Real-Time (Paradigms) (7)

3. Time and Clocks

Time is a very useful artifact to represent the ordering of events in any system.

It relates to

- ordering
- sequencing
- synchronizing

of events in any system.

The passage of time is marked by an abstract monotonically increasing **continuous** function, called *real time*

Along history, time has been represented (measured) in different ways, mainly dependent on how the unit of time,called *second*, was measured.

timeline: graphical representation of time units as sequence of points over a straight line (digitized time)

The use of time in computer systems addresses two aspects:

- observing and recording the place of events in a timeline (ordering, sequencing)
- enforcing the future positioning of events in the timeline (synchronizing)

Real-Time Paradigms (8)

UT (AT, 1833) Universal Time (UT) Mittlere Sonnenzeit, gemessen am Greenwich 0-Meridian (GMT). Basiert auf der mittleren Länge eines Sonnentags, d.h. auf der Erdrotation

Zeitzonen (1884): Gebiete für die dieselbe Zeit festgelegt ist. 1884 wird die Welt in 24 Zeitzonen aufgeteilt. Die Zeitzonen unterscheiden sich von UT (GMT) ganzzahlig um jeweils 1 Stunde
.

ET (AT, 1955) Ephimeridenzeit (ET), basiert auf der Umlaufzeit der Erde um die Sonne. Harold Spencer Jones stellte 1939 fest, daß die Rotation der Erde variiert, die Umlaufzeit um die Sonne nicht. 1 Sekunde der ET wird festgelegt als der 1/31.566.925,9747 Teil des tropische Jahres, das am Mittag des 1. Januars 1900 begann. (Tropisches Jahr: Periode zwischen zwei aufeinanderfolgenden Umläufen der Sonne durch den Himmelsäquator in derselben Richtung.)

UT2 (AT, 1960) Zeit, basierend auf und gemittelt über den lokalen Beobachtungen verschiedener über die Erde verteilter Observatorien und anschließend nochmals auf empirischer Basis korrigiert

TAI (PT, 1961) Temps Atomique International (TAI) basiert auf mehreren koordinierten Cäsium-Uhren. Fortlaufende Zeitzählung, beginnend mit dem 1.Januar 1958 0 Uhr UT2-Zeit.
1 Sekunde der TAI ist 9 192 631 770 mal die Periode der Strahlung des Atoms Cäsium 133.
Driftrate $\rho \approx 10^{-14}$, d.h. Abweichung ca. 1 Sek / 300000 Jahre

UTC (PT, 1972) Universal Time Coordinated (UTC) basiert auf TAI, wird aber ständig an UT2 angepaßt. Immer wenn UTC und UT2 mehr als 800 ms auseinander gedriftet sind, wird eine “Schaltsekunde” eingefügt. UTC beginnt am 1. Januar 1972. Seit dieser Zeit sind bis heute 32 Schaltsekunden eingefügt worden (letztmalig Silvester 2006). UTC ist damit eine an AT angepaßte physikalische Zeit.

Real-Time (Paradigms) (9)

local physical clock:

implements in hardware the mapping of real time t into a clock time pc(t), which is a monotonically increasing **discrete** function **(no real time).** They are based typically on oscillators such as quartz.

These clocks are mainly characterized by the following parameters (also representing its imperfections w.r.t. to the atomic cesium clock):

- *granularity g:* time difference between two consecutive ticks t(i) and t(i+1): g:= pc(t(i+1)) - pc(t(i))
- *drift rate* ρ: positive constant denoting the drift of a physical clock from real time
  $\rho \approx 10^{-5}$, i.e. several microseconds per second, e.g. ca. 36 ms after 1 hour, almost 1 s after 1 day
- *clock rate*: : $1- \rho \leq (pc(t(i+1)) - pc(t(i))) / \Delta t \leq 1+ \rho$ for $\Delta t = t(i+1) - t(i) = g$ (of the real time)

local clocks can be used to

- represent a timer to set *timeouts*
- timestamp local events
- measure local durations

They cannot be used for timing analysis regarding global events in a distributed systems because of ρ

−−> need to synchronize all local clocks by means of a *clock synchronization algorithm*

global clocks

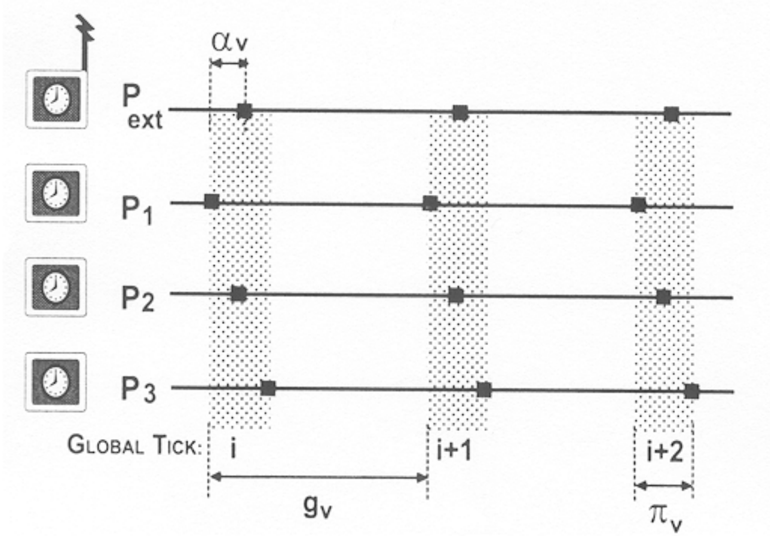
A global clock in a distributed system is built by synchronizing in periodic rounds all local clocks as close as possible to the same initial value.

virtual clock: the time vc(t) delivered by a synchronized local physical clock

The set of virtual clocks under the control of the synch. algorithm. constitutes the global clock of the system

Real-Time Paradigms (10)

Properties of a Global Clock:



precision π_v denotes the maximum deviation between two corresponding ticks of any two virtual clocks, as seen by an outside observer, measured by the external reference clock representing the real time.

π_v := max{for all i,k,l : $|vc_k(t(i)) - vc_l(t(i))|$}

granularity g_v denotes the time interval between two consecutive global ticks

accuracy α_v denotes the maximum deviation between a tick of any of the virtual clocks and the corresponding tick of the external reference clock P_{ext}.

α_v := max{for all i,k : $|vc_k(t(i)) - P_{ext}(t(i))|$}

convergence δ_v denotes the maximum deviation between any two ticks of the virtual clocks immediately after the termination of a synchronization round (minimal deviation:= maximal precision).

δ_v := max{for all k,l : $|vc_k(t(0)) - vc_l(t(0))|$}

convergence δ is a measure for the quality of the clock synch. algorithm (internal synchronization)

accuracy α is a measure for the external synchronization, e.g. by means of GPS

Real-Time Paradigms (11)

The definitions above imply the following relations: $\pi \geq \delta$, $\pi \leq 2\alpha$, $g > \pi$
(precision cannot be better than convergence and at least twice the accuracy, it is senseless to select a granularity finer than the precision)

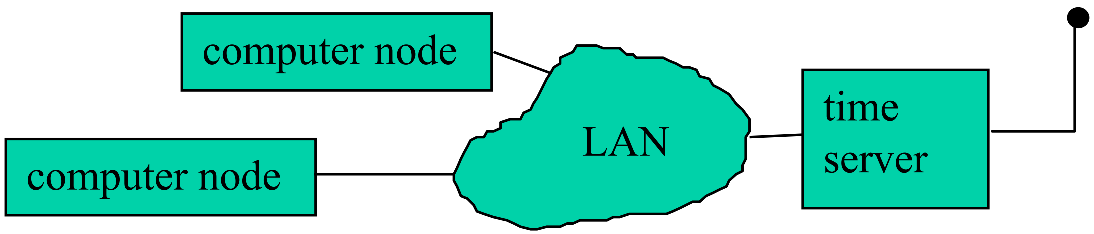
→ any globally visible event e is timestamped t(e) by different nodes of the system with at most one tick difference

→ let $d := |t(e_1) - t(e_2)|$ (No. of ticks); if $d < 2$ --> no physical order of the events e_1 and e_2 can be deduced

→ granularity (which itself depends on precision) determines the resolution of the global time grid

Required components to define a global time basis:

- an external reference time, e.g. UTC-based
- local physical clocks
- a synchronization algorithm



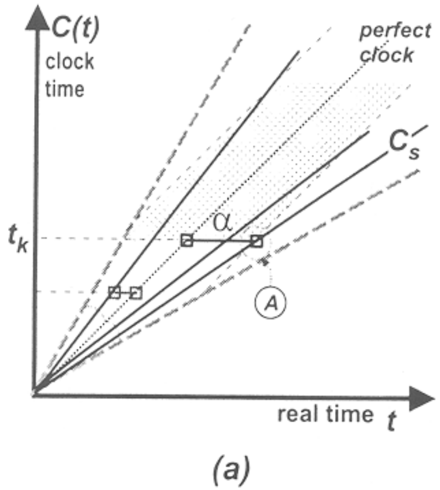
GPS (Global Positioning System):

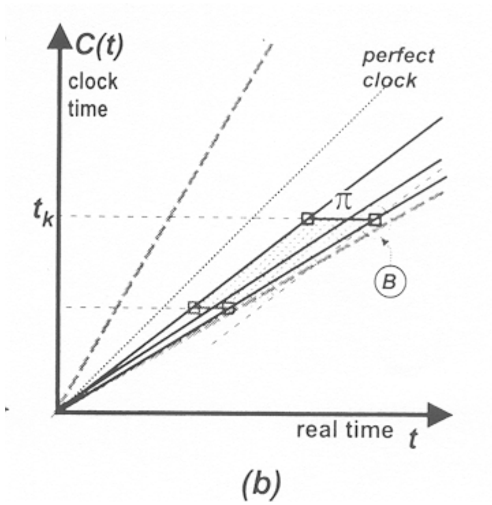
- network of 21 satellites covering earth surface
- equipped with cesium atomic clocks with high stability (ρ_g ca.10^{-14} , i.e. 1sec drift in 3 000 000 years)
- GPS-receiver clocks mostly provide UTC with an accuracy of $\alpha_g \leq 100$ns
- GPS receiver antenna must be placed externally (being under the light cone of the satellites)

4. Clock Synchronization

Assumption: the drift rate of each individual clock is bounded and time remains monotonically increasing ---> this allows to predict the maximum deviation after a given time interval.

Behavior of a Clock over Time:(a) Accuracy Drift; (b) Precision Drift





clock synchronization:
The process of maintaining the required properties of precision(*internal synch.*) and accuracy (*external* + *internal synch* ($\Pi = 2\,\alpha$) of a set of clocks

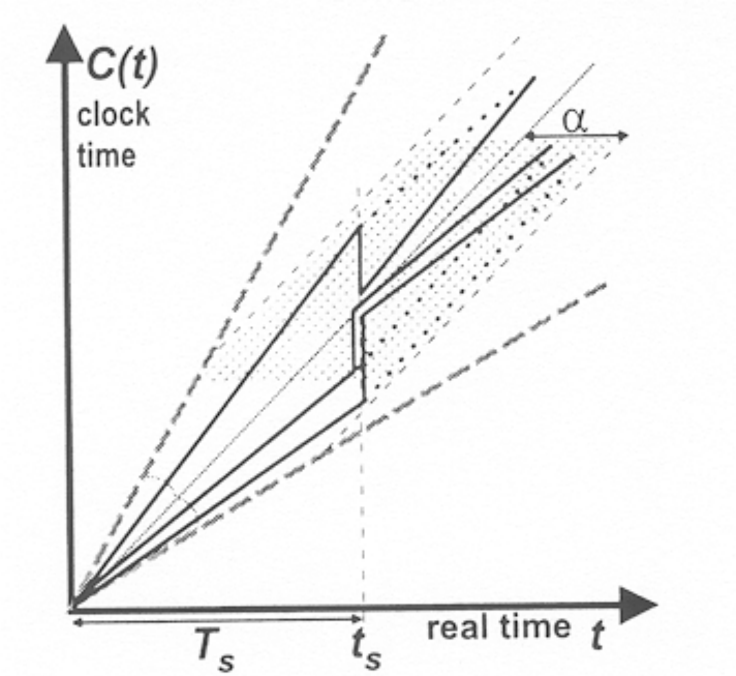
Real-Time (Paradigms) (13)

Basic result:

Convergence, i.e. the precision achieved immediately after the synchronization, cannot be made arbitrarily small due to a remote *clock reading error* caused by the variance in message delays.

resynchronization interval T_S: time interval between successive synchronizations

Clock Synchronization



amortization: rate correction factor applied when clock is read (instead of instantaneously changing the clock time)

state synchronization: adjusting clocks by changing their value (done by software, PC (hardware) clock remains unchanged)

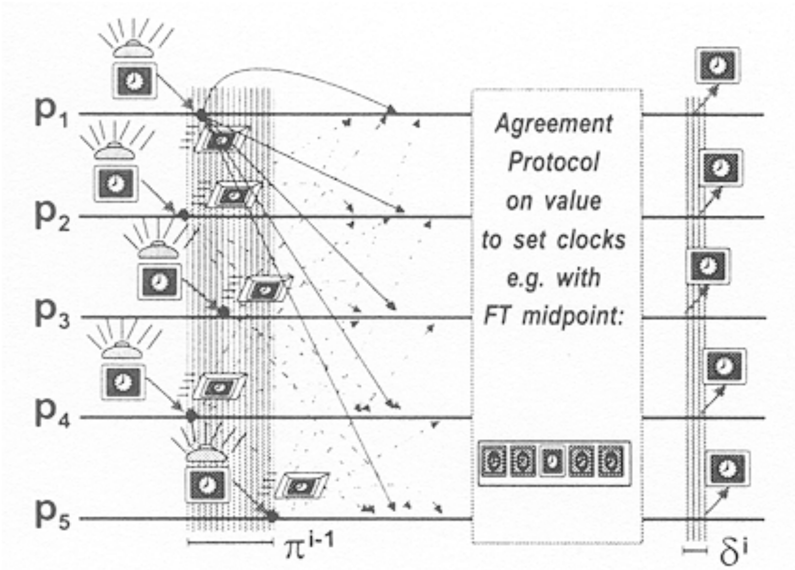
rate synchronization: adjusting the rate at which the hardware clock ticks

Real-Time (Paradigms) (14)

Internal Synchronization

Respective algorithms are normally cooperative, .i.e. each clock applies a *convergence function* after having read the values of the other clocks.

Averaging Synchronization



convergence functions could be, e.g.:

- average
- midpoint

Real-Time (Paradigms) (15)

Non-Averaging Synchronization

Instead of disseminating individual clock values and subsequently applying convergence functions agreed on, here, processors disseminate a control message to signal end of a synchronization interval.

Example