Ko-HAF
KOOPERATIVES HOCHAUTOMATISIERTES FAHREN

Motion Pattern Recognition for Maneuver Detection and Trajectory Prediction On Highways

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

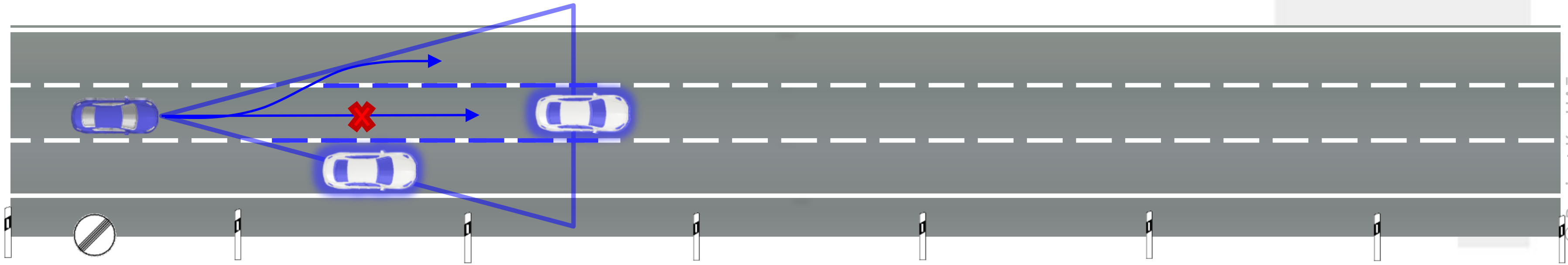
- MOTIVATION
- APPROACH
- LEARNING STAGE
- ESTIMATION STAGE
- APPLICATION

Motivation

Highly automated driving on highways

HIGHLY AUTOMATED DRIVING FUNCTIONS

SENSE | **Understand** → PLAN → ACT



Motivation

What is the driver's plan?

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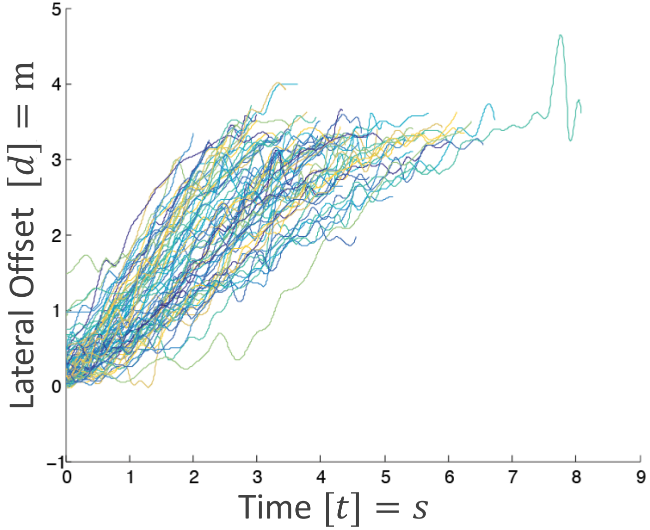
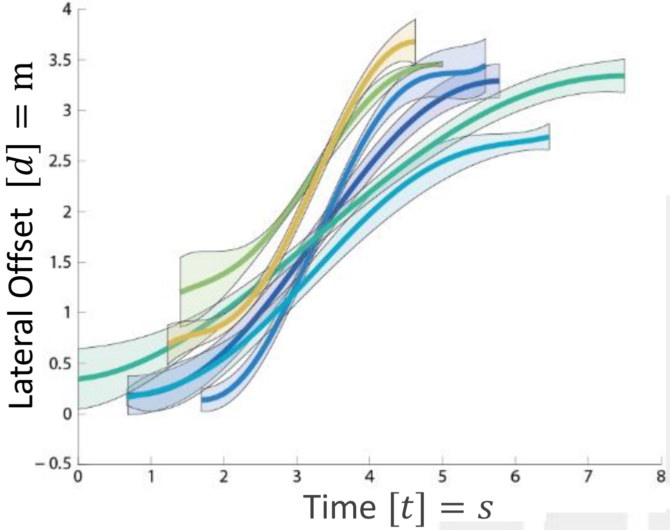
Approach
Typical Motion Patterns



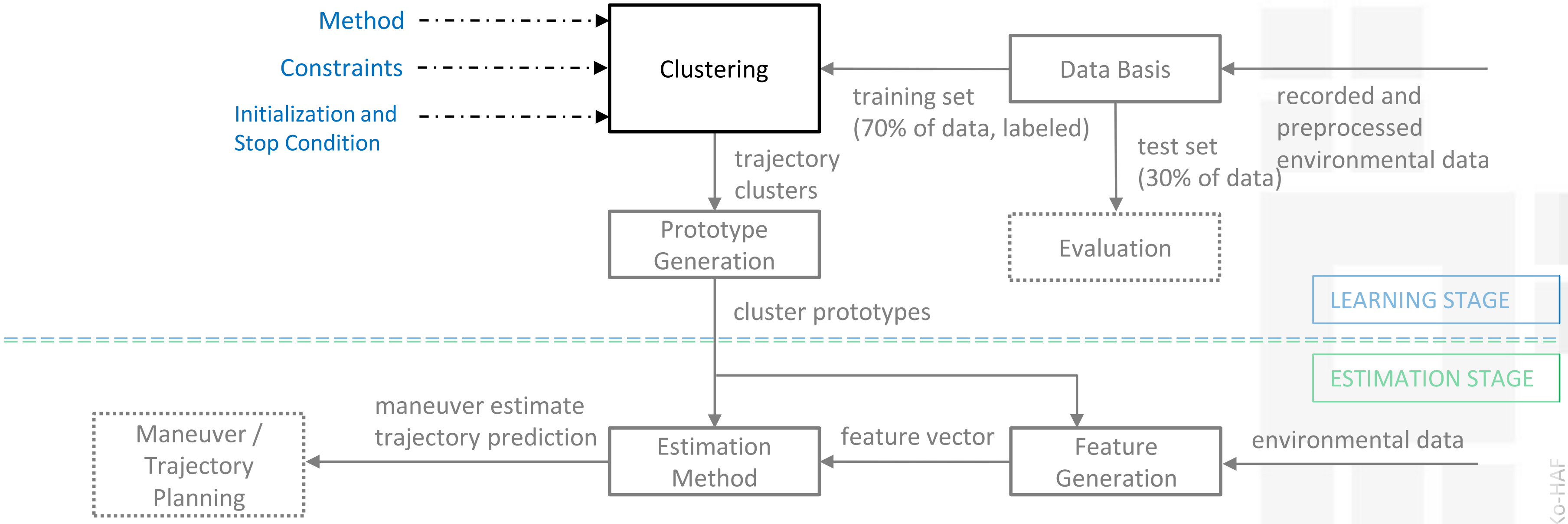
Recorded trajectories of highway lane changes to the left.



Prototype trajectories of LCL maneuvers.

Approach

Block Diagram



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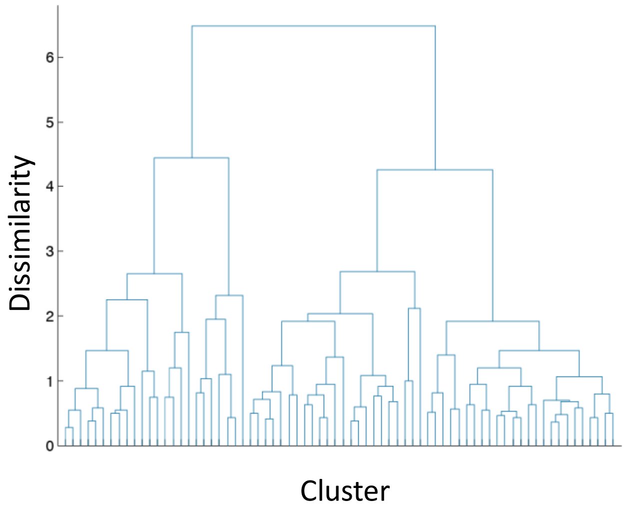
Approach

Agglomerative Hierarchical Clustering



Algorithm: Basic agglomerative hierarchical clustering algorithm.

1: Compute proximity matrix
2: **repeat**
3: Merge closest two clusters
4: Update proximity matrix to reflect the proximity between the new cluster and the original clusters
5: **until** end condition.

Approach

Agglomerative Hierarchical Clustering

Dissimilarity measure:
average Euclidean Distance

$$\delta(\mathbf{d}_i, \mathbf{d}_j) = \left(\frac{1}{T} \int_{t=t_{\min}}^{t_{\max}} (\mathbf{d}_i(t) - \mathbf{d}_j(t))^2 dt \right)^{1/2}$$

$$\boxed{t_{\min}} = \min(t_{0,i}, t_{0,j})$$

$$\boxed{t_{\max}} = \max(t_{0,i} + T_i, t_{0,j} + T_j)$$

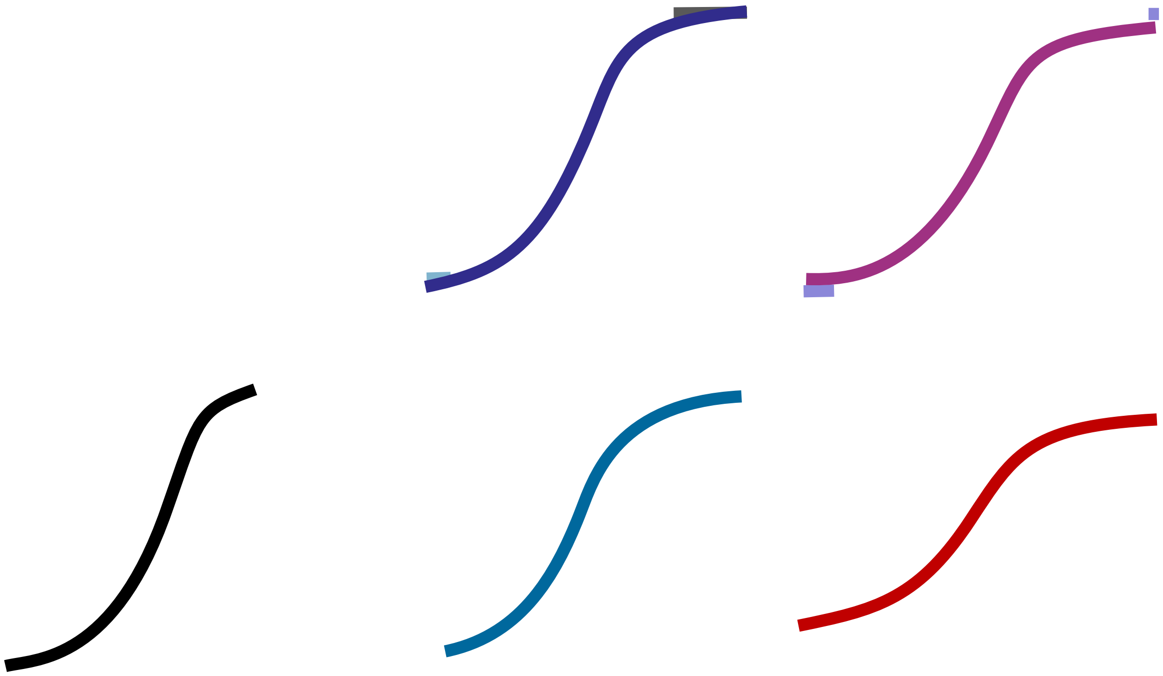
$$T = t_{\max} - t_{\min}$$

Algorithm: Basic agglomerative hierarchical clustering algorithm

1: Compute dissimilarity matrix
2: **repeat**
3: Find closest two clusters
4: **if** constraints are met
5: Merge closest two clusters
6: **end**
7: Realign clusters
8: Update dissimilarity matrix
7: **until** end condition

Agglomerative hierarchical Clustering

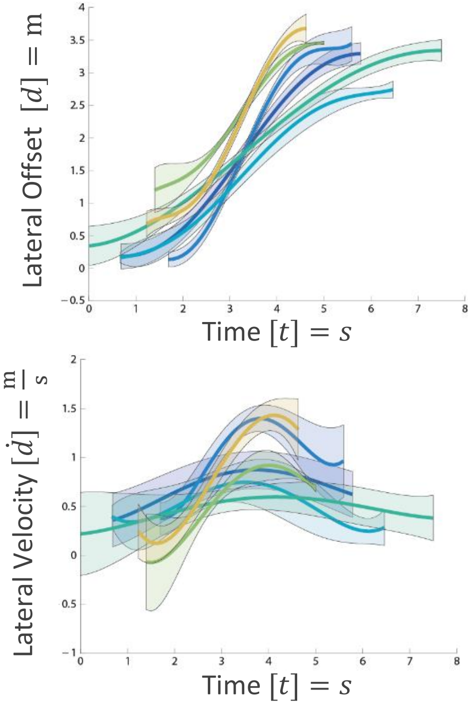
Alignment by minimal pairwise dissimilarity



Agglomerative hierarchical Clustering

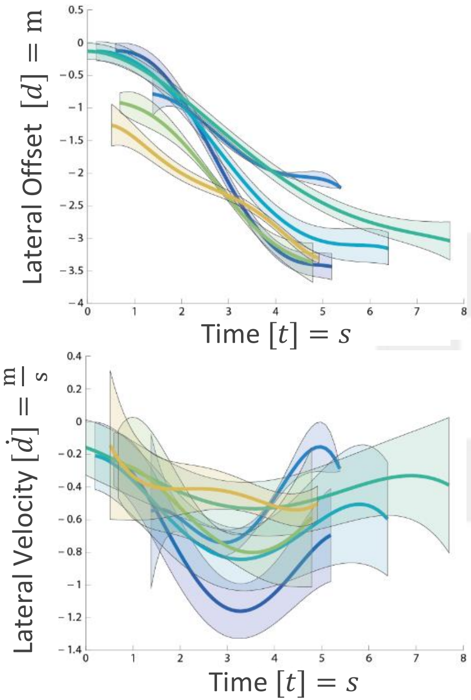
Min. pairwise dissimilarity and cohesion constraint

LCL



Prototype trajectories of LCL maneuvers.

LCR



Prototype trajectories of LCR maneuvers.

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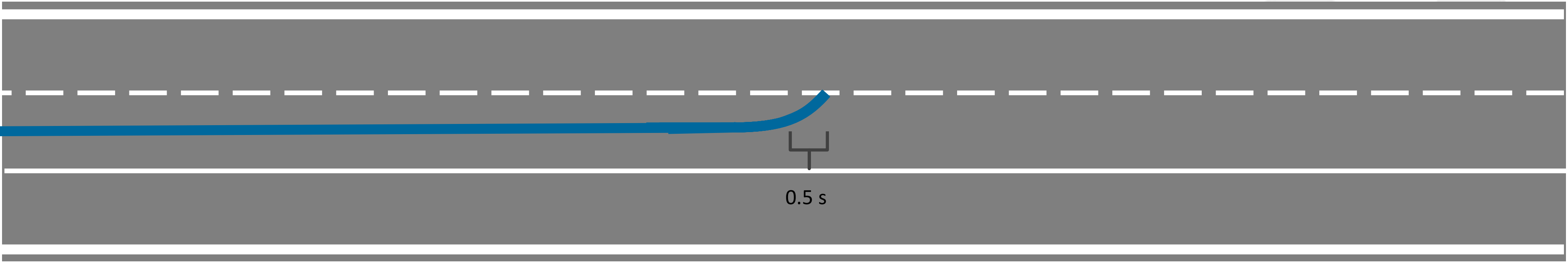
Estimation Stage

Find best match

Dissimilarity measure: average Mahalanobis distance

$$\boldsymbol{\Delta}(\mathbf{d}_p, \mu_m) = \frac{1}{T_m} \int_{-T_m}^{0} \left(\frac{(\mathbf{d}_p(t) - \mu_m(t + \tau_m))^2}{\sigma_m^2(t + \tau_m)} \right)^{1/2} dt$$

$$T_m = \min(T_{\text{buffer}}, \tau_m)$$



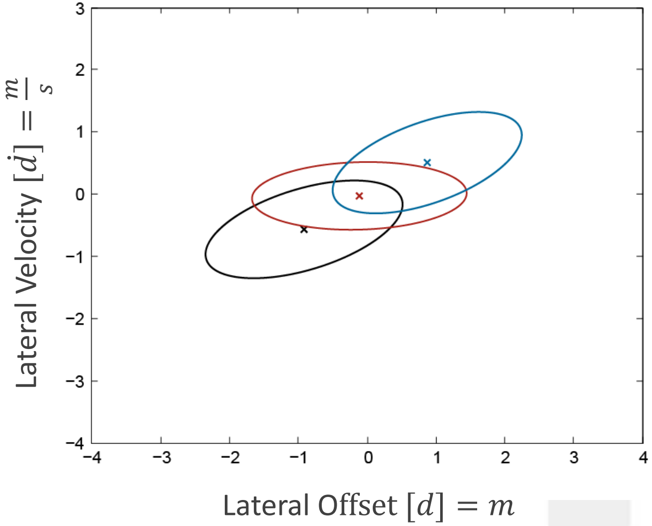
Estimation Stage

Quadratic Gaussian Discriminant Analysis

Bayesian discriminant rule for each class C_i

$$D_i(\mathbf{f}) = -\frac{1}{2}\ln|\boldsymbol{\Sigma}_i| - \frac{1}{2}(\mathbf{f}-\mu_i)^t\boldsymbol{\Sigma}_i^{-1}(\mathbf{f}-\mu_i) + \ln(p_i)$$

$$\mathbf{f} = [d, \dot{d}]^T$$



Estimation Stage

Quadratic Gaussian Discriminant Analysis

Bayesian discriminant rule for each class C_i

$$D_i(\mathbf{f}) = -\frac{1}{2}\ln|\boldsymbol{\Sigma}_i| - \frac{1}{2}(\mathbf{f} - \mu_i)^t \boldsymbol{\Sigma}_i^{-1}(\mathbf{f} - \mu_i) + \ln(p_i)$$

$$\mathbf{f} = [d, \dot{d}, f_3, f_4]^T$$

$$f_3 = \boldsymbol{\Delta}_{p,\mathrm{LCR}} - \boldsymbol{\Delta}_{p,\mathrm{LCL}}$$

$$f_4 = \boldsymbol{\Delta}_{v,\mathrm{LCR}} - \boldsymbol{\Delta}_{v,\mathrm{LCL}}$$

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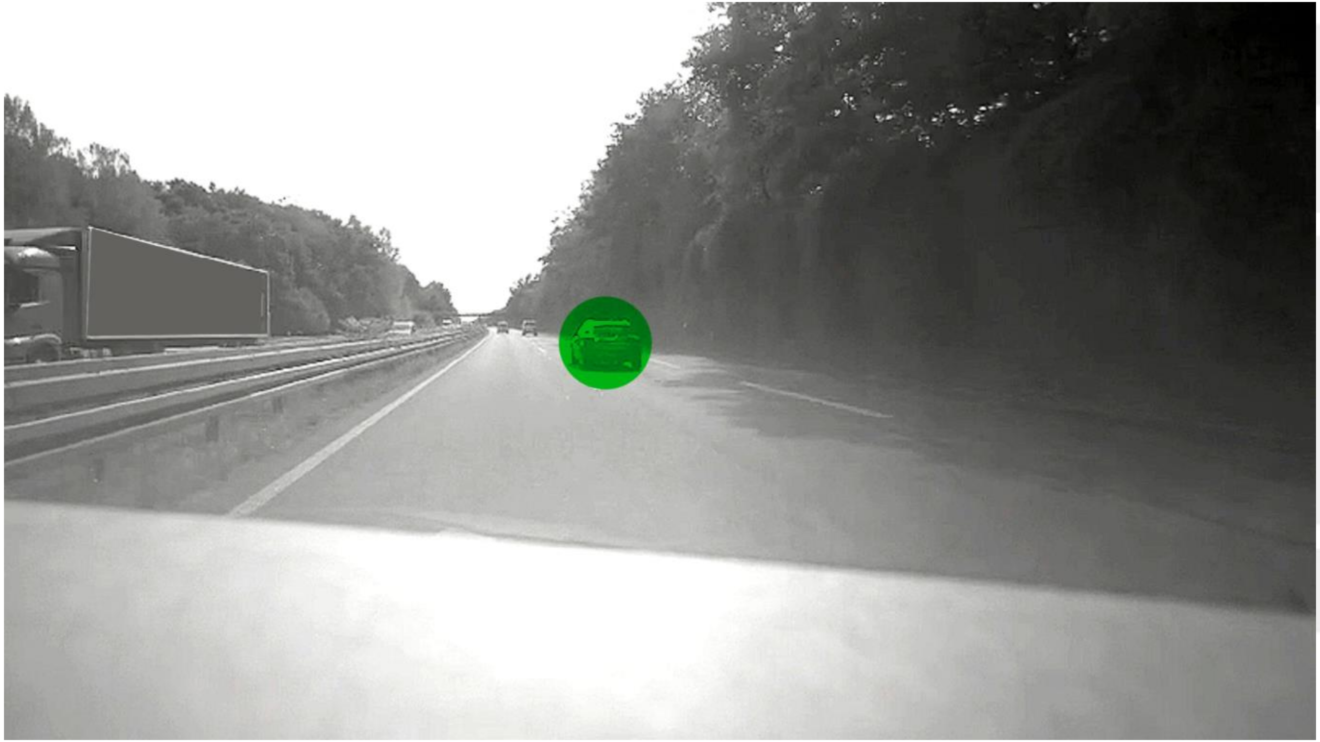
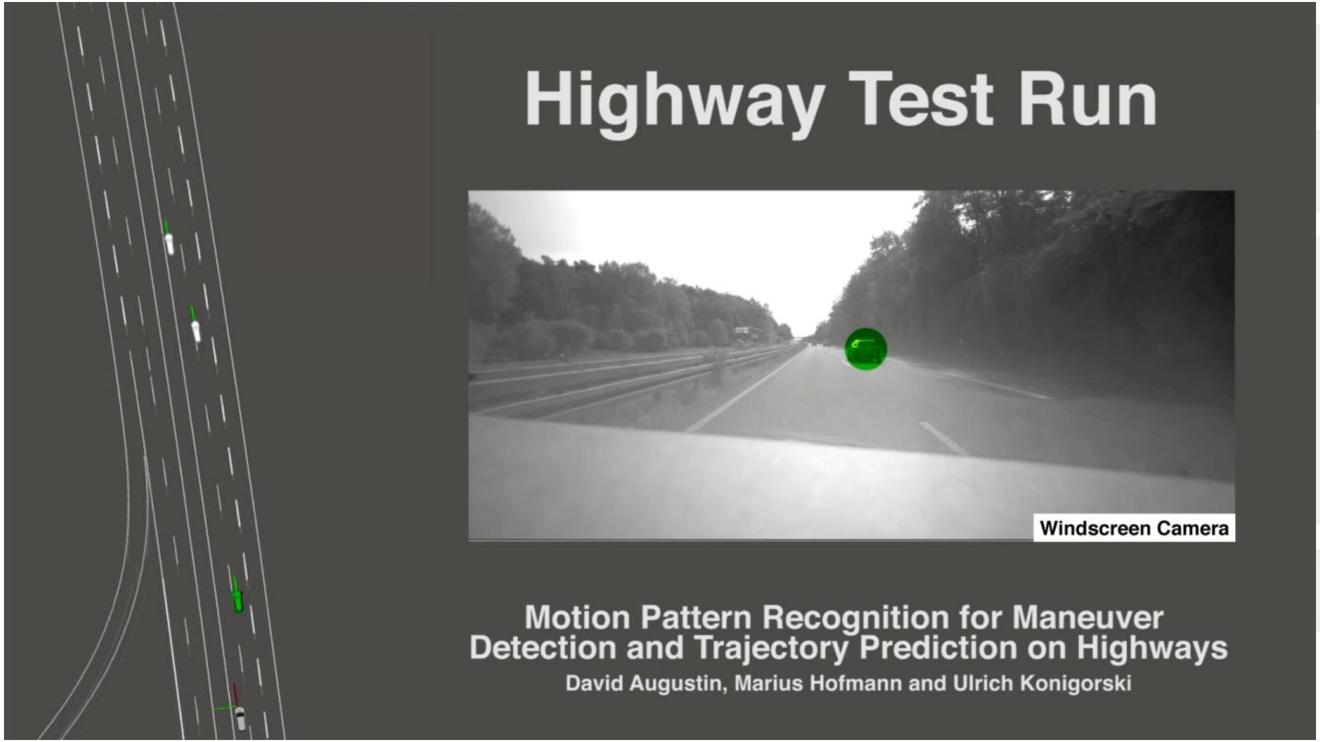
Application

What is the driver's plan?



Application
Maneuver Detection

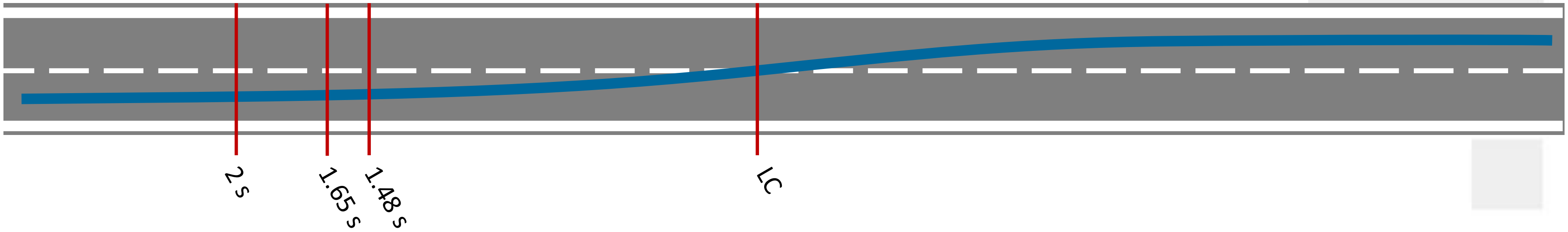


Application

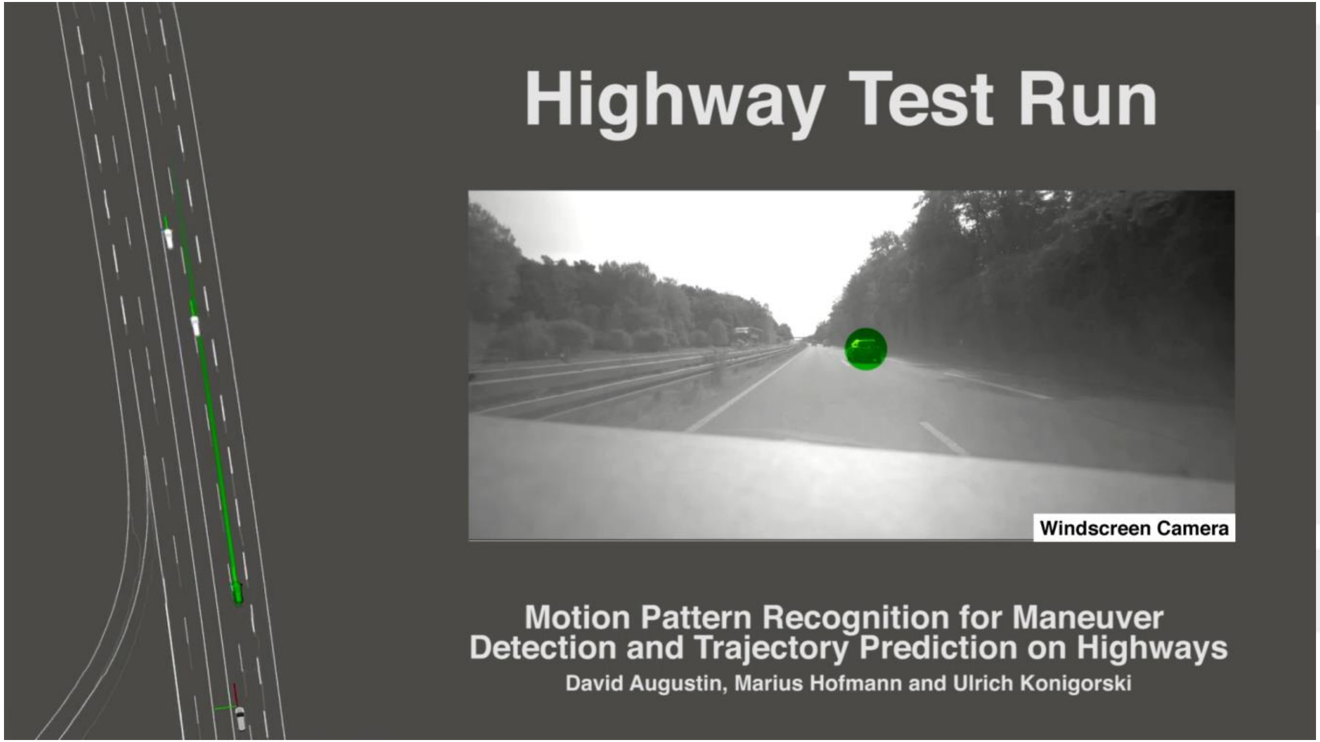
Results: Maneuver Detection

Approach		TPR	prc	F_1	ΔT (s)	Misclassification LCL	Misclassification LK	Misclassification LCR
A	LCL	0.95	1.0	0.976	1.65	0.16	0.09	0.23
	LCR	0.87	0.97	0.916				
D	LCL	0.93	1.00	0.962	1.48	0.19	0.09	0.26
	LCR	0.84	0.97	0.898				

$\Delta T \triangleq$ average prediction time before a lane change event
A: Proposed approach.
D: Quadratic Gaussian Discriminant Analysis with feature vector $\mathbf{f} = [d, \dot{d}]$

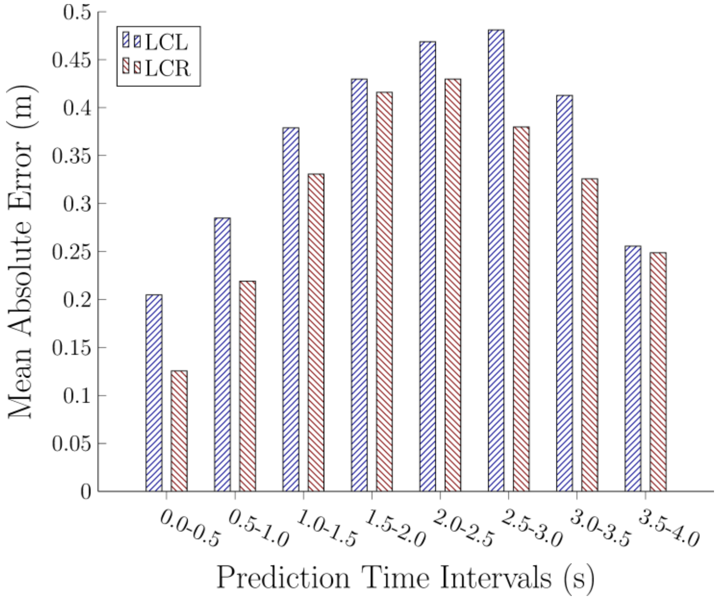


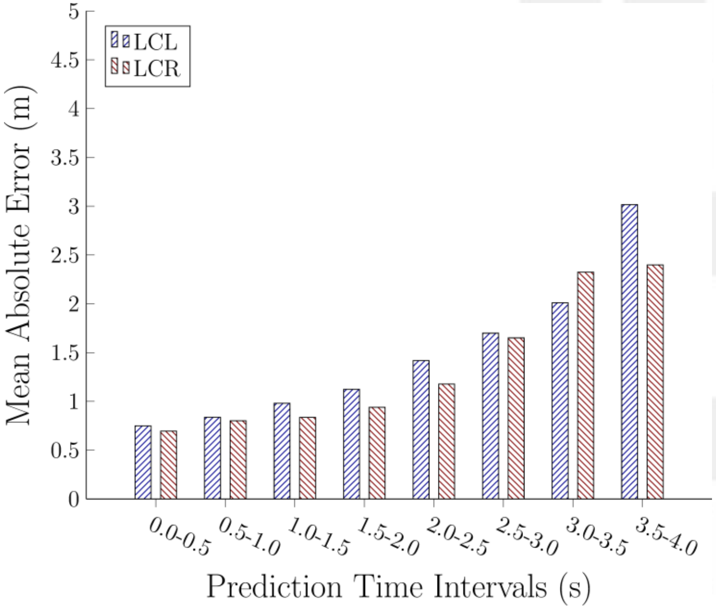
Application
Trajectory Prediction



Application

Results: Trajectory Prediction





Conclusion and Outlook

Proposed Approach

- Uncertainty-aware maneuver detection and trajectory prediction
- Trajectory alignment minimizing pairwise dissimilarity improves cluster quality
- Online-capability demonstrated

OUTLOOK

- Maneuver Prediction: Take interaction and topology of road into account
- Motion Prediction: Probabilistic selection of prototype trajectories

Thank you

for your attention!

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