Formal Verification of Perception Systems: Realistic Parameter Identification in Falsification Frameworks

Calvin Tai, Andre Jia, Elizabeth Skehan, Abhir Karande, Songmao Li

Purpose

- Semantic falsification framework for an AV perception to control pipeline in CARLA that searches environmental parameters to find scenarios that violate STL safety specs
- Maximize plausibility: We don't want to find failures that are unlikely to occur or physically impossible
- A failure/falsification in ADAS, for example, isn't just a crash. It can be a near-miss, extreme passenger discomfort, traffic law violation, etc. Rather than getting unrealistic falsification scenarios, we can find the most critical set that is at the trade-off between each of our objectives (safety, plausibility, passenger comfort)

Task Breakdown/Schedule/Assignment

- Environment Setup and Baseline Implementation, **Milestone 1 by Oct 24 (Calvin, Elizabeth)**
  - Setup Carla
  - Baseline single safety objective falsification, Bayesian Optimization loop to find worst-case failure for single objective.
- Define a multi-objective Bayesian Optimization, **Milestone 2 by Oct 31 (Songmao, Andre, Abhir)**
  - Objective 1 is safety score, Objective 2 is plausibility (based on G-Forces/acceleration), Objective 3 is passenger discomfort.
  - Adapt surrogate model and acquisition functions
- Scenario and Objective Implementation, **Milestone 3 by Nov 7 (Andre, Elizabeth, Calvin)**
  - Input parameter space for scenarios
  - Objective Metric (i.e. Time-to-Collision for safety score, adversary vehicle acceleration for plausibility score, ego vehicle jerk and lateral acceleration for comfort score
- Experimentation and Analysis, **Milestone 4 by Nov 21 (Abhir, Songmao, Andre, Elizabeth, Calvin)**
  - Execution of Falsification runs using our multi-objective Bayesian Optimization framework for 500-1000 simulations
  - Visualize the trade-offs between safety, plausibility, and comfort in order to choose a "Pareto front"

Expected Outcome

- Generation of a set of critical test scenarios, revealing the optimal trade-offs between safety, plausibility, and passenger comfort.

Resources Required

- CARLA for environment parameters and simulation

Literature Survey

- https://arxiv.org/pdf/2209.06735
- https://dl.acm.org/doi/10.1145/3126521
- https://vbn.aau.dk/ws/portalfiles/portal/698944696/Usage_aware_Falsification_for_Cyber_Physical_Systems.pdf
- https://ieeexplore.ieee.org/document/8666747 - impact of weather on ADAS systems

Immediate tasks:

-parameter set for search space (decided on weather, will look into actors/signals, etc.)

- **-https://carla.readthedocs.io/en/latest/tuto_M_custom_weather_landscape/**
- -We can change lead vehicle's dynamics: How often the lead car changes speed.
- -Weather: fog conditions

-metrics (safety (tbd), plausibility (tbd), comfort (g-force, acceleration, momentum delta))

- **-Look into how they define MP1 evals**
- -Safety: continuous metrics that measure the degree of safety or lack thereof:
  - -Time-to-collision: lower minimum TTC over a scenario indicates higher risk
  - -Minimum Distance: minimum distance between ego and lead vehicles
  - -Simulator provides `collided_event`, which is a direct binary measure
- -Plausibility can be determined by vehicle dynamics (the lead vehicle and ego vehicle's reaction should not defy physical laws.
  - -Maximum acceleration: passenger car can't brake at 2g.
  - -Maximum jerk: The rate of change of acceleration shouldn't exceed a threshold to ensure that it physically makes sense.
  - -Steering rate: How fast the steering wheel is turned
- -Passenger Comfort:
  - -Jerk: high jerk values are uncomfortable. We can aim to minimize total jerk experienced during a scenario.
  - -Lateral Acceleration: High acceleration in turns can be uncomfortable. In scenarios that involve steering, we can aim to minimize these.
  - -Hard Braking/Acceleration Events: We can count the number of times the ego vehicle's acceleration or deceleration exceeds a certain comfort threshold (> 0.3g)

Basic measurement/evals added to the MP1 eval script:
https://pastebin.com/fY4gsf1x

(calculate_minimum_ttc(), calculate_minimum_distance(), calculate_maximum_jerk())

Implementation:

-Carla (done)

-bayesian optimization (https://github.com/bayesian-optimization/BayesianOptimization)

- **-extend for multiple objectives (https://arxiv.org/pdf/2109.10964)**