Scuola Superiore Sant'Anna

Real-Time System Laboratory

Linux and Real-Time: Current Approaches and Future Opportunities

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Summary

- Why Linux for real-time applications?
- Problems in using Linux for real-time
- Making Linux more real-time
  - Interrupt Abstraction approach
  - Kernel Preemption
- Current and future approaches

Why Linux for Real-Time

- A raising interest from industry
  - small automation companies
  - big software companies (e.g. IBM and WindRiver)
- Reason for using Linux
  - Open Source License (GPL)
  - Standard Interface (POSIX)
  - Wide popularity and success
  - Available for almost all embedded processors (ARM, MIPS, PPC, etc.)
- Total Cost of Ownership (TCO)
  - lower than other commercial (closed source) RTOSs

Application areas

- Linux cannot be used everywhere

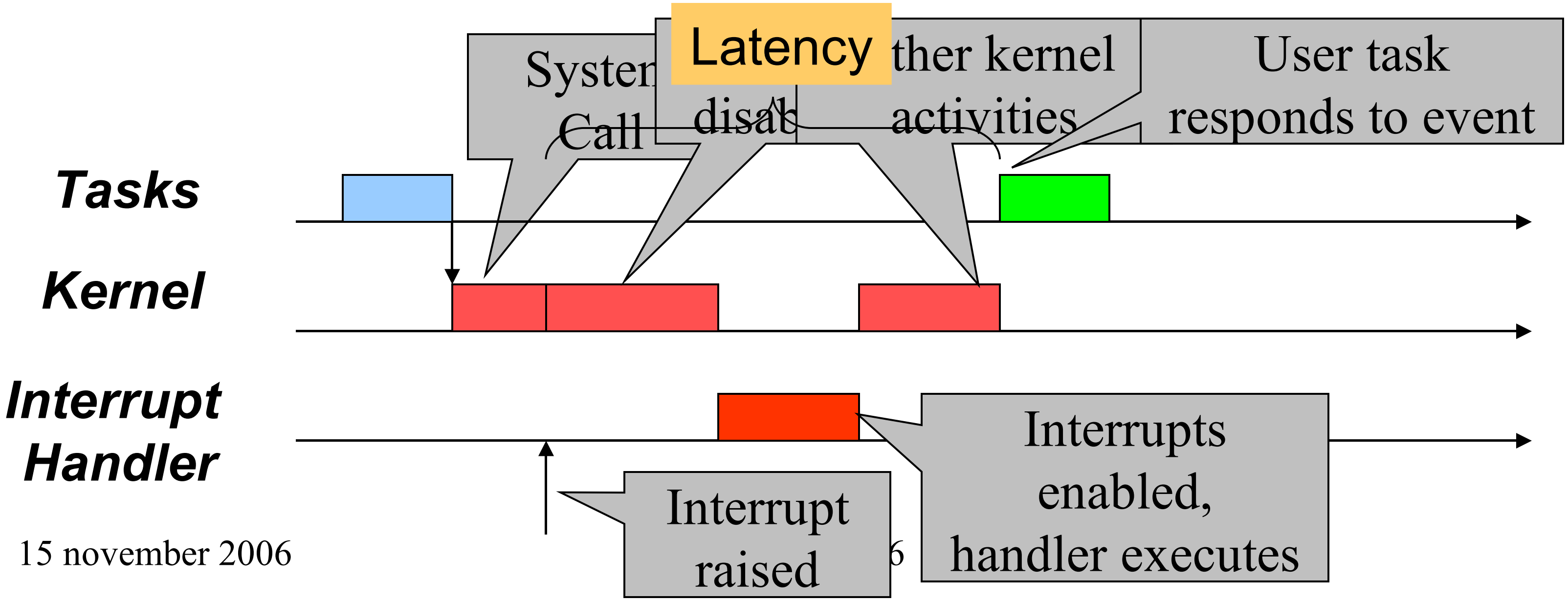
- Memory constraints
  - some embedded systems have limited memory
  - Linux requires at least 4-8 Mbytes (Flash and RAM)
- Criticality constraints
  - some application require certification of the kernel
  - Linux is too big to be certified

Problems

- Mainstream kernel
  - officially supported by Linux Torvalds
  - optimized for troughput and performance
  - not designed for real-time performance
- Latency and real-time
  - the main problem is the high worst-case latency of time-critical operations
  - average-case latency is quite small ...
  - ... but real-time systems need <u>predictability!</u>
- Scheduler
  - linux supports only Fixed Priority Scheduling

Problem: Latency

- Definition:
  - *interval of time between the arrival of an interrupt signal to the processor the start of the handler that responds to the interrupt*
  - handler = real-time task awaken by the interrupt handler



The causes of latency

- Task Latency
  - some part of the kernel cannot be interrupted (critical sections of code)
  - user-level code is scheduled only when the kernel finishes to process kernel activities
  - Kernel activities can accumulate and be very long
  - Linux 2.4.17 → max latency = 230 msec!
- Timer Resolution
  - periodic activities are wake-up by timers
  - standard timer resolution is coarse-grained (1-40 msec)

Problem: Scheduler

- Linux supports Fixed Priority Scheduling
  - standard POSIX policies SCHED_FIFO and SCHED_RR
  - both suitable for real-time
  - can only be used by process with root privileges

- Security concerns
  - a buggy process with high priority can hang the system
  - not easy to handle overload situations

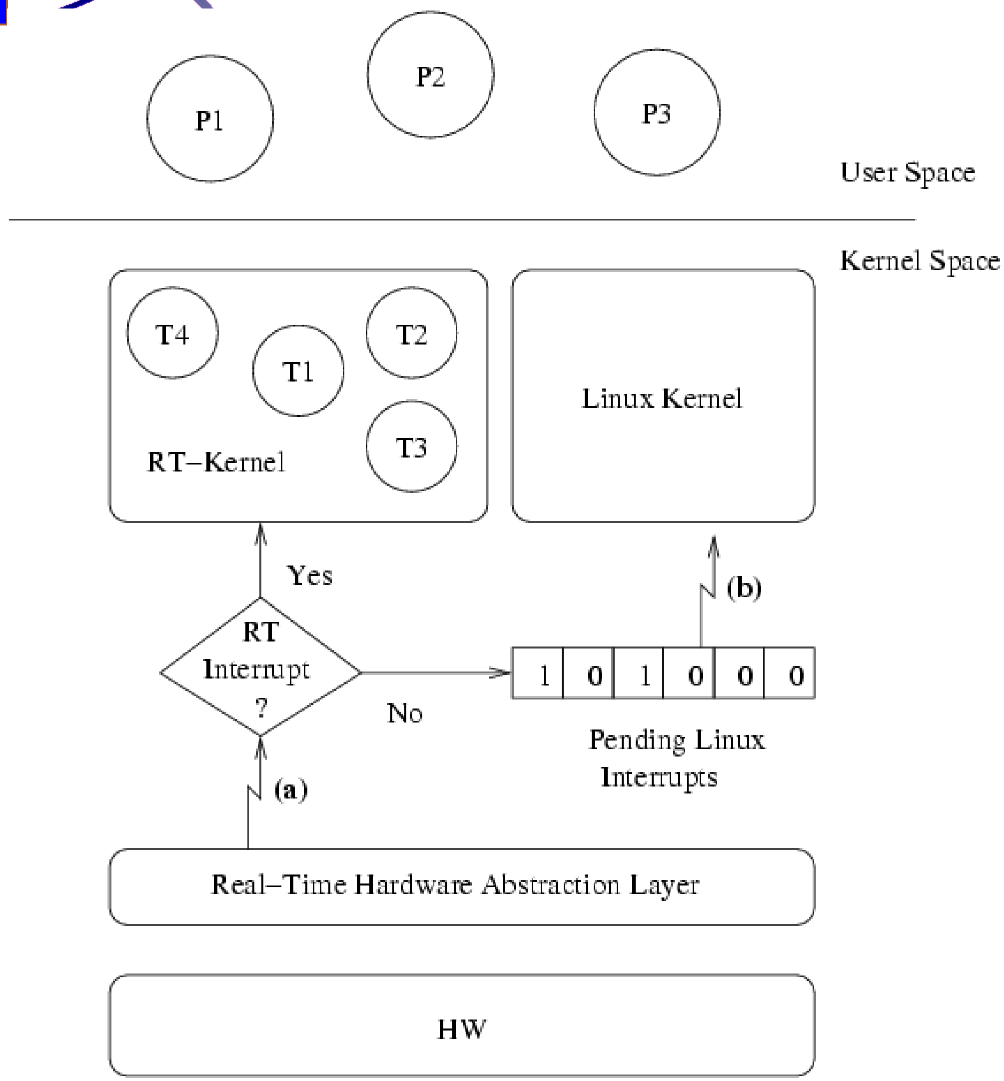
Making Linux more real-time

- Two approaches

- Interrupt Abstraction
  - uses a special micro-kernel for RT and executes Linux as a low-priority task
  - Used by RTLinux, RTAI, Xenomai

- Kernel Preemption
  - The hard way....
  - Reduce Latency in Linux

Linux-RT: Interrupt Abstraction



- The abstraction layer
  - intercepts interrupts
  - forwards to Linux of to RT
- If RT task execute
  - Linux interrupts become pending
  - RT interrupt are served immediately
- When no RT task executes
  - Linux interrupts are served all at once

Interrupt abstraction

- Advantages
  - Effective reduction of latency
  - Use of standard Linux processes for non-real-time
  - host and target platform may coincide
- Disadvantages
  - different interface for RT tasks
  - RT tasks execute in kernel memory space
  - buggy RT code can block the system
  - need to re-write Linux device drivers for RT
  - difficult to use!!

LXRT and Xenomai

- LXRT
  - an interface provided by RTAI
  - allows to execute RT tasks in user space (at the price of a higher latency)
  - useful for development and debugging
- Xenomai
  - A spin-off of RTAI
  - allows to execute RT tasks in user space with very low latency
  - allows to write device driver code in user space

Linux-RT: Kernel preemption

- Reduce Linux latency
  - this approach allows to execute Linux processes with Real-Time performance
- Modification to Linux code to:
  - Improve timer resolution
  - Insert preemption points in the kernel
  - Introduce kernel threads
  - Call the scheduler more frequently

Kernel preemption in 2.4

- Linux 2.4
  - Preemption Patch
    - Introduce preemption points in long sections of code
    - in this way, very long and non-interruptible sections of code can be split in different parts
  - Low Latency Patch
    - Call the scheduler more frequently in long sections of code
  - High Resolution Patch
    - provides an API for micro-second level precision timers
- Results
  - latency reduction
  - but not yet usable for real-time

Kernel Preemption in 2.6

- Linux 2.6
  - introduces kernel threads
    - a device driver can use a kernel thread (scheduled with the other processes)
  - O(1) scheduler
    - scalable with number of threads
- Preempt_rt patch
  - Support for many improvements
    - Priority Inheritance for reduction of task blocking time

Comparison

- The following table is provided by Paolo Mantegazza (available on Internet)

Interrupt Latency

Kernel	Aver	Max	Min	Std Dev
Std Linux 2.6	**6.8**	**555.6**	**5.6**	**7.2**
Preemption patch	**7.3**	**70.5**	**5.6**	**1.8**
Adeos (RTAI)	**7.6**	**50.5**	**5.7**	**0.7**

numbers are in micro-seconds

Which flavor of Linux RT to use?

- For hard real-time applications with very small constants of time (below the milliseconds), it is still necessary to use RTLinux,RTAI or Xenomai

- There has been a constant effort to reducing the latency of the standard Linux kernel

- It is possible to use standard Linux with Preemption Patch for
  - soft realtime applications,
  - or even hard real-time applications with large constants of time

Conclusions

- Linux has become very polular for supporting real-time applications
- Many projects have been proposed to make Linux more real-time
- In the next future, standard mainstream Linux will include RT support
  - low latency
  - appropriate scheduling policy