Deeply Embedded Real-Time Hypervisors for the Automotive Domain

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Overview of presentation

- This presentation is concerned with what drives the use of hypervisors in the automotive domain, and what an automotive-class hypervisor might look like

- The main overall driver is convergence
  - Hardware is becoming less diverse.
    - Fewer processor types.
  - Software is converging on a smaller number of operating systems.
    - AUTOSAR (international de facto automotive software standard)
    - Linux
  - Applications are converging on a smaller number of ECUs

- Coupled with a much wider range of application requirements

- Increased safety and security

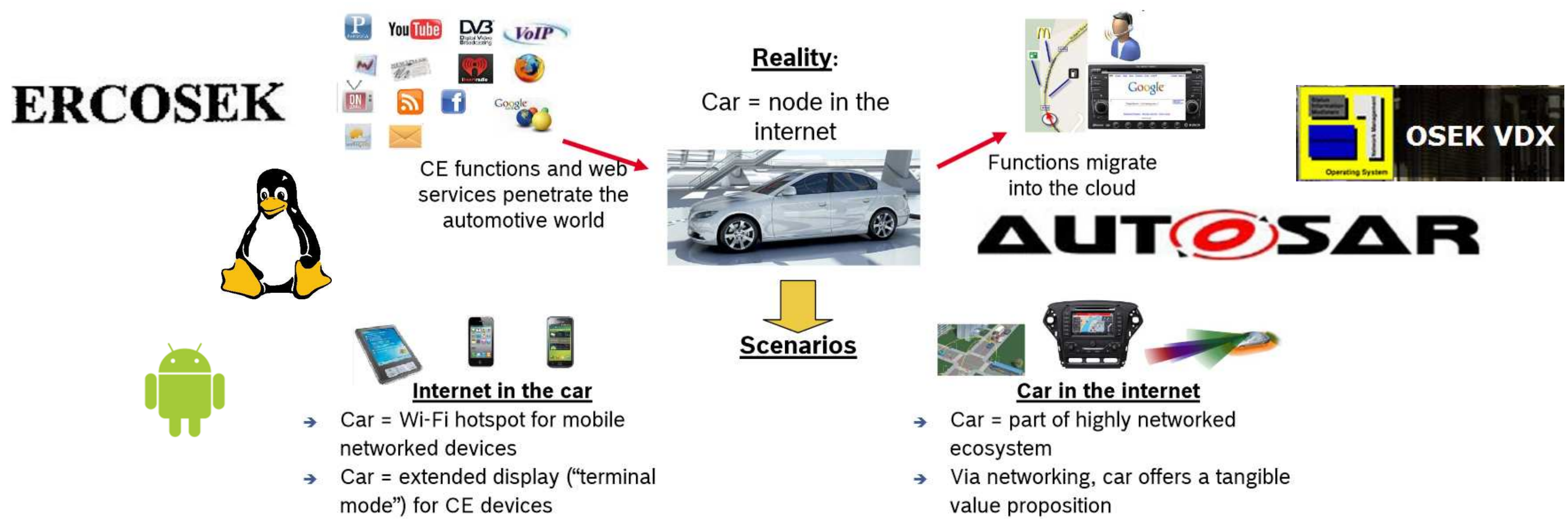
Car electrical/electronic (E/E) systems are getting more complex.

Software trends

More complex	Safe
More diverse	Secure
Dynamic	Reliable
Highly connected	

Hardware trends

More processors (multicore, manycore)
More memory
Faster, more diverse networks
COTS and CE convergence



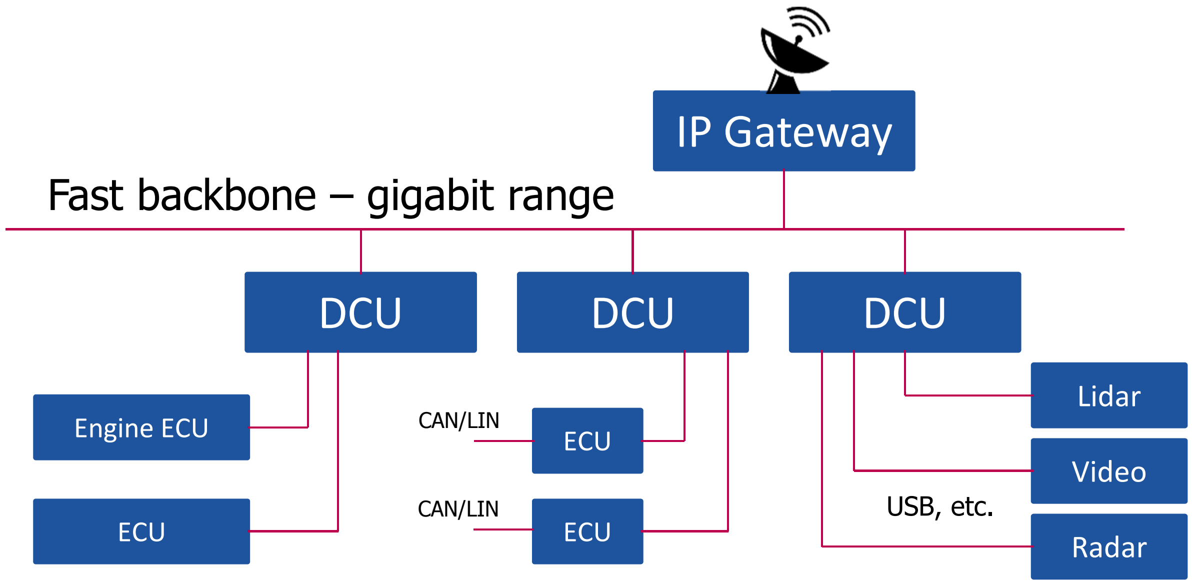
E/E system complexity needs to be reduced

E/E Complexity

- Too many ECUs
- Merge to Domain Control Units
- High speed inter-DCU links
- Legacy for control/sense

Key questions

- What's in a DCU?
- How are "virtual ECUs" isolated?
- How is the system coordinated?
- How is legacy supported?



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Hypervisor introduction

- The purpose of the hypervisor is to allow multiple ECU "images" to run on the same ECU, with appropriate levels of separation and scheduling guarantees
  - Allows different parts of the E/E system to be combined on a smaller number of ECUs.

- The hypervisor is a thin layer that sits between the hardware and the "images". It provides a virtual machine (VM) in which the "image" runs
  - This is also called a type-1 hypervisor.
  - Type-2 hypervisors run on top of an existing OS or RTOS

- In addition to separation, it also provides abstractions to allow access to hardware devices and inter-VM communications.

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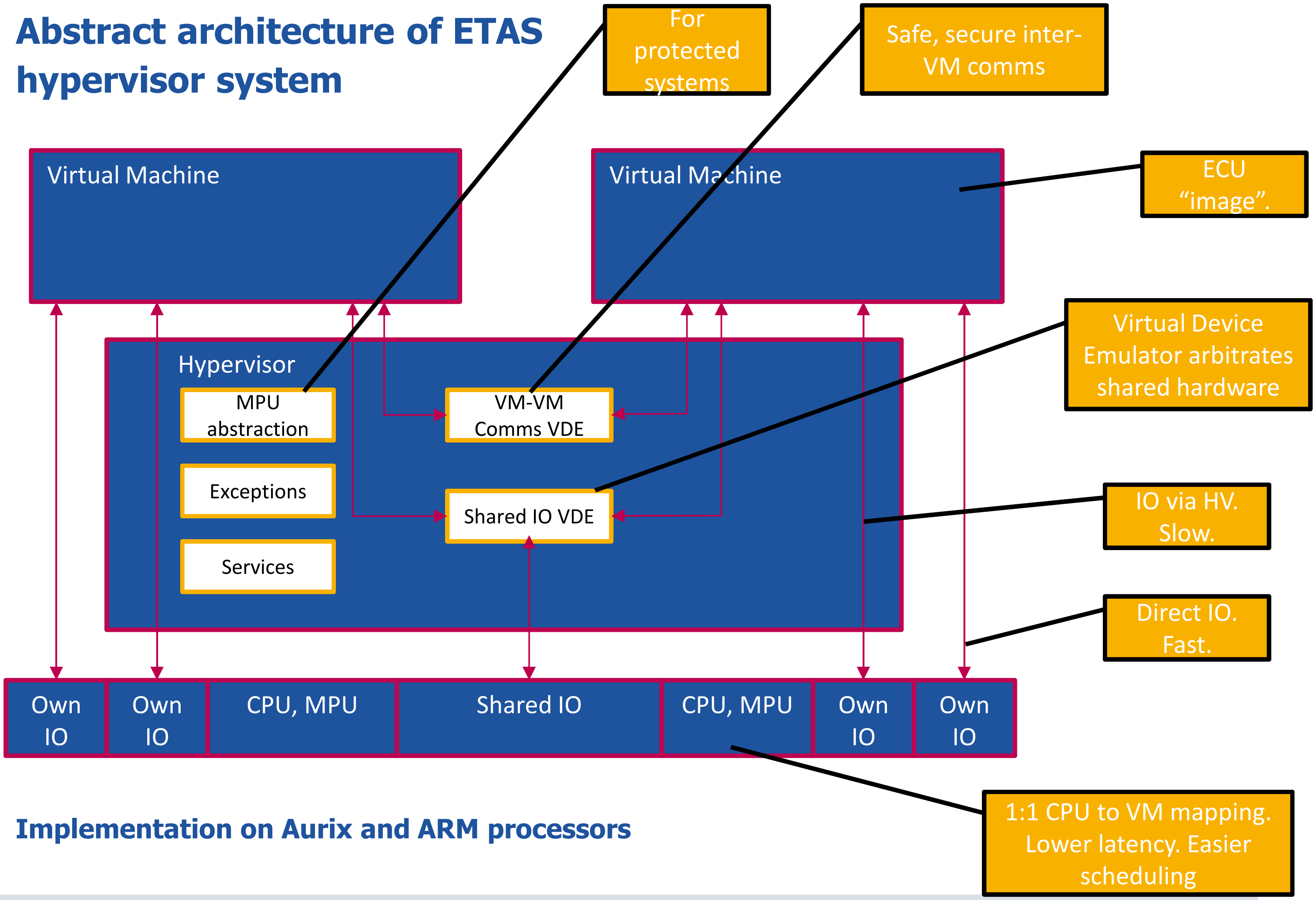
Hypervisors as part of the solution

Abstract architecture of ETAS hypervisor system



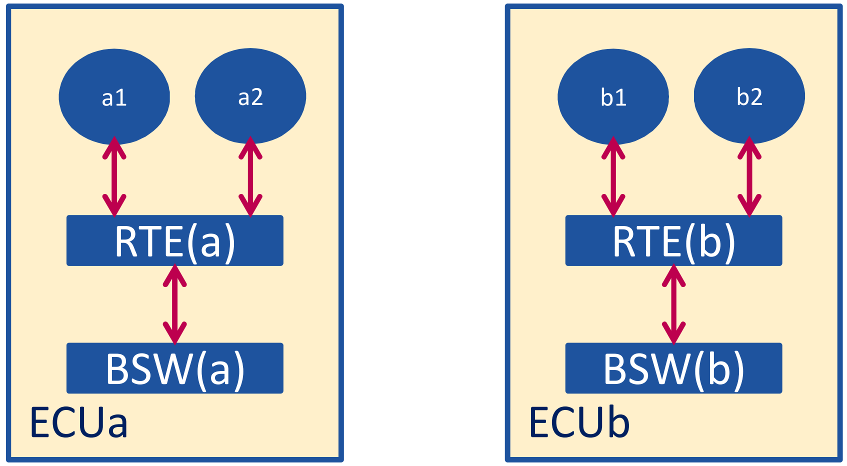
Implementation on Aurix and ARM processors

Hypervisor introduction

- Reduce integration costs
  - Less need to port old applications to new operating systems.
  - AUTOSAR facilitates semi-portable application code. Hypervisor solution competes with AUTOSAR for application integration.
    - If you have 2 or more systems, which is better?
      - Integrate using AUTOSAR
      - Integrate using a hypervisor
  - So you need to compare systems integrated with AUTOSAR with those integrated with a hypervisor

Integrating Systems

Original systems

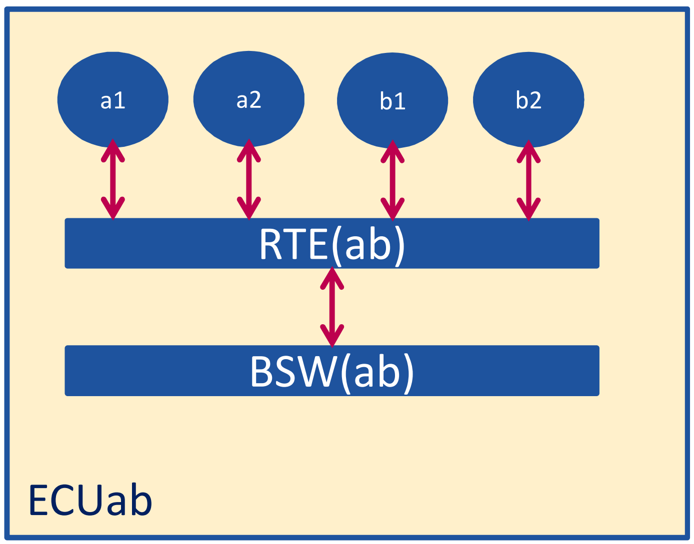


<- Applications

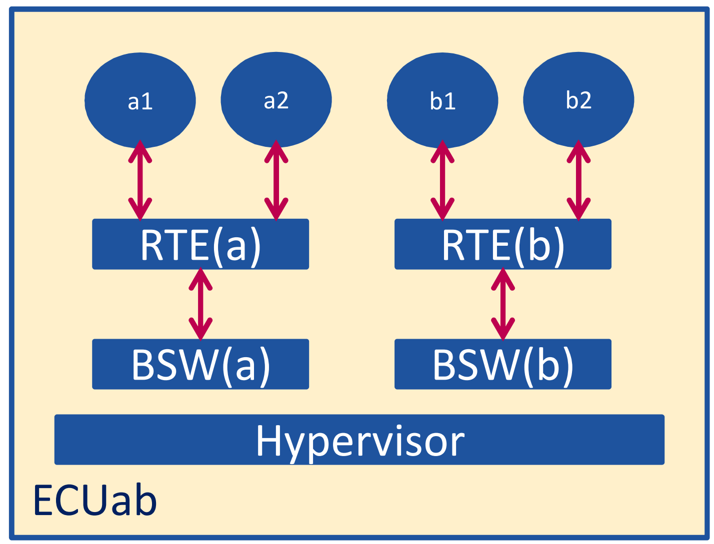
<- Communications

<- OS and drivers

Integrate with AUTOSAR



Integrate with Hypervisor



Hypervisor introduction

- Integration with AUTOSAR
  - May be hard to handle different versions of the same OS
  - Different OS's cannot be handled (e.g. AUTOSAR and Linux)
  - What is the cost of re-configuring the RTE and BSW?
  - How is mixed criticality handled?
- Integration with hypervisor
  - Better spatial separation
  - Better temporal separation
  - Better API separation
  - VM restart compared to complete ECU restart
  - Better security
  - Faster boot time
  - Some costs rise
    - Common code is duplicated in each VM rather than shared

These lead to much better support for safety systems and mixed criticality systems.

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Overview of real-time problems

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- Hardest requirements are typically in engine control
- A key performance indicator is interrupt latency
- Typical "high end" controller
  - Around 40,000 interrupts per second
    - AUTOSAR tends to concentrate interrupt onto one core
    - Overheads too high if CAT2 ISRs are used
  - Around 120 interrupt sources
  - Around <5us interrupt latency, fastest case
  - Clock speed around 300 MHz
  - 2MB FLASH
  - <512MB RAM
  - 2 or 3 cores
  - Shared RAM, FLASH and peripherals

- CPU loads are often in excess of 90%

- How do you build a hypervisor in such a small system and how do you guarantee its real-time properties?

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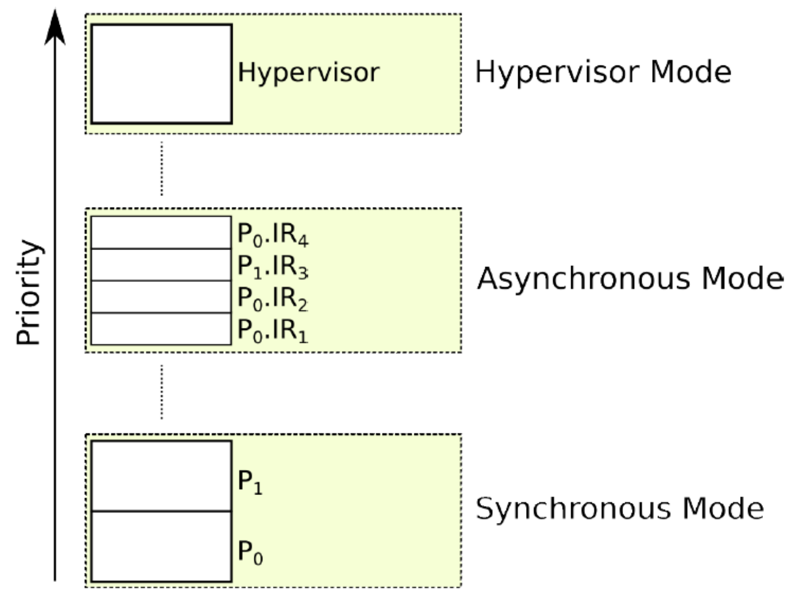
Current VM scheduling approaches

- Simplest approach: 1 VM per core.
  - Approach adopted by ETAS' hypervisor
  - No VM scheduling to worry about
  - Scheduling of HV internal operations at highest interrupt priority
  - Low interrupt latency
- Cyclic (Arinc 653)
  - Predictable
  - Fair (avoids starvation)
  - Long interrupt latency
- Hypervisor implements VM processes
  - All processes in all VMs scheduled by hypervisor
  - Bad for portability and legacy compatibility
    - Hypervisors' scheduler may not support AUTOSAR, legacy and Linux scheduling policies.

Future VM scheduling approaches

- Multiple VMs per core are required
- A scheduling model is needed which is
  - Fair to the VMs (no starvation)
  - Enforces temporal separation
  - Has low interrupt latency
  - Can be modelled and reasoned about
  - Has low run-time overheads
- Partitions have a Synchronous Mode that runs when budgets permit
- Interrupts take time from the Asynchronous Mode budget until their budget is used up
- The hypervisor always has the highest priority

- Proposed priority space assignment
- *Burns, Evripidou, Morgan*



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Automotive has many domain-specific requirements

Small systems

Low interrupt latency

Small footprint

Static configuration

Hard real time

Some requirements are contradictory and need configuration to resolve them. For example, static vs. dynamic configuration should be statically configurable.

Configuration allows some requirements to be removed. E.g. Diagnostics might be configurable.

How many of these requirements are supported by current commercial hypervisors? Very few.

Large systems

Comprehensive peripheral support

Dynamic configuration

Feature download

Soft real time

All systems

Certification

Boot loaders

Safety

Diagnostics

Portability

Calibration

Security

Configuration

Multicore

Shared-device abstractions

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An automotive hypervisor for 2018 onwards?

- Support all relevant use cases and requirements

- More than one VM per core, with predictable timing.
  - more VMs than cores

- More than one core per VM, with predictable timing.
  - support for multi-core VMs.

- VM migration
  - Migrate VMs to avoid overloaded or faulty hardware

- Timing model
  - System becomes a composition of VMs, with known timing behaviour

- Communications (RTE++)
  - System-wide inter-VM communications mechanism

Thank you for your attention

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