APEX

Autonomous Vehicle Plan Verification & Execution

A Driver's License for Autonomous Vehicles

Matthew O'Kelly, Houssam Abbas, and Rahul Mangharam, University of Pennsylvania

1 Overview

The possibility that an auto manufacturer might ultimately be deemed ***legally responsible for an autonomous vehicle's actions*** highlights the urgent need for a technology that ***can automatically and exhaustively certify the impossibility of accidents*** in various driving scenarios, and under well-defined conditions.

2 Towards Verified Decisions for Autonomous Systems

We focus on three main ***challenge problems*** which will lead to expressive, tractable, and validated models for ***formal verification of autonomy***

Problem #1
Verification of non-linear hybrid vehicle dynamics under environmental non-determinism.

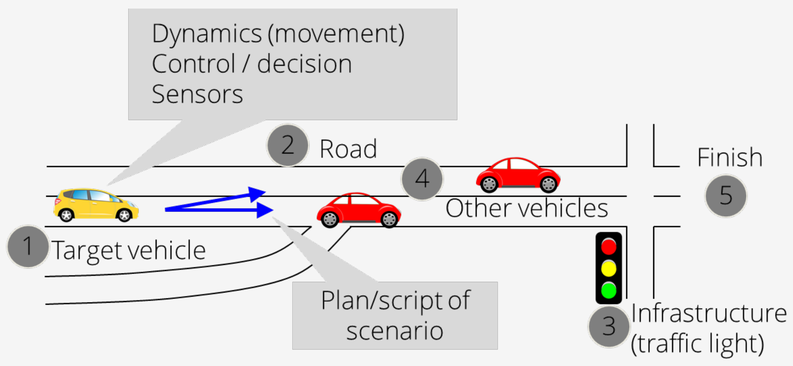
Problem #2
Composition of a verified sequence of scenarios from verified scenarios.

Problem #3
Online evaluation of behavioral controller goal sequences with respect to hierarchically ordered properties: safety, comfort, performance...

3 Intuition for Driving Scenarios

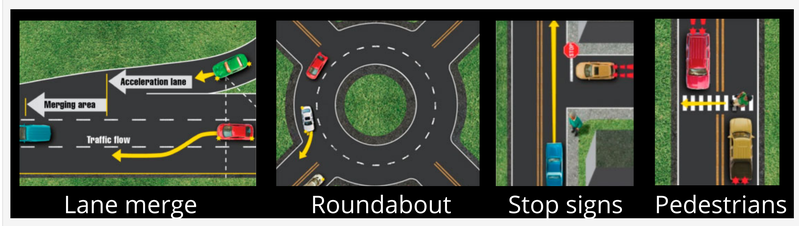
An *agent* is *an entity that functions continuously and autonomously* in an environment in which other processes take place and other agents exist

A *scenario* can be thought of as a *disembodied agent* that adjusts or *creates the environment* in which an autonomous system operates



4 Common Agents

From *representative* driving *scenarios*...



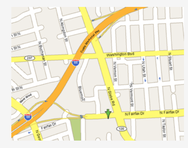
Understand ***common agents*** for more intuitive modeling:


Target Vehicle


Other Drivers

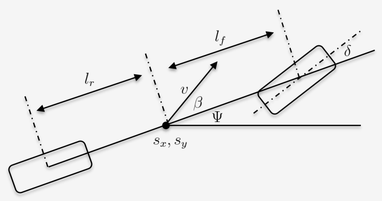

Pedestrians


Traffic Signals


Road Network

4 Vehicle Dynamics: Intermediate Representation

The ***bicycle model*** to is used as the intermediate representation (IR) because it supports verification of ***low level trajectory trackers*** and analysis with respect to first order logic necessary for ***formal verification.***



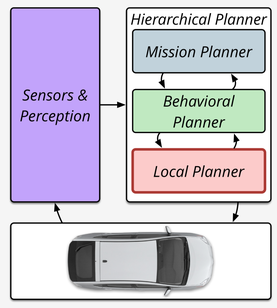
$$\dot{\beta} = \left(\frac{C_r l_r - C_f l_f}{mv^2}\right)\dot{\psi} + \left(\frac{C_f}{mv}\right)\delta - \left(\frac{C_f + C_r}{mv}\right)\beta + y_\beta$$

$$\ddot{\psi} = \left(\frac{C_r l_r - C_f l_f}{I_z}\right)\beta - \left(\frac{C_f l_f^2 - C_r l_r^2}{I_z}\right)\left(\frac{\dot{\psi}}{v}\right) + \left(\frac{C_f l_f}{I_z}\right)\delta + y_{\dot{\psi}}$$

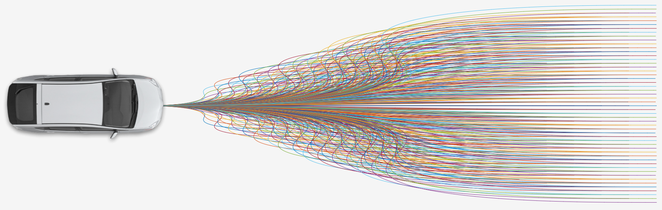
$$\dot{v} = a_x + y_v$$
$$\dot{s}_x = v\cos(\beta + \psi) + y_{s_x}$$
$$\dot{s}_y = v\sin(\beta + \psi) + y_{s_y}$$
$$\dot{\delta} = v_w + y_d$$

5 Vehicle Control: Planning Stack

APEX includes a *planning stack* for AVs which has been ***validated*** on multiple real vehicles.

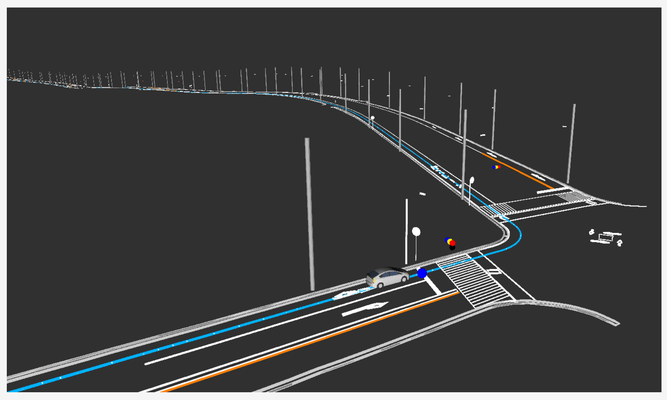


The planning stack generates a ***set of trajectories***, from which ***one is chosen*** to be followed by the AV



6 Simulation Environment

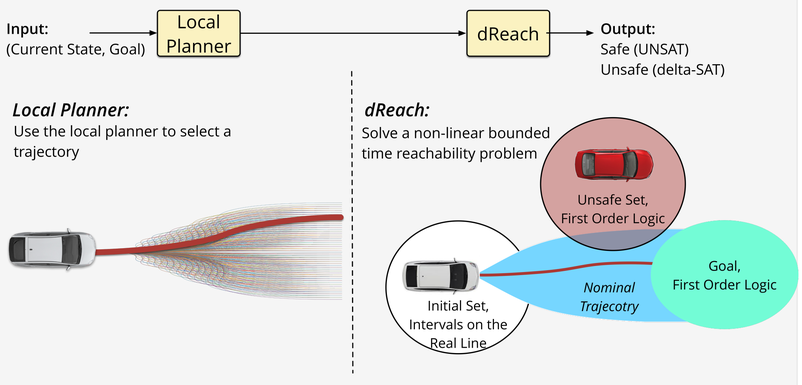
Simulation helps the user: (1) ***gain confidence*** in the ***modeling*** effort and (2) ***visualize*** and understand ***counterexamples*** returned in the verification process.



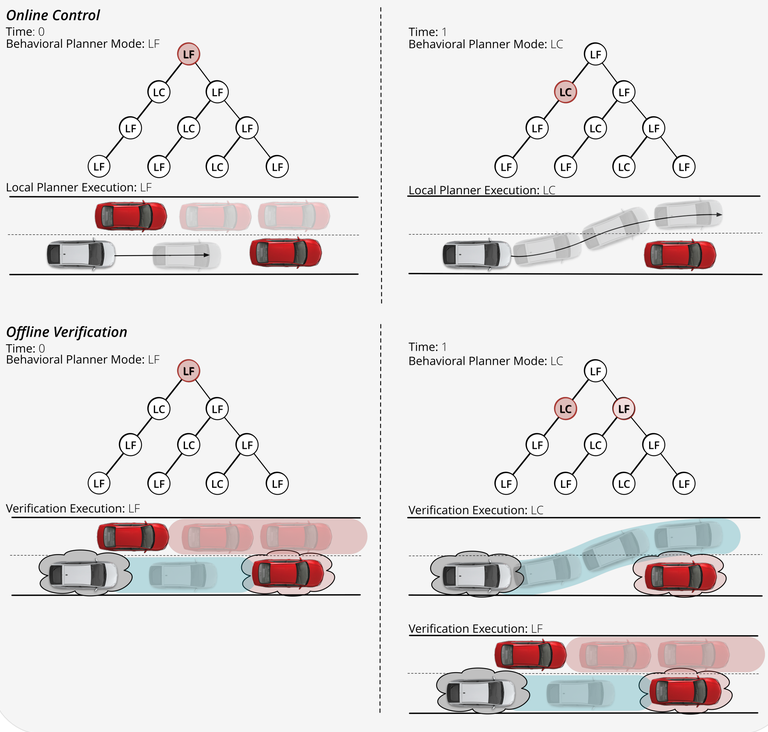
APEX includes an rViz based ***simulation*** environment capable of ***interfacing with ROS.***

7 Formalizing Driving Scenarios

In sharp contrast to a simulation based approach, the result of formal verification is that we have converted a hopeless ***brute force search over real intervals into a finite series of tractable bounded reachability problems*** automatically generated by executing the local planner...



8 Verification Engine



9 Test Bed

We have verified the effectiveness of the planning stack on a *Toyota Prius* capable of *full autonomy* with only a camera and LIDAR. Our planner is part of *Autoware*, an open source operating system for autonomous vehicles.

Penn Engineering

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