21st International Stuttgart Symposium

Virtual Verification of Cause-Effect Chains in Automotive Cyber-Physical Systems

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Agenda

- Introduction and Motivation
- Methodology to extract the Timing Behavior of Automotive Cyber-Physical Systems
- Use Case example and Architecture
- Simulation Results
- Conclusion

INTRODUCTION AND MOTIVATION

Introduction and Motivation
Evolution of the Automotive E/E Architecture

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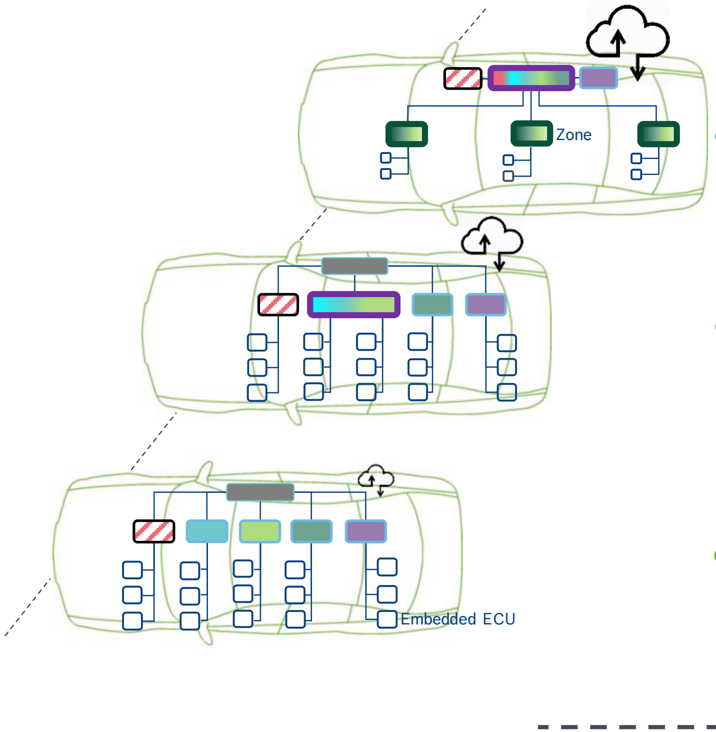
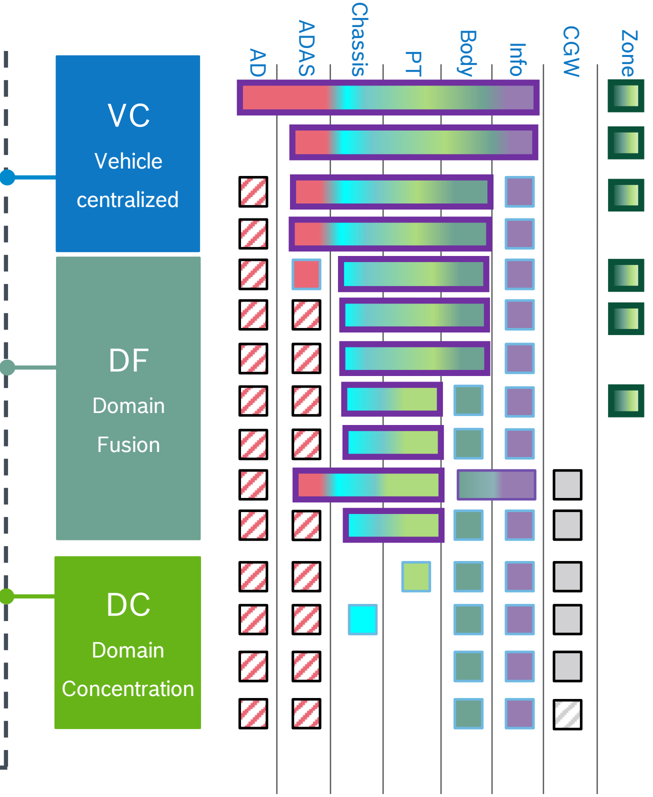
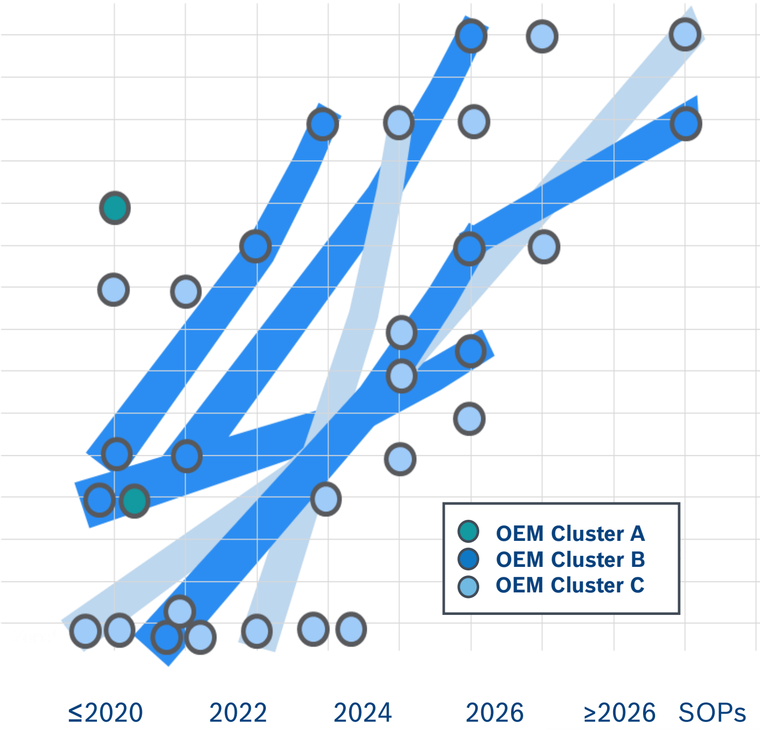
E/E Evolution



Funct. E/E Patterns*



OEM Evolution / Revolution hikes



*Shared housing concepts not shown **Slide from: R. G. de Oliveira, C. Kerstan, and A. Henkel: *Keynote: Service-Oriented Architecture. Chances and Challenges.* In: Automotive Ethernet Congress, Virtual. (2021)
ECU: Electrical Control Unit; AD: Autonomous Driving; ADAS: Advanced Driving Assistance System; PT: Power Train; CGW: Central Gateway; OEM: Original Equipment Manufacturer

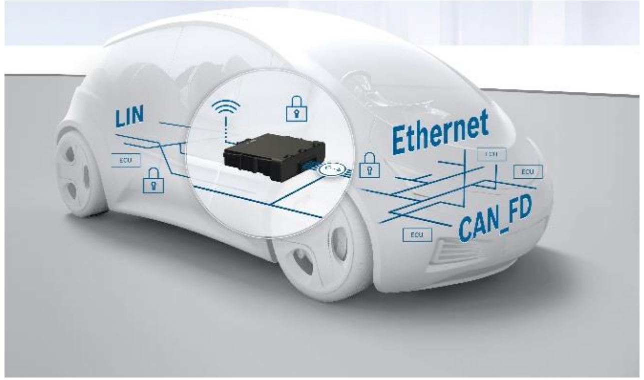
Introduction and Motivation
Challenges in Automotive Cyber-Physical Systems (CPS)

Those new automotive E/E architecture systems lead to a highly complex interaction between the cross-domain vehicle functionalities.

Such systems have mixed-criticality processes sharing the runtime environment, making not trivial the relation between the Intra-/Inter-ECU functionalities generating complex cause-effect chains.

On the Intra-ECU scope: tasks running in multi-core processors could take longer to be executed than expected.[1]

On the Inter-ECU scope: Data sent by communication channels could present additional delays and jitter.[2]



[1] R. Münzenberger and O. Schmidt: *From Assisted to Autonomous Driving and Beyond. Taking control of system timing challenges in embedded automotive systems*. Whitepaper (2019)
[2] N. Finn: *Introduction to Time-Sensitive Networking.* In: IEEE Communications Standards Magazine, June (2018)

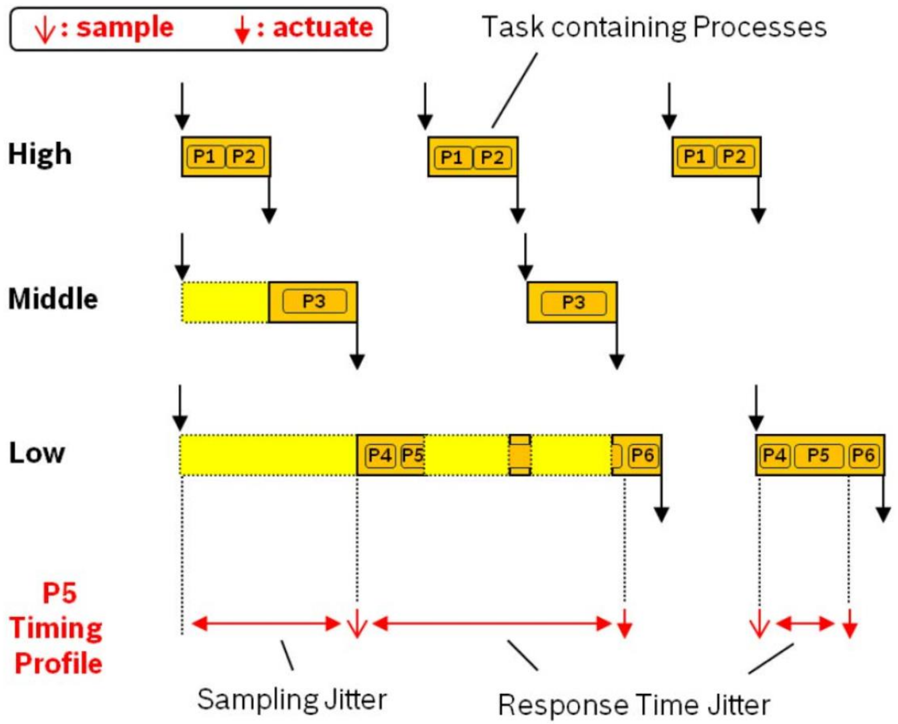
METHODOLOGY TO EXTRACT THE TIMING BEHAVIOR OF AUTOMOTIVE CPS

Methodology to extract the Timing Behavior of Automotive CPS
Timing Behavior in Automotive CPS

Automotive software systems typically consist of several dozen functionalities that are scheduled with static priority preemptive scheduling policies.

Complex functionalities are realized using several communicating processes distributed over several tasks that might be executed on different ECUs communicating via in-vehicle networks.

There is much potential for a systematic co-engineering between Real-Time and Controls engineering to increase the design efficiency and confidence in Automotive CPS.



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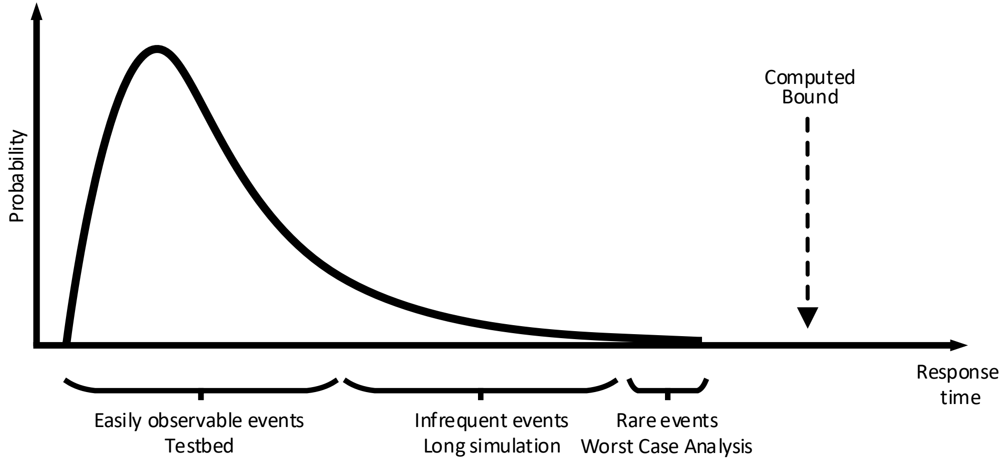
Methodology to extract the Timing Behavior of Automotive CPS
Extracting Timing Behavior

A cause-effect chain can be understood as the path from an input (e.g., sensor) across the required software elements until the desired output (e.g., actuator).

The Intra-ECU software tasks and Inter-ECU communications' timing properties affect such chains' performance, meaning there are necessary methods to extract such timing behaviors in order to verify the effects.

The processing and forwarding of data though the software devices influences the systems response time giving latencies and jitters.

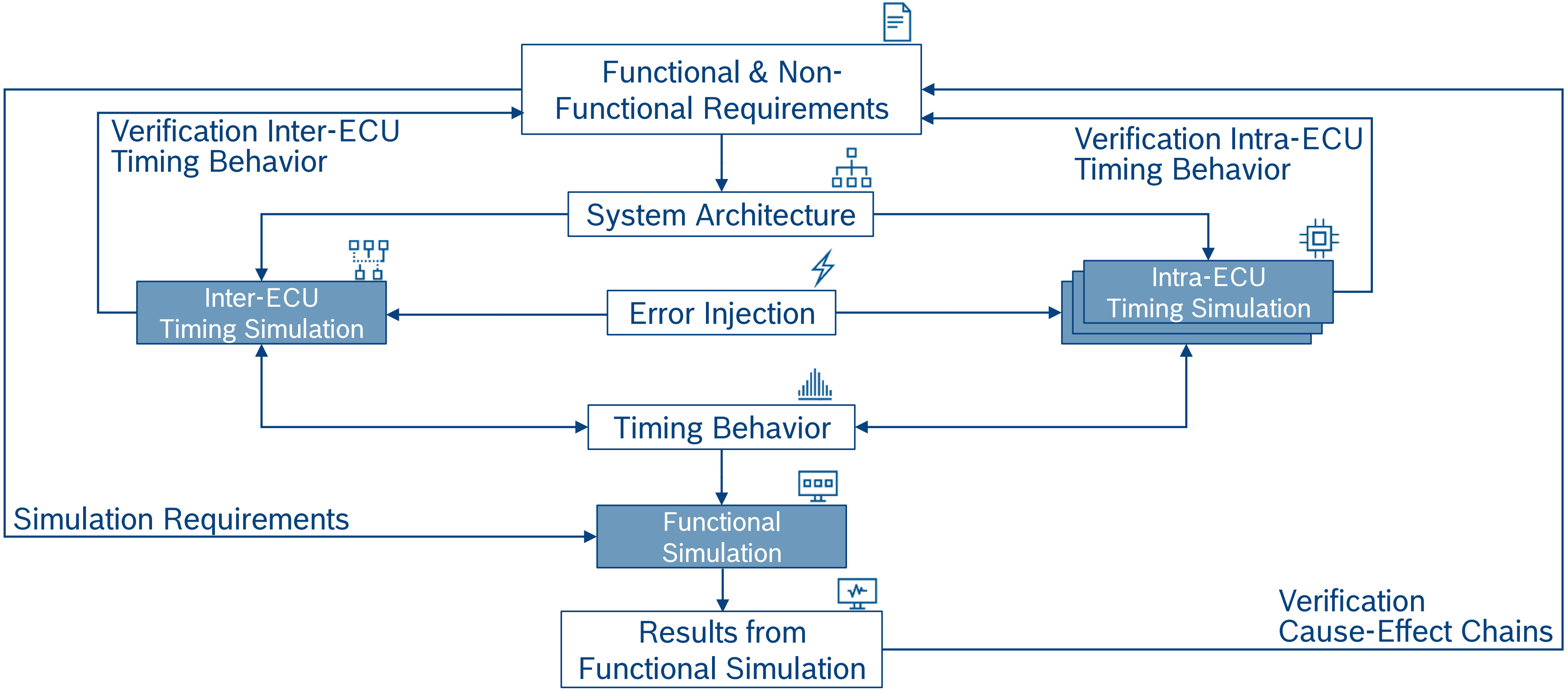
Different techniques can capture those values, such as a testbed setup or simulation.



Metrics for timing behavior and techniques to verify[1]

[1] N. Navet, S. Louvart, J Villanueva, S. Compoy-Martinez, and J. Migge: *Timing verication of automotive communication architectures using quantile estimation*. (2013)

Methodology to extract the Timing Behavior of Automotive CPS Cause-Effect Chains Verification



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USE CASE EXAMPLE AND ARCHITECTURE

Use Case Example and Architecture
Lane Keep Assist (LKA) feature and test scenario

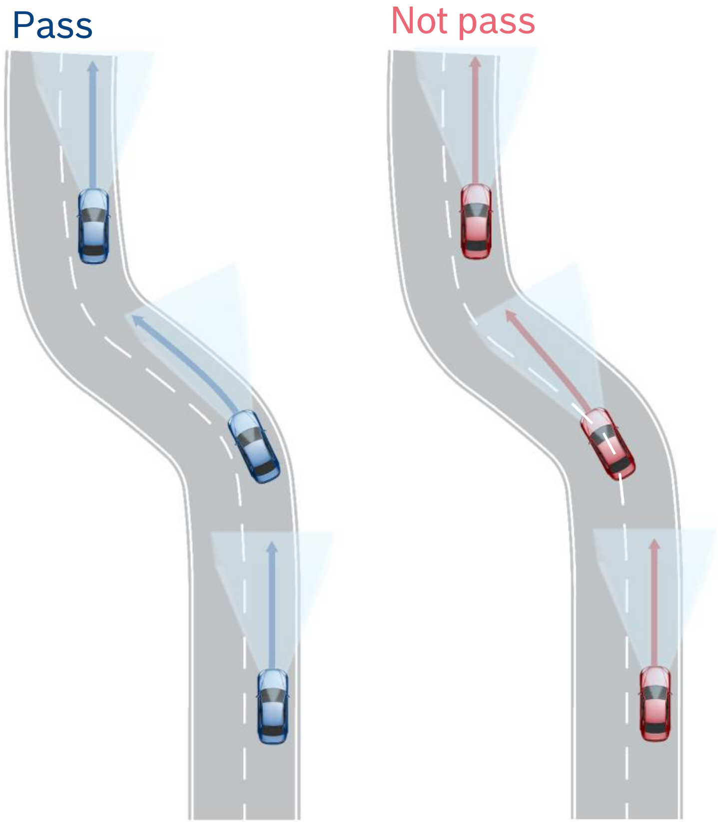
Feature:

LKA system supports to correct the course of a vehicle gradually deviating out of its lane due to driver inactivity. LKA systems typically use an array of sensors to detect different types of the lane markings, and applies an amount of steering to prevent the vehicle from leaving its lane.

Test Case:

The vehicle shall maintain the lane using solely the LKA functionality for a simulation time of 30sec with varied latency and jitter on the Inter-/Intra-ECU timing behavior.

LKA feature



LKA test scenario
Vehicle speed = 50Km/h

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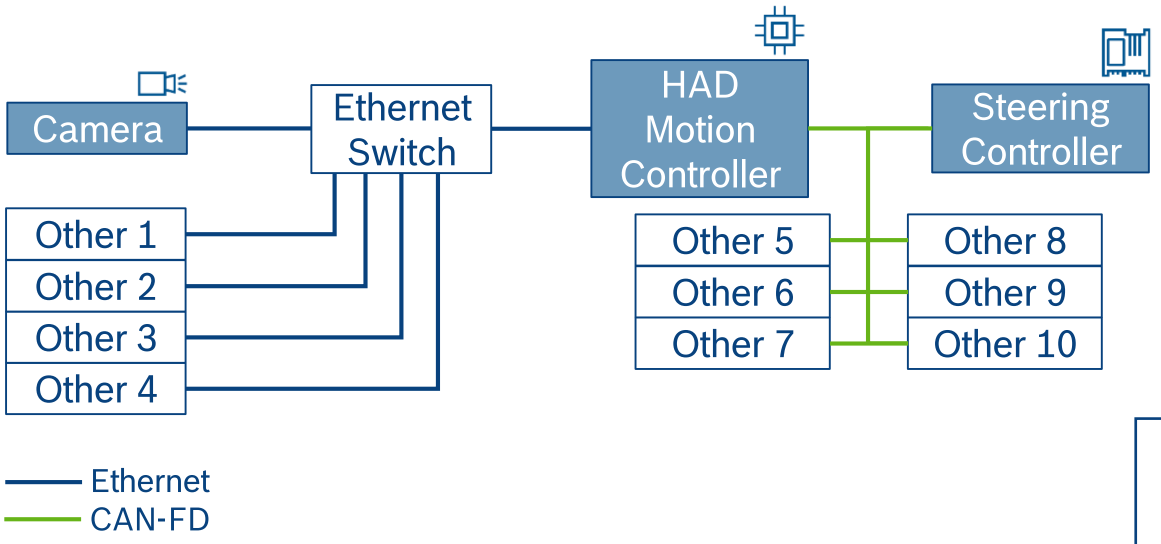
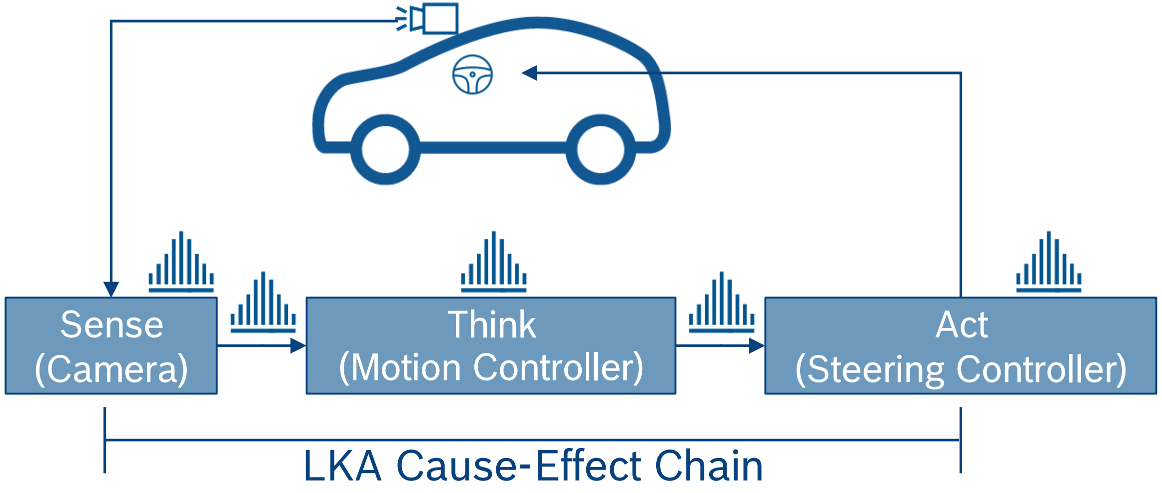
Use Case Example and Architecture
System Architecture and Cause-Effect Chain





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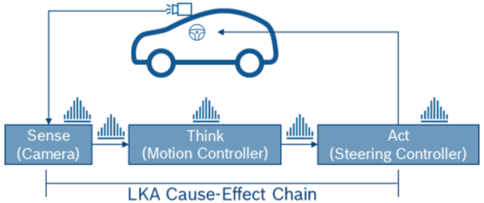
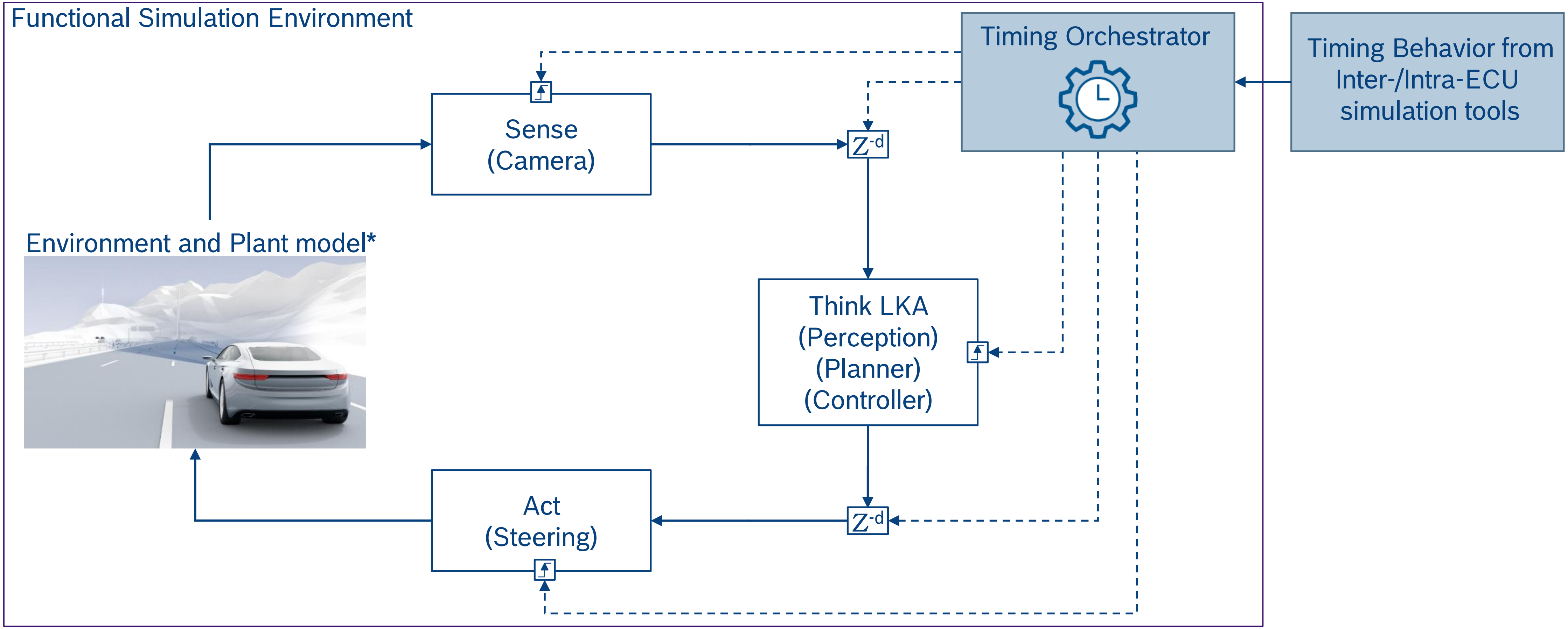
Use Case Example and Architecture
Simulation Environment Set-Up

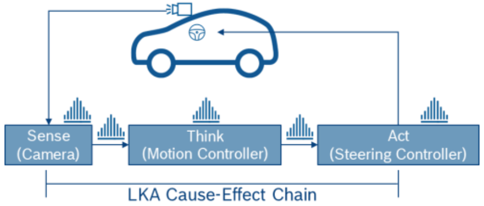


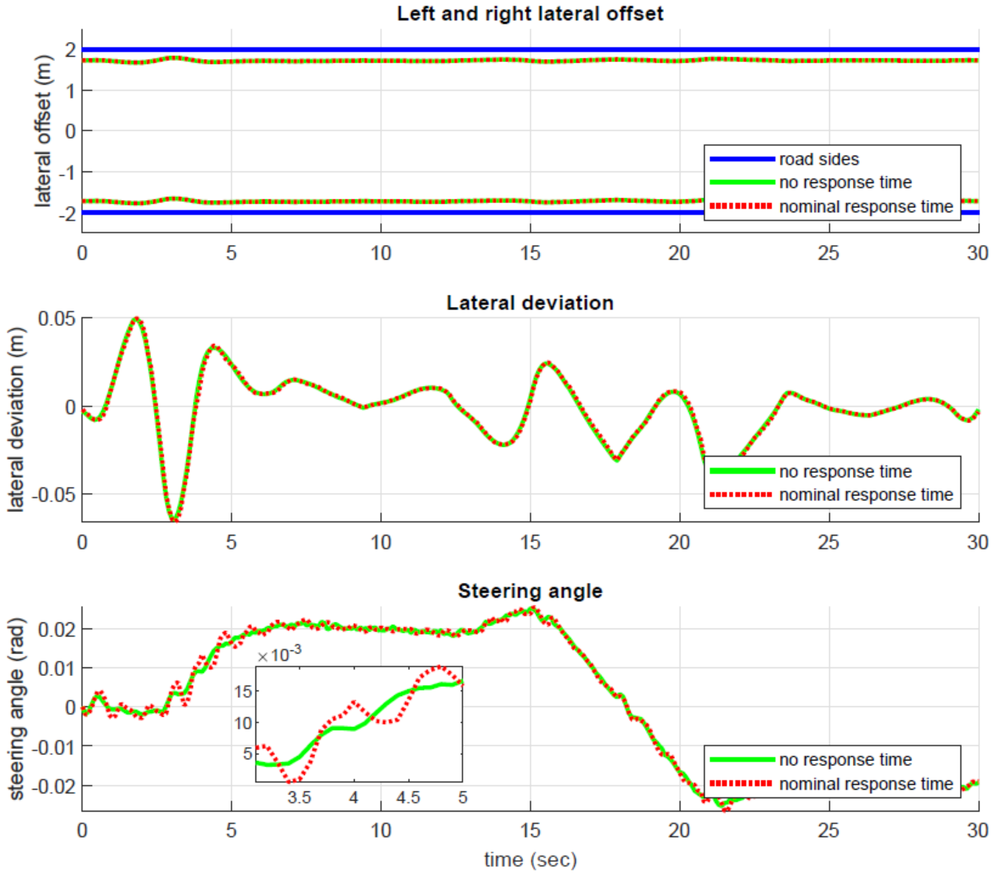


* Illustrative image. For the functional simulation was used an of-the-shelf simulation for LKA systems using the Matlab/Simulink environment

SIMULATION RESULTS

Simulation Results
Comparison LKA performance: Perfect Technology vs Runtime Response Time



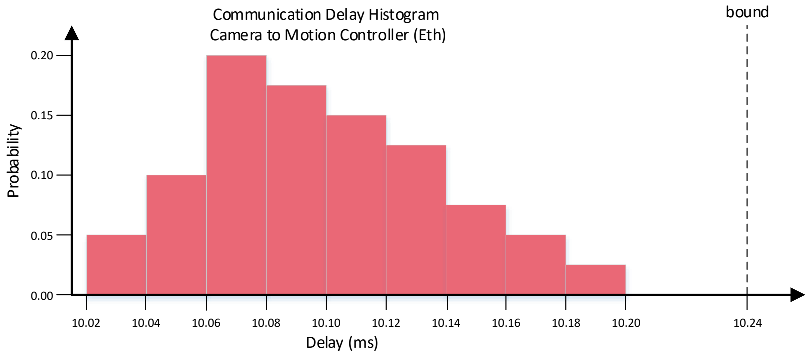


Perfect Technologies (no response time):

- Instantaneous response time

Runtime Response Time (nominal):

- Camera Eth Frames: [10ms, 10.20ms]
- HAD controller cycle time: [0.09ms, 0.11ms]
- Steering angle CAN frames: [0.2ms, 0.5ms]
- Steering controller: neglected



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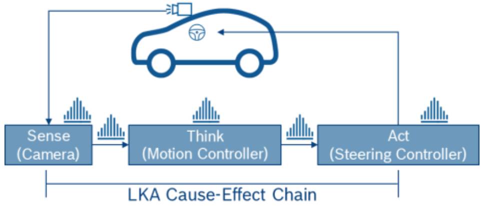
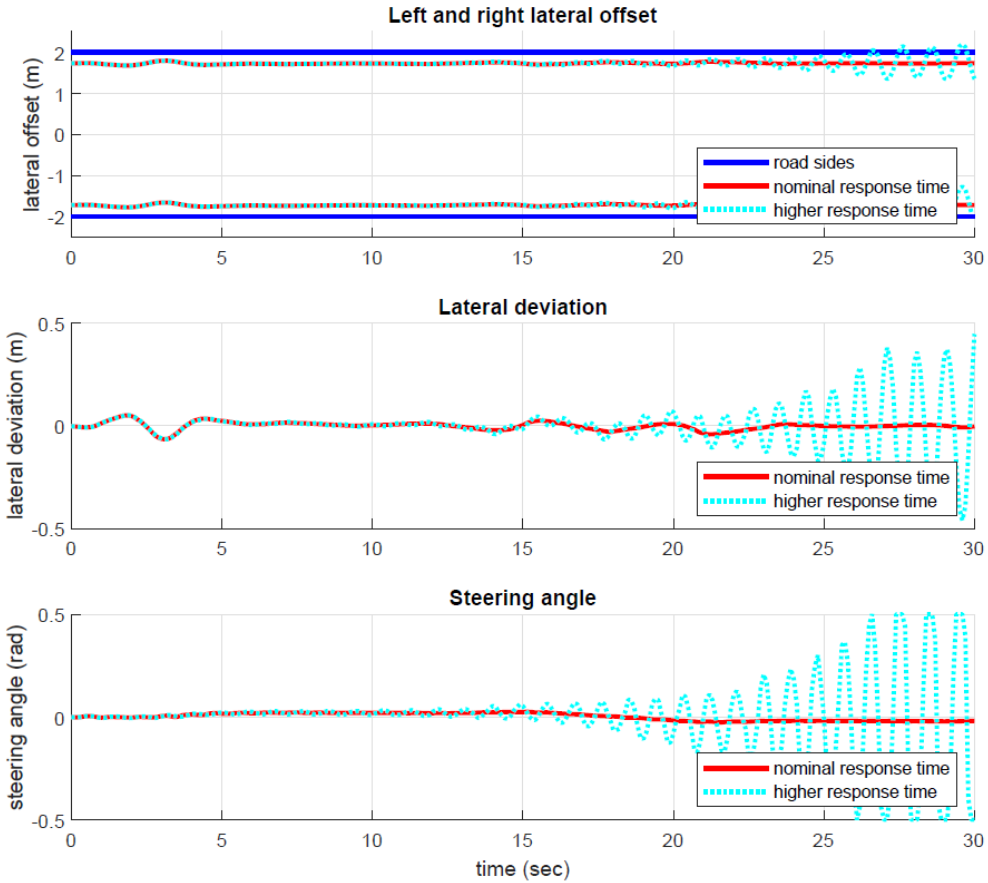
Simulation Results
Comparison LKA performance: Perfect Technology vs Runtime Response Time





Runtime Response Time (nominal):

- Camera Eth Frames: [10ms, 10.20ms]
- HAD controller cycle time: [0.09ms, 0.11ms]
- Steering angle CAN frames: [0.2ms, 0.5ms]
- Steering controller: neglected

Higher response time (duo to degraded performance):

- Camera Eth Frames: [16ms, 16.20ms]
- HAD controller cycle time: [0.09ms, 0.11ms]
- Steering angle CAN frames: [10.2ms, 10.5ms]
- Steering controller: neglected

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CONCLUSION

Conclusion

- This work proposed a methodology to extract and simulate the response time due to the runtime environment in automotive cyber-physical systems.
- With a Lane Keep Assist system as use case was demonstrated the effects of timing propagation on the functionality, especially the lateral maneuver in a simulation environment.
- Using a novel timing orchestrator was analyzed the maximum transportation delay allowed to keep the vehicle in the desired lane.
- The feasibility of the approach shall be validated in the future by comparing it with the real vehicle behavior as well, and the usage of timing orchestrator in a co-simulation environment shall be further explored.

Thank you for your attention.
Questions?

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