



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



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

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

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

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

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

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

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 stratum
 - 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`



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 $\text{nor } x \rightarrow y \text{ nor } y \rightarrow x$ holds

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



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 algorithm 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