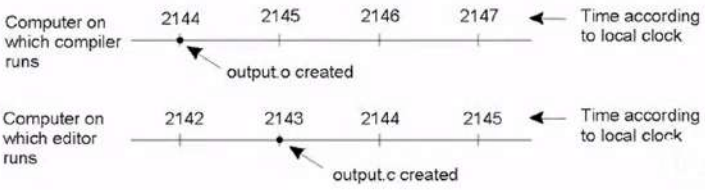
Clock Synchronization

- Time in unambiguous in centralized systems
  - System clock keeps time, all entities use this for time
- Distributed systems: each node has own system clock
  - Crystal-based clocks are less accurate (1 part in million)
  - *Problem:* An event that occurred after another may be assigned an earlier time



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Physical Clocks: A Primer

- How do you tell time?
  - Use astronomical metrics (solar day)
- Accurate clocks are atomic oscillators (one part in 10^{13})
- Coordinated universal time *(UTC)* – international standard based on atomic time
  - Add leap seconds to be consistent with astronomical time
  - UTC broadcast on radio (satellite and earth)
  - Receivers accurate to 0.1 – 10 ms
- Most clocks are less accurate (e.g., mechanical watches)
  - Computers use crystal-based blocks (one part in million)
  - Results in *clock drift*
- Need to synchronize machines with a master or with one another

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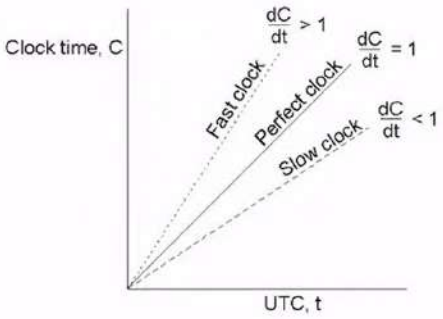
Clock Synchronization

- Each clock has a maximum drift rate ρ
  - 1-ρ <= dC/dt <= 1+ρ
  - Two clocks may drift by 2ρ Δt in time Δt
  - To limit drift to δ => resynchronize every δ/2ρ seconds



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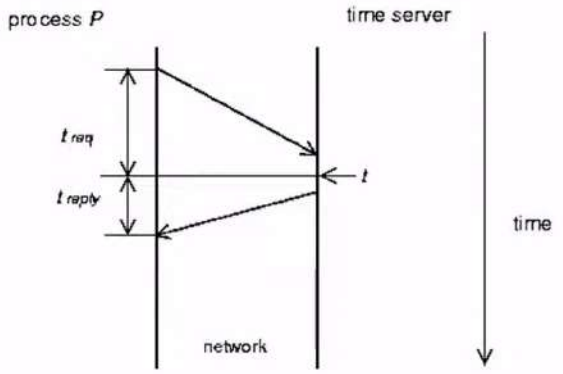
Cristian's Algorithm

- Synchronize machines to a *time server* with a UTC receiver
- Machine P requests time from server every $\delta/2\rho$ seconds
  - Receives time t from server, P sets clock to $t+t_{reply}$ where t_{reply} is the time to send reply to P
  - Use $(t_{req}+t_{reply})/2$ as an estimate of t_{reply}
  - Improve accuracy by making a series of measurements



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Berkeley Algorithm

- Used in systems without UTC receiver
  - Keep clocks synchronized with one another
  - One computer is *coordinator*, other are *workers*
  - Master periodically polls slaves for their times
    - Average times and return differences to slaves
    - Communication delays compensated as in Cristian's algo
  - Failure of master => election of a new master

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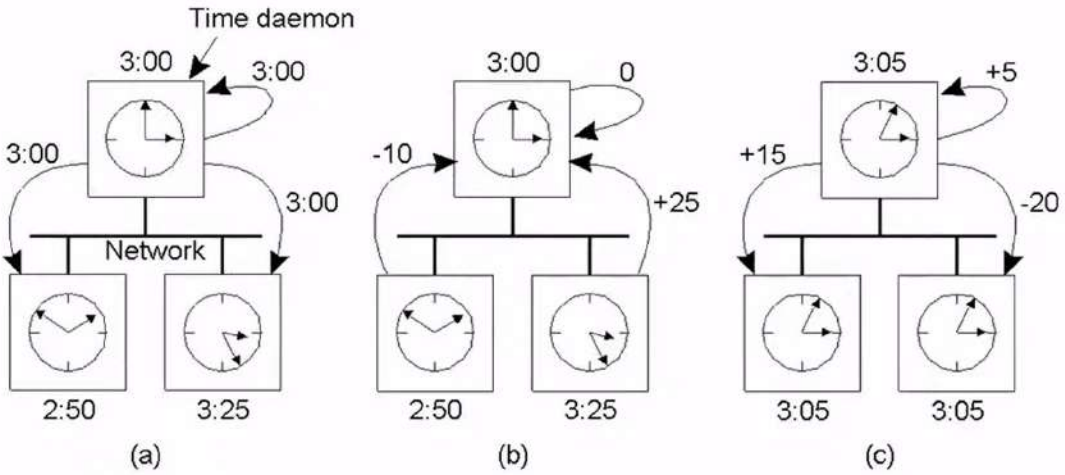
Berkeley Algorithm



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

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Distributed Approaches

- Both approaches studied thus far are centralized
- Decentralized algorithms: use resync intervals
  - Broadcast time at the start of the interval
  - Collect all other broadcast that arrive in a period *S*
  - Use average value of all reported times
  - Can throw away few highest and lowest values
- Approaches in use today
  - *rdate*: synchronizes a machine with a specified machine
  - Network Time Protocol (NTP) - discussed in next slide
    - Uses advanced techniques for accuracies of 1-50 ms

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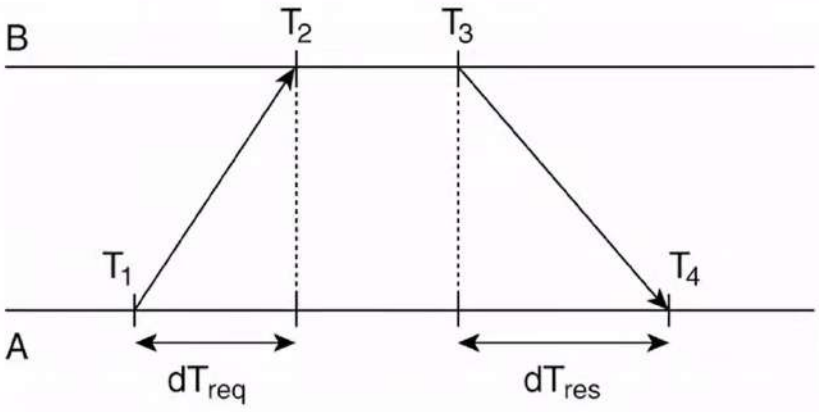
Network Time Protocol

- Widely used standard - based on Cristian's algo
  - Uses eight pairs of delays from A to B and B to A.
- Hierarchical – uses notion of stratum
- **Clock can not go backward**



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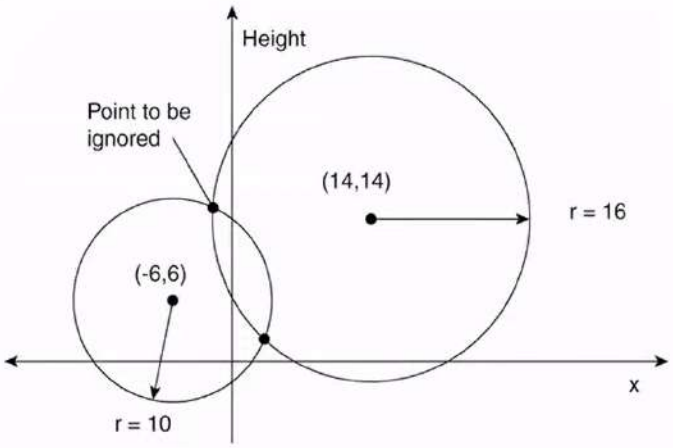
Global Positioning System

- Computing a position in a two-dimensional space.



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Global Positioning System

- Real world facts that complicate GPS
- It takes a while before data on a satellite's position reaches the receiver.
- The receiver's clock is generally not in synch with that of a satellite.

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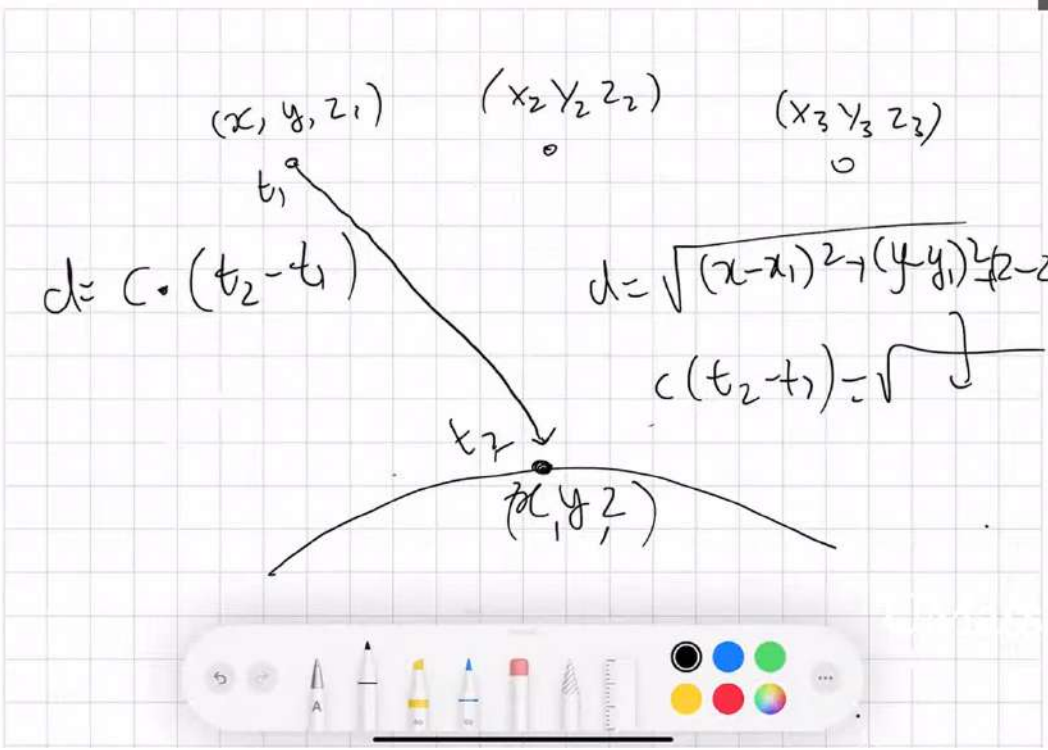
Lecture 12 Notes



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GPS Basics

- D_r – deviation of receiver from actual time
- Beacon with timestamp T_i received at T_{now}
  - Delay $D_i = (T_{now} - T_i) + D_r$
  - Distance $d_i = c\ (T_{now} - T_i)$
  - Also $d_i = \text{sqrt}[\ (x_i - x_r)^2 + (y_i - y_r)^2 + (z_i - z_r)^2\ ]$
- Four unknowns, need 4 satellites.
-

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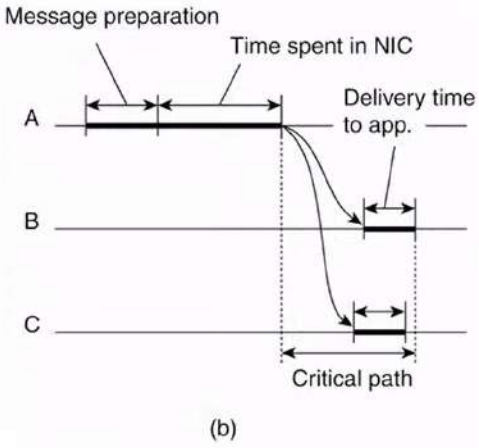
Clock Synchronization in Wireless Networ

- Reference broadcast sync (RBS): receivers synchronize with one another using RB server
  - Mutual offset = $T_{i,s} - T_{j,s}$ (can average over multiple readings)



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Logical Clocks

- For many problems, internal consistency of clocks is important
  - Absolute time is less important
  - Use *logical* clocks
- Key idea:
  - Clock synchronization need not be absolute
  - If two machines do not interact, no need to synchronize them
  - More importantly, processes need to agree on the *order* in which events occur rather than the *time* at which they occurred

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Event Ordering

- *Problem:* define a total ordering of all events that occur in a system
- Events in a single processor machine are totally ordered
- In a distributed system:
  - No global clock, local clocks may be unsynchronized
  - Can not order events on different machines using local times
- Key idea [Lamport]
  - Processes exchange messages
  - Message must be sent before received
  - Send/receive used to order events (and synchronize clocks)

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Happened Before Relation

- If *A* and *B* are events in the same process and *A* executed before *B*, then *A* -> *B*

- If A represents sending of a message and B is the receipt of this message, then A -> B
- Relation is transitive:
  - A -> B and B -> C => A -> C
- Relation is undefined across processes that do not exchange messages
  - Partial ordering on events

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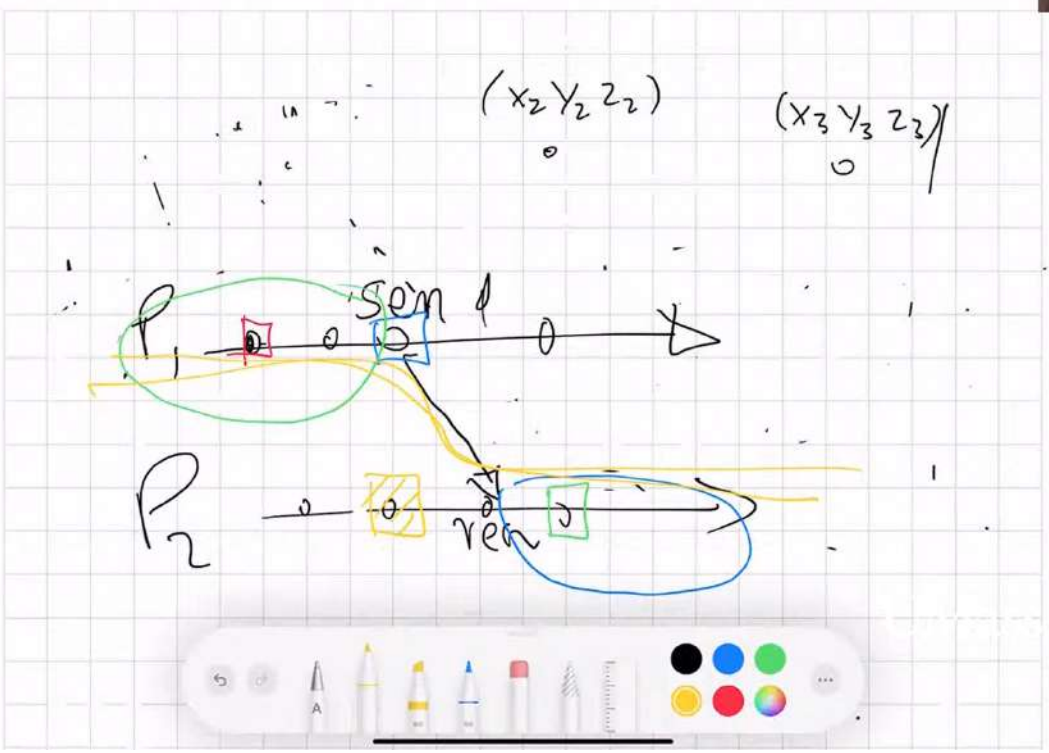
Lecture 12 Notes



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Event Ordering Using *HB*

- Goal: define the notion of time of an event such that
  - If A-> B then C(A) < C(B)
  - If A and B are concurrent, then C(A) <, = or > C(B)
- Solution:
  - Each processor maintains a logical clock LC_i
  - Whenever an event occurs locally at I, $LC_i = LC_i + 1$
  - When *i* sends message to *j*, piggyback Lc_i
  - When *j* receives message from *i*
    - If $LC_j < LC_i$ then $LC_j = LC_i + 1$ else do nothing
  - Claim: this algorithm meets the above goals

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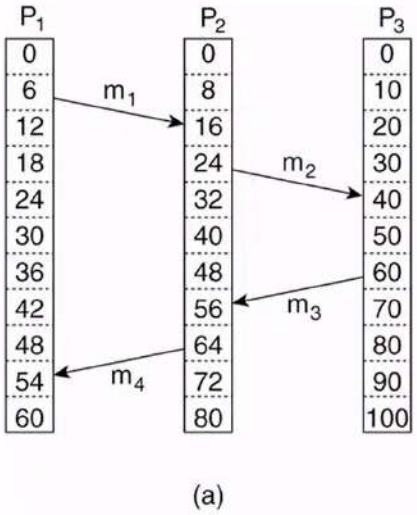
Lamport's Logical Clocks



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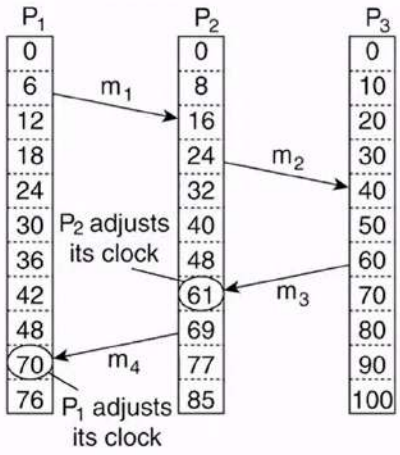

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