CommonRoad: Composable Benchmarks for Motion Planning on Roads

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Technical University of Munich

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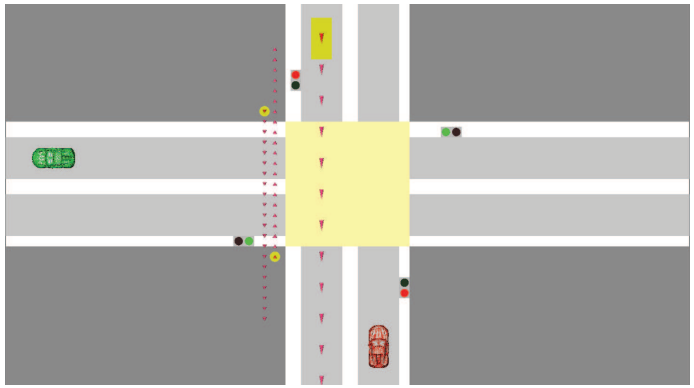
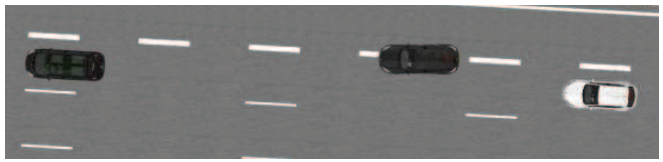
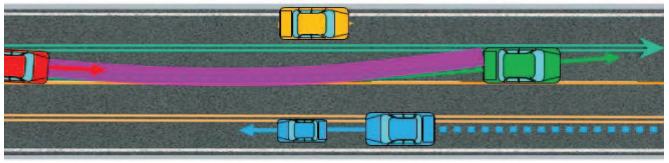
Examples of IV'16 Papers on Motion Planning



Chen et al.: Combining Task and Motion [...]

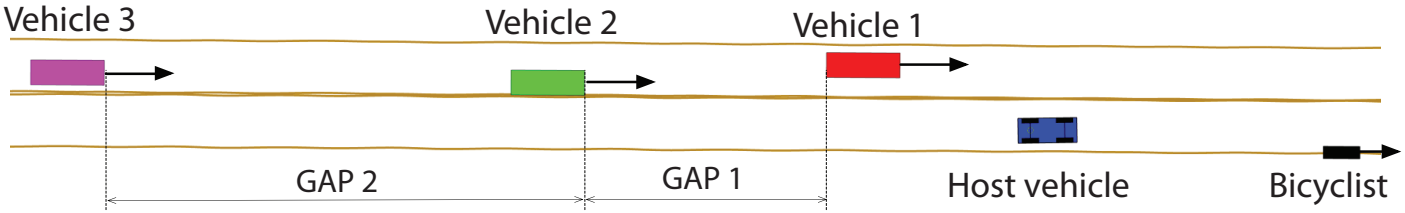


Guo et al.: Adaptive Vehicle Longitudinal [...]

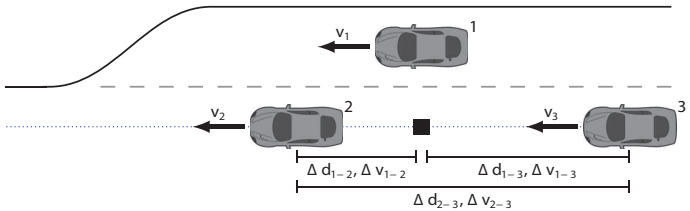


Guo et al.: Learning-based Trajectory [...]

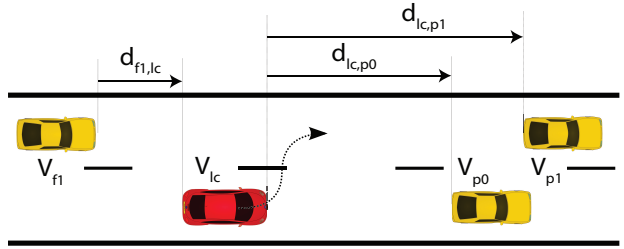
Reproducable? Comparable?



Gu et al.: Runtime-Bounded Tunable Motion Planning for Autonomous Driving

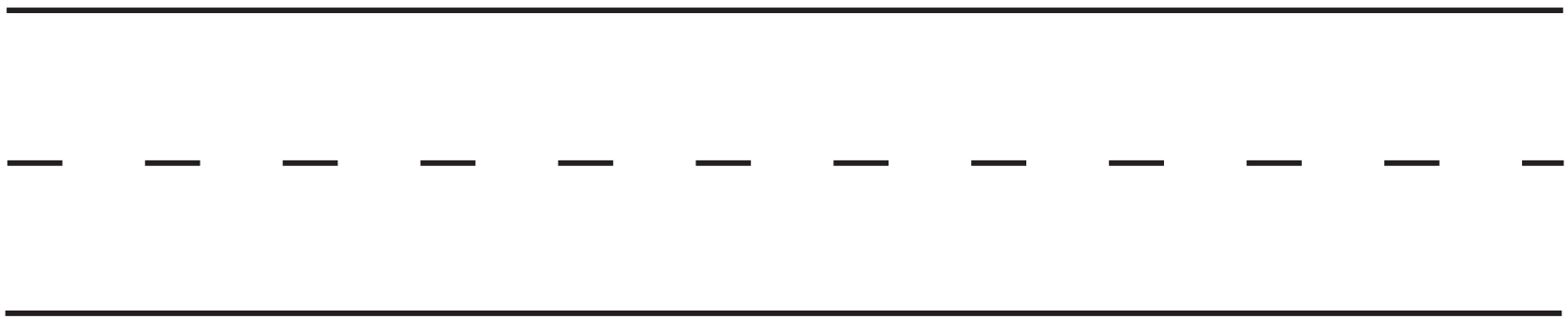


Klingelschmitt et al.: Probabilistic Situation [...]



Schmied et al.: Scenario Model Predictive [...]

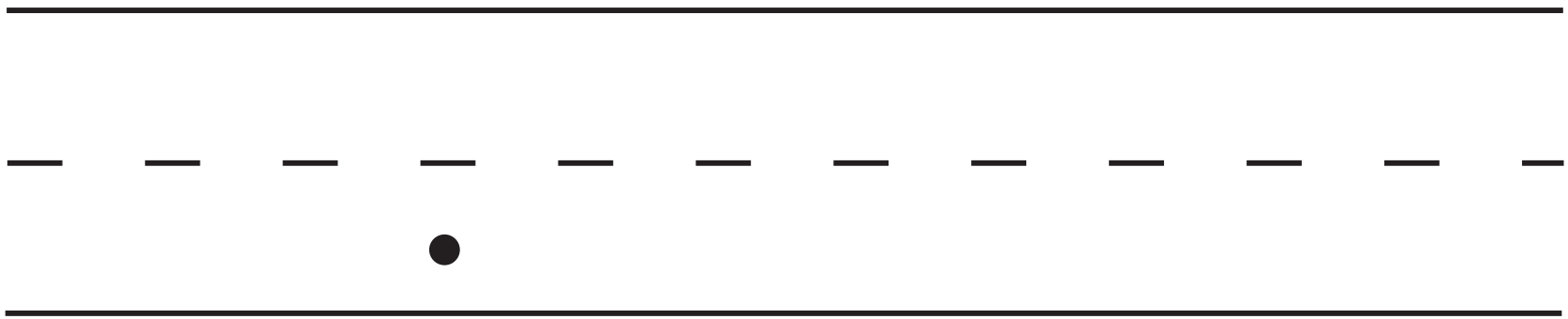
Required Ingredients for Motion Planning Problems



Scenario

Road network

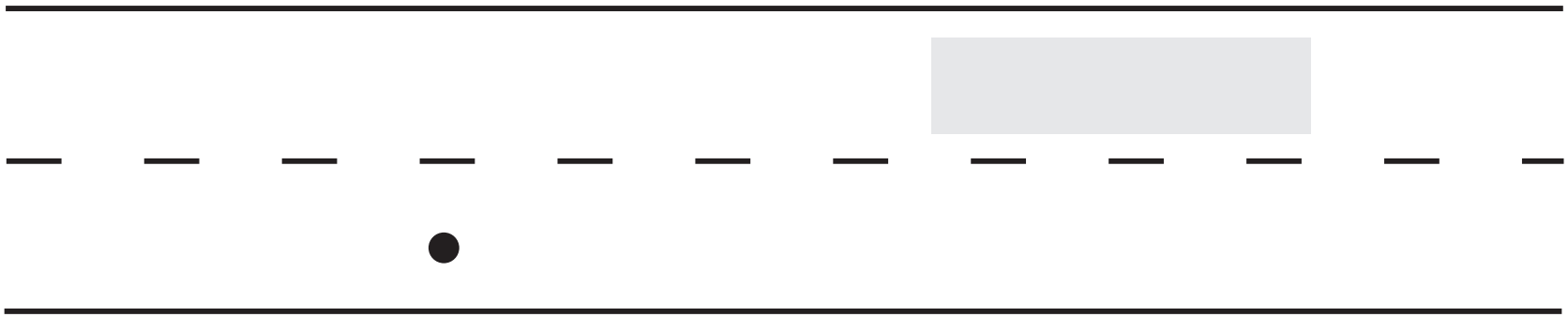
Required Ingredients for Motion Planning Problems



Scenario

Road network, initial state x_0

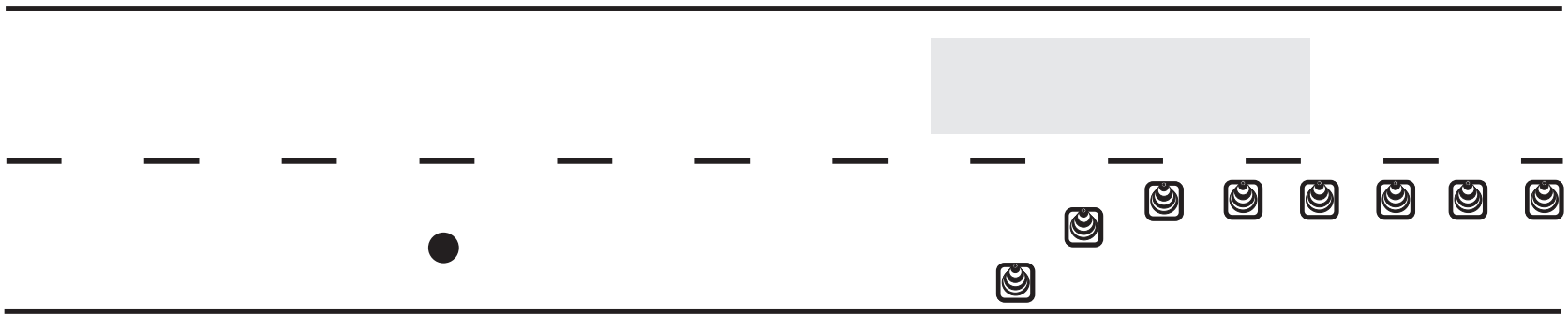
Required Ingredients for Motion Planning Problems



Scenario

Road network, initial state x_0, goal region $\mathcal{G}$

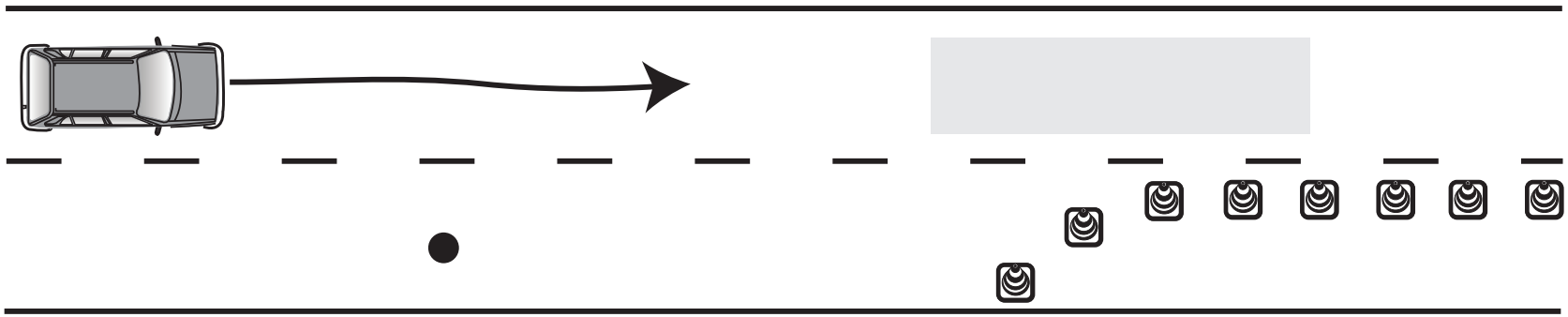
Required Ingredients for Motion Planning Problems



Scenario

Road network, initial state x_0, goal region $\mathcal{G}$, static obstacles

Required Ingredients for Motion Planning Problems



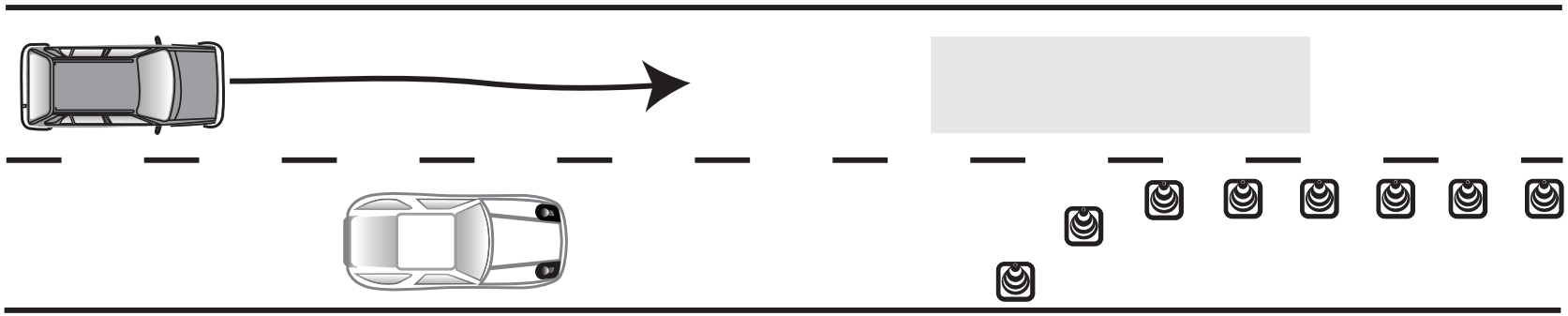
Scenario

Road network, initial state x_0, goal region $\mathcal{G}$, static obstacles, dynamic obstacles (including movement over time)

Required Ingredients for Motion Planning Problems

Vehicle model

$\dot{x}(t) = f(x(t), u(t))$
x: state, u: input



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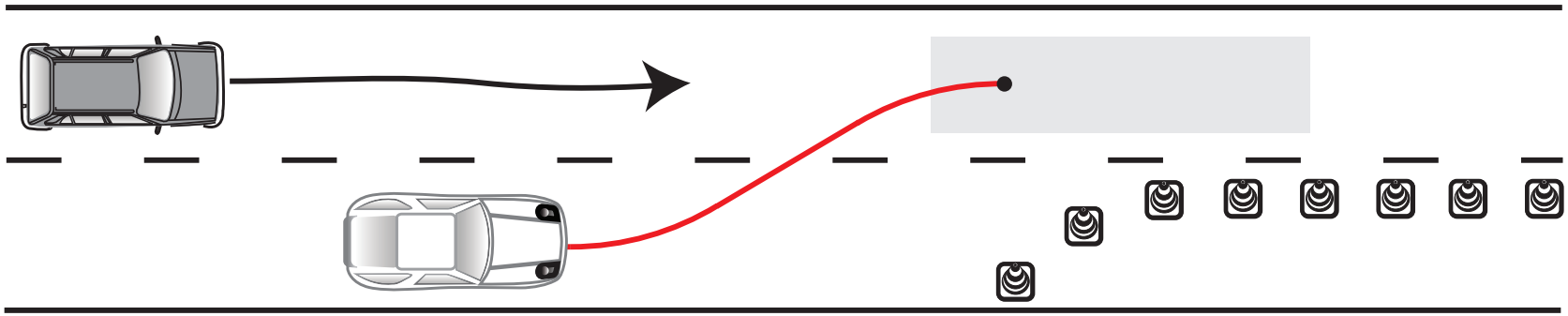
Cost function

$J_C = \Phi_C(x(t_0), t_0, x(t_f), t_f) + \int_{t_0}^{t_f} L_C(x(t), u(t), t)\,\mathrm{d}t$

Φ_C: terminal costs,

L_C: running costs



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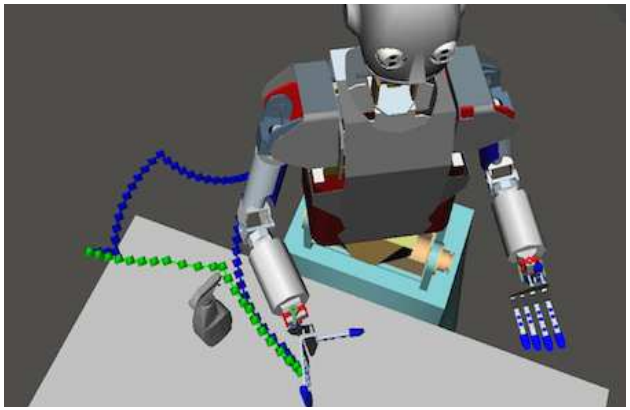
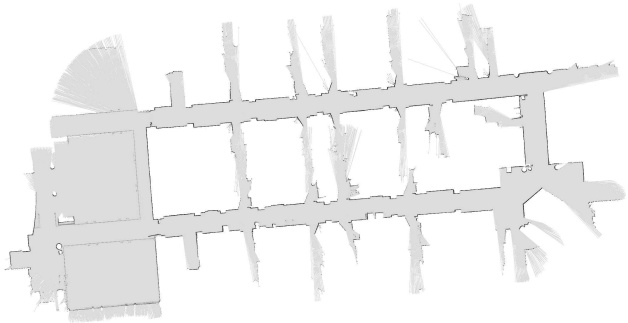
Examples of Benchmarks in Related Areas



Robotic grasping
OpenGrasp



Simultaneous localization and mapping (SLAM)
OpenSLAM

Computer vision
KITTI Vision Benchmark Suite

Composable Benchmarks with a Unique ID

Vehicle model

- Point-mass model (PM)
  - **PM1**
  - **PM2**
  - etc.
- Kinematic single-track model (KS)
- Other vehicle models

Cost function

- Bobrow et al., 1988 (**JB1**)
- Anderson et al., 2010 (**SA1**)
- Xu et al., 2012 (**WX1**)
- Other cost functions

Scenario

- Recorded highway data US 101 (**NGSIM_US101_0**)
  - Road network
  - Static obstacles
  - Dynamic obstacles
  - Initial state
  - Goal region
  - etc.
- Other scenarios

Standard ID: PM1:JB1:NGSIM_US101_0

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Individual component (IND): **IND**:M-JB1:NGSIM_US101_0

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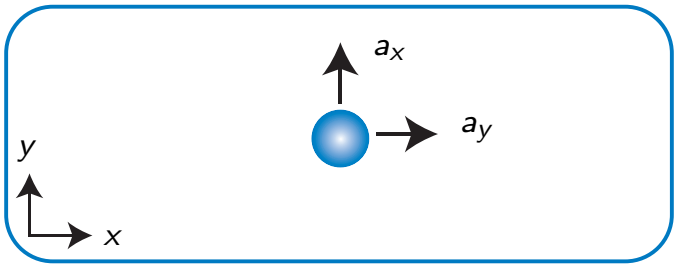
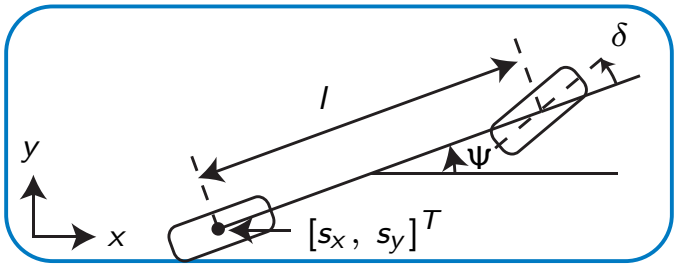
Standard ID: PM1:JB1:NGSIM_US101_0
Modification (M-): PM1:**M**-JB1:NGSIM_US101_0
Individual component (IND): **IND**:M-JB1:NGSIM_US101_0
Collaboration (C-): **[PM1,PM2]:[M-JB1,SA1]:C**-NGSIM_(...)

Models



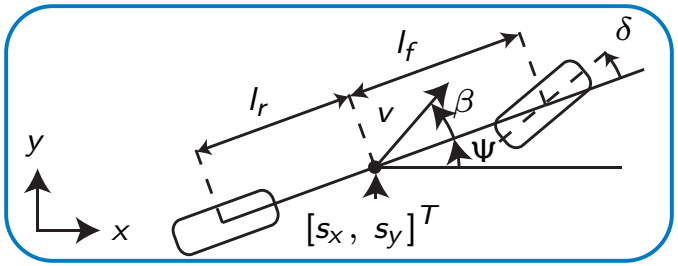
Point-mass model (PM)

- Holonomic system
- $\ddot{x} = a_x, \quad \ddot{x} = a_y$



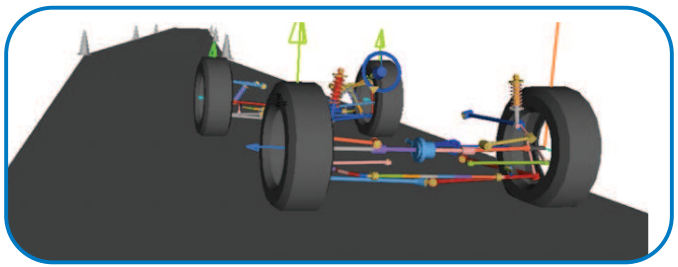
Kinematic single-track model (KS)

- Nonholonomic system
- Considers minimum turning radius
- No tire slip



Single-track model (ST)

- Considers tire slip
- Can explain understeer and oversteer
- No individual tire loads



Multi-body model (MB)

- Individual tire loads
- Effects from yaw, pitch, and roll
- Detailed suspension model

Cost Functions

Like the benchmarks, the cost functions are composable:

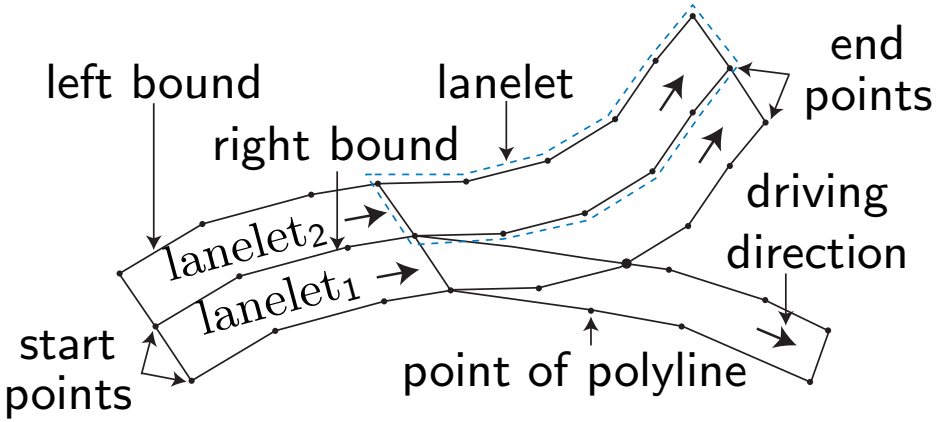
$$J_C(x(t), u(t), t_0, t_f) = \sum_{i \in \mathcal{I}} w_i \, J_i(x(t), u(t), t_0, t_f),$$

where $\mathcal{I}$ contains the IDs of partial cost functions and $w_i \in \mathbb{R}^+$ are weights. Examples:

- **Time**: $J_T = t_f$ (see Bobrow et al., 1988).
- **Acceleration**: $J_A = \int_{t_0}^{t_f} a(t)^2 \, \mathrm{d}t$ (see Ziegler et al., 2014b).
- **Jerk**: $J_J = \int_{t_0}^{t_f} \dot{a}(t)^2 \, \mathrm{d}t$ (see Werling et al., 2010).
- **Steering angle**: $J_{SA} = \int_{t_0}^{t_f} \delta(t)^2 \, \mathrm{d}t$ (see Magdici et al., 2016).
- etc.

A set of useful weights is provided by cost-function IDs (e.g. $JB1$, $SA1$, and $WX1$).

Scenarios: Road Network



P. Bender, J. Ziegler, and C. Stiller, "Lanelets: Efficient map representation for autonomous driving," in *Proc. of the IEEE Intelligent Vehicles Symposium*, 2014, pp. 420–425.

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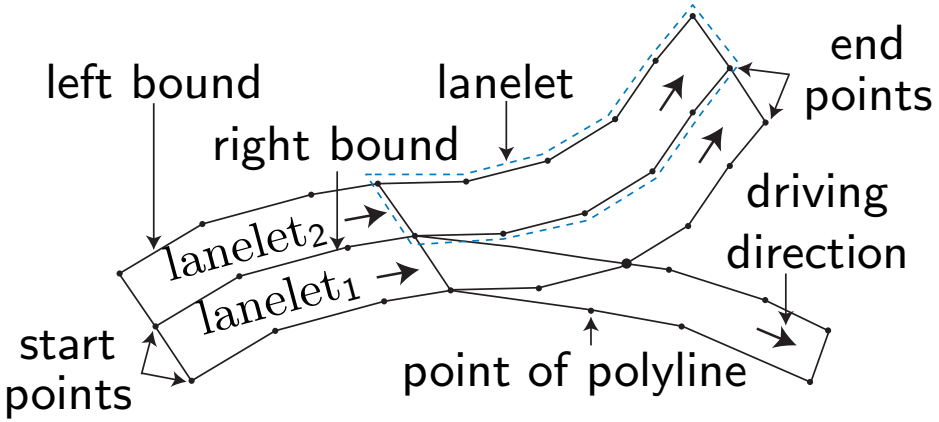

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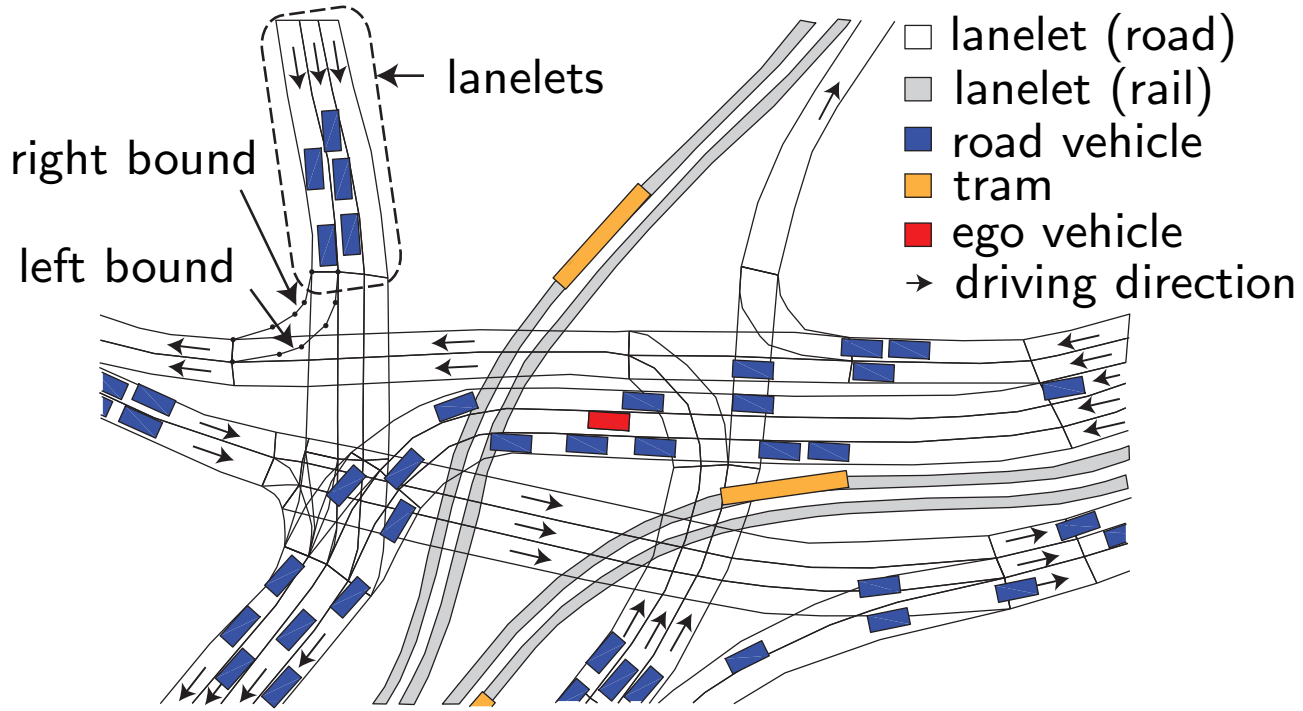
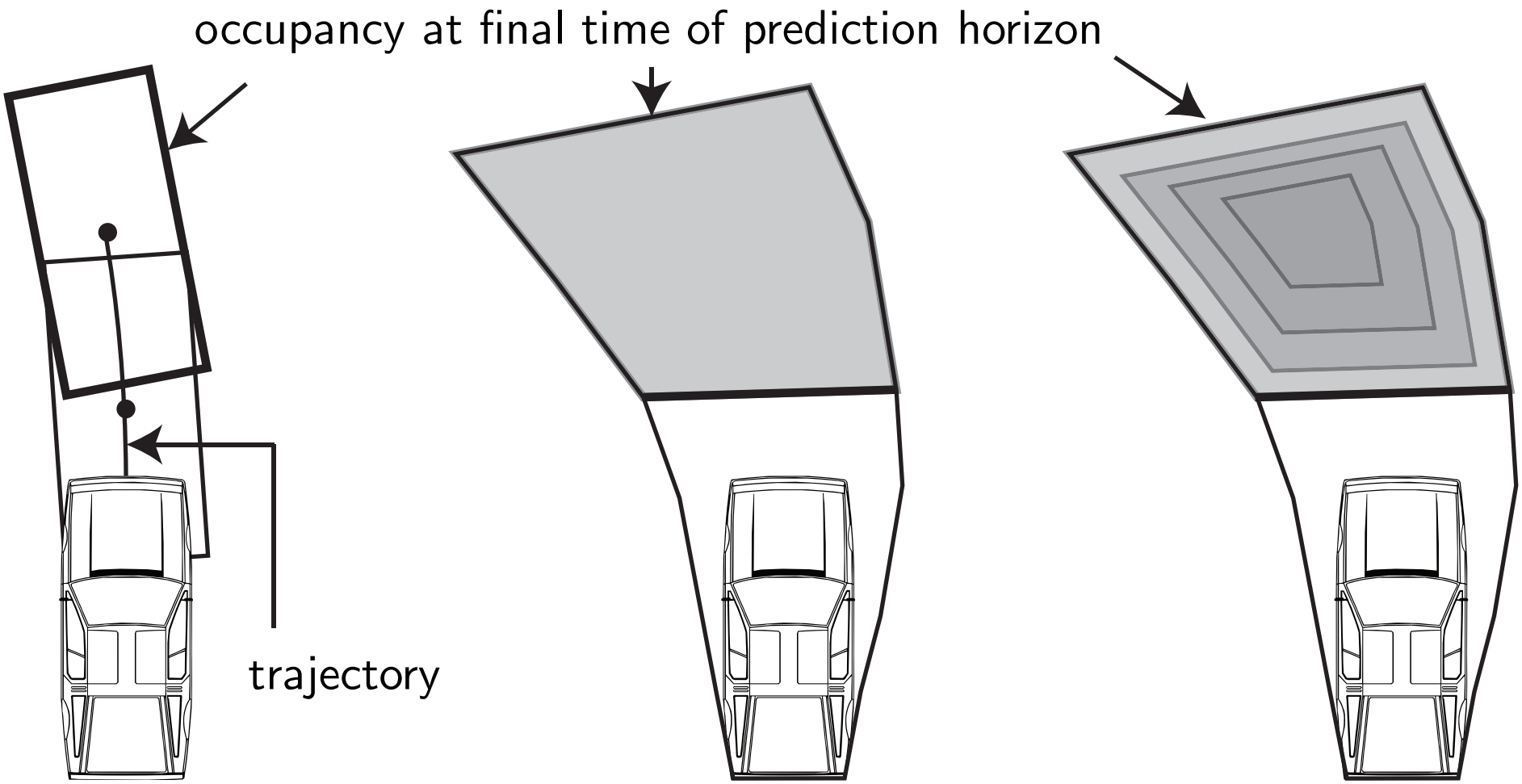
Example of a complicated crossing in Munich:

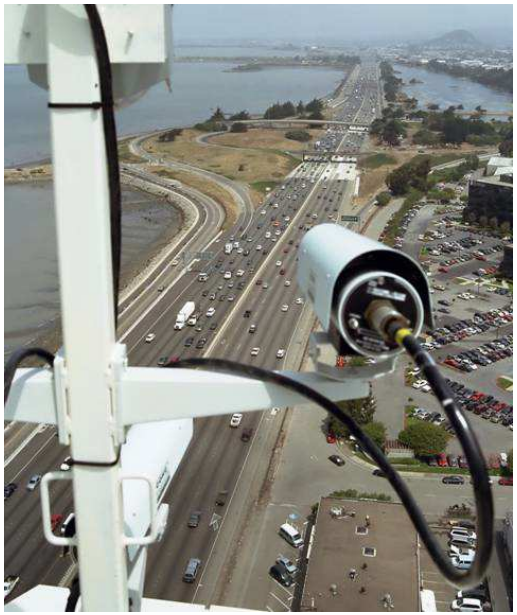


Scenarios: Obstacles

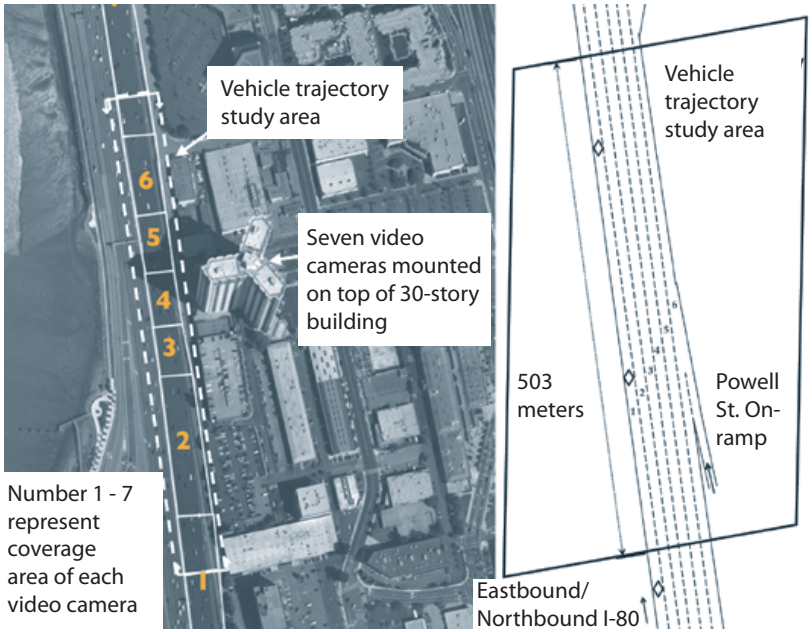


Source for Known Behavior: Recorded Data

Camera facing US Interstate 80.



Coverage of individual cameras.



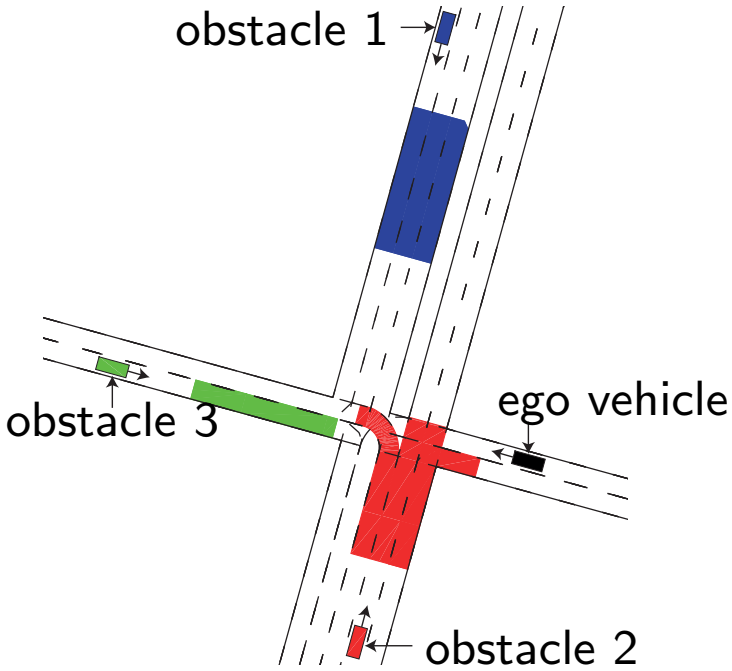
Next Generation Simulation (NGSIM) dataset:

1. Lankershim Boulevard
2. US Highway 101

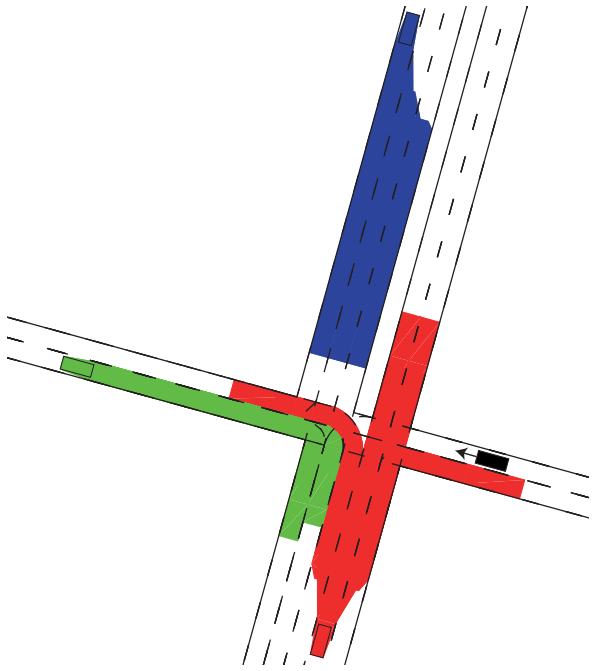
Source for Unknown Behavior: SPOT

A Tool for Set-based Prediction of Traffic Participants (SPOT). Tool presented

Example:



(a) $t \in [1.5\text{ s}, 2.0\text{ s}]$.



(b) $t \in [0\text{ s}, 3.0\text{ s}]$.

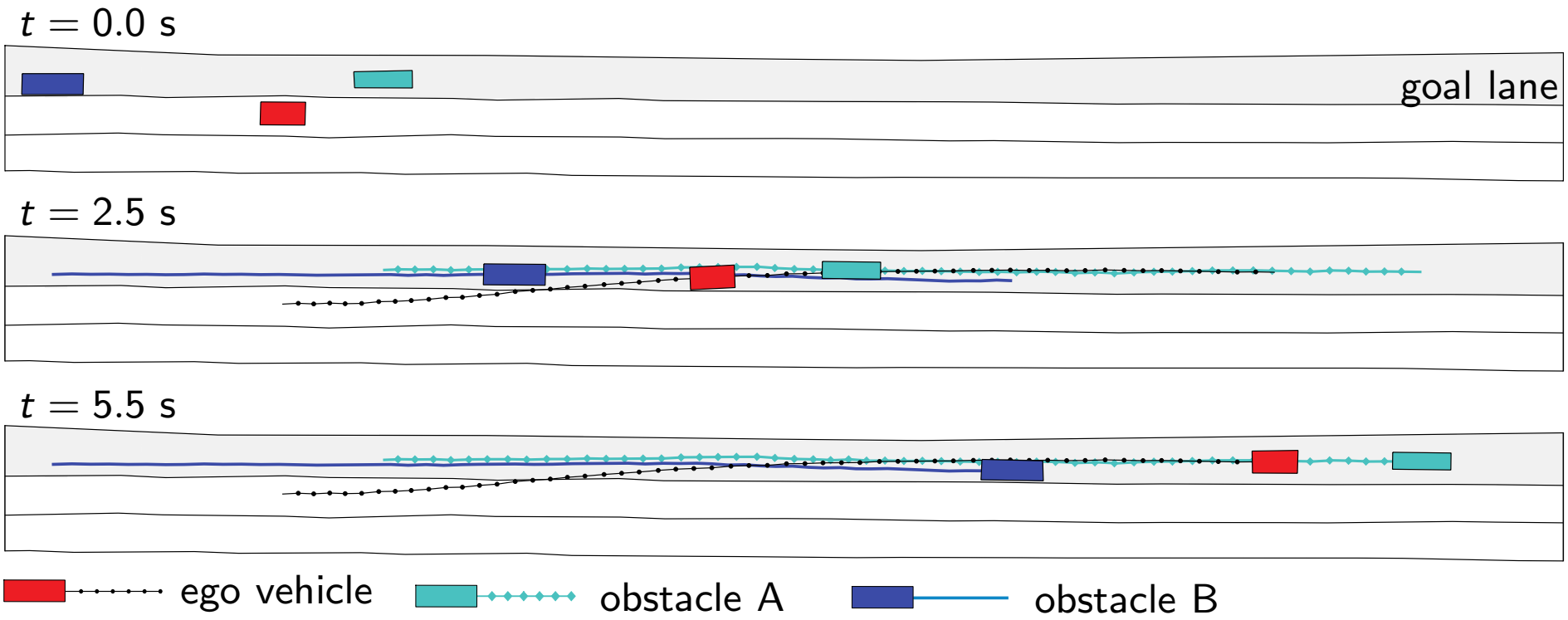
Computation time: ≈ 100 times faster than maneuver time (MATLAB, Intel i7, 2.6GHz); total time: 25 ms (3 parallel processes).

Example

- **Vehicle model:** M-KS1 (modification: v_S is changed to $v_S \to \infty$).
- **Cost function:** SM1.
- **Scenario:** NGSIM_US101_0.

Thus, the unique ID of this example is **M-KS1:SM1:NGSIM_US101_0**.

Possible solution:



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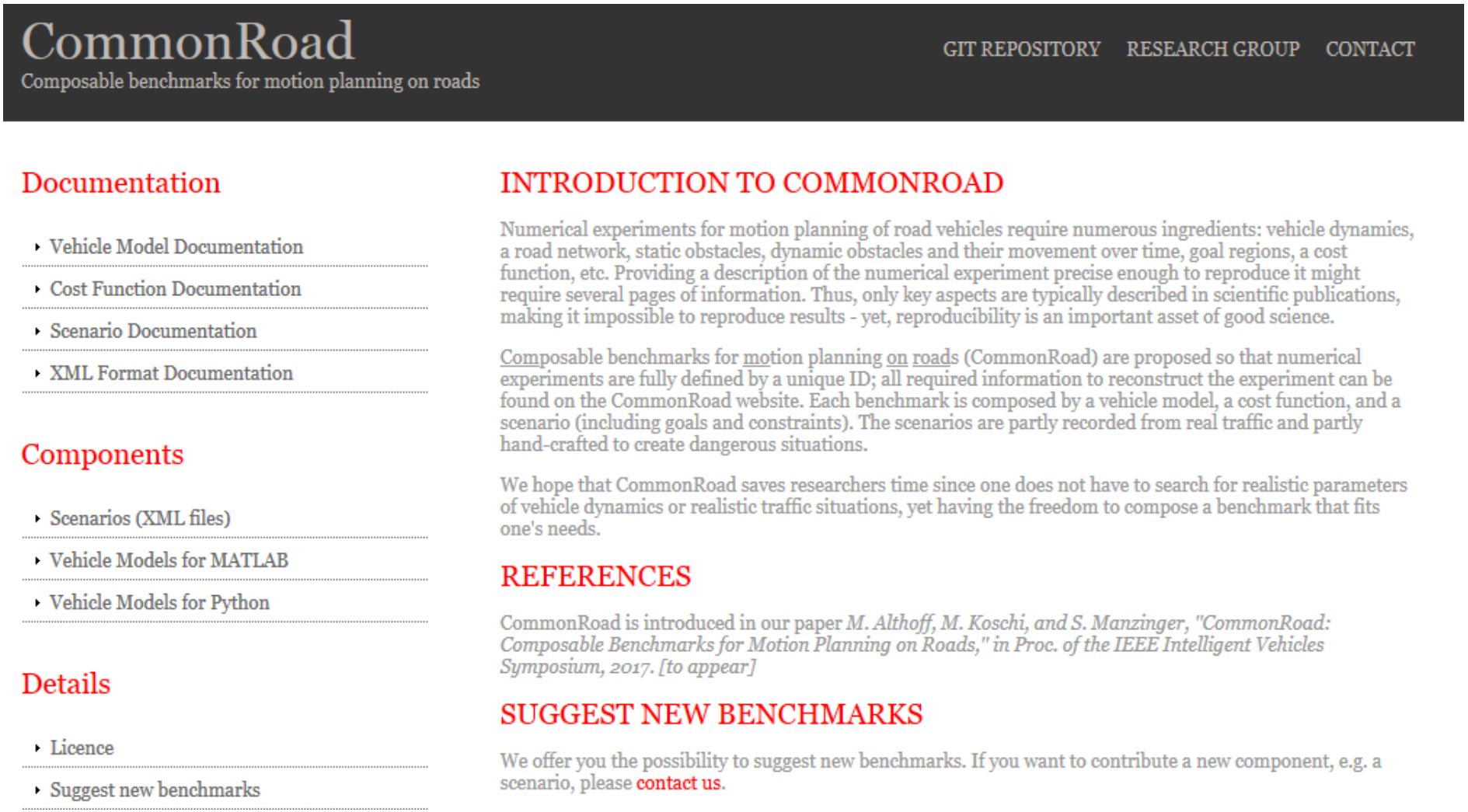
- **Independence:** Our benchmarks are independent from planning libraries.

Website: CommonRoad.in.tum.de



CommonRoad

Composable benchmarks for motion planning on roads

GIT REPOSITORY RESEARCH GROUP CONTACT

Documentation

- Vehicle Model Documentation
- Cost Function Documentation
- Scenario Documentation
- XML Format Documentation

Components

- Scenarios (XML files)
- Vehicle Models for MATLAB
- Vehicle Models for Python

Details

- Licence
- Suggest new benchmarks

INTRODUCTION TO COMMONROAD

Numerical experiments for motion planning of road vehicles require numerous ingredients: vehicle dynamics, a road network, static obstacles, dynamic obstacles and their movement over time, goal regions, a cost function, etc. Providing a description of the numerical experiment precise enough to reproduce it might require several pages of information. Thus, only key aspects are typically described in scientific publications, making it impossible to reproduce results - yet, reproducibility is an important asset of good science.

Composable benchmarks for motion planning on roads (CommonRoad) are proposed so that numerical experiments are fully defined by a unique ID; all required information to reconstruct the experiment can be found on the CommonRoad website. Each benchmark is composed by a vehicle model, a cost function, and a scenario (including goals and constraints). The scenarios are partly recorded from real traffic and partly hand-crafted to create dangerous situations.

We hope that CommonRoad saves researchers time since one does not have to search for realistic parameters of vehicle dynamics or realistic traffic situations, yet having the freedom to compose a benchmark that fits one's needs.

REFERENCES

CommonRoad is introduced in our paper *M. Althoff, M. Koschi, and S. Manzinger, "CommonRoad: Composable Benchmarks for Motion Planning on Roads," in Proc. of the IEEE Intelligent Vehicles Symposium, 2017. [to appear]*

SUGGEST NEW BENCHMARKS

We offer you the possibility to suggest new benchmarks. If you want to contribute a new component, e.g. a scenario, please contact us.

Conclusions

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- Mix of recorded and constructed scenarios as well as scenarios on highways, on rural roads, and in urban settings.
- Our platform-independent repository can be extended by other researchers and will also be extended by ourselves.