REAL-TIME SYSTEMS ENGINEERING @ BOSCH

FROM RESEARCH TO INDUSTRY AND BACK

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Bosch Product Portfolio

Bosch IoT Suite

Bosch is a leading provider of Real-Time Cyber Physical Systems

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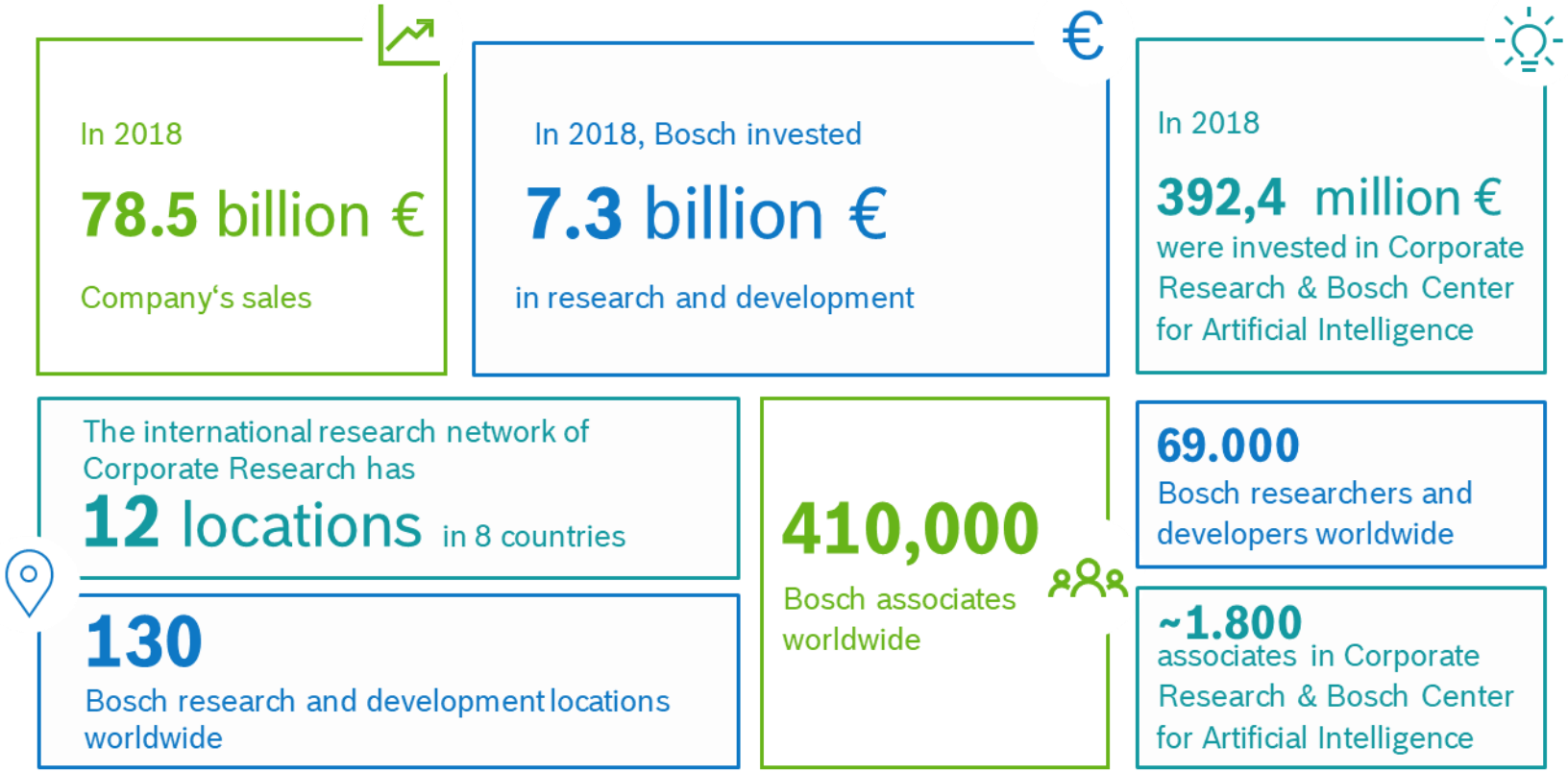
Bosch's World-wide R&D Presence



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Research and development

Corporate Research & BCAI

Bosch is one of the leading technology companies

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Bosch Corporate Research

- America 130 associates
- Europe 1,530 associates
- Asia-Pacific 115 associates

Smart Spraying

eBike System Design

Automatic Emergency Brake

Trustworthy Computing

Master Electrification by Virtual Product Engineering

Ultra Short Pulse Laser

Research that matters !

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Modelling vs. Reality

$$\sum_{i=1}^{n} \frac{C_i}{T_i} \leq n \cdot \left(\sqrt[n]{2} - 1\right)$$

$$\ln 2 \approx 69{,}3\%$$

Liu & Layland, Scheduling Algorithms for Multiprogramming in a Hard-Real-Time Environment, 1973

- Models are indispensable for increasing design efficiency (front loading)
- ***"All models are wrong, but some are useful"*** (George Box, 1976)
- A "useful model" for classical µC-based products such as engine management and ABS:
  - WCET with Rate-Monotonic Scheduling
- Why? Because it is "close enough" !
  - HW platform simple enough to derive tight WCET
  - Execution times rather static with cyclic triggering
  - Sporadic workloads can be approximated

It depends on the engineering task if a model is useful

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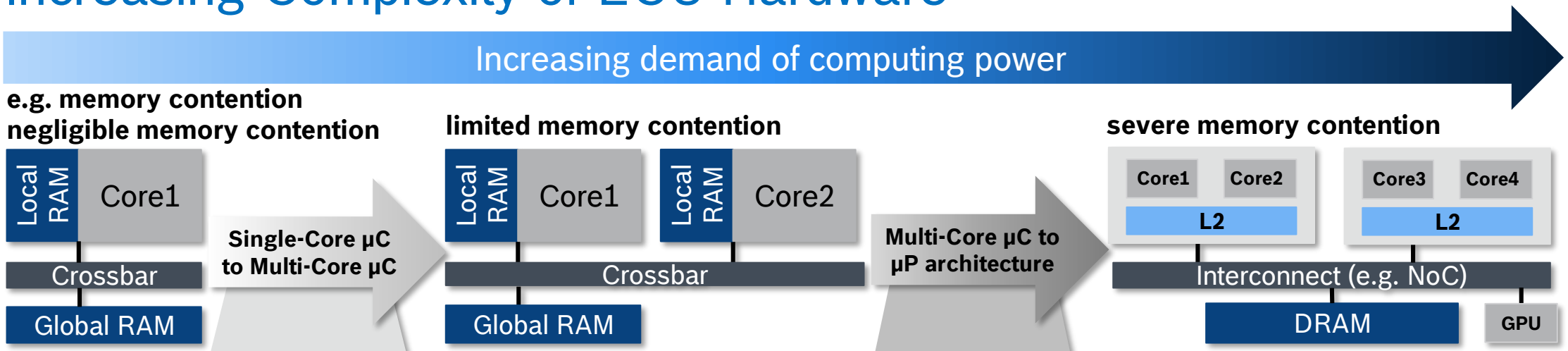
Increasing Complexity of ECU Hardware



- Recent years: Automotive has moved from single-core µCs to multi-core µCs
  - Already big pain / effort due to real-time issues
  - Real-time theory was of big help → startups out of community helped industry with tooling
  - Mastering multi-core was the challenge of the past years

- Now: Automotive is moving from multi-core µC to multi-core µP with accelerators
  - Shift from multi-core era to heterogeneous era
  - New HW mechanisms with severe impact on timing
- Will real-time theory again be of big help?

Mastering the heterogeneous system era is the new challenge

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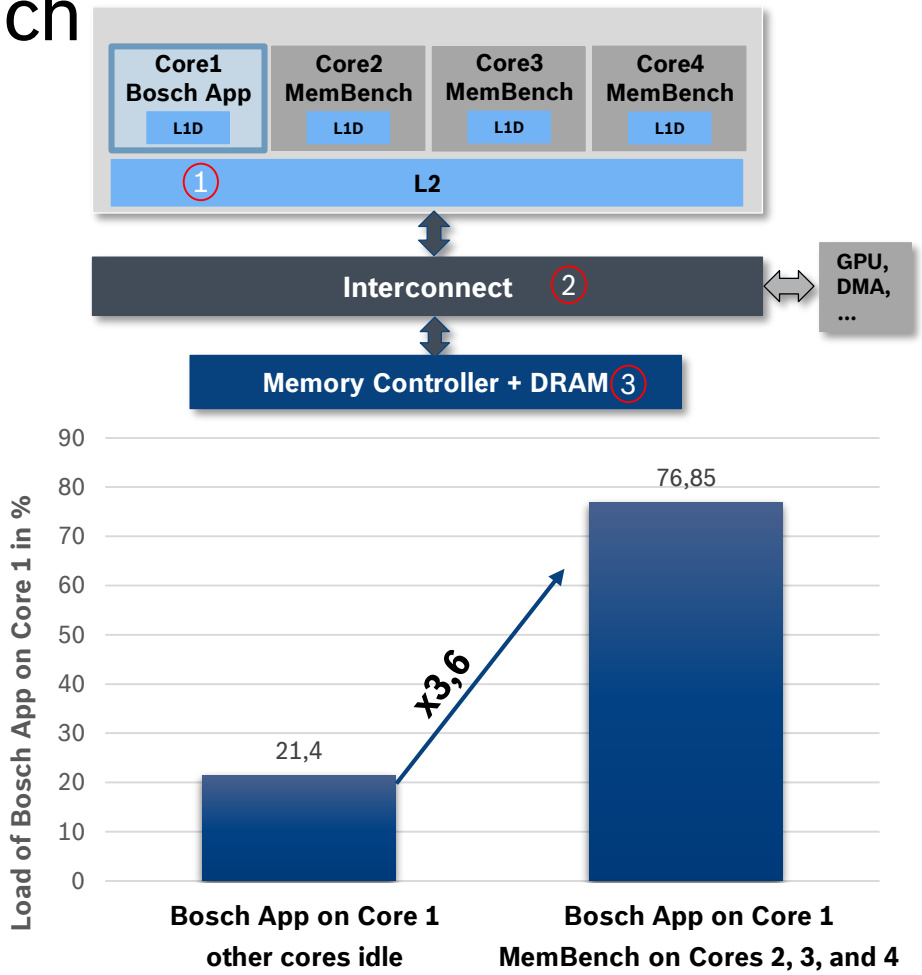
What is the main problem?

- WCET is one of the central abstractions in real-time research
- The main idea of WCET is to abstract away the underlying HW
- WCET abstraction is not adequate for heterogeneous system era
  - Dynamic interference channels are dominating factors and are not reflected (e.g. from accelerators or other cores (2))
  - Modern workloads are not static but vary heavily depending on operation condition (e.g. video)
  - More dynamic shared resources like caches (1), DRAM (3)
- New abstractions or more detailed models needed: we are facing a new HW/SW co-design problem



Heterogeneous µP hardware breaks WCET abstraction

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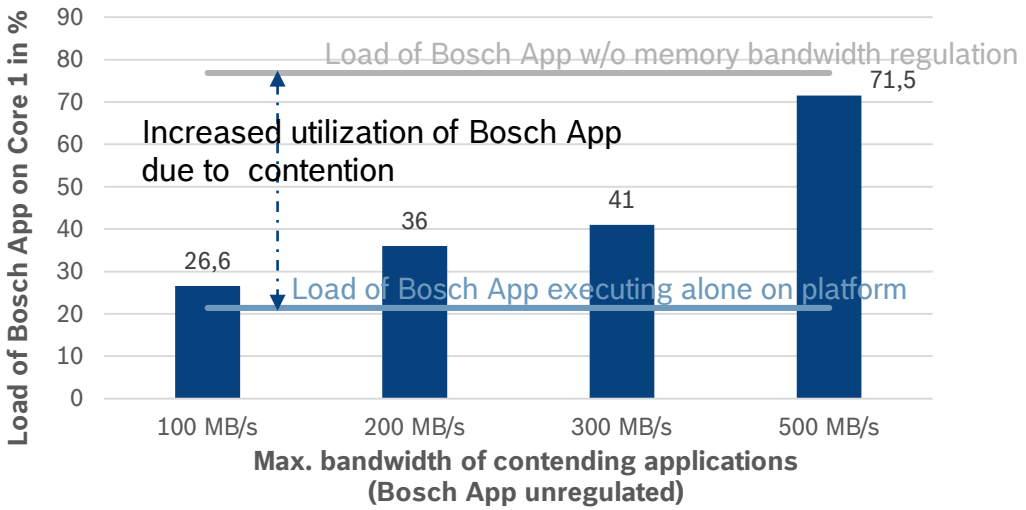
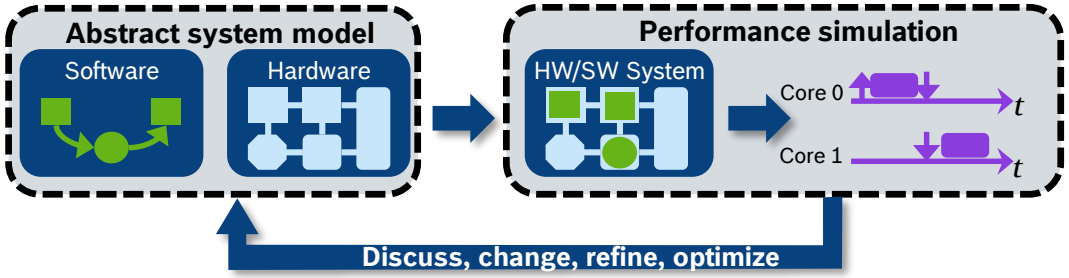
Current Bosch Research Approaches

- Mechanisms bounding memory interference
  - Idea: enforce max memory access budget per time interval and per core/task
  - Inspired by real-time research: MemGuard[1]



- Abstract performance modeling & analysis of hardware-software systems
  - Established inside Bosch for µC-based systems
  - Research extending it to upcoming µP-based systems at Bosch
  - Also prominent in your community – see WATERS challenges provided by Bosch



Need prediction as well as design for predictability

1) *MemGuard: Memory bandwidth reservation system for efficient performance isolation in multi-core platforms - H. Yun et al., University of Illinois at Urbana-Champaign*

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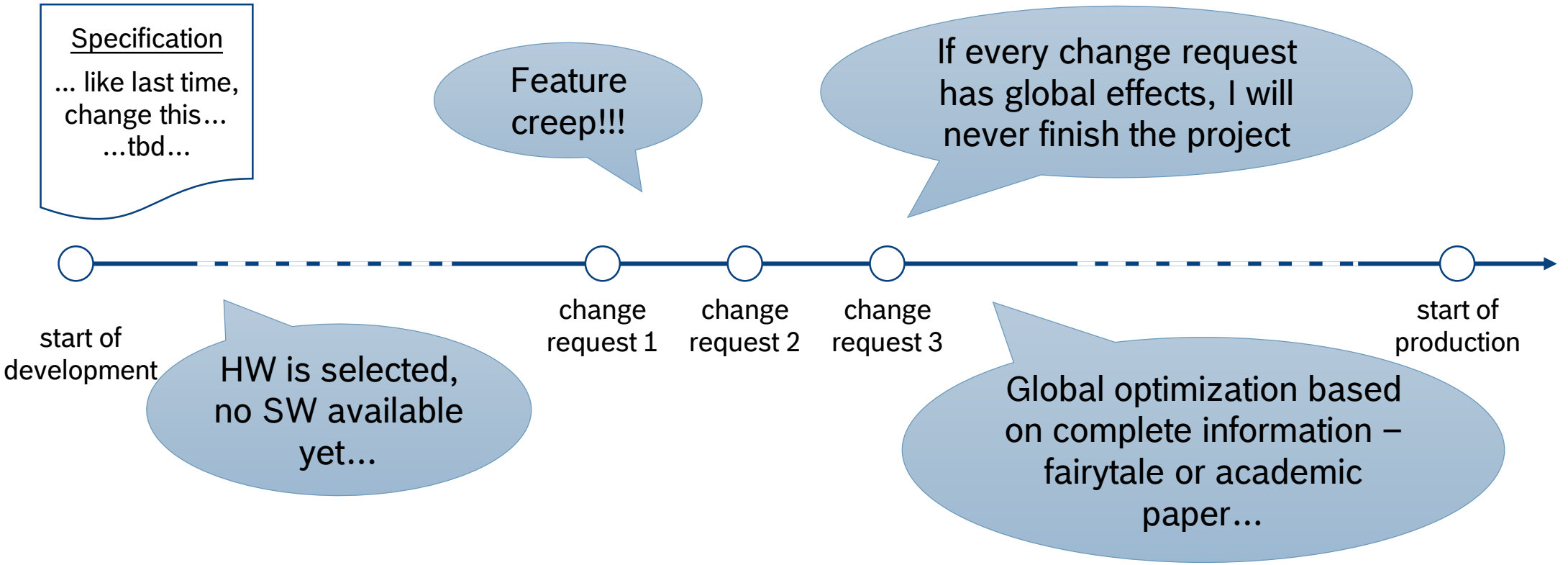
Automotive Engineering Projects Reality



Dealing with incomplete information is key

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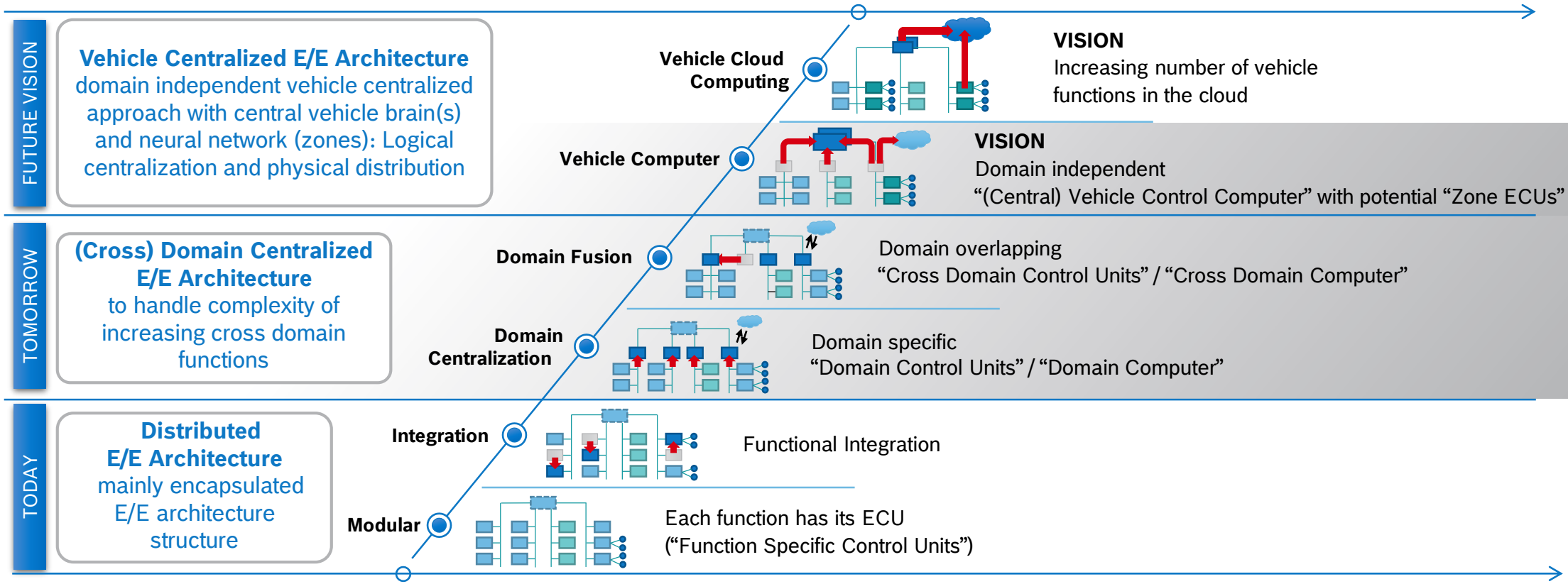
Centralized E/E Architectur



Centralization shifts integration effort from network to the ECU

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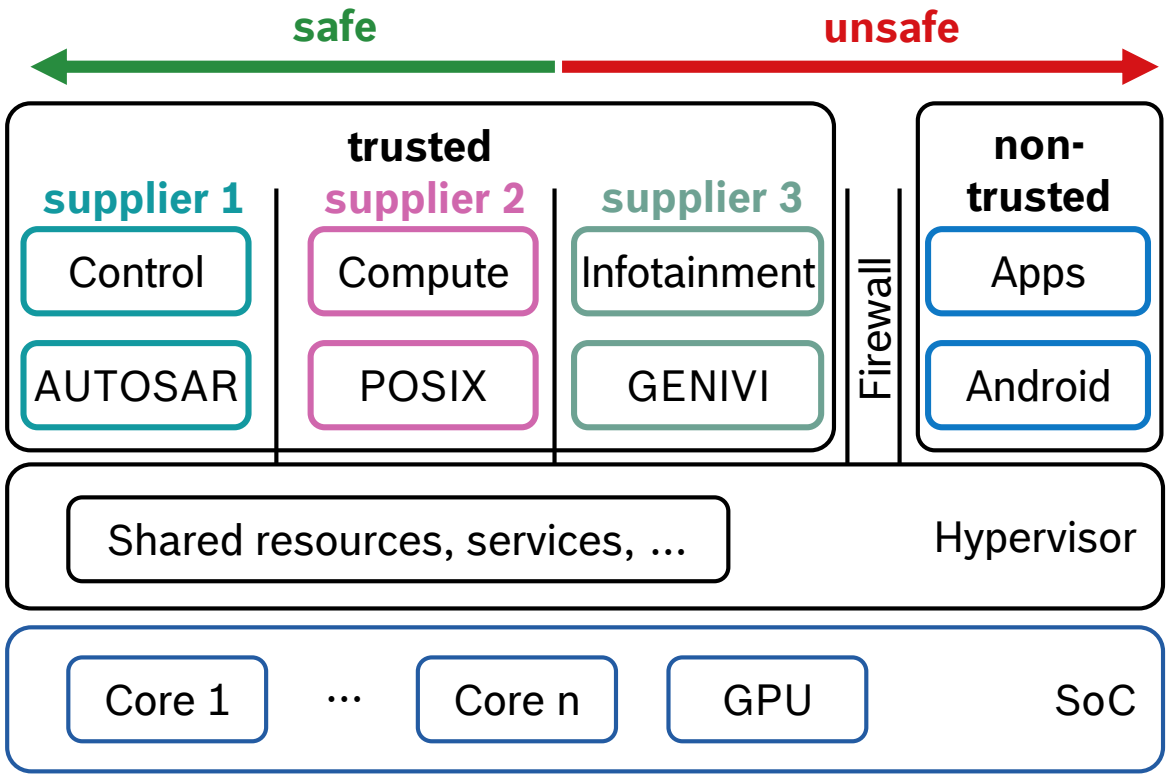
Consequences of a Centralized E/E Architecture



- Integration challenges
  - Multi-supplier
  - Mixed criticality (safety, security, timing)
- Can only be handled efficiently
  - if system parts can be tested in isolation
  - if local changes do not have global impact
- Current Hypervisors:
  - Spatial isolation ✓
  - Temporal isolation
    - No solution for bounding memory contention
    - Inefficient scheduling

Compositionality is key for development efficiency

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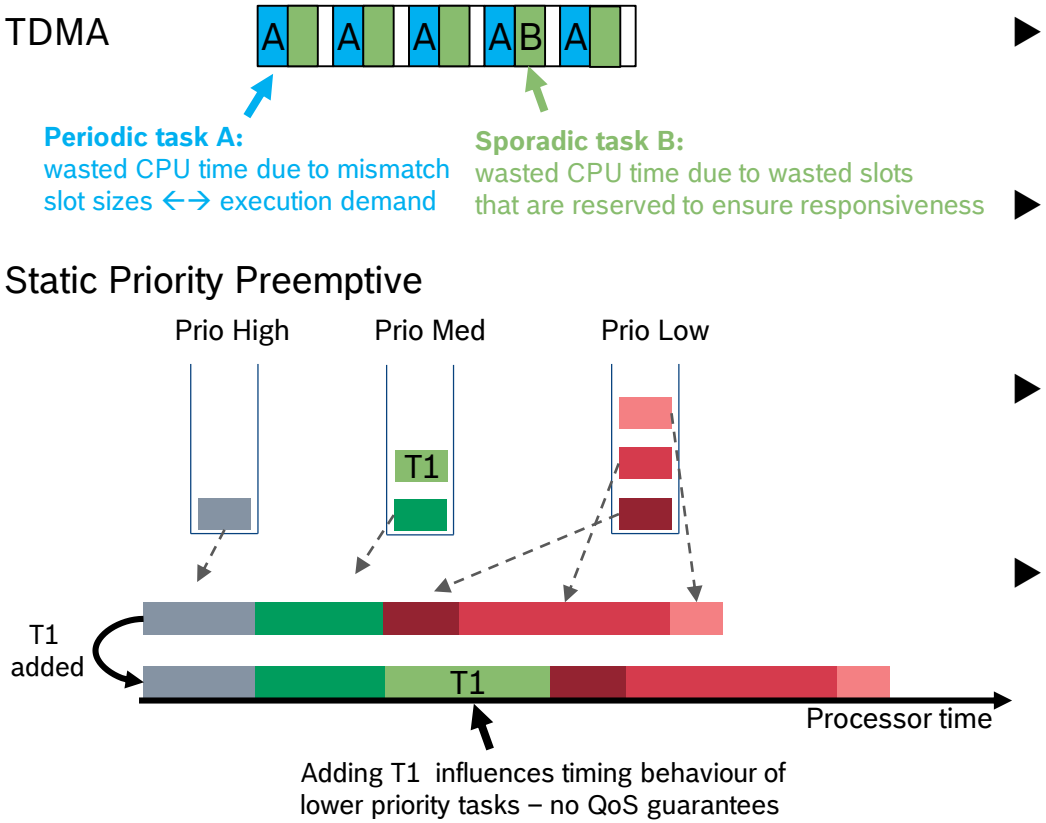
Automotive E/E Architecture Goes Connected



- And it is even worse ! – SOTA[1] requires integration to be feasible after SOP[2]
- Resources (computation, communication, memory, etc.) must be provisioned in a compositional manner
- Real-time guarantees of existing applications must not be broken when adding new applications to the system
- Scheduling mechanisms in most commercially available OSes and hypervisors are not sufficient
  - TDMA: static resource provisioning w/o flexibility
  - Static priorities: no task isolation, no notion of QoS

Compositionality is key to master future automotive systems

1: Software Over The Air 2: Start of Production

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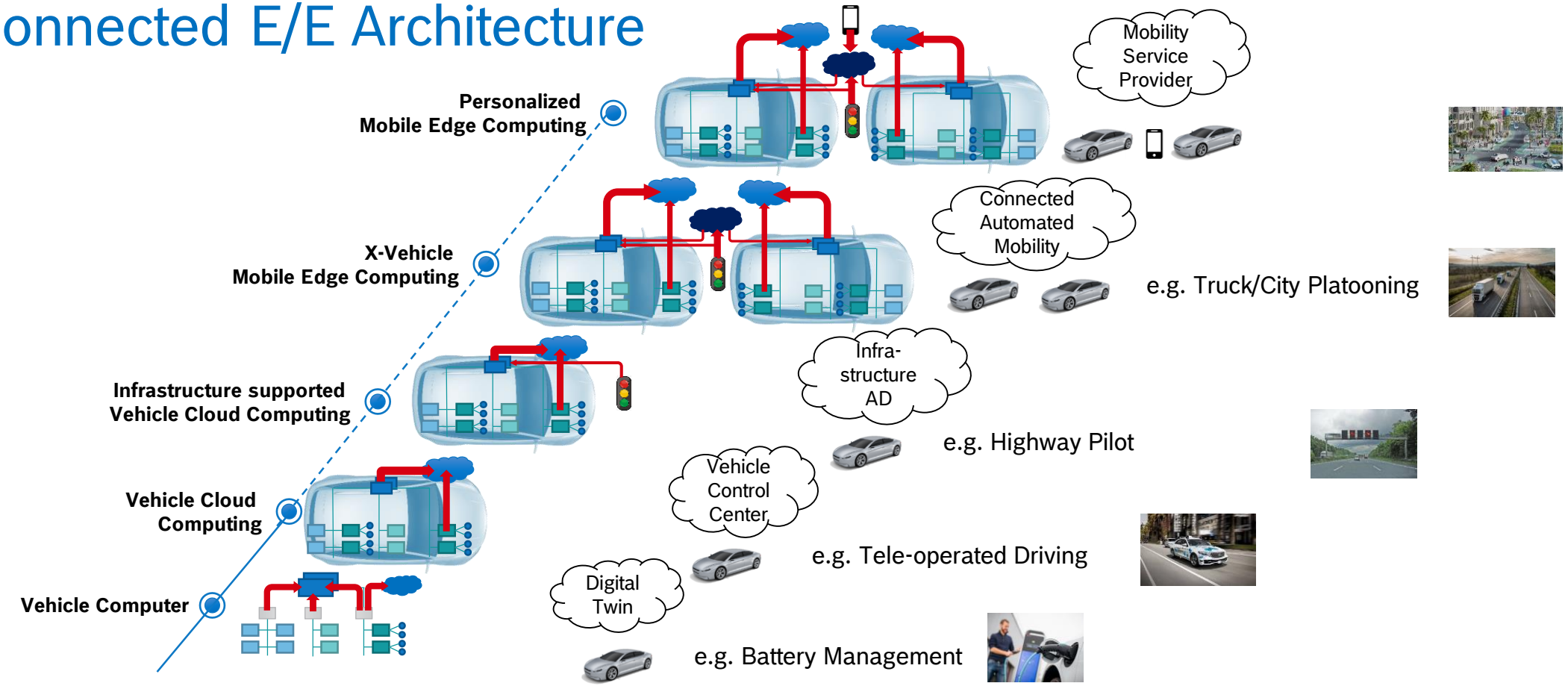
Connected E/E Architecture



Safety-critical real-time cause-effect chains beyond vehicle boundary

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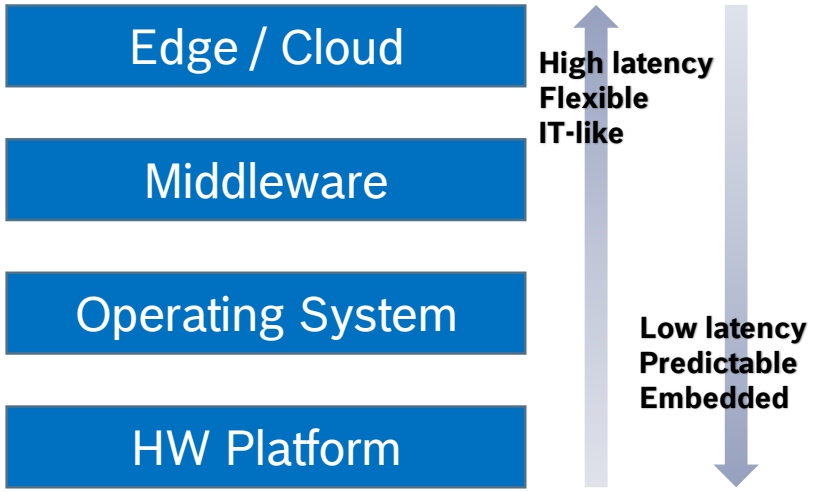
IT like SW Construction Principles Entering Automotive



- To cater for the flexibility needed for new applications IT software technology is entering automotive systems
  - High-flexibility, scalability, powerful abstractions, dynamic runtime adaptation **BUT** little control over real-time behavior
- Applications tightly interacting with physical world will still be based on embedded technology (e.g. ABS, engine management)
  - Resource efficiency, timing predictability, low latency **BUT** little flexibility, statically compiled
- A successful automotive SW platform must combine technologies from both worlds while ensuring real-time predictability
- Of course, this has a huge impact on “model usefulness”
  - Richer models from dataflow community have a good fit
  - Can they be combined with real-time models?

Real-time models need to reflect convergence of embedded and IT

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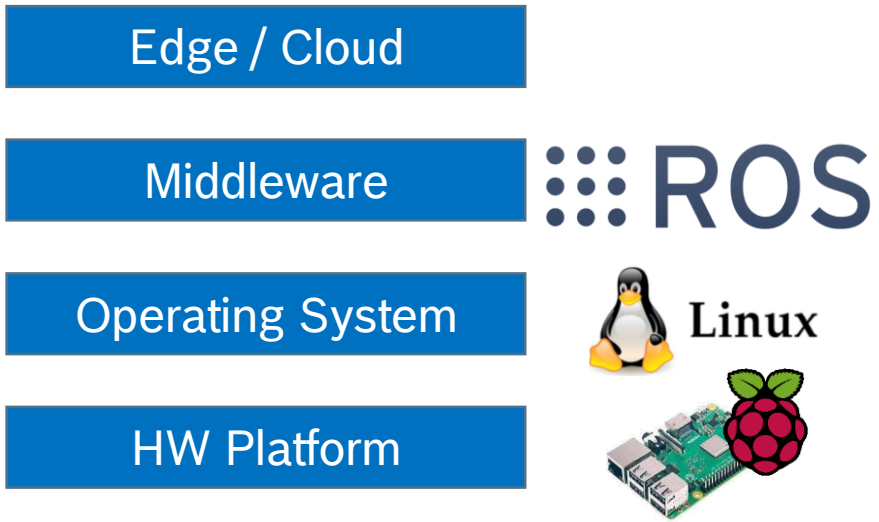
Application Domain with Similar Characteristics: Robotics



- Same construction principles as we are facing in automotive
- µP-based HW platforms
  - Same memory contention effects
- POSIX-based operating system (often Linux)
  - Richer scheduling, larger kernel overheads
- Robotic Operating System (ROS) as middleware
  - Service-orientation, marshalling, call-back queuing
- … little to learn in terms of real-time
  - Real-time often neglected in Robotics
  - Real-time problems are solved taking more powerful controller…
  - … or by tweaking/optimizing manually

Same challenges … little to learn … yet

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Current Bosch Research Approaches

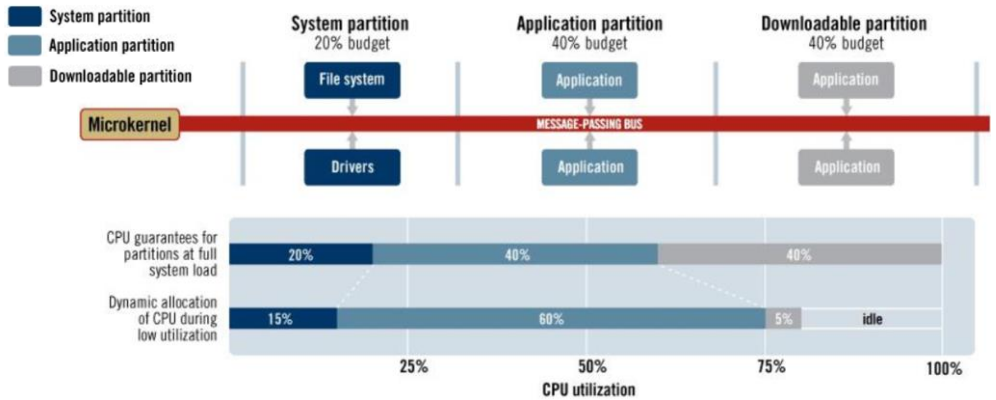
- ROS2 on resource-constrained µCs
  - RTOS, DDS-XRCE, predictable execution

µROS

https://microros.github.io/

- Response time analysis for ROS2
  - Bounding latencies of cause-effect chains in ROS2 framework
  - Revisiting ROS2 design choices from real-time perspective
  - Joint paper by Bosch/MPI/Pisa presented after lunch

- Real-time guarantees with QNX
  - QNX is one of the candidate operating systems for vehicle computers
  - Adaptive partitioning scheduling (APS) in QNX provides secure partitions with guaranteed CPU time
  - Unfortunately APS exhibits scheduling anomalies



Bosch research leverages synergies between robotics and automotive

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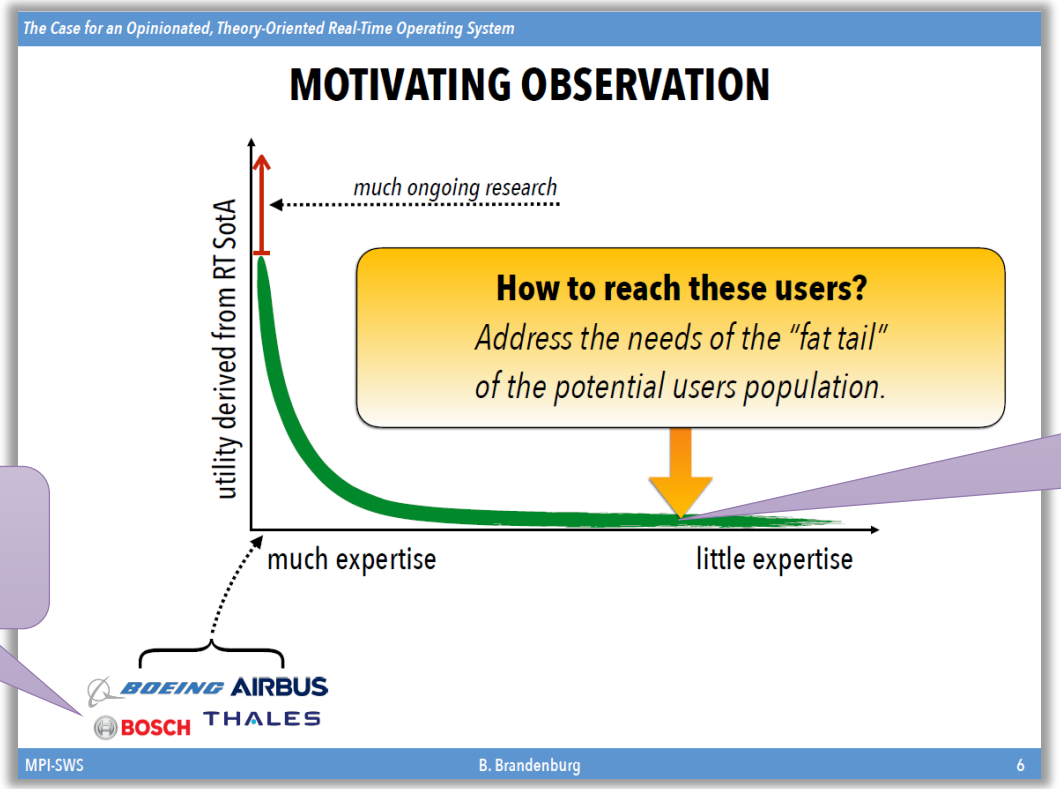
Real-time Experts are Rare – Engineers are Many



We feel honored…

… but Bosch is large and some parts are here.

Results need to be applicable for non-experts

https://www.cse.wustl.edu/~cdgill/ngoscps2019/presentations/NGOSCPS2019_Brandenburg.pdf by Björn Brandenburg, MPI for SW Systems, Kaiserslautern

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There are many challenges ahead. Solve them together with us.

THANK YOU