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thinking.cars

Results of the disruptive project on driverless automated transport

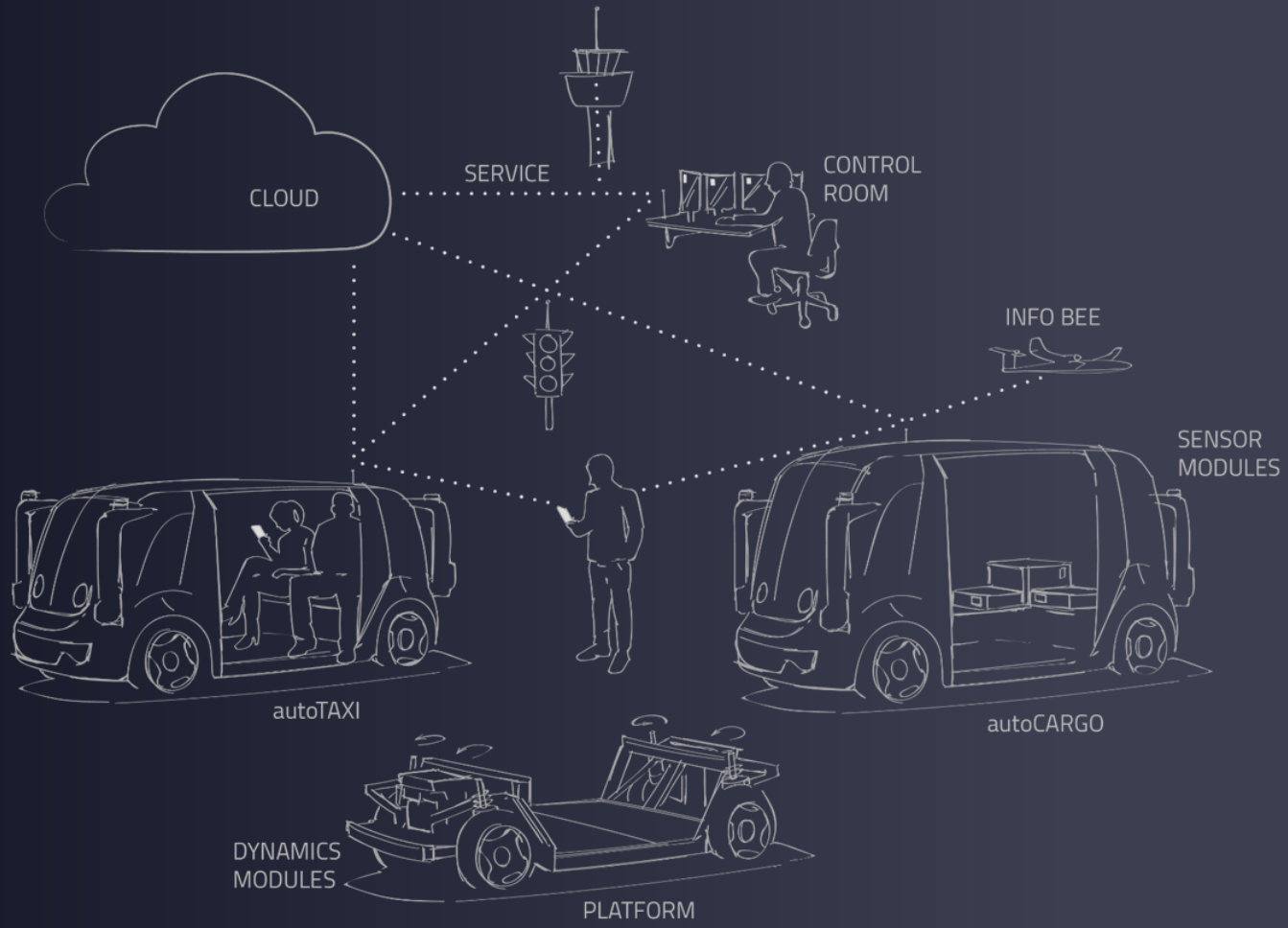
Aachen, Oct. 10th, 2023

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CLOUD
SERVICE
CONTROL ROOM
INFO BEE
SENSOR MODULES
autoTAXI
autoCARGO
DYNAMICS MODULES
PLATFORM

The Design Process

Inside-Out

How to develop prototypes quickly and agilely?

autoELF

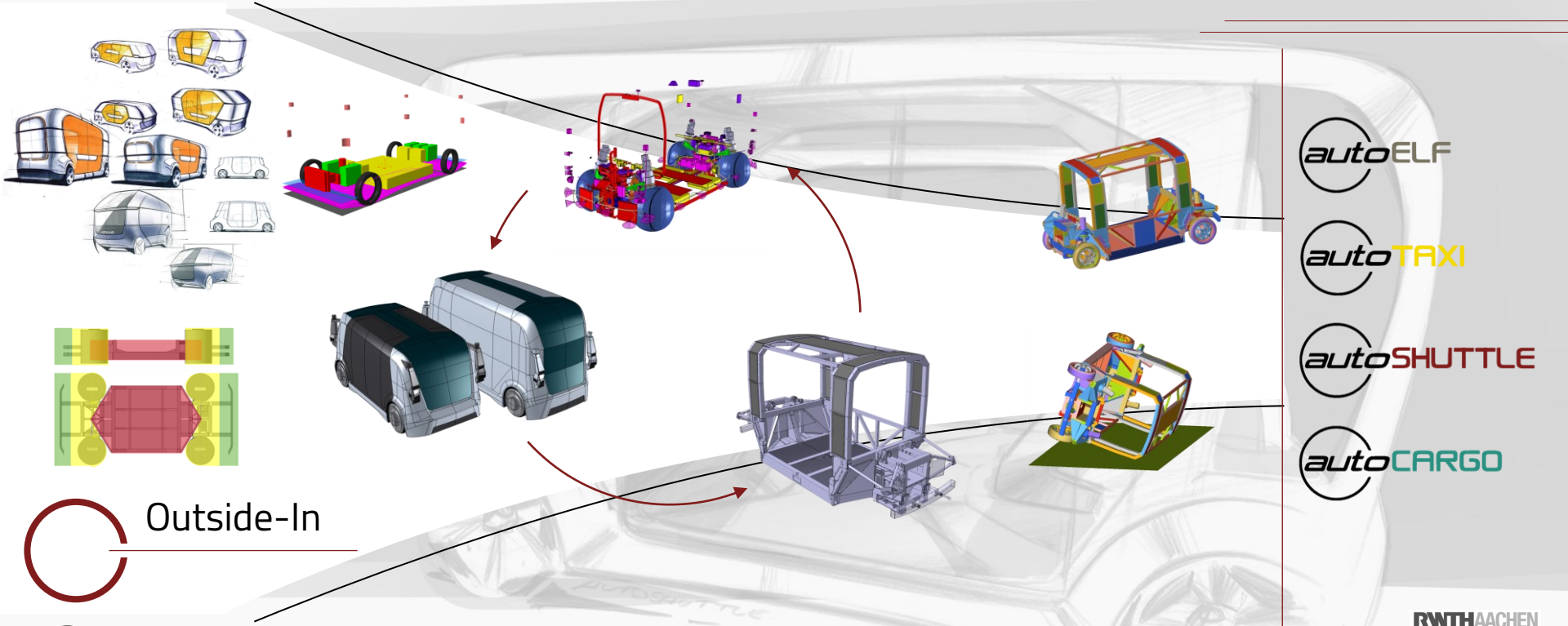
autoTAXI

autoSHUTTLE

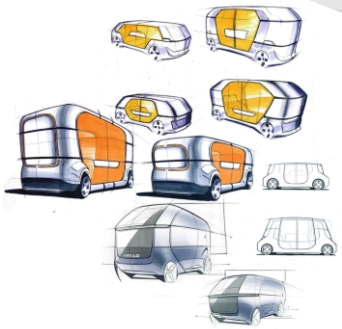
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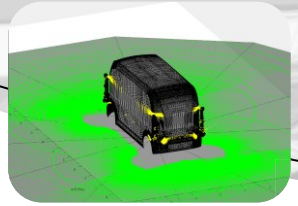
Outside-In

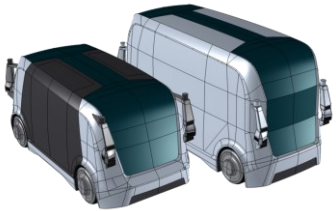
The Design Process

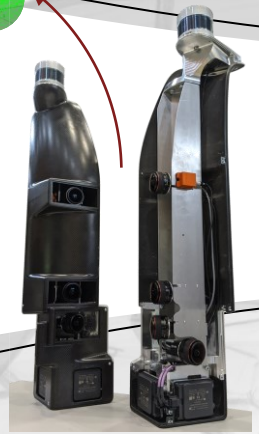


The Design Process









autoELF

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autoSHUTTLE

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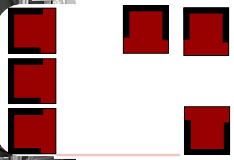
Outside-In

The Design Process

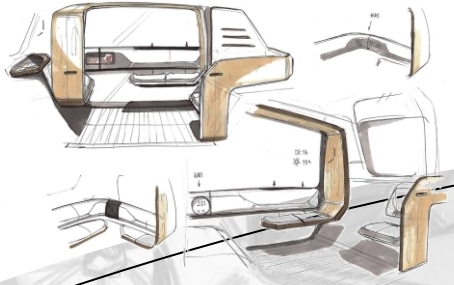
Inside-Out

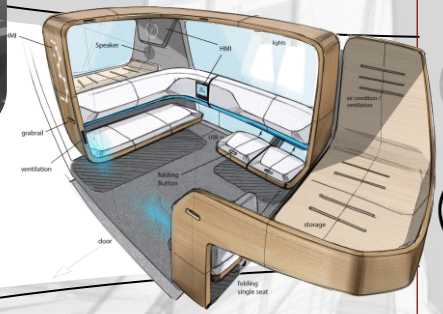












autoELF

autoTAXI

autoSHUTTLE

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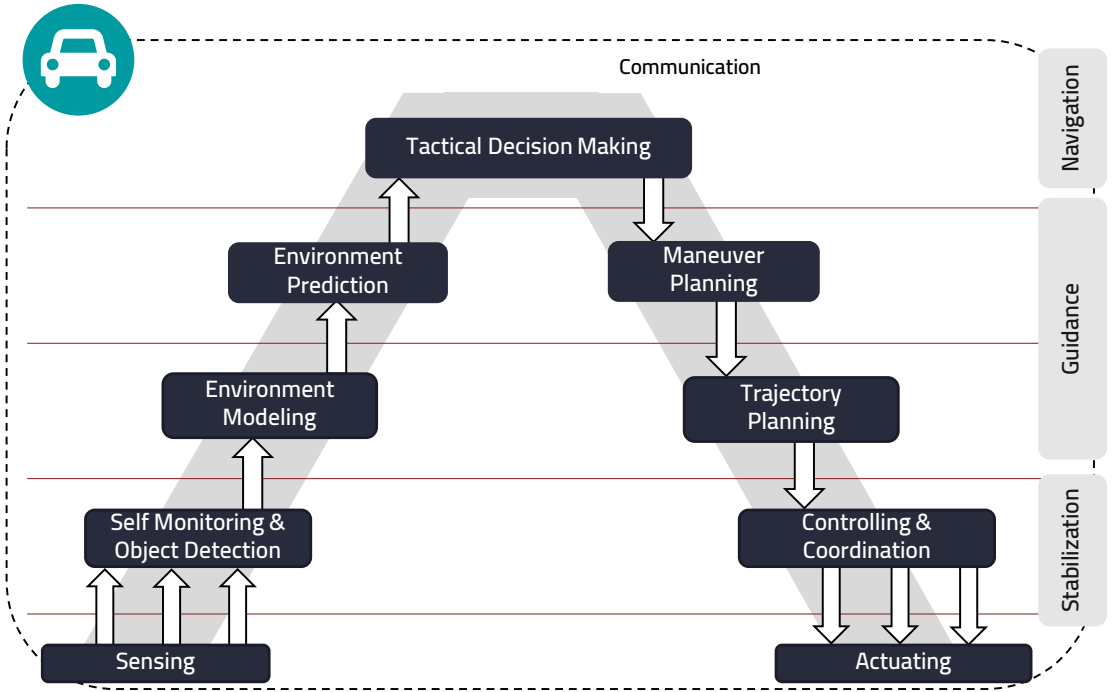
auto ELF



autoCARGO

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Functional Architecture



SENSOR MODULES

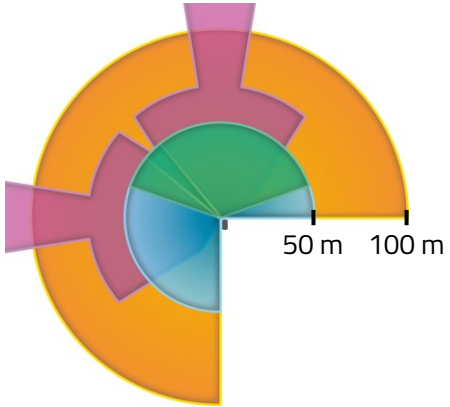
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Modular Environment Perception

- Four sensor modules per vehicle, mounted at the corners
- 270° field of view per module
- Sensor module comprises of sensors and corresponding processing unit
- Independent sensor module environment models

Sensor Setup

- Combination of different sensor modalities
- Perception in near and far field
- Redundant sensor coverage



Lidar

Radars

Stereo Camera System

Monocular Cameras



ENVIRONMENT MODELS

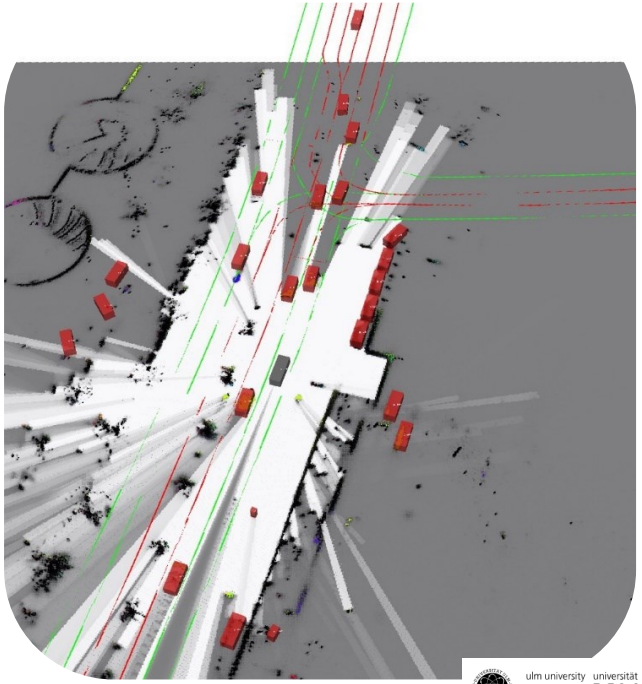
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Sensor Module Environment Model

- Object-based representation of traffic participants
  - Individual detections in sensor measurements
  - Subsequent fusion and tracking of detections
- Grid-based representation of free and occupied space

Vehicle Environment Model

- Fuses all sensor module environments on the cerebrum
- Dynamic grid map with filtered occupancy and velocities
- Redundant and accurate 360° model
- Serves as basis of the vehicle's behavior and planning



BEHAVIOR GENERATION & MOTION PLANNING

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Behavior

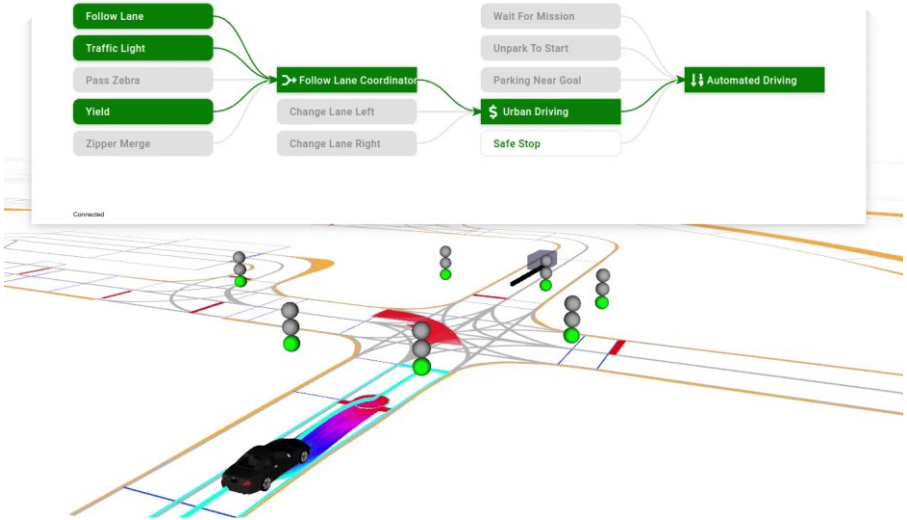
- Inputs: Ego information, object list, map, route
- Policy arbitrator uses priority, cost and traffic rules
- Output: driving corridor and reference velocity profile

Trajectory Planner

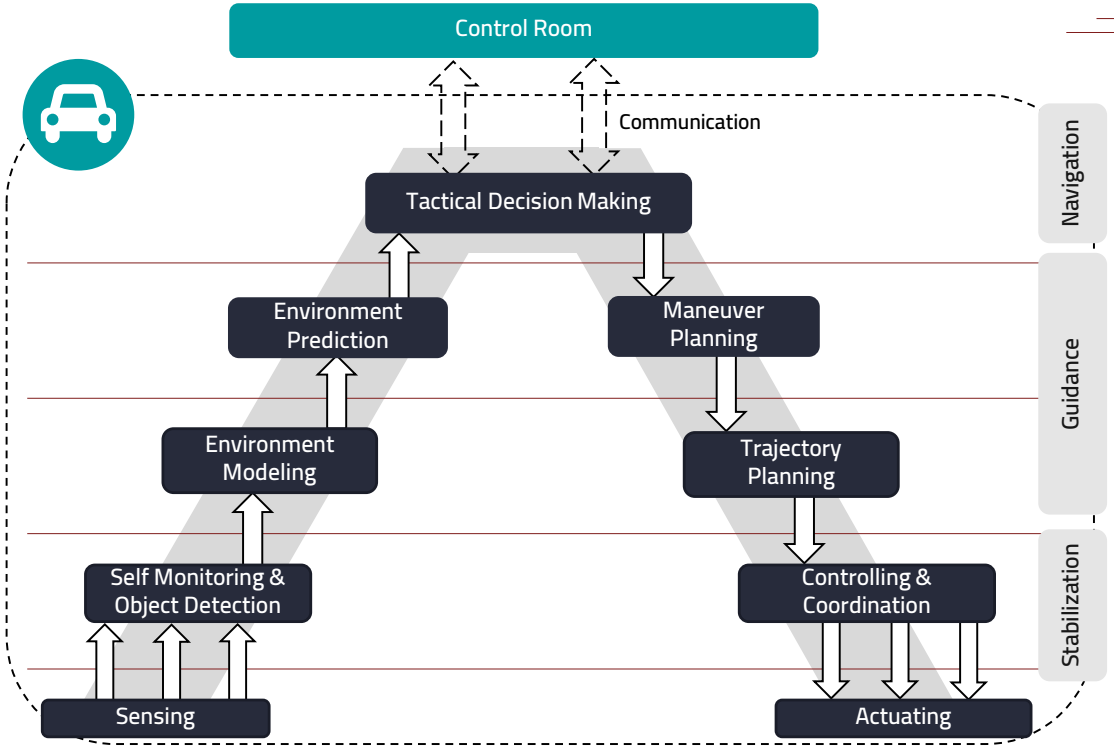
- Improve velocity profile using Intelligent Driver Model (1D)
- Optimize (2d) using car restrictions (speed, acceleration)

Parking Planner

- Path reference obtained using Hybrid A*
- Acceleration optimization along path
- Allow crab walk maneuver



Functional Architecture



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Law on Automated Driving in Germany

- *§1d: […] (3) Technische Aufsicht eines Kraftfahrzeugs mit autonomer Fahrfunktion im Sinne dieses Gesetzes ist diejenige natürliche Person, die dieses Kraftfahrzeug während des Betriebs gemäß § 1e Absatz 2 Nummer 8 deaktivieren und für dieses Kraftfahrzeug gemäß § 1e Absatz 2 Nummer 4 und Absatz 3 Fahrmanöver freigeben kann.*
- *§1e: […] (2) Kraftfahrzeuge mit autonomer Fahrfunktion müssen über eine technische Ausrüstung verfügen, die in der Lage ist*
  - *3. im Fall der Nummer 3 der Technischen Aufsicht selbständig a) mögliche Fahrmanöver zur Fortsetzung der Fahrt vorzuschlagen sowie b) Daten zur Beurteilung der Situation zu liefern, damit die Technische Aufsicht über eine Freigabe des vorgeschlagenen Fahrmanövers entscheiden kann*
  - *5. ein von der Technischen Aufsicht vorgegebenes Fahrmanöver zu überprüfen und dieses nicht auszuführen, sondern das Kraftfahrzeug selbständig in einen risikominimalen Zustand zu versetzen, wenn das Fahrmanöver am Verkehr teilnehmende oder unbeteiligte Personen gefährden würde,*

CONTROL CENTER – Enabling Teleoperation and Fleet Monitoring

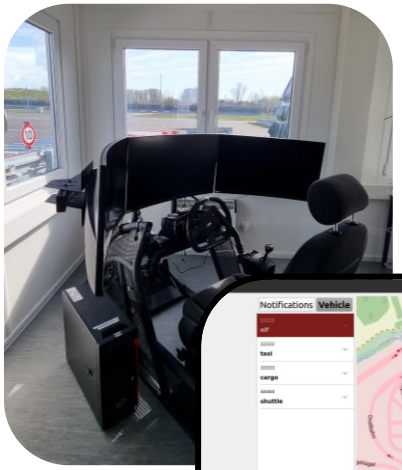
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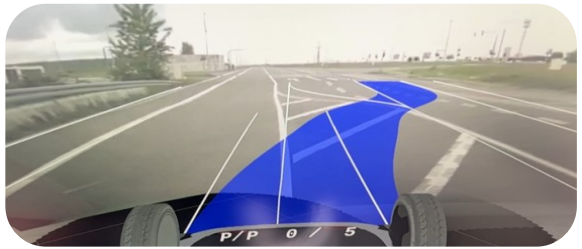
Teleoperation Services

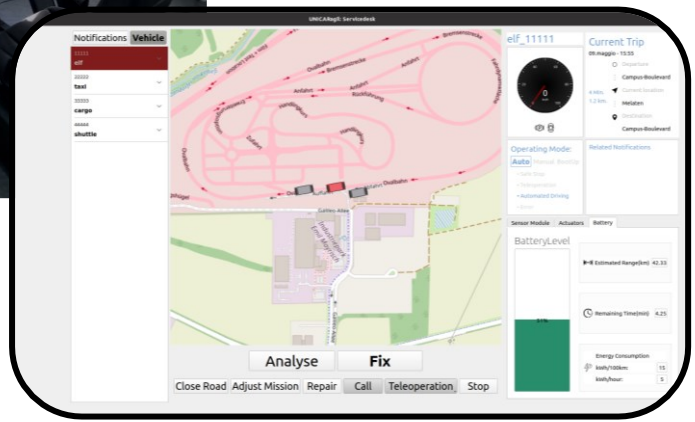
- extending the operational design domain of automated vehicles by:
  - **Direct Control – Teleoperation**
  - **Trajectory Guidance**

"Customer" Services

- **Fleet service** for mission planning and vehicle monitoring
- **Emergency service** via audio and video connection



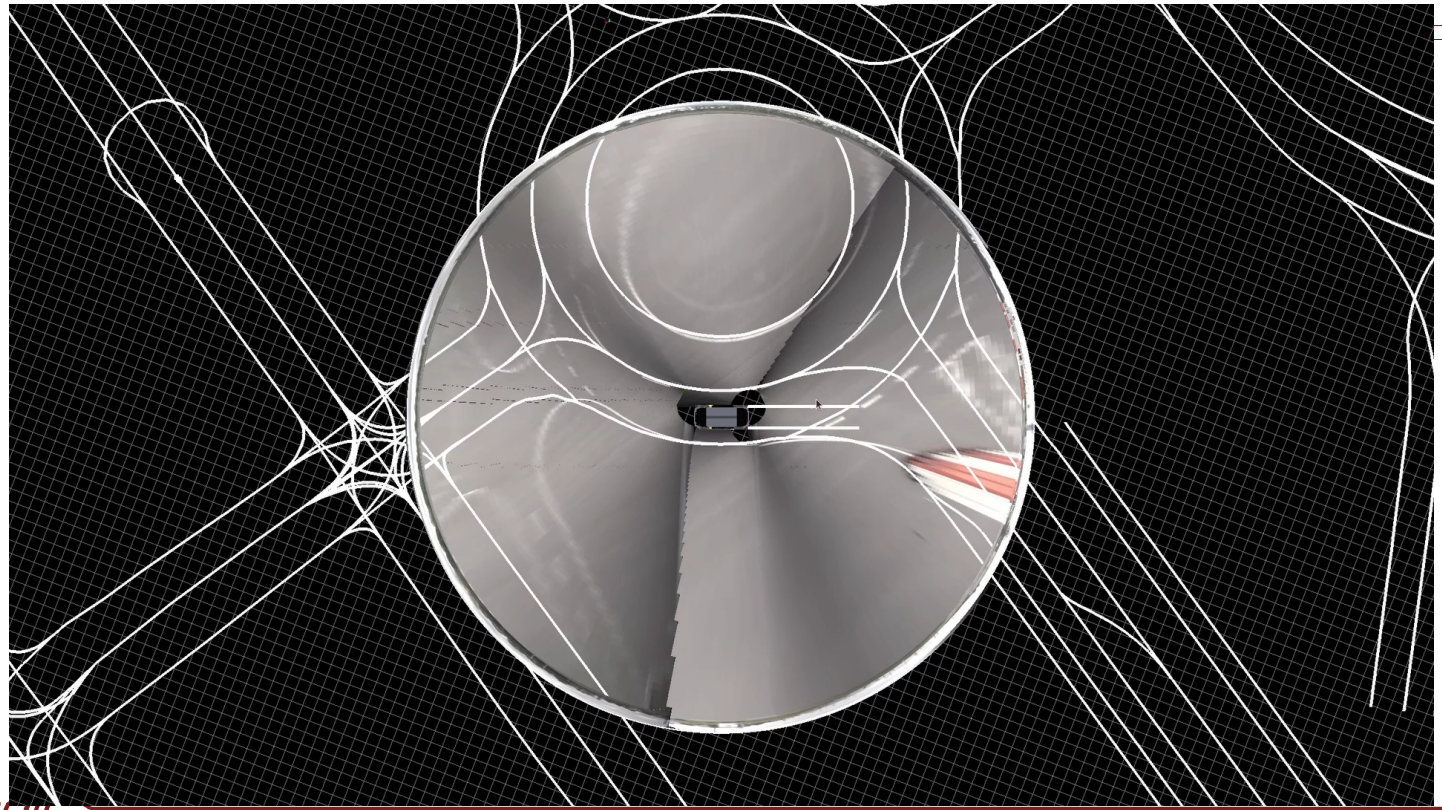




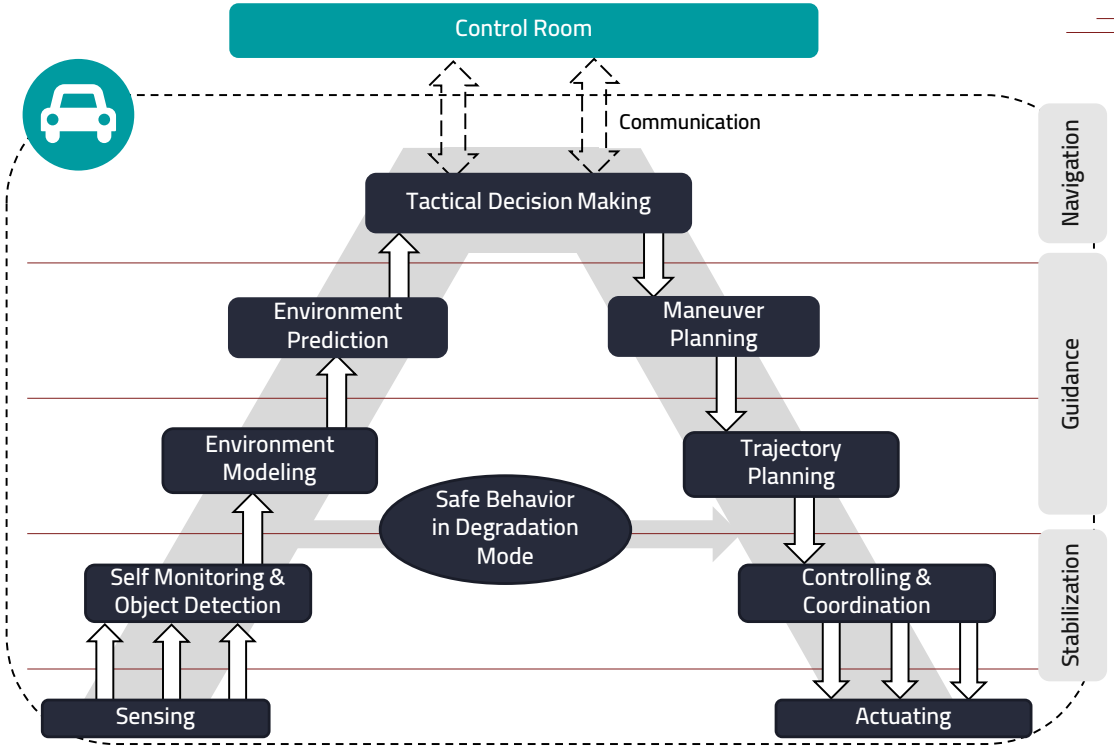
Teleoperation – Trajectory Guidance

Expanding the ODD of highly automated vehicles

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Functional Architecture



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Law on Automated Driving in Germany

- *§1d: […] (4) Risikominimaler Zustand im Sinne dieses Gesetzes ist ein Zustand, in den sich das Kraftfahrzeug mit autonomer Fahrfunktion auf eigene Veranlassung oder auf Veranlassung der Technischen Aufsicht selbständig versetzt, um unter angemessener Beachtung der Verkehrssituation die größtmögliche Verkehrssicherheit für andere Verkehrsteilnehmende und Dritte zu gewährleisten.*
- *§1e: […] (2) Kraftfahrzeuge mit autonomer Fahrfunktion müssen über eine technische Ausrüstung verfügen, die in der Lage ist […] 3. das Kraftfahrzeug selbständig in einen risikominimalen Zustand zu versetzen, wenn die Fortsetzung der Fahrt nur durch eine Verletzung des Straßenverkehrsrechts möglich wäre*

SAFE HALT

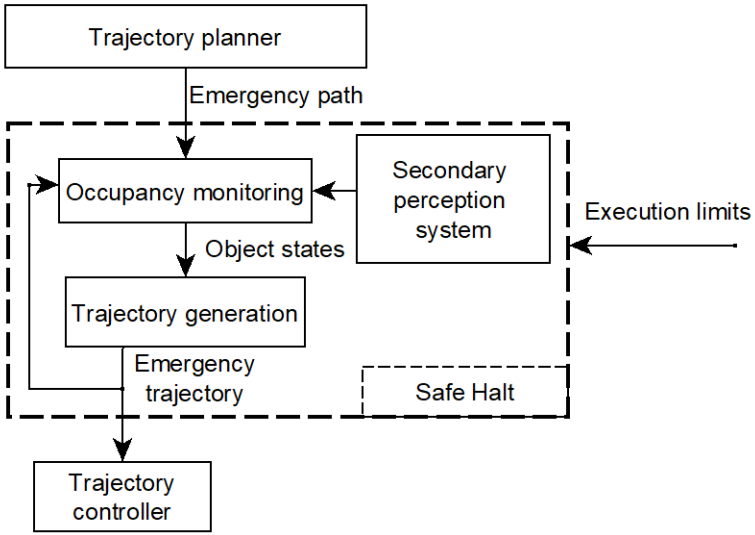
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Automated Fallback System

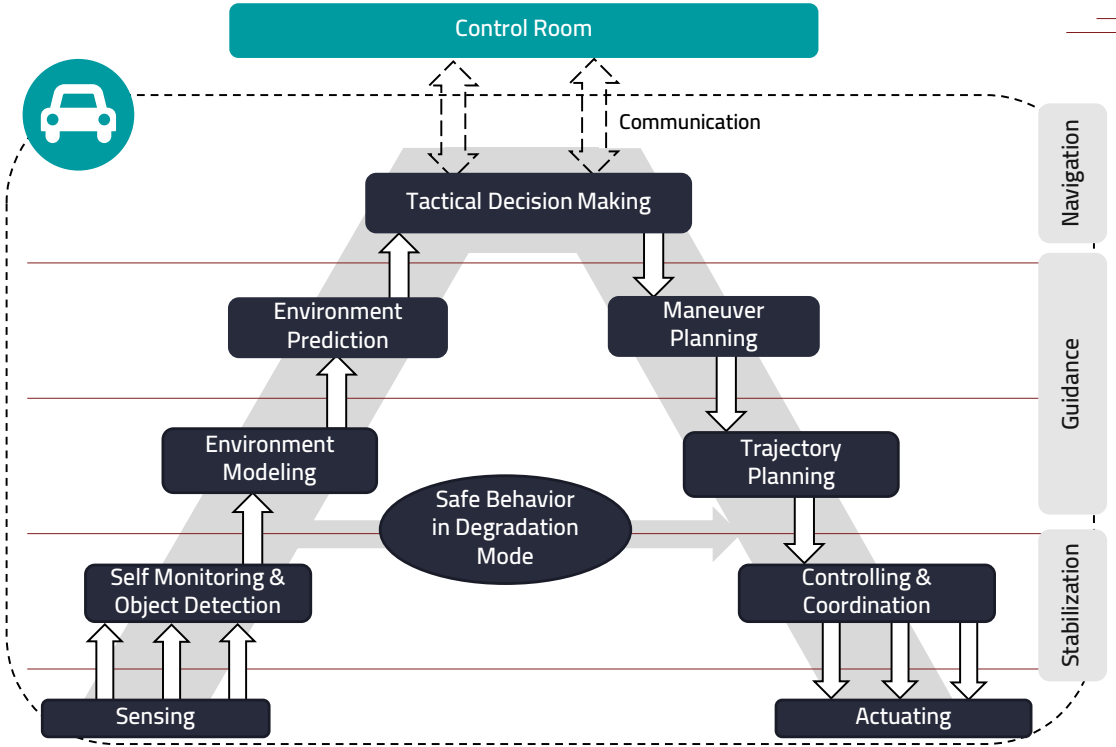
- Activated when significant degradations of vehicle functions occur
- Emergency maneuver relies on a precalculated emergency path
- Occupancy of the emergency path is monitored by the secondary perception system (platform sensors)

Emergency Path

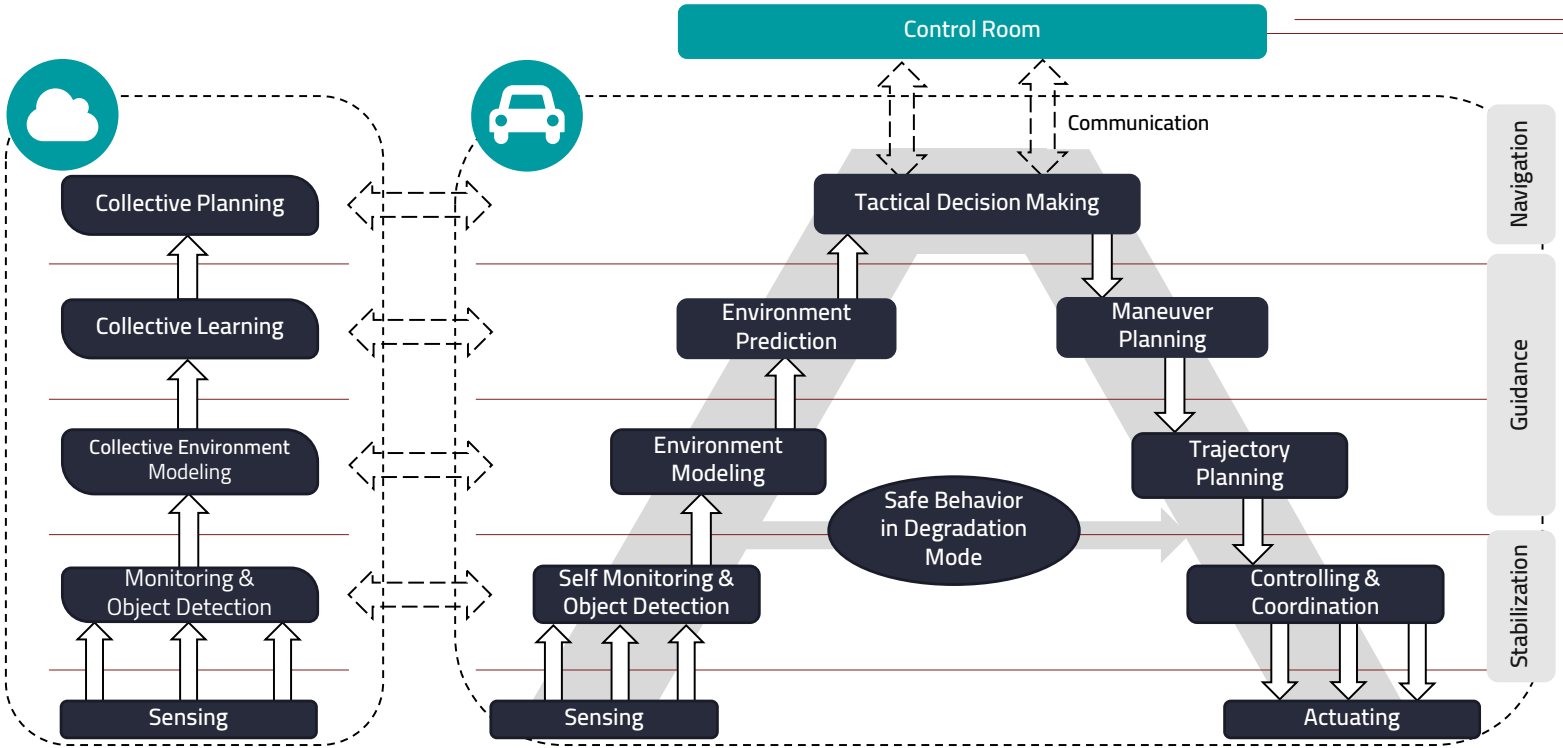
- Reference poses
- Location-dependent speed profile



Functional Architecture



Functional Architecture



COLLECTIVE CLOUD SERVICES

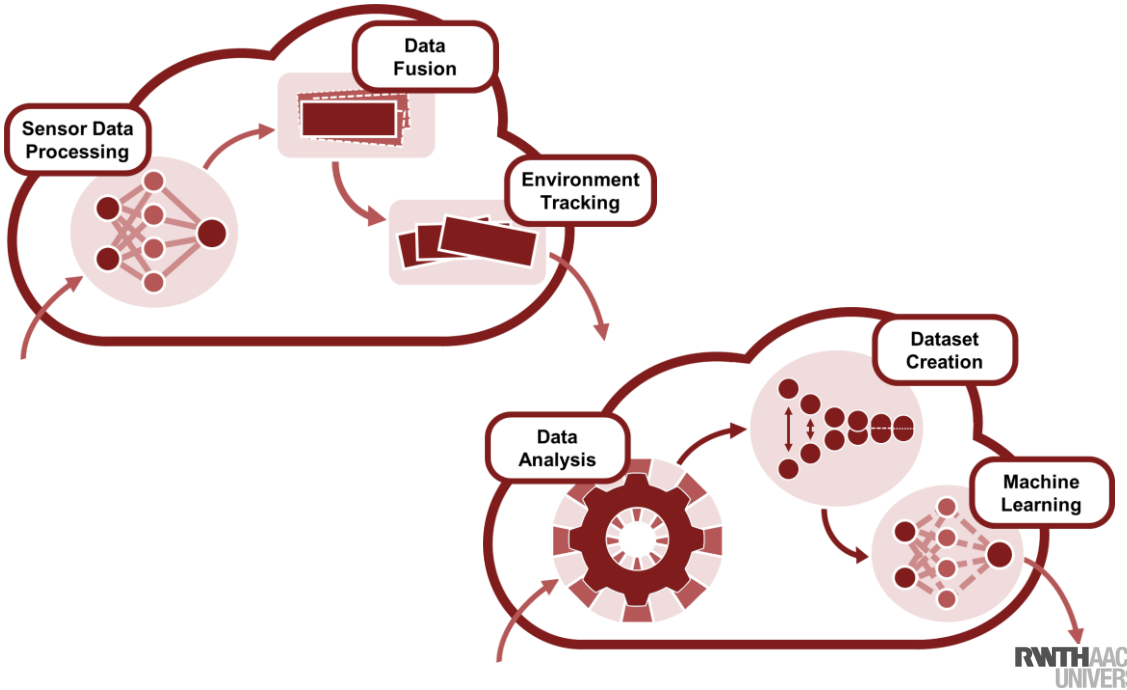
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Collective Environment Model

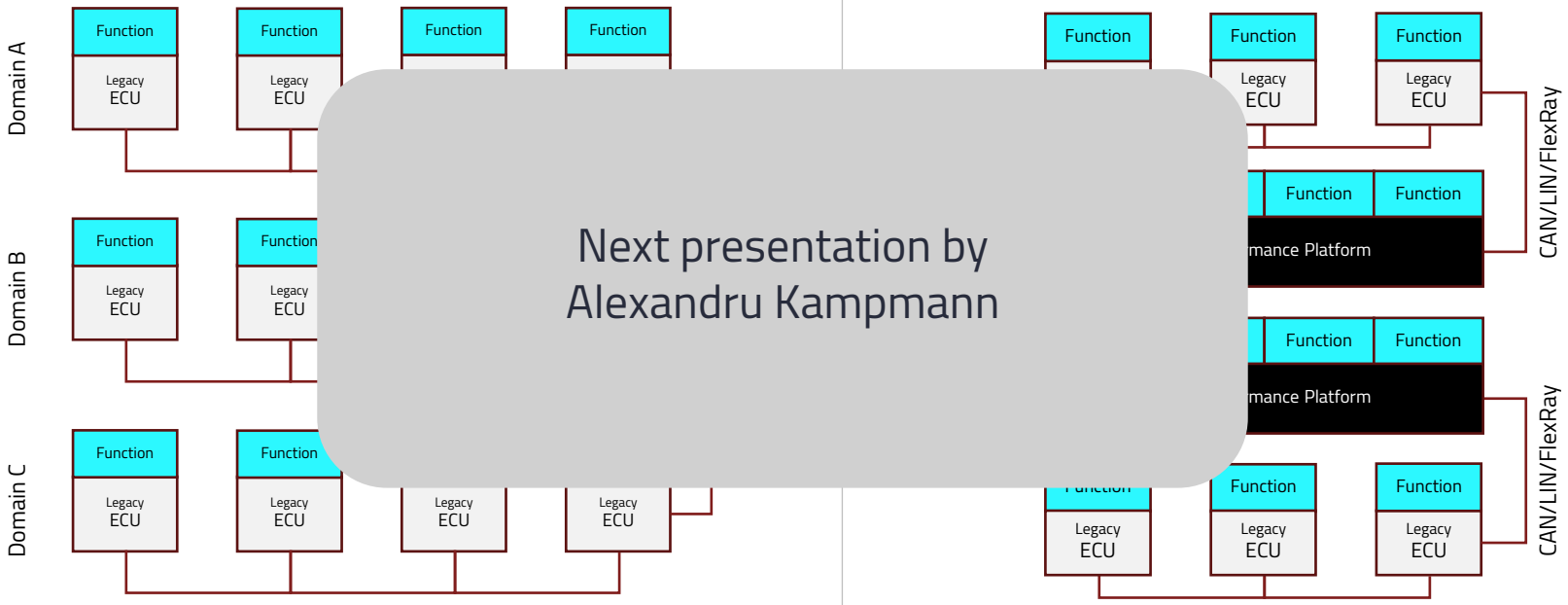
- Combination of perception data from vehicles, infrastructure, and UAVs
- Cooperative detection, fusion and tracking algorithms

Collective Memory

- Continuous selection and collection of relevant trajectory data
- Continuous improvement of trajectory recommendation models



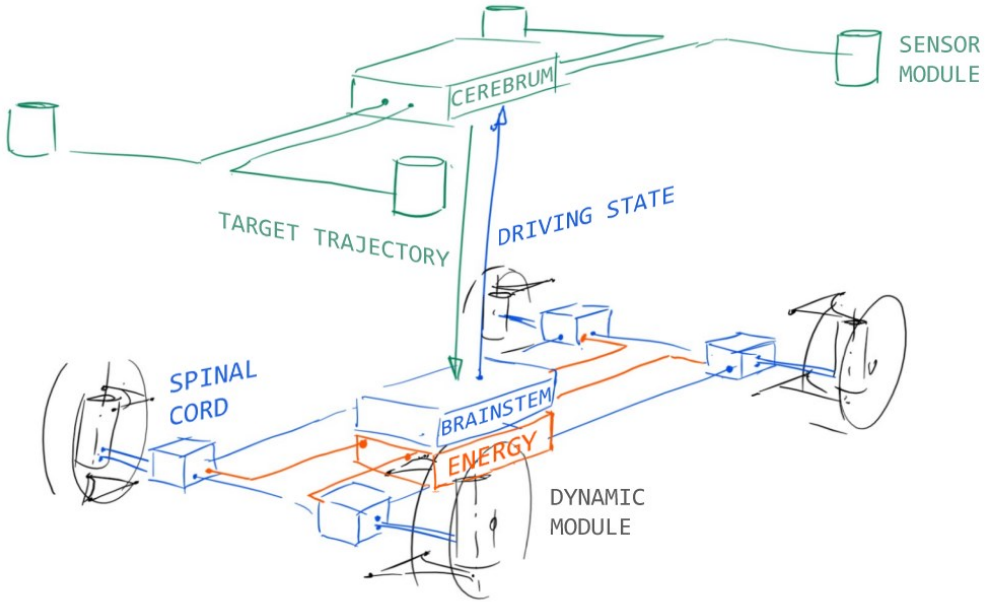
ASOA – Automotive Service Oriented Software Architecture



Traditional Architecture → **Centralized Architecture**

Mechatronic Architecture

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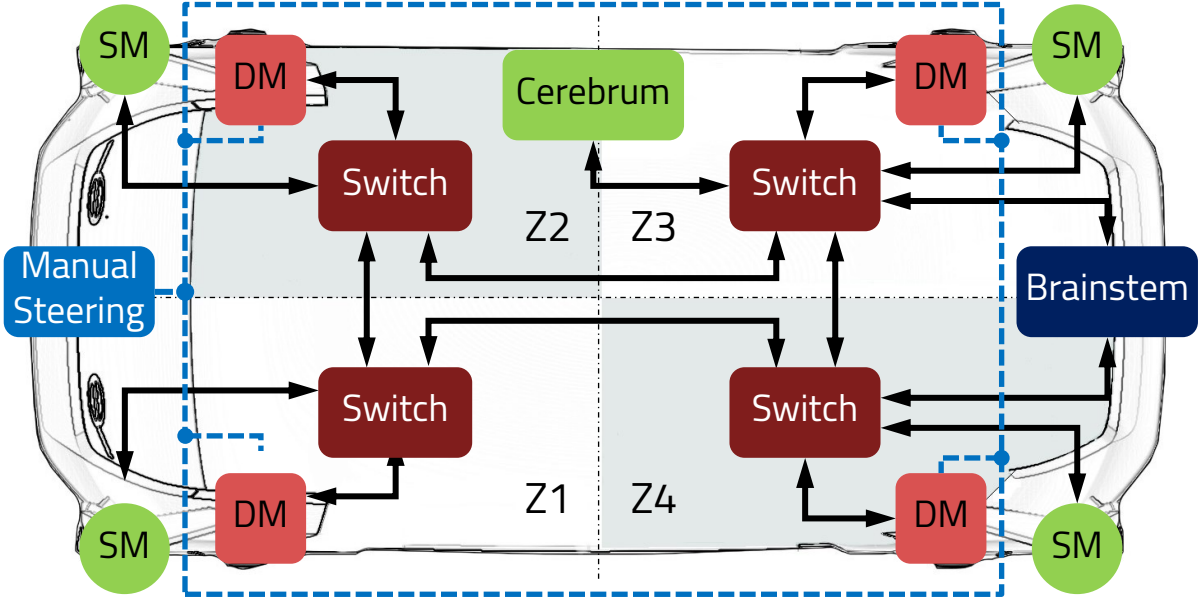
"Brain" Structure

"Cerebrum":
- Environment representation
- Behavior and trajectory planning

"Brainstem":
- Realization of desired trajectory
- Safety ECU
- Dedicated HW developed

"Spinal Cord":
- Steering angle and drive control
- Fallback in case of "Brainstem" failure

E/E Architecture



Source:
RWTH / ika,
Uni Stuttgart / IFS
(modified)

SM Sensor Module

DM Dynamic Module

Ethernet

Flexray (Spinal Cord)

Tasks

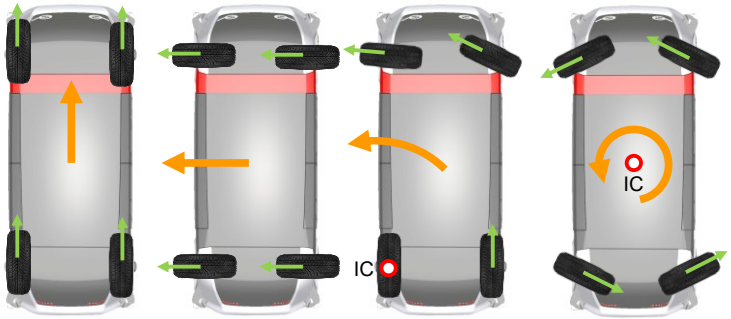
- Enable communication between various components of the network
- Support high-bandwidth, low latency in-vehicle communication networks
- Fulfill functional safety requirements

Implementation

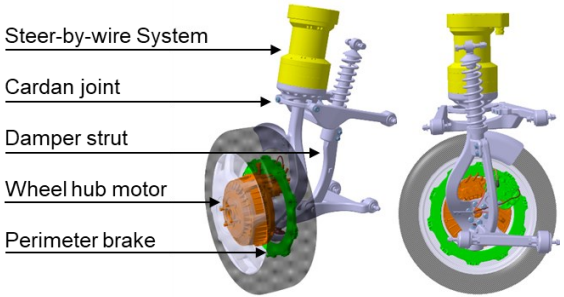
- Zonal E/E architecture
- Each with own switch, a set of sensors, ECUs, power and communication networks
- Ring topology for Ethernet backbone
- Network recovery time less than 50 ms
- Supports four QoS priority levels

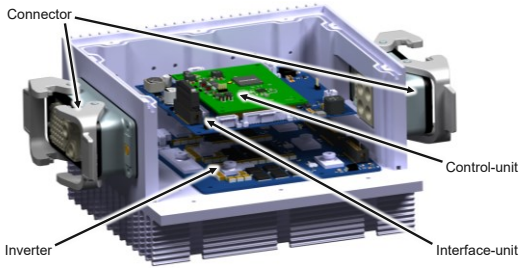
Dynamics Modules and Spinal Cord

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IC = Instantaneous centre of rotation





Tasks

- 48V drive and steering
- Support of the ASOA approach
- Steering up to 90° on each wheel
- Redundant braking system
- Automotive ethernet communication

Implementation

- Wheel hub motor and perimeter brake allow narrow packaging
- ECU developed with CAN, FlexRay and Ethernet interfaces on Aurix base
- Full ASOA compatibility




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The Final Event

- 400 guests from politics, industry and research
- 8 hours of live demonstrations of the vehicle's capabilities on track
- over 30 presentations and posters on the project’s achivements









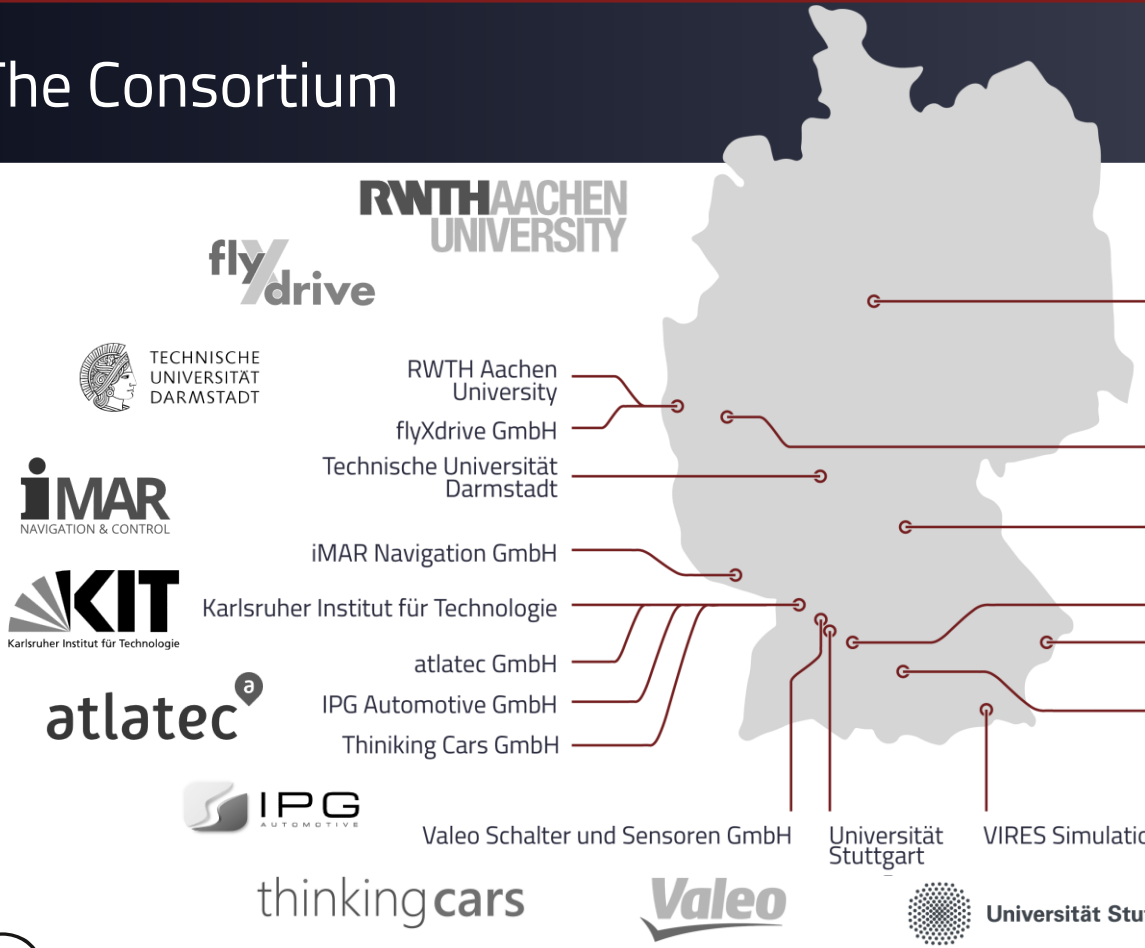


The Team!



Thanks to all the supporters for making this project possible!

The Consortium



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iMAR Navigation GmbH
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Thanks!