KI WISSEN

Automotive AI Powered by Knowledge

KI Wissen Final Event | 21-22 March 2024

Demonstration of Causality-driven Physical Conformity Checks of Vehicle Trajectories

Himanshu Agarwal | e:fs

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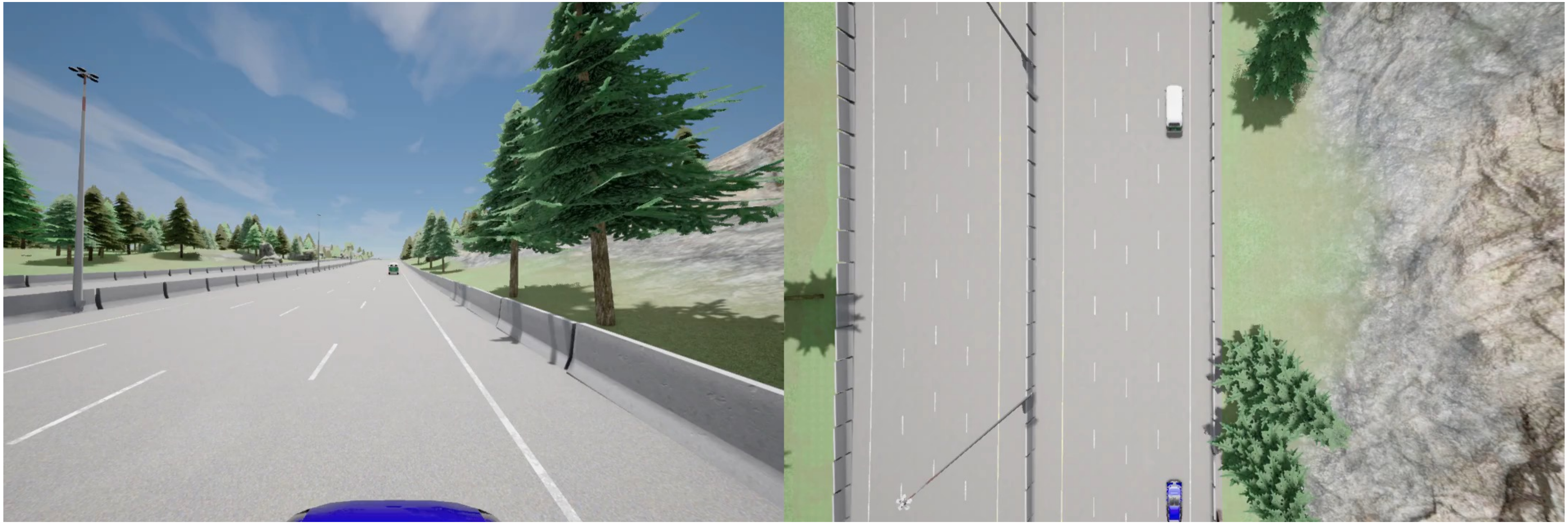
Introduction

Use Case 2.4: Lane Change of AD Vehicle in Multi-Lane Road

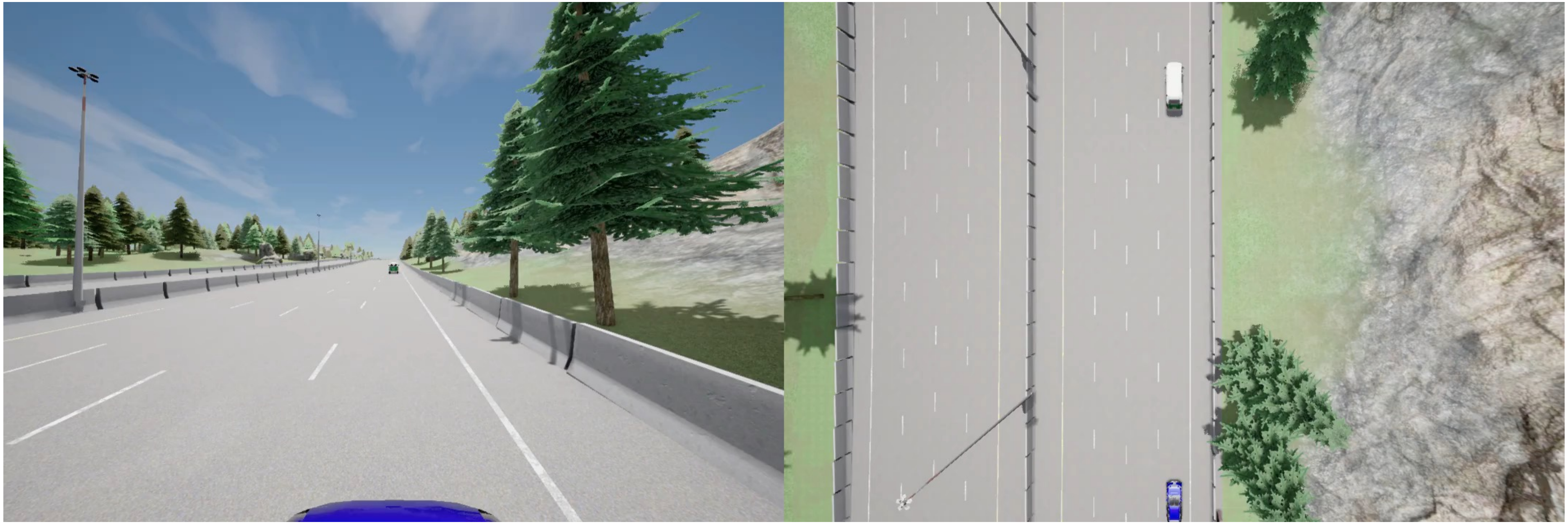
Demonstrator system without modifications:



Use Case 2.4: Lane Change of AD Vehicle in Multi-Lane Road

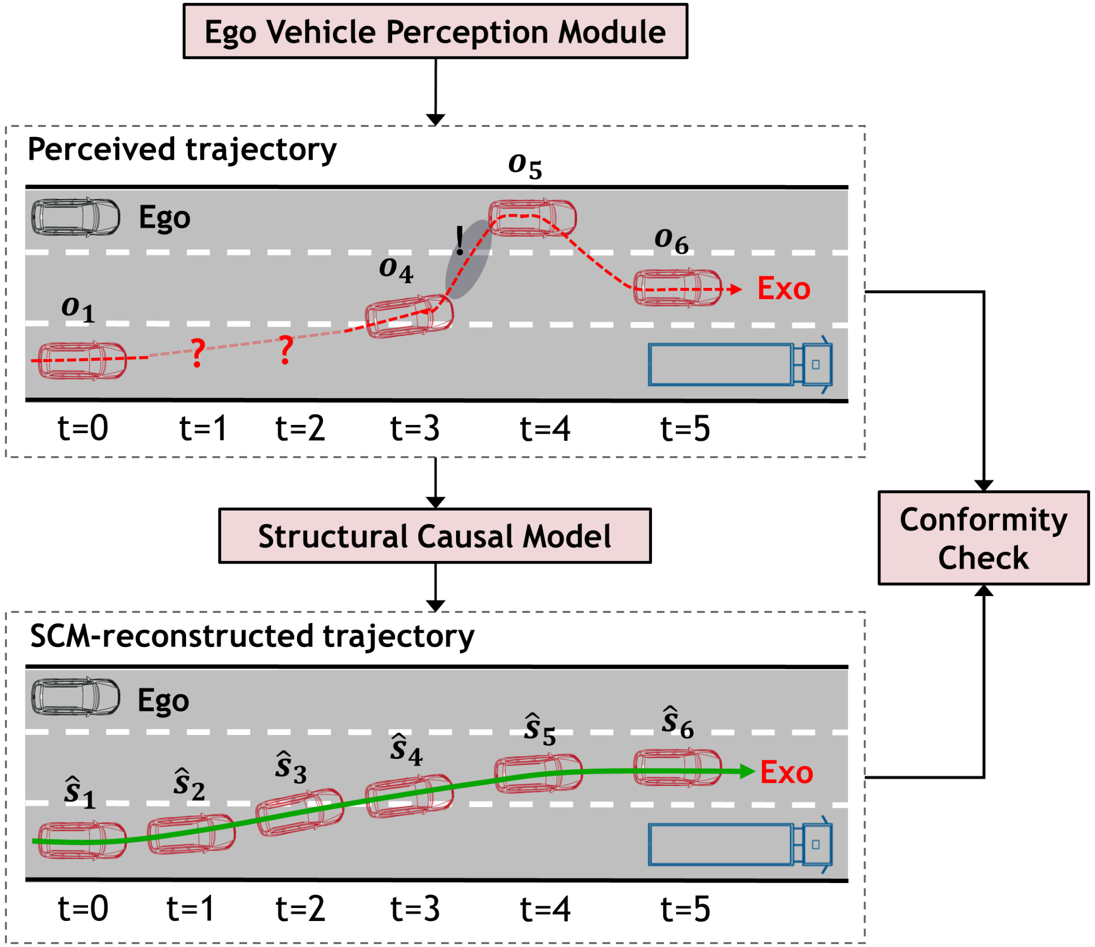
Demonstrator system with perturbed and missing observations:

⚠ **Heavy perturbations**



Causality-driven Physical Conformity Checks

- Checks for physical conformity of perceived vehicle trajectories developed in TP3
- Based on structural causal model for vehicle trajectories which combines physical equations and deep learning
- Trajectory reconstructed by the causal model is sent to downstream driving functions



Adapted from: Agarwal, Brunner, et al. "A Causal Model for Physics-Conform Vehicle Trajectories." *2023 IEEE 26th International Conference on Intelligent Transportation Systems (ITSC)*. IEEE, 2023.

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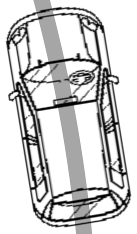
Conformity Checking Methods

Causal Knowledge about Vehicle Trajectories

Prior knowledge about vehicle trajectories:

- High-level variables (vehicle positions, vehicle velocities, driver actions, etc.)
- Temporal causal relationships of the high-level variables
- Physical constraints on vehicle movement:
  - Constraints on movement between time-steps
  - Coupling between longitudinal and lateral movement



Knowledge Building Block - Vehicle-SCM

Variables (nodes) in our Vehicle-SCM:

- s_t: Vehicle states (positions and velocities)
- o_t: Possibly noisy or missing observations of states
- a_t: Accelerations due to the driver's actions

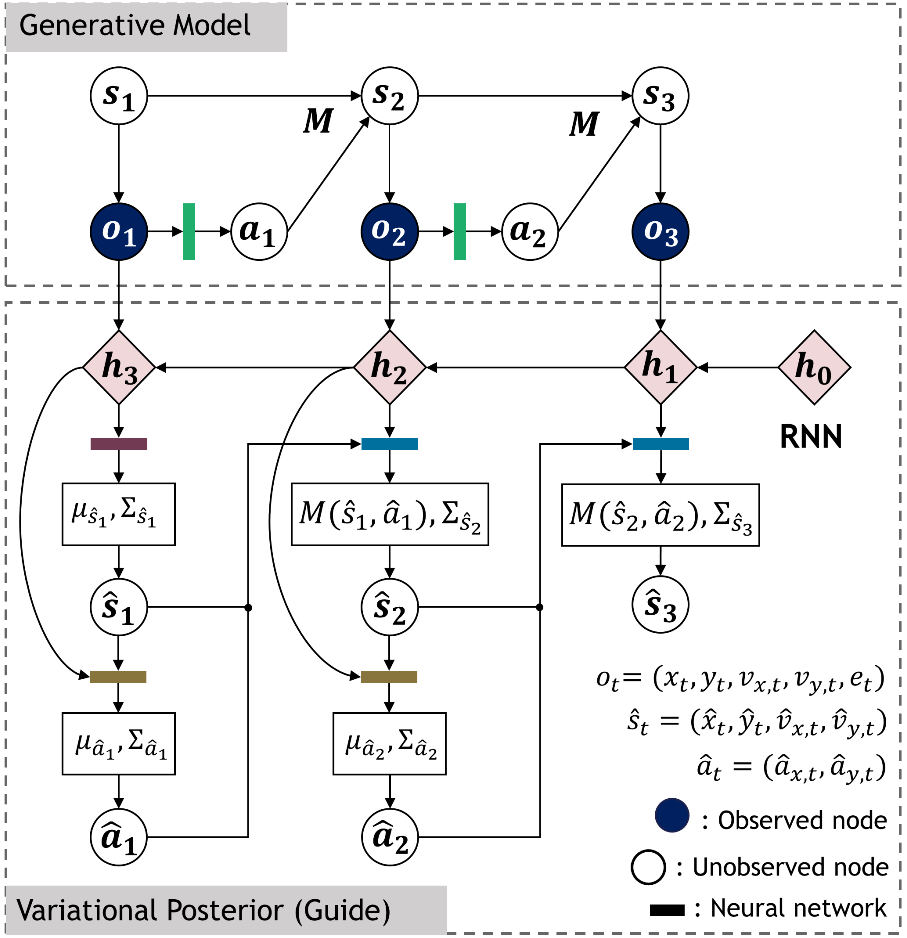
Generative model:

- $o_t \sim p(o_t \mid s_t)$
- $a_t \sim p(a_t \mid o_t)$
- $s_t \sim p(s_{t+1} \mid s_t, a_t) = M(s_t, a_t) + \epsilon_{s_t}$

Circle model

Guide (variational posterior):

- $\hat{a}_t \sim q(\hat{a}_t \mid \hat{s}_t, o_{t:T})$
- $\hat{s}_{t+1} \sim q(\hat{s}_{t+1} \mid \hat{s}_t, \hat{a}_t, o_{t:T})$



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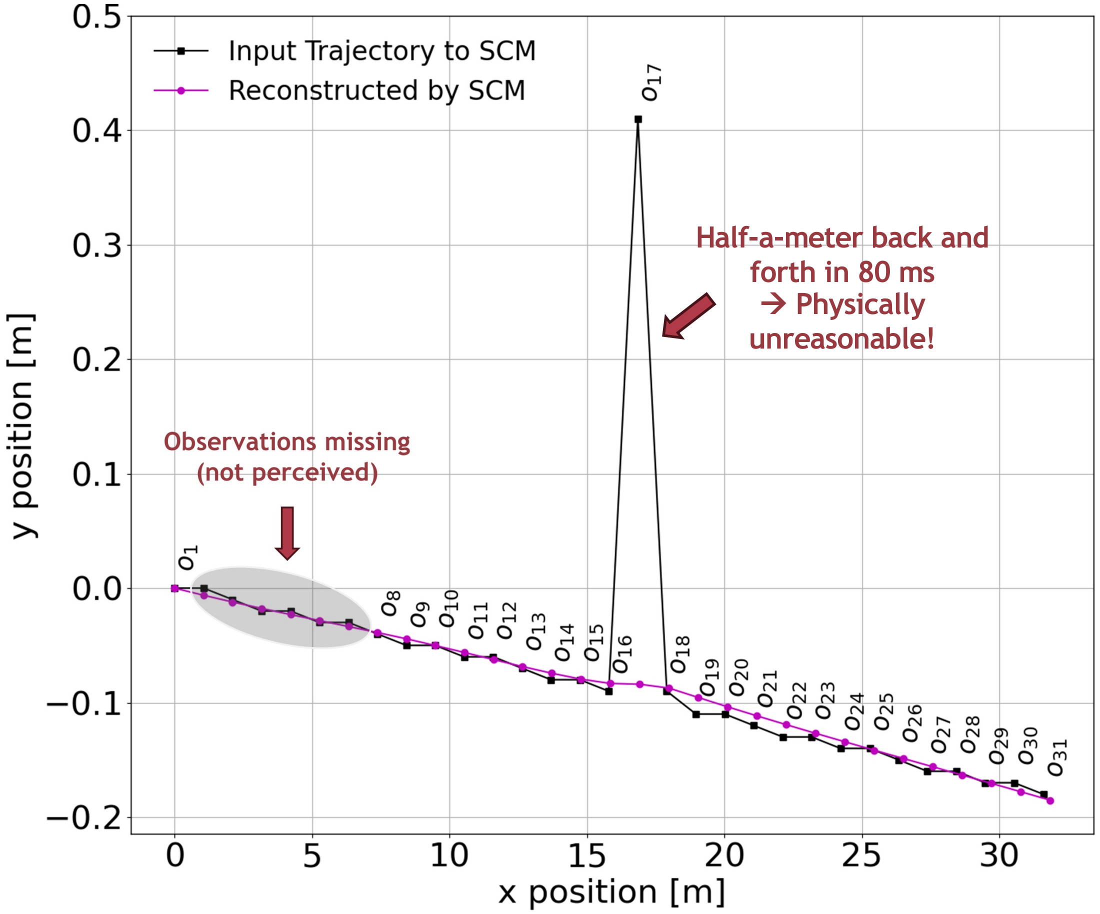
Correction of Physically Implausible Trajectories

Principle: *associational query*

- Check if SCM can reconstruct the state sequence for the given observation sequence
- Example: Trajectory from highD dataset [1] with artificially missing and disturbed observations



Half-a-meter back and forth in 80 ms → Physically unreasonable!

Observations missing (not perceived)

[1] Krajewski et al. "The highd dataset: A drone dataset of naturalistic vehicle trajectories on german highways for validation of highly automated driving systems." *2018 21st international conference on intelligent transportation systems (ITSC)*. IEEE, 2018

Proposed Conformity Check Methods

- **Methods M1 and M2:**

  Compare reconstruction by Vehicle-SCM to the given sequence of observations

- **Method M3:**

  Compare accelerations against physically realistic thresholds

Table: Overview of the conformity check methods.

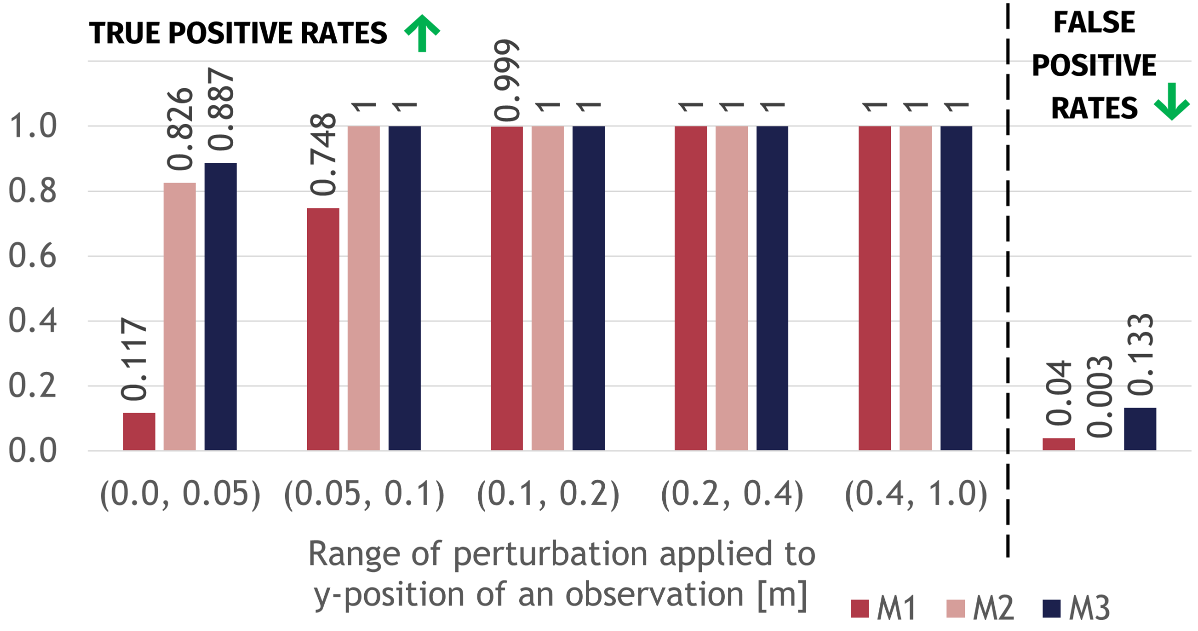
M1	Measures the Euclidean distance between positions from the input and the reconstructed trajectory.
M2	Measures the Mahalanobis distance between the observed state s_t and the SCM-estimated posterior distribution $q(s_t)$.
M3	Checks if longitudinal and lateral acceleration computed via *Circle Model* conform to realistic thresholds (obtained via expert survey).

Offline Evaluation of Conformity Check Methods

- Offline evaluation using trajectories from highD dataset [1] with 50% missing observations and artificial perturbations

- Method M2 has highest TPR as well as lowest FPR

Detection of physically non-conform and partially observed trajectories



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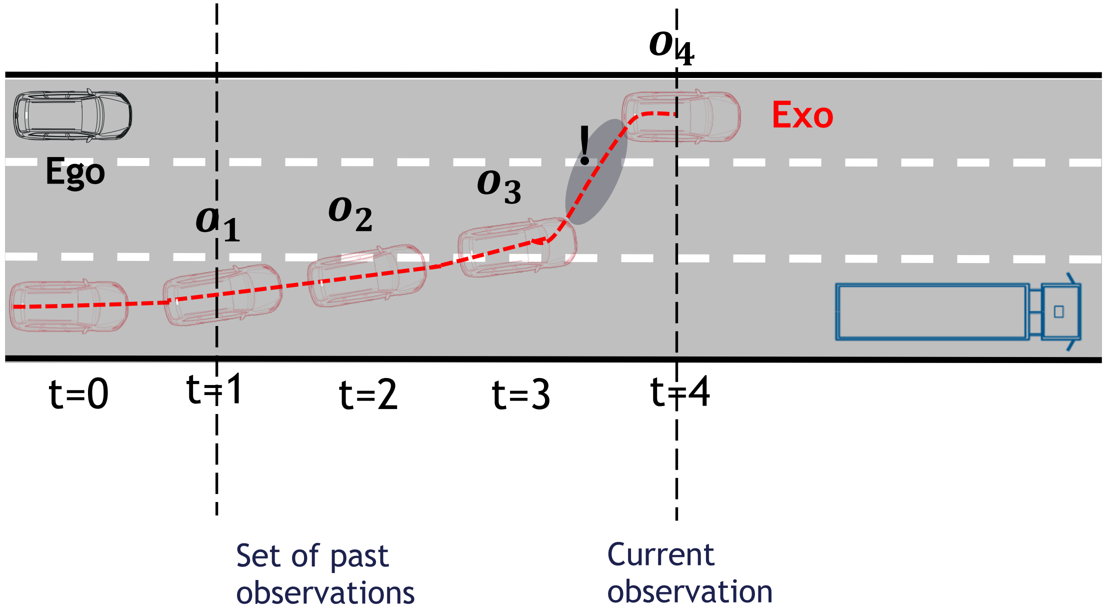
Integration in Demonstrator

Online Application of Conformity Check Methods

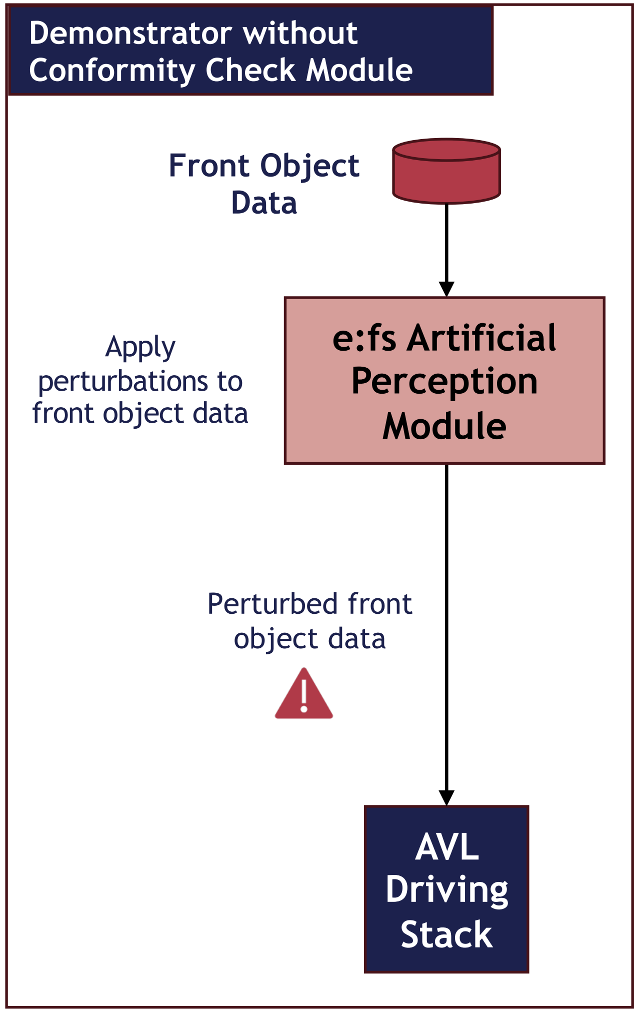
e:fs Conformity Check Module:

- Input current observation and set of past observations $o_{t-T:t}$ into the Guide
- Check if the current observation is non-conform
- If non-conform, replace it with physically conform value approximated from generative model

Perceived Trajectory



Integration of Conformity Check Methods in Demonstrator



Demonstrator without Conformity Check Module

Front Object Data

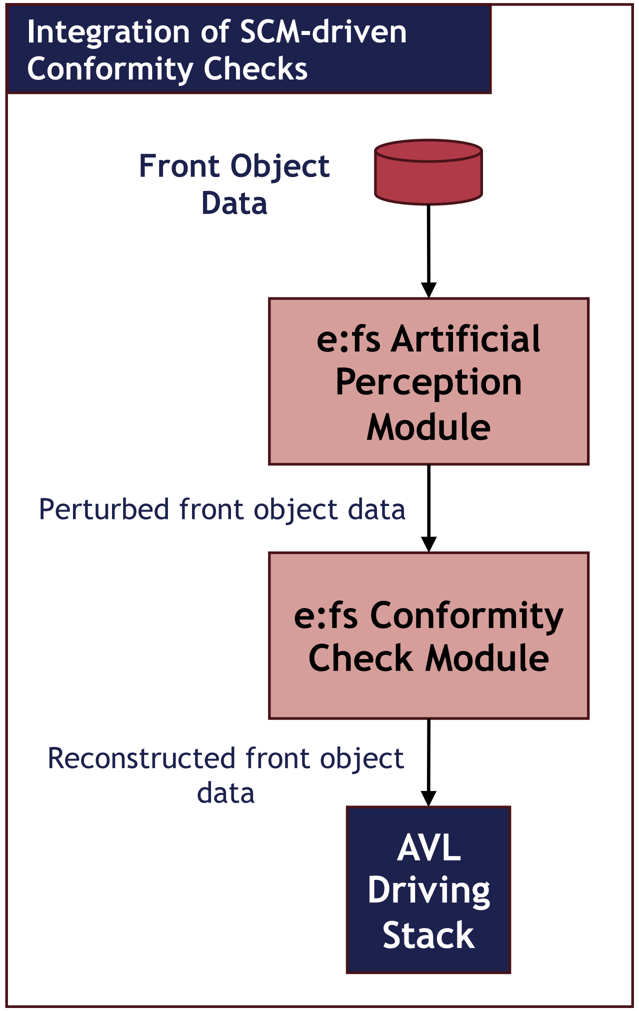
Apply perturbations to front object data

e:fs Artificial Perception Module

Perturbed front object data

⚠

AVL Driving Stack



Integration of SCM-driven Conformity Checks

Front Object Data

e:fs Artificial Perception Module

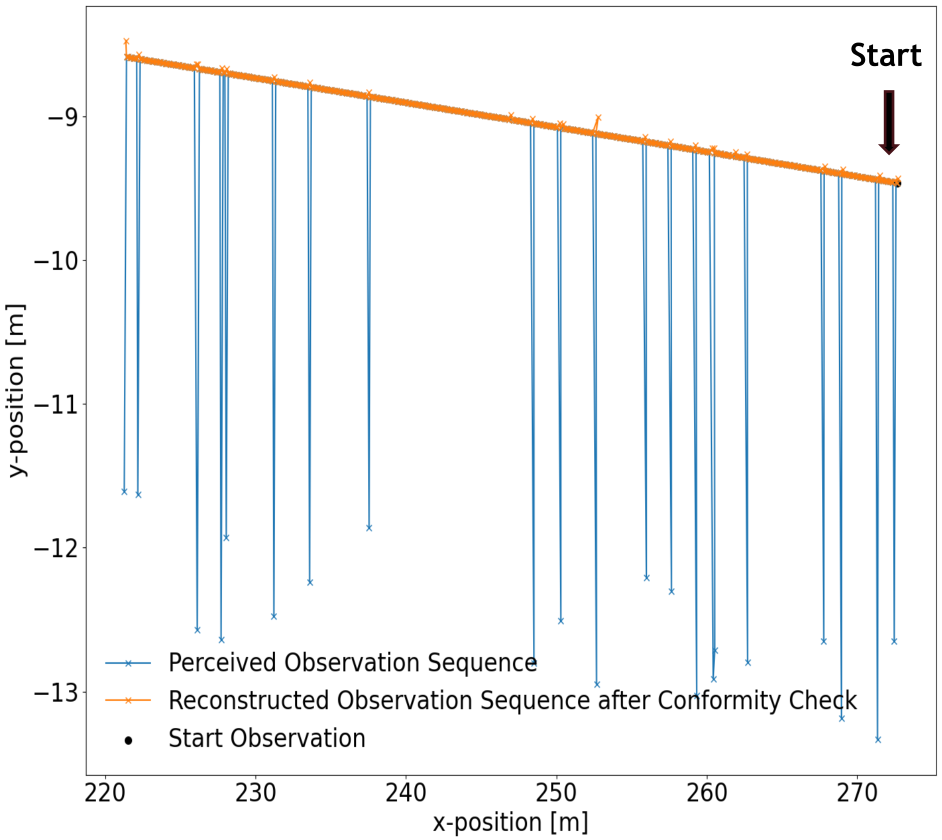
Perturbed front object data

e:fs Conformity Check Module

Reconstructed front object data

AVL Driving Stack

Comparison of Perceived (Perturbed) and SCM Reconstructed Observations



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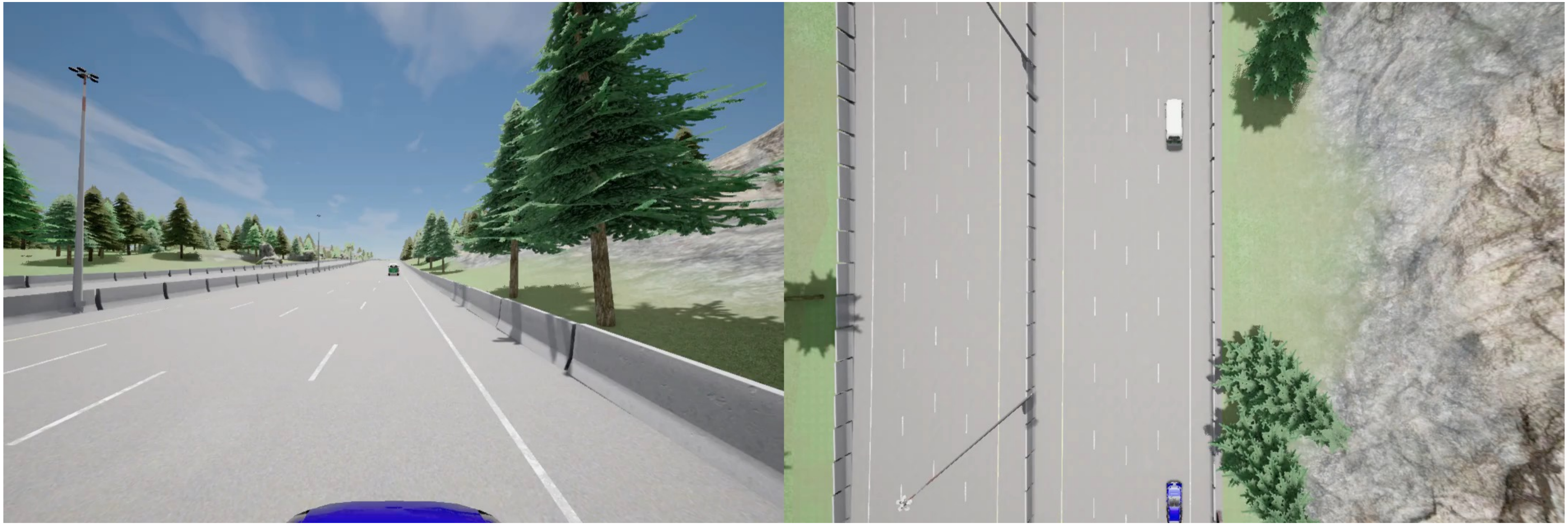
Demonstration

Use Case 2.4: Lane Change of AD Vehicle in Multi-Lane Road

Demonstrator system using physical conformity check method M2:

⚠ **Light perturbations**



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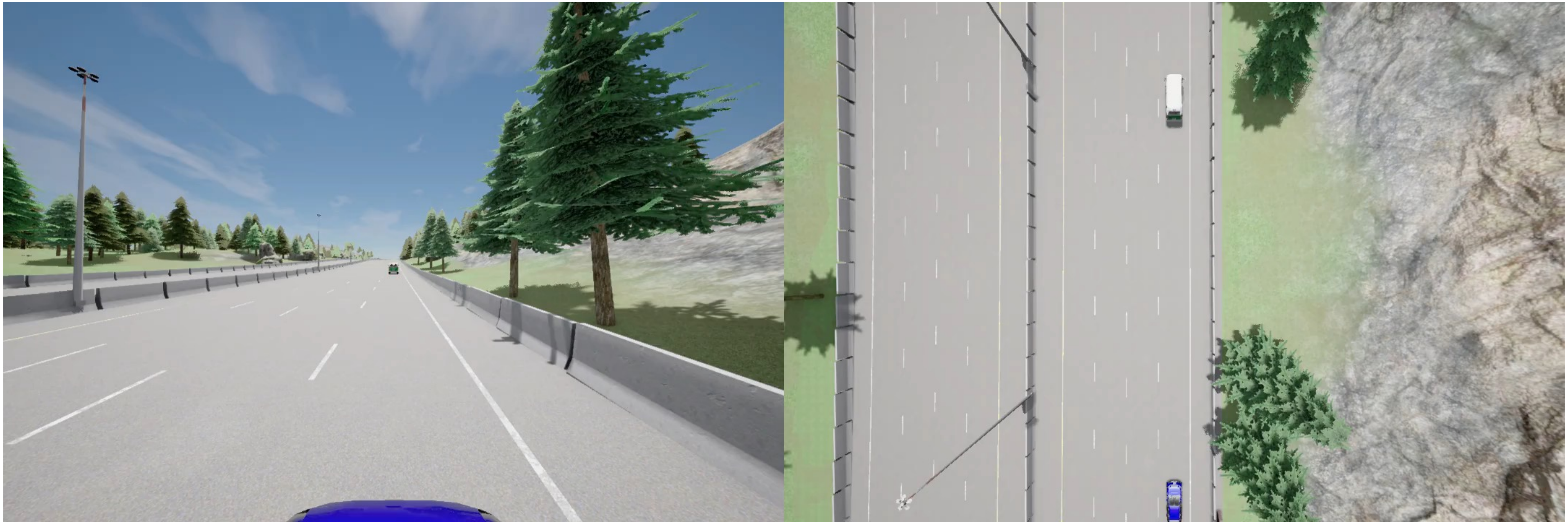

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Conclusion

Demonstration of Physical Conformity Checks

Objective

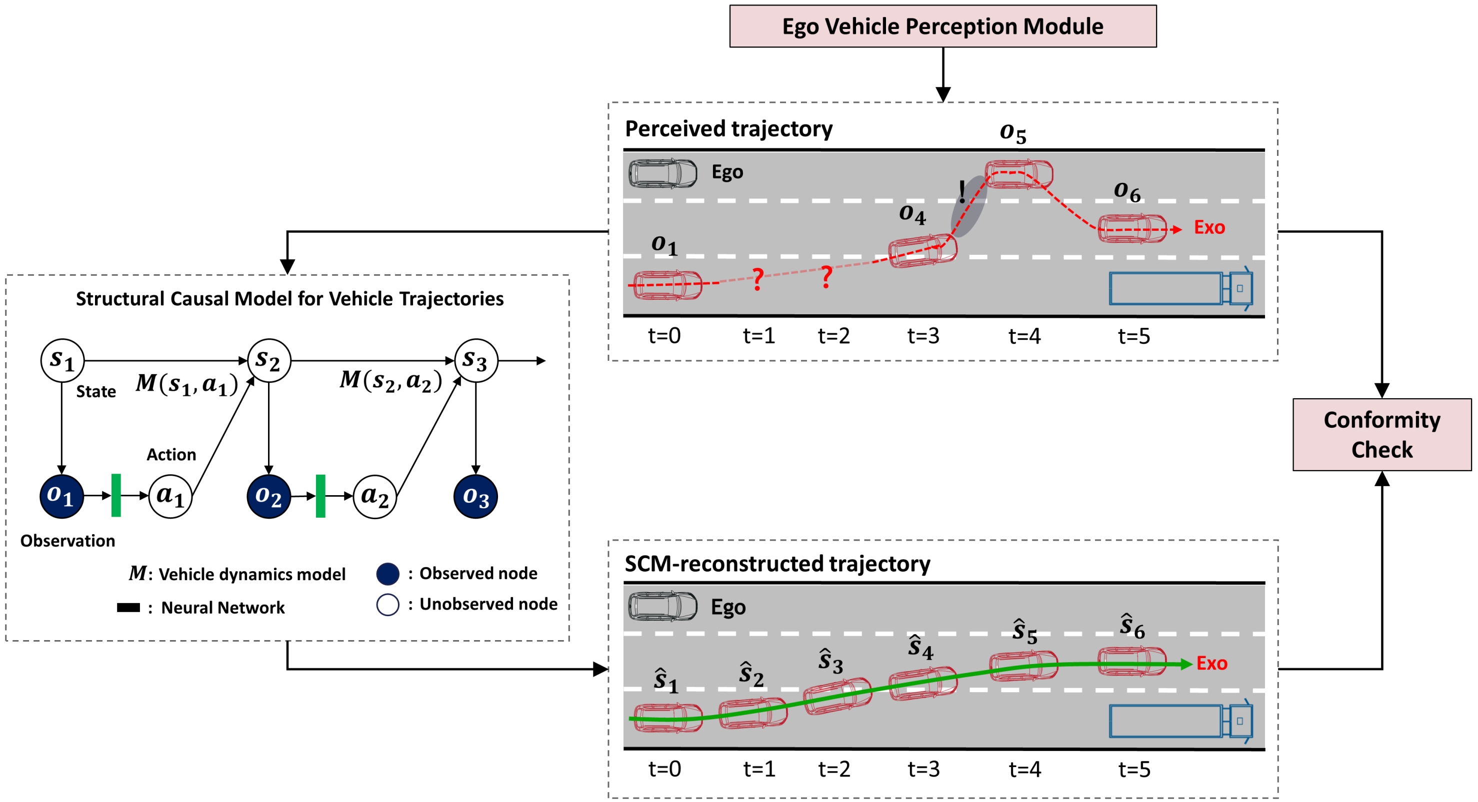
Detection and correction of physically unreasonable vehicle trajectories

Concept from AP 3.1

Structural causal model (SCM) used for conformity checks [2]

Contribution to AP4.5

Integration of SCM-driven conformity check methods in the demonstrator



[2] H. Agarwal, C. Brunner, et.al, "A Causal Model for Physics-Conform Vehicle Trajectories," 2023 IEEE 26th International Conference on Intelligent Transportation Systems (ITSC), Bilbao, Spain, 2023, pp. 4980-4987.

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KI FAMILIE

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