An Essential Relationship between Real-time and Resource Partitioning

Yoshitake Kobayashi
Advanced Software Technology Group
Corporate Software Engineering Center
TOSHIBA CORPORATION

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The latest slide is available at the following URL

http://elinux.org/ELC_Europe_2013_Presentations
Background

- **Hardware**
  - Multi-core CPU
  - Larger memory
  - Larger storage space
  - Hardware assisted virtualization

- **Software**
  - Operating system
    - Linux
  - Virtual Machine Monitor
Background

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- **Issues on real-time systems**
  - Meet its required deadline
    - ex. Control systems
  - Performance requirement
    - Interrupt latency
    - Response time
Requirement (1)

- A system needs to be able to run both real-time (RT) application and general purpose (GP) application at same time

- All Real-time application should meet its real-time constrain
  - Response time (Deadline): 100μs – 100ms
  - Event response time (Interrupt latency): 10μs – 100μs
A sample of current implementation

- Implement RT application on a specific hardware
- Implement GP application on other hardware
- Connected by a bus or share memory
Requirement (2): Make a simple world

- **A system software able to control RT and GP**
  - System software: OS, VMM

![Diagram showing Real time process and General purpose processes](image)
Hybrid OS vs. Single OS approach
Hybrid OS vs. Single OS approach

**Hybrid OS**
- More than one OS runs on same hardware
  - RT specific tasks run on RTOS (Real-Time Operating System) and the other tasks run on GPOS (General Purpose Operating System)
    - ex. Linux and uITRON
- Possible implementations
  - By VMM
  - Run GPOS as a task on RTOS
- RTOS and GPOS have different APIs
  - Xenomai

**Single OS**
- Just use one OS to run both RT and GP applications
- Same API can be used for all applications
- Possible implementations
  - Kernel level RT process
  - RT-Preempt patch
Hybrid architecture (Xenomai)

- **Xenomai**
  - Reference: [http://www.xenomai.org](http://www.xenomai.org)
  - Dual kernel approach based on Adeos/I-Pipe
  - I-Pipe works to dispatch events (ex. Interrupts)
  - Xenomai skins build on top of the Xenomai nucleus to provide RTOS APIs such as VxWoks, uITRON
Hybrid architecture (TOPPERS SafeG)

- **SafeG (Safety Gate)**
  - Dual-OS monitor
  - Execute an RTOS (Real-Time Operating System) and a GPOS (General-Purpose Operating System) on the same hardware platform
  - ARM TrustZone security extensions uses to introduce the concept of Trust and Non-Trust states
  - On the other hand, code running under Non-Trust state, even in privileged mode, cannot access memory space (devices included) that was allocated for Trust state usage, nor can it execute certain instructions that are considered critical.
Hybrid OS vs. Single OS approach

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Requirement (3): Linux

- Linux runs both RT and GP applications
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- Linux runs both RT and GP applications

- This is not a good idea if you don’t care anything
Summery of requirements

- RT process and GP process are able to run on a hardware platform
- Need to meet required deadlines
  - One of the most important perspective for embedded systems
- Use single OS approach
  - Linux
Issues to run RT process and GP process

- Determinism
  - RT process should have a deterministic behavior
  - GP process doesn’t assume deterministic behavior
How to improve real time performance?

- **Real-time Preemption Patch**
  - Fully preemptive kernel
  - Improvement for latency

- **CPU affinity**
  - Prohibit process migration from one core to another
  - Protect from GP process behaviour
  - Maybe good for determinism

![Diagram showing RT thread, GP thread, and Scheduler in RT CPU core and GP CPU core](image)
Definition of hardware resource partitioning

- Partition is a set of hardware resource
  - CPU cores, Memory, Devices, ..
- Each partition must be isolated from the others
  - No device sharing
A use case of CPU affinity for RT process

- Run a set of process and thread on specific CPU core
  - RT process
  - CPU core 1
  - CPU core 2

Advantage

- No process migration
  - Process migration is not friendly with real time behaviour
  - Migration timing cannot be expected
- Just RT process runs on specific cores
  - Isolate all GP process into the other cores
Evaluation of interrupt latency with CPU affinity

Evaluation environment

- Hardware: Pandaboard
- Period: 300μs
Evaluation of interrupt latency with CPU affinity

![Graph showing interrupt latency with and without CPU affinity.](image)
What’s occurred?

Cascade occurs here
Limitation of CPU affinity

Example for CPU core specific kernel thread

- **Timer**, High resolution timer
- Process migration
- Etc..
Cascade timer list

- **Cascade timer**
  - Register the next timer list to the end of current one

- **Impact of cascade timer to interrupt latency**
  - Runs with interrupt disabled context
  - No limits for the number of timers
  - Timer process cost is higher if tickless kernel used
Control cascade timers on RT CPU core

Solution

- Keep the timer list empty on RT core to protect from cascade timers
Three issues which cause cascade timers

(I) Registered by GP process before migration
(II) Registered by RT Core specific kernel thread
(III) Registered by RT Core specific kernel thread before RT task runs

Expired timers causes cascade
Solution for the issue (I)

- **Preparation**
  - Log all timer registration by kernel thread

- **Solution**
  - (A) Migrate kernel threads or a GP processes to GP core
  - (B) Migrate registered times to GP core refer the log
    (Timer migration)
Solution for the issues (Ⅱ) and (Ⅲ)

(Ⅱ) Registered by RT Core specific kernel thread
(Ⅲ) Registered by RT Core specific kernel thread before RT task runs

Case 1: Not enough time to migrate
   Wait for expiration

Case 2: Enough time to migrate
   Migrate the timer to GP core

Restrict to register new timers to the GP core only
Evaluation

Before

After

Cascade occurs here


**Summery**

- **Requirement**
  - RT processes and GP processes on a same hardware platform
  - Just use Linux for both processes
  - Meet its required deadline for RT process

- **Hardware resource partitioning**
  - Set of hardware resources which is isolated from the others
  - Define CPU cores as RT core and GP core

- **Issues to implement the resource partitioning**
  - Some kernel thread cannot be migrated
    - Core specific kernel thread
  - Need to care with CPU affinity feature
    - Focused on cascade in timer.c
    - Protect from cascade function on RT core
      - Keep timer list empty

- **Future plan**
  - SCHED_DEADLINE on RT core with fine granularity support