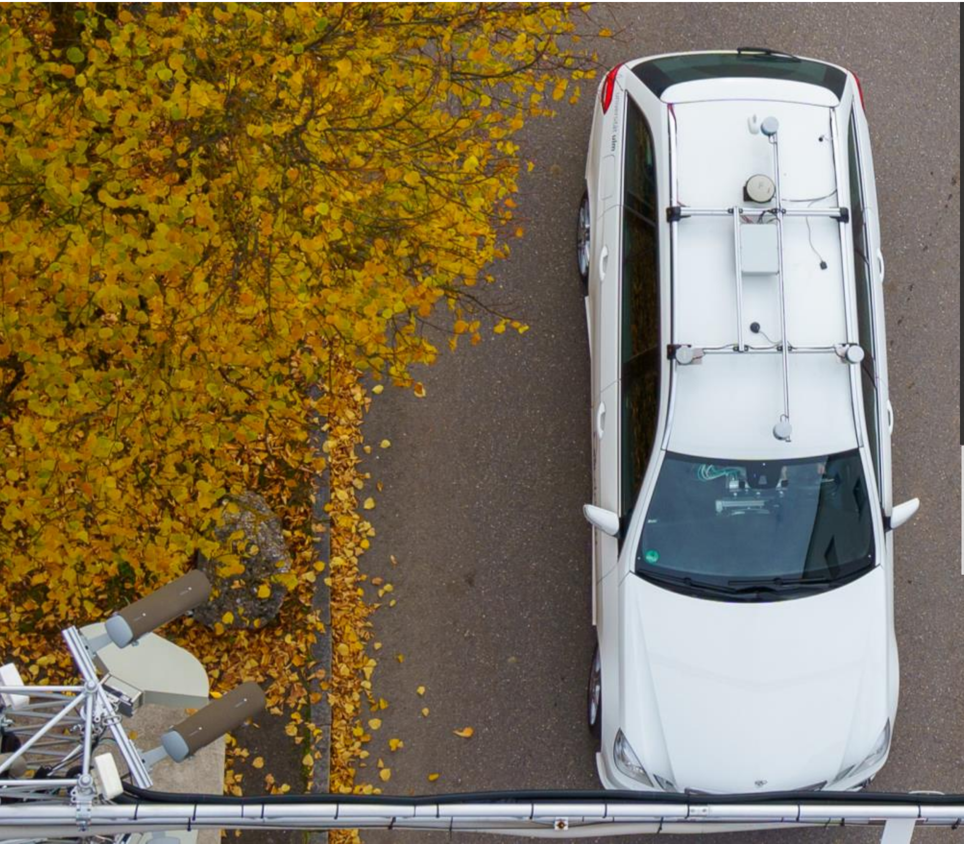
CCAM Supported by Intelligent Infrastructure

TECoSA Seminar
December 7th, 2023



Priv.-Doz. Dr.-Ing. Michael Buchholz
Institute of Measurement, Control and Microtechnology

How can intelligent infrastructure help automated vehicles?

- Exemplary driving task:
  Merge from side road on priority road
- Challenge:
  Buildings, vegetation, and/or other vehicles occlude the onboard sensors‘ field of view
- Goals:
  Increased safety, comfort, and efficiency

Video: https://www.youtube.com/watch?v=RFdIpi3buAg

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How can intelligent infrastructure help automated vehicles?

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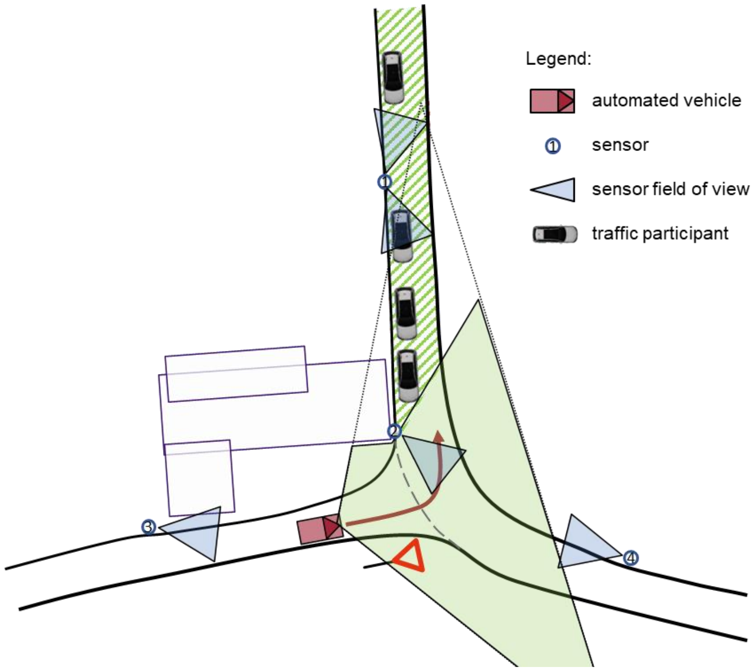
- Exemplary driving task:
  Merge from side road on priority road
- Challenge:
  Buildings, vegetation, and/or other vehicles occlude the onboard sensors‘ field of view
- Goals:
  Increased safety, comfort, and efficiency
- Solution:
  Environment model from infrastructure sensors makes occluded road users „visible“ to the connected automated vehicle



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Outline

- Background and System Architecture
- Infrastructure Environment Model with Prediction
- Reliability Estimation of External Data
- Motion Planning with External Data
- Cooperative Maneuvers
- Summary and Outlook

Project MEC-View

- Full title: “Mobile Edge Computing Based Object Detection for Highly and Fully Automated Driving“
- Funded by the German federal Ministry of Economic Affairs and Energy (BMWi) within the programme „Neue Fahrzeug- und Systemtechnologien“ (new vehicle and system technologies)
- Duration: 01.12.2016 – 31.05.2020
- Overall Budget: 11.7 M€, approx. 50% funding,
  MRM: 650 k€, 100% funding

Gefördert durch:

Bundesministerium
für Wirtschaft
und Energie

aufgrund eines Beschlusses
des Deutschen Bundestages

Project ICT4CART

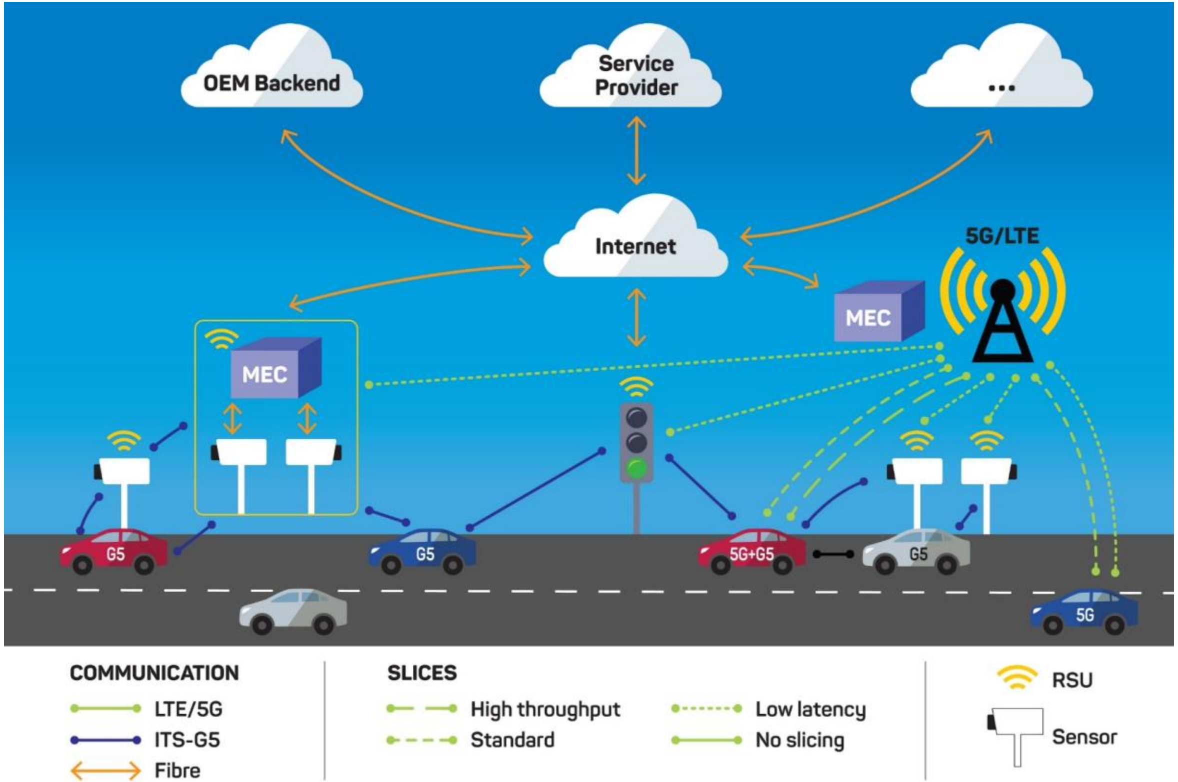
- Full title: “ICT Infrastructure for Connected and Automated Road Transport“
- Funded by the European Union’s Horizon 2020 research & innovation programme, call ART-01-07
- Duration: 01.09.2018 – 28.02.2022
- Overall budget: 10.7 M€,
  MRM: 600 k€, 100% funding
- Website: www.ict4cart.eu

ICT4CART project has received funding from the European Union’s Horizon 2020 research & innovation programme under grant agreement No. 768953. Content reflects only the authors’ view and European Commission is not responsible for any use that may be made of the information it contains

OUR PARTNERS

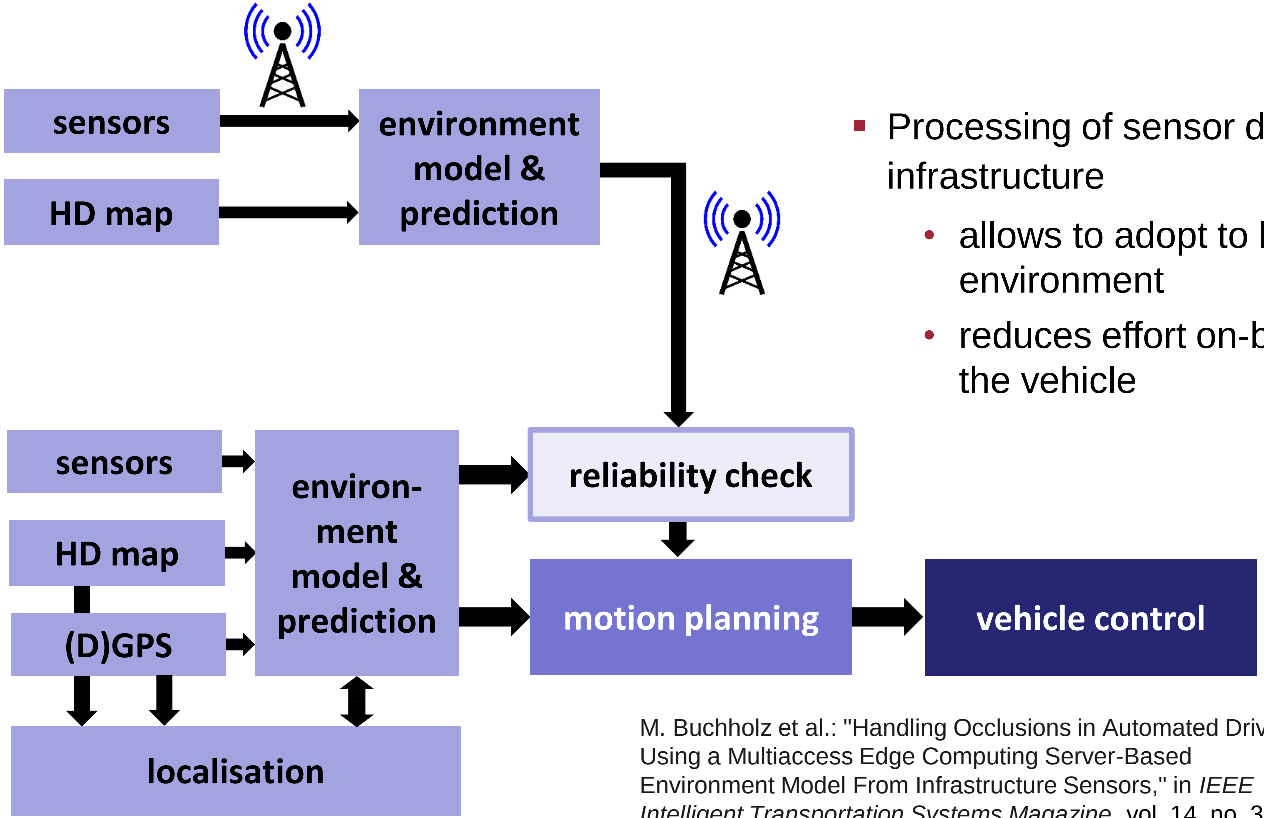
High-level System Architecture

- Hybrid connectivity with ad-hoc (ITS-G5/DSRC) and cellular (LTE/5G) mobile network
- Multi-access Edge Computing (MEC) capabilities in infrastructure (road side unit (RSU) or close to base station) for latency critical tasks



Buchholz, M. et al.: “Enabling Automated Driving by ICT Infrastructure: A Reference Architecture”. In: *8th Transportation Research Arena (TRA) 2020 (conf. cancelled)*, 2020. Online available: https://oparu.uni-ulm.de/xmlui/handle/123456789/26086

More Detailed System Architecture



- Processing of sensor data in infrastructure
  - allows to adopt to local environment
  - reduces effort on-board the vehicle

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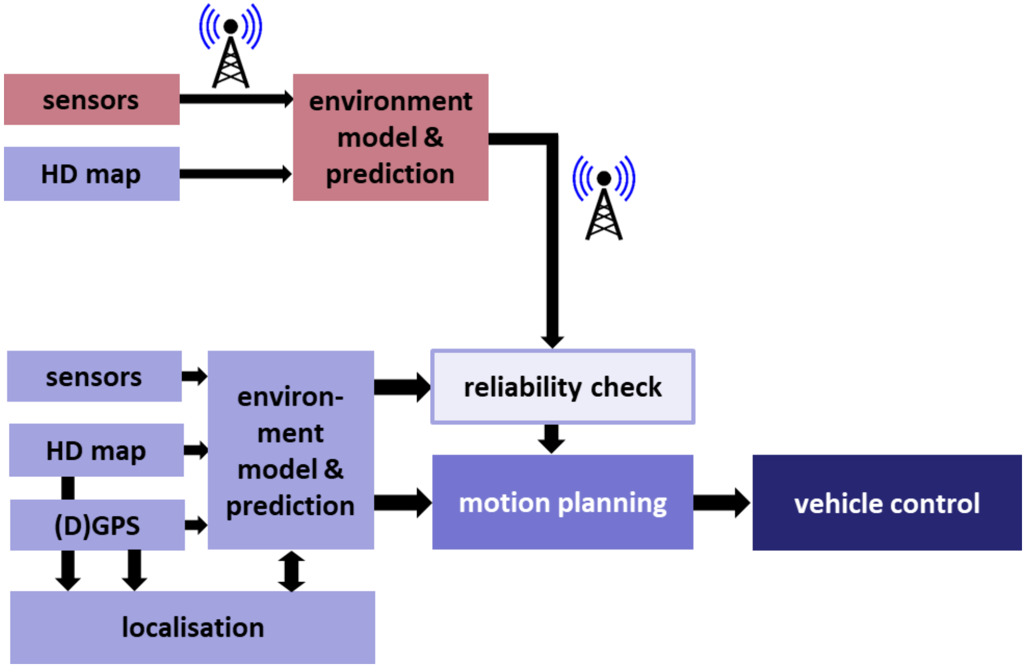
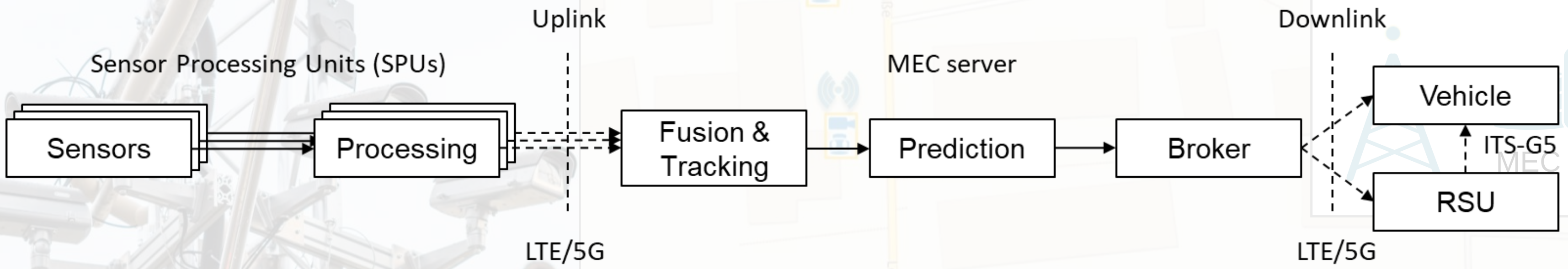


Infrastructure Environment Model with Prediction
Camera-based Object Detection

- A neural network detects the shape of road users and their direction of movement.
- Positions are estimated using a ground plane calibration.
- The most accurate side estimate (length or width) is send together with its position based on object reference points.
- Views from different perspectives allow the estimation of missing information in the following fusion and tracking step.

Video: https://www.youtube.com/watch?v=RFdIpi3buAg

Infrastructure Environment Model with Prediction Fusion and Tracking on MEC server



- We developed and implemented a generic sensor interface allowing for cheap and simple sensors.
- The resulting environment model is predicted for the next few seconds including uncertainty information using a neural network.
- Hybrid communication of the environment model is realized via an RSU acting as ITS-G5 relay at the junction.

Video: https://www.youtube.com/watch?v=RFdIpi3buAg

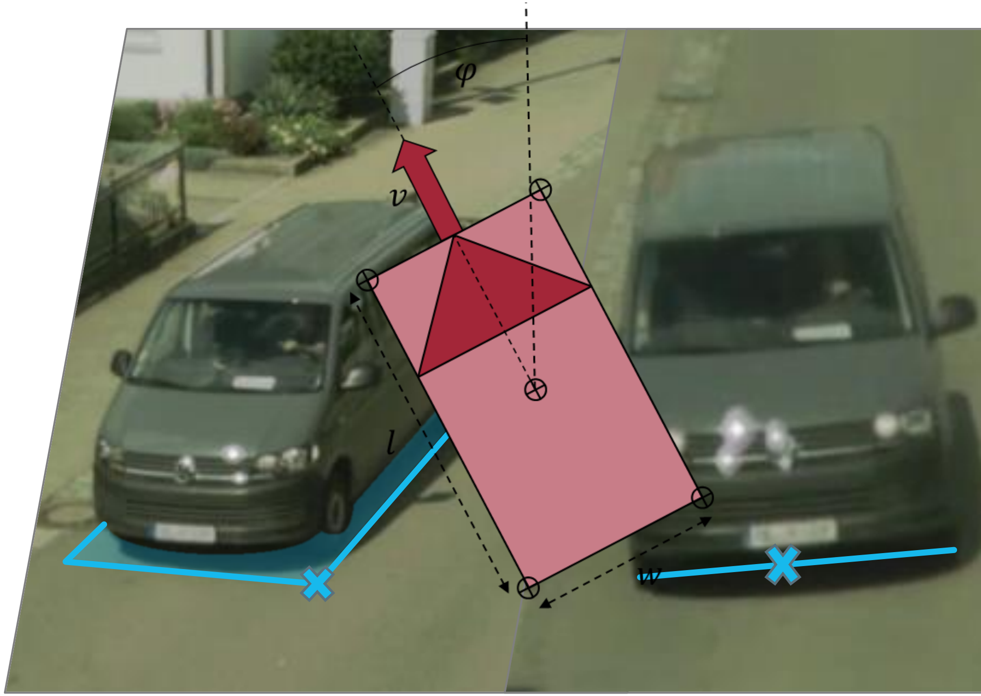
Infrastructure Environment Model with Prediction Fusion and Tracking on MEC server

- State-of-the-art multi-sensor multi-object Labeled Multi-Bernoulli (LMB) filter [1] for object tracking and data fusion
- Specific challenges and goals:
  - Limited bandwidth between distributed sensors and central fusion stage
    → no transfer of raw data
  - Cheap and simple sensors of different types should be possible
  - Limited object detection due to sensor type, position, and perspective

[1] S. Reuter, B. Vo, B. Vo and K. Dietmayer, “The labeled multi-bernoulli filter”, *IEEE Transactions on Signal Processing*, vol. 62, no. 12, pp. 3246 – 3260, 2014.

Infrastructure Environment Model with Prediction
Generic Sensor Interface

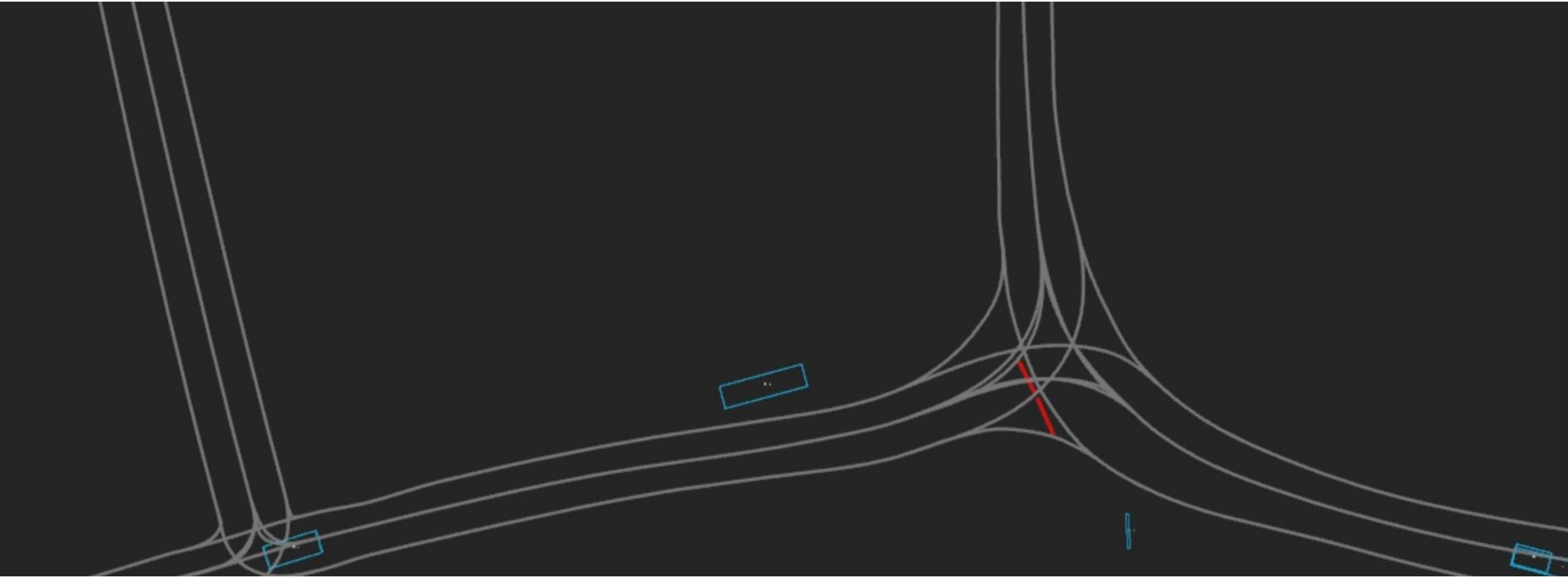
- Introduction of “object reference points”
- Sensors only need to transmit the position of one arbitrary object reference point and the time index, all other features (width, length, speed, …) are optional
- Missing dimensions are inferred from different sensor perspectives



M. Herrmann, J. Müller, J. Strohbeck and M. Buchholz, "Environment Modeling Based on Generic Infrastructure Sensor Interfaces Using a Centralized Labeled-Multi-Bernoulli Filter," *2019 IEEE Intelligent Transportation Systems Conference (ITSC)*, Auckland, New Zealand, 2019, pp. 2414-2420.

M. Herrmann, A. Piroli, J. Strohbeck, J. Müller and M. Buchholz, "LMB Filter Based Tracking Allowing for Multiple Hypotheses in Object Reference Point Association," *2020 IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI)*, Karlsruhe, Germany, 2020, pp. 197-203.

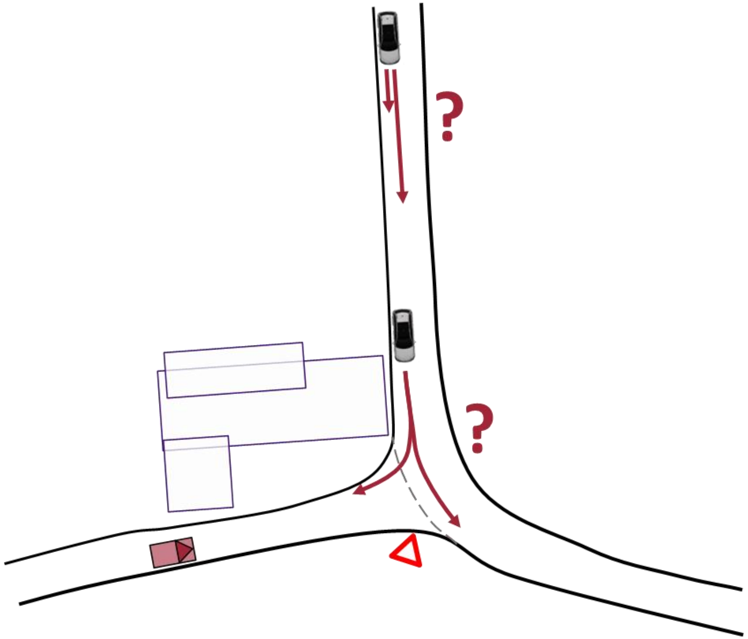
Infrastructure Environment Model with Prediction
Generic Sensor Interface



Video: https://www.youtube.com/watch?v=RFdIpi3buAg

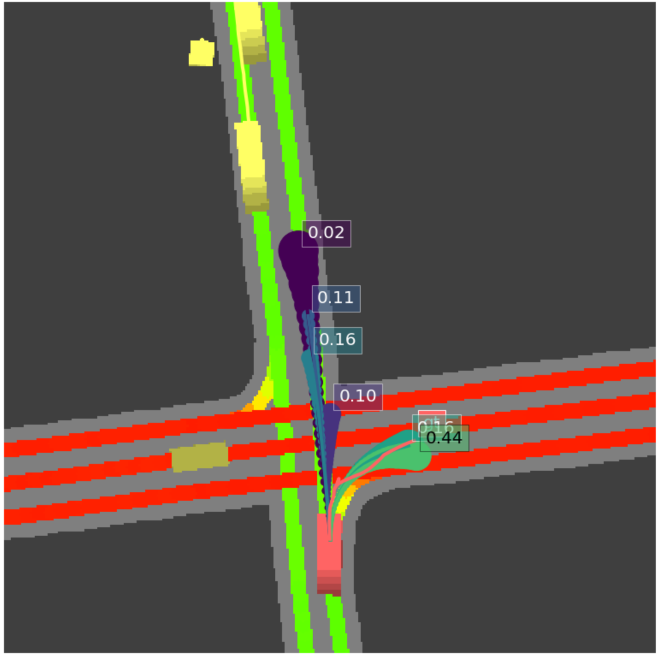
Infrastructure Environment Model with Prediction
Object Prediction

- Goals:
  - Predict the possible movement of all vehicles to account for communication and processing latencies and allow for predictive planning
  - Account for uncertainties from environment model
  - Include different possible trajectories with probabilities



Infrastructure Environment Model with Prediction
Object Prediction

- Approach using neural networks based on [2]
- Improved by processing uncertainties from environment model
- Additional use of past trajectory as further input
- Multi-task learning to cover additional predicted vehicle state dimensions, namely velocities, accelerations, orientation, and yaw rate
- Additional uncertainty in predicted trajectory

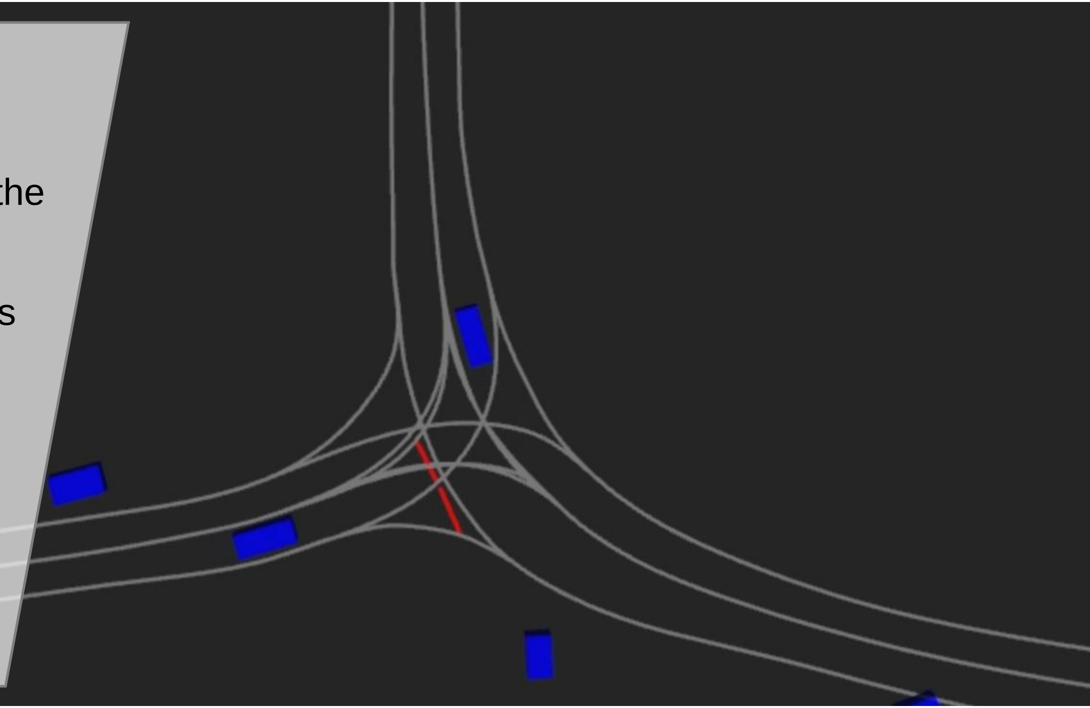


[2] H. Cui, V. Radosavljevic, F. Chou, T. Lin, T. Nguyen, T. Huang, J. Schneider, and N. Djuric, “Multimodal trajectory predictions for autonomous driving using deep convolutional networks,” *2019 International Conference on Robotics and Automation (ICRA)*, May 2019, pp. 2090–2096.

J. Strohbeck, V. Belagiannis, J. Müller, M. Schreiber, M. Herrmann, D. Wolf and M. Buchholz, "Multiple Trajectory Prediction with Deep Temporal and Spatial Convolutional Neural Networks," *2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2020)*, LV, 2020, pp. 1992-1998.

Infrastructure Environment Model with Prediction
Object Prediction

- Neural network trained on 320 hours of diverse recorded traffic situations
- Predicts how each road user will move in the next three seconds
- Generates six possible hypothesized paths per road user, each with an occurrence probability and uncertainty information
- Won the first prize in the 2019 Argoverse Motion Forecasting Challenge



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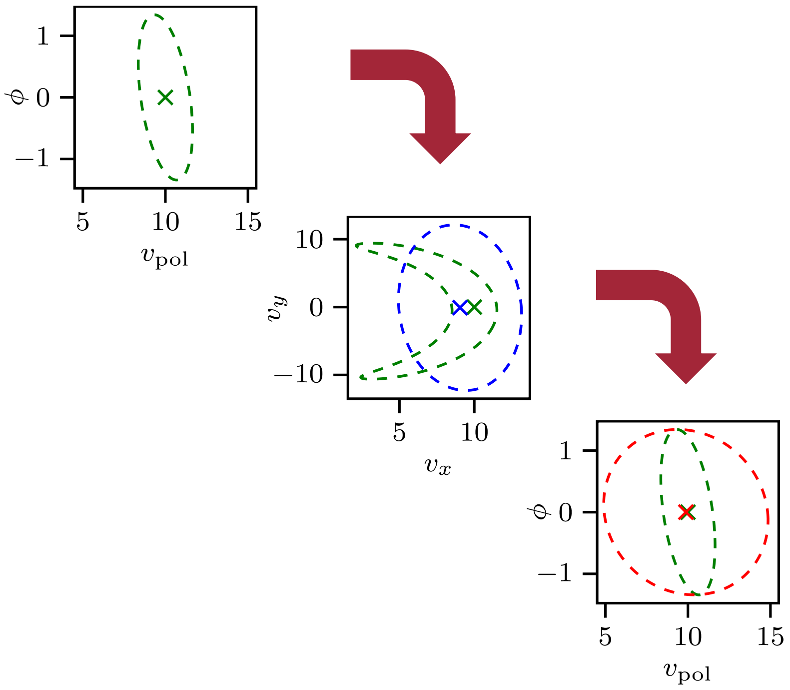
Infrastructure Environment Model with Prediction
Standardization of Collective Perception Message

- European Telecommunications Standards Institute (ETSI) defines the “Collective Perception Service” (CPS) together with the “Collective Perception Message” (CPM)
- Our practical experience has shown some limitations of the current CPM version
- Input to the ETSI working group on CPM with respect to
  - Full covariance matrices
  - Polar coordinate systems
  - Optional integration of predictions



J. Strohbeck, M. Herrmann, J. Müller, and M. Buchholz, "An Extension Proposal for the Collective Perception Service to Avoid Transformation Errors and Include Object Predictions," *2021 IEEE Vehicular Networking Conference (VNC 2021)*, pp. 40-43, 2021.

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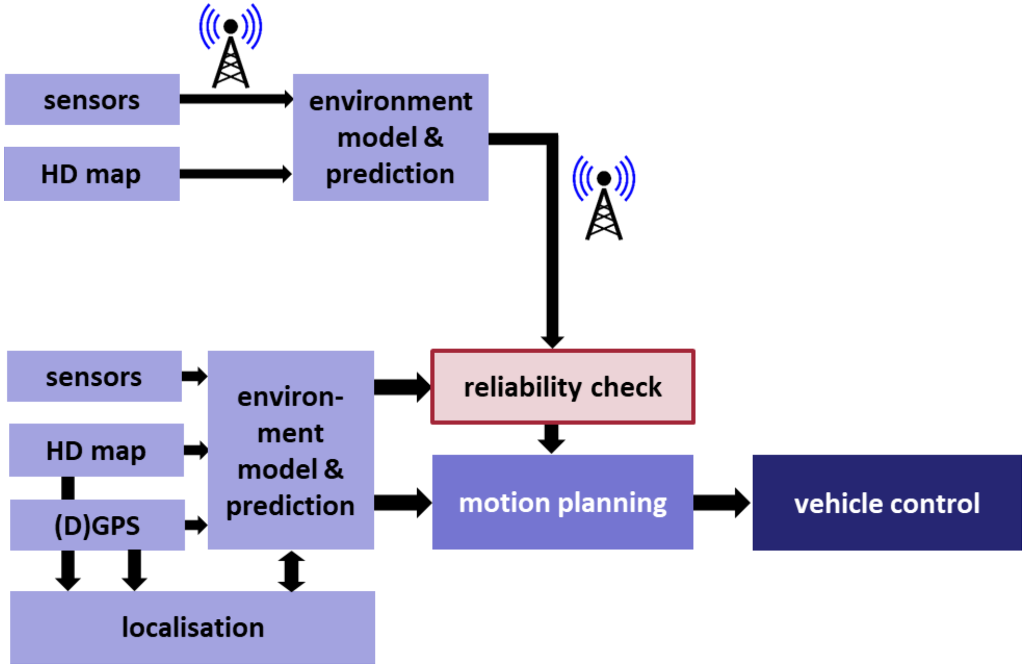
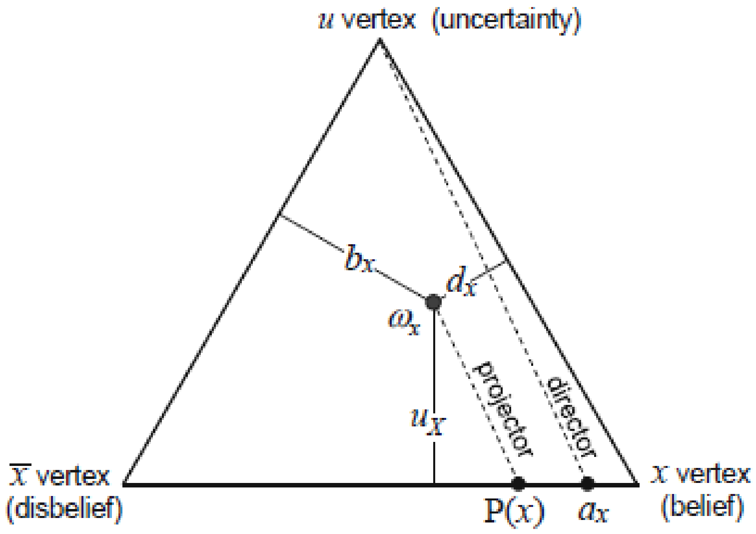


Reliability Estimation of External Data
Subjective Logic

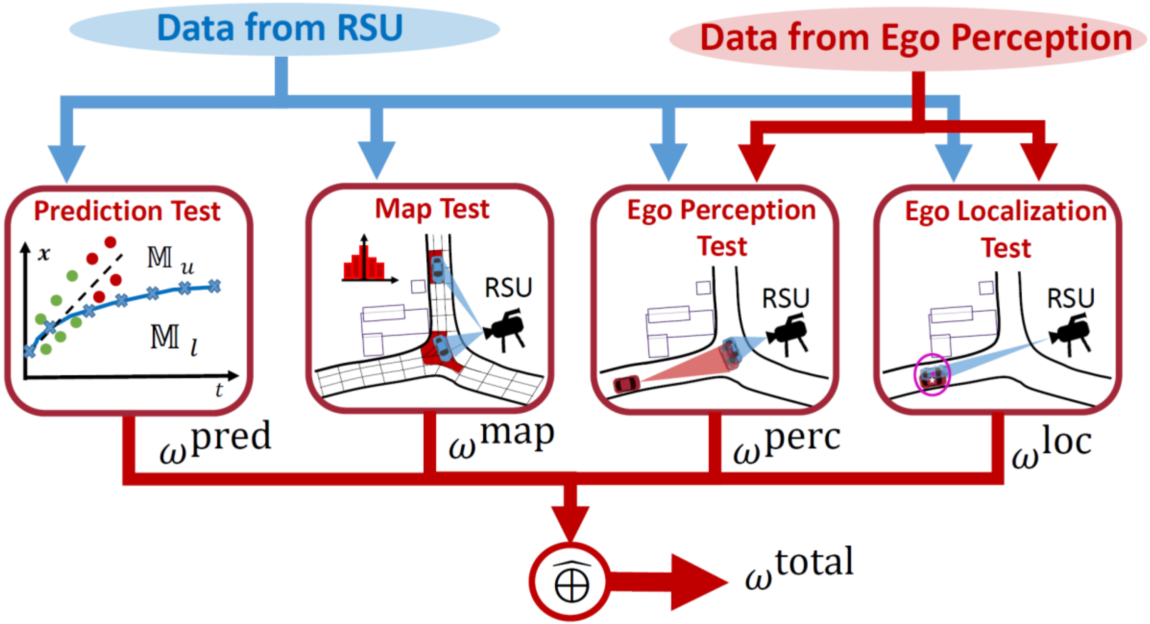
- Very limited number of samples to decide on reliability → classical statistic tests fail, use of Subjective Logic (SL) [3]
- SL allows representation of statistical uncertainty and uses a prior distribution to project on a classical probability
- SL comes with different operators to handle, e.g., statistically dependent or independent data, contradicting data, or growing uncertainty for older samples



[3] Jøsang, A., *Subjective Logic*, Springer International Publishing, 2016.

Reliability Estimation of External Data
SL-based Reliability Tests

- Prediction test: Do objects behave similar to their previously reported predictions?
- Map test: Are reported objects on driveable areas?
- Ego perception test: Do objects in joint field of view match?
- Ego localization test: Is the ego vehicle itself reported correctly?



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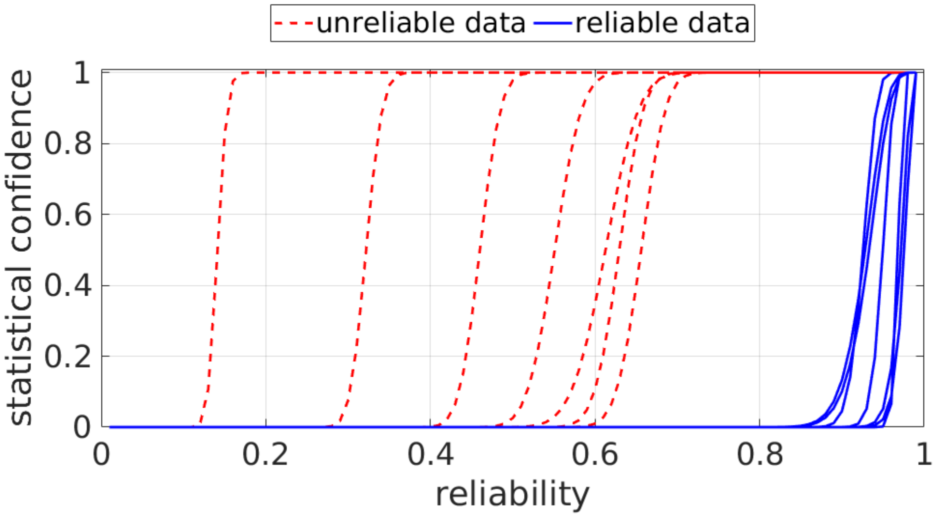
J. Müller, M. Gabb and M. Buchholz: “A Subjective-Logic-based Reliability Estimation Mechanism for Cooperative Information with Application to IV’s Safety“. In: *2019 IEEE Intelligent Vehicles Symposium (IV) (IV2019)*, pp. 1940-1946, 2019. DOI: 10.1109/IVS.2019.8814153.

Reliability Estimation of External Data
SL-based Reliability Tests

- Results from pilot site using only selected sensors to provoke unreliable data
- Reliability test yields second order probability (probability that reliability is at least x%)
- Scenarios have been manually labelled
- No unreliable sequence has a reliability above 70% with almost certain confidence
- All reliable sequences receive at least 90% confidences for at least 90% reliability



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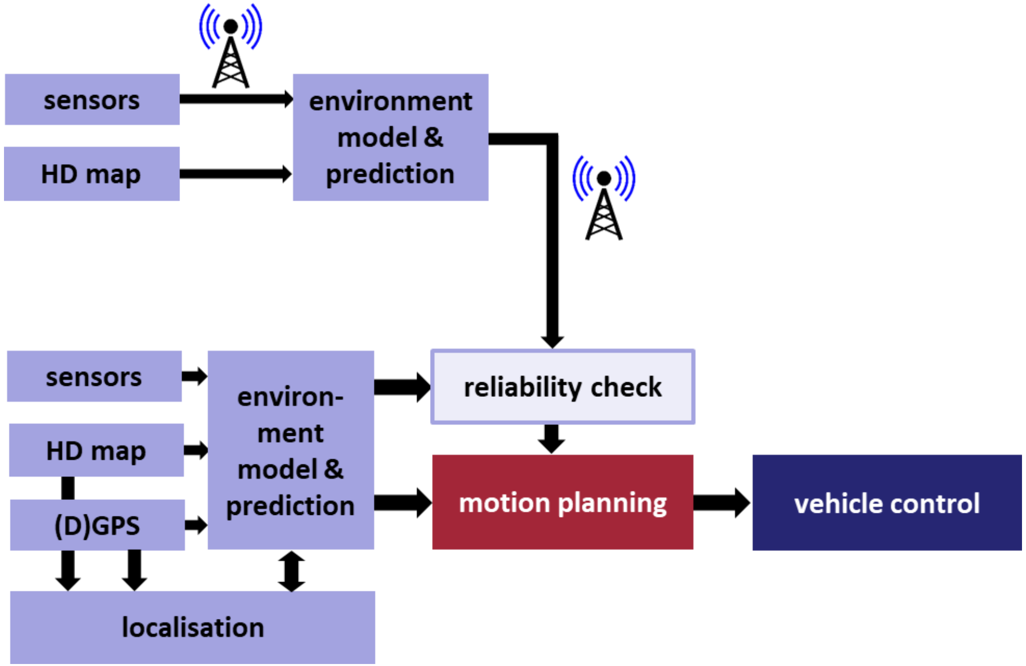
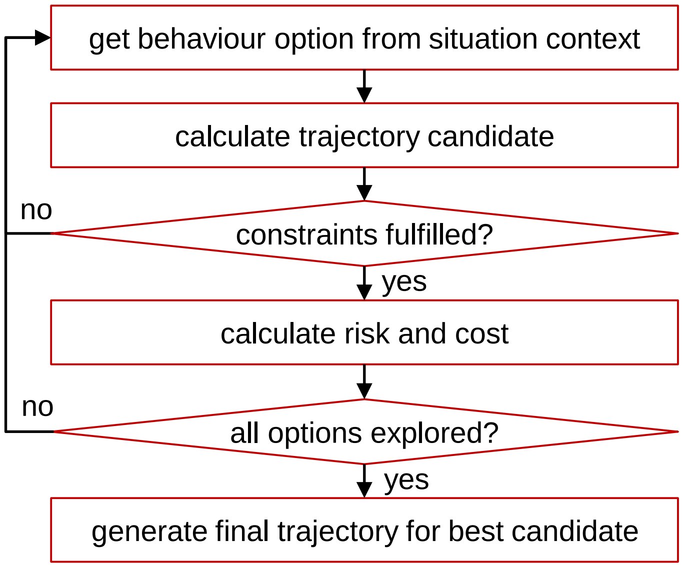


Motion Planning with External Data
Concept Overview

- Retrieve behaviour options from situation context
- Calculation of a time-weighted jerk optimal longitudinal trajectory candidate per behaviour option via analytic solution of an optimal control problem
- Check constraints along longitudinal trajectory using the external and internal environment model, and, if valid, calculate residual risk and cost
- Select best option and generate final trajectory including lateral stabilisation via numerical optimization



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J. Müller, J. Strohbeck, M. Herrmann and M. Buchholz: “Motion Planning for Connected Automated Vehicles at Occluded Intersections With Infrastructure Sensors”. Accepted for publication in *IEEE Transactions on Intelligent Transportation Systems*, DOI: 10.1109/TITS.2022.3152628 (early access).

Motion Planning with External Data Properties

- Generalization by formal context representation
- Computational efficiency
  - Priority classes for behavior options reduce average search space
  - Analytical solution for trajectory generation
- Safety
  - Residual risk is guaranteed to be below arbitrary bound
  - No interference of fail-safe option with normal driving due to priority classes

J. Müller and M. Buchholz, “Subjective logic reasoning: an urn model intuition and application to connected automated driving”, *at – Automatisierungstechnik*, vol. 69, no. 2, pp. 111-121, 2021. DOI: 10.1515/auto-2020-0097.

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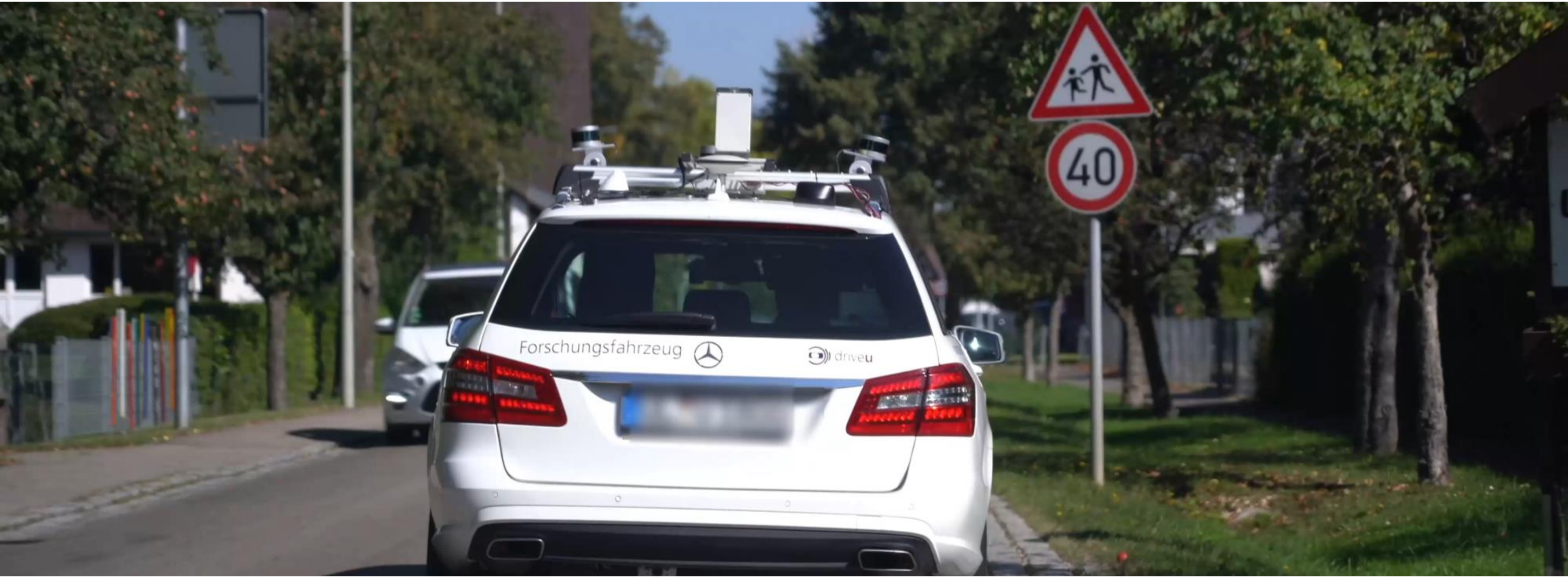
Motion Planning with External Data
Results



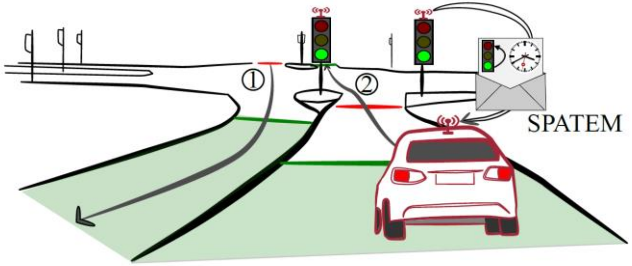
Video: https://www.youtube.com/watch?v=RFdIpi3buAg

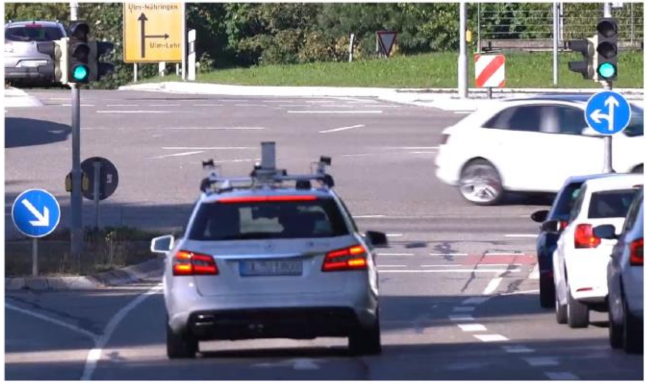
Motion Planning with External Data
Results

Video: https://www.youtube.com/watch?v=RFdIpi3buAg

Motion Planning with External Data
Connected Traffic Lights

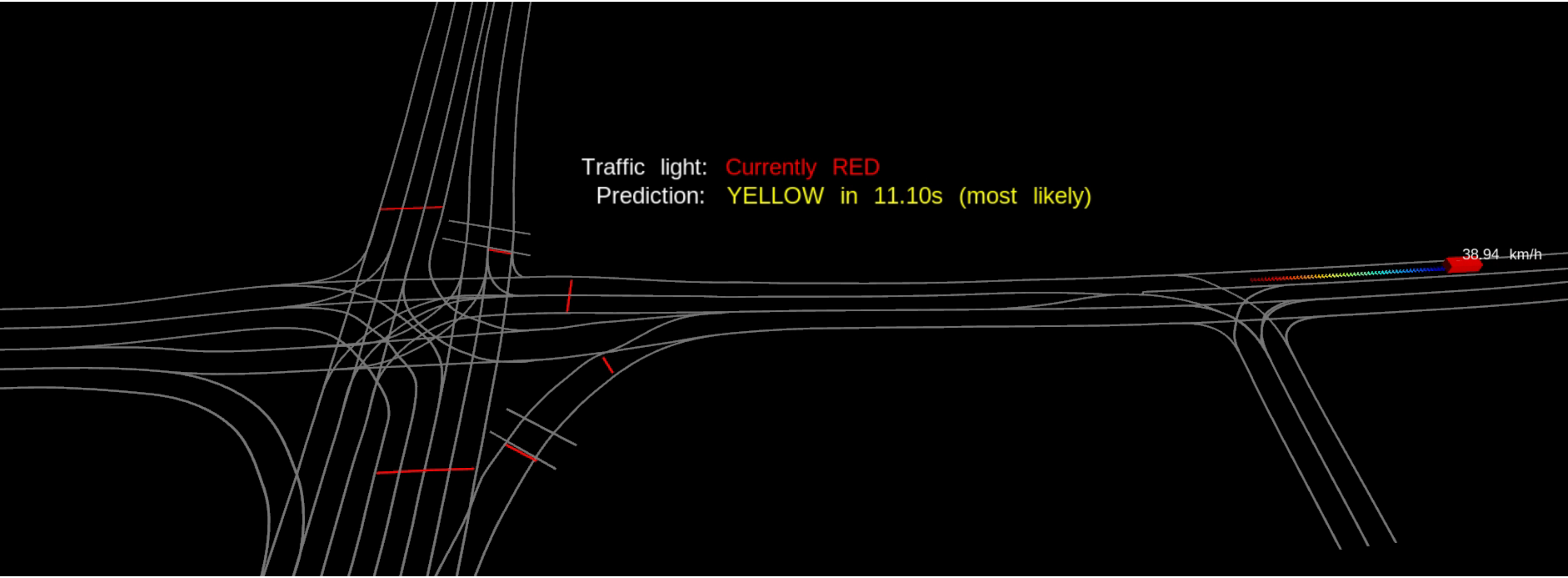
- Driving task
  - Cross the signalized intersection
- Challenge
  - Maximize comfort, efficiency and safety
- Solution
  - Use signal phase and timing data with predictions supplied by connected traffic lights
  - Use RSU for hybrid connectivity via ITS-G5 and LTE/5G





Müller, J.; Strohbeck, J.; Mertens, M. and Buchholz, M.: “Kontextbasierte Bewegungsplanung automatisierter Fahrzeuge an Kreuzungen mit vernetzten Lichtsignalanlagen.” In: 14. Uni-DAS e.V. Workshop Fahrerassistenz und automatisiertes Fahren (FAS 2022), pp. 11-20, 2022. DOI: https://doi.org/10.18725/OPARU-43451.

Motion Planning with External Data
Connected Traffic Lights: Simulation Results



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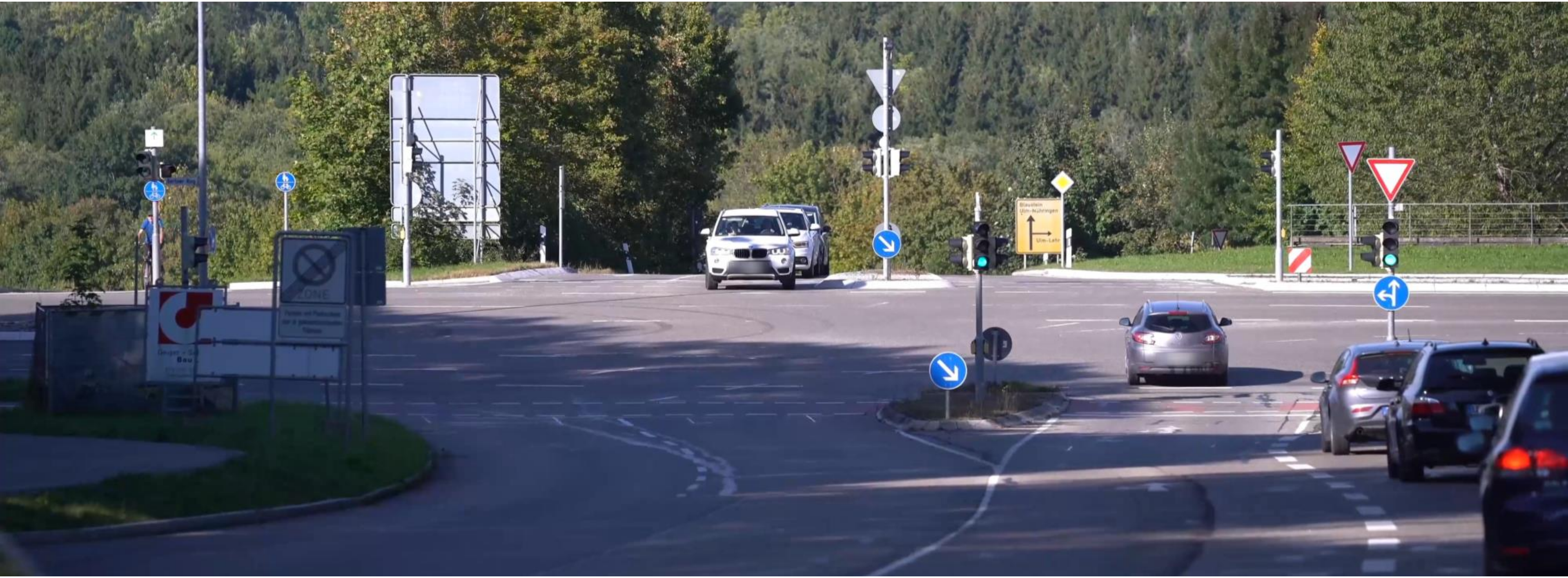
Motion Planning with External Data
Connected Traffic Lights: Results

Video: https://www.youtube.com/watch?v=RFdIpi3buAg

Motion Planning with External Data
Connected Traffic Lights: Results



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Project LUKAS

- Full title: "Local Environment Model for Cooperative Automated Driving in Complex Traffic Scenarios"
- Funded by the German federal Ministry of Economic Affairs and Energy (BMWi) within the programme „Neue Fahrzeug- und Systemtechnologien" (new vehicle and system technologies)
- Duration: 01.07.2020 – 30.09.2023
- Overall budget: 10.4 M€, approx. 55% funding,
  MRM: 1.4 M€, 100% funding
- Website: www.projekt-lukas.de

LUKAS

Gefördert durch:

Bundesministerium
für Wirtschaft
und Energie

aufgrund eines Beschlusses
des Deutschen Bundestages

BOSCH

Mercedes-Benz

IT DESIGNERS GRUPPE

NOKIA

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Intelligence makes the difference

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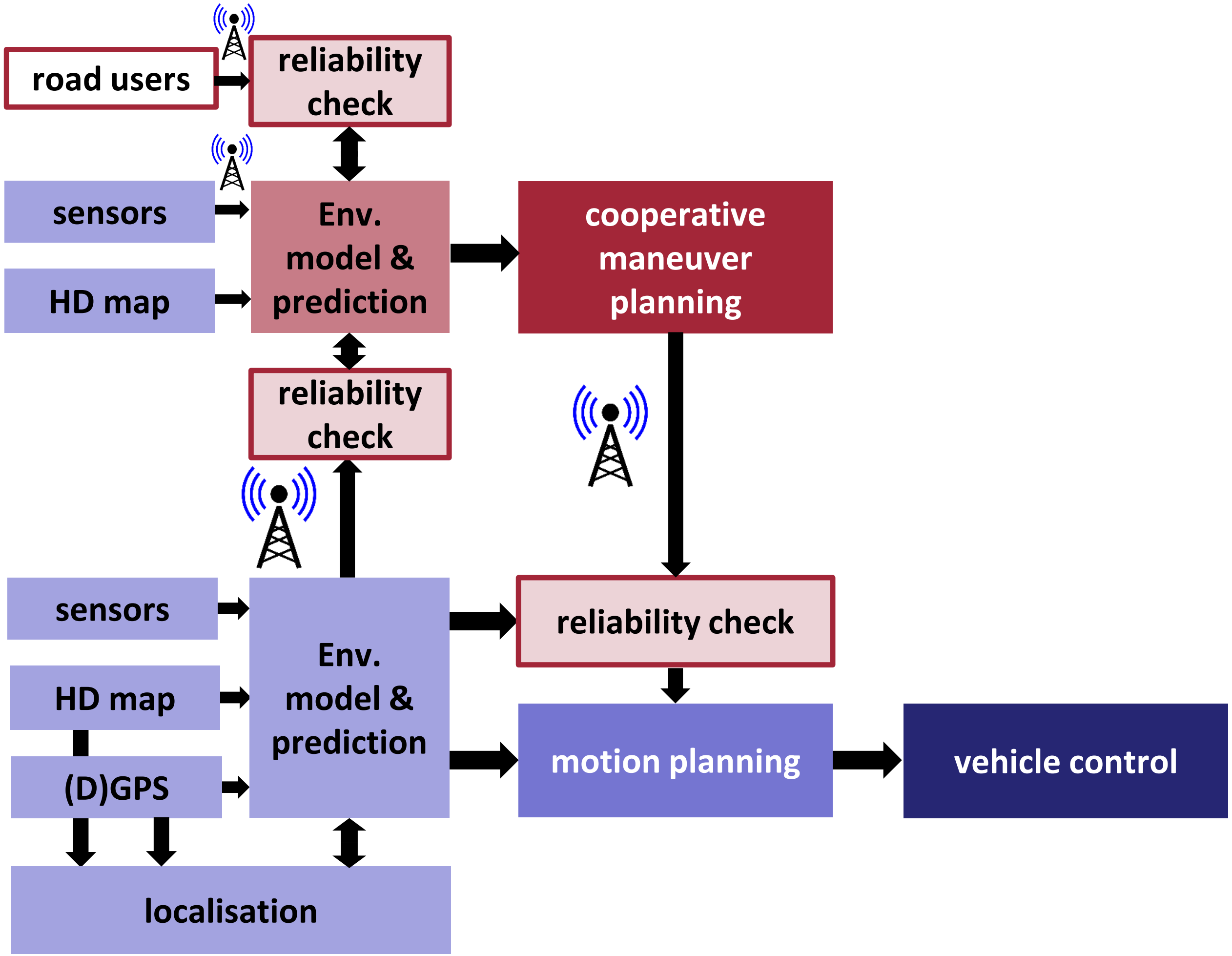
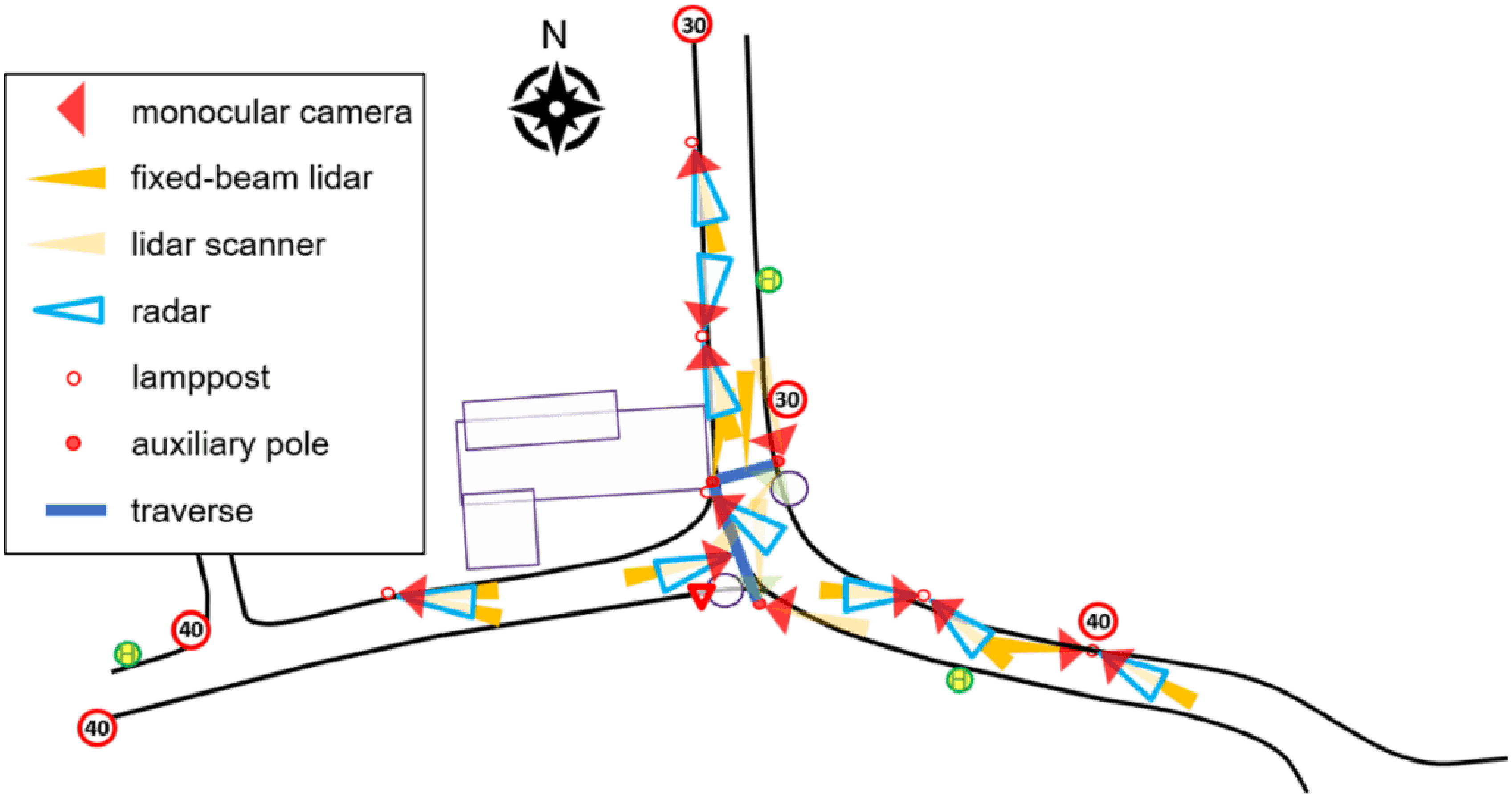
Extended System Architecture

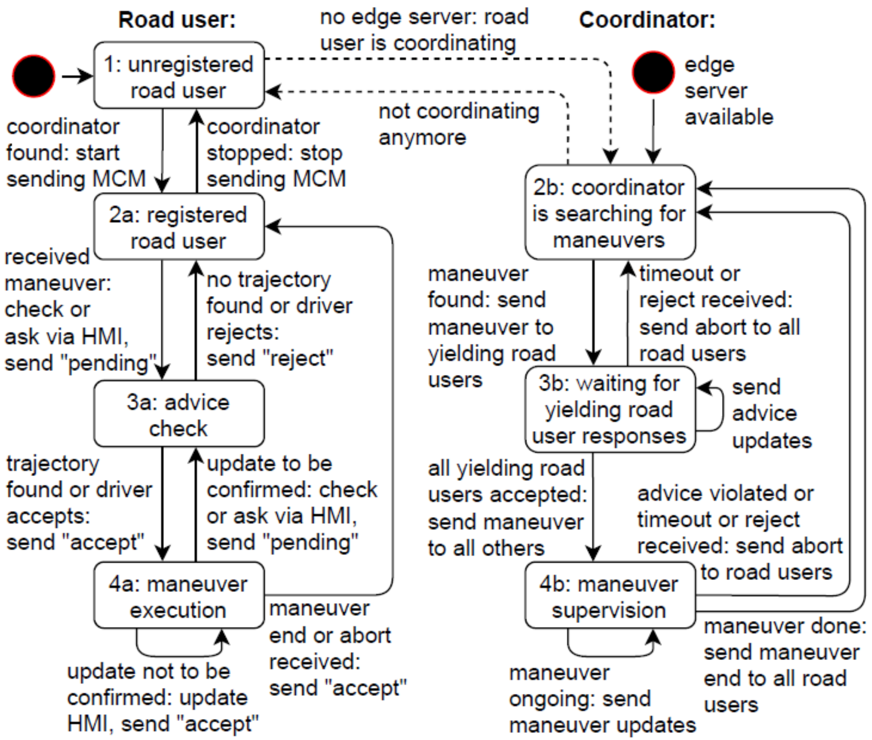


Status of the Pilot Site



Planning and Handling of Cooperative Maneuvers
State Diagram

- Proposal on Maneuver Coordination Service and respective Message (MCM) for ETSI standardization
- Covers all previously published use cases (mostly focusing on highways/merging) and extends them for several urban use cases
- Server-based planning approaches realize the centralized coordinator:
  - Optimization-based approach
  - Reinforcement learning approach



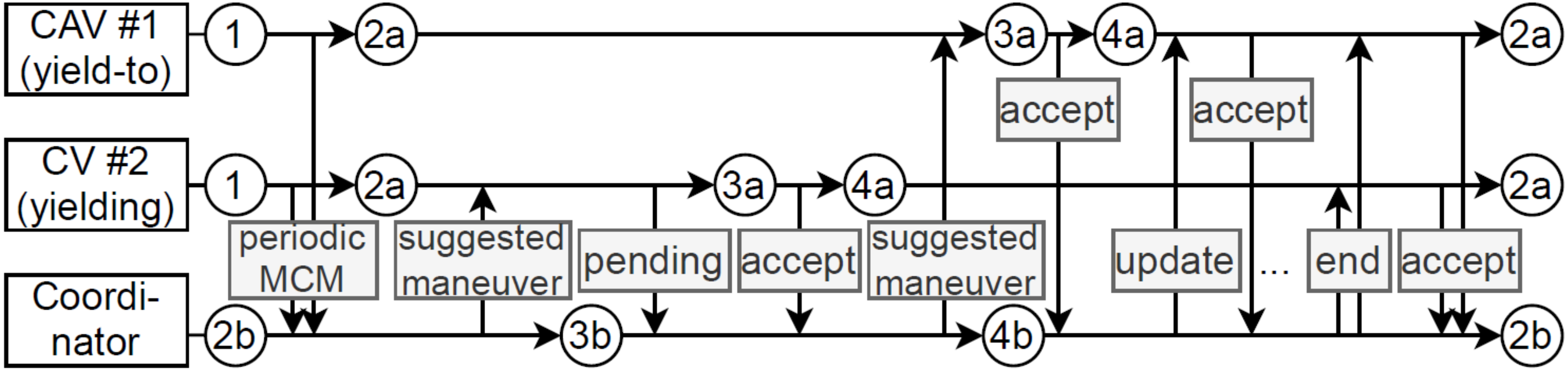
Mertens, M.; Müller, J.; Dehler, R.; Klimke, M.; Maier, M.; Gherekhloo, S.; Völz, B.; Henn, R.-W. and Buchholz, M.: "An Extended Maneuver Coordination Protocol with Support for Urban Scenarios and Mixed Traffic." In: 2021 *IEEE Vehicular Networking Conference (VNC)*, pp. 32-35, 2021. DOI: 10.1109/VNC52810.2021.9644632.

Mertens, M. B.; Müller, J. and Buchholz, M.: "Cooperative Maneuver Planning for Mixed Traffic at Unsignalized Intersections Using Probabilistic Predictions." In: *2022 IEEE Intelligent Vehicles Symposium (IV)*, pp. 1174-1180, 2022. DOI: 10.1109/IV51971.2022.9827300.

Klimke, M.; Völz, B. and Buchholz, M.: "Automatic Intersection Management in Mixed Traffic Using Reinforcement Learning and Graph Neural Networks." In: 2023 *IEEE Intelligent Vehicles Symposium (IV)*, pp. 1-8, 2023. DOI: 10.1109/IV55152.2023.10186800.

Planning and Handling of Cooperative Maneuvers
Exemplary Signal Flow

- Signal flow for two involved vehicles
- Connected Automated Vehicle (CAV) responses fast, human driver of Connected Vehicle (CV) needs longer reaction times



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Results from LUKAS
Use Case “Cooperative Turning”

LUKAS Project

Use Case Cooperative Turning

Project test site Ulm-Lehr

LUKAS

Supported by:

Federal Ministry
for Economic Affairs
and Climate Action

on the basis of a decision
by the German Bundestag

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InMach
Intelligence makes the difference

Video: https://oparu.uni-ulm.de/xmlui/handle/123456789/51329

Results from LUKAS
Use Case “Cooperative Overtaking”

Video: https://oparu.uni-ulm.de/xmlui/handle/123456789/51329

Results from LUKAS
Use Case “Cooperative Cylist”

Video: https://oparu.uni-ulm.de/xmlui/handle/123456789/51329

Results from LUKAS
Use Case “Pedestrian Crossing”

Video: https://oparu.uni-ulm.de/xmlui/handle/123456789/51329

Project PoDIUM

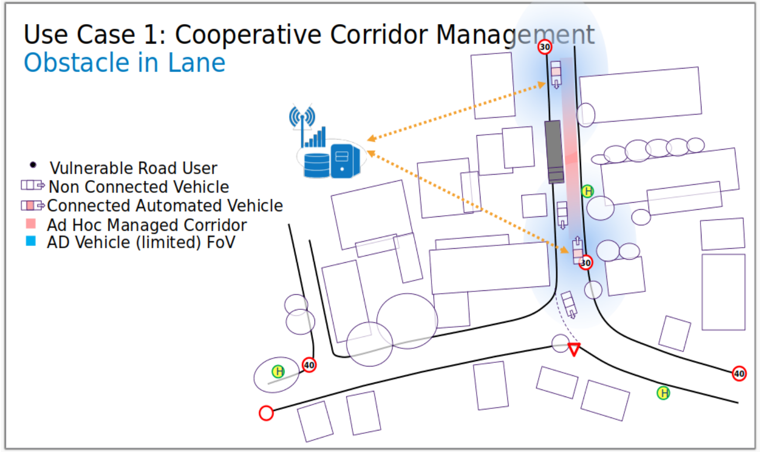
- Full title: “PDI connectivity and cooperation enablers building trust and sustainability for CCAM“
- Funded by the European Union’s Horizon Europe research & innovation programme
- Duration: 01.10.2022 – 30.09.2025
- Overall Budget: 12.2 M€, approx. 74% funding, MRM: 671 k€, 100% funding
- Website: https://podium-project.eu/
- Overall topics:
  - Multi-connectivity and hybrid data management
  - Digital twins
  - Integrity and data truthfulness
  - Integration of VRUs

Co-funded by the European Union

Project PoDIUM: German Test Site

PoDIUM

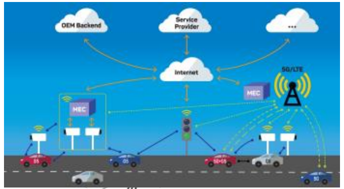
- Partners:
  Bosch, Nokia, Universität Duisburg-Essen, Universität Ulm
- Use case: Cooperative Corridor Management
- General focus of German test site:
  - Lightweight solution for environment model only from road users' communicated data
  - Redundancy in communication
  - Trust-building
- UULM's focus:
  - Data reliability estimation and its integration into the processing chain (perception, tracking, prediction, …)

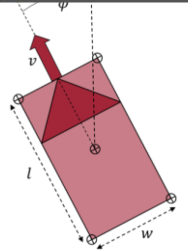


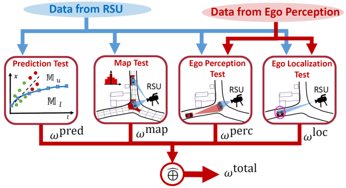
Co-funded by the European Union

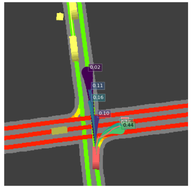
Summary and Outlook
Key Points of This Talk

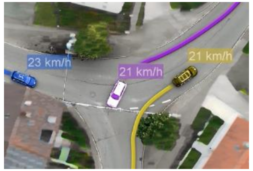
- Overall architecture for intelligent infrastructure in CCAM
- Neural network to detect road users in camera image
- Infrastructure environment model with generic sensor interface
- Award-winning probabilistic prediction of vehicle movement
- Reliability estimation for external data based on SL
- Motion planning for automated vehicle with uncertain external data
- Server-based cooperative manoeuvres enhancing efficiency and safety



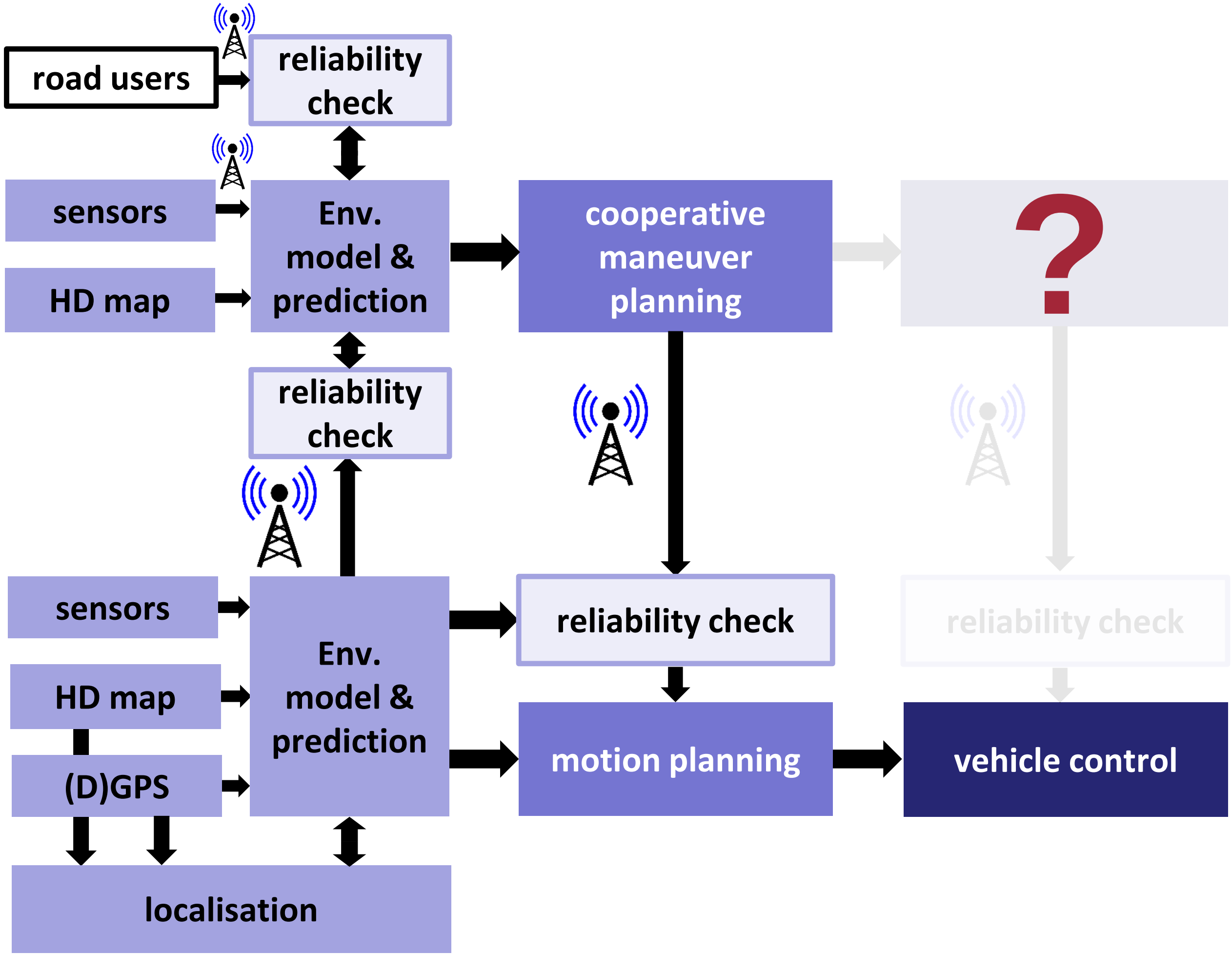








And Beyond?



road users
reliability check
sensors
HD map
Env. model & prediction
cooperative maneuver planning
?
reliability check
sensors
HD map
(D)GPS
Env. model & prediction
reliability check
reliability check
motion planning
vehicle control
localisation

List of Our Scientific Publications Related to Testsite Ulm 2023

- Hermann, C.; Herrmann, M.; Griebel, T.; Buchholz, M. and Dietmayer, K.: "The Fast Product Multi-Sensor Labeled Multi-Bernoulli Filter." In*: 2023 26th International Conference on Information Fusion (FUSION)*, 2023, pp. 1-8, DOI: 10.23919/FUSION52260.2023.10224189.
- Herrmann, M.; Luchterhand, T.; Hermann, C. and Buchholz, M.: "The Product Multi-Sensor Labeled Multi-Bernoulli Filter." In: *2023 26th International Conference on Information Fusion (FUSION)*, pp. 1-8, 2023. DOI: 10.23919/FUSION52260.2023.10224121.
- Herrmann, M.; Hermann, C.; Dietmayer, K. and Buchholz, M.: " Random-Finite-Set-basiertes Multisensor-Multiobjekttracking für automatisierte und vernetzte Fahrzeuge: Aktueller Forschungsstand und offene Fragen." In: *15. Uni-DAS e.V. Workshop Fahrerassistenz und automatisiertes Fahren (FAS 2022)*, 2023. URL: https://www.uni-das.de/images/pdf/fas-workshop/2023/FAS2023-03-Herrmann.pdf.
- Klimke, M.; Völz, B. and Buchholz, M.: "Automatic Intersection Management in Mixed Traffic Using Reinforcement Learning and Graph Neural Networks." In: *2023 IEEE Intelligent Vehicles Symposium (IV)*, pp. 1-8, 2023. DOI: 10.1109/IV55152.2023.10186800.
- Klimke, M.; Völz, B. and Buchholz, M.: "Automatisiertes Kreuzungsmanagement im urbanen Mischverkehr mit Reinforcement Learning." In: *15. Uni-DAS e.V. Workshop Fahrerassistenz und automatisiertes Fahren (FAS 2022)*, 2023. URL: https://www.uni-das.de/images/pdf/fas-workshop/2023/FAS2023-08-Klimke.pdf.
- Klimke, M.; Völz, B. and Buchholz, M.: "Integration of Reinforcement Learning Based Behavior Planning With Sampling Based Motion Planning for Automated Driving." In: *2023 IEEE Intelligent Vehicles Symposium (IV),* pp. 1-8, 2023. DOI: 10.1109/IV55152.2023.10186736.
- Ruof, J.; Mertens, M. B.; Buchholz, M. and Dietmayer, K.: "Real-Time Spatial Trajectory Planning for Urban Environments Using Dynamic Optimization." In*: 2023 IEEE Intelligent Vehicles Symposium (IV)*, 2023, pp. 1-7, DOI: 10.1109/IV55152.2023.10186535.
- Scheible, A.; Griebel, T.; Herrmann, M.; Hermann, C. and Buchholz, M.: " Track Classification for Random Finite Set Based Multi-Sensor Multi-Object Tracking." Accepted for publication at the *IEEE Symposium Sensor Data Fusion and International Conference on Multisensor Fusion and Integration (MFI 2023)*, 2023.
- Strohbeck, J.; Maschke, S.; Mertens, M. B.; and Buchholz, M.: “Graph-based Trajectory Prediction with Cooperative Information.” Presented at the *2023 IEEE 26th International Conference on Intelligent Transportation Systems (ITSC)*, 2023. To be published.
- Tsaregorodtsev, A.; Holzbock, A.; Strohbeck, J.; Buchholz, M. and Belagiannis, V.: "Automated Static Camera Calibration with Intelligent Vehicles." In: *2023 IEEE Intelligent Vehicles Symposium (IV)*, pp. 1-7, 2023. DOI: 10.1109/IV55152.2023.10186662.

List of Our Scientific Publications Related to Testsite Ulm 2022

- Buchholz, M.; Müller, J.; Herrmann, M.; Strohbeck, J.; Völz, B.; Maier, M.; Paczia, J.; Stein, O.; Rehborn, H. and Henn, R.-W.: "Handling Occlusions in Automated Driving Using a MEC Server-based Environment Model From Infrastructure Sensors." In: *IEEE Intelligent Transportation Systems Magazine*, vol. 14, no. 3, pp. 106-120, 2022. DOI: 10.1109/MITS.2021.3089743.
- Herrmann, M.; Luchterhand, T. Hermann, C.; Wodtko, T.; Strohbeck, J. and Buchholz, M.: "Notes on the Product Multi-Sensor generalized Labeled Multi-Bernoulli Filter and its Implementation", In: *2022 25th International Conference on Information Fusion (FUSION)*, pp. 1-8, 2022. DOI: 10.23919/FUSION49751.2022.9841275.
- Klimke, M.; Gerigk, J.; Völz, B. and Buchholz, M.: "An Enhanced Graph Representation for Machine Learning Based Automatic Intersection Management." In: 2022 IEEE 25th International Conference on Intelligent Transportation Systems (ITSC), pp. 523-530, 2022. DOI: 10.1109/ITSC55140.2022.9922515.
- Klimke, M.; Völz, B. and Buchholz, M.: "Cooperative Behavior Planning for Automated Driving Using Graph Neural Networks." In: 2022 IEEE Intelligent Vehicles Symposium (IV), pp. 167-174, 2022. DOI: 10.1109/IV51971.2022.9827230.
- Mertens, M. B.; Müller, J. and Buchholz, M.: "Cooperative Maneuver Planning for Mixed Traffic at Unsignalized Intersections Using Probabilistic Predictions." In: 2022 IEEE Intelligent Vehicles Symposium (IV), pp. 1174-1180, 2022. DOI: 10.1109/IV51971.2022.9827300.
- Müller, J.; Strohbeck, J., Herrmann, M. and Buchholz, M.: "Motion Planning for Connected Automated Vehicles at Occluded Intersections With Infrastructure Sensors." In: IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 10, pp. 17479-17490, 2022. DOI: 10.1109/TITS.2022.3152628.
- Müller, J.; Strohbeck, J.; Mertens, M. and Buchholz, M.: "Kontextbasierte Bewegungsplanung automatisierter Fahrzeuge an Kreuzungen mit vernetzten Lichtsignalanlagen." In: 14. Uni-DAS e.V. Workshop Fahrerassistenz und automatisiertes Fahren (FAS 2022), pp. 11-20, 2022. DOI: https://doi.org/10.18725/OPARU-43451.
- Strohbeck, J.; Müller, J.; Herrmann, M. and Buchholz, M.: "Deep Kernel Learning for Uncertainty Estimation in Multiple Trajectory Prediction Networks." In: 2022 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pp. 11396-11402, 2022. DOI: 10.1109/IROS47612.2022.9982167.
- Tsaregorodtsev, A.; Müller, J. C.; Strohbeck, J.; Herrmann, M.; Buchholz, M. and Belagiannis, V.: "Extrinsic Camera Calibration with Semantic Segmentation." In: 2022 IEEE 25th International Conference on Intelligent Transportation Systems (ITSC), pp. 3781-3787, 2022. DOI: 10.1109/ITSC55140.2022.9922338.

List of Our Scientific Publications Related to Testsite Ulm 2021

- Herrmann, M.; Hermann, C. and Buchholz, M.: “Distributed Implementation of the Centralized Generalized Labeled Multi-Bernoulli Filter.” In: IEEE Transactions on Signal Processing, vol. 69, pp. 5159-5176, 2021. DOI: 10.1109/TSP.2021.3107632.
- Müller, J. and Buchholz, M.: “Subjective logic reasoning: an urn model intuition and application to connected automated driving.” In: at - Automatisierungstechnik, vol. 69, no. 2, pp. 111-121, 2021. DOI: https://doi.org/10.1515/auto-2020-0097.
- Mertens*, M.; Müller*, J.; Dehler, R.; Klimke, M.; Maier, M.; Gherekhloo, S.; Völz, B.; Henn, R.-W. and Buchholz, M.: “An Extended Maneuver Coordination Protocol with Support for Urban Scenarios and Mixed Traffic.” In: 2021 IEEE Vehicular Networking Conference (VNC), pp. 32-35, 2021. DOI: 10.1109/VNC52810.2021.9644632.
  *First authors with equal contribution.
- Strohbeck, J.; Herrmann, M.; Müller, J. and Buchholz, M.: "An Extension Proposal for the Collective Perception Service to Avoid Transformation Errors and Include Object Predictions." In: 2021 IEEE Vehicular Networking Conference (VNC), pp. 40-43, 2021. DOI: 10.1109/VNC52810.2021.9644655.
- Strohbeck*, J., Müller*, J., Holzbock, A. and Buchholz, M.: “DeepSIL: A Software-in-the-Loop Framework for Evaluating Motion Planning Schemes Using Multiple Trajectory Prediction Networks.” In: 2021 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pp. 7075-7081, 2021. DOI: 10.1109/IROS51168.2021.9636423.
  * First authors with equal contribution.

List of Our Scientific Publications Related to Testsite Ulm 2020

- Buchholz, M.; Strohbeck, J.; Adaktylos, A.-M.; Vogl, F.; Allmer, G.; Cabrero Barros, S.; Lassoued, Y.; Wimmer, M.; Hätty, B.; Massot, G.; Ponchel, C.; Bretin, M.; Sourlas, V. and Amditis, A.: “Enabling Automated Driving by ICT Infrastructure: A Reference Architecture.” In: 8th Transportation Research Arena (TRA) 2020 (conf. cancelled), 2020. DOI: 10.18725/OPARU-26023.
- Herrmann, M.; Piroli, A.; Strohbeck, J.; Müller, J. and Buchholz, M.: “LMB Filter Based Tracking Allowing for Multiple Hypotheses in Object Reference Point Association.” In: 2020 IEEE International Conference on Multisensor Fusion and Integration for Intelligent Systems (MFI), pp. 197-203, 2020. DOI: 10.1109/MFI49285.2020.9235251.
- Strohbeck, J.; Belagiannis, V.; Müller, J.; Schreiber, M.; Herrmann, M.; Wolf, D. and Buchholz, M.: “Multiple Trajectory Prediction with Deep Temporal and Spatial Convolutional Neural Networks.” In: 2020 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), pp. 1992-1998, 2020. DOI: 10.1109/IROS45743.2020.9341327.

List of Our Scientific Publications Related to Testsite Ulm 2019

- Herrmann, M.; Strohbeck, J.; Müller, J. and Buchholz, M.: “Environment Modelling Based on Generic Infrastructure Sensor Interfaces Using a Centralized Labeled-Multi-Bernoulli Filter.” In: 2019 IEEE Intelligent Transportation Systems Conference (ITSC), pp. 2414-2420, 2019. DOI: 10.1109/ITSC.2019.8916923.
- Müller, J. and Buchholz, M.: “A Risk and Comfort Optimizing Motion Planning Scheme for Merging Scenarios.” In: 2019 IEEE Intelligent Transportation Systems Conference (ITSC), pp. 3155-3161, 2019. DOI: 10.1109/ITSC.2019.8917425.
- Müller, J.; Gabb, M. and Buchholz, M.: “A Subjective-Logic-based Reliability Estimation Mechanism for Cooperative Information with Application to IV’s Safety.” In: 2019 IEEE Intelligent Vehicles Symposium (IV) (IV2019), pp. 1940-1946, 2019. DOI: 10.1109/IVS.2019.8814153.
- Müller, J.; Griebel, T.; Gabb, M. and Buchholz, M.: “Subjective Logic-Based Identification of Markov Chains and Its Application to CAV's Safety.” In: 2019 IEEE 2nd Connected and Automated Vehicles Symposium (CAVS), pp. 1-5, 2019. DOI: 10.1109/CAVS.2019.8887769.
- Müller, J.; Herrmann, M.; Strohbeck, J.; Belagiannis, V. and Buchholz, M.: “LACI: Low-effort Automatic Calibration of Infrastructure Sensors.” In: 2019 IEEE Intelligent Transportation Systems Conference (ITSC), pp. 3928-3933, 2019. DOI: 10.1109/ITSC.2019.8917310.
- Müller, J.; Meuser, T.; Steinmetz, R. and Buchholz, M.: “A Trust Management and Misbehavior Detection Mechanism for Multi-Agent Systems and its Application to Intelligent Transportation Systems.” In: 15th IEEE International Conference on Control & Automation (ICCA), pp. 325-331, 2019. DOI: 10.1109/ICCA.2019.8899968.

Thank you for your attention!

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