Linux, the time, and the noise...

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Linux Kernel Hacking Free Course
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Outline

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1. **Time in Linux**
   - Introduction
   - Hardware devices
   - Why does Linux need timekeeping?
   - Timer
   - Tick
2. OS noise
   - Operating system overhead
   - OS noise on computer cluster
3. Bibliography

Does Linux need to keep track of flow of time?

Obviously, yes. . . but why?

- clock (`gettimeofday()` system call)
- CPUs time sharing among processes
- to support other system and user activities:
  - handling timeouts
  - delayed execution of procedures
  - keeping track of resource usage statistics
  - User mode alarm (`alarm()`, `setitimer()` system calls)

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Hardware devices (1/2)

Which hardware devices are available for timekeeping?

- Real Time Clock (RTC): battery-energized clock that keeps the current date and time even when the computer is switched off (e.g., Motorola 146818 chip in PC's)
- Time Stamp Counter (TSC): monotonically increasing counter, generally coupled with the system bus clock signal
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Wall clock time (1/2)

In Linux the *wall clock time* is the current time and date

Linux must keep track of it for:

- the `gettimeofday()` system call
- User Mode POSIX clocks and timers based on CLOCK_REALTIME (`clock_gettime()` and `timer_create()` system calls)
- for timestamps (filesystems, TCP protocol...)

Wall clock time (2/2)

Real Time Clock (RTC)

- When system is switched off the *Real Time Clock* keeps the current date and time
- typically reading RTC is slow
- RTC has low resolution and low accurancy

Wall clock time

- During the system boot Linux reads it and stores in the `xtime` variable the number of seconds elapsed since the Epoch (00:00:00 UTC, January 1, 1970)
- then continues to keep track of time without using RTC (we'll see how)

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Linux distributes CPUs time among processes according to a policy based on:

- processes' priority
- how long each process has been running

Processes with highest priority run first (with preemption!)

Once scheduled on a CPU, a process can run until:

- another process with highest priority claims a CPU
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Support for User and System activities

Linux (and in particular drivers) needs a mechanism to schedule an activity in the future and to handle timeouts:

Example (timeout)

- timeout for networking protocols
- waiting for data from a device

Example (User alarm)

- `alarm()` and `setitimer()` system calls

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Software Timer (1/2)

To handle delayed functions, periodic activities, and timeouts Linux implements a very useful mechanism, the *software timer*

A *software timer* allows to schedule the execution of a function in the future

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There are two types of timer:

High Resolution Timer

An hardware device is programmed to raise an interrupt when the HR timer expires and the related function is executed as soon as possible

Traditional Timer

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Tick: why?

To summarize, Linux needs to:

- keep track of current date and time
- keep track of how long each process has been running and execute periodically the scheduler (for CPU time sharing)
- check for traditional timer expiration
- . . . and execute other periodic activities, such as:
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  - etc. . .

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Tick: what is it? (1/2)

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Linux counts the number of ticks occurred since the system boot increasing monotonically a 64 bits variable called `jiffies_64`

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Tick: what is it? (2/2)

`jiffies_64`'s value is used to keep track of flow of time and thus to handle traditional timers, timeouts, etc. . .

Linux kernel can be configured in *dynamic tick mode*, so that when the CPU is idle ticks are stoped. In this case ticks do not respect `HZ` frequency, so `jiffies_64` needs to be adjusted using a clock source, such as TSC or ACPI_PM

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- periodically programs a device to raise one-shot interrupts at the nearest event (with High Resolution Timer support or in dynamic tick mode) , or
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What happens at each tick?

each CPU has to

- perform profiling activities
- check for expired traditional timer (and possibly execute related functions)
- account CPU time to the current process
- execute the scheduler (only if needed)

only one (elected) CPU has to

- update `jiffies_64`
- update wall clock time (`xtime`)

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Tick and operating system overhead

The *operating system (OS) overhead* is the amount of time a CPU spends while executing system's code

Ticks periodically interrupt the running process and can launch other activities (such as timer functions or scheduler)

After updating `jiffies_64` some timeouts can expire, so related functions are executed

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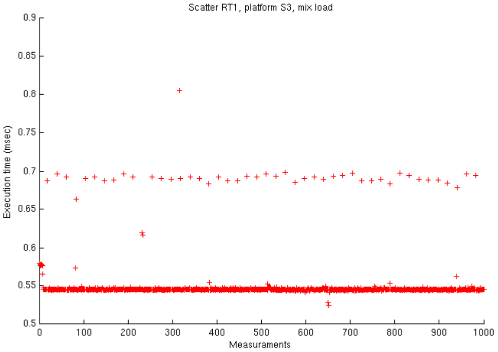
What about a running process?



Difference between a run with interrupts disabled and another with SCHED_FIFO priority on a CPU that does not handle interrupt, except the local timer interrupt (tick)

OS overhead for an application that calculates an FFT

Computer Cluster

A *computer cluster* is a group of homogeneous computers (nodes) that work together. The nodes of a cluster are interconnected to each other through a fast network

Clusters are widely used in High Performance Computing (HPC) and commonly the applications are based on Message Passing Interface (MPI) or on Parallel Virtual Machine (PVM) libraries

Typically on each node there is a number of processes equal to the number of avalaible CPUs or cores

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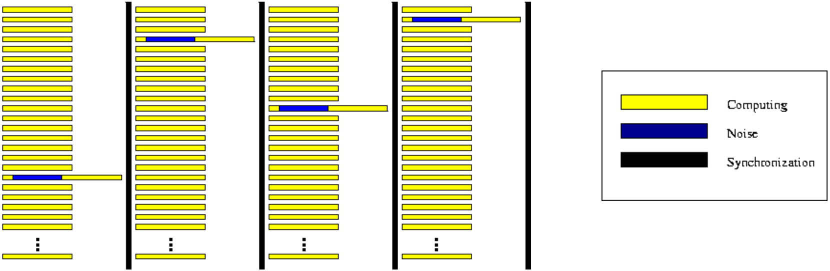
What about OS overhead in a cluster?

Even if the OS overhead in a node can be 1-2% (on average) the overhall effect on a large cluster increases considerably

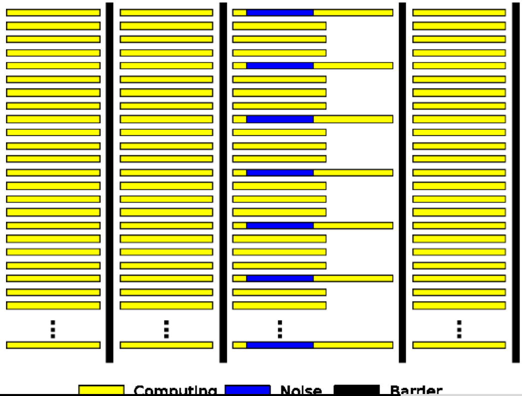


If, on each computational phase, all the processes have to wait for one slow process the whole parallel job is delayed

This can be defined **OS noise**

OS noise and clusters

On large clusters the probability that during each computational phase one process is delayed due to the OS approximates 1



A possible solution is forcing all cluster's nodes to perform system activities at the same time

Nettick

Now, I can leave you in the hands of Francesco. . .

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