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?

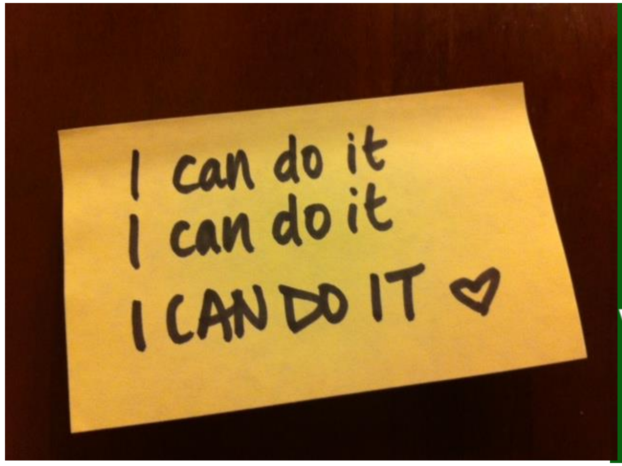
  – **So what is the desired outcome?**

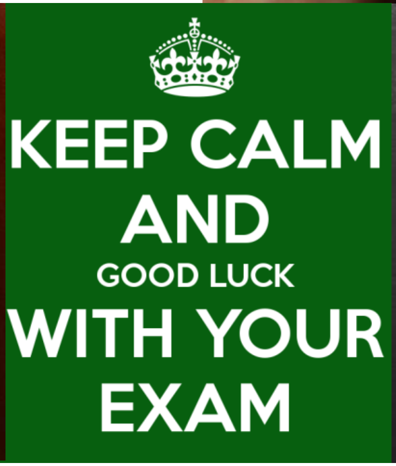
    - A student should know the fundamental building blocks of AD by name and by principle. Be able to explain them and discuss them.

    - 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…





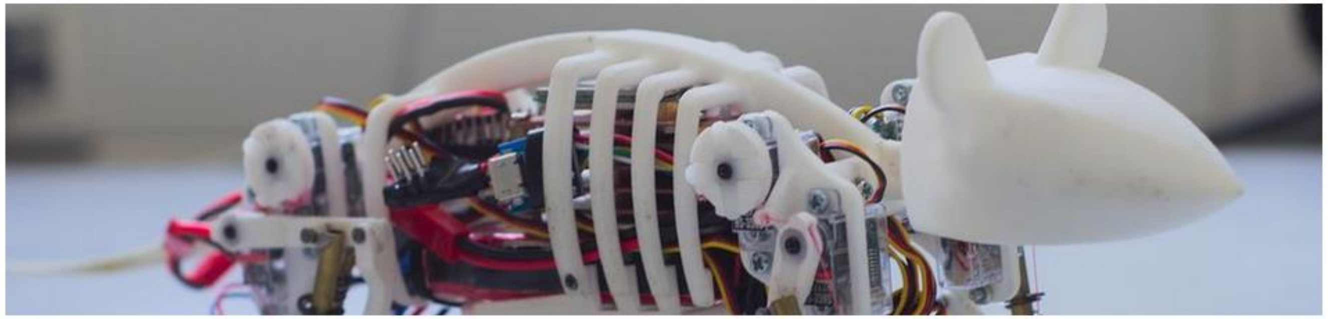
LS VI – Chair of Robotics, Artificial Intelligence and Real-time Systems

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

- Robotics and Embedded Systems
  - Sensors
    - *Vision/ Tracking*
    - *NL Processing*
    - *Multi-Modal Fusion*
    - *Collaborative Sensing*
  - Planning
    - *Trajectory Generation*
    - *Collision Avoidance*
    - *Navigation*
    - *Exploration*
  - Integration
    - *Joint Action & Safety*
    - *Mobile Manipulators*
    - *Learning*
    - *Human Interfaces*
    - *Brain/Computer Interfaces*
  - Applications
    - *Medical*
    - *Industrial*
    - *Education*
    - *New Robot Types*
- Distributed Real-time Systems

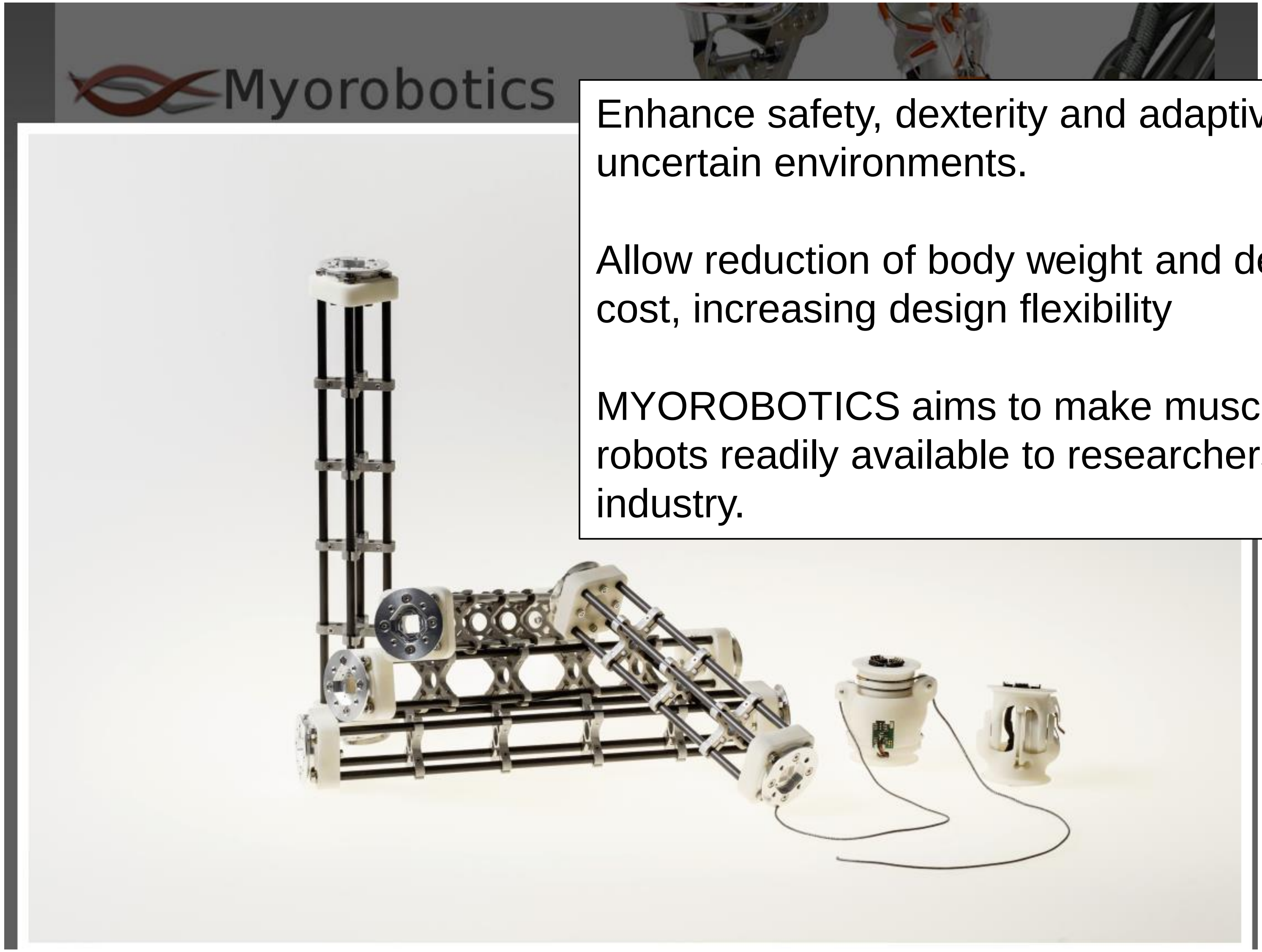
Landmark Projects: ECHORD++

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

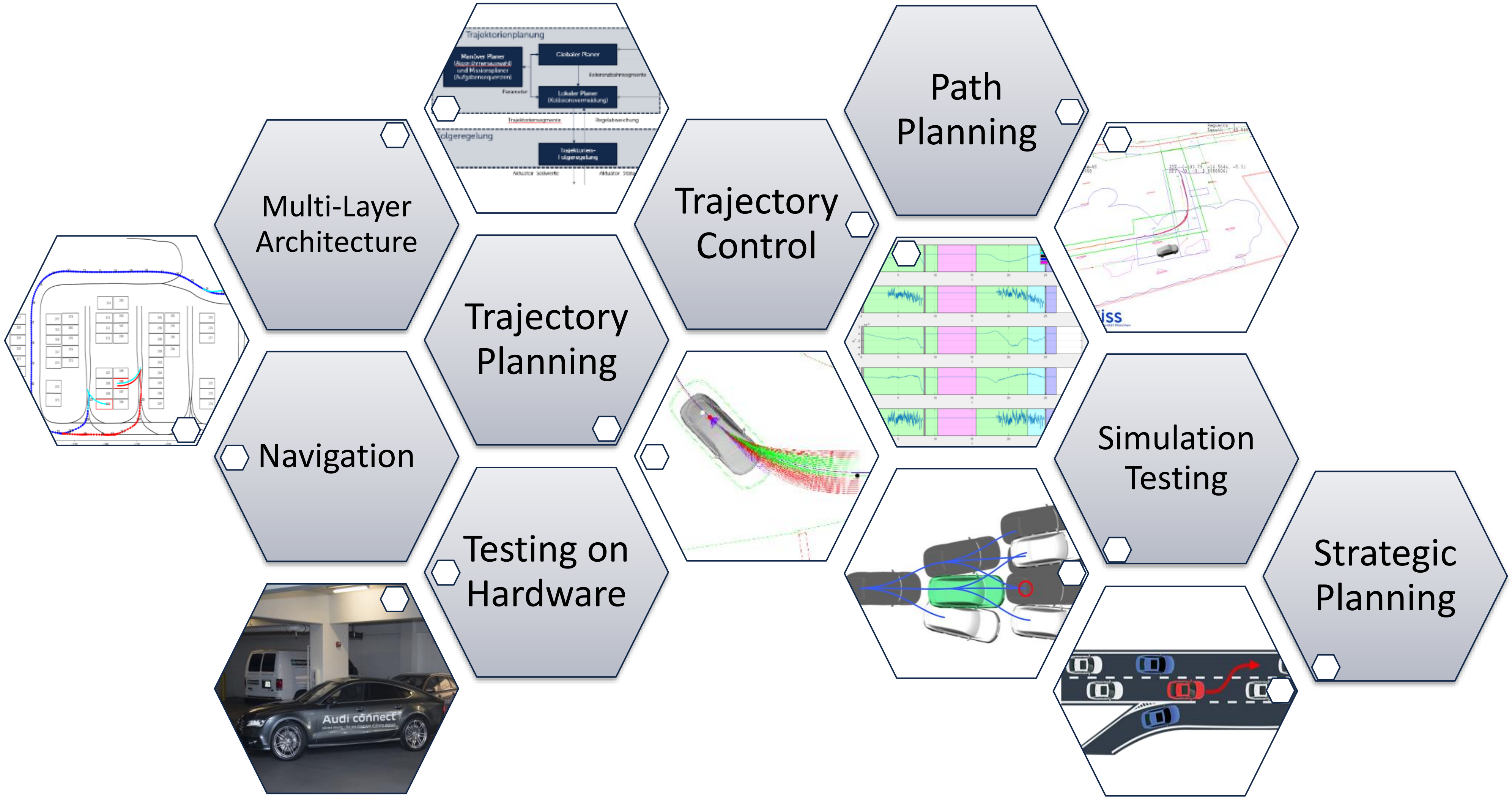
Projects & Experiences

Motion Planning, Data Fusion, Overall Systems

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

Software Development for Automated Driving

Focus: Motion Planning

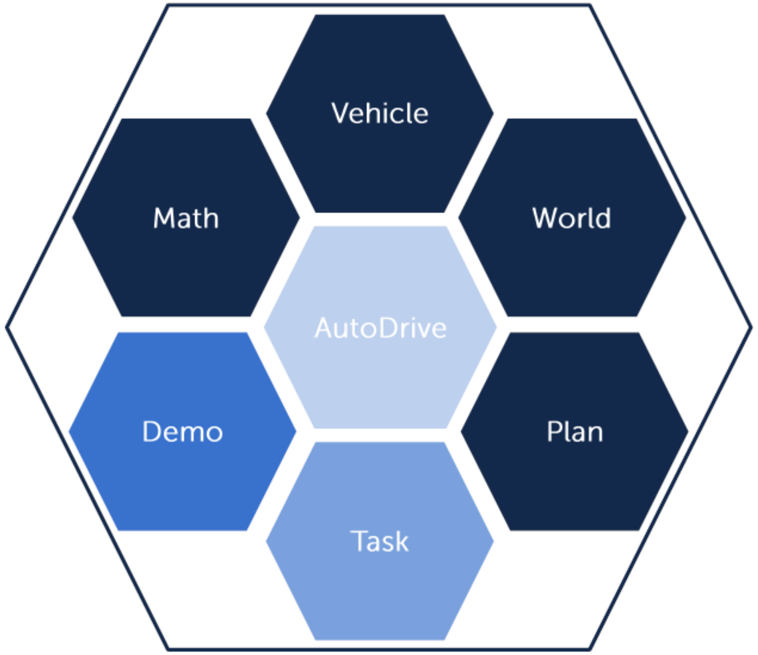


AutoDrive Library

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.)

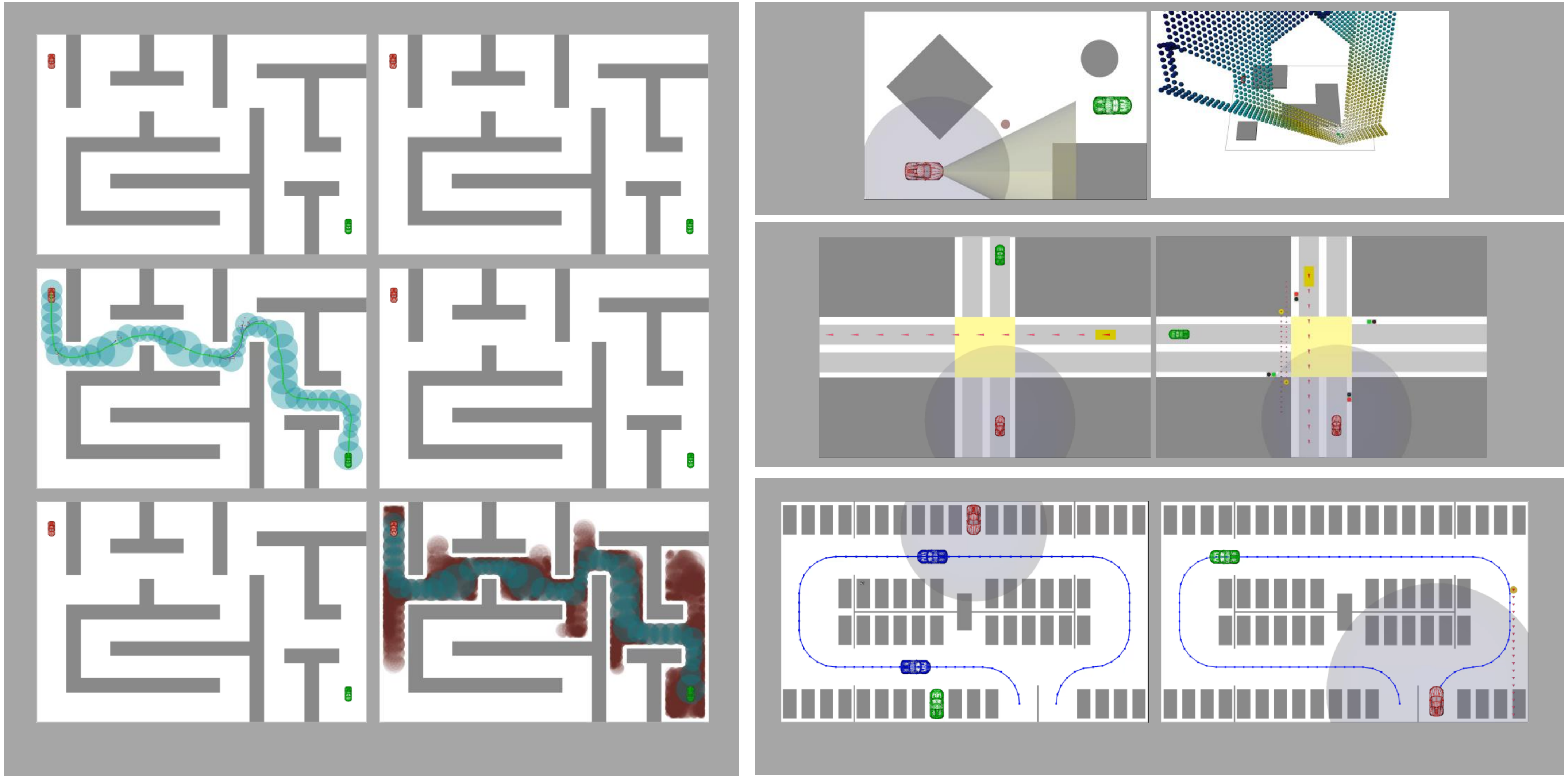
genehmigten Dissertation.

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:

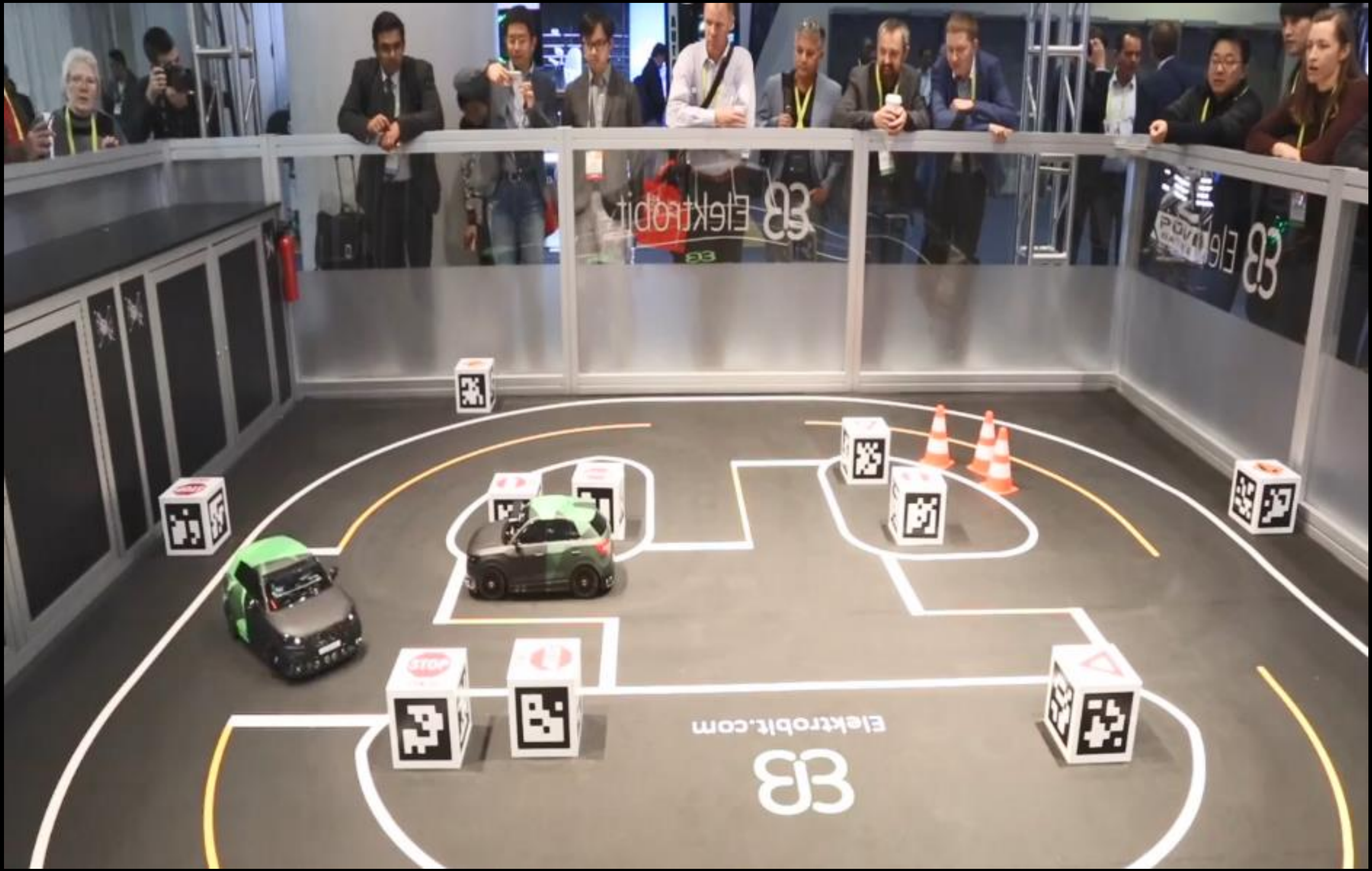
Bundesministerium für Wirtschaft und Energie

aufgrund eines Beschlusses des Deutschen Bundestages

fortiss

SIEMENS

Ingenuity for life



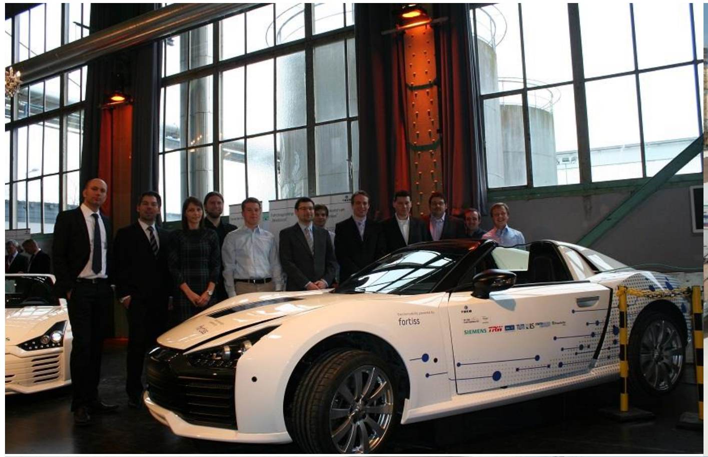
Impressions - CES 2017

Impressions - Berlinale 2016

ale 2016

Autonomous Garage

Contributions to Prototype Demonstrators





Everything seems to be ready...

fortiss

innovation in software and systems

Cyber-Physical Systems

supported by

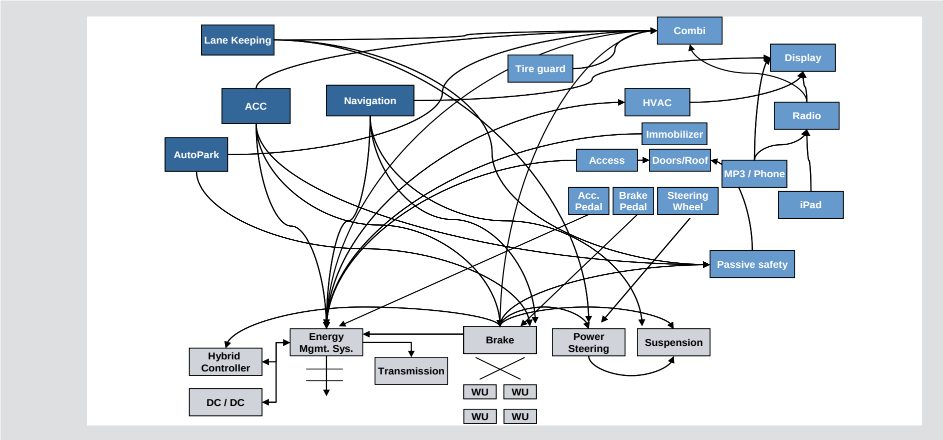
Robotics and Embedded Systems

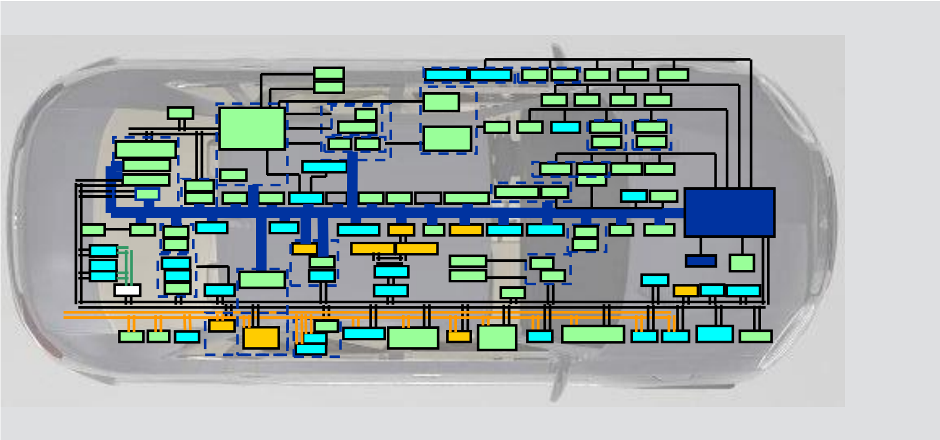
Technische Universität München

Contributions to Prototype Demonstrators: RACE

RACE

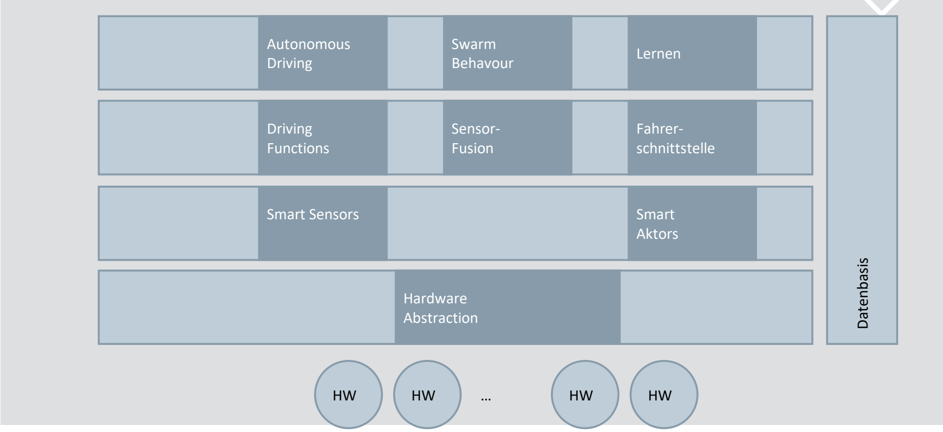
Reduction of E/E-Architecture Complexity

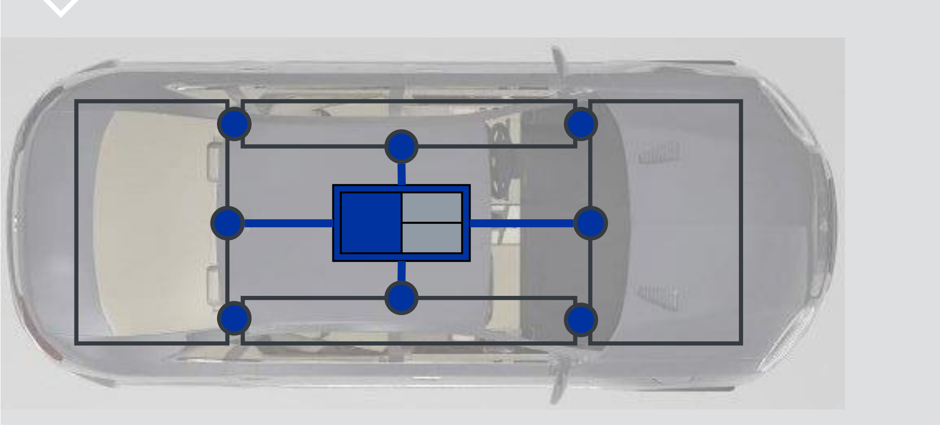




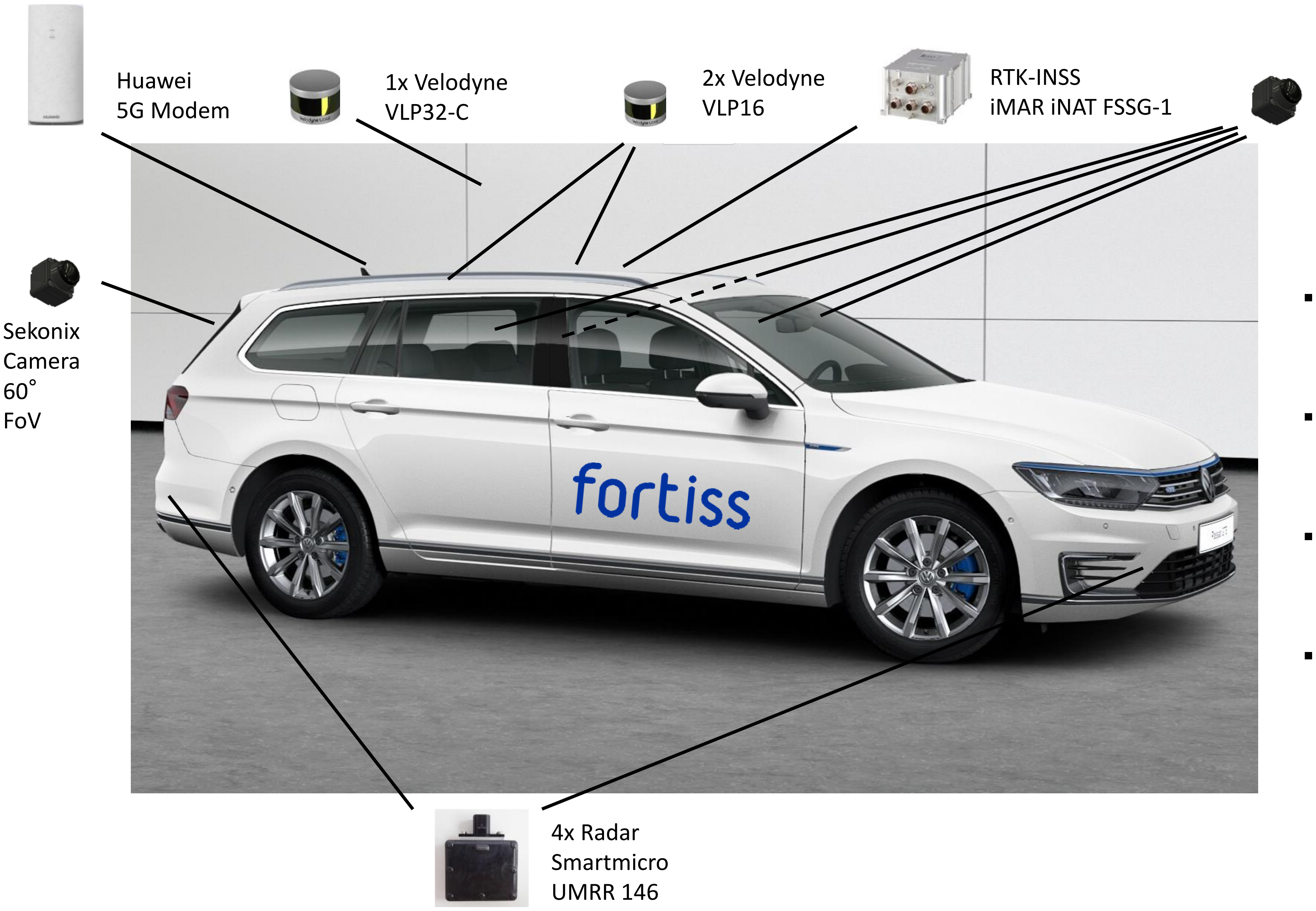
- Position independent Partitioning
- Defined Information Flow
- Hierarchical Decision
- Plug & Play Compatible

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





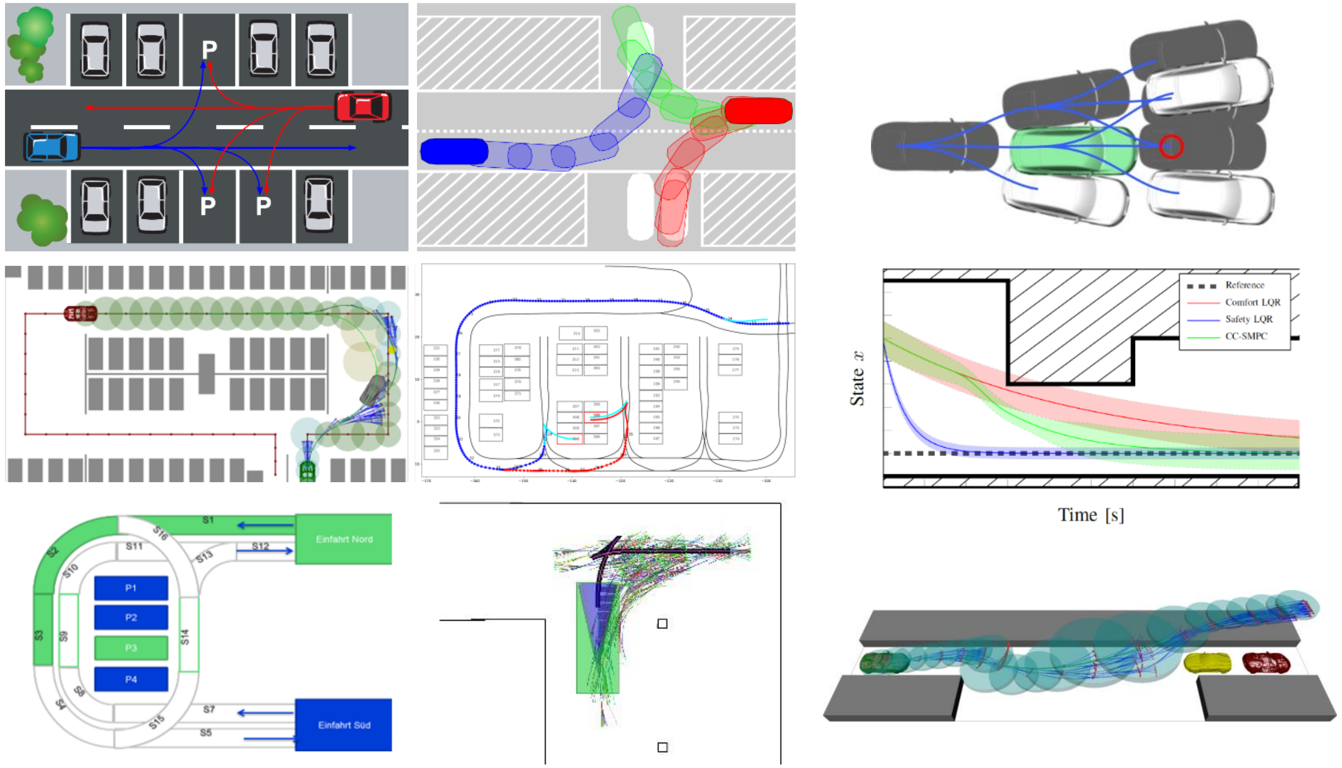
fortiss 5G Autonomous Driving Research Platform



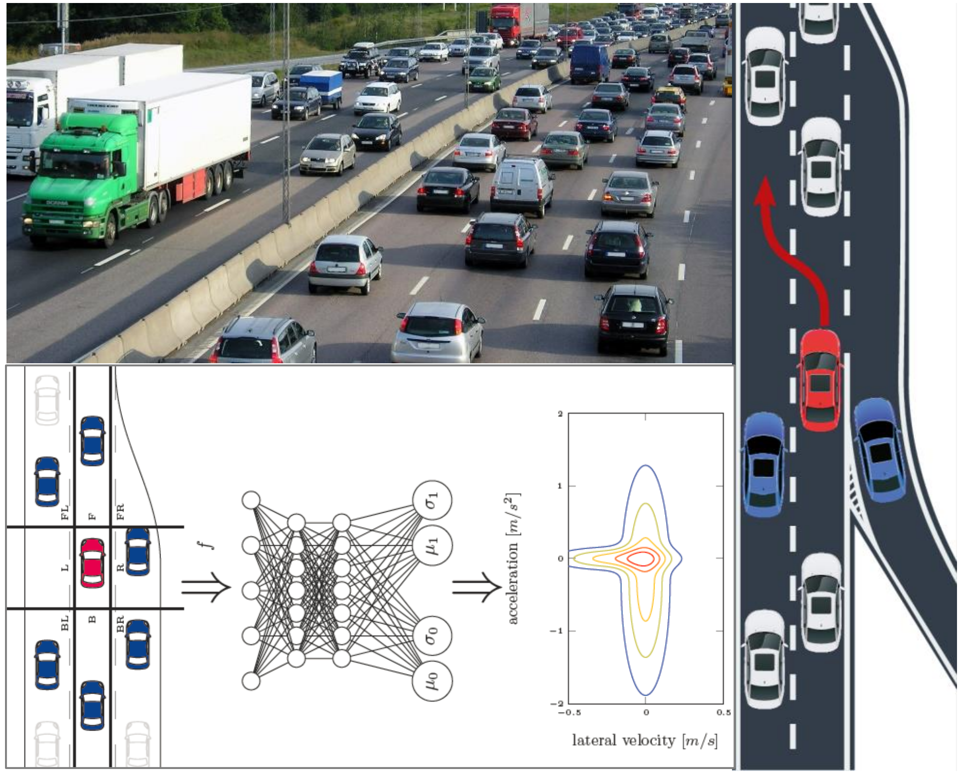
- Computer vision:
  Drive PX2
- Data fusion unit:
  CarPC1 (Nvidia GTX1050TI)
- Visualisation-/Planning unit:
  CarPC1 (Nvidia GTX1050TI)
- Realtime Prototyping:
  dSPace MicroAutobox II

Applications for motion planning, decision making and testing

Algorithms for planning and testing

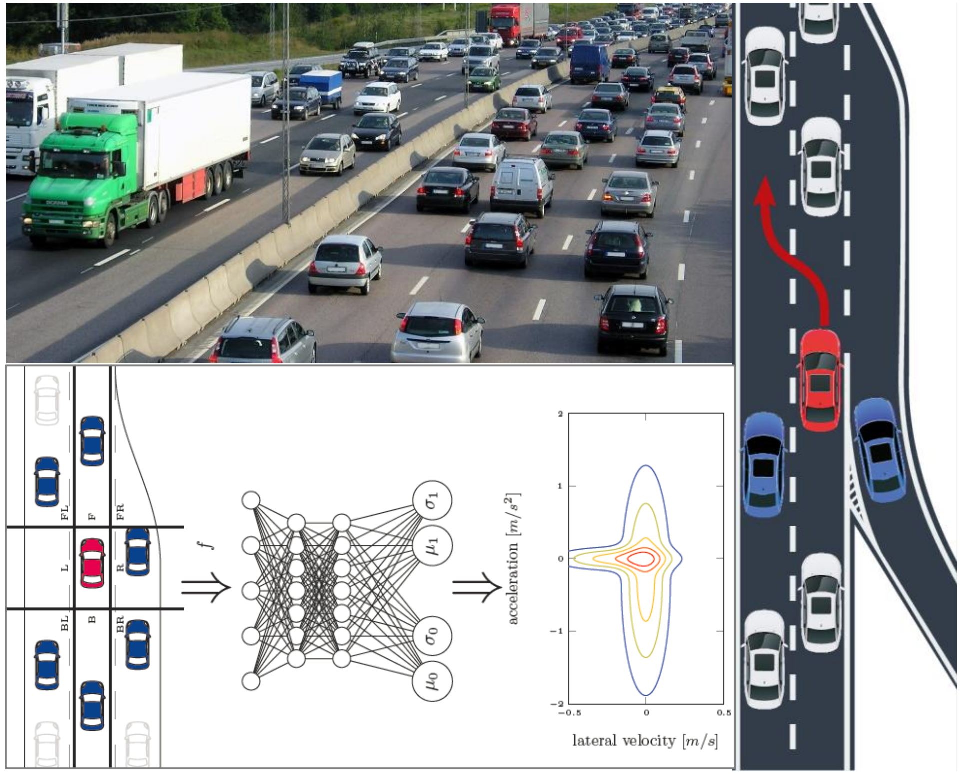


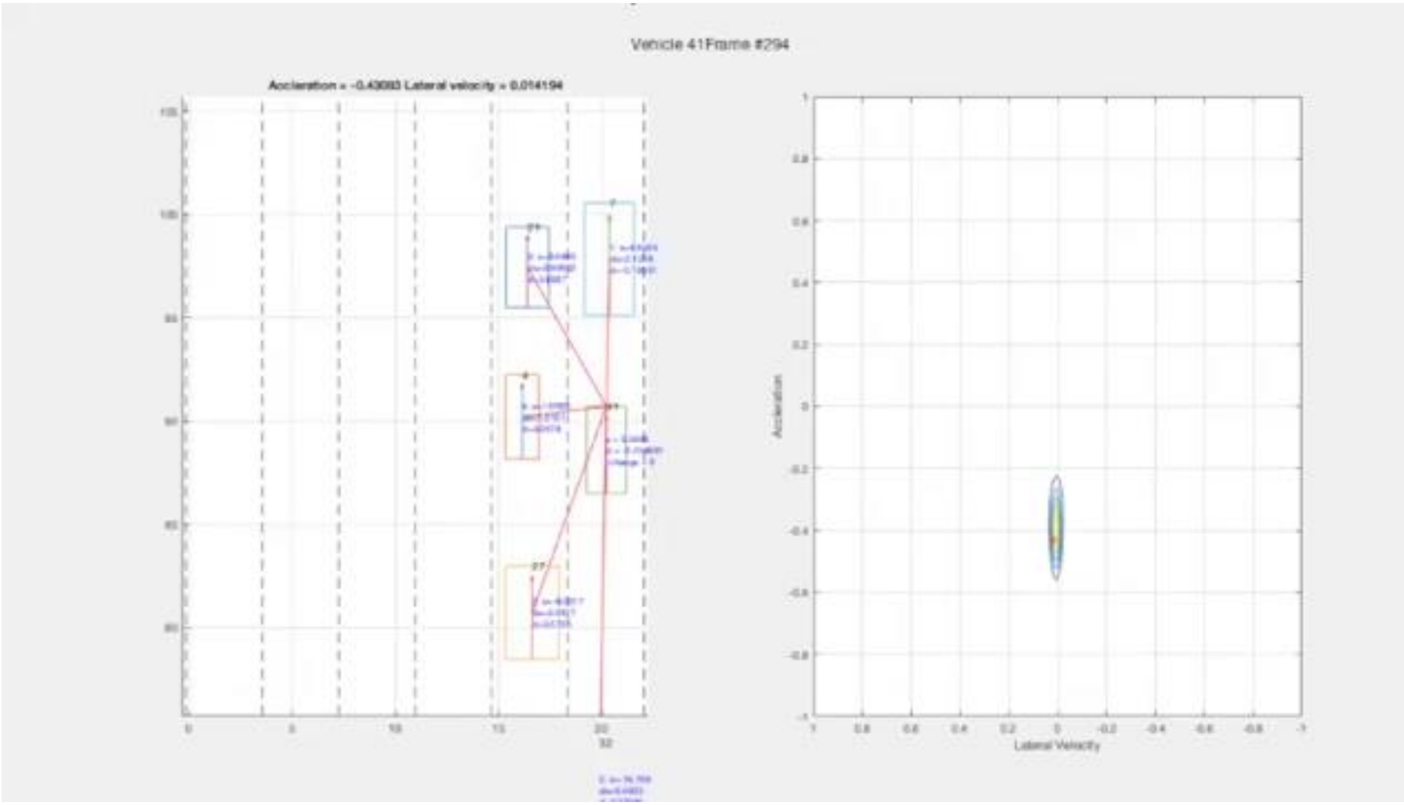
Deep Learning for strategic decision making



Deep Neural Networks for Interactive Scene Prediction

Deep Learning for strategic decision making

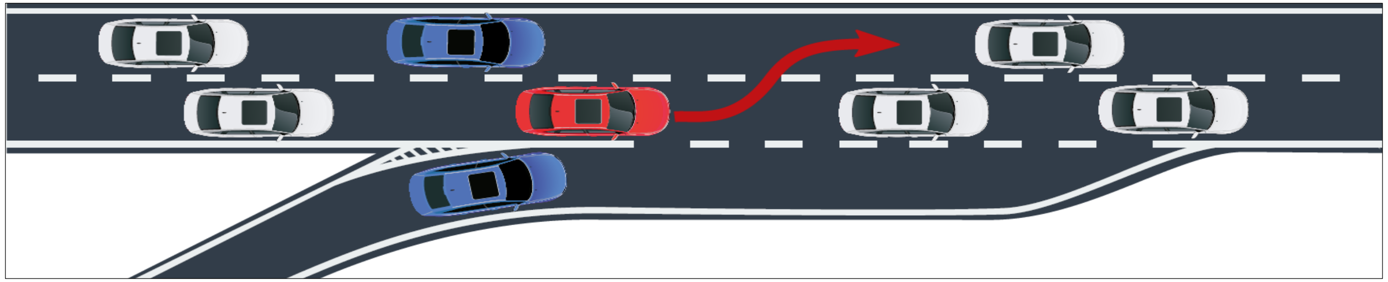


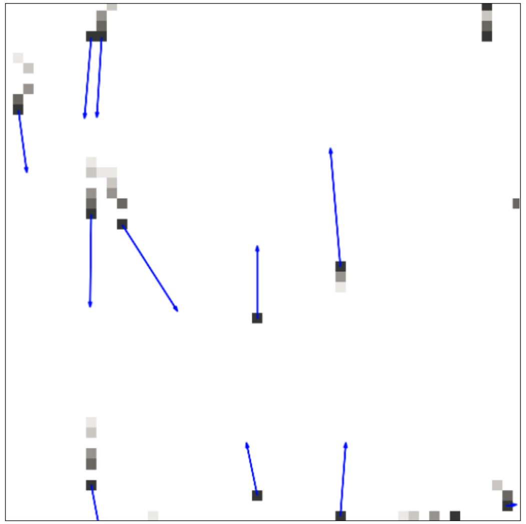


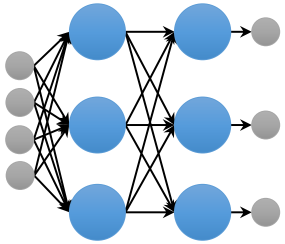
Sensor-Set Object List based Scenario Classification

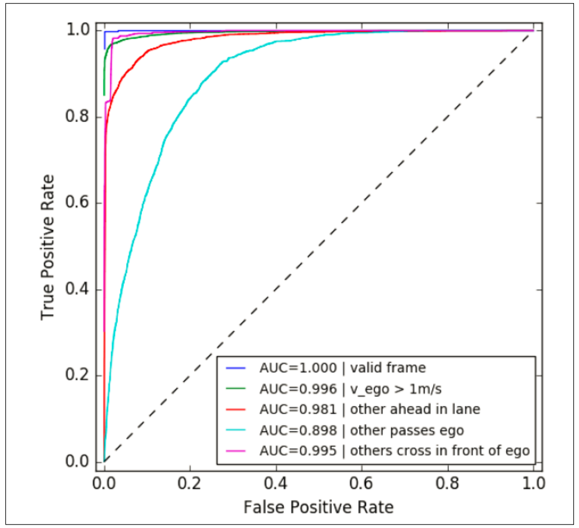
From Sensors to Scenarios

- 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

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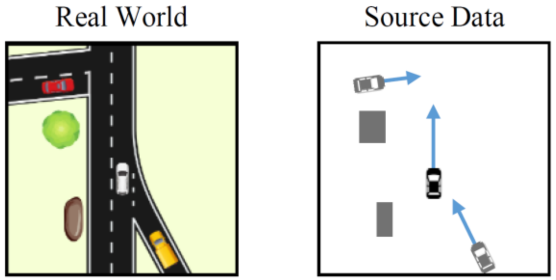
  - Lane Changes
  - …

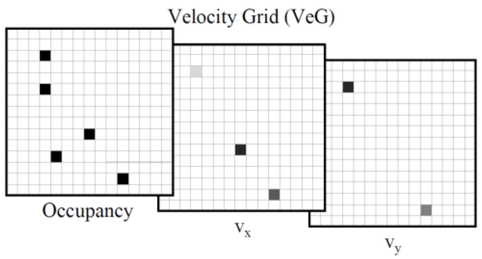
- Example Scenario Classification and Prediction

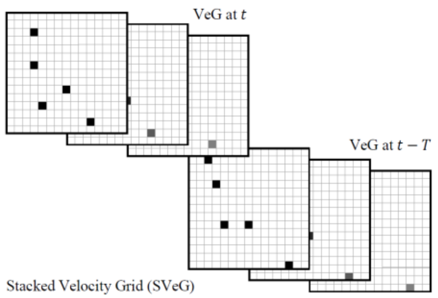
  ("Spatiotemporal representation of driving scenarios and classification using neural networks, Gruner, Hezler, Hinz et. Al., IV 2017)

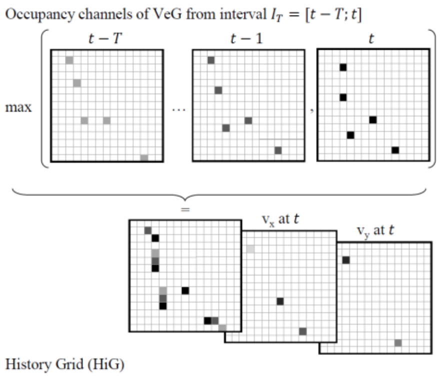
  – Use fused sensor data as input:



  – Choose Data Representation Format:



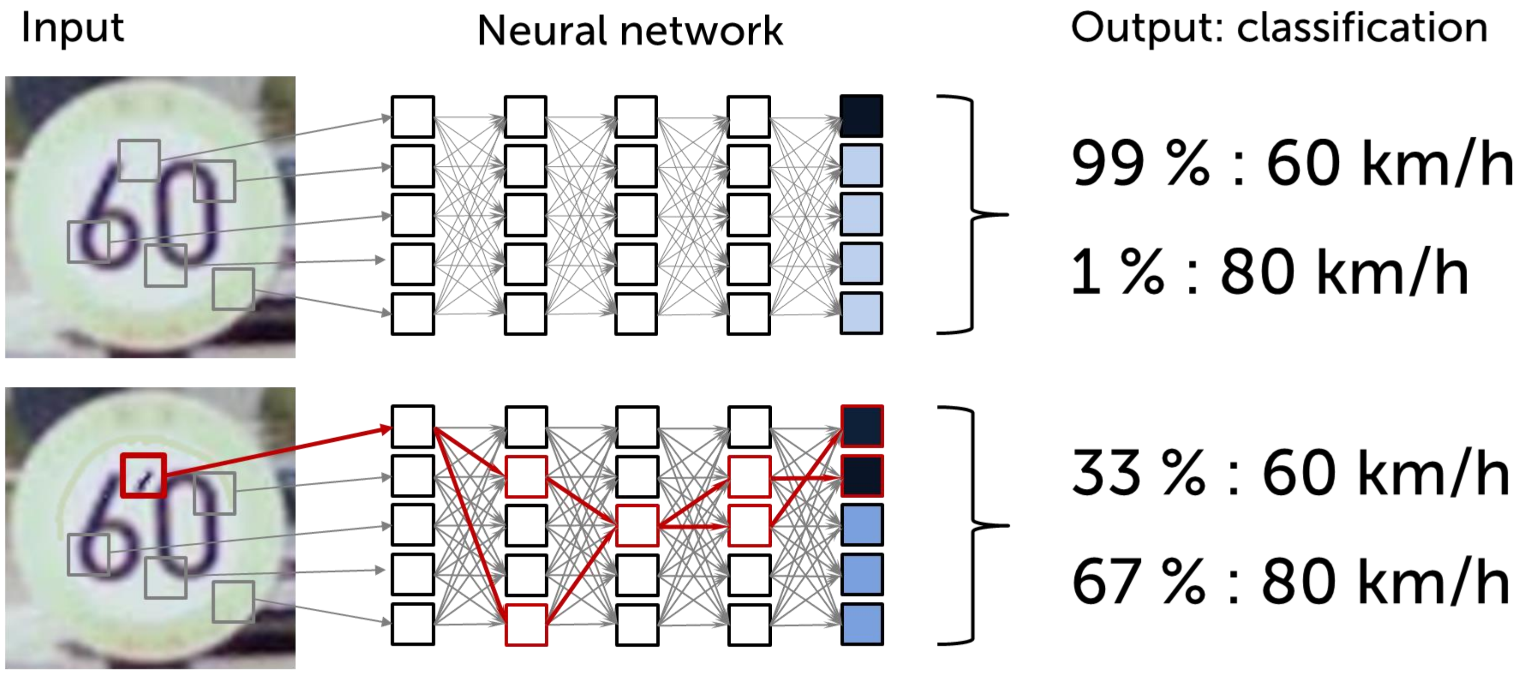




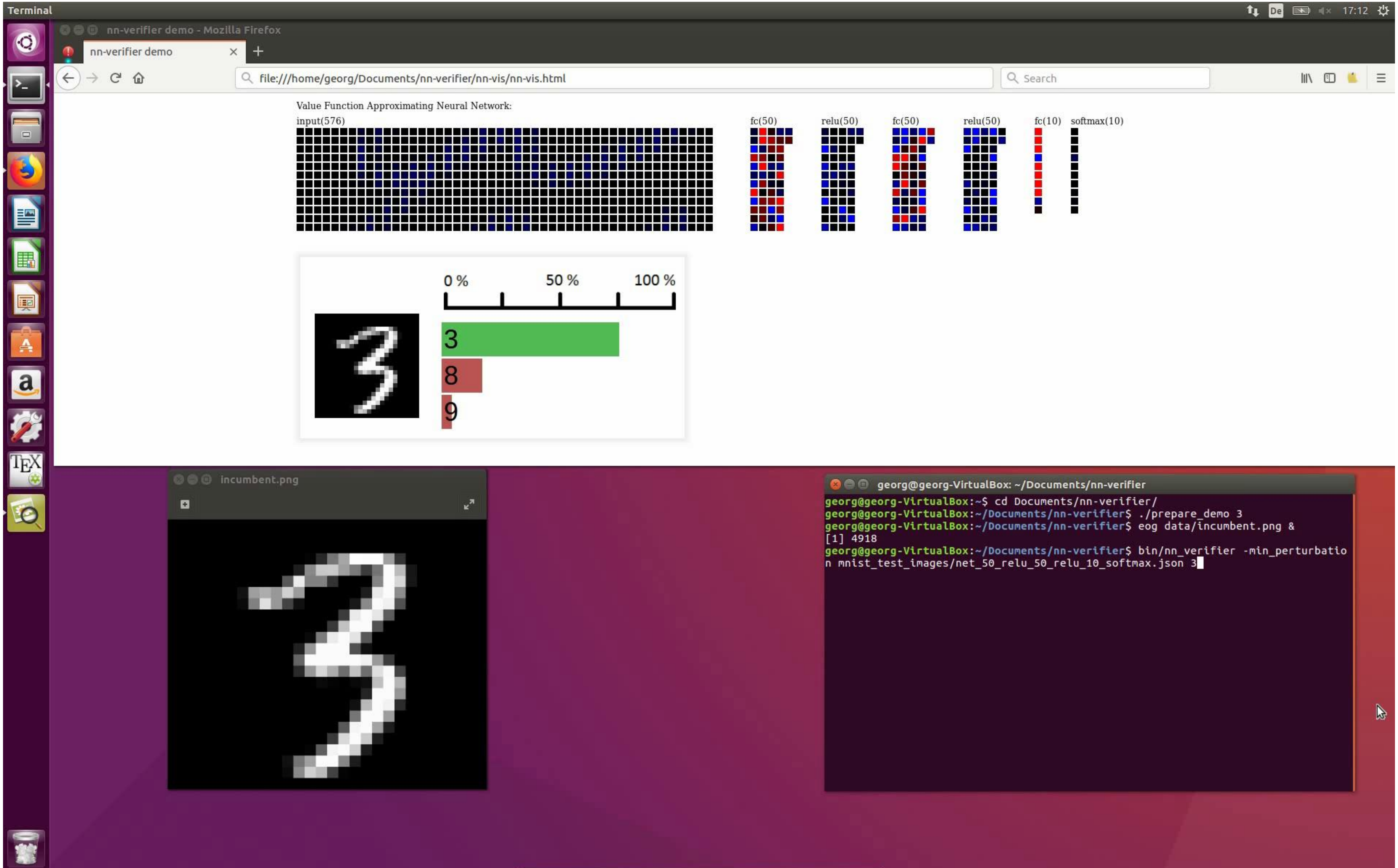
Adversarial images

The need for neural network verification in image processing

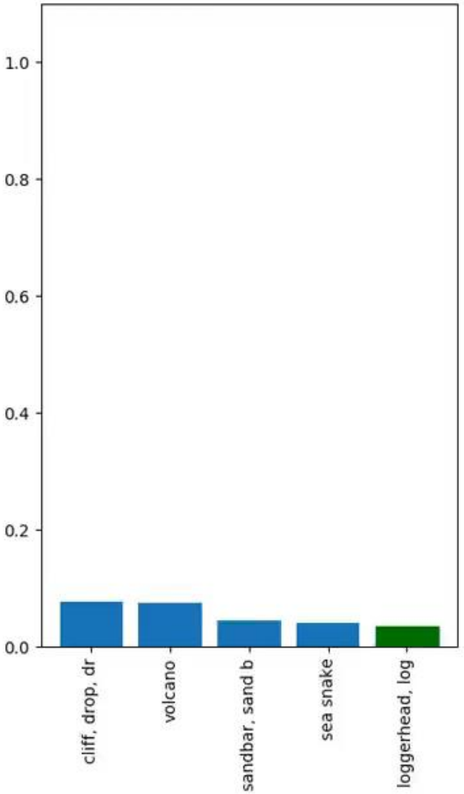
Dependable neural networks are crucial for safe and secure autonomous and decision systems



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


Terminal
17:12
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:
input(576)
fc(50)
relu(50)
fc(50)
relu(50)
fc(10)
softmax(10)
0 %
50 %
100 %
3
8
9
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?!

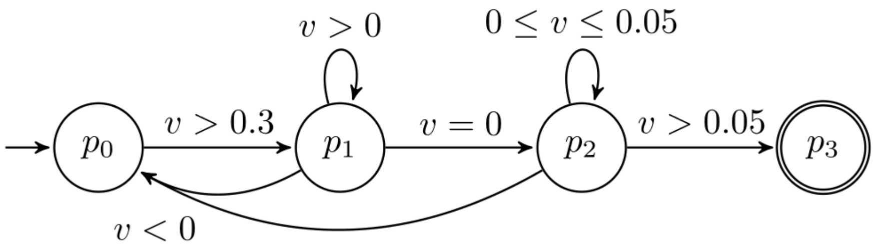
Black-box adversarial examples

- 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).

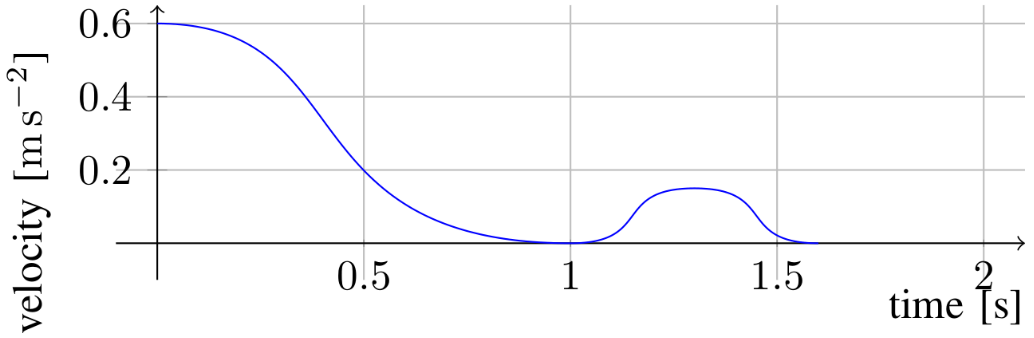
Detection and prediction of undesired Vehicle Behavior

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



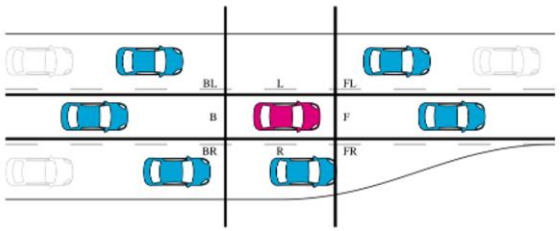
NuSMV: **SPEC** !**EF**(*G0* & **E**[*G1* **U** *G2* & **E**[*G3* **U** *G0*]]);

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



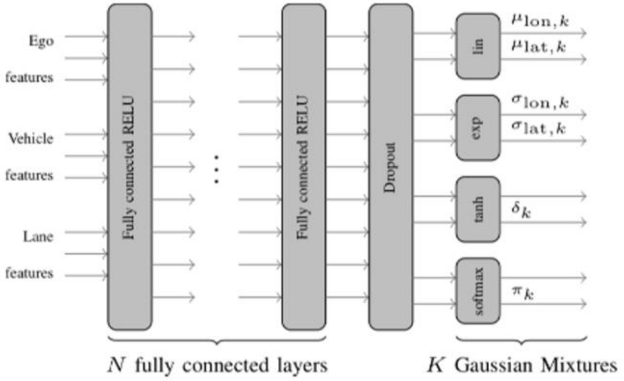
Verification of safety properties of NNs

Neural network example:



features of traffic situation

input



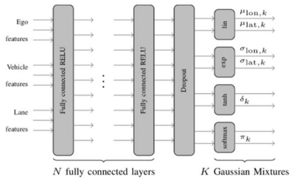
neural network

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

$$
\begin{array}{ll}
\text{maximize} & \mathbf{c}^{\mathrm{T}}\mathbf{x} \\
\text{subject to} & A\mathbf{x} \leq \mathbf{b}, \\
 & \mathbf{x} \geq \mathbf{0}, \\
\text{and} & \mathbf{x} \in \mathbb{Z}^n
\end{array}
$$

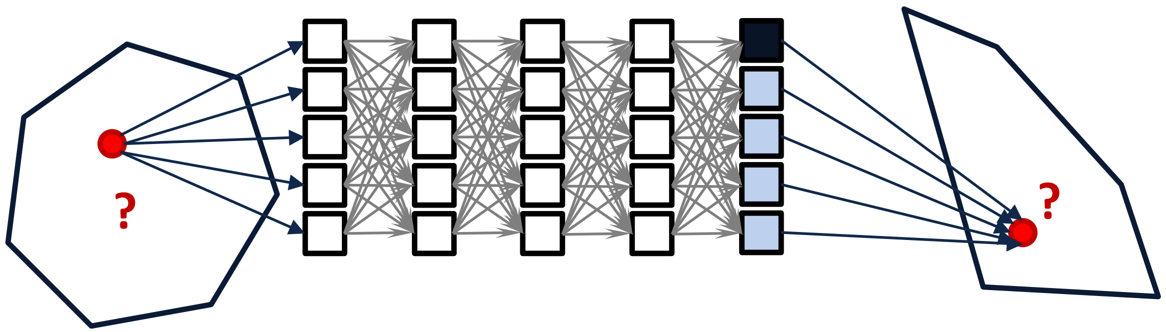
nn-verifier

- 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

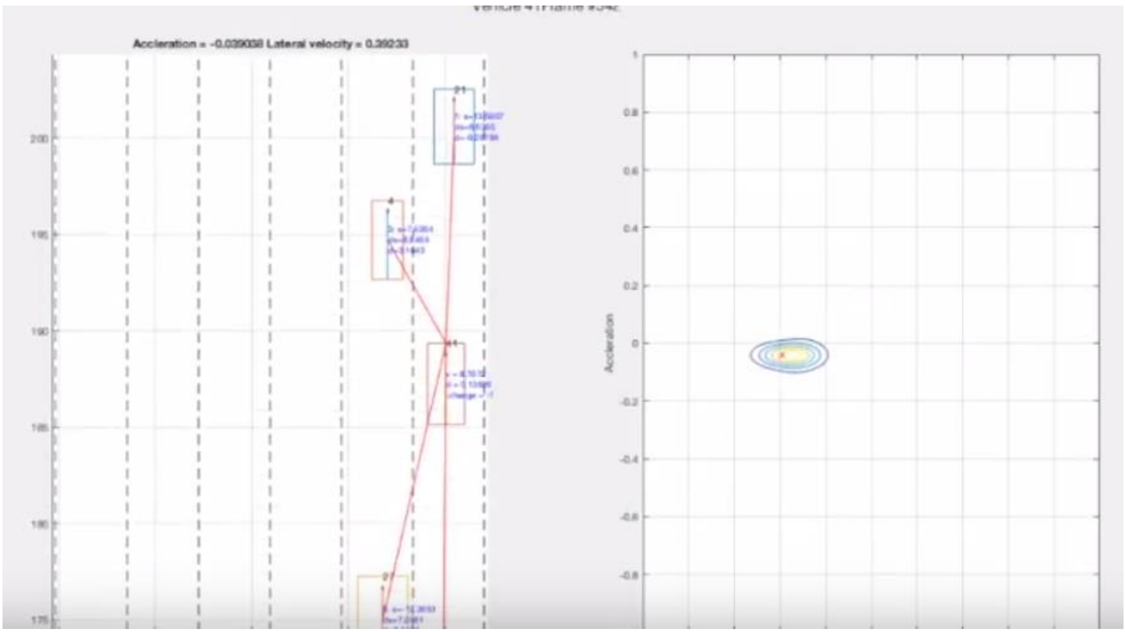


Input set

Output set

Input:
sensor data

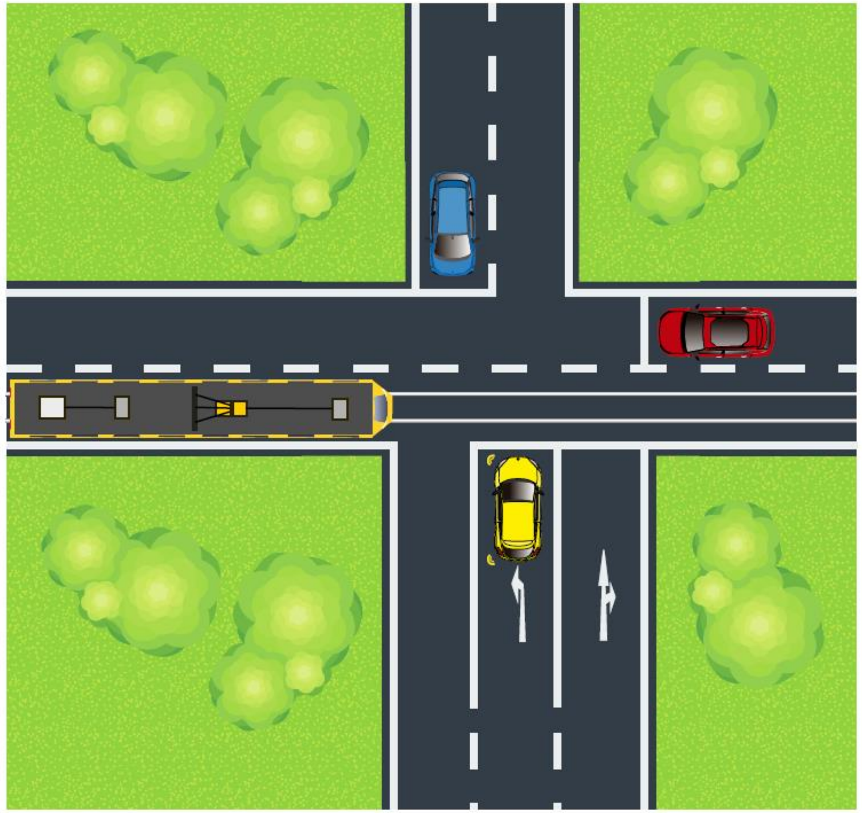
Output:
velocity prediction

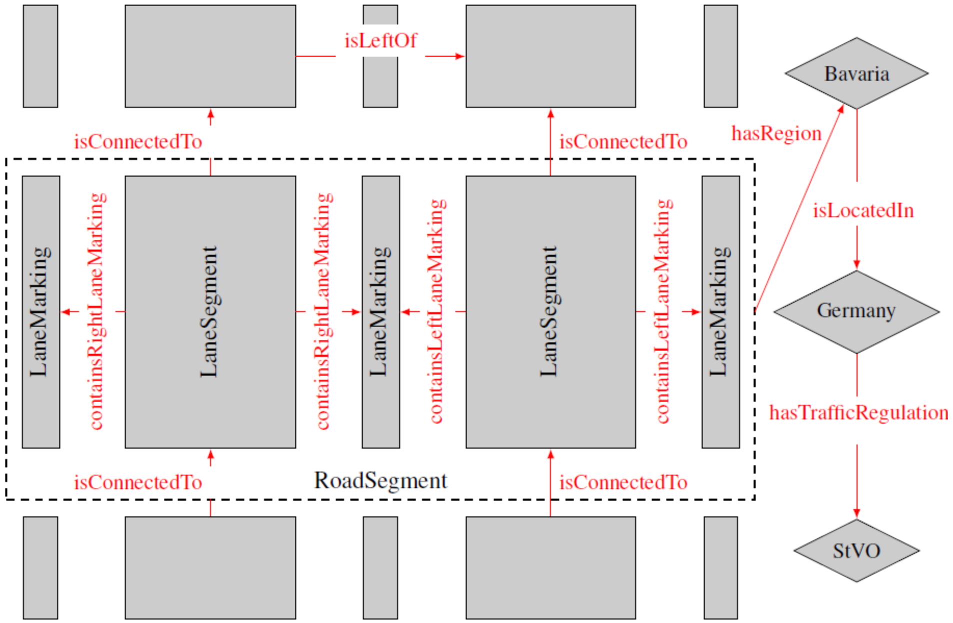


Highway motion predictor, being trained under the NGSim dataset

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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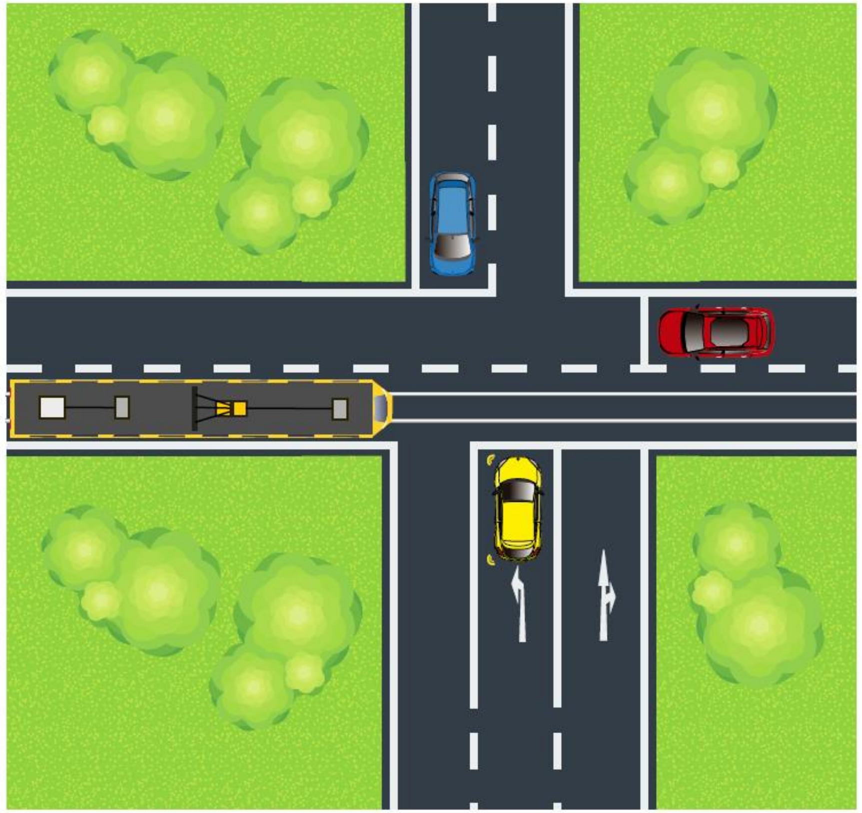

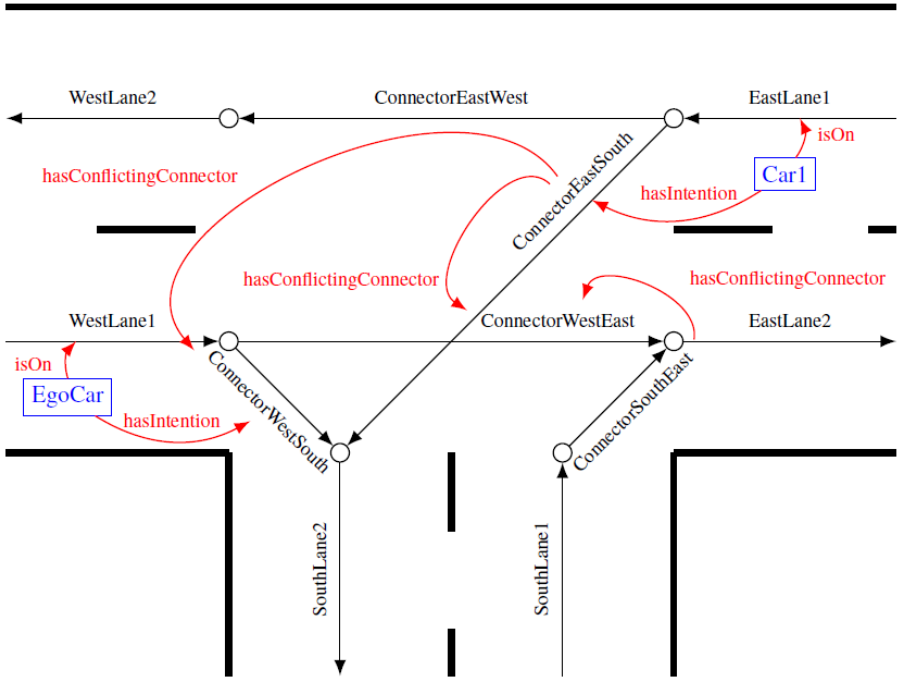

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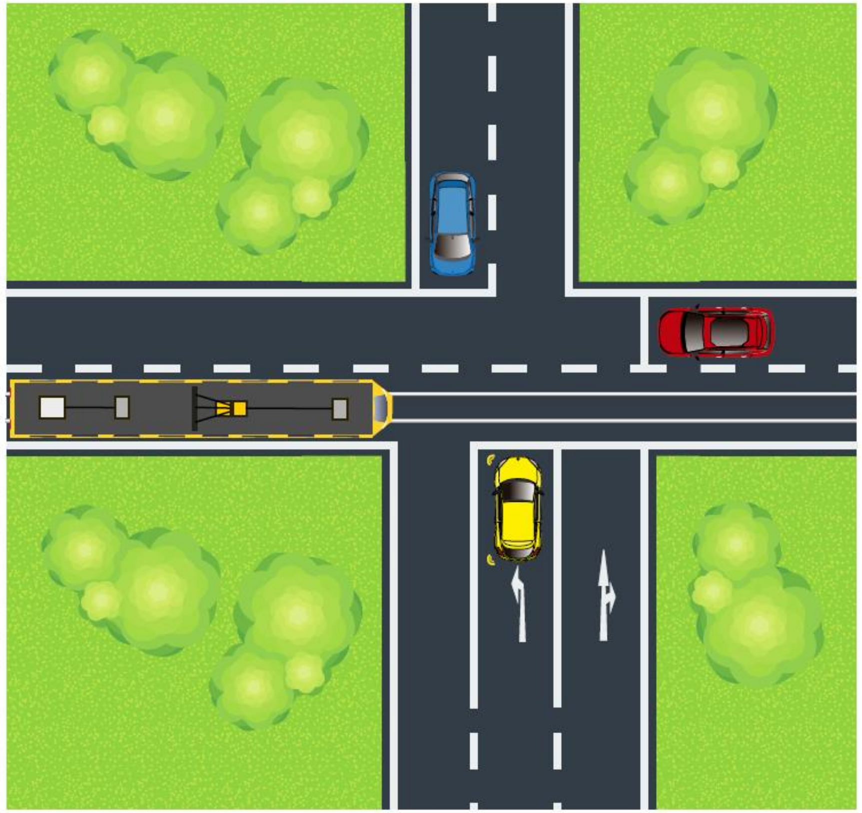

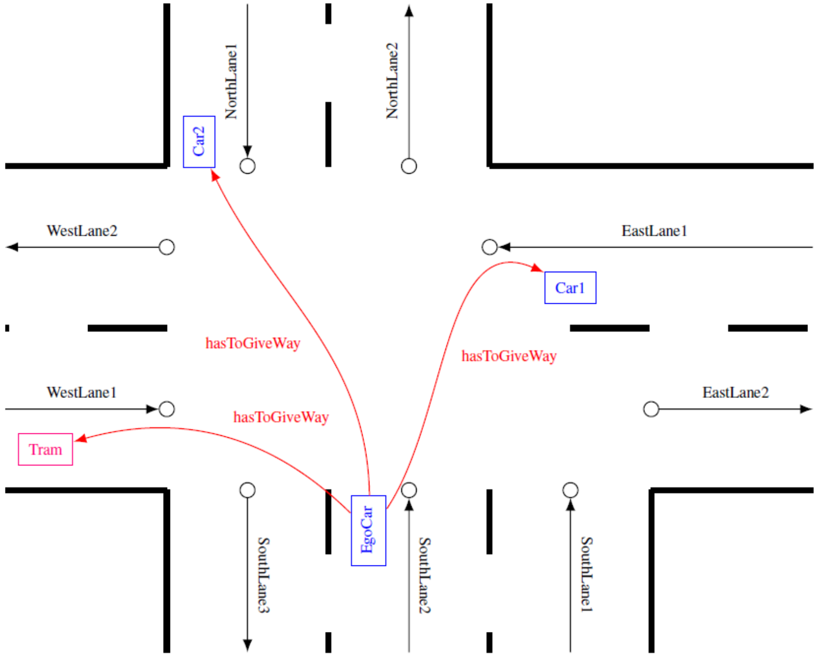

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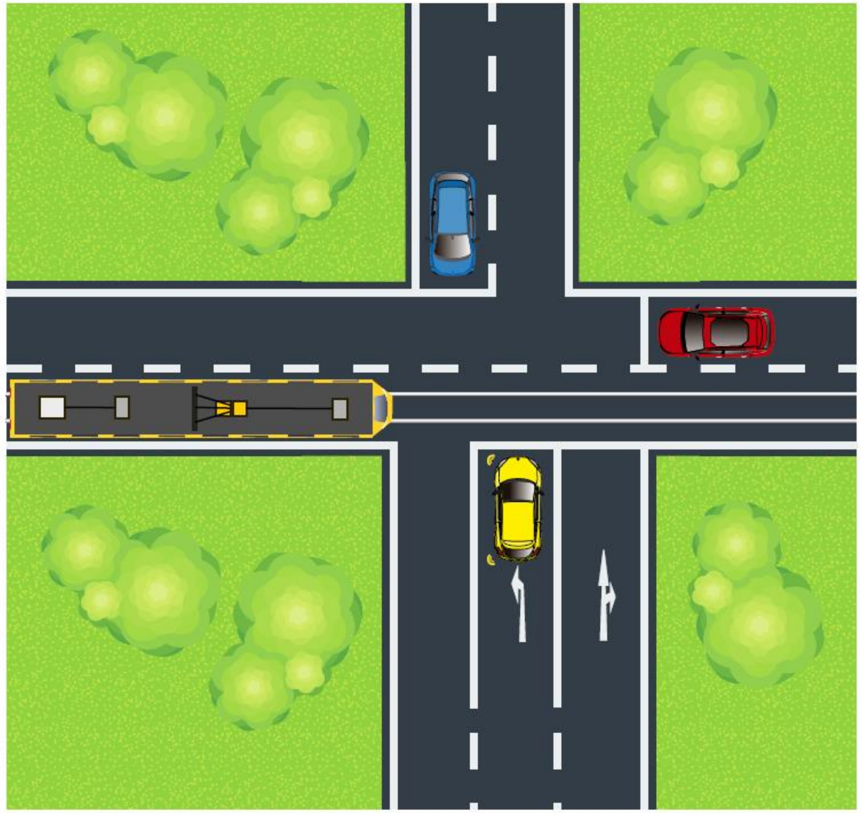

$containsTrafficLight\ some\ TrafficLight$ and
$containsTrafficRegulatingPerson$
$exactly\ 0\ TrafficRegulatingPerson$

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

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

Semantic Scenario Interpretation and Decision Making

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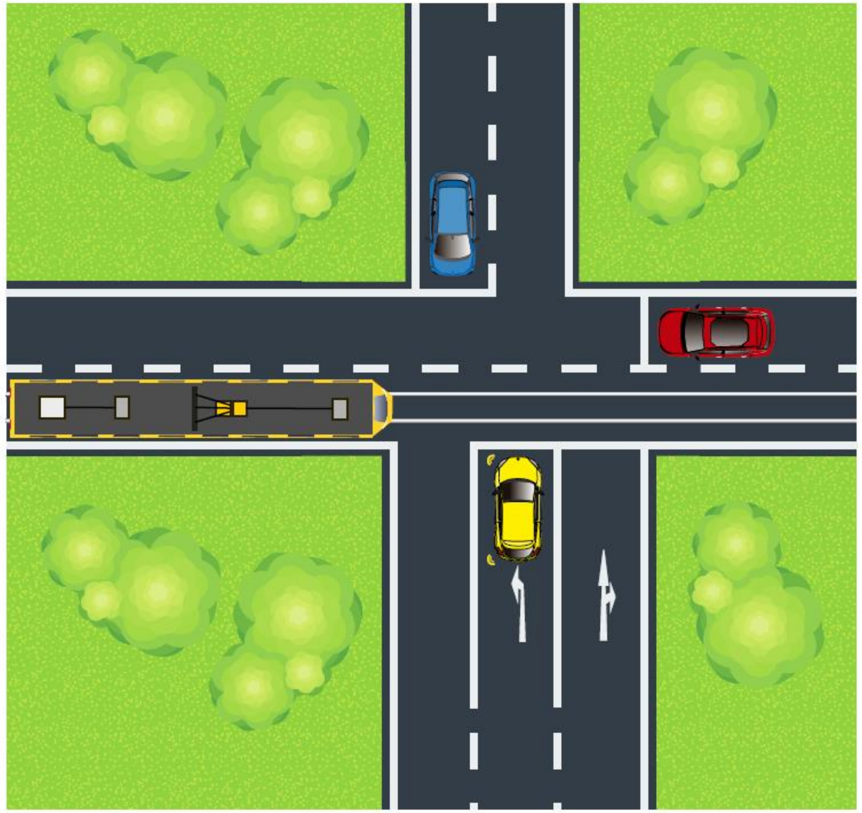


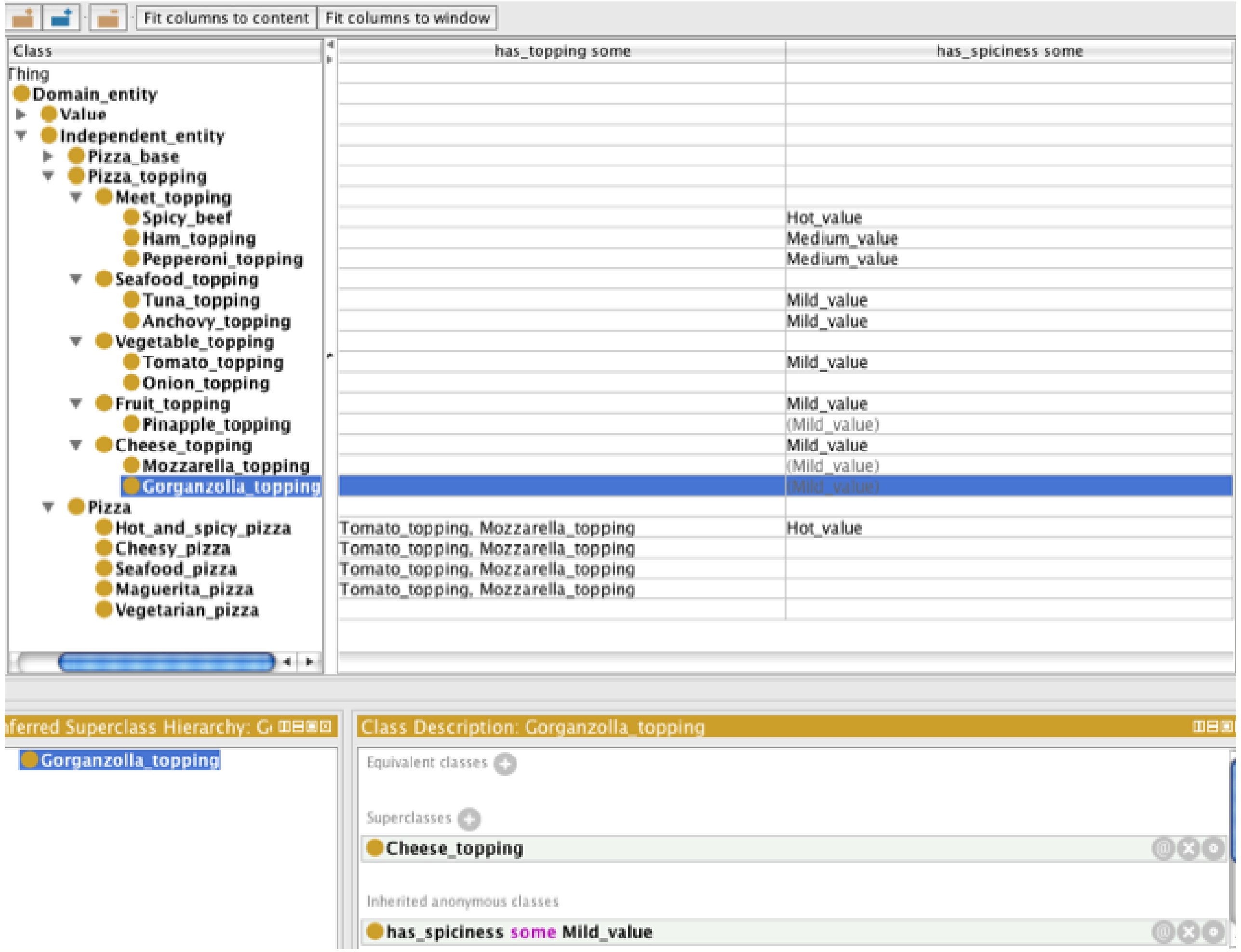
$containsTrafficLight\ exactly\ 0\ TrafficLight$ and $containsTrafficRegulatingPerson$ $exactly\ 0\ TrafficRegulatingPerson$

$$\begin{aligned}
&UncontrolledIntersection(?scen1) \\
&\wedge Vehicle(?vehicle1) \ \wedge\ Vehicle(?vehicle2) \\
&\wedge isPartOf(?vehicle1, ?scen1) \\
&\wedge hasConflictingConnector(?c1, ?c2) \\
&\wedge hasIntention(?vehicle1, ?c1) \wedge hasIntention(?vehicle2, ?c2) \\
&\Rightarrow\ hasToGiveWay(?vehicle1, ?vehicle2)
\end{aligned}$$

$$\begin{aligned}
&TrafficRegulatedPersonIntersection(?scen1) \\
&\wedge Vehicle(?vehicle1) \ \wedge\ contains(?scen1, ?vehicle1) \\
&\wedge isOn(?vehicle1, ?lane1) \ \wedge\ isBlockedBy(?lane1, ?police) \\
&\Rightarrow\ hasToWaitForTRP(?vehicle1, ?police)
\end{aligned}$$

Ontology Pizza Tutorial

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



Safety & Accident Simulation

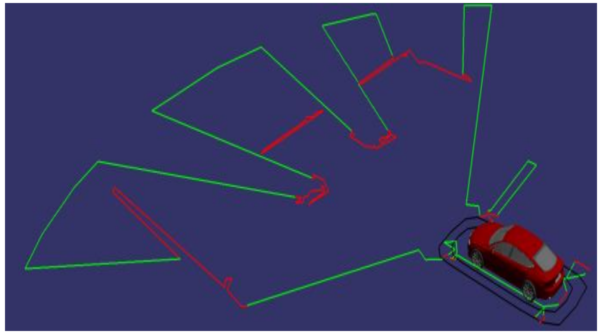
From Sensors to Scenarios

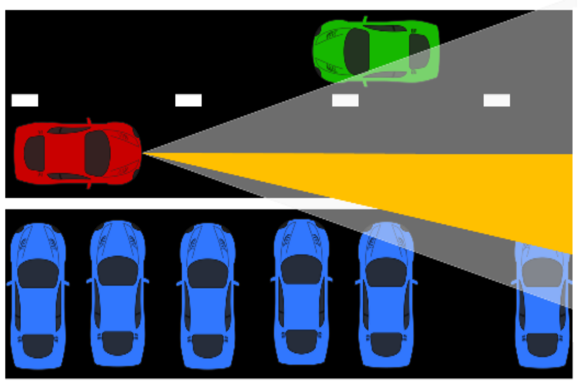
- Scenario tests
- Accident analysis
- Development of test catalogues
    - Identification of close to 1000 sensing aspects for sensor set validation

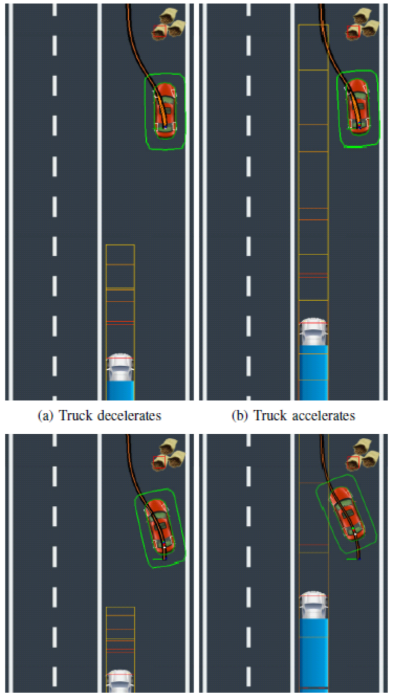
- Conceptual knowledgebase development for autonomous driving and decision making

- Sensor Simulation, data-acquisition, auto-calibration, fault detection…

Analysis, tool development, knowledgebases

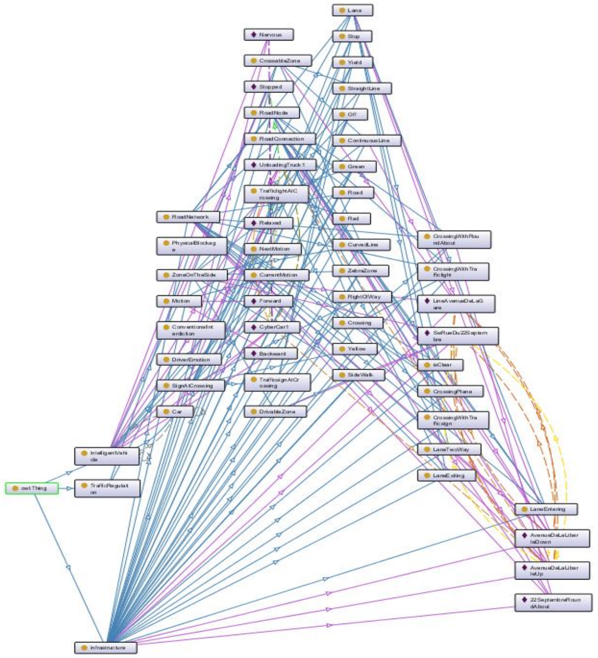






(a) Truck decelerates (b) Truck accelerates

(c) Truck decelerates (d) Truck accelerates



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


SPIEGEL ONLINE DER SPIEGEL SPIEGEL TV Anmelden

Menü | Politik Meinung Wirtschaft Panorama Sport Kultur Netzwelt 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.

Applications

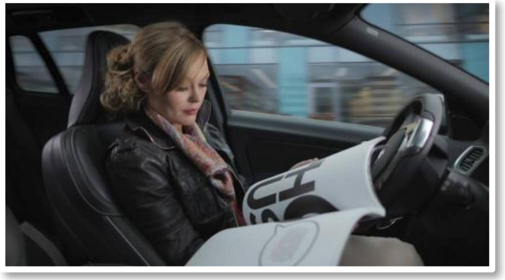
Ex. Far-Reaching View

- “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

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

Providentia - Highway Digital Twin



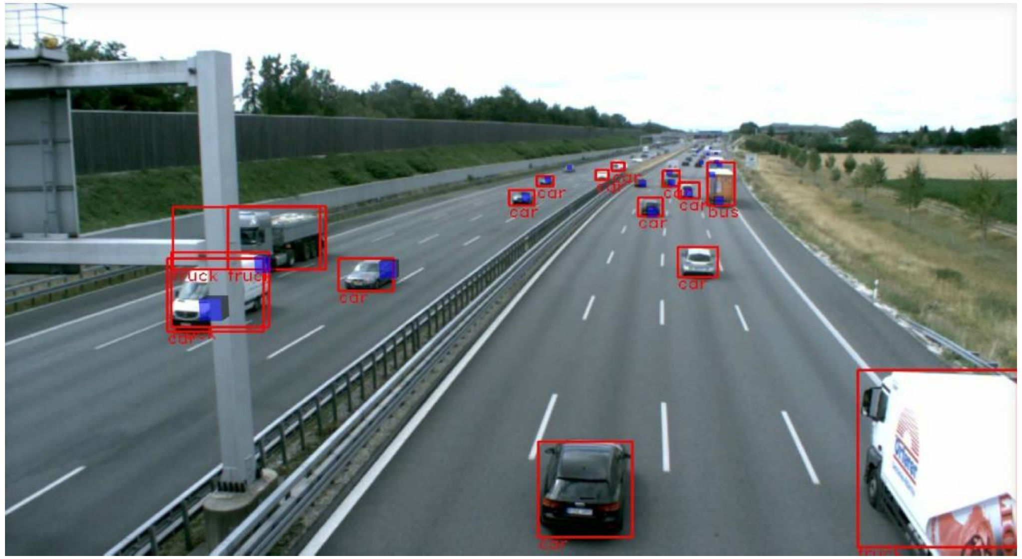
Far-reaching View	Traffic end detection	Traffic coordination	...Many more

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

Detections Camera Near → PHD-Tracker → Fusion

Detections Camera Far → PHD-Tracker → Fusion

Detections Radar → PHD-Tracker → Fusion

Fusion → Unified Environmental Model

Multisensor Data Fusion of vehicles and infrastructure

C2X Sensors

- Connected system with shared sensor information

- **Infrastructure**

  Radar

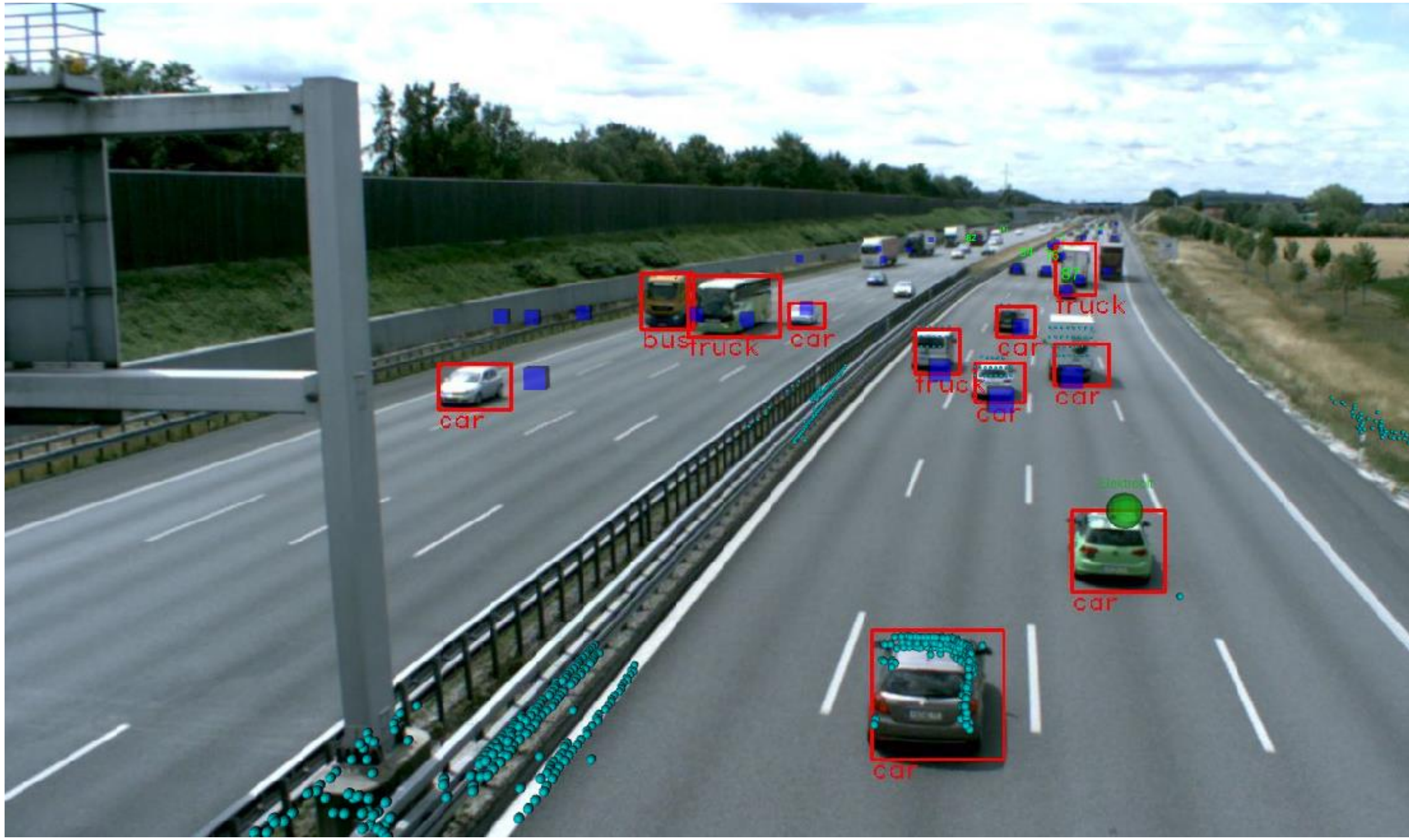
  Camera Near

  Camera Far 123

- **Fahrzeug:**

  Ego-vehicle detection

  Lidar

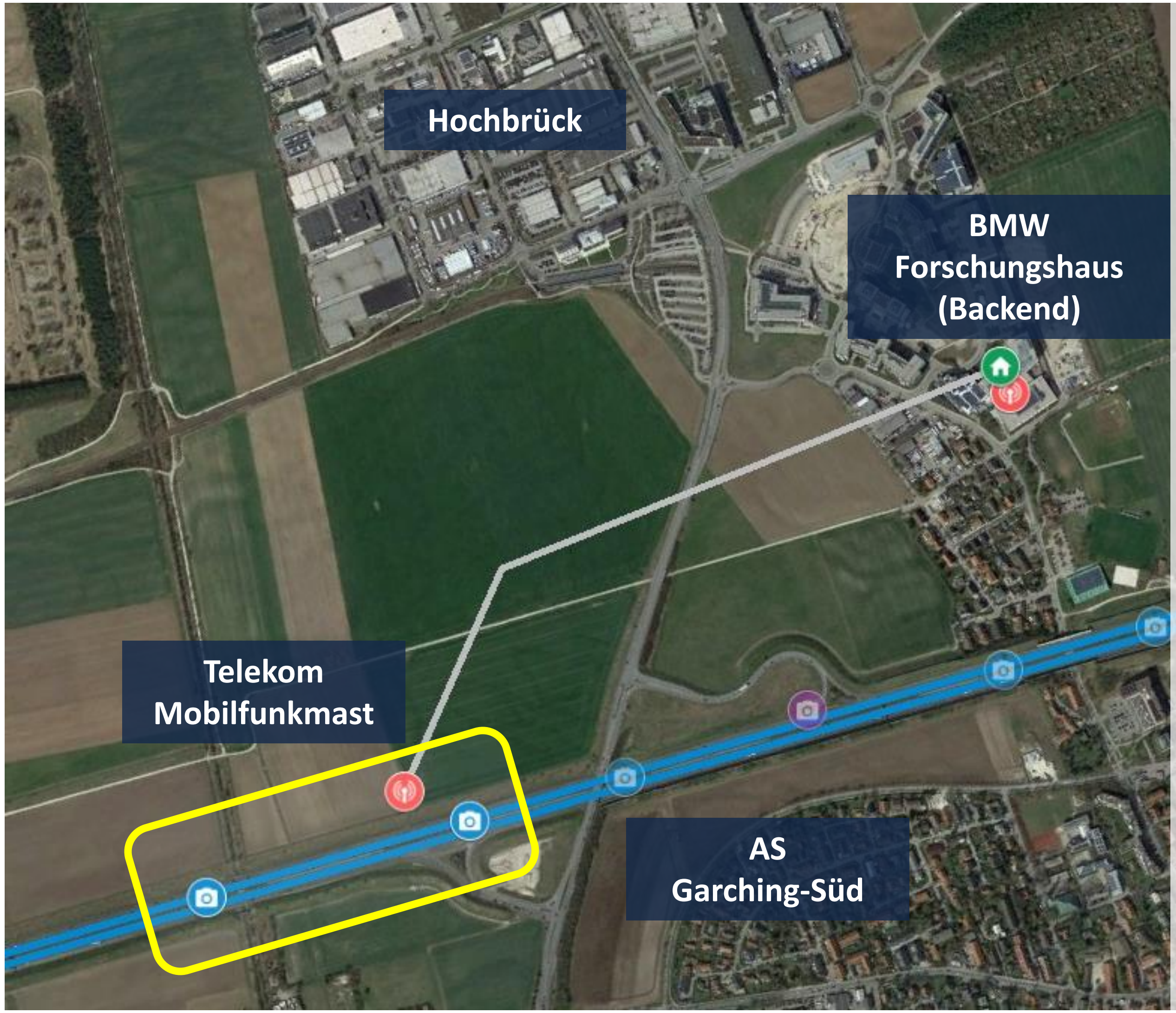


Intelligent Infrastructure

Providentia Testfield - Concept

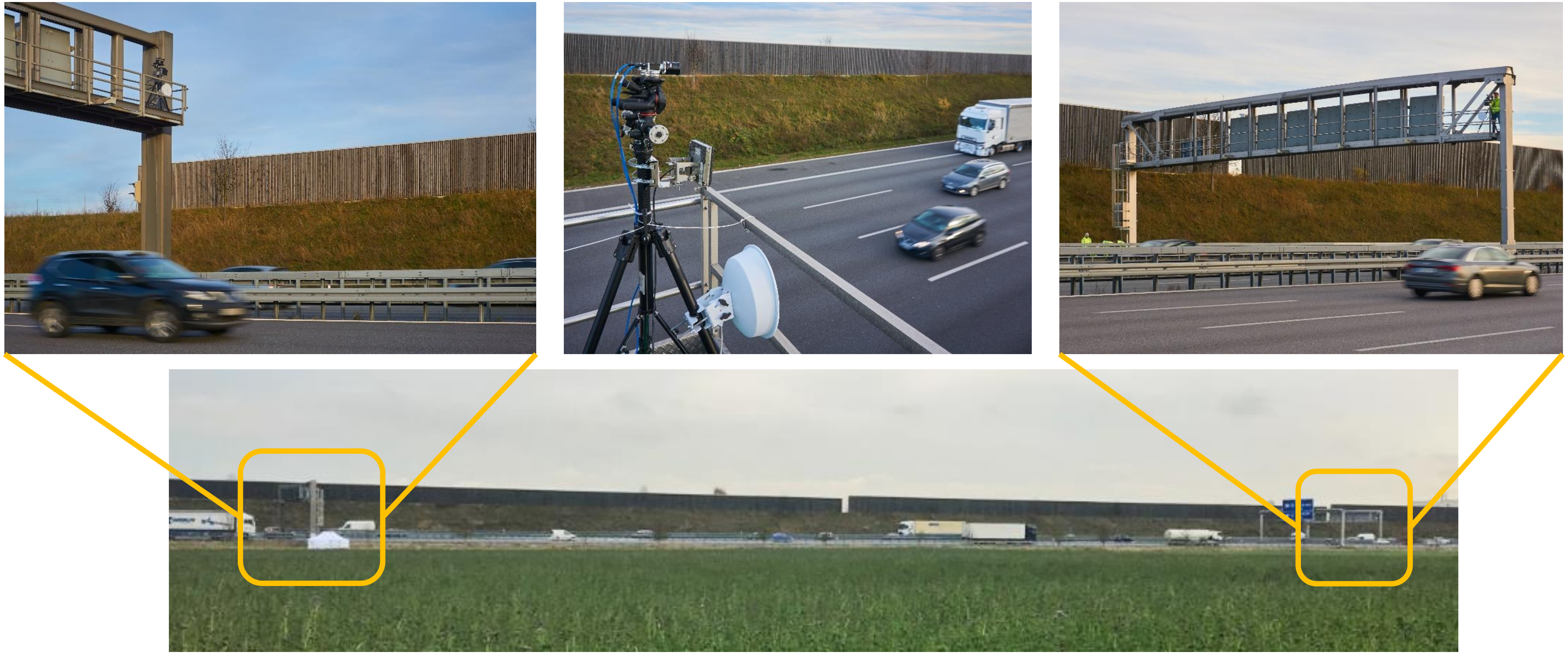
Intelligent Infrastructure

Providentia Testfield – Area 1

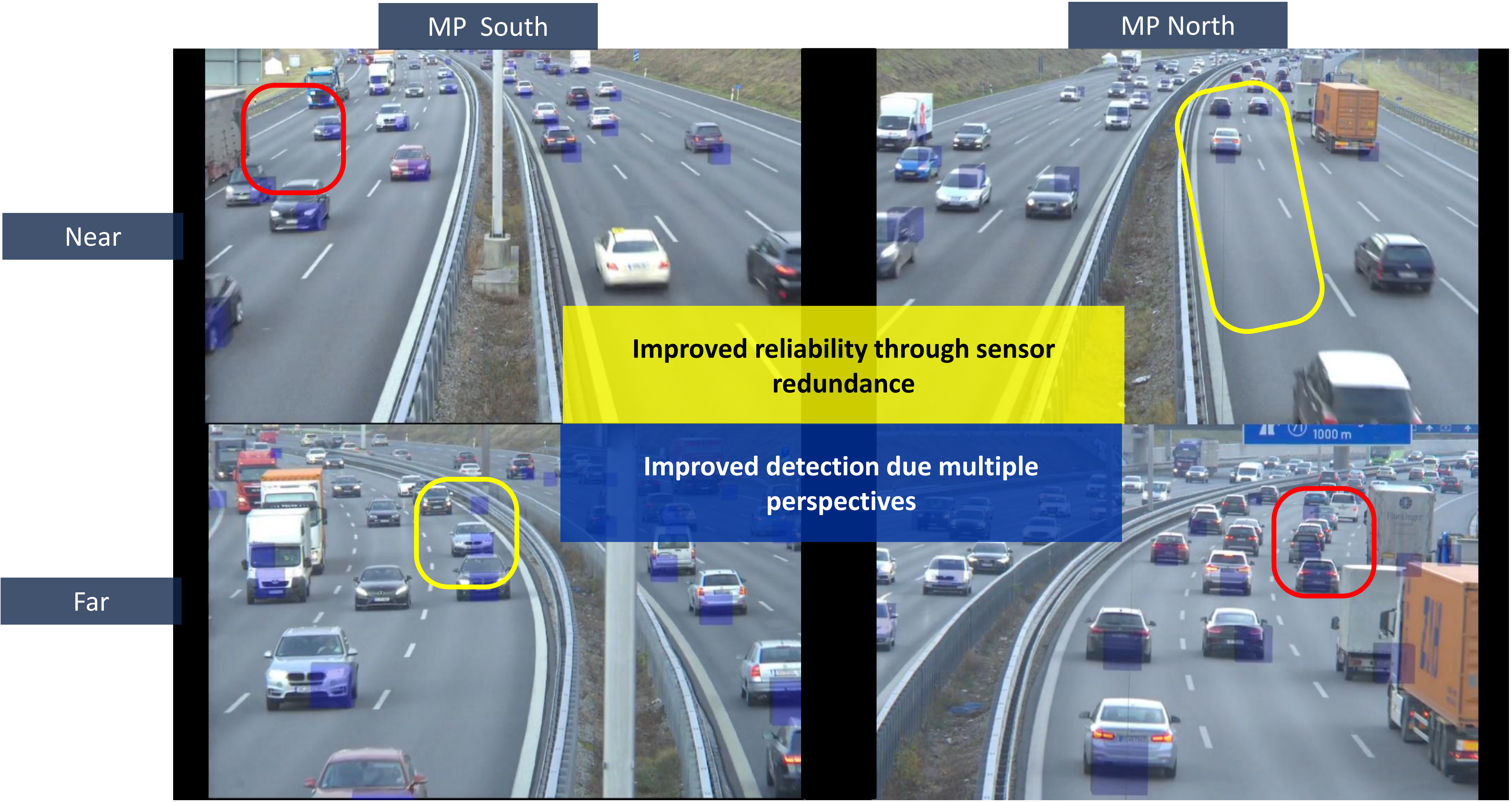


Intelligent Infrastructure

Mobile Fieldtests




MP South
MP North
Near
Far
1000 m

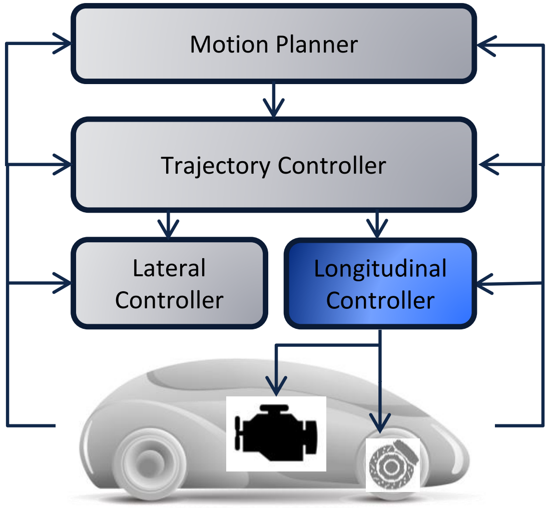

MP South
MP North
Near
Far
Improved reliability through sensor redundance
Improved detection due multiple perspectives
1000 m

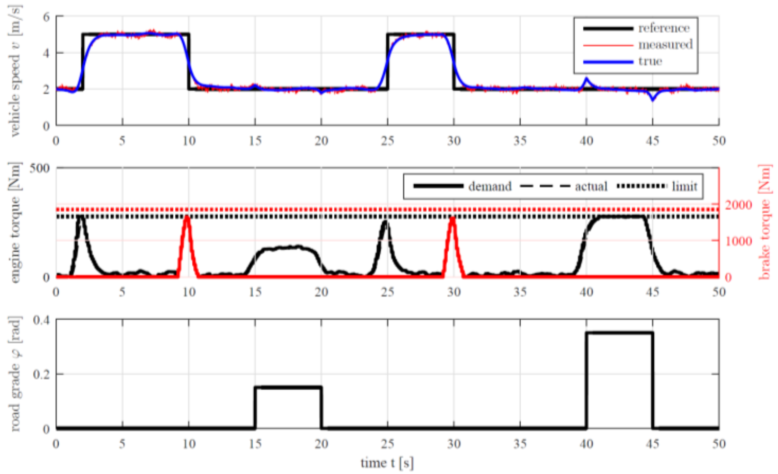
Tesla knocked out by a „bug“.

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

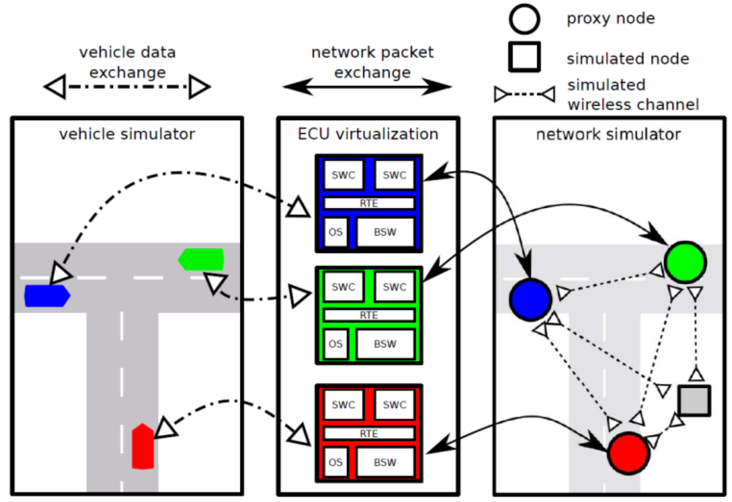


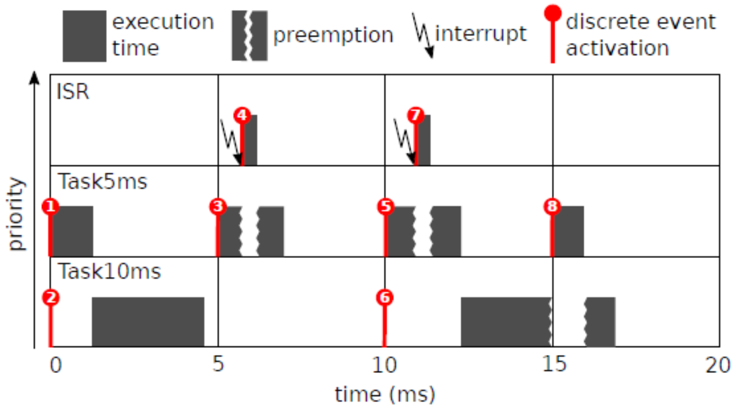


Fleet communication– Car to X

- 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





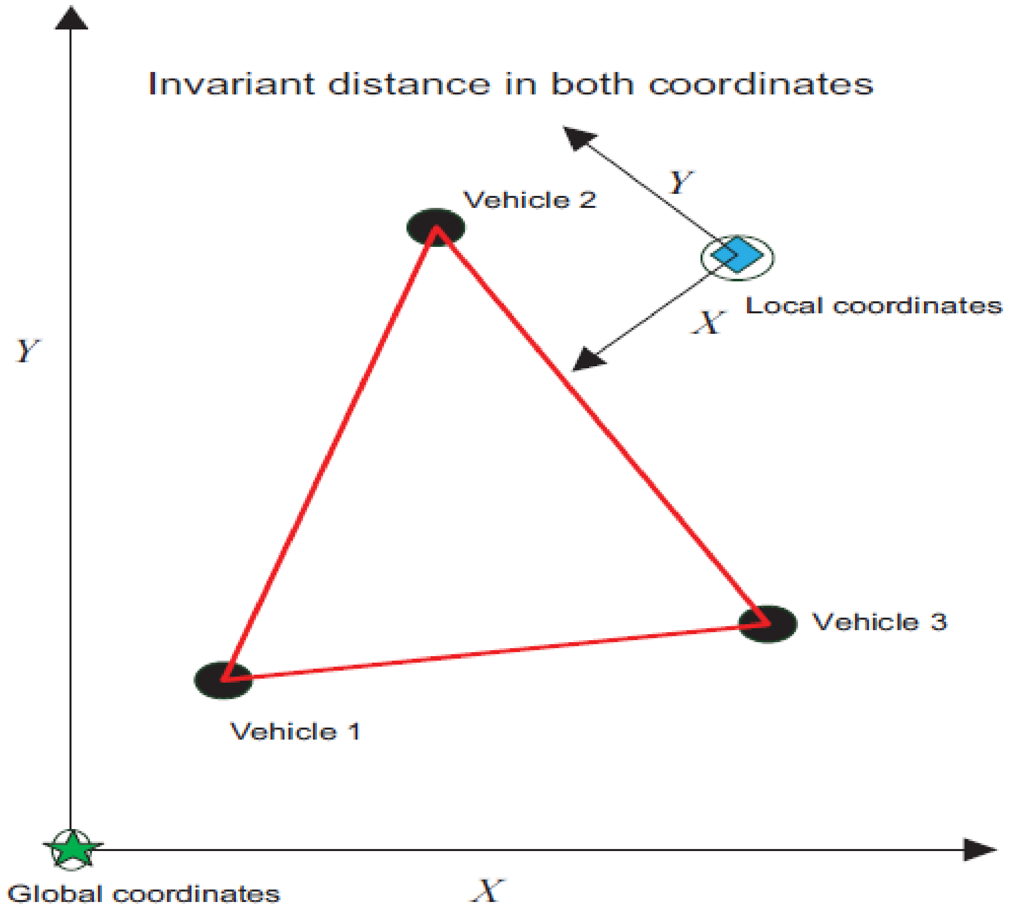
Fleet communication– Car to X

- High precision localization and tracking

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

- Can cope with large
  amounts of traffic participants

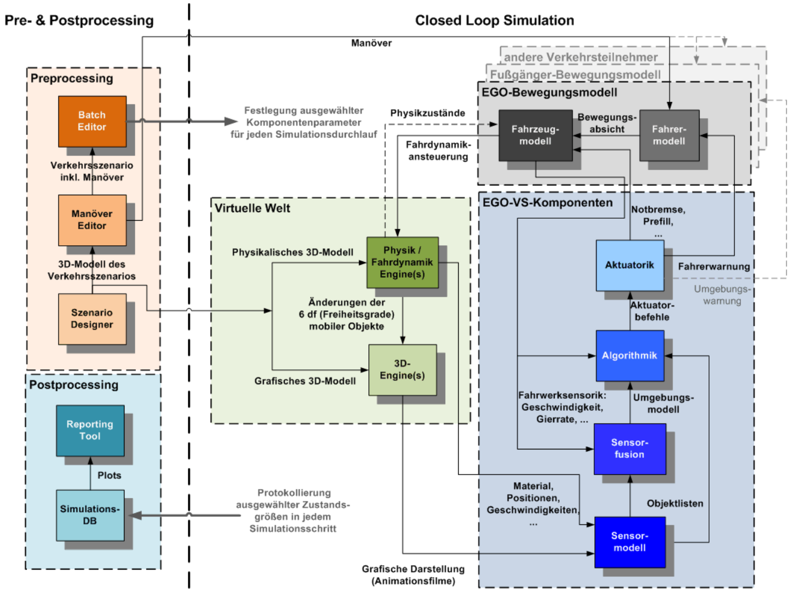
- Experience with various technologies
- PHD Filters
- GLMB Filters
- Factor Graphs
- Tracking with Neural Networks



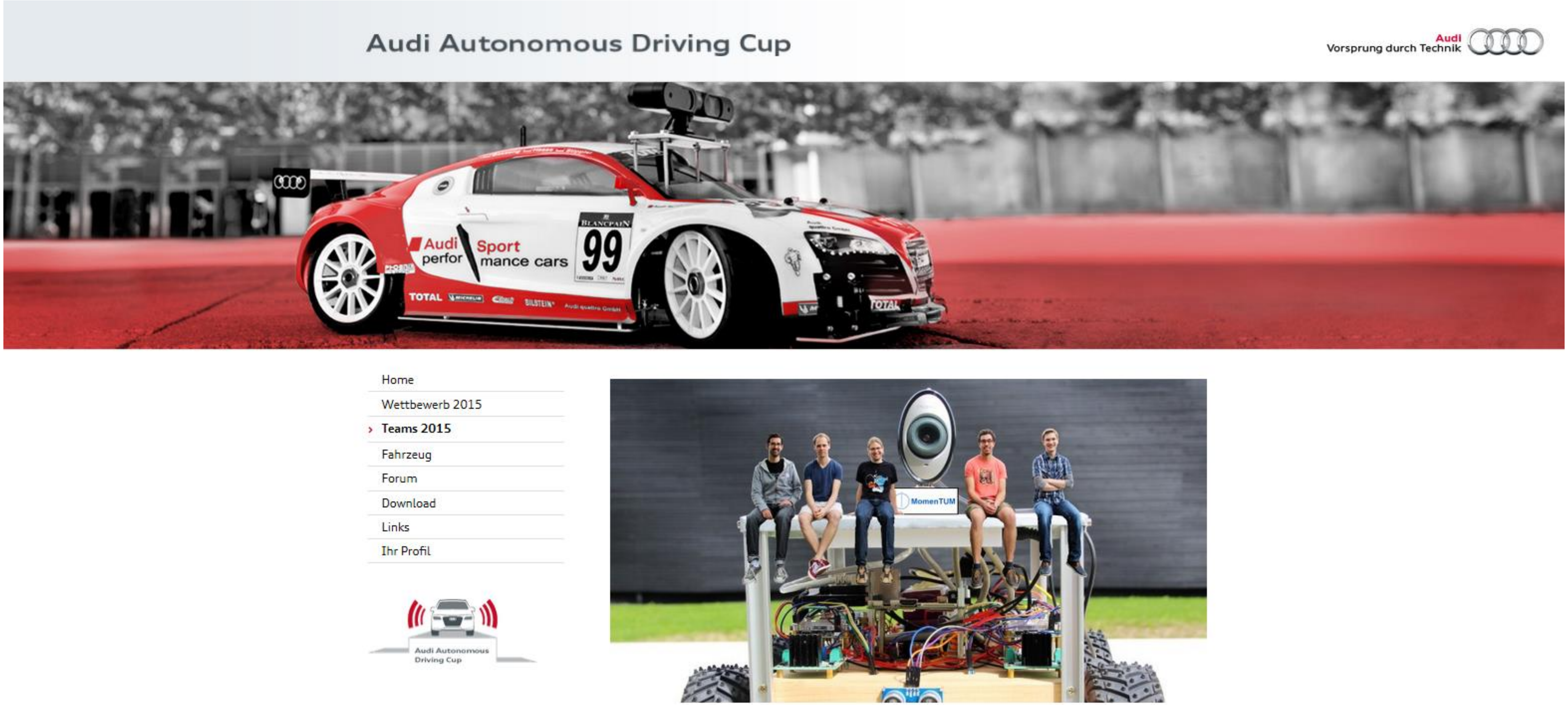
Traffic Simulations for ADAS and Self-Driving Cars

- Simulation tool concept design and development

- Traffic simulations in a variety of simulators
  - Sumo
  - Virtual Test Drive
  - CarMaker
  - …



Audi Autonomous Driving Cup



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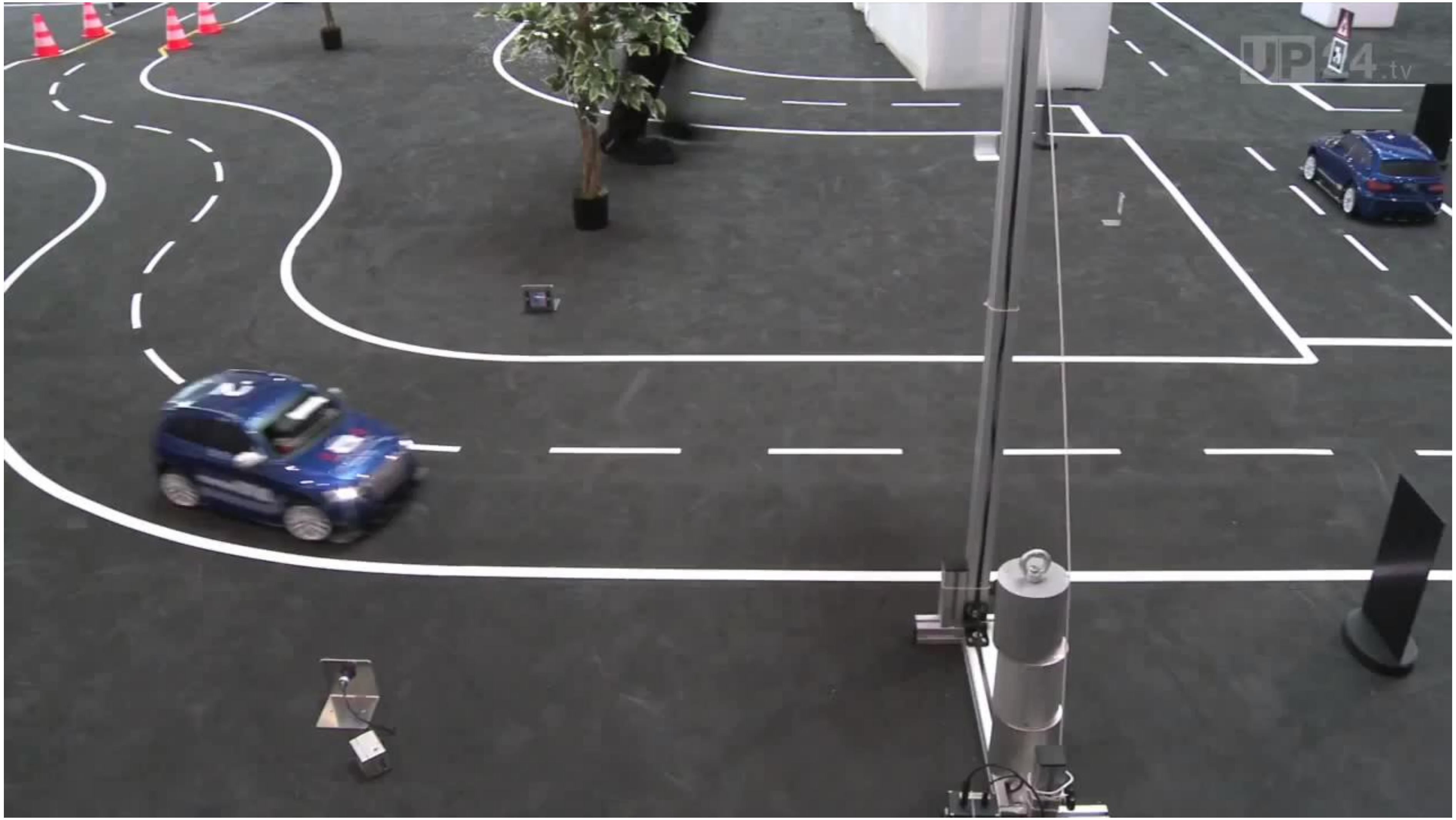


Pressemitteilung

Suchtext eingeben

Ingolstadt, 27.03.2015

Studierende der TU München gewinnen ersten Audi Autonomous Driving Cup

- **Preisgeld von 10.000 Euro für Siegerteam**
- **Audi-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.“**

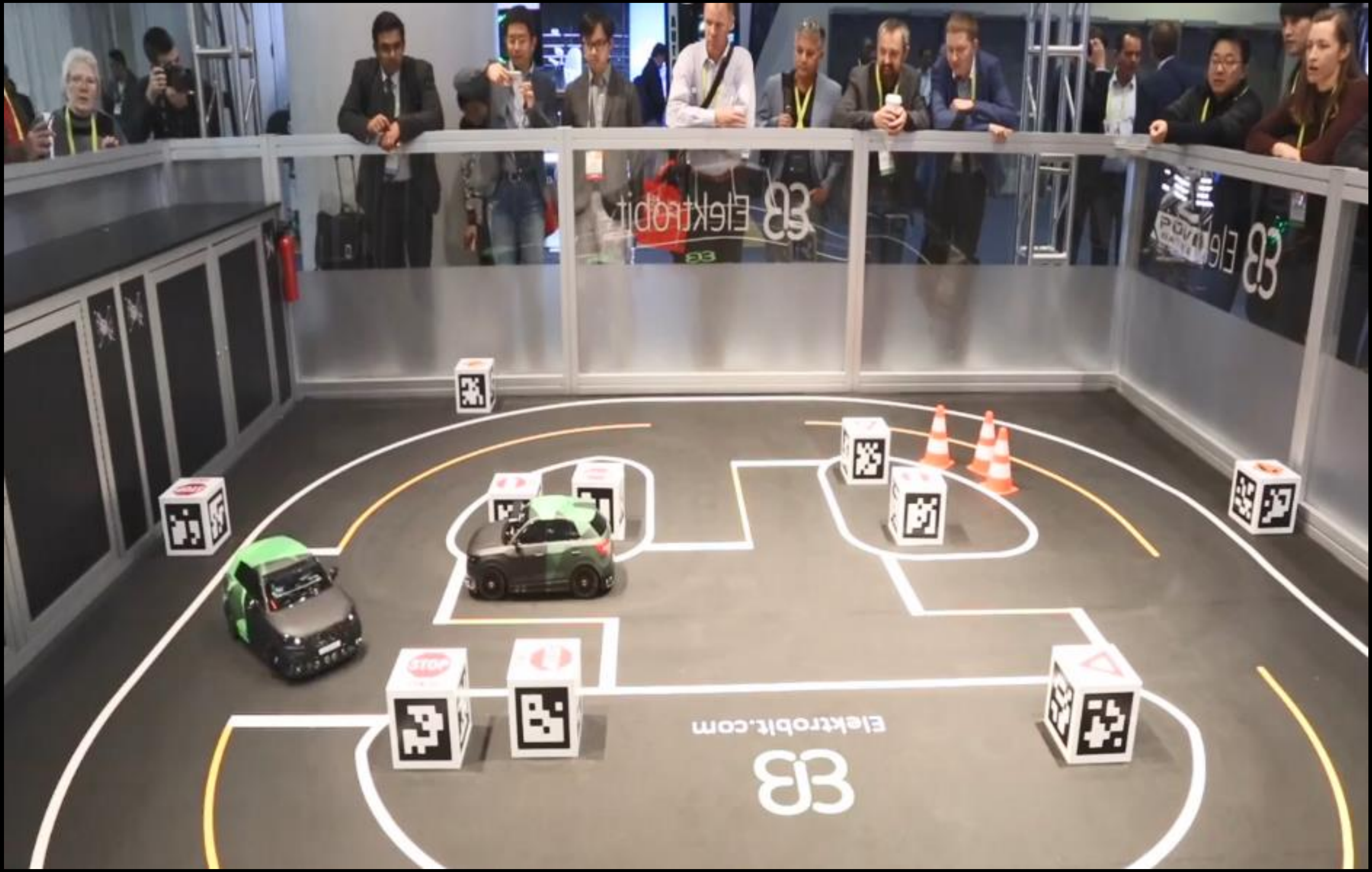
Beim Audi Autonomous Driving Cup wetteiferten rund 50 Studenten aus ganz

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

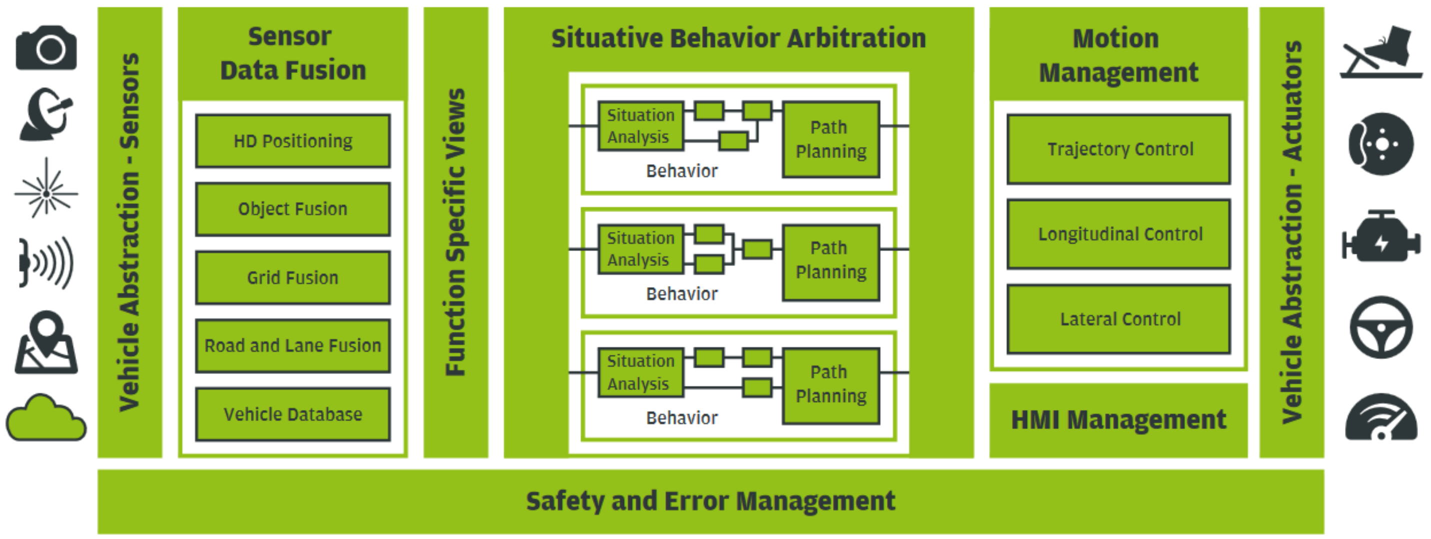
Simple AD demonstrator at CES with EB Robinos Model Cars

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

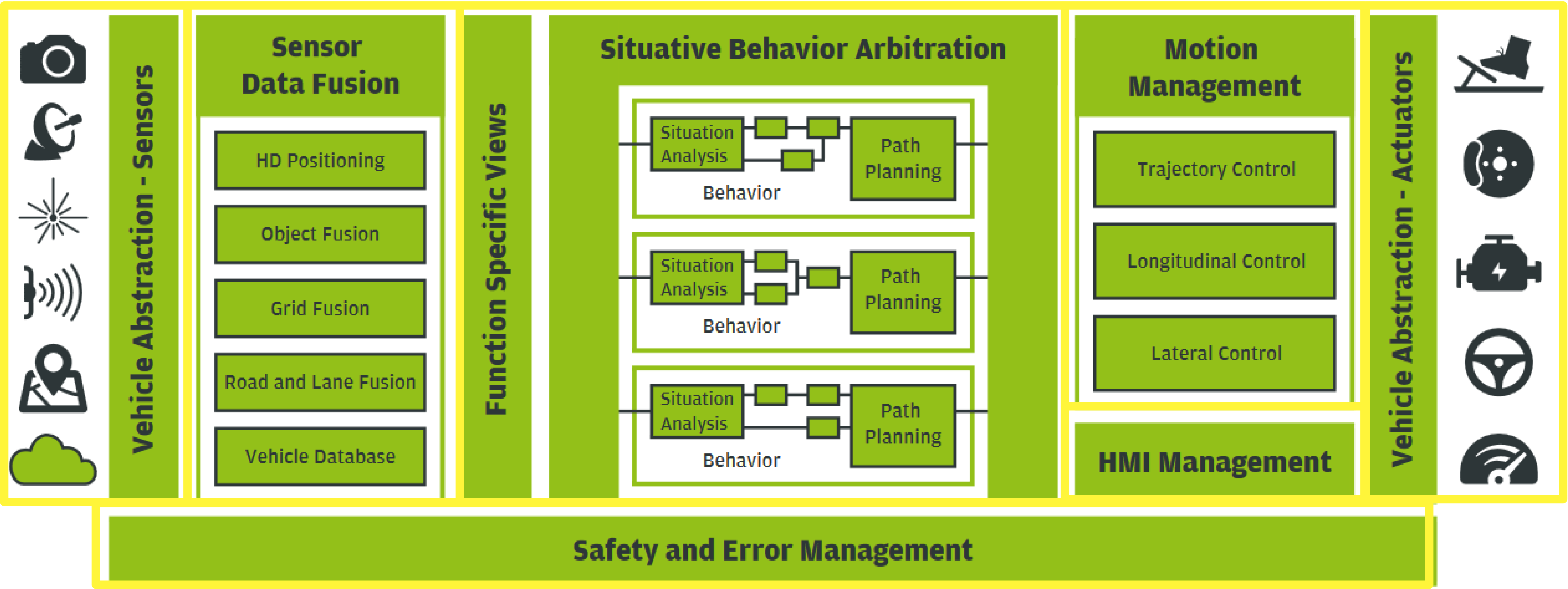
The goal was to **adapt and evaluate the feasibility of EB robinos** for Autonomous Driving and demonstrate it in an engaging manner **at the CES 2017**

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

Simple AD demonstrator at CES with EB Robinos Model Cars



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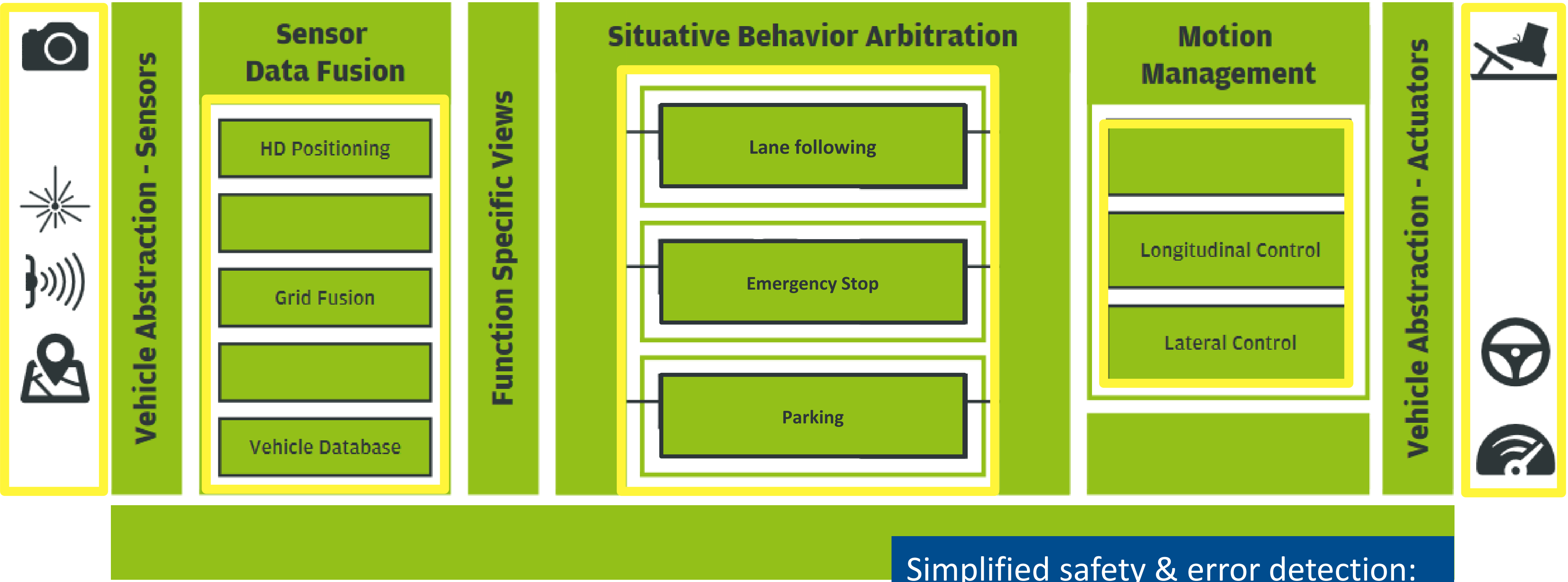


Simplified safety & error detection: Detect component failure & compensate or park

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

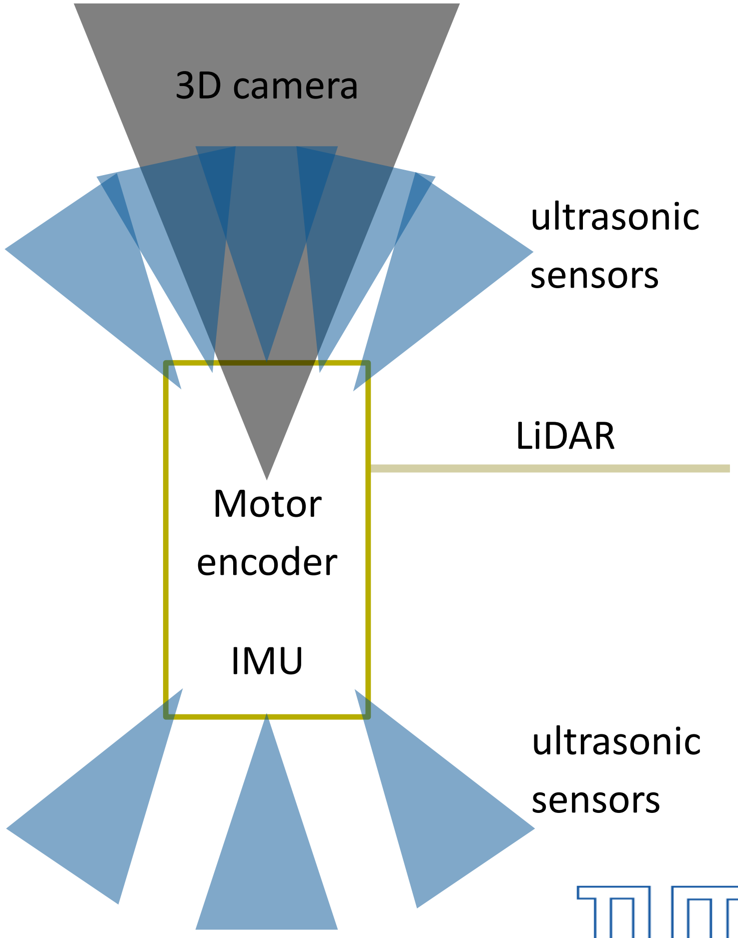
Simple AD demonstator at CES with EB Robinos Model Cars

- Model car scale 1:8
- Power train:
  - Brushless DC motor (150 W)
  - 4-wheel drive
- 2 steering axles
- Head lights, indicators, reverse light, etc.

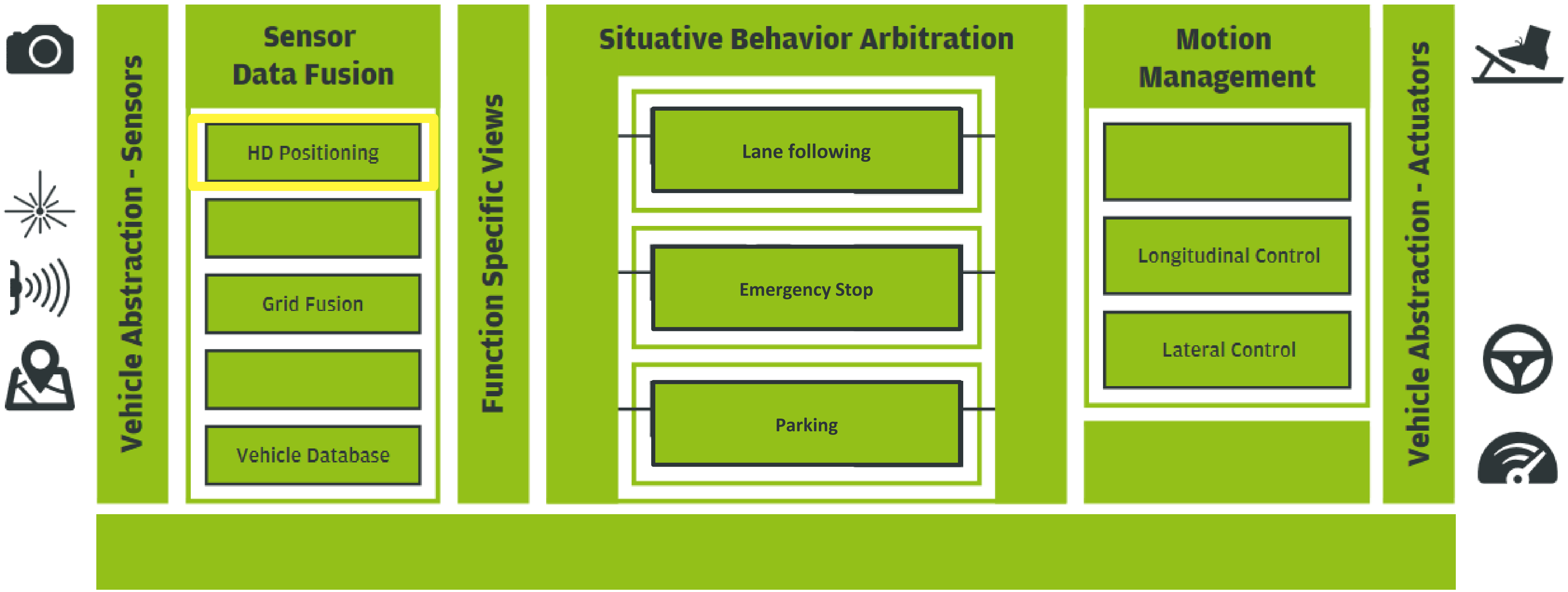
- Arduinos:
  - Sensor communication
  - Raw sensor data preprocessing
- Main processing unit:
  - Desktop motherboard
  - Intel i7 processor
  - 8 GB DDR4 RAM
  - No dedicated GPU

Simple AD demonstator at CES with EB Robinos Model Cars

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



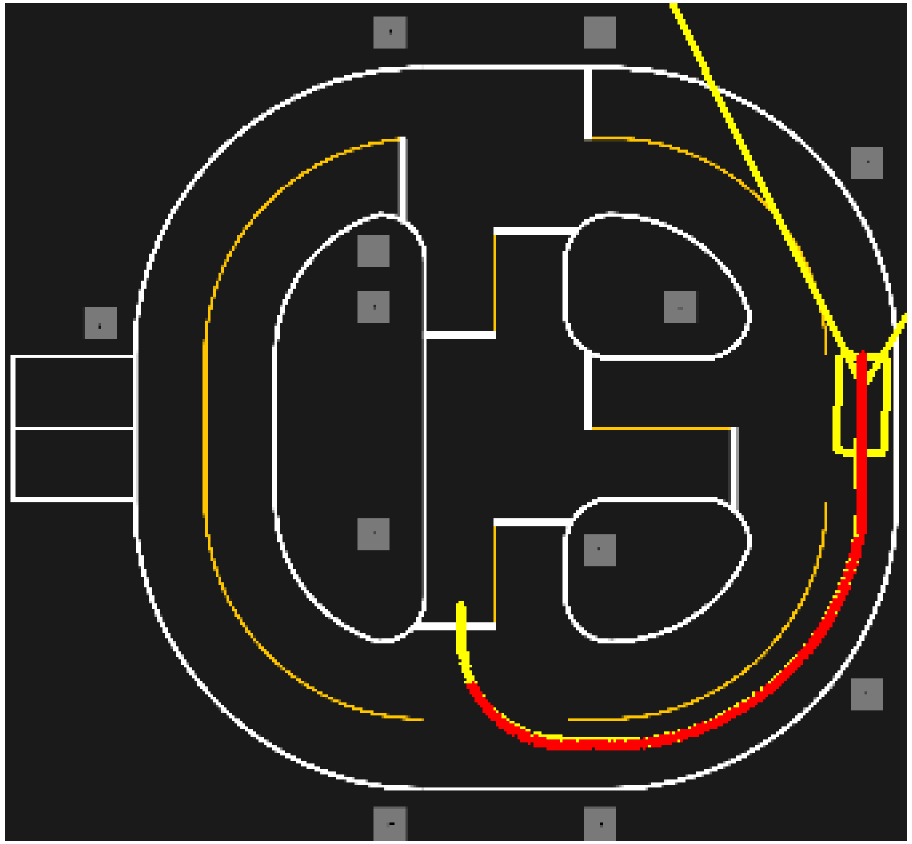
Simple AD demonstator at CES with EB Robinos Model Cars



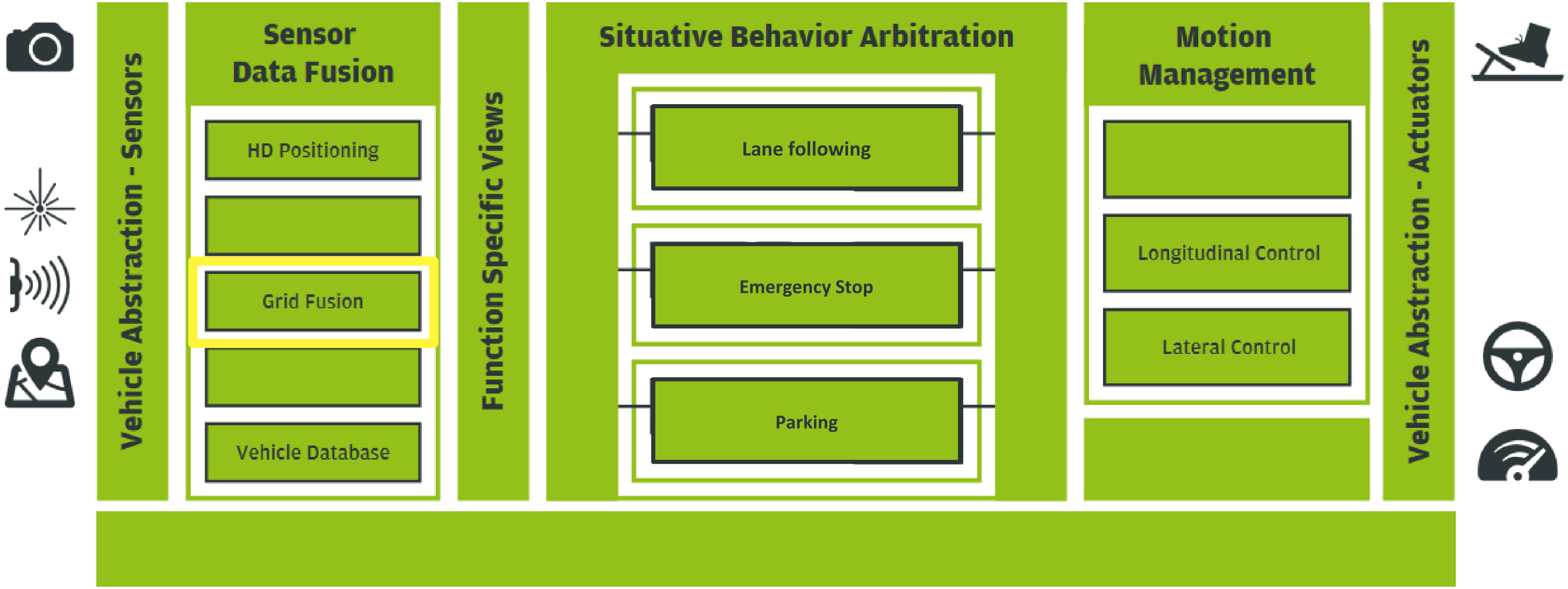
[1] Compare: EB robinos Specification, Elektrobit Automotive GmbH
https://www.elektrobit.com/products/eb-robinos/ , 12.02.2017

Simple AD demonstator at CES with EB Robinos Model Cars

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



Simple AD demonstator at CES with EB Robinos Model Cars

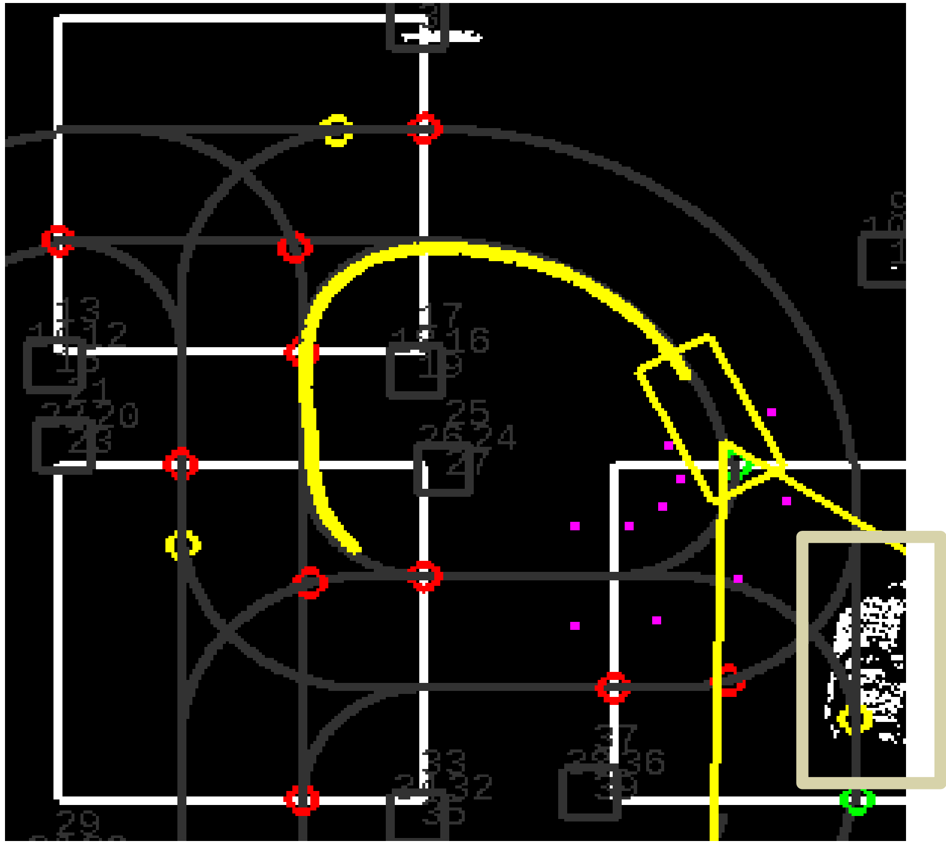


[1] Compare: EB robinos Specification, Elektrobit Automotive GmbH
https://www.elektrobit.com/products/eb-robinos/ , 12.02.2017

Simple AD demonstrator at CES with EB Robinos Model Cars

Gitter

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



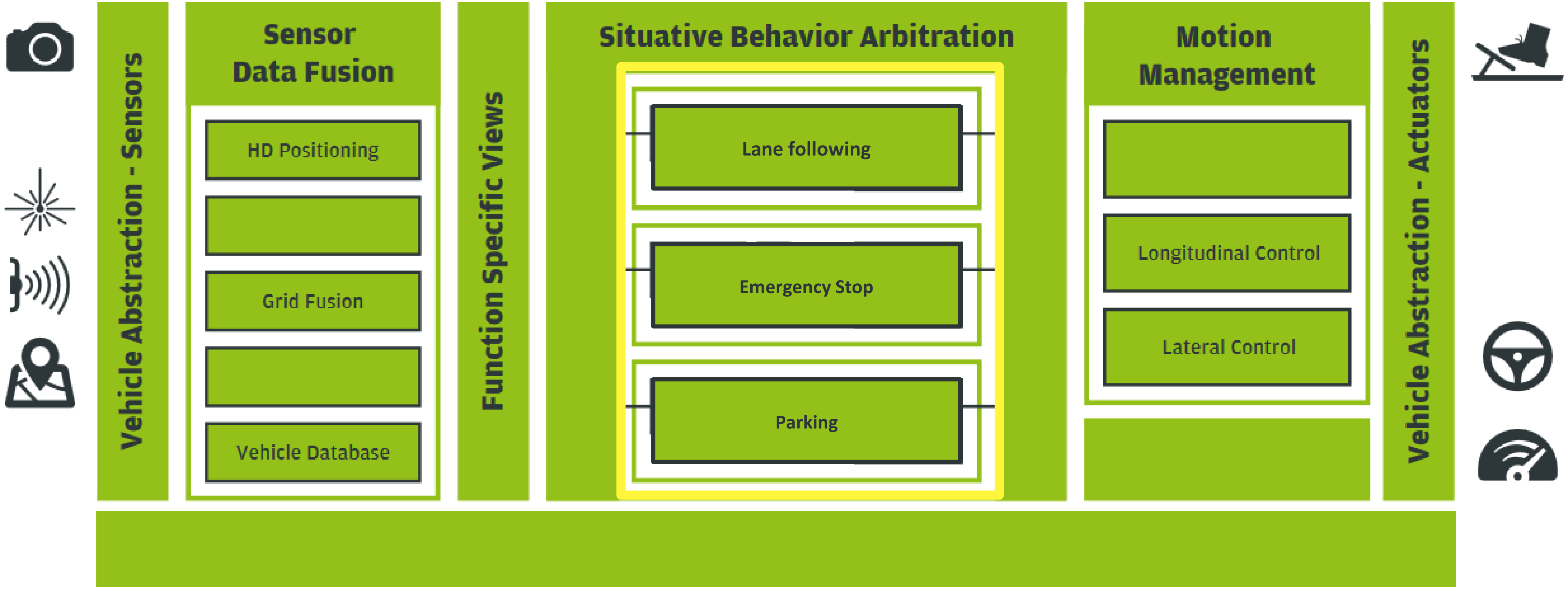
Simple AD demonstator at CES with EB Robinos Model Cars

- Grid fusion:
- Grid (matrix) cells
  - Absolute positions / areas (1 cm^2)
  - Values 0 → 255 (single Byte)

- Probabilistic interpretation
  - Three states: free, unknown, occupied
  - Inverse sensor models
  - Exponential averaging update function

Probabilistic interpretation

Simple AD demonstator at CES with EB Robinos Model Cars



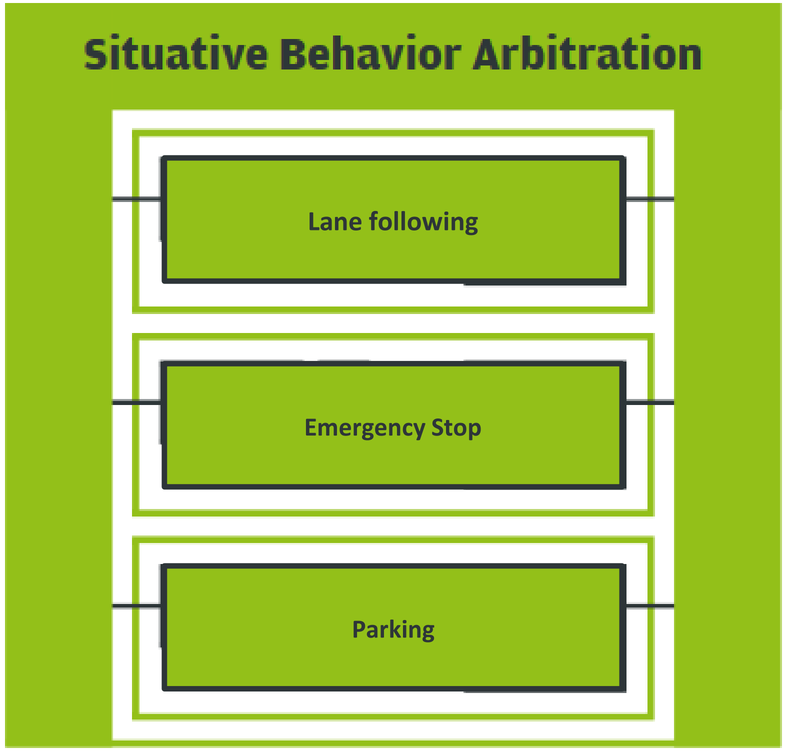
[1] Compare: EB robinos Specification, Elektrobit Automotive GmbH
https://www.elektrobit.com/products/eb-robinos/ , 12.02.2017

Simple AD demonstrator at CES with EB Robinos Model Cars

- Behavior planners:
  - Lane following
  - Emergency Stop
  - Parking

- Plan independently
- Desire value for speed and steering

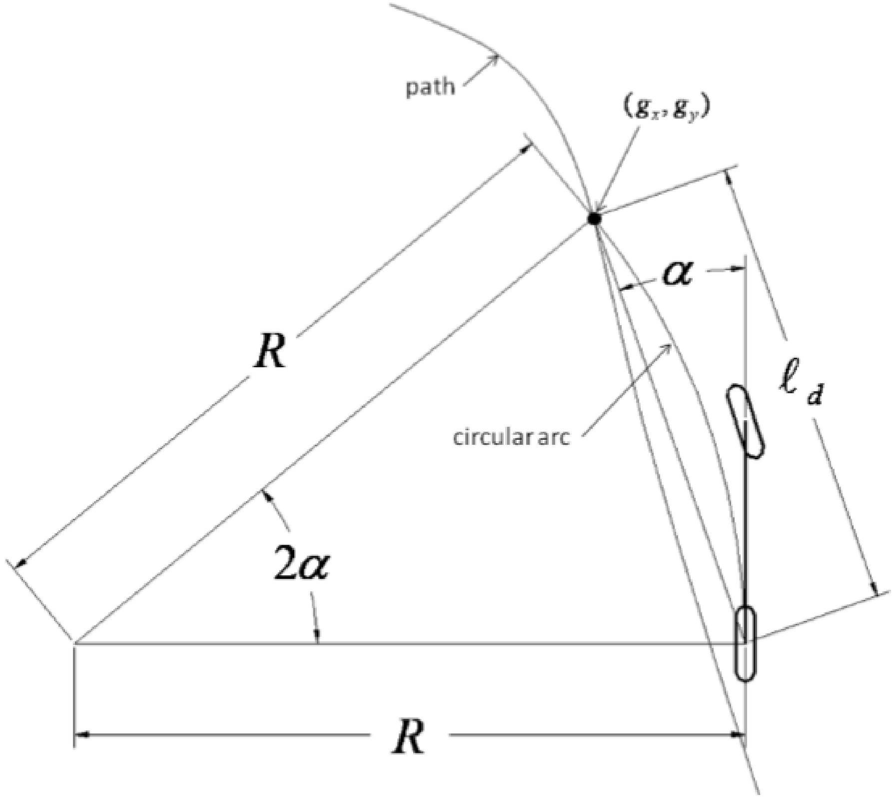
- Highest priority is selected



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

Simple AD demonstrator at CES with EB Robinos Model Cars

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



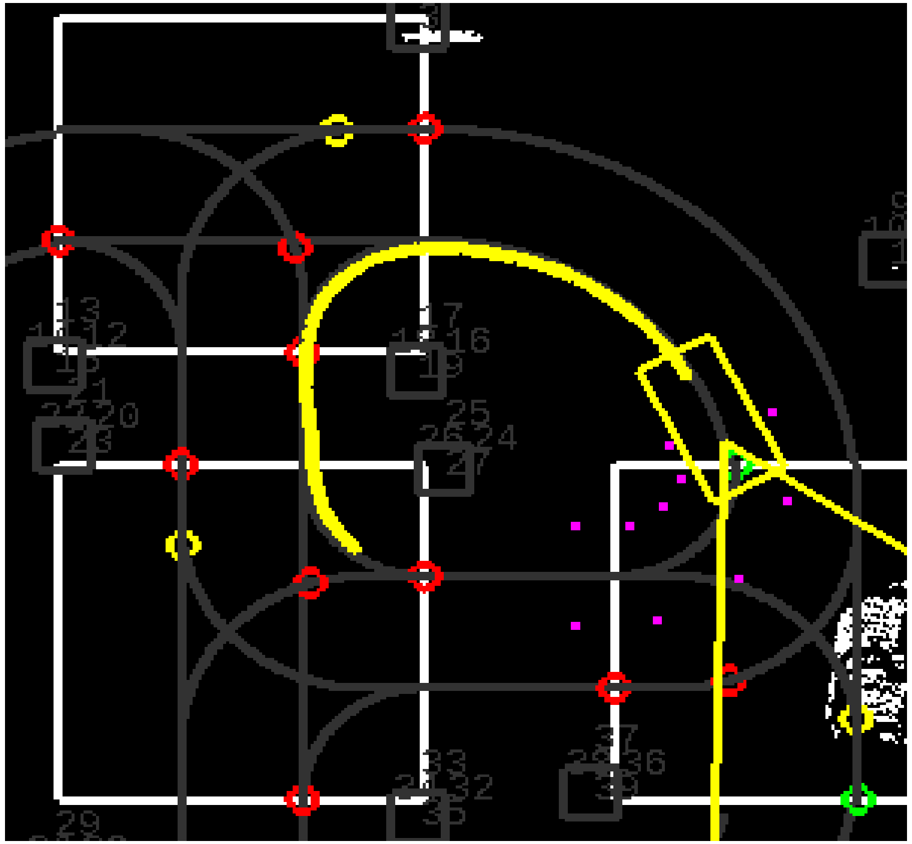
[2] Automatic Steering Methods for Autonomous Automobile Path Tracking,
Jarrod M. Snider, Robotics Institute Carnegie Mellon University Pittsburgh, Pennsylvania

Demonstrate AD at CES with EB Robinos Model Cars

- Vehicles path is predicted

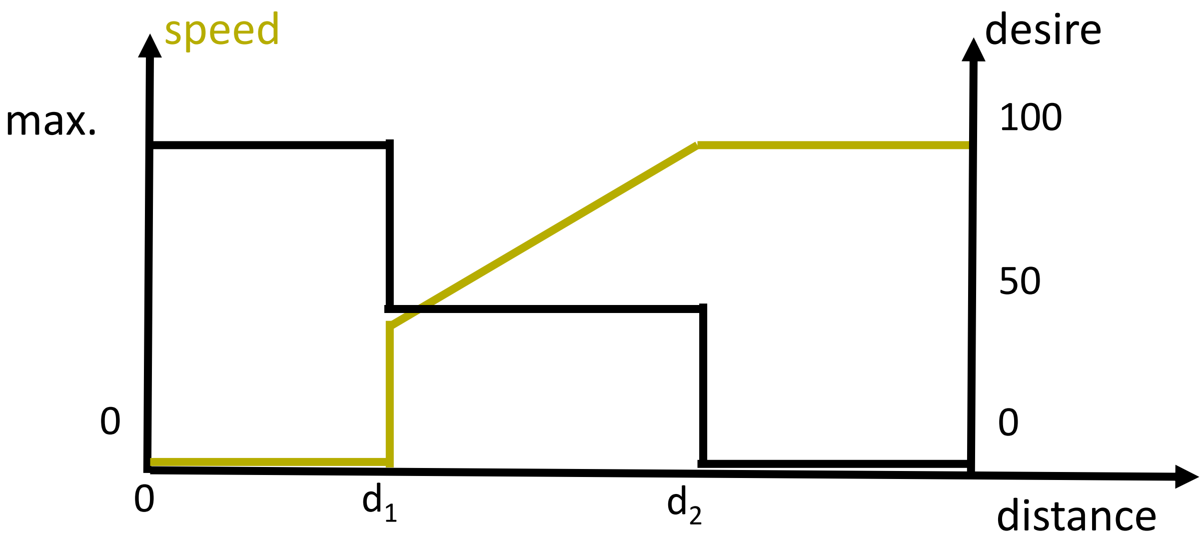
- Path is enlarged to car's dimension

  →Described by polygon



Demonstrate AD at CES with EB Robinos Model Cars

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



Speed, desire vs. distance

Demonstrate AD at CES with EB Robinos Model Cars

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

- **Applicability**: The ability of the function to operate, expressed in percent. E.g. a lane change assist that sees clear lane markings, road side boundaries, and convoy tracks, and an empty left lane, might set this to 100%; if it only sees convoy tracks and lane markings are unclear (e.g. in a construction site), it might set this to 30%; if the left lane is occupied, it will always set this to 0%.

- **Desire**: The desire of the function to operate, in percent. E.g. an adaptive cruise control function set to 130km/h on an empty highway might set this to 100%; if it finds itself behind a truck going 80km/h it might set this to 50%.

- **Risk**: A scalar, expressed in percent, giving an assessment of the risk involved when performing the behavior. A lane changing assistant that sees a perfectly clear left lane might set this to 20% (since visibility from the ego vehicle will always be obstructed), one that sees a slowly-approaching vehicle to the rear in the left lane might set this to 50%, one that sees a vehicle arriving with high difference velocity might set it to 90%.

- **Comfort**: A scalar, expressed in percent, giving an assessment of the comfort to the driver that performing a certain motion will entail; expected high lateral or longitudinal acceleration or deceleration will result in a low comfort level, gentle motions in a high one.

https://d23rjziej2pu9i.cloudfront.net/wp-content/uploads/2016/06/29073351/open_robinos_specification_1-0-1.pdf

Demonstrate AD at CES with EB Robinos Model Cars

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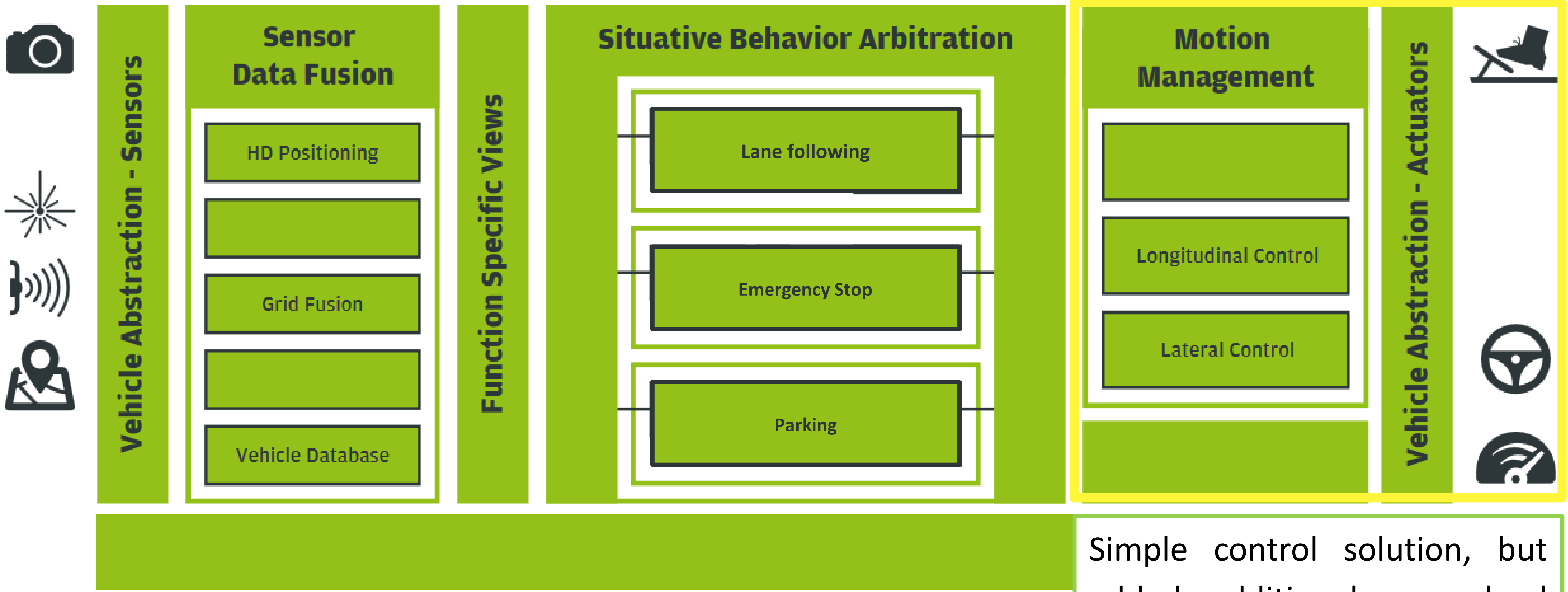
Demonstrate AD at CES with EB Robinos Model Cars

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

https://d23rjziej2pu9i.cloudfront.net/wp-content/uploads/2016/06/29073351/open_robinos_specification_1-0-1.pdf

Demonstrate AD at CES with EB Robinos Model Cars



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

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

Demonstrate AD at CES with EB Robinos Model Cars

- **Requirements:**
- 3 autonomous cars on the track
- 'Cool' CES Demo

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

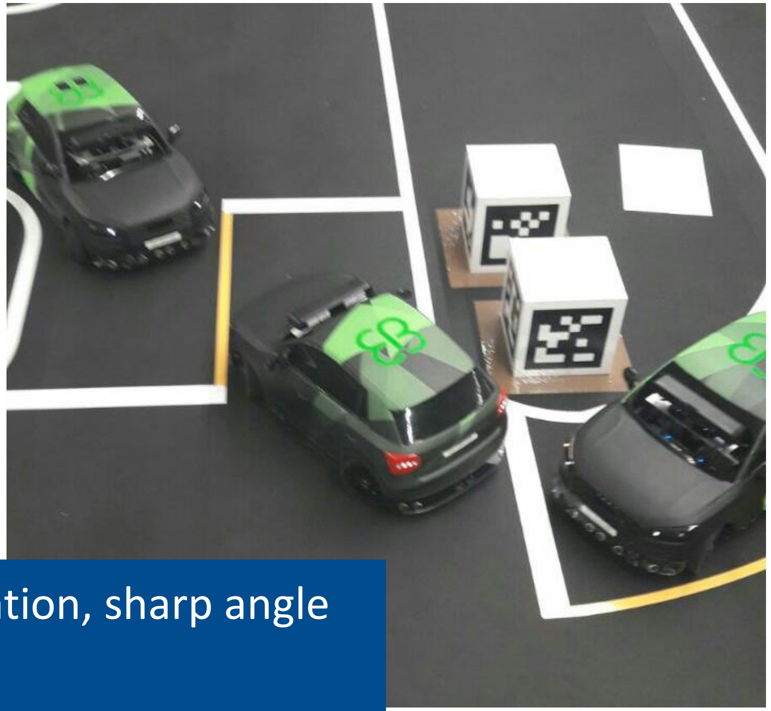
- **Result:**
- Requirements met, **expectations exceeded**. Very high number of visitors. ATZ featured..

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

Demonstrate AD at CES with EB Robinos Model Cars

Sharp Angle Blind Spot:

No detection from ultrasonic sensors.



Deadlock situation, sharp angle blind spot:
Increased occurrence due to complex car interaction

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


DTM

Piloted driving assists in traffc jams

Footage

Duration: 03:37 min

Motivation

Automated Driving for more comfort, safety and efficiency

Comfort

Safety

Efficiency

Quelle: Continental AG, Automotive Systems & Technology, 2014

Comfort

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

Future Predictions

Quelle: Continental AG, Automotive Systems & Technology, 2014

Short history of robot IKT

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

United States Patent Office

2,988,237

Patented June 13, 1961

1

2,988,237
PROGRAMMED ARTICLE TRANSFER
George C. Devol, Jr., Brookside Drive, Greenwich, Conn.
Filed Dec. 10, 1954, Ser. No. 474,574
28 Claims. (Cl. 214—11)

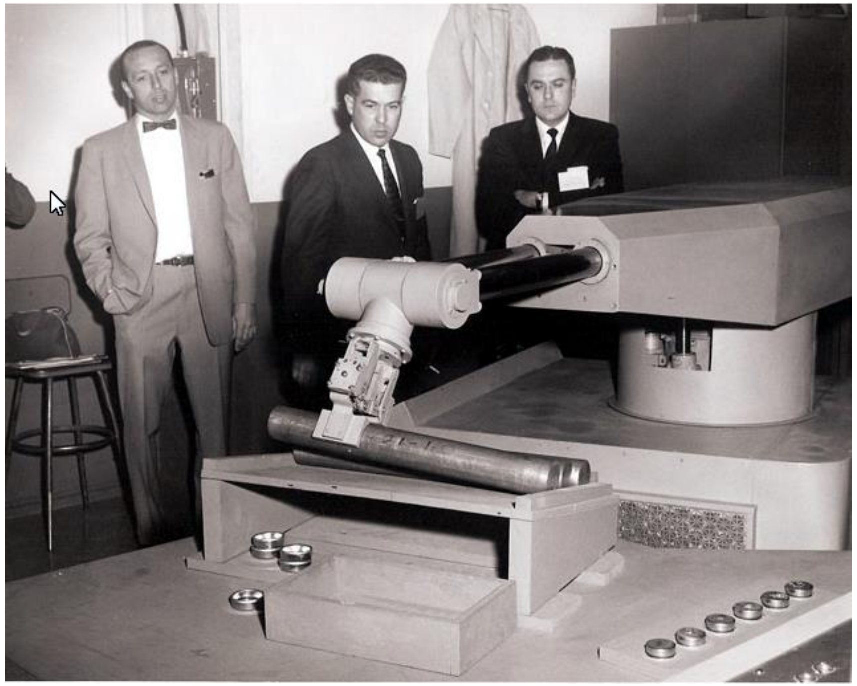
The present invention relates to the automatic operation of machinery, particularly to automatically operable materials handling apparatus, and to automatic control apparatus suitable for such machinery. The invention will also be seen to have certain related method aspects. In view of the main objective,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

2

not heretofore been met with flexible programming. The art of article transfer machines has been identified persistently over the years with motions produced by operating cams or, more recently, by limit switches that can accomplish certain few operations, yet nothing short of manual control or direct hand transfer has been devised to serve where real versatility is required.

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

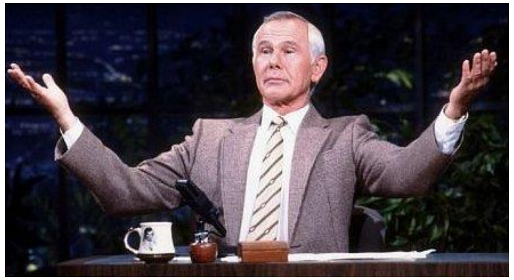
In applying one feature of this invention, for making



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

Short history of robot IKT

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



Johnny Carson: Tonight Show 1966

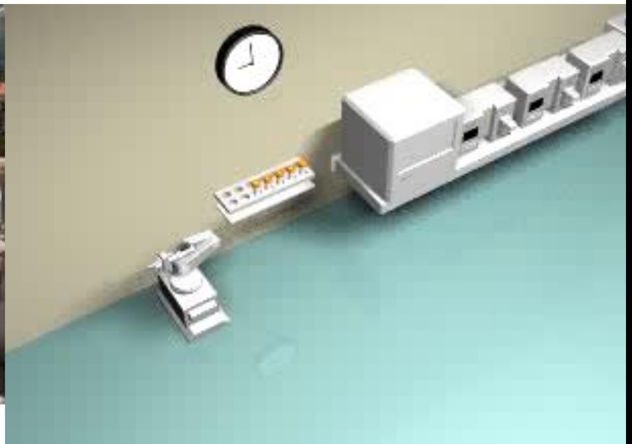
Short history of robot IKT

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

Short history of robot IKT (2000 to today…)

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

„Justin“, DLR, 2009

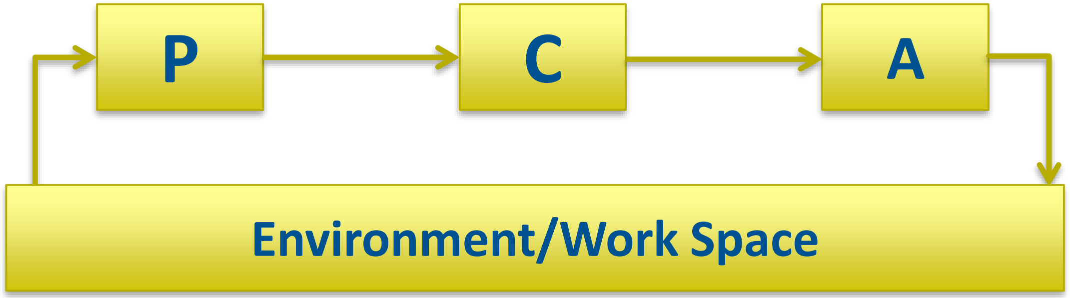


„Leonardo“, Uni Bielefeld, 2000/1

Biotech - Automation using Mobile Manipulation

In-between-summary

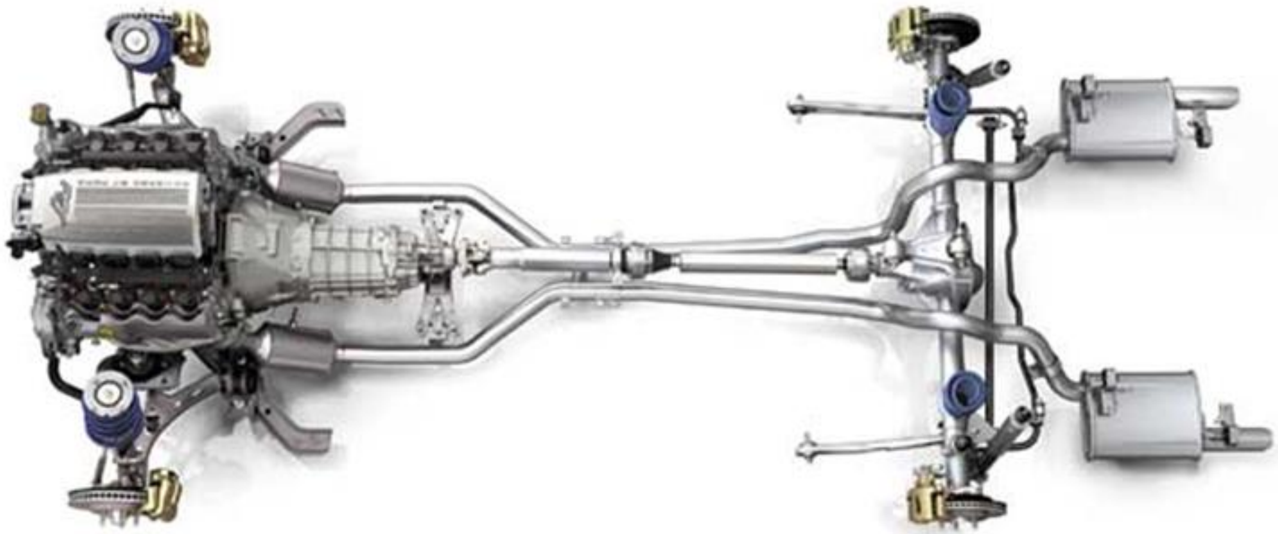
- Signature of robot architectures
  - Many sensors with different measurement principles
  - Real time reaction necessary, short reaction times
  - Various abstraction levels, direct reaction up to highlevel planning



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

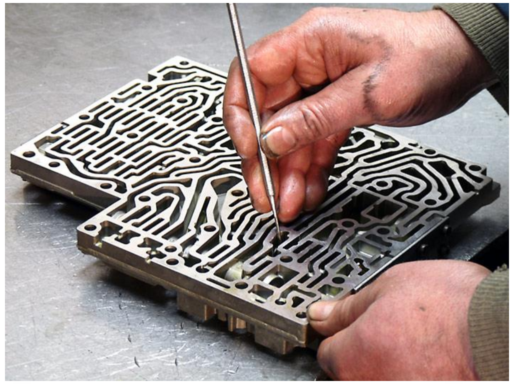
Short history of automotive IKT

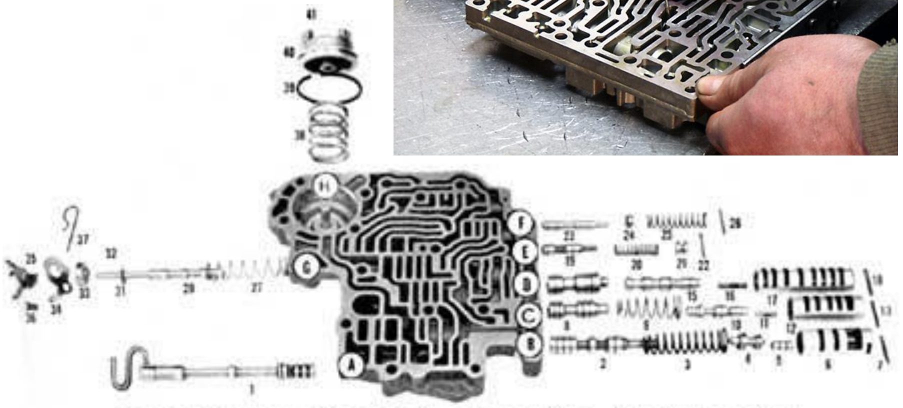
- Until 1990s no or minimala IKT in cars except for radio; control of energy flow by driver
- Three development directions:
  - **Control units** for automated gears & mechanical injection
  - **Electronic** gazoline injection
  - Anti-Blockier-System **ABS**



Short history of automotive IKT

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



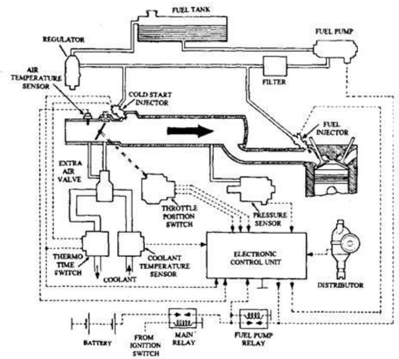


Exploded view of a valve body section. Another section containing additional valves is mated to it. On some units, a third section will contain electrical components.

Short history of automotive IKT

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

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

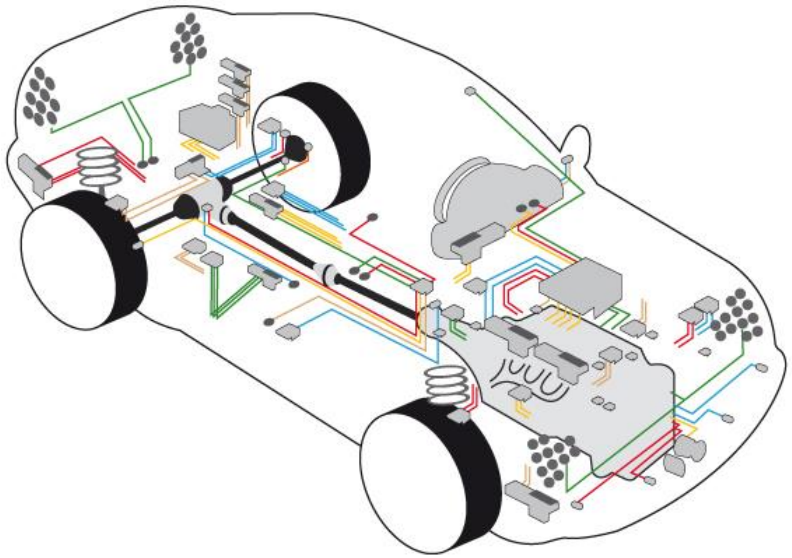


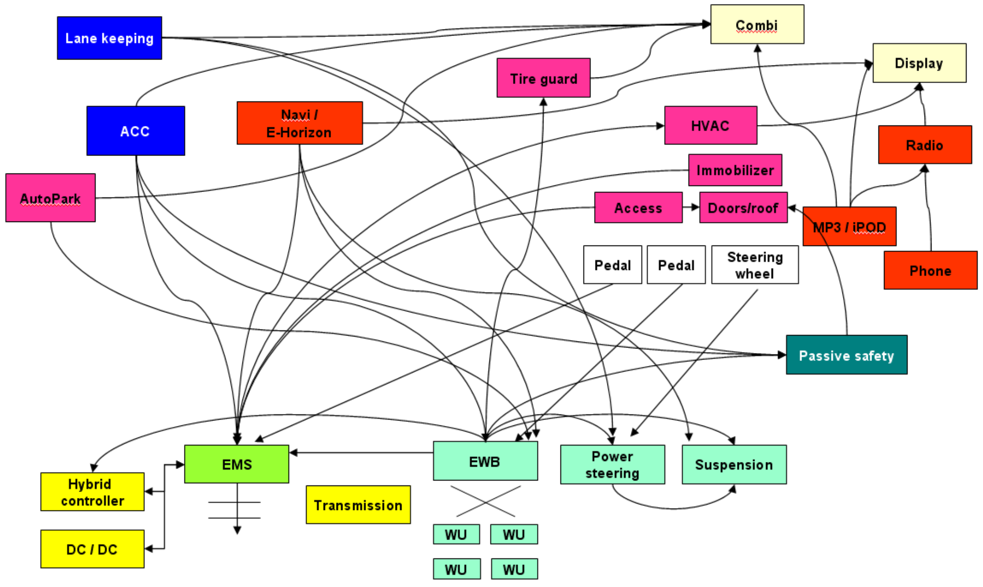
Short history of automotive IKT

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

Short history of automotive IKT

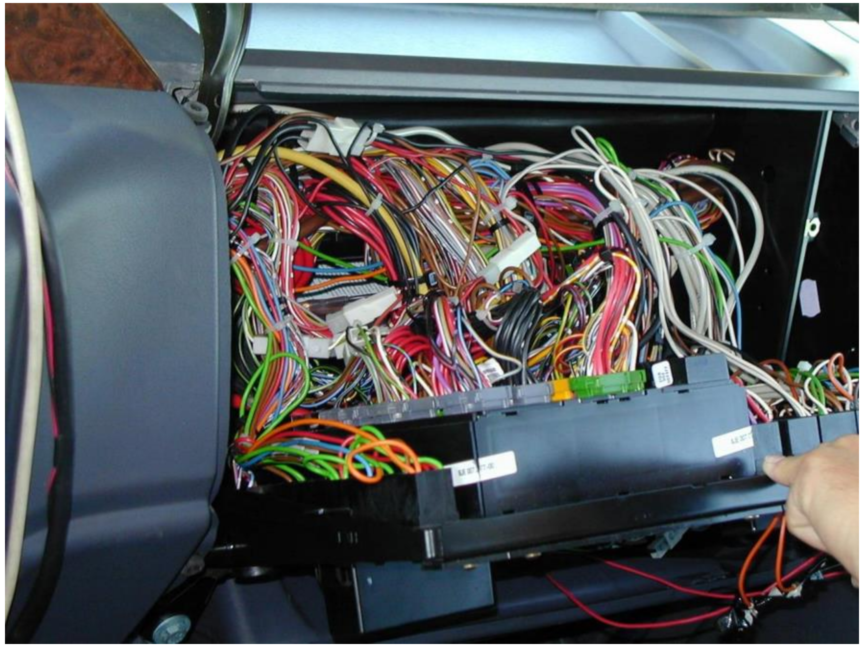
- Many functions distributed across a lot of different ECUs
- Highest communication and development complexity

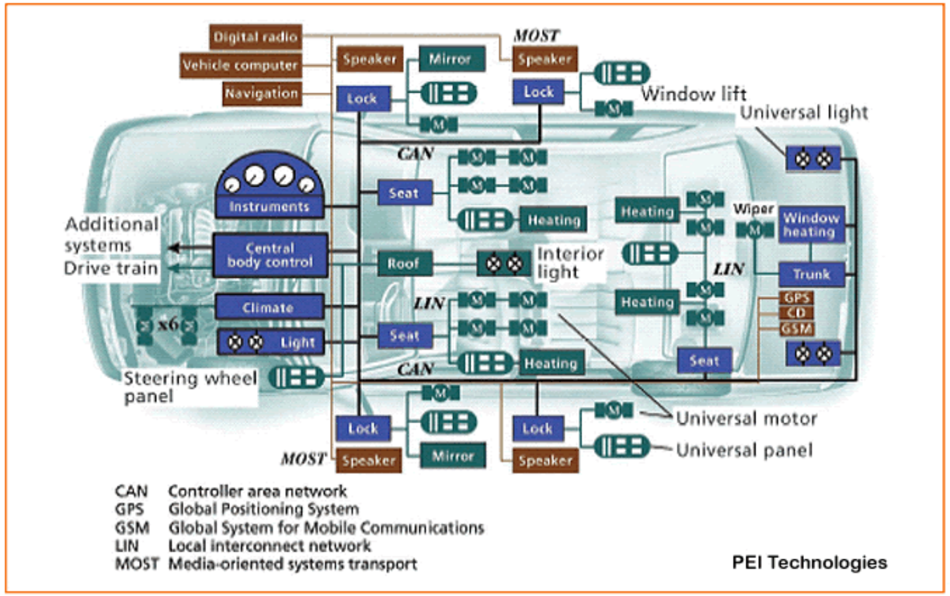




Data dependencies between all components;
Functions are spread across ECUs
(G. Spiegelberg, Siemens AG)

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





TV Commercial Audi 80 (1972)

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

In the Past ....

Industrial Robotics

- Robots are **steel arms** that do not change their location
- They can be **program-med** for complex routine operations
- They can **handle** objects and **mani-pulate** the environ-ment

Service Robotics

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

Passenger Cars

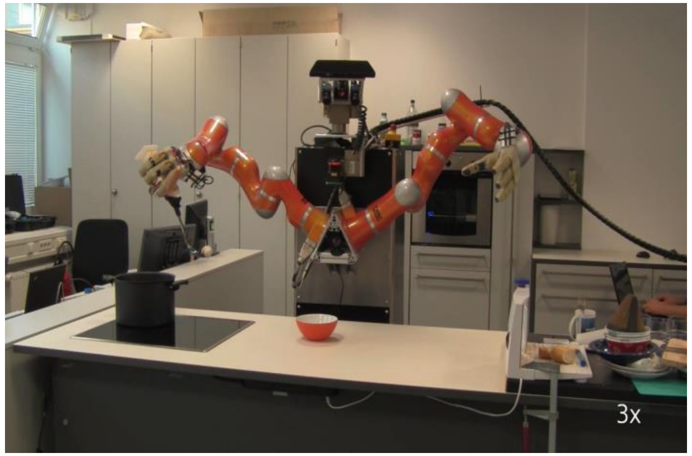
- Cars are **mobile** platforms that change their location
- They have a **simple user interface** and depend completely on human commands
- Their design implements a lot of engineering knowledge **in hardware**

… at Present …

Industrial Robotics

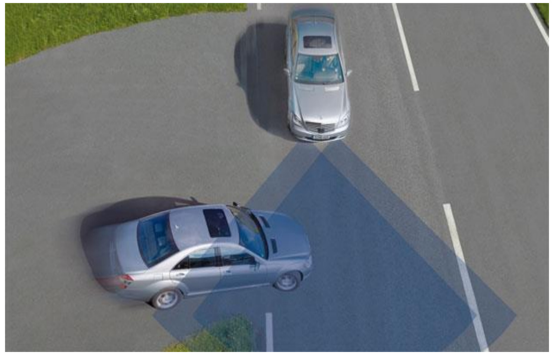
- Industrial robots are com-bined with mobility: **loco-motion and manipulation**
- They **are sensor based** and are becoming more and more autonomous
- They can perform **sequences of complex tasks**

Service Robotics



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

Passenger Cars



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

… in the Future

Industrial Robotics | **Service Robotics** | **Passenger Cars**

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

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