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PA160: Net-Centric Computing II.

Time Synchronization

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Time on a single node

- Timer (clock)
  - Oscillating quartz crystal
  - Counter
    - Each oscillation decreases the counter value
    - Interrupt when zero

    Each individual interrupt is a *tick*
  - Holding register
    - Counter initiation after interrupt
  - Stored time increased after each interrupt

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Distributed computer systems

- Each node has its own timer
  - Time is not automatically synchronized
  - Clock skew
- Relation to the absolute time
- Problems
  - Internode synchronization
  - Absolute time synchronization

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Absolute time

- Original (old) definition of the time unit
  - 1 second equals 1/86 400 solar day
- Current definition of the time unit—atomic clock
  - Electronic transition frequency of the electromagnetic spectrum of atoms
  - Cesium-133 standard in 1955
  - Chip-scale atomic clock in 2004 (125 mW)
  - 1 second equals 9 192 631 770 cycles (transitions between two energy levels of Cs-133)
- International atomic clock
  - Average measurement of around 50 world laboratories

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Universal Coordinated Time, UTC

- Atomic and solar times are not synchronized
- Leap second needed
  - Compensation for the irregularities of Earth rotation
  - Added whenever difference between atomic clock and mean solar time gets 800 ms
- Result is the Universal Coordinated Time (UTC)
  - GMT replacement
- UTC globally synchronized

Clock synchronization

- Basic assumptions
  - A set of nodes with their own clocks/timers
  - Interrupt frequency H Hz

$C_p(t)$ is the time measured by clock at node p

  - Ideally $C_p(t) = t$ for all p
  - Real behavior: If there exists ρ such as

$$1 - \rho \leq \frac{dC}{dt} \leq 1 + \rho$$

    then clock C_p works with the specification ρ
  - ρ is defined by the clock producer (it is the maximal time skew)
  - If we are looking for a clock synchronization with the highest difference δ, then the synchronization must occur at most every $\delta/2\rho$ seconds

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Cristian's algorithms

- We have a *time server*
  - synchronized with UTC
- Each $\delta/2\rho$ each node sends a request to the server
- Server replies with its own (UTC) time (as fast as possible)
- Naive solution: the node modifies its time accordingly

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Problems

- **Important**—delay compensation
  - Time stops to have linear course (shape)
    - Unexpected and undesirable effects
    - Time cannot move “backwards”
  - Solution
    - The absolute time is not increased at the interrupt
    - We “stop” the time
- **Small**—communication delay
  - Measure the time of sending (T_0) and receiving (T_1) the request
  - Add time of the transfer $(T_0 + T_1)/2$
  - Correct for the time spent at the server (request processing), if known

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Berkeley algorithm

- Active time server
  - Periodically queries nodes for their absolute time
  - Averages node times
  - Sends this new time to all nodes
- Suitable if no access to UTC source exists
  - Analogy of UTC—time based on the agreement of the nodes

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Decentralized solutions

- Re-synchronization intervals
  - A starting point T_0 globally agreed
  - Interval i starts at the time $T_0 + iR$
  - Interval i ends at the time $T_0 + (i + 1)R$
  - R is an agreed system parameter
- All nodes broadcast their absolute time at the beginning of each interval
- Each node does the following
  - Receives S messages
  - Computes the average (with the removal of m outliers)
  - Improvement possible if the message propagation delay known

NTP

- Network Time Protocol
  - Version 3 (RFC1305), version 2 (RFC1119), version 1 (RFC 1059)
  - S(imple)NTP: RFC 1769
- Hierarchical structure based on stratums
  - Stratum 1 directly connected to UTC (atomic clock, ...)
  - Stratum $i+1$ connects to server(s) at Stratum i
  - Up to 16 levels (Stratum 16)
- Highly scalable
- More than one server
  - Tolerant to server fault of precision loss
- Servers `tik.cesnet.cz` and `tak.cesnet.cz`

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Logical time

- Absolute time is not always necessary
- *Relative time* (relation between events) often more important
- *Logical time*
  - No need for absolute synchronization
  - Need agreement on the order

Lamport timestamps

- Relation “happens-before”
- $a \rightarrow b$ means that all processes agree that a happened before b
- If a represents an event of sending a particular message and b represents the receipt of the same message, then $a \rightarrow b$ holds
- Properties
  - $a \rightarrow b$ is transitive
  - Events x and y are *concurrent* iff nor $x \rightarrow y$ nor $y \rightarrow x$ holds

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Implementation

- Each process does have its own logical clock
- For events within any particular process the relation "happens-before" is trivially fulfilled
- Interprocess synchronization is the result of message passing
  - Each message contains time stamp T_s of the sender (its time of sending the message)
  - If internal receiver time T_r is lower (i.e. "younger") than the time of sending the message (T_s), we put $T_r = T_s + 1$
- Additional condition
  - No two events happen at the same time

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Summary

- Lamport's algorithm is sufficient to define and keep a global (logical) time in a distributed system
- Properties
  - If a happens before b in the same process, $C(a) < C(b)$
  - If a is sending and b receipt of the same message, $C(a) < C(b)$
  - For all events a, b such that $a \neq b$, $C(a) \neq C(b)$ holds
- The algorithms provides global (partial) order on events in a distributed system
- First published in 1978 in CACM; one of the most cited articles in Computer Science of all time