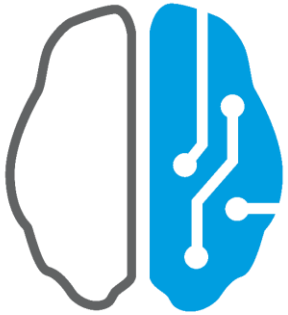
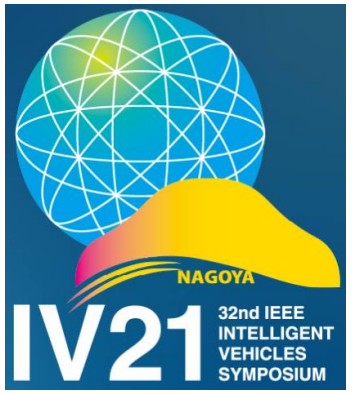


Intelligent
Embedded Systems



Probabilistic VRU Trajectory Forecasting for Model-Predictive Planning

A Case Study: Overtaking Cyclists

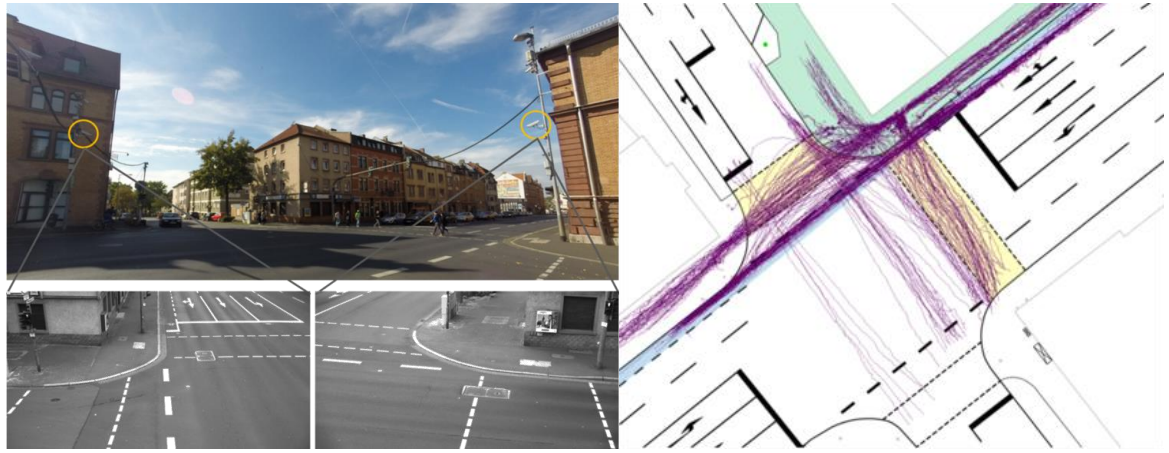
Jan Schneegans, Jan Eilbrecht, Stefan Zernetsch,
Maarten Bieshaar, Konrad Doll, Olaf Stursberg, Bernhard Sick

11 July 2021

Setting and Approach

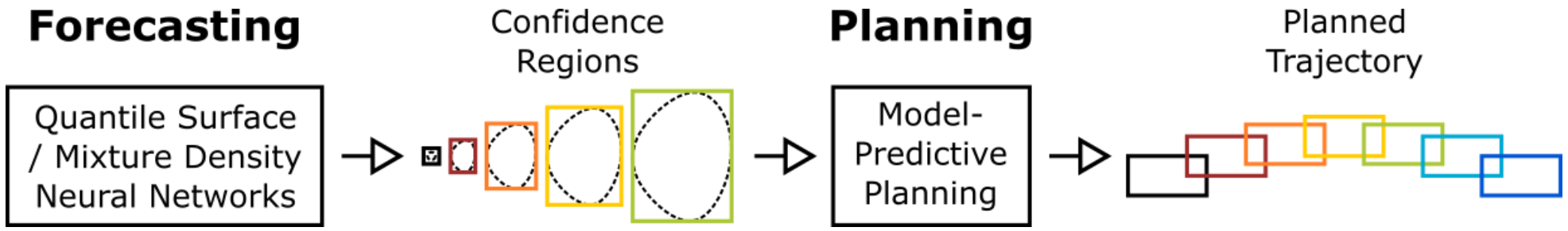
Intelligent Embedded Systems

- Dataset:
  - Public intersection Aschaffenburg
  - 1746 cyclist trajectories
  - Cameras, LiDAR, smart devices, vehicles



[48] “VRU Trajectory Dataset”, https://www.th-ab.de/vru-trajectory-dataset.

- Approach:



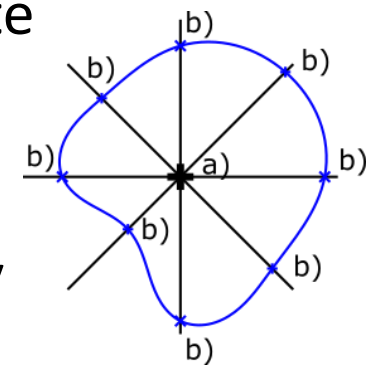
Quantile Surface Networks (QSN)

Intelligent Embedded Systems

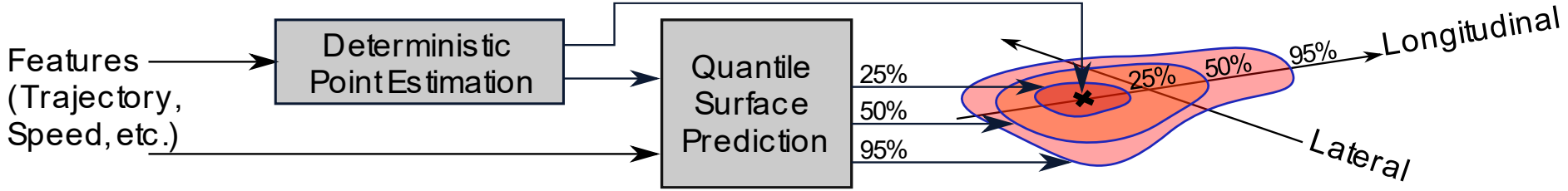
- Features based on past trajectory
  - E.g., polynomials, motion states

a) Forecast Point-Estimate

b) Predict arbitrary confidence regions



- Targets future trajectory
  - p = (0.1, 0.2, … 0.9, 0.95)
  - t = (0.5, 1, …, 2.5)



[1] M. Bieshaar, “Cooperative Intention Detection using Machine Learning–Advanced Cyclist Protection in the Context of Automated Driving”, 2021
[3] M. Bieshaar, J. Schreiber, S. Vogt, A. Gensler, and B. Sick, “Quantile Surfaces – Generalizing Quantile Regression to Multivariate Targets”, 2020

Mixture Density Networks (MDN)

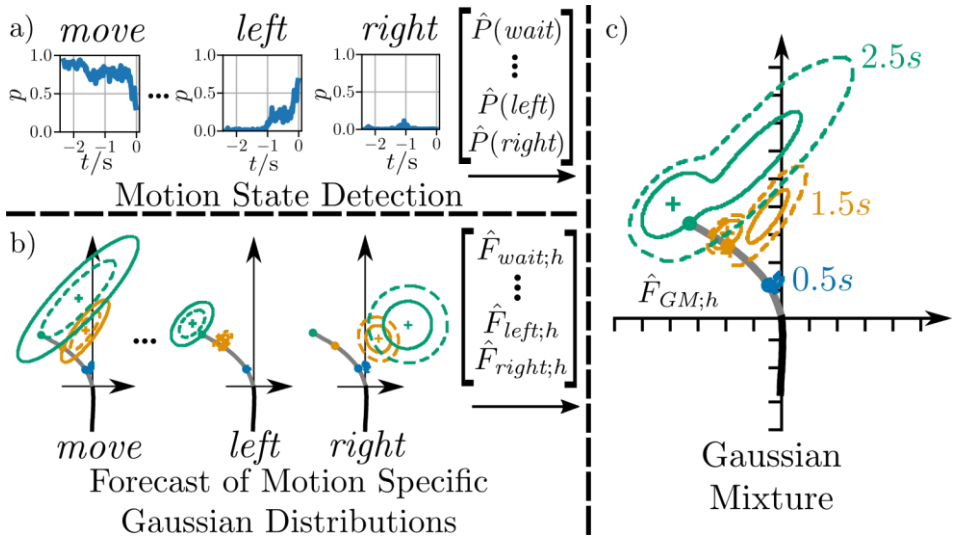
Intelligent Embedded Systems

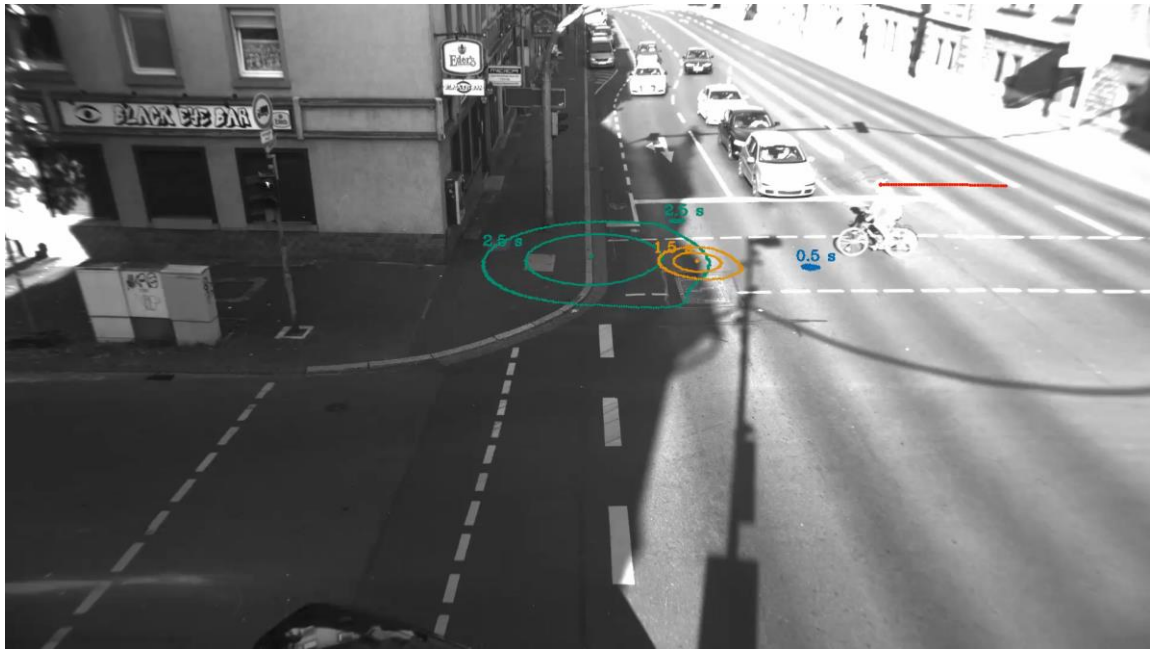
Features based on past trajectory

a) Estimate Motion state

b) Forecast Confidence Region

c) Weight b) by a)

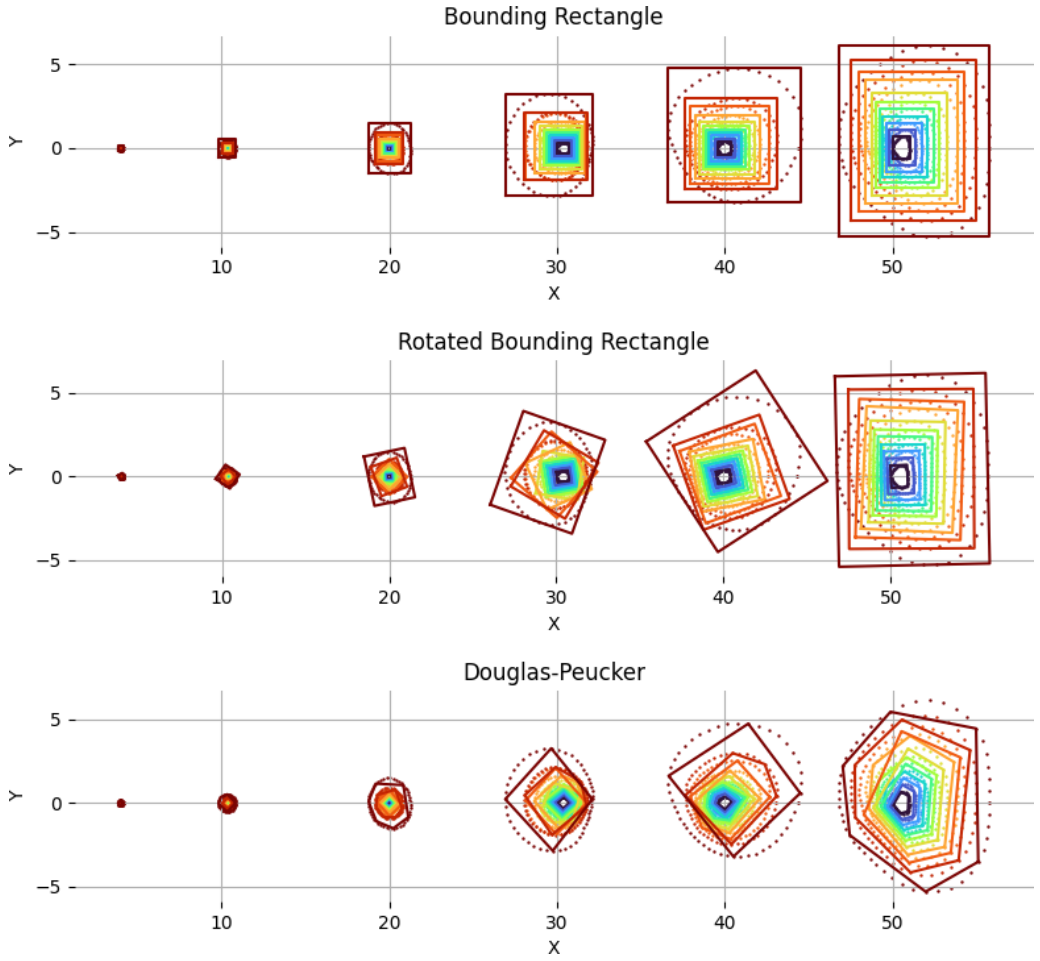




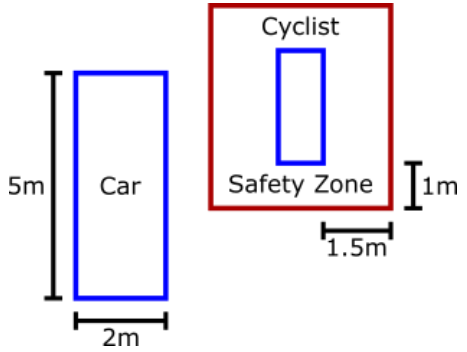
[2] S. Zernetsch, H. Reichert, V. Kress, K. Doll, and B. Sick, “Cyclist intention detection: A probabilistic approach”, 2021

Model-Predictive Planning (MPP)

Intelligent Embedded Systems



1. Confidence regions of p=0.9
2. Approximate regions with bounding rectangles
3. Extended forecasting horizon up to 7s
4. Apply MPP at each time step (240ms) to plan around the boxes

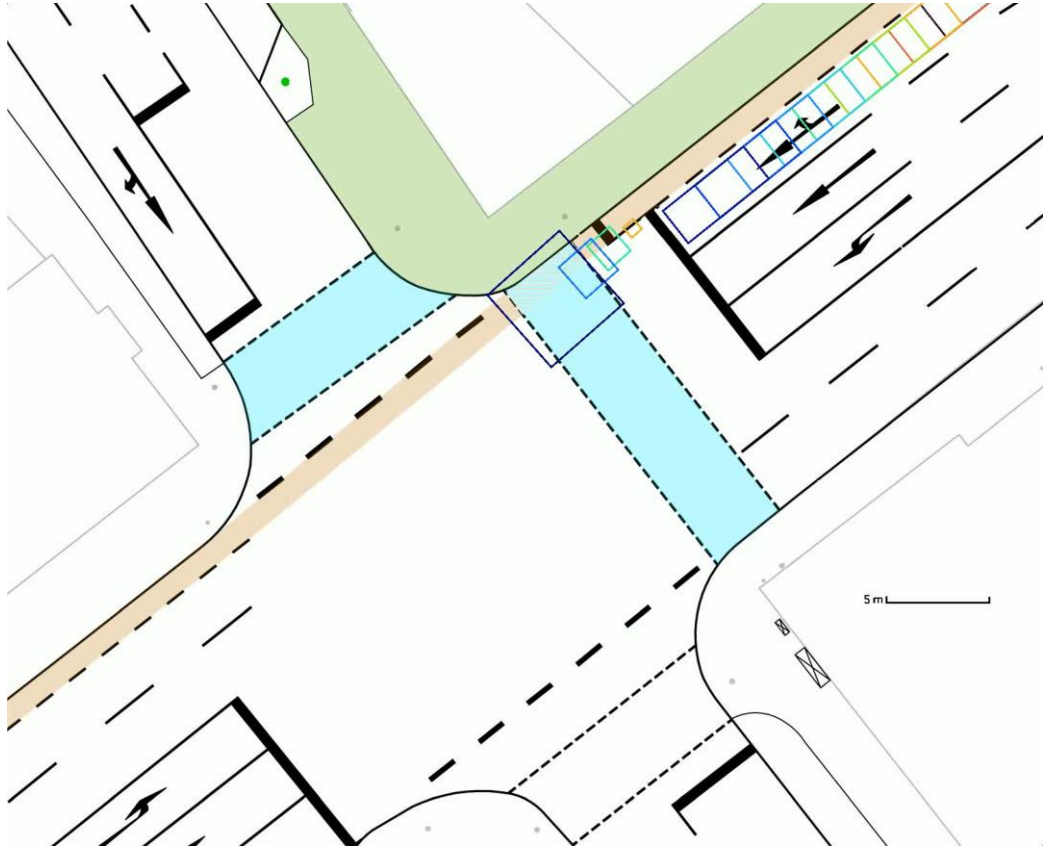


[5] J. Eilbrecht, M. Bieshaar, S. Zernetsch, K. Doll, B. Sick, and O. Stursberg, “Model-predictive planning for autonomous vehicles anticipating intentions of vulnerable road users by artificial neural networks”, 2017

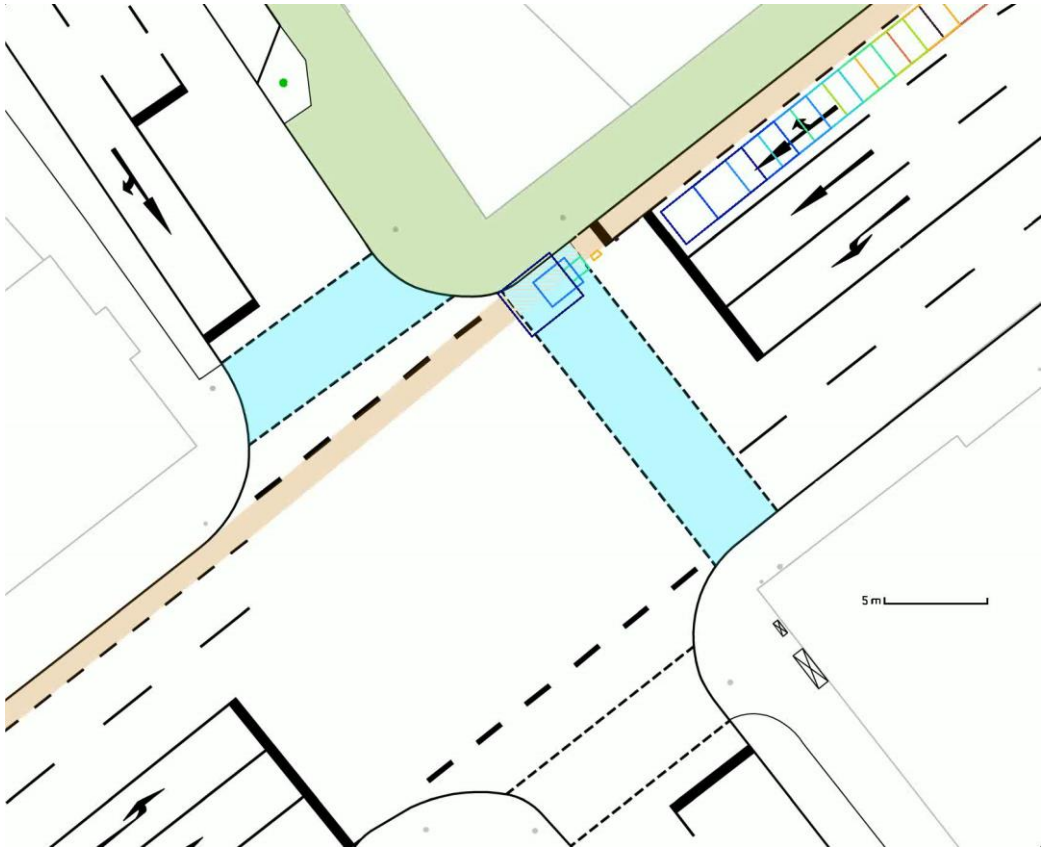
QSN and MDN Overtaking

Intelligent Embedded Systems

Quantile Surface Network



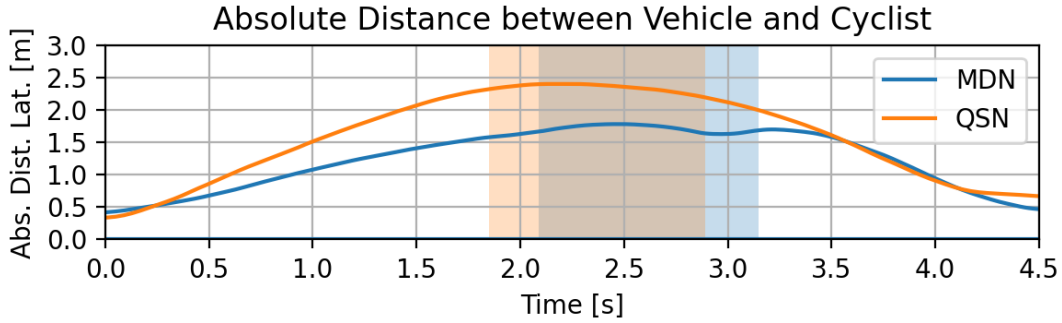
Mixture Density Network

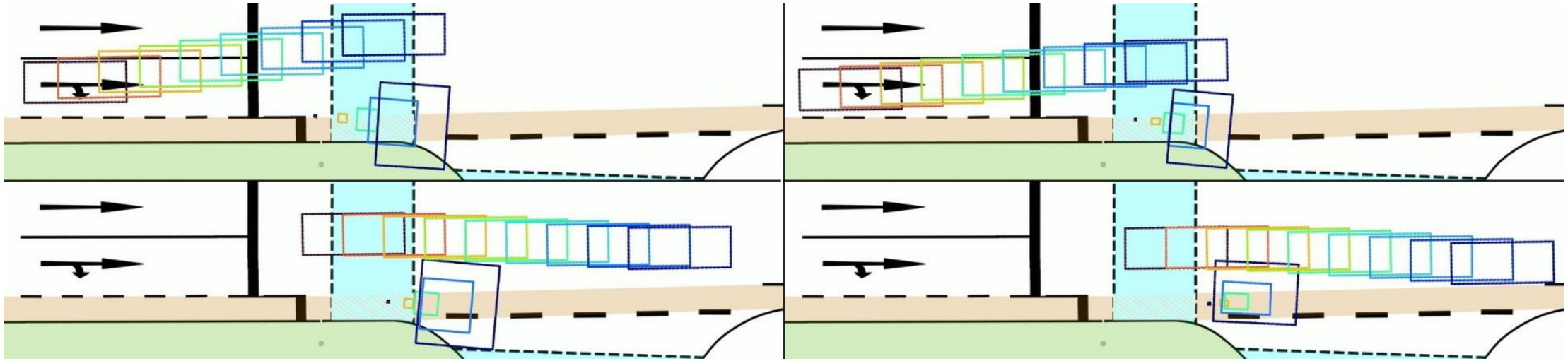


Comparison

Intelligent Embedded Systems

- MPP guaranties safety distance of 1.5m
- QSN predicts larger regions than MDN





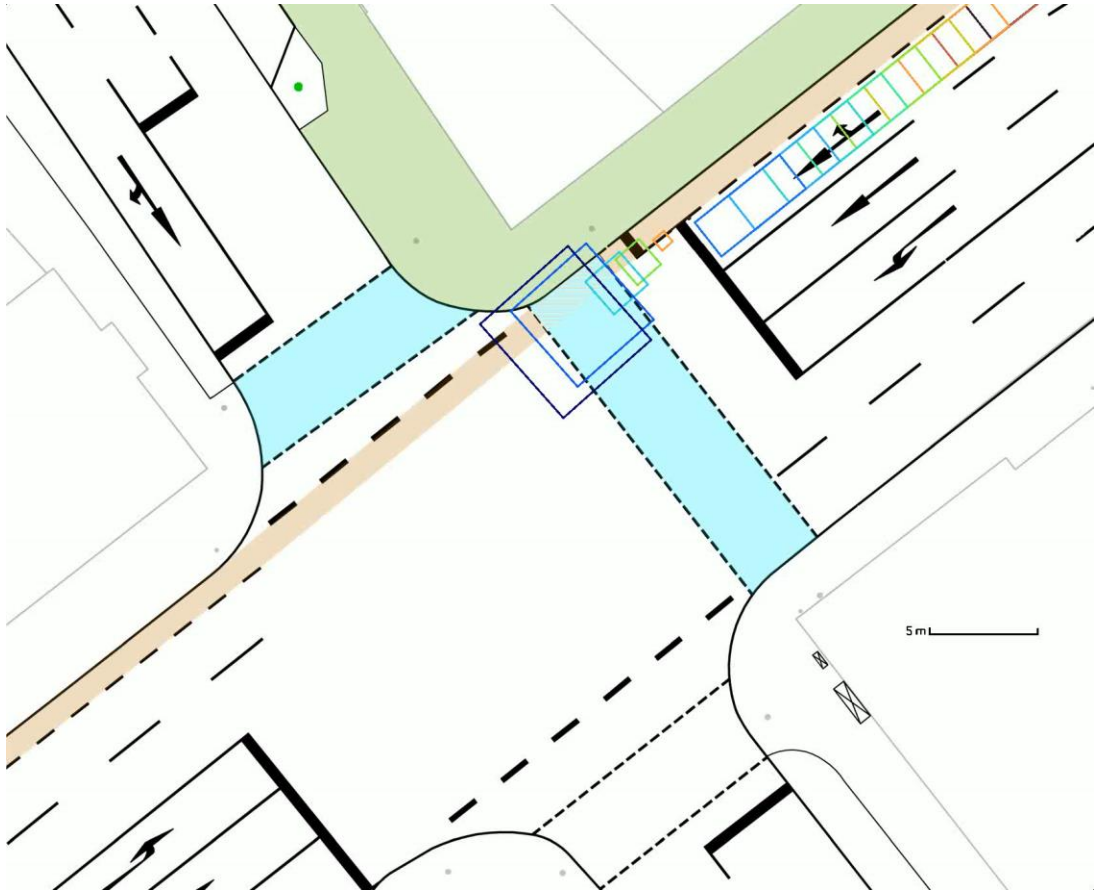
Scenario: Overtaking Not Possible

Intelligent Embedded Systems

- The vehicle must slow down behind the cyclist
- Caused by large confidence regions (p=0.95)
- Less desirable but correct behavior

➢More precise/sharp Forecasts

➢Incorporate Context



Challenges and Remedies

Intelligent Embedded Systems

The approach works, but can be advanced on several levels:

- Outlier Forecasts → Relax Planning, Smoothing
- Temporal Consistency → Regularization, Smoothing

- Context Information → Occupancy, Grid Maps, Lane Detection
- Social Interaction → Feature Exchange, Trajectory Prediction

- Limited Time Horizons → Longer Planning, Extrapolation

Intelligent
Embedded Systems

Thanks

M.Sc. Jan Schneegans

Intelligent Embedded Systems, University of Kassel