

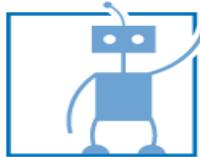
The background image shows an aerial view of a modern university campus. It features several large, light-colored buildings with flat roofs and white trim. A prominent building in the center has a large glass-enclosed entrance and a circular driveway. The campus is surrounded by green fields and includes several parking lots filled with cars.

Autonomous Driving

Summer 2019

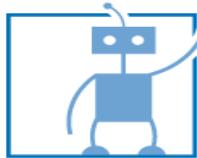
Gereon Hinz

Informatik VI – Chair of Robotics, Artificial
Intelligence and Real-time Systems



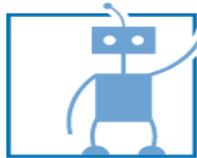
Today's Content

- Organization
- Introduction
 - TUM Chair of Robotics, Artificial Intelligence and Real-time Systems
- Autonomous Driving Impressions
- A simple AD demonstrator at CES with EB Robinos model cars
- Vehicle Intelligence History



Lecture Organization

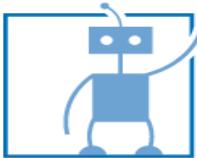
- Lecture:
 - Tuesday 16:00 ~ 18:00 in MW 1801, Ernst-Schmidt-Hörsaal (5508.01.801)
- Examination:
 - Exam (~60 minutes). Date to be announced.
- Changes will be announced via email
- Lecture slides to be uploaded on moodle
 - change every year, due to updated topics and speakers
- Questions and comments => gereon.hinz@tum.de
- Language: English



Planned schedule (up for change)

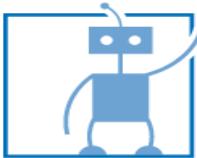
Topic	Purpose
Introduction	Participate in ongoing AD discussions
Path Planning	Plan paths and execute them
Sensor Fusion	Fuse sensors to go from data to information
Deep Learning Applications in AD	Know current application areas, strengths, weaknesses
Semantic Representations & Reasoning	Represent and infer information about your situation
Lane Modelling and Detection	Convert data into environmental model
V2X - 5G Communication	AD as part of a connected system
Virtual Testing and Development	Effective use of simulation environments
System Architecture	Build an AD architecture
Safety & Security	Current state of safety & security for AD
Industrialization of Autonomous Driving	How to scale AD development
Exam Preparation	Good luck!

Exact schedule will be announced shortly



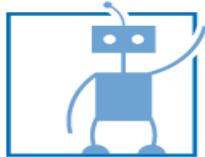
About this lecture...

- What is the goal of the Autonomous Driving lecture?
 - **What is not the goal?**
 - Present all autonomous driving related methods and equations in excruciating depth.
→ Could fill its own full university curriculum!
 - Focus on only one very small part of AD and explore that one in even more excruciating depth.
→ Good, but then the students still haven't got a good general understanding of AD.
 - Keep students as far away from industry as possible to maximize scientific spirit!
→ Good, but then the students don't know what to expect after their studies or what they learn for.
 - Interaction should be minimized, to maximize efficiency.
→ We're neither in a library, nor in a video. Interaction is desireable.

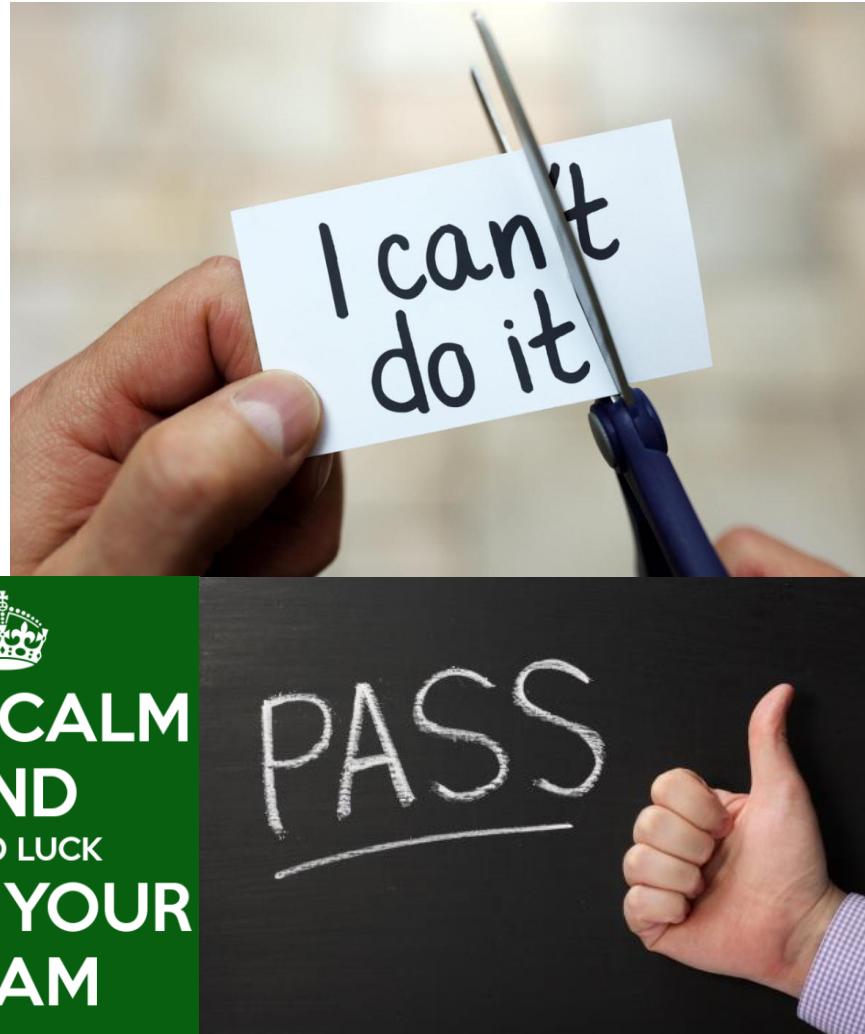
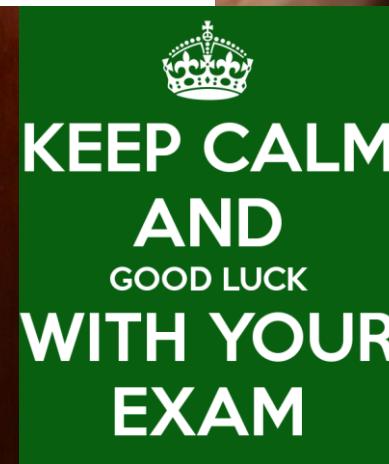
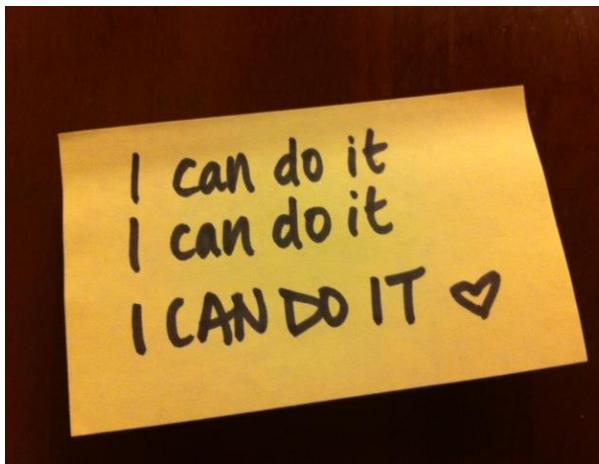


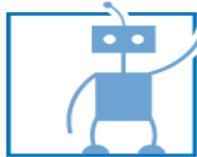
About this lecture...

- What is the goal of the Autonomous Driving lecture?
 - **So what is the desired outcome?**
 - A student should know the fundamental building blocks of AD by name and by principle. Be able to explain them and discuss them.
 - A student should be able to do simple calculations for the presented subdomains and use presented algorithms.
 - Lecturer's and student's opinion of what „simple“ means may differ.
 - For some reason the exam is not known to be easy, although the lecturer is trying his best.
 - A bit of transfer learning is also expected.
 - The lectures should be interesting and motivational.
 - If you want to explore concepts in more depth, the best practice is to go ahead and do it!
 - Ask for student assistant, thesis or other job opportunities. Opportunities are regularly available.



Desired final outcome...





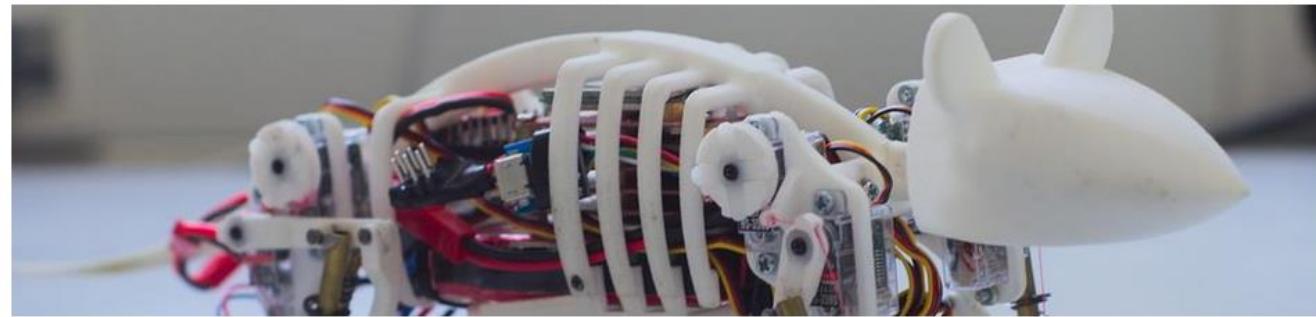
LS VI – Chair of Robotics, Artificial Intelligence and Real-time Systems

Informatics 6 - Chair of Robotics, Artificial Intelligence and Real-time Systems
TUM Department of Informatics
Technical University of Munich



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- [Publications](#)
- [Teaching](#)
- [Virtual Tour and Address](#)
- [Open Positions](#)
- [Thesis Proposals](#)
- [News](#)

Home



About Us

Our primary mission is research and education with a focus on machine perception, cognition, action and control.



The chair is organized into four research areas:

- **Human Robot Interaction and Service Robotics** including work on the integration of speech, language, vision and action; programming service robots; development of new application scenarios for sensor-

Our Course of Study

[Robotics, Cognition, Intelligence](#)

An interdisciplinary master course

Virtual Tour

Click [here](#) to go on a virtual tour of our chair in our [Indoor Viewer](#).

Some of our Affiliations and Cooperations

fortiss Institute

Top-level research with and for industry

The Human Brain Project HBP

The European Flagship project on Brain Research

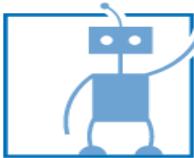
Famous Completed Projects

- [ECCEROBOT](#) (EU-FP7, 2008-2011)
- [ECHORD](#) (EU-FP7, 2008-2013)
- [JAHIR](#) (CoTeSys, 2006-2009)
- [JAST](#) (EU-FP6, 2004-2009)
- [Myorobotics](#) (EU-FP7, 2012-2015)

Winter term 2018/19

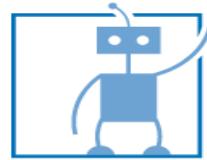
Type	Title	Duration
SE	Doctoral Seminar - Robotics (IN2137)	2
VO	Embedded Networked Systems (MSE) (IN8014)	3
PR	Labcourse - Building a modular robot (IN0012, IN2106, IN4231)	6



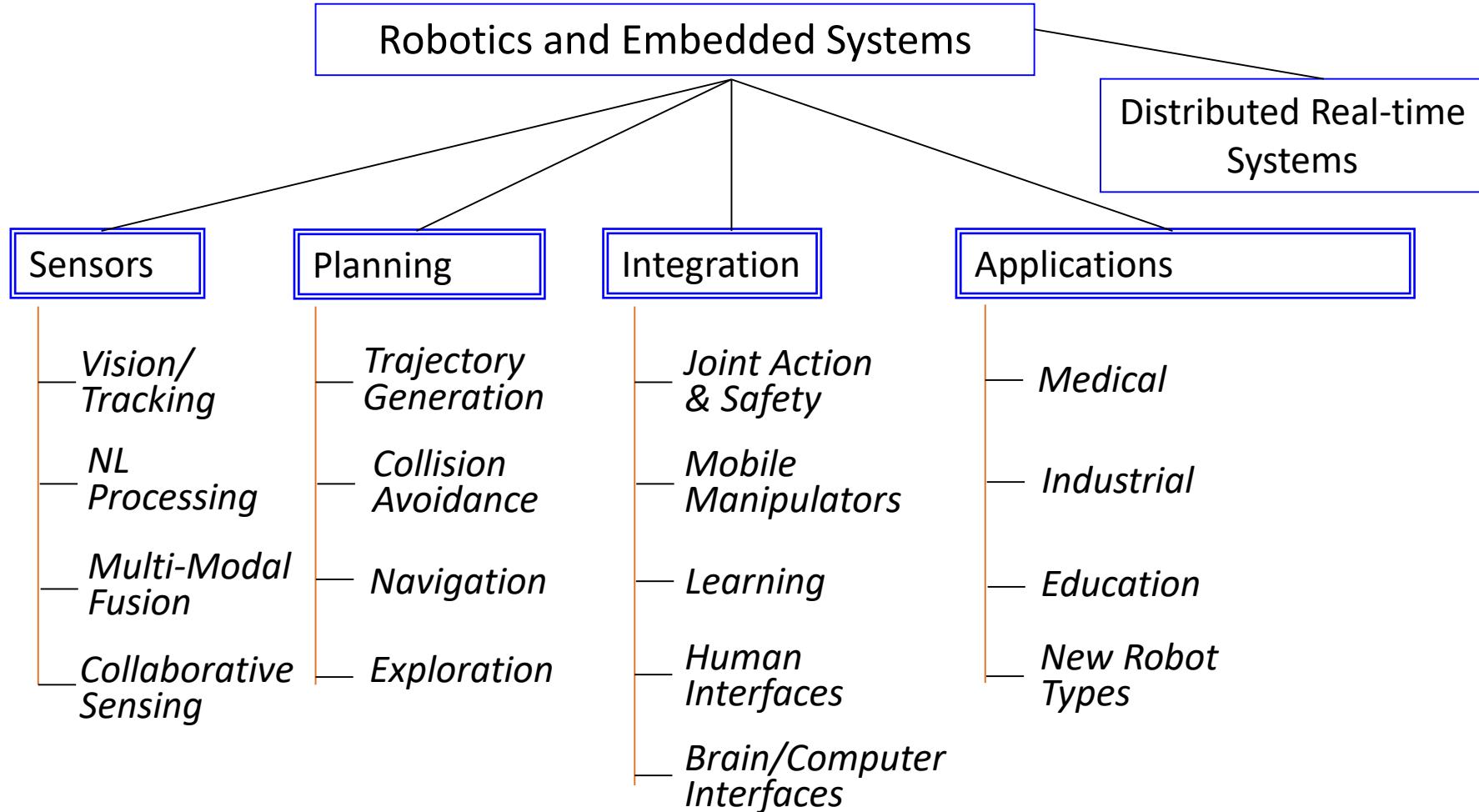


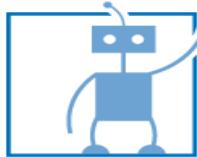
LS VI – Robotics and Embedded Systems

- Faculty in **Informatik LS VI – Robotics and Embedded Systems:**
 - **A. Knoll** Professor
 - **D. Burschka** Associate Professor *Service Robotics*
 - **M. Althoff** Associate Professor *Cyber-Physical Systems*
 - **A. Lenz** Academic Director
- **Main research directions**
 - Sensor based service and robotics
 - Cognitive robotics & man-machine-dialogue-systems
 - Embedded real time systems (automotive)
 - Artificial Intelligence



Research Structure at LS VI





Landmark Projects: ECHORD++



European Clearing House for Open Robotics Development Plus Plus

Experiments

Facilities (RIFs)

Public Procurement

News

Services

About Us

ECHORD++ aims at increasing ECHORD's productive, bilateral robotic research discourse between academia and industry via unique, tailor-made tools.

Echord++

EU-funded project aiming to strengthen the cooperation between scientific research and industry in robotics.

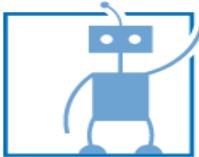
Finding common ground between manufacturers and the research community, when it comes to defining the future direction of robotics research.

A new level of cooperation, streamlining successful know-how transfers.

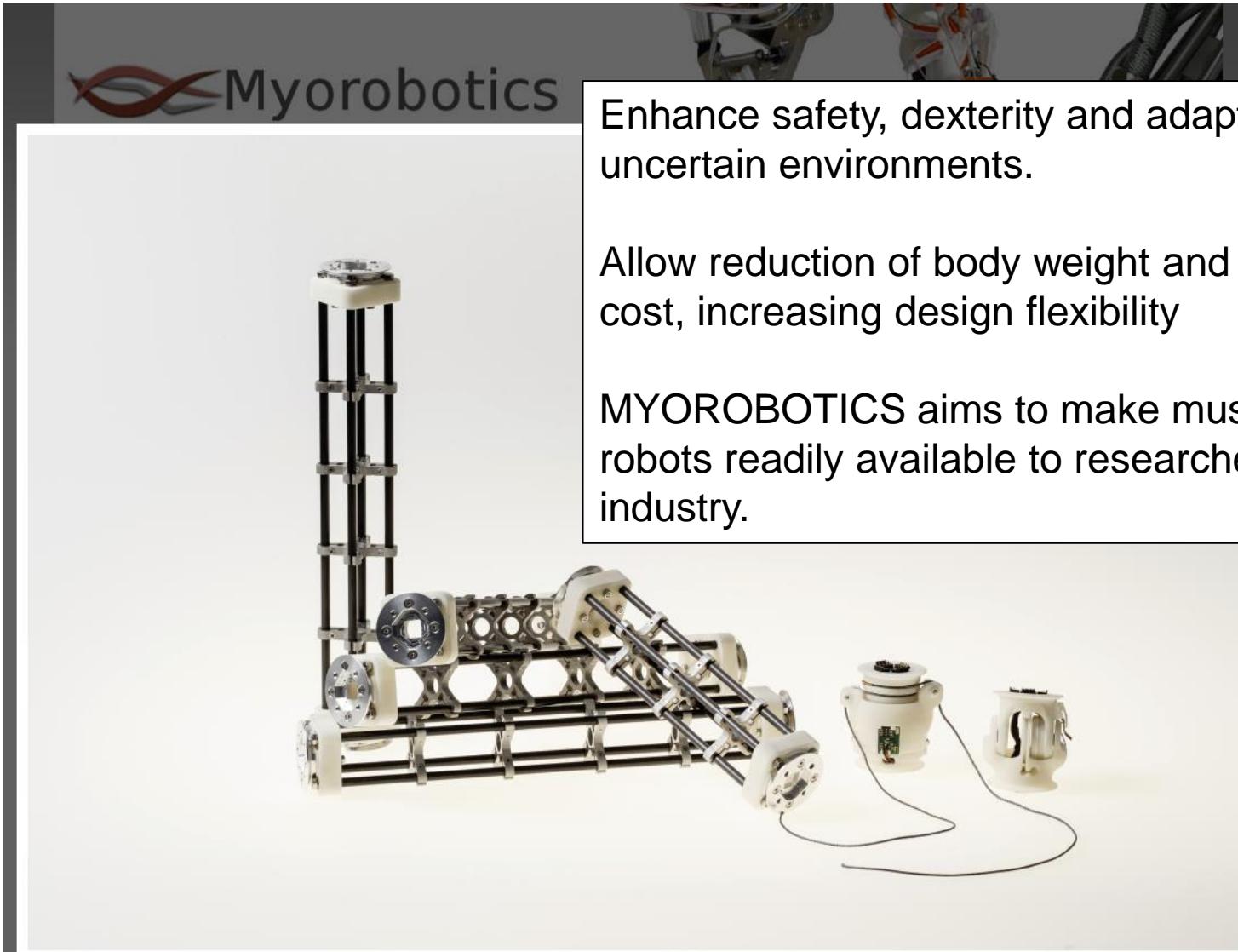
H2P Healthcare

Experiments





Landmark Projects: Myorobotics Muscoskeletal Robots

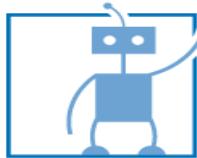


Myorobotics

Enhance safety, dexterity and adaptivity in uncertain environments.

Allow reduction of body weight and developmental cost, increasing design flexibility

MYOROBOTICS aims to make musculoskeletal robots readily available to researchers, educators industry.



Landmark Projects: Neurorobotics in the Human Brain Project

The screenshot shows the Human Brain Project website. At the top left is the project logo, a colorful hexagon with 'HBP' in the center. To its right is the text 'Human Brain Project'. Further right is the European Commission logo, and at the top right is a 'HBP Sign In' button with a dropdown arrow. Below the header is a navigation bar with links: PROJECT, PROGRAMME, HBP COMMUNITY, PARTICIPATE, NEWS, CONTACTS, and COLLABORATION. The main title 'THE HUMAN BRAIN PROJECT' is centered above a graphic. This graphic features four large circles with glowing outlines: a blue circle labeled 'Project', a green circle labeled 'Programme', a pink circle labeled 'Community', and an orange circle labeled 'Participate'. Lines connect the 'Community' and 'Participate' circles to the central 'Programme' circle, indicating their relationship.

European flagship project to address one of the greatest challenges of modern science:

understanding the human brain.

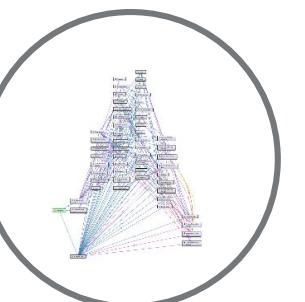
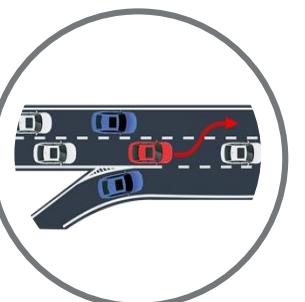
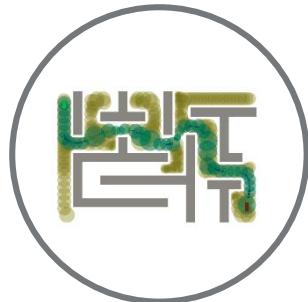
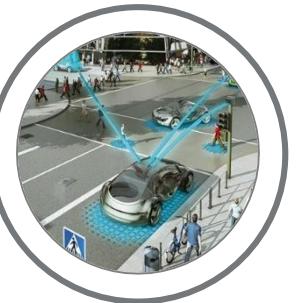
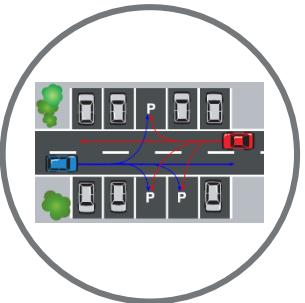
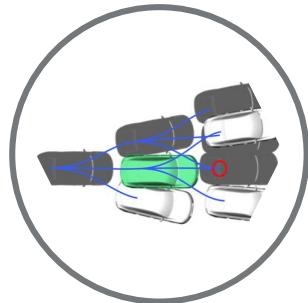
Total costs estimated: 1.19 billion euros. TUM coordinates sub-project "Neurorobotics."



Autonomous Driving Projects & Experiences - Excerpt

Projects & Experiences

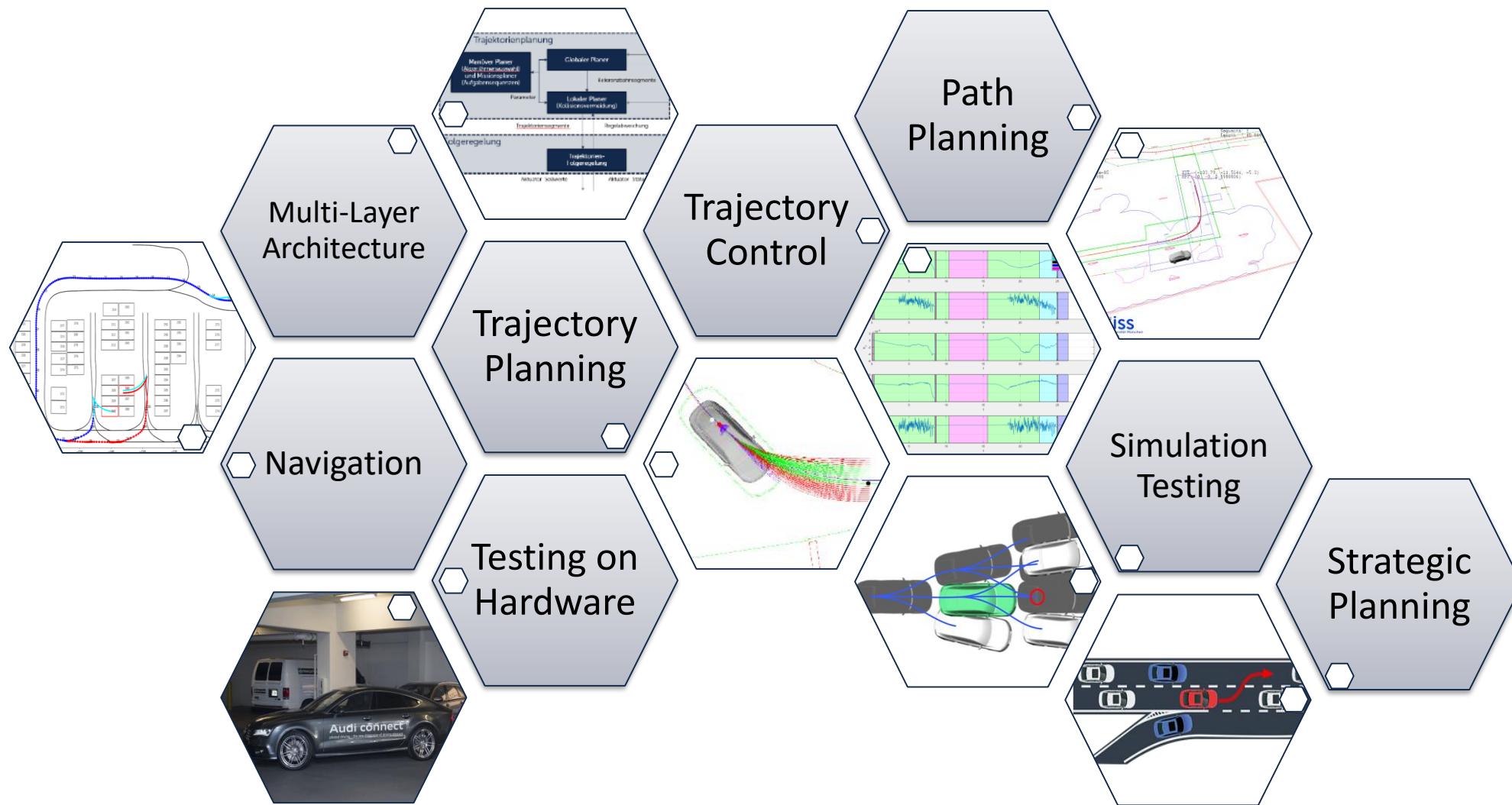
Motion Planning, Data Fusion, Overall Systems



Path Planning / Perception / Data Fusion / Demosntrators /Large Scale Projects ...

Software Development for Automated Driving

Focus: Motion Planning

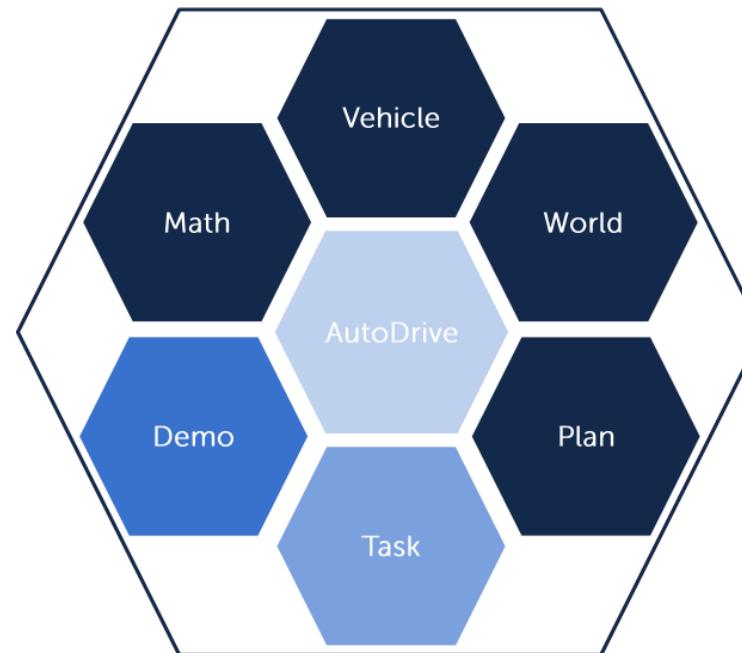


AutoDrive Library

Motion Planning for Nonholonomic Vehicles

Overview – Planning Module

- Generic Planner
- PRM – Probabilistic Road Map
- Space Exploration
 - Grid Explorer
 - Bubble Explorer
 - Duo Explorer
 - Orientation Aware Explorer
 - Space-Time Explorer
- Heuristic Search
 - Euclidean Heuristics, Grid Heuristics, Vehicle Kinematic Metrics, Bubble Heuristics...
 - Generic, A*, Hybrid A*, SEHS, Bubble Planner, Directed Bubble Planner, Time Bubble Planner...
- Trajectory Generator
 - Speed Profiles, Acceleration Profiles..



Fakultät für Informatik
Lehrstuhl für Echtzeitsysteme und Robotik

Motion Planning for Nonholonomic Vehicles with
Space Exploration Guided Heuristic Search

Dipl.-Ing. Univ. Chao Chen

Vollständiger Abdruck der von der Fakultät für Informatik der Technische Universität München
zur Erlangung des akademischen Grades eines

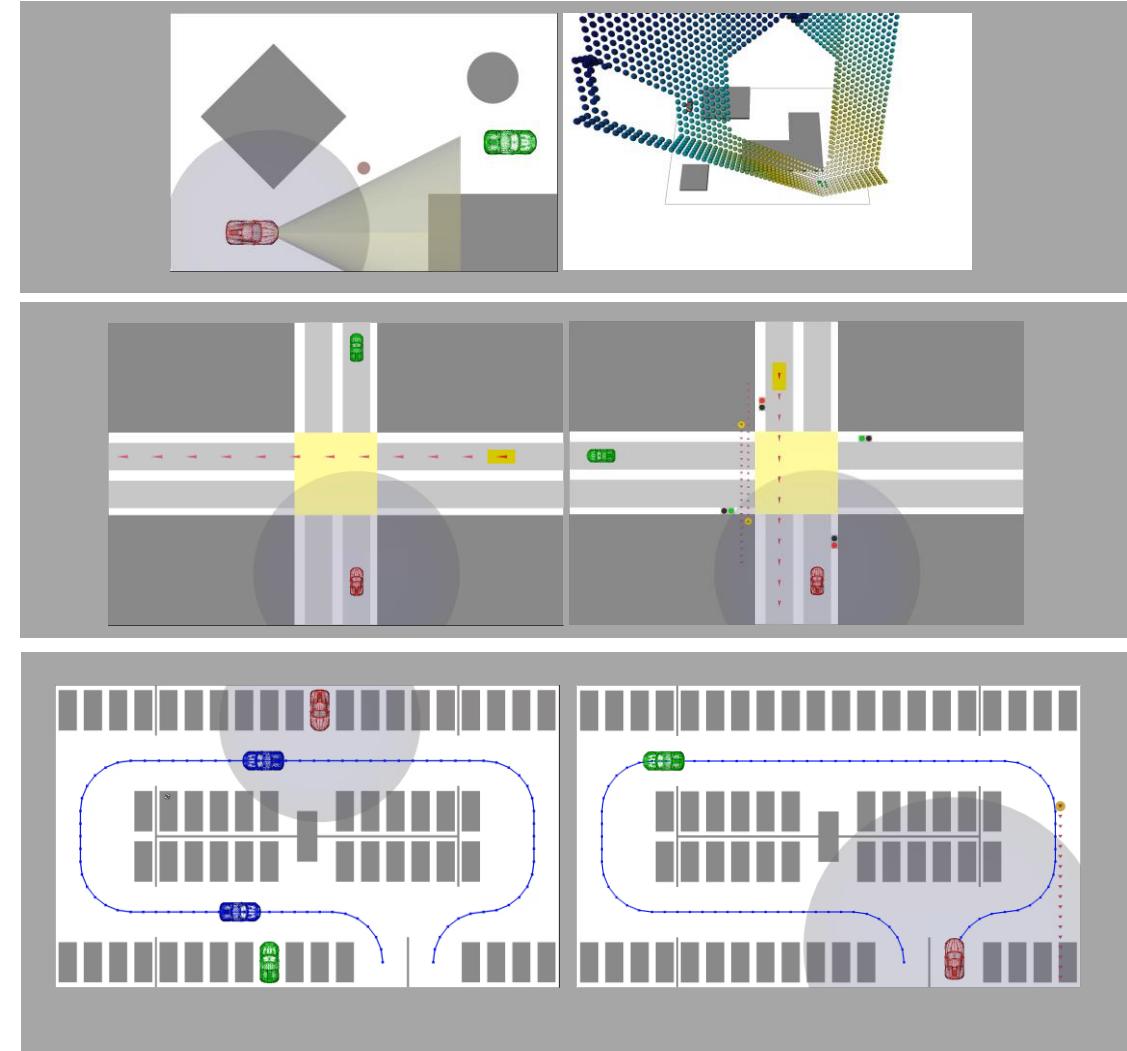
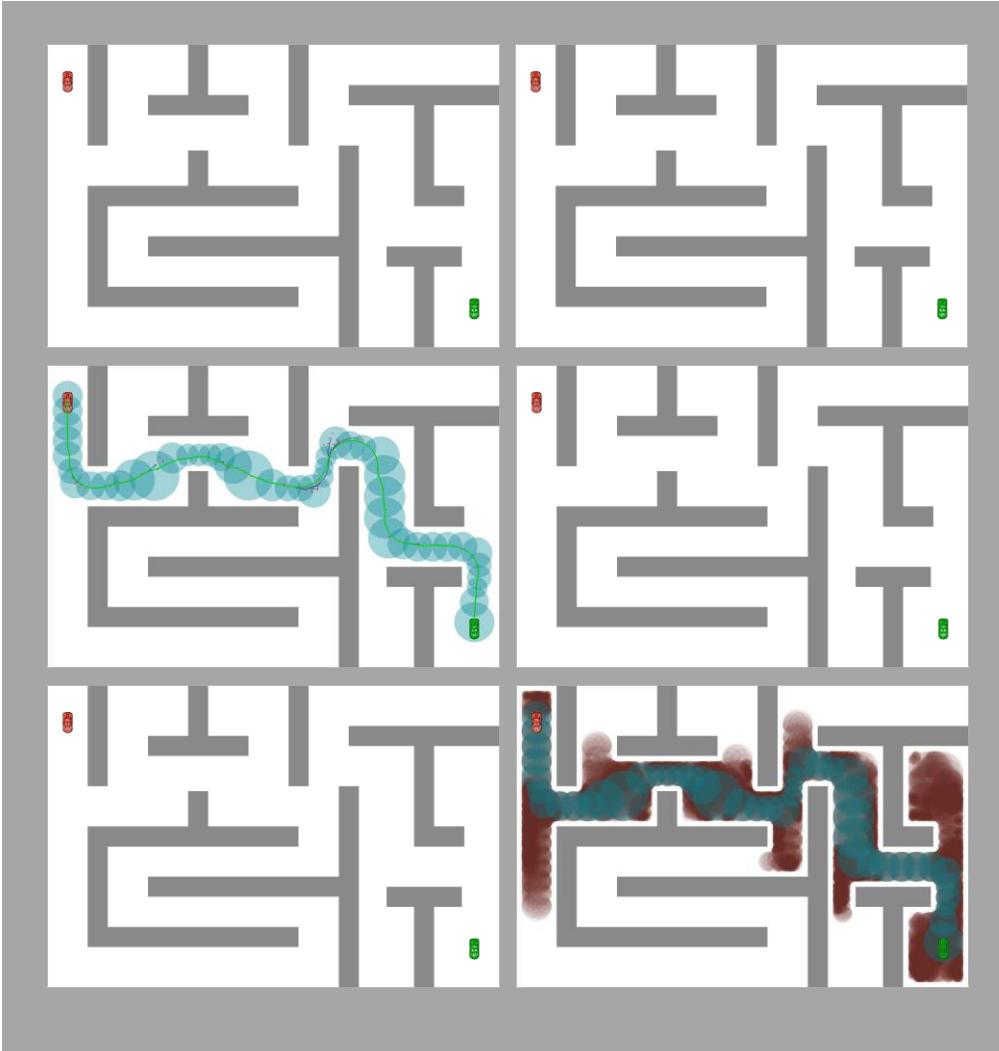
Doktors der Naturwissenschaften (Dr. rer. nat.)
genehmigten Dissertation.

Vorsitzender: Prof. Dr. Thomas Huckle
Prüfer der Dissertation: 1. Prof. Dr.-Ing. habil. Alois Christian Knoll
2. Prof. Dr.-Ing. Rüdiger Dillmann

Die Dissertation wurde am 03.03.2016 bei der Technische Universität München eingereicht und
durch die Fakultät für Informatik am 01.06.2016 angenommen.

Search Methods (Excerpt)

Video Demonstrations



Excerpt KF AS Publications 2017 only

Motion Planning, Data Fusion, Overall Systems

2017:

Autoren

Tobias Kessler, Alois Knoll

Tobias Kessler, Pascal Minnerup, David Lenz und Alois Knoll

David Lenz, Frederik Diehl, Michael Truong Le, Alois Knoll

Constantin Hubmann, Marvin Becker, Daniel Althoff, David Lenz, Christoph Stiller

Chao Chen, Markus Rickert, Alois Knoll

Gereon Hinz, Martin Büchel, Josef Eichinger, Alois Knoll

Clara Marina Martinez, Feihu Zhang, Daniel Clarke, Gereon Hinz, et al.

Dhiraj Gulati, Feihu Zhang, Daniel Malovetz, Daniel Clarke, Gereon Hinz, Alois Knoll
Graph based vehicle infrastructure cooperative localization

Chih-Hong Cheng, Frederik Diehl, Yassine Hamza, Gereon Hinz, et al.

Gereon Hinz, Guang Chen, Muhammad Aafaque, Florian Röhrbein, Jörg Conradt, Zhenshan Bing, Zhongnan Qu, Walter Stechele, Alois Knoll

Martin Buechel, Gereon Hinz, Frederik Ruehl, Hans Schroth, Csaba Gyoeri, Alois Knoll

Richard Gruner, Philip Henzler, Gereon Hinz, Corinna Eckstein, Alois Knoll

Guang Chen

Guang Chen, Zhenshan Bing, Florian Rohrbein, Jorg Conradt, Kai Huang, et al. Towards brain-inspired learning with the neuromorphic snake-like robot and the neurorobotic platform

Zhenshan Bing, Long Cheng, Guang Chen, Florian Röhrbein, Kai Huang, et al. Towards autonomous locomotion: Cpg-based control of smooth 3d slithering gait transition of a snake-like robot

Biao Hu, Uzair Sharif, Rajat Koner, Guang Chen, Kai Huang, Feihu Zhang, et al. Random finite set based bayesian filtering with opencl in a heterogeneous platform

Mingchuan Zhou, Hessam Roodaki, Abouzar Eslami, Guang Chen, Kai Huang, et al. Needle segmentation in volumetric optical coherence tomography images for ophthalmic microsurgery

Zhenshan Bing, Long Cheng, Kai Huang, Zhuangyi Jiang, Guang Chen, et al.

Zhuangyi Jiang, Zhenshan Bing, Kai Huang, Guang Chen, Long Cheng, and Alois Knoll

G. Hinz, M. Büchel, F. Diehl, G. Chen, A. Krämer, J. Kuhn, V.

Lakshmirasimhan, M. Schellmann, U. Baumgarten, A. Knoll

Titel

Multi vehicle trajectory coordination for automated parking

Systematically comparing control approaches in the presence of actuator errors

Deep neural networks for Markovian interactive scene prediction in highway scenarios

Decision making for autonomous driving considering interaction and uncertain prediction of surrounding vehicles

Motion planning under perception and control uncertainties with Space Exploration Guided Heuristic Search

Providentia: Proactive Video-based Use of Telecommunications Technologies in Innovative Motorway Scenarios

Feature uncertainty estimation in sensor fusion applied to autonomous vehicle location

Online Multi-object Tracking-by-Clustering for Intelligent Transportation System with Neuromorphic Vision Sensor

Neural Networks for Safety-Critical Applications - Challenges, Experiments and Perspectives

Ontology-based traffic scene modeling, traffic regulations dependent situational awareness and decision-making

IEEE Intelligent Vehicles Symposium (IV) for automated vehicles

Spatiotemporal representation of driving scenarios and classification using neural networks

Efficient 3D Human Motion Perception System with Un-supervision, Randomization and Discrimination

In IEEE Transactions on Cognitive and Developmental Systems

Bioinspiration & Biomimetics, 12(3):035001

Sensors

Applied Sciences

IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)

International Conference On Neural Information Processing (ICONIP)

8. Tagung Fahrerassistenzsysteme TÜV-Süd

Veröff. in

IEEE Intelligent Vehicles Symposium (IV), pages 661 - 666

IEEE Intelligent Vehicles Symposium (IV), pages 353 - 358

IEEE Intelligent Vehicles Symposium (IV)

IEEE Intelligent Vehicles Symposium (IV)

IEEE Intelligent Vehicles Symposium (IV)

5th GI/ITG KuVS, Fachgespraech Inter-Vehicle Communication(FG-IVC 2017)

IEEE Information Fusion (Fusion)

IEEE Information Fusion (Fusion)

arXiv:1709.00911 [cs.SE]

KI 2017: Advances in Artificial Intelligence

IEEE Intelligent Vehicles Symposium (IV)

PhD Thesis, MediaTUM

In IEEE Transactions on Cognitive and Developmental Systems



Autonomous Driving Impressions





Gefördert durch:



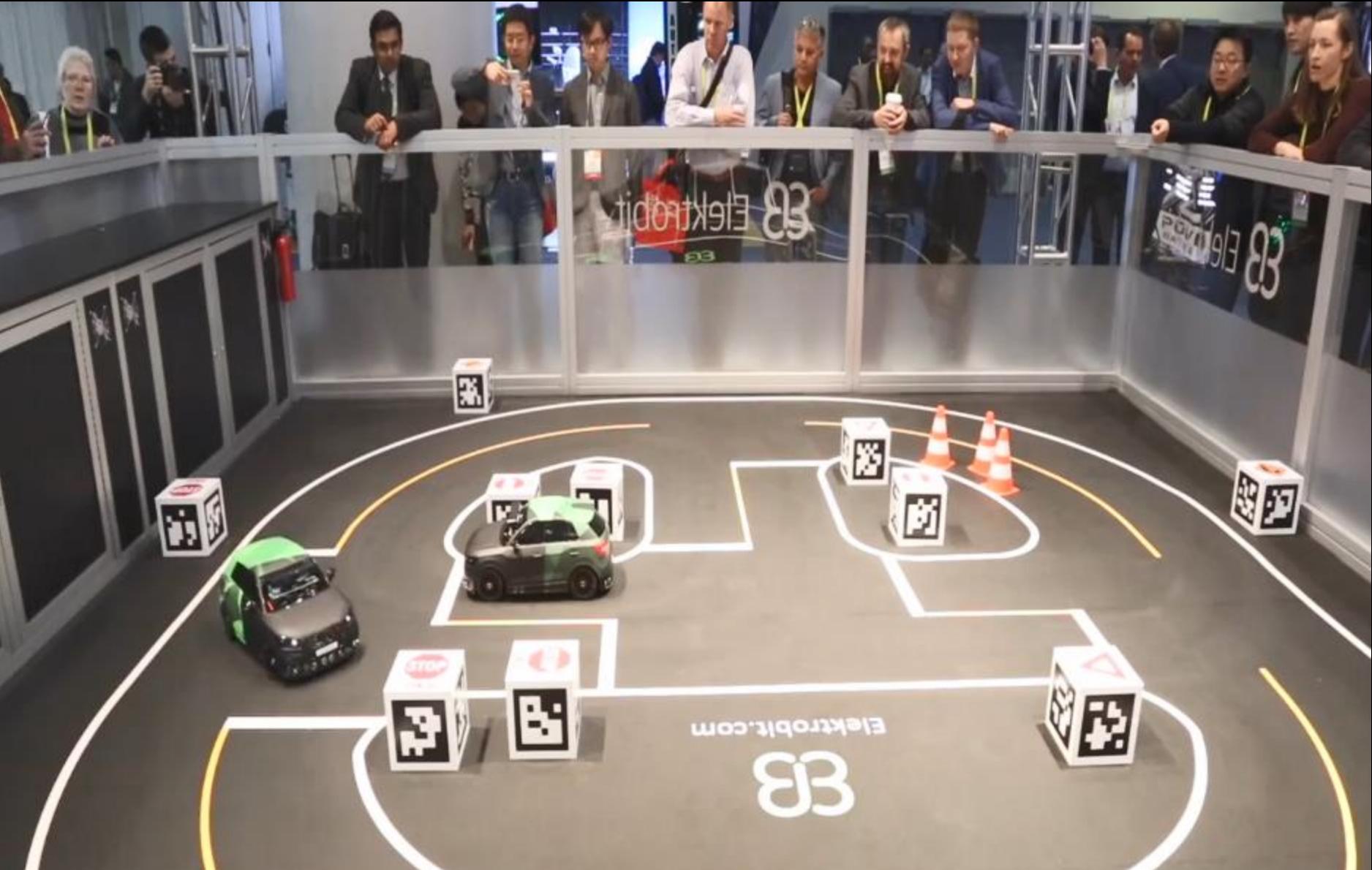
Bundesministerium
für Wirtschaft
und Energie

aufgrund eines Beschlusses
des Deutschen Bundestages

IKT FÜR
 ELEKTROMOBILITÄT

fortiss

SIEMENS
Ingenuity for life



Impressions - CES 2017



© Audi AG

Impressions - Berlinale 2016

ale 2016



Autonomous Garage

Contributions to Prototype Demonstrators





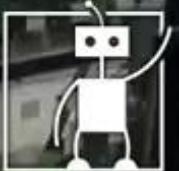
Everything seems to be ready...

fortiss

innovation in software and systems

Cyber-Physical Systems

supported by



Robotics and Embedded Systems

Technische Universität München

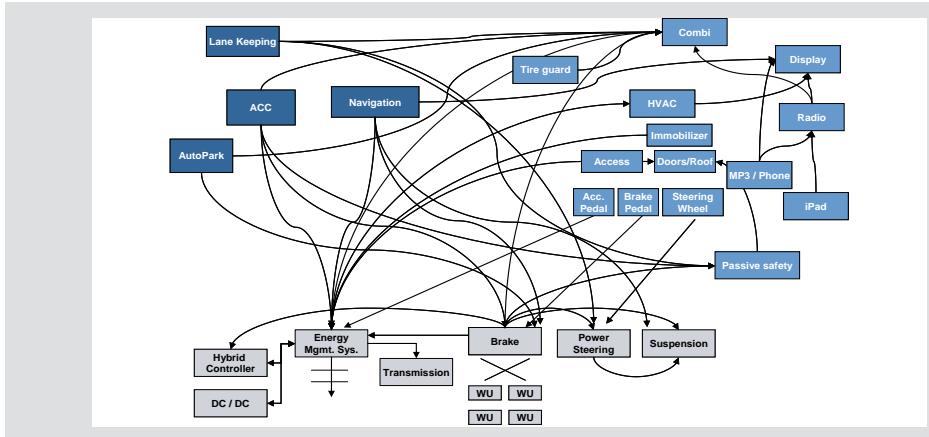


Contributions to Prototype Demonstrators: RACE

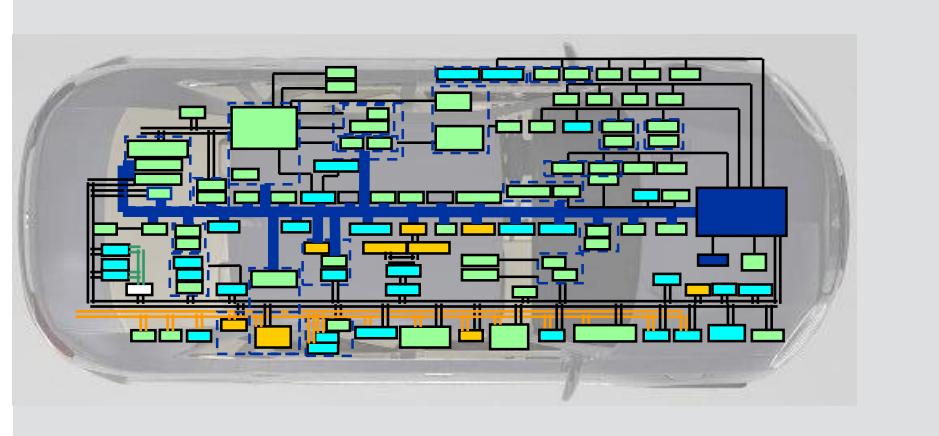
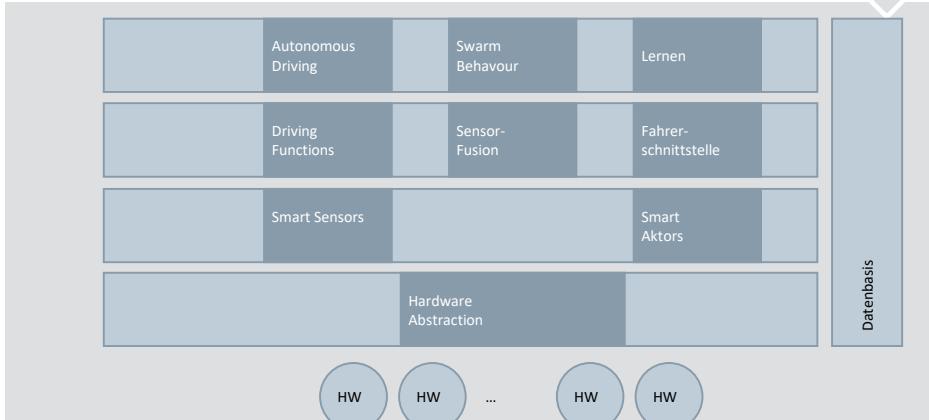


RACE

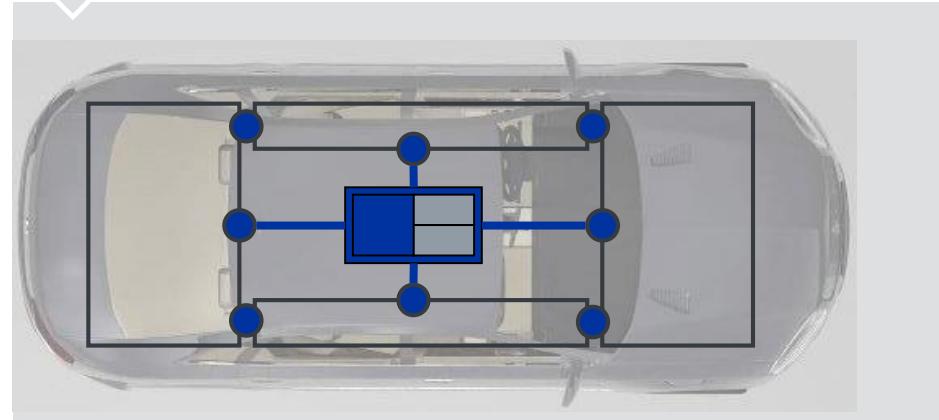
Reduction of E/E-Architecture Complexity



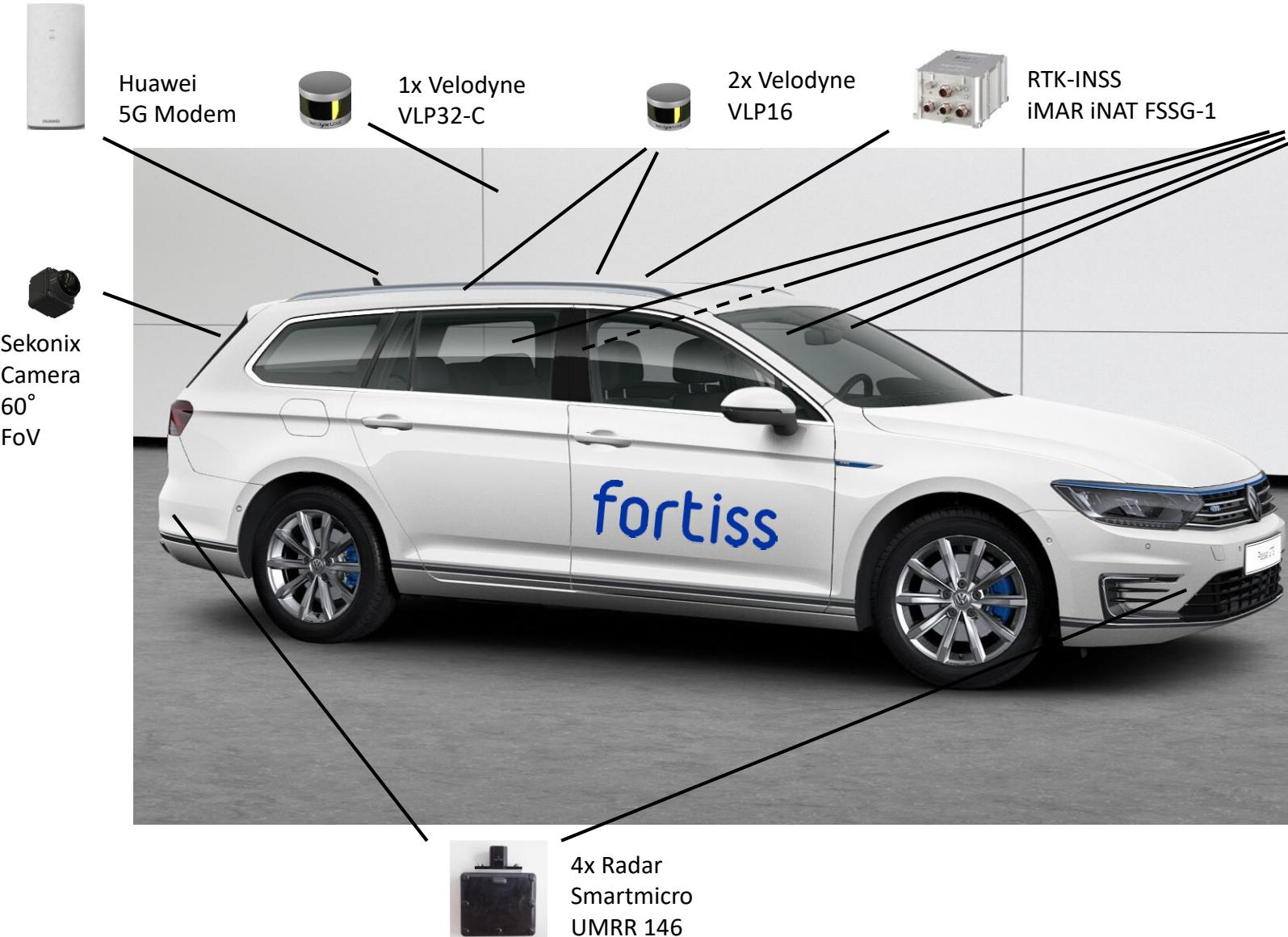
- Position independent Partitioning
 - Defined Information Flow
 - Hierarchical Decision
 - Plug & Play Compatible



- Less Controllers
 - Reduced Cable Effort
 - Less Heterogeneous
 - Plug & Play Compatible



fortiss 5G Autonomous Driving Research Platform

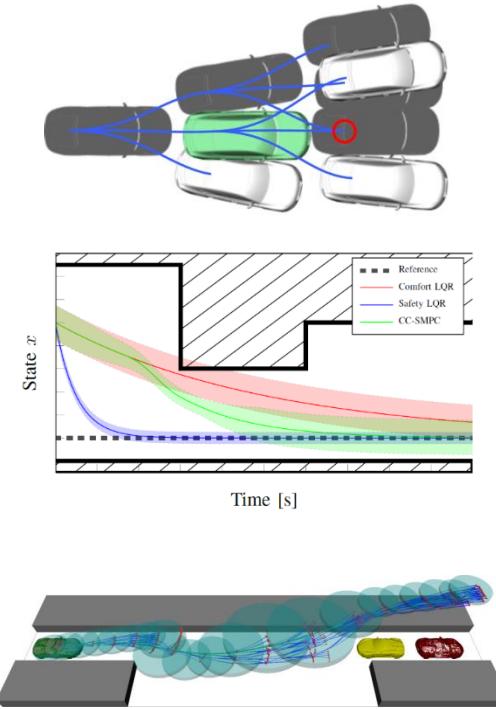
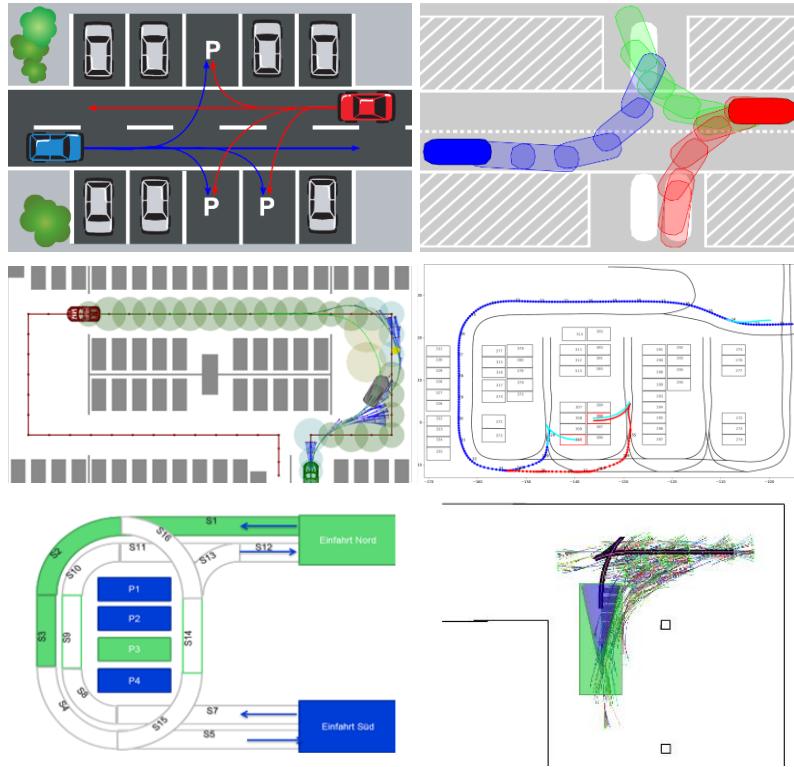


Camera
1x 120° FoV front
1x 60° FoV front
2x 120° FoV side

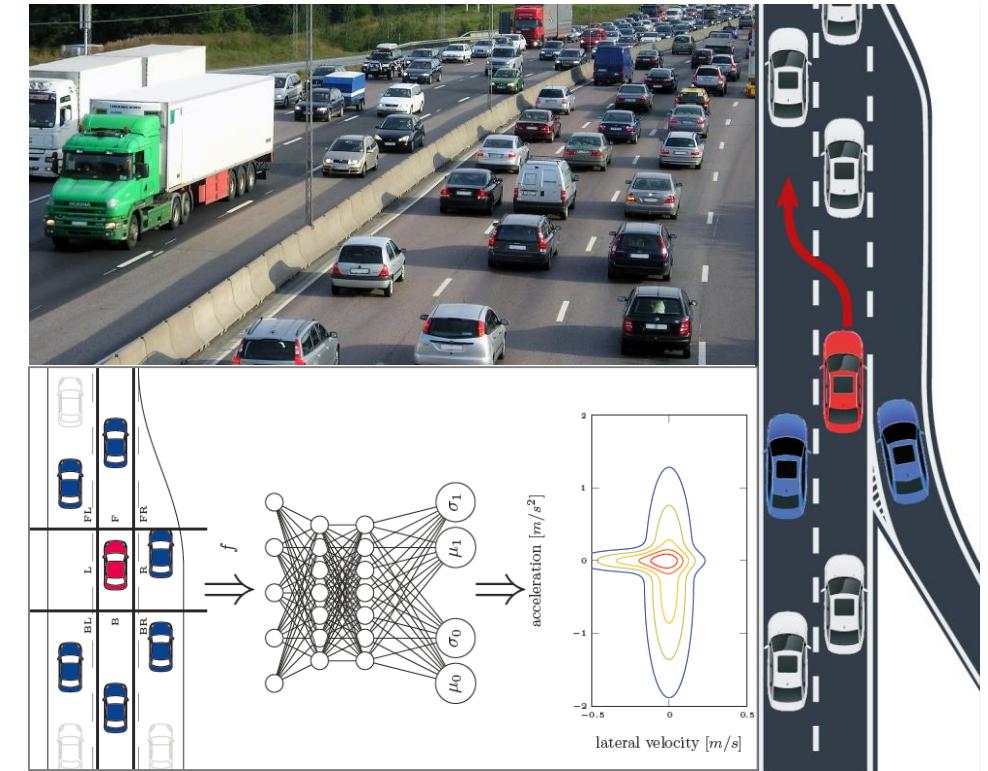
- Computer vision:
Drive PX2
- Data fusion unit:
CarPC1 (Nvidia GTX1050TI)
- Visualisation-/Planning unit:
CarPC1 (Nvidia GTX1050TI)
- Realtime Prototyping:
dSPACE MicroAutobox II

Applications for motion planning, decision making and testing

Algorithms for planning and testing

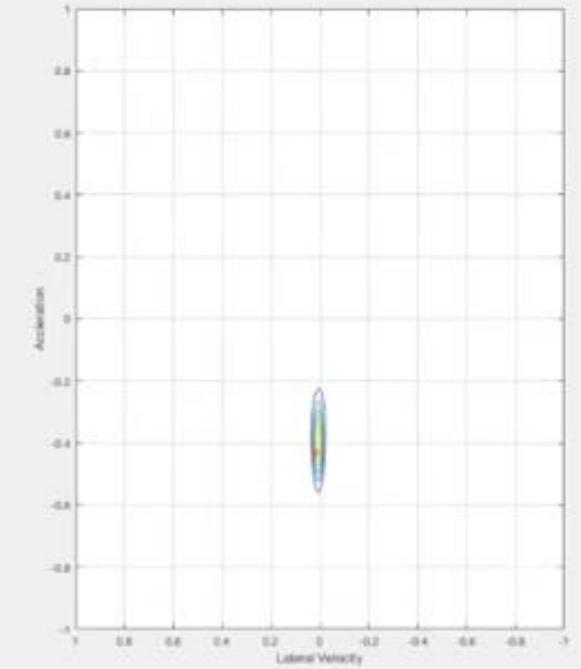
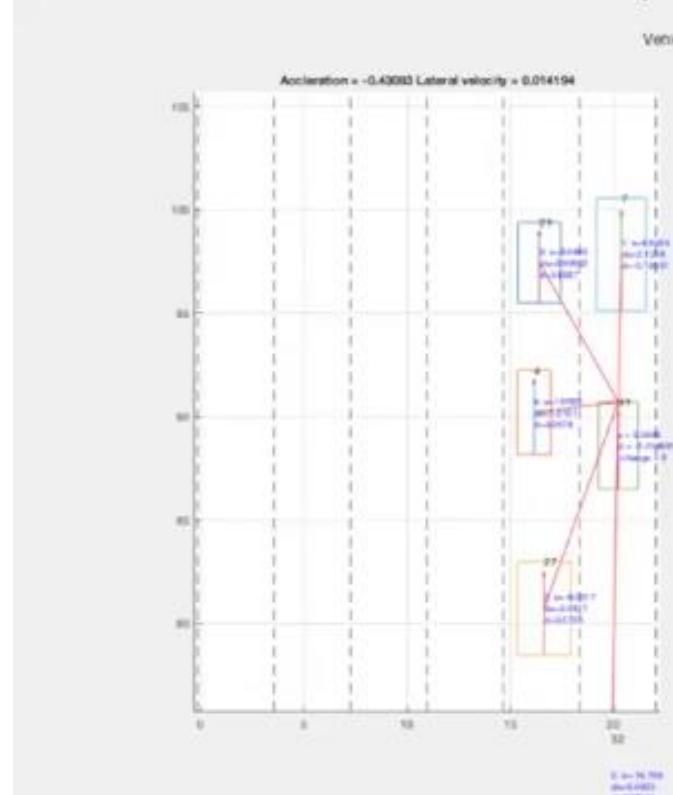
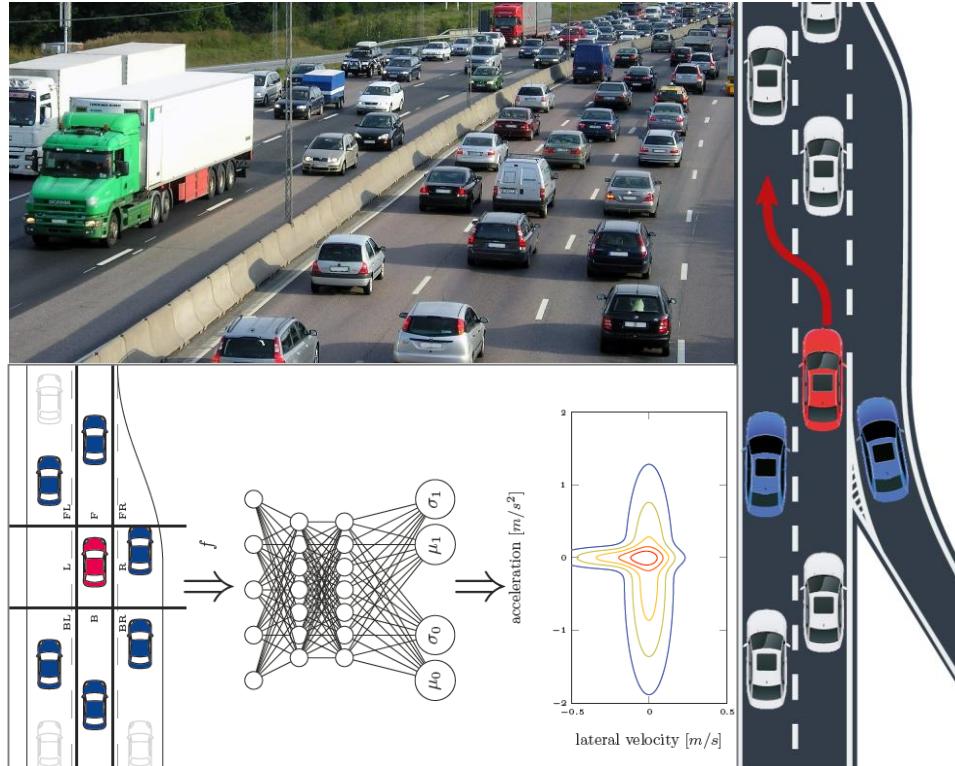


Deep Learning for strategic decision making



Deep Neural Networks for Interactive Scene Prediction

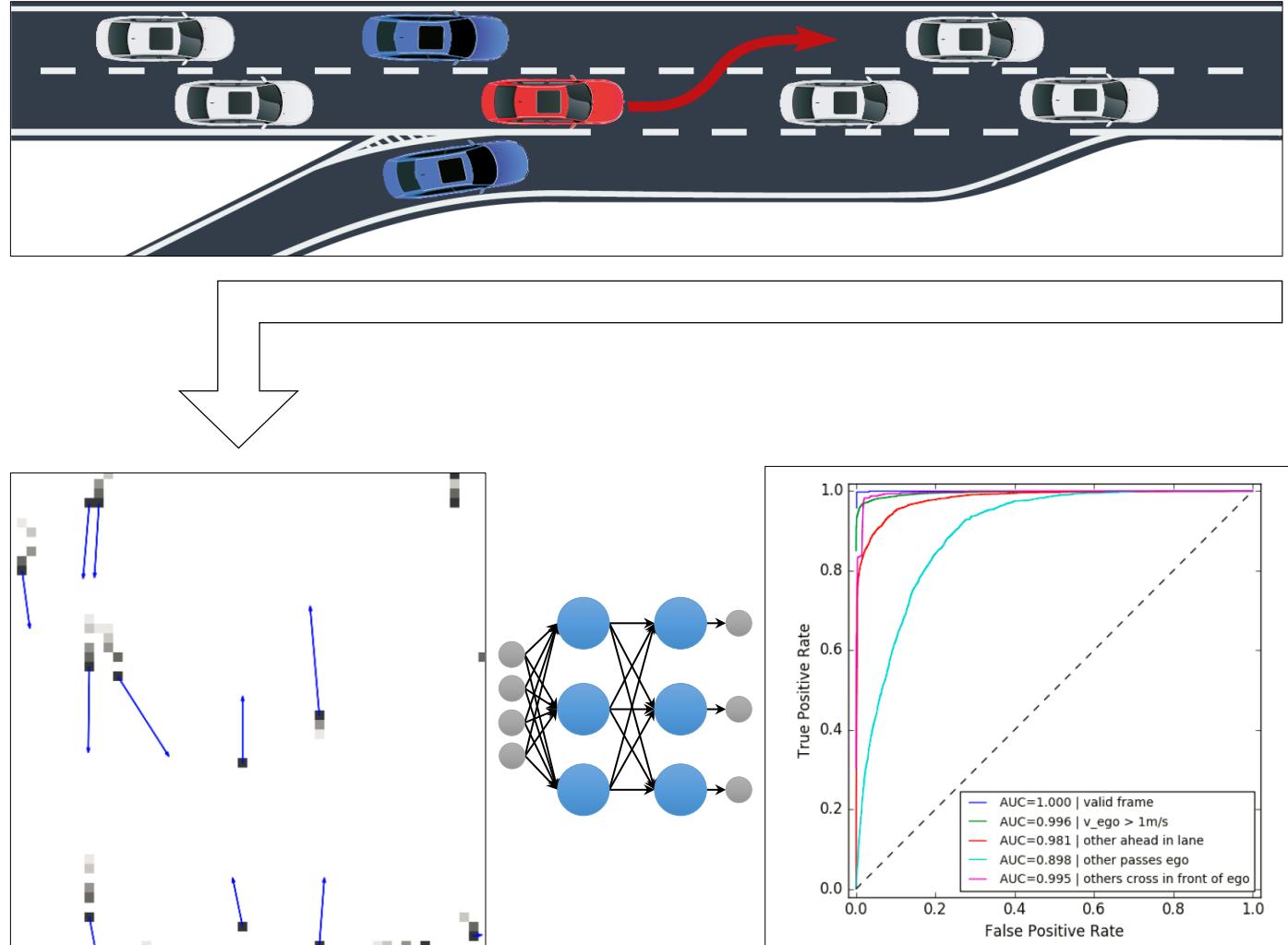
Deep Learning for strategic decision making



Sensor-Set Object List based Scenario Classification

From Sensors to Scenarios

- Going from Vehicle Perception Data Object Lists from real traffic to scenarios with Deep Learning Neural Networks
- Scenarios
 - Valid Frames
 - Velocity Based Scenarios
 - Take-Over Manneuver
 - Others Cross in Front of Ego Veihcle
 - Lane Changes
 - ...



Sensor-Set Object List based Scenario Classification

From Sensors to Scenarios

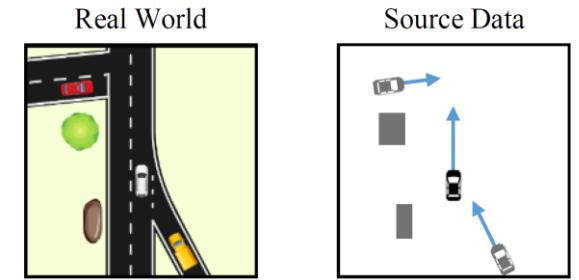
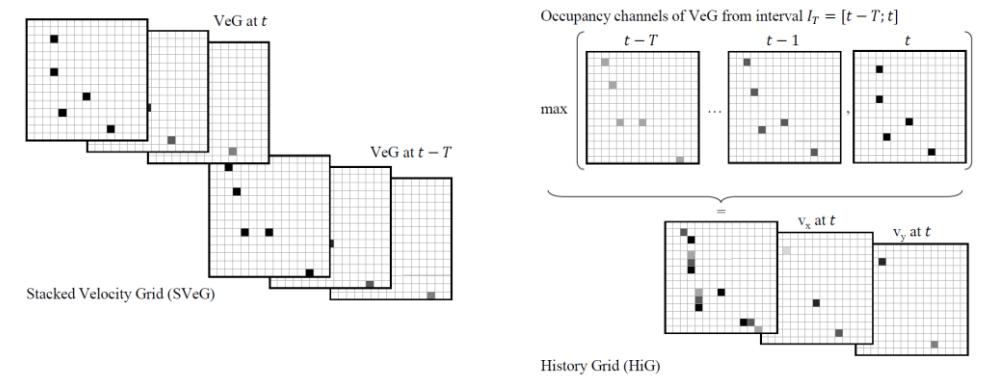
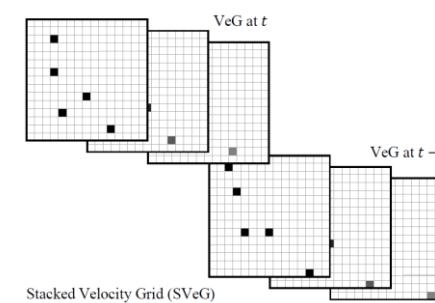
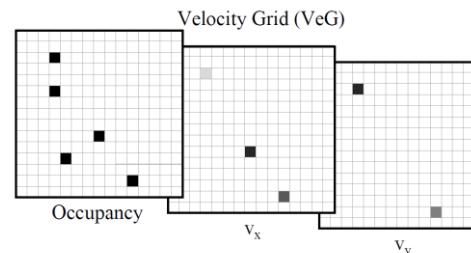
- Going from Vehicle Perception Data Object Lists from real traffic to scenarios with Deep Learning Neural Networks
- Scenarios
 - Valid Frames
 - Velocity Based Scenarios
 - Take-Over Maneuver
 - Others Cross in Front of Ego Veihcle
 - Lane Changes
 - ...

- Example Scenario Classification and Prediction

(“*Spatiotemporal representation of driving scenarios and classification using neural networks*, Gruner, Hezler, Hinz et. Al., IV 2017)

- Use fused sensor data as input:

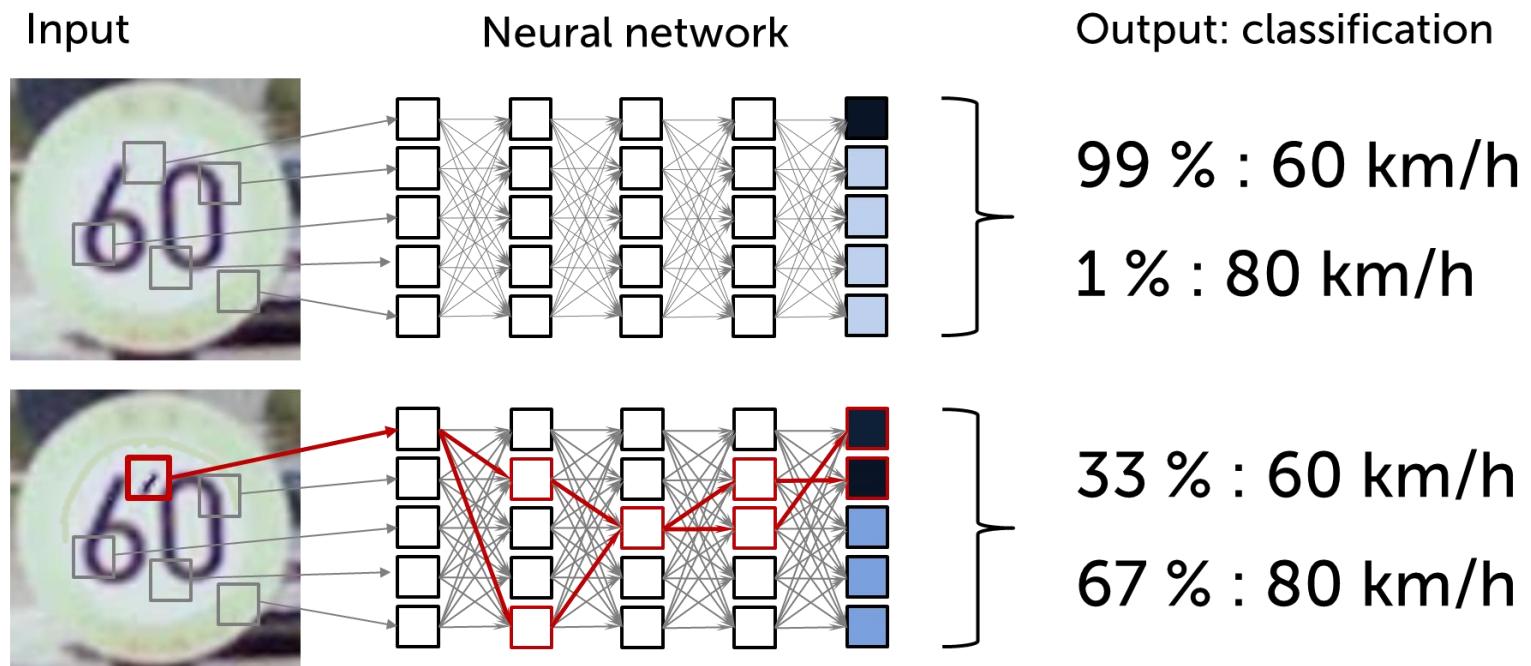
- Choose Data Representation Format:



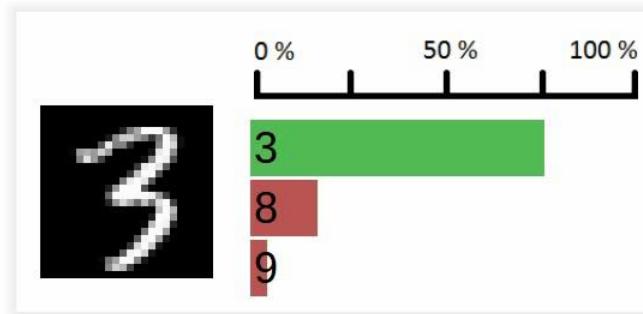
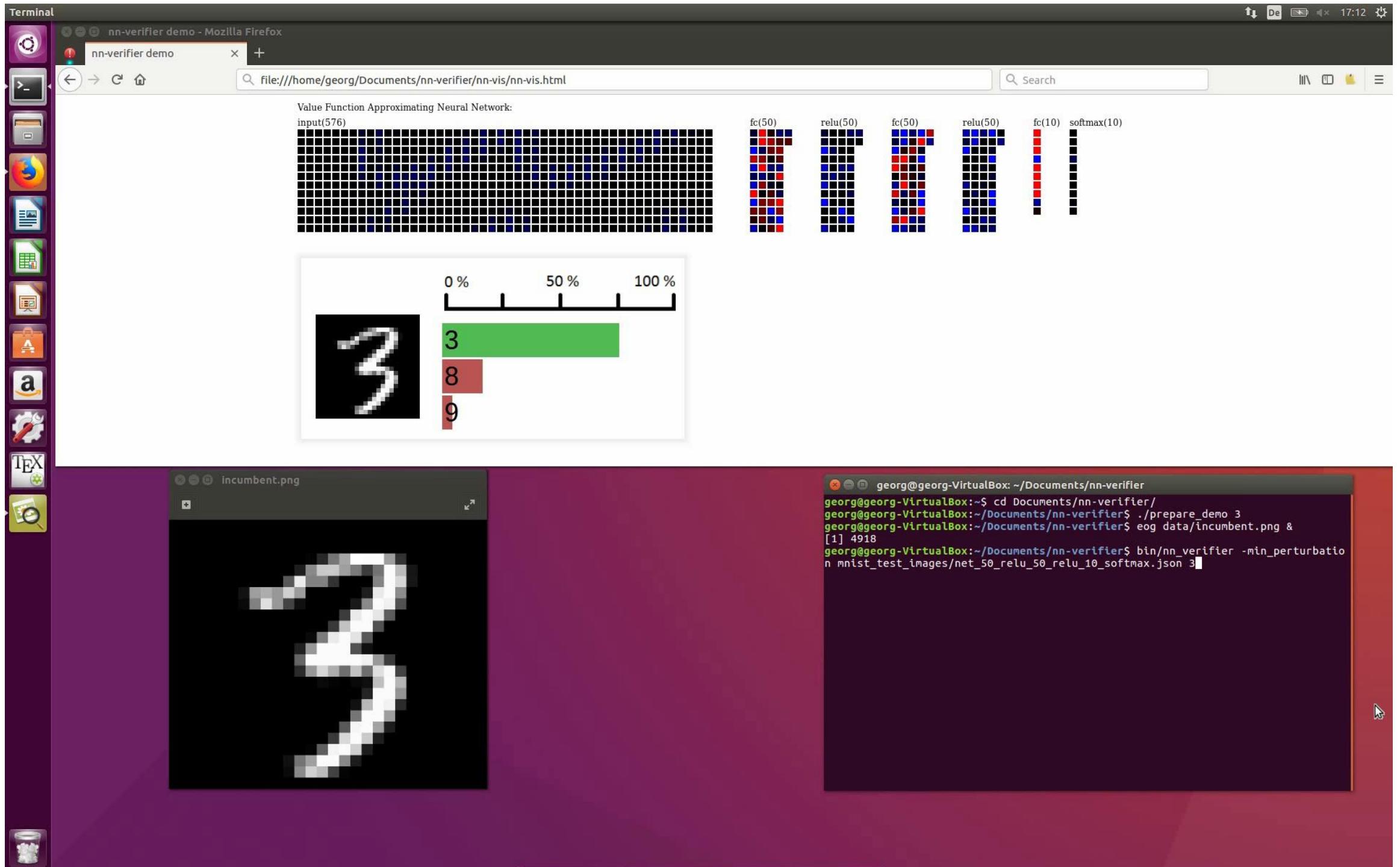
Adversarial images

The need for neural network verification in image processing

Dependable neural networks are crucial for safe and secure autonomous and decision systems

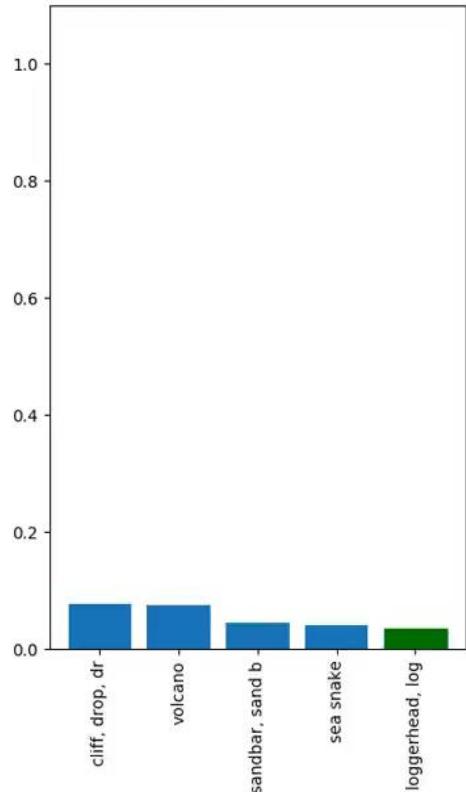


A tiny disturbance in the input causes a significant change in the classification.



```
georg@georg-VirtualBox:~/Documents/n̄-verifier$ cd Documents/n̄-verifier/  
georg@georg-VirtualBox:~/Documents/n̄-verifier$ ./prepare_demo 3  
georg@georg-VirtualBox:~/Documents/n̄-verifier$ eog data/Incumbent.png &  
[1] 4918  
georg@georg-VirtualBox:~/Documents/n̄-verifier$ bin/n̄_verifier -min_perturbation mnist_test_images/net_50_relu_50_relu_10_softmax.json 3
```

Are adversarial inputs a real threat?



<https://www.youtube.com/watch?v=YXy6oX1iNoA>

Athalye, Anish, and Ilya Sutskever. "Synthesizing robust adversarial examples." *arXiv preprint arXiv:1707.07397* (2017).

Robust adversarial examples

- Robust to translations, rotations, etc.
- can be created as physical world objects
 - not just pixel manipulations

Are we safe if the neural network is kept a secret?!

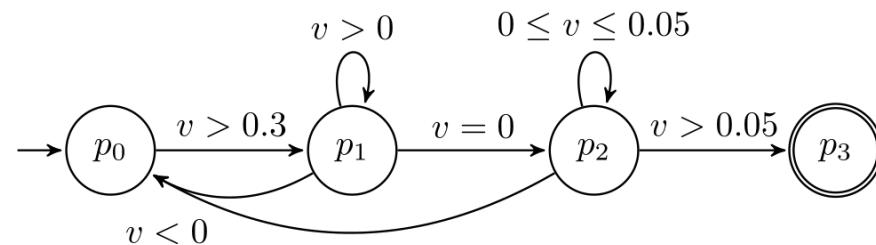
Black-box adversarial examples

- no knowledge of neural network parameters
- no extensive sampling

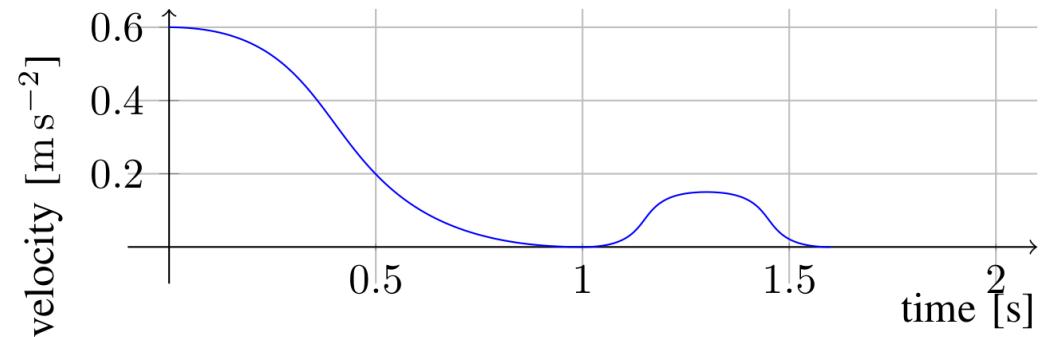
Wicker, Matthew, Xiaowei Huang, and Marta Kwiatkowska. "Feature-Guided Black-Box Safety Testing of Deep Neural Networks." *arXiv preprint arXiv:1710.07859* (2017).

Detection and prediction of undesired Vehicle Behavior

- Detect possibility of specific erroneous vehicle behavior:
 - Stop, Go, Stop
- Desired behavior:
 - Go, Stop
- Strongly facilitates debugging of complex autonomy functions

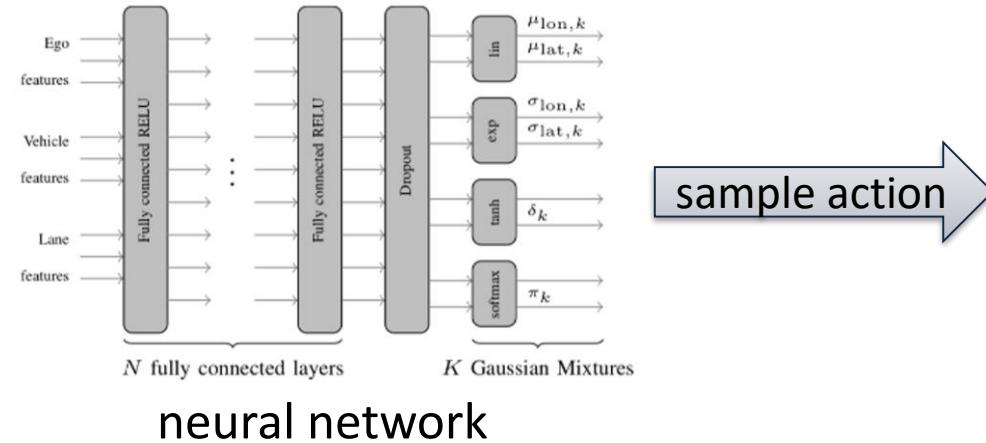
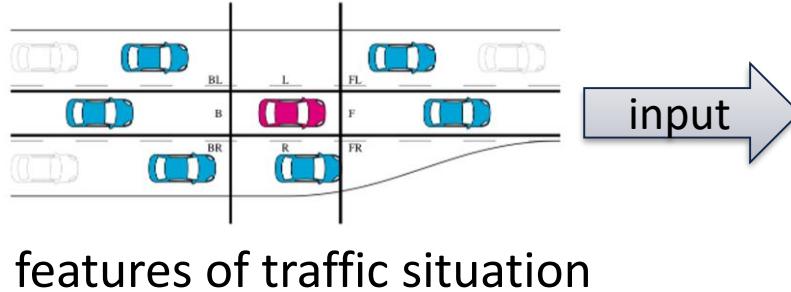


NuSMV: **SPEC !EF(G0 & E[G1 U G2 & E[G3 U G0]])**;
G0:= $v > 0.05$, G1:= $v > 0$, G2:= $v = 0$, G3:= $0 \leq v \leq 0.05$



Verification of safety properties of NNs

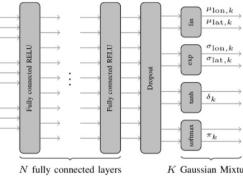
Neural network example:



- lateral velocity
- longitudinal acceleration

Neural network verification

• NN



- **Property:** Can the network predict to steer left, if there is a car in the left?

input

maximize $\mathbf{c}^T \mathbf{x}$
subject to $\mathbf{A}\mathbf{x} \leq \mathbf{b}$,
 $\mathbf{x} \geq \mathbf{0}$,
and $\mathbf{x} \in \mathbb{Z}^n$

nn-verifier

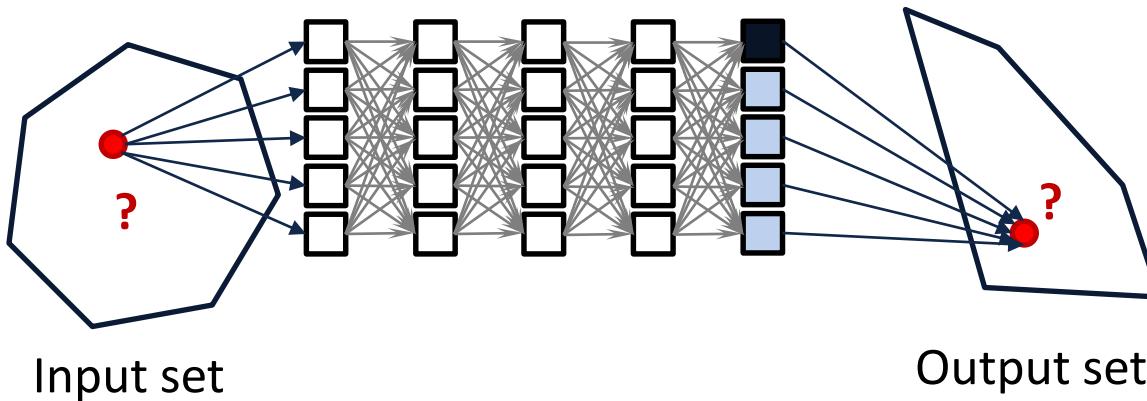


- Lenz, David, Frederik Diehl, Michael Truong Le, and Alois Knoll. "Deep neural networks for Markovian interactive scene prediction in highway scenarios." In *Intelligent Vehicles Symposium (IV), 2017 IEEE*, pp. 685-692. IEEE, 2017.
- Cheng, Chih-Hong, et al. "Neural networks for safety-critical applications-challenges, experiments and perspectives." *arXiv preprint arXiv:1709.00911* (2017).

Verifying safety properties of Neural Networks

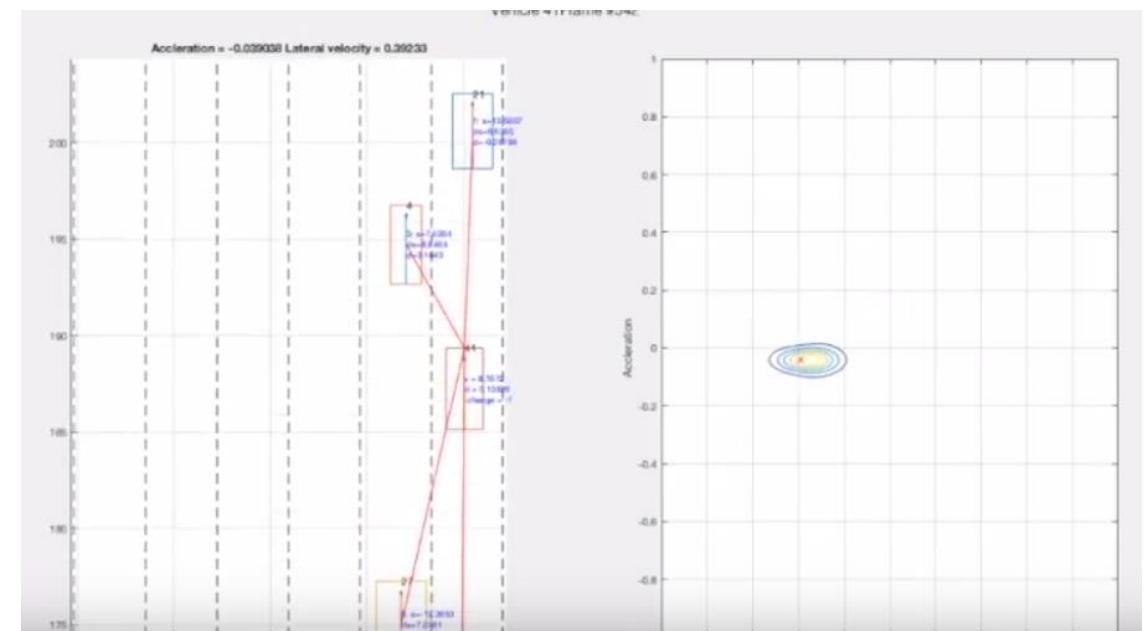
Safety of highway motion predictor

- Properties to be formally verified:
 - [Example] Is it possible for the controller to suggest go left, while there is already car in the left?
- Uses the same framework as computing resilience
- Specification of properties via convex polyhedra



Input:
sensor data

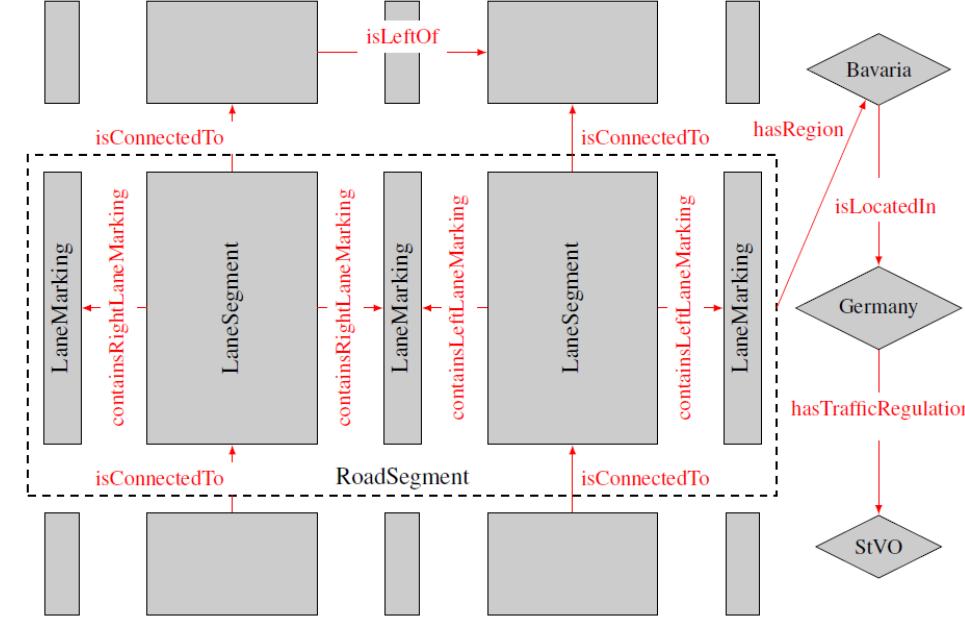
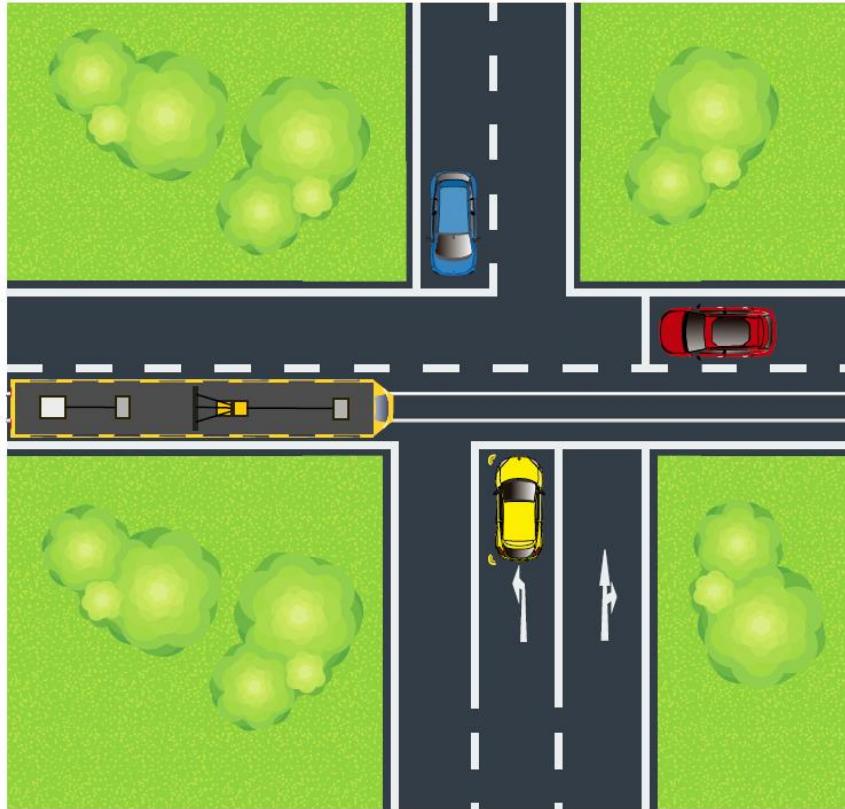
Output:
velocity prediction



Highway motion predictor, being trained under the NGSim dataset

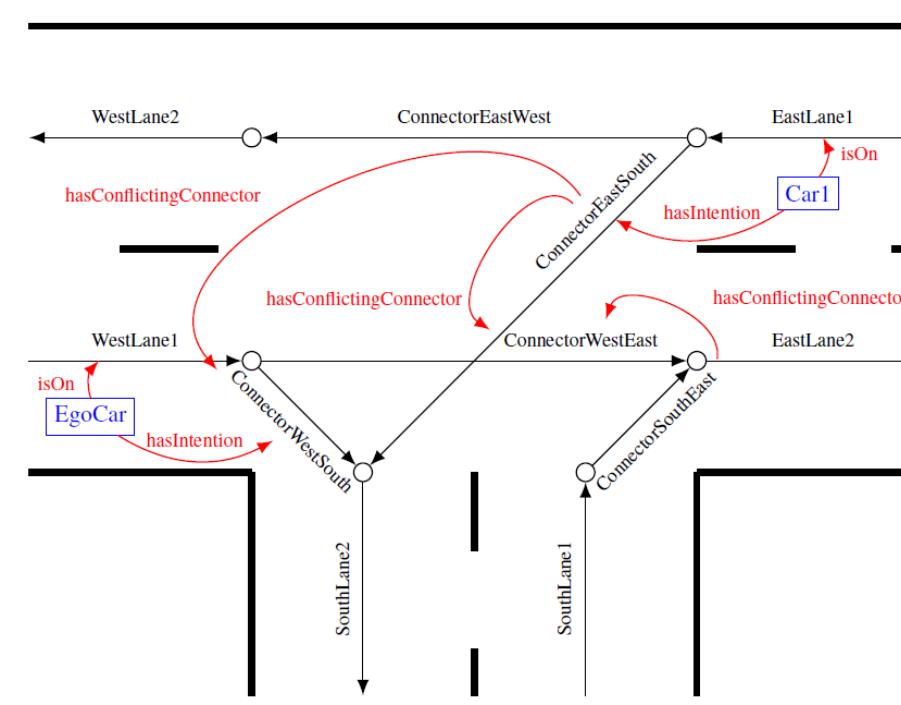
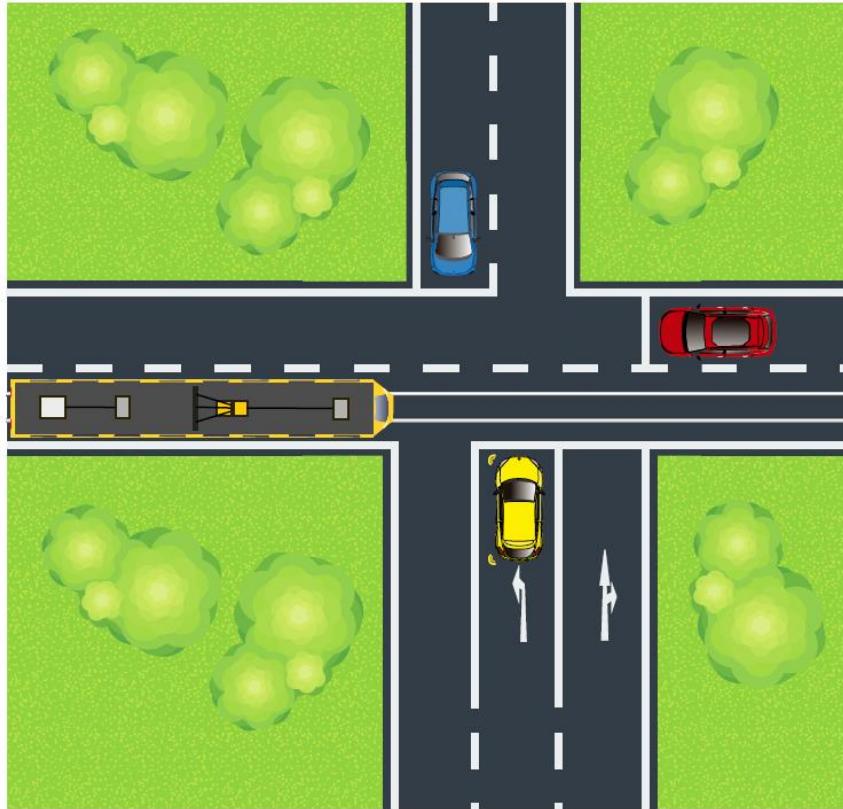
Semantic Scenario Interpretation and Decision Making

Example: “Ontology-Based Traffic Scene Modeling, Traffic Regulations Dependent Situational Awareness and Decision-Making for Automated Vehicles”, M. Büchel, G. Hinz et. Al. in *IEEE Intelligent Vehicles Symposium, 2017*.



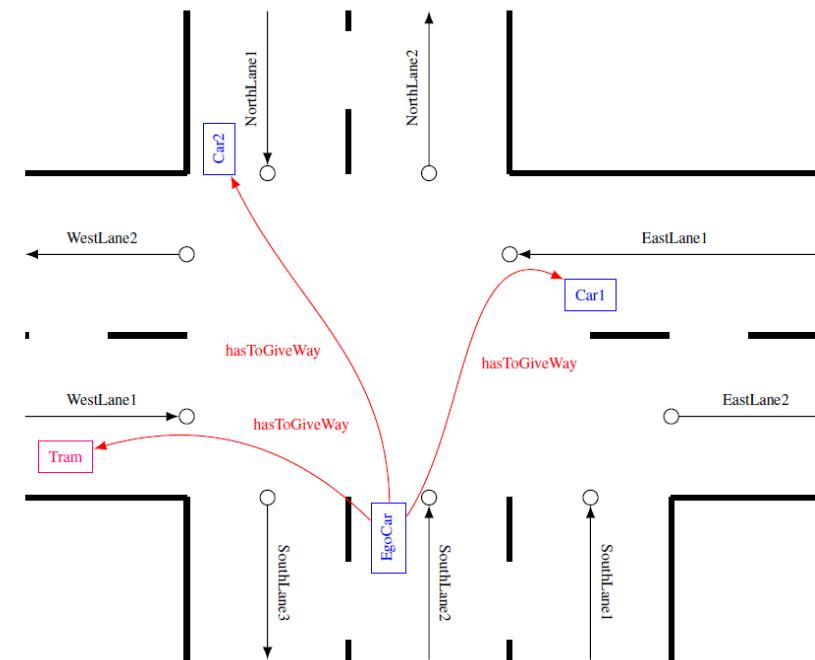
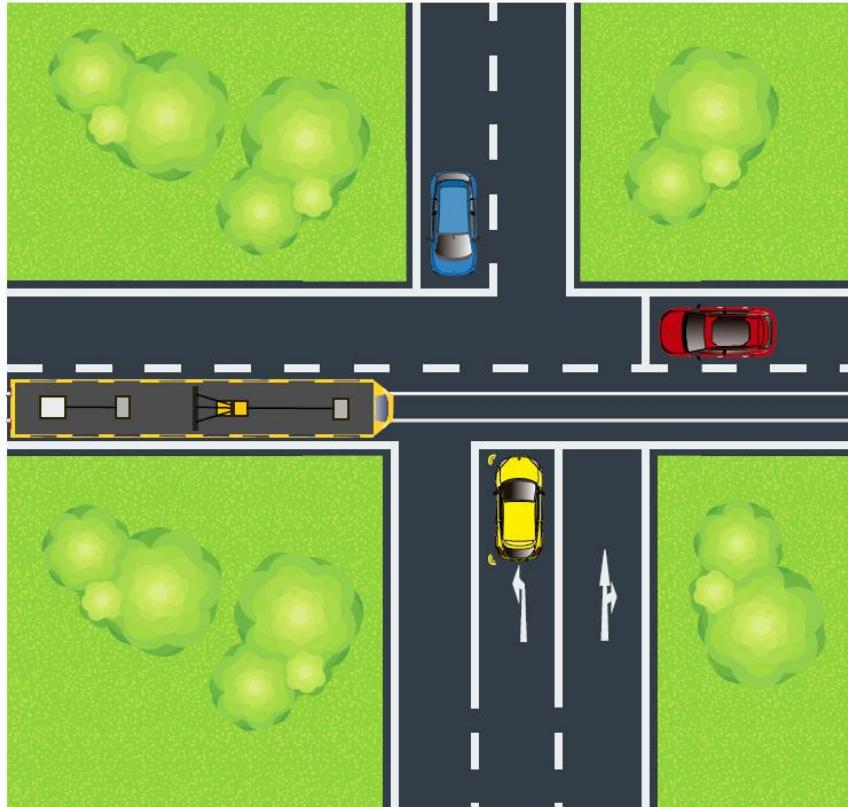
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Semantic Scenario Interpretation and Decision Making

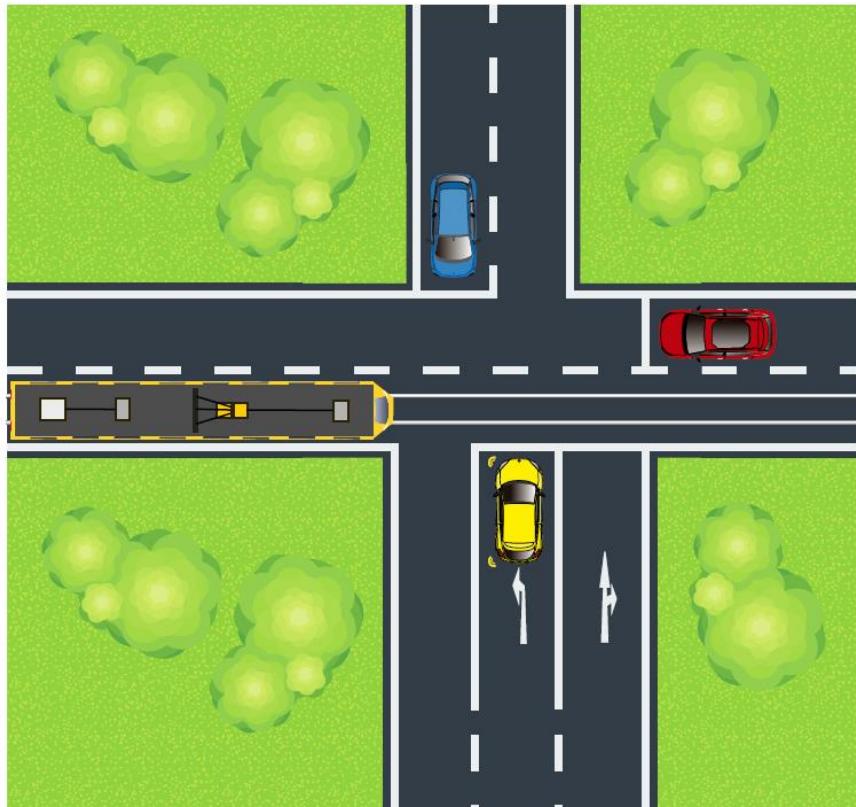
Example: “Ontology-Based Traffic Scene Modeling, Traffic Regulations Dependent Situational Awareness and Decision-Making for Automated Vehicles”, M. Büchel, G. Hinz et. Al. in *IEEE Intelligent Vehicles Symposium, 2017*.



Semantic Scenario Interpretation and Decision Making

Example: “Ontology-Based Traffic Scene Modeling, Traffic Regulations Dependent

Situational Awareness and Decision-Making for Automated Vehicles”, M. Büchel, G. Hinz et. Al. in *IEEE Intelligent Vehicles Symposium, 2017.*



*containsTrafficLight some TrafficLight and
containsTrafficRegulatingPerson
exactly 0 TrafficRegulatingPerson*

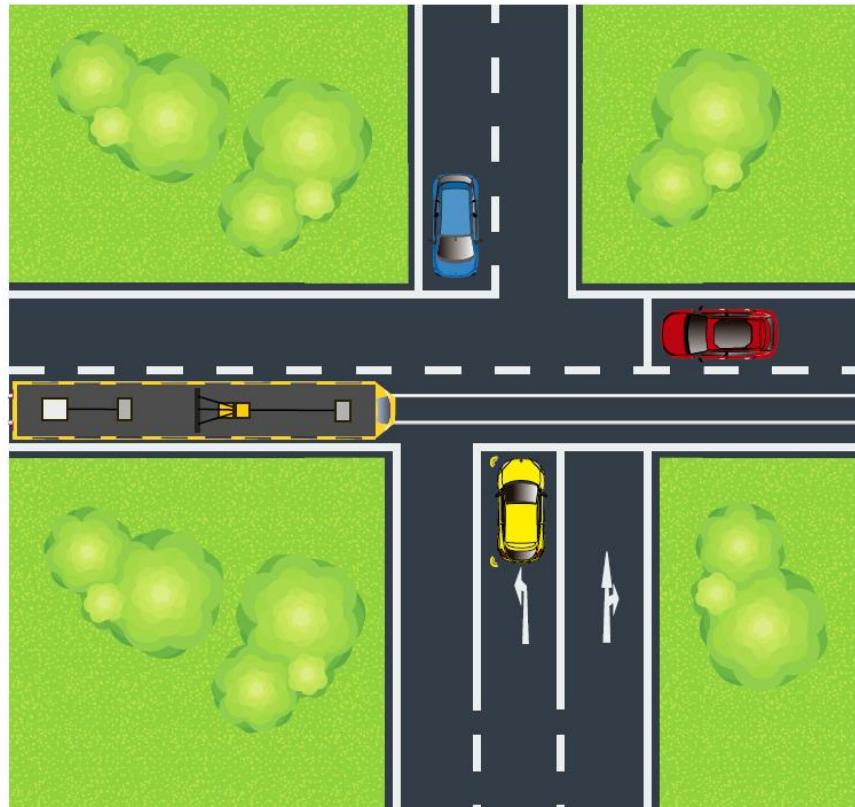
*TrafficLightRegulatedIntersection(?scen1)
^ Vehicle(?vehicle1) ^ isOn(?vehicle1, ?lane)
^ isPartOf(?vehicle1, ?scen1)
^ containsTrafficLight(?lane, ?light)
^ hasColor(?light, Red)
⇒ hasToWaitForTrafficLight(?vehicle1, ?light)*

*RoadSegment(?road)
^ preferredLane(?trafficregulations, "right")
^ hasRightMostLane(?road, ?lane)
^ hasTrafficRegulations(?road, ?trafficregulations)
⇒ hasPreferredLane(?road, ?lane)*

Semantic Scenario Interpretation and Decision Making

Example: “Ontology-Based Traffic Scene Modeling, Traffic Regulations Dependent

Situational Awareness and Decision-Making for Automated Vehicles”, M. Büchel, G. Hinz et. Al. in *IEEE Intelligent Vehicles Symposium, 2017.*



*containsTrafficLight exactly 0 TrafficLight and
containsTrafficRegulatingPerson
exactly 0 TrafficRegulatingPerson*

*UncontrolledIntersection(?scen1)
^ Vehicle(?vehicle1) ^ Vehicle(?vehicle2)
^ isPartOf(?vehicle1, ?scen1)
^ hasConflictingConnector(?c1, ?c2)
^ hasIntention(?vehicle1, ?c1) ^ hasIntention(?vehicle2, ?c2)
=> hasToGiveWay(?vehicle1, ?vehicle2)*

*TrafficRegulatedPersonIntersection(?scen1)
^ Vehicle(?vehicle1) ^ contains(?scen1, ?vehicle1)
^ isOn(?vehicle1, ?lane1) ^ isBlockedBy(?lane1, ?police)
=> hasToWaitForTRP(?vehicle1, ?police)*



Ontology Pizza Tutorial

<https://protegewiki.stanford.edu/wiki/Protege4Pizzas10Minutes>



Screenshot of the Protege4 interface showing a pizza ontology.

The left pane displays the **Inferred Superclass Hierarchy:** Gorgonzolla_topping is highlighted.

The main pane shows a table with two columns:

	has_topping some	has_spiciness some
Domain_entity		
Value		
Independent_entity		
Pizza_base		
Pizza_topping		
Meet_topping		
Spicy_beef		Hot_value
Ham_topping		Medium_value
Pepperoni_topping		Medium_value
Seafood_topping		
Tuna_topping		Mild_value
Anchovy_topping		Mild_value
Vegetable_topping		
Tomato_topping		Mild_value
Onion_topping		
Fruit_topping		
Pineapple_topping		(Mild_value)
Cheese_topping		Mild_value
Mozzarella_topping		(Mild_value)
Gorgonzolla_topping		Mild_value
Pizza		
Hot_and_spicy_pizza	Tomato_topping, Mozzarella_topping	Hot_value
Cheesy_pizza	Tomato_topping, Mozzarella_topping	
Seafood_pizza	Tomato_topping, Mozzarella_topping	
Maguerita_pizza	Tomato_topping, Mozzarella_topping	
Vegetarian_pizza		

The right pane shows the **Class Description: Gorgonzolla_topping** with the following details:

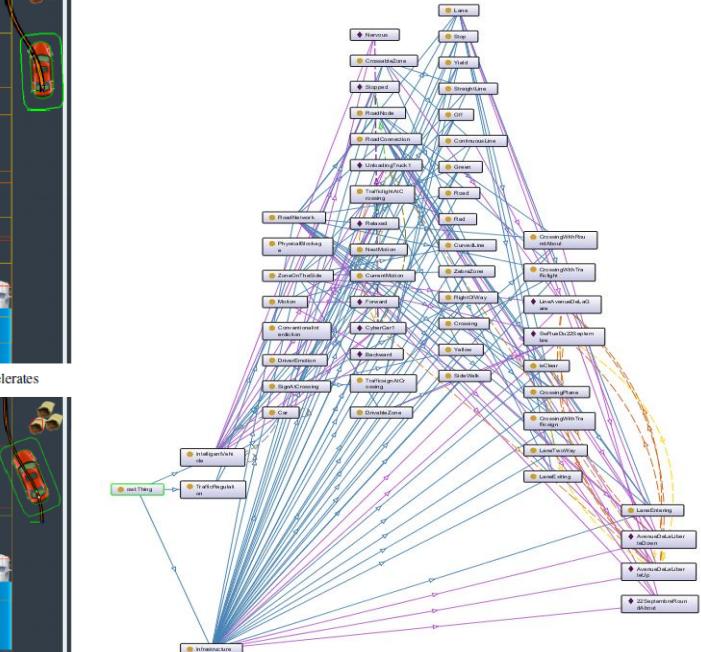
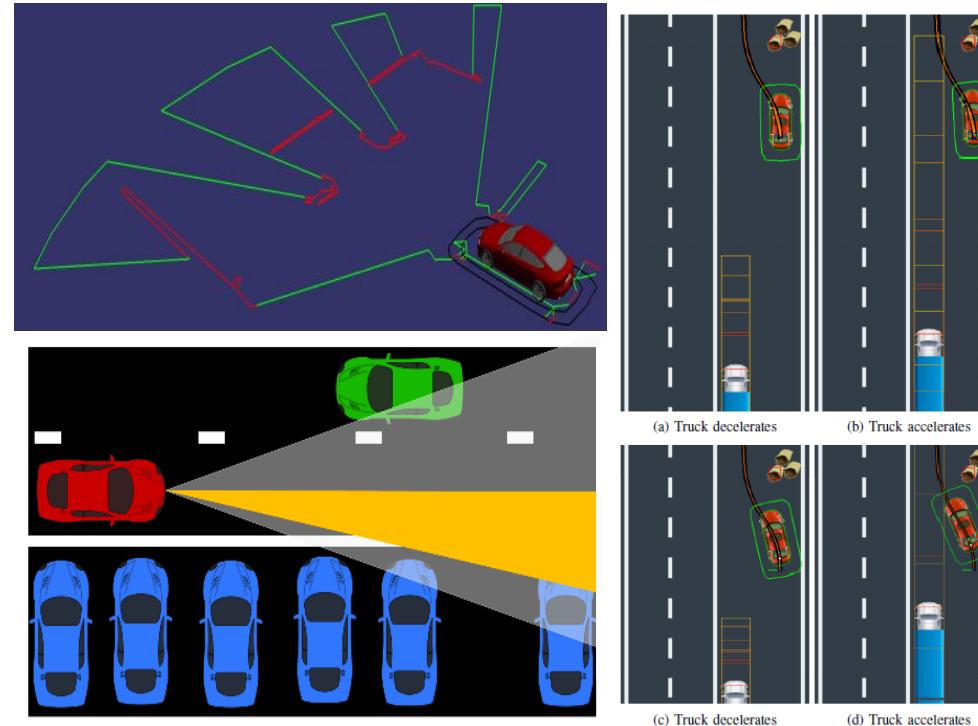
- Equivalent classes: Gorgonzolla_topping
- Superclasses: Cheese_topping
- Inherited anonymous classes: has_spiciness some Mild_value

Safety & Accident Simulation

From Sensors to Scenarios

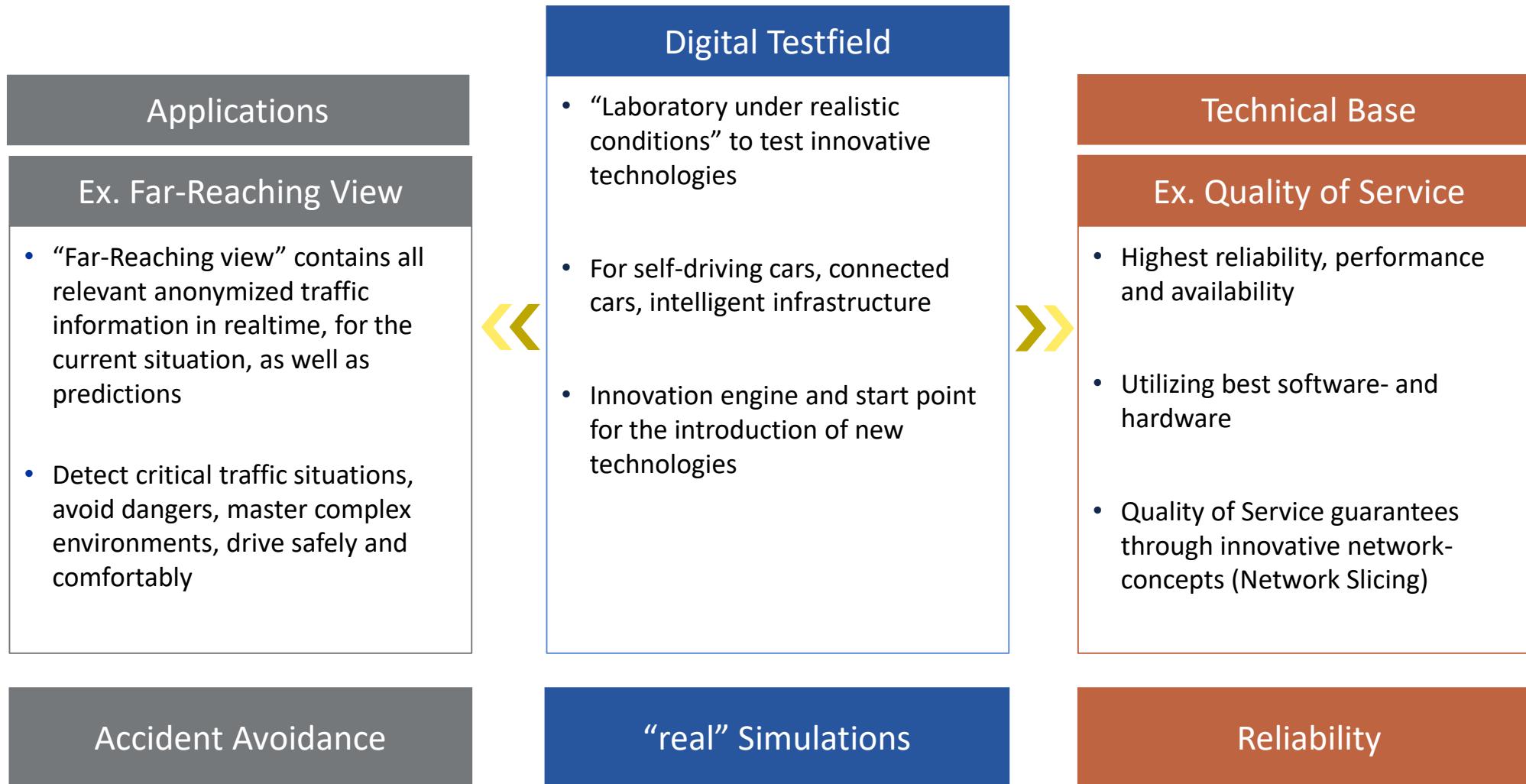
- Scenario tests
 - Accident analysis
 - Development of test catalogues
 - Identification of close to 1000 sensing aspects for sensor set validation
 - Conceptual knowledgebase development for autonomous driving and decision making
 - Sensor Simulation, data-acquisition, auto-calibration, fault detection...

Analysis, tool development, knowledgebases



Added Value – Digital Highway Opportunities

Goals, Vision and Mission



Added Value – Digital Highway Opportunities

Goals, Vision and Mission

SPIEGEL ONLINE DER SPIEGEL SPIEGEL TV  [Anmelden](#)

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AUTO Schlagzeilen | ☀ Wetter | DAX 13.315,06 | TV-Programm | Abo

Nachrichten > Auto > Aktuell > Stau-Forschung: Blick nach hinten kann Verkehrschaos mindern

Verkehrsforschung

Rückwärts-Radar könnte Staus vermeiden

Mit intelligenten und vernetzten Autos sollen Staus künftig vermieden werden. Forscher haben jetzt herausgefunden: Heutige Sensor-Systeme gucken (zum Teil) in die falsche Richtung.

„Backwards-radar could prevent traffic jams. Researchers discovered: Today's sensors face wrong direction.“



Applications

Ex. Far-Reaching View

- “Far-Reaching view” contains all relevant anonymized traffic information in realtime, for the current situation, as well as predictions
- Detect critical traffic situations, avoid dangers, master complex environments, drive safely and comfortably



Accident Avoidance

Providentia - Highway Digital Twin



Far-reaching
View

Traffic end
detection

Traffic
coordination

...Many more

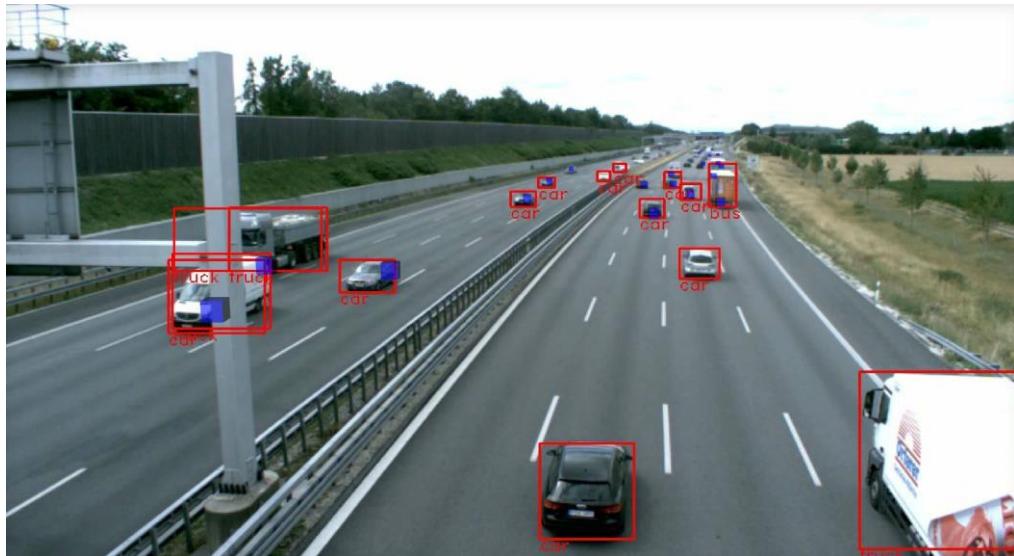
Verticals



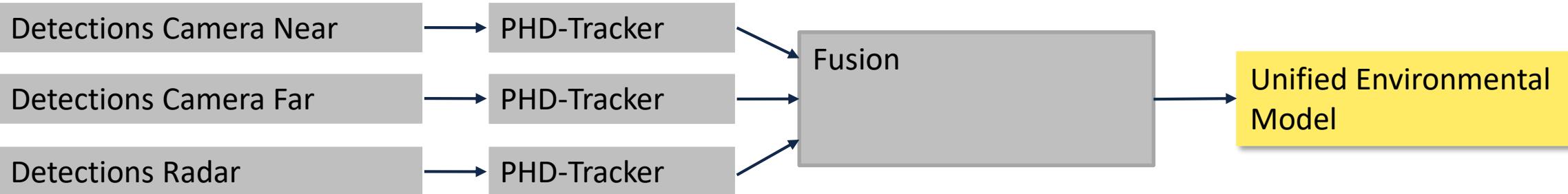
Digital Twin

- Human- and machine-readable. Object types, positions, velocities, signals, occupancies, intentions and predictions
- Realtime!
- First base-station 5G project in Munich and one of the biggest projects in the digital testfield

Multisensor Data Fusion



Flexible Multisensor Data Fusion with distributed, adaptive, autocalibrated sensors



Multisensor Data Fusion of vehicles and infrastructure

C2X Sensors

- Connected system with shared sensor information

- **Infrastructure**

Radar

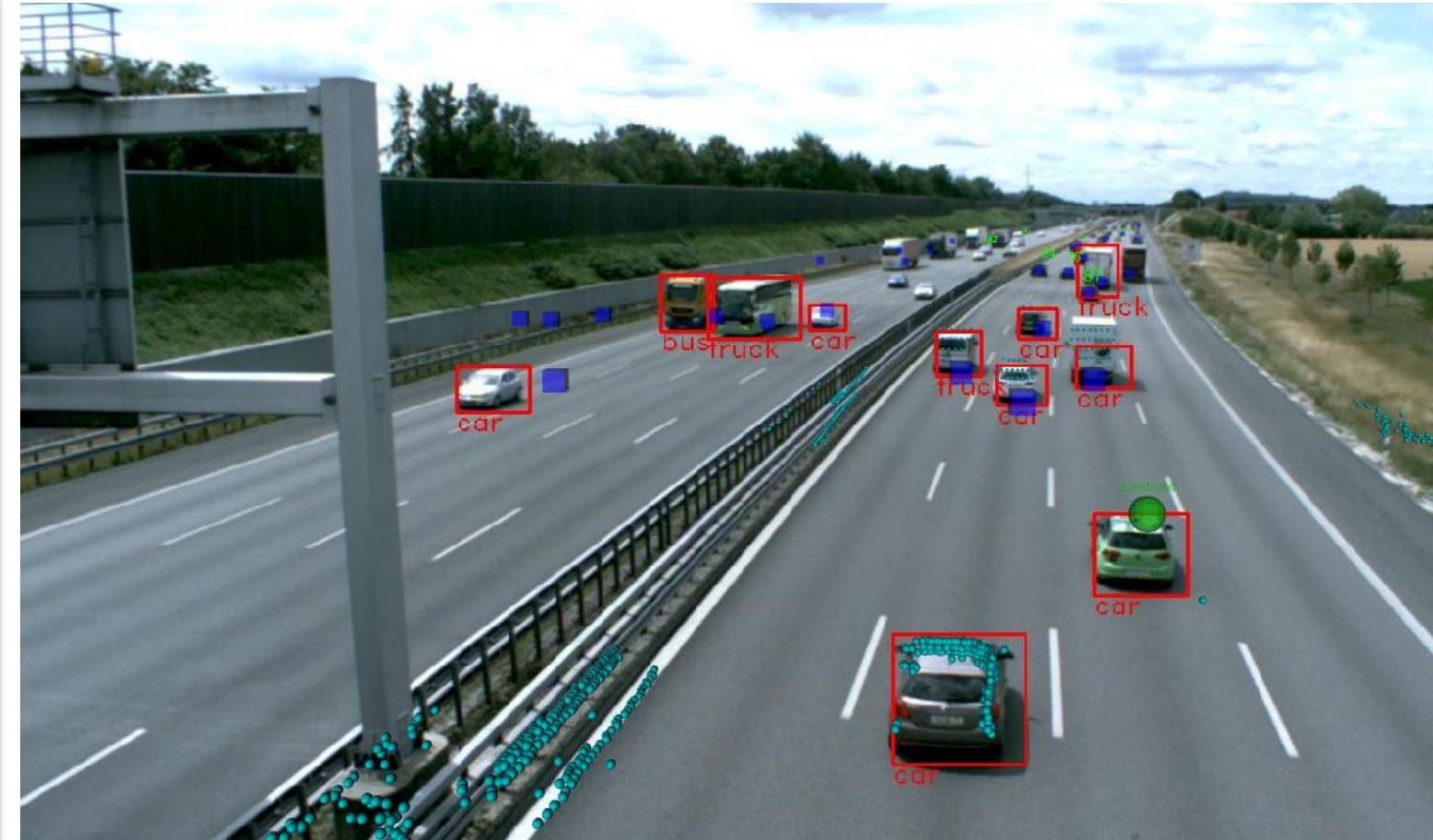
Camera Near

Camera Far 123

- **Fahrzeug:**

Ego-vehicle detection

Lidar



Intelligent Infrastructure

Providentia Testfield - Concept



Intelligent Infrastructure

Providentia Testfield – Area 1



Intelligent Infrastructure

Mobile Fieldtests



MP South



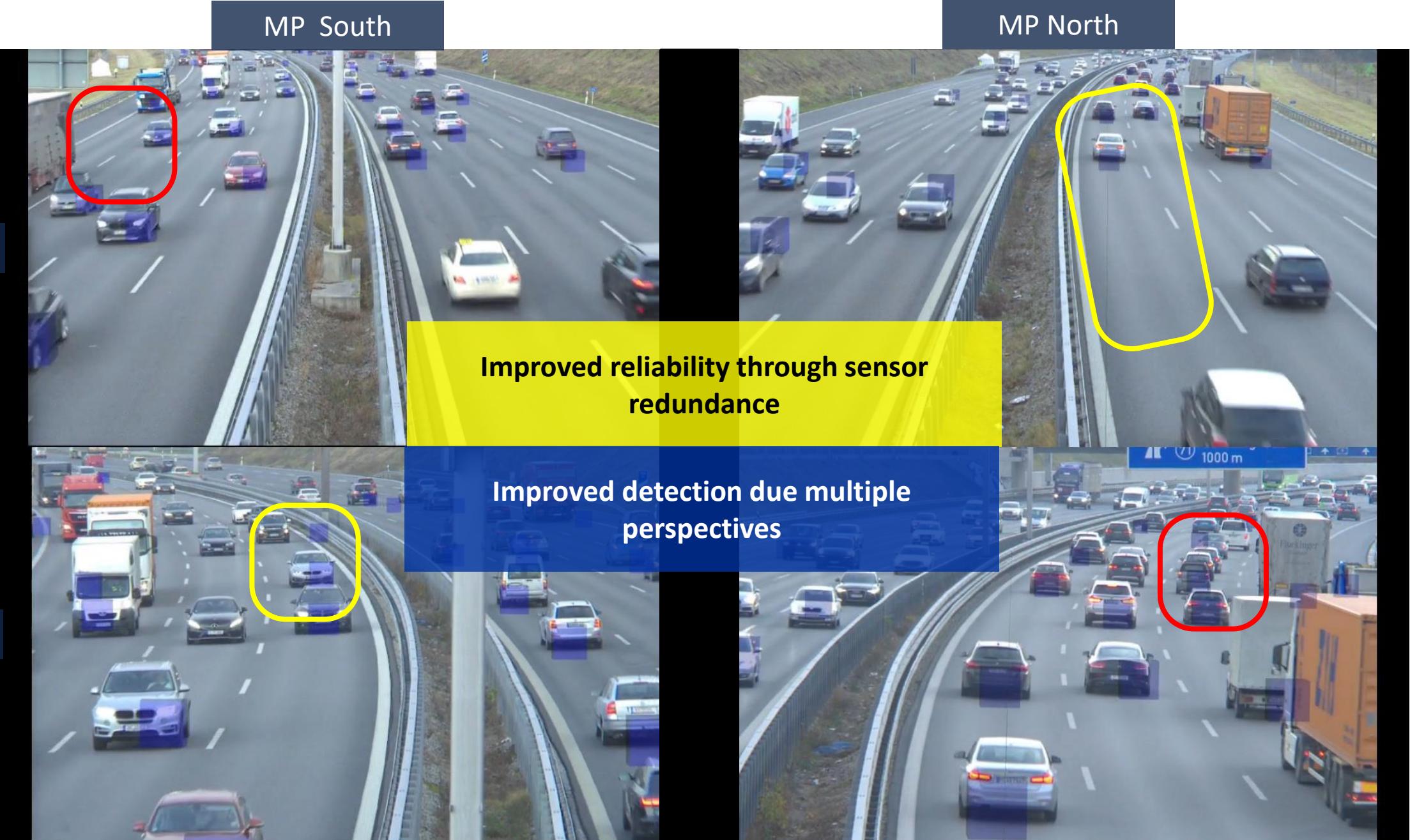
Near

MP North



Far





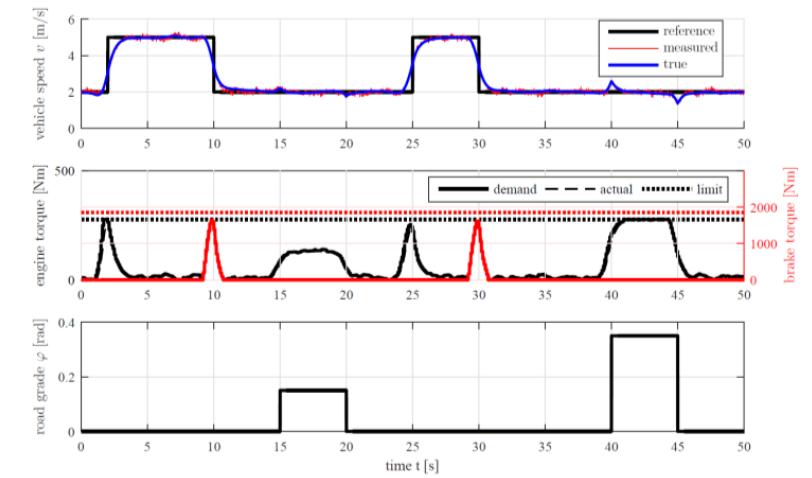
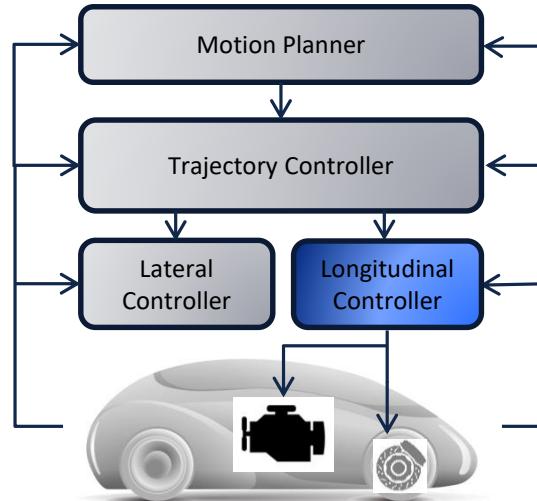


Tesla knocked out by a „bug“.

<http://www.businessinsider.com/tesla-autopilot-knocked-out-by-moth-2016-5?IR=T>

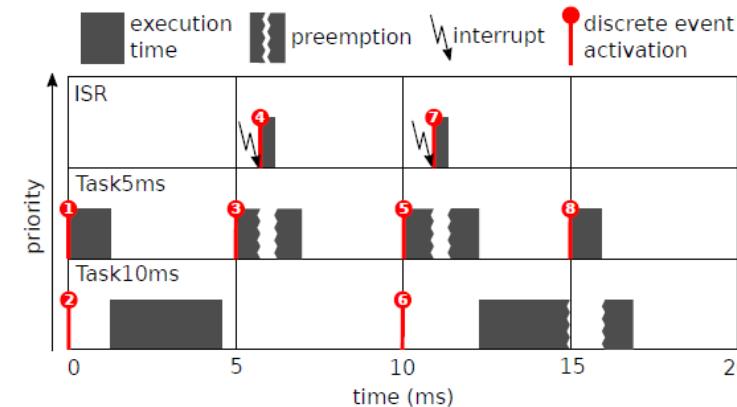
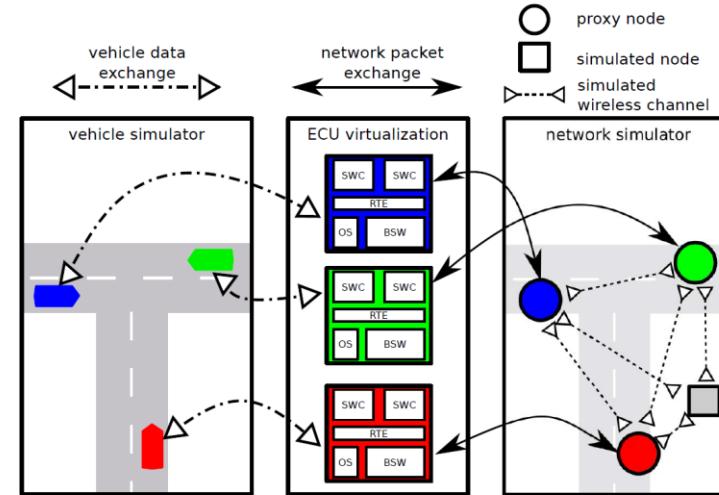
Model predictive control for Autonomous Vehicles

- Adaptive nonlinear model predictive control for improved velocity control
- Utilize knowledge available to autonomous vehicles, such as topologies from maps and path information
- Improved comfort, reduced fuel consumption



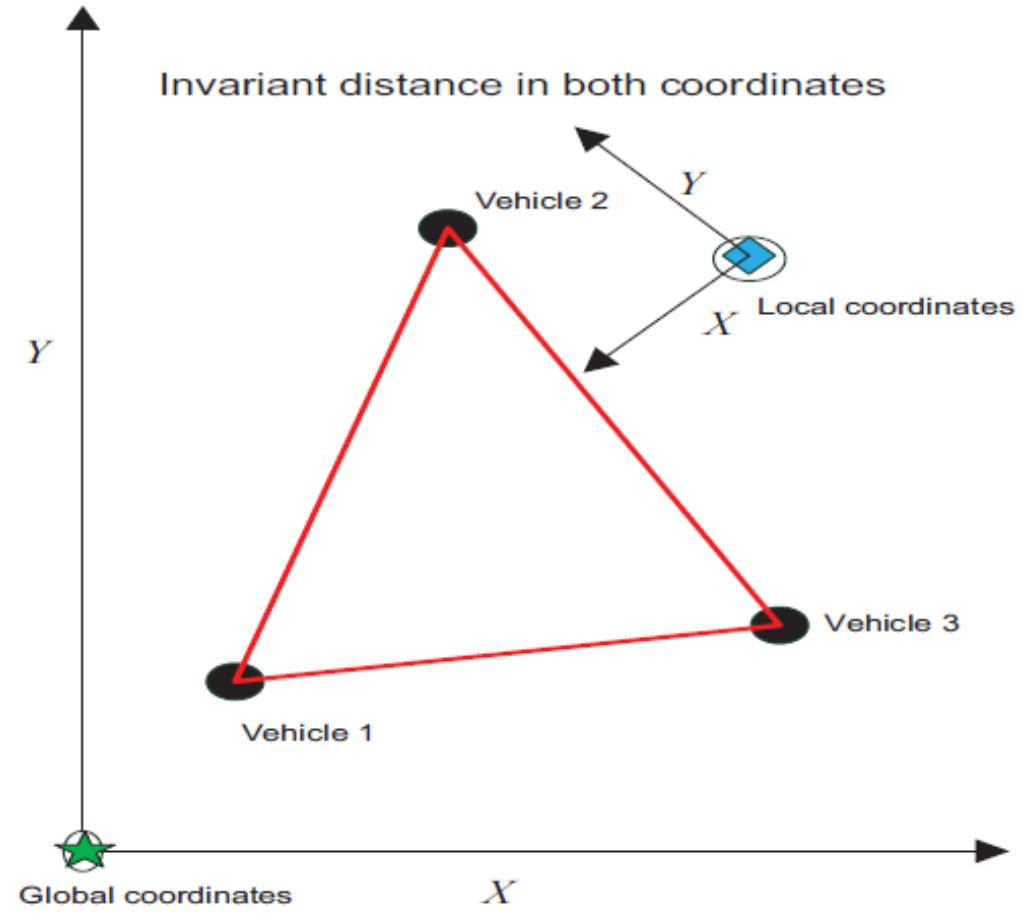
Fleet communication– Car to X

- Methods and tools for development and test of communication networks, VANETs, 4G/5G
- Simulation of large scale networks with high number of participants with synchronized network and vehicle simulation



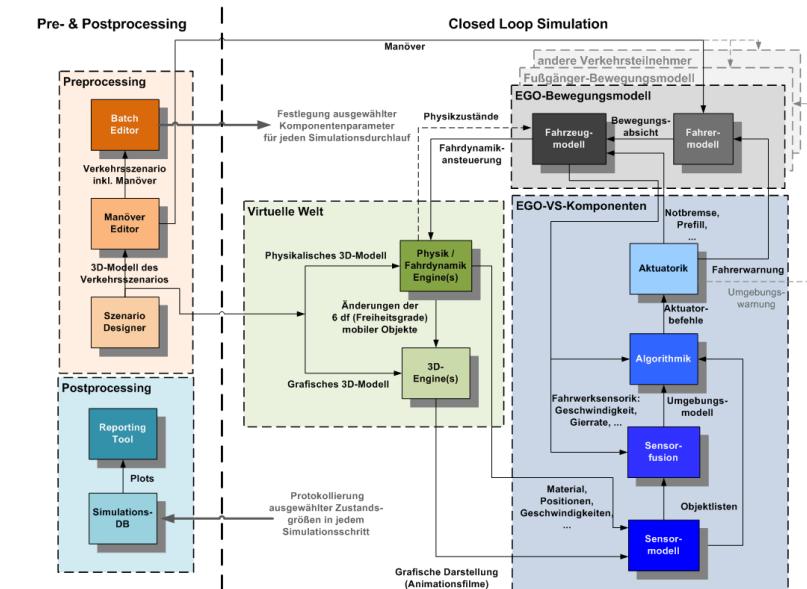
Fleet communication– Car to X

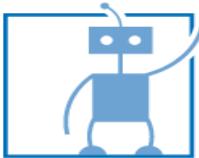
- High precision localization and tracking
- Effective solutions for:
- Bandwidth limitations
- Data-association
- Use of external sensors
- Can cope with large amounts of traffic participants
- Experience with various technologies
- PHD Filters
- GLMB Filters
- Factor Graphs
- Tracking with Neural Networks



Traffic Simulations for ADAS and Self-Driving Cars

- Simulation tool concept design and development
- Traffic simulations in a variety of simulators
 - Sumo
 - Virtual Test Drive
 - CarMaker
 - ...





Audi Autonomous Driving Cup



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[Wettbewerb 2015](#)

[Teams 2015](#)

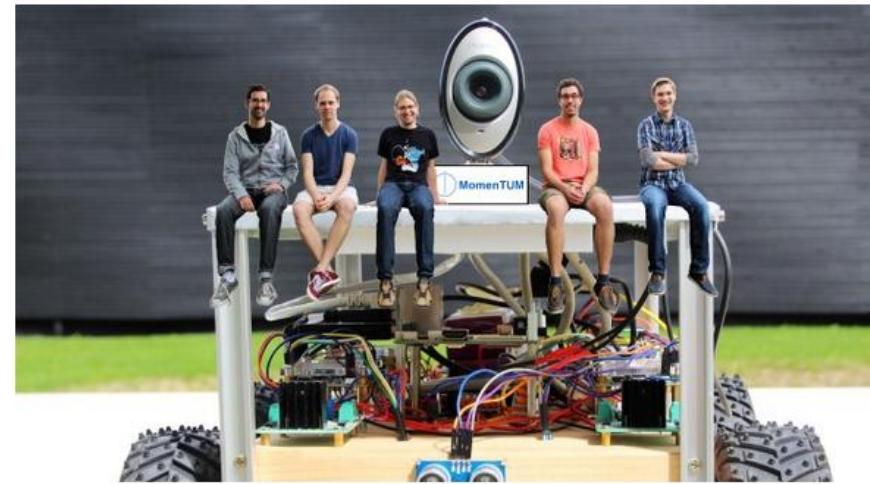
[Fahrzeug](#)

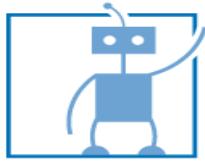
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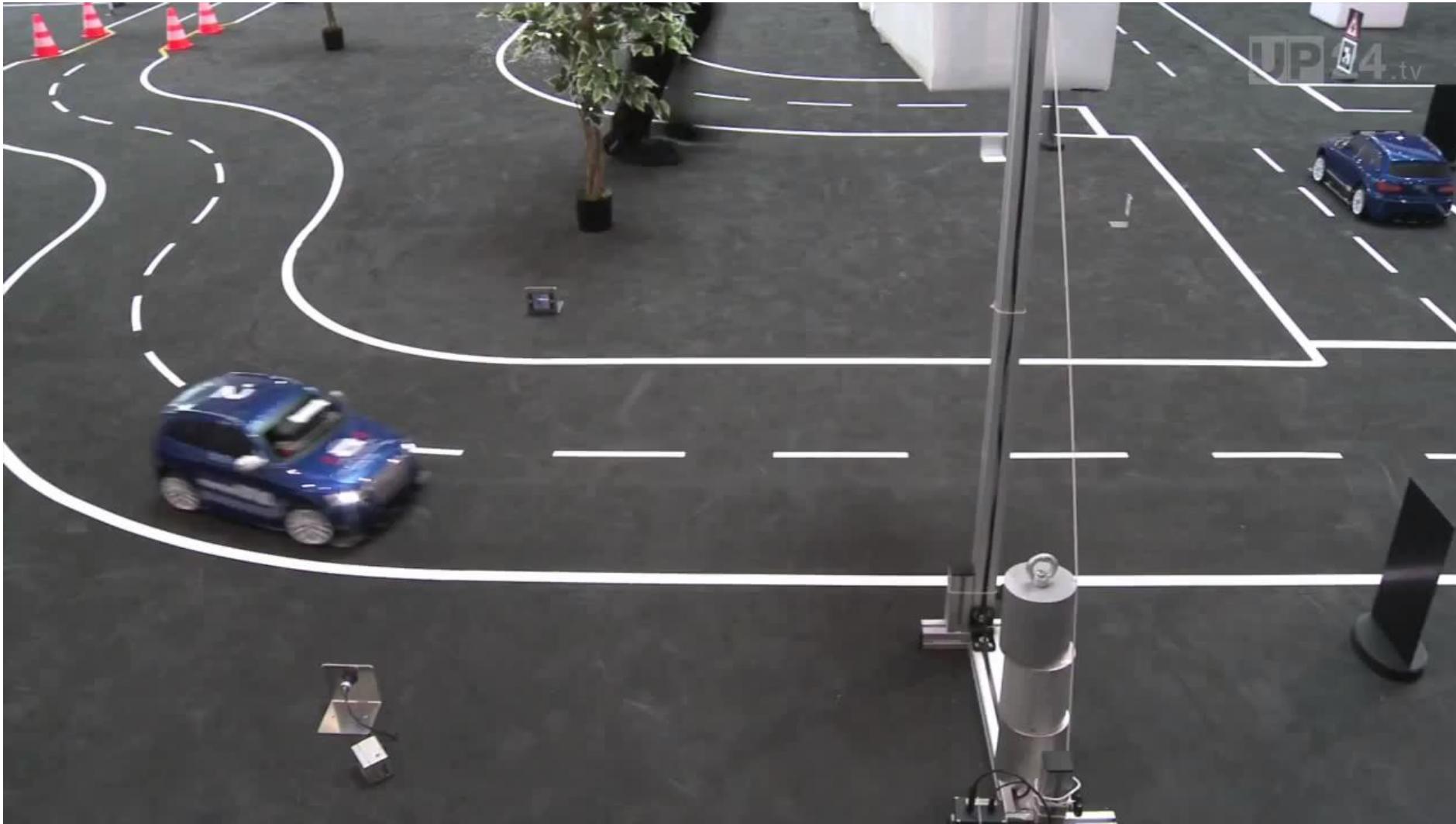
[Links](#)

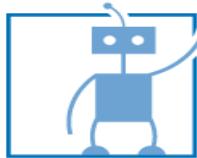
[Ihr Profil](#)





Audi Autonomous Driving Cup





Pressemitteilung

Suchtext eingeben

Ingolstadt, 27.03.2015

Studierende der TU München gewinnen ersten Audi Autonomous Driving Cup

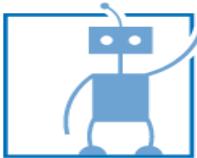
- ▶ Preisgeld von 10.000 Euro für Siegerteam
- ▶ Audi-Entwicklungs vorstand Prof. Dr. Ulrich Hackenberg: „Es ist wichtig, dass sich Studenten bereits im Studium mit wichtigen Zukunftsthemen wie dem pilotierten Fahren beschäftigen.“
- ▶ Audi-Personalvorstand Prof. h.c. Thomas Sigi: „Suchen Menschen mit Pioniergeist, die begeistert von innovativen Technologien sind.“



Beim Audi Autonomous Driving Cup wetteiferten rund 50 Studenten aus ganz



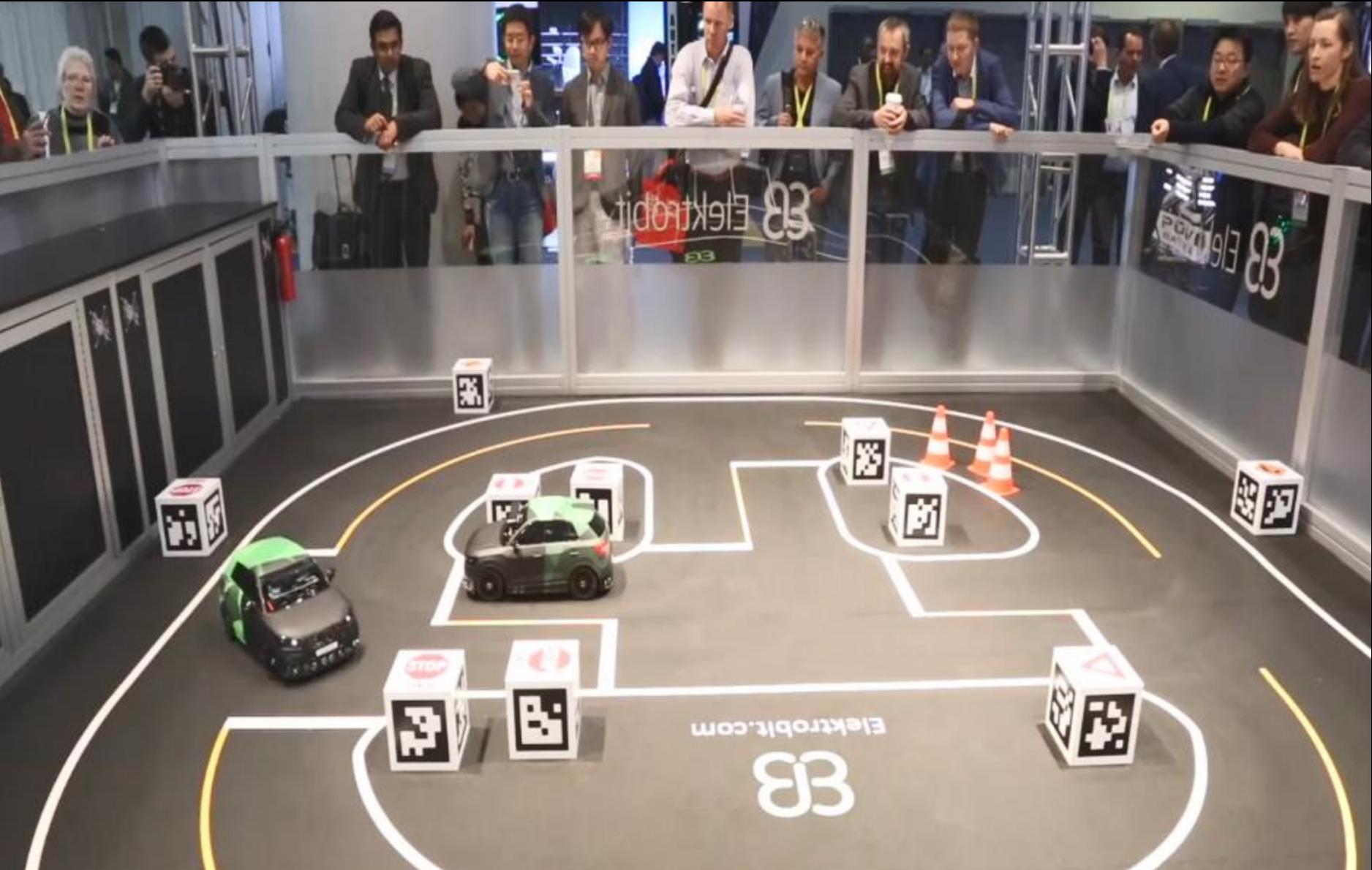
Der Preis für das beste pilotiert fahrende Modellauto geht nach München: Ein Team von fünf Studierenden der Technischen Universität (TU) München hat sich beim ersten Audi Autonomous Driving Cup gegen starke Konkurrenten aus ganz Deutschland durchgesetzt.



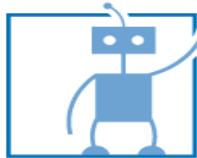
Audi Autonomous Driving Cup

„Die kreativen Lösungen, die die Studierenden präsentiert haben, haben die Jury überzeugt. Gerade für den Bereich der Fahrerassistenzsysteme und des pilotierten Fahrens sind Studiengänge von Bedeutung, die Wert auf diese Innovationsthemen legen und die Studenten dafür begeistern. Nach den guten Ergebnissen in diesem Jahr werden wir den Audi Autonomous Driving Cup auch 2016 wieder veranstalten“, so Prof. Dr. Ulrich Hackenberg, Vorstand Technische Entwicklung der AUDI AG.

Die Preise übergab Prof. h.c. Thomas Sigi, Personalvorstand und Arbeitsdirektor der AUDI AG. „Wir suchen Menschen mit Pioniergeist. Klassische Querdenker, die genauso begeistert von innovativen Technologien sind wie wir und die mutig sind, auch mal neue Wege zu gehen. Ich gratuliere den drei erstplatzierten Teams – aber für mich sind alle Sieger, die sich schon während ihres Studiums mit so komplexen Zukunftsthemen wie dem pilotierten Fahren beschäftigen.“



Impressions - CES 2017



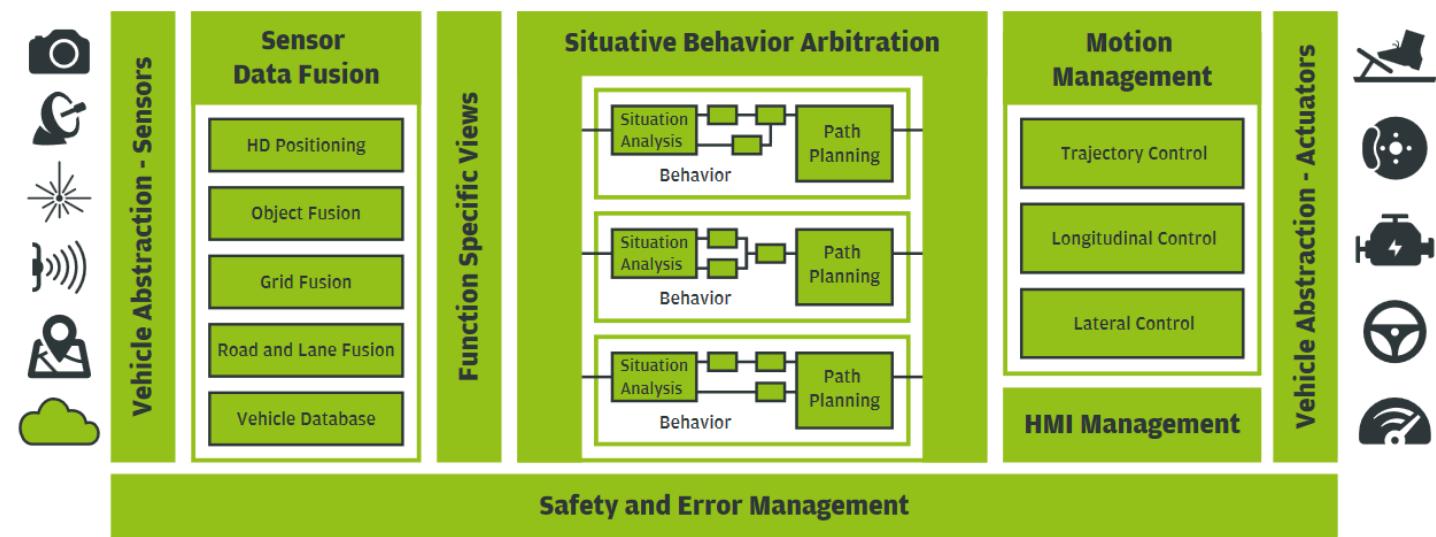
Simple AD demonstrator at CES with EB Robinos Model Cars

EB robinos: Recently developed **comprehensive, hardware-agnostic software solution for highly-automated driving systems to control and manage the increasing complexity of HAD systems and bring them to market quickly.**

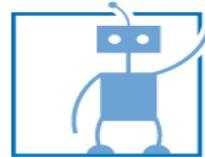
Defines structures and interfaces for common functional blocks with an **open specification** and **enables module exchanges** between companies

The goal was to **adapt and evaluate the feasibility of EB robinos** for Autonomous Driving and demonstrate it in an engaging manner **at the CES 2017**

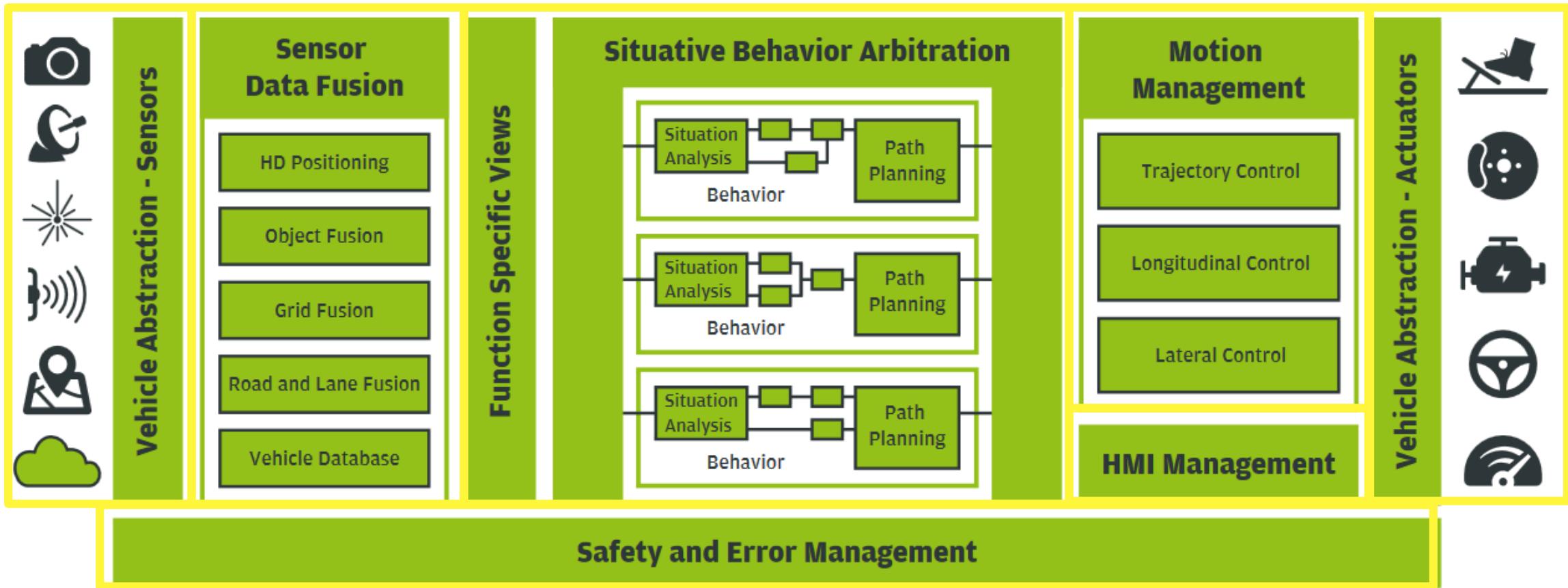
Work with Elflein & Hisch – Thanks for the good cooperation!

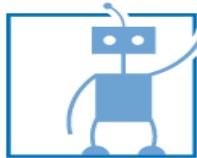


[1] EB robinos Specification, Elektrobit Automotive GmbH
<https://www.elektrobit.com/products/eb-robinos/>, 12.02.2017

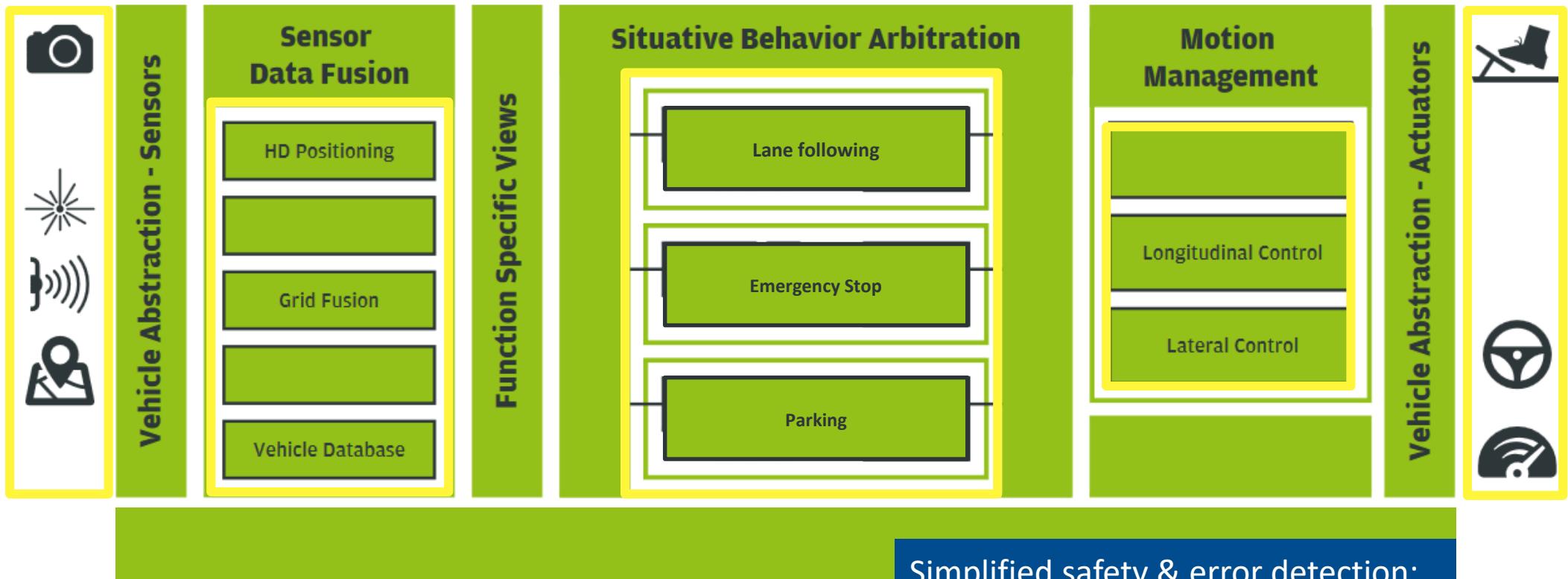


Simple AD demonstrator at CES with EB Robinos Model Cars



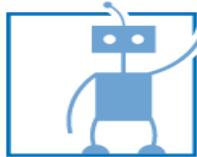


Simple AD demonstrator at CES with EB Robinos Model Cars



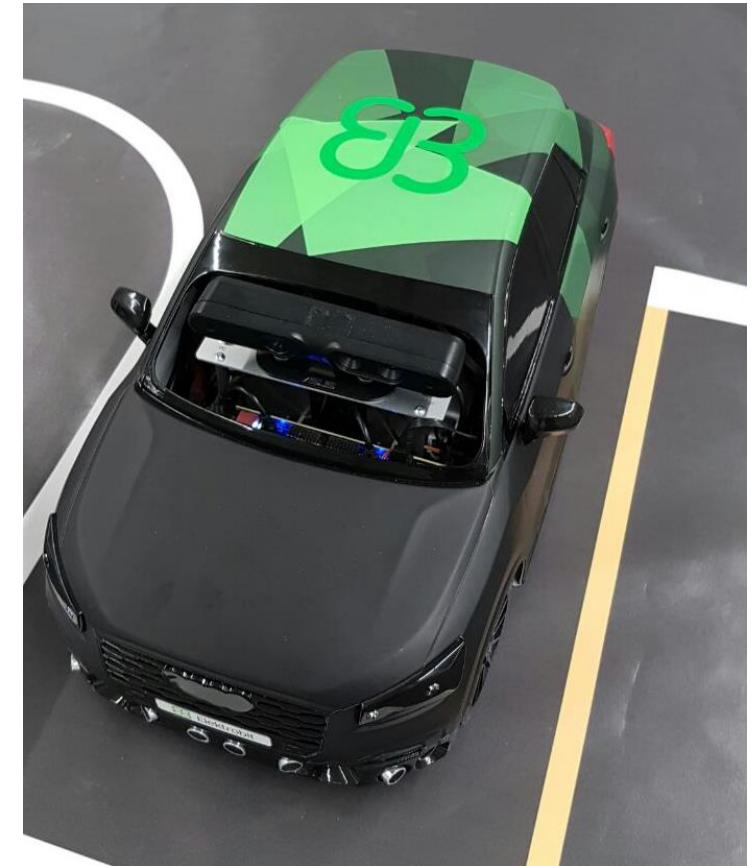
[1] Compare: EB robinos Specification, Elektrobit Automotive GmbH
<https://www.elektrobit.com/products/eb-robinos/>, 12.02.2017C

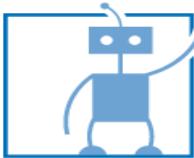
Simplified safety & error detection:
Detect component failure &
compensate or park



Simple AD demonstrator at CES with EB Robinos Model Cars

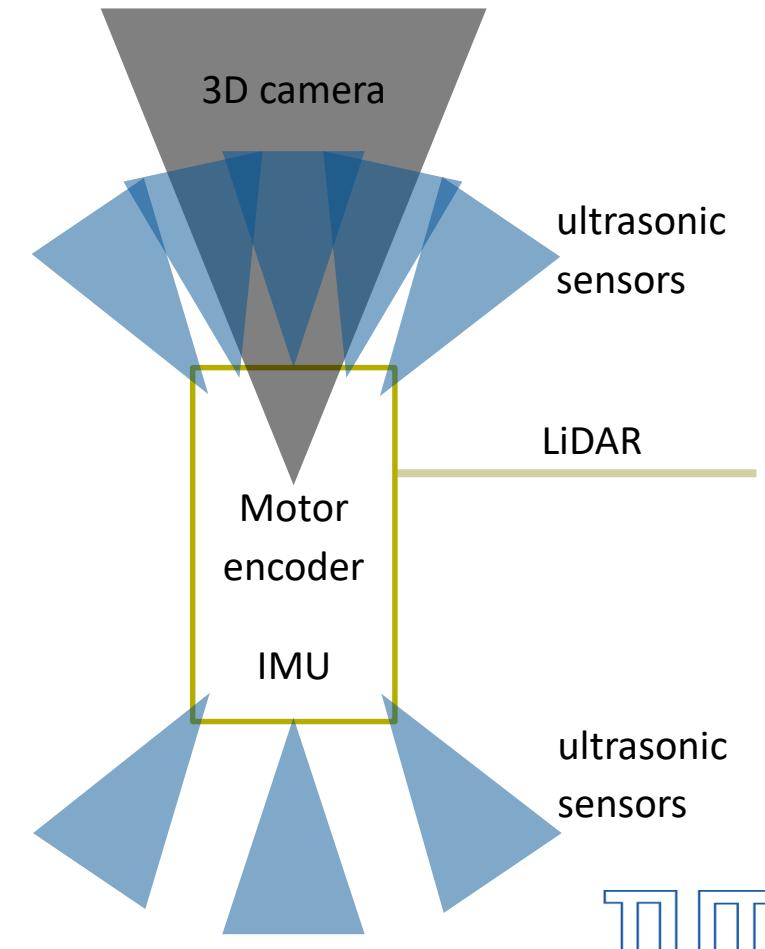
- Model car scale 1:8
- Power train:
 - Brushless DC motor (150 W)
 - 4-wheel drive
- 2 steering axles
- Head lights, indicators, reverse light, etc.
- Arduinos:
 - Sensor communication
 - Raw sensor data preprocessing
- Main processing unit:
 - Desktop motherboard
 - Intel i7 processor
 - 8 GB DDR4 RAM
 - No dedicated GPU

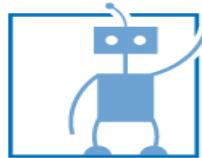




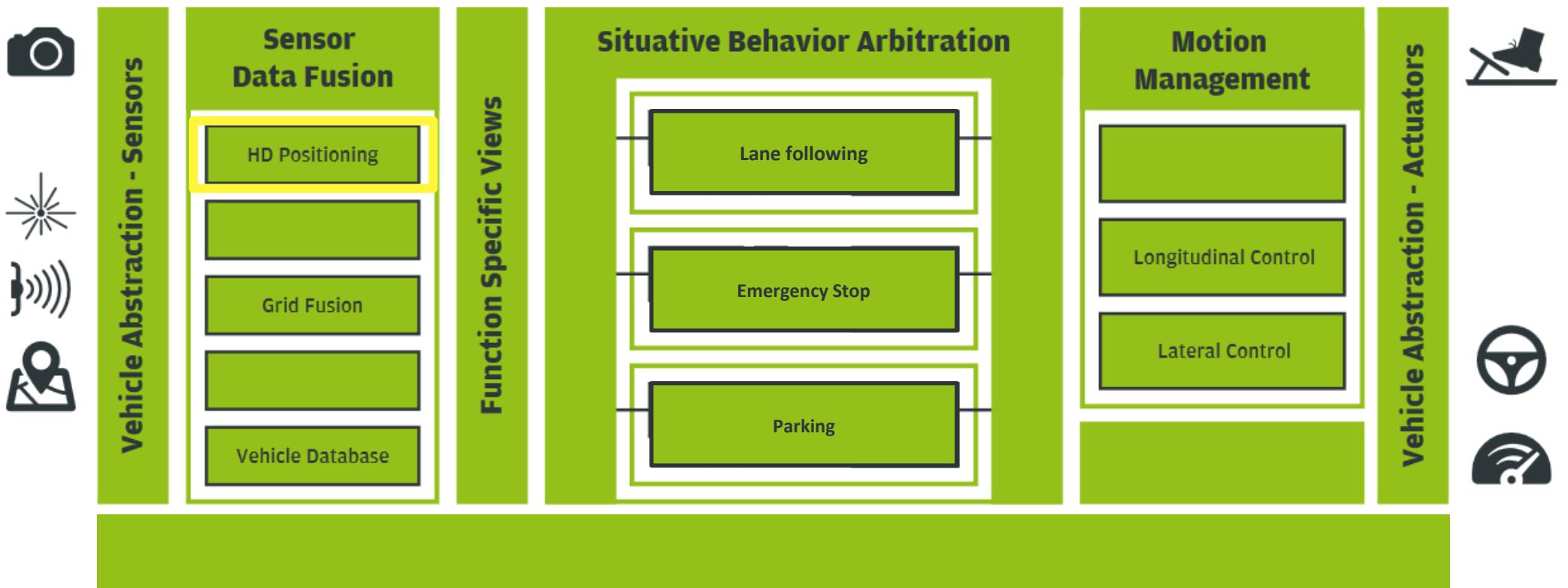
Simple AD demonstrator at CES with EB Robinos Model Cars

- Ultrasonic proximity sensors (0 – 1 m)
- 3D camera (0.8 – 3 m)
 - RGB video stream
 - Depth (distance) information (similar: Microsoft Kinect)
- Motor encoder
 - Driven distance
 - Velocity
- IMU (Inertial Measurement Unit)
 - Orientation
 - Accelerations

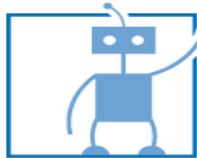




Simple AD demonstrator at CES with EB Robinos Model Cars

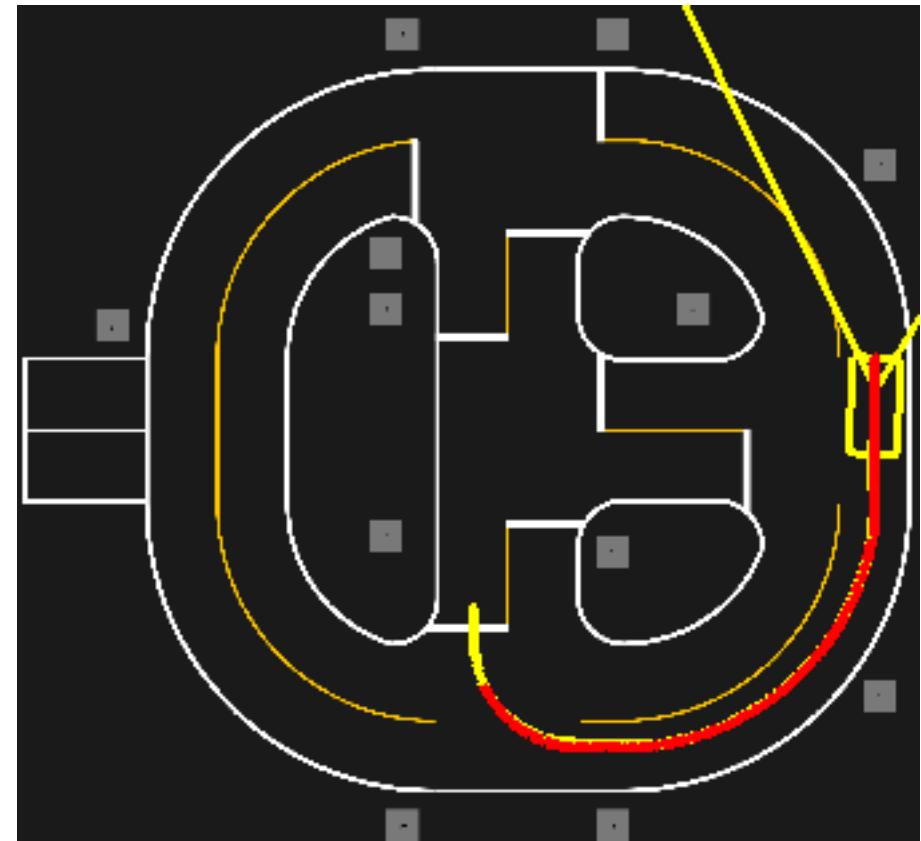


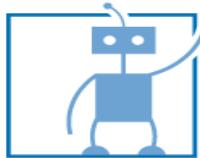
[1] Compare: EB robinos Specification, Elektrobit Automotive GmbH
<https://www.elektrobit.com/products/eb-robinos/>, 12.02.2017



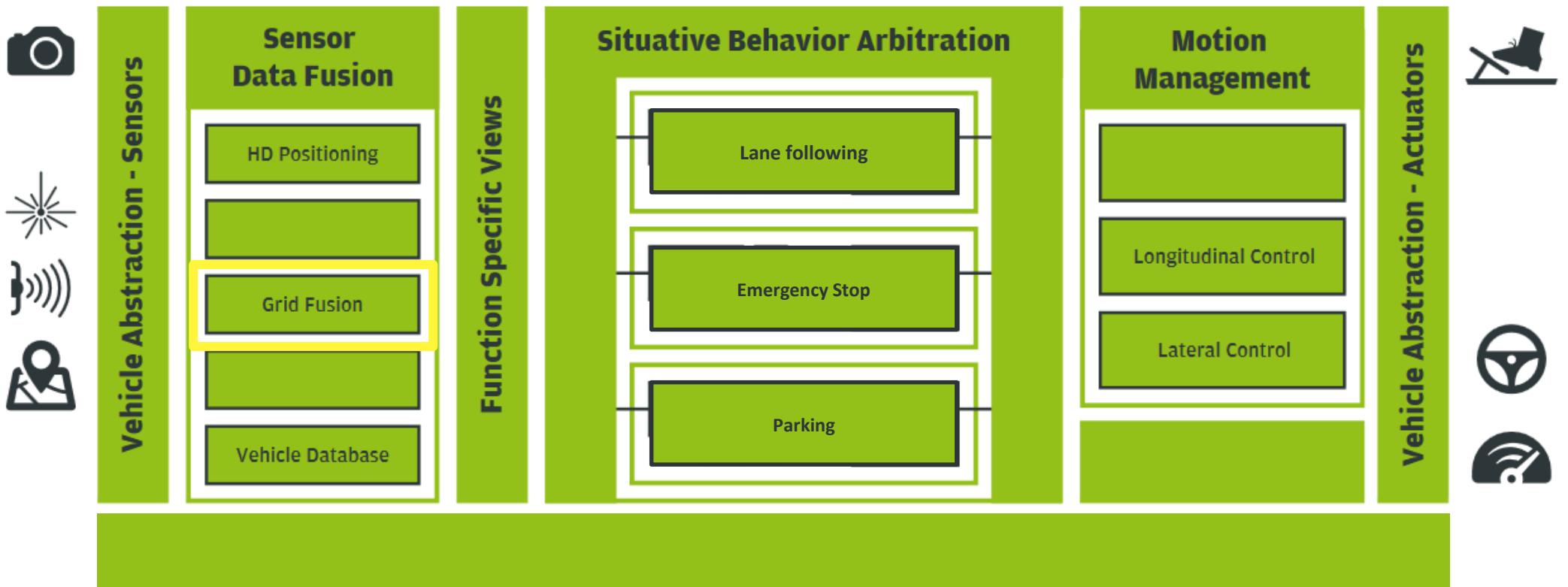
Simple AD demonstrator at CES with EB Robinos Model Cars

- **Positioning on a global map:**
- Relative Positioning
 - Integrating odometry (small movements)
 - Orientation and motor encoder
 - Extended single-track-model
- Absolute Positioning
 - Markers at known positions
 - Least squares mapping between relative and absolute positions

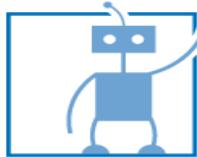




Simple AD demonstrator at CES with EB Robinos Model Cars

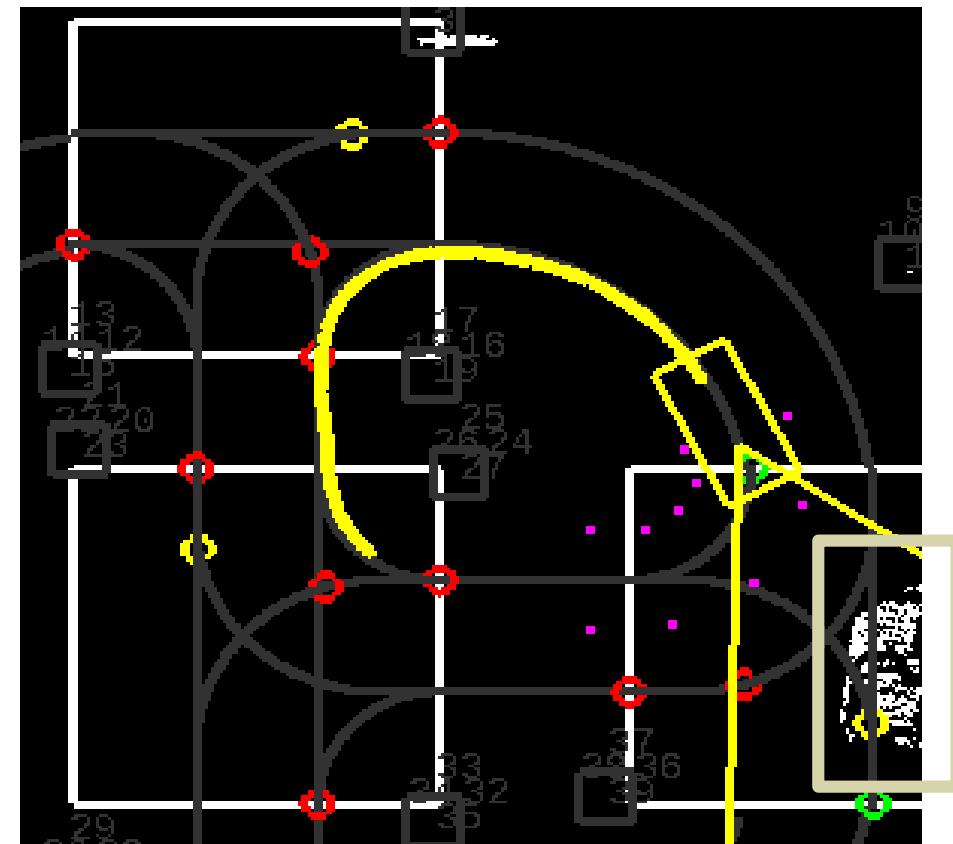


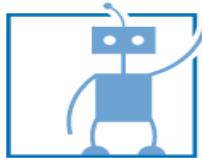
[1] Compare: EB robinos Specification, Elektrobit Automotive GmbH
<https://www.elektrobit.com/products/eb-robinos/>, 12.02.2017



Simple AD demonstrator at CES with EB Robinos Model Cars

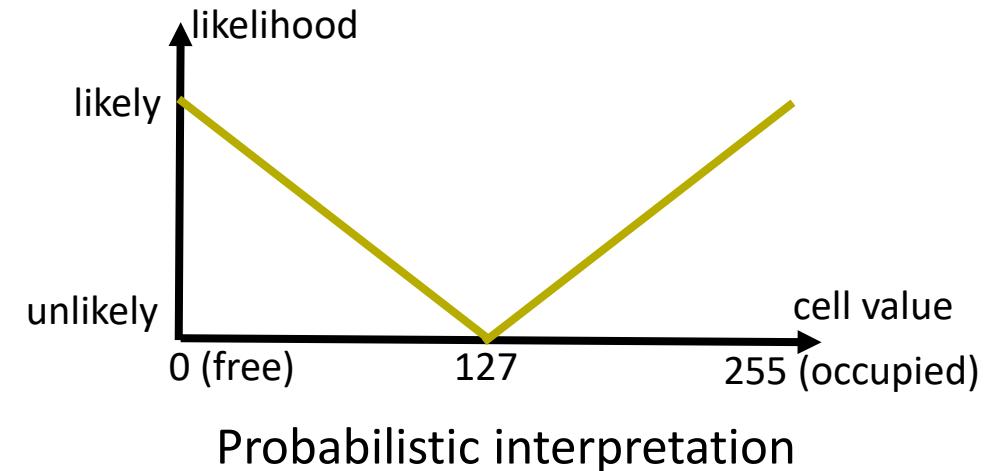
- Grid fusion:
- Grid (matrix) cells
 - Absolute positions / areas (1 cm^2)
 - Values $0 \rightarrow 255$ (single Byte)
- Probabilistic interpretation
 - Three states: free, unknown, occupied
 - Inverse sensor models
 - Exponential averaging update function

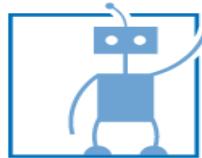




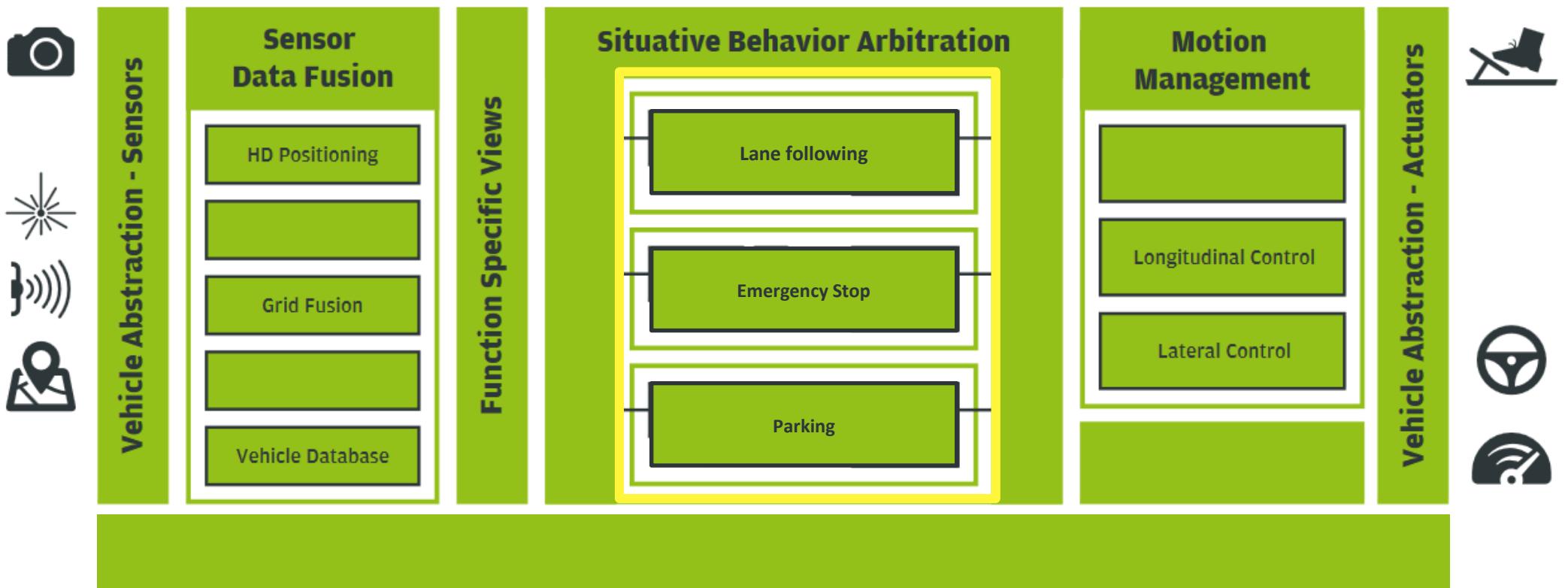
Simple AD demonstrator at CES with EB Robinos Model Cars

- Grid fusion:
- Grid (matrix) cells
 - Absolute positions / areas (1 cm^2)
 - Values $0 \rightarrow 255$ (single Byte)
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 - Three states: free, unknown, occupied
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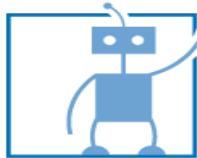




Simple AD demonstrator at CES with EB Robinos Model Cars



[1] Compare: EB robinos Specification, Elektrobit Automotive GmbH
<https://www.elektrobit.com/products/eb-robinos/>, 12.02.2017

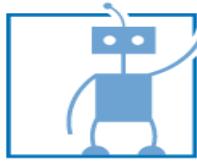


Simple AD demonstrator at CES with EB Robinos Model Cars

- Behavior planners:
 - Lane following
 - Emergency Stop
 - Parking
- Plan independently
- Desire value for speed and steering
- Highest priority is selected

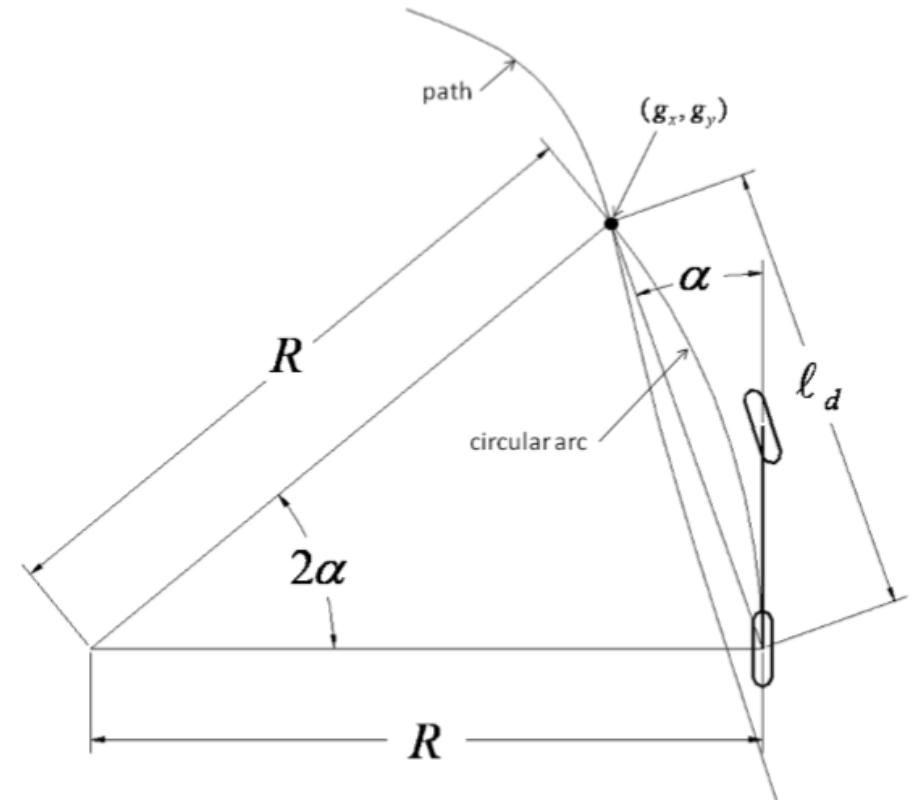


[1] Compare: EB robinos Specification, Elektrobit Automotive GmbH
<https://www.elektrobit.com/products/eb-robinos/>, 12.02.2017

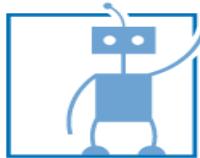


Simple AD demonstrator at CES with EB Robinos Model Cars

- Paths:
 - Crossings generate turning paths
 - Path points contain additional information
 - Speed restrictions
 - Light / indicator settings
 - Traffic rules, areas to check
- Path following:
 - Point based, no trajectory planning
 - Based on single-track-model

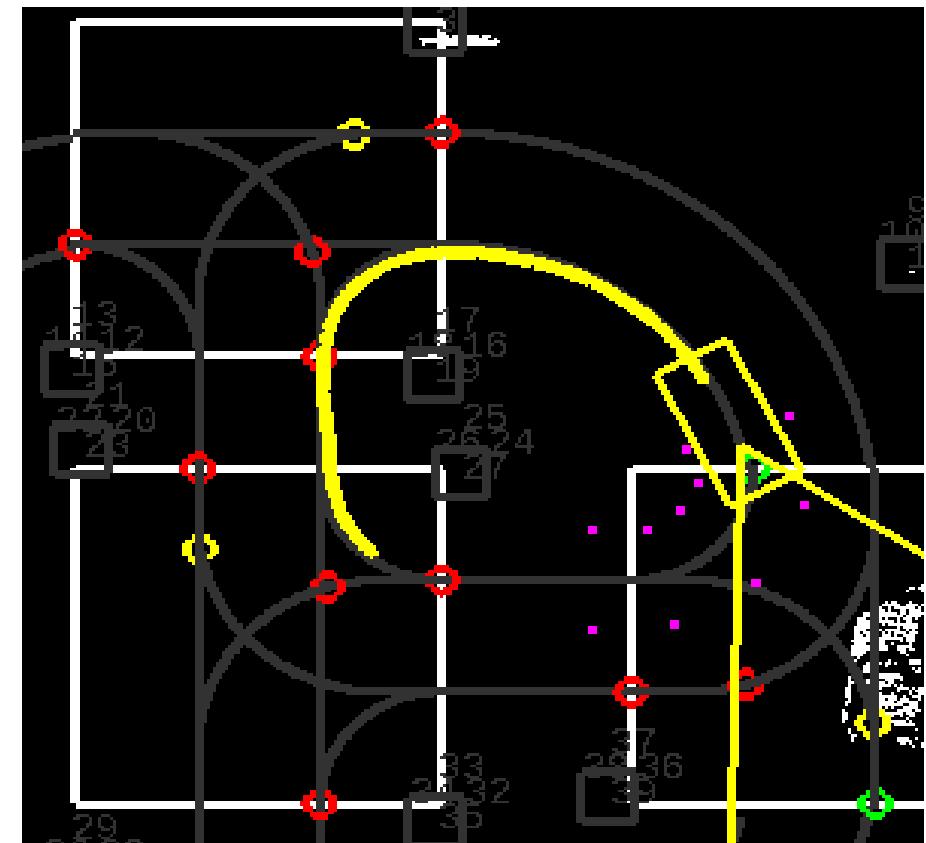


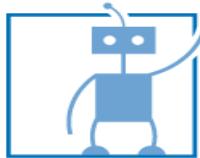
[2] Automatic Steering Methods for Autonomous Automobile Path Tracking,
Jarrod M. Snider, Robotics Institute Carnegie Mellon University Pittsburgh, Pennsylvania



Demonstrate AD at CES with EB Robinos Model Cars

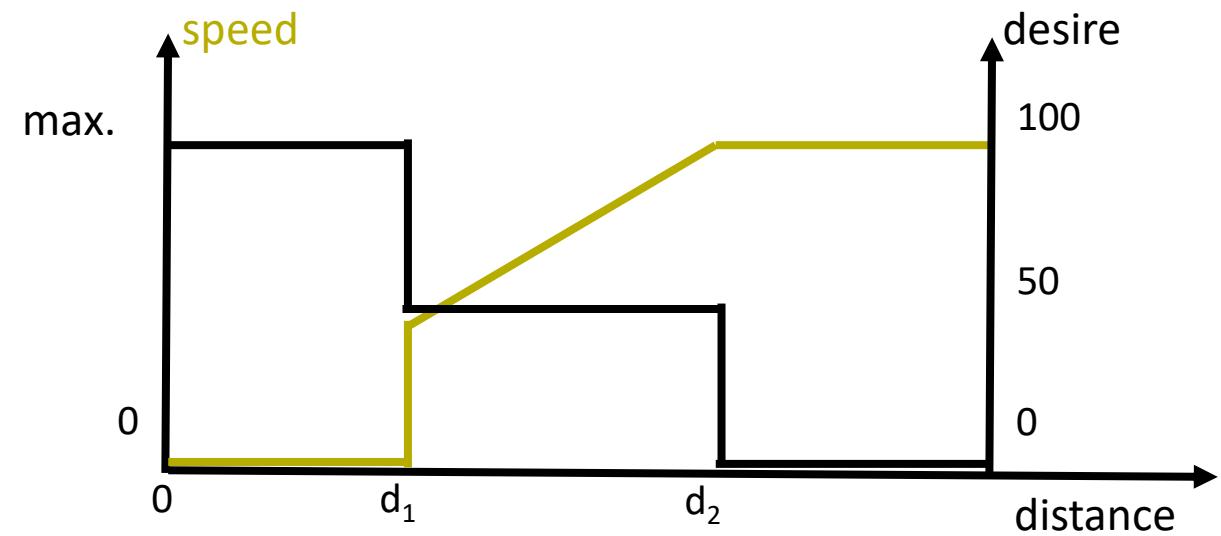
- Vehicles path is predicted
- Path is enlarged to car's dimension
→ Described by polygon



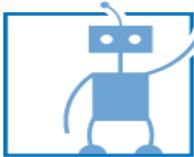


Demonstrate AD at CES with EB Robinos Model Cars

- Vehicles path is predicted
- Path is enlarged to car's dimension
→ Described by polygon
- Polygon is evaluated in grid fusion
→ Distance to closest obstacle
- Distance depended speed request closer object → lower speed, higher desire



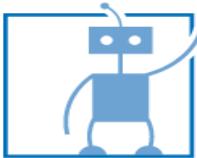
Speed, desire vs. distance



Demonstrate AD at CES with EB Robinos Model Cars

Situative behavior arbitration block, which can be thought of as a "plugin container" for the behavior (or function) modules.

- **Applicability:** The ability of the function to operate, expressed in percent. E.g. a lane change assist that sees clear lane markings, road side boundaries, and convoy tracks, and an empty left lane, might set this to 100%; if it only sees convoy tracks and lane markings are unclear (e.g. in a construction site), it might set this to 30%; if the left lane is occupied, it will always set this to 0%.
- **Desire:** The desire of the function to operate, in percent. E.g. an adaptive cruise control function set to 130km/h on an empty highway might set this to 100%; if it finds itself behind a truck going 80km/h it might set this to 50%.
- **Risk:** A scalar, expressed in percent, giving an assessment of the risk involved when performing the behavior. A lane changing assistant that sees a perfectly clear left lane might set this to 20% (since visibility from the ego vehicle will always be obstructed), one that sees a slowly-approaching vehicle to the rear in the left lane might set this to 50%, one that sees a vehicle arriving with high difference velocity might set it to 90%.
- **Comfort:** A scalar, expressed in percent, giving an assessment of the comfort to the driver that performing a certain motion will entail; expected high lateral or longitudinal acceleration or deceleration will result in a low comfort level, gentle motions in a high one.



Demonstrate AD at CES with EB Robinos Model Cars

Situative behavior arbitration block, which can be thought of as a "plugin container" for the behavior (or function) modules.

- **Applicability:** The ability of lane markings, road side boundaries, convoy tracks and lane markings. If no lane is occupied, it will always set this
- **Desire:** The desire of the function. If the ego vehicle is on an empty highway might set this to 100%.
- **Risk:** A scalar, expressed in the risk of performing the behavior. A lane change assistant that sees a vehicle approaching from the left (that always be obstructed), one that sees a vehicle arriving with a high speed, one that sees a vehicle arriving with a low speed.
- **Comfort:** A scalar, expressing the level of comfort that the motion will entail; expected high comfort in a slow motion and gentle motions in a high one.



(c) lastlemon.com 2014

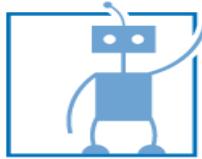
facebook.com/lifestickers

g. a lane change assist that sees clear visibility from the ego vehicle might set this to 100%; if it only sees the left lane might set this to 30%; if the left lane is

rise control function set to 130km/h on an empty highway it might set this to 50%.

I when performing the behavior. A lane change assistant that sees a vehicle approaching from the left lane might set this to 50%, one

to the driver that performing a certain action will result in a low comfort level,



Demonstrate AD at CES with EB Robinos Model Cars

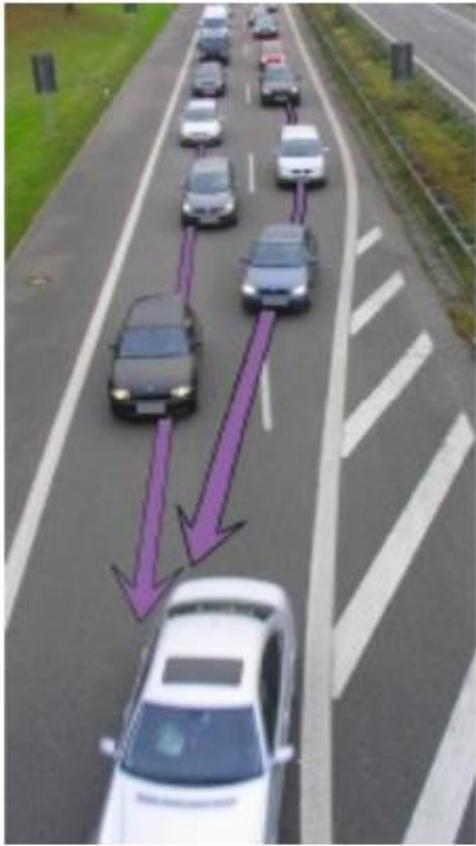
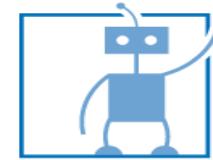
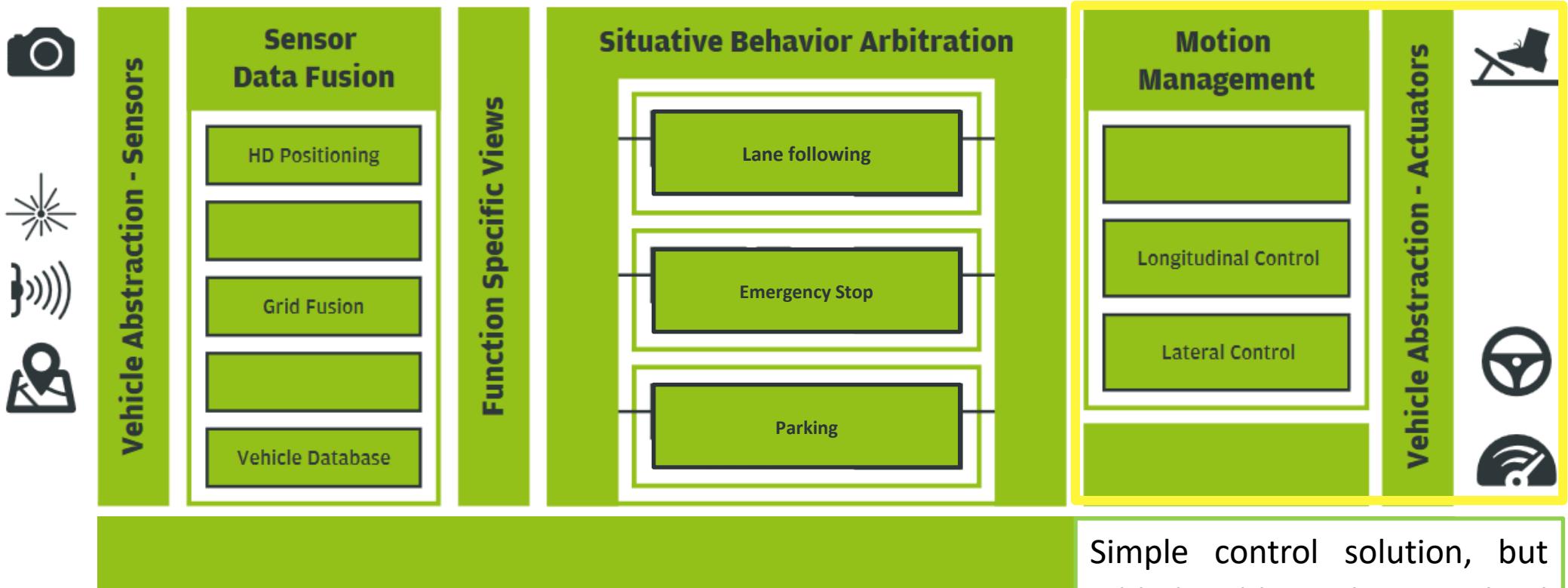


Figure 8: Merging Convoy Tracks (source: M. Reichel, *Situationsanalyse für fortschrittliche Fahrerassistenzsysteme*, Dissertation, Braunschweig, 2013)



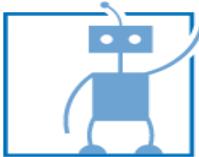
Demonstrate AD at CES with EB Robinos Model Cars



[1] Compare: EB robinos Specification, Elektrobit Automotive GmbH
<https://www.elektrobit.com/products/eb-robinos/>, 12.02.2017

Simple control solution, but added additional rear-wheel steering to save space and enable demo.





Demonstrate AD at CES with EB Robinos Model Cars

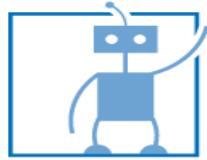
- Requirements:
- 3 autonomous cars on the track
- ‘Cool’ CES Demo

- Background:
- CES: Consumer Electronics **Show** should be exciting. Also don’t spend 300 MM on perfection (not safety critical).

- Result:
- Requirements met, **expectations exceeded**. Very high number of visitors. ATZ featured..



[1] Model Cars at CES 2017. Successful implementation of the adapted EB robinos architecture and our HAD functions.

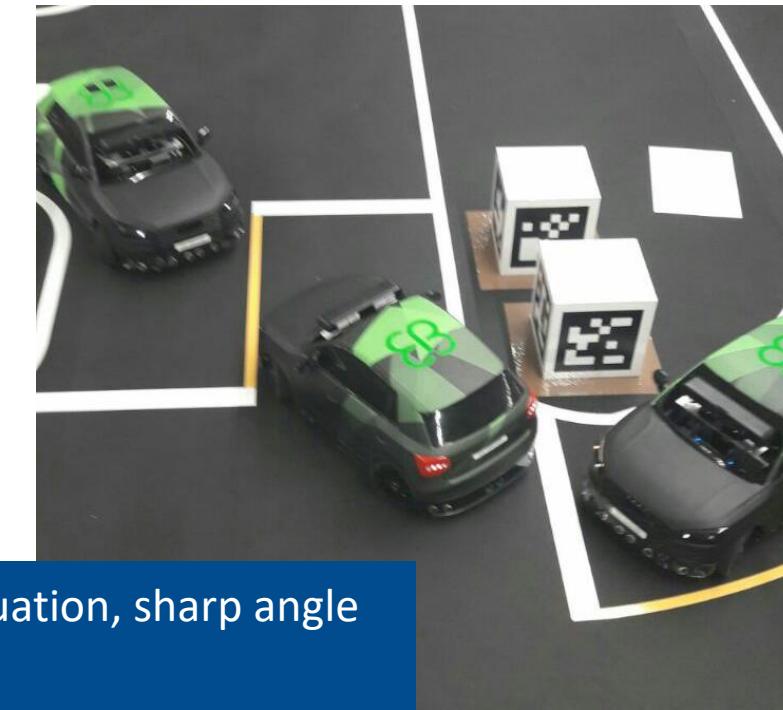


Demonstrate AD at CES with EB Robinos Model Cars



Sharp Angle Blind Spot:

No detection from
ultrasonic sensors.



Deadlock situation, sharp angle
blind spot:

Increased occurrence due to
complex car interaction

Solution: Improve physical
sensor-set & Algorithms or use
Car2X (60GHz)







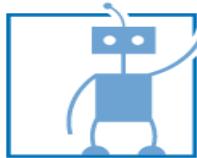
B 375 mi HOT 97.5 | ☰ | ⚡



Piloted driving assists in traffic jams

Footage
Duration: 03:37 min





Motivation

Automated Driving for more comfort, safety and efficiency

Comfort

Germans spend on average 36 hours p.a. in traffic jams.



Safety

90% of all accidents depend on human error.

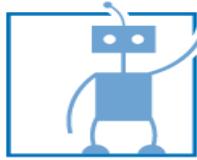


Efficiency

The manner of driving has an impact on the fuel consumption up to 20%.



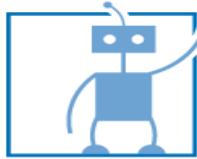
Quelle: Continental AG, Automotive Systems & Technology, 2014



Comfort



Quelle: Continental AG, Automotive Systems & Technology, Mobility Study 2013

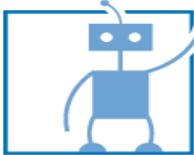


Future Predictions

Automated Driving in evolutionary steps



Quelle: Continental AG, Automotive Systems & Technology, 2014



Short history of robot IKT

- 1954, George Devol US-Patent No. 2,988,237 “Programmed Article Transfer”
- Unimation founded 1956 delivered 1961 first robot to General Motors
- “... Unimation ... first turned a profit in 1975 after **19 years of research, development and market building, ...**” (N.Y. Times, Mar 21, 1982)

1

2,988,237

PROGRAMMED ARTICLE TRANSFER
George C. Devol, Jr., Brookside Drive, Greenwich, Conn.
Filed Dec. 10, 1954, Ser. No. 474,574
28 Claims. (Cl. 214—11)

The present invention relates to the automatic operation of machinery, particularly to automatically operable materials handling apparatus, and to automatic control apparatus suitable for such machinery. The invention will also be seen to have certain related method aspects. In view of the main objective, the following disclosure is addressed particularly to the handling of materials. However, certain of the novel features disclosed will be recognized as having more general application.

Universal automation, or “Unimation,” is a term that may well characterize the general object of the invention. It makes article transfer machines available to the factory and warehouse for aiding the human operator in a way that can be compared with business machines as an aid to the office.

In applying one feature of this invention, for making

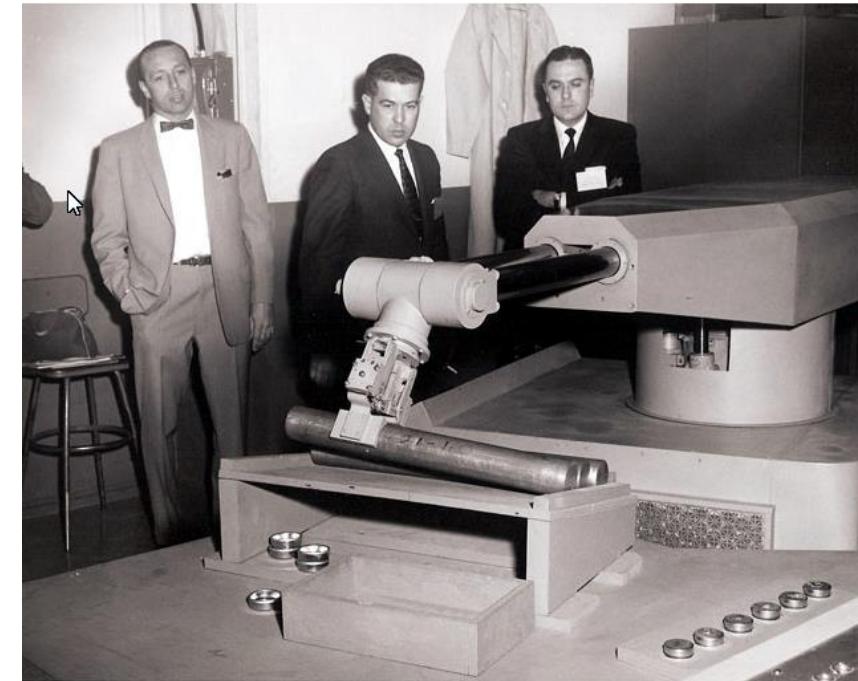
not heretofore been met with flexible programming. The art of article transfer machines has been identified persistently over the years with motions produced by operating cams or, more recently, by limit

switches that can accomplish certain few operations, yet

nothing short of manual control or direct hand transfer

has been devised to serve where real versatility is re-

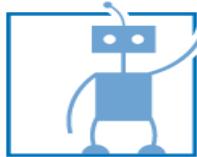
quired.



Unimation President, Joe Engelberger in his trademark bowtie, development engineer George Munson, and Unimation chief engineer Maurice Dunne prep Unimate serial #001 for shipment to the first installation; GM's die casting plant in Trenton, NJ. Circa 1961.

Source: <http://www.botmag.com>



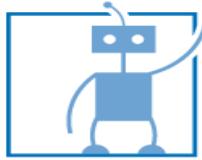


Short history of robot IKT

- First functional robot: **Unimate 1961**
- Signature: electrical/hydraulic engine
- Digital Control, programmable
- No communication device
- No external sensors



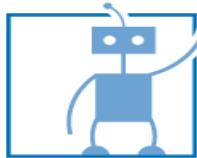
Johnny Carson: Tonight Show 1966



Short history of robot IKT

- Connected, communicating systems started ~ 1990
- Cooperative systems ~ 2000
- Simple or no sensors



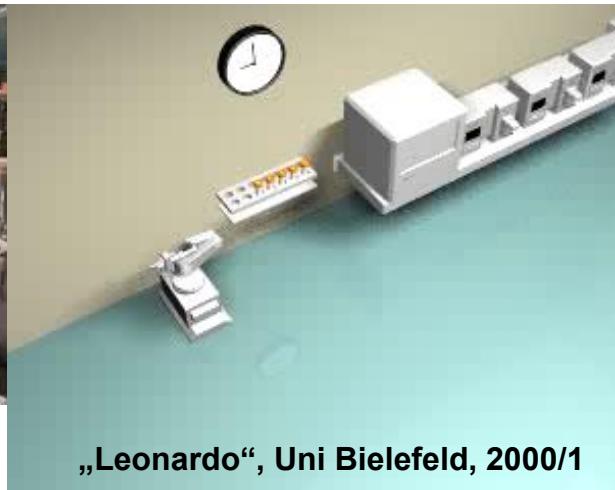


Short history of robot IKT (2000 to today...)

- Connected systems with lots degrees of freedom
- Many sensors enabling adaptivity, partial autonomy, program by guidance
- Mobile to change work location
- Physical cooperation with humans
- Multi modal for information exchange with humans



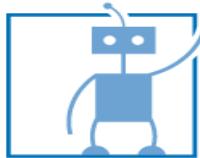
„Justin“, DLR, 2009



„Leonardo“, Uni Bielefeld, 2000/1

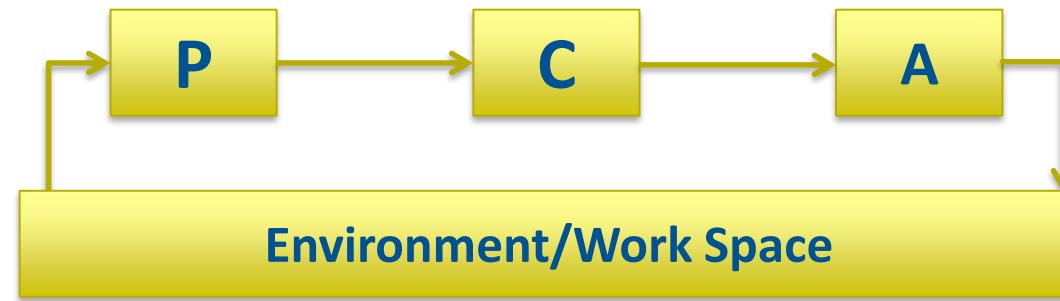


Biotech - Automation using Mobile Manipulation

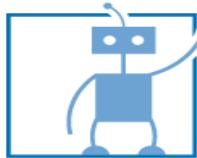


In-between-summary

- Signature of robot architectures
 - Many sensors with different measurement principles
 - Real time reaction necessary, short reaction times
 - Various abstraction levels, direct reaction up to highlevel planning

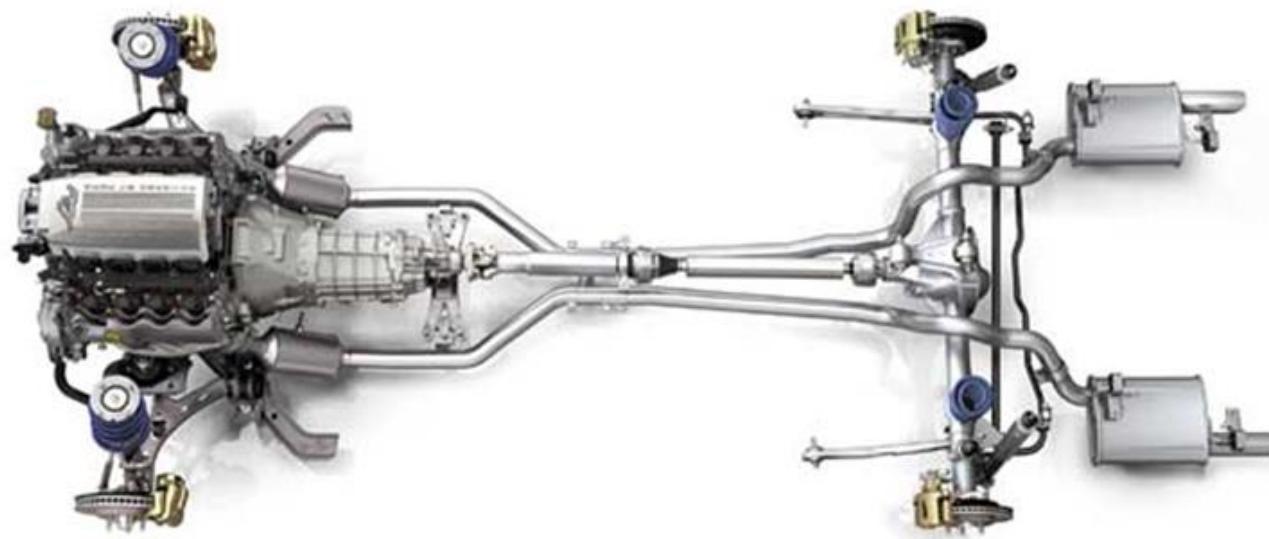


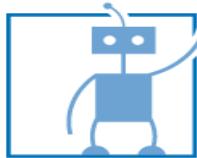
- Perception → Cognition → Action
- **Information flow is decisive**
 - Energy flow is less important



Short history of automotive IKT

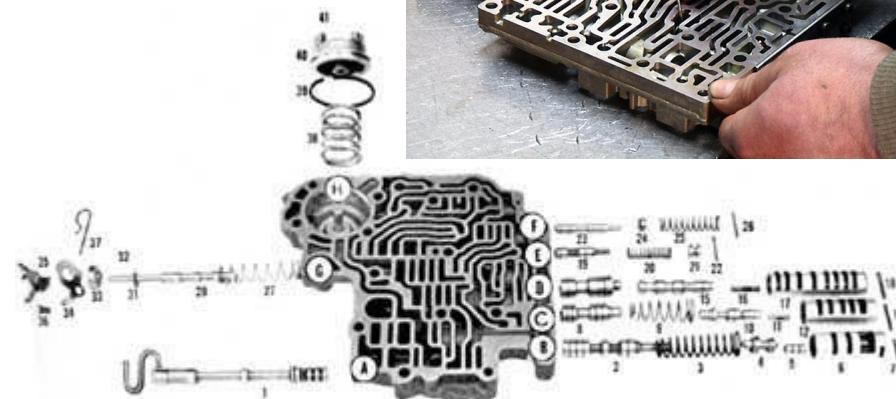
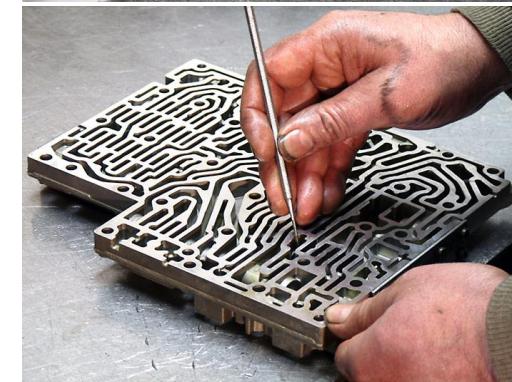
- Until 1990s no or minimal IKT in cars except for radio; control of energy flow by driver
- Three development directions:
 - **Control units** for automated gears & mechanical injection
 - **Electronic** gasoline injection
 - Anti-Blockier-System **ABS**



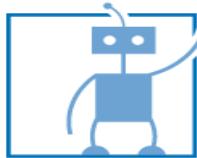


Short history of automotive IKT

- GM **Hydramatic** 1939: hydraulic clutch, planetary gears
- GM **Dynaflow** 1948: torque converter and planetary gears
- Chrysler **TorqueFlite** 1956: Touchdetector control
- First control purely hydraulic; continuous develop towards mechatronic control



Exploded view of a valve body section. Another section containing additional valves is mated to it. On some units, a third section will contain electrical components.

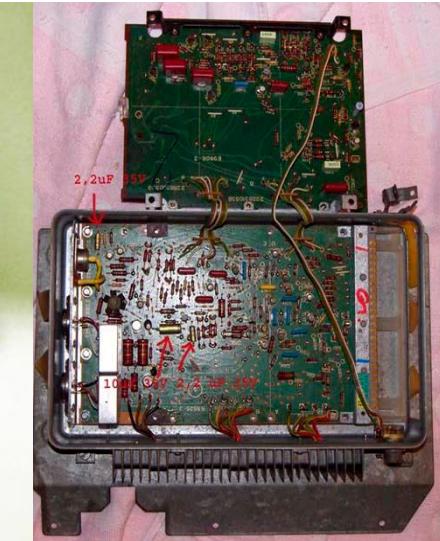


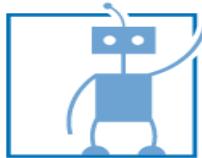
Short history of automotive IKT

- (Mechanical) gasoline injection, introduction in airplanes in 1930s in Germany, by Bendix in USA in the 1950s
- First vehicles with electronic gasoline injection 1958 Chrysler's sport models D300, Adventurer, D500 and Fury with **Bendix Electrojector**
- First German car with electronic injection (Bosch D-Jetronic): VW Typ 3 (1600 E), 1967, first control units (analog)



http://www.ch300imp.com/bendix_us.htm

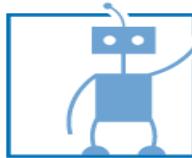




Short history of automotive IKT

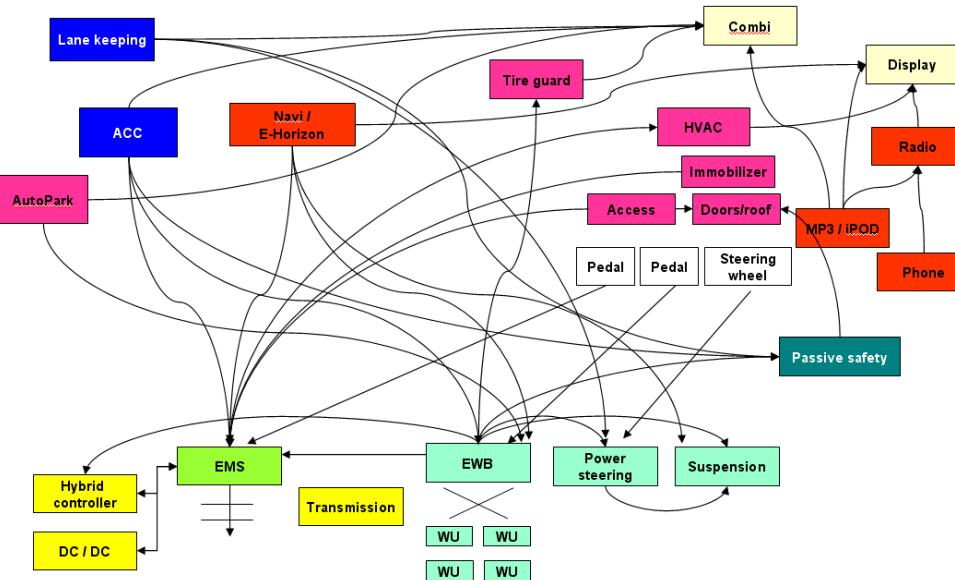
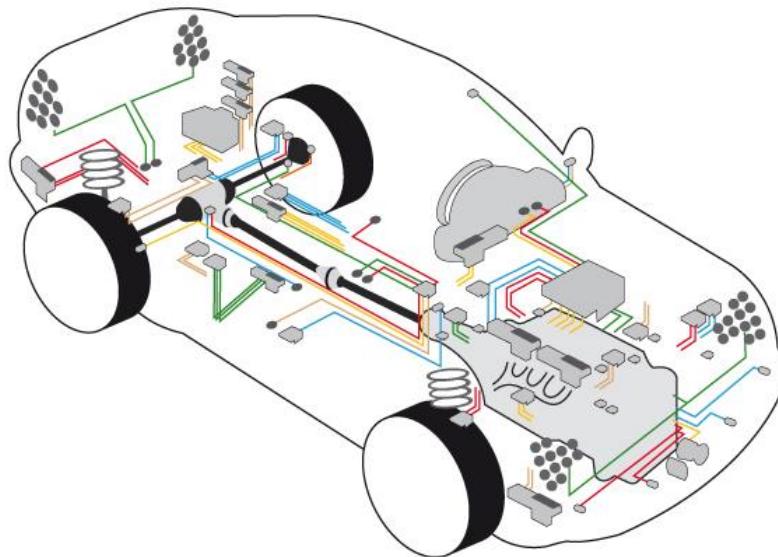
- First ABS demonstration by Mercedes-Benz 1970
- Series introduction 1978 in S-Klasse
- First digital control units, base for digitalization in cars



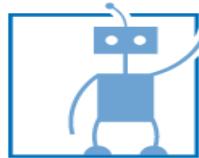


Short history of automotive IKT

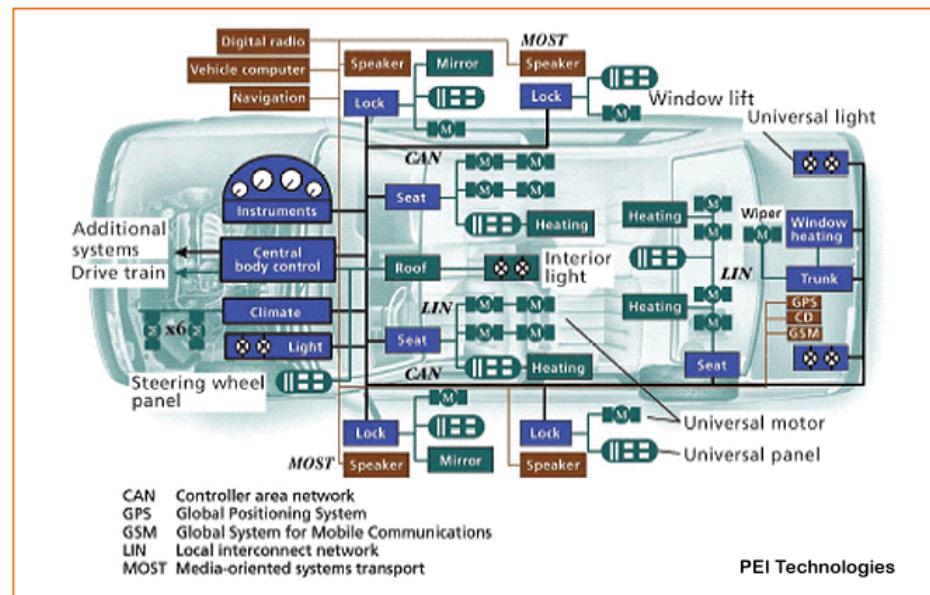
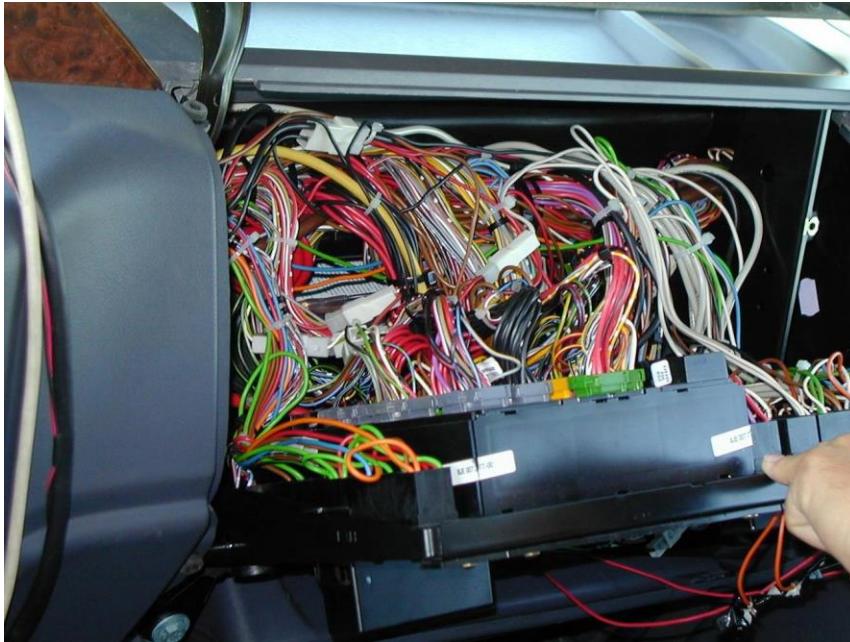
- Many functions distributed across a lot of different ECUs
- Highest communication and development complexity

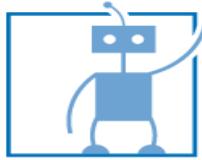


Data dependencies between all components;
Functions are spread across ECUs
(G. Spiegelberg, Siemens AG)



State of the art: “hard cabled” architecture with distributed control units and dedicated bus systems

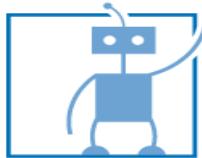




TV Commercial Audi 80 (1972)

- Ingenious Hardware Design: highly reliable, simple, cheap
- But: no adaptation, no complex functions





In the Past

Industrial Robotics



- Robots are **steel arms** that do not change their location
- They can be **programmed** for complex routine operations
- They can **handle** objects and **manipulate** the environment

Service Robotics

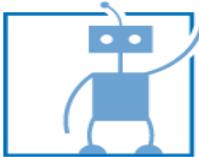


- Robots are **mobile** platforms that change their location
- They can implement **simple tasks** without user programming
- They can **transport** objects and perform **simple tasks**

Passenger Cars



- Cars are **mobile** platforms that change their location
- They have a **simple user interface** and depend completely on human commands
- Their design implements a lot of engineering knowledge in **hardware**



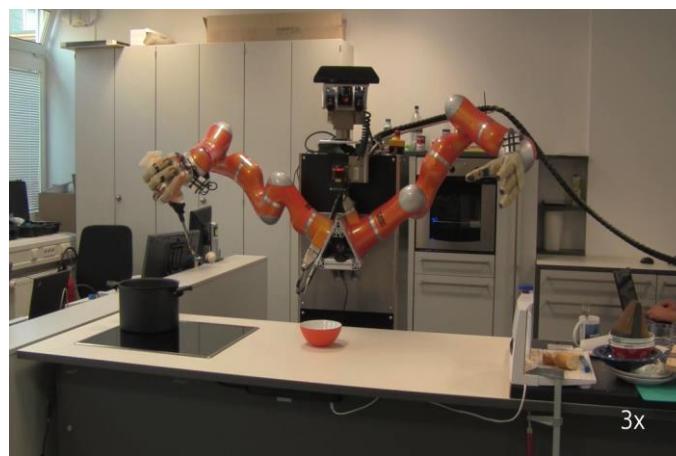
... at Present ...

Industrial Robotics



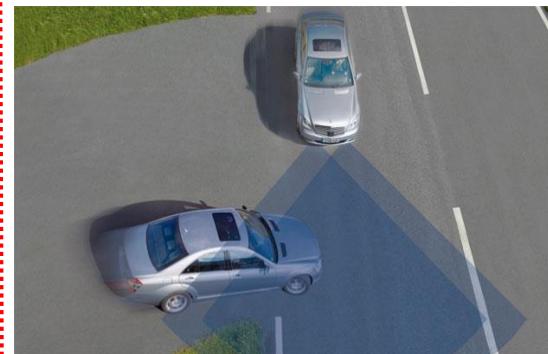
- Industrial robots are combined with mobility: **loco-motion and manipulation**
- They are **sensor based** and are becoming more and more autonomous
- They can perform **sequences of complex tasks**

Service Robotics

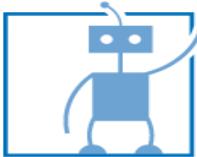


- Robots are (prototype) mobile platforms with the **ability to handle objects**
- They are **sensor based** and are becoming more and more autonomous
- They can perform **sequences of complex tasks**

Passenger Cars



- Cars are mobile platforms **with assistance systems**
- They are **sensor based** and are becoming more and more autonomous
- They can perform **sequences of complex tasks** (e.g., parking)



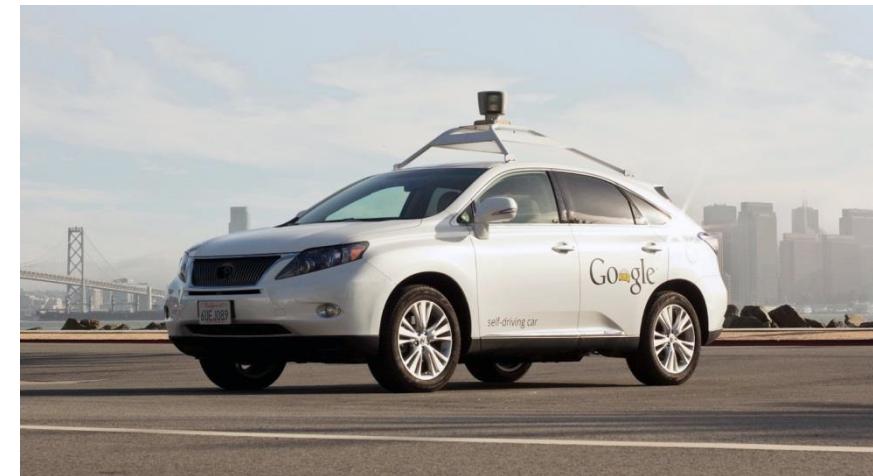
... in the Future

Industrial Robotics

Service Robotics

Passenger Cars

- There will be a **unification** of two strands: service in the industry, object handling **at home and for everyone, mobility indoor and outdoor**
- The **basic technologies** converge, i.e., sensors, cognition, path planning, behaviour generation, human-robot-interaction, ... automatic self-configuration, ... different kinds of bodies ... growth, and **architectures**
- However, there will not be a “universal robot”, but **specific** mechanical designs with less or more adaptivity → lots of new opportunities



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