

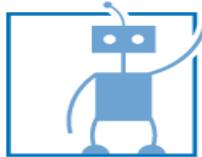
The background image shows an aerial view of a modern university campus. It features several large, light-colored buildings with flat roofs and white trim. A prominent building in the center has a large glass-enclosed entrance and a circular driveway. The campus is surrounded by green fields and trees,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

# Autonomous Driving

## Summer 2019

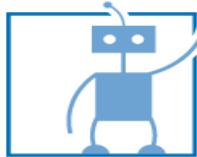
Gereon Hinz

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



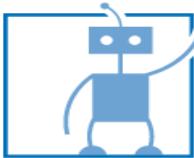
## Today's Content

- 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

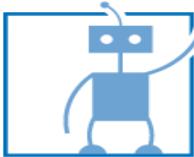
- Lecture:
  - Tuesday 16:00 ~ 18:00 in MW 1801, Ernst-Schmidt-Hörsaal (5508.01.801)
- Examination:
  - Exam (~60 minutes). Date to be announced.
- Changes will be announced via email
- Lecture slides to be uploaded on moodle
  - change every year, due to updated topics and speakers
- Questions and comments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



## Planned schedule (up for change)

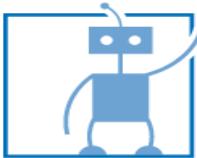
Topic	Purpose
Introduction	Participate in ongoing AD discussions
Path Planning	Plan paths and execute them
Sensor Fusion	Fuse sensors to go from data to information
Deep Learning Applications in AD	Know current application areas, strengths, weaknesses
Semantic Representations & Reasoning	Represent and 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



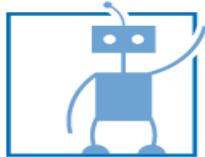
## About this lecture...

- 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.

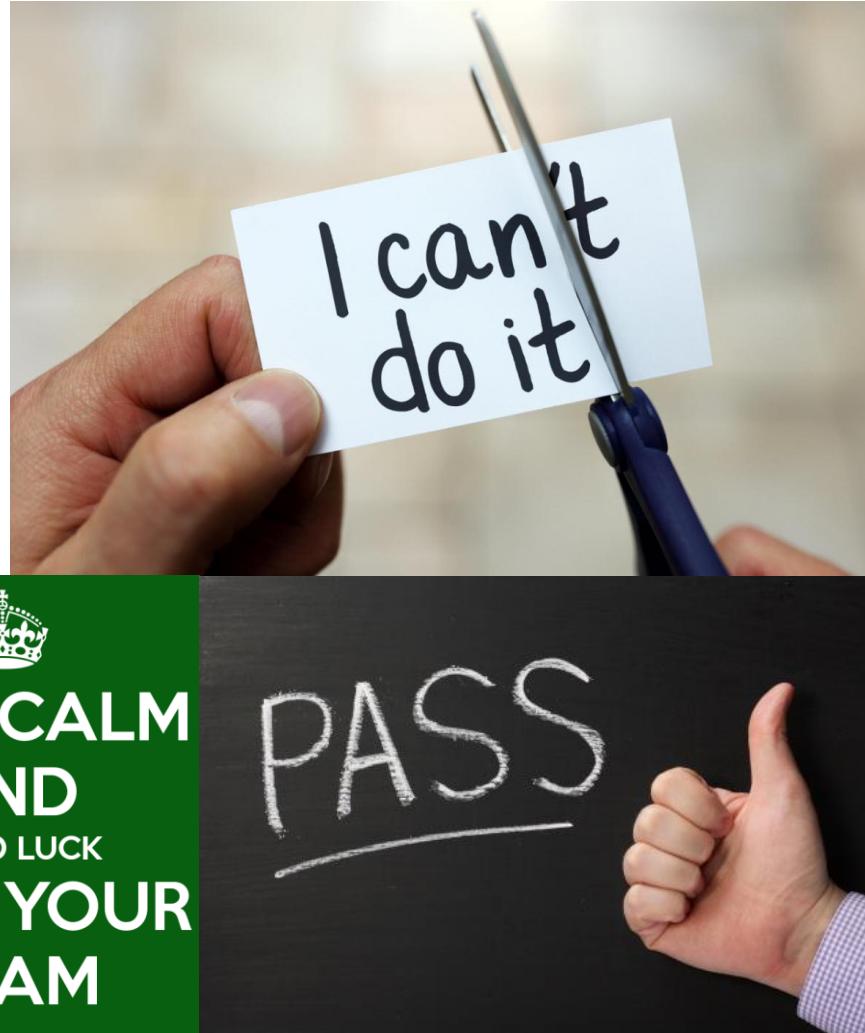
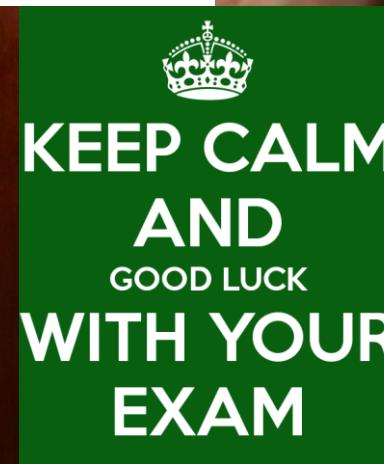
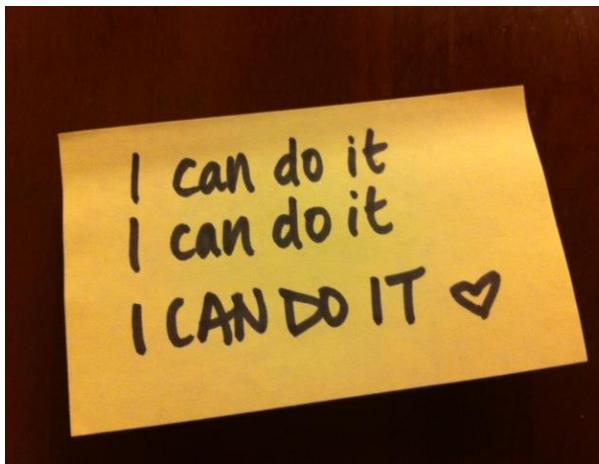


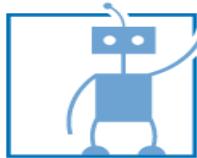
## About this lecture...

- 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...





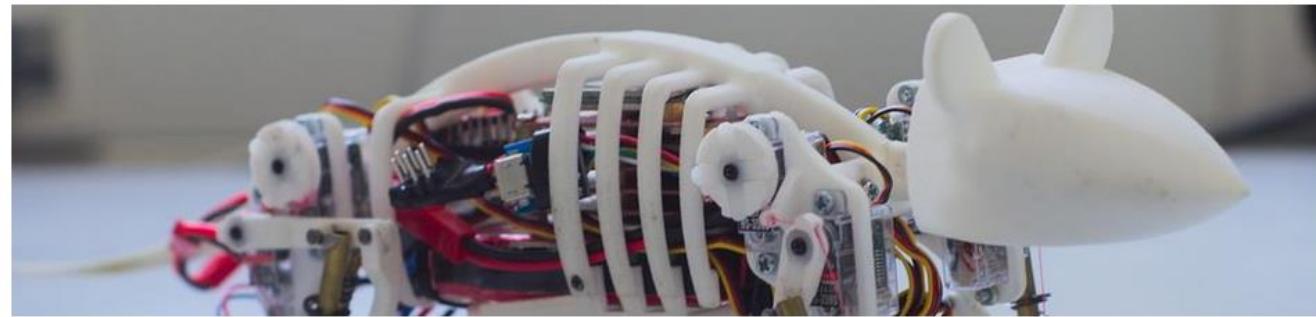
# LS VI – Chair of Robotics, Artificial Intelligence and Real-time Systems

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



- [Home](#)
- [People](#)
- [Research](#)
- [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

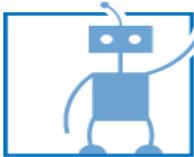
## Famous Completed Projects

- [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

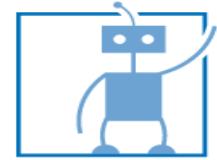
Type	Title	Duration
SE	<a href="#">Doctoral Seminar - Robotics (IN2137)</a>	2
VO	<a href="#">Embedded Networked Systems (MSE) (IN8014)</a>	3
PR	<a href="#">Labcourse - Building a modular robot (IN0012, IN2106, IN4231)</a>	6



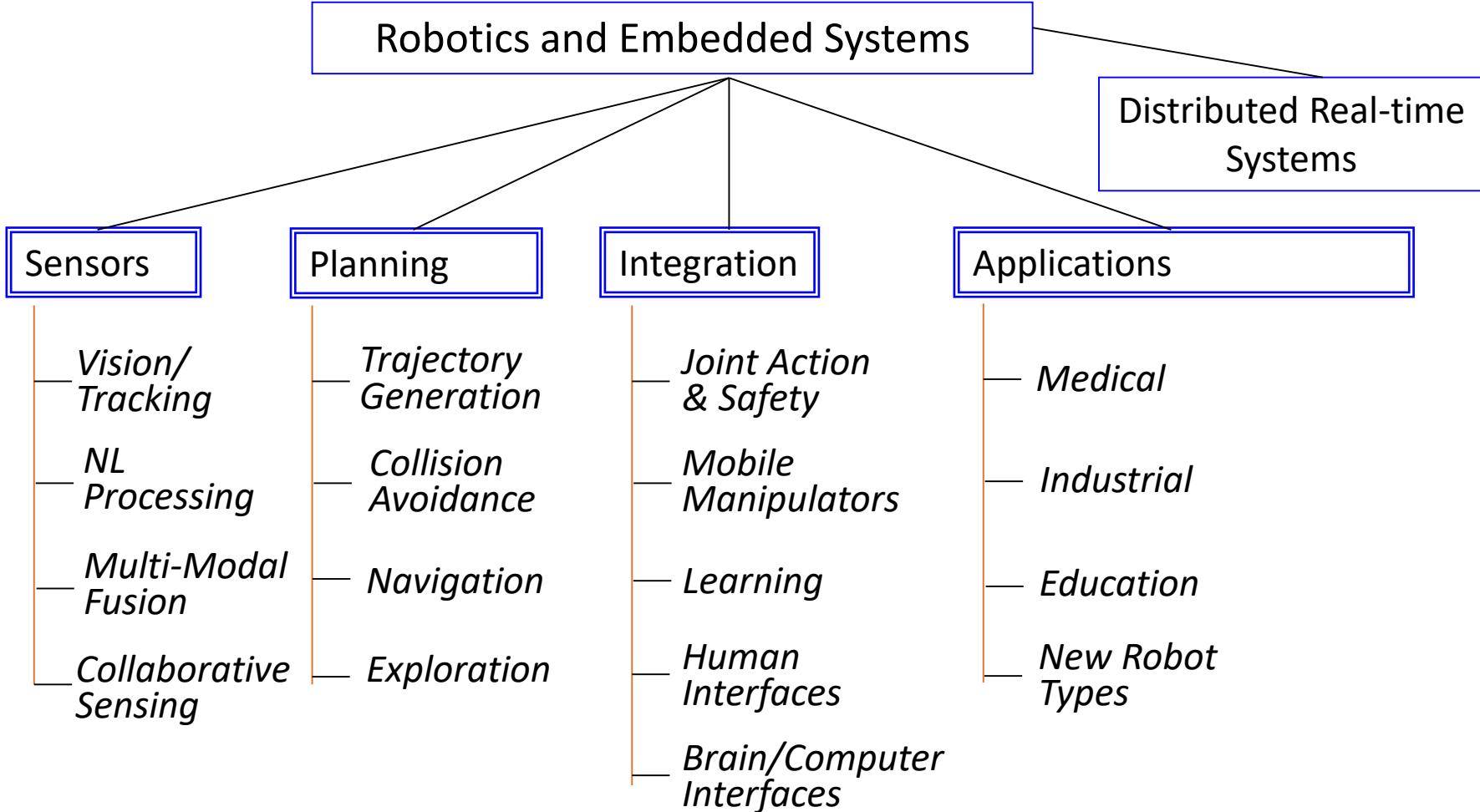


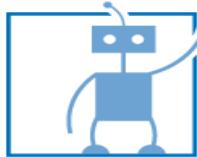
## LS VI – Robotics and Embedded Systems

- 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.

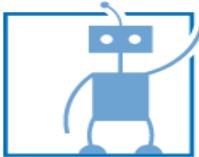
Finding common ground between manufacturers and the research community, when it comes to defining the future direction of robotics research.

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

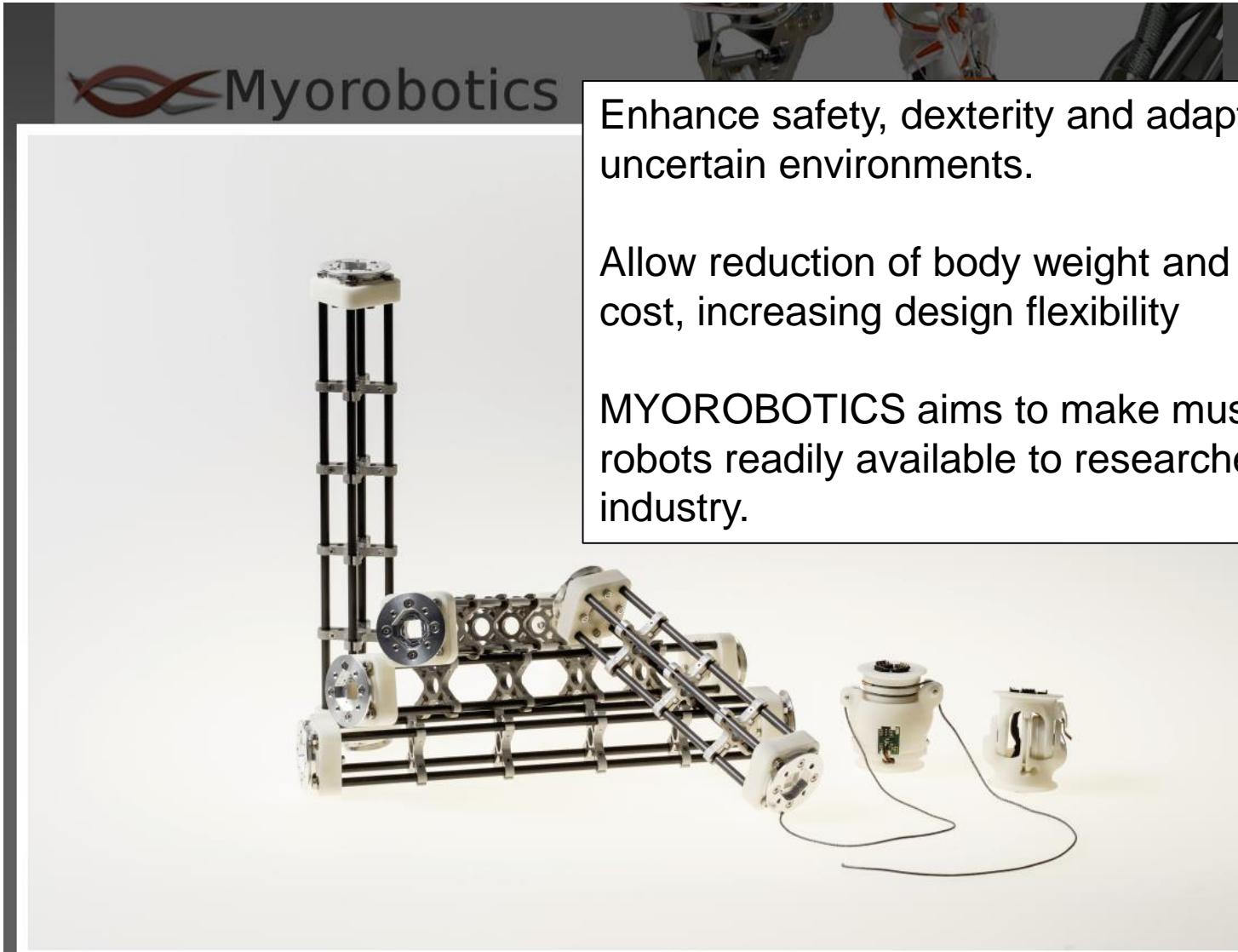
H2P Healthcare

Experiments





## Landmark Projects: Myorobotics Muscoskeletal Robots

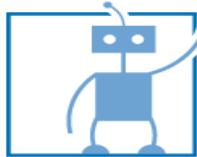


**Myorobotics**

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.

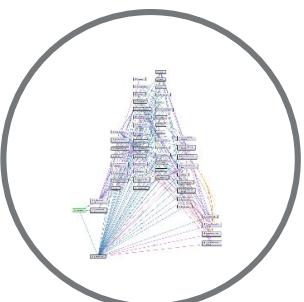
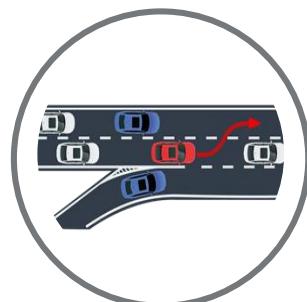
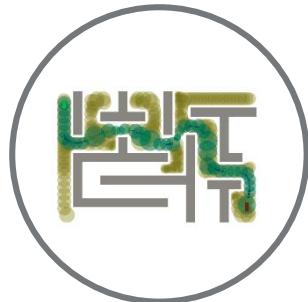
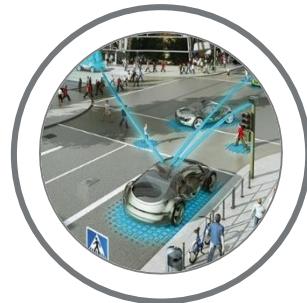
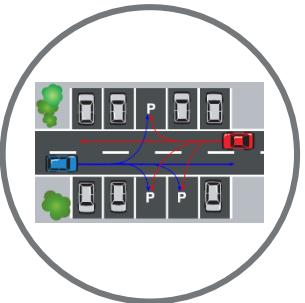
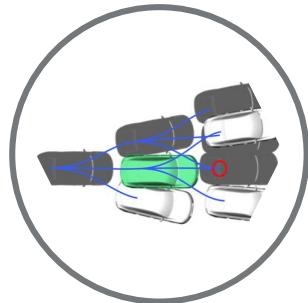
Total costs estimated: 1.19 billion euros. TUM coordinates sub-project "Neurorobotics."



# Autonomous Driving Projects & Experiences - Excerpt

# Projects & Experiences

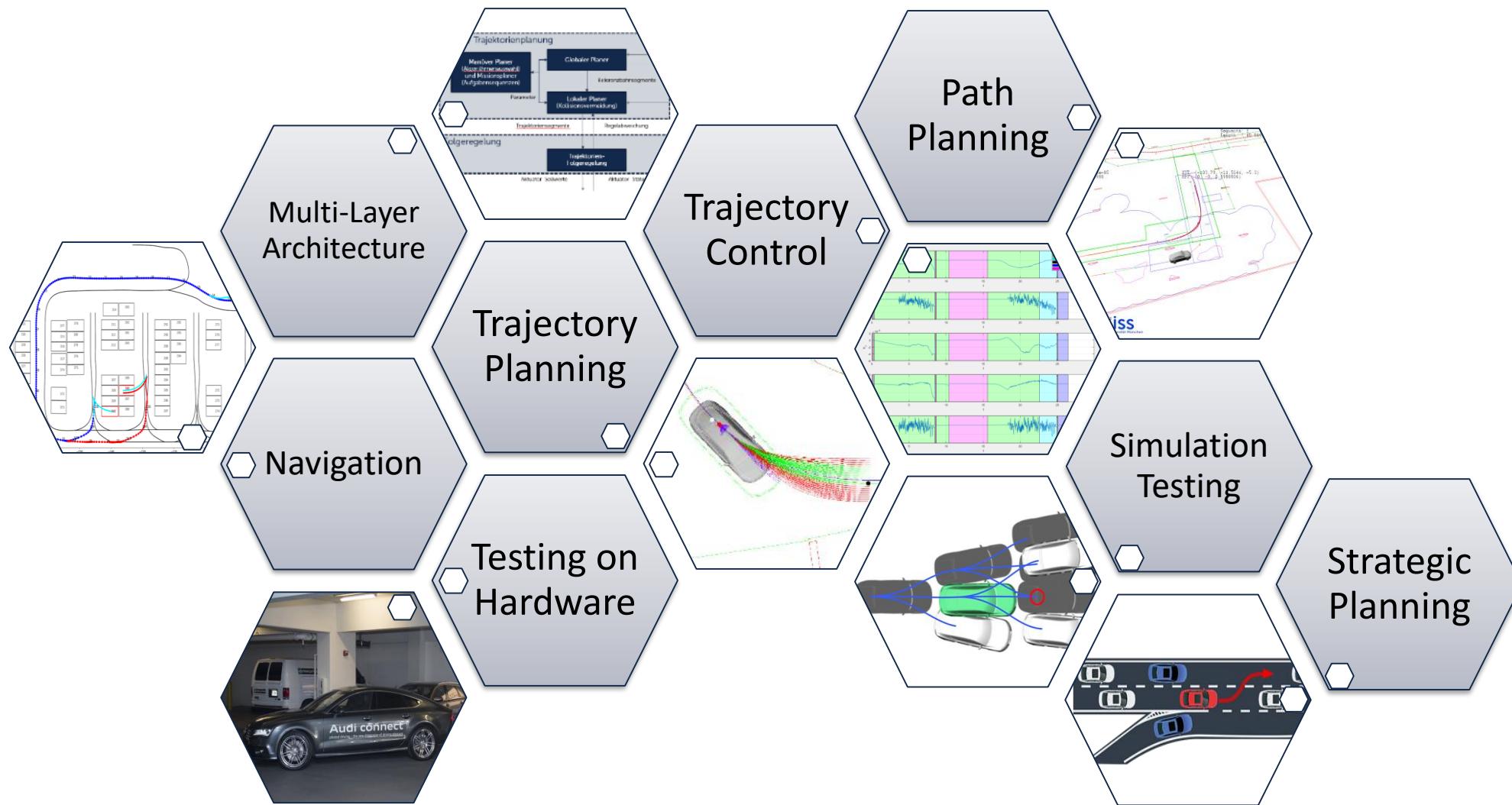
Motion Planning, Data Fusion, Overall Systems



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

# Software Development for Automated Driving

Focus: Motion Planning

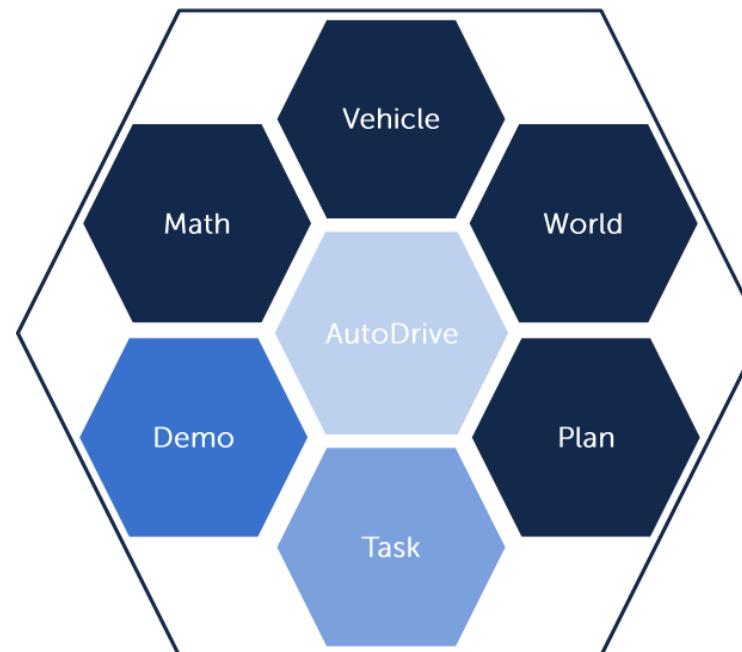


# AutoDrive Library

## 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

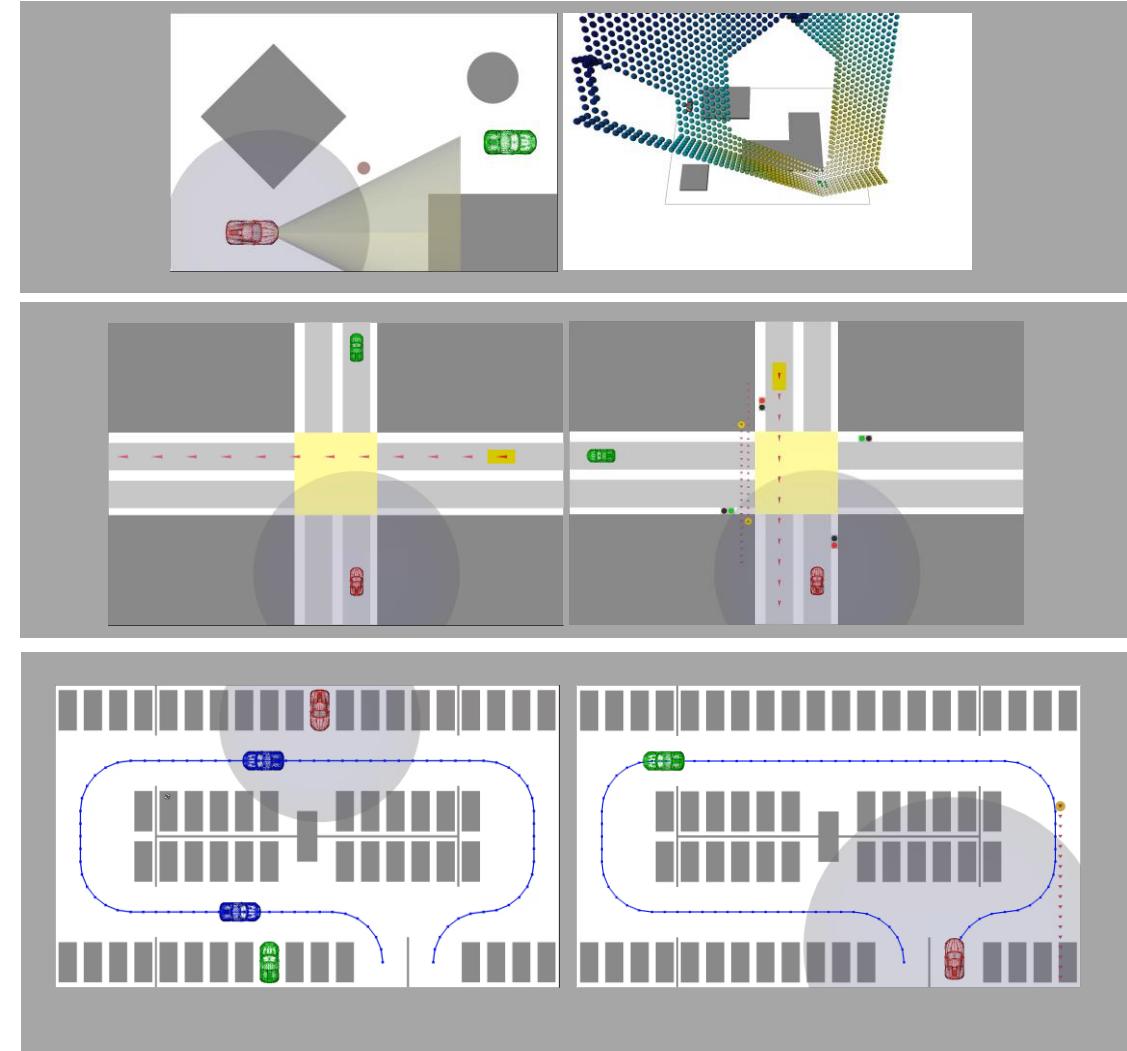
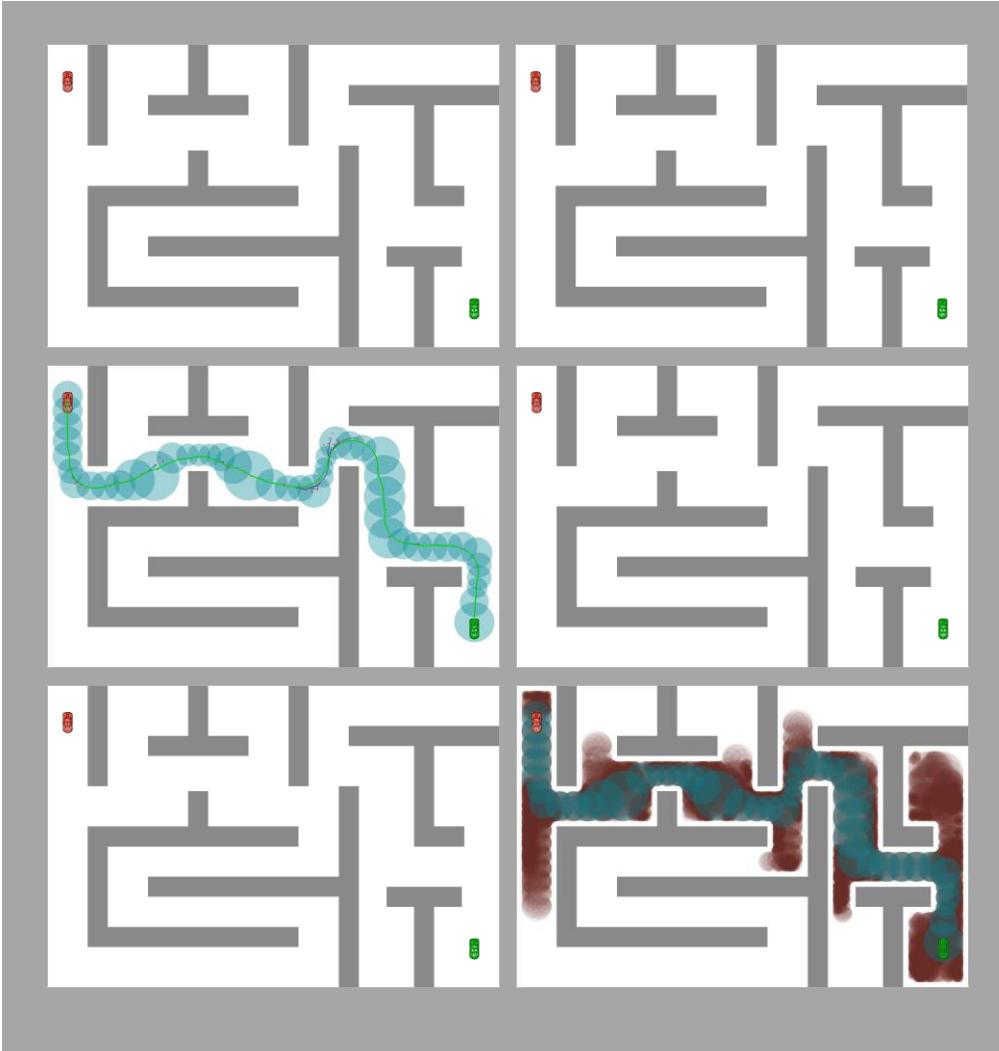
Doktors der Naturwissenschaften (Dr. rer. nat.)  
genehmigten Dissertation.

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

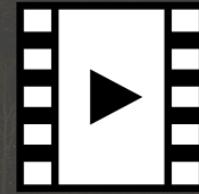
IEEE Intelligent Vehicles Symposium (IV)

PhD Thesis, MediaTUM

In IEEE Transactions on Cognitive and Developmental Systems



# Autonomous Driving Impressions





Gefördert durch:



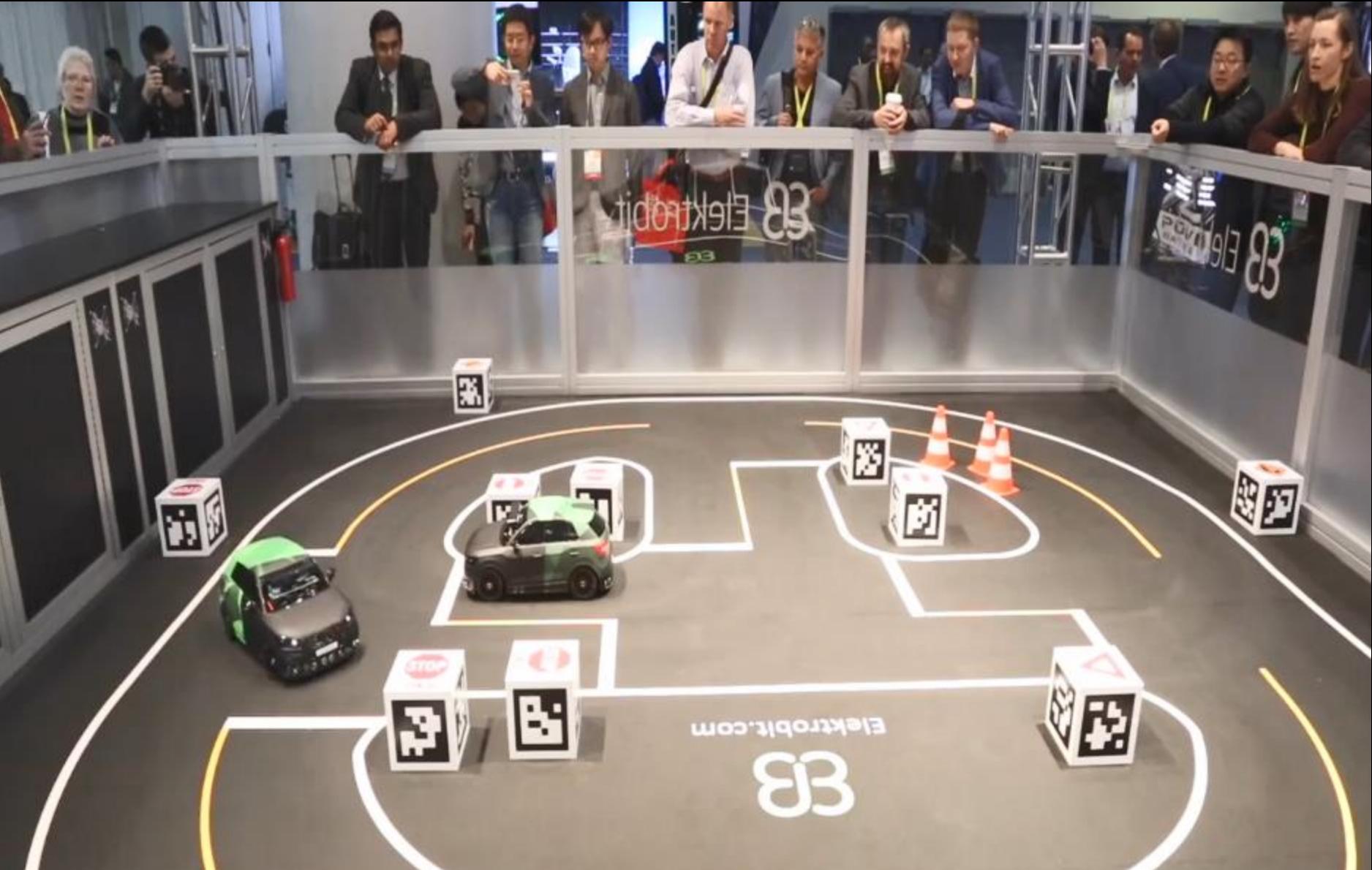
Bundesministerium  
für Wirtschaft  
und Energie

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





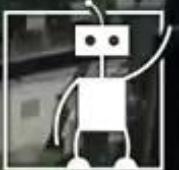
Everything seems to be ready...

# fortiss

innovation in software and systems

Cyber-Physical Systems

supported by



Robotics and Embedded Systems

Technische Universität München

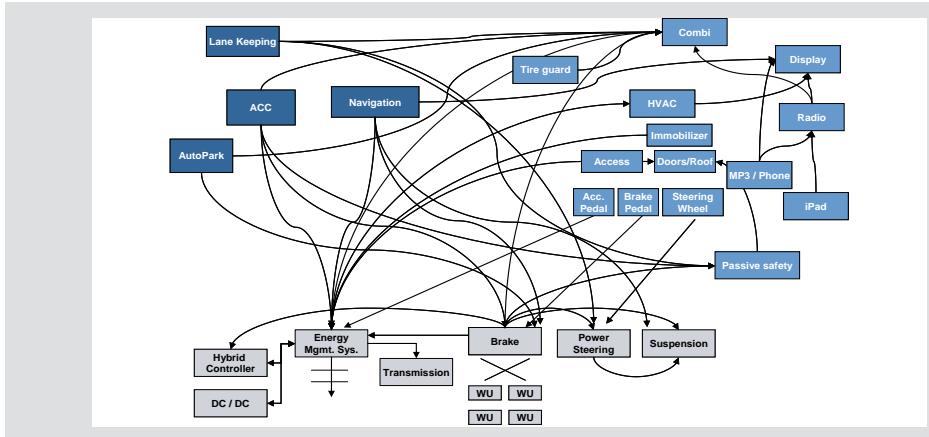


# Contributions to Prototype Demonstrators: RACE

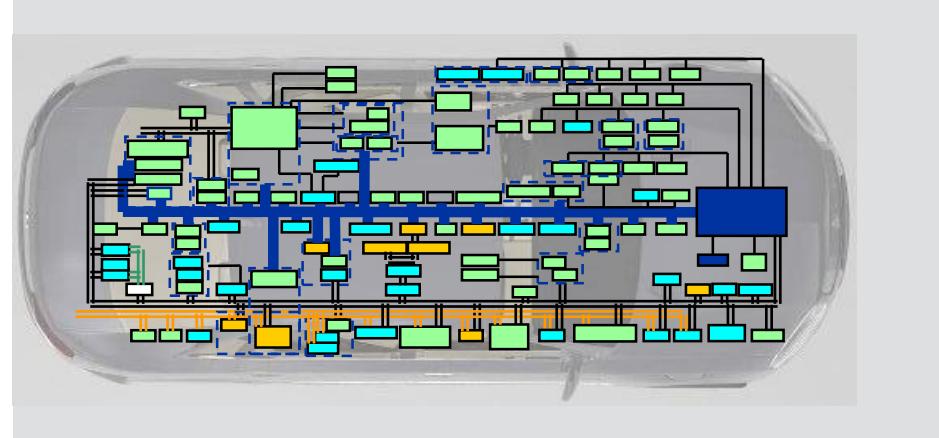
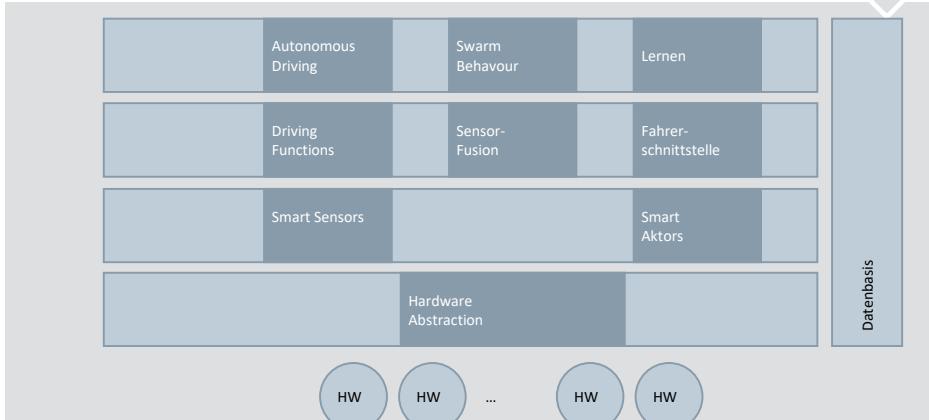


# RACE

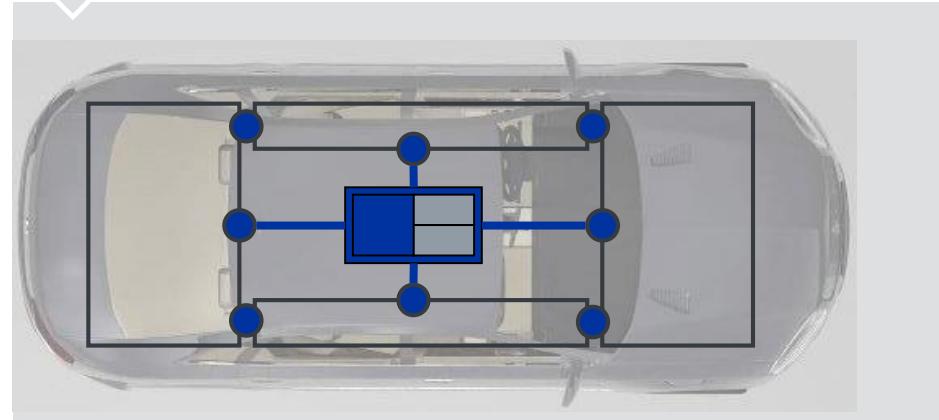
# Reduction of E/E-Architecture Complexity



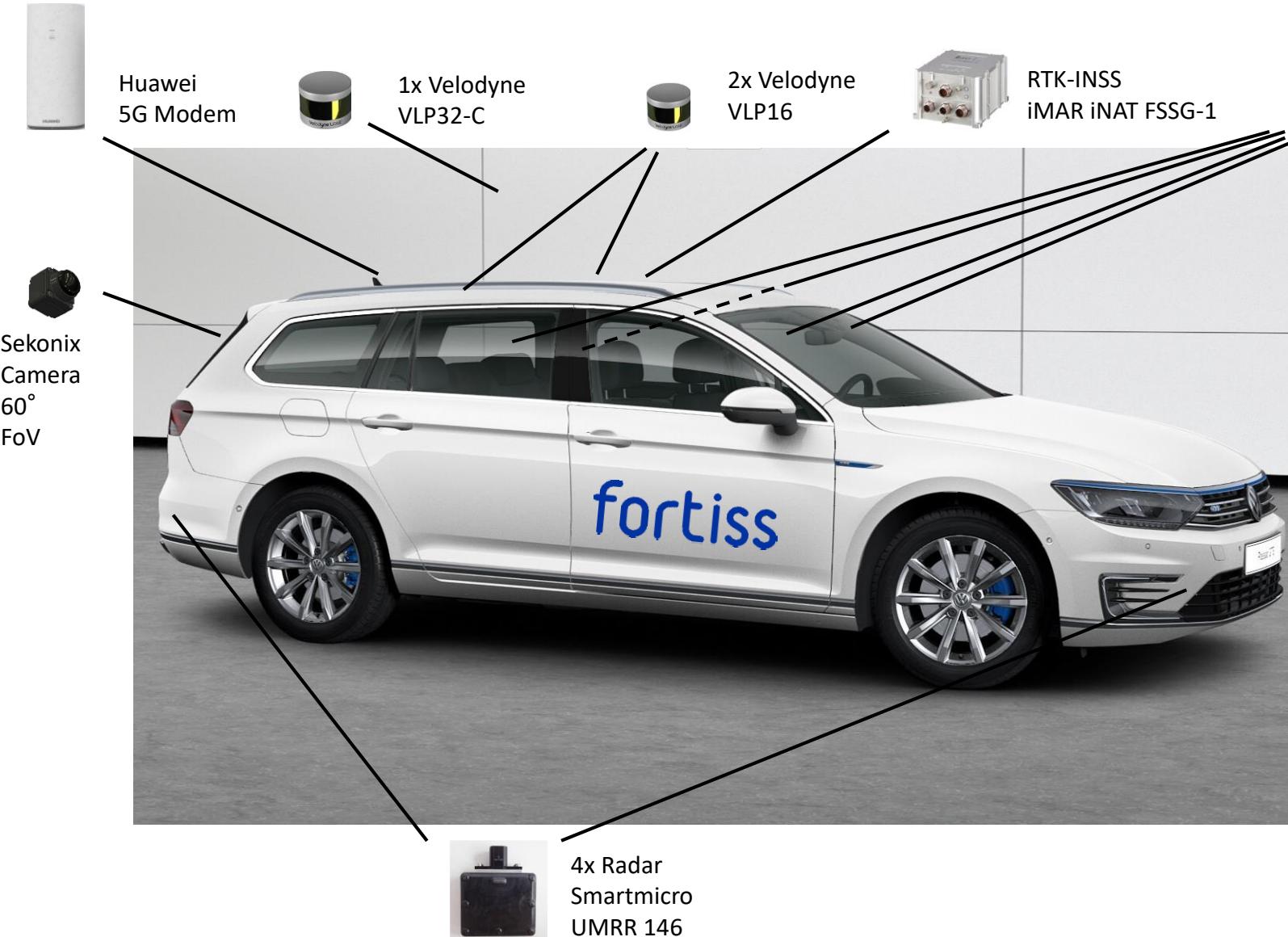
- Position independent Partitioning
    - Defined Information Flow
      - Hierarchical Decision
    - Plug & Play Compatible



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



# fortiss 5G Autonomous Driving Research Platform

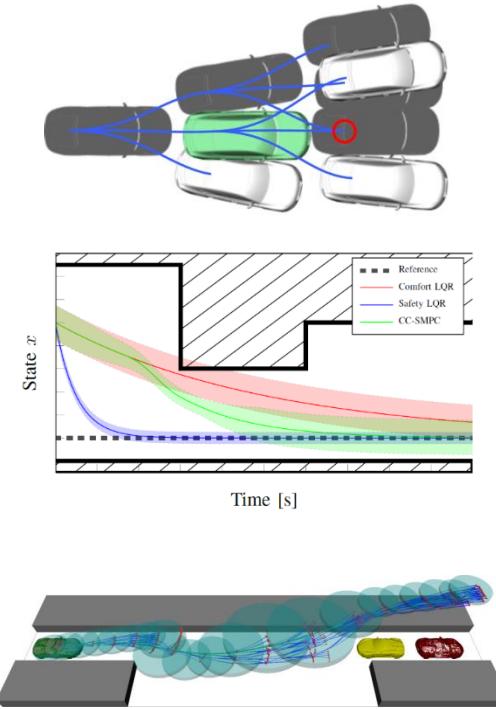
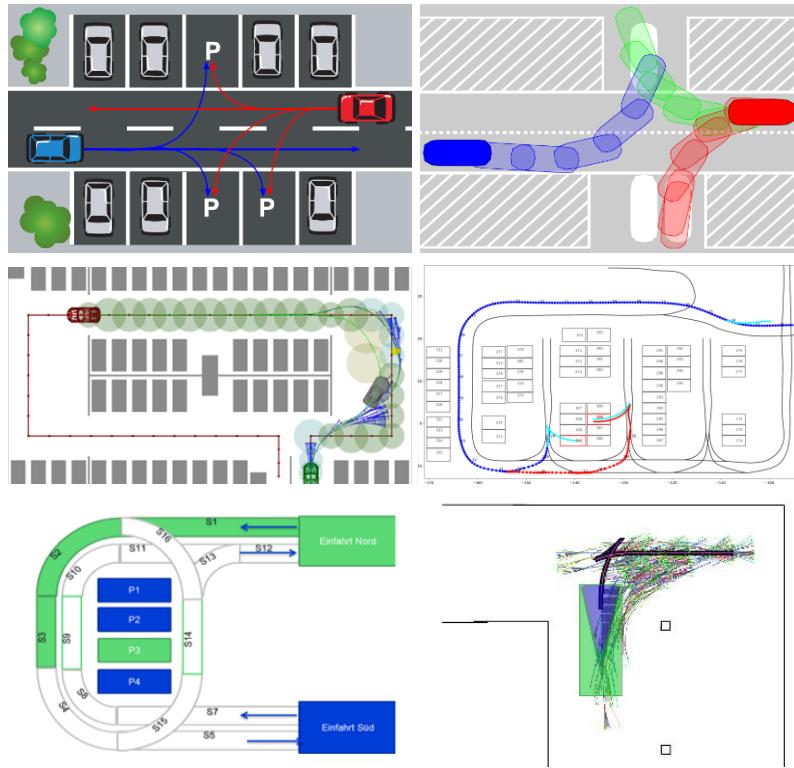


Camera  
1x 120° FoV front  
1x 60° FoV front  
2x 120° FoV side

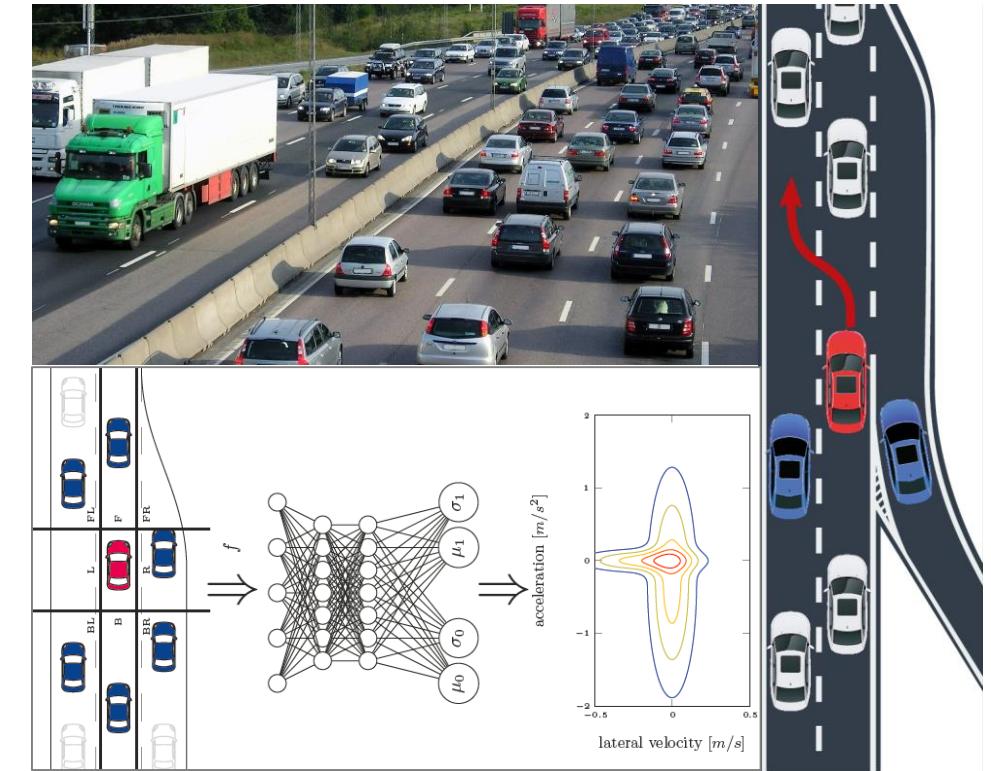
- Computer vision:  
Drive PX2
- Data fusion unit:  
CarPC1 (Nvidia GTX1050TI)
- Visualisation-/Planning unit:  
CarPC1 (Nvidia GTX1050TI)
- Realtime Prototyping:  
dSPACE MicroAutobox II

# Applications for motion planning, decision making and testing

Algorithms for planning and testing

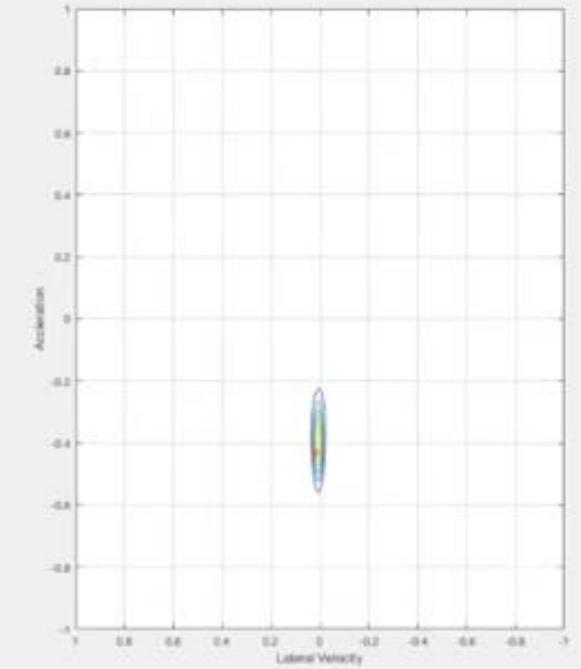
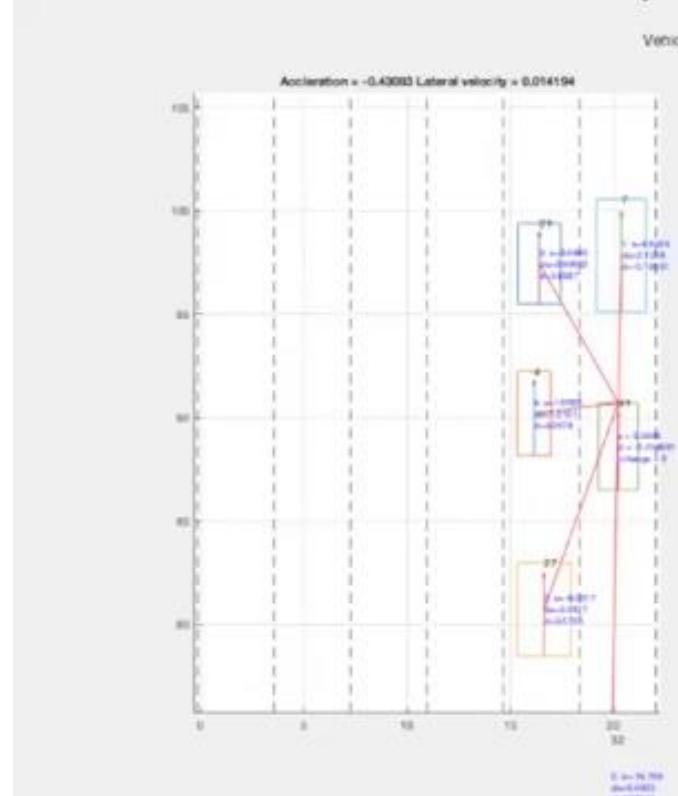
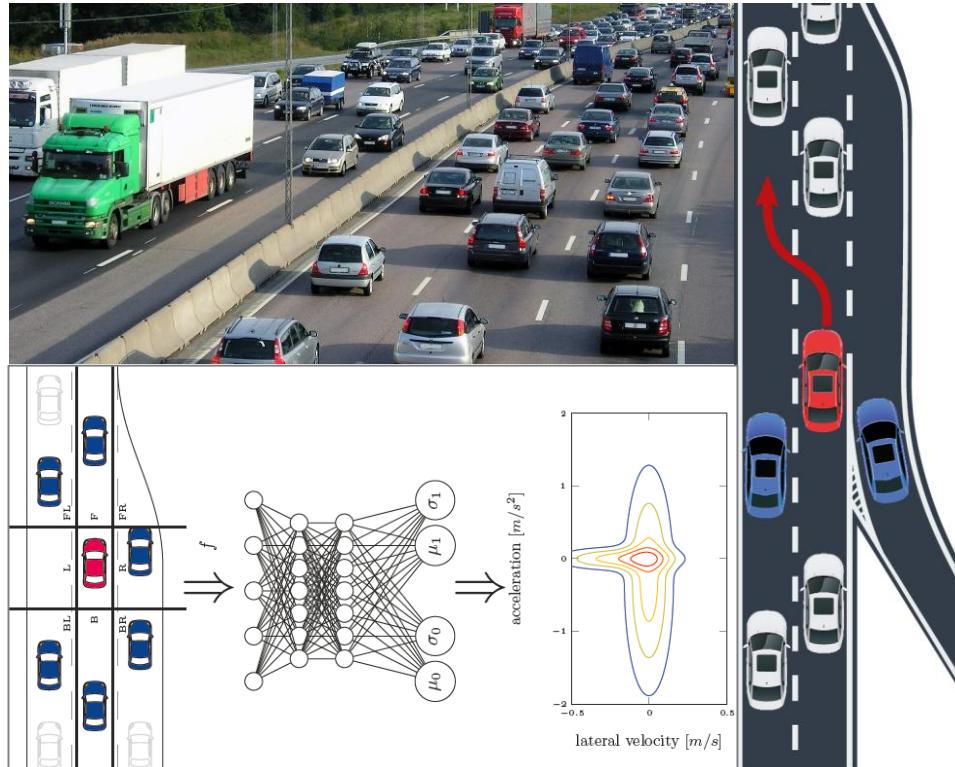


Deep Learning for strategic decision making



# Deep Neural Networks for Interactive Scene Prediction

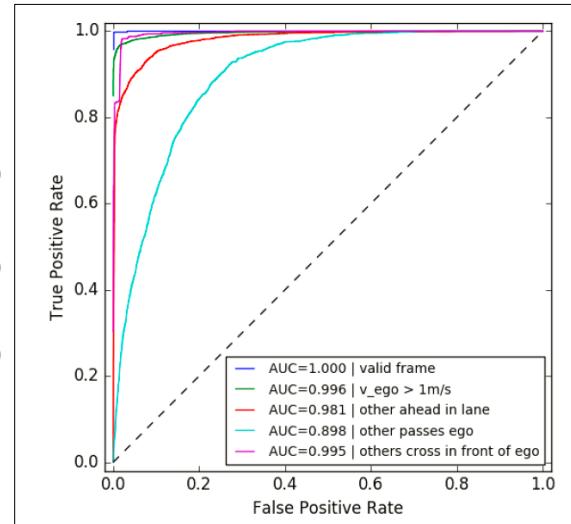
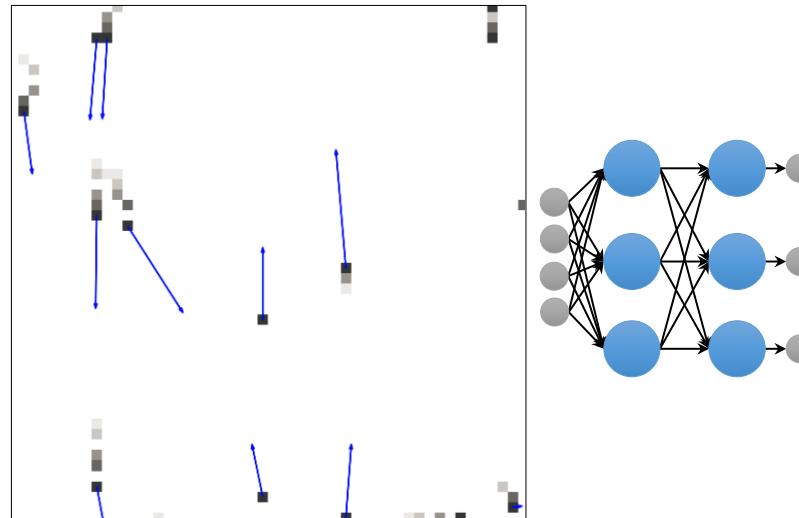
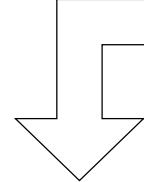
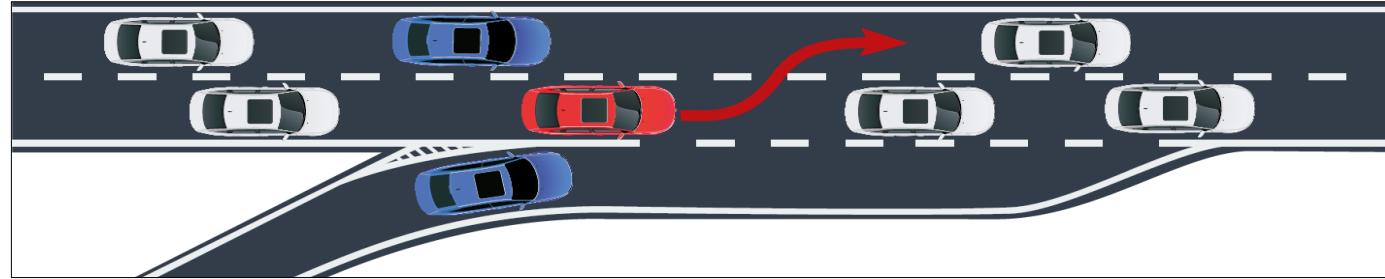
Deep Learning for strategic decision making



# 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

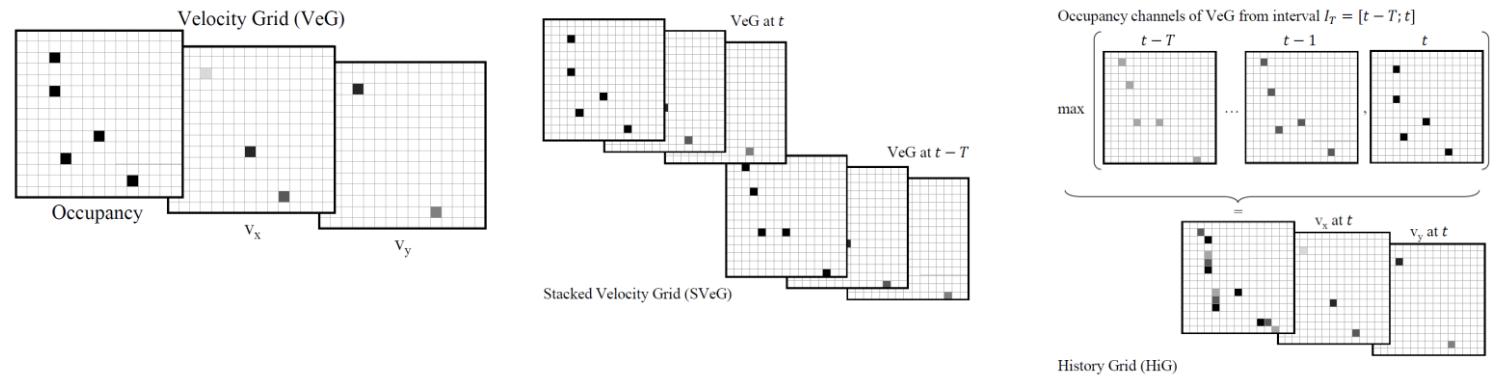
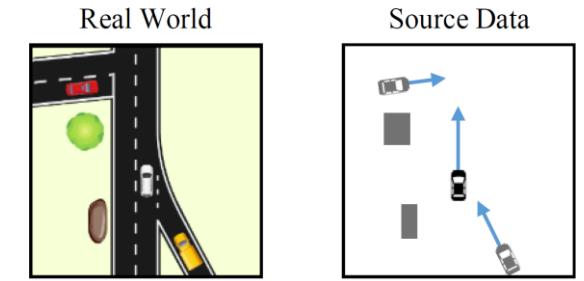
- Going from Vehicle Perception Data Object Lists from real traffic to scenarios with Deep Learning Neural Networks
- Scenarios
  - Valid Frames
  - Velocity Based Scenarios
  - Take-Over Maneuver
  - Others Cross in Front of Ego Veihcle
  - Lane Changes
  - ...

- 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:

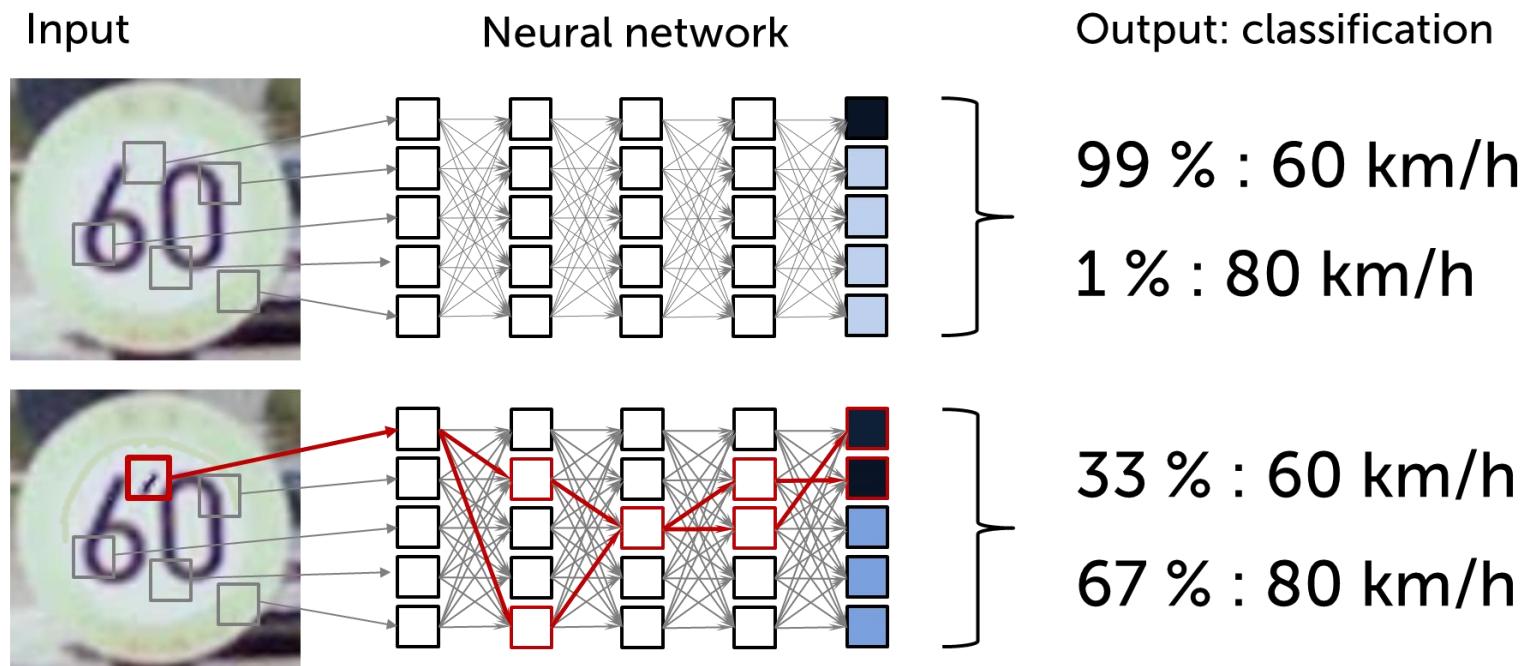
- Choose Data Representation Format:



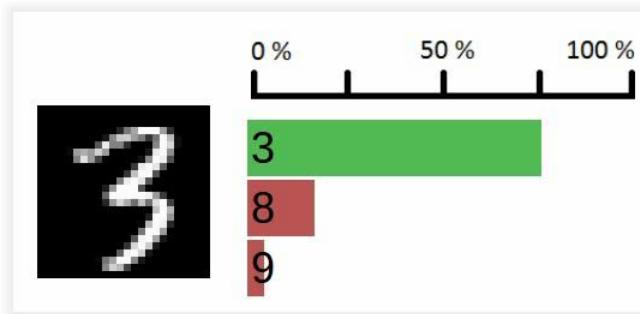
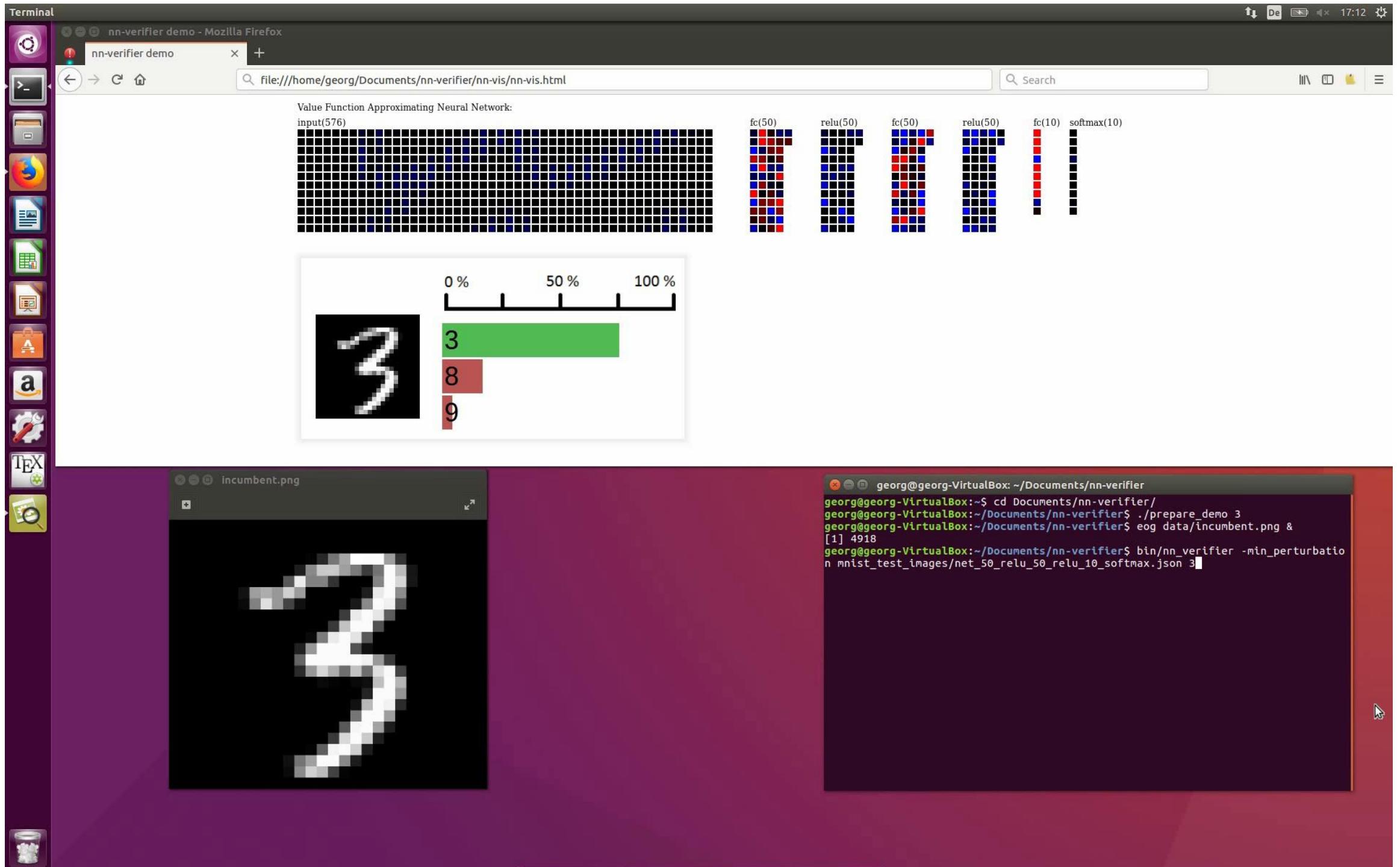
# Adversarial images

The need for neural network verification in image processing

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

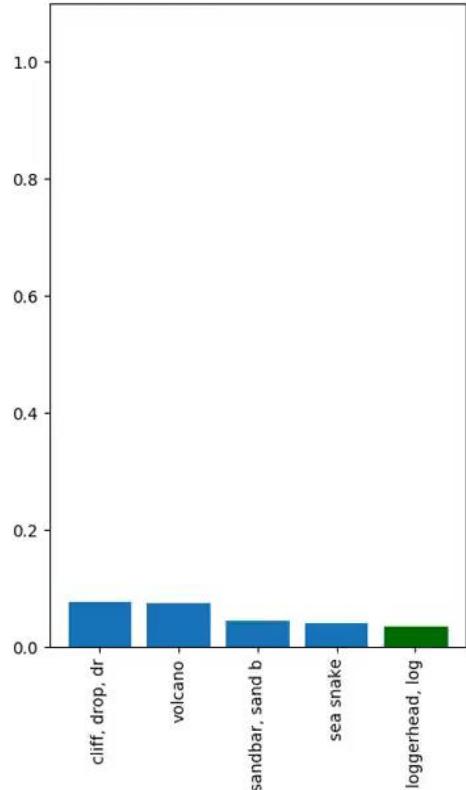


A tiny disturbance in the input causes a significant change in the classification.



```
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?!**

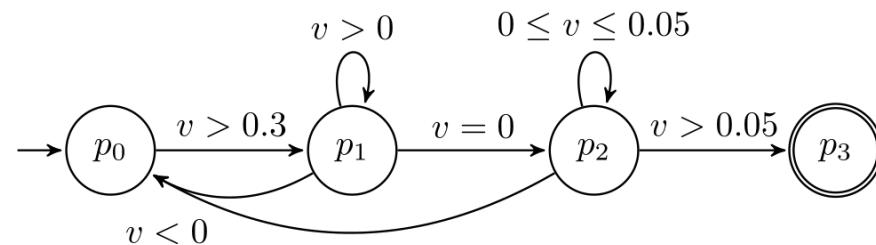
## Black-box adversarial examples

- no knowledge of neural network parameters
- no extensive sampling

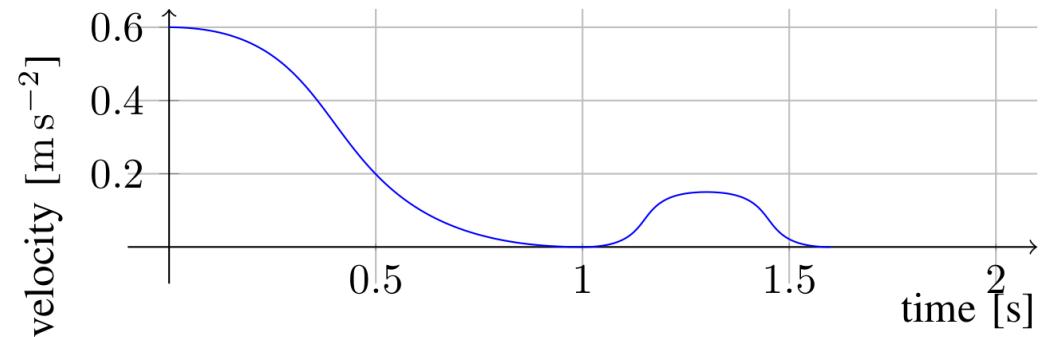
Wicker, Matthew, Xiaowei Huang, and Marta Kwiatkowska. "Feature-Guided Black-Box Safety Testing of Deep Neural Networks." *arXiv preprint arXiv:1710.07859* (2017).

# 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

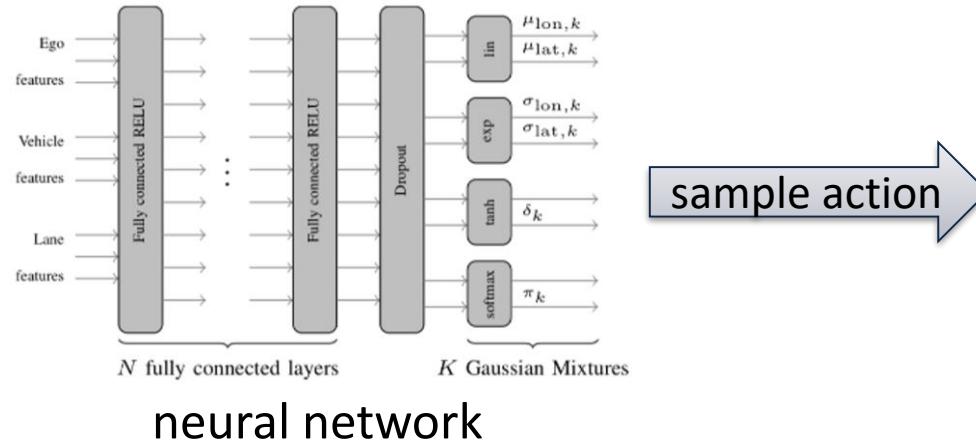
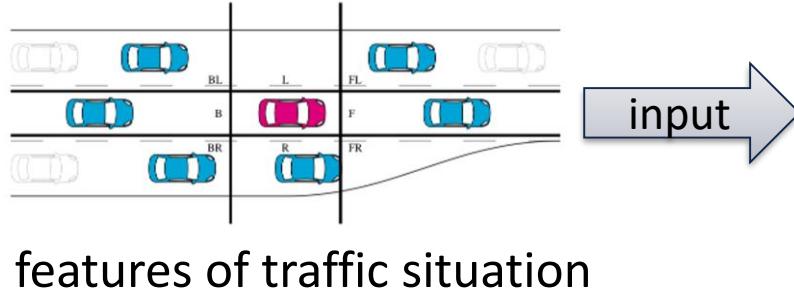


NuSMV: **SPEC !EF(G0 & E[G1 U G2 & E[G3 U G0]])**;  
**G0:=**  $v > 0.05$ , **G1:=**  $v > 0$ , **G2:=**  $v = 0$ , **G3:=**  $0 \leq v \leq 0.05$



# Verification of safety properties of NNs

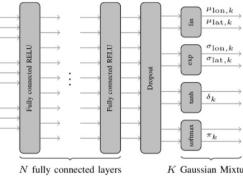
## Neural network example:



- 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  $A\mathbf{x} \leq \mathbf{b}$ ,  
 $\mathbf{x} \geq \mathbf{0}$ ,  
 $\mathbf{x} \in \mathbb{Z}^n$   
and



nn-verifier

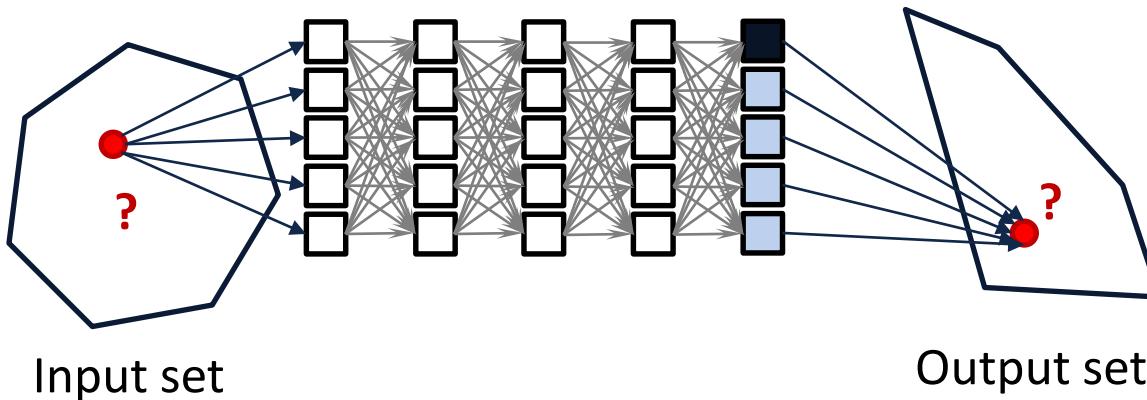


- Lenz, David, Frederik Diehl, Michael Truong Le, and Alois Knoll. "Deep neural networks for Markovian interactive scene prediction in highway scenarios." In *Intelligent Vehicles Symposium (IV)*, 2017 IEEE, pp. 685-692. IEEE, 2017.
- Cheng, Chih-Hong, et al. "Neural networks for safety-critical applications-challenges,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

# Verifying safety properties of Neural Networks

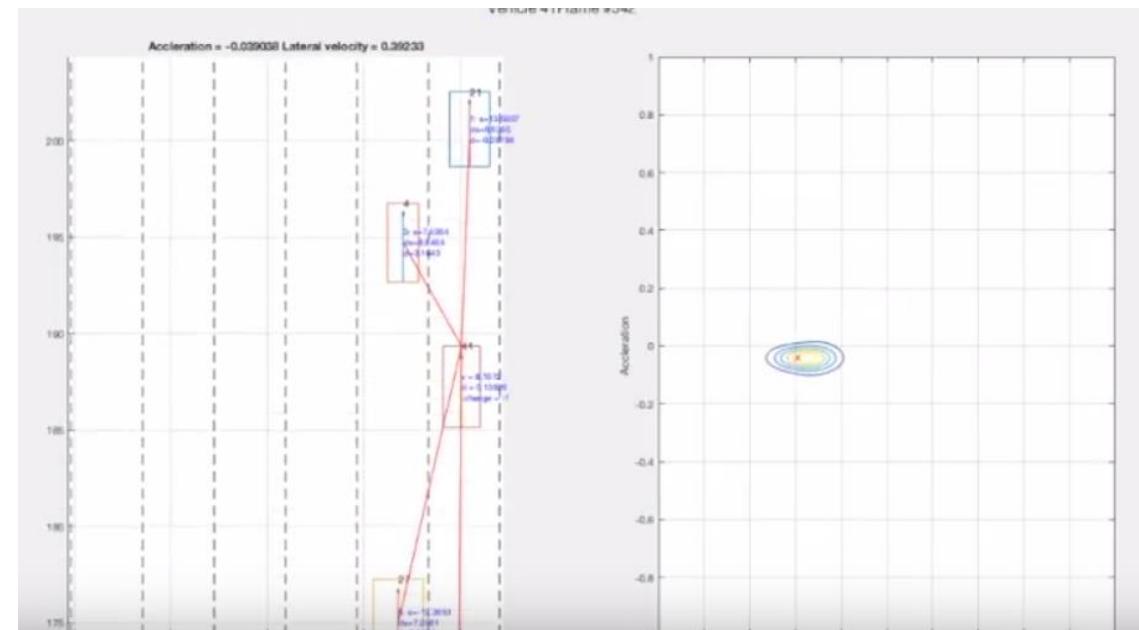
## Safety of highway motion predictor

- 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

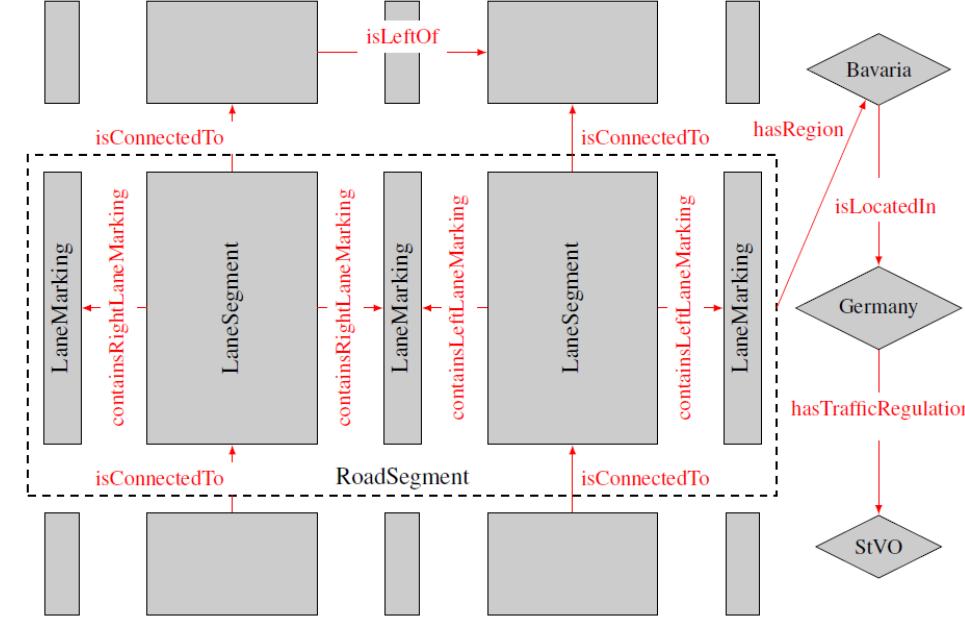
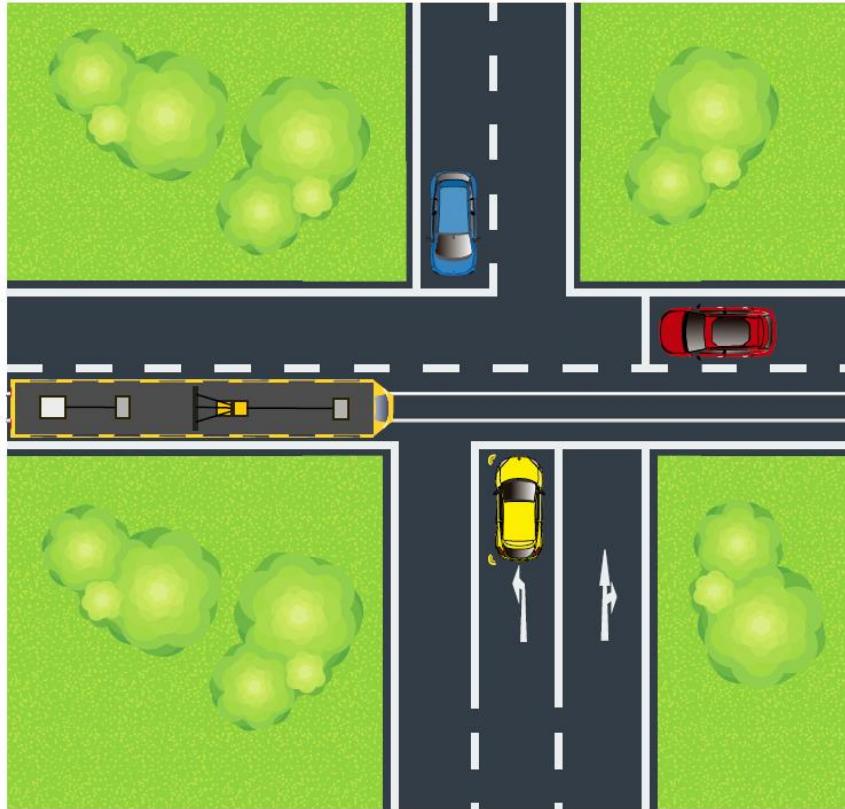
Output:  
velocity prediction



Highway motion predictor, being trained under the NGSim dataset

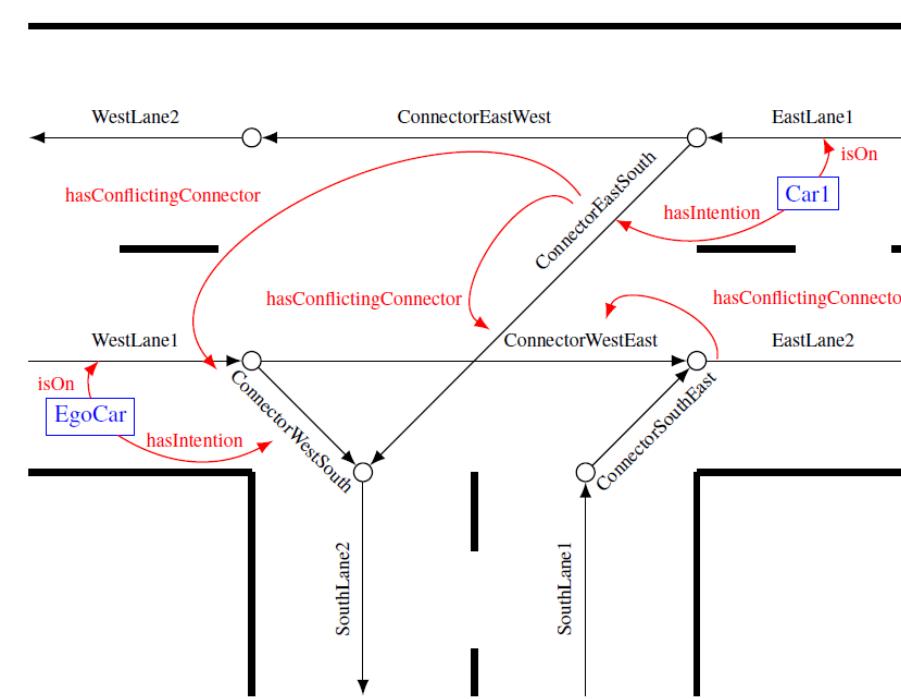
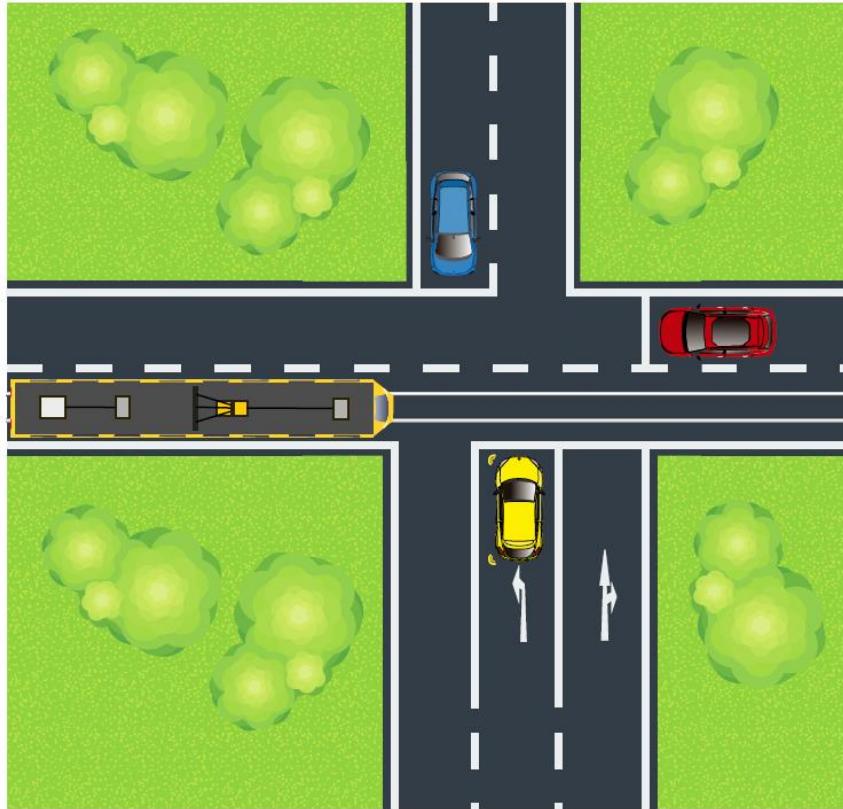
# Semantic Scenario Interpretation and Decision Making

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*.



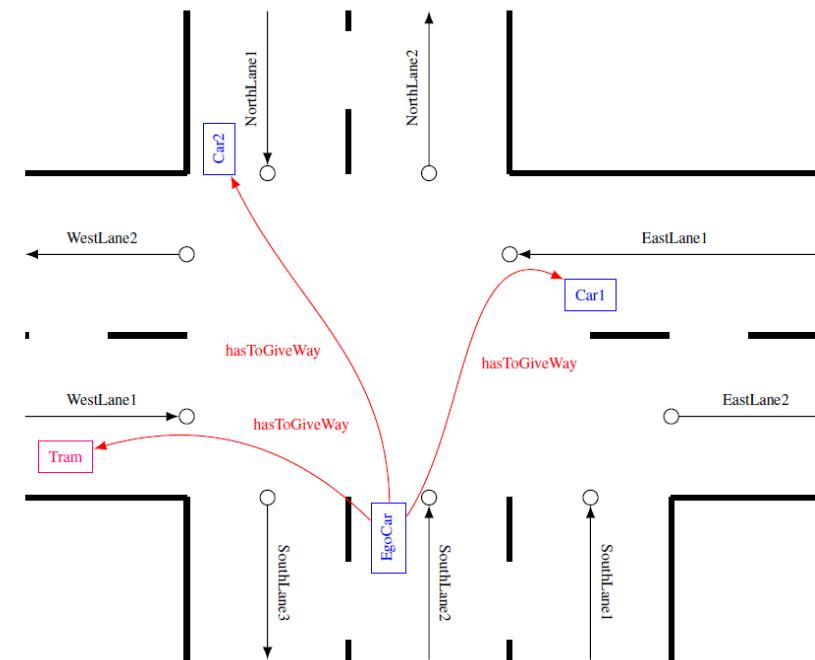
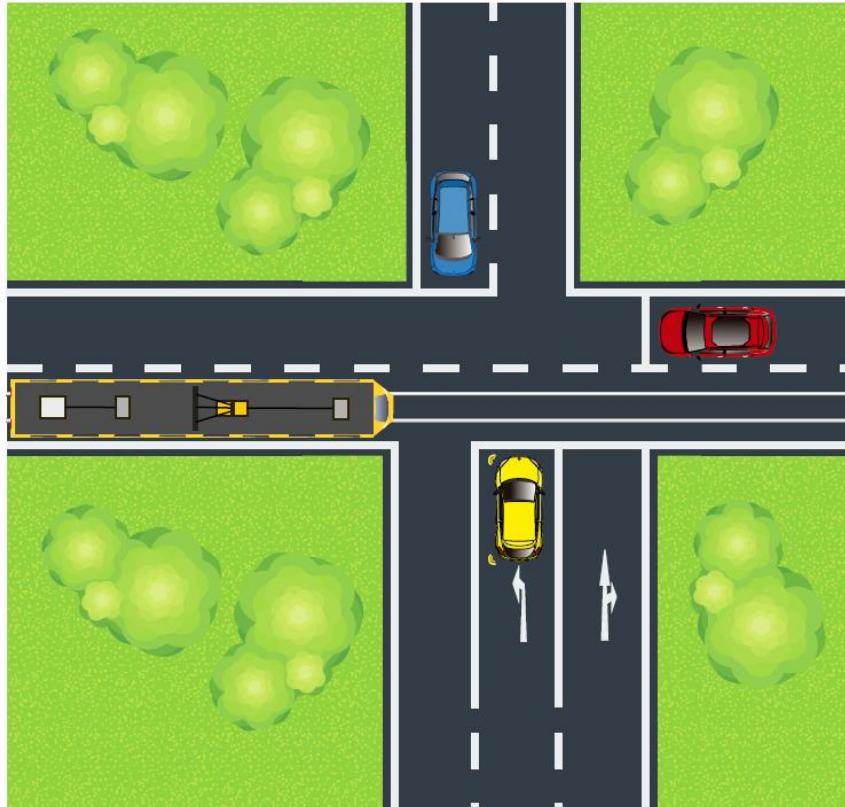
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# Semantic Scenario Interpretation and Decision Making

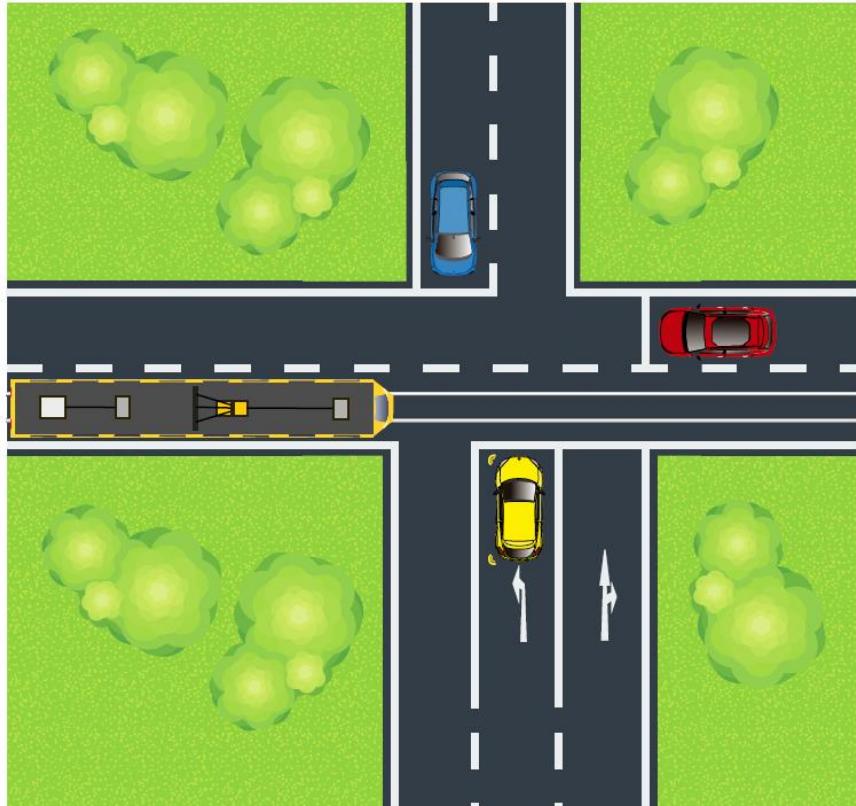
Example: “Ontology-Based Traffic Scene Modeling, Traffic Regulations Dependent Situational Awareness and Decision-Making for Automated Vehicles”, M. Büchel, G. Hinz et. Al. in *IEEE Intelligent Vehicles Symposium, 2017*.



# 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*

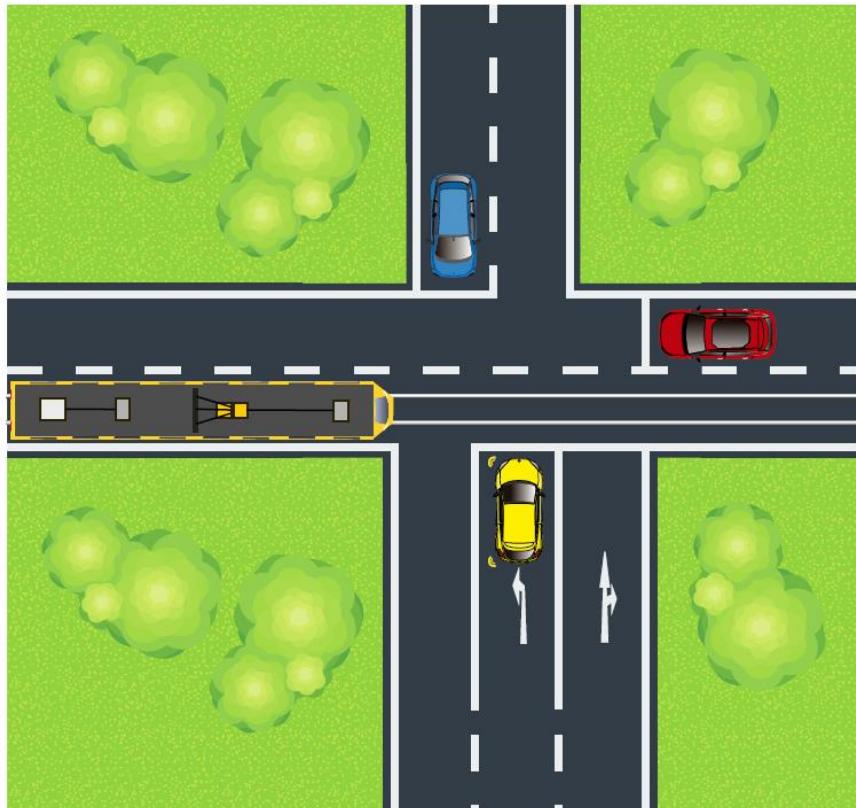
*TrafficLightRegulatedIntersection(?scen1)  
^ Vehicle(?vehicle1) ^ isOn(?vehicle1, ?lane)  
^ isPartOf(?vehicle1, ?scen1)  
^ containsTrafficLight(?lane, ?light)  
^ hasColor(?light, Red)  
⇒ hasToWaitForTrafficLight(?vehicle1, ?light)*

*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:

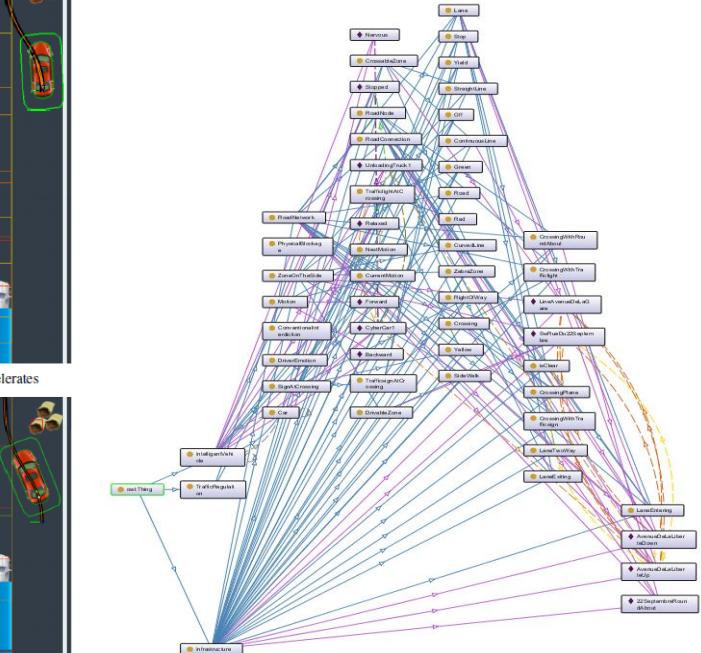
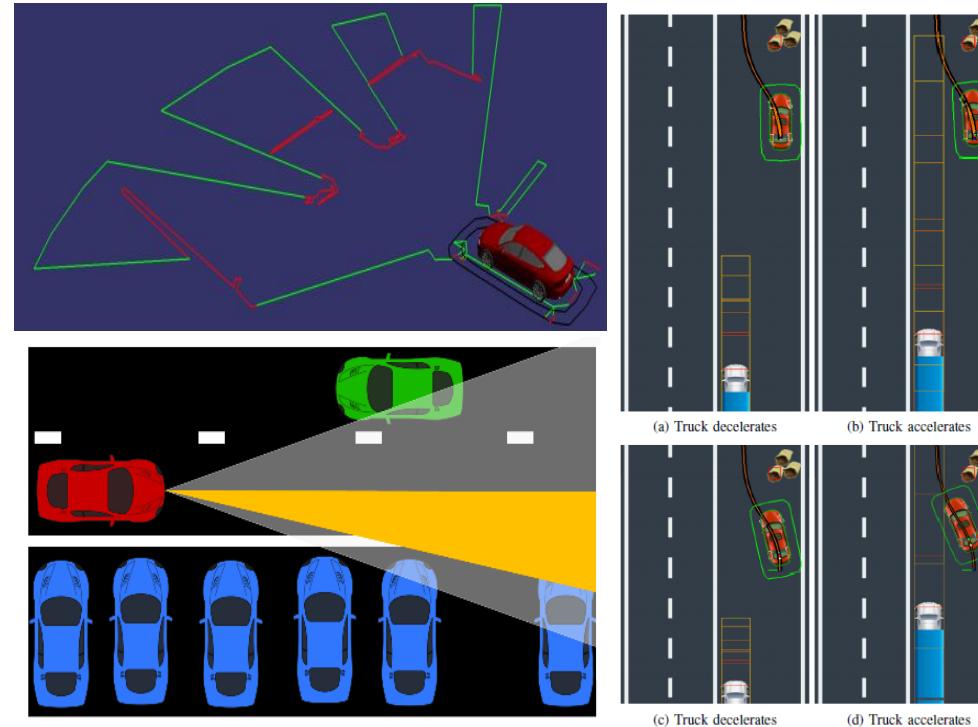
- Equivalent classes: Gorgonzolla\_topping
- Superclasses: Cheese\_topping
- Inherited anonymous classes: has\_spiciness some Mild\_value

# Safety & Accident Simulation

## From Sensors to Scenarios

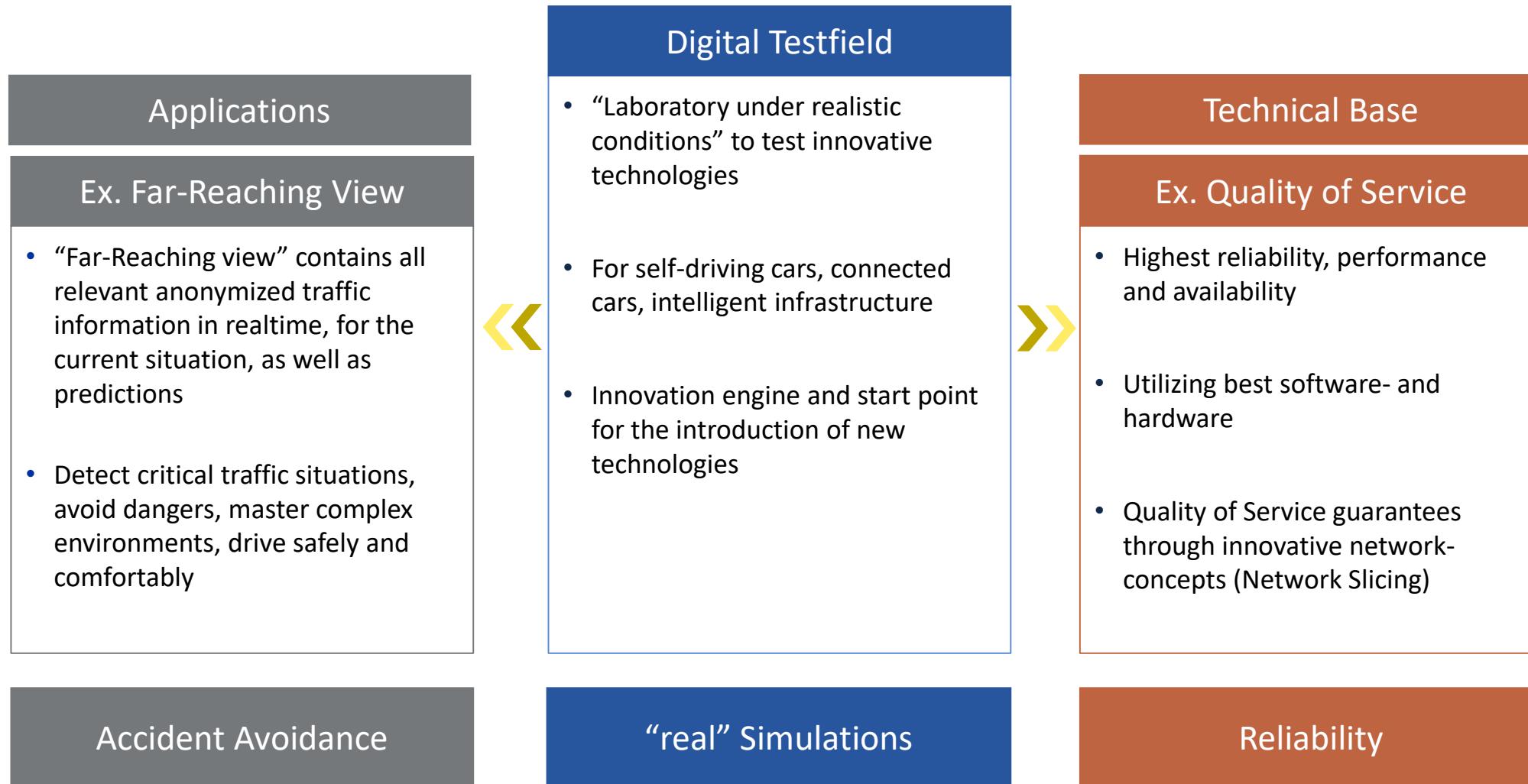
- Scenario tests
  - Accident analysis
  - Development of test catalogues
    - Identification of close to 1000 sensing aspects for sensor set validation
  - Conceptual knowledgebase development for autonomous driving and decision making
  - Sensor Simulation, data-acquisition, auto-calibration, fault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

☰ Menü | Politik Meinung Wirtschaft Panorama Sport Kultur Netzwerk Wissenschaft mehr ▾

**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

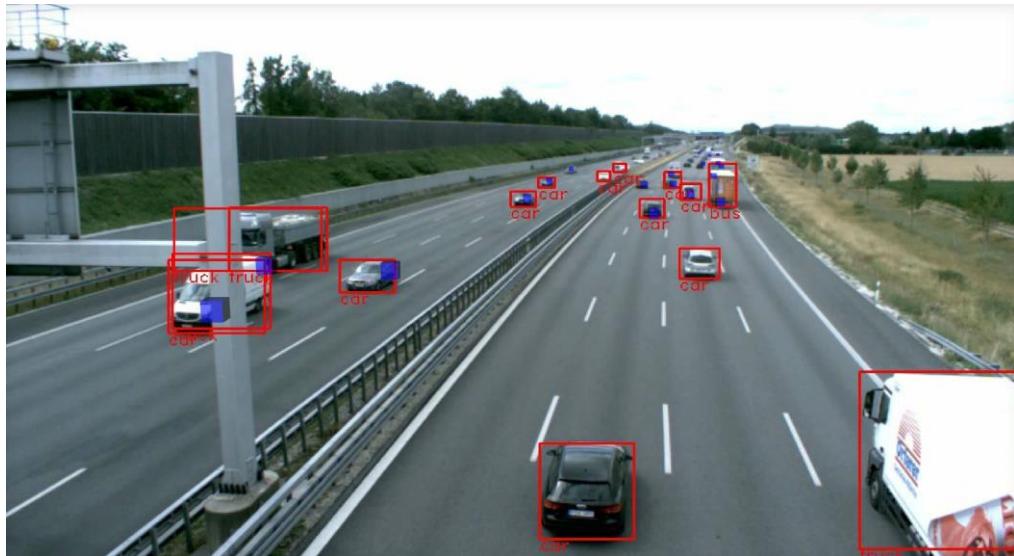
Verticals



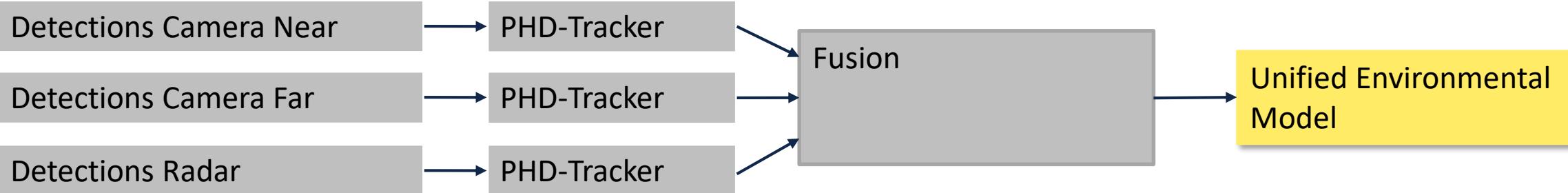
Digital Twin

- 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     

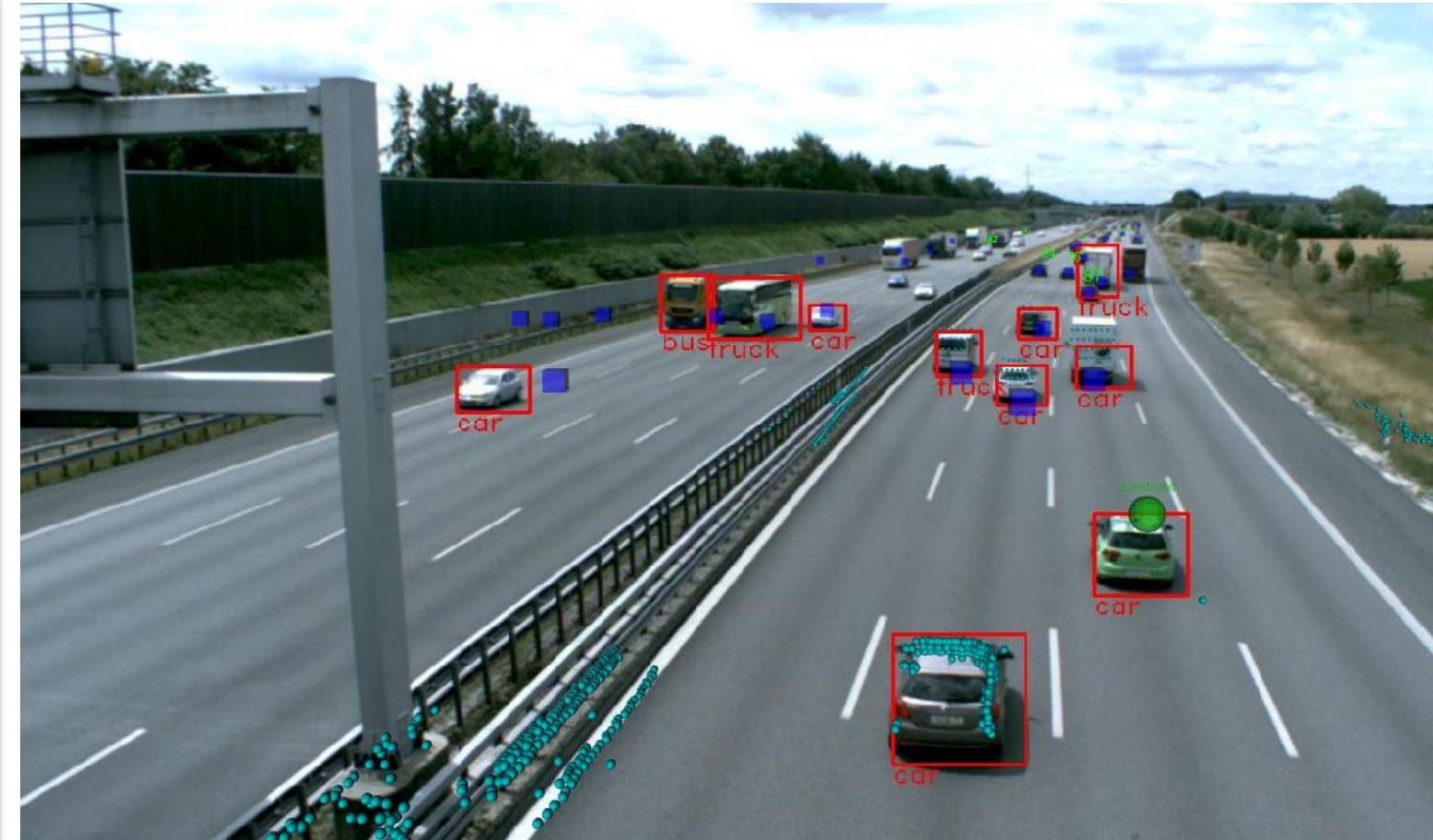
Camera Near     

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



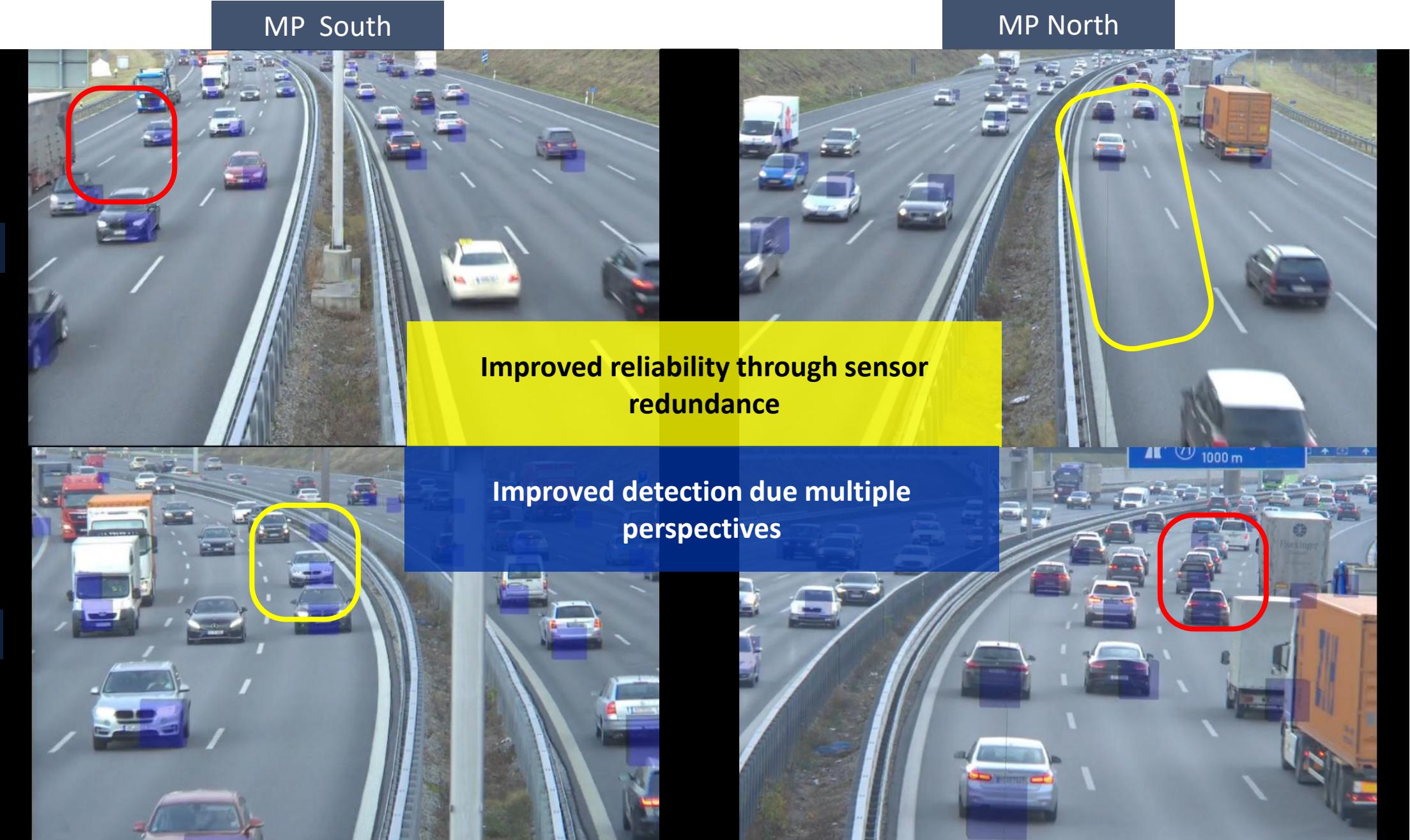
Near

MP North



Far





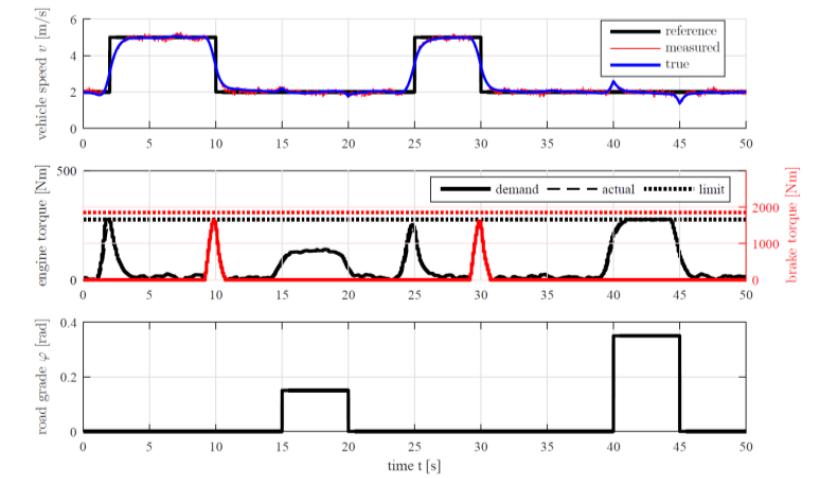
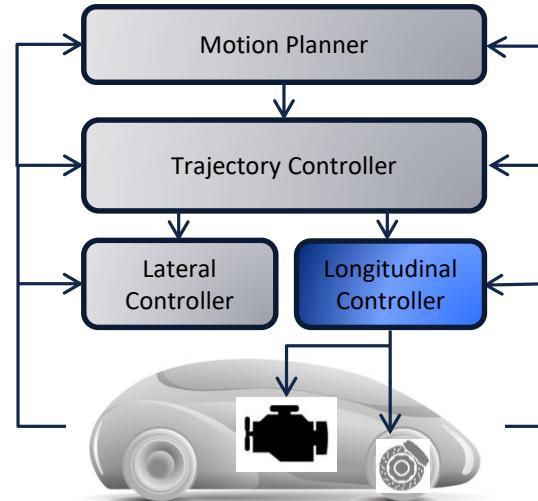


Tesla knocked out by a „bug“.

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

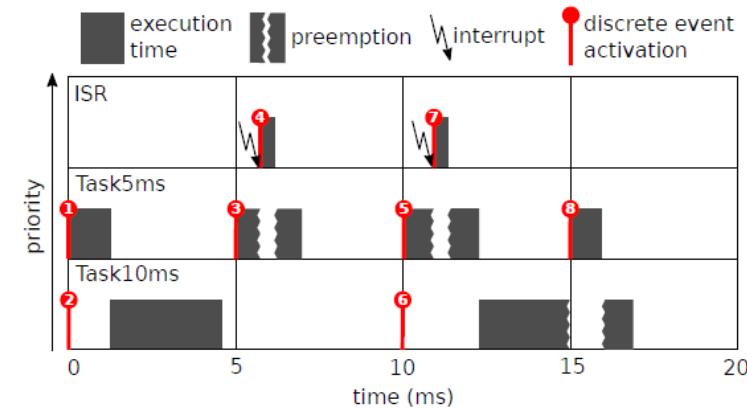
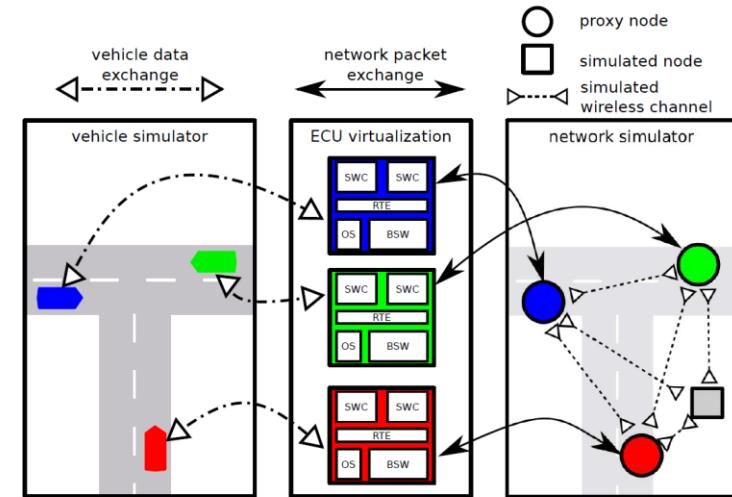
# Model predictive control for Autonomous Vehicles

- 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



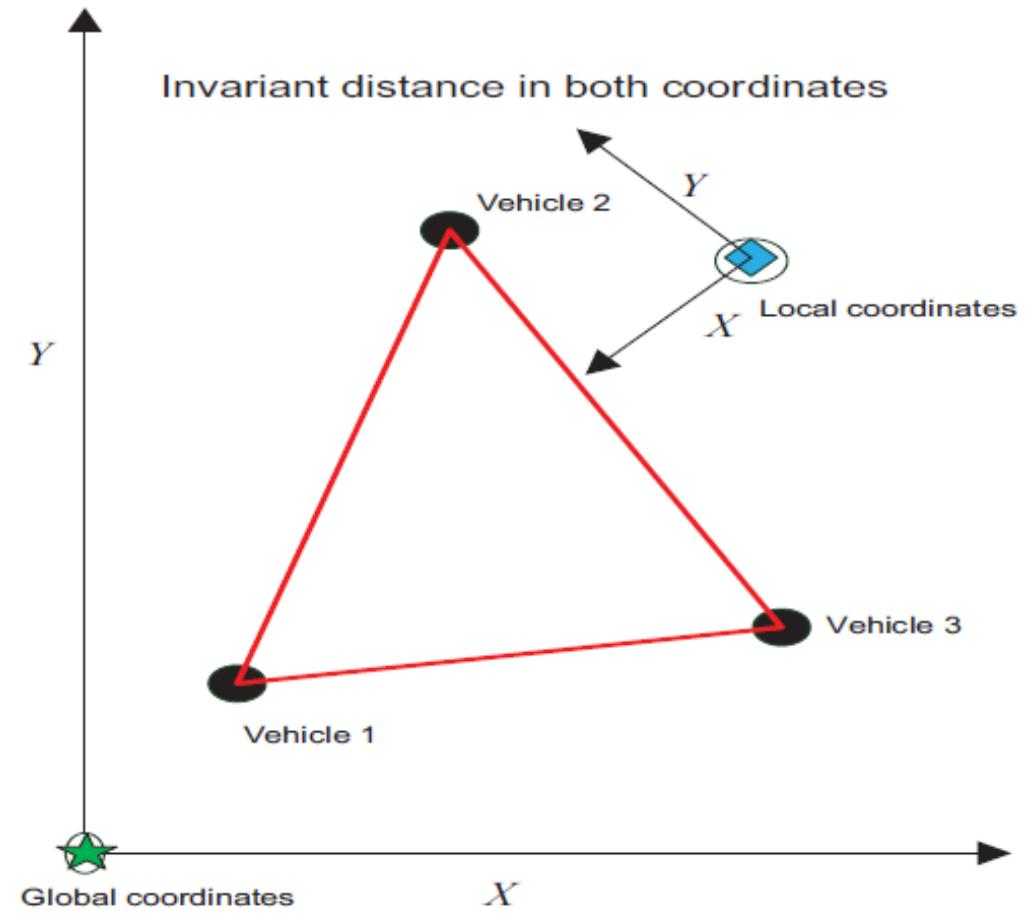
# Fleet communication– Car to X

- 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



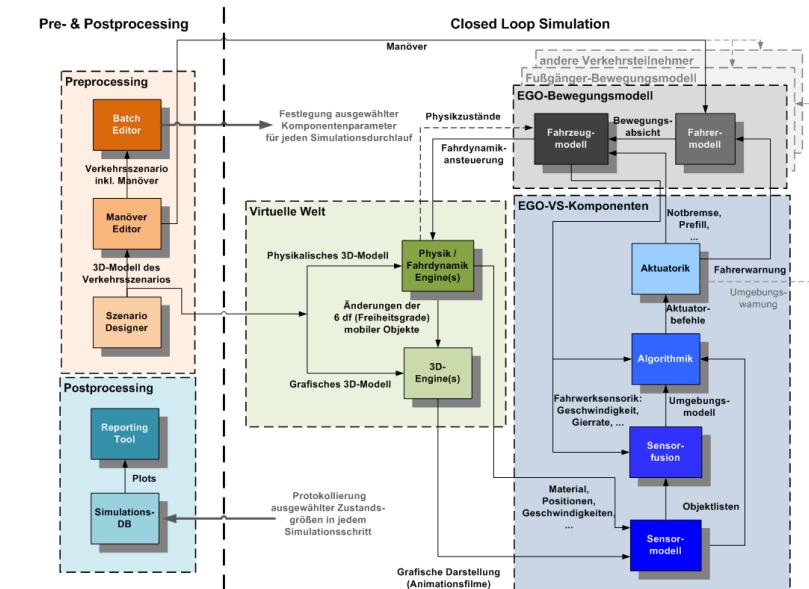
# Fleet communication– Car to X

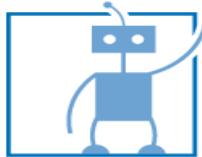
- High precision localization and tracking
- Effective solutions for:
- Bandwidth limitations
- Data-association
- Use of external sensors
- Can cope with large amounts of traffic participants
- Experience with various technologies
- PHD Filters
- GLMB Filters
- Factor Graphs
- Tracking with Neural Networks



# 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



[Home](#)

[Wettbewerb 2015](#)

[Teams 2015](#)

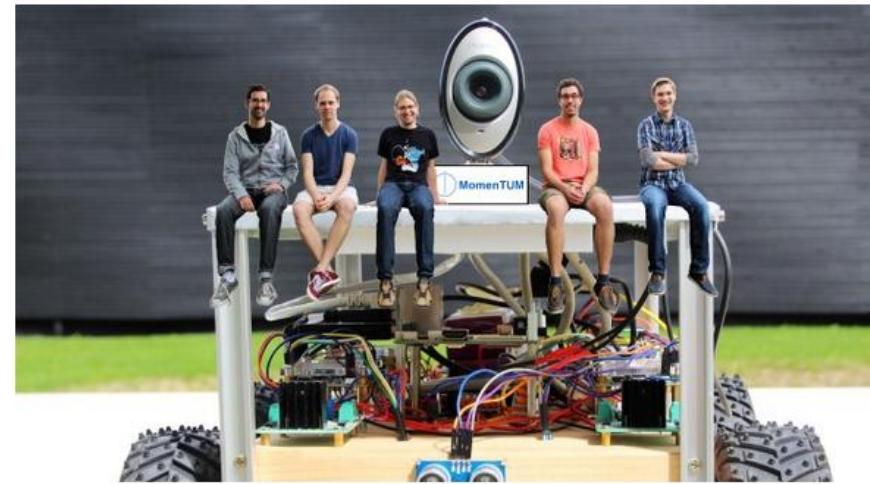
[Fahrzeug](#)

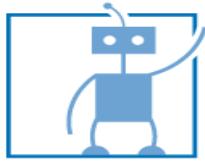
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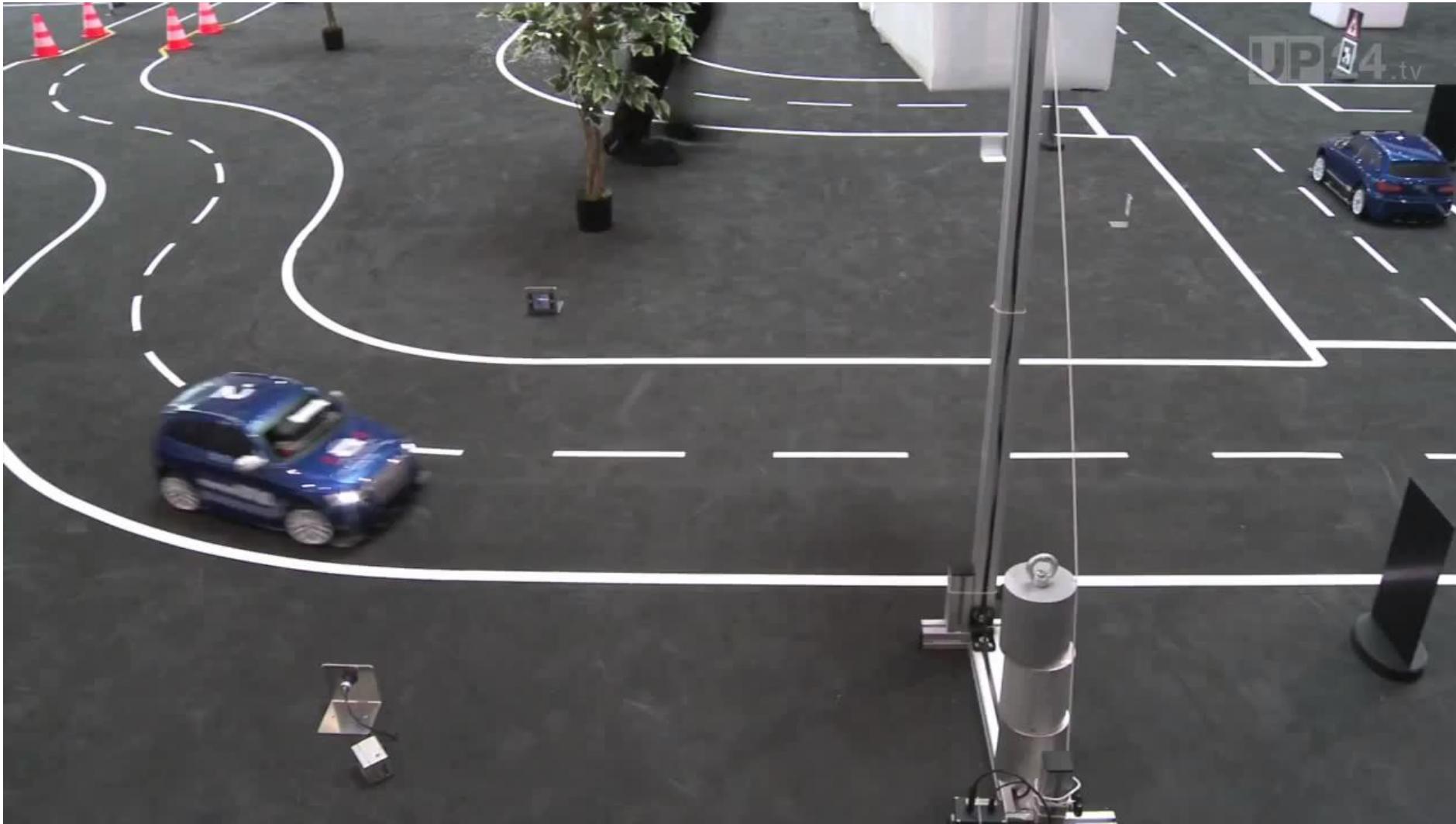
[Links](#)

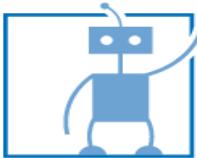
[Ihr Profil](#)





## Audi Autonomous Driving Cup





# Pressemitteilung

Suchtext eingeben

Ingolstadt, 27.03.2015

## Studierende der TU München gewinnen ersten Audi Autonomous Driving Cup

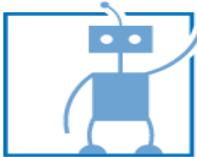
- ▶ Preisgeld von 10.000 Euro für Siegerteam
- ▶ Audi-Entwicklungs vorstand Prof. Dr. Ulrich Hackenberg: „Es ist wichtig, dass sich Studenten bereits im Studium mit wichtigen Zukunftsthemen wie dem pilotierten Fahren beschäftigen.“
- ▶ Audi-Personalvorstand Prof. h.c. Thomas Sigi: „Suchen Menschen mit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



Beim Audi Autonomous Driving Cup wetteiferten rund 50 Studenten aus ganz



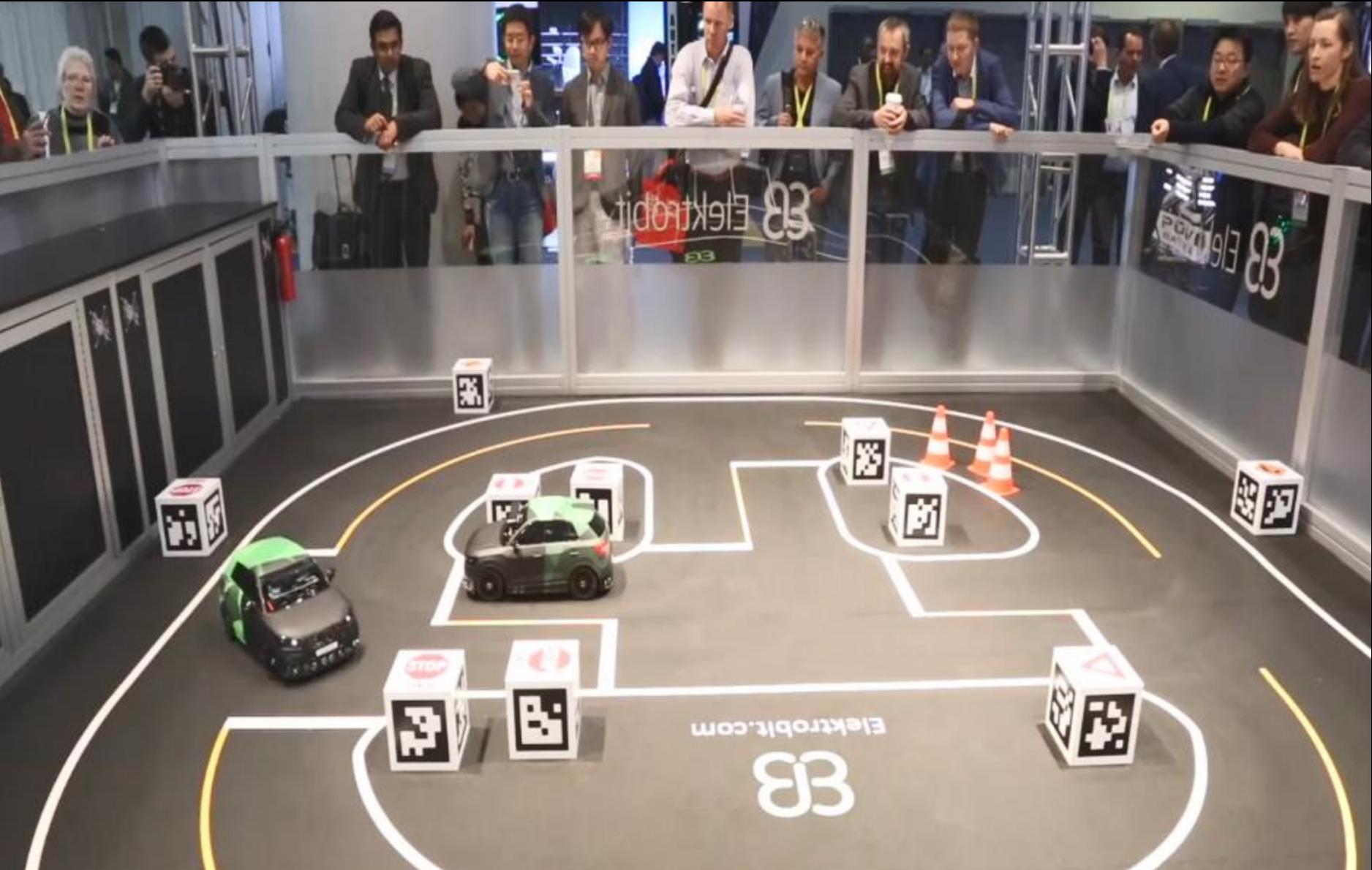
**Der Preis für das beste pilotiert fahrende Modellauto geht nach München: Ein Team von fünf Studierenden der Technischen Universität (TU) München hat sich beim ersten Audi Autonomous Driving Cup gegen starke Konkurrenten aus ganz Deutschland durchgesetzt.**



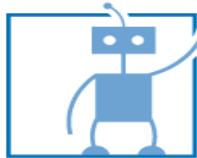
## Audi Autonomous Driving Cup

„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



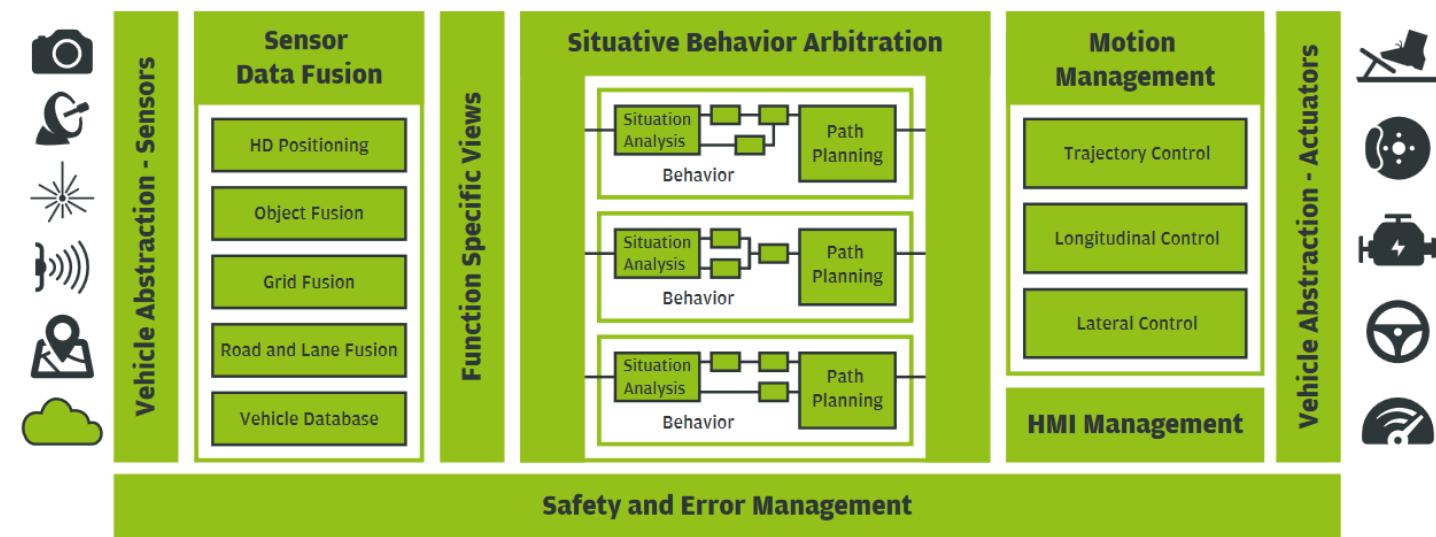
# Simple AD demonstrator at CES with EB Robinos Model Cars

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