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EMBEDDING TECHNOLOGY

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Linux in ambito industriale, real-time, hypervisors e boot veloce

Paolo Gai, pj@evidence.eu.com

Bruno Morelli, bruno@evidence.eu.com

Applicazioni industriali e real-time su dispositivi eterogenei multi/many-core

T3Lab, Bologna, 18/10/2017

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The company

Founded in 2002 as spin-off company of the
Real-Time Systems Lab at Scuola Superiore S.Anna

- ~22 qualified people with an average age of 38 years
- 15+ years of experience in academic and industrial projects
  - One third of the company has a PhD degree

Our Mission:
We design and develop great software for small electronic devices

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products and services

RTOS , Firmware, Embedded Linux

- AUTOSAR, OSEK/VDX, device drivers
- Embedded Linux: 12 Yrs experience BSPs, GCC, U-Boot, Kernel drivers
- Initial developers of the SCHED_DEADLINE patch
- Hypervisors, Android, Ubuntu Core, QEMU and emulators

Application Development

Model-based design

- Matlab/Simulink/Stateflow
- National Instruments LabView
- E4Coder toolset for code generation
- UML/SYSML/Ecore/ Eclipse/Acceleo

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Linux and Real-Time

Why is a Real-Time Linux interesting?

- Merge together the real-time part and the HMI on the same machine
- Availability of Linux API and device drivers with real-time properties

What is the current status of Real-Time Linux?

It depends a lot on…

- the CPU architecture chosen for the product
- the peripherals (mainly the device drivers!)
- the needed quality of service

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Linux, Real-Time and QoS

- Hard Real-Time < 1ms
  - Multi-OS Approach (with/without hypervisor)
  - Dual-OS Approach (RTAI/Xenomai)
- Soft Real-Time 1-10ms
  - Preemption Patch
  - Real-Time priorities
  - SCHED_DEADLINE/GRUB
- Soft Real-Time > 10ms
  - Unpatched kernel
  - Real-Time priorities
  - SCHED_DEADLINE/GRUB

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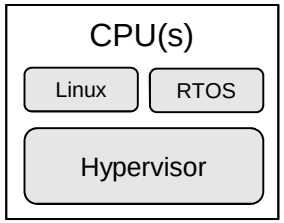
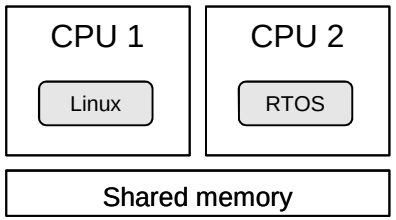
Multi-OS configurations

Main Idea: Linux on one CPU, RTOS on another CPU



1. Hypervisor:

- One/more CPU running both Linux and a certified RTOS
- Open-Source hypervisors (KVM, Xen, Jailhouse)



2. Multi-core platform:

- Example: i.mx6, i.mx8, soloX
- One core: Linux
- Other core: RTOS
- The «other core» can be a «small» core

…we'll see some examples later on in the presentation

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Dual-OS configurations

- Linux is patched to route the “important” IRQs to a small microkernel
  - **RTAI** or **Xenomai**
    - Abstraction Layer with full control of interrupts and system timers
    - Linux executed as a background task
    - Web: http://www.rtai.org and http://www.xenomai.org

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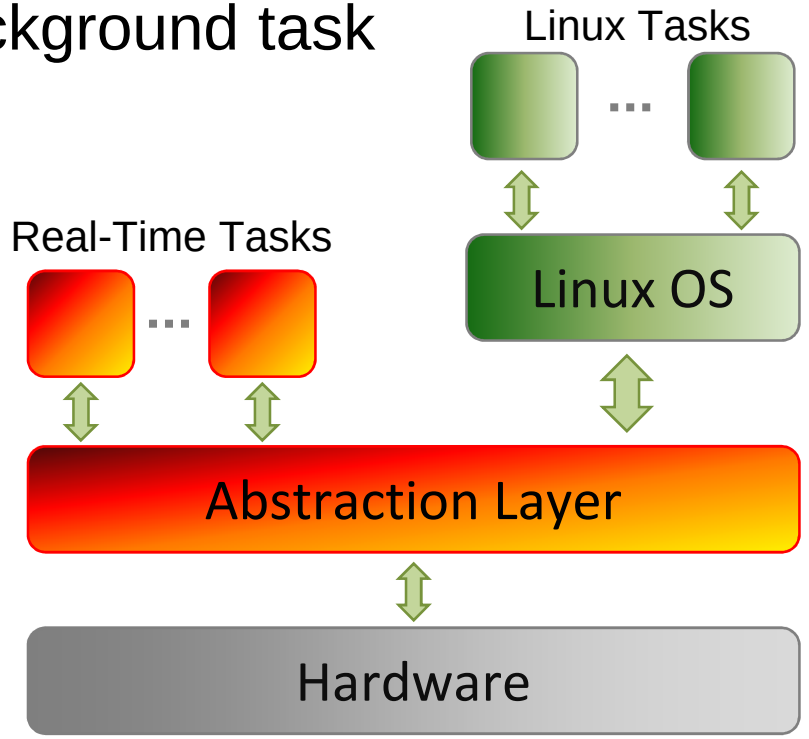
Real-Time Linux: RTAI / Xenomai

- Basic idea: Hardware Abstraction Layer (HAL)
  - Full control of interrupts and system timers
  - Linux executed as a background task
- Various projects
  - RTAI / Xenomai
  - Rt-Linux / Partikle



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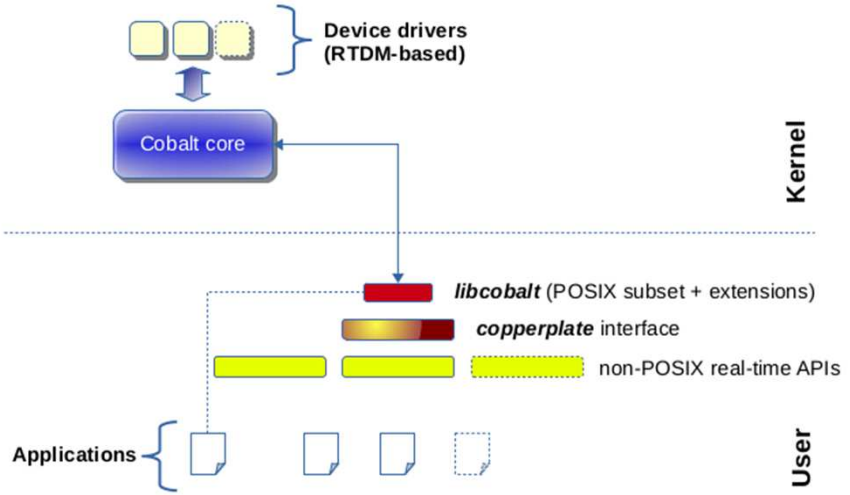
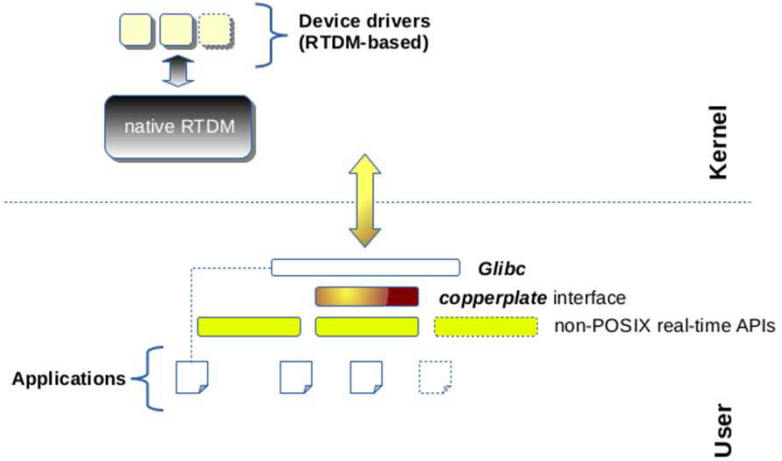
Xenomai 3

- Started in 2001 as an emulation of traditional RTOS API
- Skins implementing various APIs of traditional RTOS such as VxWorks, as well as the POSIX API, and a ``native'' API.

Dual OS configuration



As a user library



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Soft Real-Time: PREEMPT_RT

- It reduces maximum latencies through threaded interrupts and preemptible spinlocks
- A Linux Foundation project:
  https://wiki.linuxfoundation.org/realtime
  Main contributors: I. Molnar, S. Rostedt, T. Gleixner
- Available for the most recent Linux kernel releases
- Supports all the major embedded architectures
- Makes all but the most critical kernel code involuntarily preemptible

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PREEMPT_RT (2)

- Preemptible spinlocks:
  - Replaces most spinlocks with preemptible priority-inheritance mutexes
  - Benefit: reduce maximum latency
- Threaded interrupts:
  - Converting interrupt handlers into preemptible kernel threads
  - Reduces latency by running soft IRQs and selected or all hard interrupts in a dedicated kernel thread (managed in process context by the regular Linux scheduler).
  - Thanks to this, real-time tasks can have priority over some or all IRQs. Previously, even soft IRQs were run before any task managed by the scheduler.
- Priority Inheritance
  - Merged inside vanilla kernel since Linux 2.6.18

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Myths about PREEMPT_RT

- It will improve throughput and overall performance
  - Wrong: it will degrade overall performance.
- It will reduce average latency
  - Often wrong. The maximum latency will be reduced.
- The primary goal is to make the system predictable and deterministic!

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SCHED_DEADLINE

- Real-time CPU scheduler created by Evidence Srl
  - Made in collaboration with ReTiS Lab of Scuola Sant'Anna
  - It allows real-time isolation between running tasks
  - http://www.evidence.eu.com/sched_deadline.html
  - http://en.wikipedia.org/wiki/SCHED_DEADLINE
- Integrated into the official Linux kernel
  - Available since kernel 3.14
  - Reclaiming added in kernel 4.13

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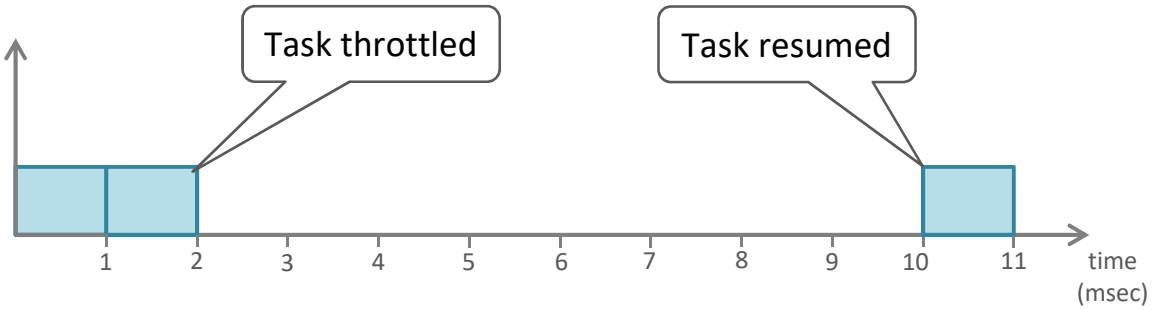
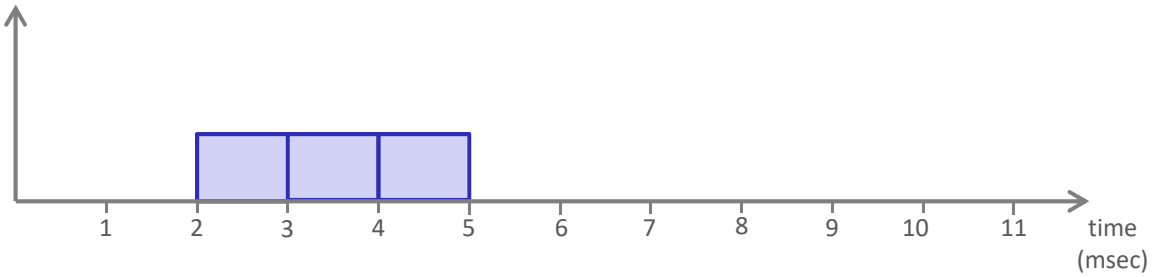
SCHED_DEADLINE

SCHED_DEADLINE task
runtime = 2 msec
period = 10 msec



SCHED_DEADLINE task
runtime = 3 msec
period = 20 msec



- "Hard reservation" rule to avoid starvation of lower-priority tasks
- Non work-conserving: RT tasks blocked even if system is idle
- http://en.wikipedia.org/wiki/SCHED_DEADLINE

Merged into the official Linux kernel since 3.14 (2014)

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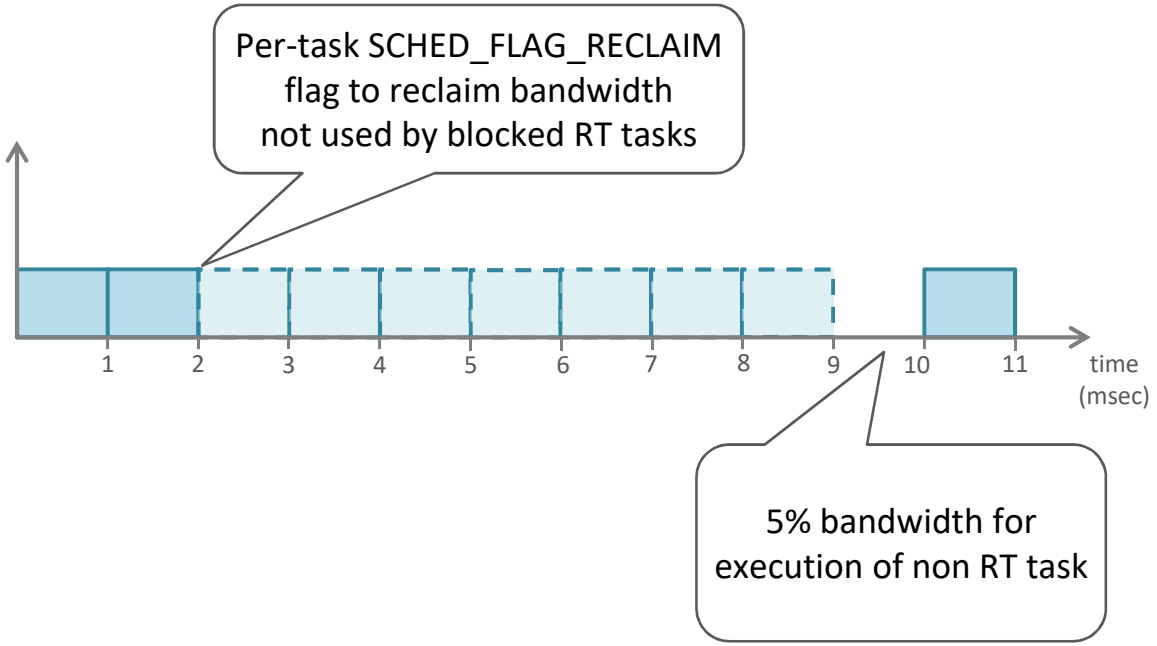
GRUB

- Greedy Reclamation of Unused Bandwidth (GRUB) algorithm:

SCHED_DEADLINE task
runtime = 2 msec
period = 10 msec



- G. Lipari, S. Baruah, *Greedy reclamation of unused bandwidth in constant-bandwidth servers*, 12th IEEE Euromicro Conference on Real-Time Systems, 2000.
- L. Abeni, J. Lelli, **C. Scordino**, L. Palopoli, *Greedy CPU reclaiming for SCHED_DEADLINE*, Real-Time Linux Workshop (RTLWS), Dusseldorf, Germany, 2014.

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Multi-OS on Linux

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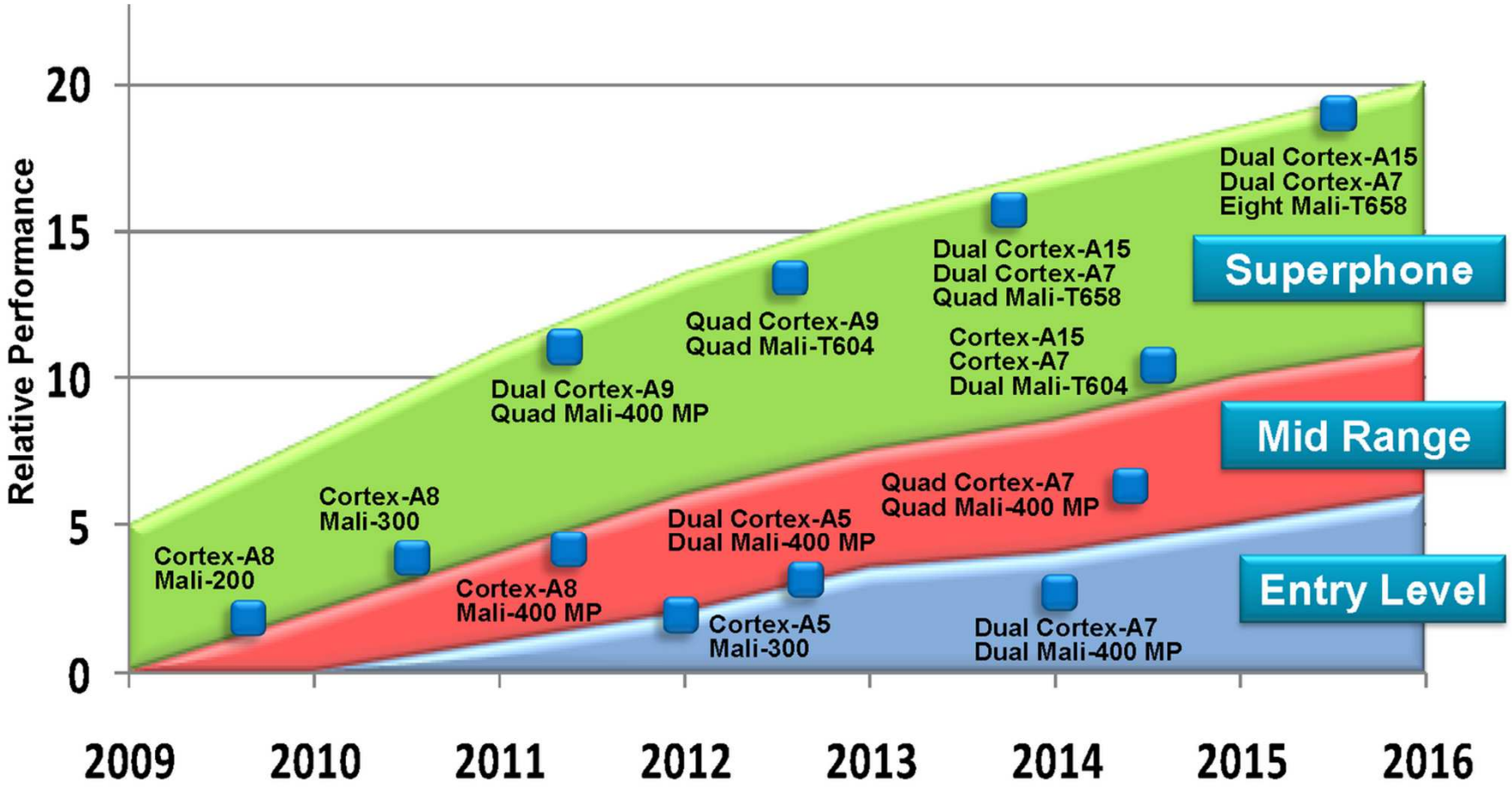
Rationale



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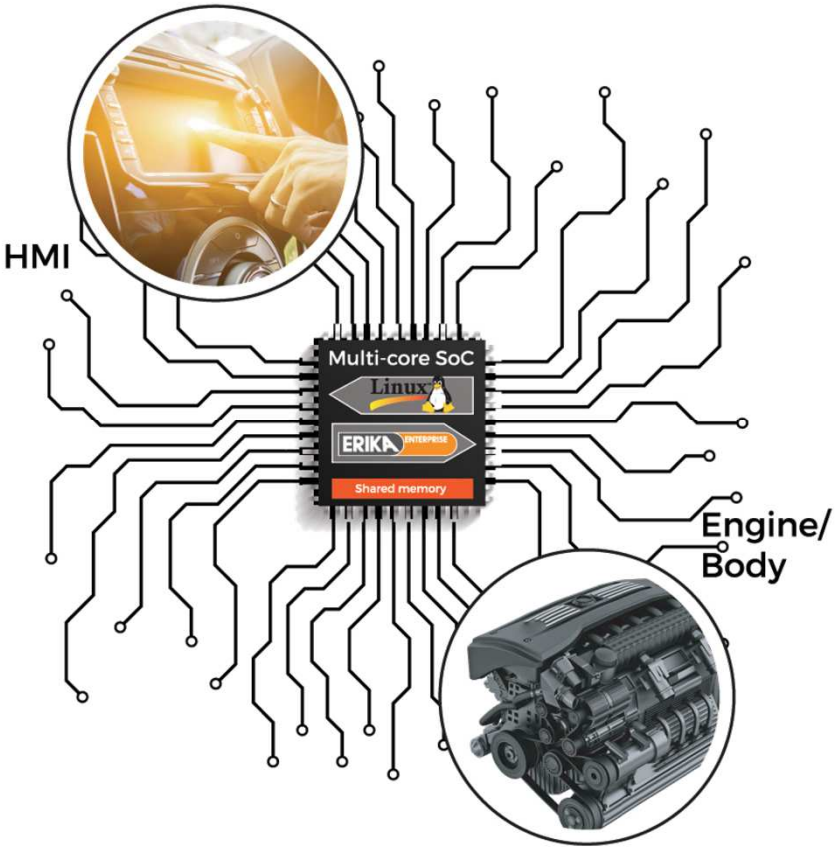
AMP configuration: with/without Hyp.

Real-time and quality of service for IVI systems with/without hypervisor!

- ERIKA running on one core
- Linux on the other cores
- No Hypervisor
- …or JailHouse Hypervisor



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ERIKA Enterprise (v2 and v3)

http://erika.tuxfamily.org

http://www.erika-enterprise.com

- ERIKA Enterprise is an RTOS OSEK/VDX certified
- ERIKA Enterprise implements the AUTOSAR OS API
- open-source license and double licensing options allowing static linking of closed src code
- Used by various industries and research projects

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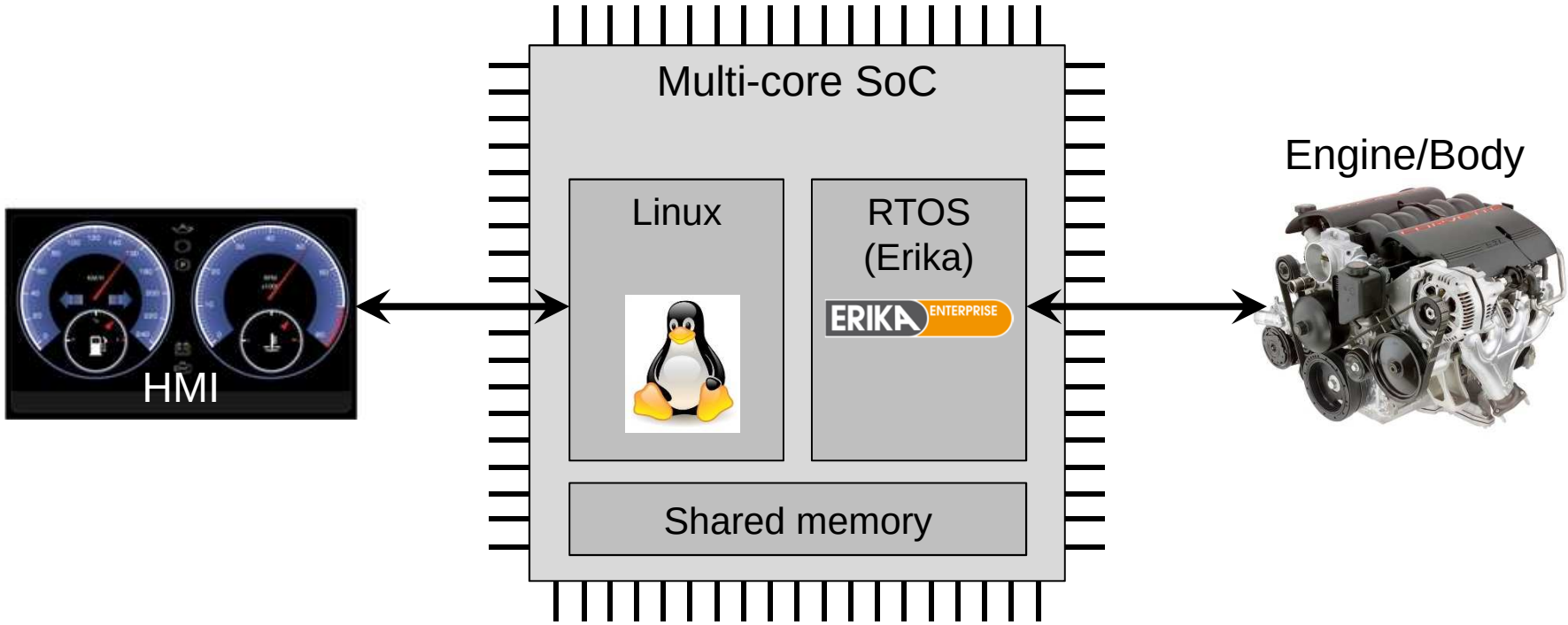
Linux + ERIKA without hypervisor

We envision the possibility to exploit multi-cores to run Linux and Erika Enterprise complementing each other!



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Demo presented at AGLW 2013

Based on a Freescale iMX6

We let U-Boot handle the multicore boot

- ERIKA starts almost immediately
- Linux can start afterwards

No hypervisor

- could be useful in some cases to protect the behavior of misbehaving applications
- limited need because we statically allocate a CPU to each OS

Can be used with other CPUs

- Example – SoloX (Cortex A + Cortex M)

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AMP: Interaction model

Linux → ERIKA

- Linux can trigger the following actions:
  - activate a task
  - set an event
  - start an Alarm
  - increment a counter

  (similar to those doable on a remote core of an AUTOSAR OS)
- Linux can stop and reload the ERIKA application

Linux ←→ ERIKA

- Simple asynchronous message passing allowing asynchronous read/write of variable length buffers on predefined channels

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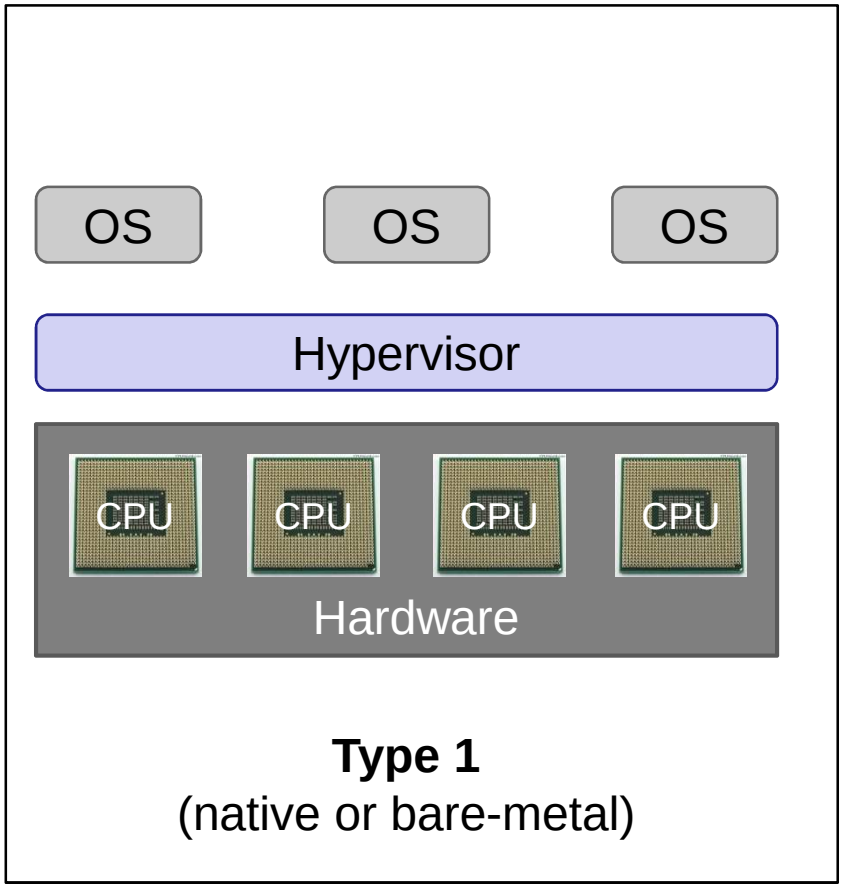
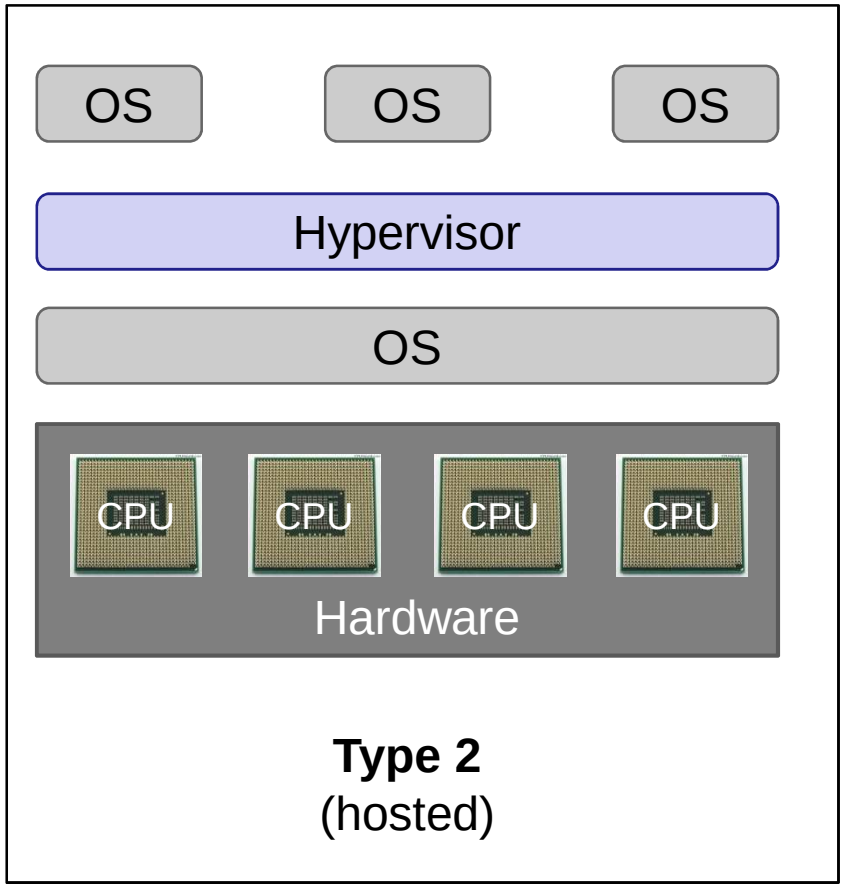
Classification of hypervisors



Type 1
(native or bare-metal)



Type 2
(hosted)

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AMP Configuration: ERIKA with XEN

+

http://xenproject.org/about/events/viewevent/154-linuxcon-eu-integrating-linux-and-the-real-time-erika-os-through-the-xen-hypervisor.html

In collaboration with the University of Modena, Arianna Avanzini integrated ERIKA Enterprise as domU under XEN
on a CubieBoard (Allwinner A20)

Presented at CloudCon Europe October 15th 2014, Dusseldorf

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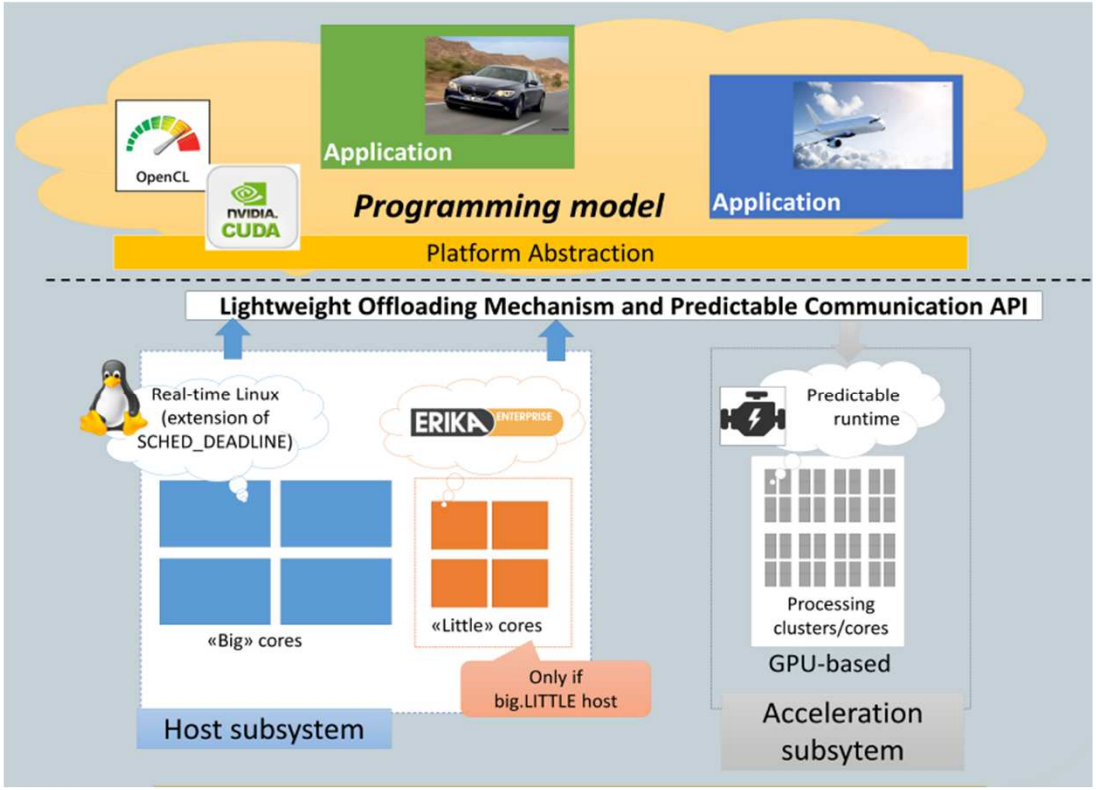
Hypervisor configuration – H2020 Hercules

Architecture and platform for customized low-power heterogeneous computing systems, for Automotive and Avionics

Jan 2016-Dec 2018

Partners:

- UNIMORE
- Magneti Marelli
- Airbus
- Evidence
- Pitom
- CTU
- ETH Zurich



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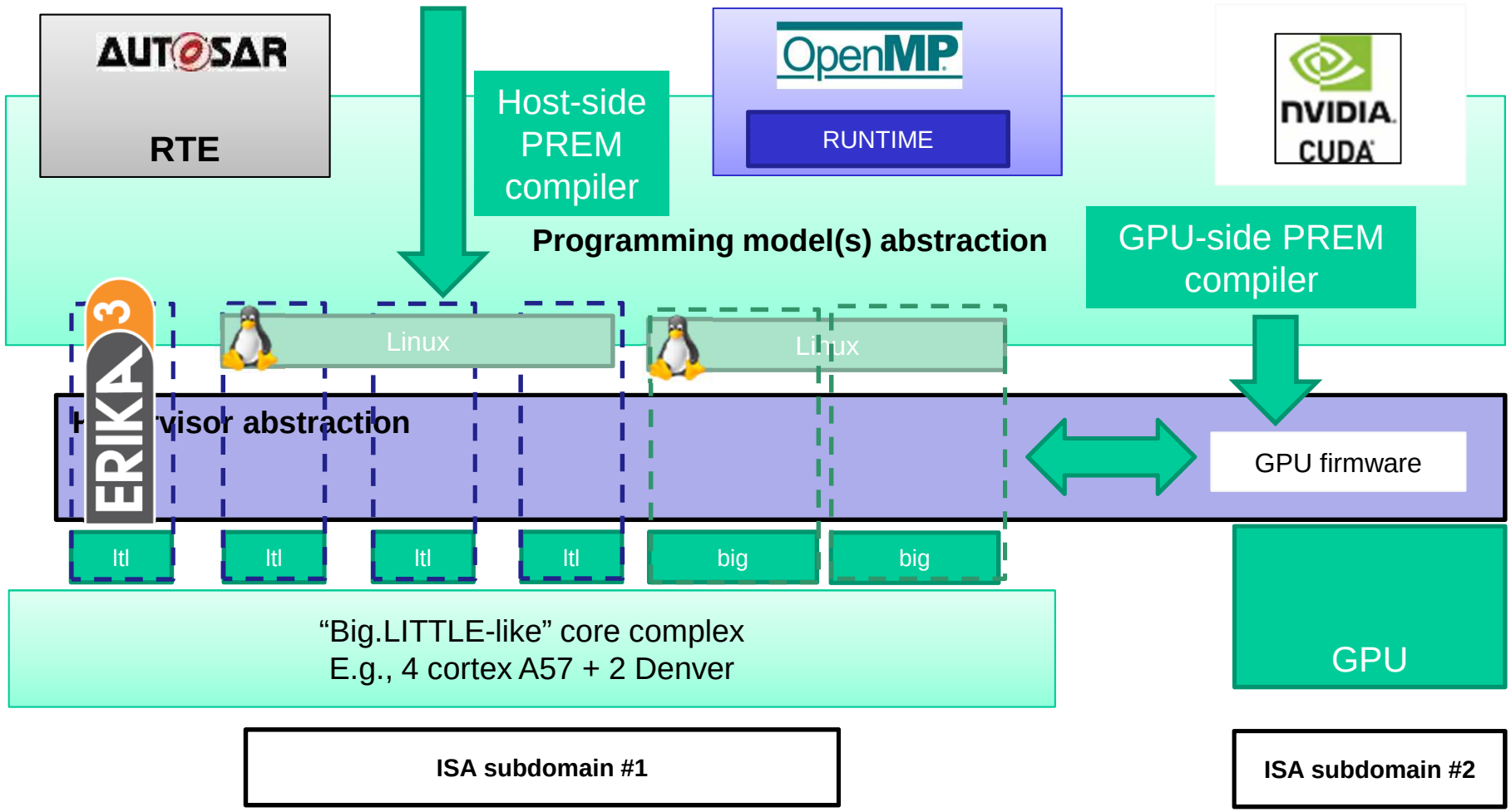
Slide architettura hercules GTC



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Jailhouse

- Small, lightweight hypervisor
- Young project (2013) by Siemens
- License: GPLv2
- Code hosted on GitHub
- Goals: safety-critical & certification
  (goal: 10.000 lines of code per architecture)

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Jailhouse (2)

A tool to run

... real-time and/or safety-critical tasks
... on multi-core platforms
... aside Linux

It provides

... strong & clean isolation
... bare-metal like performance & latencies

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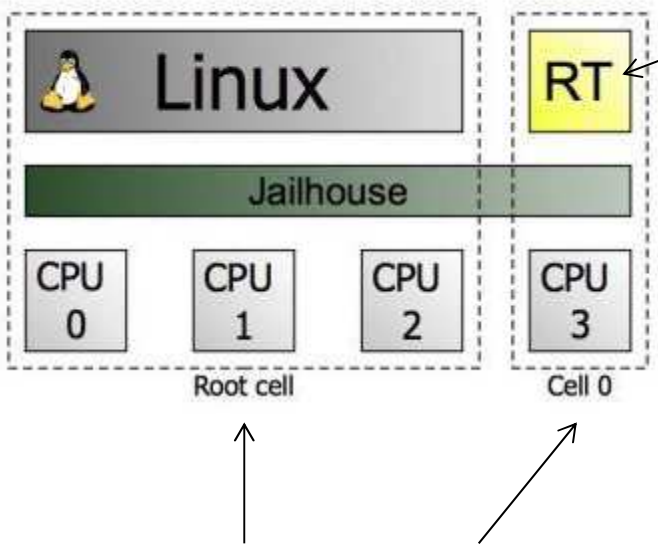
Jailhouse (3)

The guest software is called **inmate**



The isolated compartments are called **cells:**

- One root cell
- One or more non-root cells

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Jailhouse (4)

- Partitioning hypervisor
  - More focused on isolation and resource assignment than on virtualization
- Linux is required ("root" cell)
  - Similar to Xen's dom0 but w/out full control of hw
  - Type-1 (Linux used only for management interface and load/unload guests)
- Can't run unmodified OSs
  - Even Linux on non-root cells need to be patched

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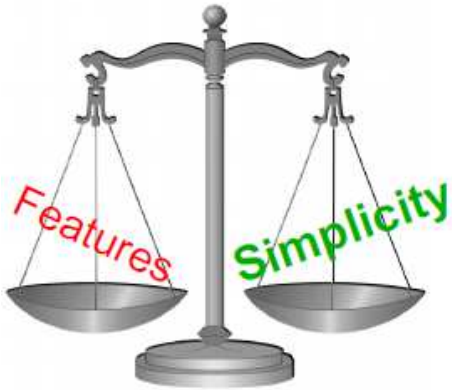
Jailhouse (5)

- Static design:
  - 1:1 resource assignment
  - Guests can't share a core (no scheduling)
  - It doesn't support overcommitment of resources (like CPUs, RAM or devices).
  - No hw emulation
- Real-time guarantees:
  - Must be provided by the guest OS



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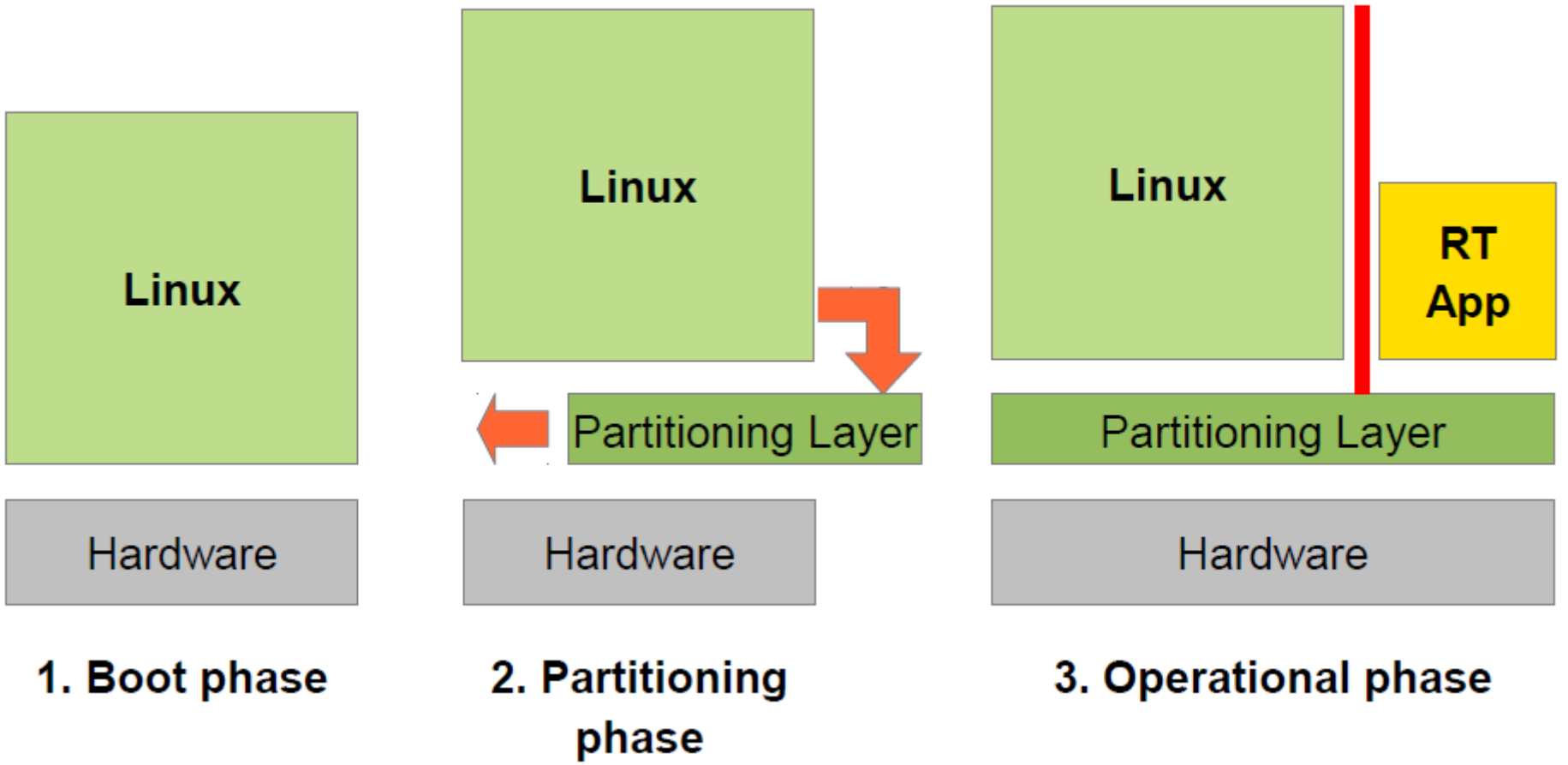
Late partitioning



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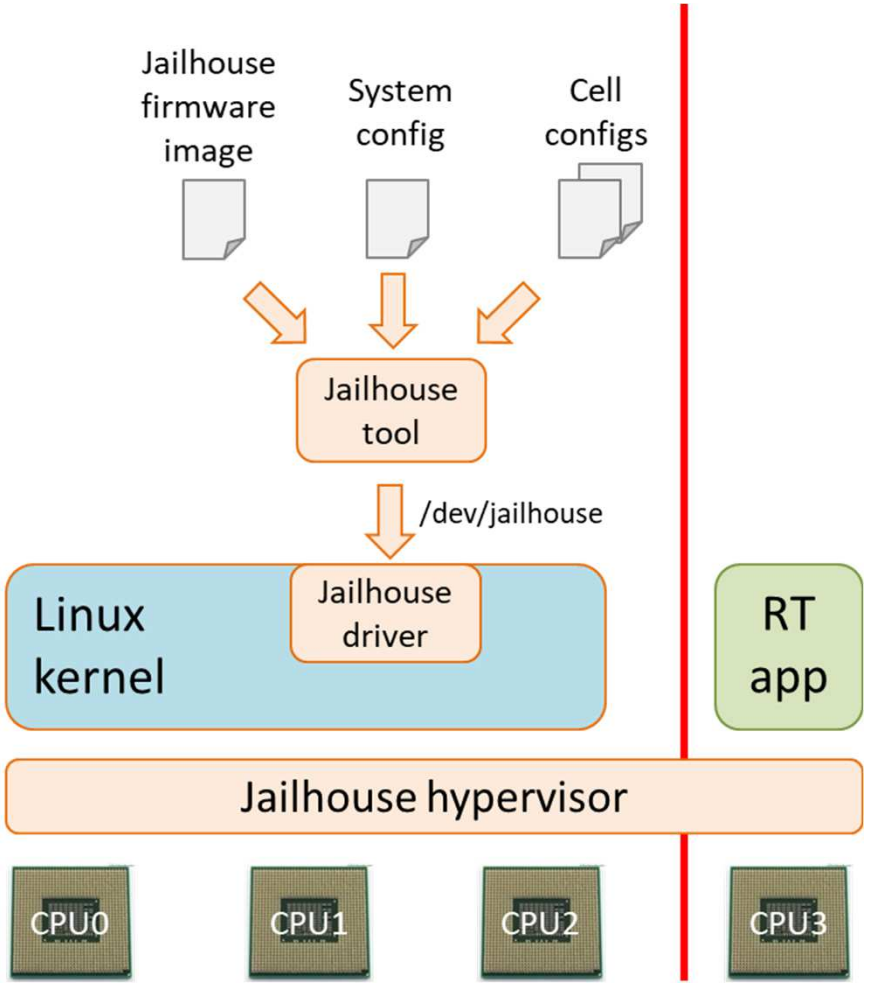
Jailhouse architecture



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Demo on Nvidia TX1

- Demo

- Similar demo available on Drive PX2 / Xilinx Ultrascale+

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Fast boot on Linux

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Fast Boot

- It’s a race over the fastest booting system…
- In reality what is important is the time between power up and the availability of some given services
  - Final user application
  - Splash screen
  - CAN bus active in the first x ms
  - …
- Depending on the requirements, there are various optimizations that can be done
- Most of the boot time can be shrinked with a few main actions. Then the ms tuning require… art!

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Typical tweaks to reduce boot time

- Splash screen to simulate an early start
- No boot loader
- Peripheral initialization postponed
- Service daemons postponed
- Pre-boot e preload (example when opening the car door)
- Filesystem choice to allow fast boot
  (with/without compression, read-only/write)
- Kernel optimizations

- It is useful to have a tracing tool in HW
  or, whenever not possible, in SW

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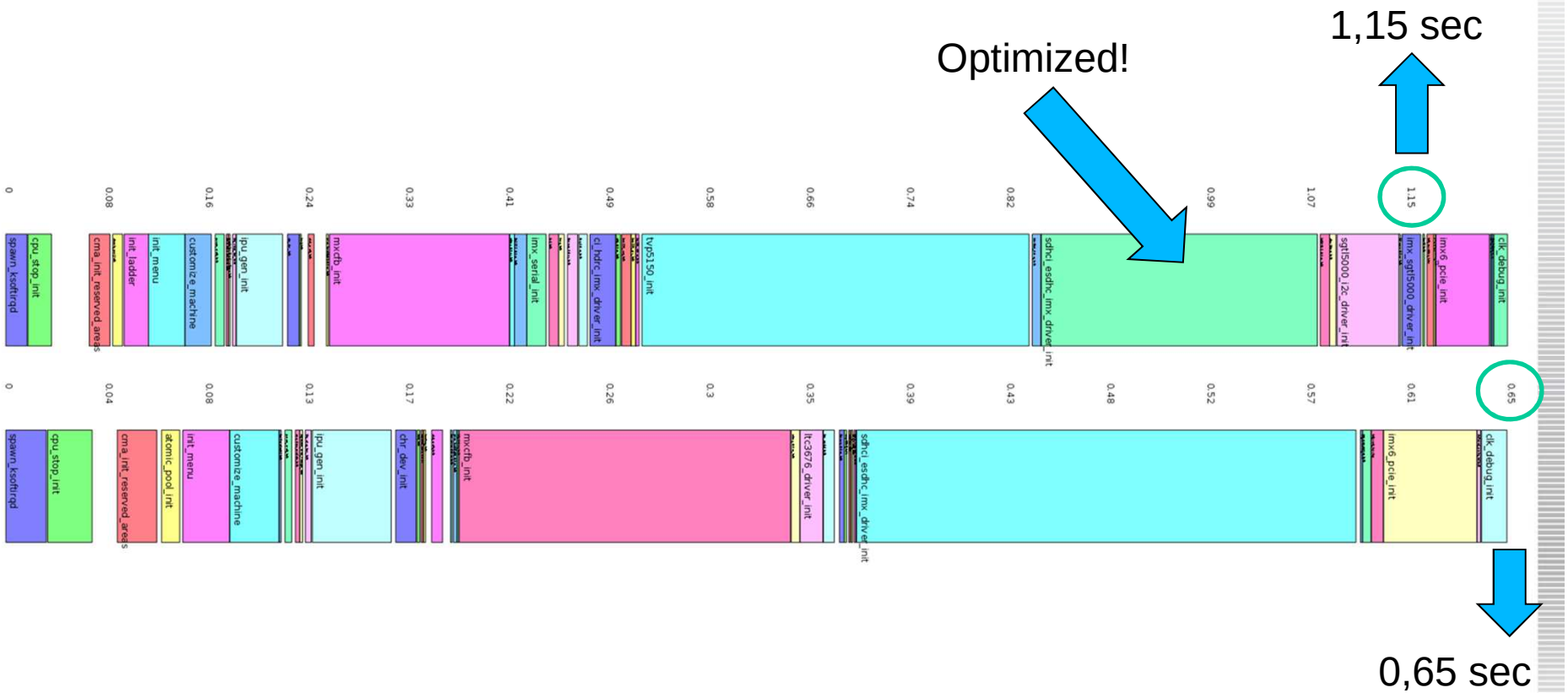
Linux Boot Charts

Example of chart taken from the timings of the Linux boot



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Linux Fast Boot

COBOO

- Linux Fast boot on iMX6 Dual
  - U-Boot with USB support
  - Linux kernel with Video support, Touchscreen, USB and CAN
  - Qt application
- Results
  - 1.8s - First CAN message from userspace
  - 3.9s - Qt Application

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Contacts

Evidence Srl

Via Carducci 56

56010 S.Giuliano Terme

Pisa - Italy

Web: http://www.evidence.eu.com

E-mail: info@evidence.eu.com

Phone: +39 050 99 11 224

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