Distributed Systems

Time, clocks, and Ordering of events

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Notes

- Today:
- Time, clocks, NTP
  - Ref: CDK
- Causality, ordering, logical clocks:
  - Ref: VG, CDK

Time

- Ordering of events are important:
  - Which happened first
- Need synchronization between sender and receiver
- Which event happened when
- Coordination of joint activity
- Etc..

UTC

- UTC
  - Coordinated universal time
  - Time maintained for civil use (on atomic clock)
  - Kept within 0.9 seconds of exact mean time for Greenwich

Clocks

- Piezoelectric effect:
  - Squeeze a quartz crystal: generates electric field
  - Apply electric field: crystal bends:

- Quartz crystal clock:
  - Resonation like a tuning fork
  - Accurate to parts per million
  - Gain/lose ½ second per day

Challenges

- Two clocks do not agree perfectly
- **Skew:** The time difference between two clocks
- Quartz oscillators vibrate at different rates
- **Drift:** The difference in rates of two clocks
- If we had two perfect clocks

Challenges

- Two clocks do not agree perfectly
- **Skew:** The time difference between two clocks
- Quartz oscillators vibrate at different rates
- **Drift:** The difference in rates of two clocks
- If we had two perfect clocks
  - Skew = 0
  - Drift = 0

When we detect one clock has a skew

- Eg: it is 5 seconds behind
- Or 5 seconds ahead

- What can we do?

When we detect a clock has a skew

- Eg: it is 5 seconds behind
  - We can advance it 5 seconds to correct
- Or 5 seconds ahead
  - Pushing back 5 seconds is a bad idea
    - Message was received before it was sent
    - Document closed before it was saved etc..

  - We want **monotonicity**: time always increases

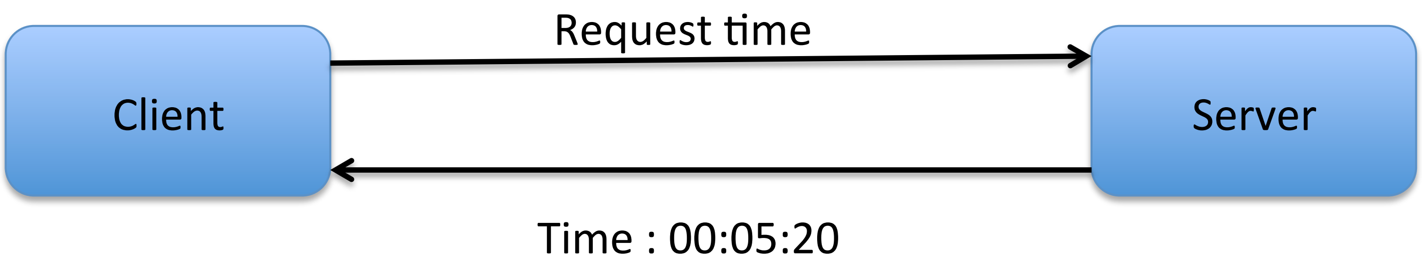
When we detect a clock has a skew

- Solution: Adjust slowly, maintaining monotonicity
- Eg: it is behind
  - Run it faster until it catches up
- It is ahead
  - Run it slower until it catches up

- This does not guarantee correct clock in future
  - Need to check and adjust periodically

How clocks synchronize

- Obtain time from time server:



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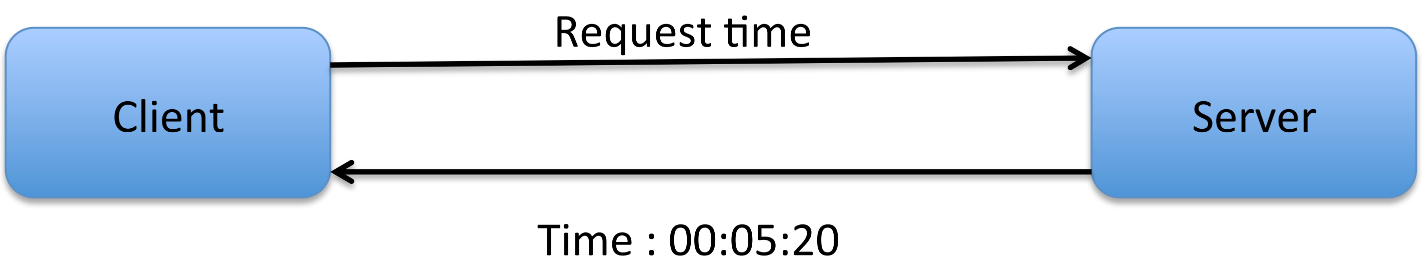
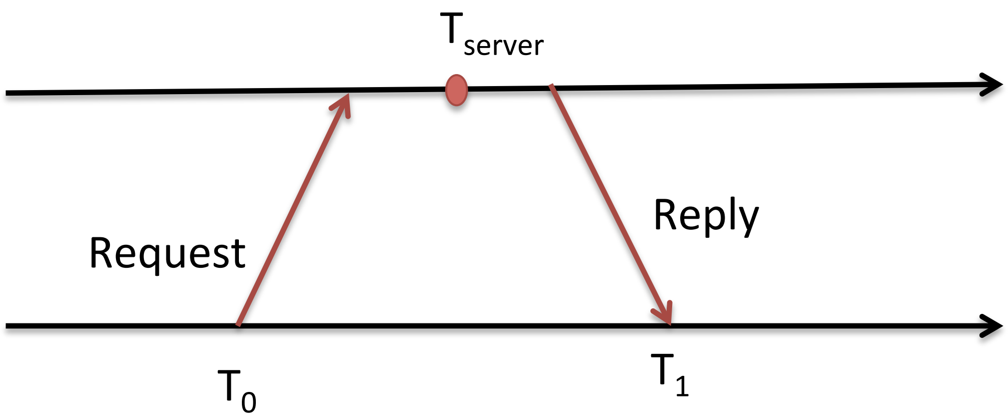


- Time is inaccurate
  – Delays in message transmission
  – Delays due to processing time
  – Server's time may be inaccurate

Christian's algorithm

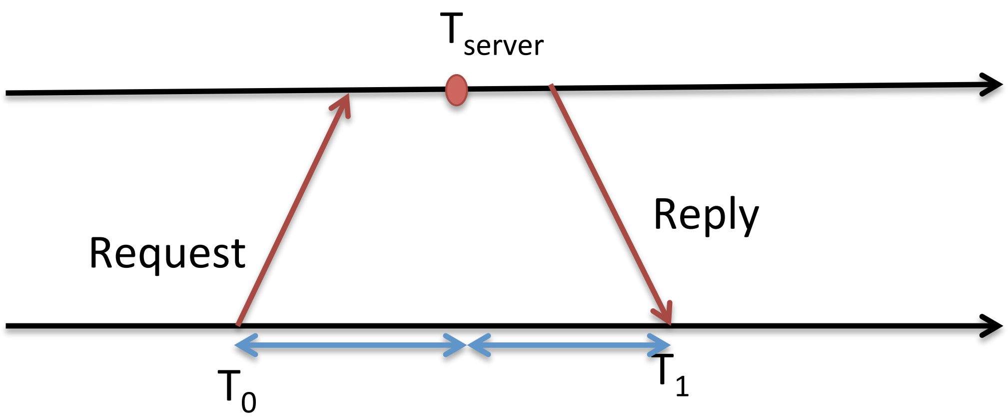
- Compensate for delays
  - Request sent at T_0
  - Reply received at T_1



  - Assume delays are symmetric

Christian's algorithm

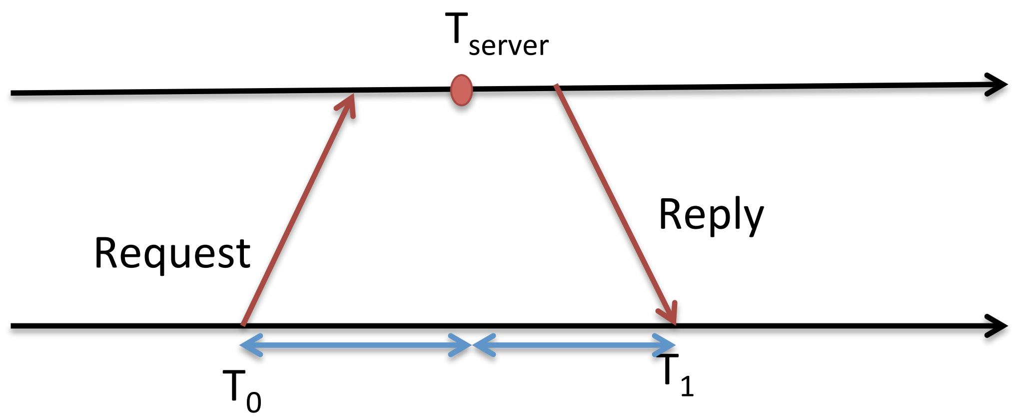
$$T_{new} = T_{server} + (T_1 - T_0)/2$$



Christian's algorithm

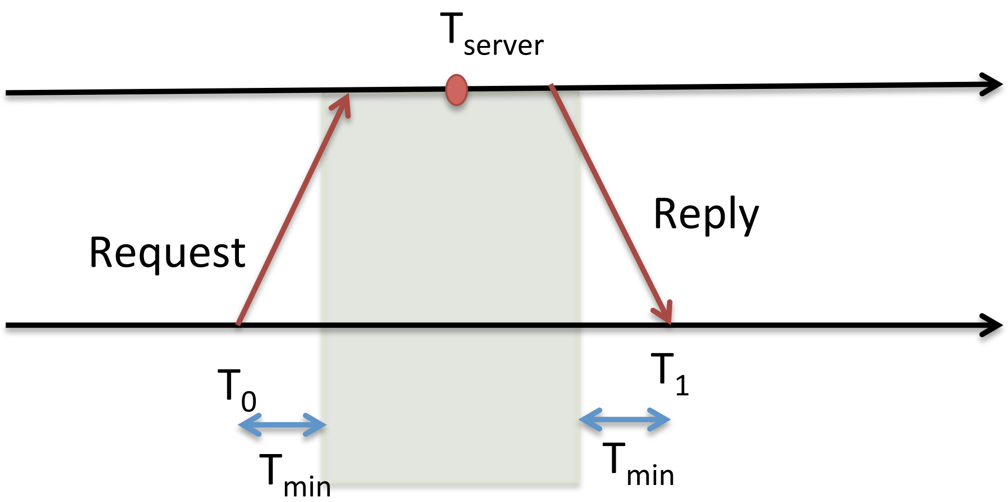
$T_{new} = T_{server} + (T_1 – T_0)/2$

Example: T_0 = 5:05:08.100, T_1 = 5:05:9.500, T_{server}= 5:05:9.100
T_{new} = 5:05:09:800



Christian's algorithm

- If minimum message transit time T_{min} is known
- Range = $T_1 - T_0 - 2T_{min}$
- Accuracy of result: $(T_1 - T_0 - 2T_{min})/2$



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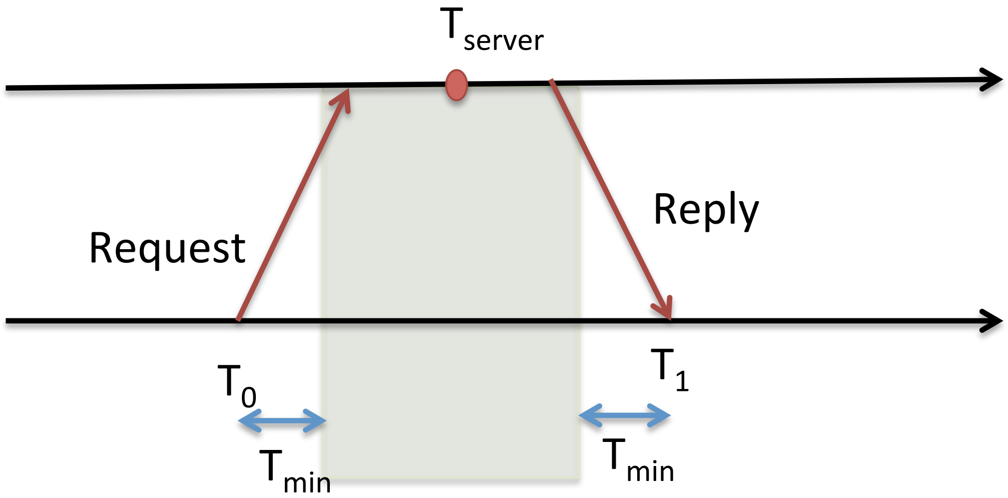

Berkeley algorithm

- Assumes no machine has perfect time
- Takes average of participating computers
- Sync all clocks to average

Berkeley algorithm

- One computer is elected as server (master)
  - Others are slaves
- Master polls each machine for time
- Compute average
  - Idea average will cancel out skews
- Send each clock the offset by which it needs to adjust time

Berkeley algorithm

- One computer is elected as server (master)
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- Compute average
  - Idea average will cancel out skews
- Send each clock the offset by which it needs to adjust time
  - Sending time itself is susceptible to network delays

Berkeley algorithm

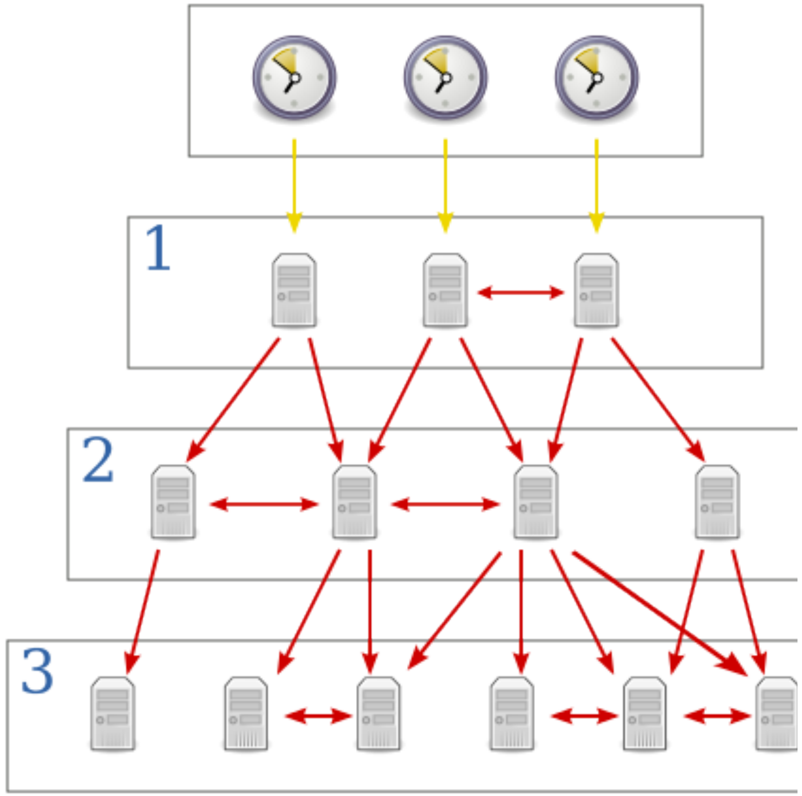
- Fault tolerance
  - Ignore readings of clocks with too large skews
  - If master fails: run an election algorithm and a slave becomes master

Network time protocol

- Enable clients to synchronize to UTC with reasonable accuracy
- Reliable:
  - Redundant servers and paths
- Scalable:
  - Enable many clients to synchronize frequently
- Security
  - Authenticate sources

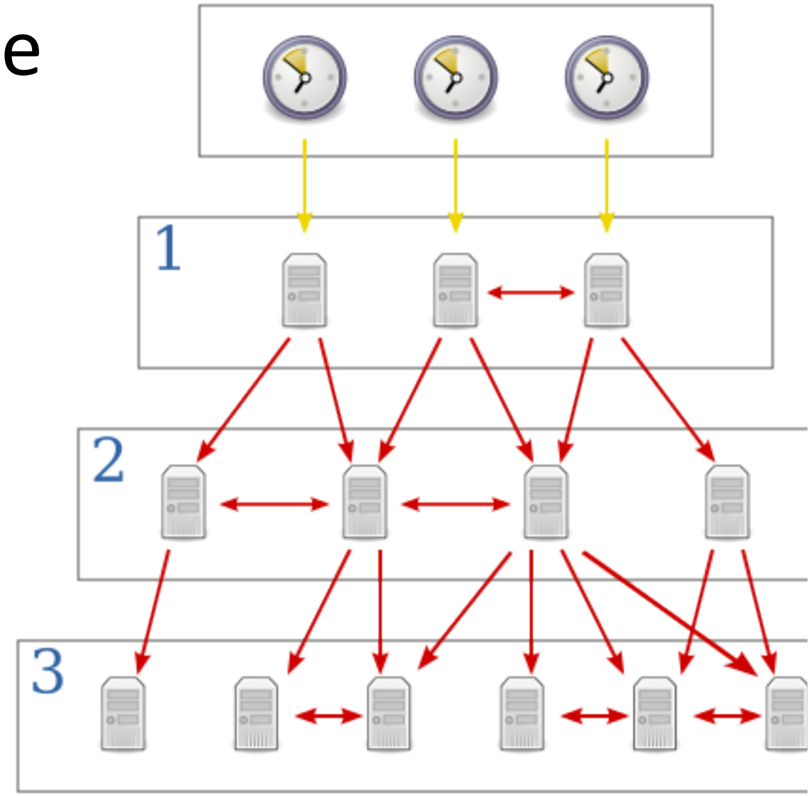
Network time protocol

- Servers in strata
- 1: directly connected to atomic, GPS etc clock
  - May inter-communicate for cross checks
- 2: few microseconds of level 1 etc



Network time protocol

- Uses multiple rounds of messages to get better time
- Large number of servers
- Uses an MST for inter-server sync

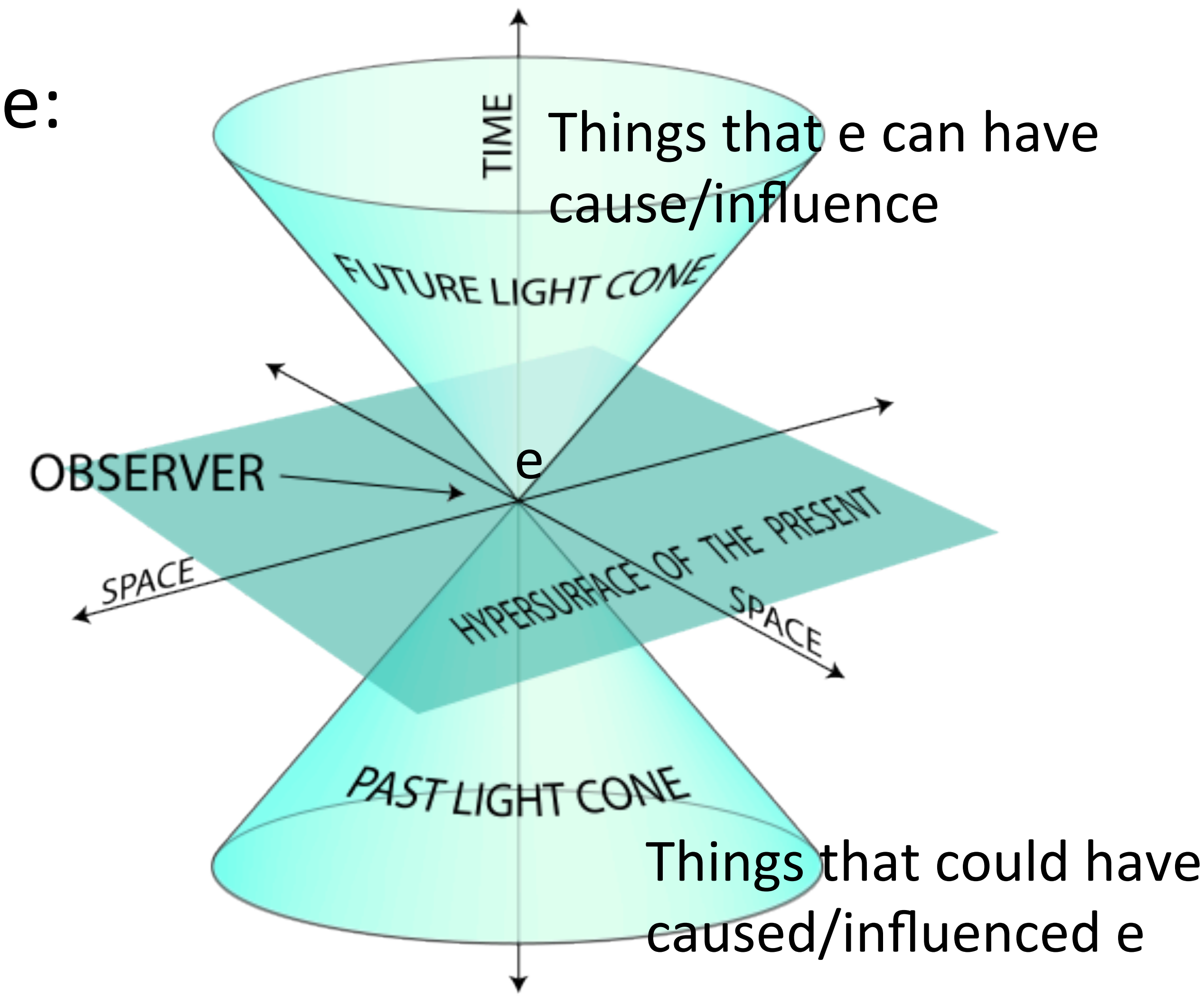


Time and synchronization

- Important topic in distributed systems
- Many different methods
  – Depending on systems, requirements…
- No perfect solution

Special relativity

- Light cone:



GPS

- Satellites: Have very accurate atomic clocks
- Transmit signals: “satID, time T_0,…”
- Receivers measure distance:
  - $(T_1 - T_0)*c$ [c = speed of light]
  - Distance from multiple satellites gives location
  - Complex computation, taking into account possible errors, clock drift and skew etc..
- Needs relativistic computation
  - Special relativity: Clocks on fast moving satellites run slow (microseconds per day drift for satellites)
  - General relativity: Clocks far from heavy bodies run fast (microseconds per day)