CprE 450/550X
Distributed Systems and Middleware

# Synchronization

## (Clock Synchronization)


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## Mid-term Exam and Course Project

- Mid-term exam
  - Close-book test
  - You can bring one sheet of note.
- Course project
  - Set environment

Create .bashrc and/or add the following two lines:

PATH=$PATH:/usr/local/java/bin

MANPATH=$MANPATH:/usr/local/java/man

  - Find a sample program to start with.
  - A book: "Java Network Programming and Distributed Computing"

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## Readings for Today's Lecture

- References
  - Section 5.1, Chapter 5 of "Distributed Systems: Principles and Paradigms"

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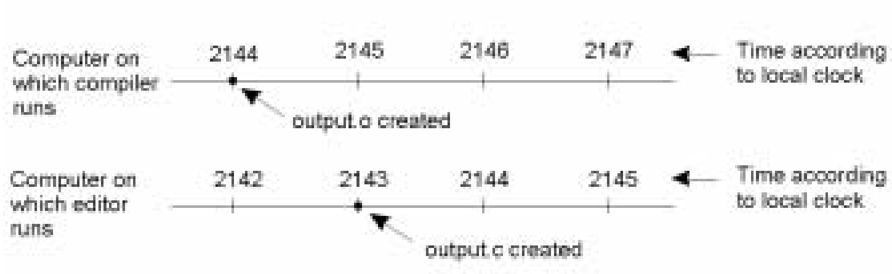
## Clock Synchronization

- In a centralized system, time is unambiguous
- In a distributed system, achieving agreement on time is not trivial.
- Example: UNIX makefile

  A change to one source file only requires one file to be recompiled, not all the files
- How make works?
  - Examine the times at which all the source and object files were last modified.
  - In a distributed system in which there is no global agreement on time, how?
- **Is it possible to synchronize all the clocks in a distributed system?**

# Clock Synchronization




When each machine has its own clock, an event that occurred after another event may nevertheless be assigned an earlier time.



# Physical Clocks

- Almost all computers have a circuit for keeping track of time.
- Computer Timer is a machined quartz crystal
  - When kept under tension, quartz crystal oscillates at a well-defined frequency, depending on the kind of crystal, how it is cut, and the amount of tension.
  - Two registers: a counter and a holding register
  - Each oscillation decrements the counter by one, when it gets to 0, an interrupt is generated and the counter is reset from the holding register.
  - Each interrupt is called a clock tick.
  - When the system is booted initially, date and time are required to be entered and deposited in CMOS RAM.
  - Each clock tick increases the time stored in CMOS RAM by one such that software clock can be maintained.

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# Physical Clocks

- It doesn't matter if the clock is off by a small of amount for a single computer with a single clock.
- For multiple CPUs with their own clocks, things change:
  - Though the frequency at which a crystal oscillator runs is fairly stable, it is impossible to guarantee the crystals on different computers run at the same frequency.
  - The crystals will run at slightly different rates, which result in the clocks out-of-sync. The time value difference is called clock skew.
  - Programs depending on the time associate with files, objects, messages may fail due to these clock skew.
- **How do we synchronize the clocks with real-world clocks?**

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# Physical Clocks

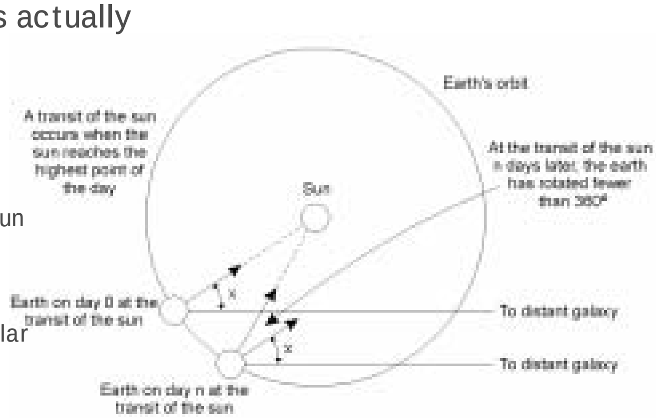
How time is actually measured?

Time has been measured astronomacally.

•Transit of the sun

•Solar day (24h)

•Solar second (1/86400 of a solar day)




Computation of the mean solar day.

## Physical Clocks

- With the invention of atomic clock in 1948, measuring time becomes more accurately by counting transitions of the cesium 133 atom.
- Physicists took over the job of timekeeping from astronomers
- A second is defined as the time it takes the cesium 133 atom to make exactly 9, 192,631,770 transitions. This number makes an atomic second equal to the mean solar second.
- BIH averages the number of clock ticks from 50 laboratories in the world to produce International Atomic Time (TAI).
- TAI=the mean number of ticks of the cesium 133 clocks since midnight on Jan. 1, 1958 divided by 9, 192,631,770 .



## Physical Clocks

- 86,400 TAI seconds is 3 msec less than a mean solar day.
- Over the years, noon would become earlier and earlier.
- BIH introduce leap seconds whenever the difference between TAI and solar time grows to 800 msec.
- Universal Coordinated Time (UTC) (replaced Greenwich Mean Time, which is astronomical time)
- NIST operates a shortwave radio station with call letters WWV from Fort Colins, CO.
- WWV broadcasts a short pulse at the start of each UTC second. +-1msec (+-10msce due to atmosphere fluctuations).
- Similar services, UK's MSF, GEOS (earth satellite), etc.

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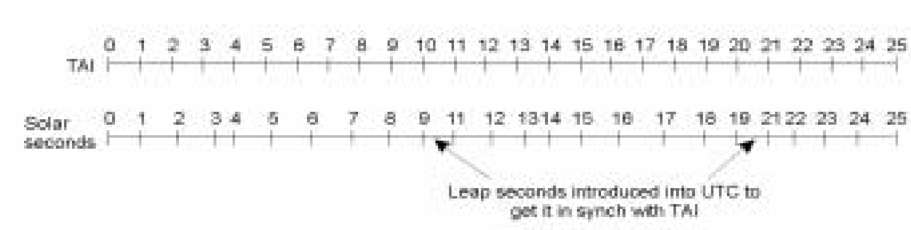
# Physical Clocks




TAI seconds are of constant length, unlike solar seconds. Leap seconds are introduced when necessary to keep in phase with the sun.

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# Clock Synchronization Algorithms

- Each machine is assumed to have a timer that causes an interrupt *H* time a second. When the timer goes off, the interrupt handler adds one to a software clock.

  C: value of the clock

  $C_p(t)$: The value of the clock at machine p at UTC time t.

- Ideally, $C_p(t)=t$ for all p and t. i.e., $dC/dt=1$
- In practice, the relative error obtainable with modern timer chips is $10^{-5}$.
- Maximum drift rate r, where $1-r <= dC/dt <= 1+r$.

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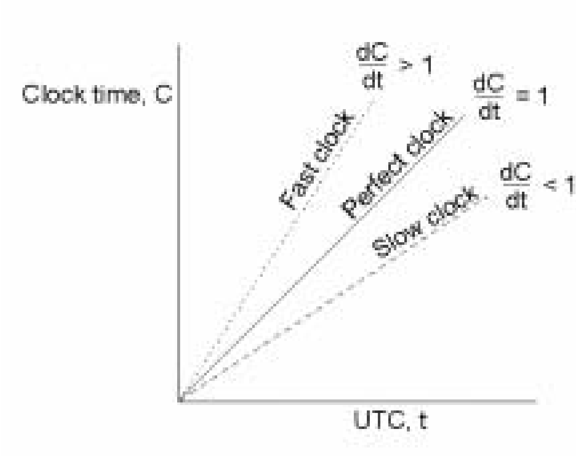
# Clock Synchronization Algorithms




The relation between clock time and UTC when clocks tick at different rates.

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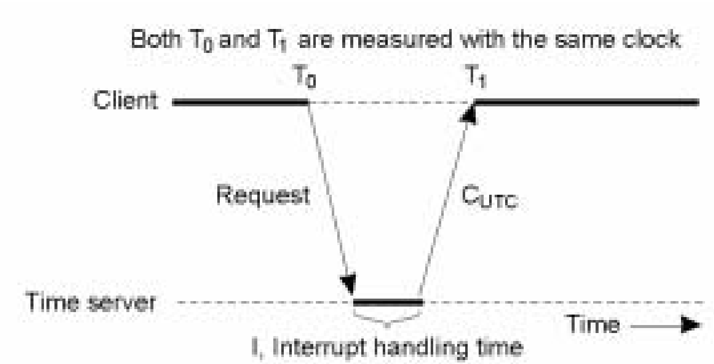
# Cristian's Algorithm




Getting the current time from a time server.

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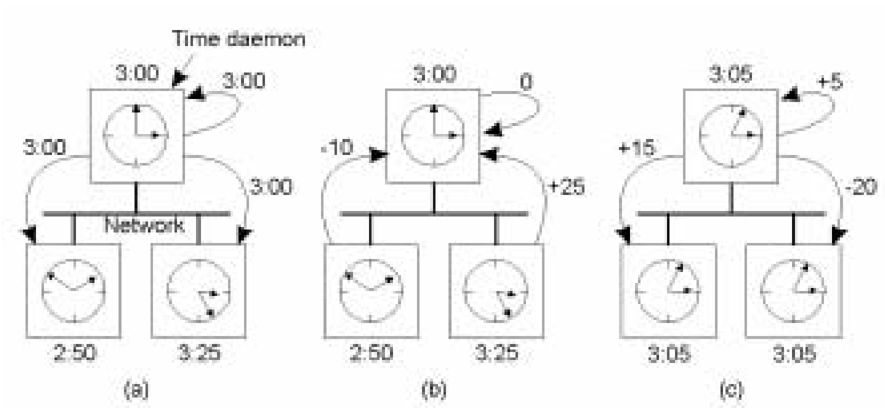
## The Berkeley Algorithm




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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## Averaging algorithm

- Dividing time into fixed-length re-sync intervals.
- At the beginning, each machine broadcasts its own time.
- After a machine broadcasts its time, it starts a local timer to collect all other broadcasts that arrive during some time interval S.
- Then,
  - Average the values from all the other machines
  - Discard the m highest and m lowest values, and average the remaining ones.
  - NTP (Network Time Protocol)
  - Can be further improved

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## Multiple External Time Sources

- WWV, GEOS receivers

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## Use of Synchronized Clocks

- At-most-once message dilivery
  - Message seq number, what about system crashes and reboots?
  - ConnID+timestamp

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Have a Good and Safe Spring Break!