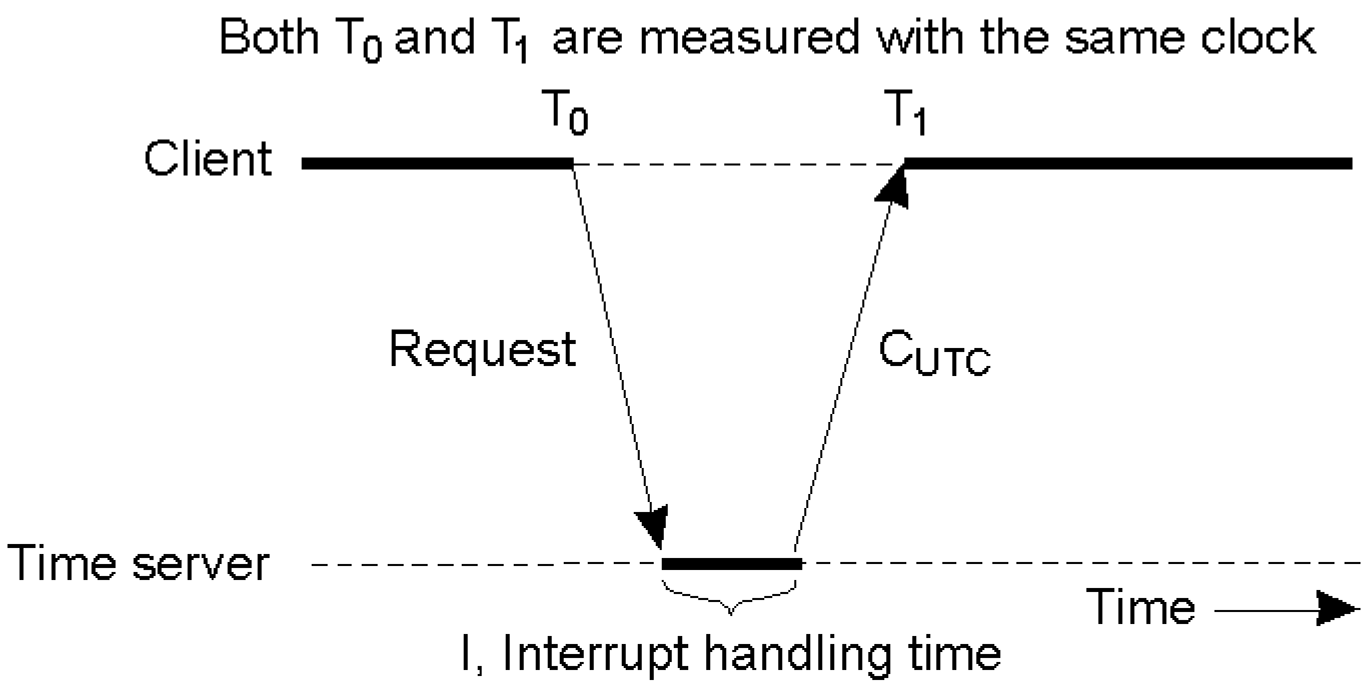
Coordinated Universal Time (UTC)

- International Atomic Time is based on very accurate physical clocks (drift rate 10^{-13})
- UTC is an international standard for time keeping
- It is based on atomic time, but occasionally adjusted to astronomical time
- It is broadcast from radio stations on land and satellite (e.g. GPS)
- Computers with receivers can synchronise their clocks with these timing signals
- Signals from land-based stations are accurate to about 0.1-10 millisecond
- Signals from GPS are accurate to about 1 microsecond

Clock Synchronisation

- There exists a time server receiving signals from a UTC source
  - Cristian’s algorithm (Cristian 1989)
- There is no UTC source available
  - Berkeley’s algorithm
- Exact time does not matter!
  - Lamport’s algorithm

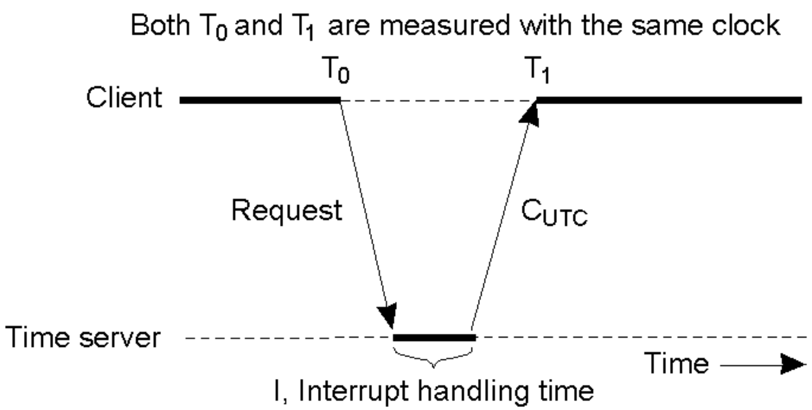
Clock Sync. Algorithm: Cristian's



1. Every computer periodically asks the “time server” for the current time
2. The server responds ASAP with the current time C_{UTC}
3. The client sets its clock to C_{UTC}

Problems

- Major problem: if time from time server is less than the client – resulting in time running backwards on the client! (Which cannot happen – time does not go backwards).

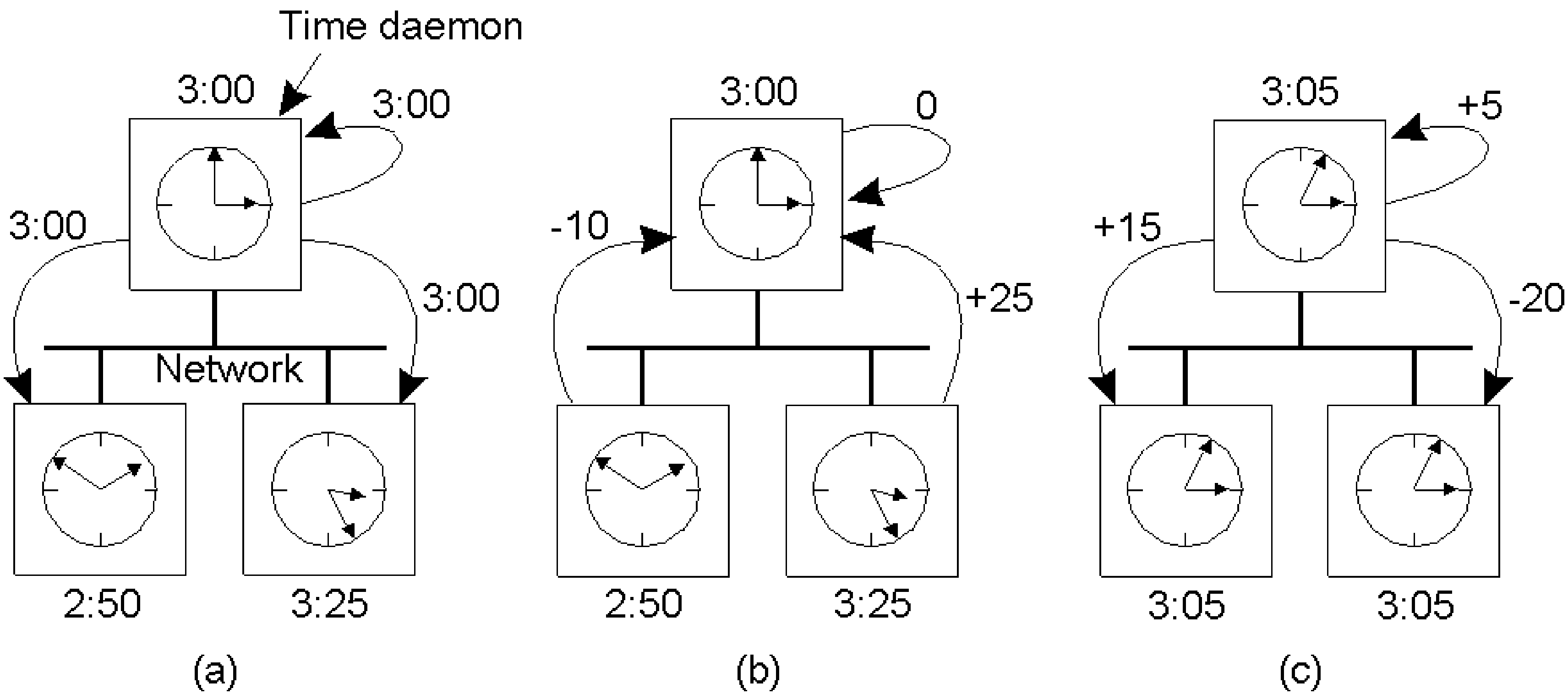


- Introduce changes gradually
- Minor problem: results from the delay introduced by the network request/response: latency
- *Best estimate* $(T_1\text{-}T_0)/2$
- If the interrupt handling time, I, is known, $(T_1\text{-}T_0\text{-}I)/2$
- **Use series of measurements**

Berkeley Algorithm

- An algorithm for internal synchronisation of a group of computers
- A master polls to collect clock values from the others (slaves)
- The master uses round trip times to estimate the slaves’ clock values
- It takes an average
- It sends the required adjustment to the slaves (better than sending the time which depends on the round trip time)
- If master fails, can elect a new master to take over

The Berkeley Clock Sync. Algorithm



- Clocks that are running fast, are slowed down
- Clocks running slow, jump forward

Berkeley Algorithm at Work (1)

Computers	Clock Reading
A (daemon)	3:00
B (left)	2:50
C (right)	3:25

Computers	Ahead/Behind
A (daemon)	0:00
B (left)	-0:10
C (right)	+0:25

Berkeley Algorithm at Work (2)

- Average time: 3:05

Computers	**Needed Adjustment**
A (daemon)	+0:05
B (left)	+0:15
C (right)	-0:20

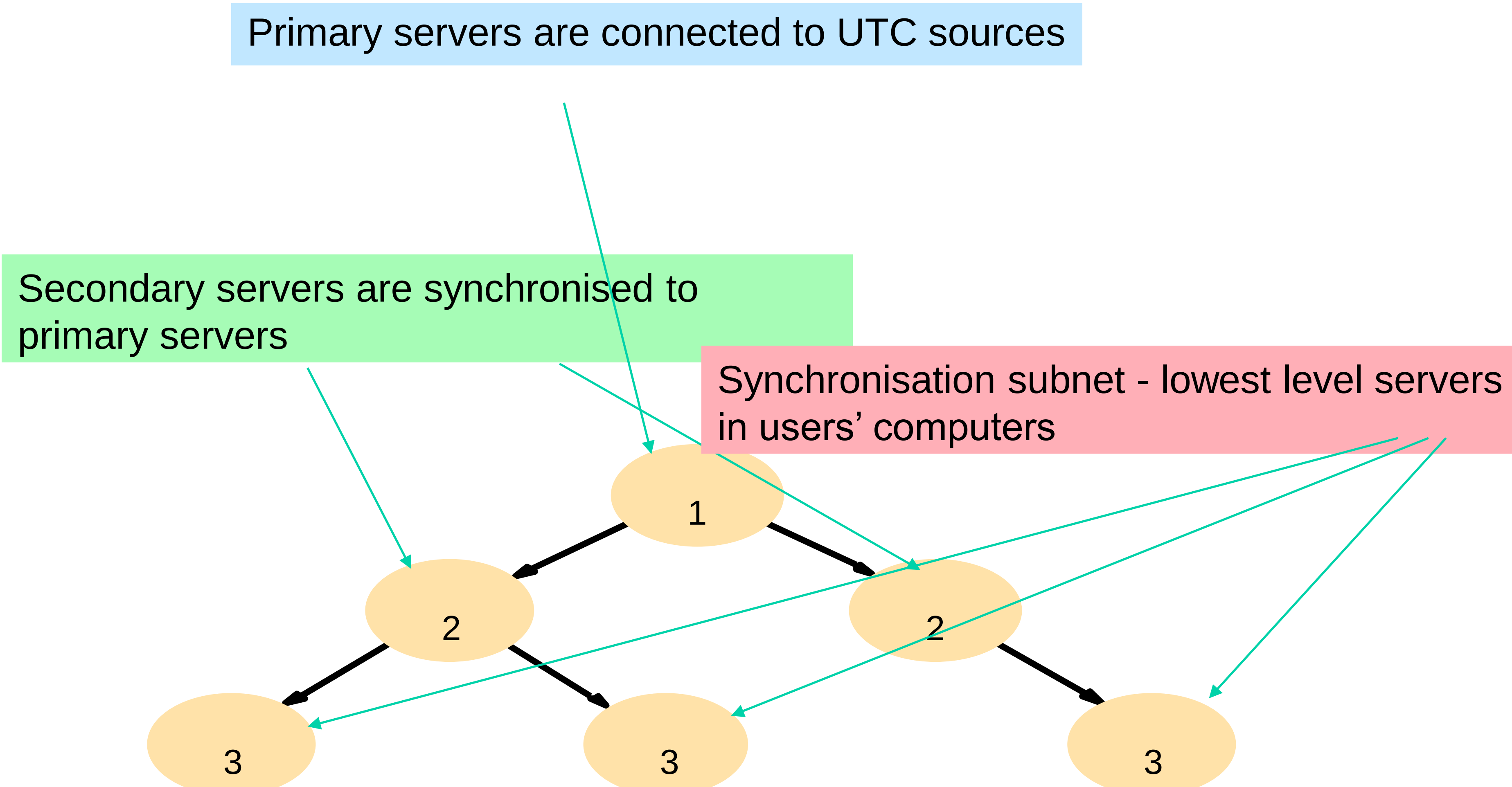
Other Clock Sync. Algorithms

- Both Cristian's and the Berkeley Algorithm are centralised algorithms

- Decentralised algorithms also exist, and the Internet's Network Time Protocol (NTP) is the best known and most widely implemented

- NTP can synchronise clocks to within a 1-50 msec accuracy

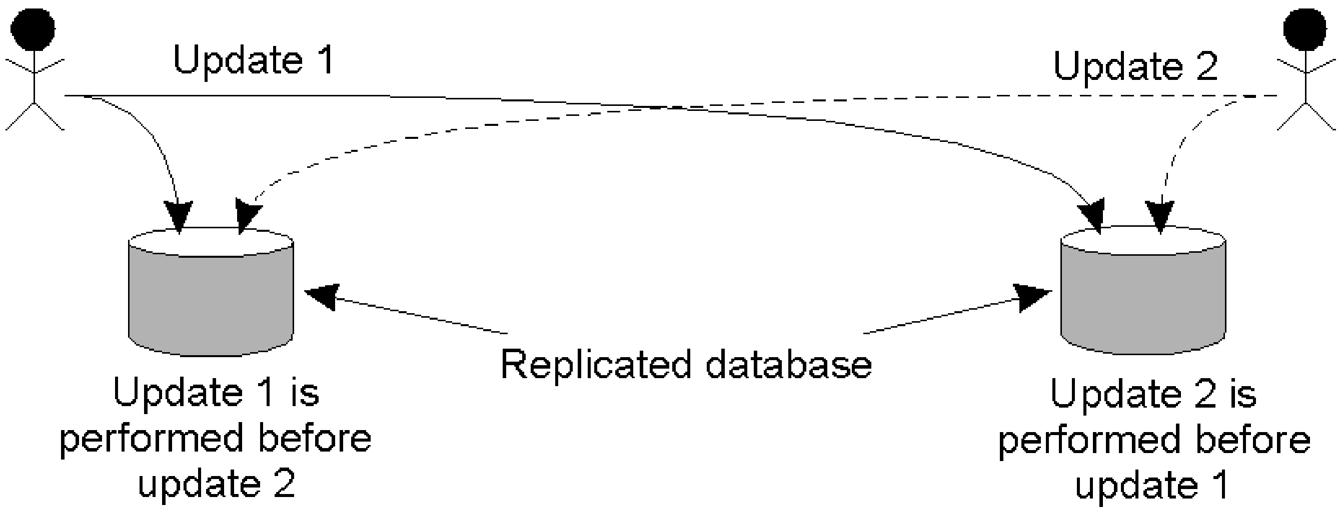
Network Time Protocol (NTP)



Logical Clocks

- Synchronisation based on relative time
- Note that (with this mechanism) there is no requirement for relative time to have any relation to the real time
- What's important is that the processes in the Distributed System agree on the ordering in which certain events occur
- Such "clocks" are referred to as Logical Clocks

What Can Go Wrong-2



- Updating a replicated database
- Even if the clock is synchronised, due to network delays, the updates may come in different order
- **Whoops!**

Lamport’s Logical Clocks

- **First point**: if two processes do not interact, then their clocks do not need to be synchronised – they can operate concurrently without fear of interfering with each other.

- **Second (critical) point**: it does not matter that two processes share a common notion of what the “real” current time is. What does matter is that the processes have some agreement on the order in which certain events occur.

- Lamport used these two observations to define the “happened-before” relation (also often referred to within the context of Lamport’s Timestamps).

The “Happened-Before” Relation (1)

- If A and B are events in the same process, and A occurs before B, then we can state that *“A happened-before B”* is true
- Equally, if A is the event of a message being sent by one process, and B is the event of the same message being received by another process, then *“A happened-before B”* is also true
  - (Note that a message cannot be received before it is sent, since it takes a finite, nonzero amount of time to arrive … and, of course, time is not allowed to run backwards)
- Also, if *“A happened-before B”* and “*B happened-before C”*, then it follows that *“A happened-before C”*

The “Happened-Before” Relation (2)

- Now, assume three processes are in a DS: A, B and C.
- All have their own physical clocks
- A sends a message to B
- If the time the message was sent (attached to the message) exceeds the time of arrival at B, things are NOT OK (as *“A happened-before B”* is not true, and this cannot be allowed as the receipt of a message has to occur *after* it was sent)

The “Happened-Before” Relation (3)

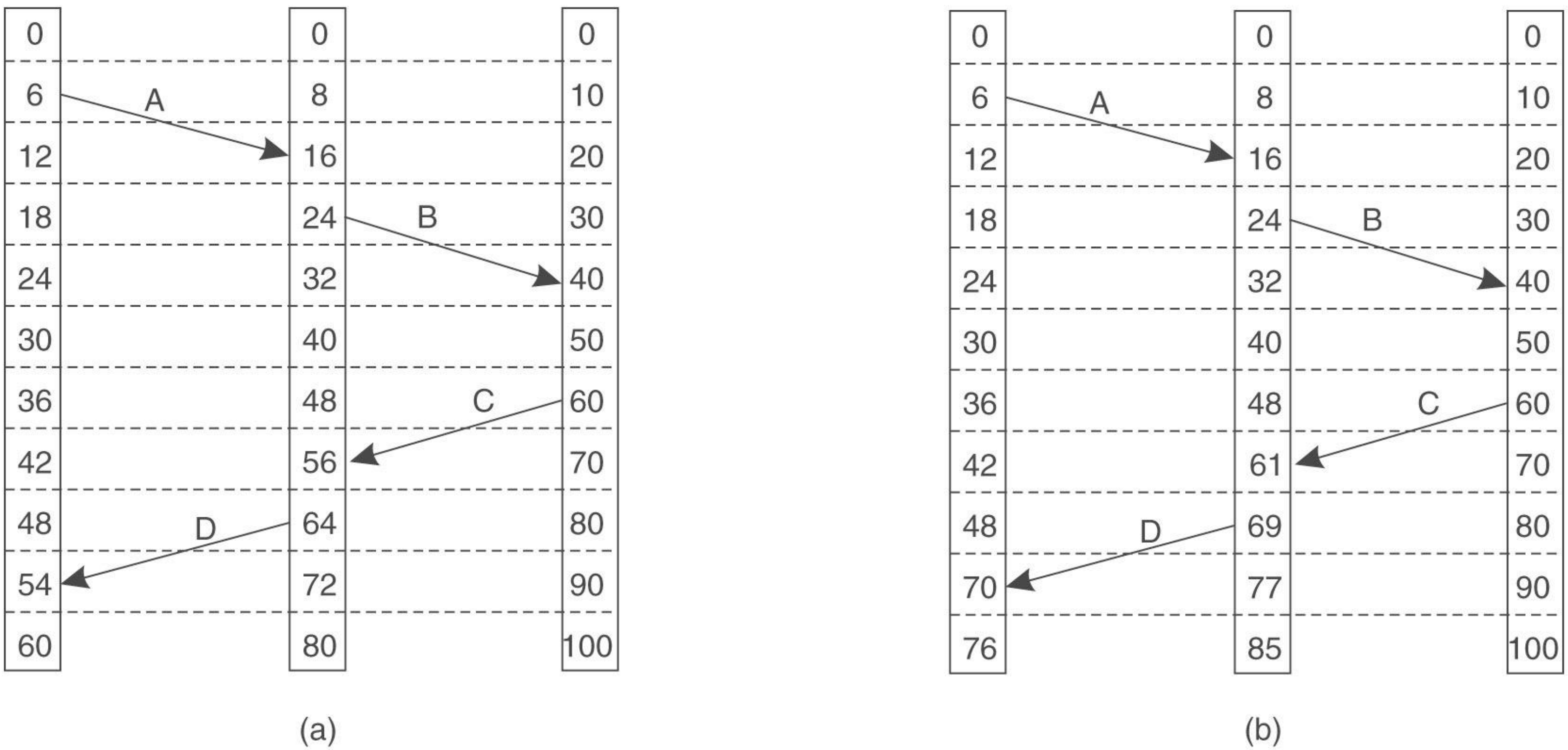
- The question to ask is:

How can some event that *“happened-before”* some other event possibly have occurred at a later time??

- The answer is: it can’t!

- So, Lamport’s solution is to have the receiving process adjust its clock forward to one more than the sending timestamp value.
  - This allows the *“happened-before”* relation to hold, and also keeps all the clocks running in a synchronised state. The clocks are all kept in sync relative to each other

Example of Lamport's Timestamps



- Lamport's algorithm corrects the clock

Lamport's Timestamps: Overview

- It is hard to synchronise time across two systems
- Every message is timestamped
- If the local clock disagrees, update the local clock (and always move it forward!)

- If two systems do not exchange messages, they do not need a common clock
  - If do not communicate, no ordering
- Is it possible to achieve total ordering of events in the system?

Totally-Ordered Multicast

- *A multicast operation by which all messages are delivered in the same order to each receiver*

- Solution:
  - Each message is timestamped with the current (logical) time of its sender.
  - (Copies of) multicast messages are sent to the sender.
  - Assume all messages sent by one sender are received in the order they were sent and that no messages are lost.

Protocol

- Receiving process puts a message into a local queue ordered according to the timestamp.
- The receiver multicasts an ACK to all other processes.
  - the timestamp of the received message is lower than the timestamp of the ACK.
- All processes will eventually have the same copy of the local queue → consistent global ordering.
- Message is delivered to applications only when
  - It is at head of queue
  - It has been acknowledged by all involved processes

Total Multicast at Work

- Message m1 is sent by client 1 and message m2 is sent by client 2. (m1 and m2 are time stamped s.t. m1 ~ m2)
- server A receives m1, m2 and server B receives m2, m1
- servers A and B multicast the acknowledgements including to themselves.
- Server A will wait for the acknowledgement from server B for both m1 and m2 before handing them to its application.
- Server B will wait for the acknowledgement from server A for both m1 and m2 before handing them to its application
- Both servers order the messages according to the time stamps of the messages and execute.

Applications of Lamport's Timestamps

- Vector Timestamps (to capture causality)
- Global state
- Local state of each process + messages in transit
  - Termination detection

- Consult the book (if you want)