Migration of Components and Processes as means for dynamic Reconfiguration in Distributed Embedded Real-Time Operating Systems

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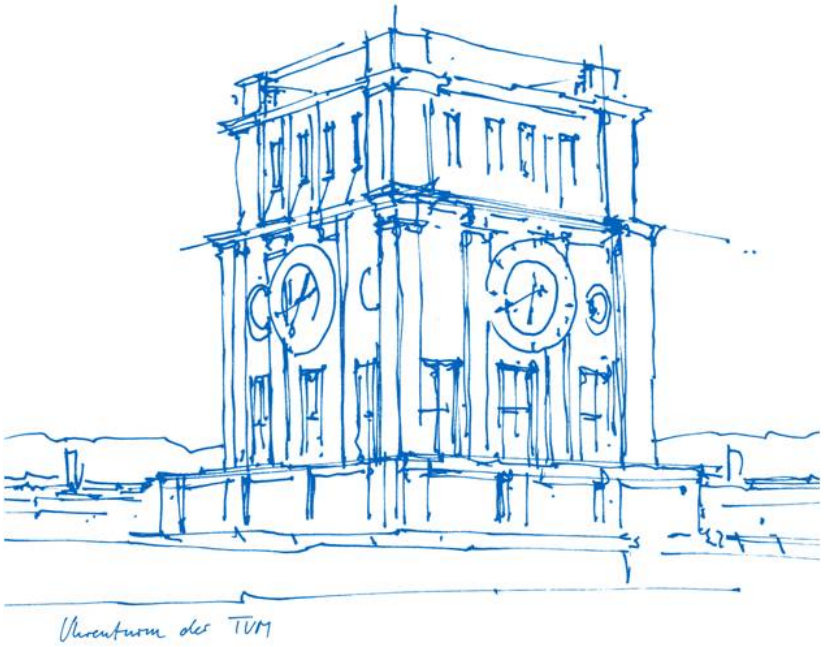


Agenda

- Research Environment
- Challenge
- Proposed Solution: Dynamic Reconfiguration
- Operating System Design
  - Partitioning
  - Migration Support
- Implementation (Current State)
- Evaluation (Test Setup)
- Next Steps
- Conclusion

Research Environment

- Future cyber-physical-systems (CPS) as **distributed, embedded, real-time systems** in a criticality-aware environment

- Key demands
  - Multi-core hardware support
  - Mixed-criticality support
  - Context-sensitive reaction behavior support

- Examples
  - Automotive Systems (e.g. Autonomous Driving, C-ITS)
  - Industrial Automation (e.g. Industry 4.0)

Challenge

- Vision: Offer context-sensitive reaction behavior via **Dynamic Reconfiguration** at run-time
- **Tradeoff:** Flexibility vs. Reliability/Safety
- State-of-Art **safety guarantee**: physical separation of software components (spatial & temporal isolation)
- State-of-Art reconfiguration: **Semi-statically configured systems**
  - **Mode-switch** mechanism (run-time substitution of a set of precalculated, offline schedules)
  - Hardware-supported **redundancy** (device switch)

Proposed solution

- Idea: (Online) Dynamic reconfiguration via **migration at runtime**
  - Migration of **software components and processes**
  - **Between different devices**
  - Integration into **operating system (OS) layer**
- Background: adoption of run-time adaptation concepts from data centers (**virtual machine migration**)
  - Efficient resource management
  - Fault tolerance/availability
  - Scalability

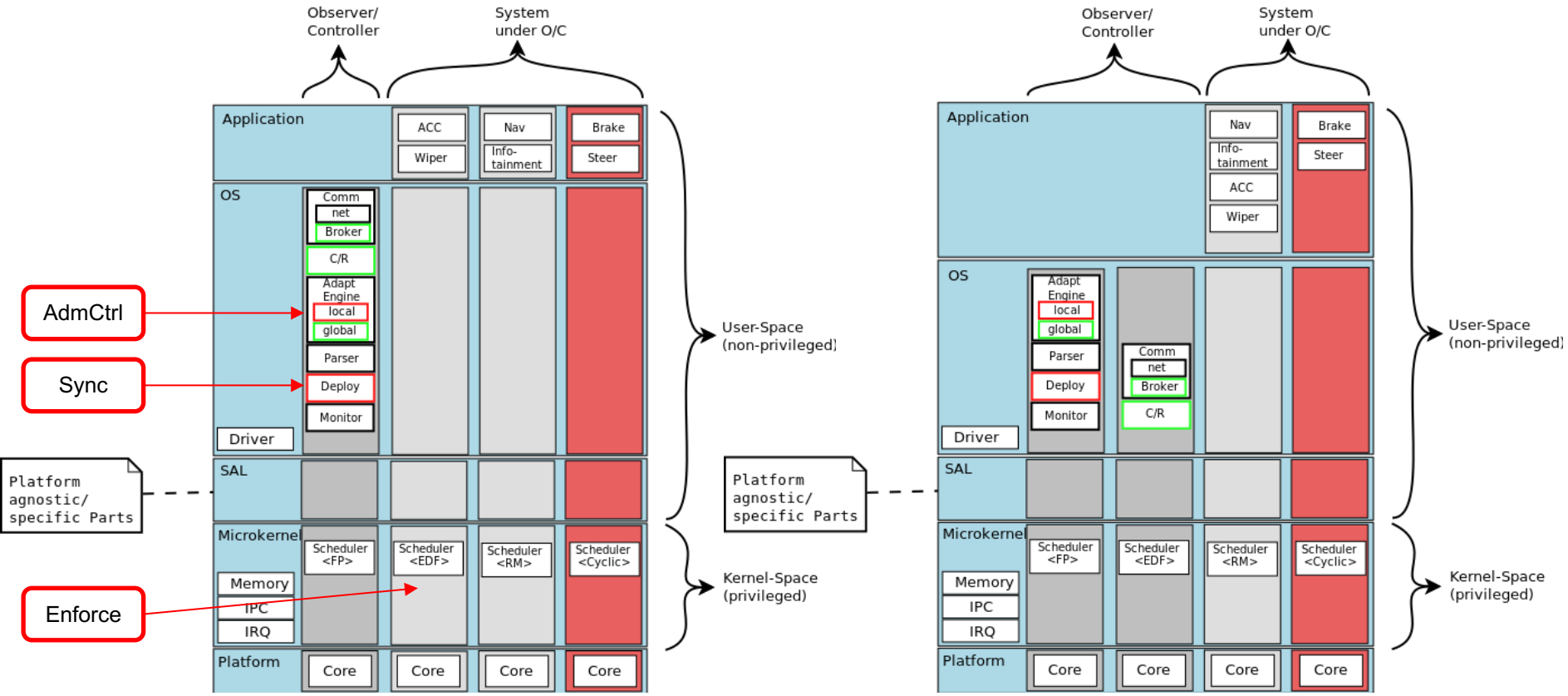
General Design Assumptions

- Application of (heterogeneous) **COTS hardware**
- **Homogeneous** software-based run-time environment (RTE)
- Real-Time Operating System (**RTOS**)
- **L4 microkernel** based OS (small & minimalist base)
- Migration: **Extension of OS** via
  - Migration decision making
  - Migration execution

Operating System Design

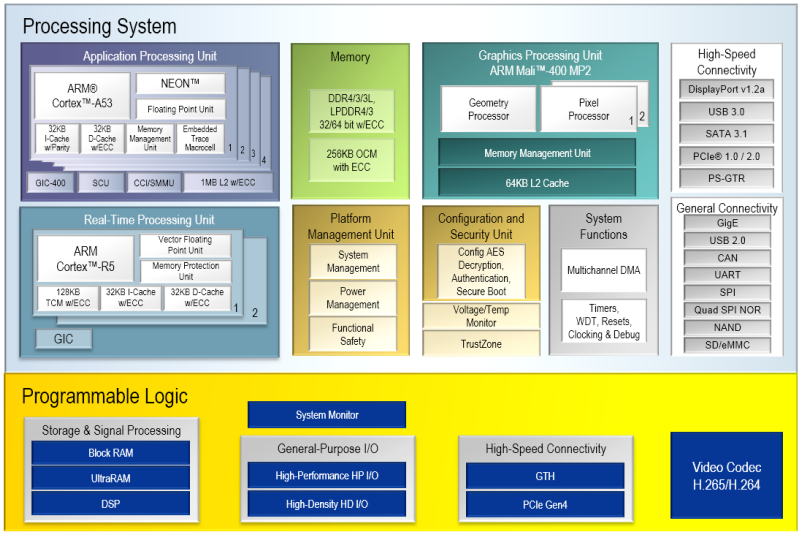
- Premise: Keeping up a system‘s real-time capability
- Implementation in Userland
- Base: **Multi-core platform** (concurrent execution)
  - Goal: Temporal isolation
  - Limitation: **Shared resources** (e.g. system buses, caches)
- Approach
  - **Partitioning:** Mapping of software components of different criticality level to corresponding cores
  - **Migration:** Stepwise evaluation (from migration of lower-critical components to dealing with harder constraints)
- Implementation: L4 Fiasco.OC & Genode OS Framework

Partitioning – Partitioned Scheduling

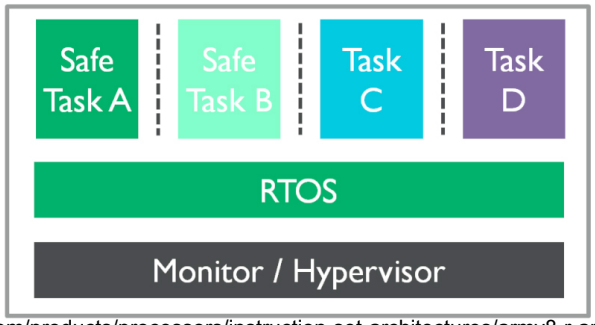


Combined management of best-effort, soft and hard real-time tasks.

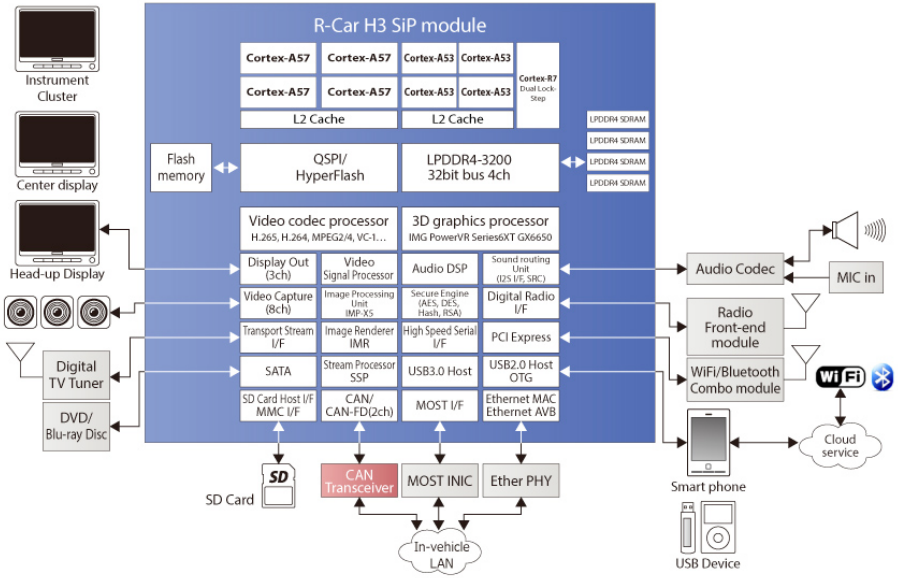
Background: Future Trends



https://www.xilinx.com/products/silicon-devices/soc/zynq-ultrascale-mpsoc.html

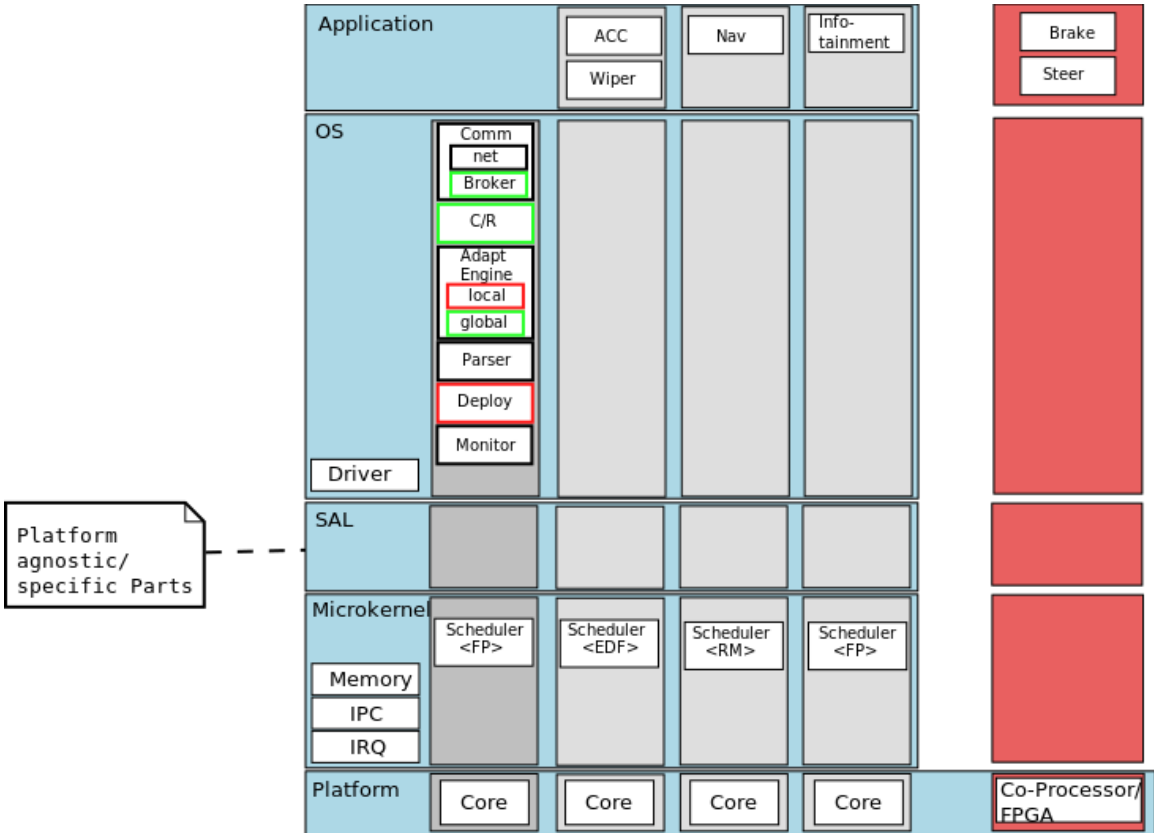


https://www.arm.com/products/processors/instruction-set-architectures/armv8-r-architecture.php



https://www.renesas.com/en-eu/solutions/automotive/products/rcar-h3.html

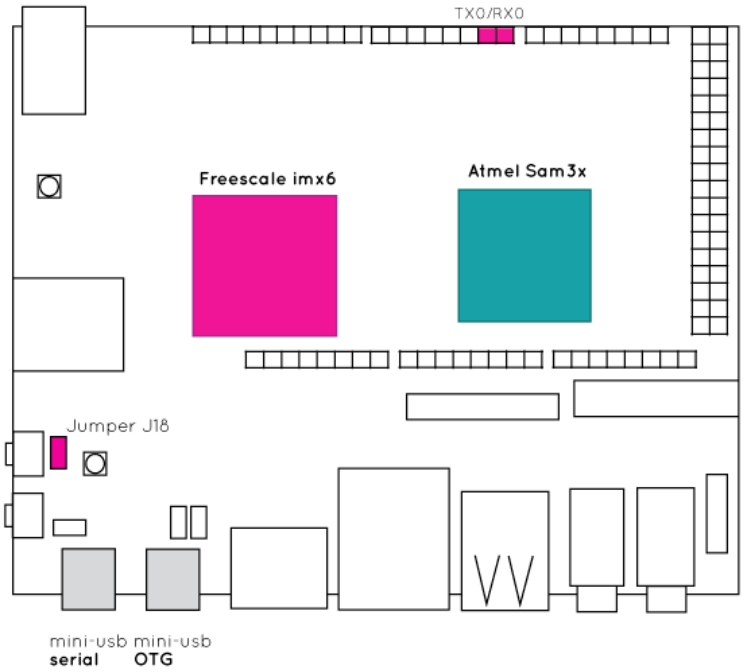
Partitioning – MPSoC platform



Physically separated management of best-effort, soft and hard real-time tasks.

Partitioning – Prototypical Development

- UDOO Dual/Quad (NXP i.MX6 Cortex-A9 + Arduino Due-compatible ATMEL Cortex-M3)



http://www.udoo.org/docs/Hardware_&_Accessories/IMX6_And_Sam3X_Communication.html

Migration Process

- Runtime Monitoring
- Global Migration Decision (Analysis, Planning)
- Migration
  - Checkpointing (save all necessary process data)
  - Serialisation (prepare data for transport)
  - Transfer (send data to target platform)
  - De-Serialisation (unpack data on target platform)
  - Restore (restart process on target platform)
  - OPTIONAL: Reorganisation (restore communication paths)
- Local Admission Control
- Synchronisation
- Real-Time Scheduling

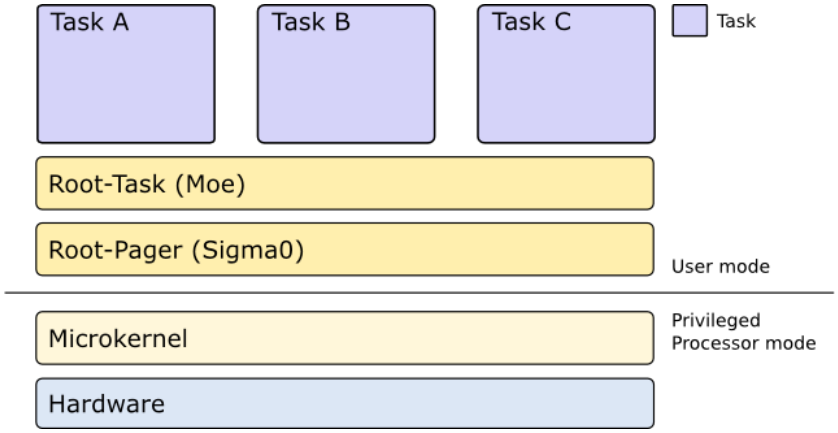
Migration - OS Components

- Observer/Controller (**migration planning**)
  - Runtime Monitoring
  - Admission Control (local online schedulability analysis)
  - Global Planning (global online schedulability analysis)
- Core OS (**migration execution**)
  - Snapshot (Checkpoint/Restore, De/Serialization)
  - Storage (In-Memory)
  - Networking (Transfer)
  - Synchronisation (Deployment)
  - Real-Time Scheduling (Enforcement)

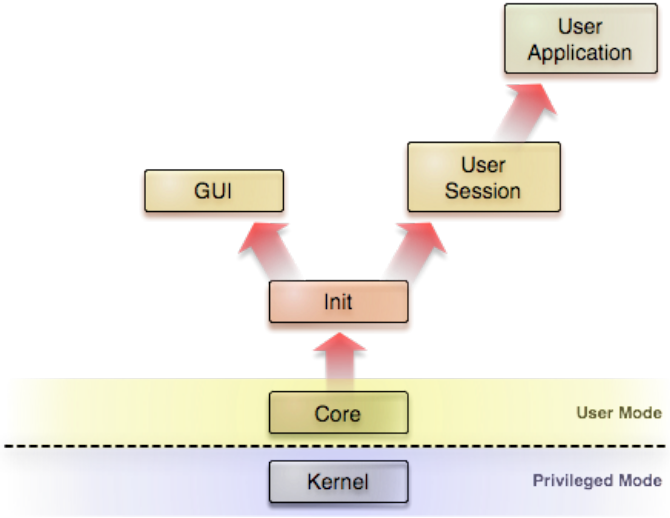
Core OS – Checkpoint/Restore

- **Periodic** snapshot creation: context switch **(**scheduler preempt**)**
- Target: Reducing **duration of memory checkpointing** by
  - Snapshot granularity (full, partial, **incremental** memory dump)
  - Processing implementation
    - Sequential (Single-Core based Stop/Start)
    - **Parallel** (Multi-Core based **Copy-on-Write**)
  - Type of Memory Access (Separated-, Shared-, Redundant-Memory)
- Dedicated **hardware support** (e.g. Co-Processor/FPGA based)

Background: L4 Fiasco.OC & Genode

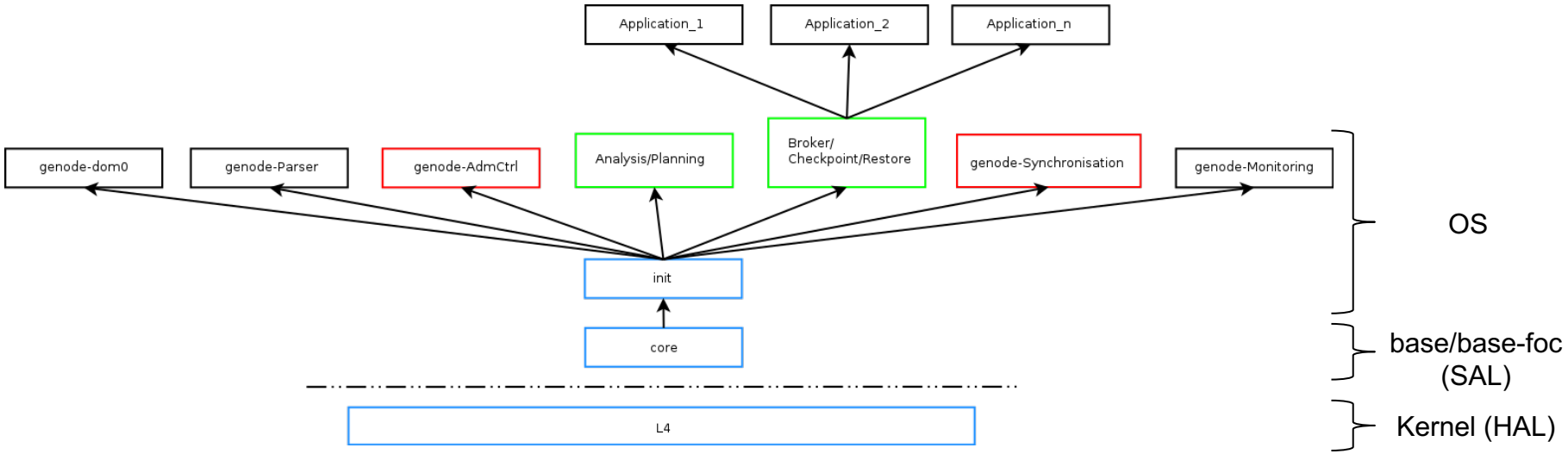


https://l4re.org/doc/l4re_intro.html



http://genode.org/documentation/general-overview/index

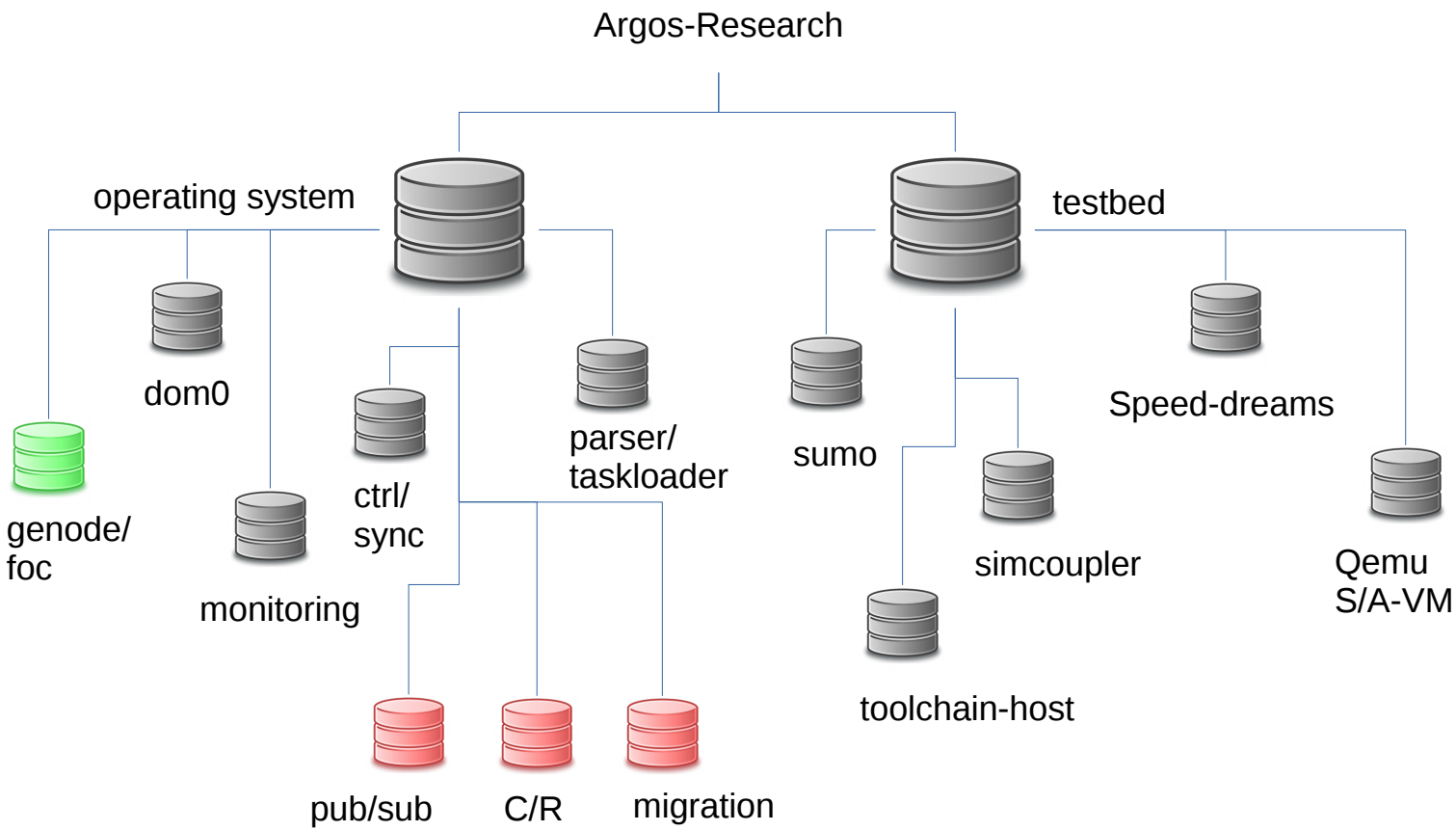
Hierarchical component structure



Current Development – Embedded System

- **Operating System**
  - Runtime Monitoring
  - Checkpoint/Restore (Shared Memory)
    - Granularity (Full, Partial, Incremental)
    - Method (Stop/Start, Copy-on-Write)
    - Multi-Core mapping
  - Partitioning (Affinity)
  - Admission Control (Online schedulability analysis)
  - Synchronisation (in idle mode)
  - Real-Time Scheduling (FPP, EDF)
- **Hardware Support** (Porting to ARM Quad-Core platforms)

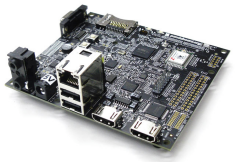
Open Source – Argos-Research

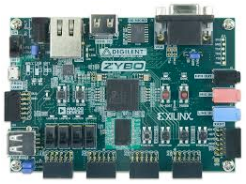


For more info see
https://github.com/argos-research

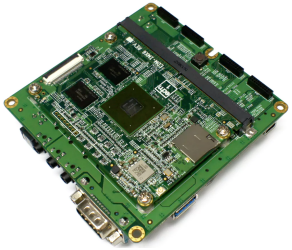
Current Development – Hardware support

- **Current support:** ARMv7-A (Cortex-A9, **Dual-Core**)
  - Pandaboard ES (TI OMAP 4)
  - Digilent Zybo (Xilinx Zynq-7000)
  - QEMU (RealView Platform Baseboard Explore) (PBX-A9)





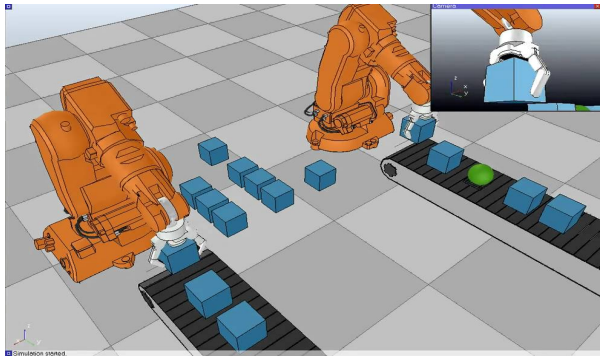
- **Future support:** ARMv7-A (Cortex-A9, **Quad-Core**)
  - ODROID U3 (Samsung Exynos 4412)
  - Wandboard (NXP i.MX6)
  - UDOO Board (NXP i.MX6)



Test Cases – Automotive/Robotics

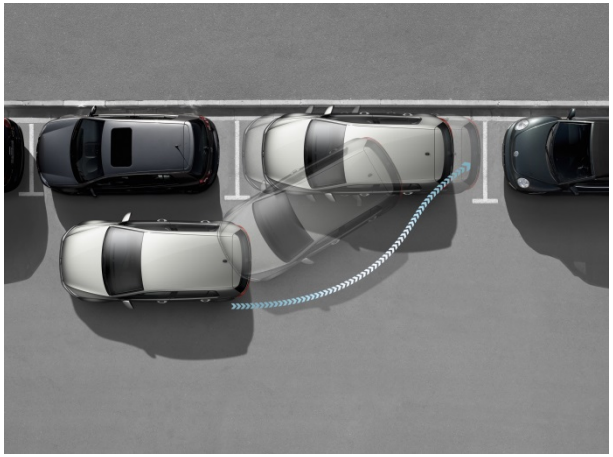
- Production line (industrial automation)

  -> energy saving scenario



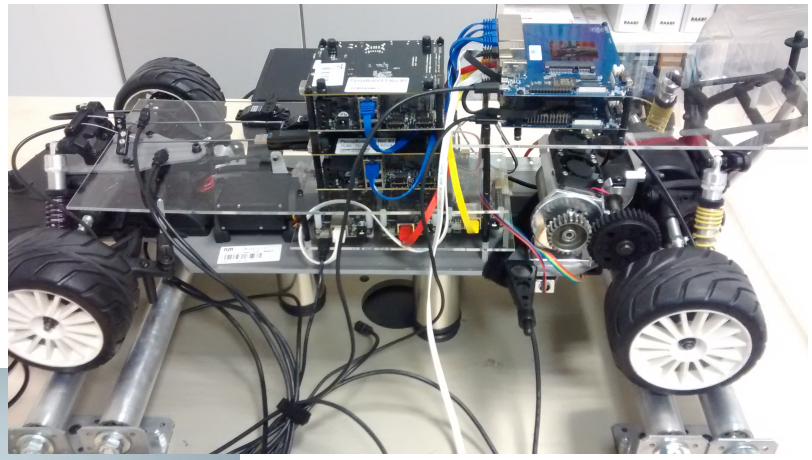
- Autonomous Parking

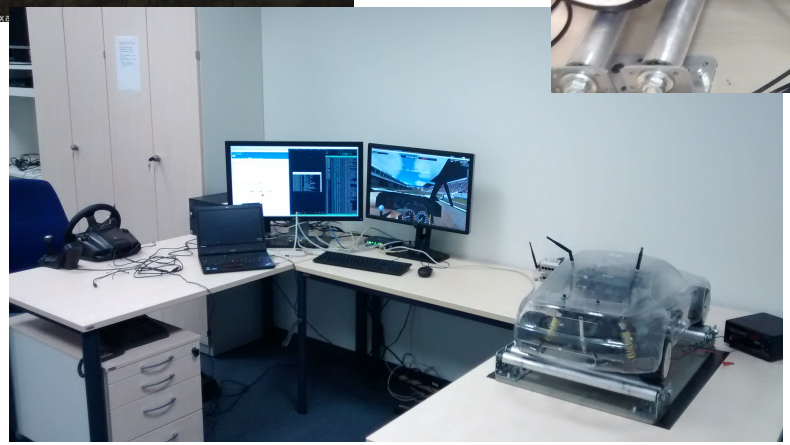
  -> fault-tolerance scenario (e.g. fail-safe)



http://www.whichcar.com.au/media/1841/image94342_c.jpg?width=500&height=372.23168654173764

Test Setup – Hybrid Simulator





Next Steps – Operating System

- **Migration Execution**
  - (De-)Serialization
  - Transfer
- **Checkpoint/Restore** (Redundant Memory)
- **Hardware-supported Checkpoint/Restore**
  - Co-Processor (e.g. PB ES Cortex-M3)
  - FPGA-based (e.g. Enhanced MMU)
- **Hardware support (e.g. placement) of further migration related components** (Runtime Monitoring, Analysis, Planning)
- **Flexible thread management** (intelligent synchronisation vs. idle mode)

Conclusion

- Motivation: Future CPS
- Dynamic Reconfiguration: Migration of software-based components
- Relevant OS research areas
  - Mixed-Criticality-aware Partitioning
  - Migration decision
  - Migration execution
- Development
  - Implementation: L4 Fiasco.OC/Genode OS Framework
  - COTS-Hardware (physical/virtual)
- Test Setup & Test Cases
  - Hybrid Simulator
  - Automotive & Robotics

Thank you!

https://www.os.in.tum.de/

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