KI WISSEN
Automotive AI Powered by Knowledge

2.10 Motion Planning Under Temporal Logic Specifications

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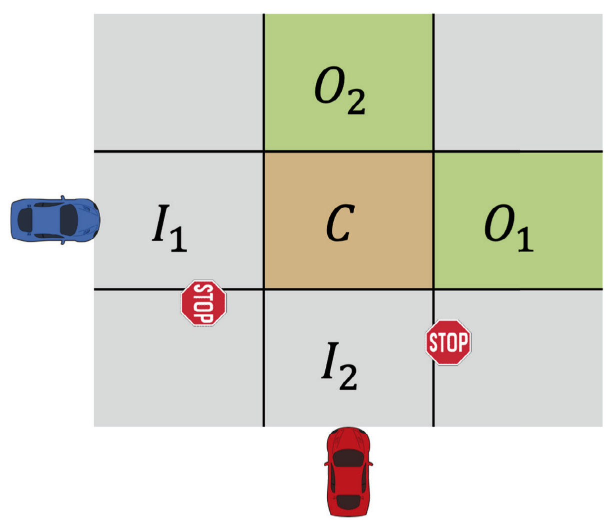
Trajectory Prediction and Motion Planning

Motivation

We consider the problem of modelling and control of vehicle motion at urban intersections (Figure 1). Such scenarios exhibit a combination of constraints arising from

1. continuous agent dynamics and
2. discrete logical constraints,

rendering the control task very challenging.



$$G\neg(x_1 \in C \wedge x_2 \in C) \wedge F(x_1 \in O_1) \wedge F(x_2 \in O_2)$$

Figure 1: Urban intersection and temporal logic formalization

Prior work has put forward temporal logics for formalization and monitoring of traffic rules [1]. Planning methods, however, have so far been restricted to sampling-based or local gradient-descent methods on quantitative semantics. We propose a globally optimal planning scheme that maintains formal correctness guarantees.

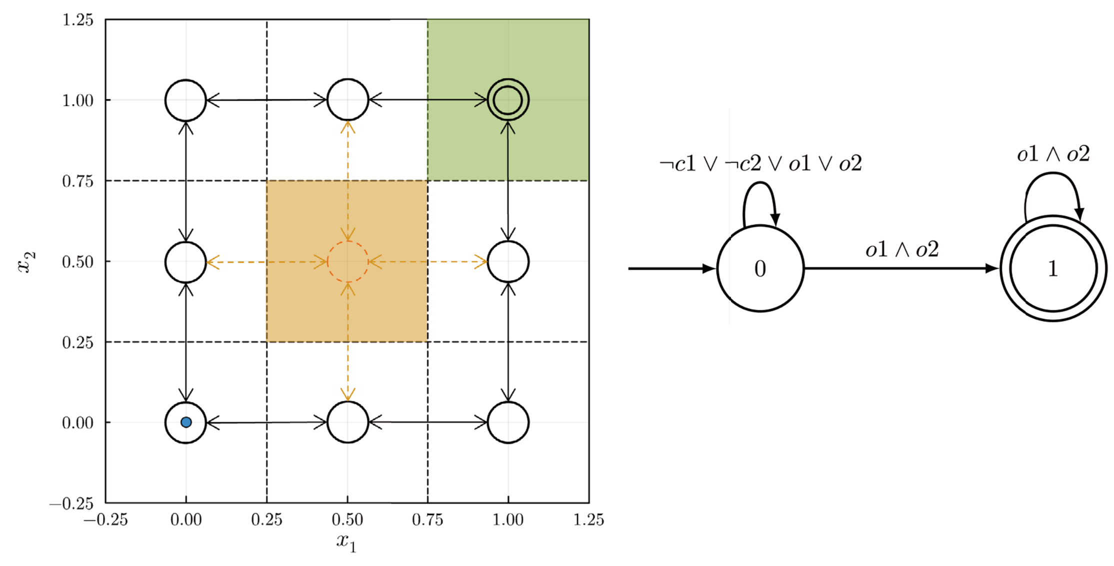


Figure 2: Hybrid automaton (left) and Büchi automaton (right)

Method

We convert the temporal logic rules to Büchi automata and construct a hybrid automaton by taking the product with the continuous multi-agent system (Figure 2).

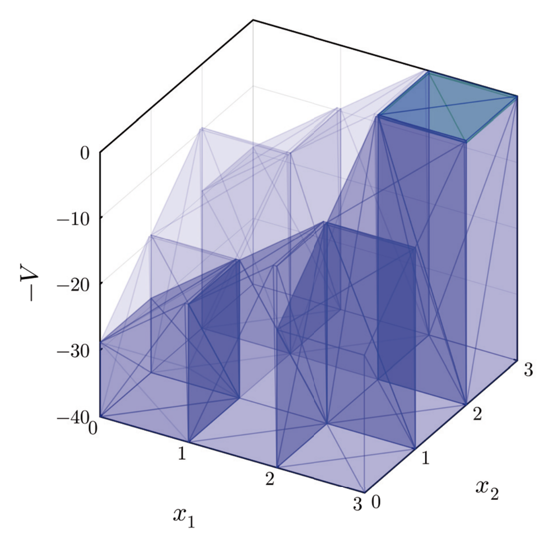


Figure 3: Reachable terminal set and value function

We formulate the resulting hybrid control problem as a quasi-infinite horizon mixed-integer optimal control problem subject to terminal constraints and terminal costs [2].

$$\min_{x,u,q} \int_0^T c(x,u)dt + V(x(T))$$
$$\text{s.t.} \quad x(T) \in \mathcal{T} \quad D(q) \leq 0$$
$$C(x,u) = 0 \quad S(q,x) \leq 0$$

We propose to propagate accepting sets backward in time using reachability to compute control invariant terminal sets, as well as an upper bound on the terminal cost (Figure 3).

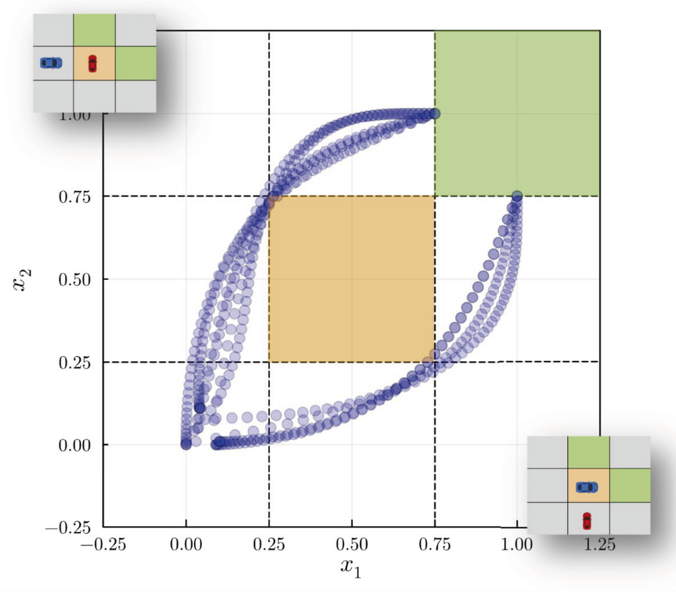


Figure 4: Computed trajectories for varying initial conditions

Results

Figure 4 shows computed trajectories for varying initial conditions, displaying two crossing traversal modes. Figure 5 shows further results on intersection schemes with different rule sets.

References:

[1] Maierhofer, et al.: Formalization of interstate traffic rules in temporal logic, 2020
[2] Bemporad, et al.: Control of systems integrating logic, dynamics, and constraints, 1999

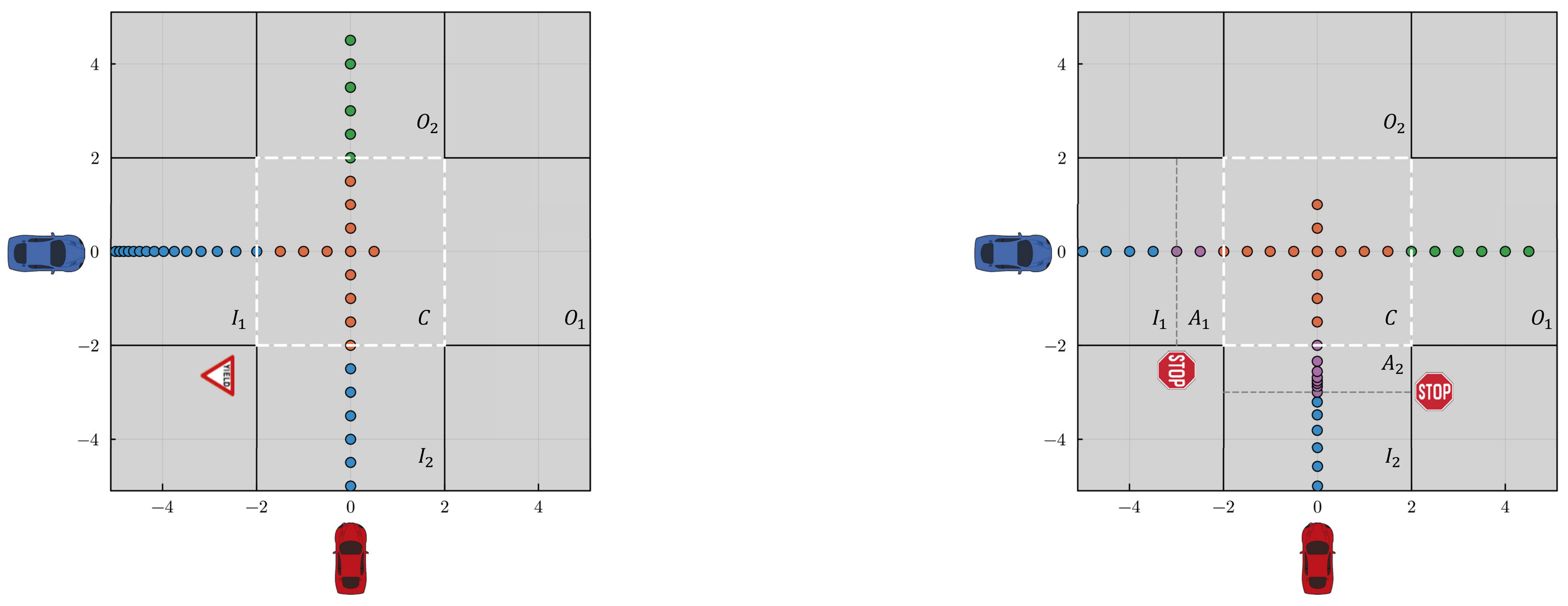


Figure 5: Example trajectories for a prioritized intersection (left) and a first-in-first-out four-way stop (right) (© FZI)

Partners

Continental, Bosch, Valeo, [at], AVL, BTC embedded systems, Capgemini engineering, e:fs, DFKI, DLR, fortiss, Fraunhofer IAIS, Fraunhofer FOKUS, FZI, Universität des Saarlandes, bast

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