Applications of Compositional and Distributed Verification to Automotive Challenge Problems

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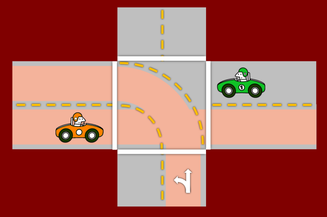
Overview

Issue: The major difficulties in the verification of advanced cyber-physical systems and biological systems are caused by scalability issues, nonlinearities in the system dynamics, and distribution mechanisms.

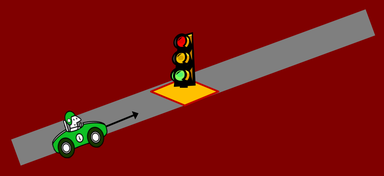
Objective: Develop compositional verification approaches for analyzing cyber-physical systems such as distributed hybrid systems. Verifying the system compositionally with hierarchical reasoning principles enables us to tackle systems which would be too big to handle otherwise.

Safe Intersections:
At the Crossing of Hybrid Systems and Verification

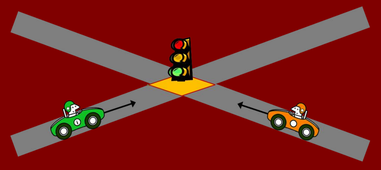
The Intersection Problem:



Real world intersection scenario



Single lane stoplight



X-Intersection

Modeling and Verification:

Cars can stop initially → [X-Intersection] No collision

discrete control / continuous dynamics

Initially safe → [((check if stoplight is red); (stoplight is green); $x' = v, v' = a)^*$] No collision

✔ **Verified semi-automatically in KeYmaera**

Challenges:

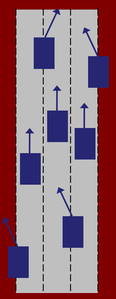
- Infinite, continuous, and evolving state space, $\mathbb{R}^\infty$
- Continuous dynamics
- Discrete control decisions
- Distributed dynamics
- Arbitrary number of cars, changing over time
- Emergent behaviors
- Simulation and testing only partially prove safety
- Large branching factor

Solutions:

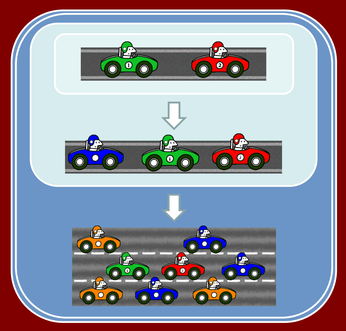
- Quantifiers for distributed dynamics and changing numbers of cars
- Compositionality – using small problems to solve the big ones
- Hierarchical and modular verification
- Verification for X-intersection with 2 cars
- Semi-automated verification
- Verification can handle high branching factor (9184 branches)

Adaptive Cruise Control:
Hybrid, Distributed, and Now Formally Verified

The Distributed Car Control Problem:

Local Lane Control	Global Lane Control	Local Highway Control	Global Highway Control
			
2 vehicles 1 lane No lane change	n vehicles 1 lane No lane change	n vehicles 1 lane lane changes	n vehicles m lanes lane changes

Hierarchical Modularity



Modeling and Verification:

discrete control / continuous dynamics

$(x_f < x_l) \rightarrow [(\text{ctrl};\text{dyn})^*]\ (x_f < x_l)$

✔ **Verified semi-automatically in KeYmaera**

discrete control / continuous dynamics

$(x_f < x_l) \rightarrow [((\text{if } Safe_\varepsilon, \text{set } a \in [-B, A]);\ (\text{otherwise set } a \in [-B, -b]);\ x' = v, v' = a)^*]\ (x_f < x_l)$

Street-Level Verification