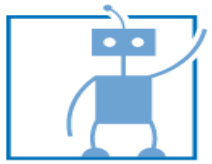
Autonomous Driving
Summer 2019

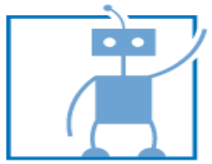
Gereon Hinz

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



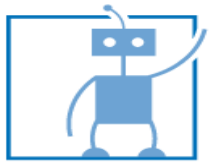
Today‘s Content

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



Lecture Organization

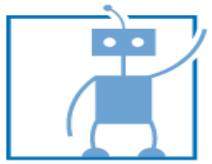
- Lecture:
  - Tuesday 16:00 ~ 18:00 in MW 1801, Ernst-Schmidt-Hörsaal (5508.01.801)
- Examination:
  - Exam (~60 minutes). Date to be announced.
- Changes will be announced via email
- Lecture slides to be uploaded on moodle
  - change every year, due to updated topics and speakers
- Questions and comments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



Planned schedule (up for change)

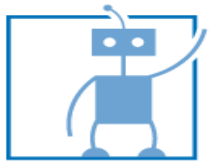
Topic	Purpose
Introduction	Participate in ongoing AD discussions
Path Planning	Plan paths and execute them
Sensor Fusion	Fuse sensors to go from data to information
Deep Learning Applications in AD	Know current application areas, strengths, weaknesses
Semantic Representations & Reasoning	Represent and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

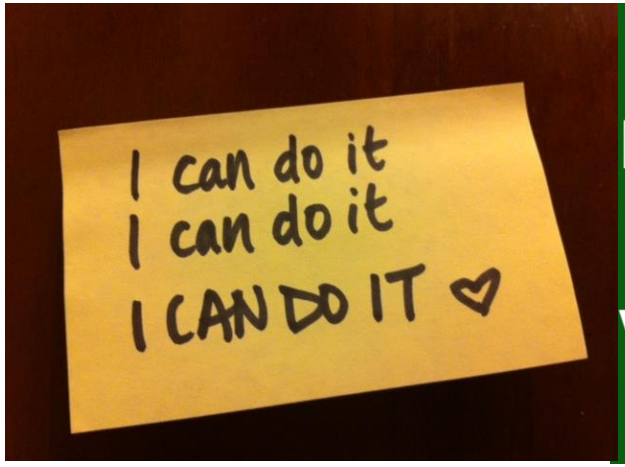
- What is the goal of the Autonomous Driving lecture?
  - **What is not the goal?**
    - Present all autonomous driving related methods and equations in excruciating depth.
      → Could fill its own full university curriculum!
    - Focus on only one very small part of AD and explore that one in even 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, nore in a video. Interaction is desireable.

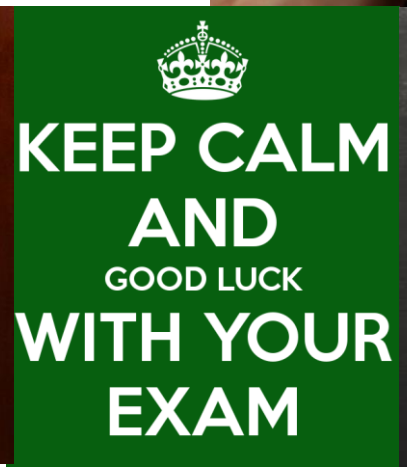


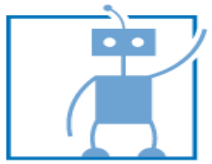
About this lecture…

- 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, allthough 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…





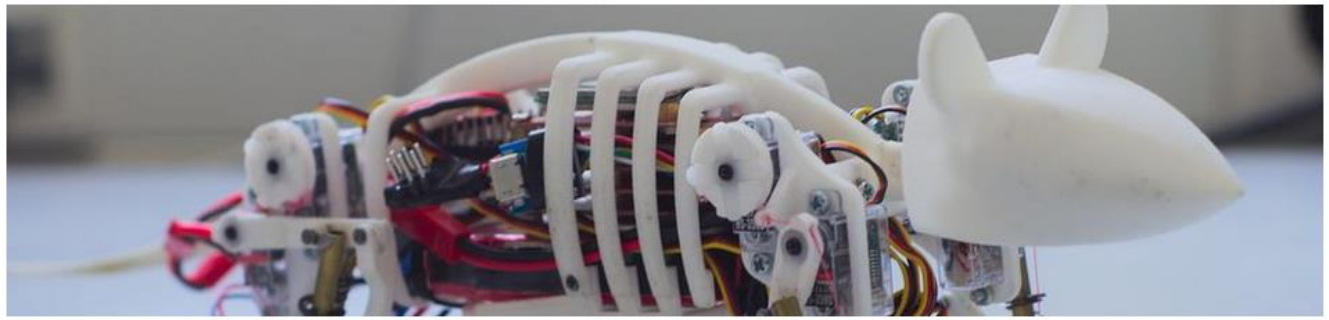


LS VI – Chair of Robotics, Artificial Intelligence and Real-time Systems

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

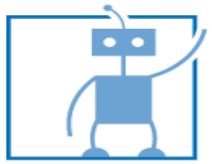
The Human Brain Project HBP
The European Flagship project on Brain Research

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

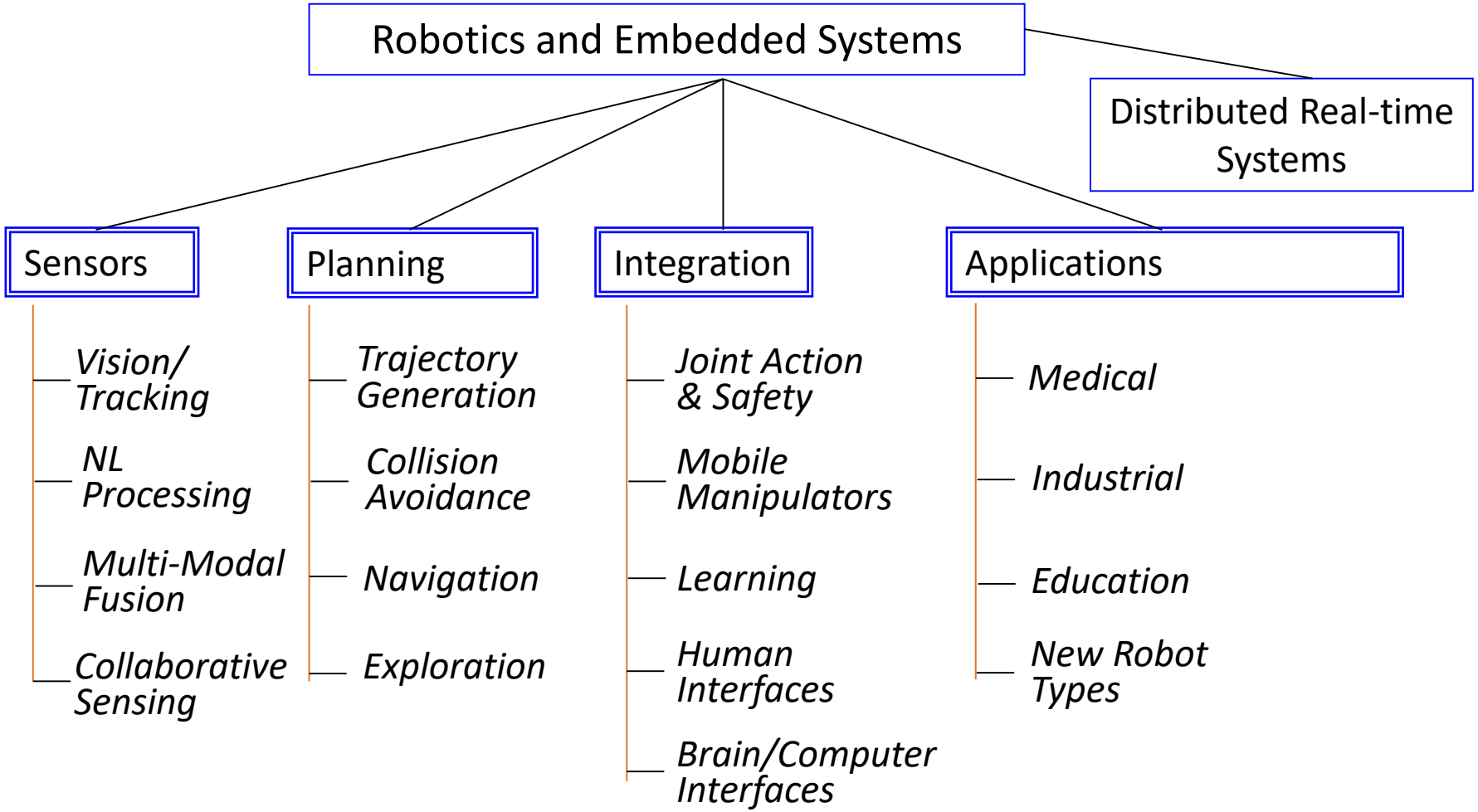


LS VI – Robotics and Embedded Systems

- 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



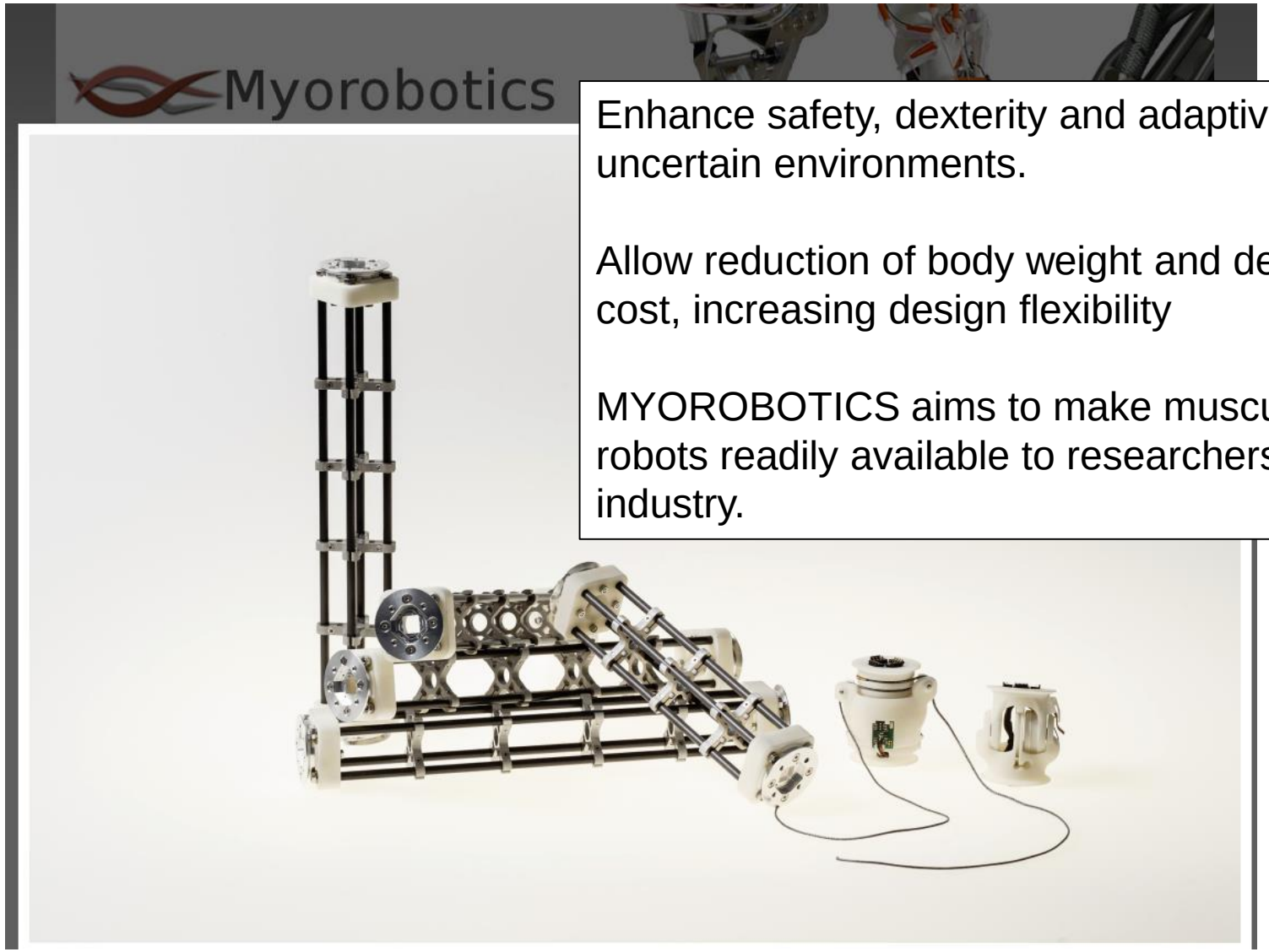
Landmark Projects: ECHORD++

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.

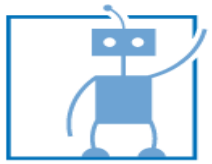
Landmark Projects: Myorobotics Muscoskeletal Robots



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

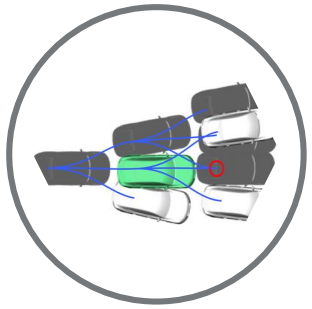
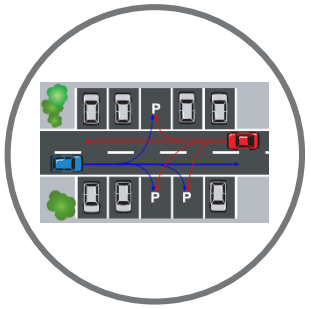
European flagship project to address one of the greatest challenges of modern science:

understanding the human brain.
Total costs estimated: 1.19 billion euros. TUM coordinates sub-project "Neurorobotics."

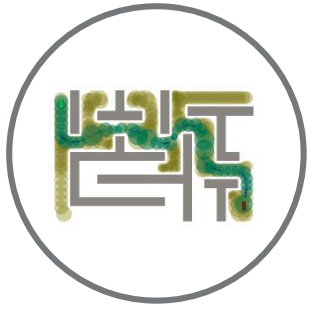
Autonomous Driving
Projects & Experiences - Excerpt

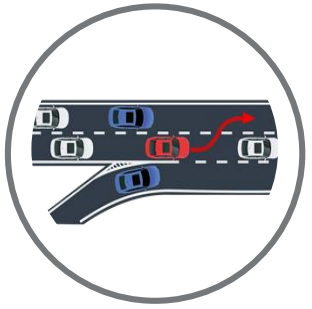
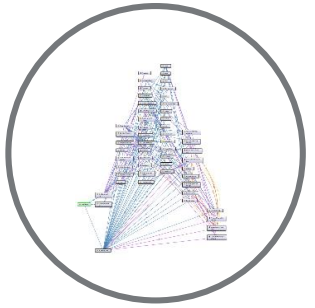
Projects & Experiences

Motion Planning, Data Fusion, Overall Systems



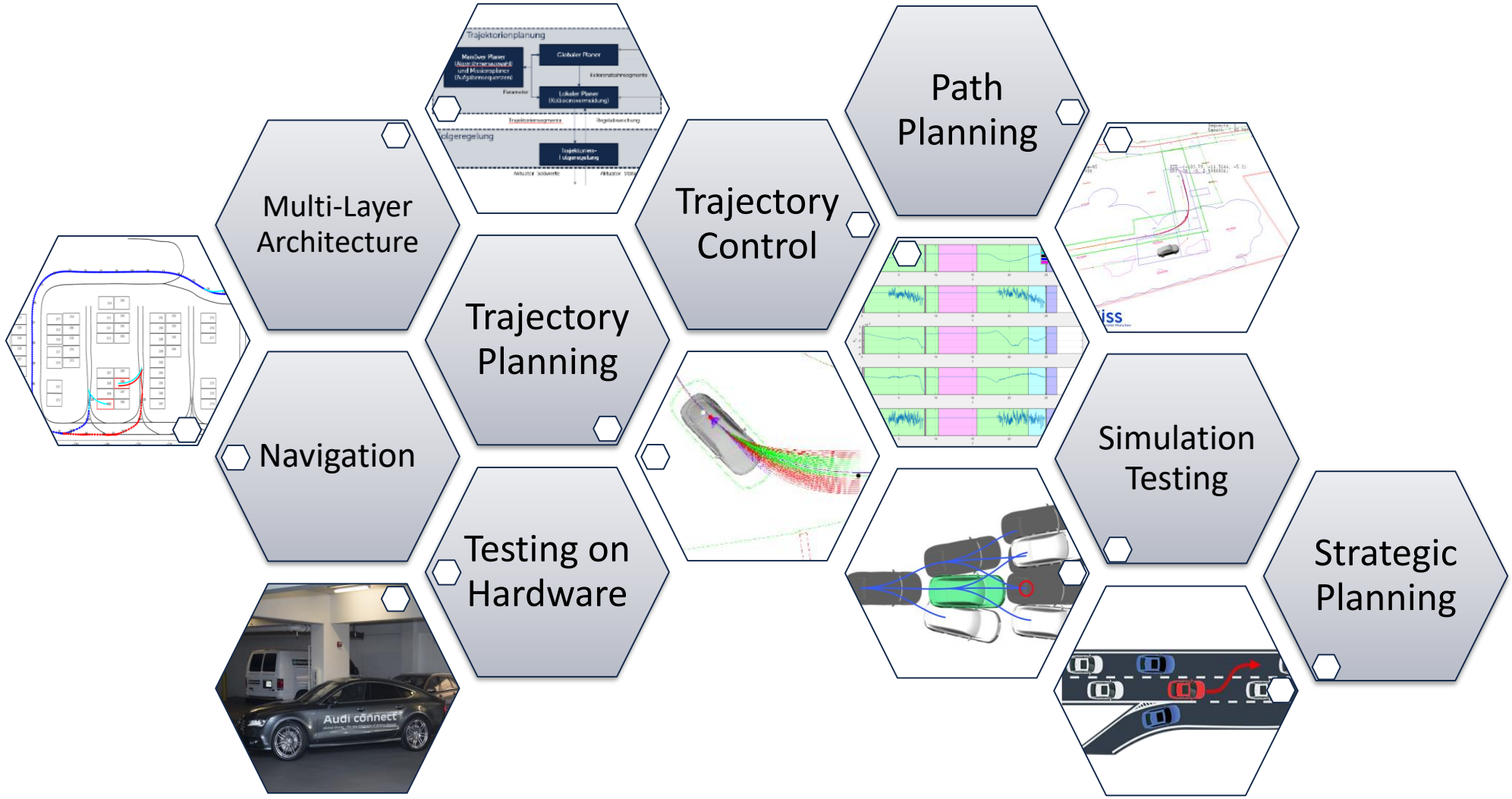



Path Planning / Perception / Data Fusion / Demosntrators /Large Scale Projects …

Software Development for Automated Driving

Focus: Motion Planning

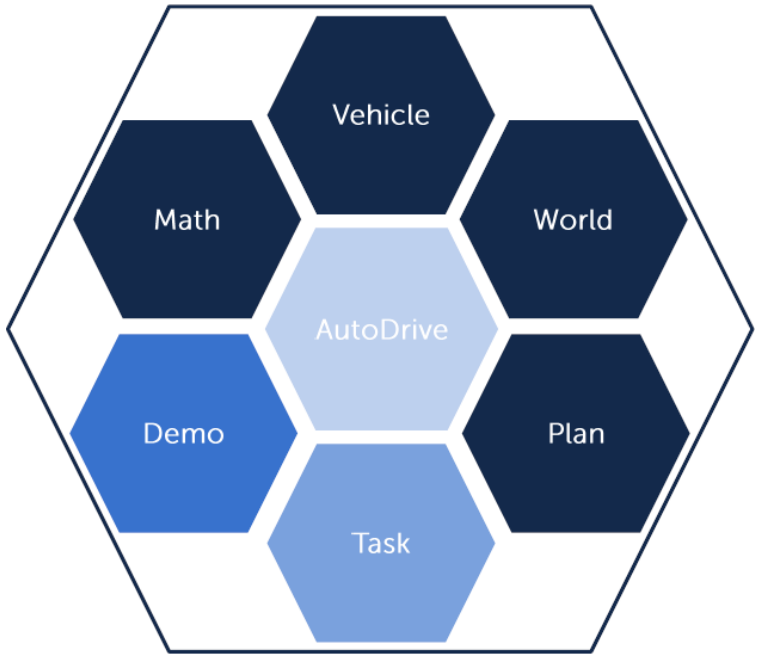


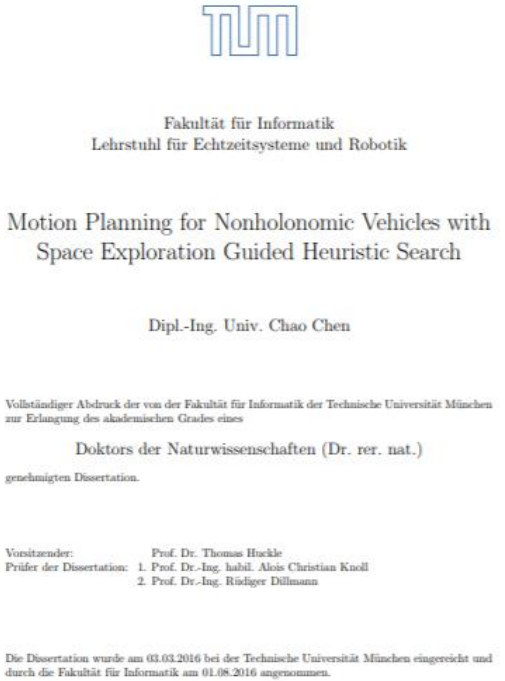
AutoDrive Library

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.)

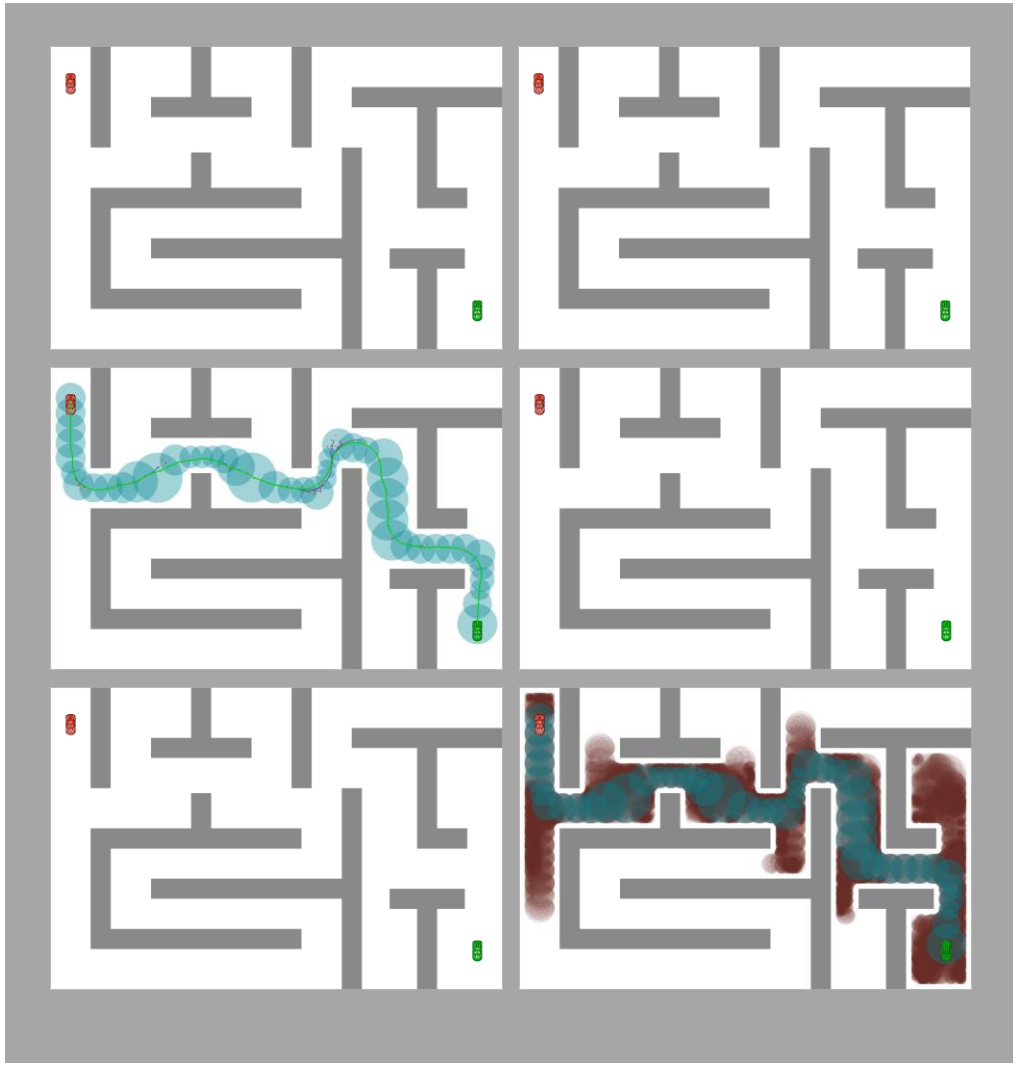
genehmigten Dissertation.

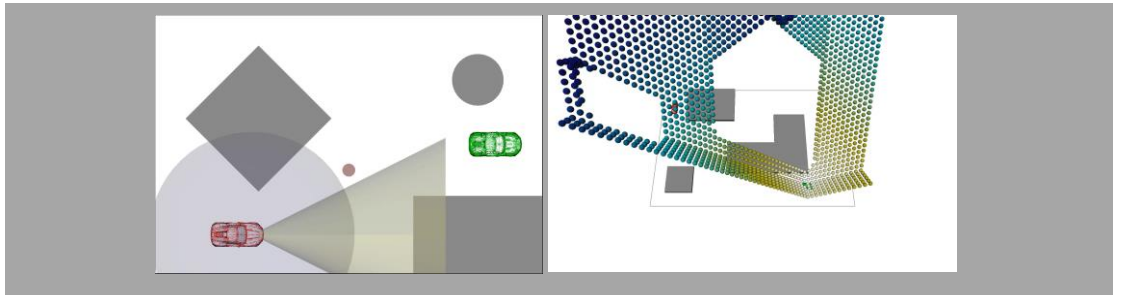
Vorsitzender: Prof. Dr. Thomas Huckle
Prüfer der Dissertation: 1. Prof. Dr.-Ing. habil. Alois Christian Knoll
2. Prof. Dr.-Ing. Rüdiger Dillmann

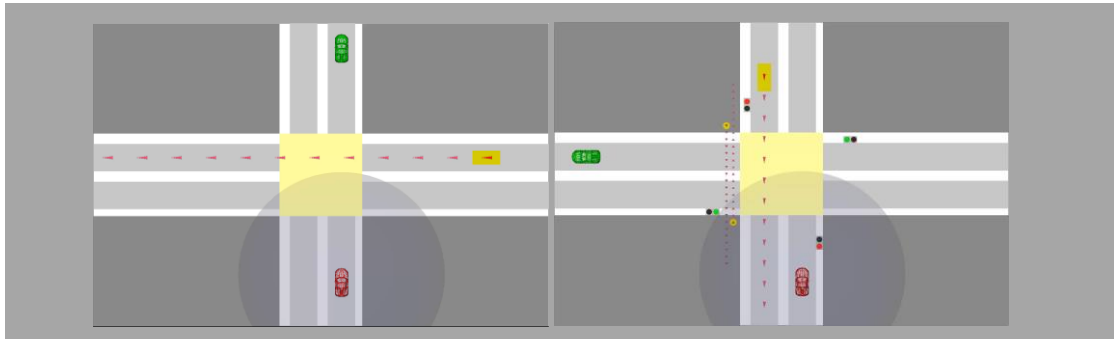
Die Dissertation wurde am 03.03.2016 bei der Technische Universität München eingereicht und durch die Fakultät für Informatik am 01.08.2016 angenommen.

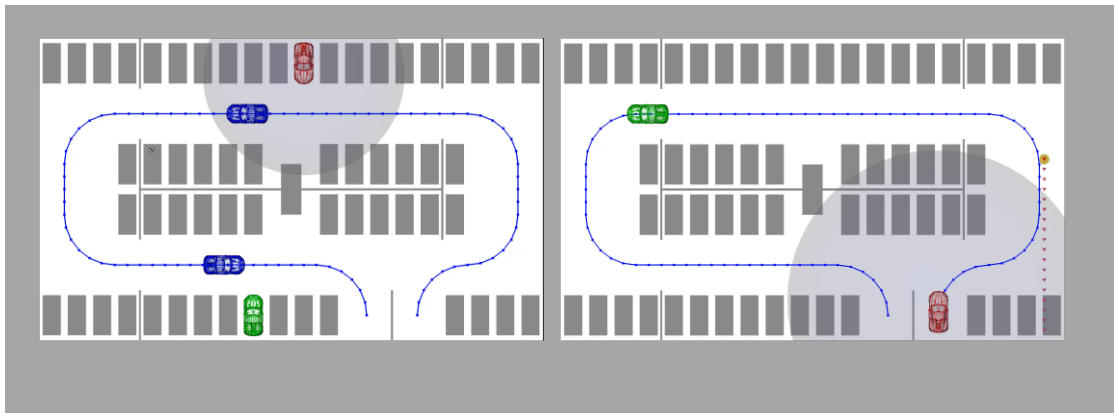
Search Methods (Excerpt)

Video Demonstrations









Excerpt KF AS Publications 2017 only

Motion Planning, Data Fusion, Overall Systems

2017:		
Autoren	**Titel**	**Veröff. in**
Tobias Kessler, Alois Knoll	Multi vehicle trajectory coordination for automated parking	IEEE Intelligent Vehicles Symposium (IV), pages 661 - 666
Tobias Kessler, Pascal Minnerup, David Lenz und Alois Knoll	Systematically comparing control approaches in the presence of actuator errors	IEEE Intelligent Vehicles Symposium (IV), pages 353 - 358
David Lenz, Frederik Diehl, Michael Truong Le, Alois Knoll	Deep neural networks for Markovian interactive scene prediction in highway scenarios	IEEE Intelligent Vehicles Symposium (IV)
Constantin Hubmann, Marvin Becker, Daniel Althoff, David Lenz, Christoph Stiller	Decision making for autonomous driving considering interaction and uncertain prediction of surrounding vehicles	IEEE Intelligent Vehicles Symposium (IV)
Chao Chen, Markus Rickert, Alois Knoll	Motion planning under perception and control uncertainties with Space Exploration Guided Heuristic Search	IEEE Intelligent Vehicles Symposium (IV)
Gereon Hinz, Martin Büchel, Josef Eichinger, Alois Knoll	Providentia: Proactive Video-based Use of Telecommunications Technologies in Innovative Motorway Scenarios	5th GI/ITG KuVS, Fachgespraech Inter-Vehicle Communication(FG-IVC 2017)
Clara Marina Martinez, Feihu Zhang, Daniel Clarke, Gereon Hinz, et al.	Feature uncertainty estimation in sensor fusion applied to autonomous vehicle location	IEEE Information Fusion (Fusion)
Dhiraj Gulati, Feihu Zhang, Daniel Malovetz, Daniel Clarke, Gereon Hinz, Alois Knoll	Graph based vehicle infrastructure cooperative localization	IEEE Information Fusion (Fusion)
Chih-Hong Cheng, Frederik Diehl, Yassine Hamza, Gereon Hinz,et al.	Neural Networks for Safety-Critical Applications - Challenges, Experiments and Perspectives	arXiv:1709.00911 [cs.SE]
Gereon Hinz, Guang Chen, Muhammad Aafaque, Florian Röhrbein, Jörg Conradt, Zhenshan Bing, Zhongnan Qu, Walter Stechele, Alois Knoll	Online Multi-object Tracking-by-Clustering for Intelligent Transportation System with Neuromorphic Vision Sensor	KI 2017: Advances in Artificial Intelligence
Martin Buechel, Gereon Hinz, Frederik Ruehl, Hans Schroth, Csaba Gyoeri, Alois Knoll	Ontology-based traffic scene modeling, traffic regulations dependent situational awareness and decision-making for automated vehicles	IEEE Intelligent Vehicles Symposium (IV)
Richard Gruner, Philip Henzler, Gereon Hinz, Corinna Eckstein, Alois Knoll	Spatiotemporal representation of driving scenarios and classification using neural networks	IEEE Intelligent Vehicles Symposium (IV)
Guang Chen	Efficient 3D Human Motion Perception System with Un-supervision, Randomization and Discrimination	PhD Thesis, MediaTUM
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	In IEEE Transactions on Cognitive and Developmental Systems
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	Bioinspiration & Biomimetics, 12(3):035001
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	Sensors
Mingchuan Zhou, Hessam Roodaki, Abouzar Eslami, Guang Chen, Kai Huang, et al.	Needle segmentation in volumetric optical coherence tomography images for ophthalmic microsurgery	Applied Sciences
Zhenshan Bing, Long Cheng, Kai Huang, Zhuangyi Jiang, Guang Chen, et al.	Towards autonomous locomotion: Slithering gait design of a snake-like robot for target observation and tracking	IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)
Zhuangyi Jiang, Zhenshan Bing, Kai Huang, Guang Chen, Long Cheng, and Alois Knoll	Event-based target tracking control for a snake robot using a dynamic vision sensor	International Conference On Neural Information Processing (ICONIP
G. Hinz, M. Büchel, F. Diehl, G. Chen, A. Krämmer, J. Kuhn, V. Lakshmirasimhan, M. Schellmann, U. Baumgarten, A. Knoll	Designing a far-reaching view for highway traffic scenarios with 5G-based intelligent infrastructure	8. Tagung Fahrerassistenzsysteme TÜV-Süd

Autonomous Driving Impressions

SADA

IKT FÜR ELEKTROMOBILITÄT

Gefördert durch:

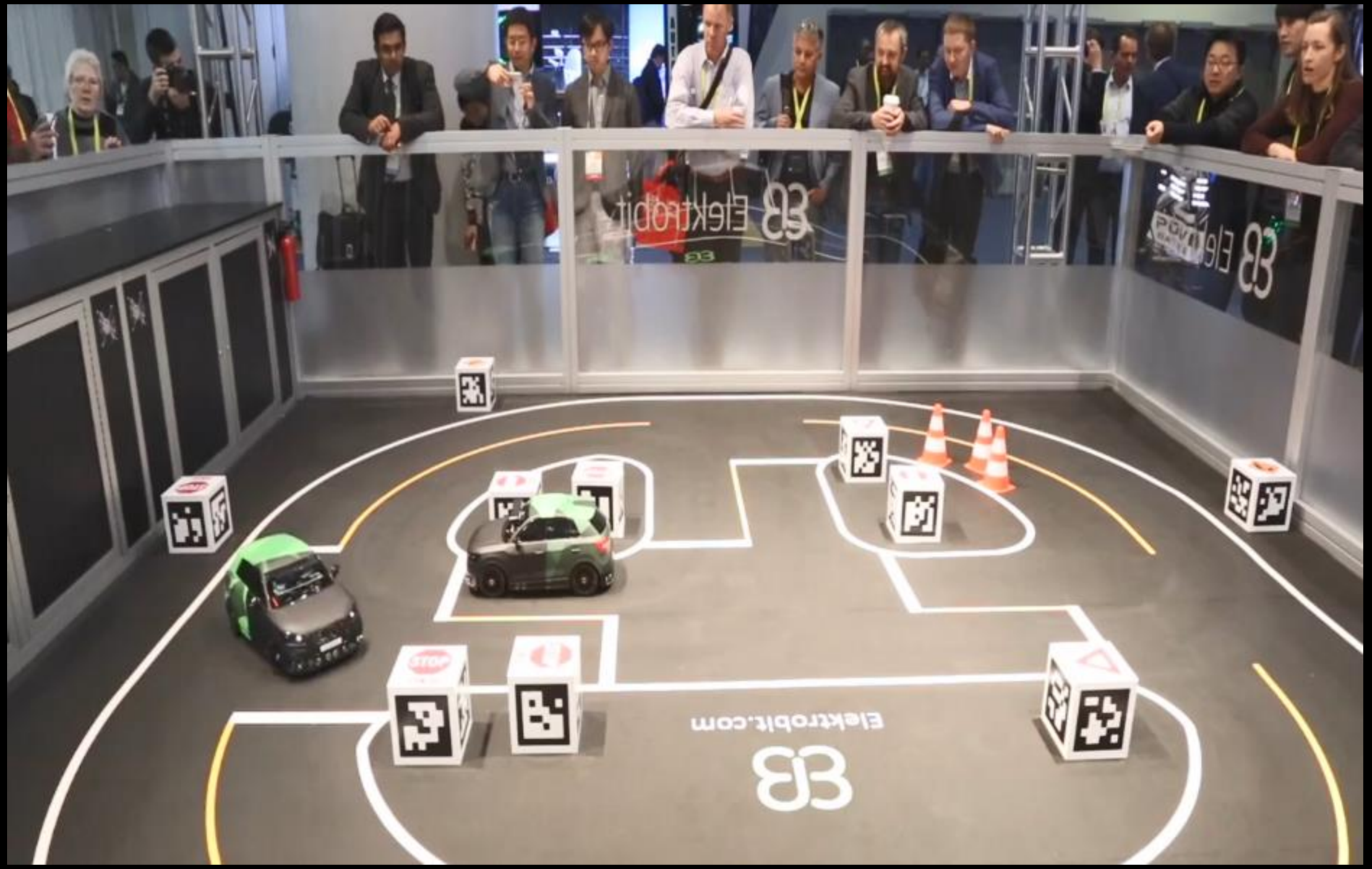
Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

fortiss

SIEMENS

Ingenuity for life



Impressions - CES 2017

Impressions - Berlinale 2016

Autonomous Garage

Contributions to Prototype Demonstrators

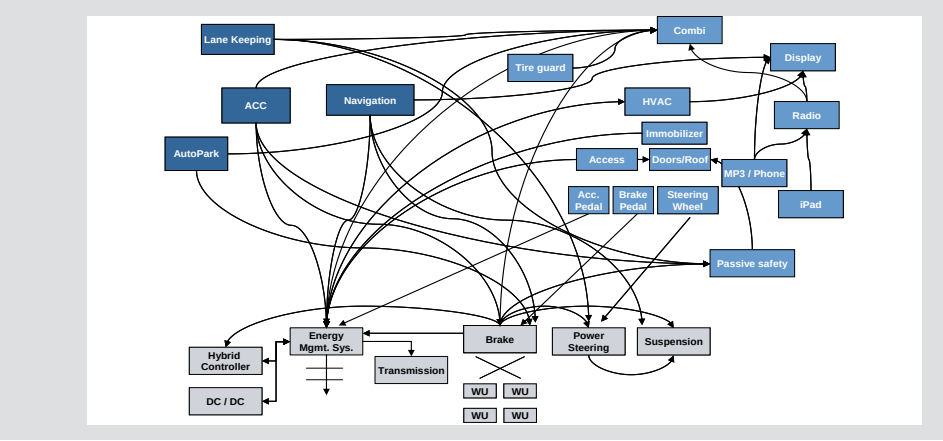

SIEMENS
RAFI
Everything seems to be ready...

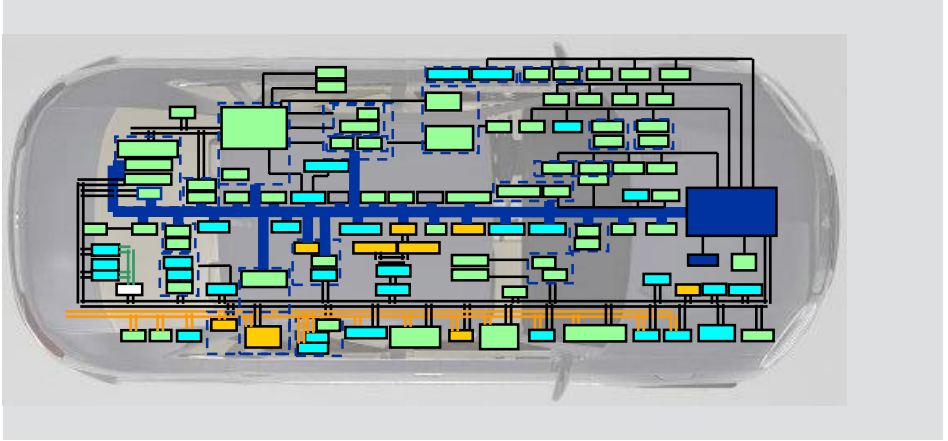

fortiss
innovation in software and systems
Cyber-Physical Systems
supported by
Robotics and Embedded Systems
Technische Universität München

Contributions to Prototype Demonstrators: RACE

RACE

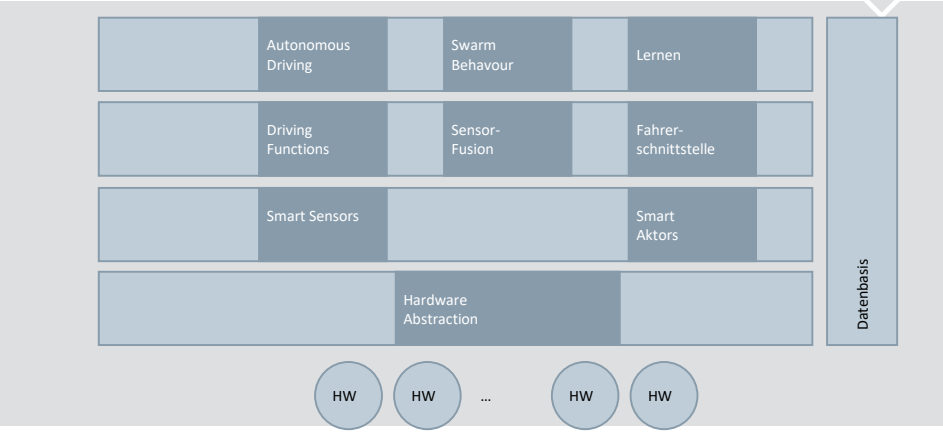
Reduction of E/E-Architecture Complexity

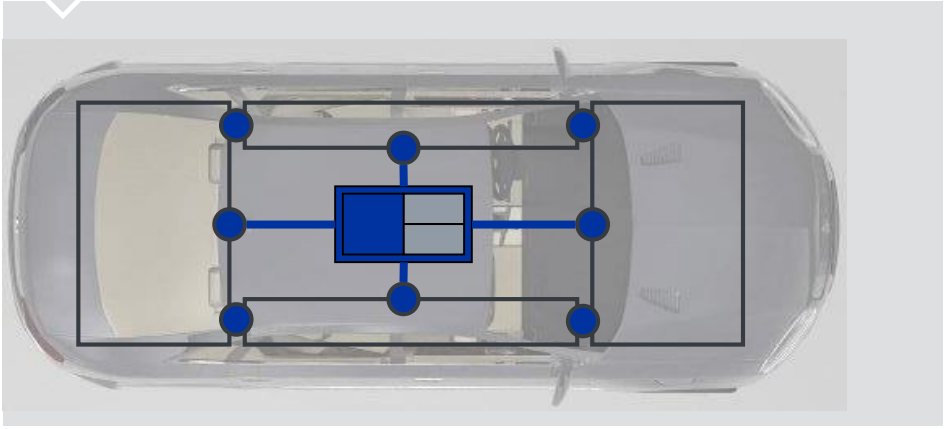




- Position independent Partitioning
  - Defined Information Flow
    - Hierarchical Decision
    - Plug & Play Compatible

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





fortiss 5G Autonomous Driving Research Platform

Huawei
5G Modem

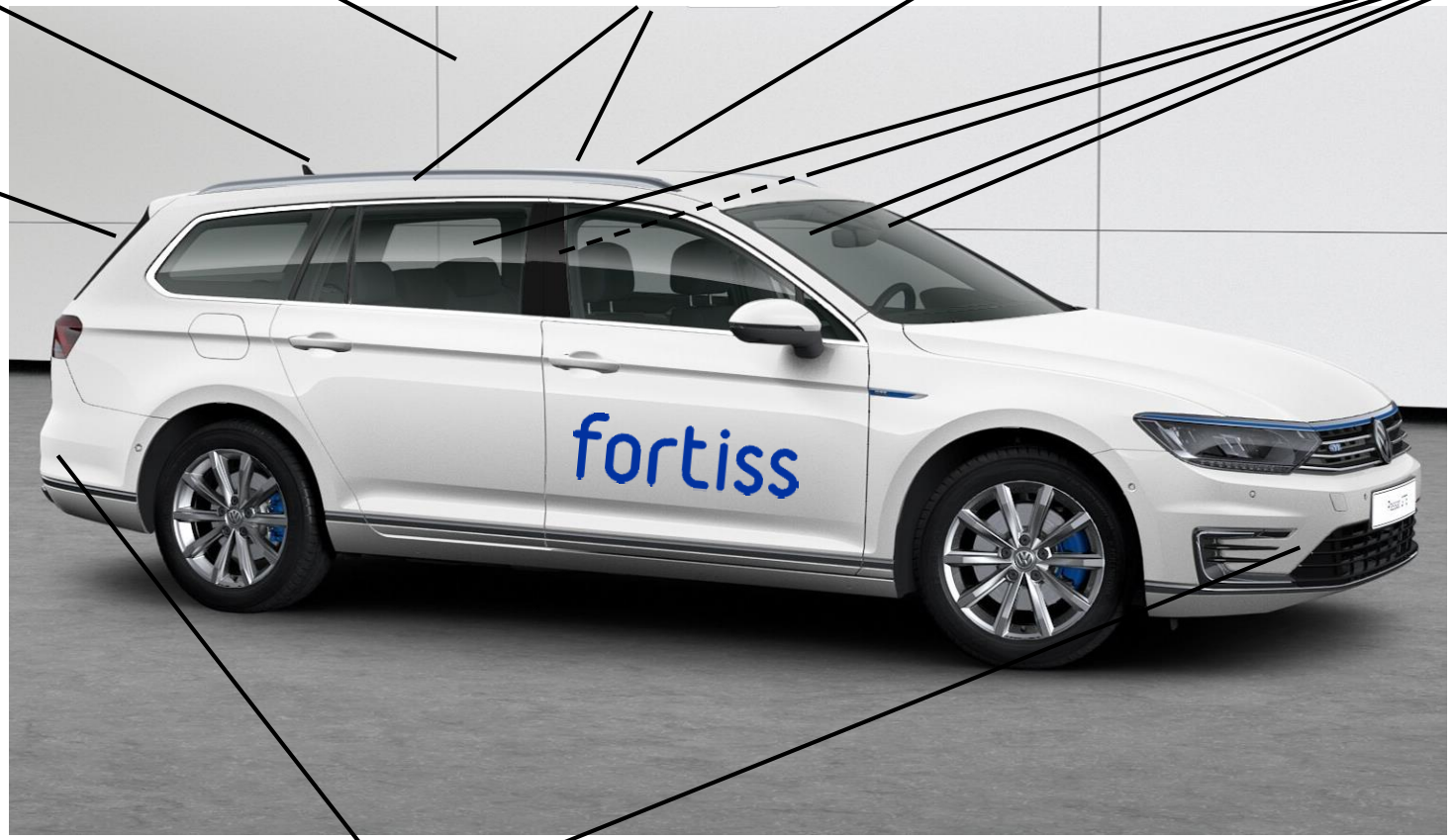
1x Velodyne
VLP32-C

2x Velodyne
VLP16

RTK-INSS
iMAR iNAT FSSG-1

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

Sekonix
Camera
60°
FoV

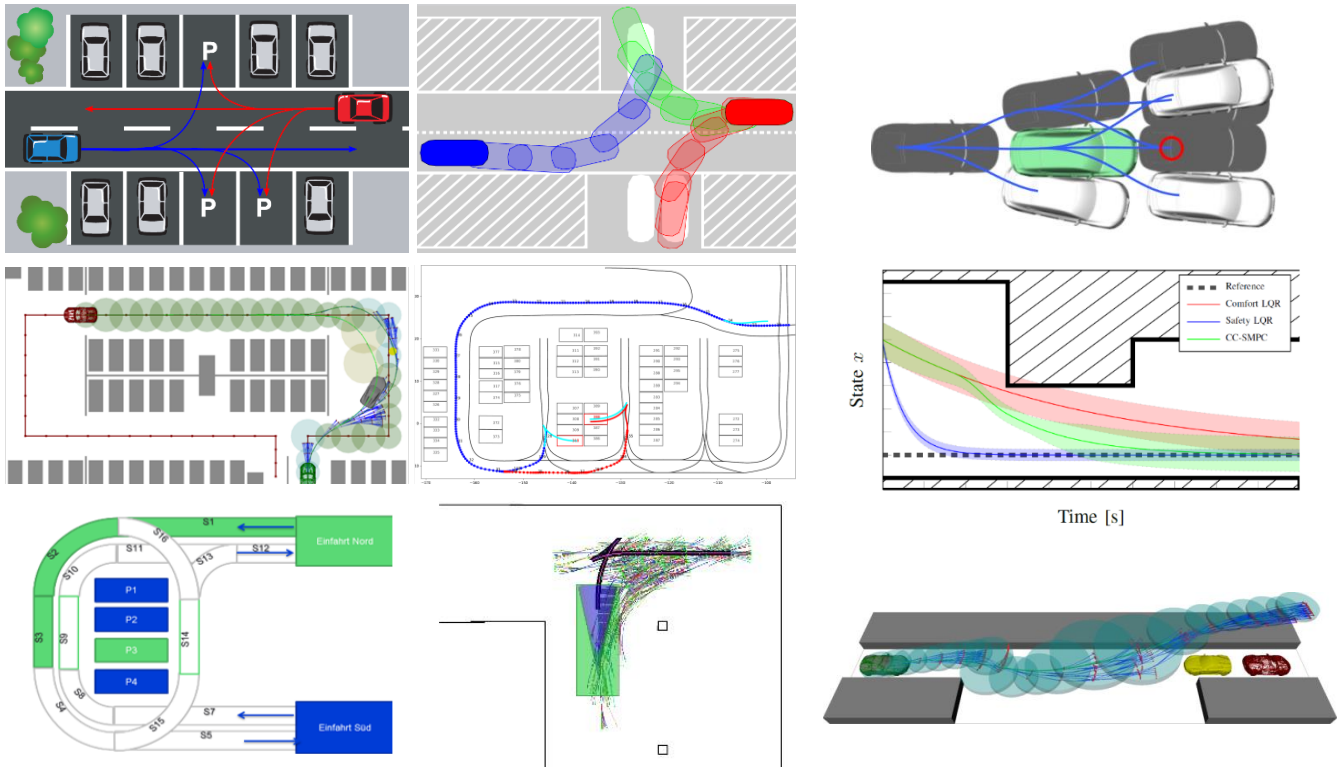


4x Radar
Smartmicro
UMRR 146

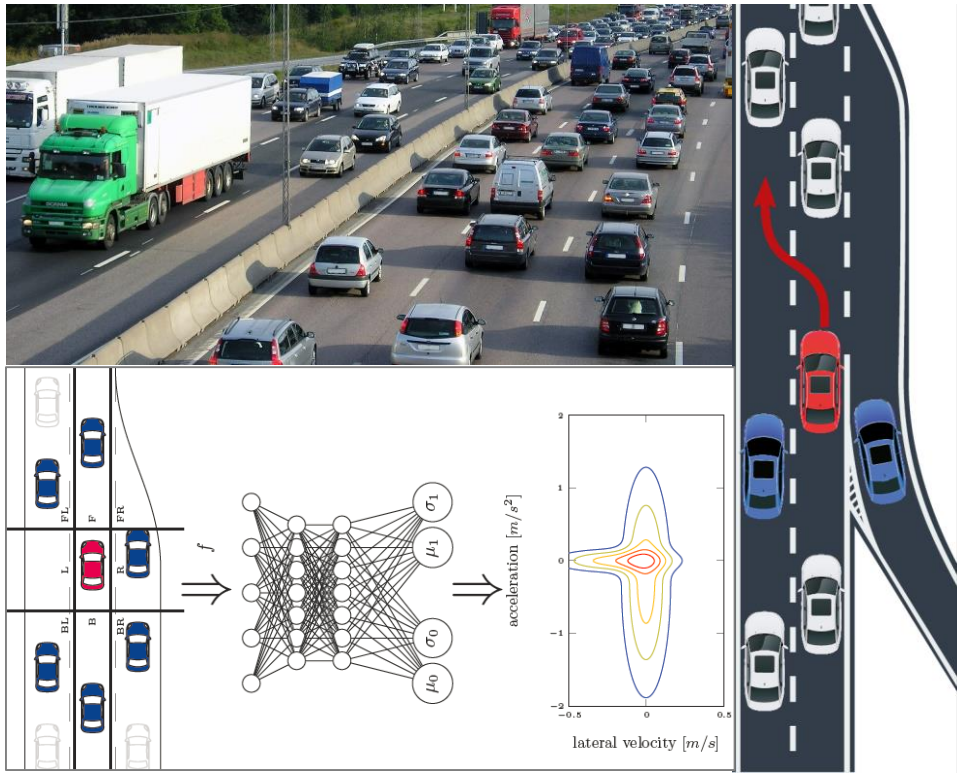
- Computer vision:
  Drive PX2
- Data fusion unit:
  CarPC1 (Nvidia GTX1050TI)
- Visualisation-/Planning unit:
  CarPC1 (Nvidia GTX1050TI)
- Realtime Prototyping:
  dSPace MicroAutobox II

Applications for motion planning, decision making and testing

Algorithms for planning and testing

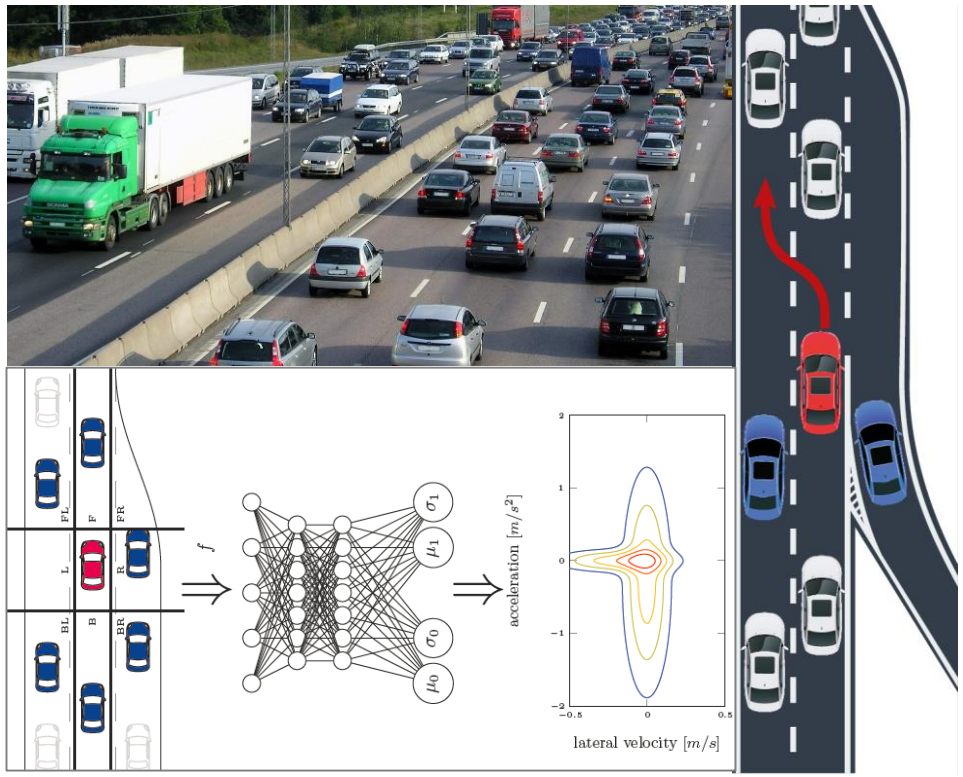


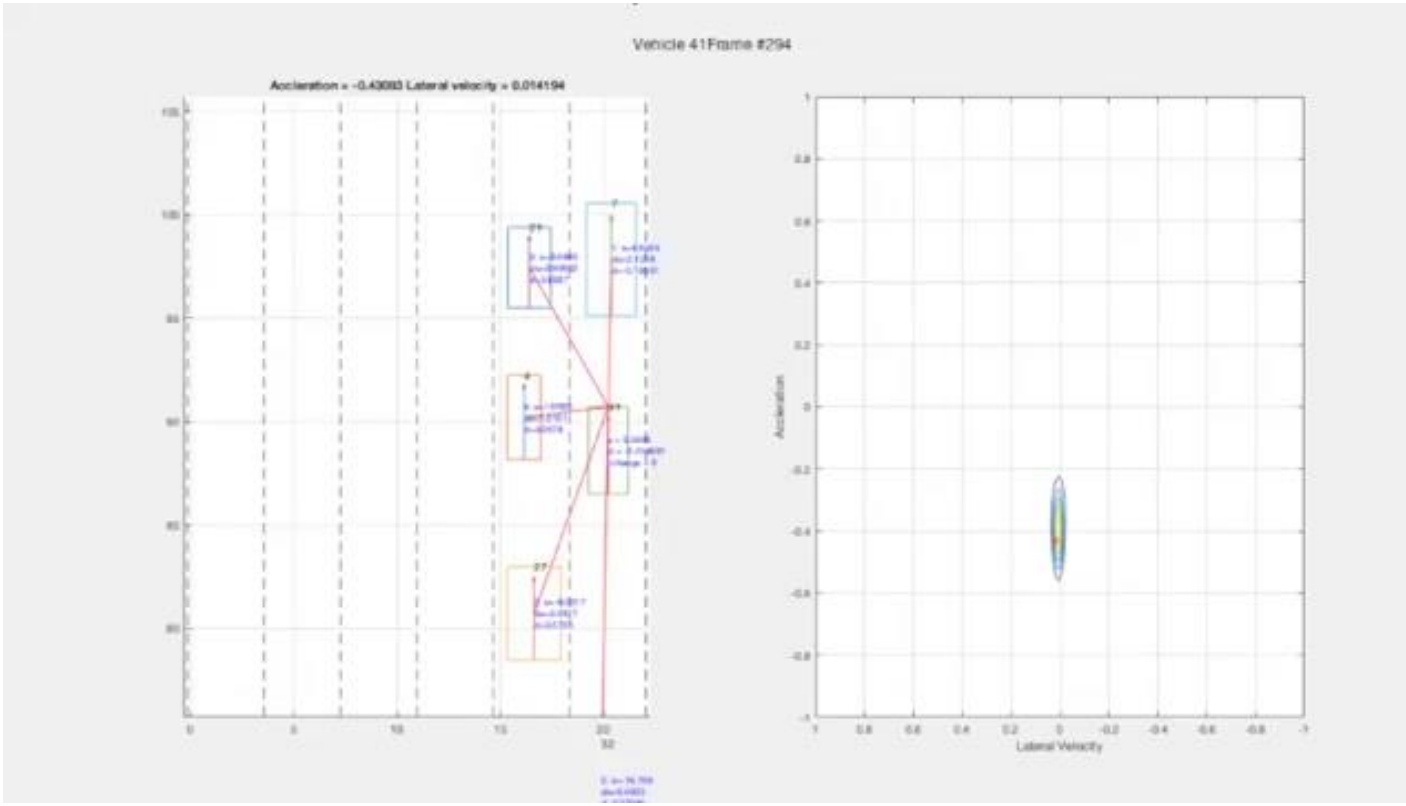
Deep Learning for strategic decision making



Deep Neural Networks for Interactive Scene Prediction

Deep Learning for strategic decision making



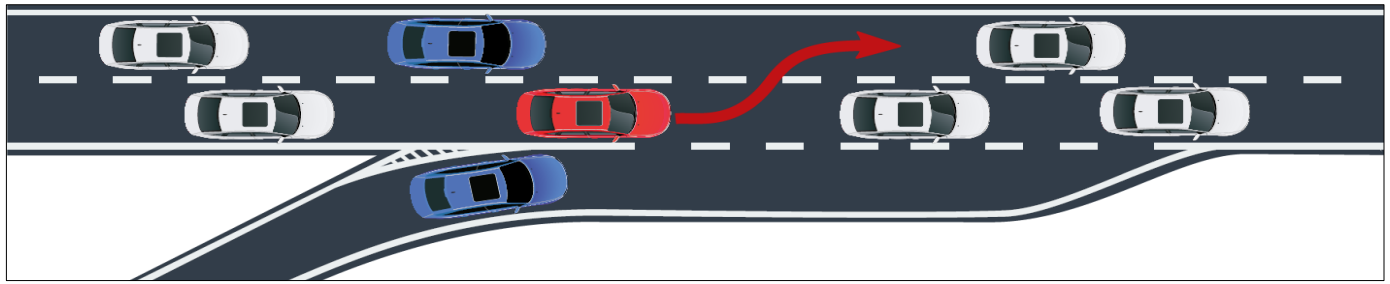


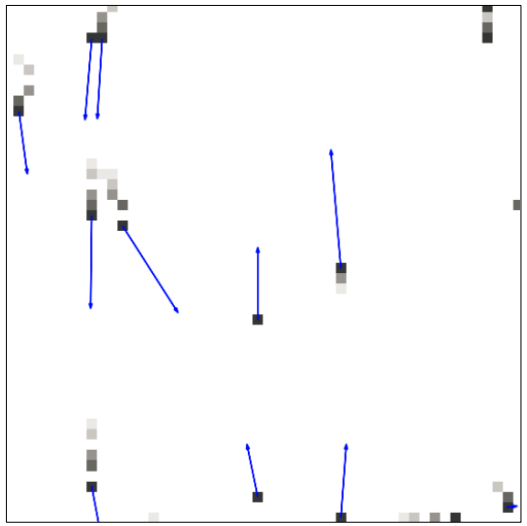
Sensor-Set Object List based Scenario Classification

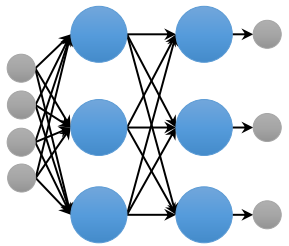
From Sensors to Scenarios

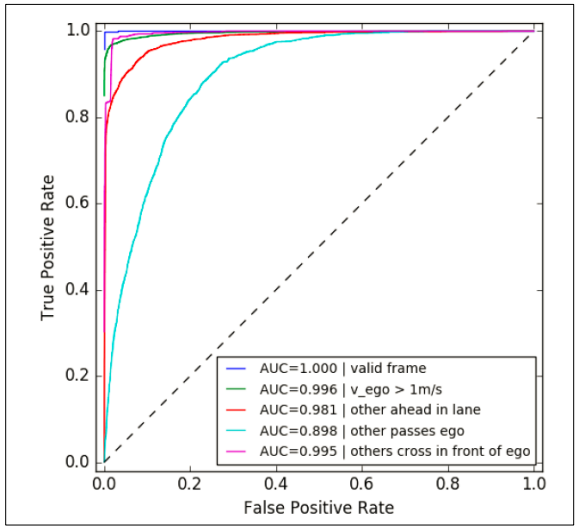
- Going from Vehicle Perception Data Object Lists from real traffic to scenarios with Deep Learning Neural Networks

- Scenarios
  - Valid Frames
  - Velocity Based Scenarios
  - Take-Over Manneuver
  - Others Cross in Front of Ego Veihcle
  - Lane Changes
  - …









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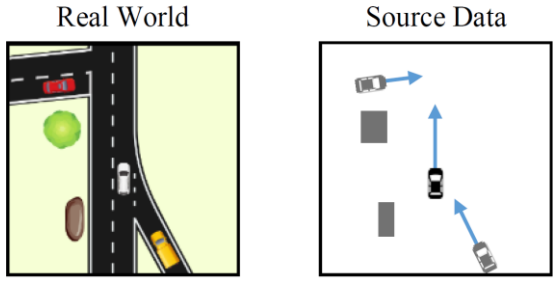
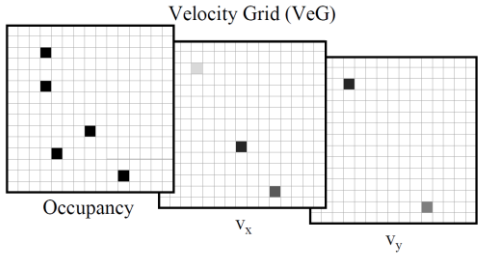
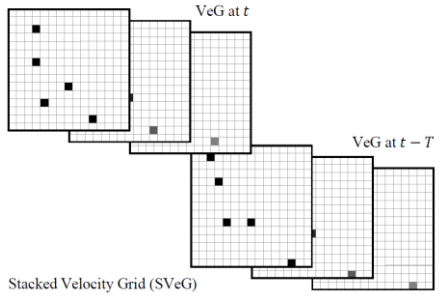
  - Lane Changes
  - …

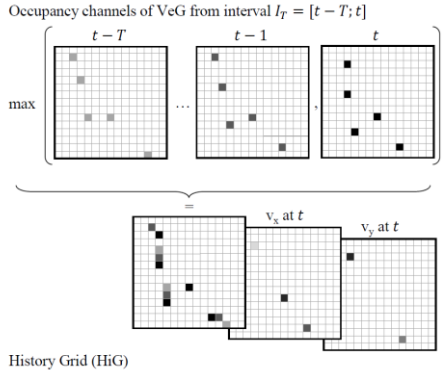
- Example Scenario Classification and Prediction
  ("Spatiotemporal representation of driving scenarios and classification using neural networks, Gruner, Hezler, Hinz et. Al., IV 2017)
  – Use fused sensor data as input:



  – Choose Data Representation Format:



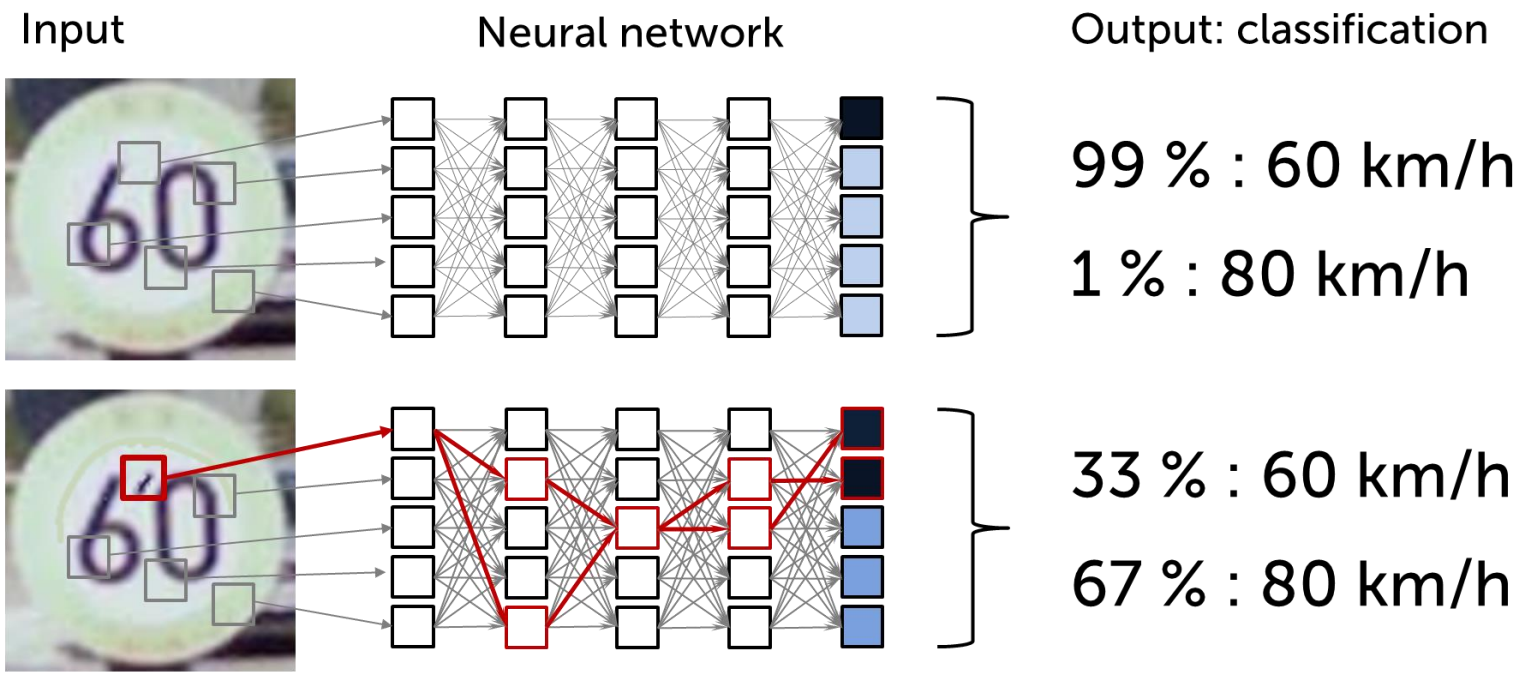




Adversarial images

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.

Terminal

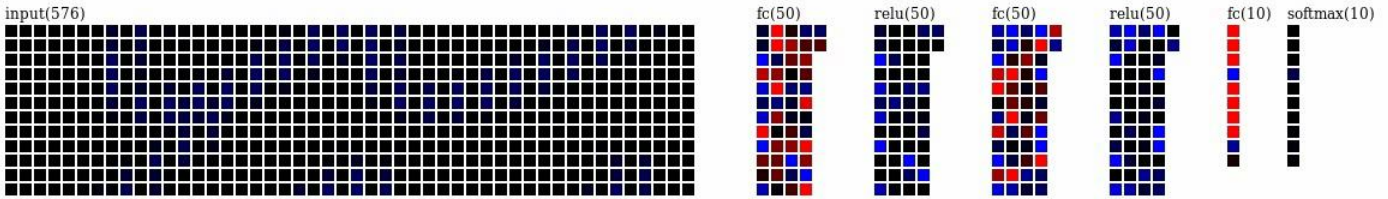
nn-verifier demo - Mozilla Firefox

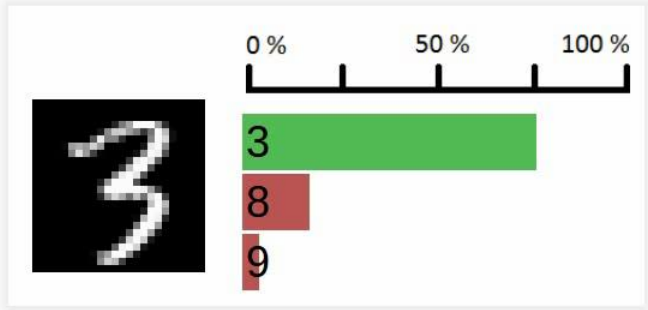
nn-verifier demo

file:///home/georg/Documents/nn-verifier/nn-vis/nn-vis.html

Search

Value Function Approximating Neural Network:



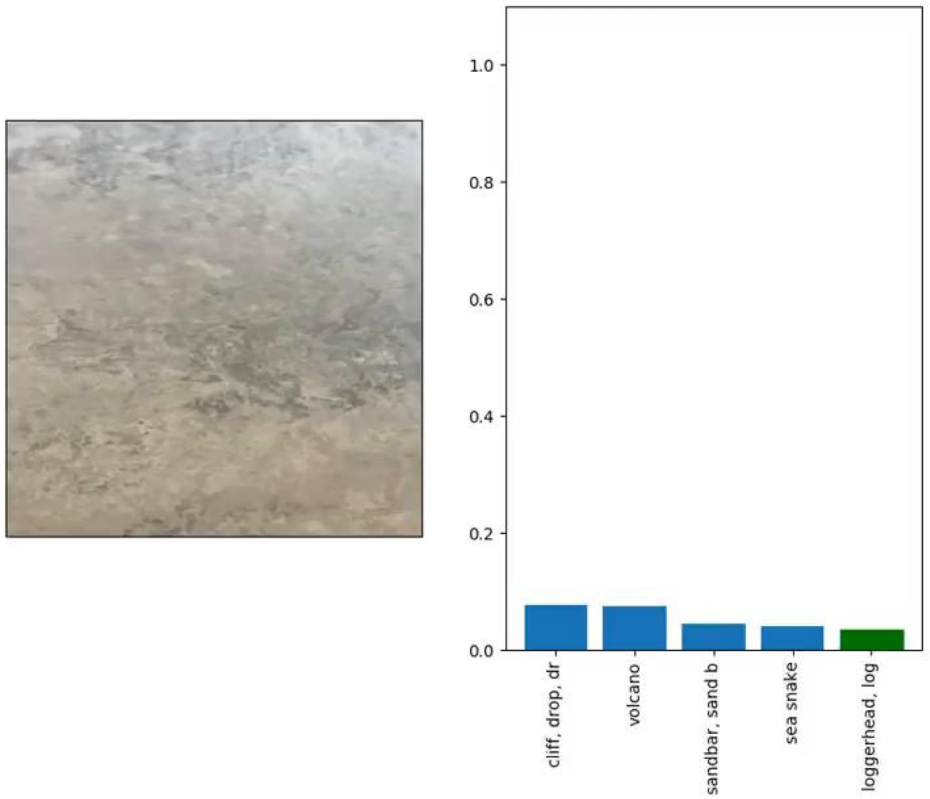


incumbent.png

georg@georg-VirtualBox: ~/Documents/nn-verifier

```
georg@georg-VirtualBox:~$ cd Documents/nn-verifier/
georg@georg-VirtualBox:~/Documents/nn-verifier$ ./prepare_demo 3
georg@georg-VirtualBox:~/Documents/nn-verifier$ eog data/incumbent.png &
[1] 4918
georg@georg-VirtualBox:~/Documents/nn-verifier$ bin/nn_verifier -min_perturbatio
n 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?!

widersprüchlich

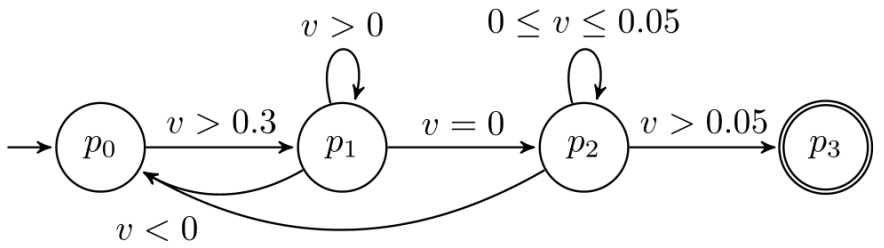
Black-box adversarial examples

- 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).

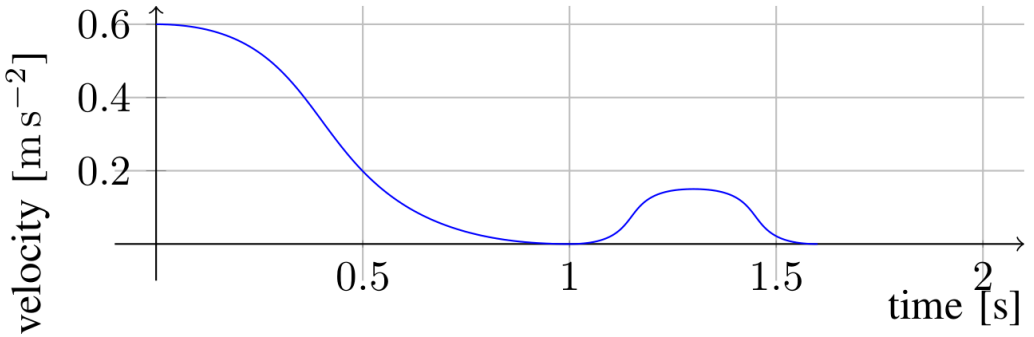
Detection and prediction of undesired Vehicle Behavior

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



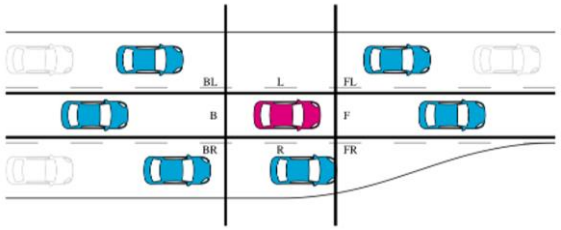
NuSMV: **SPEC** !**EF**(*G0* & **E**[*G1* **U** *G2* & **E**[*G3* **U** *G0*]]);

G0:= v>0.05, G1:= v>0, G2:= v=0, G3:= 0<=v<=0.05



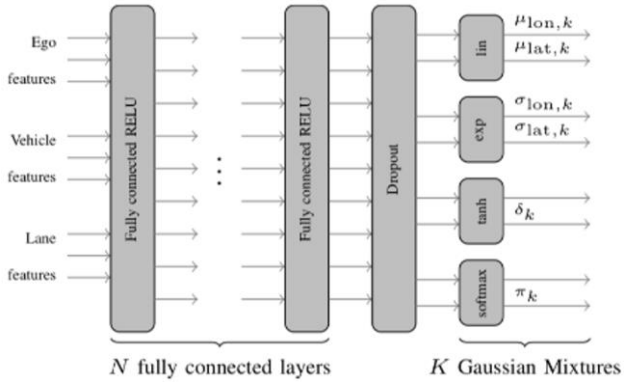
Verification of safety properties of NNs

Neural network example:



features of traffic situation

input



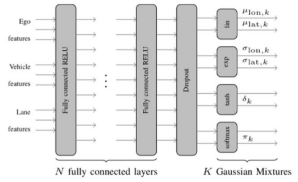
neural network

sample action

- lateral velocity
- longitudinal acceleration

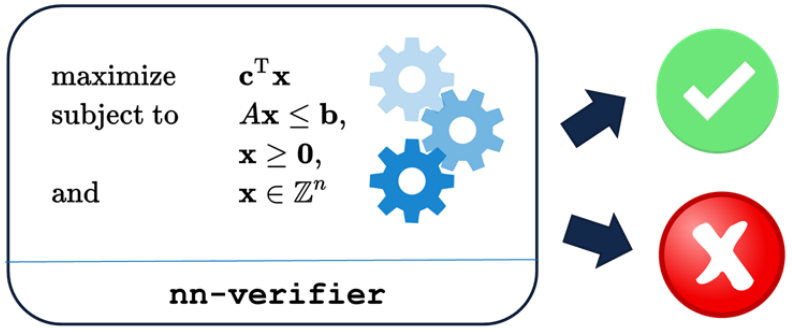
Neural network verification

- **NN**



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

input



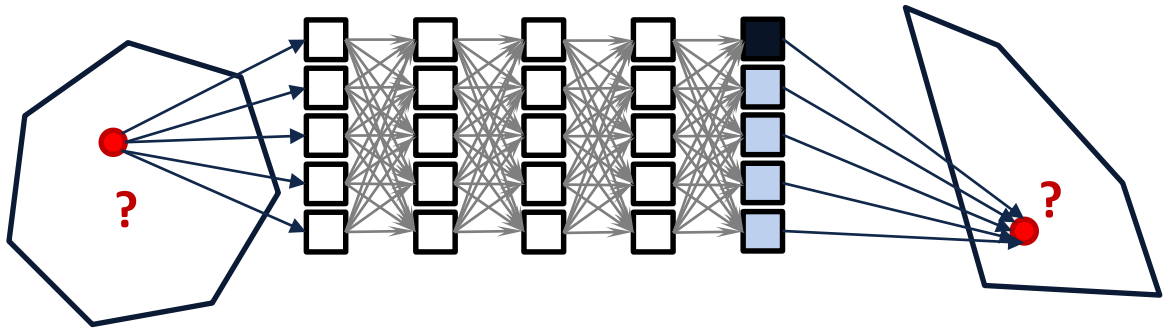
- Lenz, David, Frederik Diehl, Michael Truong Le, and Alois Knoll. "Deep neural networks for Markovian interactive scene prediction in highway scenarios." In *Intelligent Vehicles Symposium (IV), 2017 IEEE*, pp. 685-692. IEEE, 2017.
- Cheng, Chih-Hong, et al. "Neural networks for safety-critical applications-challenges,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

Verifying safety properties of Neural Networks

Safety of highway motion predictor

Eigenschaften

- 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

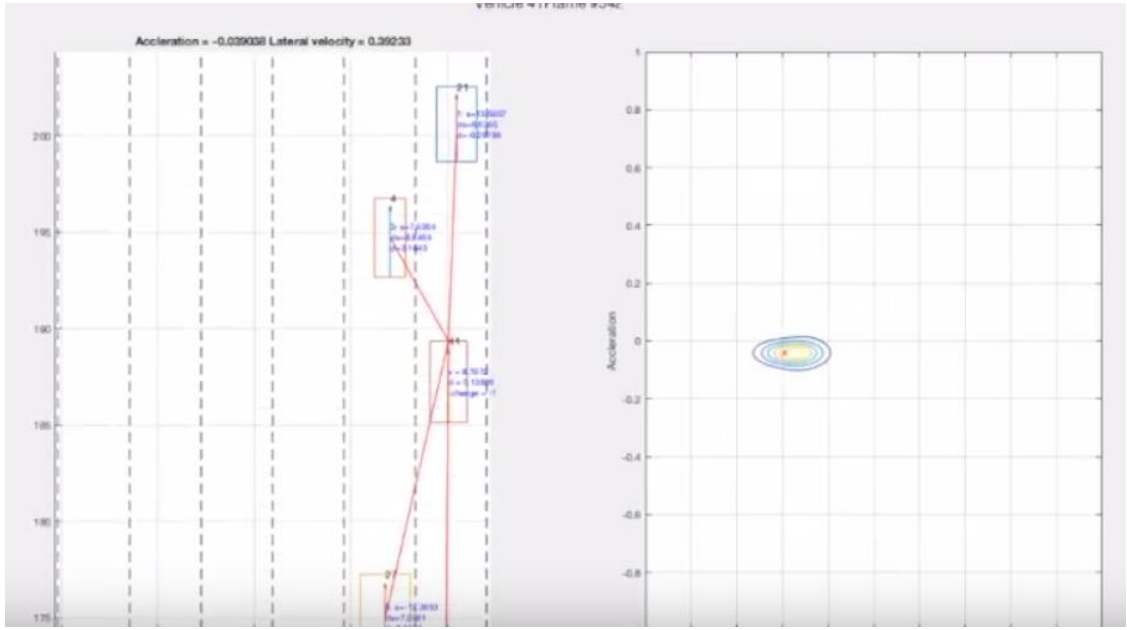


Input set

Output set

Input:
sensor data

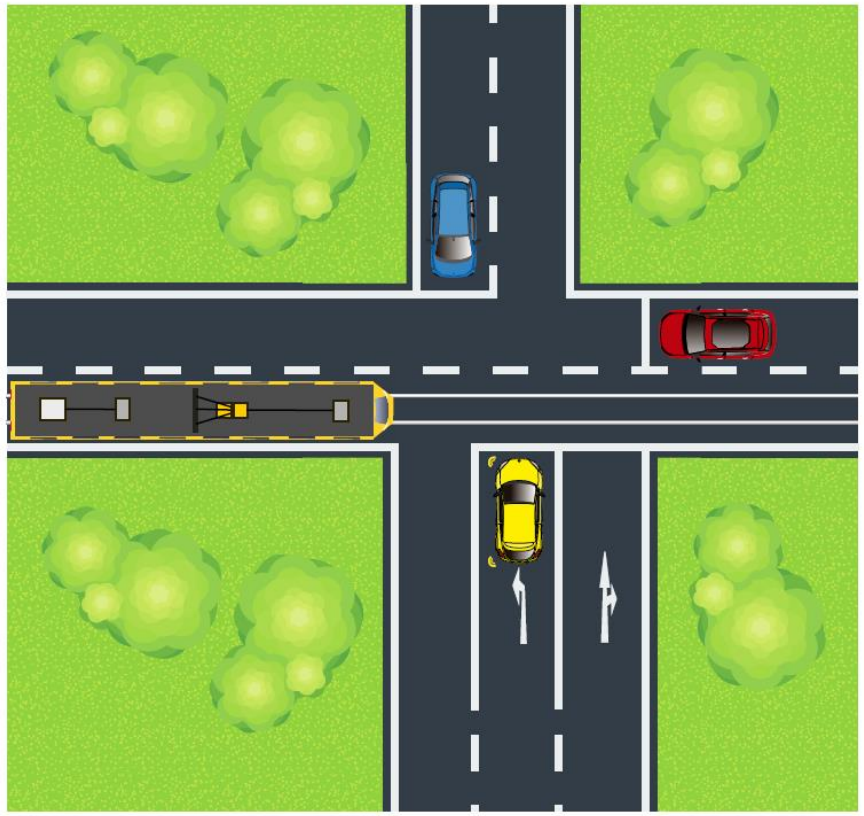
Output:
velocity prediction

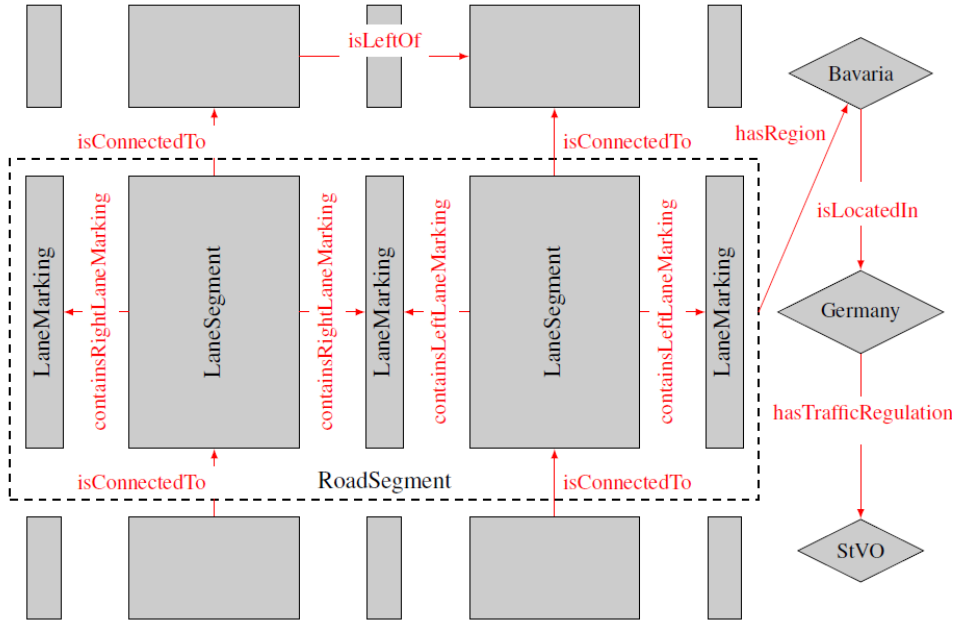


Highway motion predictor, being trained under the NGSim dataset

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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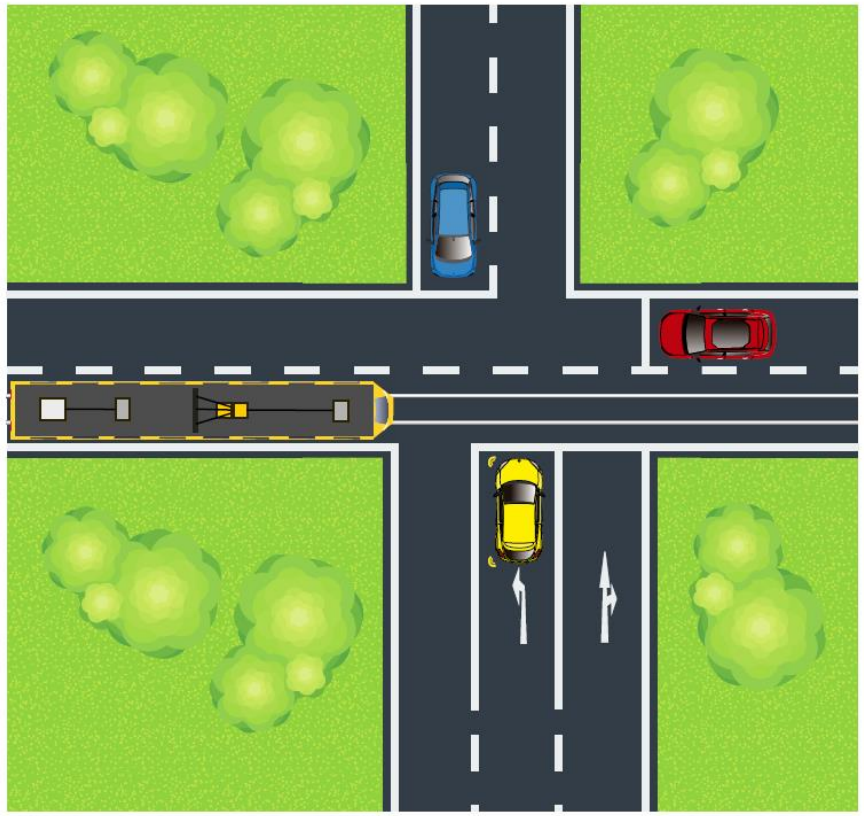

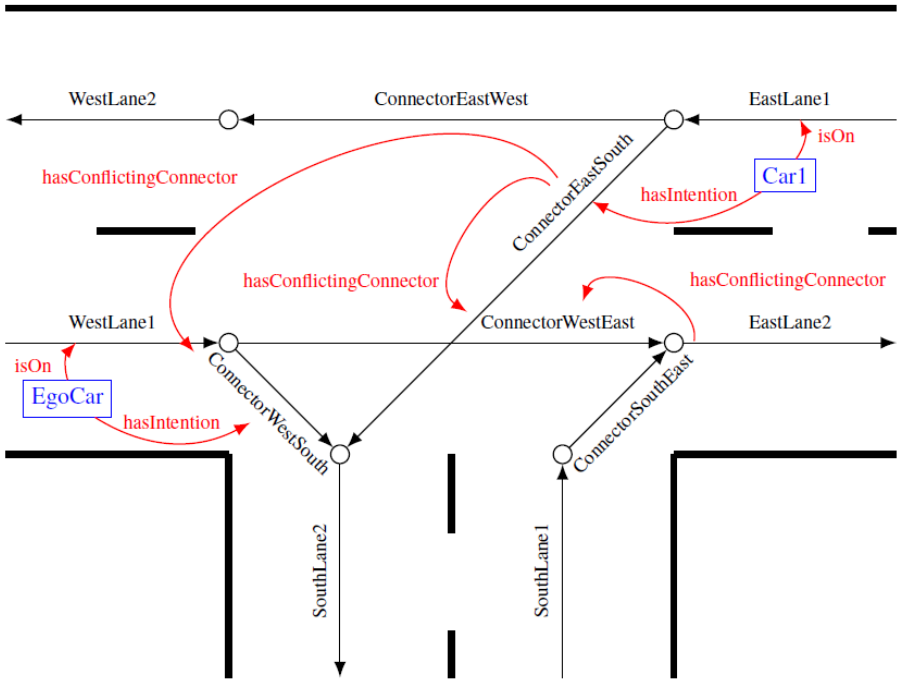

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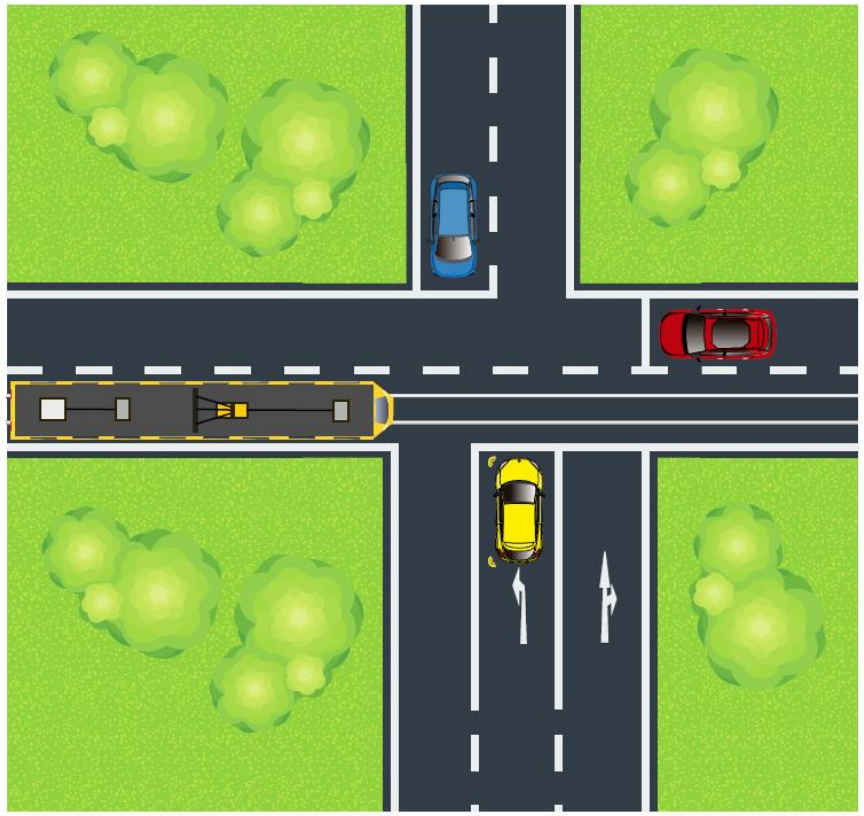

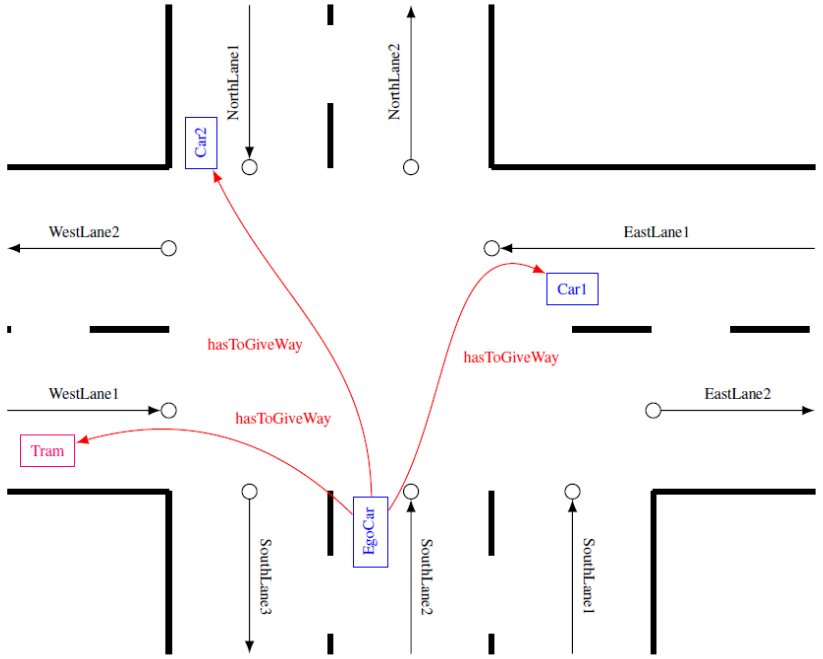

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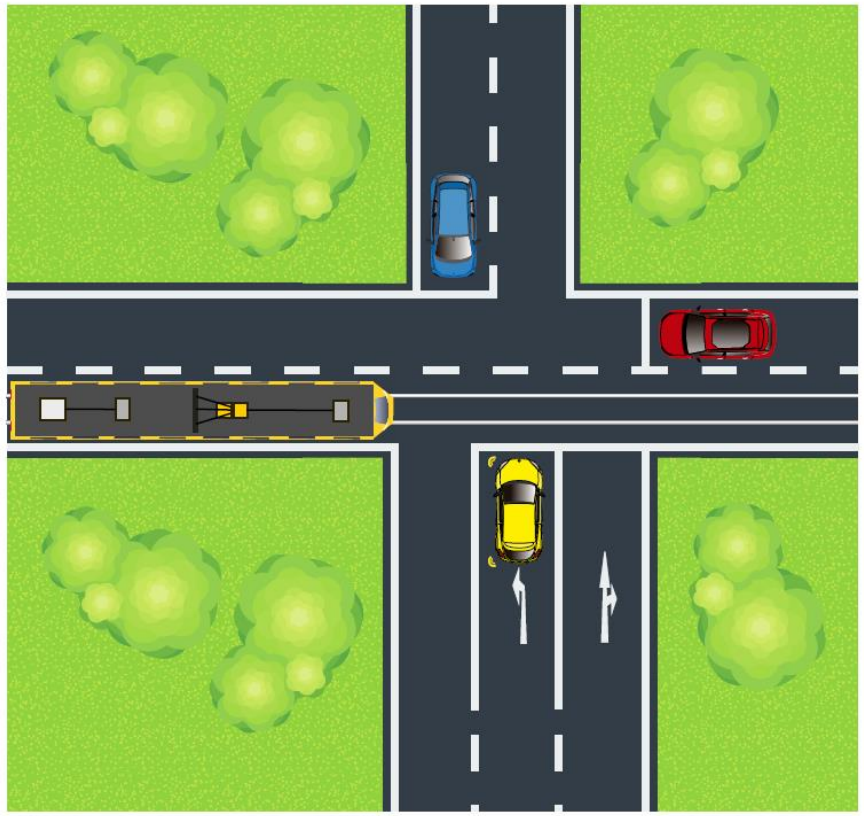


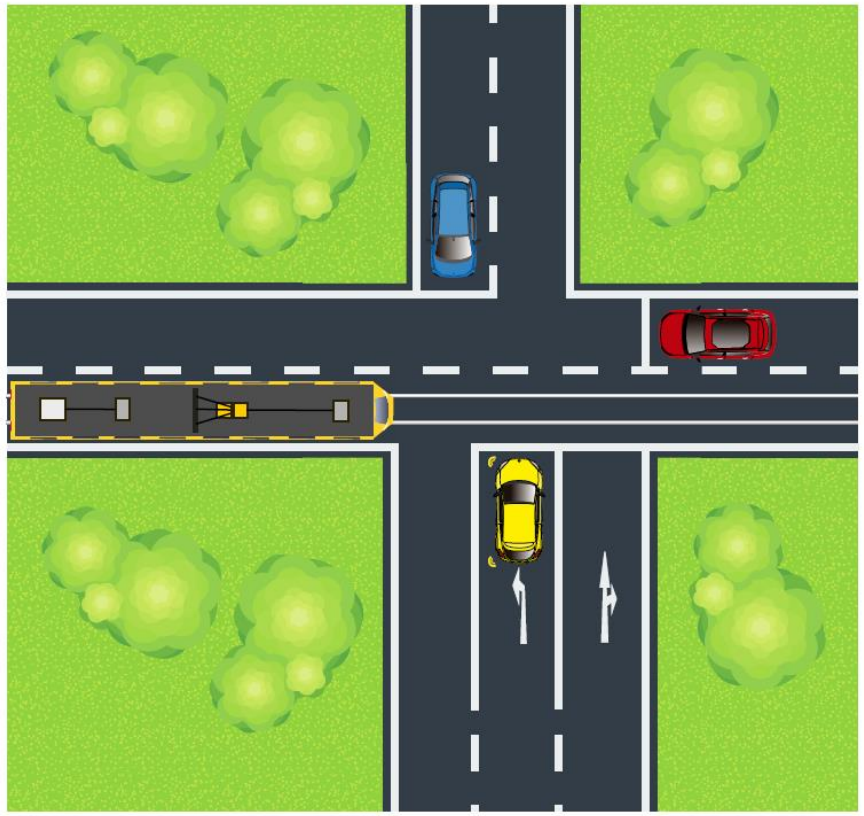
$$
\begin{aligned}
&containsTrafficLight\ some\ TrafficLight \text{ and}\\
&containsTrafficRegulatingPerson\\
&exactly\ 0\ TrafficRegulatingPerson
\end{aligned}
$$

$$
\begin{aligned}
&TrafficLightRegulatedIntersection(?scen1)\\
&\wedge Vehicle(?vehicle1)\ \wedge\ isOn(?vehicle1, ?lane)\\
&\wedge isPartOf(?vehicle1, ?scen1)\\
&\wedge containsTrafficLight(?lane, ?light)\\
&\wedge hasColor(?light, Red)\\
&\Rightarrow\ hasToWaitForTrafficLight(?vehicle1, ?light)
\end{aligned}
$$

$$
\begin{aligned}
&RoadSegment(?road)\\
&\wedge preferredLane(?trafficregulations, "right")\\
&\wedge hasRightMostLane(?road, ?lane)\\
&\wedge hasTrafficRegulations(?road, ?trafficregulations)\\
&\Rightarrow\ hasPreferredLane(?road, ?lane)
\end{aligned}
$$

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*.



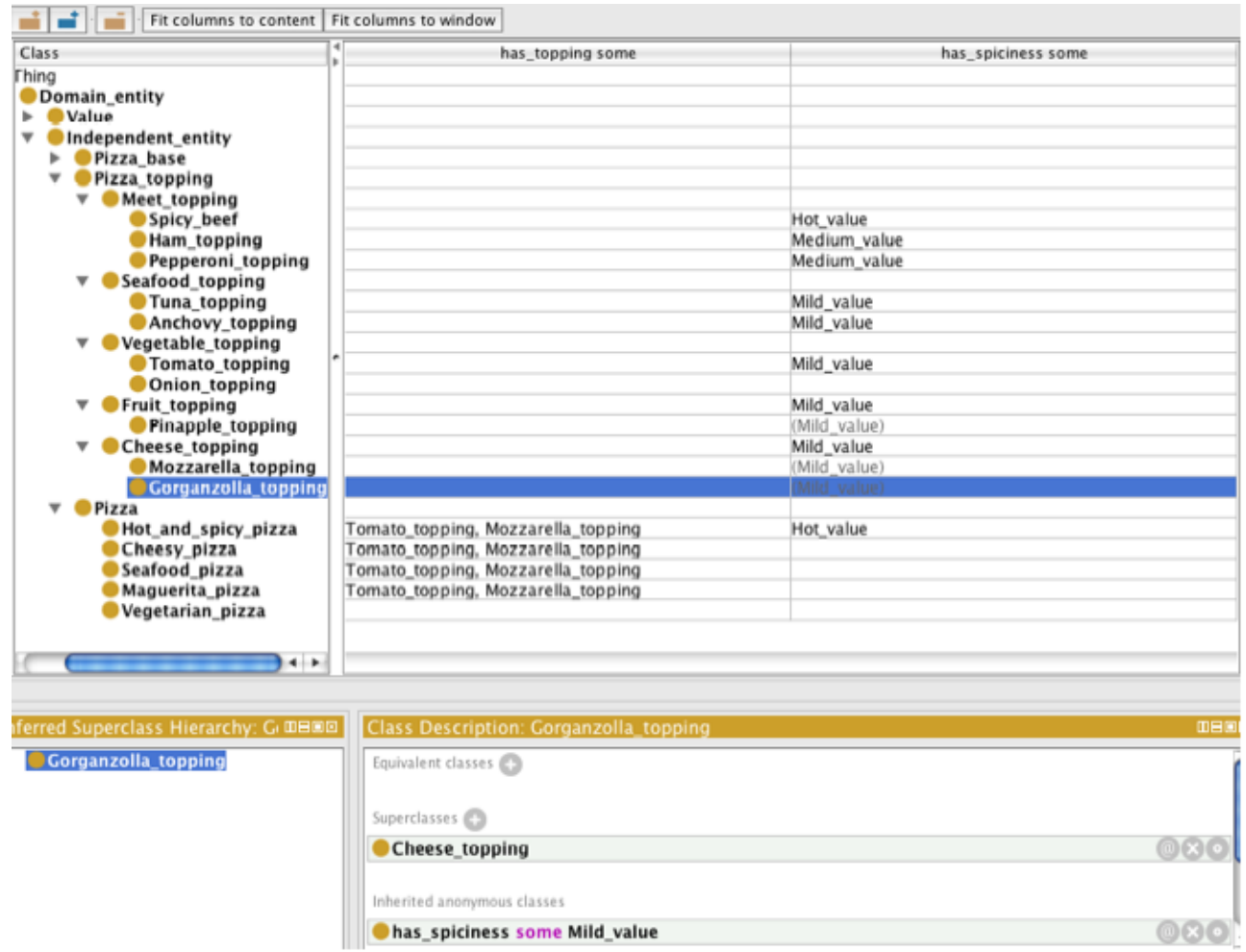
$$containsTrafficLight\ exactly\ 0\ TrafficLight \text{ and}$$
$$containsTrafficRegulatingPerson$$
$$exactly\ 0\ TrafficRegulatingPerson$$

$$UncontrolledIntersection(?scen1)$$
$$\wedge\ Vehicle(?vehicle1)\ \wedge\ Vehicle(?vehicle2)$$
$$\wedge\ isPartOf(?vehicle1, ?scen1)$$
$$\wedge\ hasConflictingConnector(?c1, ?c2)$$
$$\wedge\ hasIntention(?vehicle1, ?c1) \wedge hasIntention(?vehicle2, ?c2)$$
$$\Rightarrow\ hasToGiveWay(?vehicle1, ?vehicle2)$$

$$TrafficRegulatedPersonIntersection(?scen1)$$
$$\wedge\ Vehicle(?vehicle1)\ \wedge\ contains(?scen1, ?vehicle1)$$
$$\wedge\ isOn(?vehicle1, ?lane1)\ \wedge\ isBlockedBy(?lane1, ?police)$$
$$\Rightarrow\ hasToWaitForTRP(?vehicle1, ?police)$$

Ontology Pizza Tutorial

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

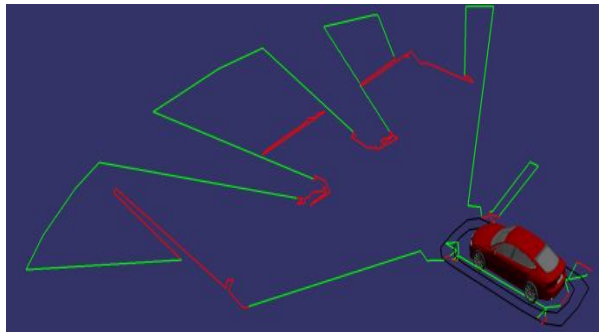


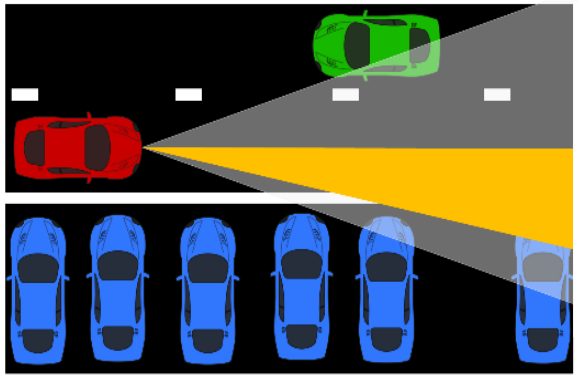
Safety & Accident Simulation

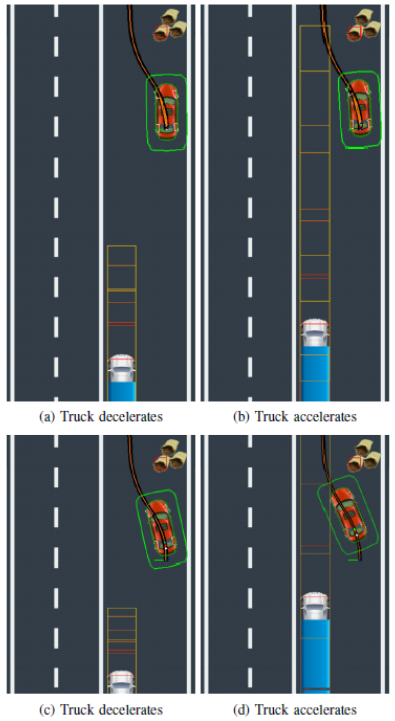
From Sensors to Scenarios

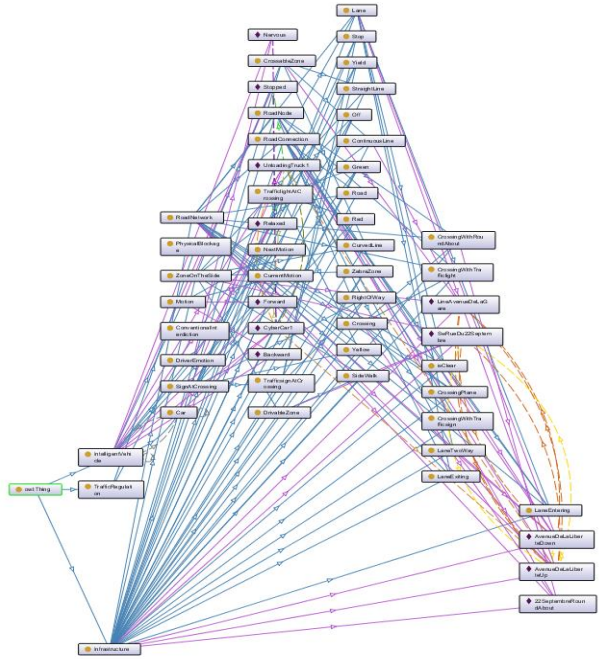
- Scenario tests
- Accident analysis
- Development of test catalogues
  - Identification of close to 1000 sensing aspects for sensor set validation
- Conceptual knowledgebase development for autonomous driving and decision making
- Sensor Simulation, data-acquisition, auto-calibration, fault detection…

Analysis, tool development, knowledgebases









Added Value – Digital Highway Opportunities

Goals, Vision and Mission

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

Digital Testfield

- "Laboratory under realistic conditions" to test innovative technologies
- For self-driving cars, connected cars, intelligent infrastructure
- Innovation engine and start point for the introduction of new technologies

"real" Simulations

Technical Base

Ex. Quality of Service

- Highest reliability, performance and availability
- Utilizing best software- and hardware
- Quality of Service guarantees through innovative network-concepts (Network Slicing)

Reliability

Added Value – Digital Highway Opportunities

Goals, Vision and Mission

providentia

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

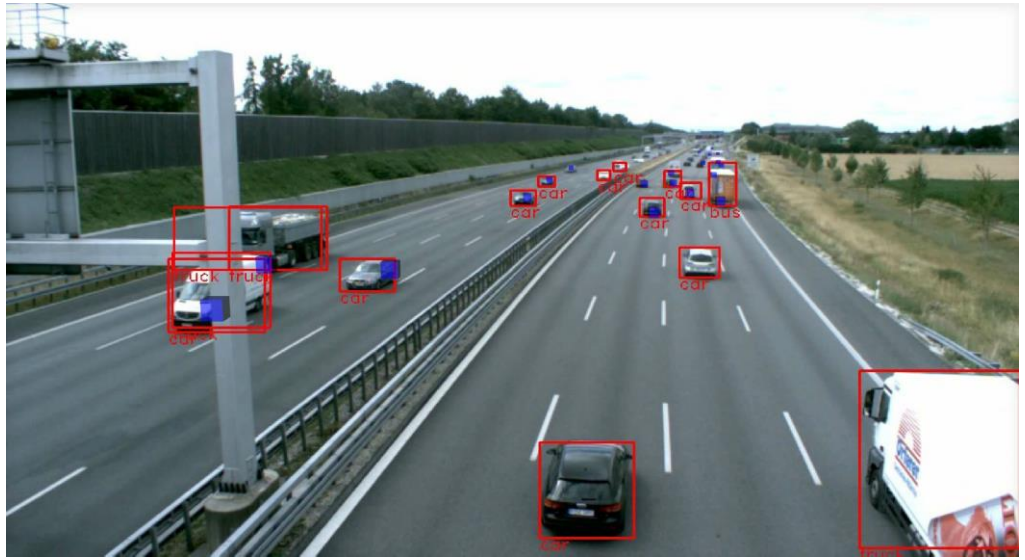
Far-reaching View	Traffic end detection	Traffic coordination	…Many more

Verticals

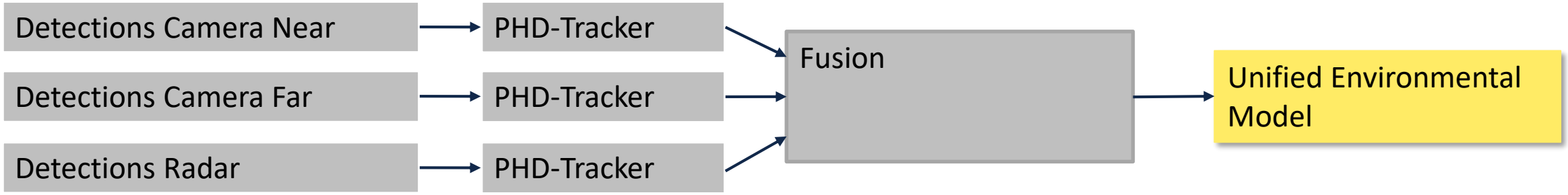
Digital Twin

- 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



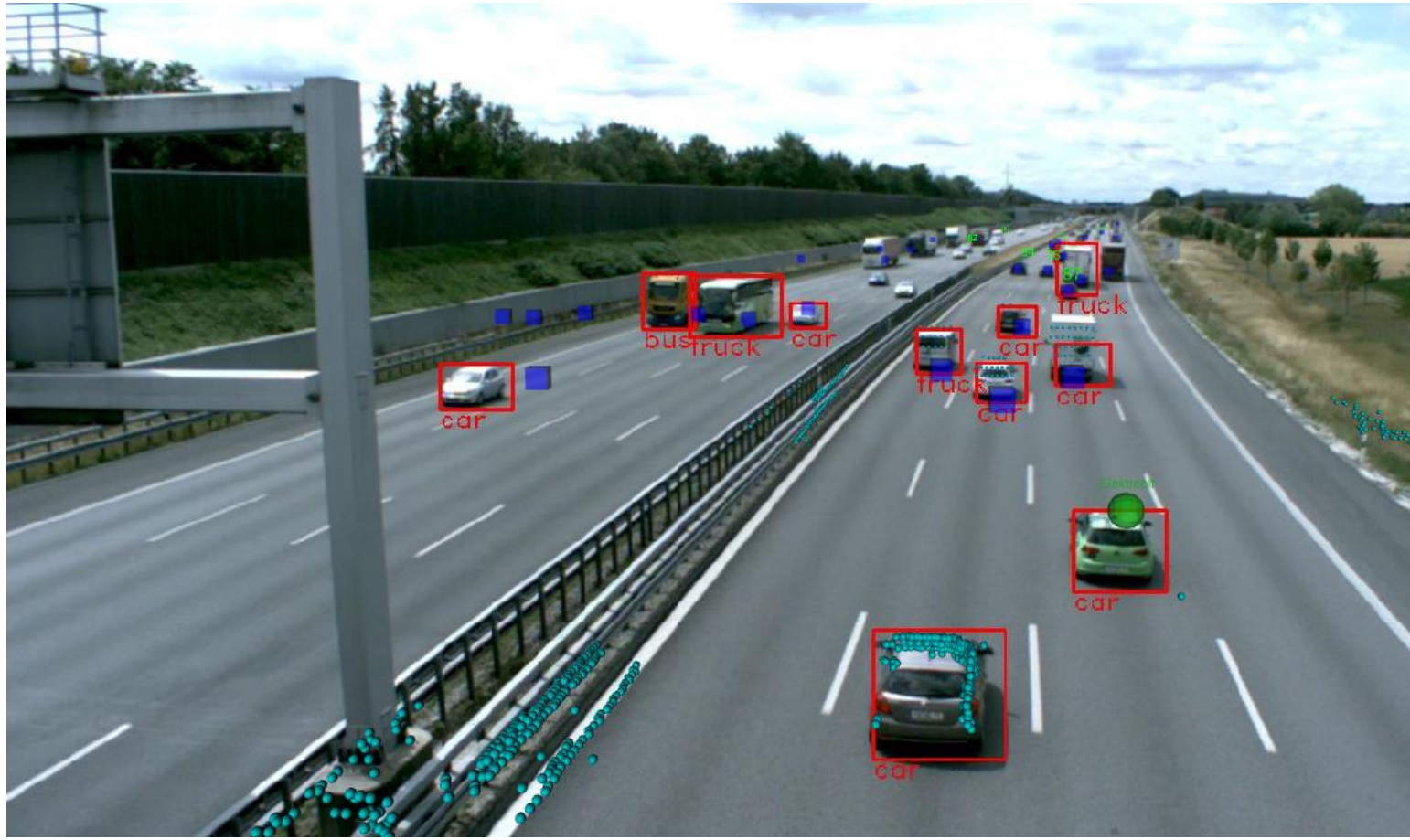
Multisensor Data Fusion of vehicles and infrastructure

C2X Sensors

- Connected system with shared sensor information

- **Infrastructure**
  - Radar
  - Camera Near
  - Camera Far 123

- **Fahrzeug:**
  - Ego-vehicle detection
  - Lidar

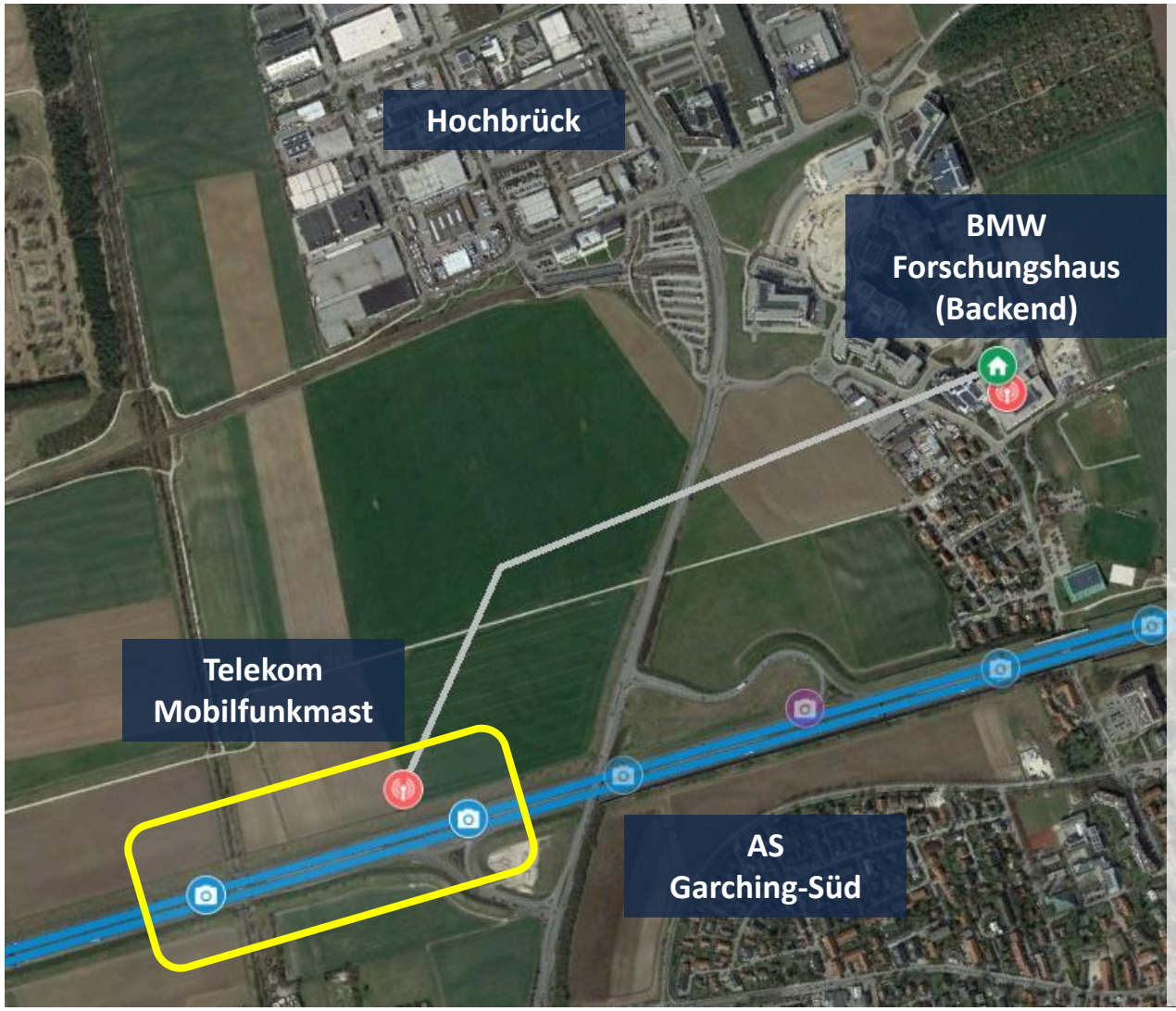


Intelligent Infrastructure

Providentia Testfield - Concept

Intelligent Infrastructure

Providentia Testfield – Area 1



Intelligent Infrastructure

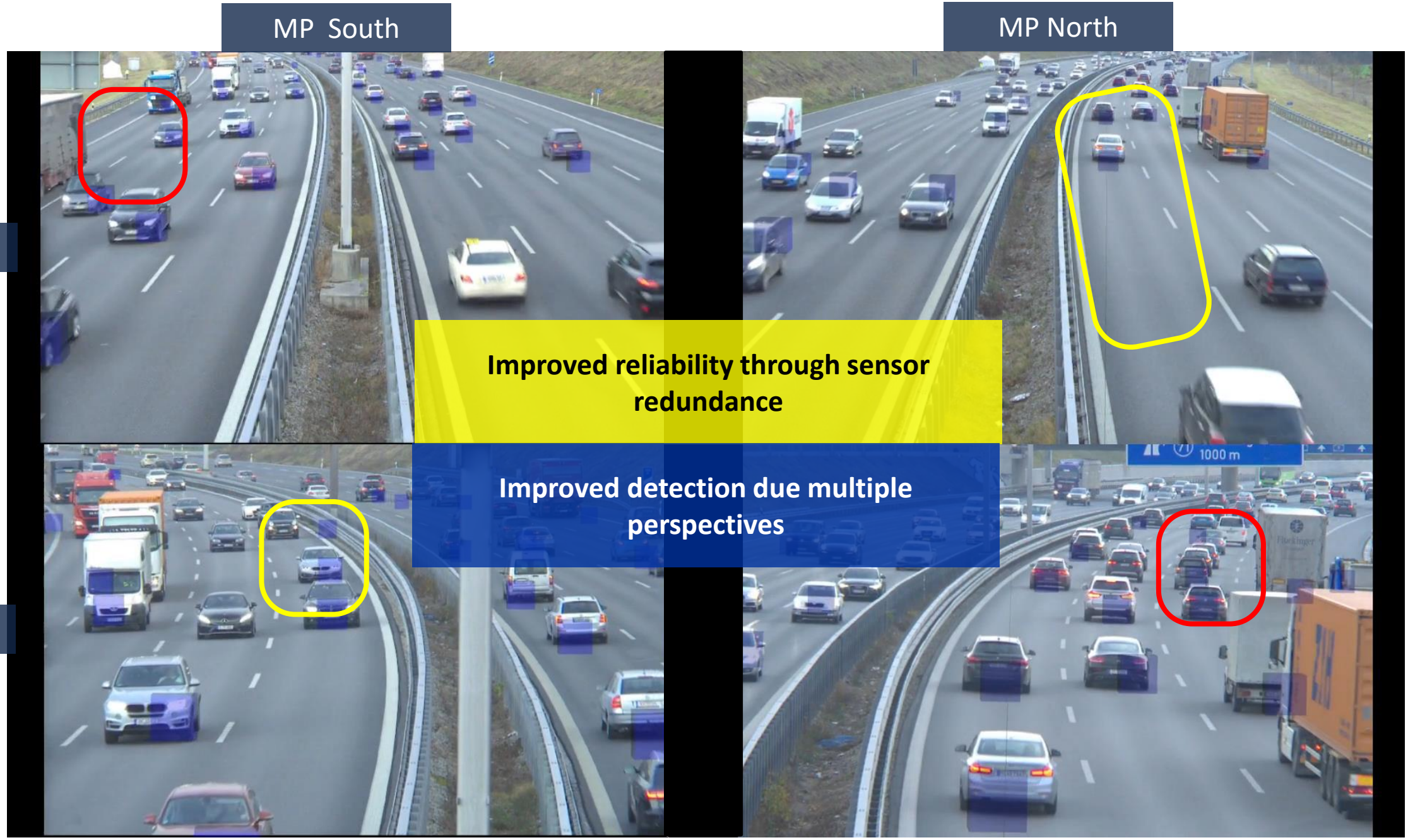
Mobile Fieldtests

MP South

MP North

Near

Far

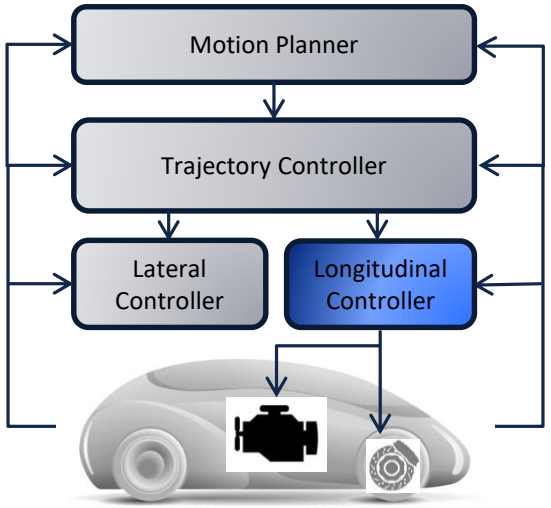

MP South
MP North
Near
Far
Improved reliability through sensor redundance
Improved detection due multiple perspectives
1000 m

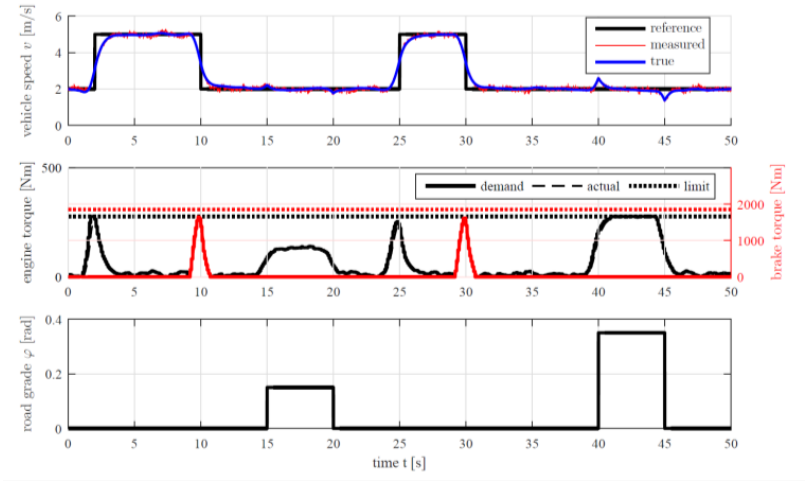
Tesla knocked out by a „bug“.

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

Model predictive control for Autonomous Vehicles

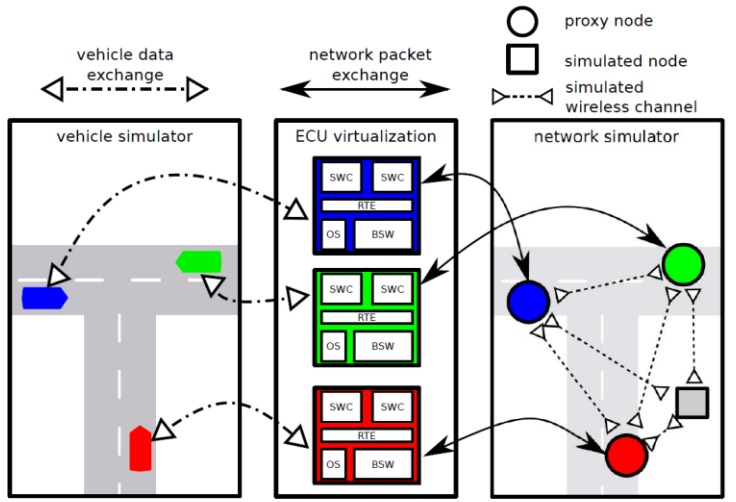
- Adaptive nonlinera model predictive control for improved velocity control
- Utilize knowledge available to autonomous vehicles, such as topologies from maps and path information
- Improved comfort, reduced fuel consumption

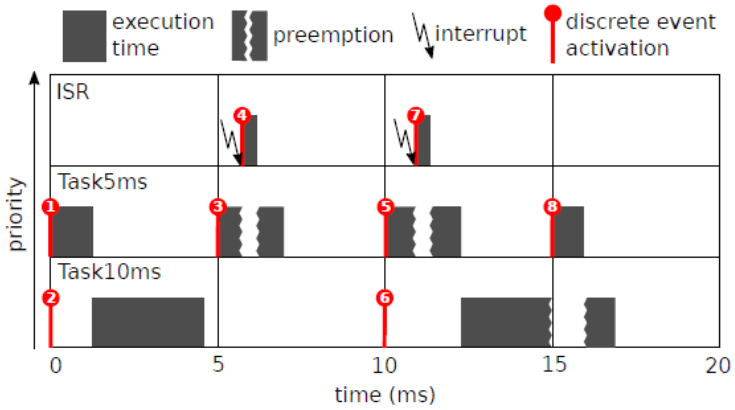




Fleet communication– Car to X

- 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





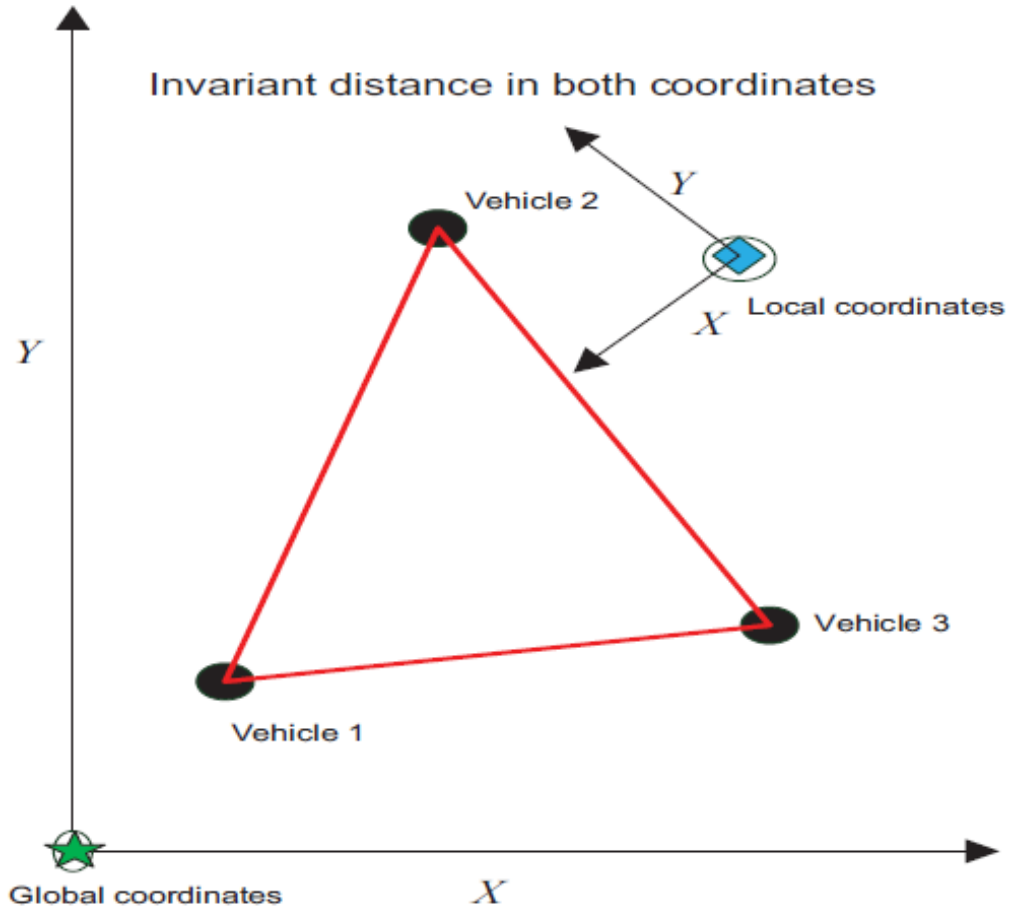
Fleet communication– Car to X

- High precision localization and tracking

- Effective solutions for:
- Bandwidth limitations
- Data-association
- Use of external sensors

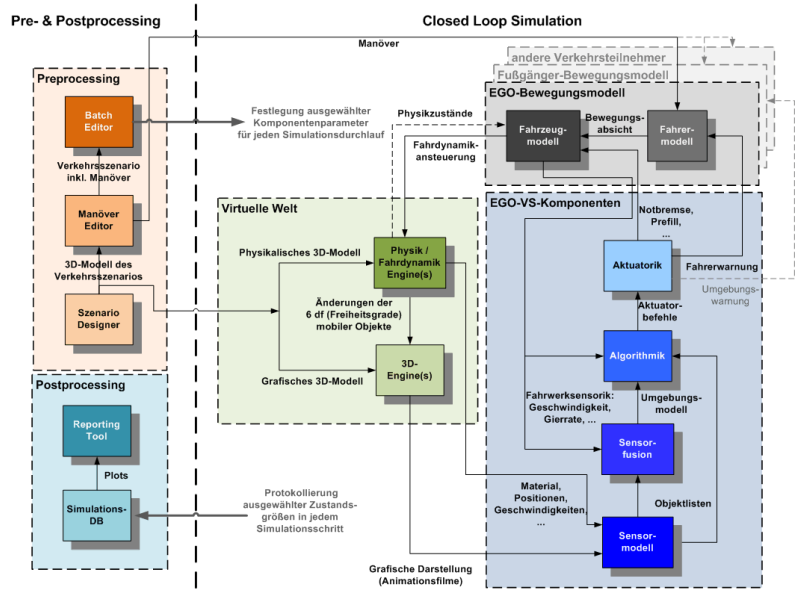
- Can cope with large
  amounts of traffic participants

- Experience with various technologies
- PHD Filters
- GLMB Filters
- Factor Graphs
- Tracking with Neural Networks



Traffic Simulations for ADAS and Self-Driving Cars

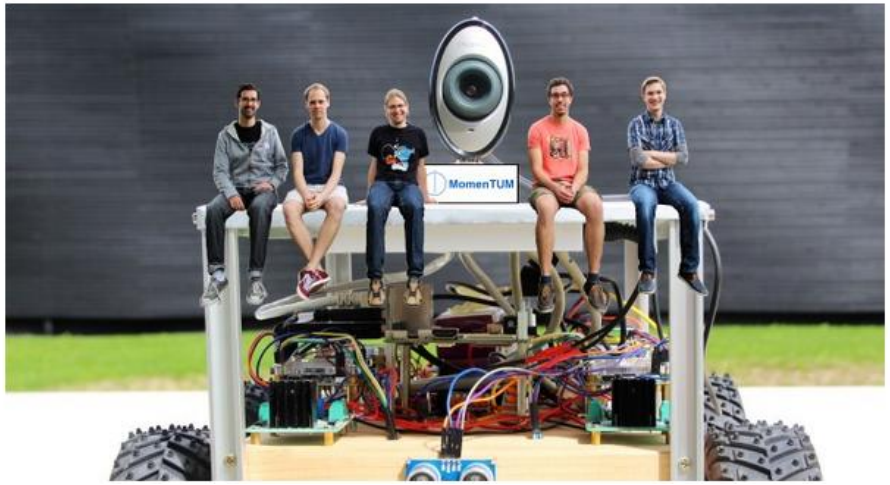
- Simulation tool concept design and development
- Traffic simulations in a variety of simulators
  - Sumo
  - Virtual Test Drive
  - CarMaker
  - …



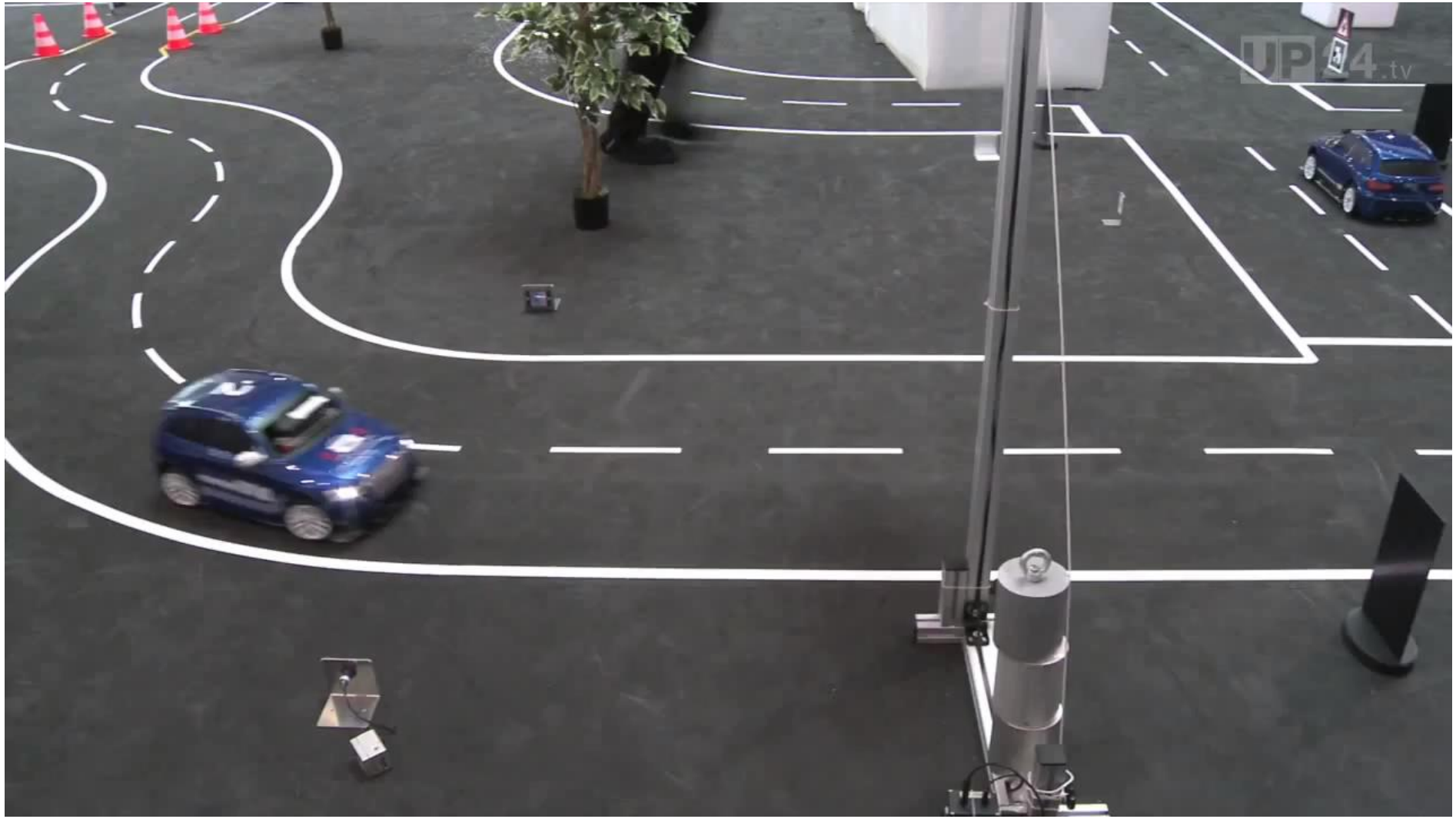
Audi Autonomous Driving Cup

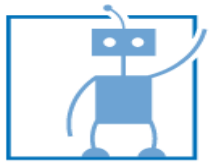
- Home
- Wettbewerb 2015
- **Teams 2015**
- Fahrzeug
- Forum
- Download
- Links
- Ihr Profil

Audi Autonomous Driving Cup



Audi Autonomous Driving Cup





Pressemitteilung

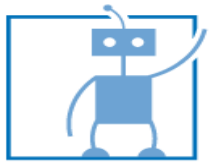
Ingolstadt, 27.03.2015

Studierende der TU München gewinnen ersten Audi Autonomous Driving Cup

- **Preisgeld von 10.000 Euro für Siegerteam**
- **Audi-Entwicklungsvorstand 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

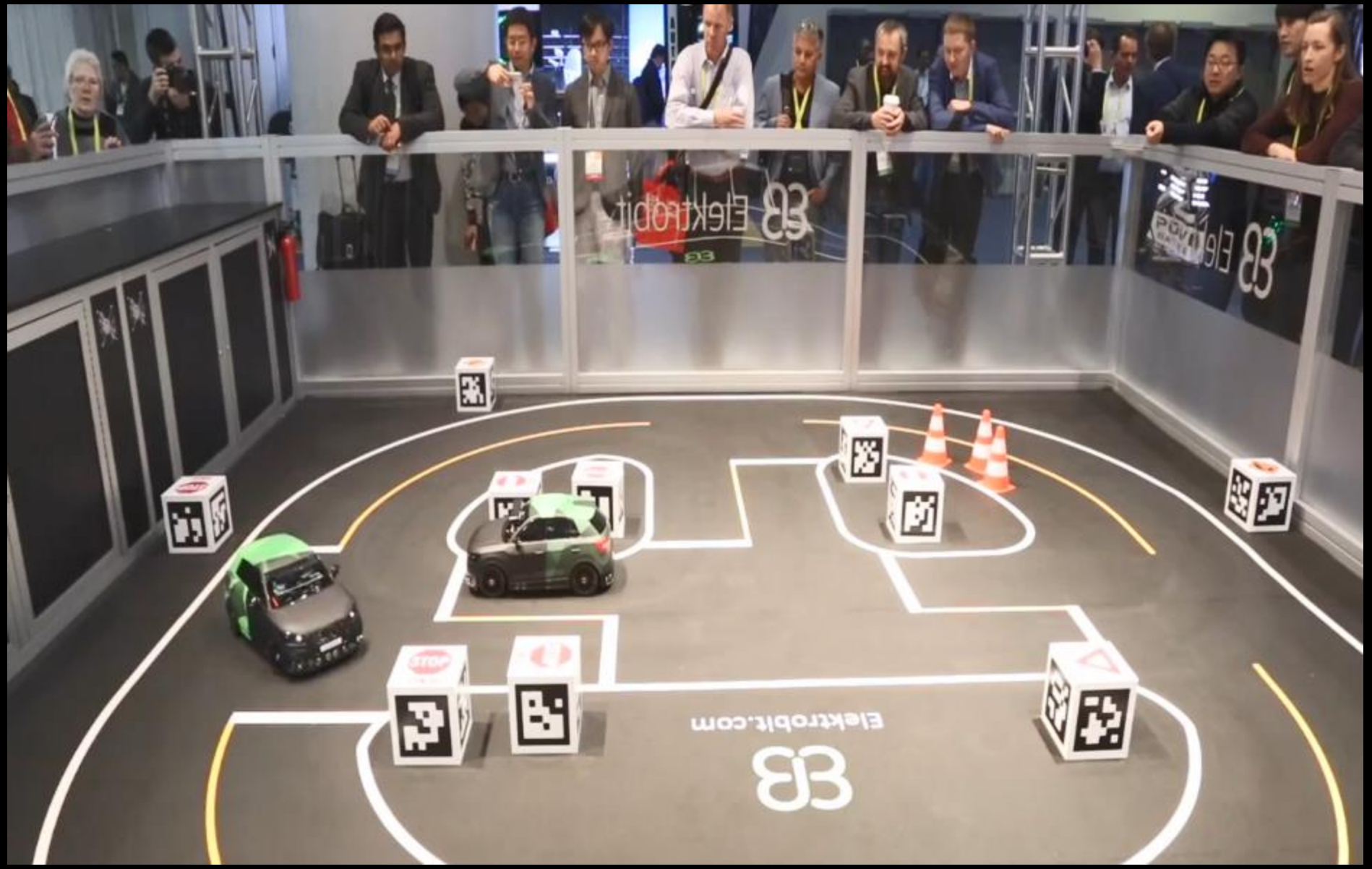
Der Preis für das beste pilotiert fahrende Modellauto geht nach München: Ein Team von fünf Studierenden der Technischen Universität (TU) München hat sich beim ersten Audi Autonomous Driving Cup gegen starke Konkurrenten aus ganz Deutschland durchgesetzt.



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

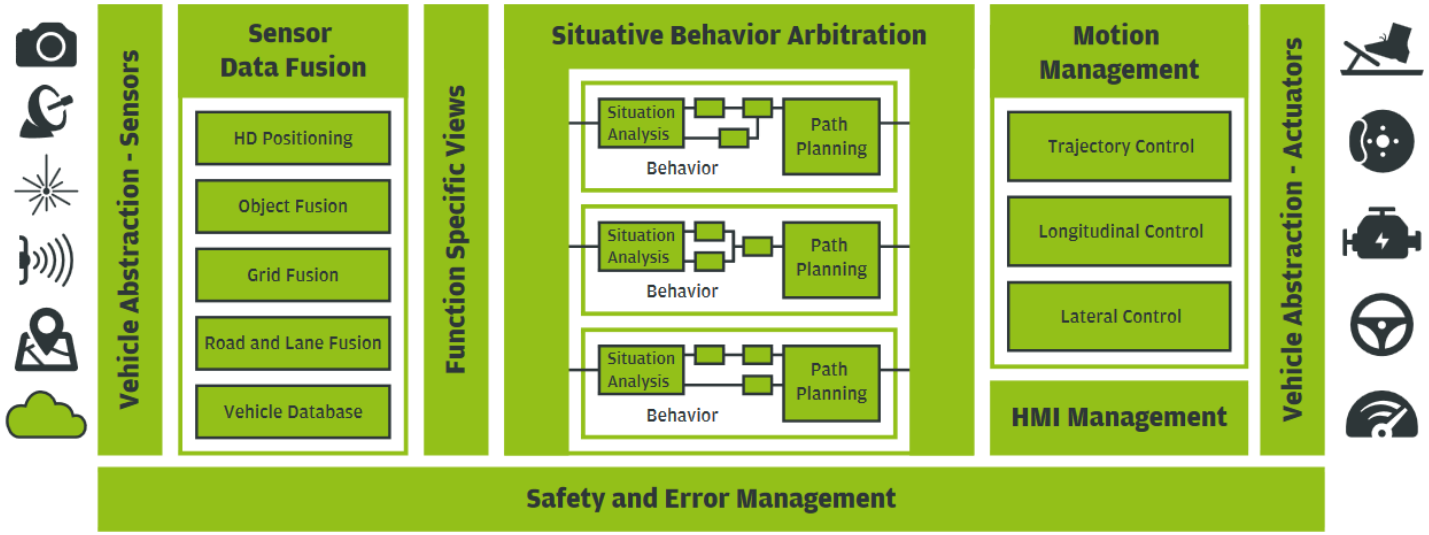
Simple AD demonstrator at CES with EB Robinos Model Cars

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