Silent Testing of Automated Driving Functions

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Automotive Engineering at TU Darmstadt / Fahrzeugtechnik TU Darmstadt (FZD) in a Nutshell

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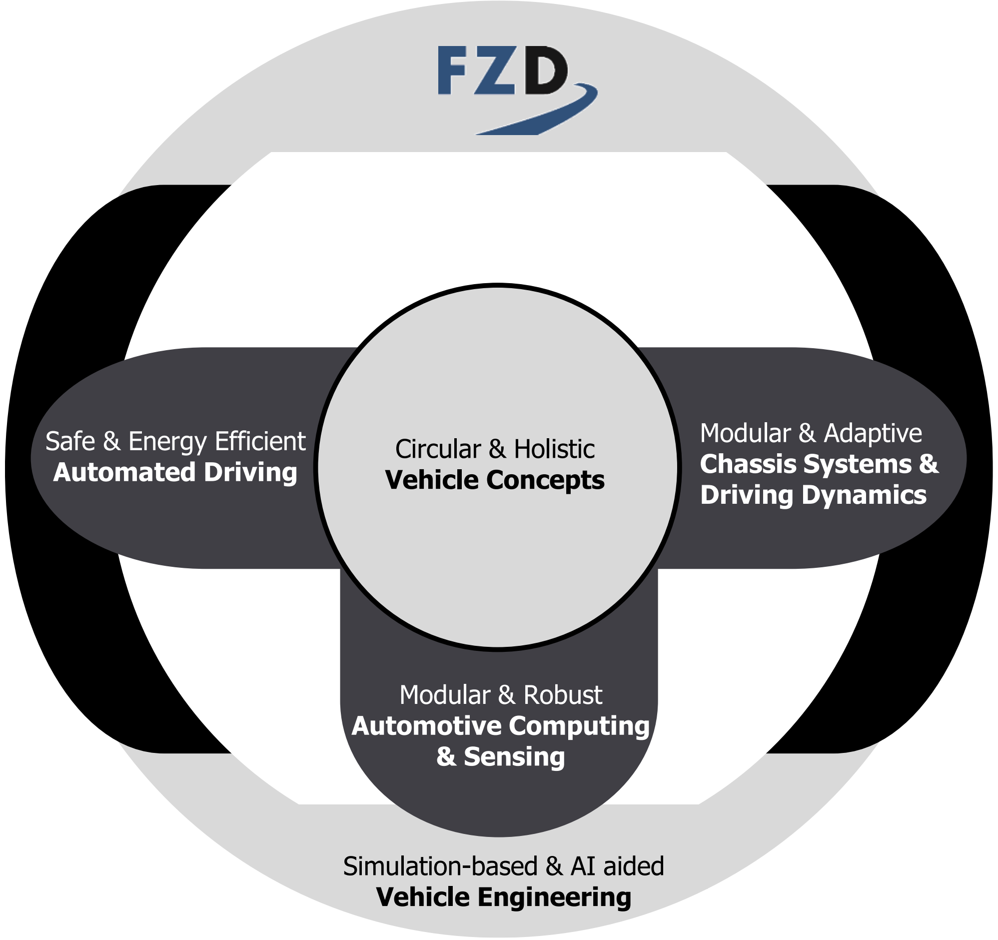

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Our Vehicles for Research & Teaching

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Definitions

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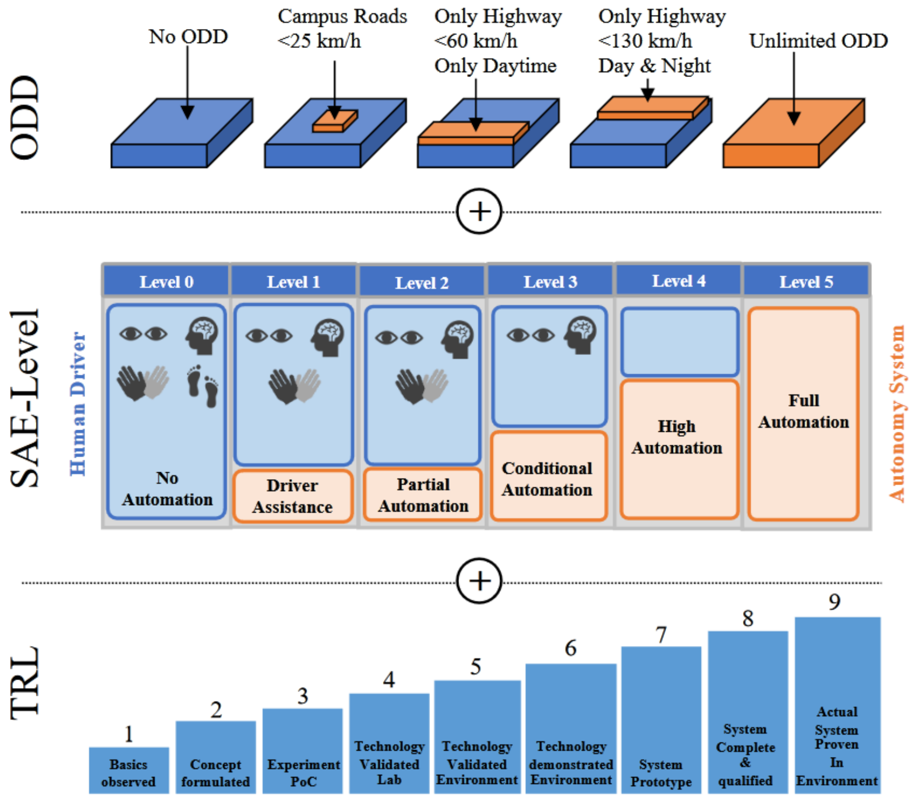
Operational Design Domain (ODD): defines under which conditions (e.g. day & night, velocities…) and where (highway, urban…) a system can fulfill a given SAE-Level

SAE-Level: defines the Level of „Autonomy“ of a System

Technology Readiness Level (TRL): defines maturity of a technology (in general) based on the original work by NASA



Source: Betz, J.; Lutwitzi, M.; Peters, S.: A new Taxonomy for Automated Driving: Structuring Applications based on their Operational Design Domain, Level of Automation and Automation Readiness; IV 2024 Workshop Paper, accepted

A „usual“ AD-stack

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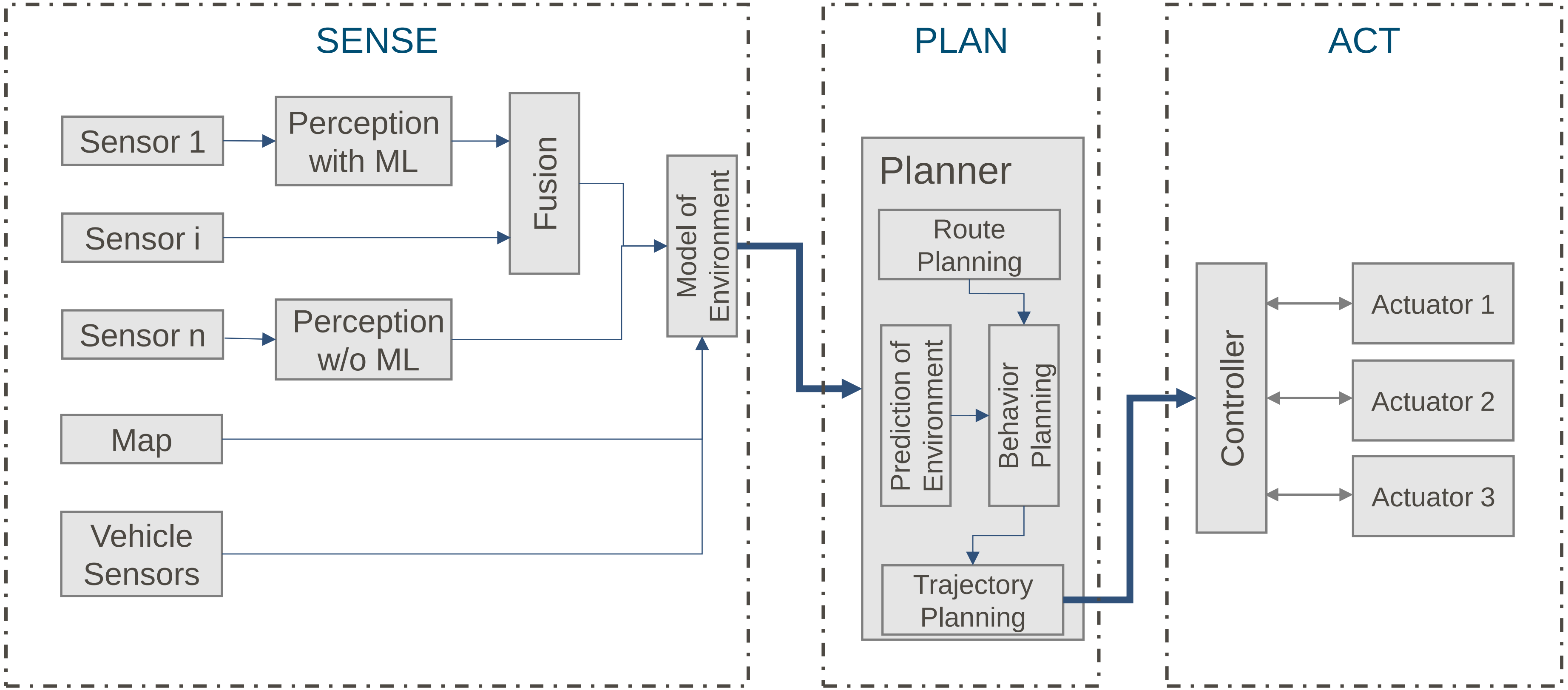

Source: FZD

Current State of Automated Driving

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Vehicle Industry‘s Moon Landing:

Mercedes-Benz Drive Pilot - L3

- minimal risk use case with ODD: max. 60 km/h, good weather, within one lane on congested highway… but privately owned

Computer Industry‘s Moon Landing:

Waymo One - L4

- complex use case / ODD: very few selected (sunny) cities but operated by Waymo

Different industries, different approaches, different strategies, but both with very limited operational design domain (ODD) due to safety restrictions.

Current Roadblocks

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Safety Approval

- Proofing that a system is at least as save as humans is hard and gets harder with each and every new ADAS system which improves safety

Energy Consumption

- Roughly 1 kW for computation (& sensors) for L4 systems

Images: Mercedes-Benz AG

The Problem of Safety Approval

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Some figures from statistics

Assumption: automated driving shall be at least as save as a human driver

- distance between fatal accidents on German highways (based on 2012): $660 \cdot 10^6$ km[1]

Statistical hypothesis test:

- Distribution: Poisson (accidents are rare events)
- Null hypothesis: „AD is not saver than human (= successful test due to luck and not real capability)“
- Significance level: $\alpha = 5\%$ (risk of rejecting null hypothesis which in fact is true)
- Procedure: reject null hypothesis if no fatal accident occured during $2 \cdot 10^9$ km of driving on German highway[1]

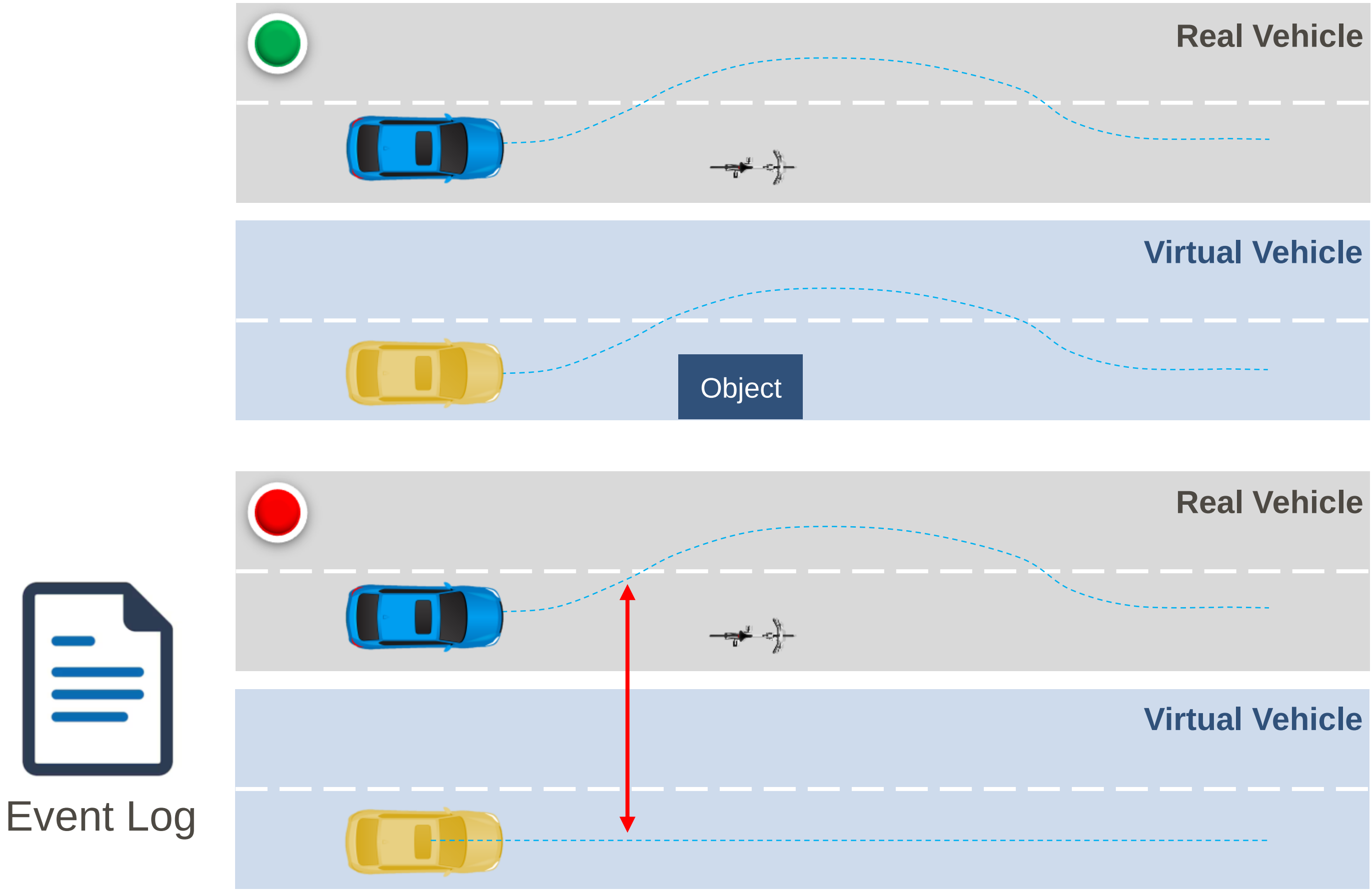
Source: 1: Wachenfeld & Winner

Image: Pexels

Silent Testing to Cover the Distance Highway

Approach

- Open-loop integration of the AD stack in high-volume production vehicles
- Perception and planning tasks performed by the AD system
- Outputs of the actuation tasks <u>are not</u> processed
- AD system is not sold as a customer feature
- Logs of any events where the AD system *would* behave differently to the human driver are created and reported to the manufacturer for review.



Silent Testing to Cover the Distance Highway

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Benefits

- Test mileage can be distributed across a fleet of vehicles
- Providing real sensor data to stimulate the AD-stack
- Risk-free execution of real-world scenarios
- Utilization for delta approval

Drawbacks

- AD systems can cause scenarios that human drivers never encounter
- Not every reported difference in behavior can be interpreted as an unwanted behavior of the AD system
- Closed-loop influence of the AD system‘s behavior on the input data is neglected
- Installation of expensive sensors without charging of customers

→ MINDED

Source: Wang, 2021

Silent Testing to Cover the Distance Highway

Funded by the European Union

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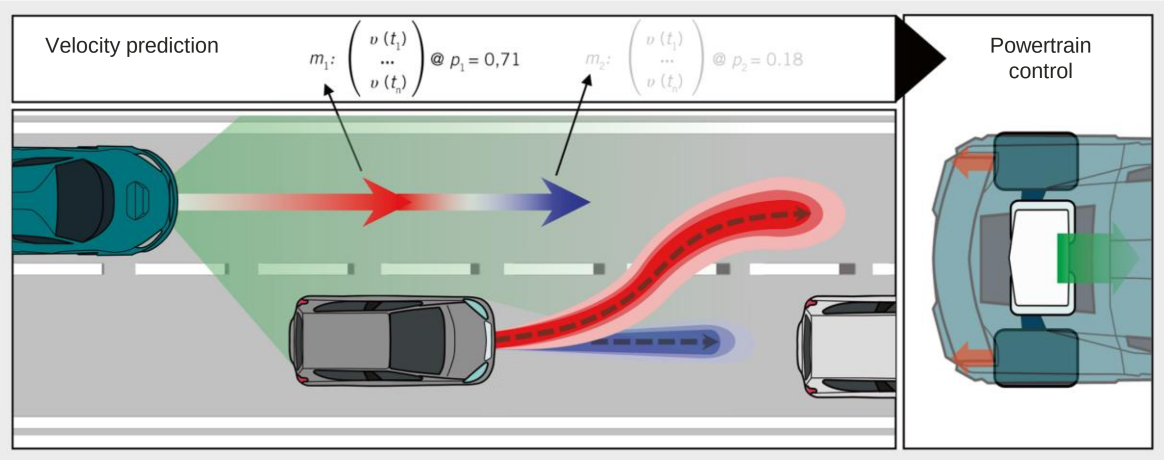
Concept:

- Silent Testing in combination with predictive powertrain control
- Technology for AD/ADAS can be used for accurate velocity prediction based on machine learning
- Velocity predictions make predictive control strategies for powertrain and thermal management possible



Source: Lutwitzi et al, ATZelektronik, 2023

Benefits (in addition to those of silent testing):

- Range, durability and comfort can be improved, <u>which adds value for customers</u>

Silent Testing to Cover the Distance Urban

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Idea:

Make use of a sensor equipped tram in daily operation in the city of Darmstadt to compare driver behaviour to an automation

- Tram fitted with two lidar sensors, three radar sensors, three cameras and a stereo camera pair
- Data collection over the timespan of one year providing many edge cases and rare occurences
- Many differences in behaviour stem from unique challenges due to close distances in railbound environment and limitations in intention detection
- Conclusion for *urban* situations: the analysis of potentially safety relevant events can not be automated and requires human oversight → tremendeous effort[2]

Source: Ruppert, 2024 Image: FZD (P. Pintscher)

Silent Testing to Cover the Distance Urban

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Examplaric challenges:

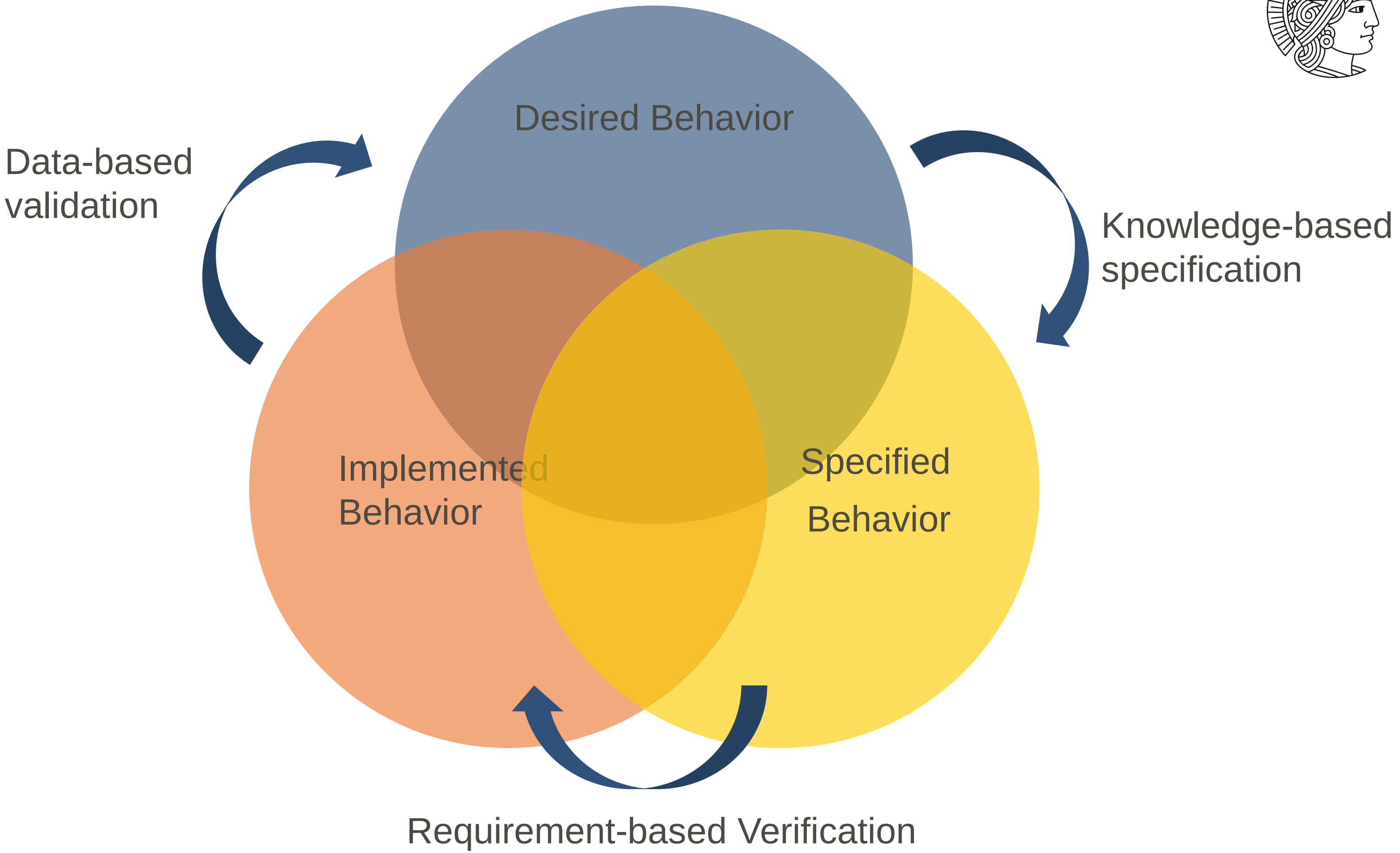
- Year round changing vegetation close to or on the tracks poses a challange
- evasive maneuvers are not possible, therefore high perception accuracy (Lidar Blooming, Fog, etc.) is necessary to ensure the path ahead is clear
- unkown intention of other traffic participants in conjunction with close proximities and longer breaking distances than cars complicate motion planning

Vegetation reaching into the gauge

Unclear intention combined with close proximity

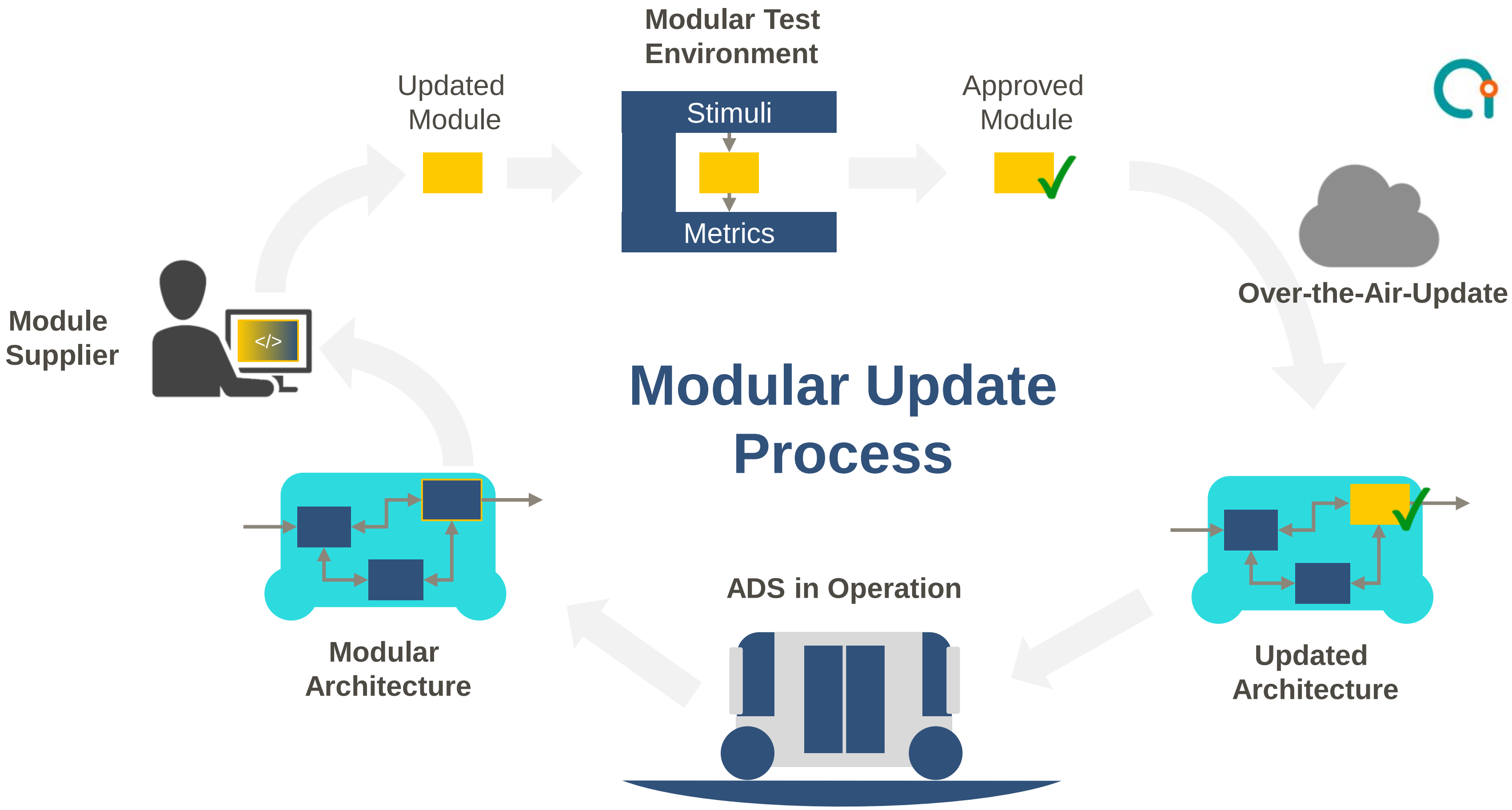
Source: Ruppert, 2024 Image: Ruppert, 2024

Current (Generic) Way for Safety Approval



Source: SOTIF

Outlook: Modular Approvable Architectures in the Dawn of SDV



Outlook: Modular Approvable Architectures in the Dawn of SDV

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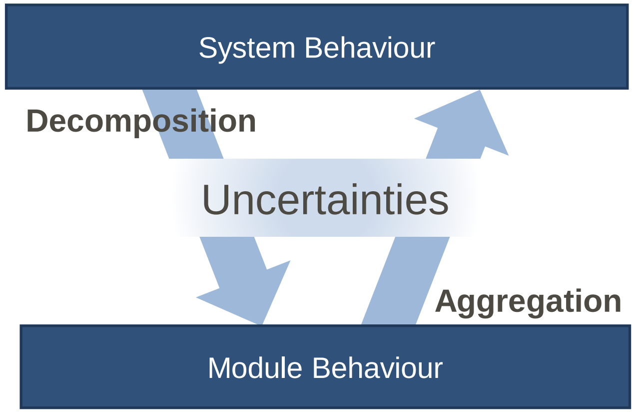
Decomposition of safety requirements[1]

- Collision avoidance
- Compliance to traffic rules
- …

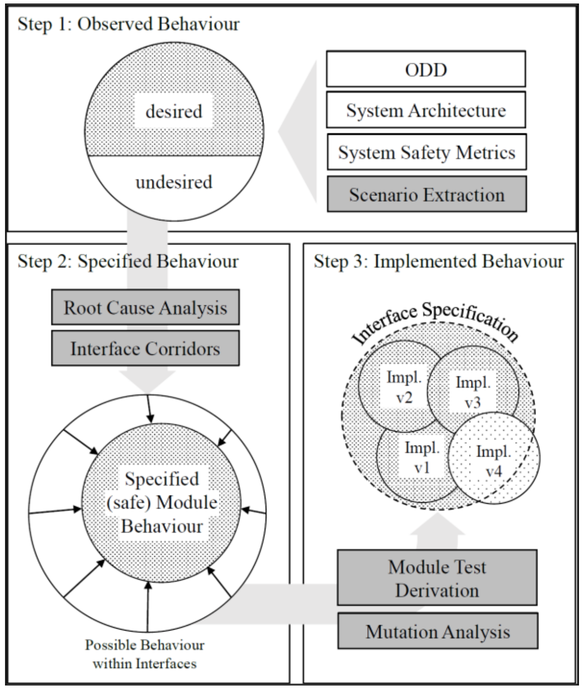


Modul-Tests

- Module-specific Stimuli
- Module-specific Pass-/Fail-Criteria

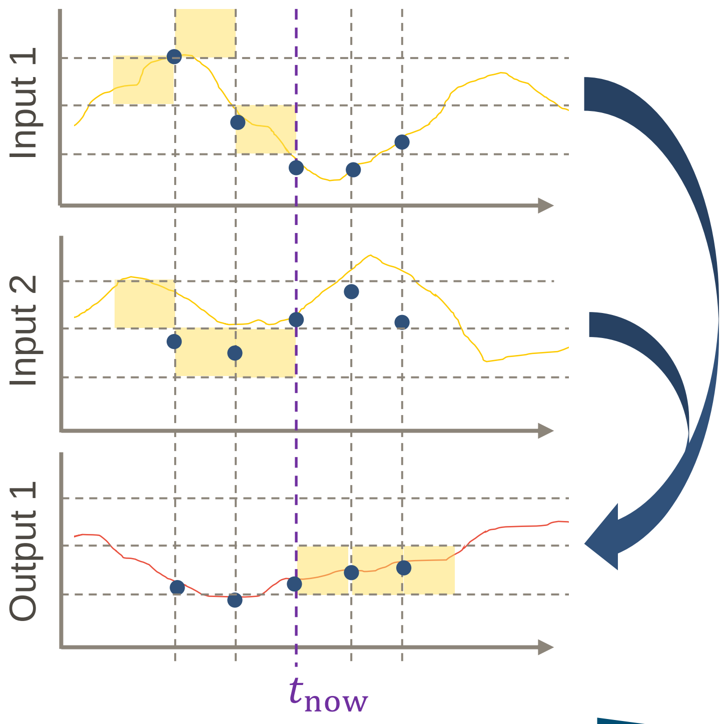
Source 1: Klamann, 2024

Data-driven specification process[2]



Source 2: Blödel, 2024

Specification of the desired module behaviour as a characteristic signal pattern



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Thanks

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