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FINAL EVENT
unicaragil

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Geometry

Mechatronics

Software

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Safety & Security

AGENDA

from 08:00 Registration

09:00 – 10:00 Opening

- Welcoming addresses by the German Ministry of Education and Research and the NRW Ministry of the Environment, Nature and Transport
- Introduction by Overall Coordinator

Prof. Dr. Lutz Eckstein & Project Manager Timo Woopen

10:00 – 10:30 Coffee & Opening Live Demonstrations

10:30 – 12:00 Introduction of the Domains

Lunch & Exhibition Opening **12:00 – 13:30**

Poster Session 1 **13:30 – 15:00**

- Geometry
- Mechatronics

Poster Session 2 **15:00 – 17:00**

- Software
- Automation
- Safety & Security

Closing & Outlook **17:00 – 18:30**

- Introduction of the Follow-up Project AUTOtech.*agil* by Project Manager Raphael van Kempen

As project leaders, we are incredibly proud to be able to present the results of the UNICAR*agil* project after five years of intensive research work.

The four autonomous vehicles developed by this excellent consortium are a milestone in automated driving and demonstrate how safely and reliably this technology can be used on the road. We deliberately chose not to convert or expand existing vehicles and instead developed a completely new vehicle structure that allows for flexible interior design and maximum flexibility in hardware and software with minimal development effort. The goal of the project, to create the foundations for a user-centered concept of driverless driving, has been achieved. We are convinced that automated and connected vehicles will play a key role in addressing the challenges arising from increasing mobility needs and advancing urbanization.

The UNICAR*agil* project has made an important contribution to the state of the art and will continue to contribute to advancing it in the future with its successor project, AUTOtech.*agil.*

We would like to thank all the universities and companies involved in supporting us in this project, as well as the German Ministry of Education and Research (BMBF) provided us with the financial resources. Without this collaboration, this project would not have been possible.

We hope that the results of the UNICAR*agil* project will help make the mobility of the future safer, more efficient, and more sustainable. The newsletter contains further information on the posters and a map that may be of interest to those attending our final event. The UNICAR*agil* project has taken a pioneering role in the development of automated and connected vehicles and will continue to help address the challenges of increasing mobility demand and advancing urbanization in the future.

We wish you and ourselves a great final event!

Timo Woopen
& Raphael van Kempen

Introducing the Domain "Geometry"

Highly automated driving is about to be launched into the market worldwide, leading to far-reaching changes in the way vehicles are used. For the first time, the task of driving and the driving persons can be separated. This enables access to mobility solutions for previously excluded groups such as people with impaired driving ability (e.g. blind people, people with cognitive impairments) or people without a driving permission (e.g. children). Furthermore, the delegation of the driving task results in new usage scenarios such as the (efficiently) shared private vehicle, autonomous freight transport or ride-hailing approaches. From a sustainability perspective, a shift from private owned vehicles to more centralized fleet operations can be assumed, especially in urban areas. This will lead to fundamental changes in the overall vehicle architecture and, in the upcoming years of technology maturity, to more exploratory development problems with relatively small unit numbers compared to today's vehicle derivatives from leading OEMs.

Within UNICAR*agil* we addressed this challenge by designing the vehicle concept from the ground up. We believe that a simple adaption of existing topologies will not be enough to address the awaited changes and to fully enable the potential and freedom in design that automation can offer. Disruptive new approaches are needed for the vehicle concept itself as well as for the development process used.

Starting point was the vision of a purpose-built vehicle with six main goals: continuous modularization, novel electronic architecture, service-oriented software architecture, collective cloud functionalities, continuous safety orientation within the design and user centered development approaches. Four use cases were chosen for further analysis, ride hailing, public transport, parcel services and the privately owned vehicle. To get a macro perspective of the user needs, online surveys were conducted. Based on the results, personas and associated scenarios were defined. These scenarios were the foundation for the item definition and the ODD. Starting from there, possible technical solutions for the desired functionalities were drafted. In parallel, a design competition was

initiated to have an aesthetic concept. User centered methods were deployed to define the User Experience within the vehicles as well as the associated ergonomic concepts and the HMI (exterior and interior) Technical draft, design idea and ergonomic concept were then the starting point for the geometric design.

Iteratively, a technical package, a structural design and more detailed interiors were developed. The biggest challenge was to satisfy the individual demands coming from the four diverging use cases while at the same time ensuring a maximum amount of carry over parts in between the developed derivates. The solution was a modular and scalable toolbox. The overall product structure can be separated into three functional entities. First, the scalable (600 mm in length) platform which includes all intelligence needed for the automation as well as all components to fulfill the driving task. Second, a hut module which is scalable in length (600 mm) and height (650 mm) and in combination with the platform provides the safety cell for the individual interior concepts. In addition, it provides the outer shell, individual door systems and sensor modules to perceive the environment. Within the safety cell, the four different interior modules were realized (third entity).

The structural concept was virtually tested with respect to operating loads as well as crash requirements. All for prototypes were built up as full functional prototypes.

*auto*SHUTTLE

The *auto*SHUTTLE seats up to eight people and is part of a new, better public transport system. Optimally adapted to the needs of users at all times, it represents the public transport system of the future.

The *auto*SHUTTLE is designed to shorten travel times on public transport by means of an intelligent routing system. The routes of the individual vehicles are laid out in a fixed station network in such a way that similar routes of different passengers' are combined. By moving away from fixed timetables and route networks, the shortest and fastest route for the current group of passengers will be selected.

The interior will also adapt to the current situation. While six passengers can be seated comfortably in the a*uto*SHUTTLE when passenger volume is low, the interior can be transformed to accommodate other usage scenarios. Up to three seats can be stowed away to allow the freed-up space to be used as standing room during rush hour, increasing the vehicle's capacity to eight passengers. This area can also be used to transport bulky luggage, provide bicycle transport, or accommodate a wheelchair user. The interior also features luggage space in the front and back.

There are two main information displays in the *auto*SHUTTLE, which show the next stops of the current route as well as periodically displaying news, weather forecasts or information about nearby points of interest. The passengers can interact with the vehicle via a third, touch-sensitive display. This allows them to log into their booked route and change it or – in the case of a problem or an emergency – call the control room. It can also be used to show information about the state of the vehicle, e.g. current speed.

*auto*CARGO

Not only passenger transport but also urban logistics on the so-called „last mile" will look different in the future. It will benefit from research and developments in the fields of autonomous driving and robotics.

*auto*CARGO is the automated delivery vehicle for parcel delivery and pickup. It drives and delivers autonomously and electrically, is locally emission-free and designed for urban spaces. It makes receiving and sending parcels independent of the presence of its customers. Connected with other vehicles and information systems, *auto*CARGO can respond flexibly to traffic disruptions. Various fleet and order management systems work in the cloud in the background for this purpose.

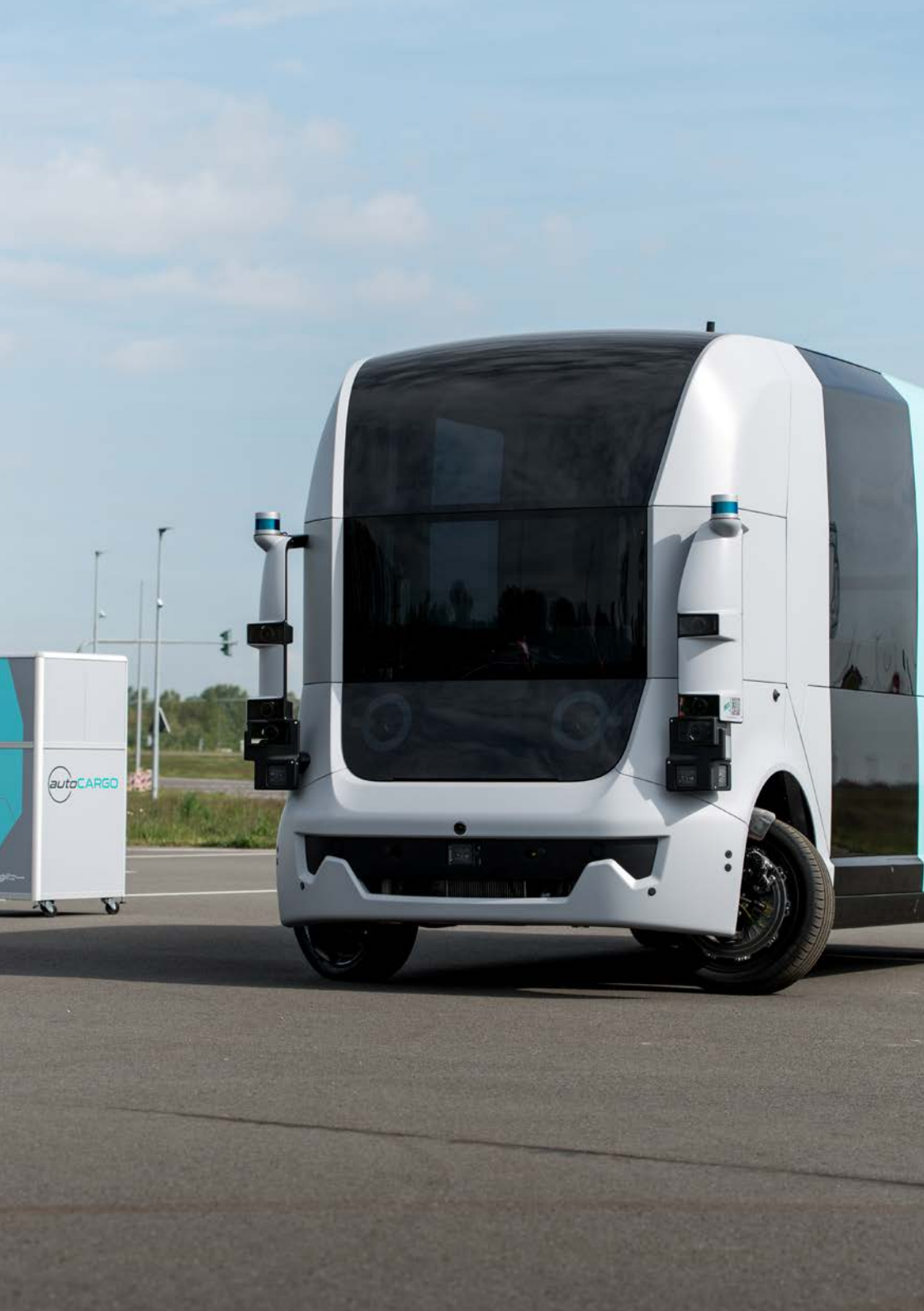
On its route, all parcel boxes to which shipments are to be delivered or from which they are to be picked up are targeted. Various private and public parcel boxes can accommodate individual or even very large numbers of parcels. For this purpose an underground parcel storage facility can be connected to the parcel box. In this way, urban space can be used as efficiently as possible.

The associated *auto*CARGO app can be used to order the dispatch of parcels. The desired parcel box can be selected individually, easily and flexibly for each shipment (dispatch or pickup). The app informs about parcels ready for pickup just as reliably as about the delivery to the recipient.

The parcels to be delivered are stacked in the loading container outside the vehicle in a transport-optimized manner, i.e., taking into account the acceleration forces to be expected during the journey. This is loaded into the autonomous parcel delivery vehicle at the parcel center. The batteries of the *auto*CARGO vehicle are also charged independently and inductively in the parcel center.

Overall, *auto*CARGO is more than an autonomous research vehicle. *auto*CARGO is a logistics system consisting of:

- the actual vehicle with exchangeable parcel storage, the loading container,
- the parcel center,
- private and public parcel boxes for the delivery and collection of parcels by customers
- the *auto*CARGO app,
- as well as the components available to the entire vehicle family, e.g. a control room and info bees).


autoCARGO

*auto*TAXI

The *auto*TAXI is a vehicle designed to transport up to four passengers at a time in a comfortable and sustainable way.

The *auto*TAXI's interior is a marvel of innovation, designed to cater to the needs of all passengers. Two of the seats are equipped with foldable tables, making it easy for passengers to work or do other activities during the ride. The other two seats are designed for relaxation, with an innovative design based on comfortable home chairs. Passengers can sit back and relax during the autonomous ride.

The *auto*TAXI can be booked using an app and also allows ride-hailing, which means other passengers can join the ride if they are going in the same direction. This makes the vehicle an ideal option for those who want to save money and reduce their carbon footprint.

One of the highlights of the *auto*TAXI's interior is the seat substructure, which is made of "Malve," a fast-growing and sustainable plant. This makes the vehicle not only comfortable but also environmentally friendly.

During the ride, a tablet app serves as user interface, allowing passengers to conveniently and interactively communicate with the vehicle. The app displays information about route and estimated arrival time. With its intuitive touch screen interface, the tablet app offers an engaging and user-friendly experience, making autonomous travel more accessible and enjoyable.

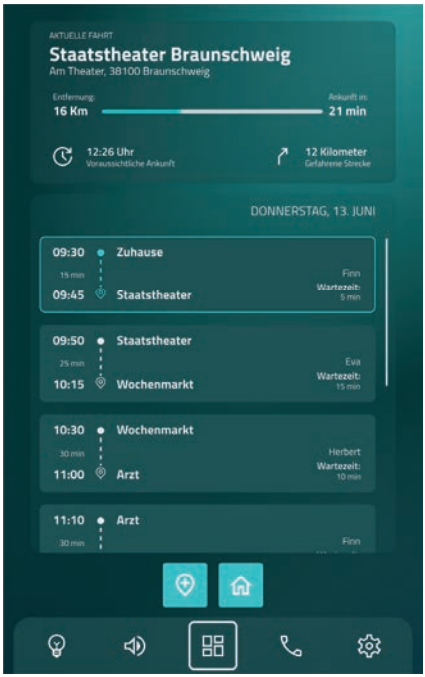
The *auto*TAXI is a glimpse into the future of transportation. With its innovative interior design and sustainable features, it offers a solution for both transportation and environmental concerns. As we move towards a more sustainable future, the *auto*TAXI is leading the way in the world of autonomous vehicles.

*auto*ELF

The autoELF represents a completely individual and private family vehicle. With its accessible and inclusive design, all family members can fully enjoy their journeys. Like the autoTAXI, the autoELF is a smaller vehicle version and is developed to provide as many members of a family as possible with individual mobility and to meet their individual needs while driving.

The needs of individual family members can be very different. Those dependent on the support of a companion who can drive a conventional vehicle have particularly high demands. Possible applications include driving grandparents to a doctor's appointment or driving children to a sports club.

In the future, physically handicapped people will also be able to be mobile without barriers and there will be no need for an accompanying person. In this way, autoELF helps its users to achieve new autonomy in everyday life. The concept of the autonomous family vehicle is completed by an elegant exterior design and a homely interior adapted to its users' diverse needs. In addition to the selection of materials, which is rather unusual for a vehicle interior, striking features of autoELF are integrated functions for operating the vehicle: autoELF is equipped with a user interface that can be adapted to three different user types, including children. The usability and acceptance of this unique vehicle were tested in a scientific study. Here, individuality is at the forefront.



eHMI

The car eHMI is the user interface that provides the driver and passengers with a variety of information and functions, such as battery charging status, navigation and safety alerts. These interfaces can be integrated into a vehicle's body and should coordinate the communication with external road users.

Car eHMI technology has advanced significantly in recent years, with features such as augmented reality, facial recognition, and personalized settings becoming more common. These interfaces are designed to improve the driving experience by providing drivers with more intuitive and user-friendly controls and reducing distractions.

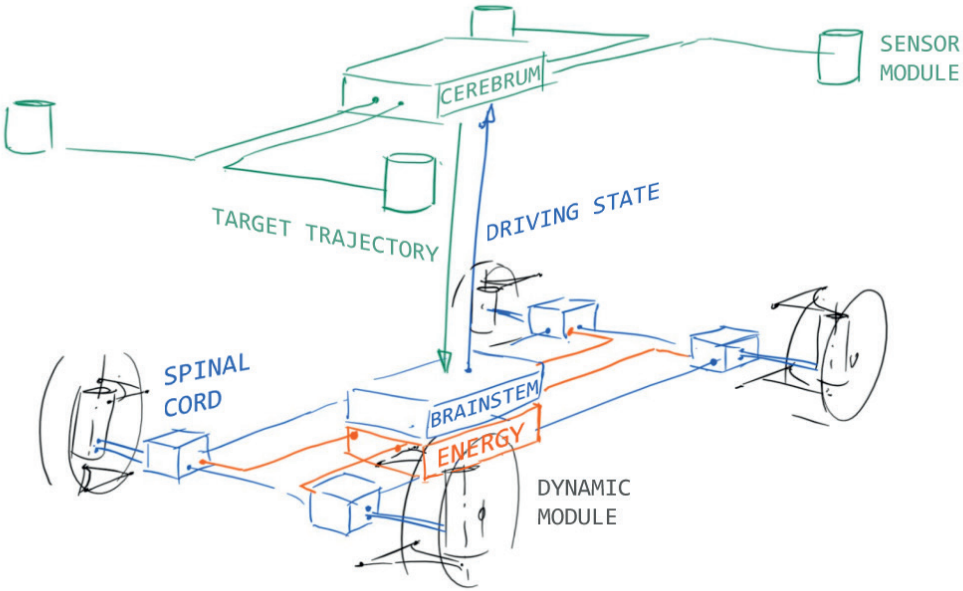
Overall, the eHMI is an important aspect of modern car design, and it will continue to evolve as new technologies emerge and user expectations change. Within the UNICAR*agil* cosmos, various RGB matrix panels are integrated at the front back and sides to secure a solid communication with other road users. Therefore, a service was created zeller that handles incoming events and displays the correct eHMI symbols accordingly.

A Holistic Security Concept for Safe Automated Driving

Implementing the updatable, service-oriented, and networked software architecture in the UNICAR*agil* vehicles paves the way for new and better mobility concepts. The dynamic software architecture enables us to load software dynamically and communicate with external entities such as infrastructure, promising safer and more efficient automotive ecosystems. However, this also raises security concerns as the number of external interfaces increases. To ensure the safety of our passengers and UNICAR*agil* vehicles, we have developed a comprehensive security concept that encompasses the entire vehicle life cycle. This holistic approach enables us to react quickly to a continuously changing attack surface by adjusting risks and security requirements. Our security solution aligns with our project's design philosophy of strongly decoupled and optionally isolated software components, and we aim to minimize management complexity. To this end, we enable developers to specify security requirements interactively and visually, eliminating the need to manually distribute and update security attributes such as keys and certificates. Our system takes responsibility for secure software roll-out and enforces the specified security objectives during runtime, guaranteeing software integrity and communication security. Our demo showcases how we protect the Automotive Software-Oriented Architecture (ASOA) from network attackers attempting to inject safety-critical commands to take control of the UNICAR*agil* vehicle.

Introducing the Domain “Mechatronics”

The mechatronic architecture of the vehicles in the UNICAR*agil* project had to meet several requirements: being a fundament for innovative, disruptive and safe vehicle concepts, supporting the ASOA approach and enabling simultaneous work at different locations in Germany are only some of them. By supplying all components with electric power and providing a fail operational data network, including Ethernet, CAN and Flexray connections, the mechatronic architecture supports the modular design of the UNICAR vehicle family. In addition to the mentioned E/E architecture, the domain Mechatronics also includes the entire heating and cooling network.



Overview on the UNICAR*agil* E/E Architecture

Automotive electrical and electronic (E/E) architecture plays a crucial role in enabling autonomous driving. Vehicle E/E architectures are evolving from distributed architectures into zonal structure, which clusters ECUs and connections in physical areas of the vehicle.

Zone-based E/E architecture can help to reduce complexity, and wiring cost, while enhancing safety and reliability. The E/E architecture in the UNICAR*agil* project is designed to provide a modular and safe infrastructure that can enable communication between different components within the network. Therefore, UNICAR*agil* vehicles use zone-based E/Earchitecture approach.

The architecture supports the implementation of Automotive Service-Oriented Software Architecture (ASOA), which is developed by the RWTH Aachen University. This leads to achieving a high degree of upgradability and updateability. In the UNICAR*agil* vehicles, four zones are defined. Each zone has its own set of sensors, processors, and power and communication networks that allow them to work independently and communicate with other zones when needed. As a result, if a fault occurs in one zone, the rest of the vehicle's systems continue to operate normally.

Another key feature of the designed E/E architecture is the use of high-speed data communication networks. A ring-shaped Ethernet backbone is used to connect zones to each other. The network supports transmission rates up to 1 Gbit/s and has a recovery time of under 50 ms. To meet Quality of Service (QoS) requirements, four priority levels are considered for traffic data. A Virtual LAN (VLAN) is set up, which makes the QoS implementation possible

The switches use strict priority algorithm for high priority control traffic and data synchronization is enabled with Ethernet-based PTP. An intra-vehicle backbone network model will be presented at the final event to provide a more detailed overview of the UNICAR*agil* E/E architecture, since IVN is an essential but invisible infrastructure of all vehicles.

The Dynamics Modules

A key element in the project UNICAR*agil* is modularity, which is also implemented in the powertrain. In contrast to conventional drives with a central motor and separate steering and braking system, four dynamics modules provide the functions propulsion, steering and braking. In addition to modularity, the dynamics module meets a wide range of functional, electrical and mechanical requirements. Two main requirements where defined at the beginning of the project. The maximum voltage level of 48 V and the use of electric wheel hub motors in order to realize large steering angles up to 90°.

Longitudinal dynamics simulations show that the maximum acceleration capacity with the maximum torque of 500 Nm at 14 kW power is approx. 1.8 m/s² and can be delivered up to a speed of 32 km/h. To simulate the maximum climbing capacity, the continuously available power of 10 kW is considered. With that, gradients of up to 8% can be driven with just over 45 km/h.

The idea of modularity is also reflected in the wheel suspension. For the scalable vehicle platforms with wheelbases of 2800 mm and 3400 mm, the chassis consists of four equivalent dynamics modules. Besides the integration of the wheel hub motor and an additional mechanical brake the following three driving maneuvers are the main geometrical requirements for the dynamics module.

Driving sideways with a steering angle of 90° at all wheels. Turning maneuver with the rear inner wheel set as instantaneous center. Turning on the spot around the vertical axis of the vehicle.

For the dimensioning of the electric steering actuator a single lane change, a full deceleration, quasi-static cornering at constant radius and steering in standstill with brakes applied are considered. The maneuver that requires the highest steering torque is steering in standstill with 1290 Nm. As normal rims are not applicable because of the necessary integration of the wheel hub motor and the perimeter brake, custom-made wheels, mechanically validated with finite element analysis, from the project partner Maxion Wheels are used.

The various control units in the UNICAR*agil* vehicles communicate using an automotive service-oriented architecture via Ethernet. In contrast to that, the wheel hub motors and the brake system communicate via CAN while the sensors from the steering actuator are using BiSS. The dynamics modules themselves are connected via FlexRay, which can also be used for manual user inputs via sidestick. A custom-designed control unit based on the Aurix™ TriCore™ provides all these interfaces and controls the integrated inverter of the steering actuator. At the final event, you will be able to experience some of the agile driving maneuvers on the test track and to take a closer look at the components of the dynamics module at the poster session.

The Brainstem

An automated vehicle needs a safe and fault tolerant control system. Unlike manually controlled vehicles, automated vehicles from automation level 3 on cannot rely on a human mechanic fallback system but must keep on working, even in a case of fault. This makes a fault tolerant control system a crucial part of the whole automation process.

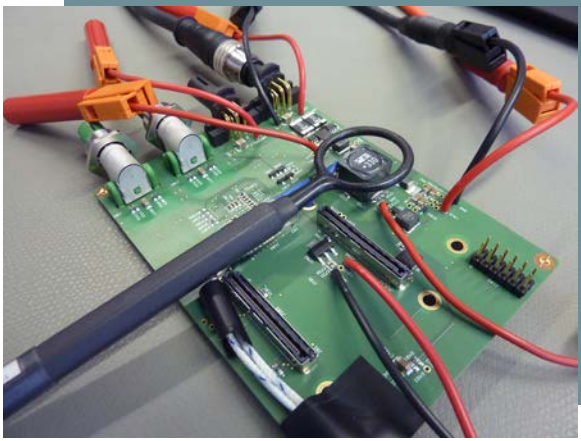
On the other hand, fault tolerance by duplication of the full control system comes along with a high hardware overhead and conflicts with requirements from other aspects like security or cost efficiency. Therefore, we developed a system of redundancies and fallback resources, that enables fail operational behavior without full system duplication.

UNICAR*agil* provides a combination of several redundancy architectures. The cerebrum always generates two trajectories in parallel: a target trajectory and a fallback trajectory. In case of an imminent collision or if the cerebrum does not generate any trajectory at all any more, the safe halt mechanism switches to the fallback trajectory and brings the vehicle into a safe state (safe halt), much like a horse, that scrutinizes the directions of its equestrian. Even though the hardware and software at the cerebrum level themselves cannot be totally secured due to their complexity, the control system can be safe without completely replicating it, due to the "Horse-Rider principle". In order to offset any mistakes in the main system, expensive and complicated safety procedures are centered on a relatively small and affordable subsystem. The term "graceful degradation" also refers to the idea of functional reduction to a safety-critical minimum in the case of an error.

The brainstem hardware is built on a duo-duplex architecture in order to satisfy the stringent safety criteria. More particular, it adheres to a redundant, two-level structure: Running the same program simultaneously on two processors allows single-bit errors to be caught at a lower level. By contrasting the two units, it is possible to identify signal interference, such as that caused by radioactive or cosmic radiation. In this scenario, it is possible to either retry the operation or, in

the worst case scenario, shut down the processor pair. The integrity of the data is ensured by this so-called lockstep procedure and the subsequent fail-silent behavior, which filters out inaccurate results. For total failures, such as those caused by disturbances in the energy supply, a second level of redundancy is necessary. The entire control unit is doubled in this instance. Compared to triple redundancy (TMR), this two-level architecture offers cost reductions of up to 33% while ensuring system integrity and dependability.

If you are interested, you can try out this mechanism with our demonstrator at the final event.



Thermal Management

The UNICAR*agil* vehicle concepts require new approaches for the thermal management system. The use of wheel hub drives and steering actuators on all four wheels means that an inherently more complex cooling system is required than in conventional vehicles with just one engine. The automated driving functions require high computing power, which is provided by the four sensor module data processing units (DPU) and the cerebrum. Computationally intensive algorithms are used to generate the environment models, which run even when the vehicle is stationary where cooling airflow is sparse.

High waste heat is generated at a relatively low temperature level. The cooling of these computing units is critical to safety, as the automated driving function can no longer be ensured if the components derate or fail due to overheating. For this reason, an independent cooling circuit for the sensitive computing hardware is provided.

The thermal management system comprises two separate coolant circuits with different temperature levels and a refrigerant circuit for cabin air conditioning. One circuit is managing the dynamic modules (DM) and the other circuit manages the DPUs and cerebrum. By using liquid-cooled components in the data processing units, their excess heat can be used to heat the cabin. This approach was chosen because the data processing units are always running during vehicle operation and the heat output is independent of the driving condition. The dynamic modules on the other hand may supply a very low amount of heat depending on vehicle speed, gradient or load.

An additional electric heating element was integrated to further heat the cooling liquid if needed before entering the cabin heat exchanger. Two cooling packs are mounted on the cross beam in front of the vehicle platform. The air supply is provided by the inlet opening in the lower part of the bumper. Each cooling pack comprises a heat exchanger fitted with two fans in a pull configuration. They are necessary to maintain cooling capacity during a standstill, which is expected to account for a non-negligible proportion of the planned use cases. To cool down the cabin, a refrige-

rant circuit with a 48 V compressor and modular HVAC-Box with several controllable air inlets and outlets is used. This modularity allows the system to adapt to each of the four different interior concepts. Inlets for cabin ventilation are situated in different locations depending on the vehicle interior concept.

The HVAC box supports recirculating and fresh air modes as well as three individually controllable zones for air outlets. To save energy, the recirculating mode is primarily used and the cabin air is constantly monitored using a carbon dioxide (CO2) as well as a relative humidity sensor to efficiently control the fresh air mode.

A second sensor in the cabin air intake detects total volatile organic compounds (tVOC), CO2 equivalent, relative humidity and temperature of the intake air. These sensor signals also influence the recirculation mode state, but CO2 concentration and relative humidity of the cabin air are prioritized in the control strategy at all times. The developed HVAC-ECU allows the support of the ASOA framework. By this, the ECU can communicate with other services in the vehicle.

The current interior and exterior temperatures measured by the ECU for example are provided as a service and can be used by other control units in the vehicle. In addition, services such as the interior human–machine interface (HMI) can influence the parameters of interior climate control if needed.

A Modular and Reliable zone-based Vehicle Powernet

Digitalization, electrification and autonomous driving functions require an energy supply that is more efficient, modular and reliable. Since there are interfaces to every electrical device as well as the hardware architecture, the complexity as well as the optimization potential for the entire vehicle are of significant importance. Modularity within a vehicle was achieved through four zones, which are over 90% identical. This enables the mapping of functional redundancies also on an energetic level and reduces cable paths. In relation to all four UNICAR*agil* vehicles, an electrical power system was designed that meets the specific requirements of the individual vehicles and yet is over 80 % identical. The powernet has four zones, each with its own battery and voltage converter. The batteries were connected as a ring topology in order to continue supplying the entire vehicle even if individual batteries fail. Additionally, individual faulty zones can be disconnected energetically from the entire vehicle. This ensures greater reliability in the event of electrical faults caused by batteries or loads.

During the final demonstration, it is not possible for you to see the vehicle's power supply system. It is distributed throughout the vehicle and ensures that all electrical devices are reliably supplied. The batteries are located in the underbody directly below you, while the voltage converter and computing unit are housed in the front and rear of the vehicle. You can take a look inside one of the battery modules in the poster area.

Charging

Each of the four vehicles has three options (AC, DC and inductive charging) for charging the batteries. Firstly, the vehicle batteries can be charged using a 3.3 kW on-board charger (AC charging) via a household socket. For charging at higher power up to 10 kW, specially designed mobile charging stations are manufactured for the vehicles.

They charge the vehicle batteries with the appropriate direct current (DC) at a system voltage of 48V. The third option for charging vehicle batteries is inductive charging. This involves placing the secondary coil on the underside of the vehicle and the corresponding primary coil on the ground. Intelligent position detection ensures that the two coils overlap as precisely as possible, which is essential for good efficiency. The distance between the coils is detected and evaluated by magnetic field sensors mounted on the underside of the vehicle. This information is used to position the vehicle over the primary coil.

Wireless communication is used for data exchange between the charging station and the vehicle. You can experience the charging stations for DC charging in the home zones. Inductive charging is demonstrated with a test platform.

Introducing the Domain "Software"

The „Software" domain forms the centerpiece of the vehicles, responsible for implementing automation functions and enabling the seamless operation of highly complex systems. The core element is the service-oriented middleware ASOA. In response to the evolving landscape, various technical domains are adopting architectures to realize the SDV vision. However, we believe that a comprehensive, end-to-end SDV software architecture is still absent.

Contrary to traditional design-time integrated architectures, ASOA enables dynamic integration at the system's execution, distinguishing it from traditional, design-time integrated architectures. ASOA empowers the separation of non-modular aspects related to system integration from system-agnostic software services. This separation provides the advantage of adapting the software architecture with minimal impact on software services. Moreover, ASOA facilitates introspection of processing within its services, enabling optimization of causality chains spanning multiple services. Furthermore, the introspection capability enables automated, systematic deployment calculation on shared, high-performance platforms.

We firmly believe that the ASOA approach is a pivotal enabler in reducing development cycles and accelerating time to market for software innovations. ASOA comes with a portable implementation and offers collaborative system engineering tools, further enhancing its applicability. The ASOA SDK allows to implement services both on microcontrollers, such as Infineon Aurix TriCore, as well as on high-performance, Linux-based platforms.

ASOA paves the way for a future where software plays a central role in shaping the automotive industry. Its dynamic integration, modularity, and introspection capabilities set ASOA apart, making it an indispensable solution for tomorrow's SDVs

A Cloud Architecture for Networked and Autonomous Vehicles

The UNICAR*agil* project is a collaborative effort aimed at developing an innovative autonomous driving system that is capable of integrating multiple components and actors within its ecosystem. One key aspect of this project is the use of a cloud-based infrastructure, which serves as a central hub for connecting all the various actors and components within the system.

UNICAR*agil* project is designed to provide a service-oriented infrastructure that can easily connect all the different components and actors within the system. This enables the system to be easily adjustable and adaptable to changing requirements, while also providing a high degree of flexibility in terms of integration and collaboration.

Another key aspect of the cloud infrastructure is its ability to provide information on UNICAR*agil* vehicles and traffic in general. This information can be used to optimize the performance of the system, ensuring that it operates safely and efficiently in all conditions. In addition, the cloud infrastructure serves as an interface for users to interact with the system, providing a convenient and user-friendly means to control and monitor the system.

This cloud concept includes various services that can help manage and optimize the UNICAR*agil* vehicles. For instance, it contains a service to manage the vehicle fleet and coordinate its individual missions. This service could help ensure that vehicles are assigned to the most appropriate tasks and routes based on factors such as traffic conditions, vehicle availability, and passenger demand.

Overall, the cloud infrastructure with its high computing power serves as a central point within the UNICAR*agil* ecosystem and plays a critical role in supporting the system with relevant information and communication infrastructure.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Enabling and exploiting data flow determinism in distributed systems

The development of safety-critical automotive software has undergone fundamental changes. Instead of restricting to a local scope, automated driving functions involve complex and distributed cause-effect chains, including long processing pipelines and data fusion. Implemented on heterogeneous hardware/software architectures, the different functions suffer from timing interferences between each other. Due to the induced jitter in computation and communication times, the data flow within dependent cause effect chains may be affected, threatening deterministic functional behavior. In addition, the required agility in the development process adds to the effect, since frequent updates and modifications become the rule rather than the exception. Robustness against such changing runtime conditions, as well as a composable timing design, are key enablers of a disruptive development process.

The Logical Execution Time (LET) paradigm is a promising candidate for an abstraction of the runtime behavior. Its applicability and benefits have already been demonstrated in the automotive domain. Nevertheless, LET is restricted to the scope of a single component. Within this project, a novel system level timing abstraction called "System Level LET (SL-LET)" has been developed. SL-LET is capable of abstracting communication with distributed clocks (loosely synchronized) as well as pipelined execution, where latencies are far larger than the period. Especially for complex systems with dependent cause-effect chains, it effectively solves the problem of data-age deviation. SL-LET has been introduced in the AUTOSAR standard (R22-11 release), whereby it became usable for the automotive industry.

The improved timing model allows for further optimizations in the communication design. By separating sensor data streams in time instead of by prioritization, complex congestion situations can be avoided. The periodic SL-LET specification can provide an overall framework where optimization can take place, without enforcing a system-wide time-driven scheduling.

This enables a significant reduction of sensor data sample worst-case communication times (WCCTs). Thereby, small time-sensitive control messages are not affected as they are transmitted on a higher priority without a noteworthy impact on the latencies of the much larger sensor data. At the same time, SL-LET can be further used to improve the architecture of an Ethernet-based communication stack. It allows to introduce a lightweight filter stack that separates critical from non-critical traffic while preserving the full stack functionality for non-critical traffic. Contrary to expectation, the determinism gained by SL-LET permits an efficient implementation that enables significantly lower end-to-end latencies for critical traffic. As a result, SL-LET programming rather reduces than extends latencies.

Introducing the Domain "Automation"

Following the overall project goal, the automation concept in UNICAR*agil* is based on modularity and redundancy, realizing an SAE level 4 driverless functionality. For that, the automation of the UNICAR*agil* vehicles makes use of the concepts and results developed within the other UNICAR*agil* domains, like the modular electronic structure of the mechatronic architecture. The resulting electronic architecture for automation is inspired by a biological nervous system, featuring a spinal cord, a brain stem, and cerebrum.

On the software side, the UNICAR*agil* automation is based on the automotive service-oriented architecture (ASOA), realizing the different parts of the automation chain as services. In addition to the on-board functionality for driverless SAE level 4 operation of each UNICAR*agil* vehicle, the automation concept also includes connected services to additionally support the vehicles. A short overview on the overall functionalities is given in the following, followed by detailed articles on the different modules on the following pages.

Concentrating on-board the vehicles first, the automation processing chain starts with the environment perception task. This is realized by four identical sensor modules, one on each corner of the vehicle, which surveil the vehicle's surroundings redundantly and calculate one environment model each with their own electronic control units (ECUs). The sensor module's environment models are then fused into the overall into a vehicle environment model on a central ECU, the so-called cerebrum.

Furthermore, the cerebrum provides the computing power for behavior planning and planning for both normal as well as safe-halt operation. The required information on the current dynamic state of the UNICAR*agil* vehicle and its global localization are provided by a respective estimation module as part of another ECU, the. so-called brain stem, together with dedicated hardware sensors. The brain stem also receives the calculated trajectories from the cerebrum and calculates the control inputs for the wheels. Each wheel is part of a so-called dynamics mo-

dule, which realizes propulsion, braking and steering individually for each wheel, and using low-level controls to achieve the desired speed and steering angle from the brain stem commands. The ECUs of the dynamic modules therefore form the spinal cord. For the case of a severe degradation of the automation system detected by the self-assessment of the vehicle, the brain stem switches to a Safe Halt mode, for which is makes use of its own sensors, named platform sensors.

The off-board parts of the UNICAR*agil* automation architecture comprises a control room, collective cloud services and a sensor-equipped drone, the so-called Info Bee. The fleet management is provided by the control room, which additionally offers support to the vehicles' automation by a teleoperator. The collective cloud services represent the overall knowledge of all vehicles of the fleet, e.g., on the current environment models or learning from previous manoeuvres to improve the overall behavior of the fleet. In case of limited on-board sensor view in special cases, the info-bee supports the vehicles and/or the control room with additional information from its bird's eye perspective.

The development and testing of such a modular automation stack is simplified by the Open Automated Driving Framework (OADF), which was developed within the UNICAR*agil* project to support software-in-the-loop testing.

Sensor Modules

The UNICAR*agil* vehicles have four identically equipped sensor modules These modules are self-contained from the mechatronic as well as the functional point of view. Each sensor module comprises radar sensors, monocular cameras, a lidar sensor, a stereo camera system, an inertial measurement unit, and an associated computing unit for sensor data processing.

The sensors are placed so that each module covers a horizontal field of view of 270° around the respective vehicle corner with all sensor principles. The processing unit handles all sensor data and builds a module-specific environment model.

The environment model consists of a list of all dynamic objects located in the sensor module's visual range with information on the object type, geometric extent, position, orientation, and the object's current dynamic motion state. Additionally, information about the free space is provided in a complementary environment representation as an occupancy grid map. For this, the vehicle environment is divided into quadratic cells, for which the probability of whether an object occupies the cell is determined.

Due to the overlapping fields of view, the sensor-module-specific environment model calculation can be performed reliably, even if one of the three sensor principles fails or degrades, e.g., due to weather conditions. The cameras are further used for video-based self-localization of the vehicle relative to a high-precision digital map.

The sensor module perception is an integral part of all vehicle demonstrations at the final event. Furthermore, to provide more insights into the environment representation, we will have a live demonstrator on which all data processing steps are individually shown.

Vehicle Environment Model

The vehicle environment model is calculated centrally in the cerebrum of the UNICAR*agil* vehicles to give a full 360° perception coverage of the environment. For this purpose, the four sensor modules' partially redundant sensor environment models are transmitted to the cerebrum via a 10 GBit/s Ethernet connection and fused in the vehicle environment model. Based on the present traffic situation, the driving maneuver is planned downstream in the behavior and trajectory planning and transmitted to the brain stem.

The four sensor modules are mounted at the corners of the vehicle, giving each a field of view of approximately 270°, mostly overlapping with neighboring sensor modules. When all four sensor modules are fused in the vehicle environment model, the result is 360° coverage around the vehicle. The redundant coverage ensures that a more accurate fusion is possible. In addition, this allows the vehicle to continuously provide the environment model, even if a sensor module fails.

The vehicle environment model consists of several subcomponents for object-based and grid-based representations of the environment. The results of the multi-object tracking of the individual sensor modules are merged into a fused object list. The object list contains objects with a unique ID, the dynamic properties of the object (pose, velocity, acceleration), the object extent (length, width, height), the object type (car, pedestrian, ...), and an existence probability.

The individual sensor modules' video-based localization is fused to improve the general vehicle localization. With the localization, elements from the digital map can be considered for downstream behavior and trajectory planning. The digital map includes infrastructure elements such as lanes, stop lines, crosswalks, traffic lights, and traffic signs.

The dynamic occupancy grid map is calculated using each sensor module's static occupancy grid map. For the detection of the dynamic parts or objects respectively, a particle filter is applied that estimates a velocity for each cell along with the occupancy probability using the constant velocity model. The dynamic occupancy grid map thus allows the detection of dynamic and static obstacles and the drivable free space

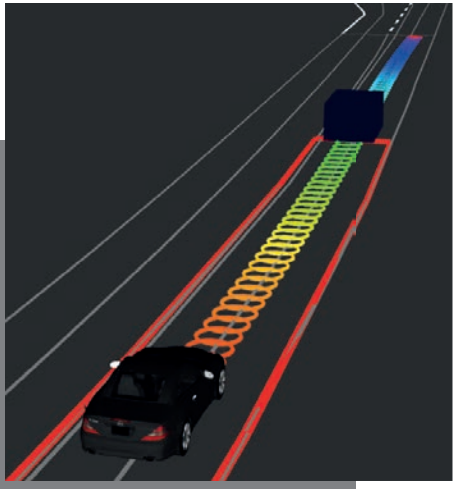
Behavior and Trajectory Planning

The UNICAR*agil* vehicles with their four-wheel steering allow very flexible movements. To operate them we developed a modular vehicle behavior and trajectory planning software that is able to operate the vehicles automatically.

It allows driving in urban environments and it makes use of the flexible steering abilities of the vehicles. The behavior software can make the vehicles turn on the spot, park with a sideways movement, move through tight curves, deal with intersections and perform lane changes, among others.

The decision which behavior is adequate for a given situation is made in a modular arbitration framework which allows to combine self-contained behavioral blocks into an arbitration graph in a generic and resilient way.

At final event we will show live demos of urban automated vehicle movements, plus 3 posters on four-wheel steering control, Safe Halt, and behavior arbitration.



Localization and Motion Control

Localization and motion control are implemented in UNICAR*agil* by two services: Vehicle Dynamic State Estimation (VDSE) and Trajectory Tracking Control (TTC). While VDSE uses a dedicated ECU the TTC service is running on the brain stem hardware. Both services jointly connect the planning services on the cerebrum layer with the actuating elements on the spinal cord layer, to transfer the planned trajectory into vehicle motion. In this process mechatronic peculiarities of the UNICAR*agil* vehicles (wheel-individual actuating, very large steering angles up to 90°) are utilized, which makes the side slip angle an independent degree of freedom of vehicle motion.

Localization is executed in UNICAR*agil* vehicles by the VDSE service. It determines the vehicle's current motion state in terms of position, velocity, acceleration, attitude, turn rate (all in 3D) and side slip angle. Beside these estimates quality parameters describing their accuracy and integrity are provided. The current motion state is communicated to other services in the car by use of ASOA communication protocol, middleware, and service architecture. One important recipient of the VDSE output is the TTC service.

The VDSE is carried out on its own ECU (with four µ-controller-boards, IMUs, GNSS OEM-board). It executes sensor data fusion using two diverse MEMS-IMUs (one mid performance, one commercial grade), the integrated GNSS receiver (multi-GNSS/ multi-frequency OEM board with RTK function for cm-accurate positioning, and dual antenna for GNSS heading), and optionally odometry by use of wheel angles and turn rates provided by the dynamic modules.

The VDSE data processing architecture consists of two fusion layers. On the first fusion layer dissimilar fusion filters utilize different subsets of available sensors, the filters being developed by different developers. The use of redundant sensors and development by different teams aims to minimize the risks due to sensor failures or design flaws in single fusion filters. On the second fusion layer the outputs from the individual first fusion layer filters are merged to obtain the final VDSE result. In this step plausibility checks, approval voting, and data fusion methods are used to calculate a consolidated motion state in a robust way with high accuracy and integrity.

The TTC service primarily has to execute planned target trajectories originating from varying sources (cerebrum, Safe Halt, control center) by generating setpoint commands for the dynamics modules. An interface for a direct control by an operator within the control center is also provided. While driving, the stability of the vehicle must be ensured.

The TTC is encapsulated from the asynchronous planning stage to ensure software reusability with different planning algorithms and to enable the use of different steering kinematics within planned trajectories. A two-degree-of-freedom structure with a predictive feedforward control and a state feedback for each of the vehicles three independent degrees-of-freedom is used to implement the TTC, allowing agile maneuvers such as sideways parking and varying vehicle sideslip angles. The current vehicle dynamics state for the state feedback is provided by the VDSE.

Furthermore, an estimation of the vehicle's kinematic and dynamic limits is provided as feedback to the trajectory planning services to ensure feasible target trajectories. The TTC is implemented within ASOA middleware as part of the 'brainstem' running on embedded real-time hardware.

Teleoperation - A Key Technology for safe and efficient Operation of highly-automated Vehicles

Despite the rapid advancements in different aspects of technology, automated vehicles (AV) can still encounter a diverse and dynamic range of real-world driving scenarios that challenge their autonomous decision-making capabilities or even go beyond their operational design domain (ODD). With increasing popularity in recent years, teleoperation technology has been identified as a fallback solution for automated driving (AD). Requesting remote human support whenever an AD function reaches its limits, the goal of teleoperation is to provide a safe and efficient interaction to resolve these situations. Finally, once the AV has been brought back into its nominal ODD, it can again continue its journey fully automated as before. In UNICAR*agil*, we developed and integrated our teleoperation technology within the UNICAR*agil* ecosystem.

Control Center

The control center for the teleoperation of autonomous vehicles serves as the center for managing, monitoring, and remotely operating a fleet of self-driving vehicles.

Equipped with state-of-the-art communication technologies and robust infrastructure, the control center enables seamless interactions between human operators and autonomous vehicles. By providing real-time data visualization, the control center empowers operators to make informed decisions, intervene when necessary, and maintain overall safety and efficiency. The operators can track the state of each vehicle in the fleet, establish voice communication with the passengers, retrieve the video streams to assess the situation, trigger the safe continuation of service, or initiate teleoperation of the vehicle.

Vehicle Teleoperation

In case the control center is requested by the vehicle for assistance, the remote operator will be assigned the task of vehicle teleoperation. Depending the on the situation's complexity, the operator can choose between two interaction concepts:

Direct Control - The operator is provided with the vehicle data and video streams of the environment over the mobile network. Once ready, the operator provides control signals, such as steering wheel angle, throttle, and brake pedal position, and remotely operates the vehicle.

Trajectory Guidance - the operator specifies discrete waypoints within a 3D map interface through mouse clicks. These waypoints are then fitted into a path that, together with a corresponding velocity profile, constructs a reference trajectory sent to the vehicle. This way of interaction relieves the operator, especially in situations where network latency might pose challenges.

Visit our control center and experience teleoperation technology live at the final event, where we will remotely operate the *auto*TAXI as well as communicate and monitor all other UNICAR*agil* vehicles in real-time.

Cloud Services for Automated Driving

Future vehicles will not only be automated but also connected to other traffic participants and to supporting cloud infrastructure. Together, these elements form a Cooperative Intelligent Transport System (C-ITS), in which traffic participants can make use of additional cloud services. In UNICAR*agil*, we developed and implemented concepts for these new possibilities. At the final event, we will demonstrate the UNICAR*agil* Cloud in an oral presentation, on multiple posters, and using other digital media.

The elements in the UNICAR*agil* Cloud concept allow:

- Collective environment perception in edge-clouds;
- Collective learning from large amounts of continually gathered data;
- Collective cloud-based behavior planning.

These functionalities are implemented in the software components Collective Environment Model, the Collective Memory and the Collective Behavior. They are designed to run on cloud or edge-cloud servers and can support the automated vehicles developed in UNICAR*agil.*

The Collective Environment Model aims at combining the environment models and - when possible - the sensor data of multiple vehicles that are located in the vicinity of each other. It can also incorporate data from smart infrastructure and is designed to receive additional data from the Info Bee developed in UNICAR*agil*. It computes collective environment models and provides these as a service to traffic participants such that the accuracy and range of the vehicle-based environment model can be improved, and occlusions can be dealt with.

The Collective Memory acts as the short- and long-term memory of the cloud-based system in UNICAR*agil* and is capable to improve functions based on the gathered data. Three different software components were developed to achieve these capabilities. The Short-Term Memory (STM) is responsible for data analysis and filtering. It buffers and anaylzes all available data, including data transmitted by connected vehicles as well as data processed by other components of the cloud architecture. Once the analysis identifies data to be relevant, it is transferred from the Short-Term a Long-Term Memory. The Long-Term Memory (LTM) provides functionality for convenient access to and modification of the LTM database. The database is designed to be a long-term storage for data that was identified to be relevant in the STM. As such, the LTM's purpose is to provide data for the training of data-driven algorithms and other use cases relying on data of all kinds. The Machine Learning module aims to intelligently use the data available in the Long-Term Memory to train, improve, and validate advanced machine learning models such as neural networks.

The Collective Behavior module runs the behavior models trained and provided by the Collective Memory, and aims to compute desired future behavior for traffic participants. These behavior recommendations are then provided as a service to traffic participants.

In conclusion, UNICAR*agil's* Cloud concept offers significant potential for the development of Cooperative Intelligent Transport Systems. Cloud services will play an increasingly important role in the development of automated driving technology.

Info Bee

The Info Bee is a camera-equipped unmanned aerial vehicle (UAV) designed to gather traffic information from an aerial perspective. The system can contain various types of information, ranging from long-term conditions like lane closures due to construction sites to short-term details like the availability of parking spaces. Another use case could be the detection of fallen trees blocking rural roads in the aftermath of a storm.

Being airborne, the Info Bee can quickly reach the respective target area by flying directly to the destination in a straight line. In addition, it is not bound by speed limits and can fly over traffic lights as well as congested streets at speeds of up to 100 km/h. In Aachen, for example, any point in the city can be reached within two minutes starting from the city center.

The Info Bee is a tilt-wing aircraft, i.e. it can tilt both its wing and tailplane around the transverse axis. Therefore, the Info Bee can take off and land in hover configuration while also achieving high speeds and long flight times in cruise configuration. The nose of the Info Bee can rotate around the longitudinal axis, such that the contained camera can face straight down even during turns.

As the camera's coverage area is wider than the width of most roads, the Info Bee does not need to follow the center of the road exactly. This advantage is utilized in the calculation of the UAV's flight path: As Figure 2 shows, the Info Bee's path can have greater turn radii than the road, such that even tight intersections can be flown over at high speed.

The data recorded by the Info Bee's camera is sent to the cloud, where it can be accessed by other users. For instance, when an obstacle on the road occludes an important part of a vehicle's field of view, a teleoperator can use the live aerial images to resolve the conflict. Also, as each image is tagged with the precise location and orientation of the camera, objects detected in the images can be used to enrich the Collective Environment Model, thereby augmenting the vehicles' knowledge of their surrounding.

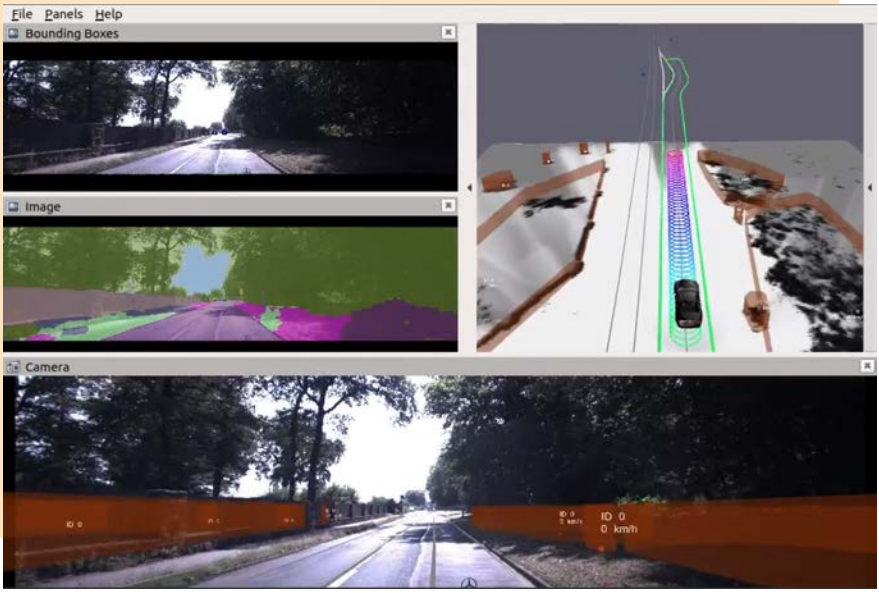

unicar agil

Open Automated Driving Framework

Publicly available software has fostered the development in many areas. For automated driving, we developed the Open Automated Driving Framework, a publicly available software suite for autonomous driving for scientific purposes. It comes with code for behavior generation and control and has interfaces to the vehicle simulators Carla, CoInCarSim, and IPG CarMaker. Furthermore, it provides a benchmark suite for camera based image environment perception. It allows you to add your own code and integrate it into your experimental vehicle.

The Open Automated Driving Framework serves as basis for the behavior software of the UNICARagil vehicles and it has also been used in a traditional vehicle with front-wheel steering only which shows the flexibility of the software suite.

The Open Automated Driving Framework software is distributed via GitHub at https://github.com/KIT-MRT/OADF. The perception benchmarks are available at https://www.mrt.kit.edu/english/unicar.agil.php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IPG

Introducing the Domain "Safety & Security"

The operation of driverless vehicles in the public domain - just like the use of conventional vehicles - will never be completely free of risks. Accordingly, throughout the entire duration of UNICAR*agil*, all developers were faced with the task of avoiding risks in principle, but also of dealing with the existing residual risks of automated vehicles and their systems. Describing these residual risks and communicating them publicly will contribute significantly to broad social acceptance of the new technologies. Consequently, the domain "Safety" has been a central component of the entire UNICAR*agil* project from the very beginning: safety aspects have been investigated in numerous work packages at different locations and from different architectural perspectives. The safety activities were coordinated by the TU Braunschweig and incorporated into a system-wide safety concept.

In UNICAR*agil*, (almost) all modules are affected by safety concerns, especially since automation introduces a very high degree of complexity. The safety of UNICAR*agil* vehicles is an emergent property that had to be considered across locations and components of individual partners.

Within the domain, key safety functionalities such as self-perception and the safe halt have been developed, as well as methods for managing complexity, e.g., for investigating timing behavior. Systematic safety considerations inspired by the concept phase as defined in ISO 26262, as well as contributions to verification and validation, provided the background for these activities. The topic of security was also incorporated into the development process. Finally, a comprehensive safety documentation was prepared by the domain "Safety".

A System-wide Safety Concept for UNICAR*agil*

As the system maturity of the vehicle prototypes progressed, the focus of the safety considerations increasingly shifted to the design and documentation of a safety concept for testing and demonstration. In a combination of top-down and bottom-up approaches, requirements from system-wide safety considerations were aligned with component-level safety mechanisms. Failure modes that could not be sufficiently mitigated in the project context, in particular from emergent system behavior or due to the use of prototypical components, had to be countered with additional system-wide fallback measures for the testing and public demonstration of the vehicles. The most important example of this is the remote emergency stop system "safety watch". Based on the system-wide safety concept, five different release levels were implemented for each experimental vehicle, paving the way for the final demonstration.

Safe Halt: A New Concept for Fail-Safe Automated Driving Systems

Automated Driving Systems (ADS) are becoming increasingly popular and common in today's world. However, the safe operation of these systems remains a major concern, as they can fail for a variety of reasons. The concept of Safe Halt is designed to ensure that a vehicle can be brought to a safe state in the event of an ADS failure. This is particularly important because in the absence of a human driver, the ADS must be fail-safe, i.e. it must be able to maintain the vehicle in a safe state and transition the vehicle to a Minimal Risk Condition (MRC). In the UNICAR*agil* research project, the concept was evaluated and found to be highly effective for the subset of fault combinations of an ADS for which Safe Halt provides a fail-safe property.

The Safe Halt concept provides a Dynamic Driving Task (DDT) fallback solution for an ADS. The idea is that if an ADS fault occurs, Safe Halt will transition the vehicle to a Minimal Risk Condition (MRC) by selecting a situation-dependent MRC characterized by the global MRC with respect to the length of the maneuver and the residual risk of the MRC itself. For this purpose, pre-planned implicit emergency trajectories generated by the UNICAR*agil* planning service are used and an independent environment perception system ensures the execution of the MRC at an average low speed.

The fault-tolerance regime chosen for this project is based on the assumption that most of the fault combinations of an ADS occur in the sensing, processing, and world modeling as well as in the planning of the UNICAR*agil* vehicles, and that all other functions can be made fault-tolerant with reasonable effort. Therefore, Safe Halt is optimally positioned in the ADS effect chain.

If Safe Halt fails, an MRM must be executed in Automated Driving vehicle mode. Therefore, it is not necessary to configure the environment perception of Safe Halt to be fail-operational.

Safe Halt is a candidate for inclusion as a standard in future functional architectures of ADS, as it provides an architectural and functional solution to the challenge of the fail-safe nature of an AV. In addition, the flexibility provided by the planning of the implicit emergency trajectory makes it possible to introduce specific requirements for MRM, such as those to be maintained in SAE J3164.

Self-Perception and Capability Monitoring

The UNICAR*agil* vehicles are designed to be completely driverless, requiring a self-perception system to ensure their safety: It is required to monitor the vehicle's behavior and create an overall picture of its health for decision-making entities to access. To model safe vehicle behavior, the vehicles' capabilities are identified and structured in a directed capability graph that models their dependencies on each other.

A model is derived for runtime implementation to determine the current quality of the system's capabilities by considering their relations to functional and technical components. Behavioral adaptions are required if there are changes in quality, e.g. due to degradations, such as modifying the current maneuver or taking an alternative action.

For example, if a sensor module is fully covered and cannot detect objects with sufficient quality, the vehicle may be forced to come to a Safe Halt as this capability is critical for safe operation. In the UNICAR*agil* project, a software framework is developed to implement a capability-oriented system-level model, access it at runtime, apply quality information to it and infer the system's overall performance with respect to its admissible actions in the current scenario.

Modular Safety Approaches in the Context of Environment and System Complexity

The safety validation of automated vehicles is highly complex. On the one hand, the vehicles themselves are complex systems and on the other hand, they are confronted with a complex environment. With the help of modularization approaches, we break down the overall complexity into less complex subsystems and sub-environments. This simplifies the safety validation itself and creates a modularity with various advantages, as shown below.

The complex system of the automated vehicle is broken down into modules that are largely independent of each other. The goal in UNICAR*agil* is a safety approval of each module individually, thus, dispending on system tests, requires module development and testing that addresses all remaining dependabilities in addition to state-of-the-art module or component testing. For this, we developed the new detailed semantic interface description S2I2 that gathers information required for modular testing. It includes attributes that describe the syntax and semantics (including, e.g., a behavior description) that are expected at an interface but also influences that may change semantics or impacts that these semantics may have, e.g., on the overall system. Consequently, the next challenge is to fill this description. Therefore, we also developed methods to describe known and systematically search for unknown dependencies, e.g., using modelling languages. This is also supported by a risk analysis method that uses the fault tree analysis (FTA) and system theoretic process analysis (STPA) to identify risks on module level, particularly those based on dependencies between modules.

With the ongoing integration of the simulation environment and the real UNICAR*agil* vehicles, we were able to apply our methods to a real system while accompanying the whole development process. During the development and integration testing, we revealed shortcomings in our methods and applied measures to improve, e.g., by adding attributes to our interface description. The developed methods and description language provide a baseline for a

modular safety approval of automated vehicles. In our further research, we want to improve and supplement these methods, in particular, to fill the relevant information for module interfaces. With a functioning system, the previously used knowledge-based approaches can be supplemented by a data-based approach, providing additional proof of safety.

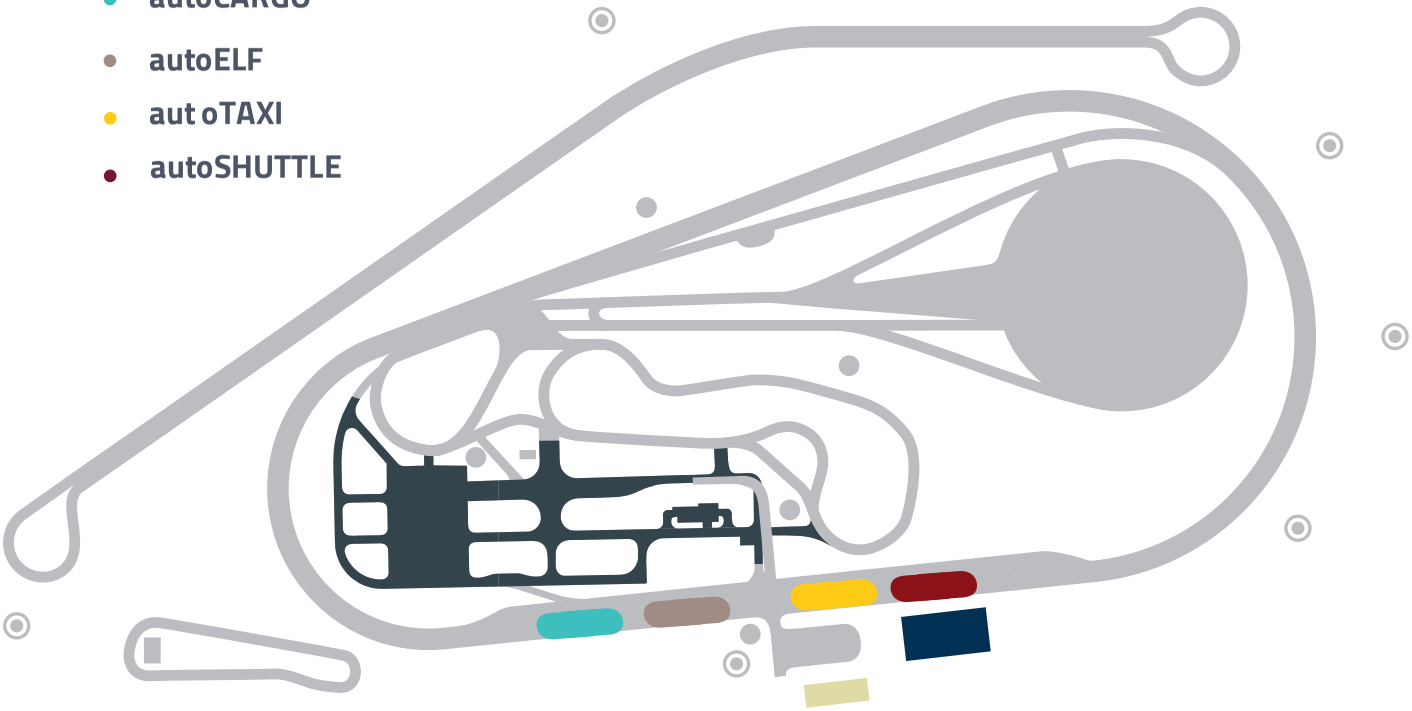
In addition to the vehicles as complex systems themselves, the vehicle environment is modularized. For this purpose, behavioral demands are first identified and classified based on the static traffic environment, the scenery. Behavioral demands result directly from a combination of the scenery and the applicable traffic rules, so that an automated vehicle is given clear behavioral limits in road traffic. Based on an abstract classification of these behavioral limits, the initially complex vehicle environment can now be described very simply at the behavioral level - we call this description Behavior-Semantic Scenery Description (BSSD). With the help of the BSSD, a direct link is created between the complex vehicle environment and the target behaviors of automated vehicles. This link is created via so-called behavior spaces, which explicitly bind the behavioral limits of the environment to the scenery. In this way, the complex vehicle environment is broken down into many, but less complex, behavior spaces. For each behavior space, driving requirements are derived that demand specific driving capabilities of the vehicles.

The operational domain of the vehicles is thus described and specified with the aid of many individual spaces. The safety validation of a vehicle is thus broken down into smaller and more manageable operational areas. In addition, it is possible to validate similar areas, i.e. the same behavior spaces with the same driving requirements, only once. This enables the transferability of individual safety validations, so that the validation effort can be reduced.

In addition to advantages for the safety validation itself, the presented method enables capability-based route planning such that only route sections for which a safety validation is available are driven during vehicle operation.


autoCARGO

- Live Demonstration
- autoCARGO
- autoELF
- aut oTAXI
- autoSHUTTLE



- Prestations & Posters
- Additonal Demonstartions