MaRTE-OS: Minimal Real-Time Operating System for Embedded Applications

FOSDEM 2009 Ada Developer Room

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About us and MaRTE-OS

The presents...

**Miguel Telleria**
- **User** of MaRTE-OS since 2006
- Devel of FRESCOR code for CPU scheduling... in C
- Firm Adaist defender since 1998

**Daniel Sangorrín**
- **User and devel** of MaRTE-OS since 2004 in Ada and C
- **Maintainer** of MaRTE-OS drivers and the web
- Implementor of FRESCOR code for Network scheduling in Ada
- Firm Adaist defender since 2003

... and the absents:

**Mario Aldea**  Originator and mainmaintainer of MaRTE-OS

**Michael González Harbour**  Leader of our lab for MaRTE-OS project
Outline

1. What is MaRTE OS
   - MaRTE-OS features and architecture

2. Real Time systems
   - Real Time generalities
   - Minimal Real Time POSIX 13 Subset
   - Ada 2005 Annex D. Services
   - Application Defined Scheduling

3. FRESCOR and flexible scheduling
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MaRTE is an Operating System

Like any other OS... It manages tasks, devices and memory

- Schedules tasks.
- Manages memory.
- Handles I/O and interrupts.

... somethings make it special ...

- Real time oriented: Time predictability.
- Has nice scheduling features.
- Easy to deploy in embedded systems.
- It is written in Ada (runtime exception checking).
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**Developed at CTR, University of Cantabria**

- Main maintainer: Mario Aldea (this was his Ph.D.)
- First presented in Ada Europe 2001 (Leuven)
- Contributions from other institutions: AdaCore (GNAT runtime), Valencia (TLSF), Zaragoza (Wifi and industrial drivers), York (jRate)
- Releases available (GPL) at [http://marte.unican.es](http://marte.unican.es)

**Initial academic objective**

- Provide students a Free and simple Real Time Embedded OS Playground for our research (scheduling policies, Ada & POSIX standards...)

**Now used in industrial applications**

- Welding robot
- GPS receiver
What is Real Time systems FRESCOR and flexible scheduling architecture

History and evolution

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Characteristics

Follows the Minimal Real-Time POSIX.13 subset

- Concurrency at thread level (all program is a single process)
- Single memory space (threads, driver and OS)
- Static link: Output is a single bootable image. No filesystem required.

\(^a\) An experimental FAT filesystem is available

(almost) unique features

- Implements new Ada 2005 Annex D (Real Time) services.
- Implements Application Defined Scheduling proposal.
Architecture

Ada Application
- POSIX-Ada Interface
- Ada Run-Time System (GNARL) and Ada standard packages (Ada.*)
- POSIX Interface
- MaRTE OS Kernel
- Abstract Hardware Interface
- Platform

C Application
- POSIX-C header files (*.h)
- POSIX Interface
- MaRTE OS Kernel
- Abstract Hardware Interface
- Device Drivers
- Platform

Ada application running on MaRTE-OS

C application running on MaRTE-OS
Three modes

- **x86_arch**
  - Standalone bootable image.
  - Access hardware with MaRTE drivers.
  - Provides full real time behaviour.
  - Debug through serial console or ethernet traces.

- **linux_arch**
  - Statically linked executable file on Linux.
  - Threads use MaRTE-OS scheduler.
  - Linked exclusively with MaRTE-OS libs.
  - Functional testbench debuggable with GDB

- **linux_lib**
  - Dynamically linked executable file on Linux.
  - Threads use MaRTE-OS scheduler.
  - Linked with the system’s glibc (and other external libs).
  - Can use Linux filesystem.
  - Way to use scheduling features of MaRTE on Linux.
GNAT run-time library has been adapted for MaRTE-OS. New RTS:marteuc

- Exceptions, run-time checks etc are handled by GNARL the usual way.
- The low level part of GNARL uses a POSIX thread interface and it has been re-routed to MaRTE kernel.
- Some low level POSIX calls are rerouted to Linux for linux_arch and linux_lib
- MaRTE RTS is developped specifically for a GNAT version. We follow AdaCore GNAT GPL editions.

Support has been added for C++ run-time.

- Constructor and destructor calls.
- uSTL library.
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**Concept of Real Time**

Having the results **on time** is as important as the results themselves.

**Goal: Time predictability**
- In hardware (detection of events, transmissions of commands)
- In operating system and network (context switch, timed services, network Tx/Rx)
- At the application level (through analysis techniques)

<table>
<thead>
<tr>
<th></th>
<th>Goal</th>
<th>Overload</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non Real Time</td>
<td>Maximum throughput</td>
<td>Global fair impact</td>
</tr>
<tr>
<td>Real Time</td>
<td>Attain all deadlines</td>
<td>Penalize only low priority tasks</td>
</tr>
</tbody>
</table>

**Real Time doesn’t mean maximum throughput**
- Extensive computing: Overload is fairly distributed among tasks
- Real Time computing: Overload is distributed to the lowest priority tasks
Real Time generalities

Real Time tools

How to achieve time predictability in the OS

- Strict preemptive scheduling policies (priority and/or deadline driven).
- Use O(1) queueing algorithms to be independent of nr of tasks, pending timers, etc.
- Implement a mechanism to avoid priority inversion in synchronisation.
- Use real time network protocols that avoid unbounded collision time.
- Eliminate active (polling) waits.

Tools offered for the application

- Tools to implement waiting synchronisation and mutual exclusion.
- Tools to measure time (elapsed and consumed).
- Efficient mechanisms to trigger time events.
- Analysis tools exist offline (e.g. MAST) and online (FRESCOR) to ensure the schedulability of the system.
The whole POSIX (Portable Operating System Interface) too large for real time.

- POSIX.13 defines four real-time system subsets (profiles)

### POSIX profiles

<table>
<thead>
<tr>
<th>Profile</th>
<th>File System</th>
<th>Multiple Processes</th>
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<tbody>
<tr>
<td>Minimal</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Controlled</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Dedicated</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>Multi-purpose</td>
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</table>
Minimal Real time POSIX 13 Subset Cont’d

Functionality included in the minimal profile:

- Threads (policies FIFO, Round-Robin and Sporadic Server)
- Mutexes, condition variables, semaphores
- Signals Clocks and timers
- Clocks and timers
  - CPU-time clocks and timers
- Thread suspension, absolute and relative delays.
- Device “files” and device I/O (open(), read(), write(), ...)

Ada was always concerned with supporting timing aspects

- Provides native types for time: Duration and Time Span
- Defines a FIFO priority based scheduling policy (dispatching model)
- Provides operation for absolute and relative delays.

With Ada 2005 Annex D. POSIX features have been added

- New dispatching policies: Earliest Deadline First and Round-Robin
- Timing events.
- Execution-time clocks and timers (and also for task sets)
- Dynamic priorities for Protected Objects
- Priority ceilings on Protected Objects

MaRTE OS is the first platform to support all these new Ada 2005 additions.
Application Defined Scheduling

We interfere with the scheduler to produce a new policy.
Real Time systems FRESCOR and flexible scheduling

Application Defined Scheduling

Example: Sporadic server

- Aperiodic Requests
- Task
  - High
    - (T, C) (3, 0.5)
  - Sporadic Server
  - Low
    - (12, 5)

Budget

0  1  2  3  4  5  6  7  8  9  10  11  12

0  1  2  3  4  5  6  7  8  9  10  11  12

0.5  1.0  1.5

0.0  0.5  1.0  1.5

A1  S1  R1  A2  S2  A3  S3  R2  A4

Task
  - C=0.5, T=3
  - C=1.5, T=6
  - C=5, T=12

Sporadic server
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FRESCOR: Framework for Real-time Embedded Systems based on COntRacts

Goal: Facilitate the adoption of flexible real time scheduling.
Hard real time vs Flexible real time

**Traditional real-time**
- Worst case response.
  - Static resource allocation.
    - Single mode
  - No time protection.
  - No adaptation to load change.

**Flexible real-time**
- Worst case response + QoS
  - Dynamic resource allocation
    - Multiple mode
  - Time protection.
  - Load change adaptation:
    - **Spare capacity**: (mode change)
    - **Dynamic reclamation**: (execution)

**Benefits of Flexible Scheduling**
- Maximise resource usage.
- Integration of heterogeneous resource requirements.
- Real time theory implicitly integrated in system.
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Flexible Scheduling Execution

- **Mode 1**: $C_A = 3$ $T_A = 6$ $C_B = 1$ $T_B = 3$
- **Mode 2**: $C_A = 1$ $T_A = 3$ $C_B = 3$ $T_B = 6$
Contract model

Requirements specified in contract

- Min-max budget, period and deadline.
- Task model: Job-based, continuous, background.
- Importance and weight as criteria for spare capacity distribution.
- Critical sections (with their WCET) on shared objects.

Negotiation and binding

FRESCOR ensures that no task goes over its budget. It can also perform an acceptance analysis.
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Real Time systems FRESCOR and flexible scheduling

**FRESCOR project**

- **QoS Adapter**
- **MyCCM Component Framework**
- **distributed Transaction layer**
- **FRSH Middleware**
- **RapiTime WCET tool**

- **Response-time analysis**
- **FSF evolves into FRSH**

**Execution Platforms**
- OSE
- AQuoSA
- PaRTiKle
- MaRTE OS
- RapiTime simulator
and now some hands-on work...