

Modeling Safety of Lane Change Maneuvers Based on Driver Gaze and Vehicle Operation Behavior

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Outline

- Introduction
- Data collection
- Subjective evaluation of risk level
- Modeling gaze and vehicle operation
- Risky lane changes detection
- Evaluation of long-term risk level
- Conclusion

Background

- Detection of risky driving behavior
 - Vehicle operation behavior (most common method)
 - Gaze behavior
- Previous studies of driver gaze behavior
 - Investigating the Relationships Between Gaze Patterns, Dynamic Vehicle Surround Analysis, and Driver Intentions [Doshi, et al., 2009]
 - Changes in the Correlation Between Eye and Steering Movements Indicate Driver Distraction [Yekhshatyan, et al., 2012]
- Purpose of our study

**Integrated modeling of
gaze and operation behavior**

Driving data collection

Focus: Lane changes on expressways

Conditions

Subjects	11 drivers 5 instructors 6 ordinary drivers
Course	Expressways around Nagoya (83km in total)
Data length	90 min. per driver

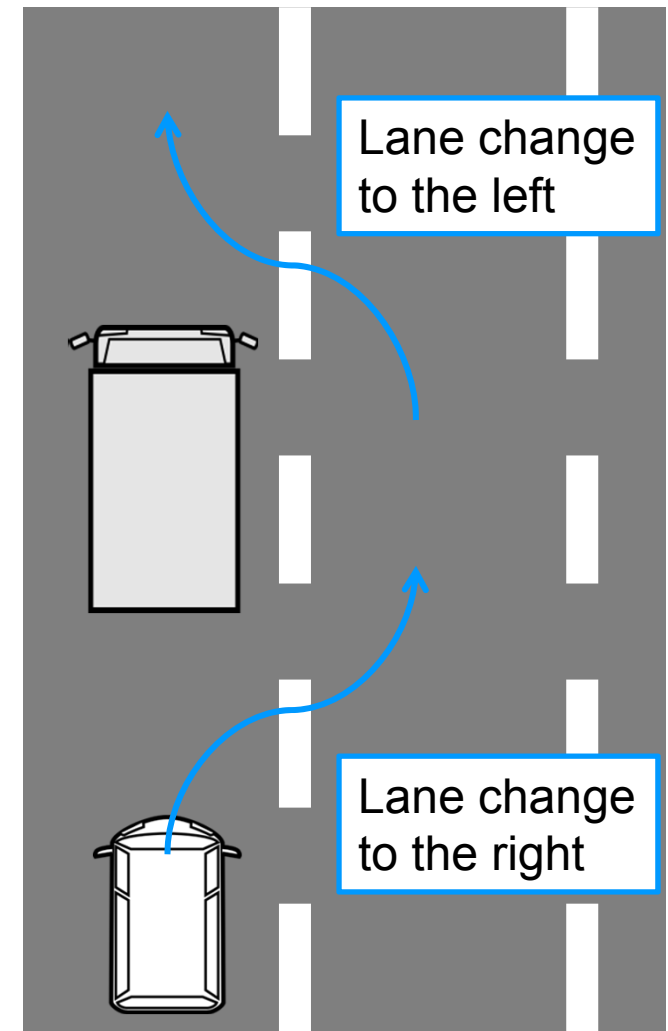


Definition of a lane change

- ❑ Drivers were instructed to pass leading vehicles as often as possible.
- ❑ Each passing maneuver involved two lane changes:
 - one into the right lane
 - one back into the left lane

We collected approx. 1000 lane changes in total:

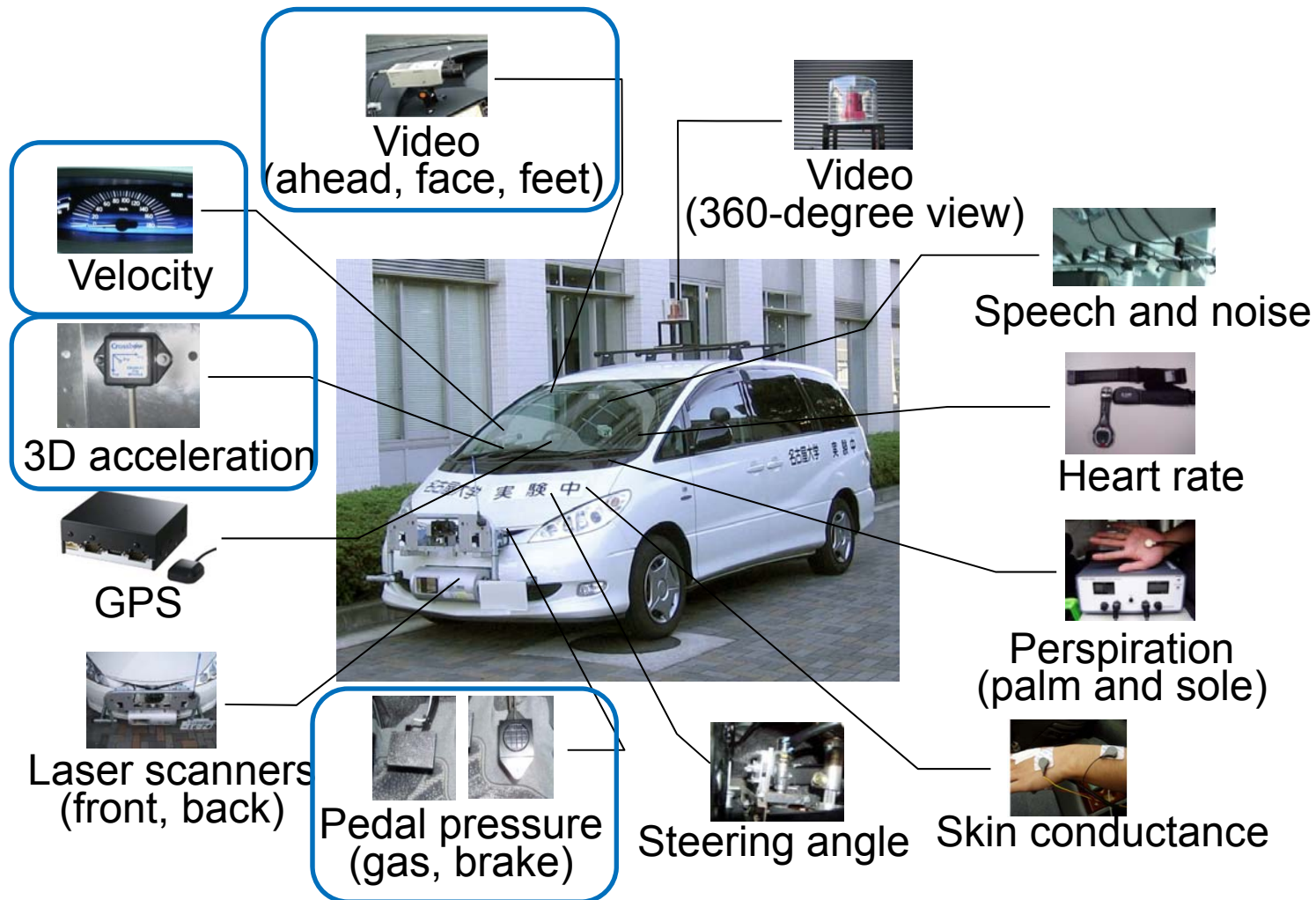
496 to the left and 492 to the right



One passing maneuver

Instrumented vehicle for data collection

Hybrid TOYOTA ESTIMA



Representation of driving behavior

Four sequences of discrete acts

Gaze

Gaze direction

- Front
- Front-right
- Right mirror
- Right
- Front-left
- Left mirror
- Left
- Rear-view mirror
- Speed meter
- Other

Operations

Pedal operation

- Brake
- None
- Gas-low
- Gas-high

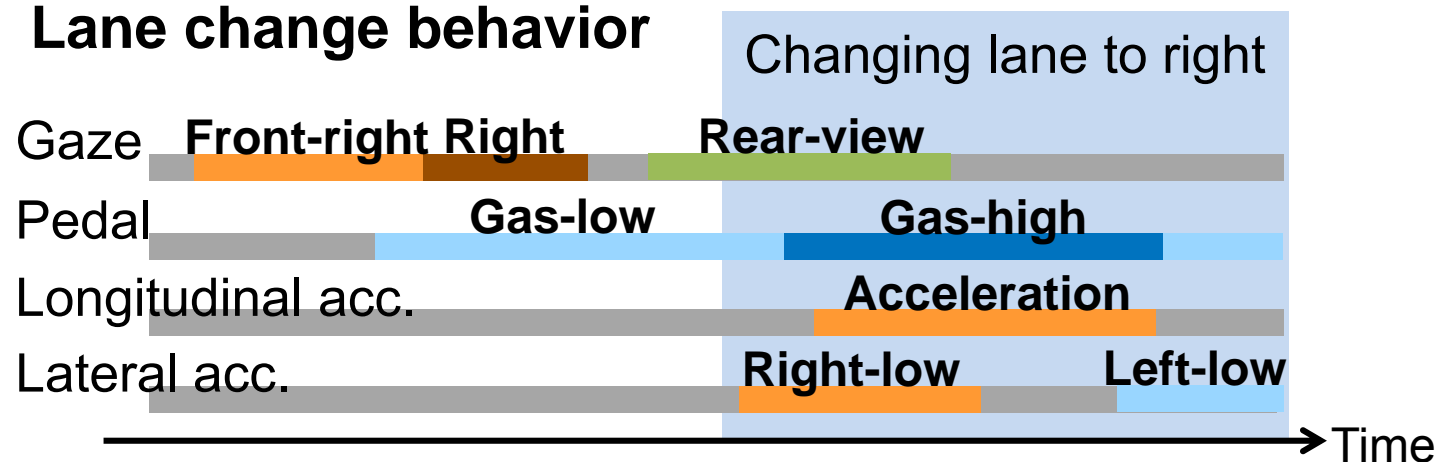
Longitudinal acceleration

- Deceleration
- Steady speed
- Acceleration

Lateral acceleration

- Right-high
- Right-low
- None
- Left-low
- Left-high

Lane change behavior



Gaze direction annotation

- An annotator manually labeled driver gaze into one of ten directions for each video frame:



Rear-view Mirror



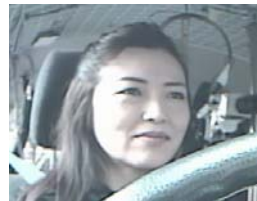
Right



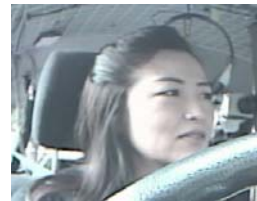
Right Mirror



Front-Right



Front



Front-Left



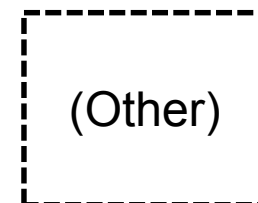
Left Mirror



Left



Speedometer



Representation of driving behavior

Four sequences of discrete acts

Gaze

Gaze direction

- Front
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Operations

Pedal operation

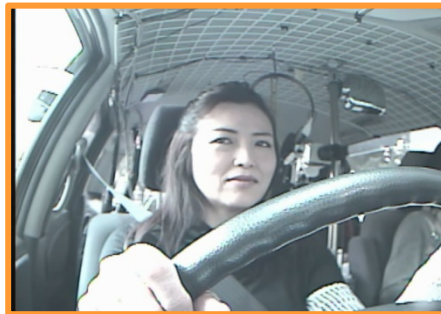
- Brake
- None
- Gas-low
- Gas-high

Longitudinal acceleration

- Deceleration
- Steady speed
- Acceleration

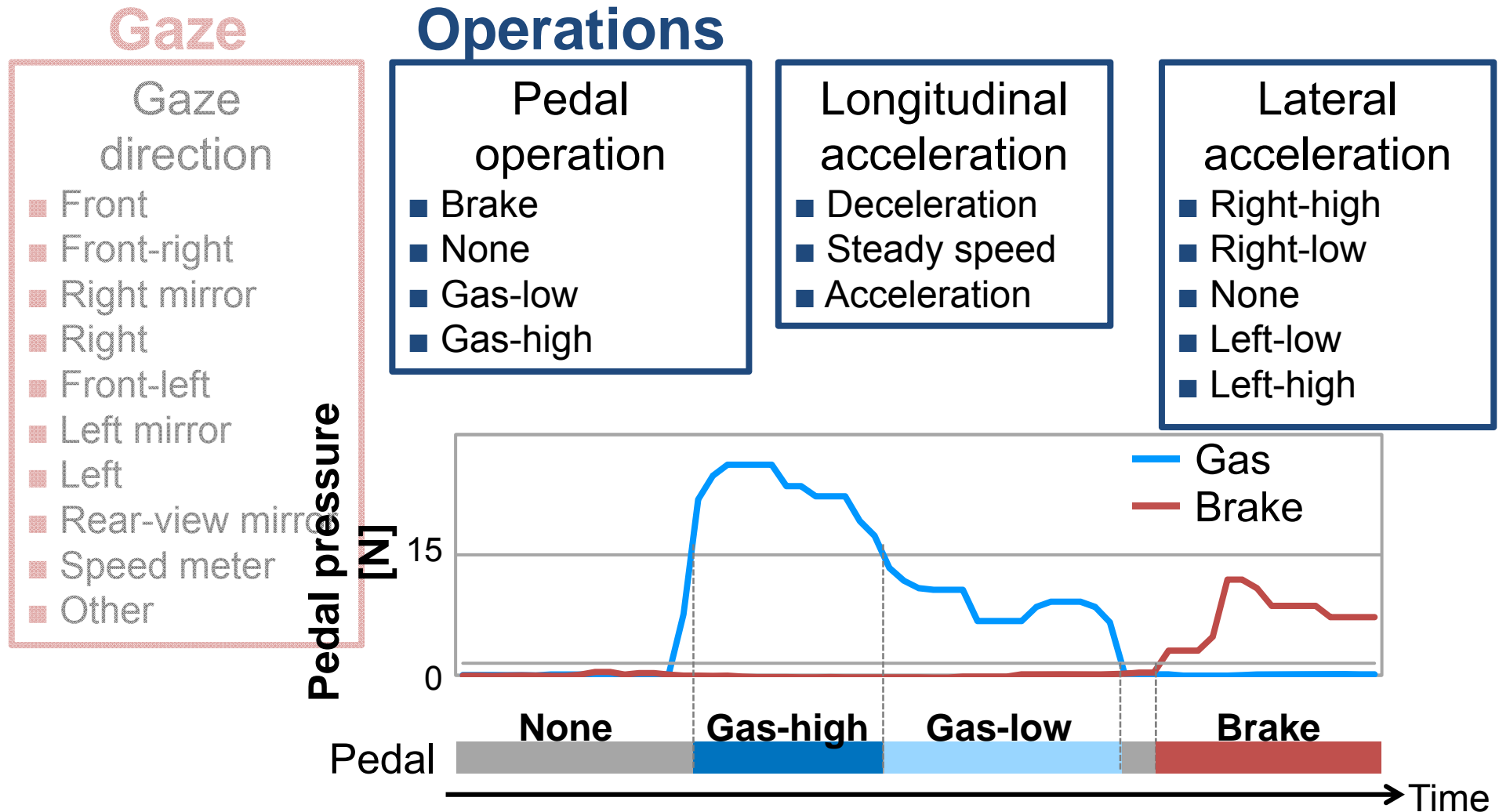
Lateral acceleration

- Right-high
- Right-low
- None
- Left-low
- Left-high



Representation of driving behavior

Four sequences of discrete acts



Ground-truth risk level of lane changes

Risk level of each lane change determined by ten subjects



- 1: very safe
- 2: safe
- 3: neither safe nor risky
- 4: risky
- 5: very risky

**Ground-truth
risk level**

Original score	Lane change scenes		
	Scene 1	Scene 2	...
Subject 1	3	4	...
Subject 2	1	1	...
:	:	:	...
Subject 10	3	2	...



Likert's sigma method

Normalized score	Lane change scenes		
	Scene 1	Scene 2	...
Subject 1	-0.54	0.54	...
Subject 2	-0.44	-0.44	...
:	:	:	...
Subject 10	0.03	-0.95	...
Average	0.07	-0.14	...

Extraction of risky and safe events

	Lane changes to the left (sorted by risk level)						
	1	...	25	...	472	...	496
Risk level	2.01	...	1.21	...	-0.83	...	-1.13

Risky
Left 1

Safe
Left 1

25 risky lane changes to the left

25 safe lane changes to the left

	Lane changes to the right (sorted by risk level)						
	1	...	25	...	468	...	492
Risk level	2.41	...	1.10	...	-0.77	...	-1.02

Risky
Right 1

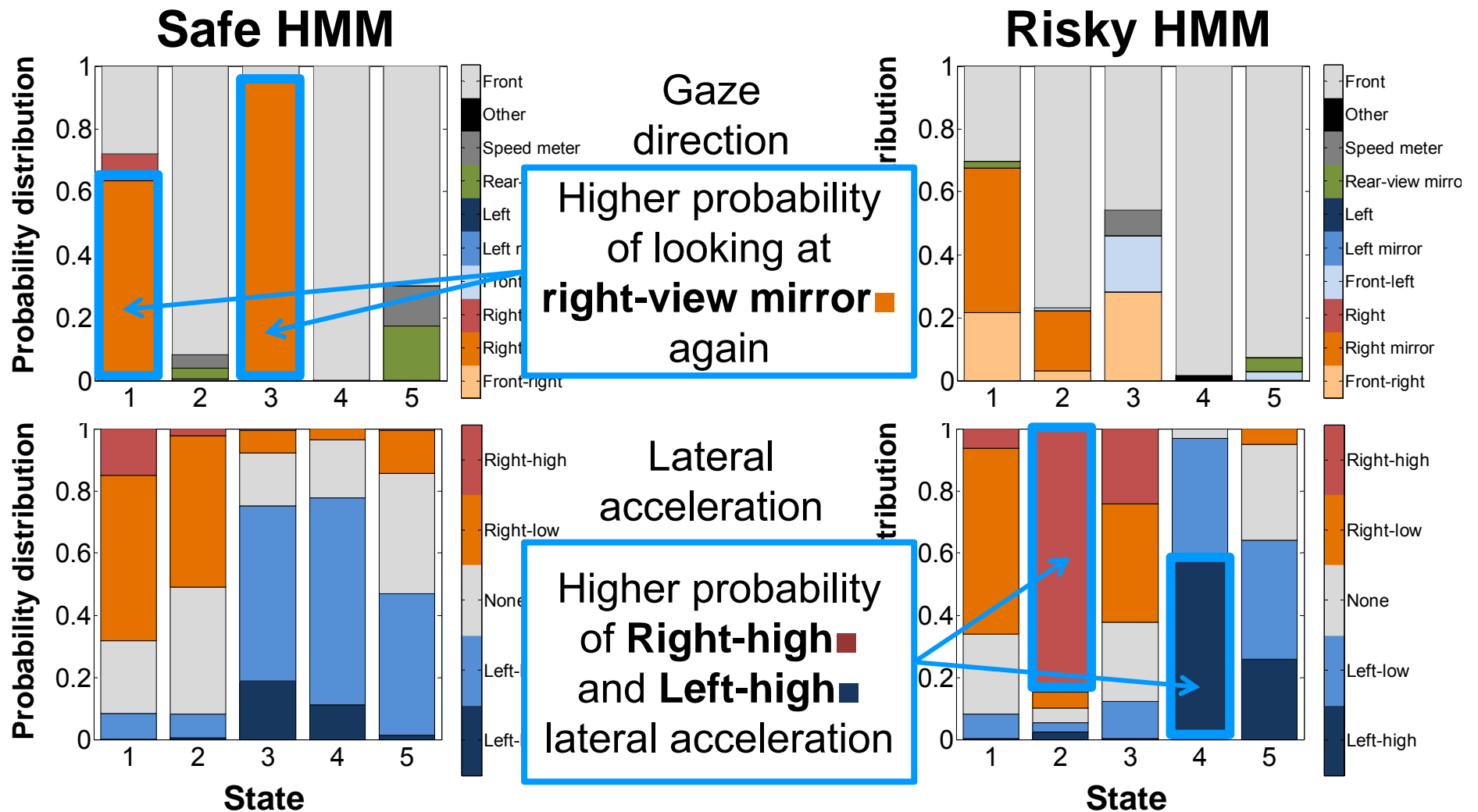
Safe
Right 1

25 risky lane changes to the right

25 safe lane changes to the right

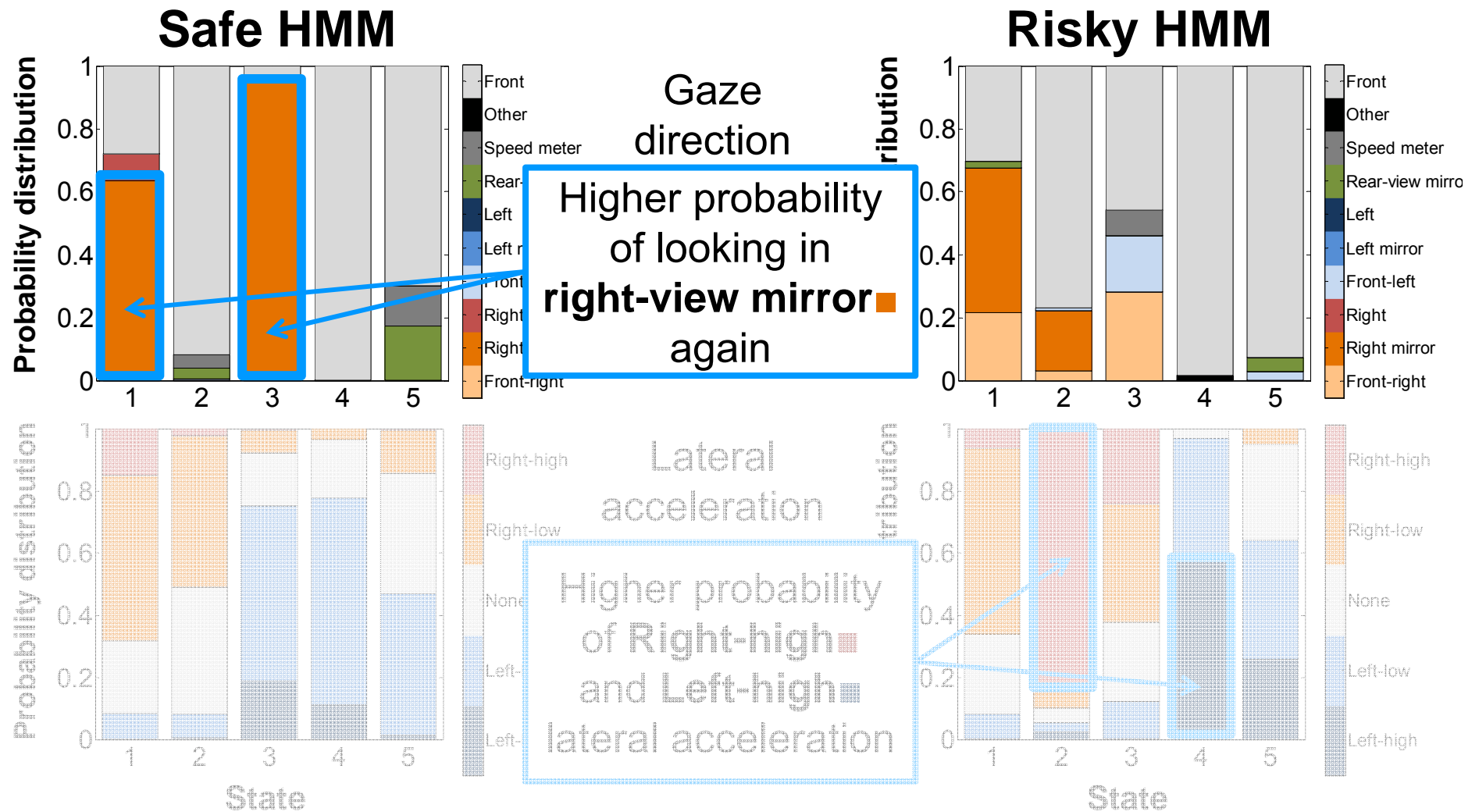
Modeling risky/safe behavior

Modeling sequences using multi-stream discrete HMMs



Modeling risky/safe behavior

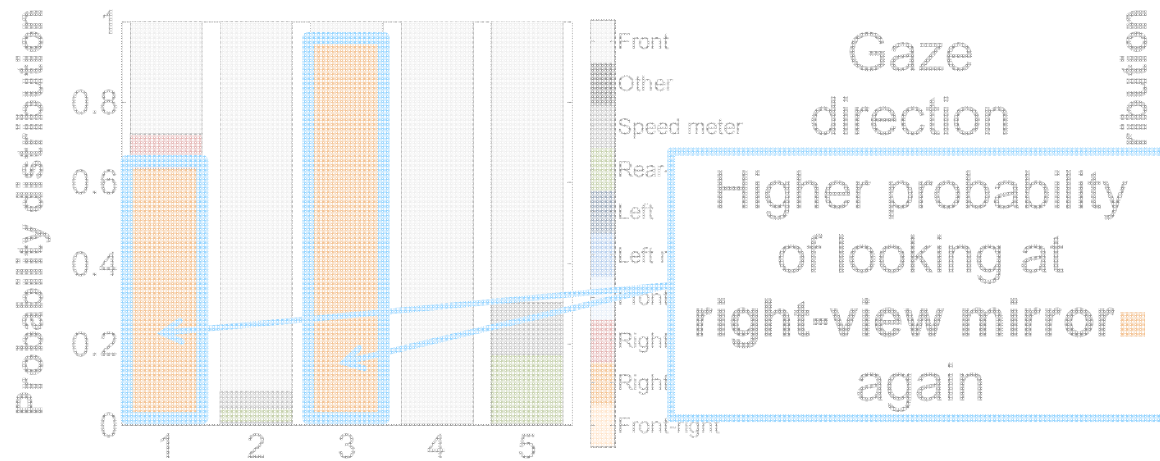
Modeling sequences using multi-stream discrete HMMs



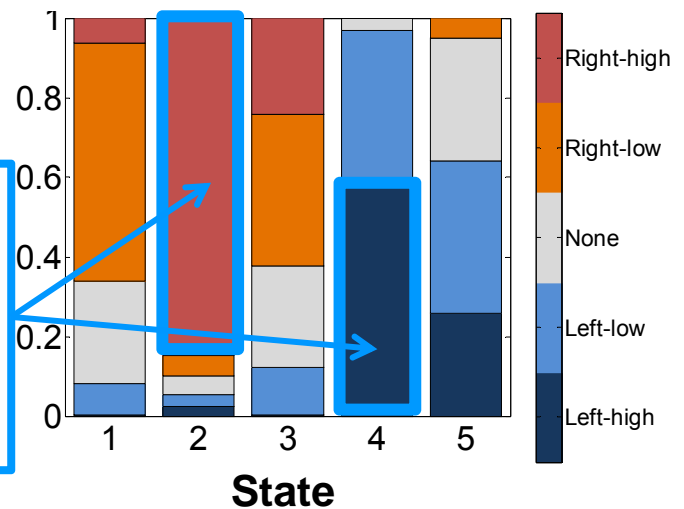
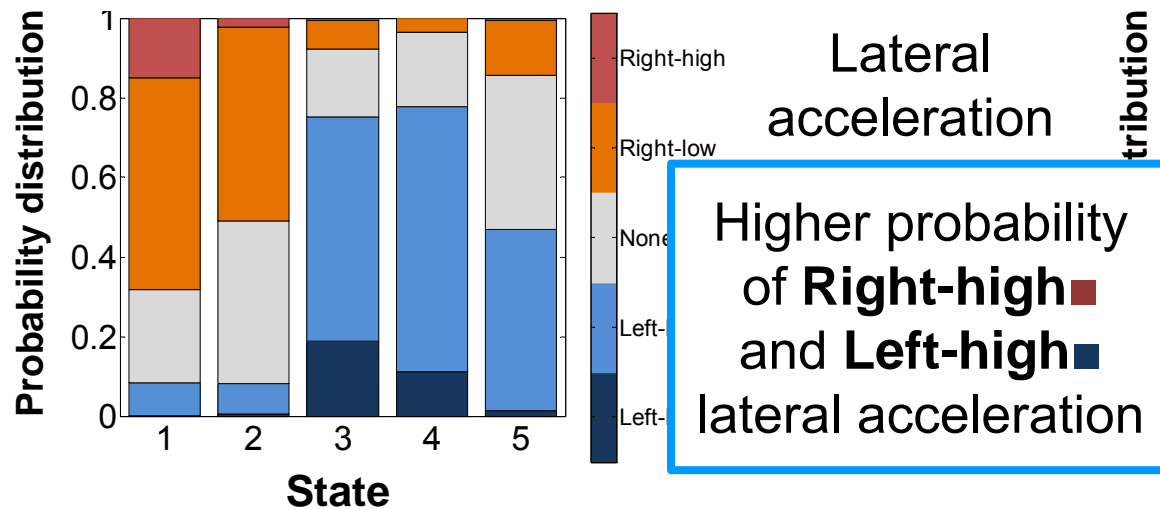
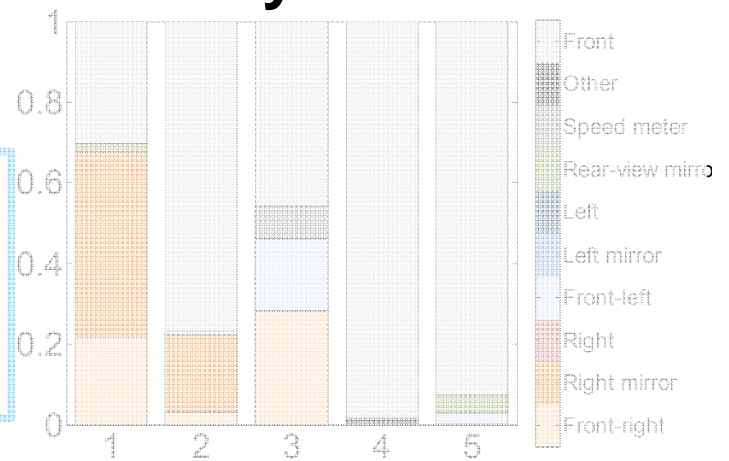
Modeling risky/safe behavior

Modeling sequences using multi-stream discrete HMMs

Safe HMM



Risky HMM



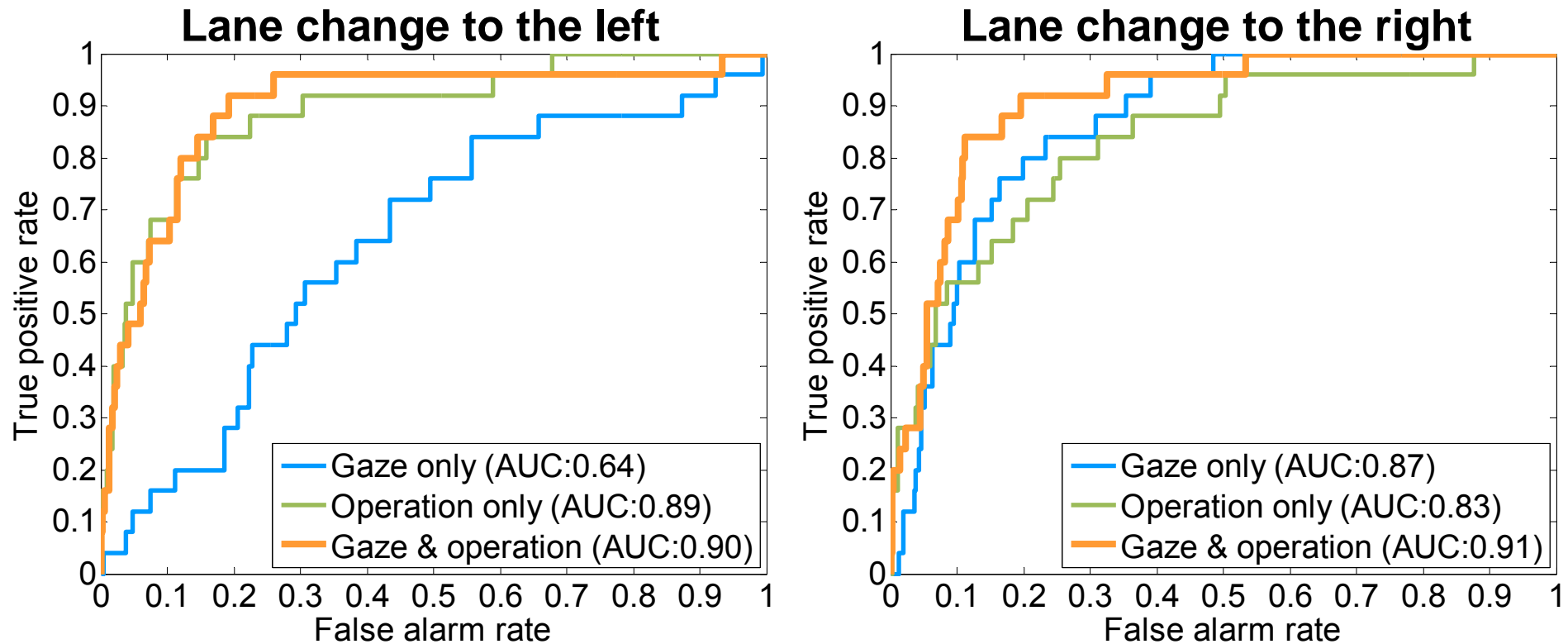
Risky lane change detection

Risky lane changes are detected based on an **HMM log-likelihood ratio** l_n

$$l_n = \underbrace{\log p(\mathbf{O}_n | \lambda_R)}_{\text{Score of risky model}} - \underbrace{\log p(\mathbf{O}_n | \lambda_S)}_{\text{Score of safe model}}$$

The higher l_n , the more likely lane change n is risky

Risky Lane Change Detection Performance

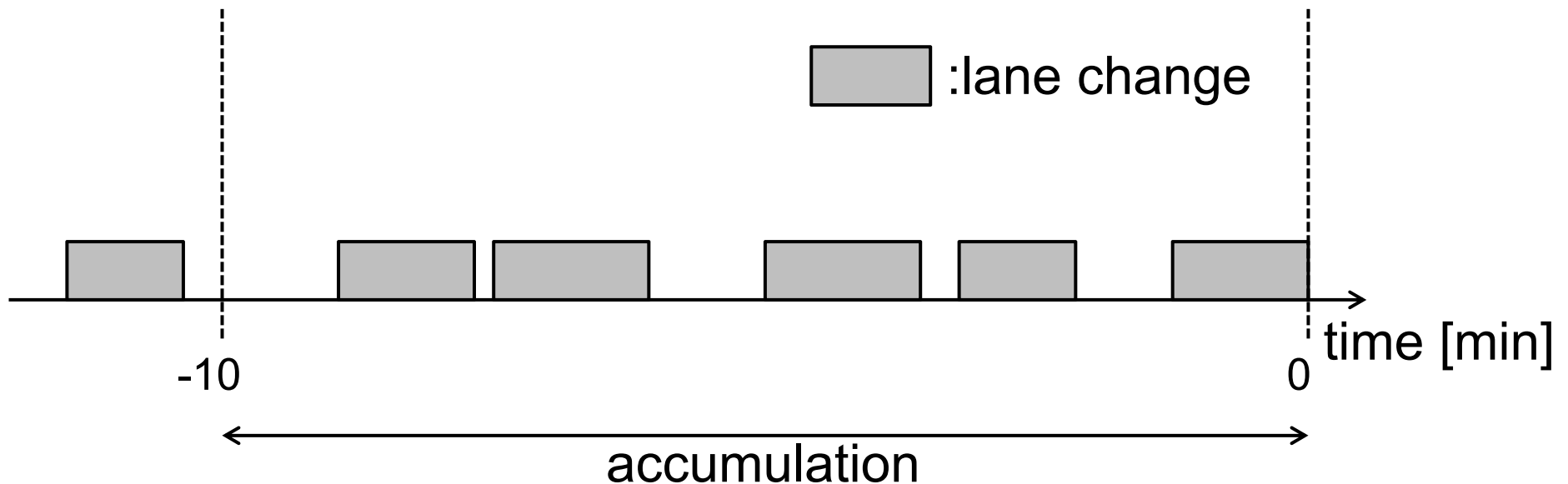


The integrated model performed better than the gaze only and operation only models.

Evaluation of Long-term Risk

We accumulated risk scores over a period of time.

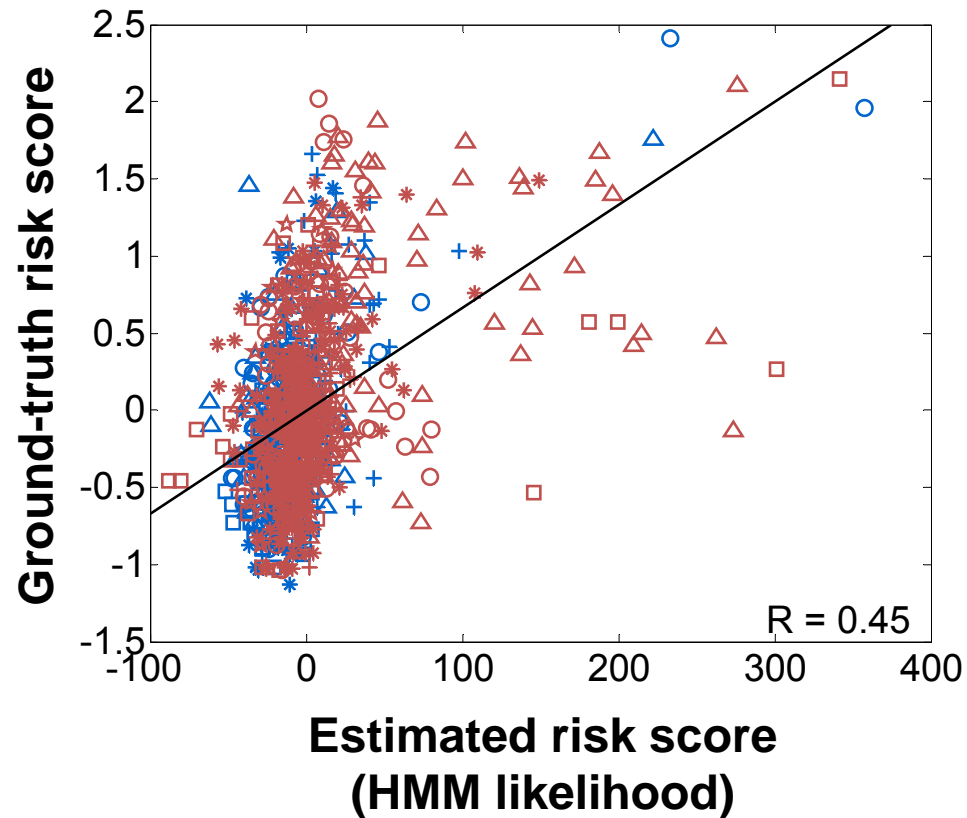
- Scores are accumulated over past T [min]. ($T = 0 - 30$)



Correlations Between Estimated and Ground-Truth Risk Scores Calculated Using Single/Multiple Lane-Change Events

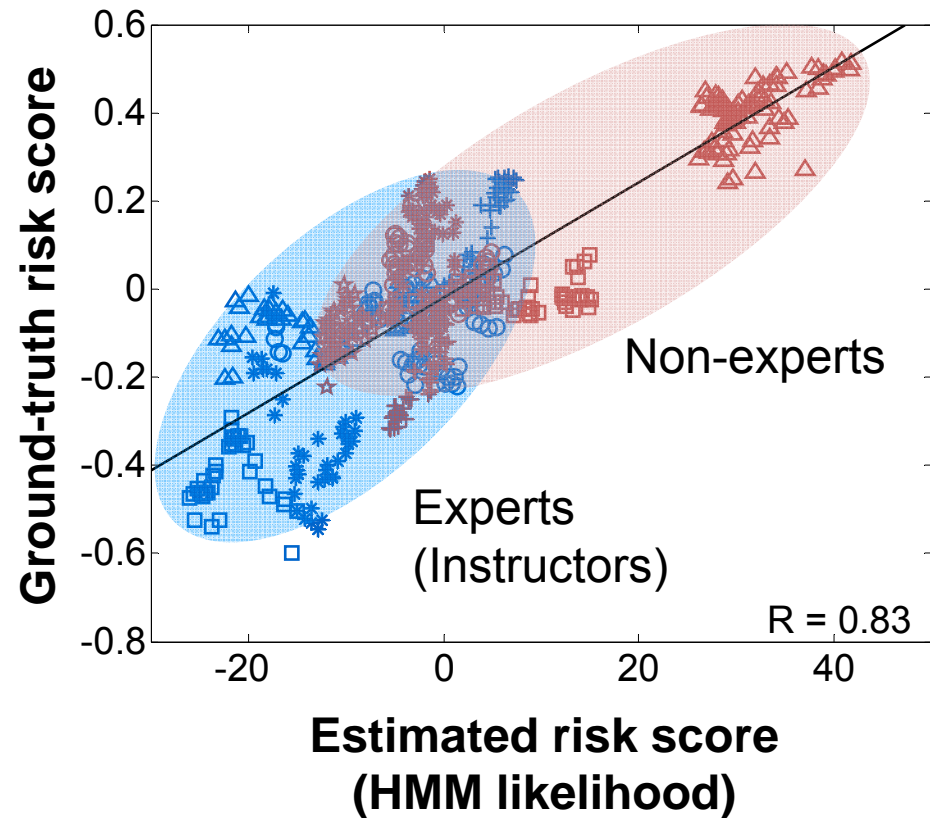
Single Event

T = 0 (Not accumulated)

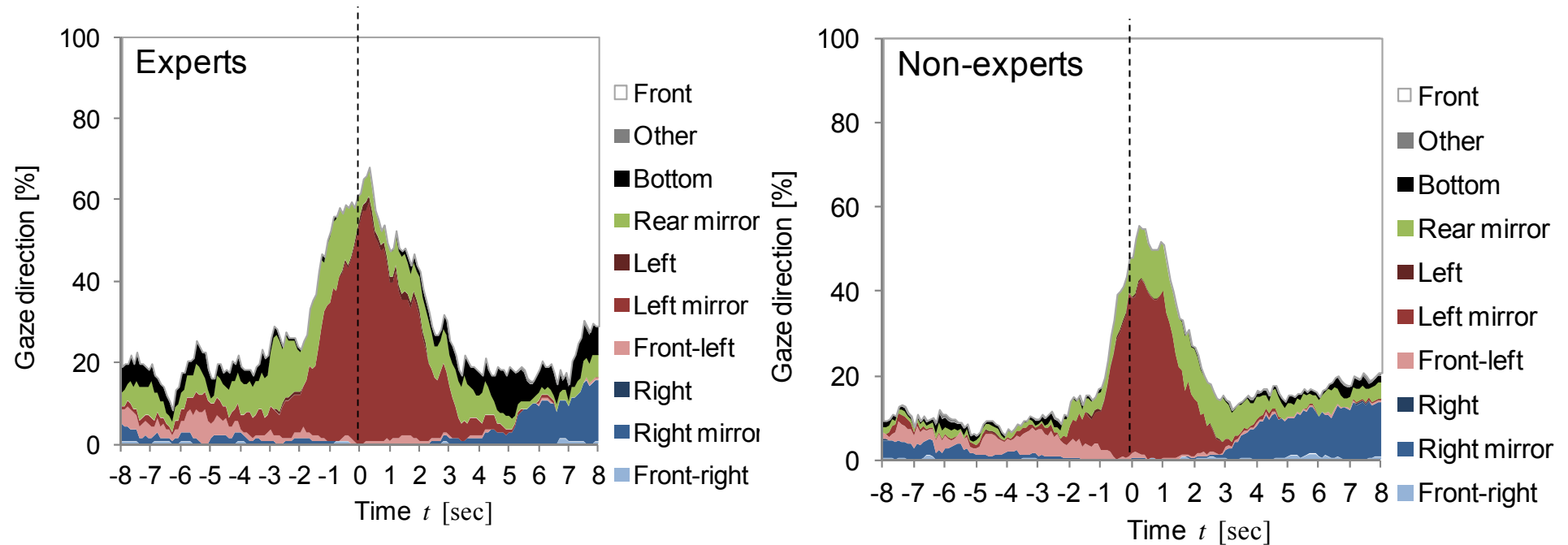


Multiple Events

T = 20 [min]



Differences in Gaze Directions During Lane Change Between Expert and Non-Expert Drivers



Conclusion

Integrated modeling of driver gaze and vehicle operation behavior

- Gaze and vehicle operations were represented as sequences of discrete acts
- Lane change behavior was modeled using HMMs.
- Integrated modeling improved risky lane change detection performance.
- Significant differences between expert and non-expert drivers was observed using accumulated HMM scores.

Future Work

- Employing automatic methods to detect gaze direction
- Extending our modeling to other types of driving situations