VOLKSWAGEN
AKTIENGESELLSCHAFT
GROUP INNOVATION

CLASSIFICATION OF DRIVING MANEUVERS IN URBAN TRAFFIC FOR PARAMETRIZATION OF TEST SCENARIOS

Lukas Hartjen, Robin Philipp, Fabian Schuldt, Falk Howar and Bernhard Friedrich

PROBLEM STATEMENT

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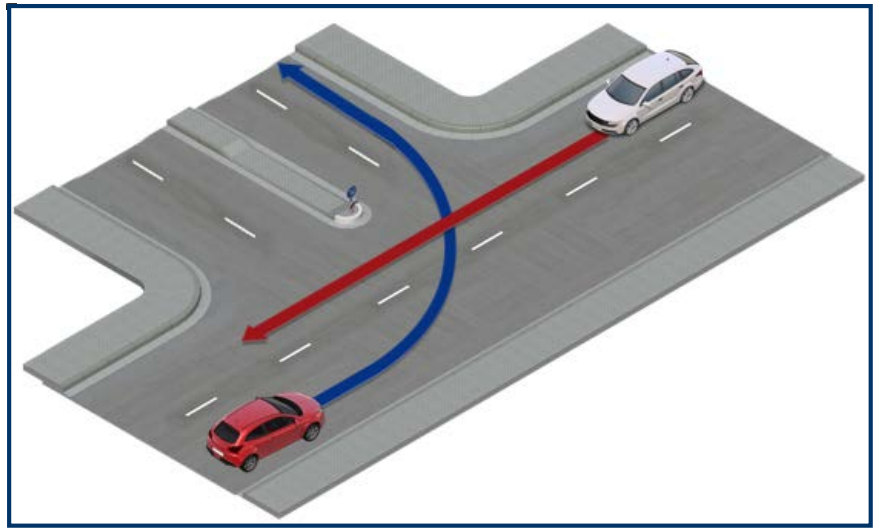
Scenario-Based Testing of Automated Driving Systems

Needed: A Set of Scenarios for Testing of Automated Driving Systems

Example: Left Turn at a T-Junction

- How can the behavior of an oncoming vehicle be described?
- How can it be parameterized?



Challenge: How can we describe scenarios explicitly?
Approach: Semantic Classification

DEFINITIONS & CONCEPT

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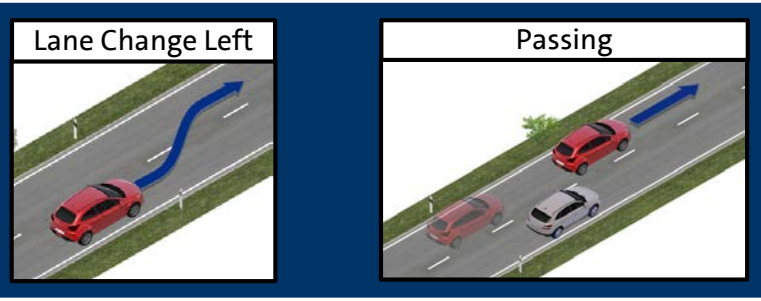
Maneuver Definition

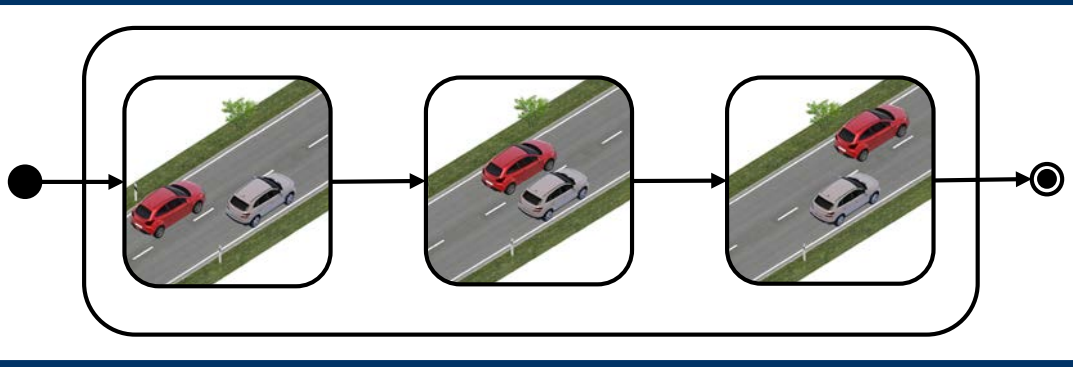
How can behavior of traffic participants be semantically classified?

→ Maneuvers!



What characterizes a maneuver?

Definition 1. Maneuver *A maneuver is the intentional transfer of a traffic participant from one defined state into the next, which can also be identical.*



Which traffic participant states do exist? Which are useful considering the definition of maneuvers?

→ A maneuver catalog for urban traffic is needed

DEFINITIONS & CONCEPT

Urban Vehicle Maneuver Catalog

4 Basic Maneuvers (+3 special cases) regarding the vehicle state

Layer 1: Vehicle State Maneuver

Accelerate	Keep Velocity	Decelerate	Reversing
Driveaway	Standstill	Halt	

11 Basic Maneuvers regarding four different infrastructure elements

Considers lane markings, junctions, crosswalks and parking spaces

Layer 2: Infrastructure Maneuver

Follow Lane	Lane Change {left, right}	
Approach Junction	Cross Junction	Turn {left, right, U}
Approach Crosswalk	Cross Crosswalk	
Park		

4 Basic Maneuvers regarding two different types of surrounding objects (leading vehicle, neighboring vehicle)

Layer 3: Object-related Maneuver

Follow Object	Approach Object	Fall behind
Passing		

DEFINITIONS & CONCEPT

Urban Vehicle Maneuver Catalog – Vehicle State Maneuver

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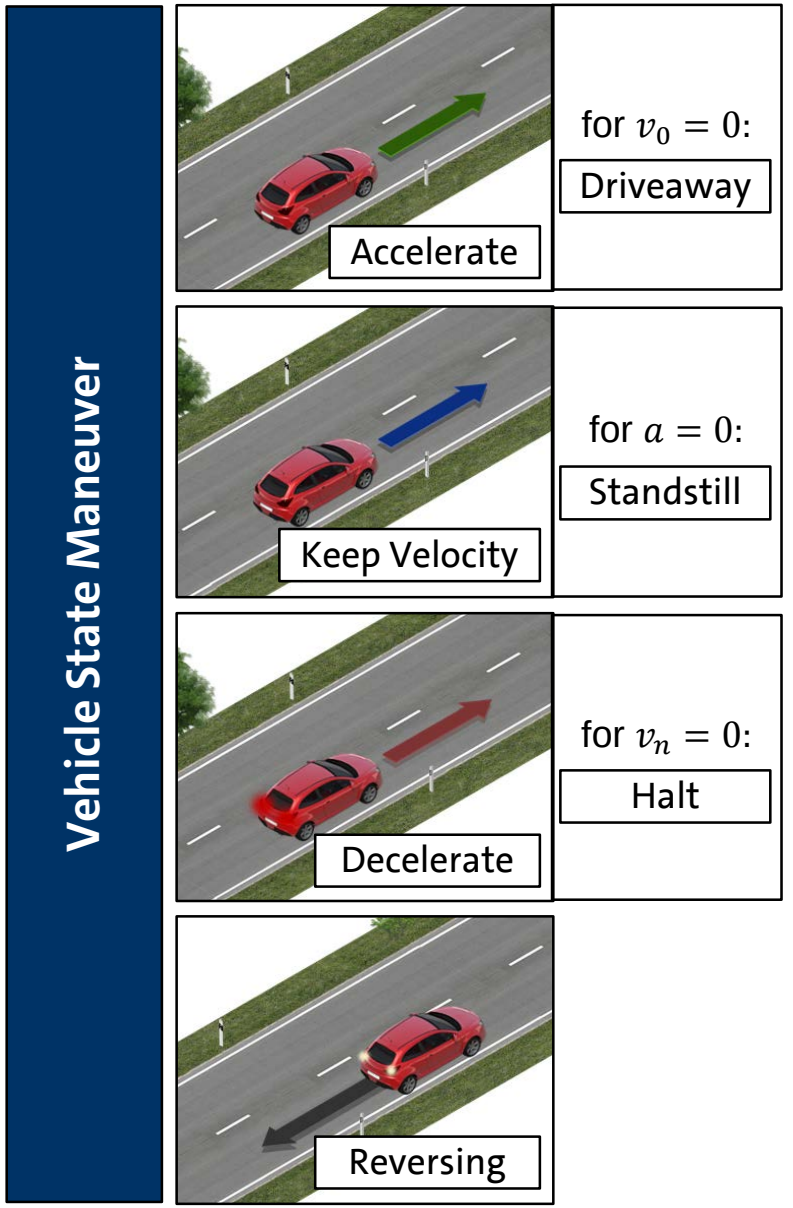


DEFINITIONS & CONCEPT

Urban Vehicle Maneuver Catalog – Infrastructure Maneuver

Layer 1: Vehicle State Maneuver

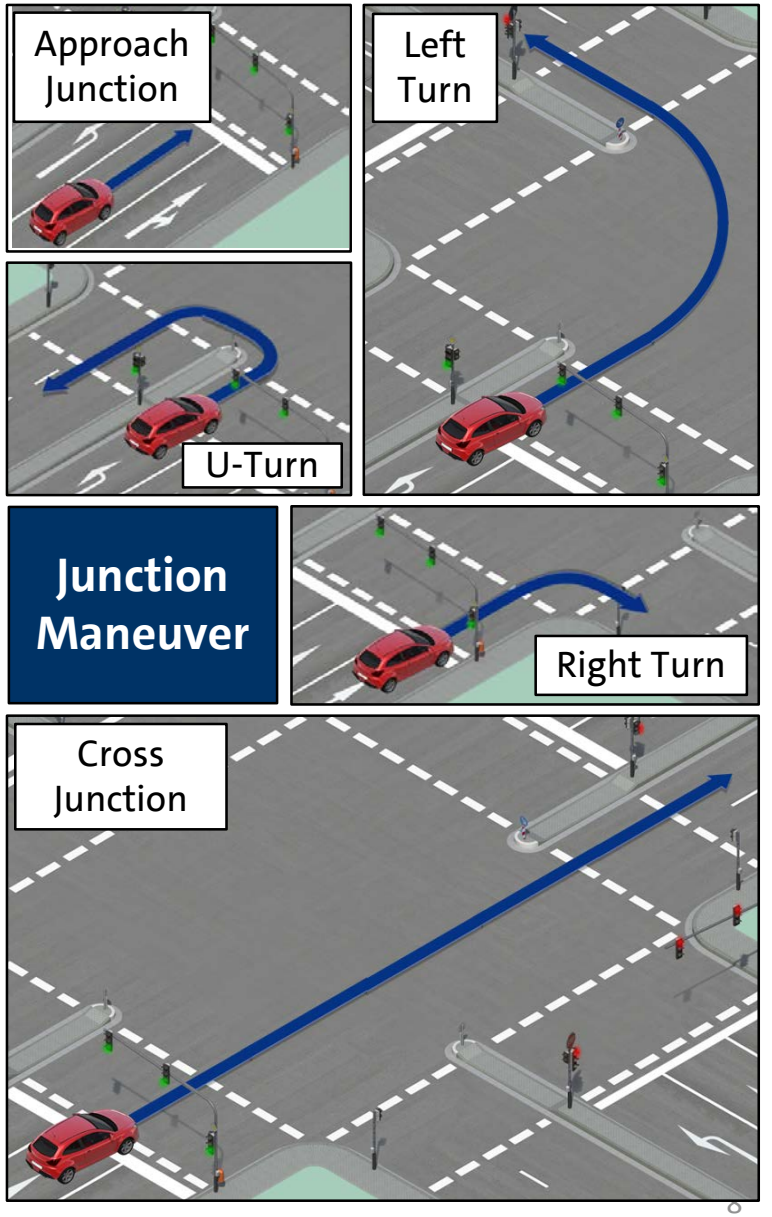
Accelerate	Keep Velocity	Decelerate	
Driveaway	Standstill	Halt	Reversing

Layer 2: Infrastructure Maneuver

Follow Lane		Lane Change {left, right}
Approach Junction	**Cross Junction**	**Turn {left, right, U}**
Approach Crosswalk		Cross Crosswalk
Park		

Layer 3: Object-related Maneuver

Follow Object	Approach Object	Fall behind
Passing		



DEFINITIONS & CONCEPT

Urban Vehicle Maneuver Catalog – Infrastructure Maneuver

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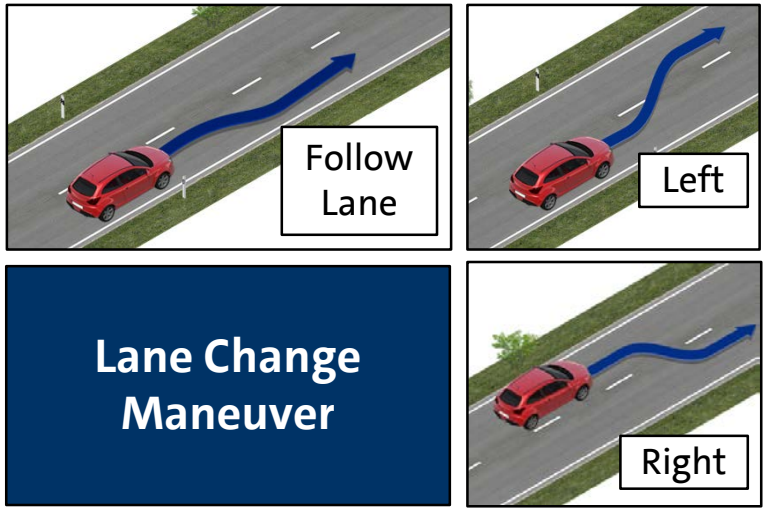

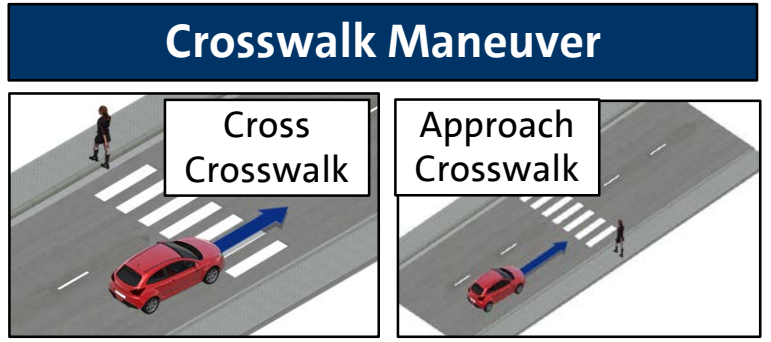

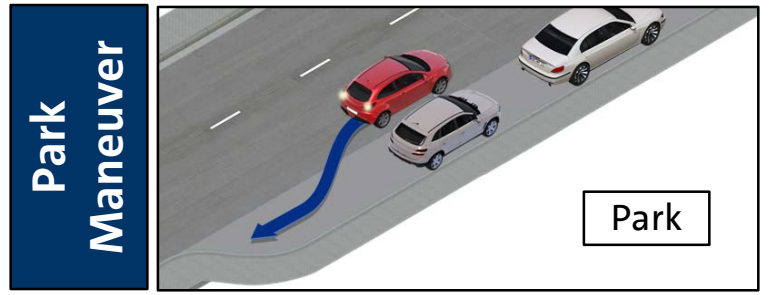

DEFINITIONS & CONCEPT

Urban Vehicle Maneuver Catalog – Object-related Maneuver

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Accelerate	Keep Velocity	Decelerate	Reversing
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Follow Lane	Lane Change {left, right}	
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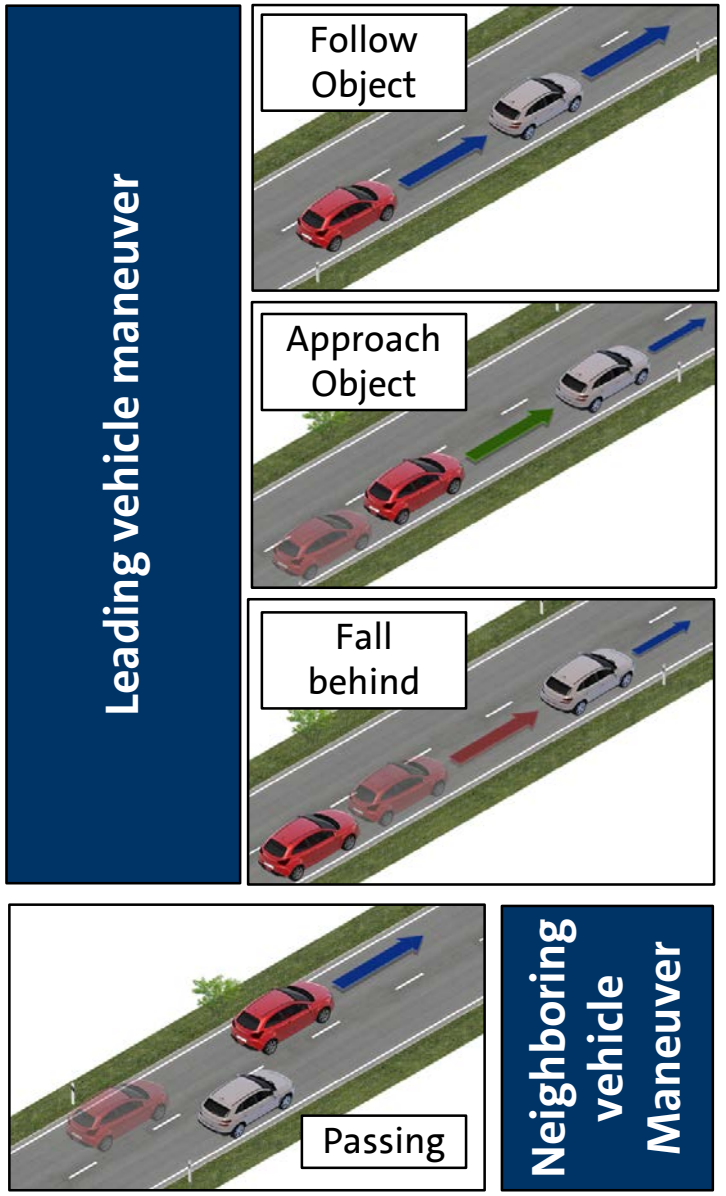
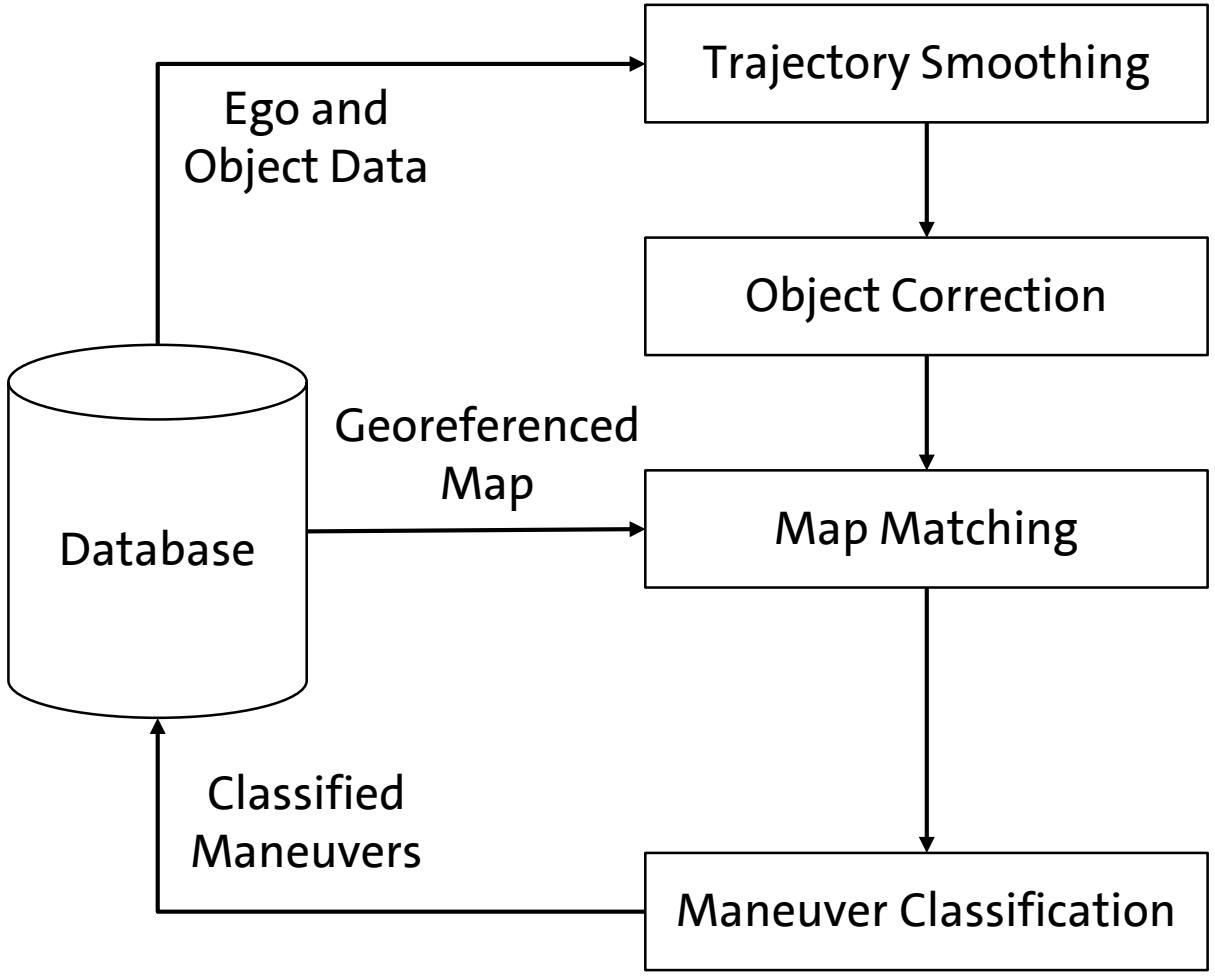


DEFINITIONS & CONCEPT

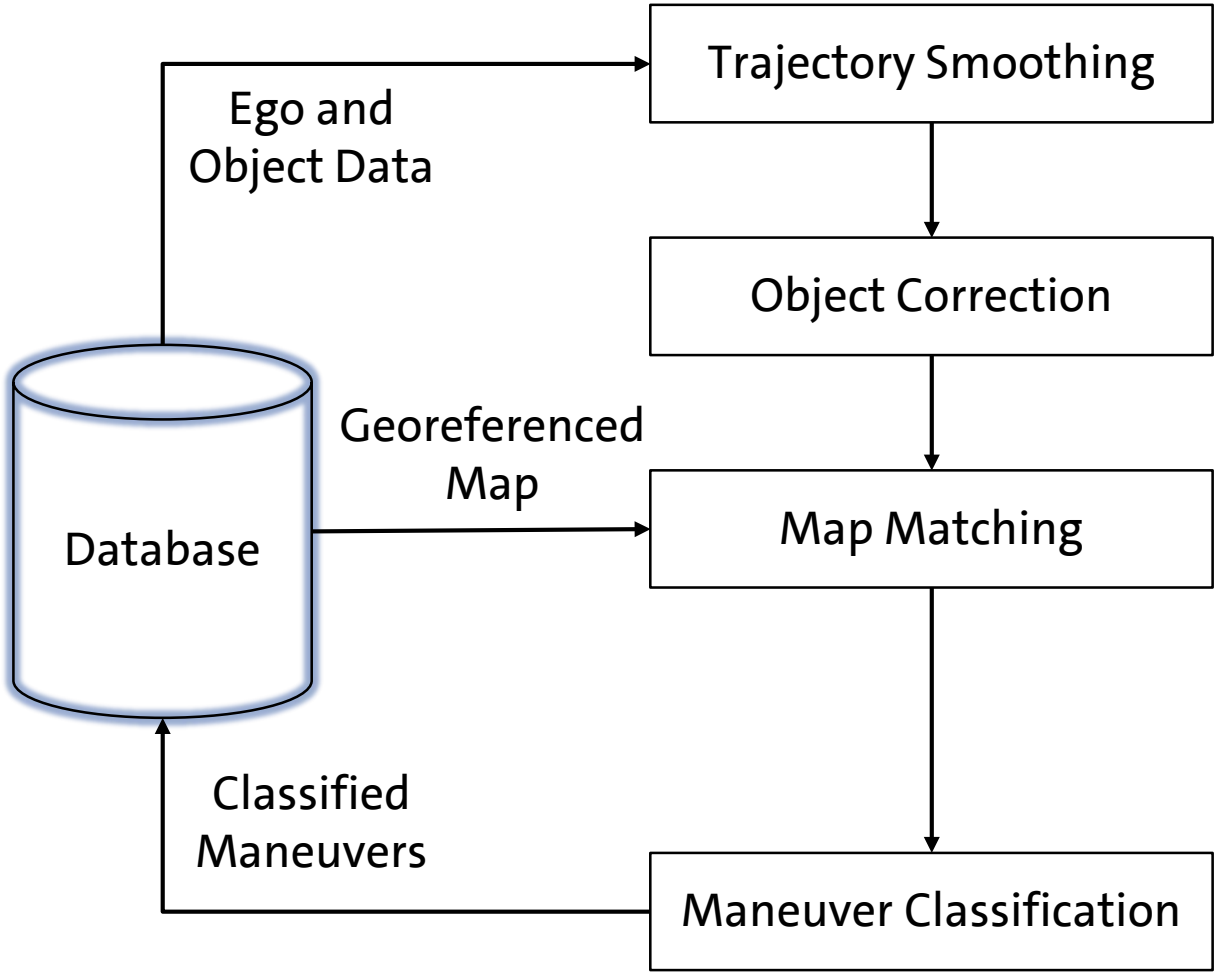
Maneuver Extraction Process



1. Record test drive and store it in the database
2. Smooth trajectories by Gaussian filtering
3. Correct static object attributes
4. Match object positions onto lanes
5. Rule-based maneuver classification
6. Store extracted maneuvers in database

DEFINITIONS & CONCEPT

Maneuver Extraction Process



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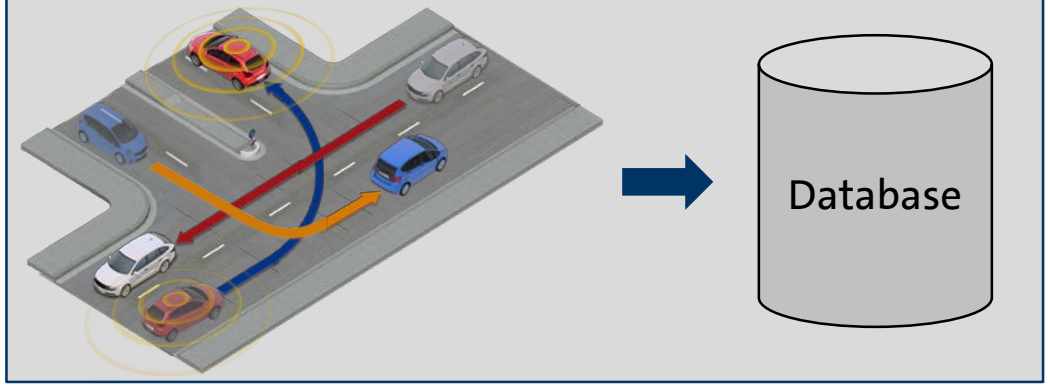

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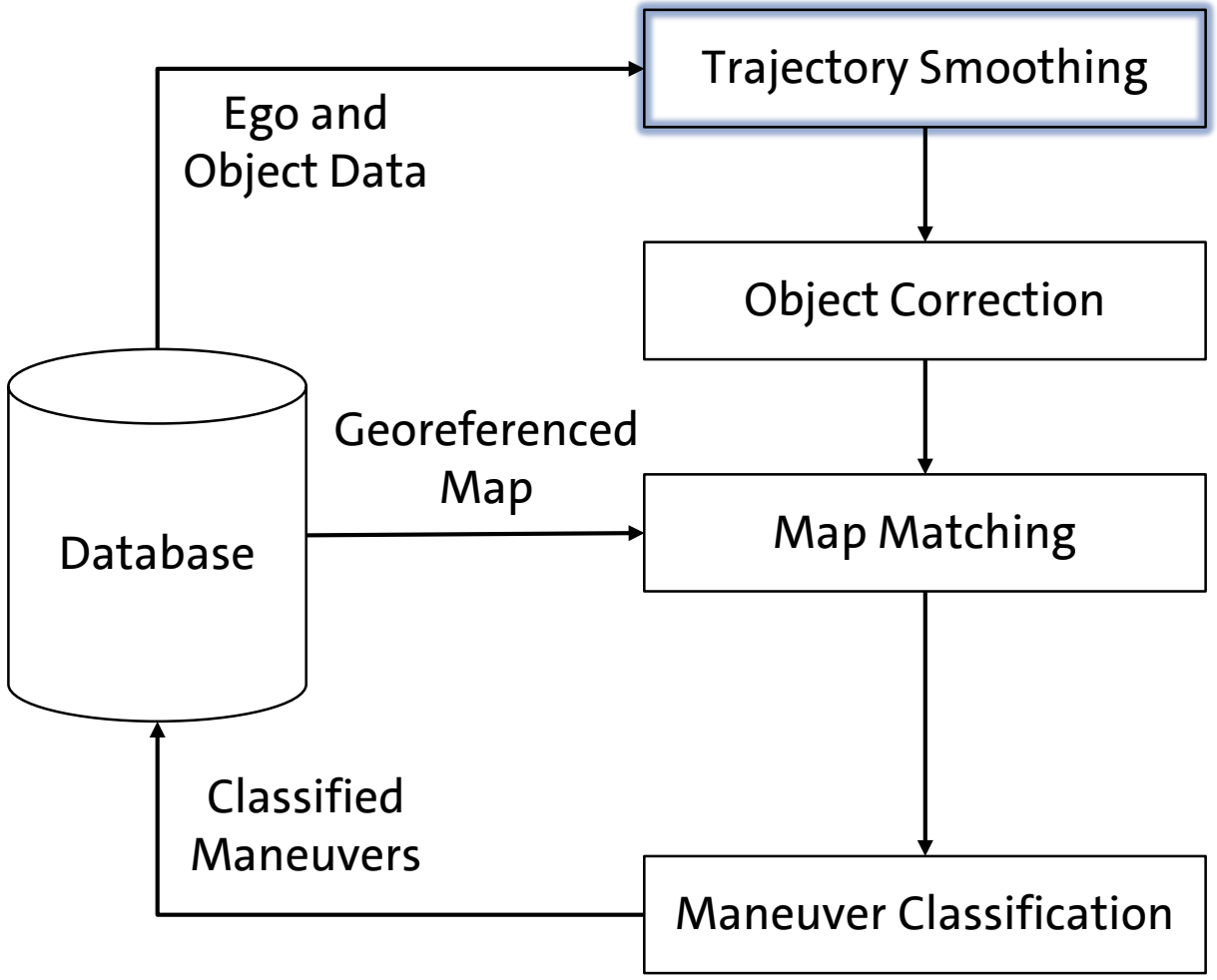

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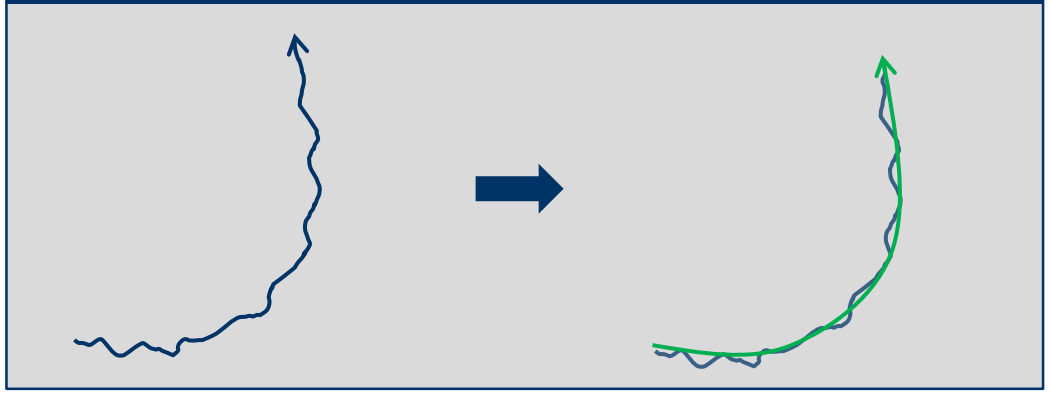

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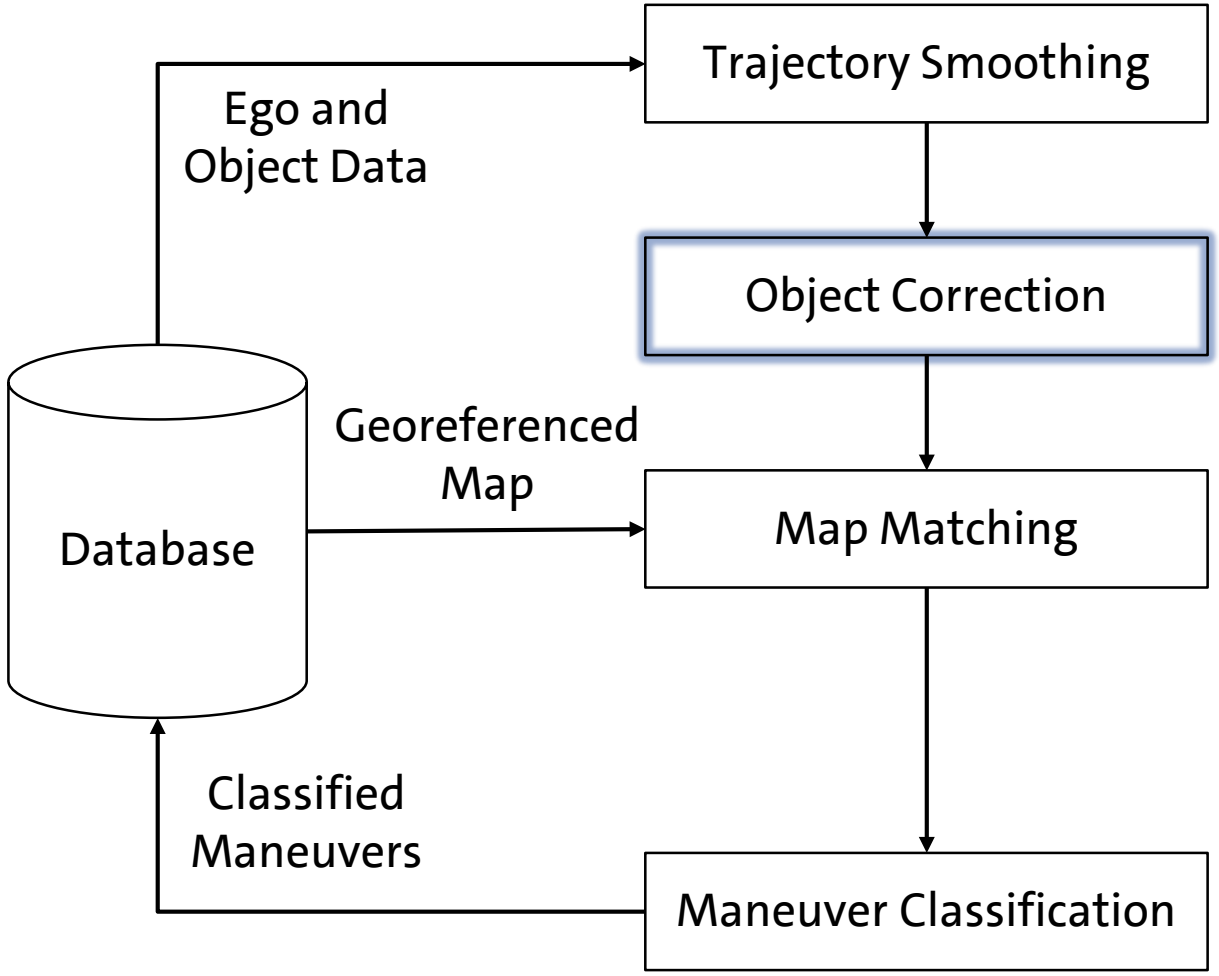
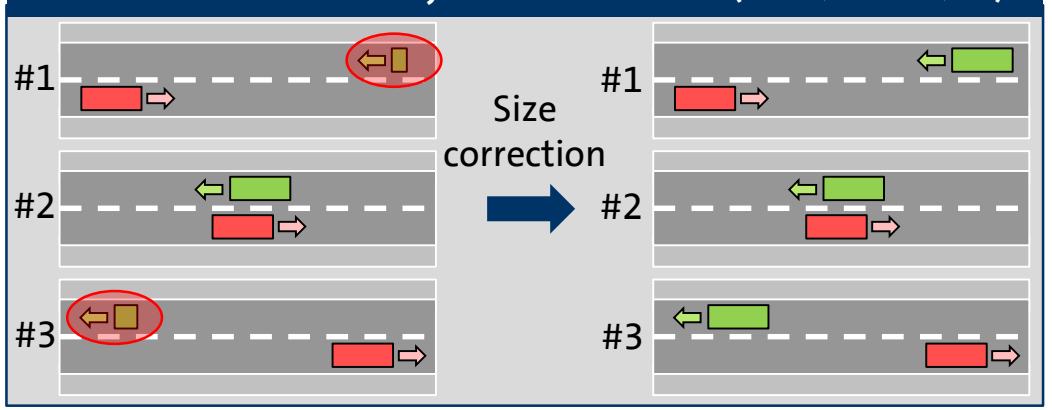


1. Record test drive and store it in the database
2. Smooth trajectories by Gaussian filtering
3. Correct static object attributes (size, class, ...)



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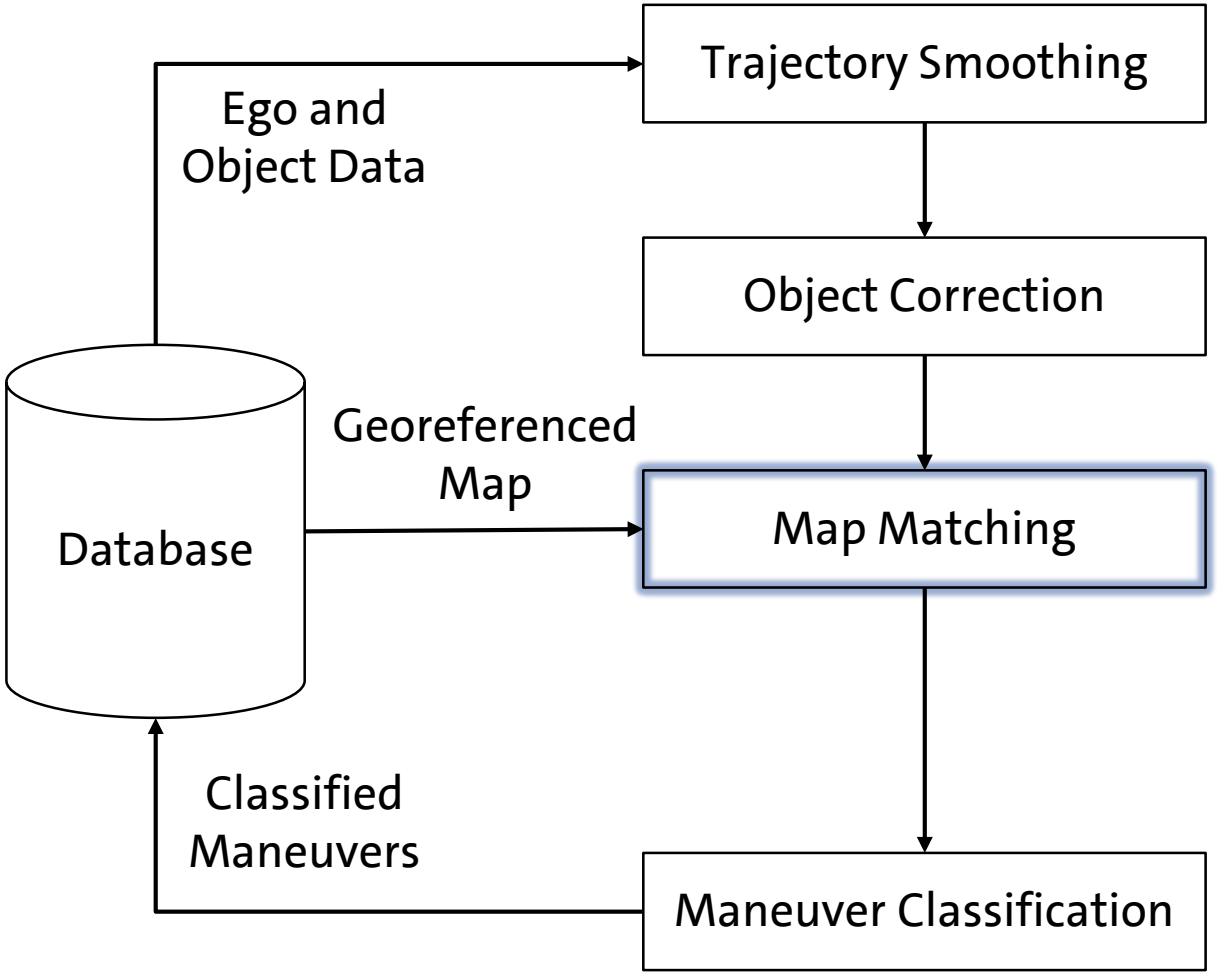

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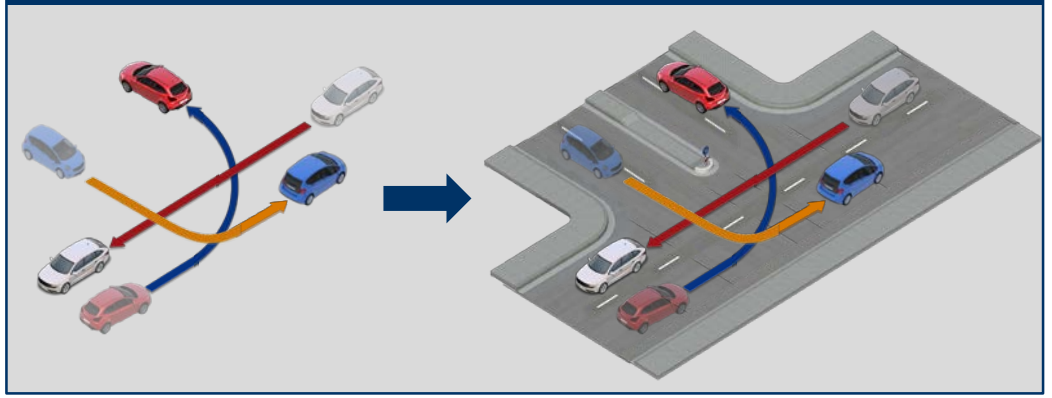

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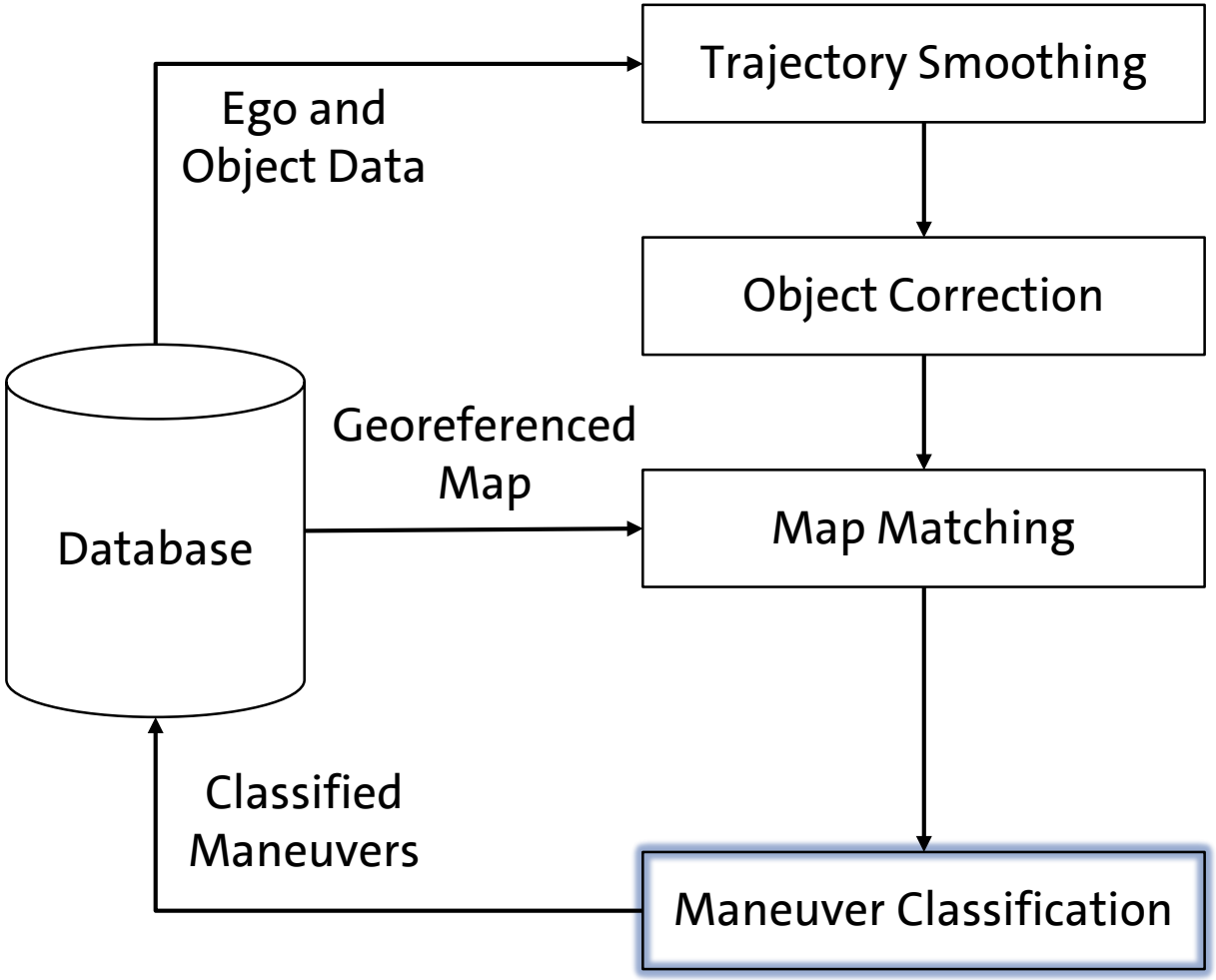

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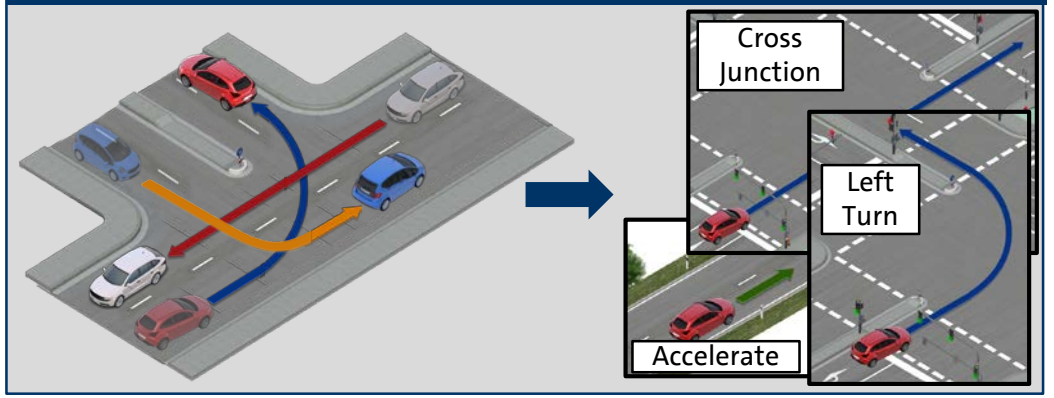

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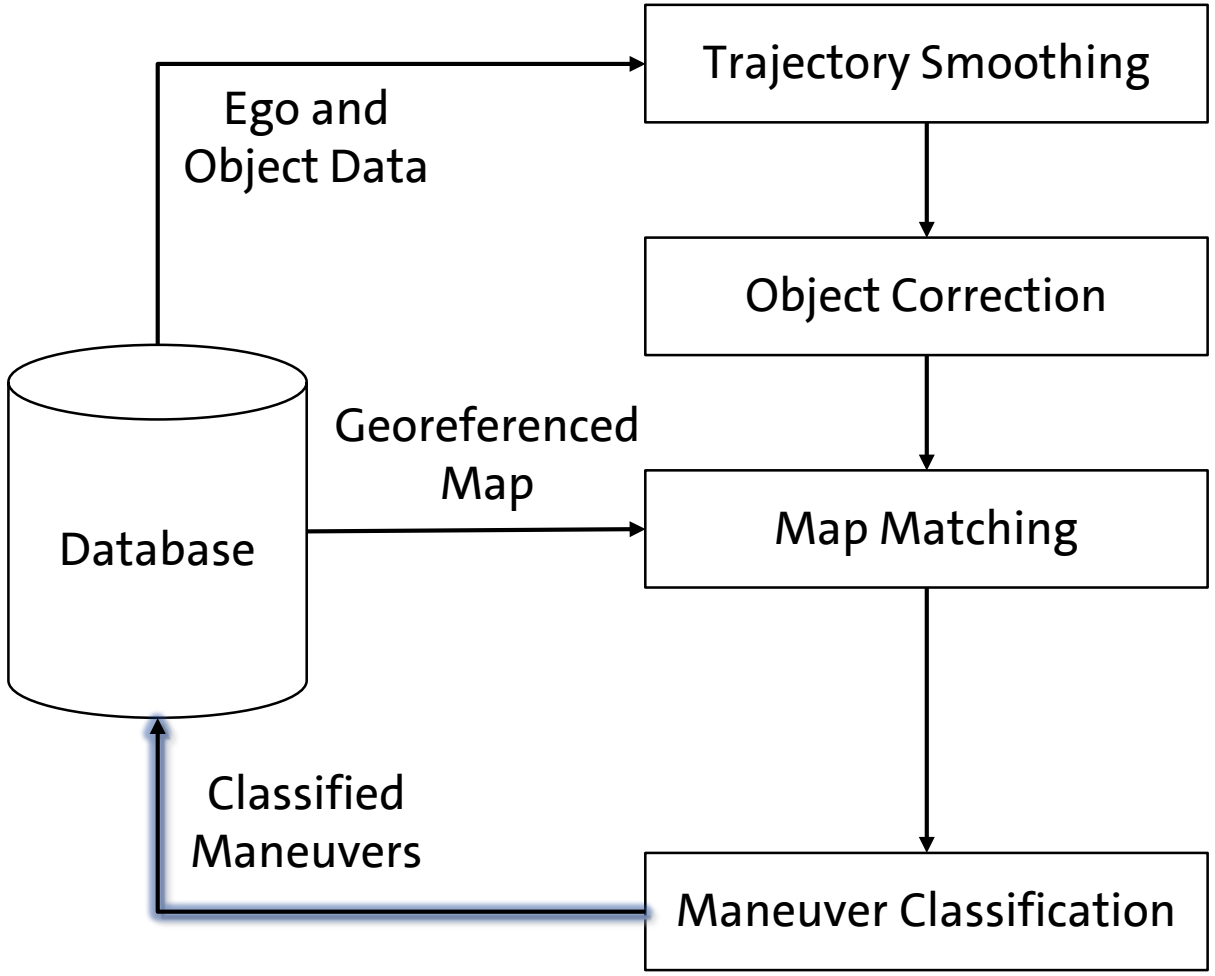

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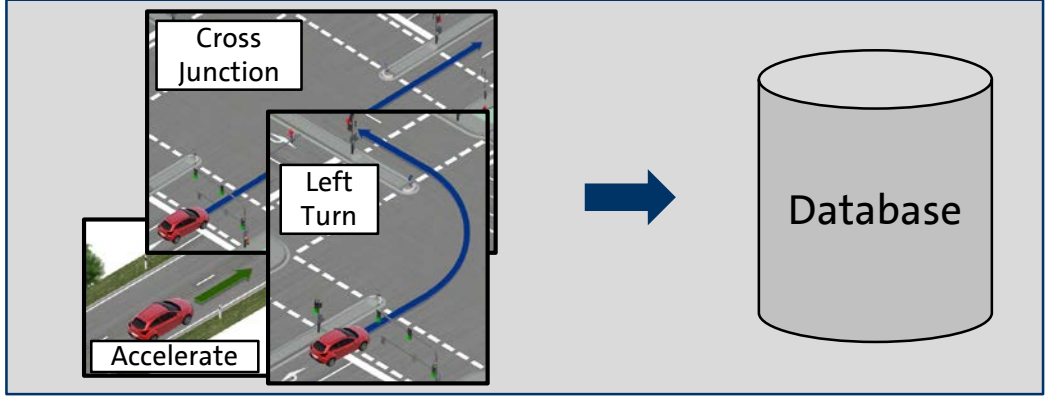

INITIAL APPLICATION

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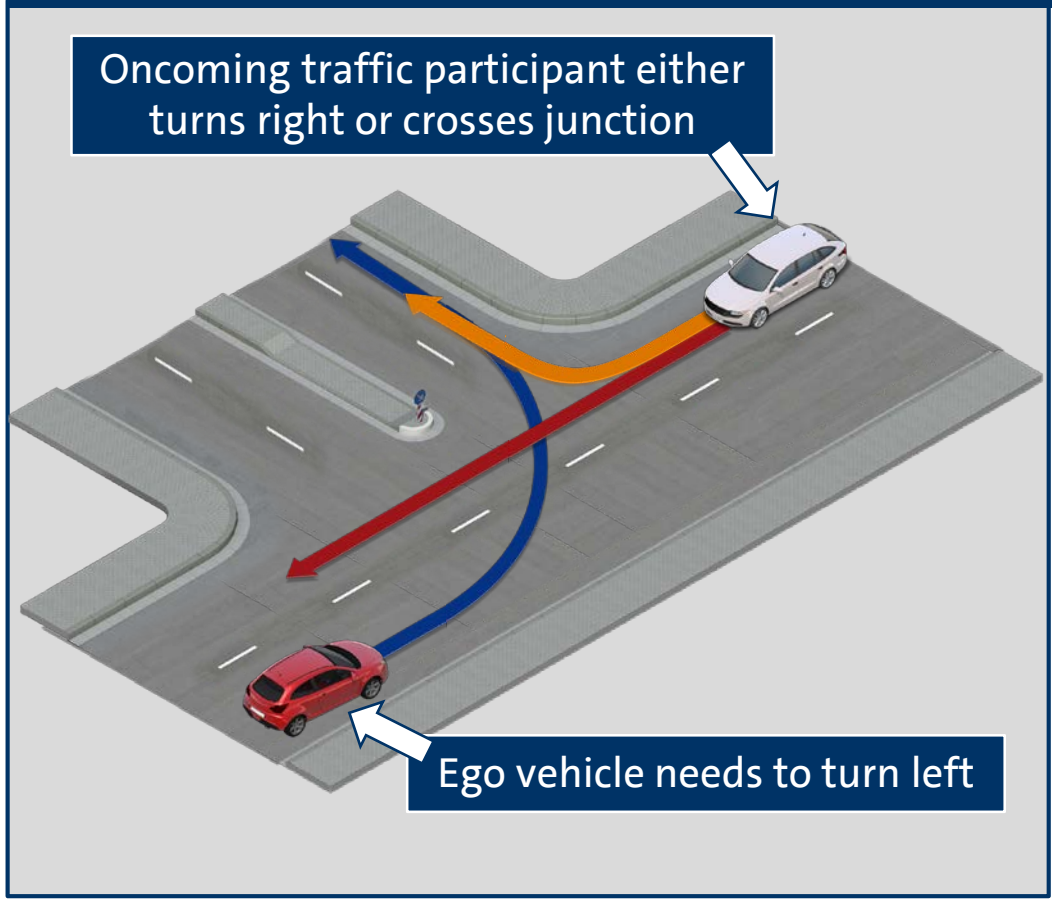
Exemplary *Functional Scenario*: „Unprotected Left Turn“

Functional Scenario “Unprotected Left Turn”



Unprotected Left Turns pose a challenge for Automated Driving Systems

Well-arranged dependencies:

- Ego needs to give way
- Oncoming vehicle has right of way

Influence of varying infrastructure on vehicle behavior is neglected by focusing on this fixed exemplary junction

Analyzed junction

Satellite image: https://map.openaerialmap.org/

INITIAL APPLICATION

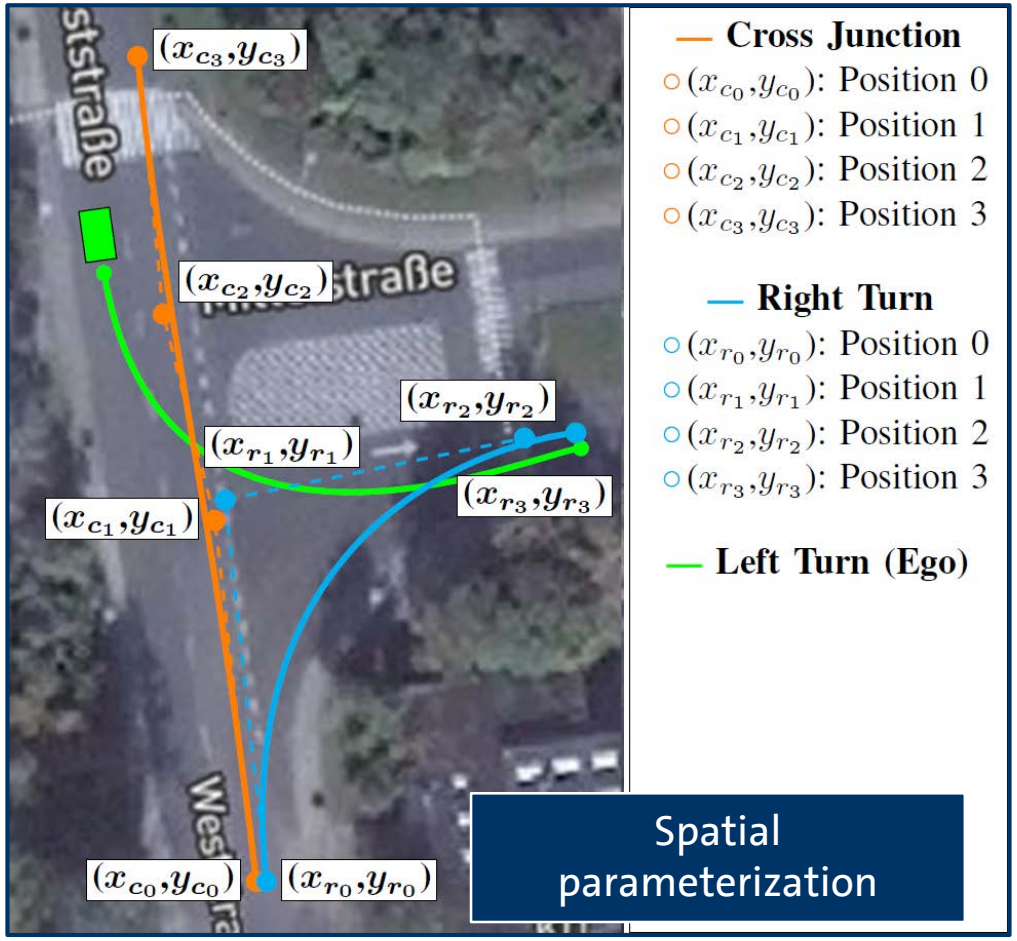
Parameterization of the Maneuvers *Cross Junction* and *Right Turn*

Spatio-temporal course of both *Left Turn* and *Cross Junction* are parameterized as three-dimensional Bézier curves of third order:

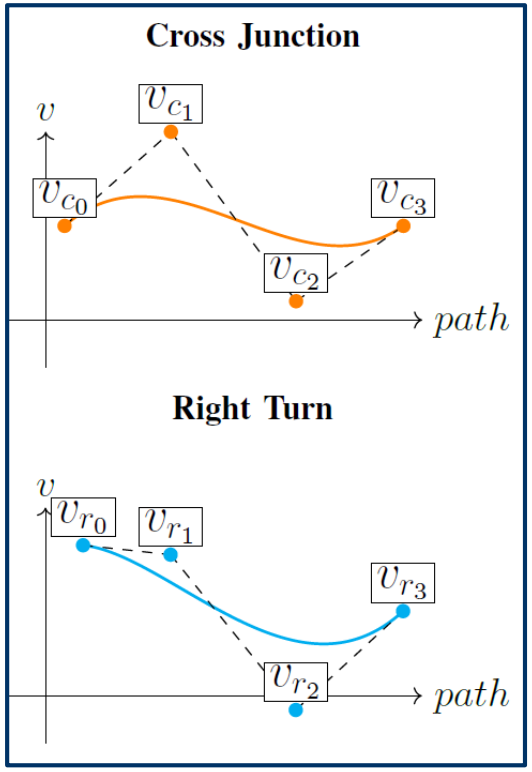
$$b(t) = \sum_{i=0}^{3} \binom{3}{i} t^i (1-t)^{3-i} b_i, 0 \leq t \leq 1$$

Additional trigger parameter d_{ego} to specify junction entry of oncoming vehicle relative to ego position

→ Functional Scenario consists of 13 parameters



Spatial parameterization

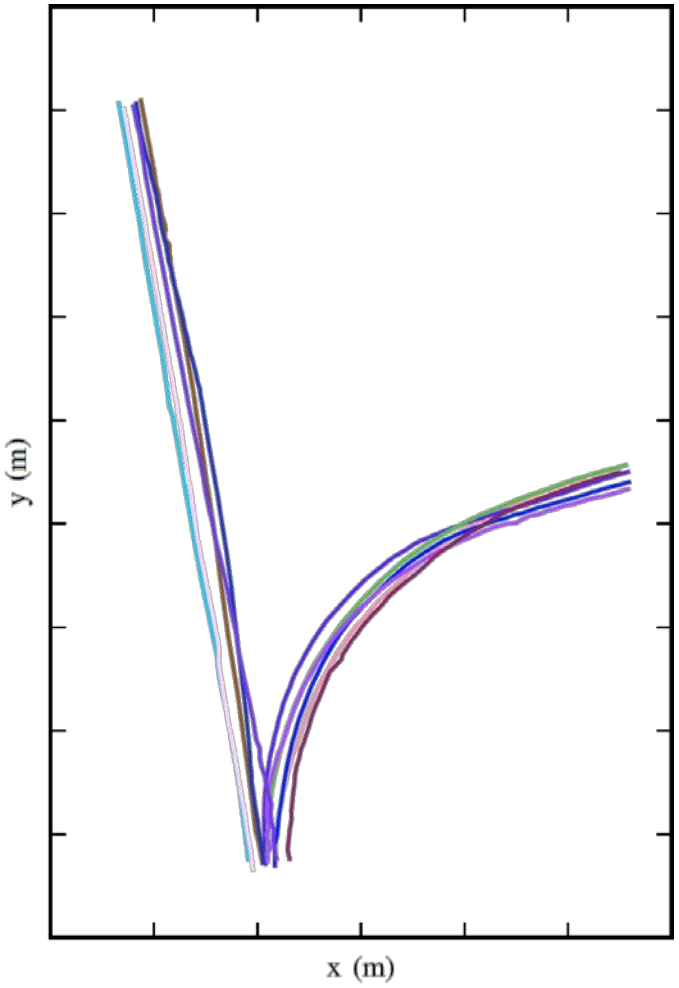


Temporal parameterization

Satellite image: https://map.openaerialmap.org/

INITIAL APPLICATION

Observed Maneuvers and resulting Parameter Distributions



Cross Junction

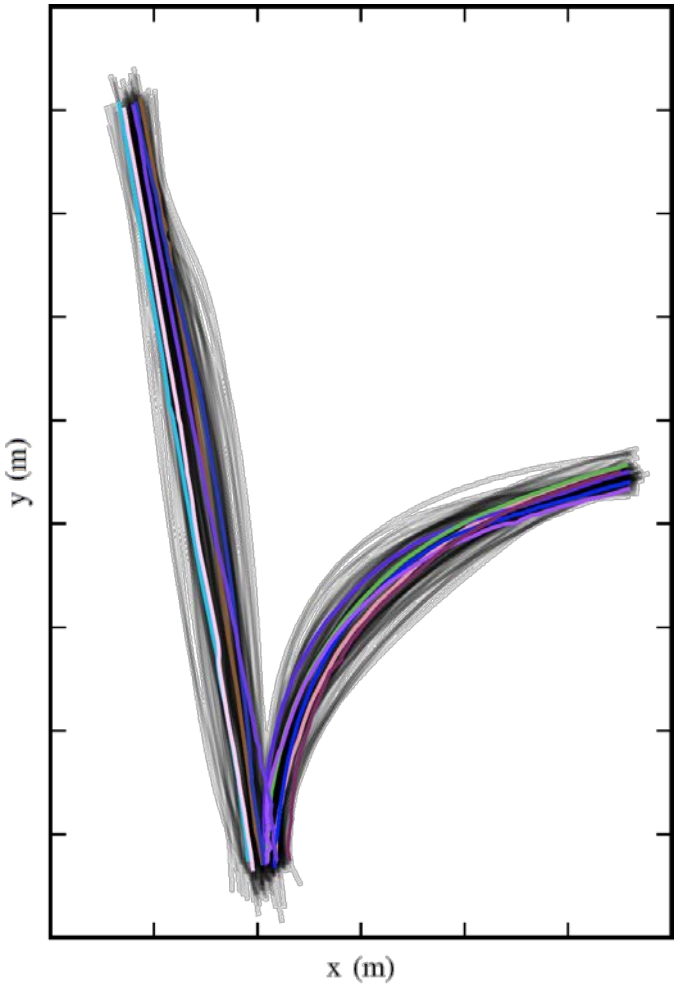
[m]	μ	σ	[m]	μ	σ	[m/s]	μ	σ
x_{c_0}	619787.4	0.22	y_{c_0}	5810521.4	1.10	v_{c_0}	10.91	1.29
x_{c_1}	619780.9	2.97	y_{c_1}	5810563.1	15.36	v_{c_1}	9.9	3.14
x_{c_2}	619781.3	2.97	y_{c_2}	5810564.5	6.29	v_{c_2}	3.0	8.71
x_{c_3}	619776.4	1.05	y_{c_3}	5810593.6	1.53	v_{c_3}	10.2	2.38
d_{Ego}	53.1	21.97						

Right Turn

[m]	μ	σ	[m]	μ	σ	[m/s]	μ	σ
x_{r_0}	619787.7	0.88	y_{r_0}	5810521.9	0.73	v_{r_0}	9.4	0.44
x_{r_1}	619789.7	3.09	y_{r_1}	5810549.1	3.70	v_{r_1}	8.9	1.47
x_{r_2}	619803.9	4.97	y_{r_2}	5810552.7	1.16	v_{r_2}	7.2	2.39
x_{r_3}	619822.2	1.67	y_{r_3}	5810559.8	0.85	v_{r_3}	8.1	2.23
d_{Ego}	53.2	12.00						

INITIAL APPLICATION

Resulting Parameter Distributions



Recorded trajectories are shown in color

200 new trajectories were sampled (grey)

Samples extend the parametric coverage achieved by the recordings alone

Trajectories are turned into *OpenSCENARIO* files for use in a simulation environment

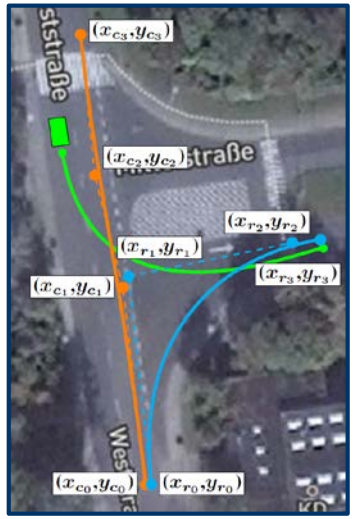
Simulation of mean *Functional Scenario* „Left Turn“

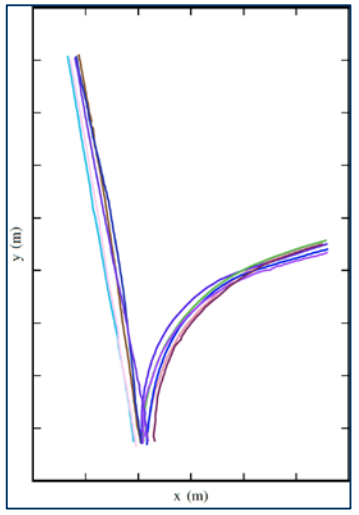
CONCLUSION AND FUTURE WORK

CONCLUSION

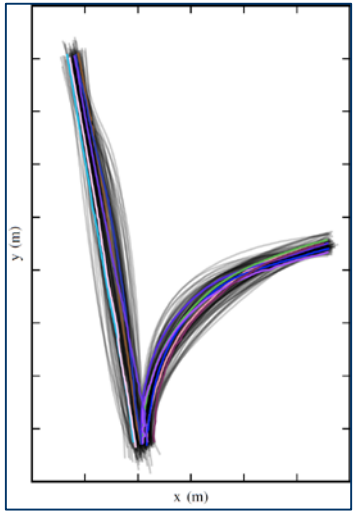
Discussion of the Initial Results

Quantification of Exposure is possible for Scenario Layer 4 (Movable Objects)





Systematic Scenario Variation for the Testing of Automated Driving Systems



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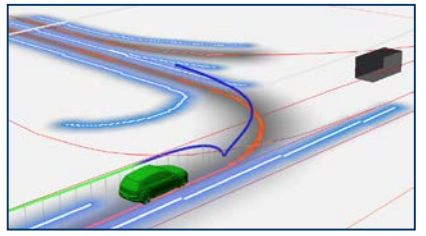
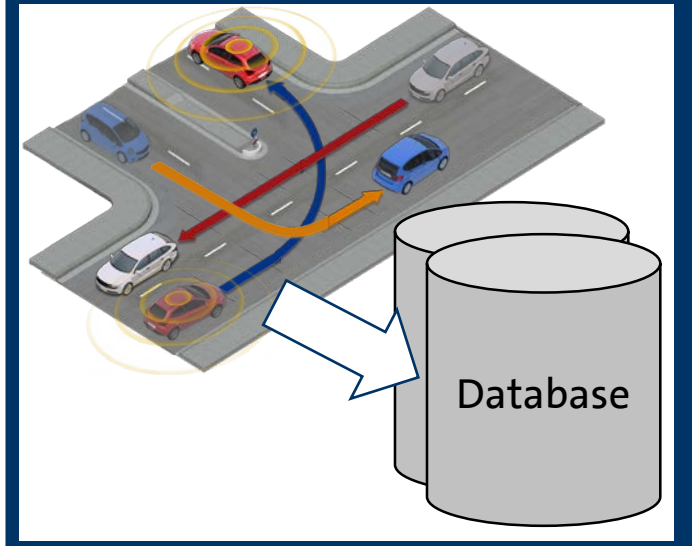


Small Dataset, Results not expected to be representative

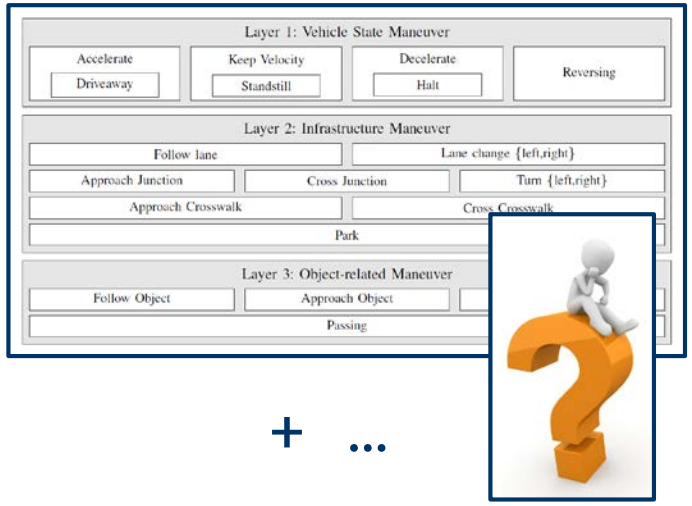


Satellite image: https://map.openaerialmap.org/

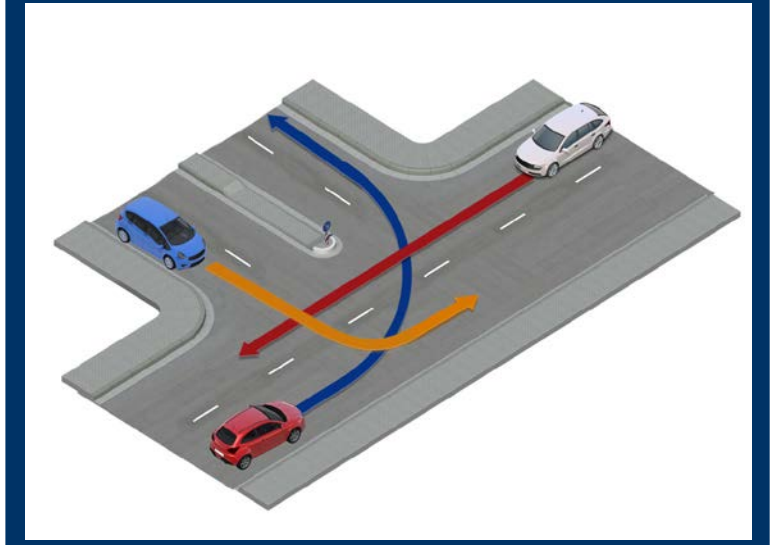
FUTURE WORK

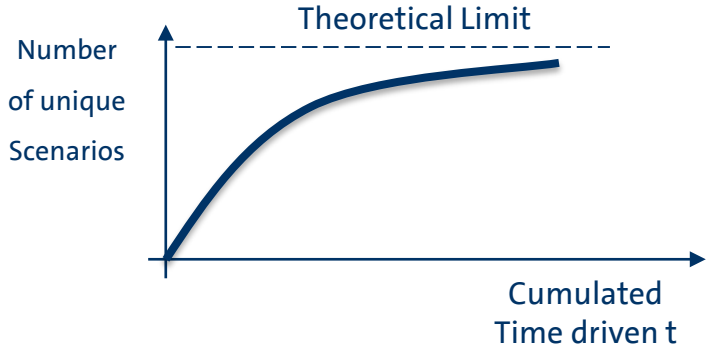
Outlook

Evaluate Completeness of the Maneuver Catalog



Extend Methodology to more complex Scenarios



Ensure Representativity of the collected Dataset

→ Study Saturation Effects