# 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 main maintainer of MaRTE-OS

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

# Outline

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

# 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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# History and evolution

## 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`

## 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

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# Characteristics

## Follows the Minimal Real-Time POSIX.13 subset

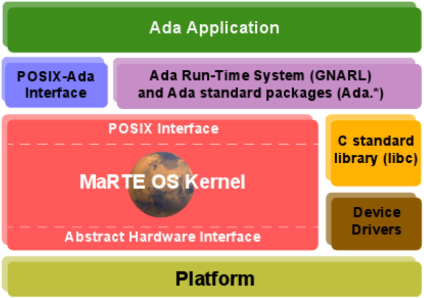
- Concurrency at thread level (all program is a single process)
- Single memory space (threads, driver and OS)
- Static link: Output is a single bootable image. No filesystem required [a]

[a] An experimental FAT filesystem is available

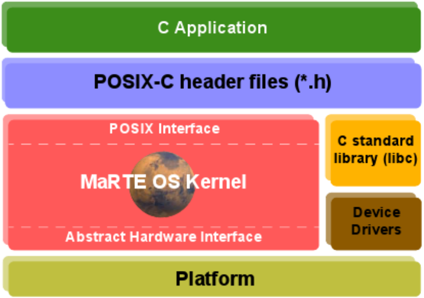
## (almost) unique features

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

# Architecture




Ada application 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.

# Architecture (cont'd)

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.

# Outline

# 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)

| | Goal | Overload |
|---|---|---|
| Non Real Time | Maximum throughput | Global fair impact |
| Real Time | Attain all deadlines | Penalize only low priority tasks |

## 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

# 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 schedulabiloity of the system.

# Minimal Real time POSIX 13 Subset

The whole POSIX (Portable Operating System Interface) too large for real time.

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

## POSIX profiles

| **Profile** | **File System** | **Multiple Processes** |
|---|---|---|
| Minimal | No | No |
| Controlled | Yes | No |
| Dedicated | No | Yes |
| Multi-purpose | Yes | Yes |

# 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()`, ...)

Available for C and Ada (Ada bindings implemented in FLORIST).
Implemented in Ada.

# Ada 2005 Annex D. Services

## 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.

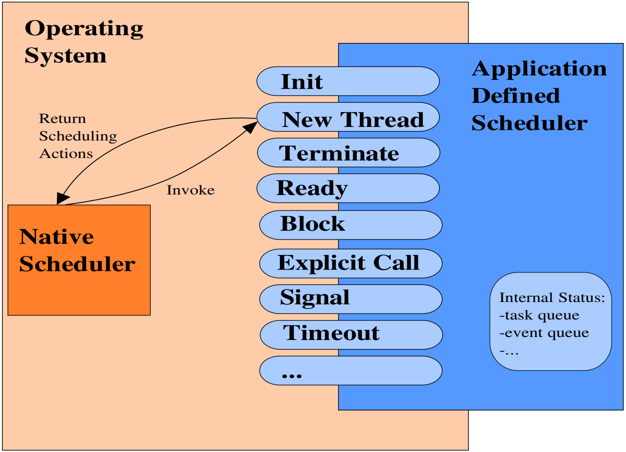
## With Ada 2005 Annex D. POSIX features have been added

- 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

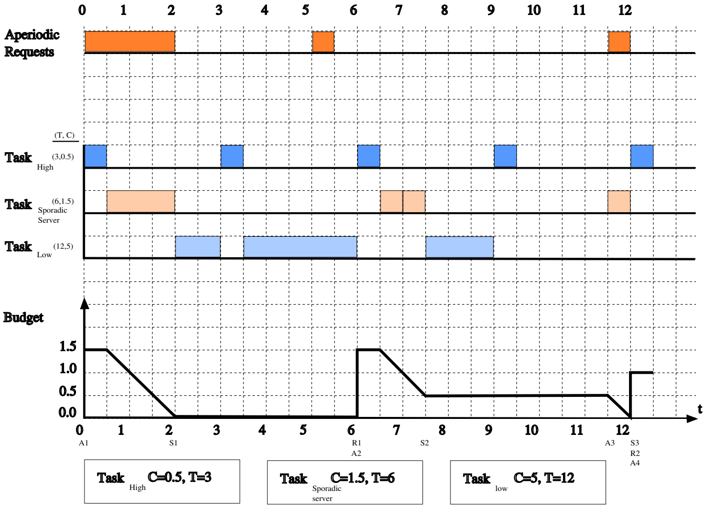
MaRTE OS is the first platform to support all these new Ada 2005 additions.

# Application Defined Scheduling

We interfere with the scheduler to produce a new policy.

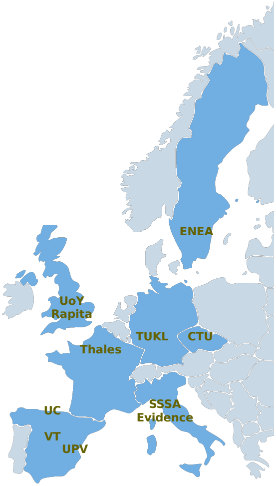


# Example: Sporadic server



# Outline

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




frescor

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 implicitely integrated in system.

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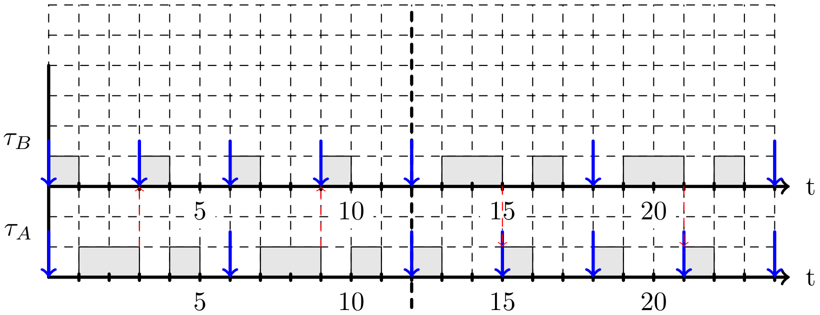
# Flexible Scheduling Execution

- **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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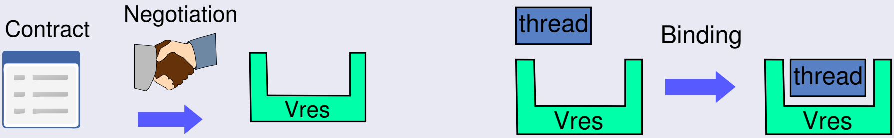


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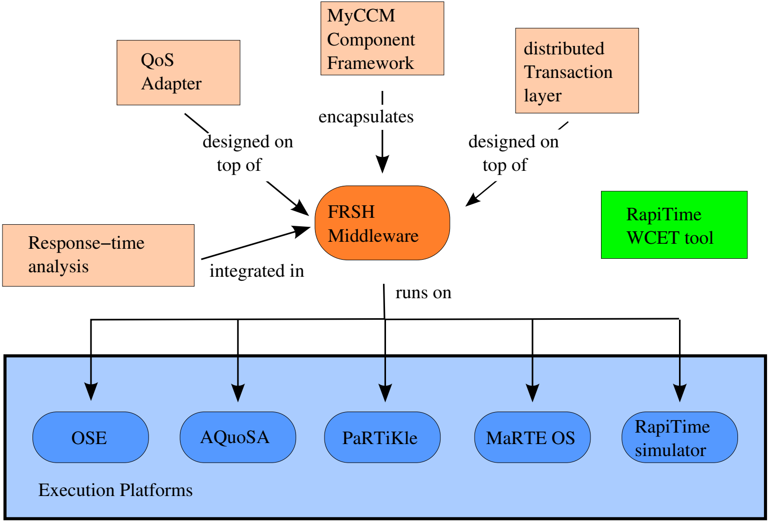
# FRESCOR project




FSF evolves into FRSH

and now some hands-on work...