Universität Stuttgart
Institute of Industrial Automation and Software Engineering

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Picture: SofDCar-Project Consortium, 2023

Software-defined Car

Pathways and challenges towards IT for future automotive applications

30.06.2023

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Michael Weyrich

What is a Software-defined Cars / Vehicle?

"A Software-Defined Vehicle is any vehicle that manages its operations, adds functionality, and **enables new features primarily or entirely through software**.")[1]

"(Software- defined Vehicles are) the gradual **transformation** of automobiles from highly electromechanical terminals **to intelligent, expandable mobile electronic that can be continuously upgraded.**")[2]

"In 2018 Software-defined vehicles become an **industry hot topic**, 2019 Volkswagen CEO Herbert Diess said that Volkswagen would become a software-driven car company")[2]

)[1] according to QNX: https://blackberry.qnx.com/en/ultimate-guides/software-defined-vehicle

)[2] according to Deloitte https://www2.deloitte.com/cn/en/pages/consumer-business/articles/software-defined-cars-industrial-revolution-on-the-arrow.html

Where are we positioned in our German Automotive Industry?

Memo: Annual sales of the German automotive industry of around **411 billion euros**)*

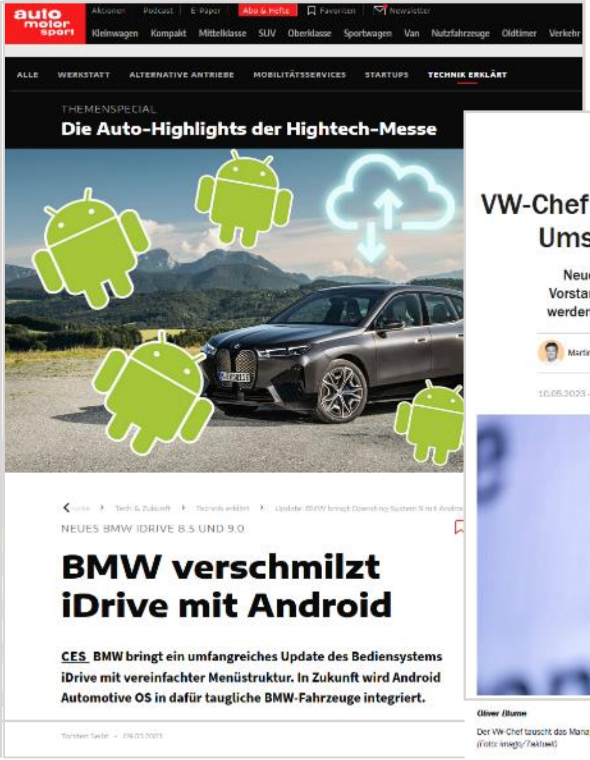
Restructuring and new alliances …


Handelsblatt

CHIPHERSTELLER

Nvidia-Chef: „Mercedes wird die wertvollste Luxusmarke des Planeten werden“

Die Partnerschaft zwischen Nvidia und Mercedes-Benz ist in Stuttgart umstritten. Nvidia-Chef Jensen Huang setzt nun auf eine Charmeoffensive.


THEMENSPECIAL

Die Auto-Highlights der Hightech-Messe

NEUES BMW IDRIVE 8.5 UND 9.0

BMW verschmilzt iDrive mit Android

CES BMW bringt ein umfangreiches Update des Bediensystems iDrive mit vereinfachter Menüstruktur. In Zukunft wird Android Automotive OS in dafür taugliche BMW-Fahrzeuge integriert.


Handelsblatt

VOLKSWAGEN

VW-Chef Oliver Blume beginnt mit der Umstrukturierung von Cariad

Neuer Chef der Volkswagen-Tochter wird ein Bentley-Vorstand. VW muss schneller in der Softwareentwicklung werden, weitere Verzögerungen würden Milliarden kosten.

AV winter is coming …


NAHVERKEHR

Mobileye beantragt keine Zulassung für autonomes Fahren

In Darmstadt und Offenbach wollte Verkehrsminister Wissing Autos fördern, die ohne Fahrer Menschen transportieren. Nun winken die Unternehmen ab.

Fahrzeug mit Technik von Mobileye

)* As per 2021, Source: Kleine Anfrage an den Bundestag zur Zukunft der deutschen Automobilindustrie“, Drucksache 20/361 as of 05.10.2022

Content

- State-of-the Art
- Research in Software-defined Vehicles
- Examples of Research Projects
- Conclusion

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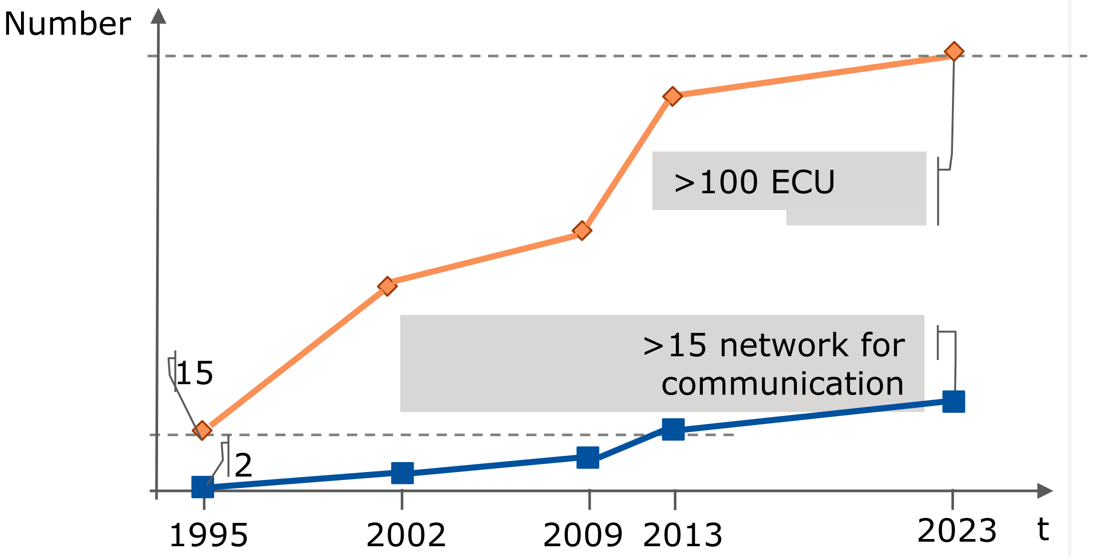
Automotive-IT: State-of-the-Art

It works, but there is an increasing complexity that needs to be managed

Increase of ECUs and network derivatives in a luxury car



AUTomotive Open System Architecture (AUTOSAR) was launched in 2003 has become very complex and needs improvements.

AUTOSAR


NIKKEI ASIAN REVIEW

News by Location | Business | Markets | Tech | Politics | Economy | Features | Opinion

AUTOMOBILES

Tesla teardown finds electronics 6 years ahead of Toyota and VW

Self-driving AI sends shivers through traditional supply chains

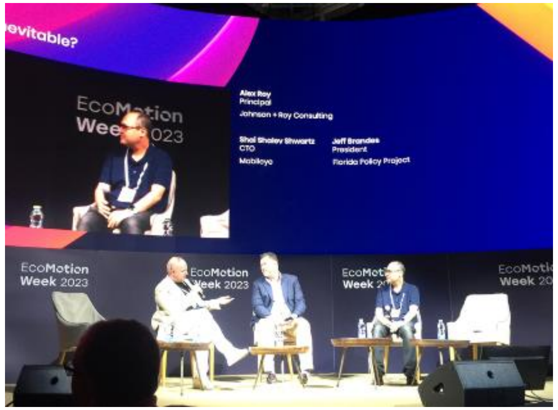
A teardown of the Model 3 shows Tesla so far ahead of more established peers that its technology could end the auto supply chain as we know it. (Nikkei xTech)

Oct. 2020 Media report on Tesla's advanced architecutre.

There are lots of Ideas for IT in Automotive and Mobility

The race for "new smart and connected" functionality in cars and automotive infrastructure is on. Hundreds of Startups are creating innovative ideas about smart future mobility.

For instance: More that 100 Startups and 3600 visitors during the EcoMotion week 2023 in Tel Aviv hunting for innovative ideas in IT, software and services for mobility

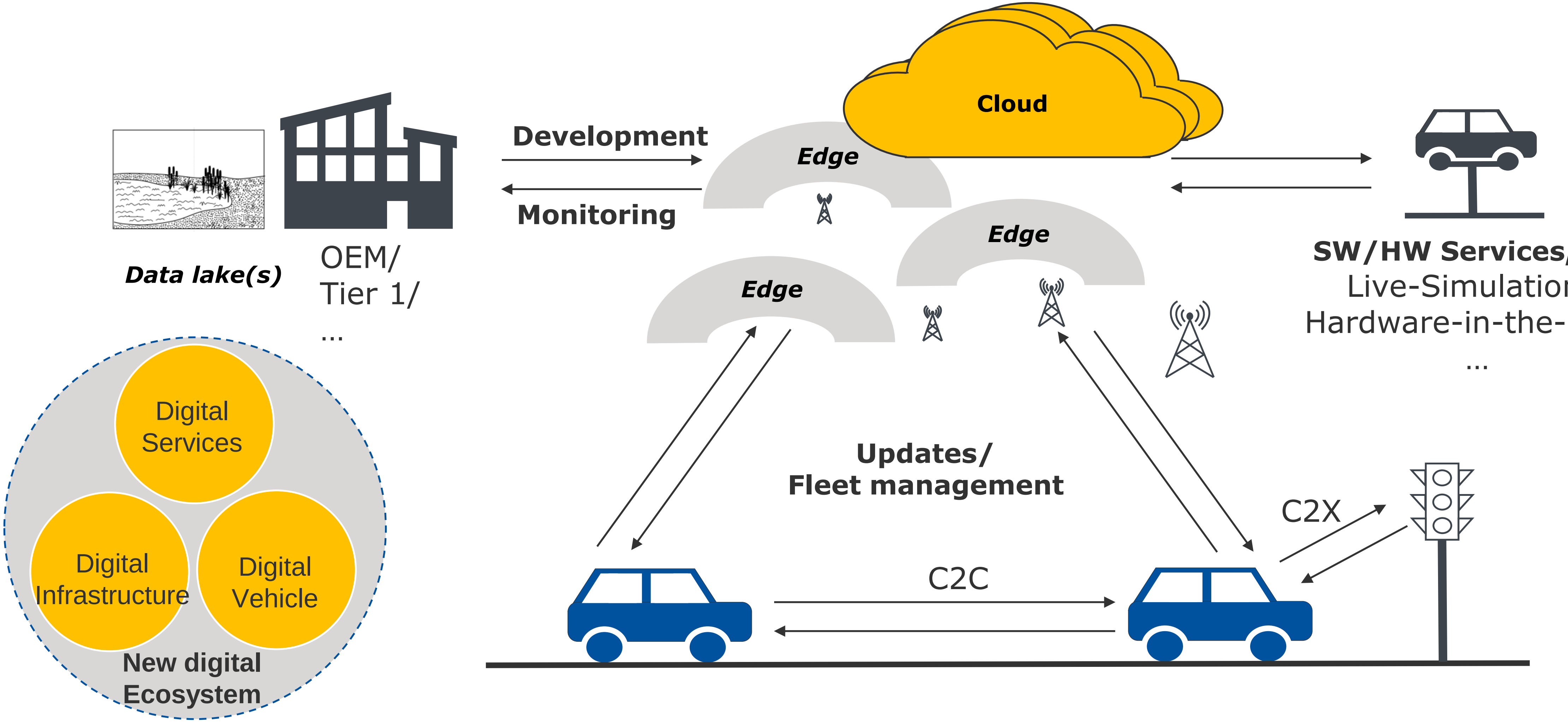


*Jeff Brandes, (ex-) Governor of Florida: „**Only those will achieve who are managing to combine the technological development with a business model**"*

Pictures: Michael Weyrich, 2023

Software and Data provide new Functions and Services

Today the race towards a new digital Ecosystem is on: The architecture of the future has to be in line with the "big business" strategy of the top players.

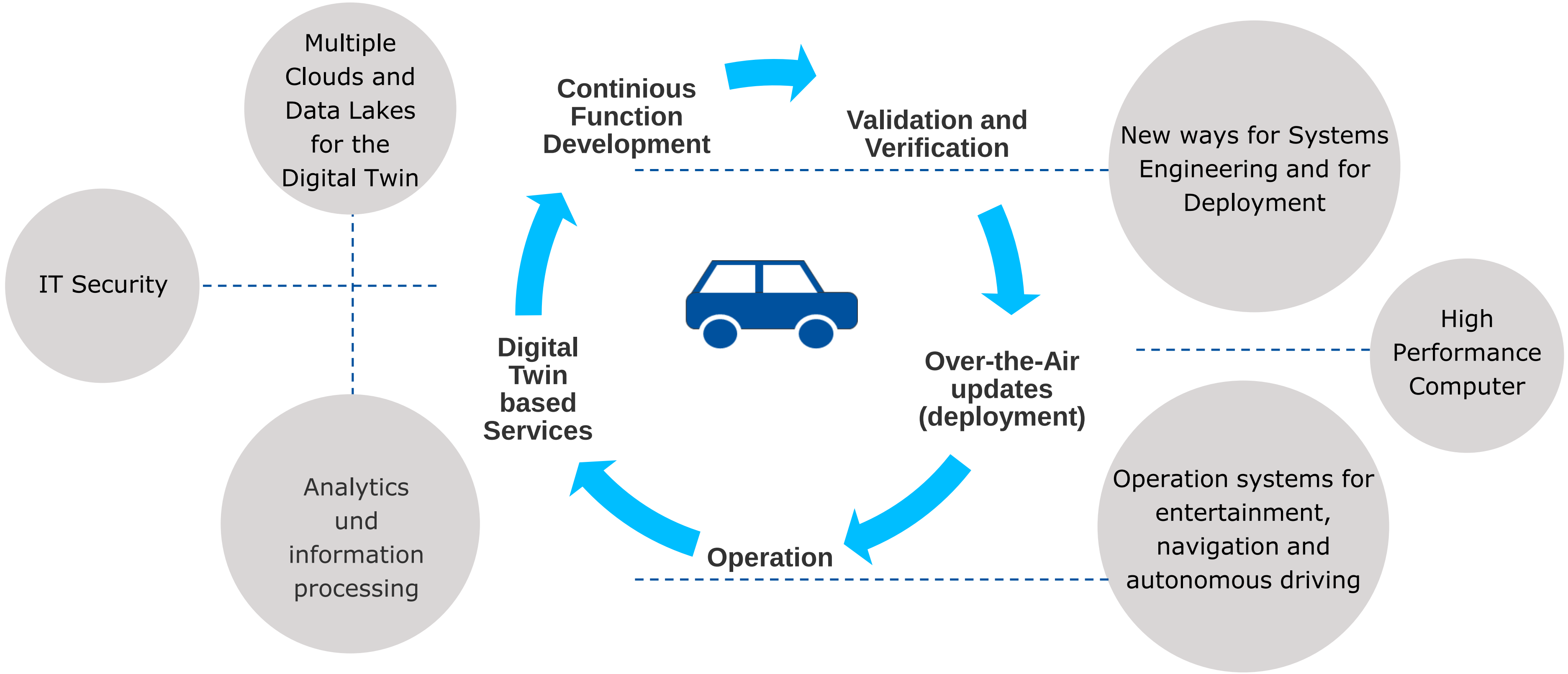


Automotive-IT: It works, but there is an increasing complexity of software and the value add of new functions is unclear

Automotive IT has very specific rules due to many different models, the tier structure of suppliers and the complexity of its "deep tech".

How to manage Complexity?

How to create value-adding features /functions?



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Software-defined Vehicles (SofDCar lead project)

SofDCar consortium addresses the challenges of future E/E and software architecture in vehicles.

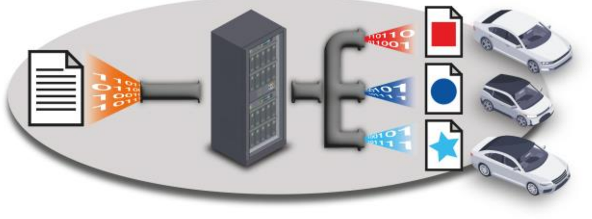
- Vehicles are considered as part of a **network of all vehicles and infrastructure**

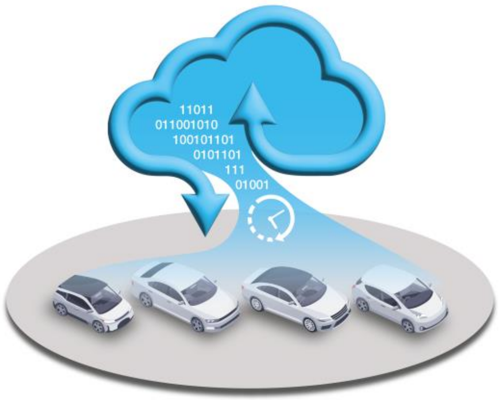
- **Digital twins** based on efficient data structures form a virtual image of the physical vehicles

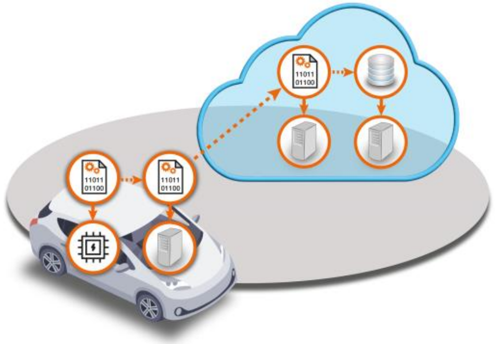
- A **data loop** enables a connection between the vehicle in operation and development, e.g. for the re-deployment of software.

Research Topic: Re-Deployment

How can CI/CD approaches be deployed for the Vehicles?







Development of variant-rich software for the software-defined vehicle

Intelligent complexity management of variant-rich software, considering the wide range of customer requirements

Over-the-air update for vehicle fleets

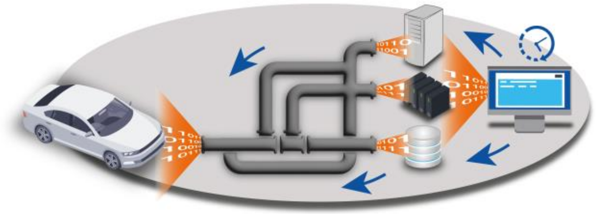
Updating entire fleets of vehicles Over-the-Air while considering the role of cloud elasticity due to different workloads

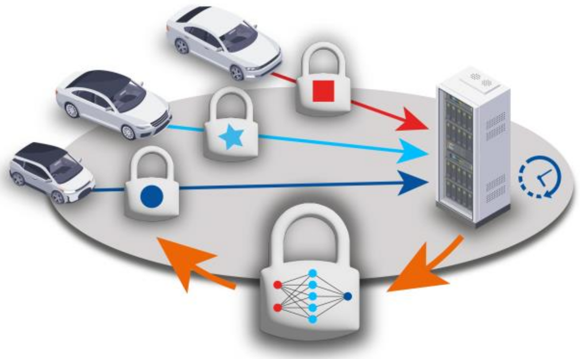
Orchestration of vehicle components

Variant modeling of deployment models with the goal of orchestrating software and hardware in the vehicle and the cloud (install, configure, and update)

Research Topic: Data Loop

How can Data be exchanged and stored?





Data stream and update analysis

Continuous analysis of the 5G architecture for a dynamic error management and as feedback for future software updates

Federated learning for improved connectivity and privacy

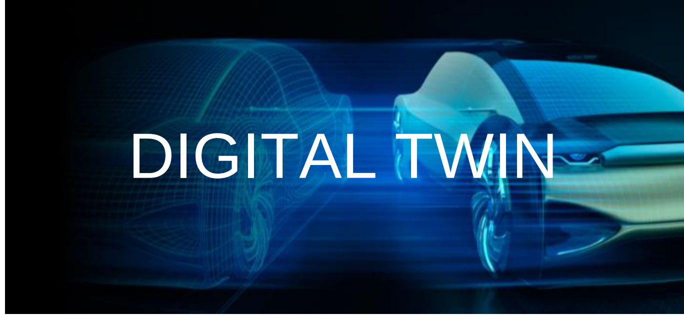
Training of machine learning models with decentralized data in vehicles by avoiding the disclosure of personal information and improving connectivity

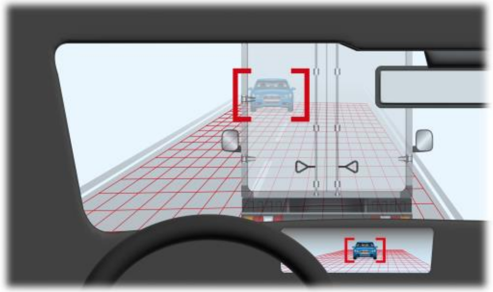
Privacy

Anonymization and policies to protect the privacy of the drivers, which is guaranteed by the operation of the pipelines.

Research Topic: Digital Twin

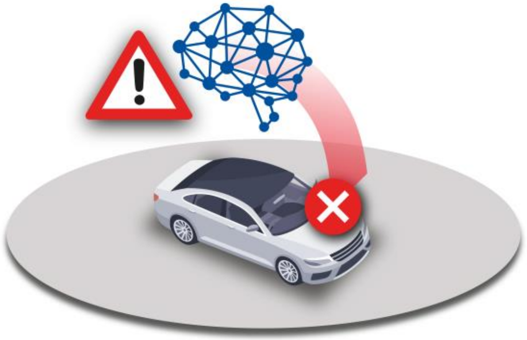
How to build and deploy a Digital Twin?





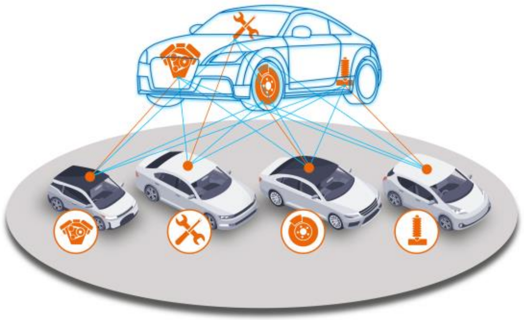
Improved environmental detection

Extension of the sensor acquisition range through data exchange



Anomaly detection

Configuring the most appropriate AI-based anomaly detection methods depending on the context.

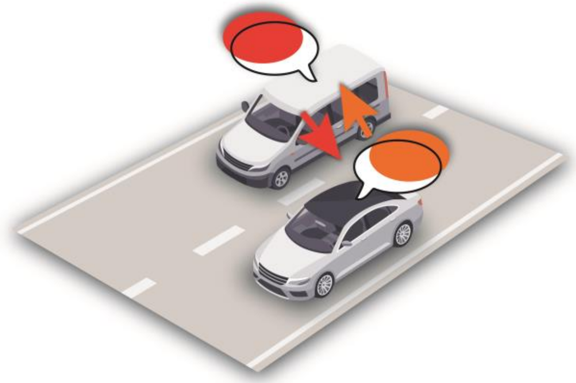


Semantic integration of digital twins

Linking of different models for different aspects of a digital twin of an automobile and exchange of information between these different models

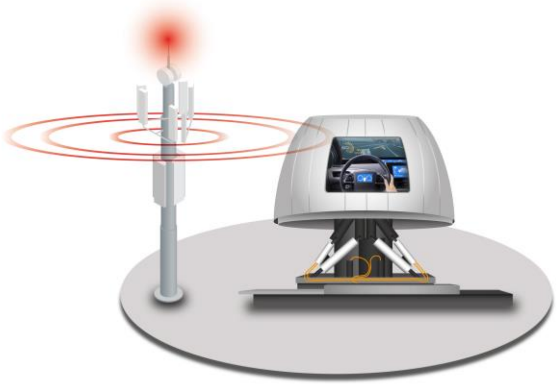
Research Topic: Demonstrator

How to investigate on real world scenarios?



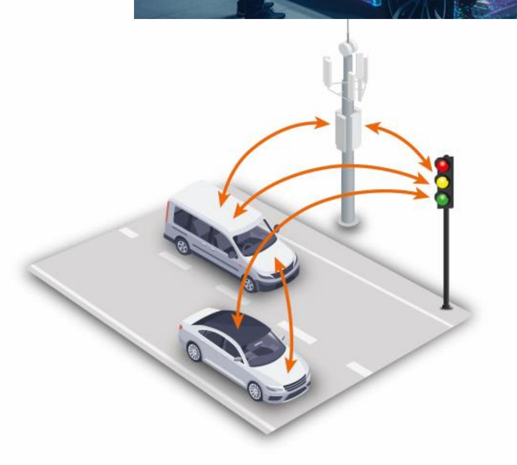
Event-based communication of vehicles

Exchange of information between vehicles in order to coordinate an overtaking process (cooperative overtaking) and carry it out autonomously



Test bench integration

Integration of the vehicle dynamics test bench and the Stuttgart driving simulator into a 5G environment



Multi-agent systems smart infrastructure

A highly connected smart infrastructure with vehicles that communicate with the infrastructure to use location-based and decentralized services while respecting privacy requirements

More Projectes of the Innovation Campus Mobility

Projects are dedicated to utilize distributed data and update software over-the air

- **Over the Air Communication for sustainable Energy Management of Fleets** (Otrace/INDU2)
  Objective: increase the range of electric vehicles by sharing data from the fleet of city buses.

- **Integrated approaches for the software development of upgradeable vehicles** (SWUpCar / SdMobi2)
  Objective: possible enhancement to the vehicle in operation with additional hardware and software components should be considered at in the design phase.

- **Standardized Test Procedure for Highly Configurable Software Defined Mobility Systems in Operation** (TESSOF / SdMobi5)
  Objective: development of a new generation of test methods for the validation of highly configurable mobility software systems in time and space.

- **Improvement of product creation and operation by identification of fault and abnormal situations in the powertrain and vehicle dynamics** (Networked e cars / SdMobi1)
  Objective: Vehicles and their components are connected using 5G and a digital twin, to then make assessments and derive improvements both "online" and in the simulation.

Bild: Univ. of Stuttgart, IAS

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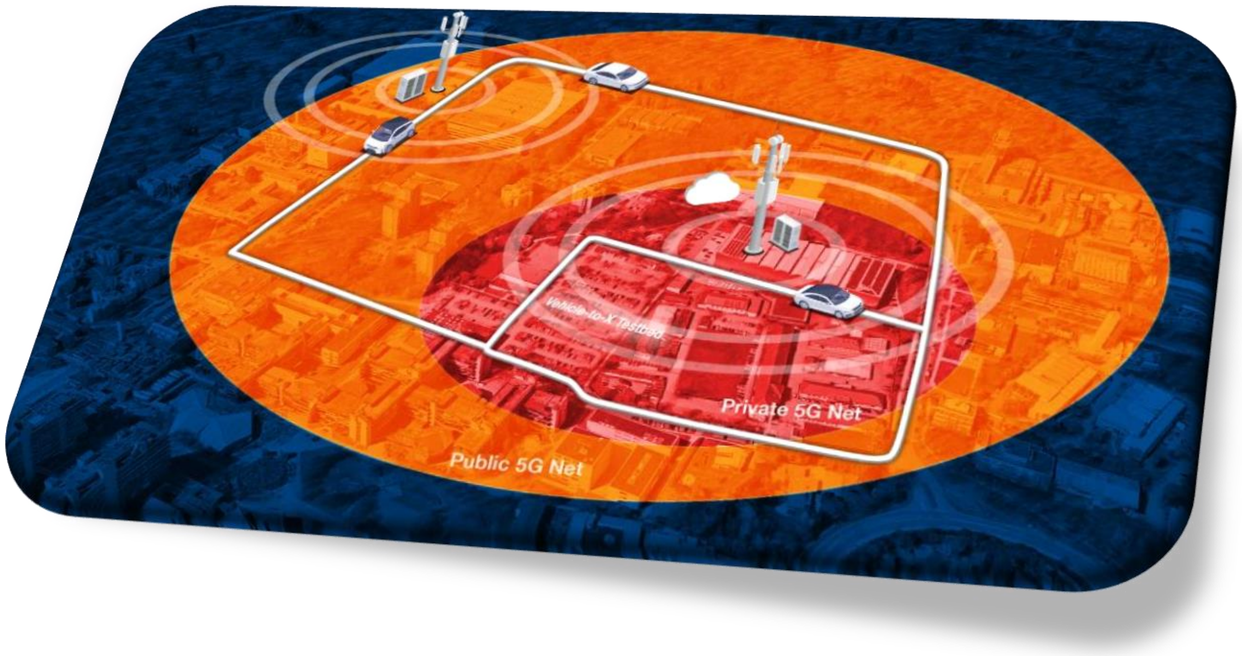
Testbed 1: 5G for networked Vehicles

During operation in the field vehicles and their components can communicate with each other, the infrastructure and the development departments.

- **Secure networking:** Edge and cloud communication on Internet protocols between vehicles, and traffic infrastructure
- **Management and reliable (re-)deployment** for variant-rich software with software product lines
- **Analysis and reliable synchronization of data** and information with the digital twin
- **Remote function provision (with Collective Perception)** for the vehicle from the back-end



Source: Univ. Stuttgart, IAS

5G test site (network: private and public) with edge and cloud at the Uni of Stuttgart, Paffenwaldring campus.

Testbed 2: Advanced Cockpit for new Features and Functions

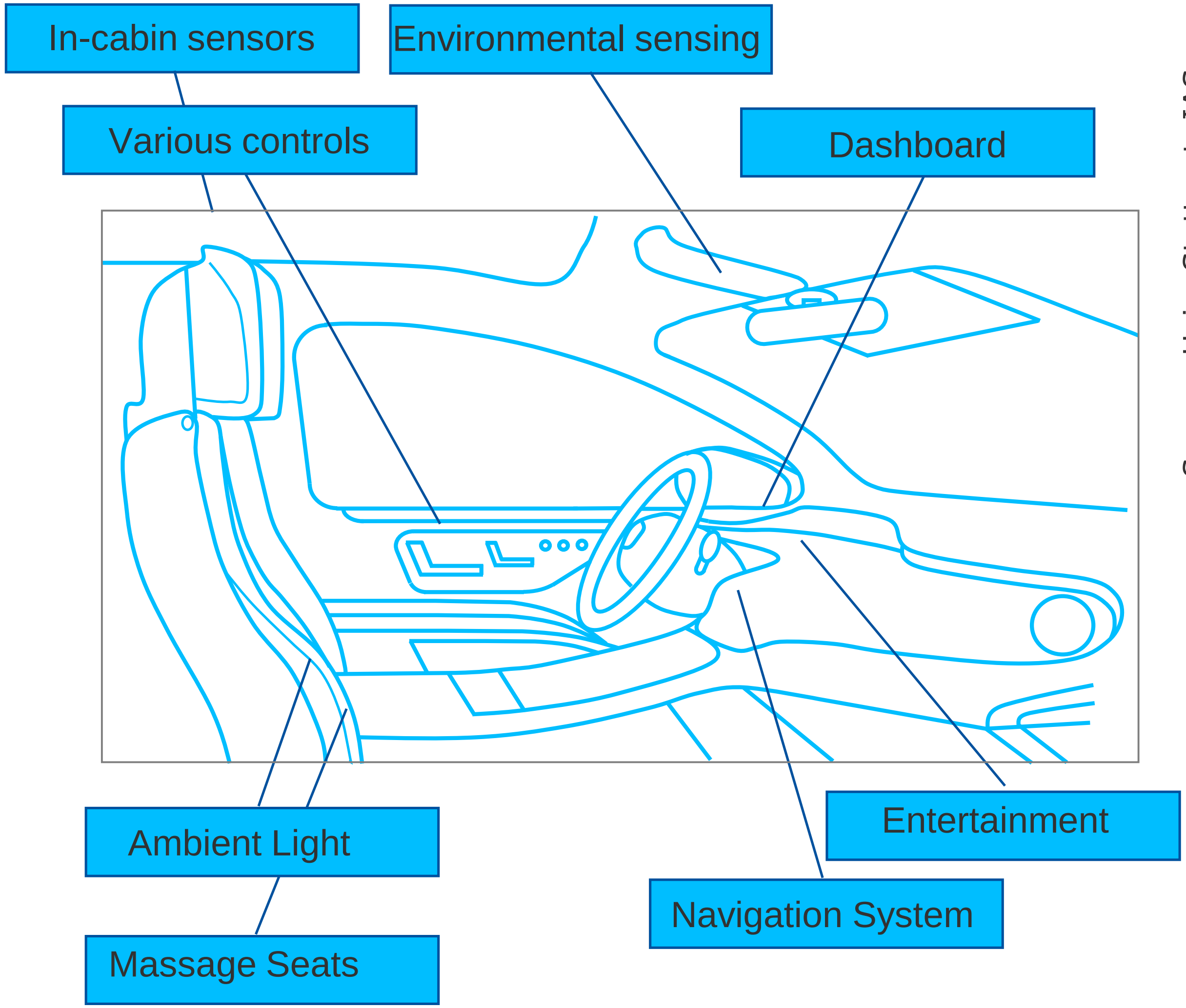
The testbed enable the development of innovative features / functions for the user based on sensorical information of the car and of other cars.

Utilize networked information for:

- **New features/ functions** based on in-cabin sensors and the fleet
- Enhancement of **saftey and security**
- Assisted control of the interior („**autonomous comfort**")

Also:

- **integration of multiple controls** utilizing Dev Ops in real car set-ups and automotive tier-organizations

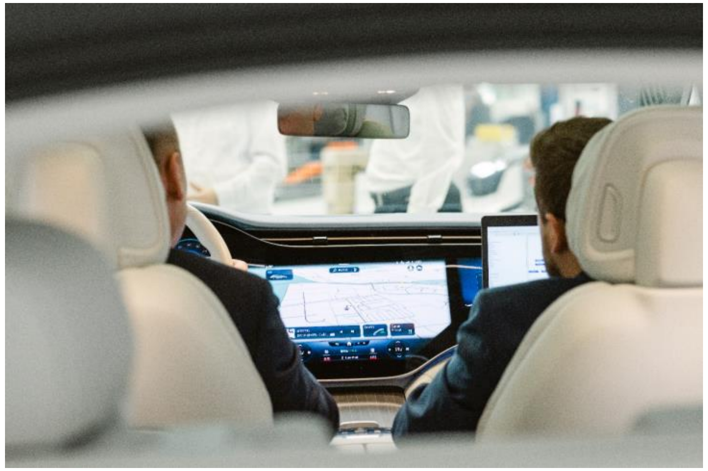


Source: Univ. Stuttgart, IAS

Status of the Testbeds 1 and 2 (as per June 2023)

About 60% of the allocated budget is freed, call for tender process about to be started:

- **Public 5G net of German telecoms** along with advance functionality (e.g. positioning, edge services) to be available autumn / winter 2023
- **Cockpit installation** about to be purchased but require significand **E/E integration** effort to be ready for tests
- **Private 5G net** with edge core and mobile test installations are still stuck in release processes of funding organization



Source: Univ. Stuttgart, IAS

Software Erosion in Automotive Software Systems

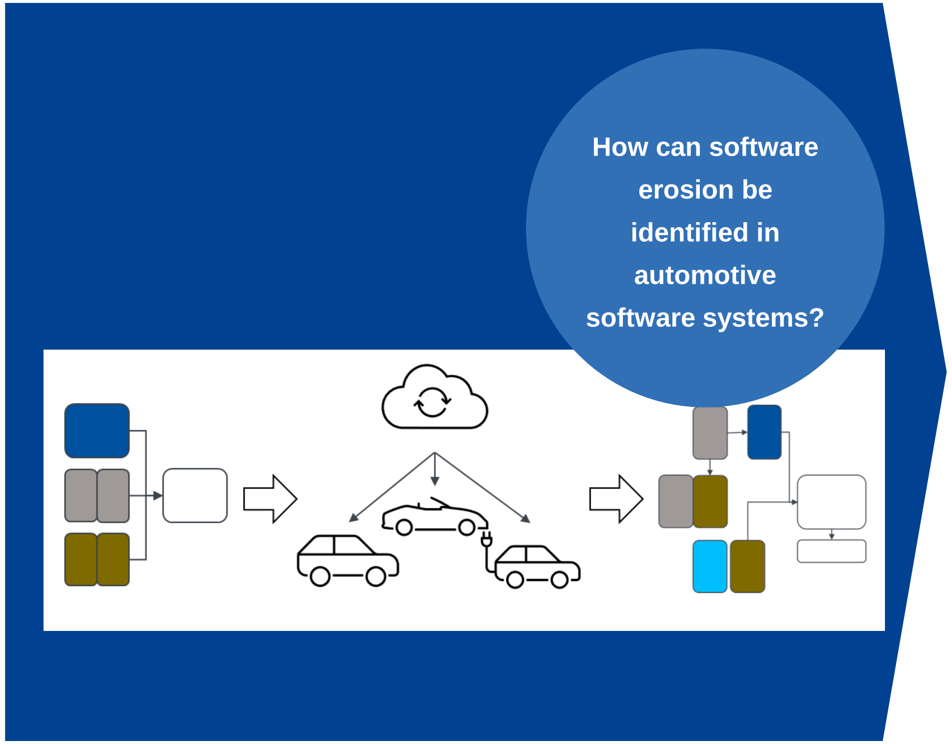
Identifying Software Erosion in Automotive using AI-Based Methods

Requirements:

- Analyze evolved software architectures in terms of software decay
- Detecting and tracing software erosion

Core technologies:

- Graph Theory
- Natural Language Processing (NLP)
- Large Language Models (LLM)



Motivation

- Variance and system evolution introduced by OTA updates leads to complex automotive software systems with a high risk of architecture erosion

Approach

- Understanding the characteristics of software erosion in automotive software systems
- AI-assisted detection and recognition of eroded software architecture

➢ Mastering complexity with AI-based methods

Efficient system verification in context of the evolution of development methods

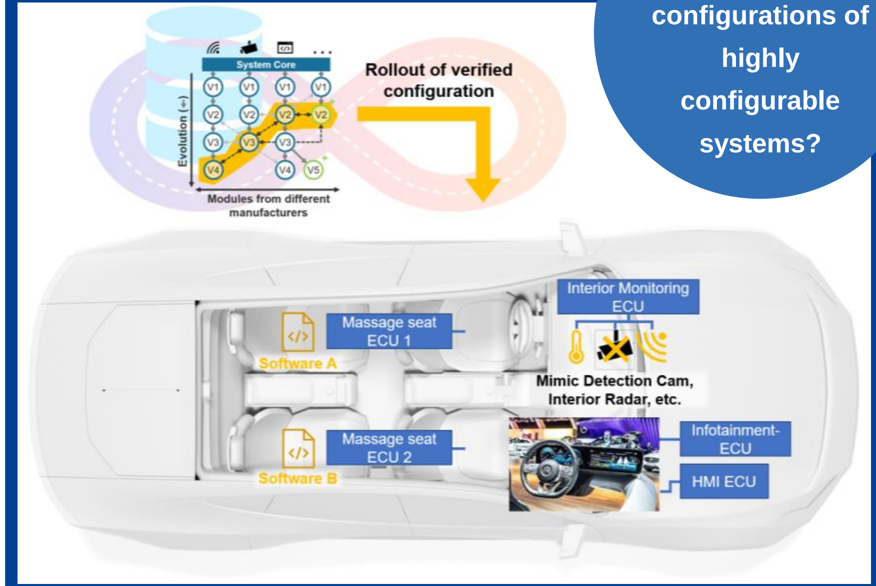
Requirements:

- Ensure functionality of large configuration spaces under strict DevOps time requirements
- Selection of few relevant key configurations for function … ation

Core technologies:

- Impact analysis of system changes
- AI-assisted and risk-based selection of key configurations

How to identify the most relevant configurations of highly configurable systems?



Motivation

- Modularization and Product Lines support development of configurable systems, BUT time efficient methods for verification still missing

Approach

- Perform change impact analysis to identify verification-relevant parts of the system
- Simulation-based functional verification of AI-assisted prioritized configurations

Update Analysis and Optimization for networekd Vehicles

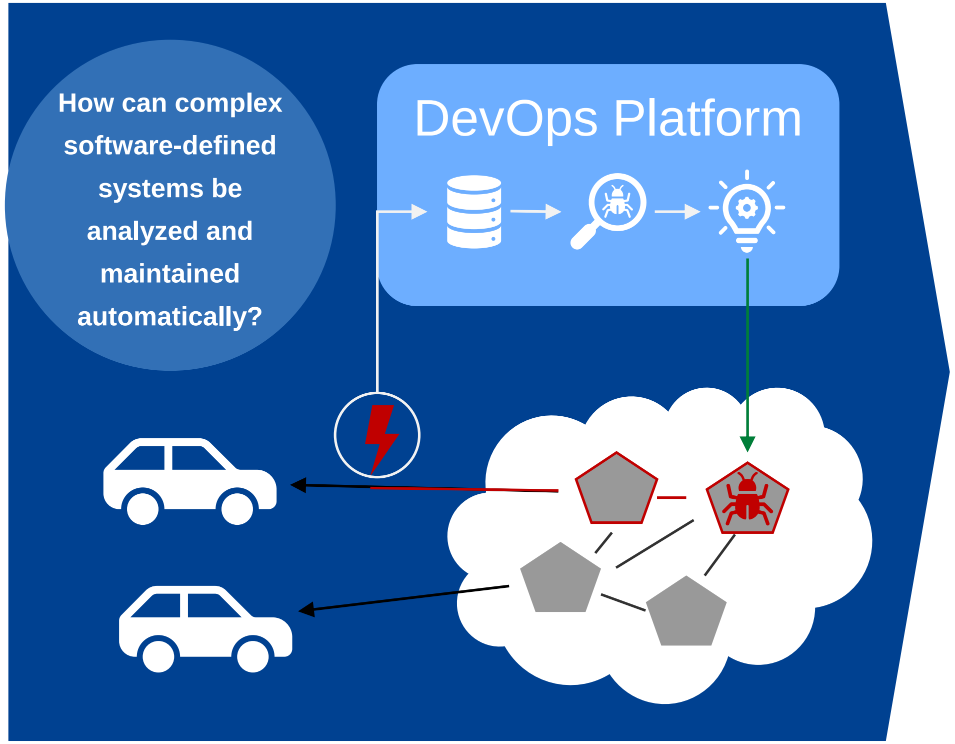
Analyzing software updates during runtime as an enabler for frequent update cycles

Requirements:

- Integration of heterogenous cloud data
- Automated analysis of newly deployed software
- Integration in connected vehicle environment

Core technologies:

- Continuous Integration and Deployment
- Data Lake and Lakehouse
- Self-Learning Analysis Pipelines



Motivation

- Updates for connected vehicles require data loop to exchange information, but slowed down by system complexity

Approach

- Mapping of software dependencies
- Adaptive detection of anomalies and tracing of root causes by probabilistic methods
- Generation of automated actions and workflows

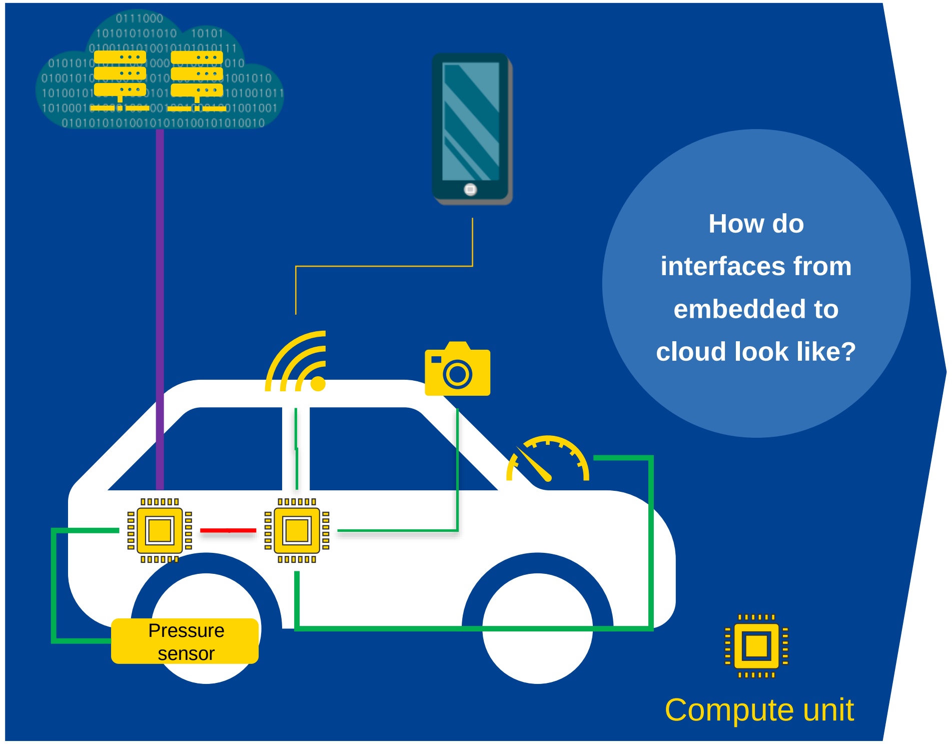
Flexible vehicle API management
Design principles for software interfaces for IT vehicle architectures

Requirements:

- Comprehension of interfaces and embedded systems in the vehicle
- Design and testing of interfaces from embedded systems to the cloud

Core technologies:

- Software architectures and pattern
- Cloud technology (as reference)
- IoT technology (as reference)



Motivation

- Flexible software-defined interface in the vehicle

Approach

- Abstraction of current interfaces for future connected vehicles
- Design and conception for interfaces from embedded to the cloud

Cooperative perception for connected vehicles

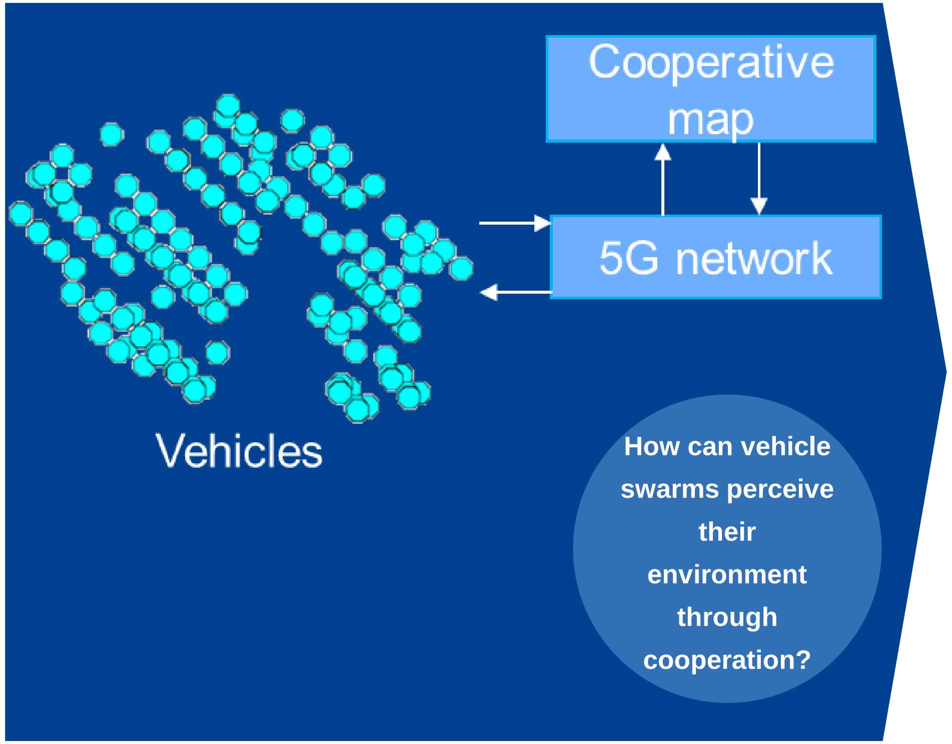
Cooperative map generation for swarms of vehicles

Requirements:

- Improve incomplete sensor data by combining data from multiple perspectives
- Bandwidth optimized data transmission

Core technologies:

- 5G communication network
- Object detection and tracking
- Micro map generation



Motivation

- Vehicles can manoeuvre in dynamic situations, but environmental perception is limited due to occlusion, which limits the performance

Approach

- Enabling cooperative environmental perception via 5G with optimized bandwidth usage
- Definition of transport mechanisms to distribute data and obstacles based on detection confidence
- Intelligent cooperative perception

Functionality of highly configurable software-defined systems

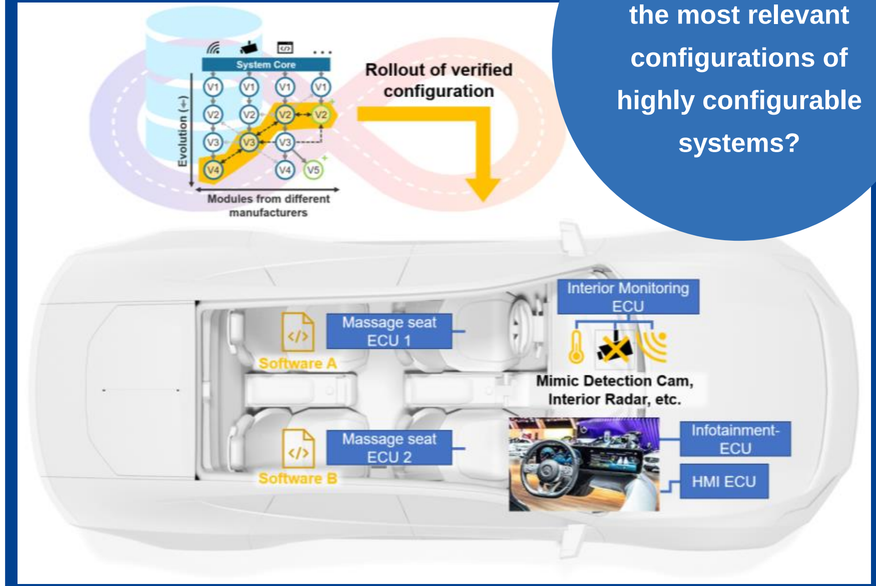
Efficient system verification in context of the evolution of development methods

Requirements:

- Ensure functionality of large configuration spaces under strict DevOps time requirements
- Selection of few relevant key configurations for functio[...]ation

Core technologies:

- Impact analysis of system changes
- AI-assisted and risk-based selection of key configurations



How to identify the most relevant configurations of highly configurable systems?

Motivation

- Modularization and Product Lines support development of configurable systems, BUT time efficient methods for verification are still missing

Approach

- Perform change impact analysis to identify verification-relevant parts of the system
- Simulation-based functional verification of AI-assisted prioritized configurations

Personal autonomous comfort with Federated Learning

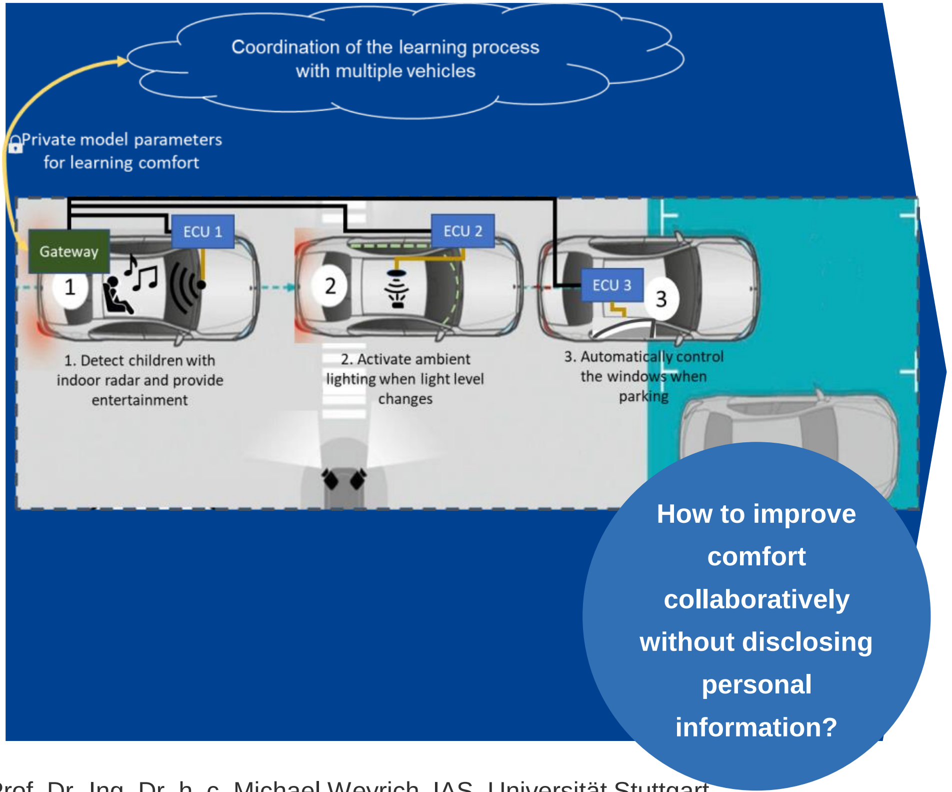
Secure and personal enhanced driving experience through collaborative sensing

Requirements:

- Consideration of various data that contribute to driving comfort
- Ensuring the privacy of personal data
- Timely reaction to changing conditions

Core technologies:

- ML Methods (e.g. Reinforcement Learning)
- Cryptographic methods (e.g. Homomorphic Encryption)



Motivation

- Modern vehicles promise a high level of comfort, but collect and process a lot of personal data.

Approach

- Collection of individual sensor data, local training of ML models, and protection of model updates.
- Jointly build a better-performing global model

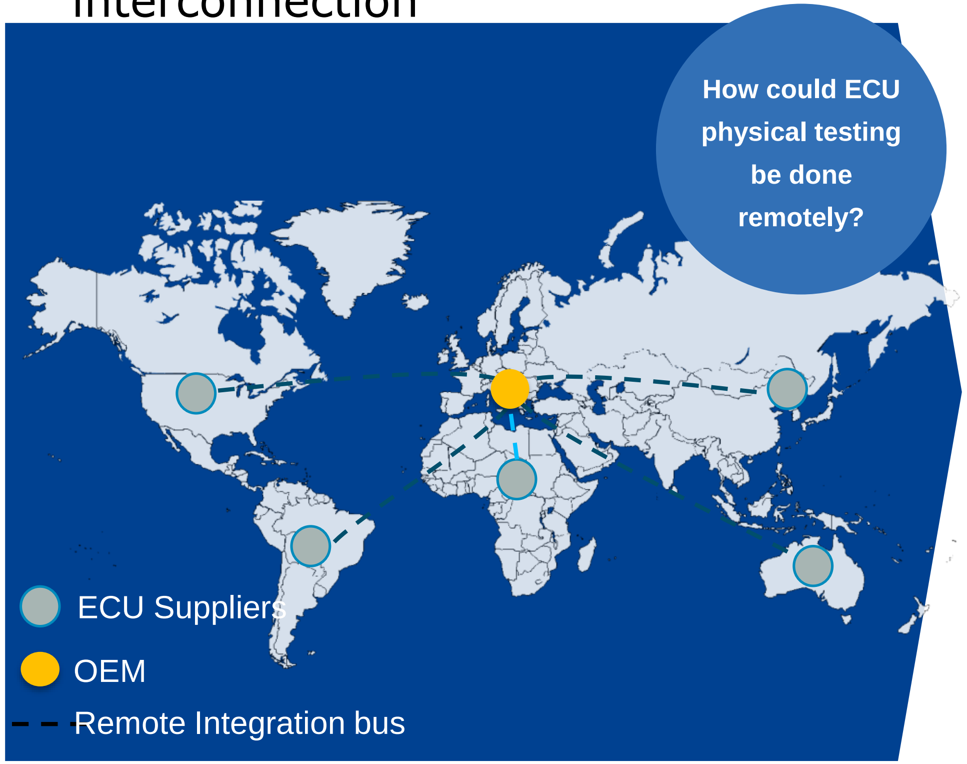
➢ Private and proactive comfort learned from individual experiences

Distributed Integration of ECUs

Remote physical testing of geographically distributed Automotive Electronic Control Units (ECUs)

Requirements:

- Analysis of the network implications of a distributed test environment
- Analysis of technical requirements for an external gateway that enables remote interconnection



Core technologies:

- Time Sensitive Networking
- Communication bus Analysis
- Hardware in the Loop (HiL), Software in the loop (SiL)

Motivation

- Long delays in shipping ECU devices from external Suppliers to the OEM for integration testing
- Late development errors during physical testing

Approach

- Remote testing via external gateways over the Internet
- Long distance latency correction

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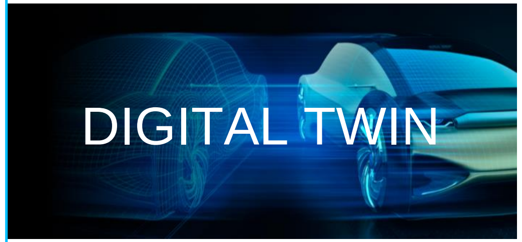
Conclusion: There are many questions …

Here are some examples, but there are many more facets with lots of depth.

- How can topics of cooperative perception of connected vehicles be utilized?

- What are the issues of software product lines and software erosion in the upcoming software systems, which rely on CI/CD toolchain?



- How can future function be based on a Digital Twin and deploy techniques of modelling, synchronization, real-time processing etc.?

- What are the “real world” problems and issues such as latencies, different formats, open source framework limitations etc.?