



# Motion Pattern Recognition for Maneuver Detection and Trajectory Prediction On Highways

David Augustin, Opel Automobile GmbH

Gefördert durch:



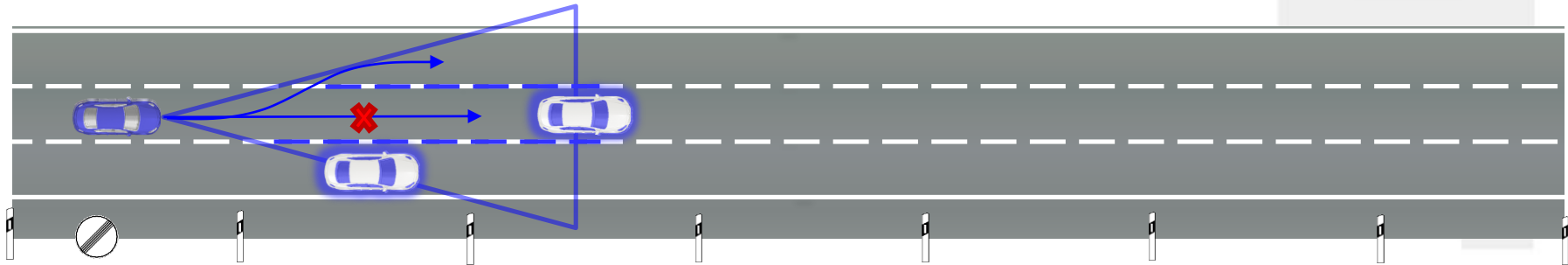
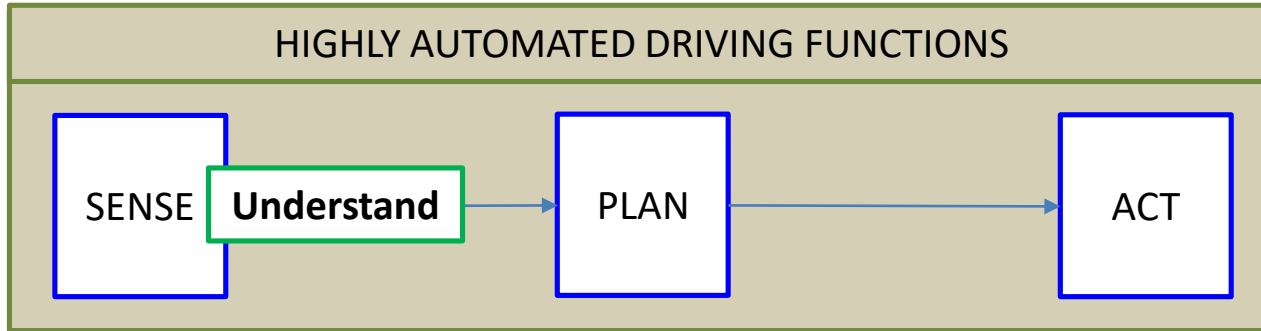
aufgrund eines Beschlusses  
des Deutschen Bundestages

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- APPROACH
- LEARNING STAGE
- ESTIMATION STAGE
- APPLICATION



# Motivation

Highly automated driving on highways



# Motivation

What is the driver's plan?

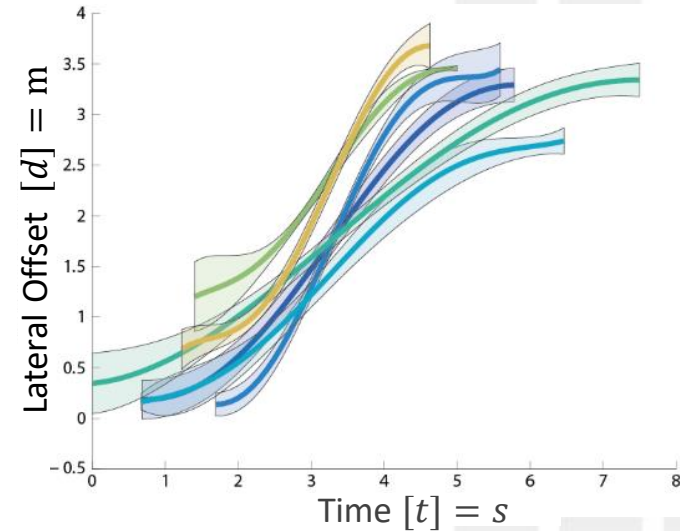
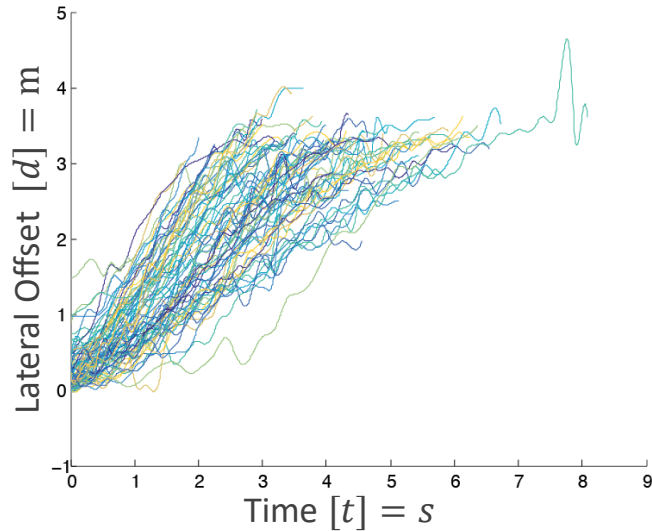


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# Approach

## Typical Motion Patterns

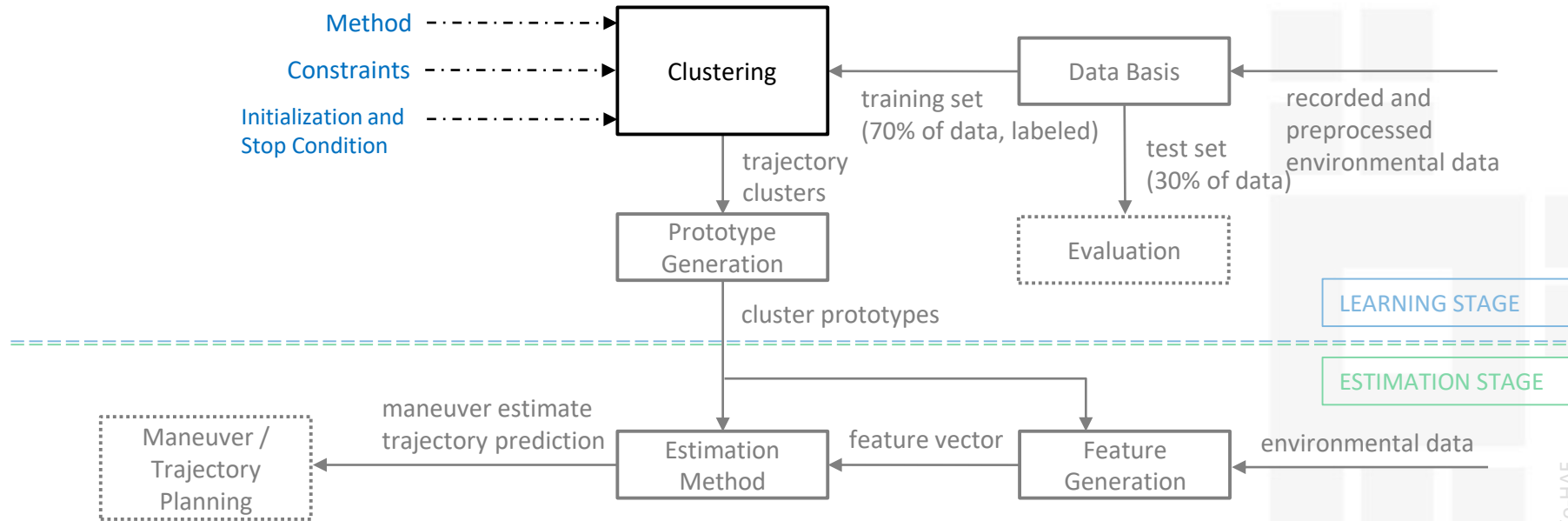


Recorded trajectories of highway lane changes to the left.

Prototype trajectories of LCL maneuvers.

# Approach

## Block Diagram



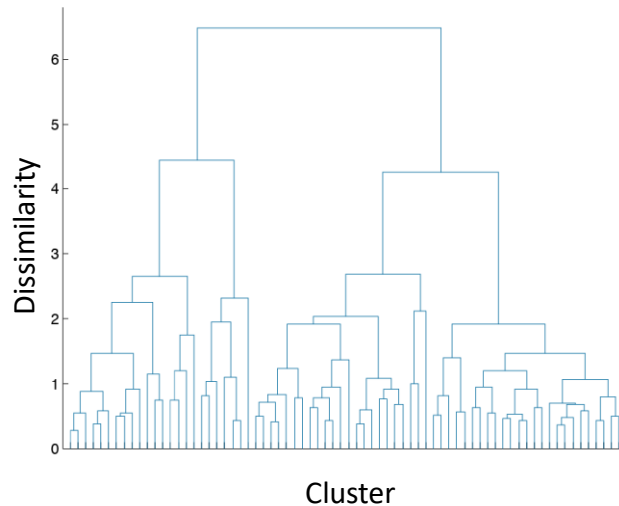
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# Approach

## 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

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

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

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

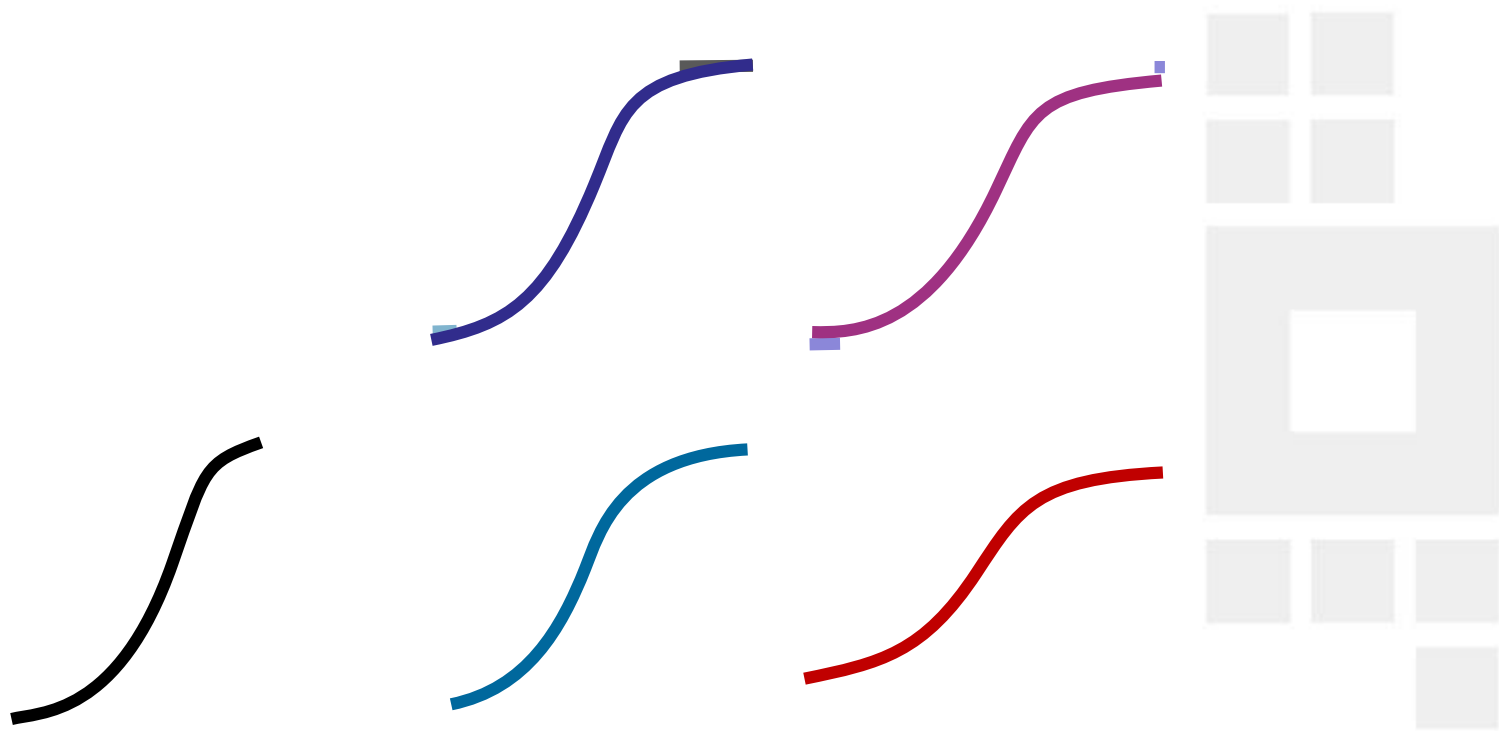
$$T = t_{\max} - t_{\min}$$

**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

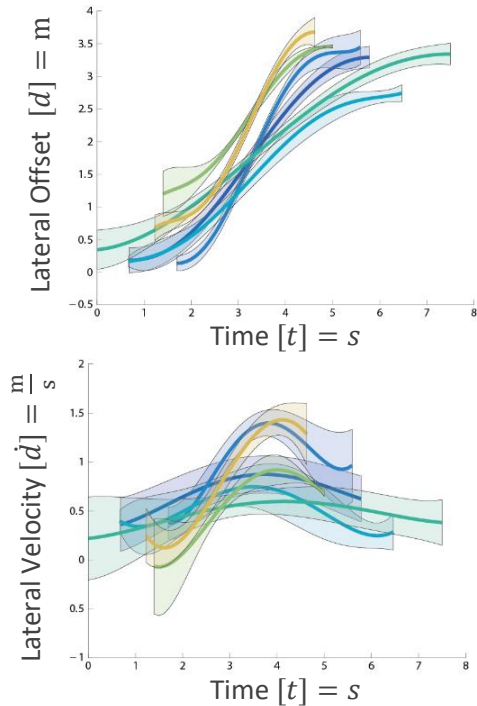
## Alignment by minimal pairwise dissimilarity



# Agglomerative hierarchical Clustering

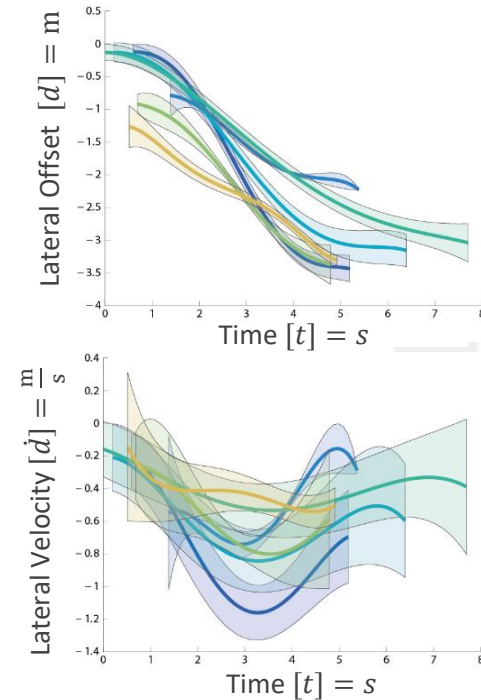
Min. pairwise dissimilarity and cohesion constraint

LCL



Prototype trajectories of LCL maneuvers.

LCR



Prototype trajectories of LCR maneuvers.

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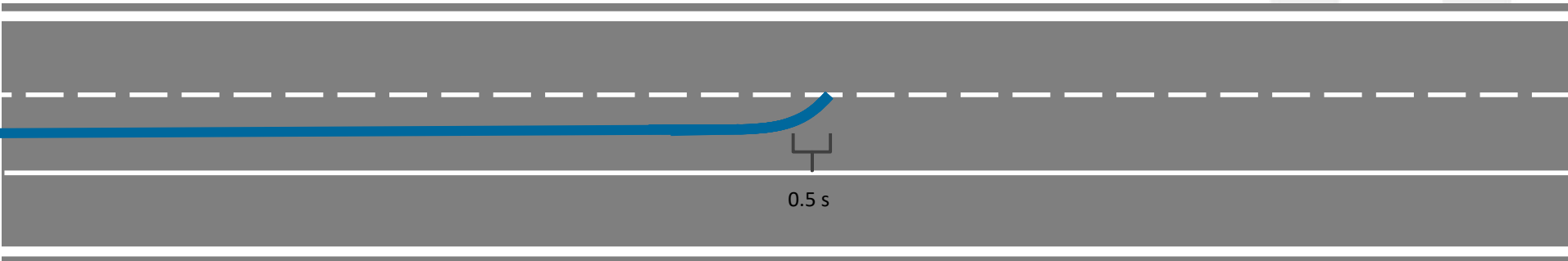
# Estimation Stage

Find best match

Dissimilarity measure: average Mahalanobis distance

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

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



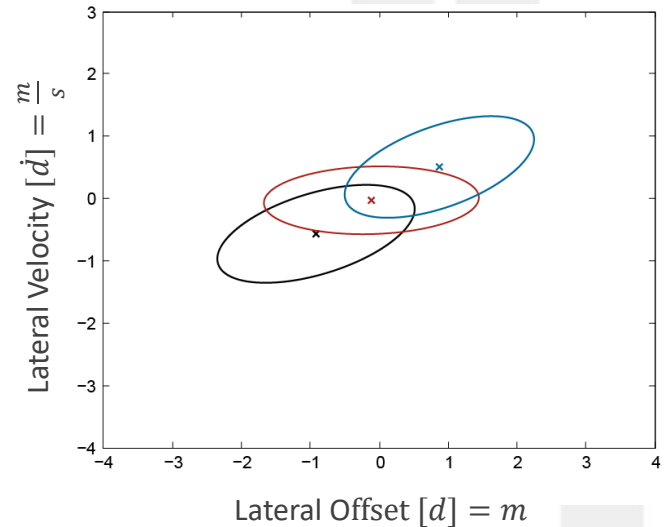
# Estimation Stage

## Quadratic Gaussian Discriminant Analysis

Bayesian discriminant rule for each class  $C_i$

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

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



# Estimation Stage

## Quadratic Gaussian Discriminant Analysis

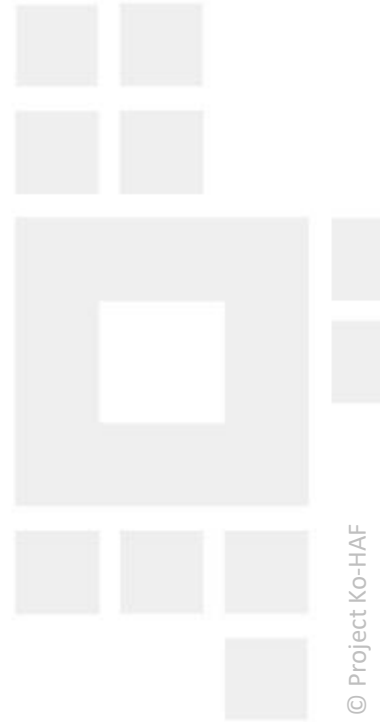
Bayesian discriminant rule for each class  $C_i$

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

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

$$f_3 = \Delta_{p,LCR} - \Delta_{p,LCL}$$

$$f_4 = \Delta_{v,LCR} - \Delta_{v,LCL}$$



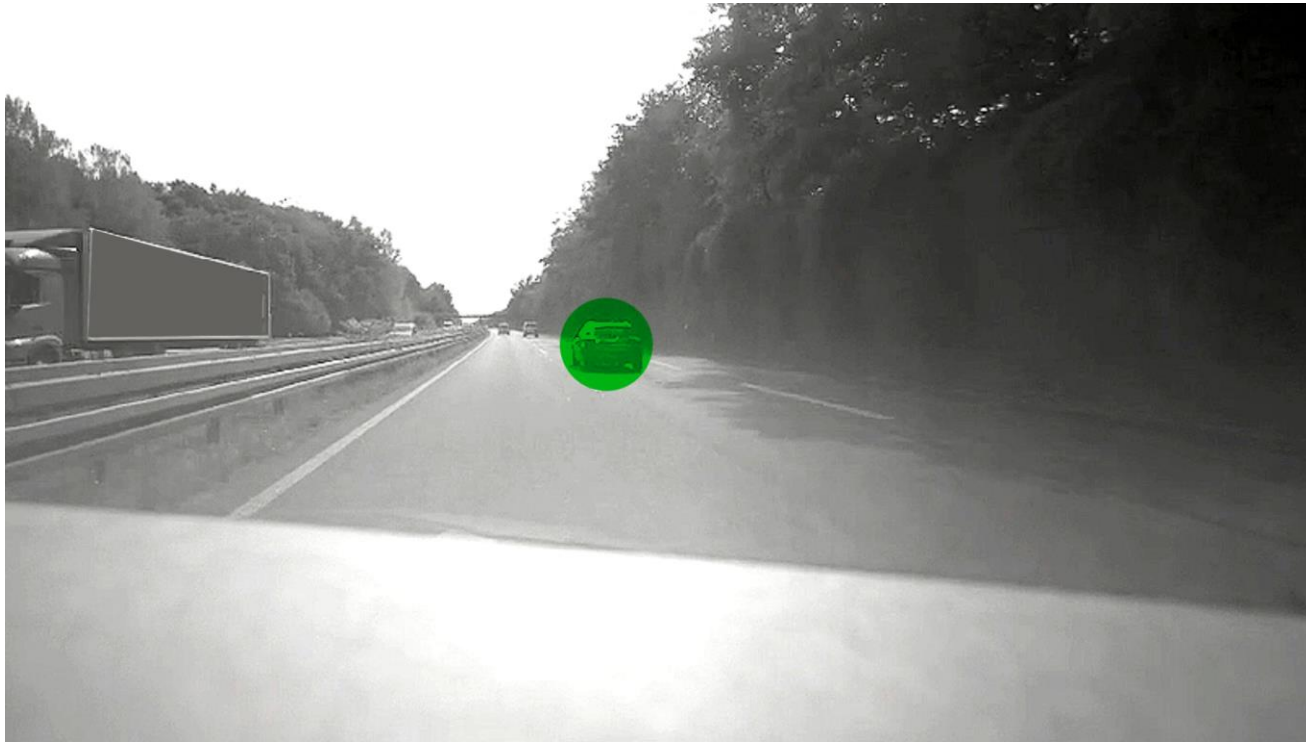


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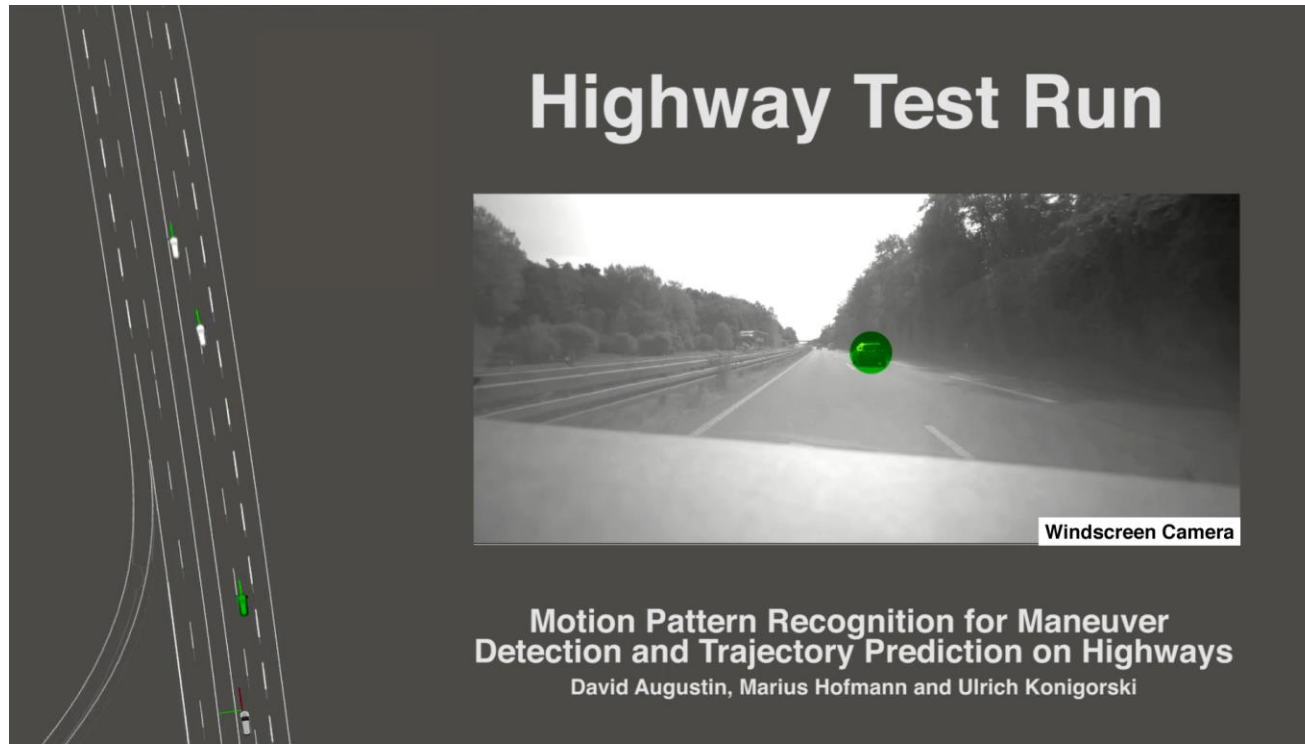
# Application

What is the driver's plan?



# Application

## Maneuver Detection



The image displays a highway test run visualization. On the left, a top-down view of a multi-lane highway shows several vehicles represented by small icons with green motion vectors. The main part of the image is a first-person perspective from a 'Windscreen Camera' looking down a highway. A green circular marker is overlaid on the road ahead, indicating a specific point of interest or a predicted trajectory. The text 'Highway Test Run' is prominently displayed at the top, and 'Motion Pattern Recognition for Maneuver Detection and Trajectory Prediction on Highways' is at the bottom, along with the authors' names: David Augustin, Marius Hofmann and Ulrich Konigorski.

# Application

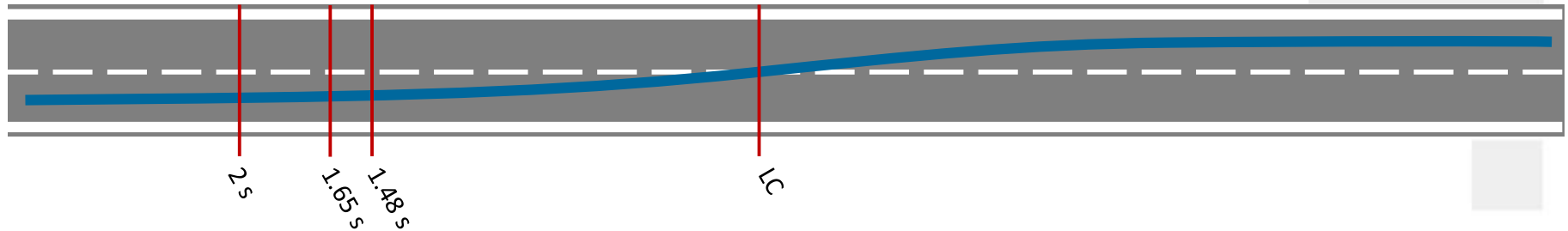
## Results: Maneuver Detection

Approach		$TPR$	$prec$	$F_1$	$\Delta T$ (s)	Misclassification		
						LCL	LK	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

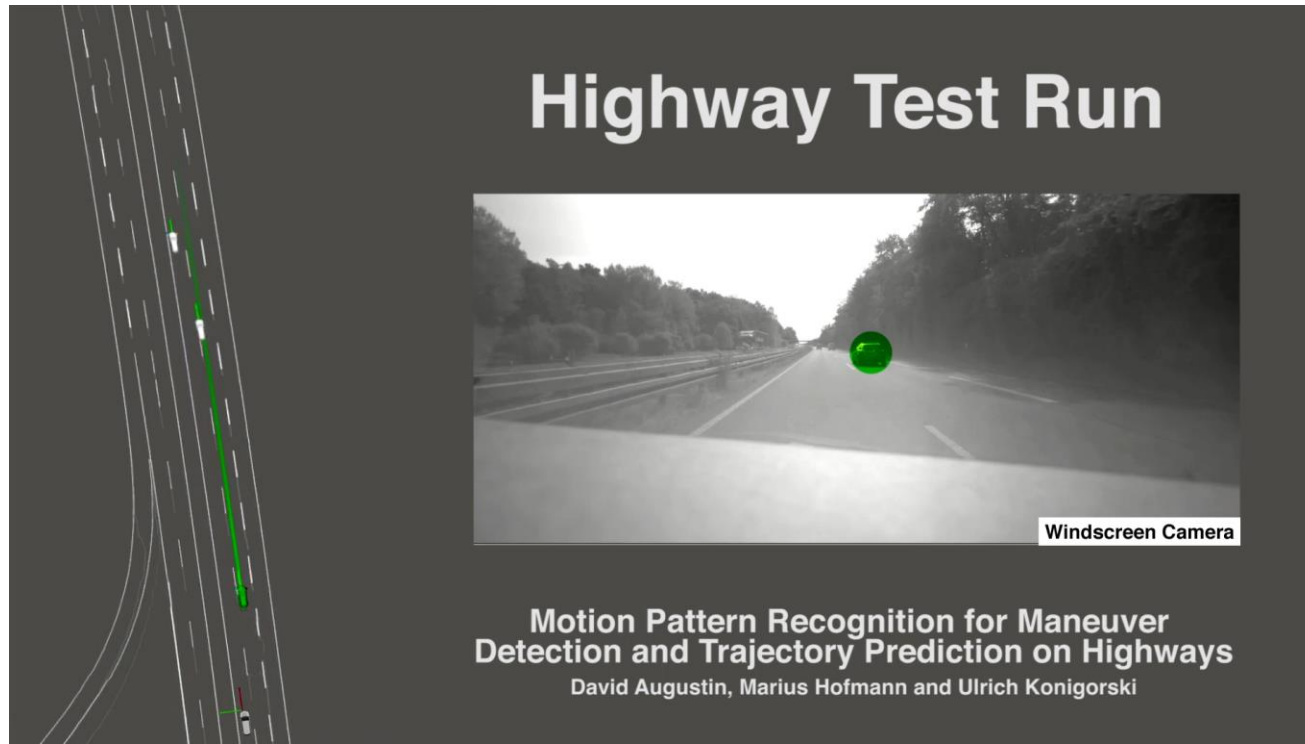
A: Proposed approach.

D: Quadratic Gaussian Discriminant Analysis with feature vector  $\mathbf{f} = [d, \dot{d}]$



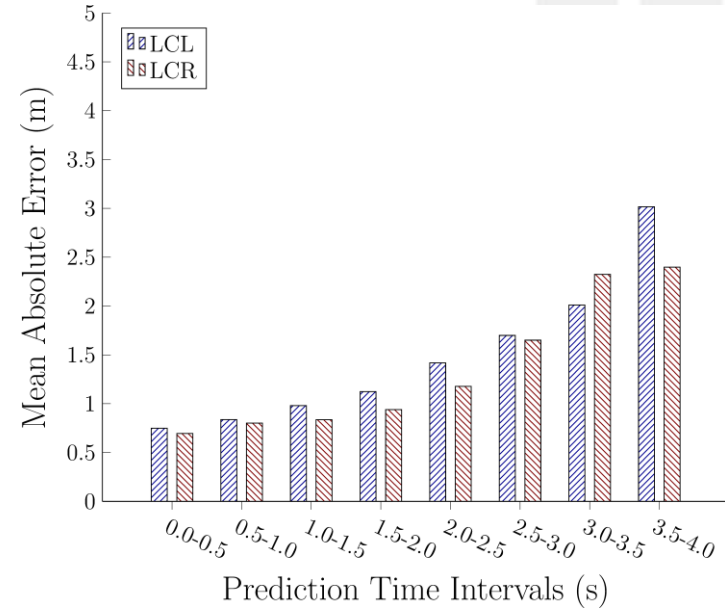
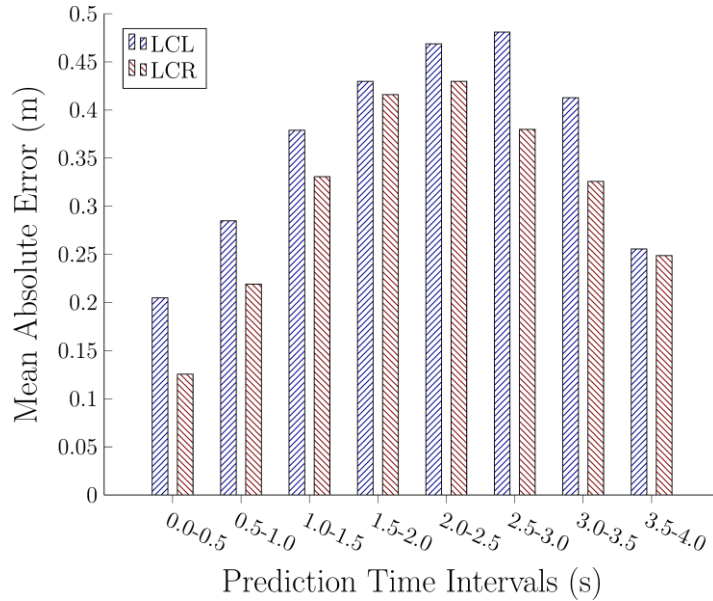
# Application

## 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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