KOOPERATIVES HOCHAUTOMATISIERTES FAHREN

Online Localization and Fusion via Vehicle Sensor and Backend HD Map Data

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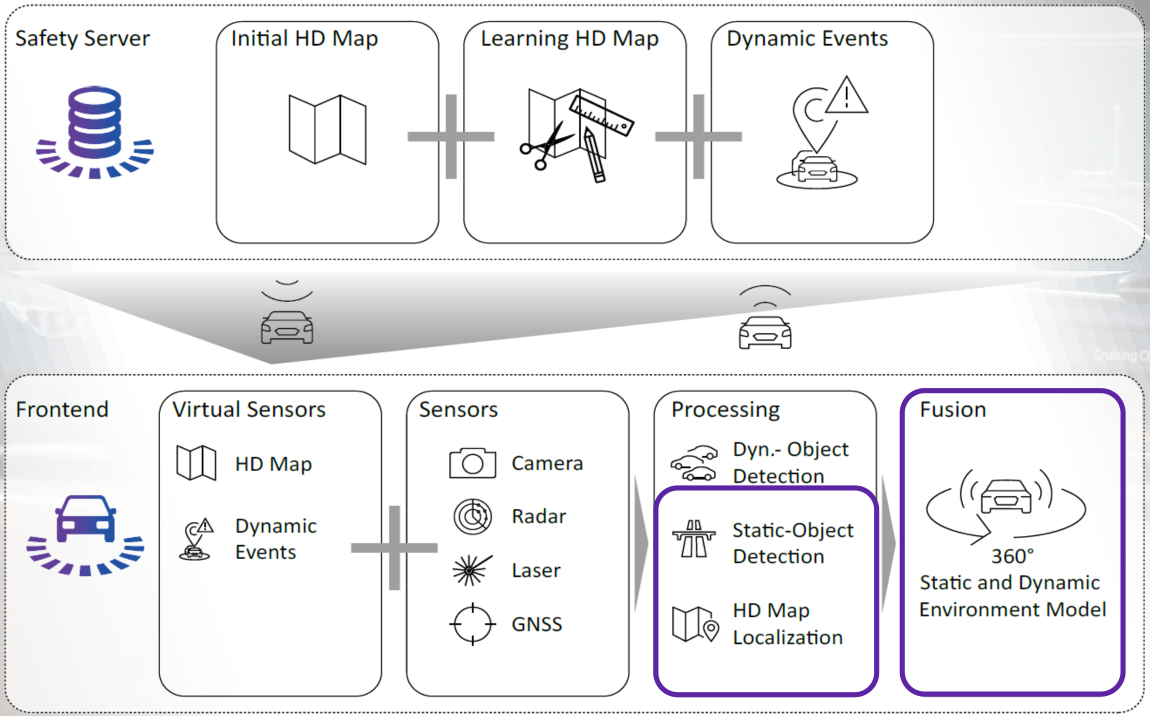
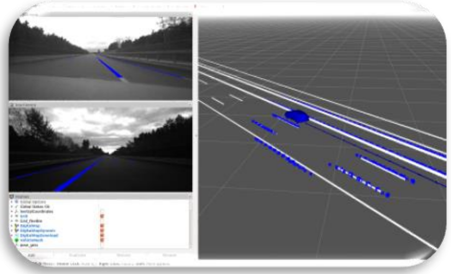
Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

Frontend HD Map Localization & Fusion



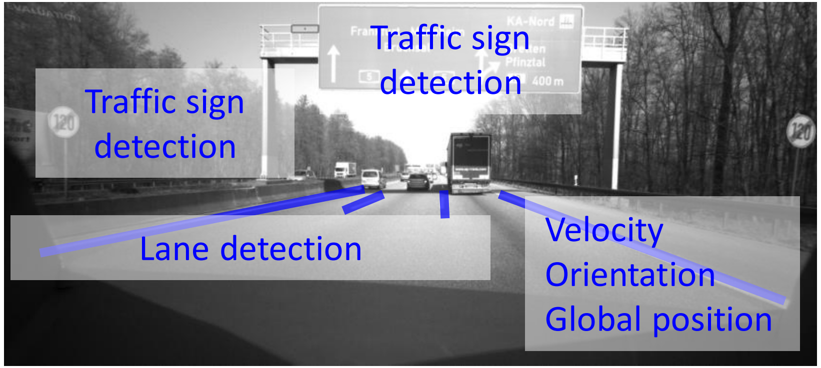
Outline

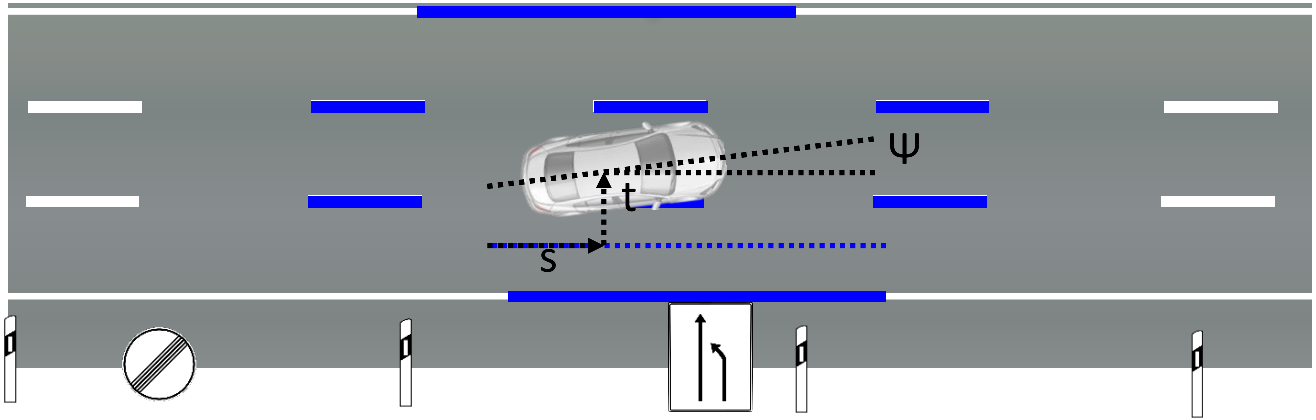
- **Localization on HD Maps**
  - Motivation
  - Localization through Graph Optimization
  - Application



- **Online Fusion of Vehicle Sensor and HD Map Data**
  - Motivation, Aims, and Contribution
  - Fusion Challenges
  - High-Level Road Model Fusion
  - Fusion Summary

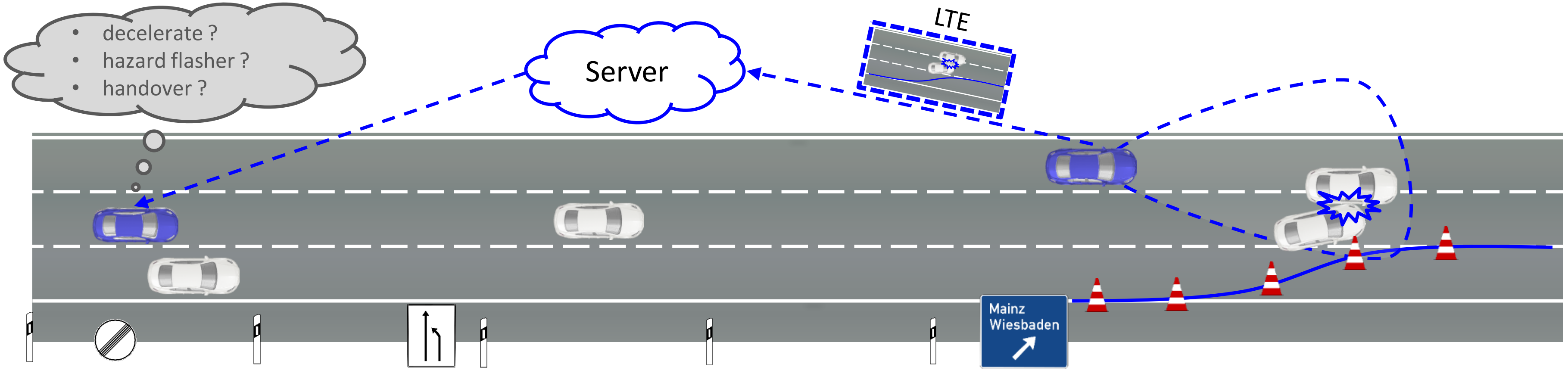
Motivation I



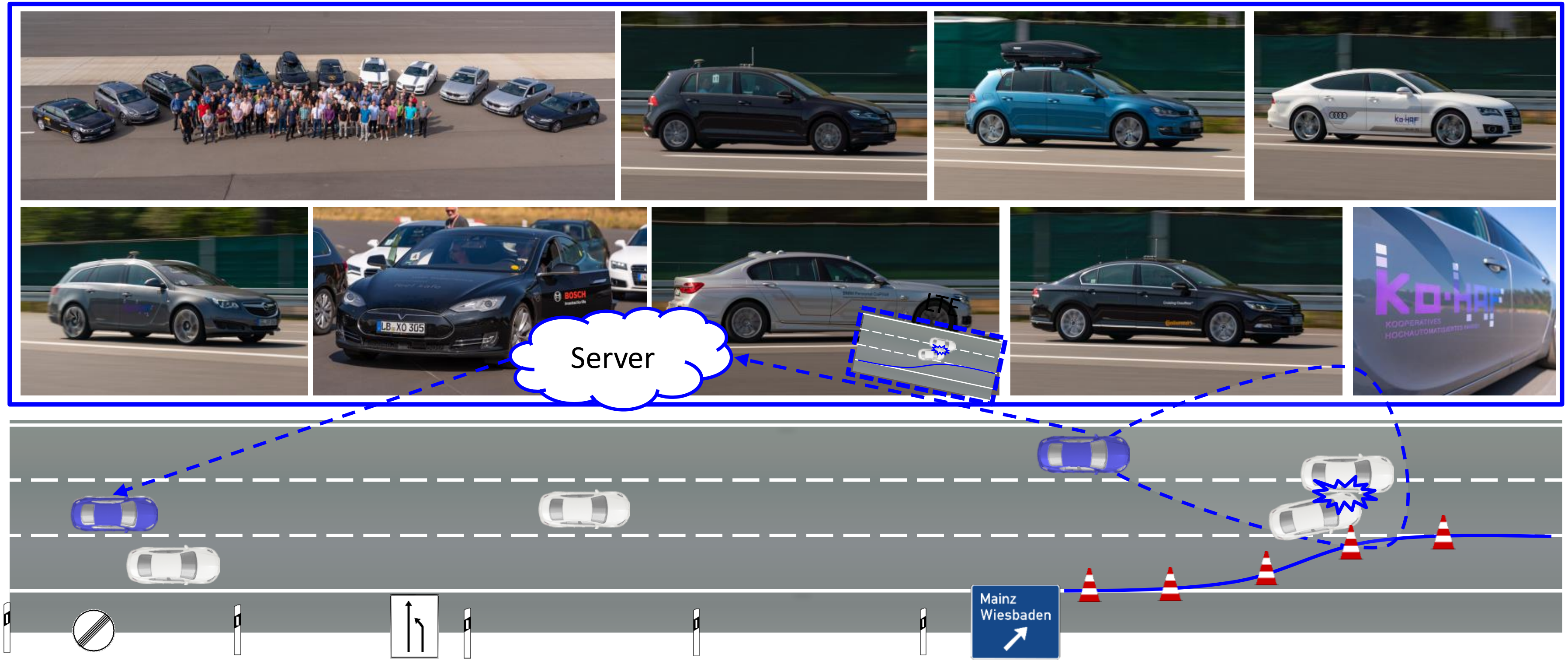


Motivation II

- More comfortable, foresightful driving
- Increased safety and efficiency
- ... through data exchange



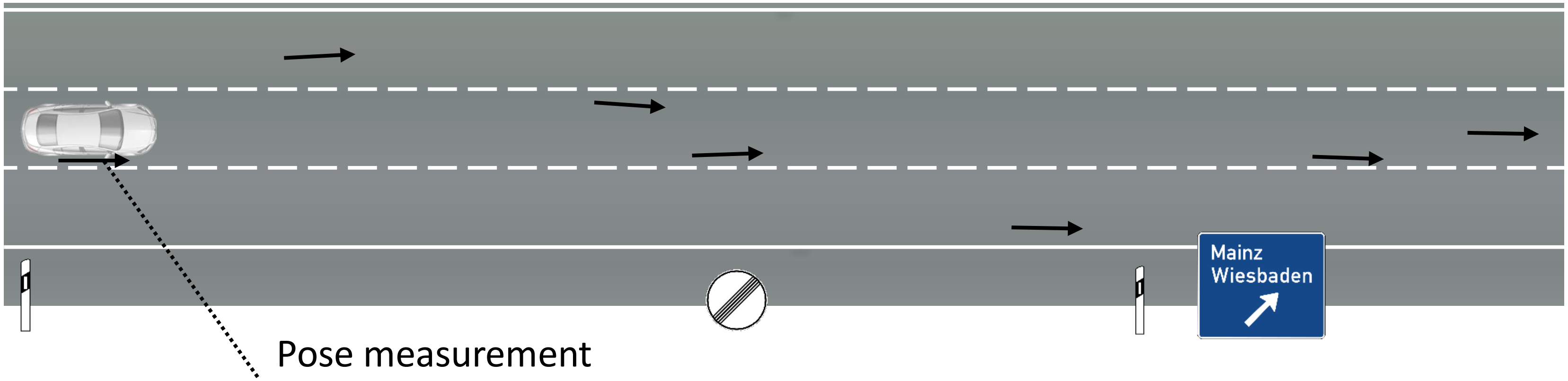
Motivation II



Single-Shot Measurements

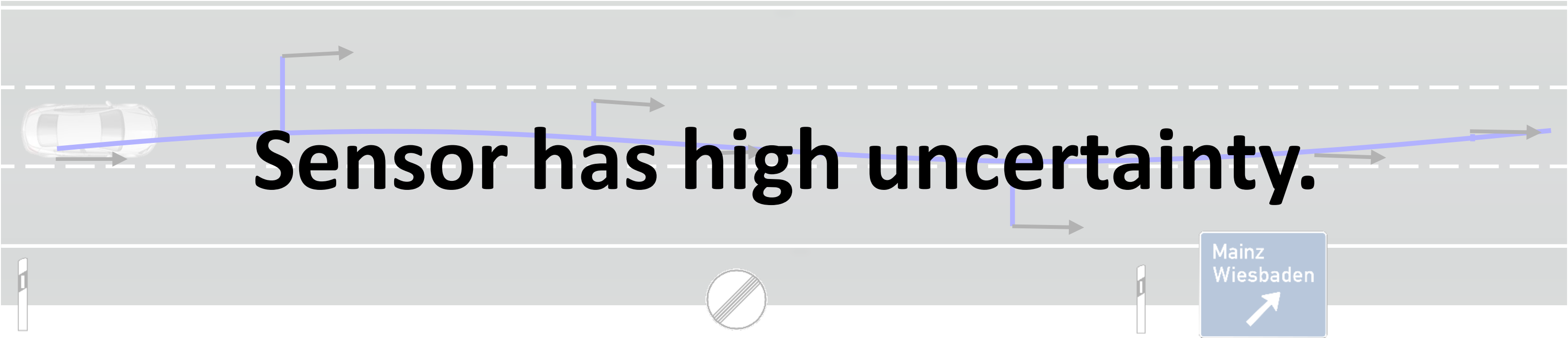
- Detect lanes
- Align lanes with map

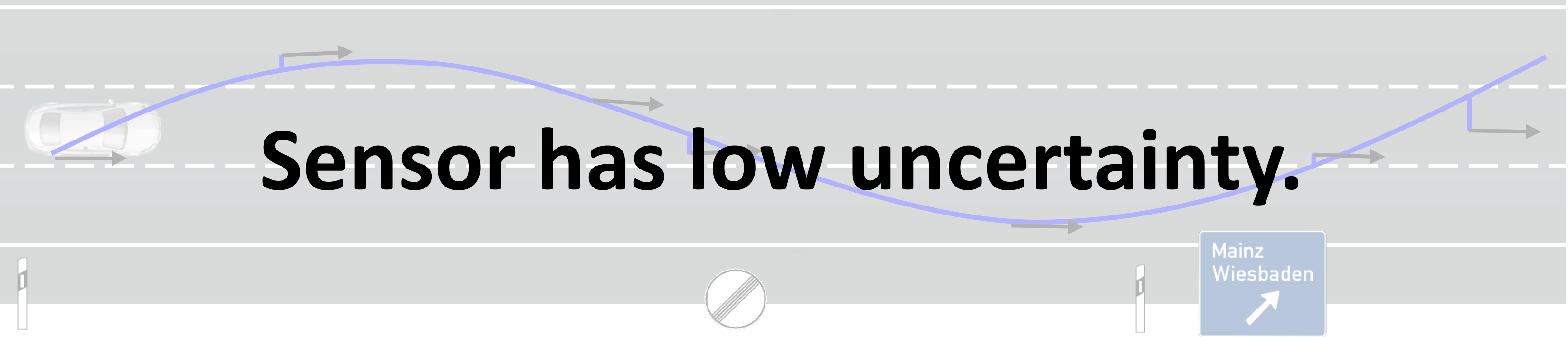
✓ Done ... best solution?



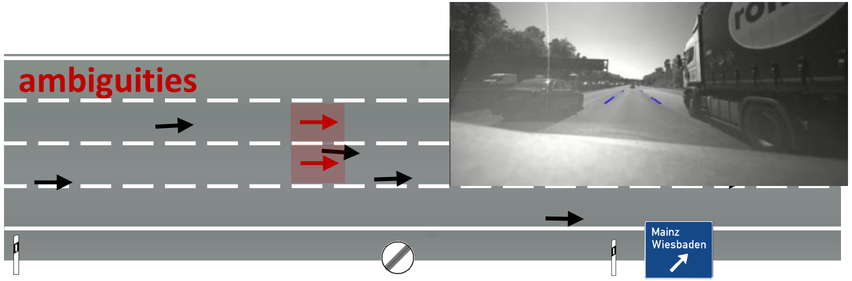
Pose measurement
(position + orientation)

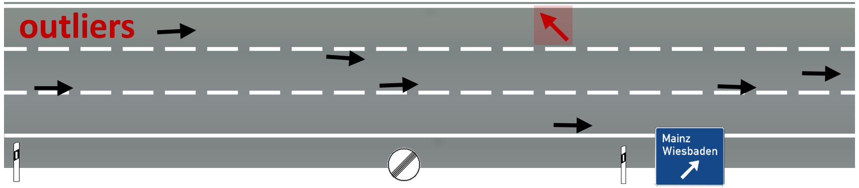
Data Fusion – Uncertainty





Real-World Application





Fusion algorithm requirement:

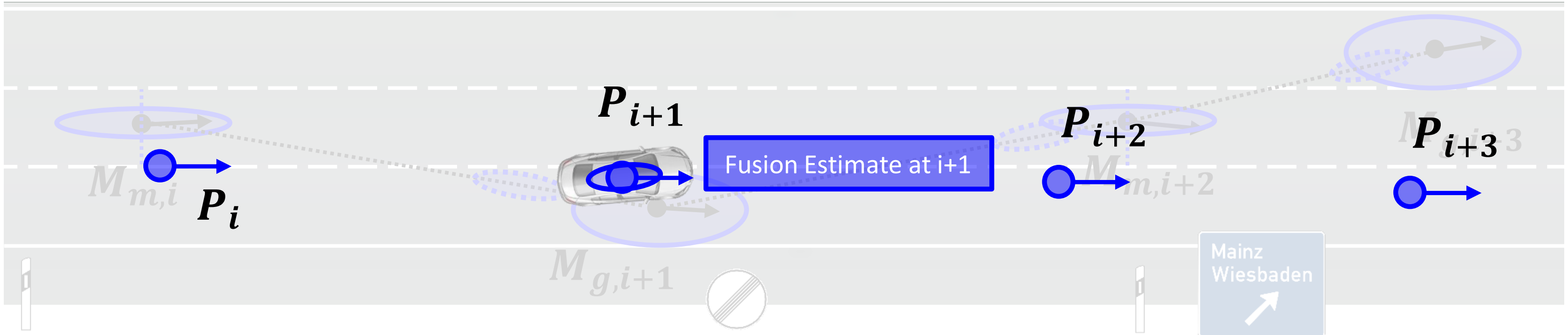
- Robust against outliers and short-term sensor outage
- Resolve ambiguities

➢ Model optimization problem instead of Bayes Filter

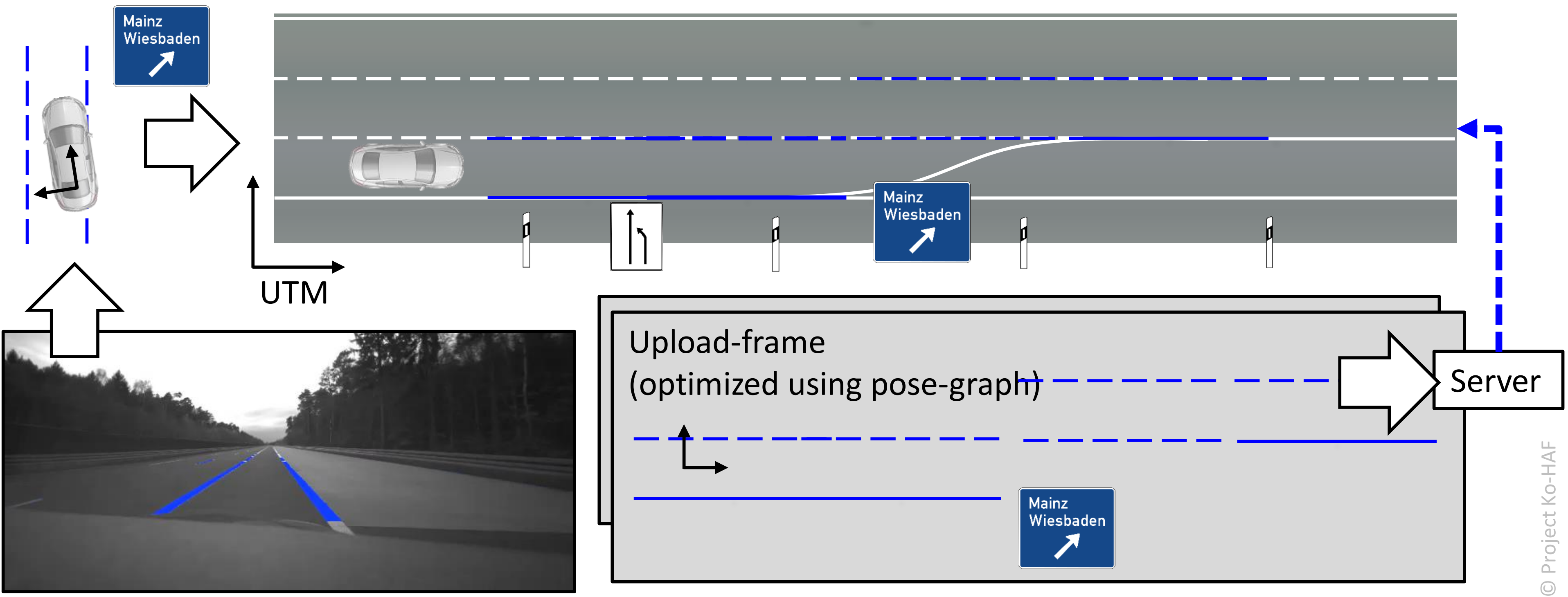
Graph-Based Optimization

Optimize:

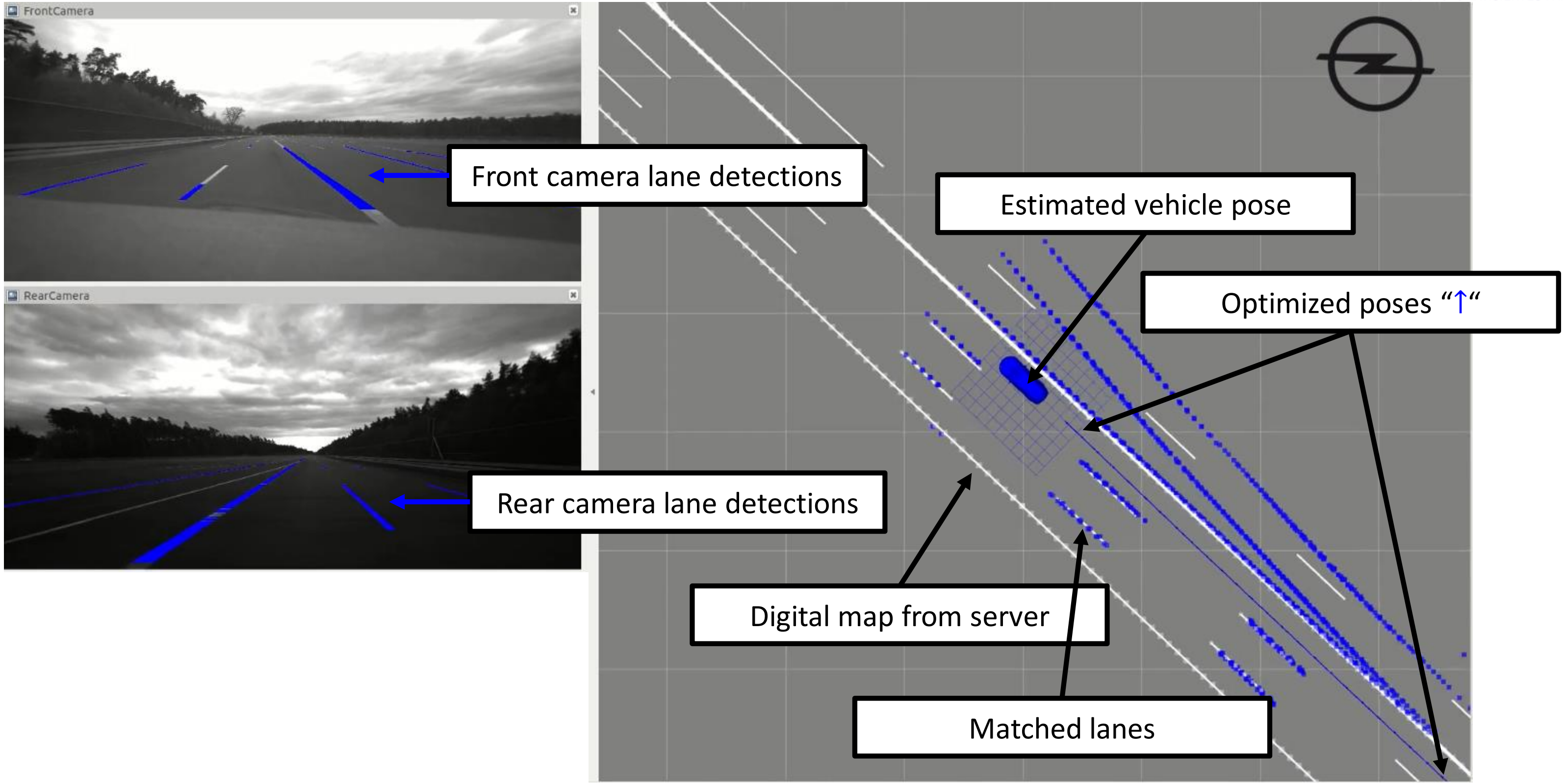
- Mahalanobis distance to sensor measurements
- Allow but penalize sensor outage
- Constrain parameters

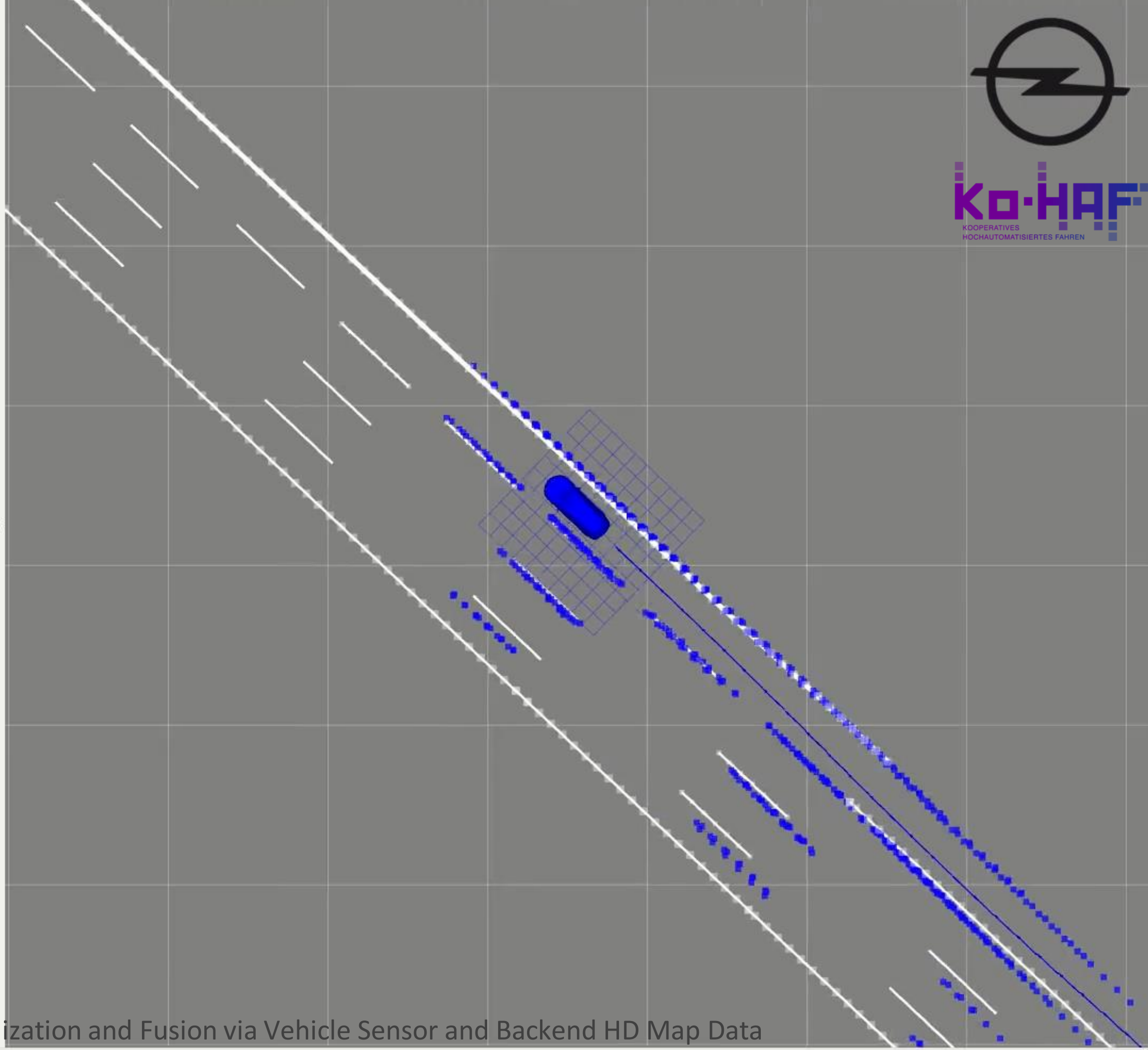


Map Upload


Mainz
Wiesbaden
UTM
Mainz
Wiesbaden
Upload-frame
(optimized using pose-graph)
Mainz
Wiesbaden
Server

Application: Explanation



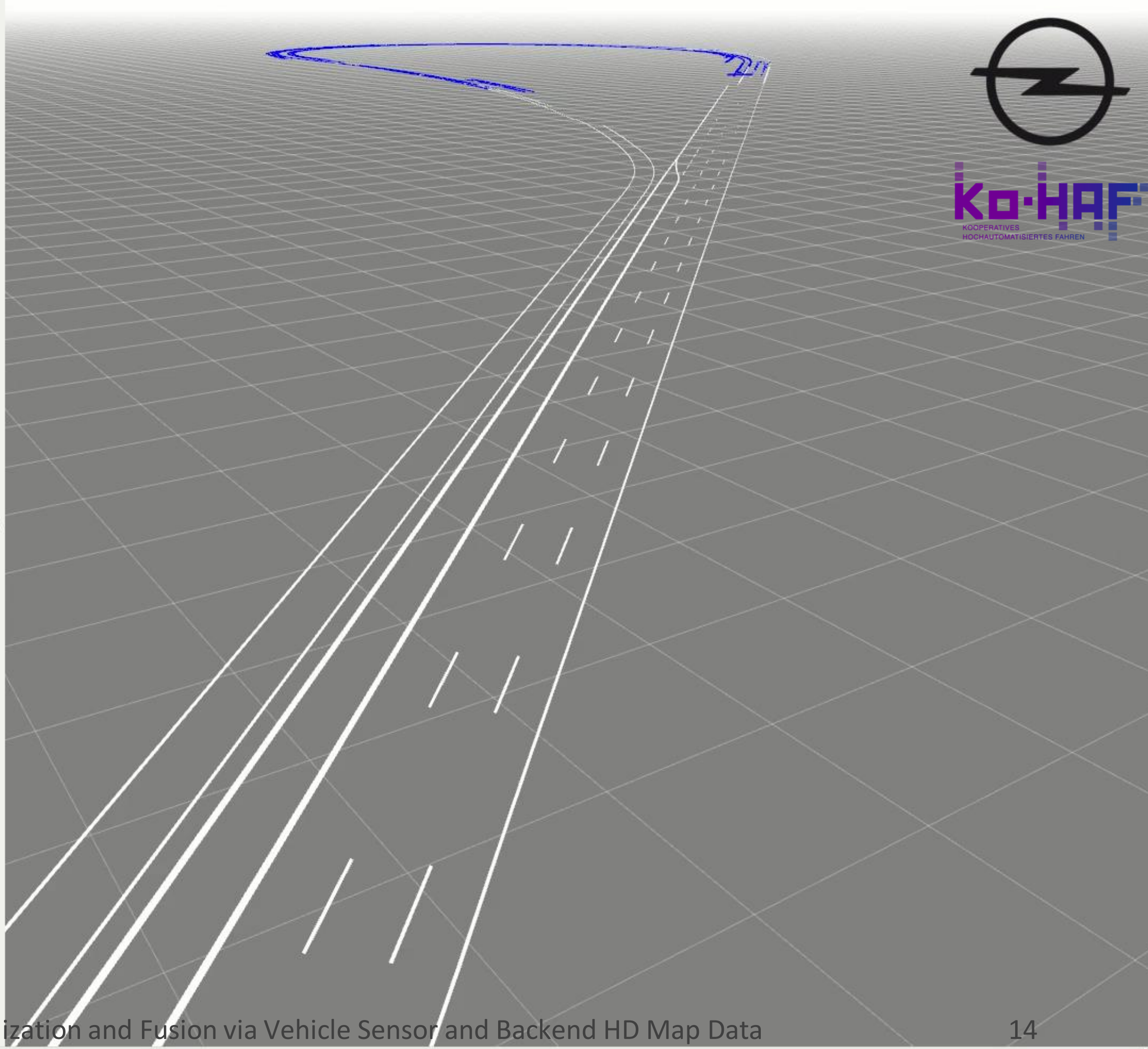


Poster: Außenbereich, Zelt.

Paper: M. Harr, J. Janosovits, S. Wirges, and C. Stiller.

Fast and Robust Vehicle Pose Estimation by Optimizing Multiple Pose Graphs.

In 21th International Conference on Information Fusion, 2018.



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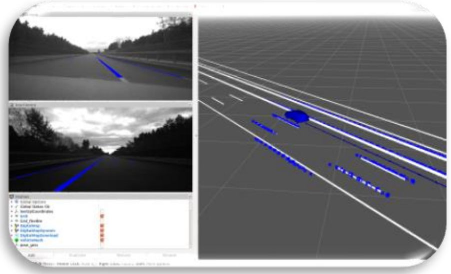
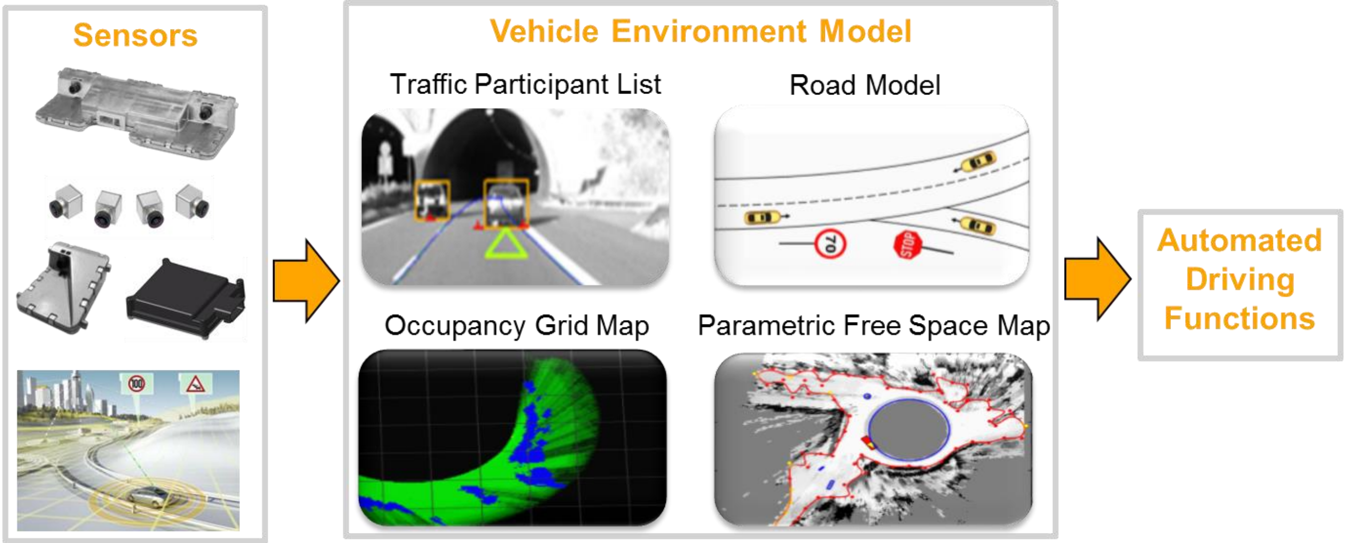


- **Online Fusion of Vehicle Sensor and HD Map Data**
  - Motivation, Aims, and Contribution
  - Fusion Challenges
  - High-Level Road Model Fusion
  - Fusion Summary

Motivation, Aims, and Contribution

- **Automated driving functions** need a **consistent** and **robust** representation of the driving environment (= **environment model**) for proper behavior planning and decision making.



- Adequate fusion **of vehicle sensor** and **backend HD map data** for additional i) **redundancy**, ii) **accuracy**, and iii) **range** of the environment model.

Motivation, Aims, and Contribution

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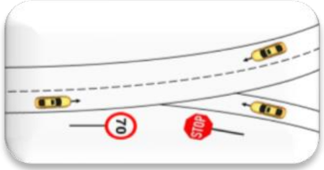
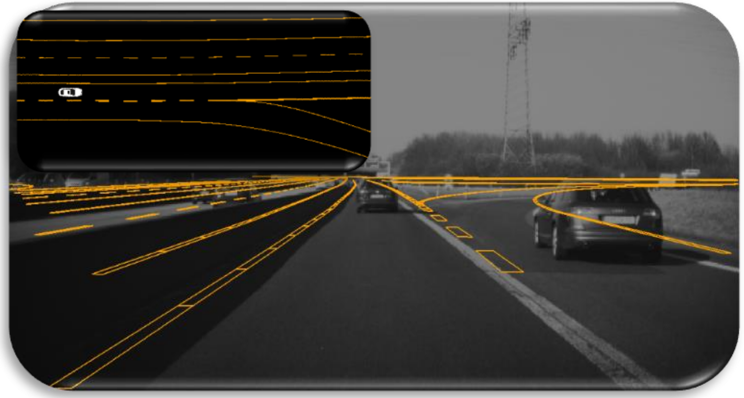
- The **road model** is a bird's-eye view representation of
  - the road/lane **geometry**,
  - the road/lane **topology**, and
  - traffic-rule related **attributes**.

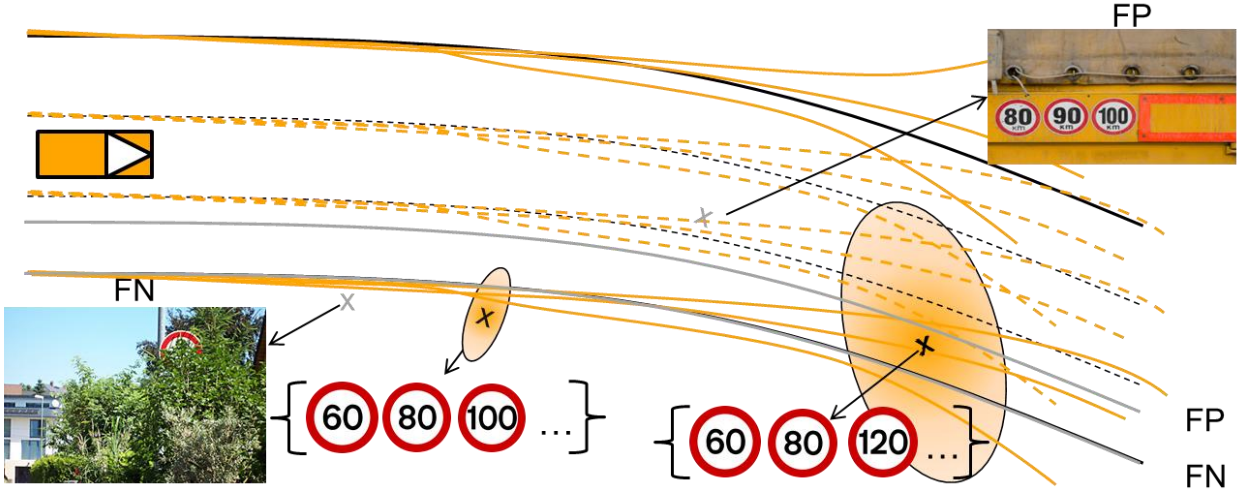




- The road model can either be derived from
  - sensor data (→ **sensor-based road model**) or
  - digital map data (→ **map-based road model**).
- **Contribution:** Presentation of a general **High-Level Road Model Fusion** concept to infer **lane-specific traffic rules** by combining
  - regulatory traffic elements,
  - lane geometry, and
  - backend HD map data.

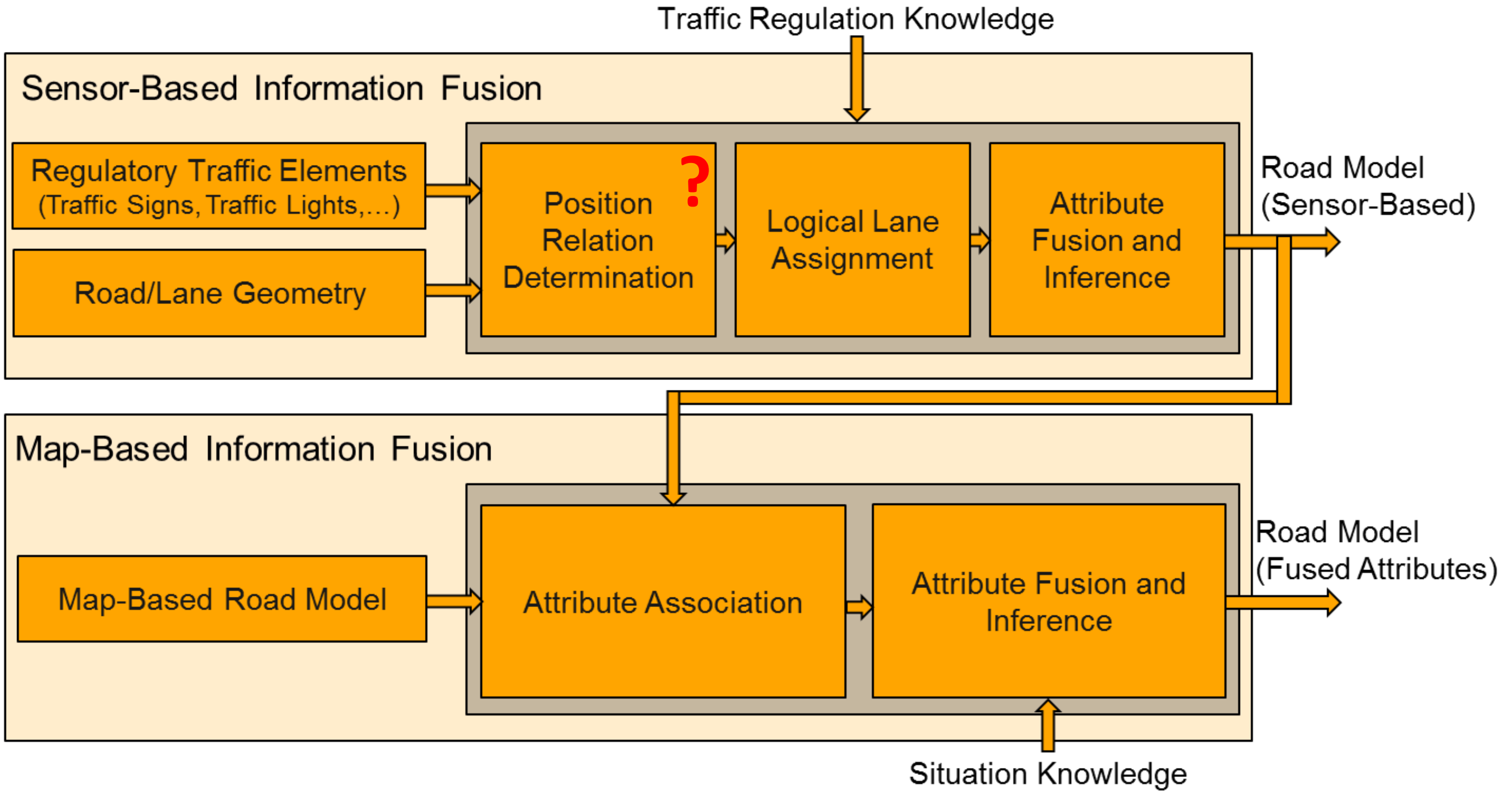
Fusion Challenges

- Coping with incomplete, uncertain, and inconsistent information sources.
- Adequate consideration of i) **spatial**, ii) **existence**, and iii) **attribute** uncertainties.



- **Ko-HAF result: Unified uncertainty representation** across all partners.
- The online road model fusion should take these uncertainties into account without „thresholding".

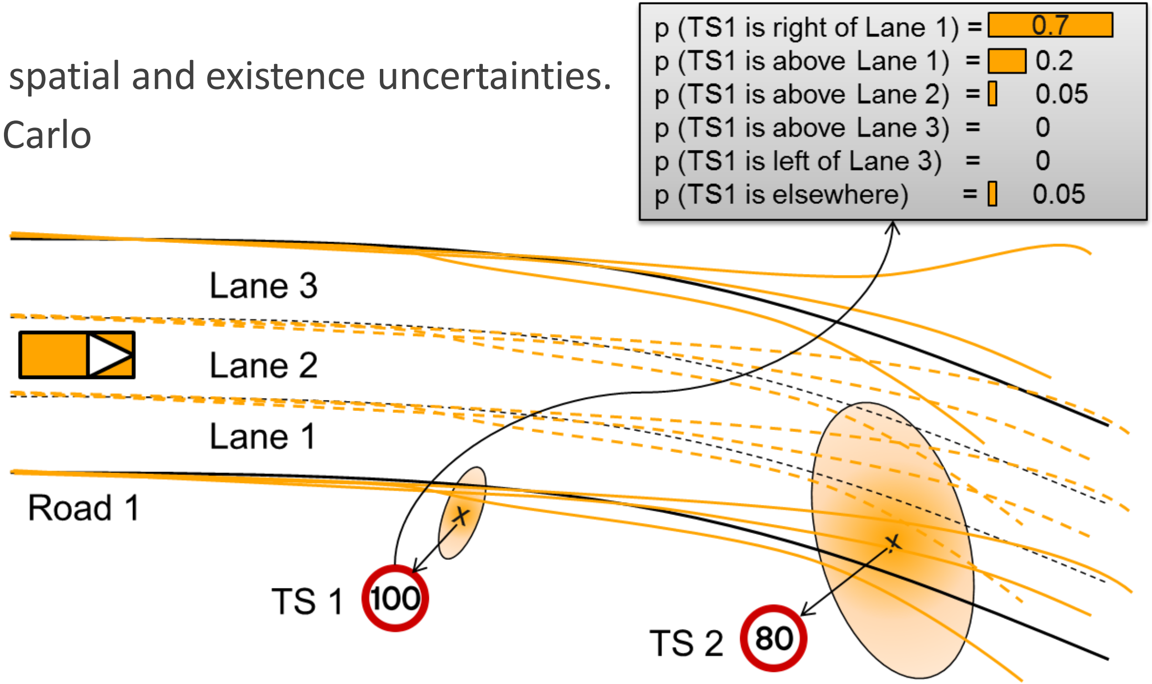
High-Level Road Model Fusion



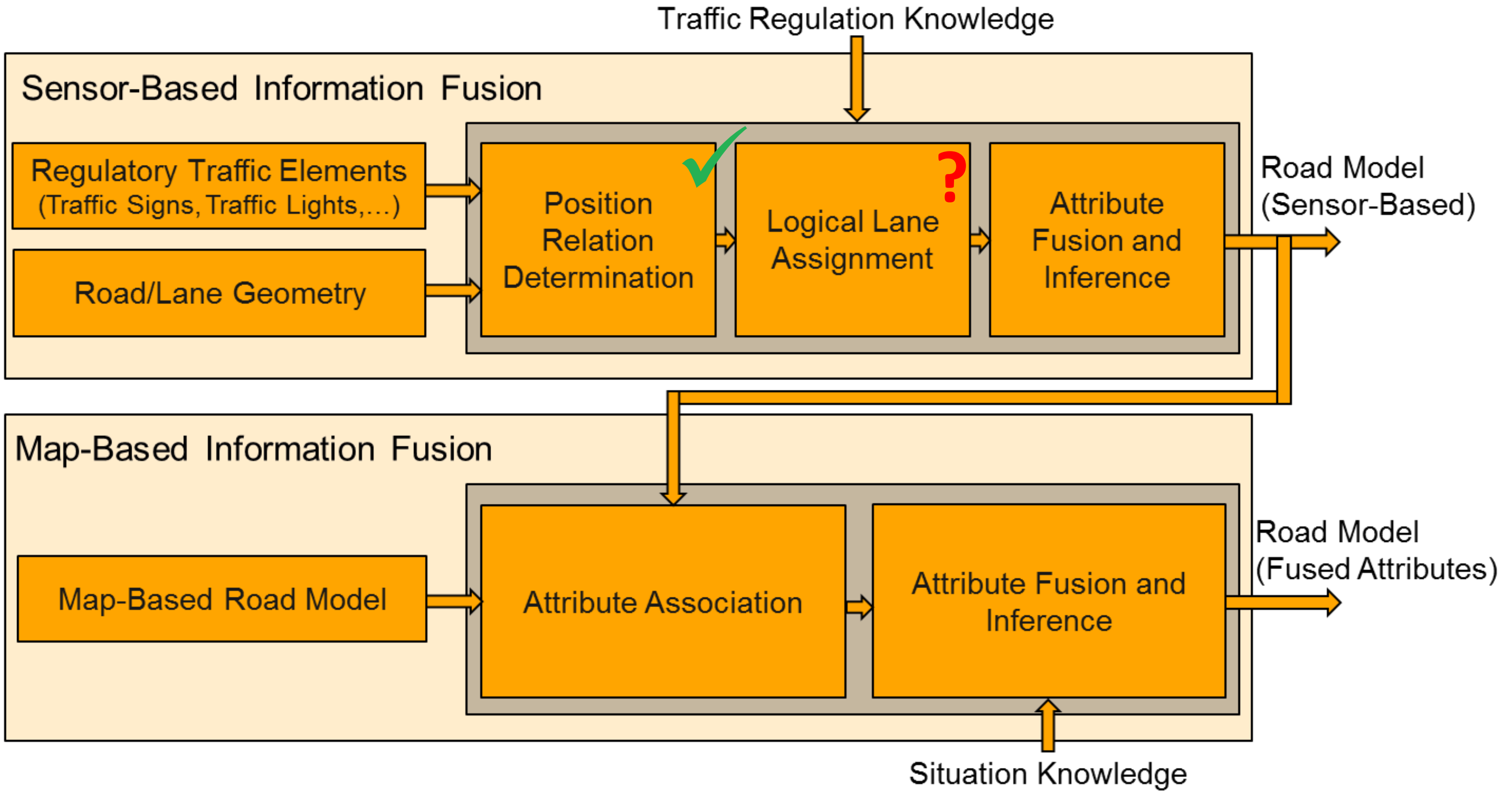
High-Level Road Model Fusion

Position Relation Determination

- Determination of **probabilistic position relations** between lanes and regulatory traffic elements.
- Consideration of spatial and existence uncertainties.
- **Method:** Monte Carlo



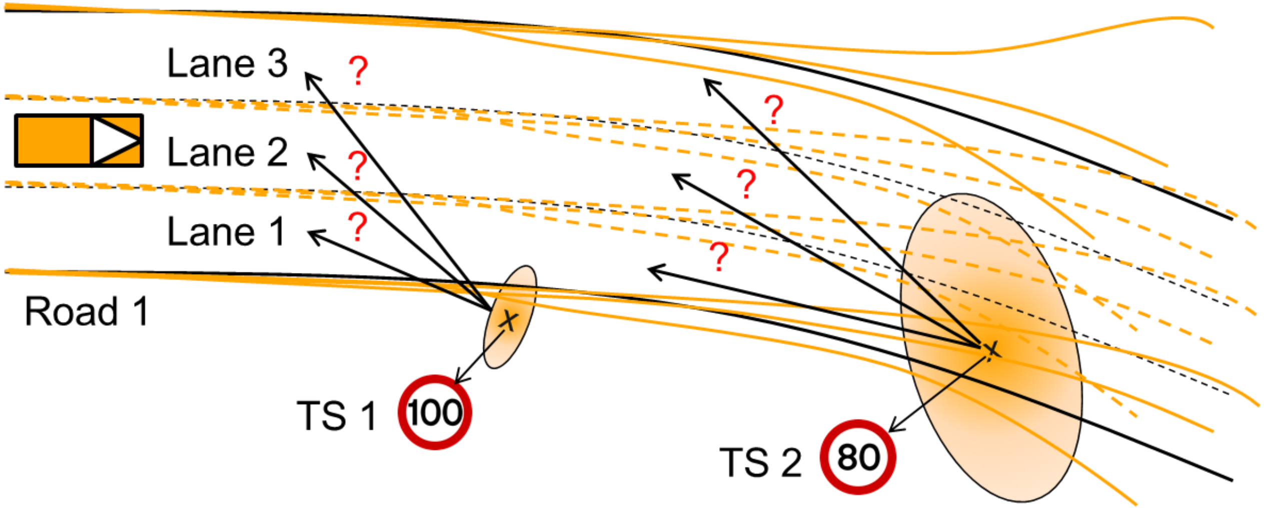
High-Level Road Model Fusion



High-Level Road Model Fusion

Logical Lane Assignment

- Inference of logical lane assignments, i.e. which regulatory traffic element is valid for which lane.
- Consideration of soft position relation evidences and traffic regulation knowledge.
- **Method:** Bayesian Networks



High-Level Road Model Fusion

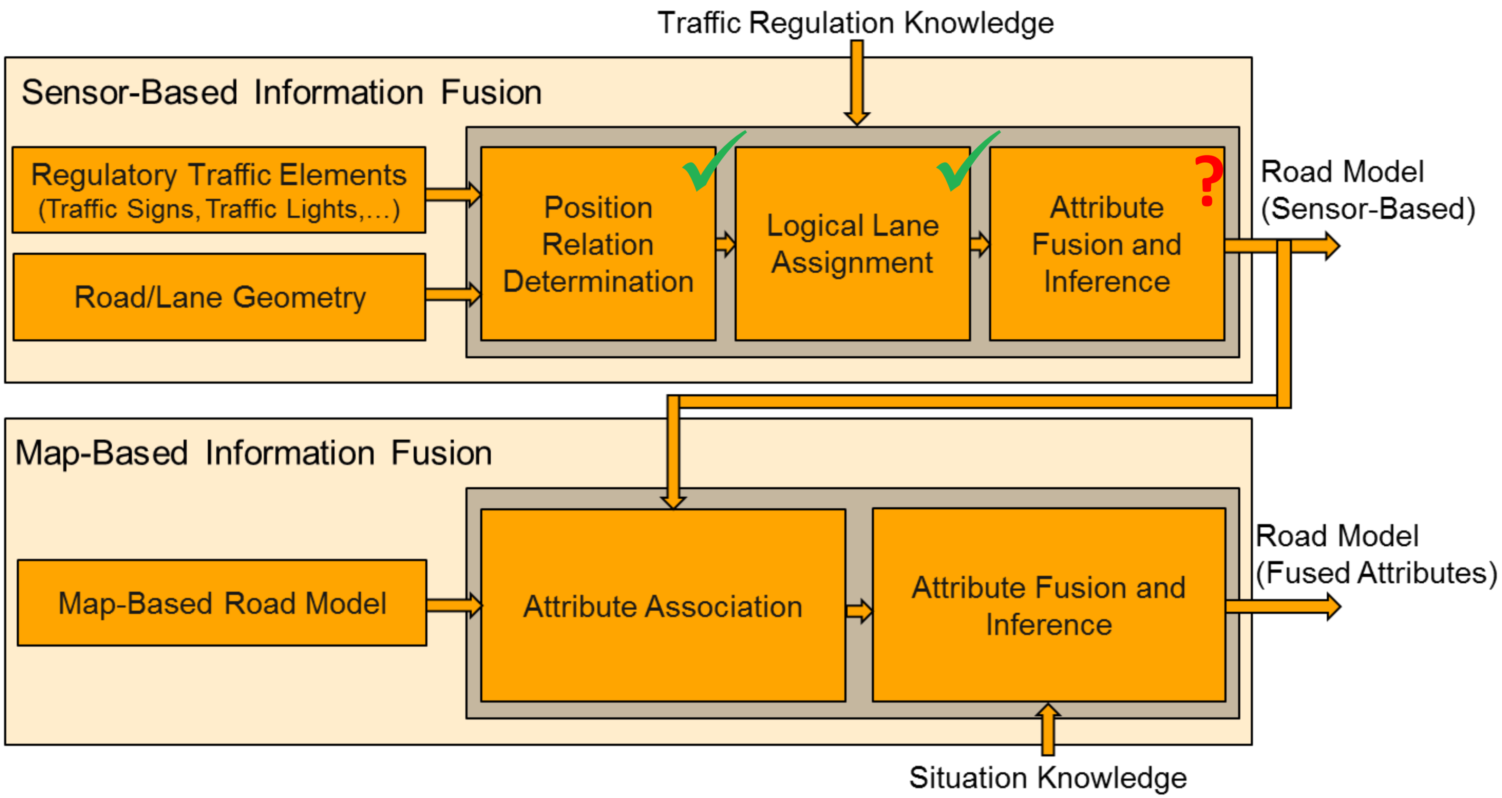
Logical Lane Assignment

Ko-HAF KOOPERATIVES HOCHAUTOMATISIERTES FAHREN

- Example: Simple **Bayesian network** for logical lane assignments of speed limit signs.

- Traffic regulation knowledge is encoded in **conditional probability tables**.
- Logical lane assignments are inferred (estimated) via **causal reasoning**.
- Inference via **junction tree algorithm** for arbitrary discrete, multiply-connected networks.

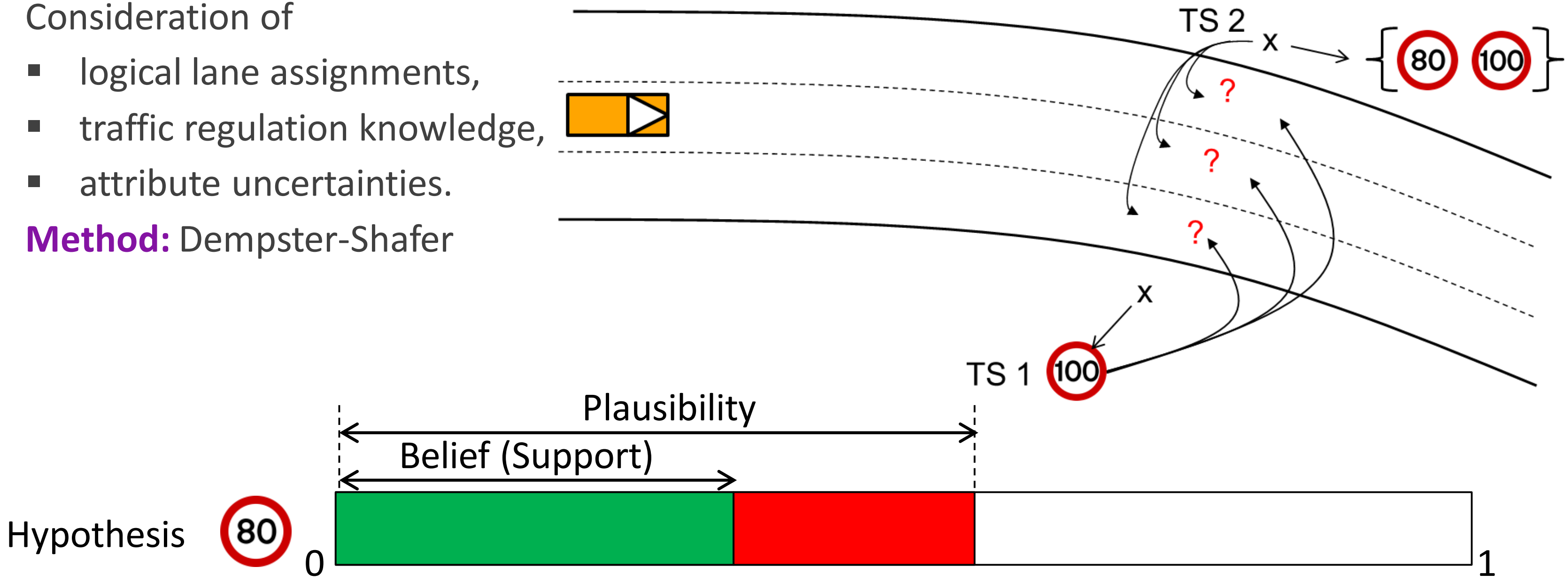
High-Level Road Model Fusion



High-Level Road Model Fusion

Attribute Fusion and Inference

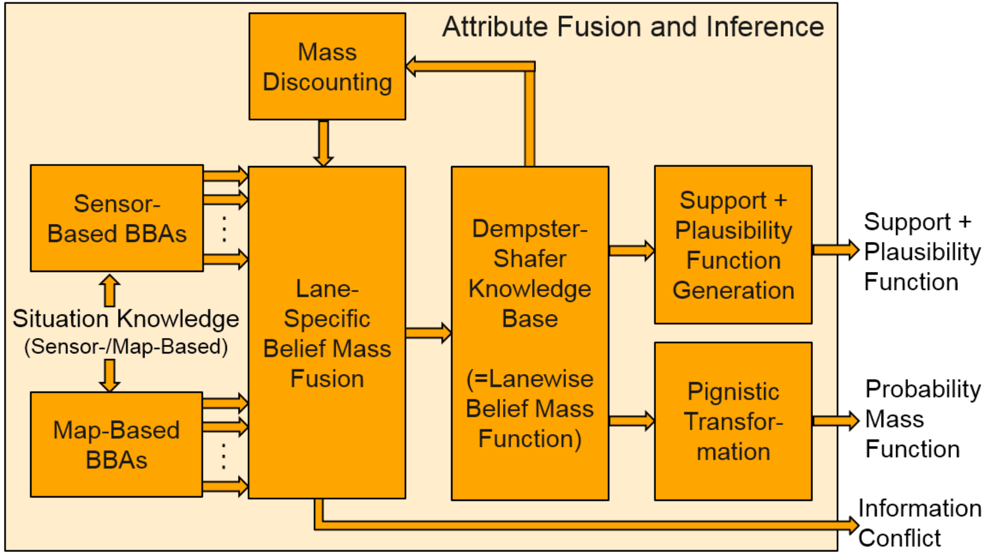
- Attribute fusion and inference of hidden attribute state ranges of non-observed lanes.
- Consideration of
  - logical lane assignments,
  - traffic regulation knowledge,
  - attribute uncertainties.
- **Method:** Dempster-Shafer

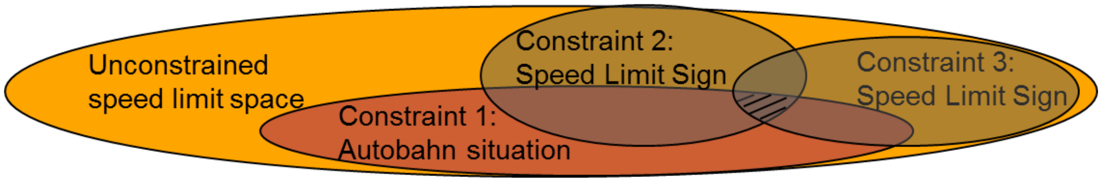


High-Level Road Model Fusion

Attribute Fusion and Inference

- Generation of sensor-based and map-based **Basic Belief Assignments** (BBAs).
- Lane-specific belief mass fusion to recursively update a **Dempster-Shafer knowledge base** of traffic rule knowledge.
- Dempster's rule of combination as fusion operator **for stochastic constraint combination**.





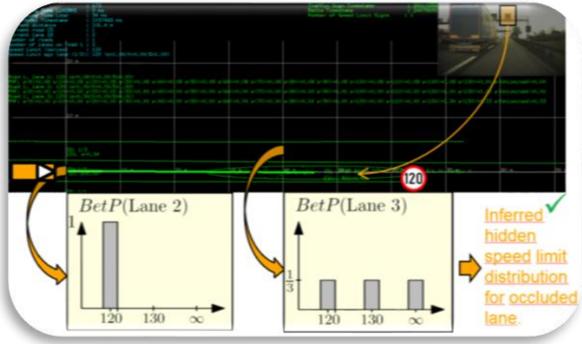
High-Level Road Model Fusion

Attribute Fusion and Inference

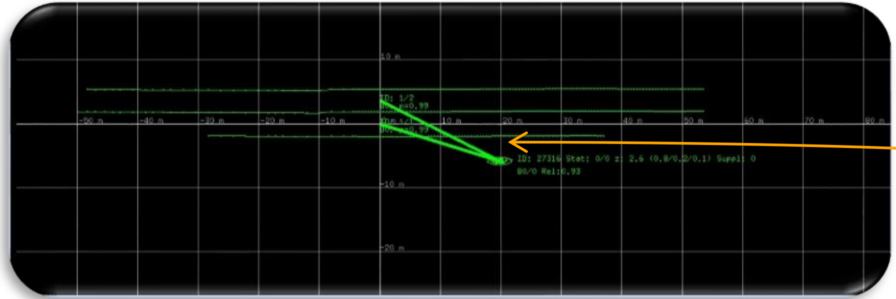
Ko-HAF
KOOPERATIVES HOCHAUTOMATISIERTES FAHREN

- Correction of false classifications.

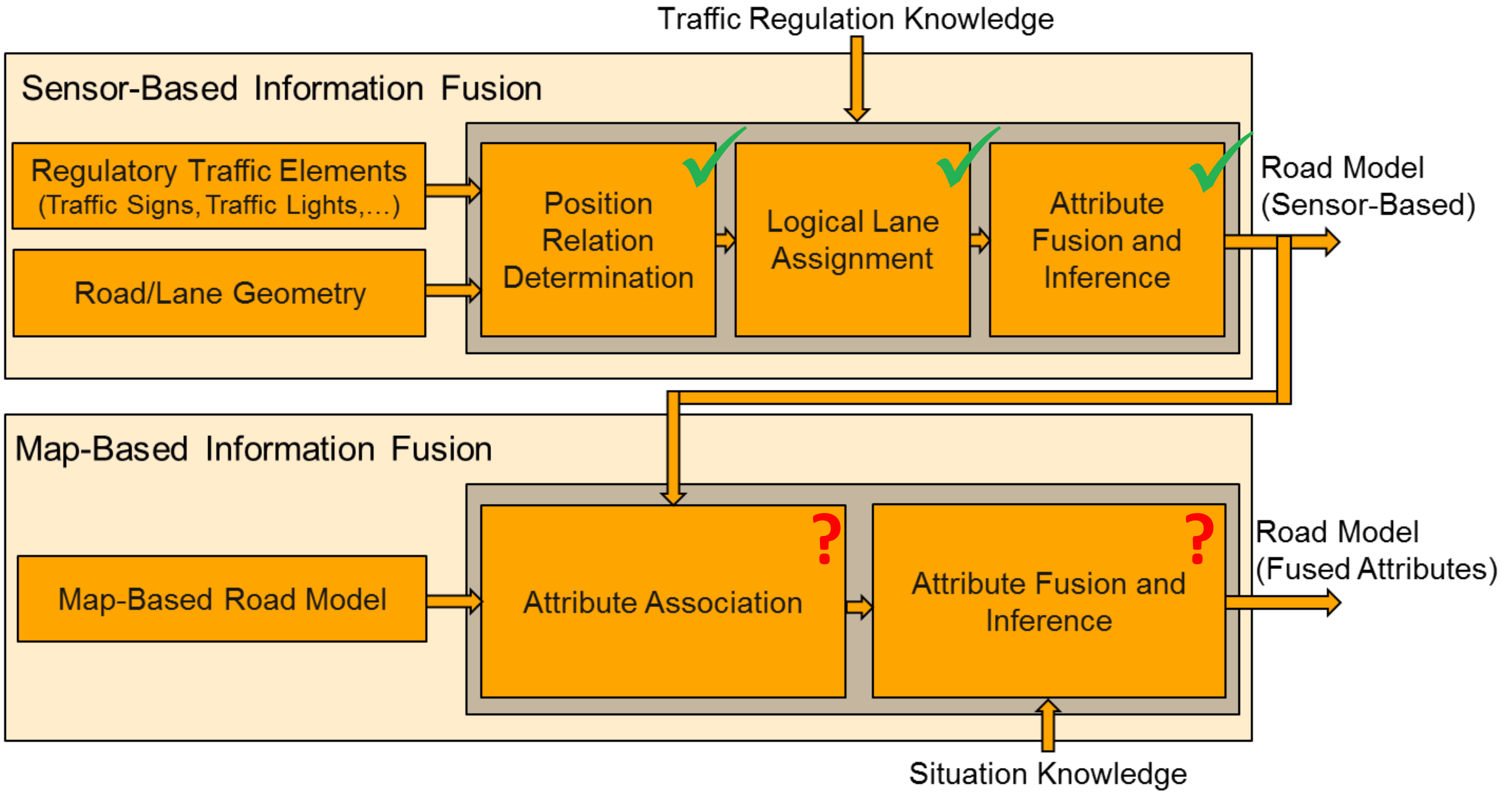
- Inference of hidden speed limit state ranges.



- However, there are situations in which backend map data becomes vital.



High-Level Road Model Fusion

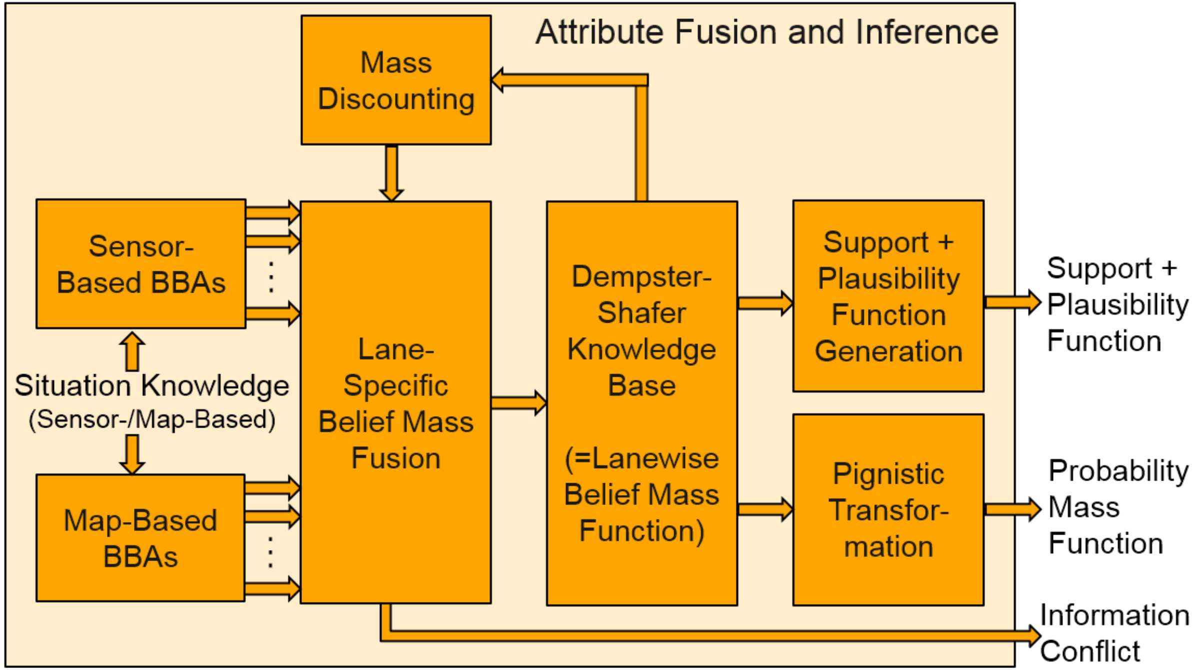


High-Level Road Model Fusion

Attribute Fusion and Inference

- Map-based BBAs are generated from **backend map data**.
- Fusion performed the same way as with sensor-based BBAs.
- Output either in form of
  - **support** and **plausibility** functions or
  - **probability mass functions**

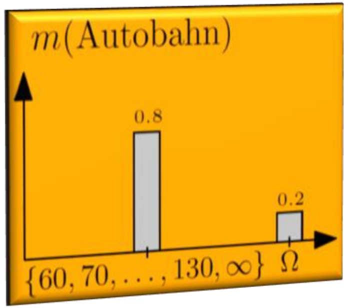
  including **information conflicts**.

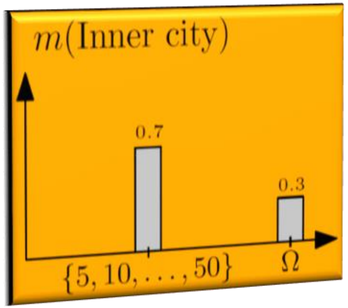


High-Level Road Model Fusion

Attribute Fusion and Inference

- Map-based BBAs are set up from
  - map speed limit attributes with attribute uncertainty provided by backend map,
  - map-based situation classes (autobahn, inner city, …).



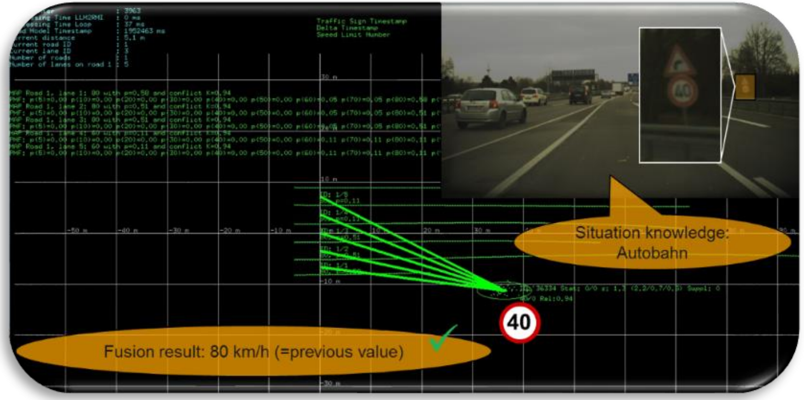


- Map-based speed limits are **adapted** depending on uncertain **situation knowledge**, e.g.
  - Dempster-Shafer map mass discounting in case of detected **variable message signs**.
  - Dempster-Shafer map mass discounting according to detected **construction sites**.

High-Level Road Model Fusion

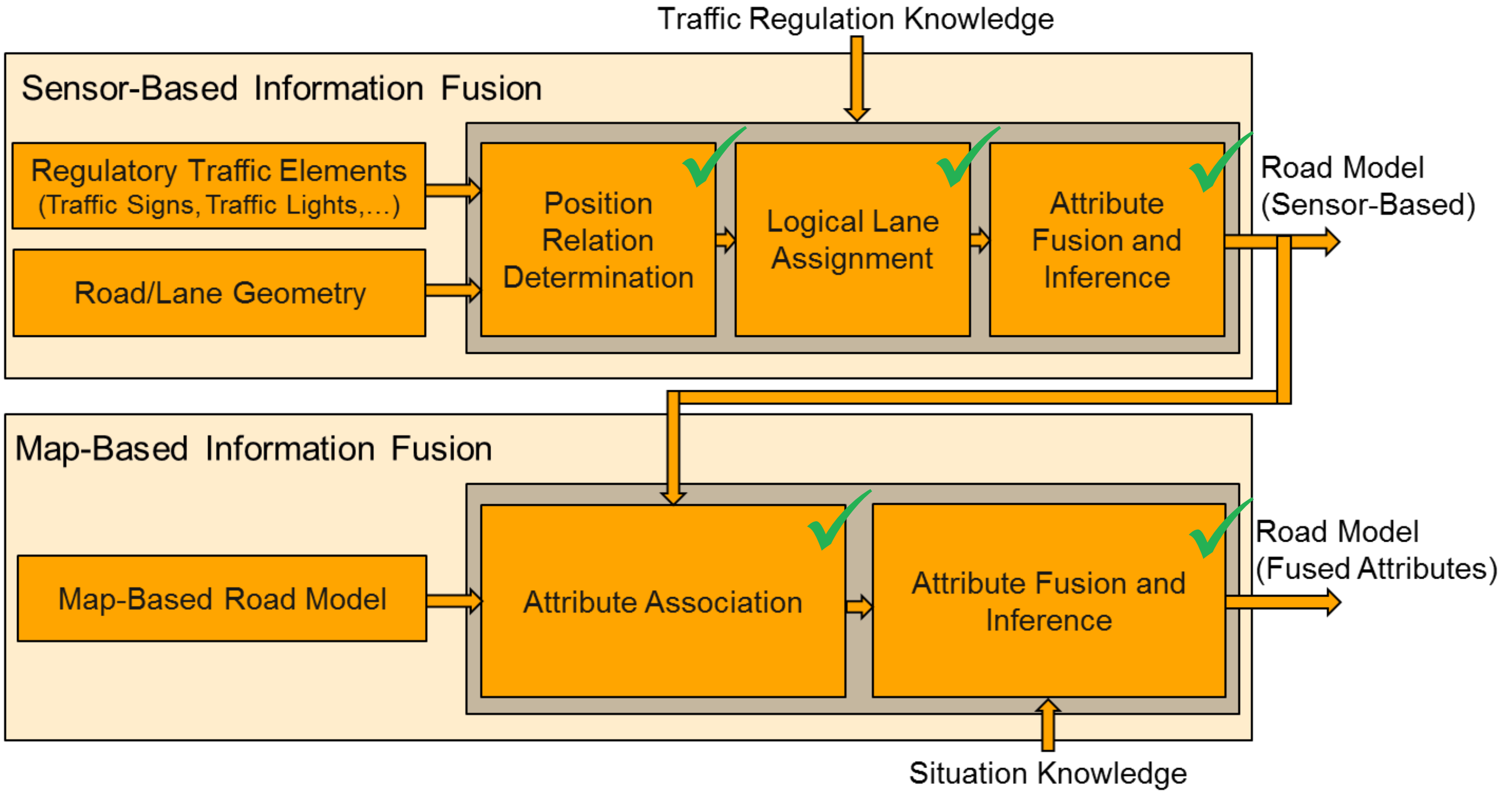
Attribute Fusion and Inference – Speed Limit Fusion Examples

- Correct fusion result in construction sites despite outdated map speed limits by using situation knowledge.
- Correct fusion result on the autobahn despite wrong speed limit sign associations by using situation knowledge.



→ Situation-adaptive fusion of **vehicle sensor** and **backend map data** leads to more **accurate environment models** and **resolves** unjustified fusion **conflicts**.

High-Level Road Model Fusion



Fusion Summary

- Presentation of a **road model fusion** concept for **traffic rule inference**, which
  - takes different kinds of uncertainties into account,
  - allows the seamless integration of multiple information sources,
  - uses traffic regulation knowledge for Bayesian network-based logical lane assignments,
  - incorporates situation knowledge within a Dempster-Shafer-based attribute fusion, and
  - permits plausibility checks between digital map content and sensor-inferred lane attributes.
- Exemplary concept demonstration and implementation for the task of **multi-lane speed limit inference**, but usable for other lane-specific attribute fusion tasks, e.g.
  - lane marker type fusion, no passing zone fusion, traffic light state fusion, dynamic backend event fusion (e.g. broken down vehicles), lane turn direction fusion, etc.

Further details: „Schreier, M. et al.: *„A High-Level Road Model Information Fusion Framework and its Application to Multi-Lane Speed Limit Inference*", IEEE Intelligent Vehicles Symposium 2017, June 2017, Redondo Beach, CA, USA.

Thank you

for your attention!

Gefördert durch:

Bundesministerium für Wirtschaft und Energie

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