CPS: Synergy: Collaborative Research: Collaborative Vehicular Systems

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Introduction

The ongoing research aims to develop rules to study and methods to coordinate a network of fully and partially self-driving vehicles, interacting with conventional vehicles driven by people on a complex road grid, so that overall safety and efficiency of the traffic system can be improved. The potential outcomes of the research can add to the collective understanding of more general systems with hierarchical structures; help create designs with minimal computation and communication delay; and provide mathematical proofs for safety and reliability of a class of systems that combine physical, mechanical, and biological components with purely computational ones.

Researchers at the Control and Intelligent Transportation Research (CITR) Laboratory at The Ohio State University and Cyber-Physical Systems Laboratory (CPSLab) at Arizona State University are collaborating to address a series of vehicular-CPS problems, with applications in the entire range of Cyber-Physical Systems.

CONTACT

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CITR Control and Intelligent Transportation Research Lab
CPSLab Cyber-Physical Systems Lab

Mission and Focus

Motivated by our earlier efforts:

- "Autonomous Driving in Dense, Mixed Traffic Environments" (OSU, NSF Supported)
- "Model Exploration for Cyber-Physical Systems" (ASU, NSF Supported)

Three main concerns:

1. **Collaboration:**
   - Autonomous (semi-autonomous) and totally "human-driven" in mixed-mode traffic.
   - Subsets of vehicles making decision and exchanging information securely.
   - Objective: Safe and reliable traffic flow.
2. **Scalability:**
   - Scalability through hierarchies
   - Grouping CPS entities as teams, convoys, regions, etc.
3. **Testability and Verifiability:**
   - CPS calculus as a modeling and verification tool to prove safety conditions.
   - Automated selection of test parameters and initial conditions through optimization methods

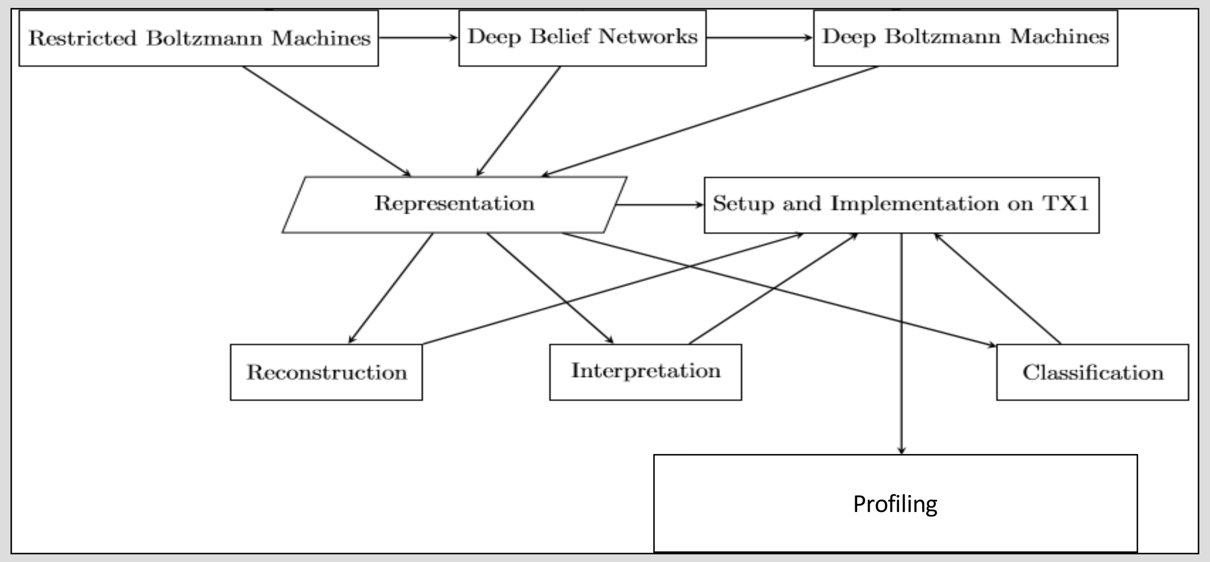
Collaboration

- An experiment for basic forms of collaboration was performed at OSU
- CACC + Lane Change
- Partial automation in mixed traffic

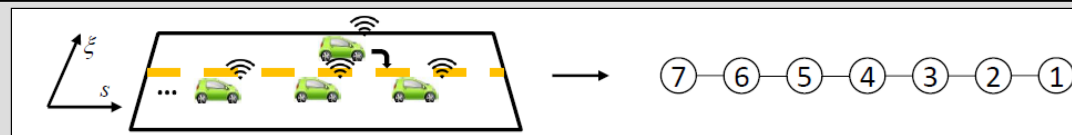
Opening up a gap in an automated convoy for a new vehicle, followed by automated gap alignment and human-controlled merge

Real-time Traffic Scene Perception via Deep Learning

- Latent (hidden) variables – generative models
- Supervised vs. Unsupervised Learning
- Training is time and work intensive → GPGPU



Cooperation Via DMPC

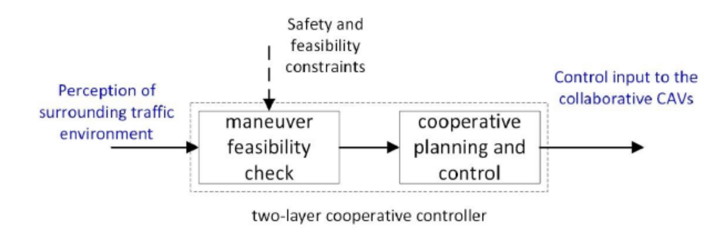


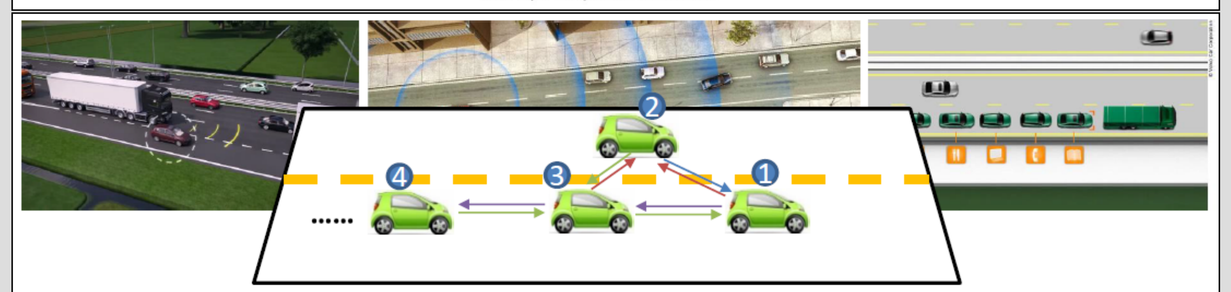
Flexible platooning problem

Given a vehicle platoon of n_1 vehicles and n_2 merging/leaving vehicles that request cooperation, $n_1, n_2 \geq 1$, the flexible platooning problem is to find a set of feasible maneuvers $\{\eta^i\}$ and control inputs $\{u^i\}$, $i = 1, \dots, n_1 + n_2$, that minimize a given optimization index J

$$J^*(t) = \min_{\{u^i\},\{\eta^i\}} J(\{x^i\},\{u^i\},\{\eta^i\},t) \quad (1\text{-}1)$$
$$s.t. \lim_{t\to\infty} \| x^i(t) - \hat{x}^i \| = 0$$
$$x^i(t+1) = f^i(x^i(t), u^i(t))$$
$$x^i \in \mathcal{X}^i, \quad u^i \in \mathcal{U}^i, \quad \eta^i \in \mathcal{Y}^i$$

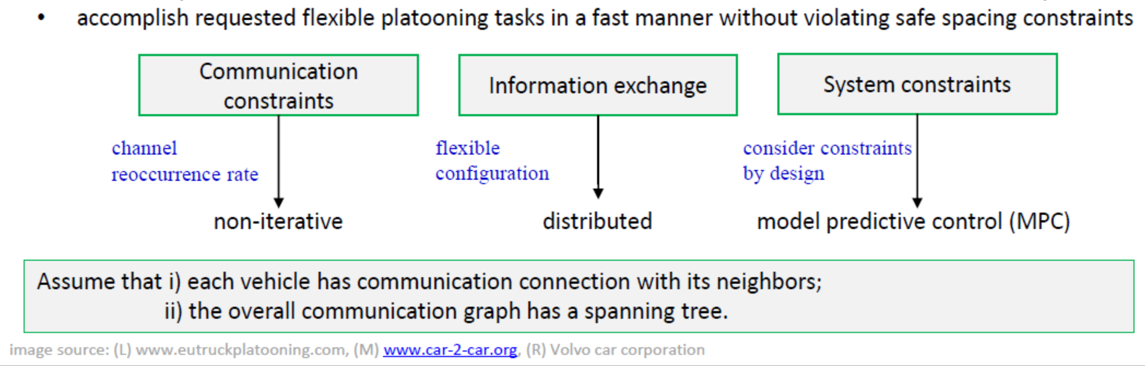
where $f^i(\cdot,\cdot)$ is the state equation of vehicle i. $\{\hat{x}\}$ denotes the reference states. $\mathcal{X}^i, \mathcal{U}^i, \mathcal{Y}^i$ are the state constraint, input constraint, and maneuver feasibility constraints, respectively.





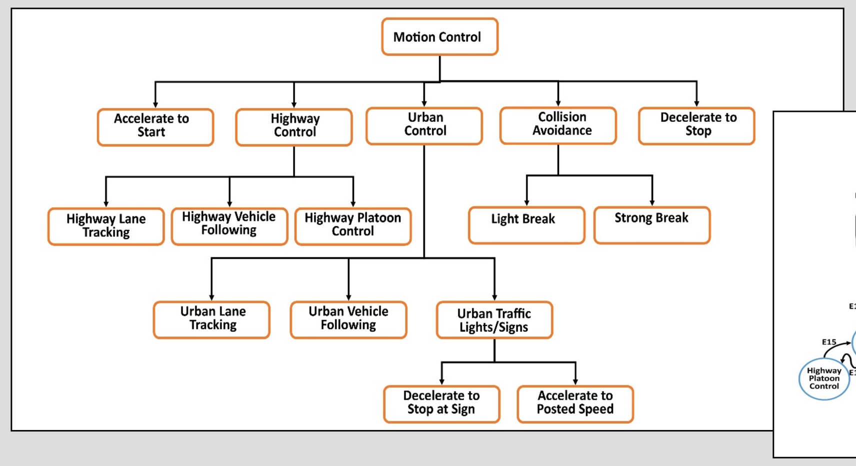
Require a (cooperative) control scheme that:

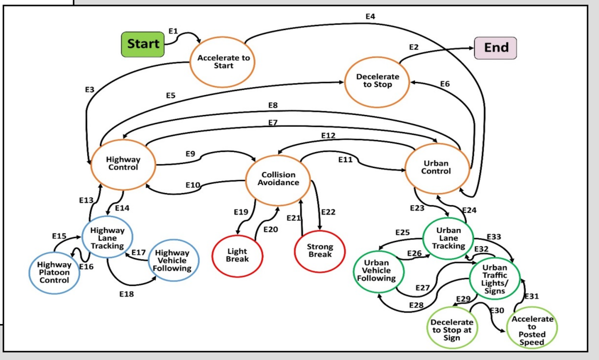
- can properly utilize shared information from neighboring vehicles to achieve formation cooperation.
- address input constraints, state constraints, and communication constraints that related to safety
- accomplish requested flexible platooning tasks in a fast manner without violating safe spacing constraints



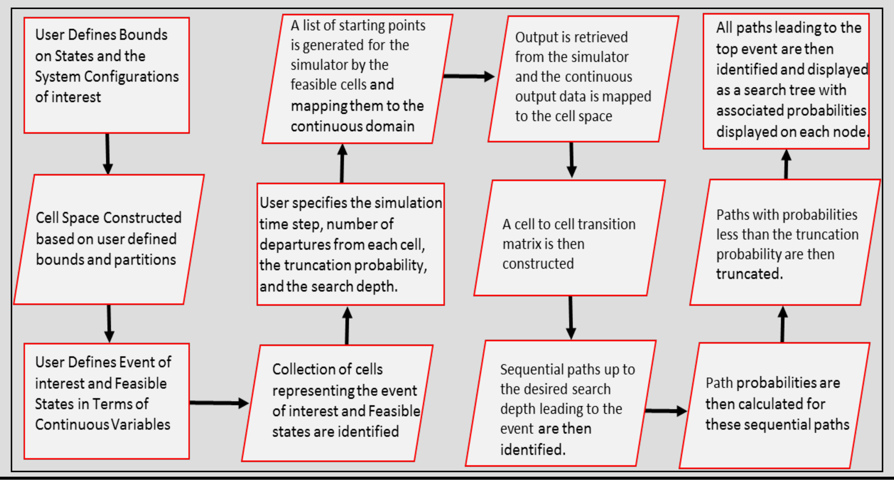
Validation Via Functional Hierarchies and Backtracking

- An intelligent controller is built for an Unmanned Ground Vehicle (UGV).
- The system is decomposed using a functional hierarchy.
- A hybrid state controller is constructed based on this decomposition.





Backtracking Process Algorithm



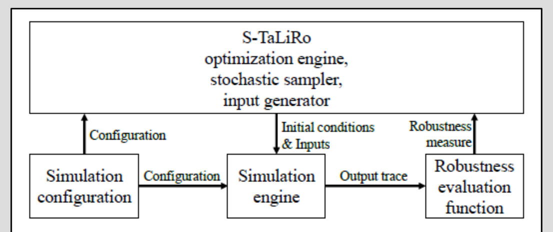
Automatic Test Case Generation

Problem Description

Given
- **a set of Vehicles Under Test (VUT)**
  - High fidelity models (complex dynamics)
  - Full control architecture (in contrast to specific control algorithms).
    Possibilities:
    - Black box systems
    - Gray box systems (in case specific control modes must be targeted)
- **a set of dummy actors**
  - Static or moving actors
  - Simple dynamics or kinematics or non-physics based motion
- **the environment**
  - Parameterized road network

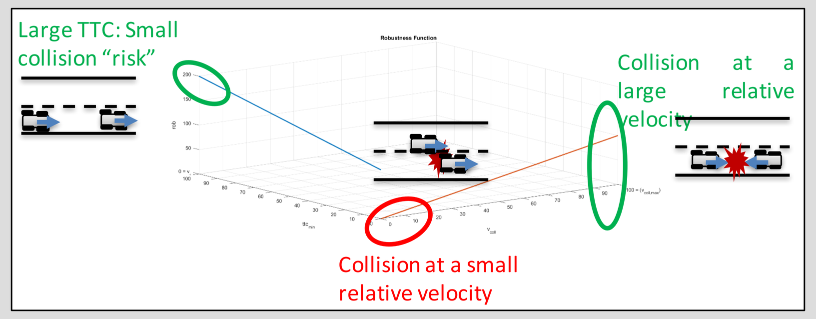
Compute
- the initial conditions and vehicle trajectories which lead to a behavior on the boundary between safe and unsafe behavior

Framework



- S-TaLiRo for initial state / input sampling
- Optimization goal: Minimize robustness value
- User selected simulation engine

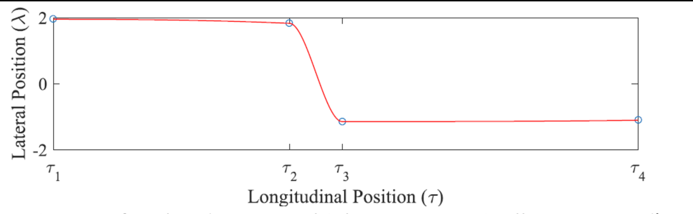
Robustness Metric



Case Study - Demonstration of framework

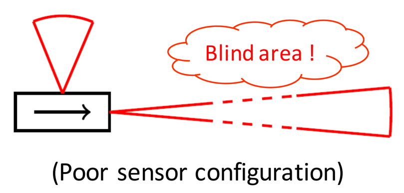
Simulation Configuration:

- Two vehicles under test (platooning)
- One dummy vehicle
- Two-lane straight road

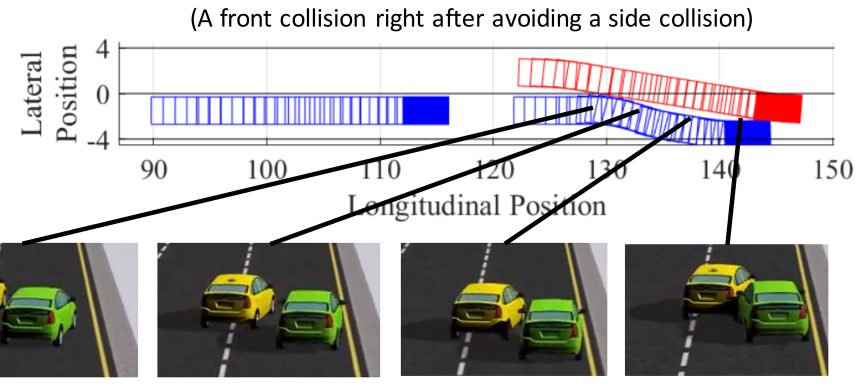


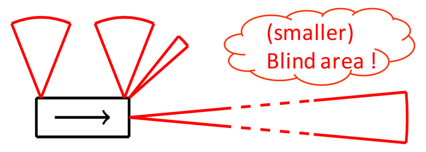
(The trajectory for the dummy vehicle – automatically generated)

(A front collision right after avoiding a side collision)

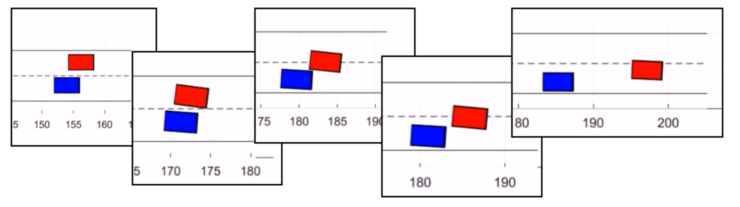


(Poor sensor configuration)



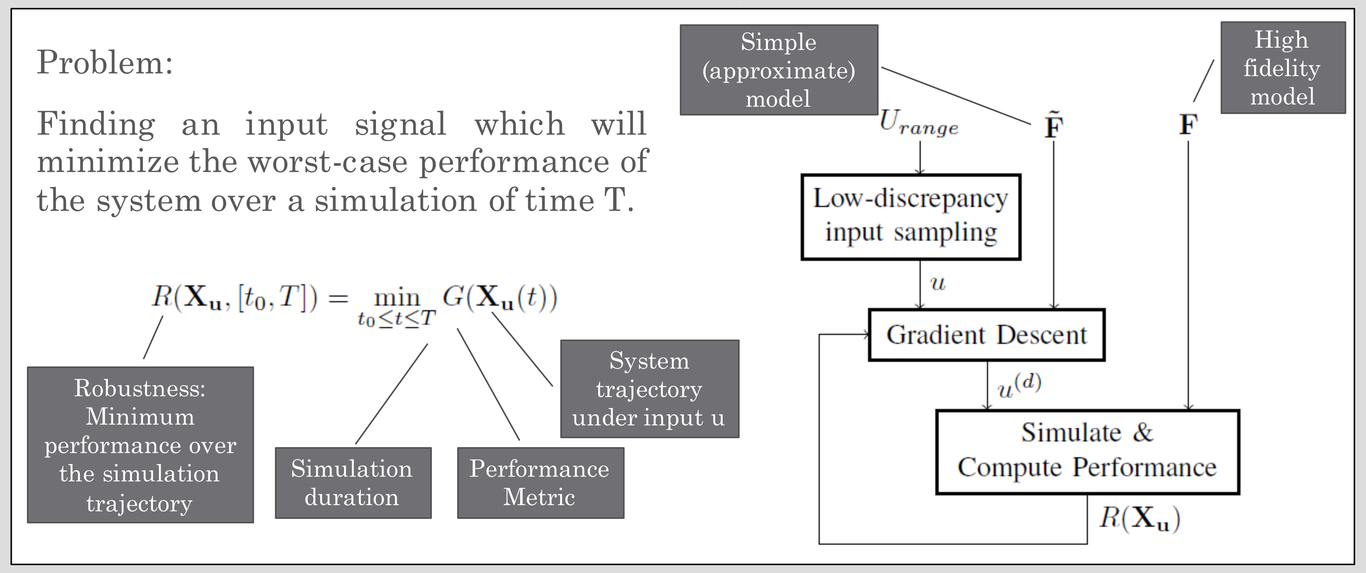


(Improved sensor configuration)



(Non-robust scenario automatically created by our framework under the new sensor configuration)

Test generation using Gradient Descent and Multi-fidelity models



References

For a list of references, please contact the PIs using the contact information on the left.