416 Distributed Systems

Time Synchronization

Jan 25, 2016

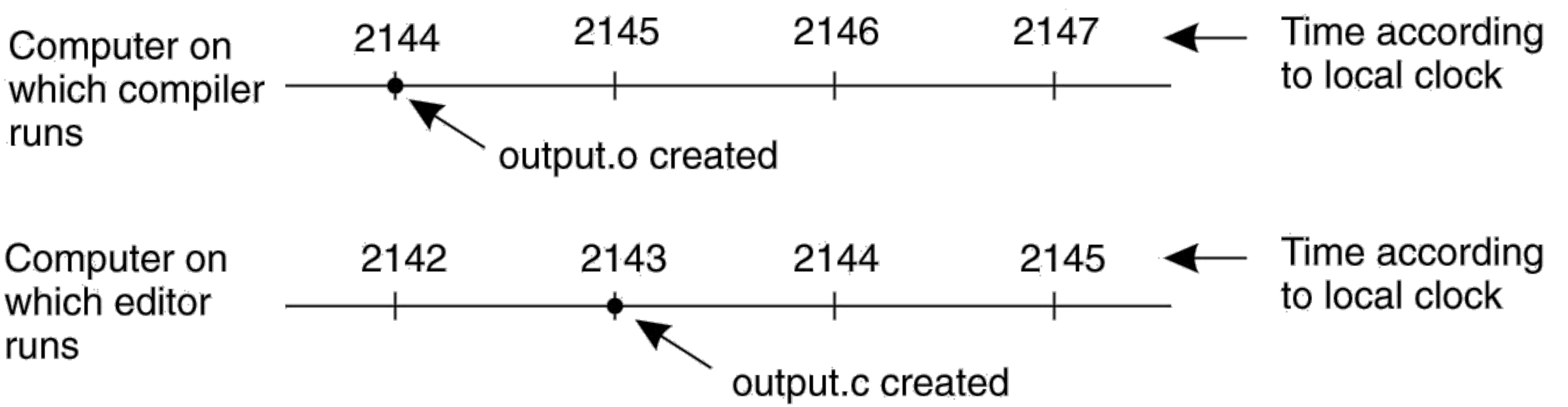
Today's Lecture

- Need for time synchronization
- Time synchronization techniques
- Lamport Clocks
- Vector Clocks

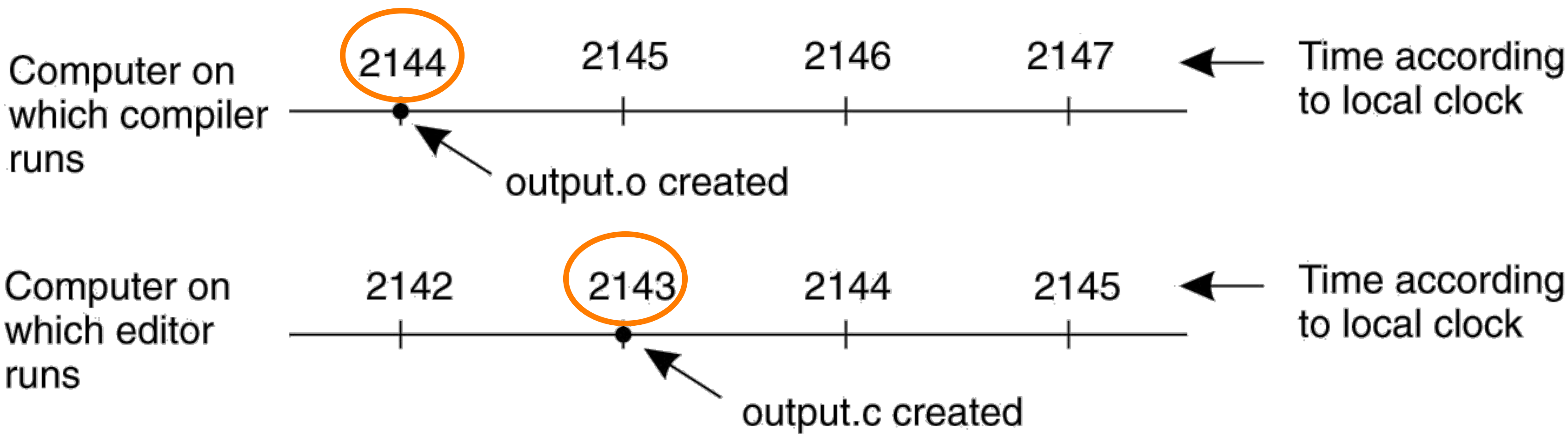
Why Global Timing?

- Suppose there were a globally consistent time standard
- Would be handy
  - Who got last seat on airplane?
  - Who submitted final auction bid before deadline?
  - Did defense move before snap? (football reference)

Impact of Clock Synchronization

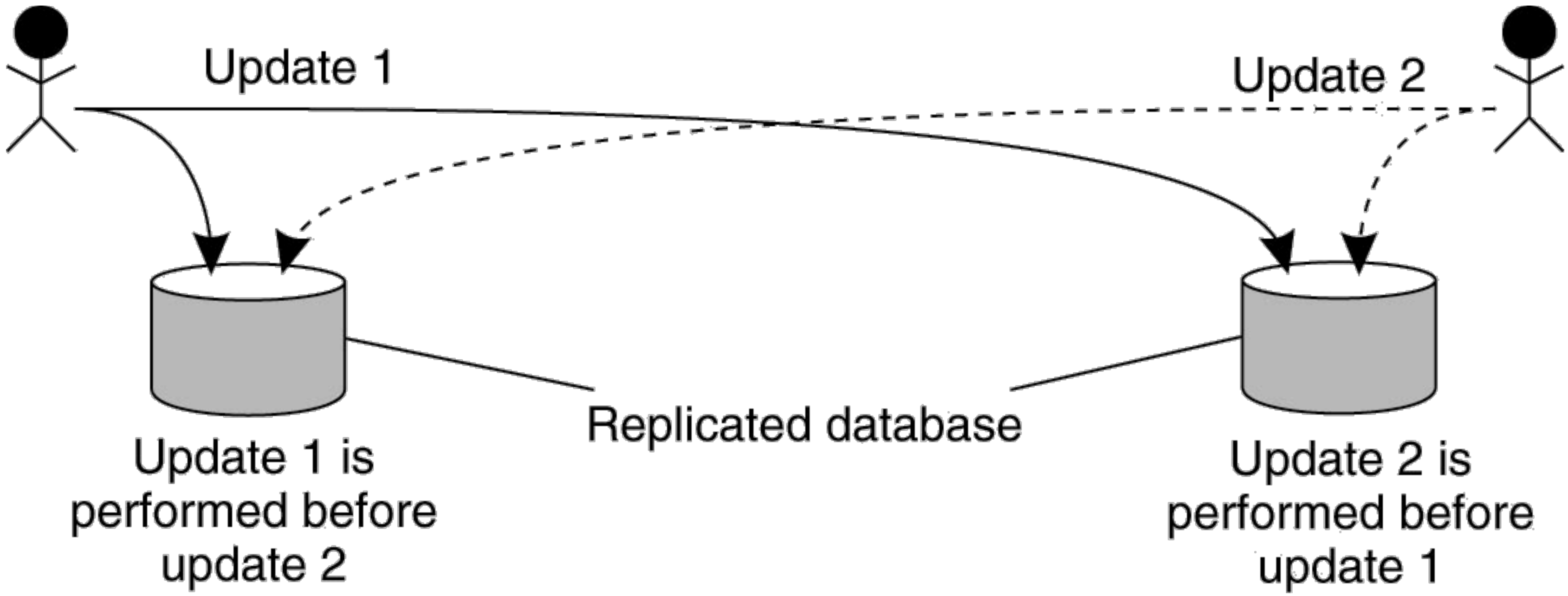


Impact of Clock Synchronization



- When each machine has its own clock, an event that occurred after another event may nevertheless be assigned an earlier time.

Replicated Database Update

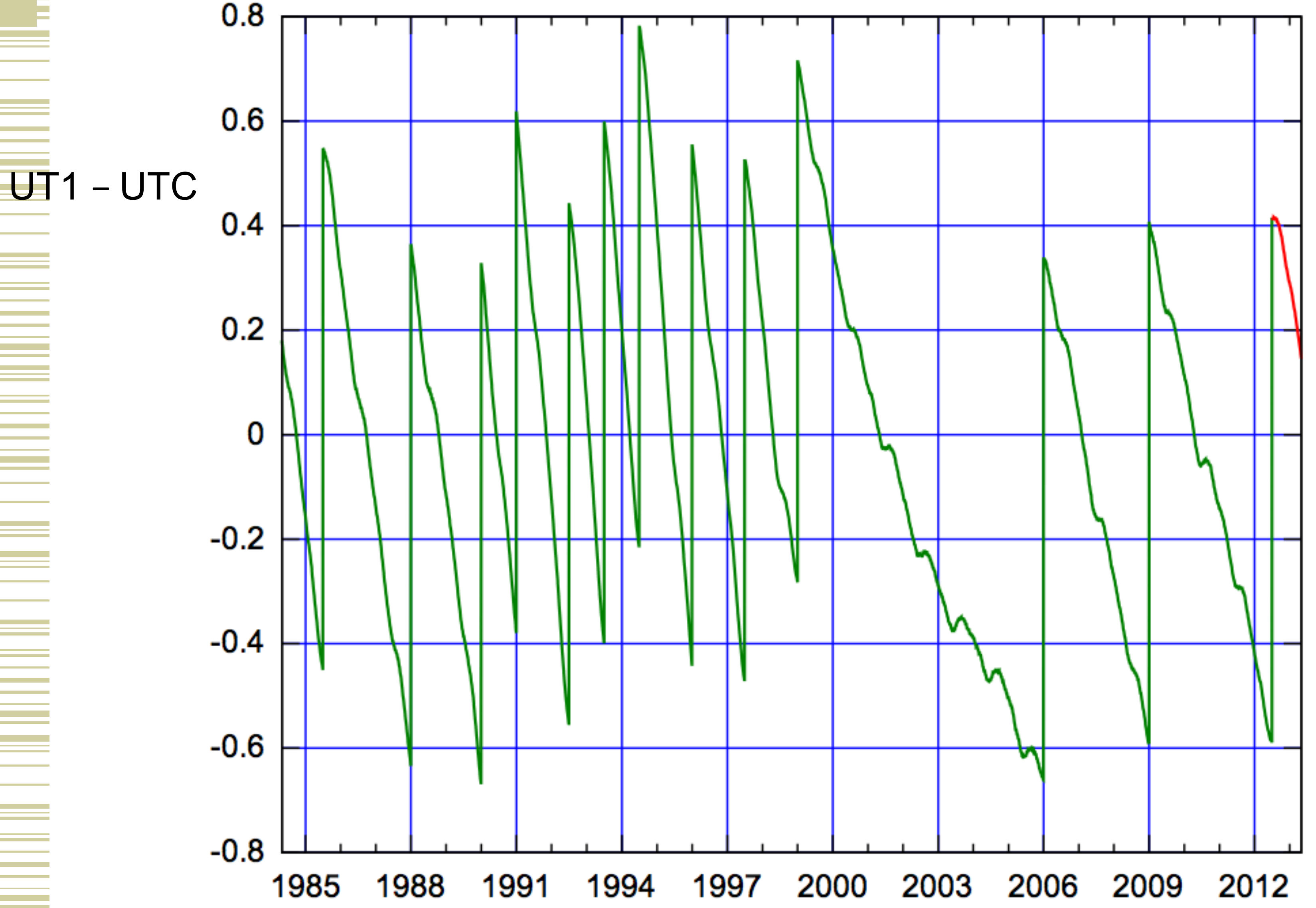


- Updating a replicated database and leaving it in an inconsistent state

Time Standards

- UT1 (universal time)
  - Based on astronomical observations
  - ~ “Greenwich Mean Time” (GMT)
- TAI (international atomic time)
  - Started Jan 1, 1958
  - Each second is 9,192,631,770 cycles of radiation emitted by Cesium atom
  - Has diverged from UT1 due to slowing of earth’s rotation
- UTC (coordinated universal time)
  - TAI + leap seconds to be within 0.9s of UT1
  - Currently 36s
  - Most recent update: June 30, 2015

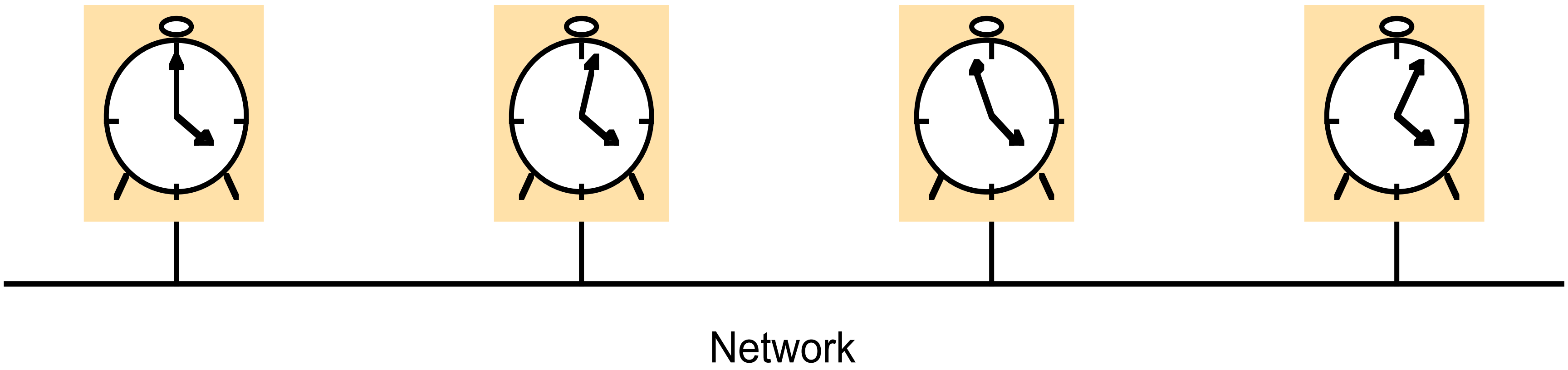
Comparing Time Standards



Coordinated Universal Time (UTC)

- Is broadcast from radio stations on land and satellite (e.g. GPS)
- Computers with receivers can synchronize 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
  - Why can't we use GPS receivers on all our computers?

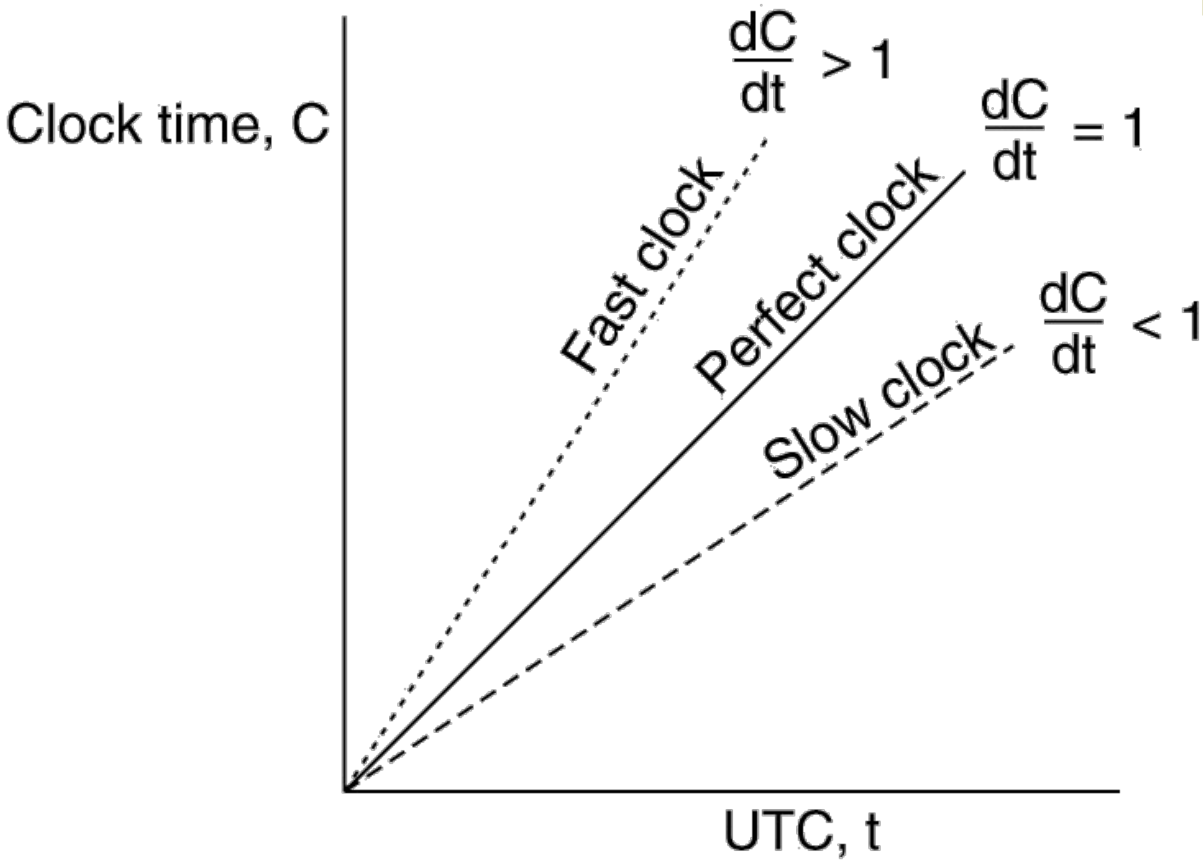
Clocks in a Distributed System



- Computer clocks are not generally in perfect agreement
  - **Skew**: the difference between the times on two clocks (at any instant)

- Computer clocks are subject to clock drift (they count time at different rates)
  - **Clock drift rate**: the difference per unit of time from some ideal reference clock
  - Ordinary quartz clocks drift by about 1 sec in 11-12 days. (10^{-6} secs/sec).
  - High precision quartz clocks drift rate is about 10^{-7} or 10^{-8} secs/sec

Clock Synchronization Algorithms



- The relation between clock time and UTC when clocks tick at different rates.

Today's Lecture

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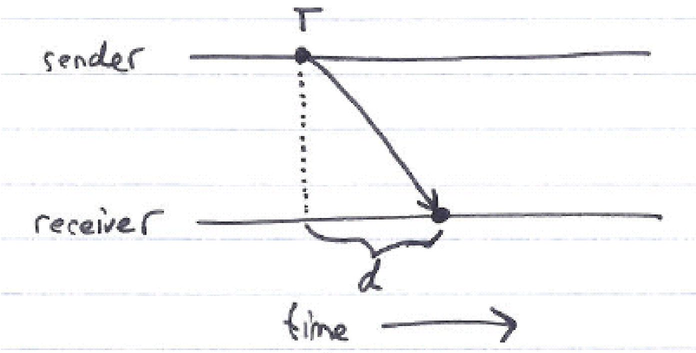
- Vector Clocks

Perfect networks

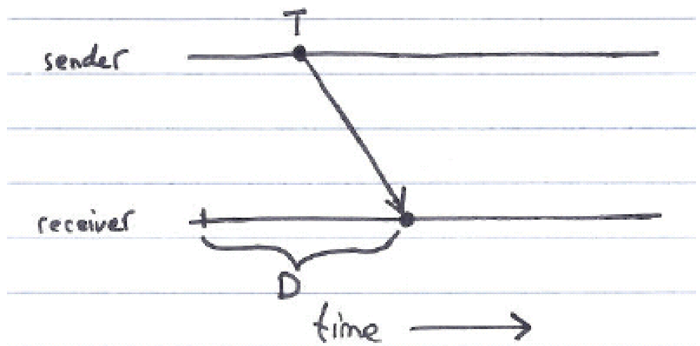
- Messages always arrive, with propagation delay exactly *d*



- Sender sends time *T* in a message
- Receiver sets clock to *T+d*
    - Synchronization is exact

Synchronous networks

- Messages always arrive, with propagation delay *at most* *D*



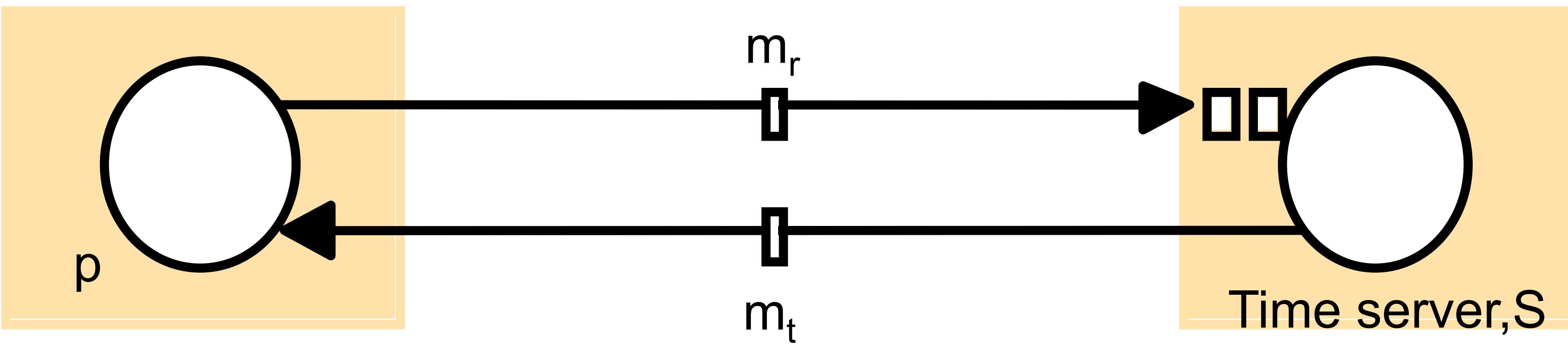
- Sender sends time *T* in a message
- Receiver sets clock to *T* + *D/2*
    - Synchronization error is at most *D/2*

Synchronization in the real world

- Real networks are asynchronous
  - Message delays are arbitrary
- Real networks are unreliable
  - Messages don’t always arrive

Cristian's Time Sync ('89)

- A time server S receives signals from a UTC source
  - Process p requests time in m_r and receives t in m_t from S
  - p sets its clock to $t + T_{\text{round}}/2$
  - Accuracy ± ($T_{\text{round}}/2$ - min) :
    - because the earliest time S puts t in message m_t is min after p sent m_r.
    - the latest time was min before m_t arrived at p
    - the time by S's clock when m_t arrives is in the range [t+min, t + T_{round} - min]



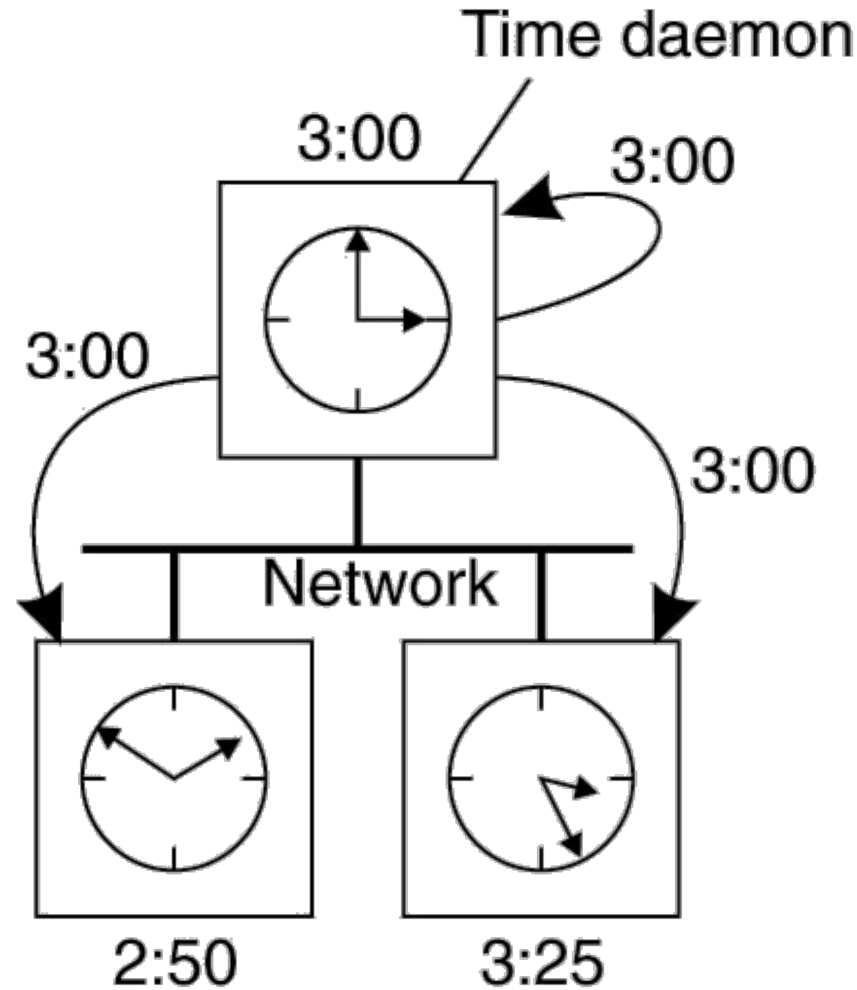
T_{round} is the round trip time recorded by p
min is an estimated minimum on way delay

Berkeley algorithm

- Cristian's algorithm -
  - a single time server might fail, so they suggest the use of a group of synchronized servers
  - it does not deal with faulty servers
- Berkeley algorithm (also 1989)
  - An algorithm for internal synchronization 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 (eliminating any above average round trip time or with faulty clocks)
  - It sends the required adjustment to the slaves (better than sending the time which depends on the round trip time)
  - Measurements
    - 15 computers, clock synchronization 20-25 millisecs drift rate < 2×10^{-5}
    - If master fails, can elect a new master to take over (not in bounded time)

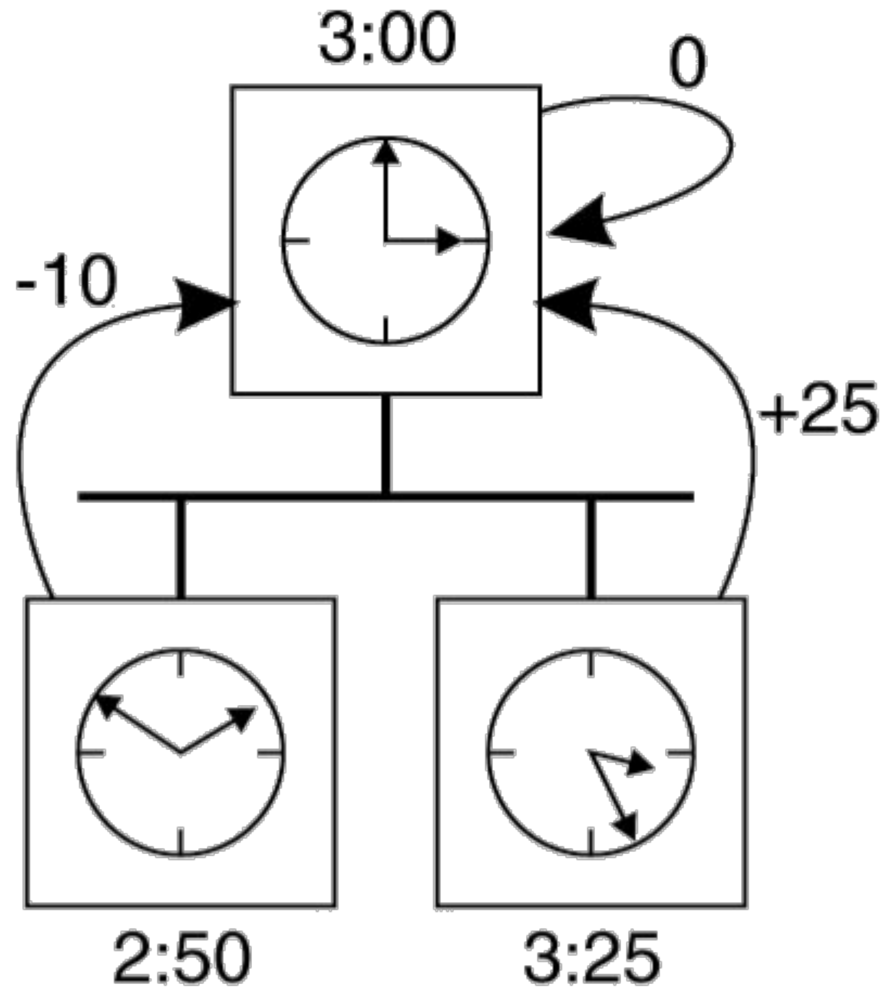
The Berkeley Algorithm (1)

- The time daemon asks all the other machines for their clock values.



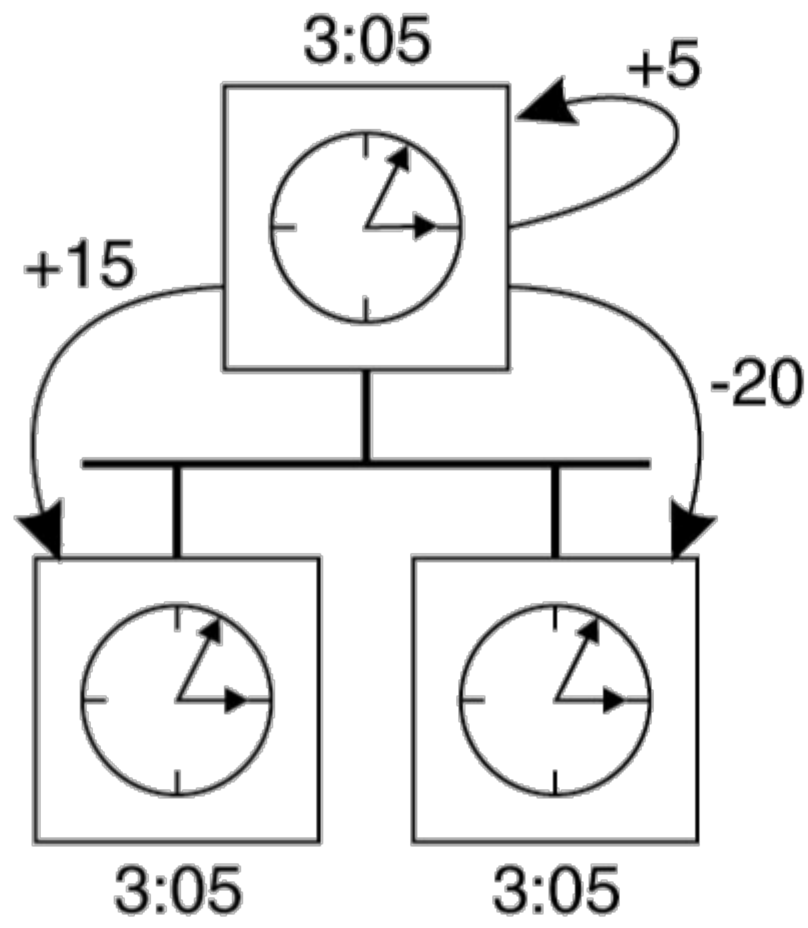
The Berkeley Algorithm (2)

- The machines answer.



The Berkeley Algorithm (3)

- The time daemon tells everyone how to adjust their clock.



Network Time Protocol (NTP)
(invented by David Mills, 1981)

- A time service for the Internet - synchronizes clients to

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Primary servers are connected to UTC sources

Secondary servers are synchronized to primary servers

Synchronization subnet - lowest level servers in users' computers

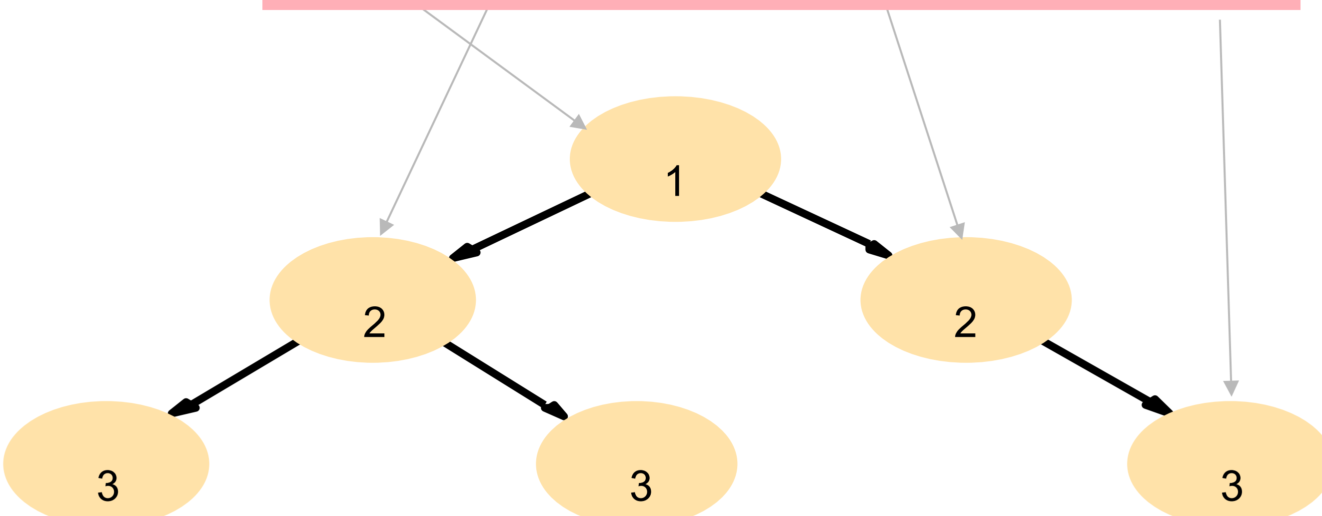


Figure 10.3

The Network Time Protocol (NTP)

- Uses a hierarchy of time servers
  - Class 1 servers have highly-accurate clocks
    - connected directly to atomic clocks, etc.
  - Class 2 servers get time from only Class 1 and Class 2 servers
  - Class 3 servers get time from any server (usually 3)
- Synchronization similar to Cristian's alg.
  - Modified to use multiple one-way messages instead of immediate round-trip
- Accuracy: Local ~1ms, Global ~10ms

NTP Reference Clock Sources (1997 survey)

- In a survey of 36,479 peers, found 1,733 primary and backup external reference sources
- 231 radio/satellite/modem primary sources
  - 47 GPS satellite (worldwide), GOES satellite (western hemisphere)
  - 57 WWVB radio (US)
  - 17 WWV radio (US)
  - 63 DCF77 radio (Europe)
  - 6 MSF radio (UK)
  - 5 CHU radio (Canada)
  - 7 modem time service (NIST and USNO (US), PTB (Germany), NPL (UK))
  - 25 other (precision PPS sources, etc.)
- 1,502 local clock backup sources (used only if all other sources fail)
- For some reason or other, 88 of the 1,733 sources appeared down at the time of the survey

U. Delware Master Time Facility (MTF) (from January 2000)

Spectracom 8170 WWVB Receiver

Spectracom 8183 GPS Receiver

Spectracom 8170 WWVB Receiver

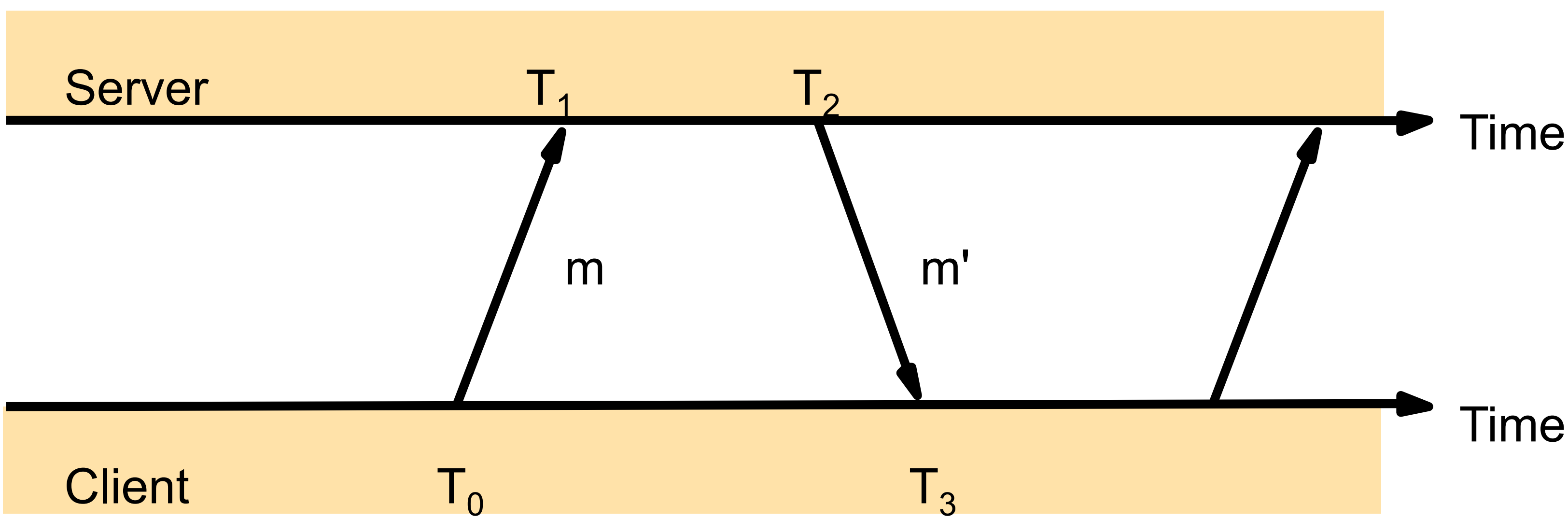
Spectracom 8183 GPS Receiver

Hewlett Packard 105A Quartz Frequency Standard

Hewlett Packard 5061A Cesium Beam Frequency Standard

NTP Protocol

- All modes use UDP
- Each message bears timestamps of recent events:
  - Local times of Send and Receive of previous message
  - Local times of Send of current message
- Recipient notes the time of receipt T_3 (we have T_0, T_1, T_2, T_3)



Accuracy of NTP

- Timestamps
  - t_0 is the client's timestamp of the request packet transmission,
  - t_1 is the server's timestamp of the request packet reception,
  - t_2 is the server's timestamp of the response packet transmission and
  - t_3 is the client's timestamp of the response packet reception.

- RTT = wait_time_client – server_proc_time
  = $(t_3-t_0) - (t_2-t_1)$
- Offset = $((t_1-t_0) + (t_2-t_3))/2$

- NTP servers filter pairs $<rtt_i, offset_i>$, estimating reliability from variation, allowing them to select peers
- Accuracy of 10s of millisecs over Internet paths (1 on LANs)

How To Change Time

- Can’t just change time
  - Why not?

How To Change Time

- Can’t just change time
  - Why not?
- Change the update rate for the clock
  - Changes time in a more gradual fashion
  - Prevents inconsistent local timestamps

Important Lessons

- Clocks on different systems will always behave differently
  - Skew and drift between clocks
- Time disagreement between machines can result in undesirable behavior
- Clock synchronization
  - Rely on a time-stamped network messages
  - Estimate delay for message transmission
  - Can synchronize to UTC or to local source
  - Clocks never exactly synchronized
- Often inadequate for distributed systems
  - might need totally-ordered events
  - might need millionth-of-a-second precision