Bridging Simulation and the Real World with VerifAI and Scenic

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Berkeley
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VehiCal
http://vehical.org

Improving Safety of Autonomous Vehicles with Formal Methods

- Need to handle **complex neural network-based perception & prediction** including interaction with planning & control

- Need toolchain that **integrates design and verification with data generation and training/testing** of ML components

- **Simulation important for complex environment scenarios** for which for which real world data is hard/impossible to gather

ars TECHNICA BIZ & IT TECH SCIENCE POLICY CARS GAMING & CULTUR

DRIVERLESS CAR SAFETY —

Report: Software bug led to death in Uber's self-driving crash

Sensors detected Elaine Herzberg, but software reportedly decided to ignore her.

TIMOTHY B. LEE - 5/7/2018, 3:12 PM

SCENIC: Environment Modeling and Data Generation

- *Scenic* is a probabilistic programming language defining *distributions over scenes*
- *Use cases:* data generation, test generation, verification, debugging, design exploration, etc.

```
from gta import Car, curb, roadDirection

ego = Car

spot = OrientedPoint on visible curb
badAngle = Uniform(1.0, -1.0) * (10, 20) deg
Car left of (spot offset by -0.5 @ 0),
    facing badAngle relative to roadDirection
```

Platoons

Images created with GTA-V

Bumper-to-bumper

[D. Fremont et al., "Scenic: A Language for Scenario Specification and Scene Generation", TR 2018, PLDI 2019.]

Some Applications of Scenic

- Data Generation, (Re)-Training
  - More controllable, interpretable
  - Improves performance significantly
  - Rare scenarios, controlled distributions, etc.

Car detection with occlusions

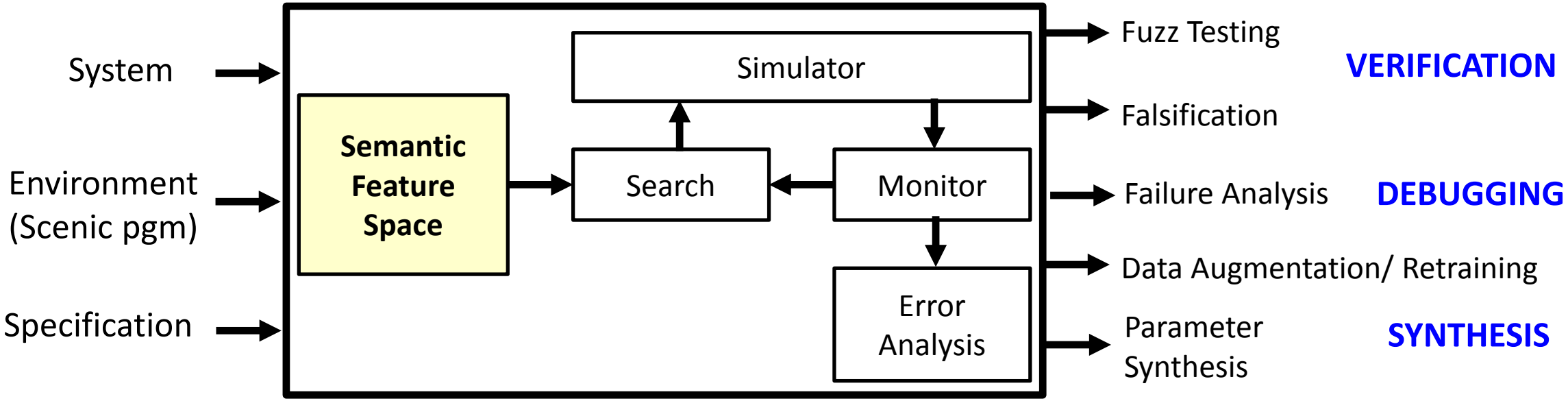
- Debugging Failures
  - Vary scenarios systematically
  - Explain failures of ML

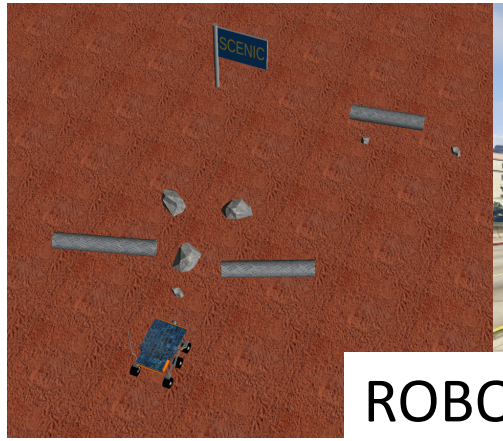
Test Hypothesis: does the car model lead to a mis-detection?

- Design Space Exploration

VERIFAI: A Toolkit for the Design and Analysis of AI-Based Systems [CAV 2019]

https://github.com/BerkeleyLearnVerify/VerifAI





ROBOTICS

AUTONOMOUS DRIVING

AIRCRAFT

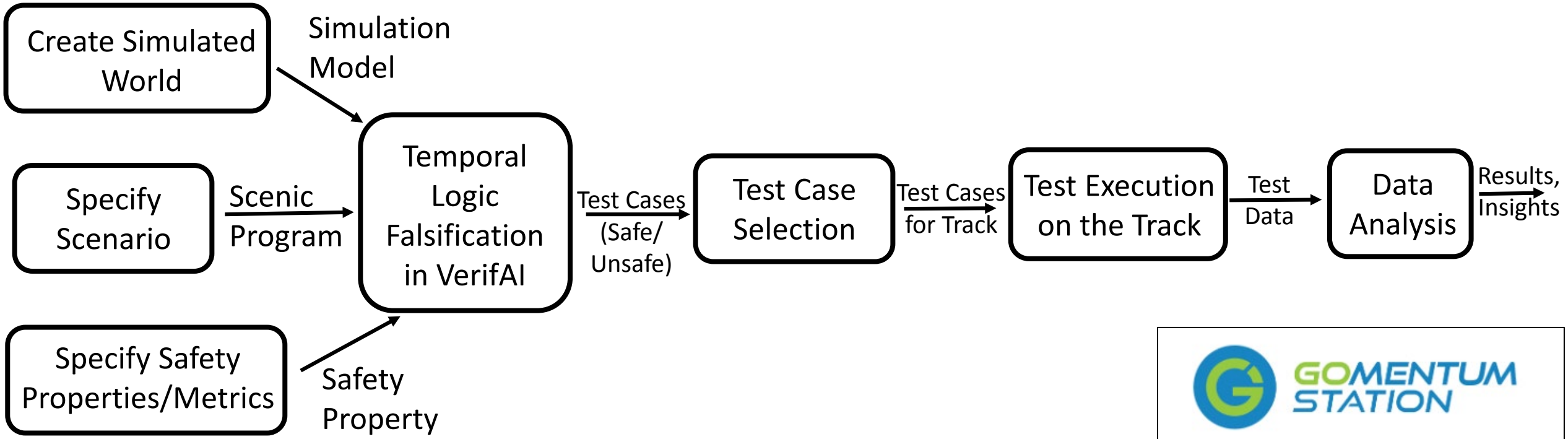
Key Questions

1. We can find LOTS of safety violations in simulation.
   - Do these transfer to the real world? How well?

2. Real world testing is expensive, tedious, and time-consuming.
   - Can we use formally-guided simulation to effectively *design* real-world tests/experiments?

Fremont, Kim, Pant, Seshia, Acharya, Bruso, Wells, Lemke, Lu, Mehta, "Formal Scenario-Based Testing of Autonomous Vehicles: From Simulation to the Real World", Arxiv e-prints, https://arxiv.org/abs/2003.07739.

Formal Scenario-Based Test Generation with VerifAI and Scenic



GOMENTUM STATION

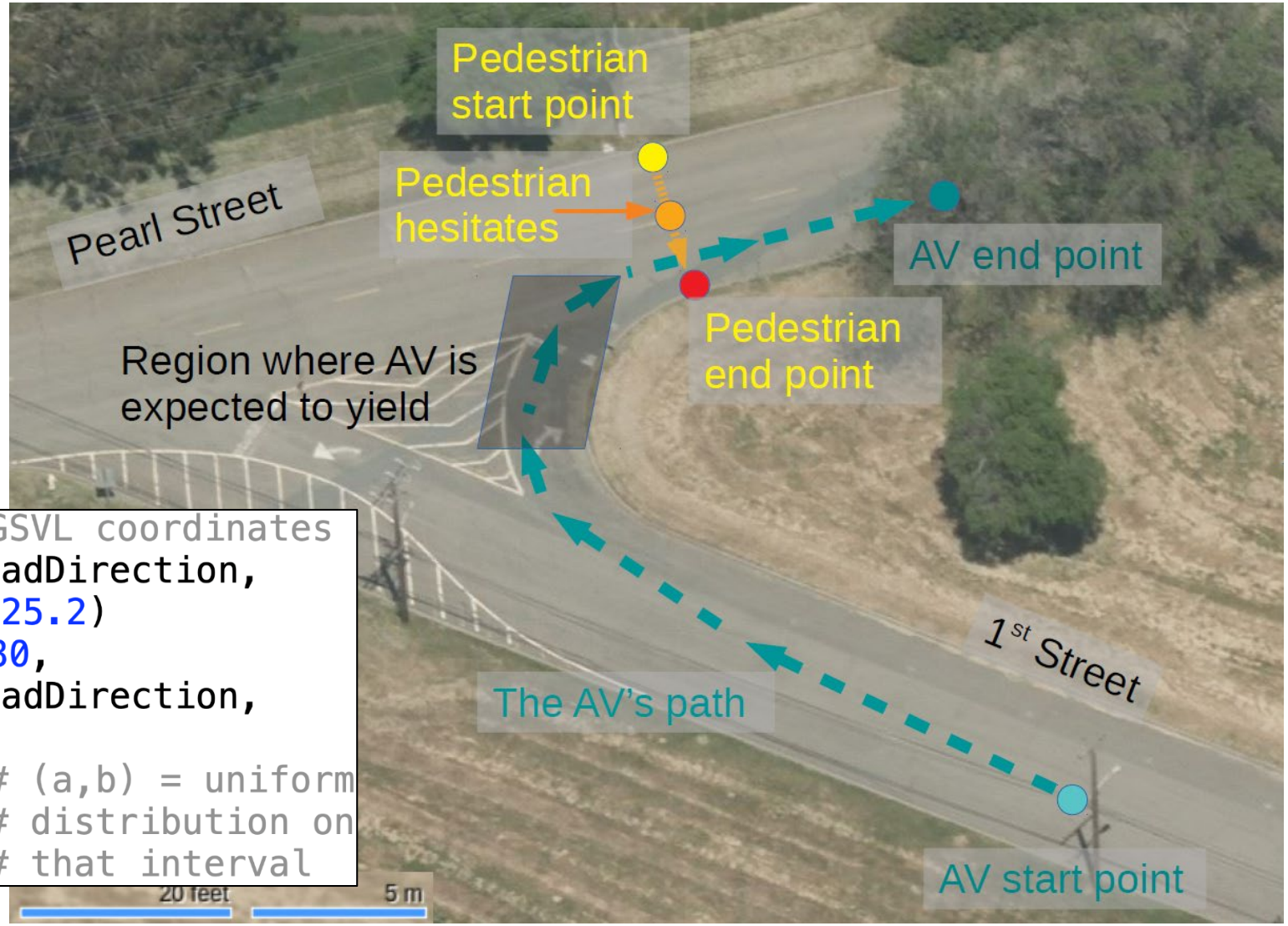
Owned and Operated by AAA NCNU

<u>Collaboration with AAA and LG:</u>

- AAA's GoMentum Testing Grounds (near Concord, CA)
- LGSVL Simulator (open source, including full AV Stack simulation) and LG's AV running Baidu's Apollo software

Example Scenario: AV making right turn, pedestrian crossing

Lincoln MKZ running Apollo 3.5




```
ego = EgoCar at 38.6 @ 183.9,  # LGSVL coordinates
       facing 10 deg relative to roadDirection,
       with behavior DriveTo(40 @ 225.2)
ped = Pedestrian at 19.782 @ 225.680,
       facing 90 deg relative to roadDirection,
       with behavior Hesitate,
       with startDelay (7, 15),    # (a,b) = uniform
       with walkDistance (4, 7),   # distribution on
       with hesitateTime (1, 3)    # that interval
```

Snippet of Scenic program

Results: Falsification and Test Selection

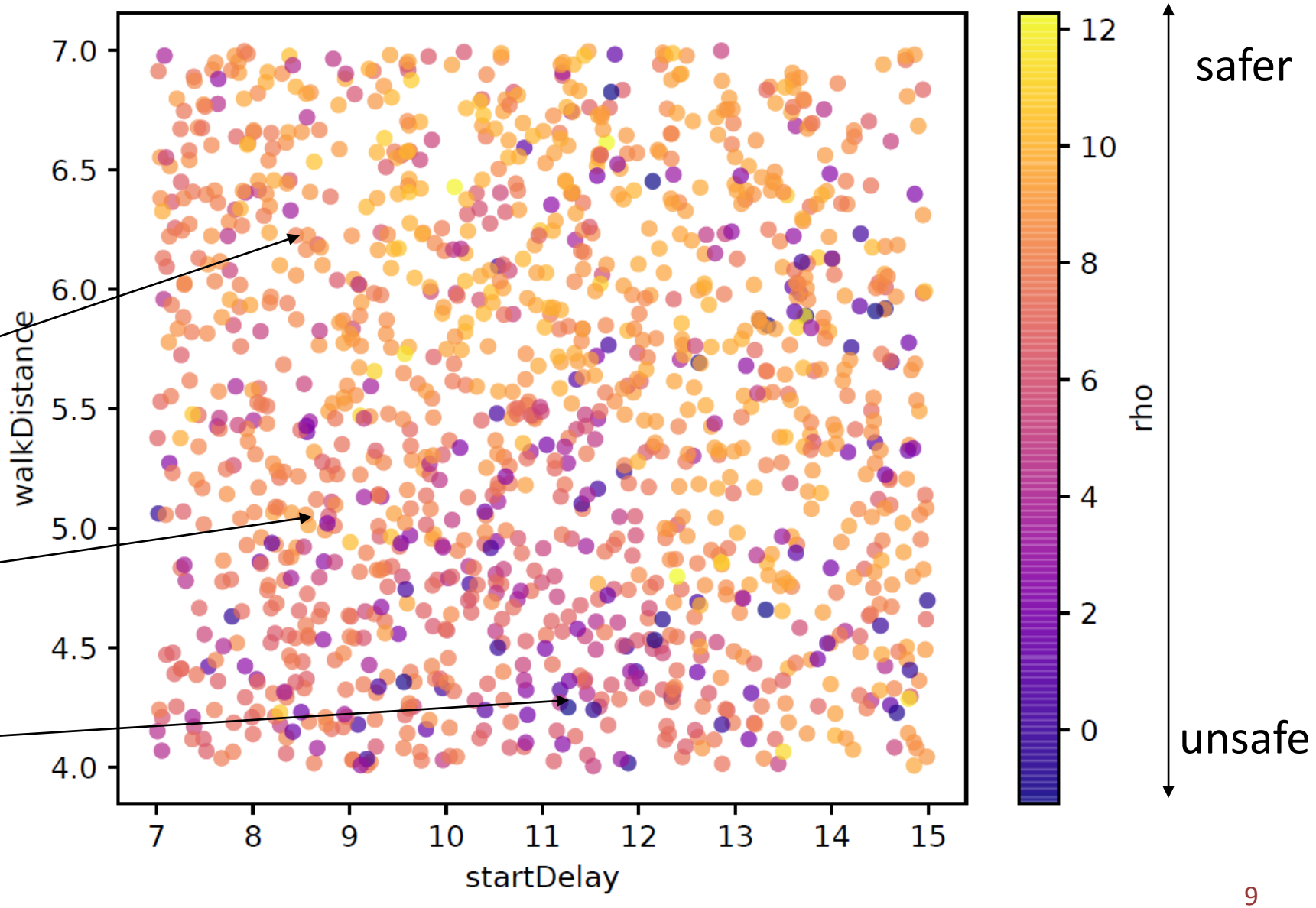
1294 simulations explored
2% violated safety property

Total 7 test cases selected

S2: robustly safe

M2: marginally safe

F2: collision



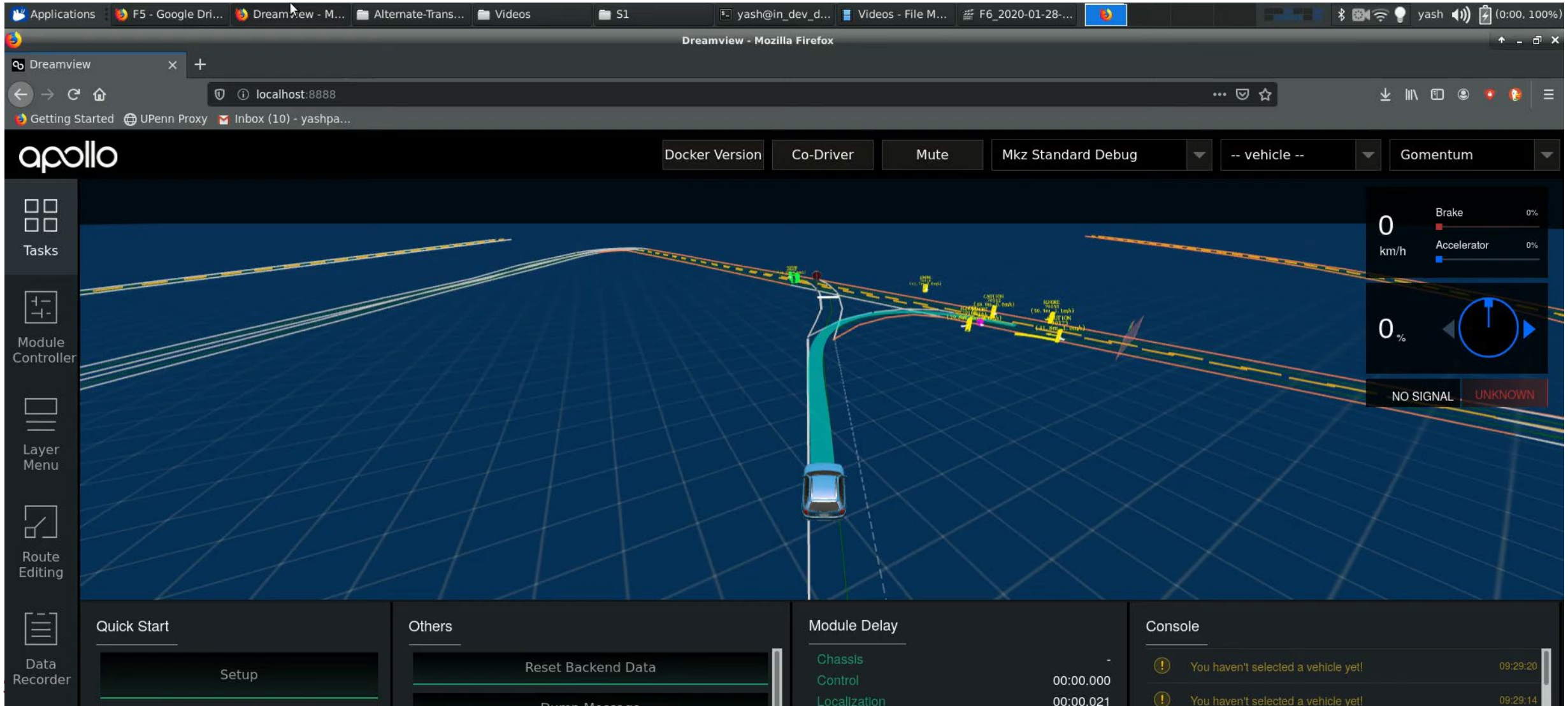
Results: Does Safety in Simulation → Safety on the Road?

Unsafe in simulation → unsafe on the road: **62.5% (incl. collision)**

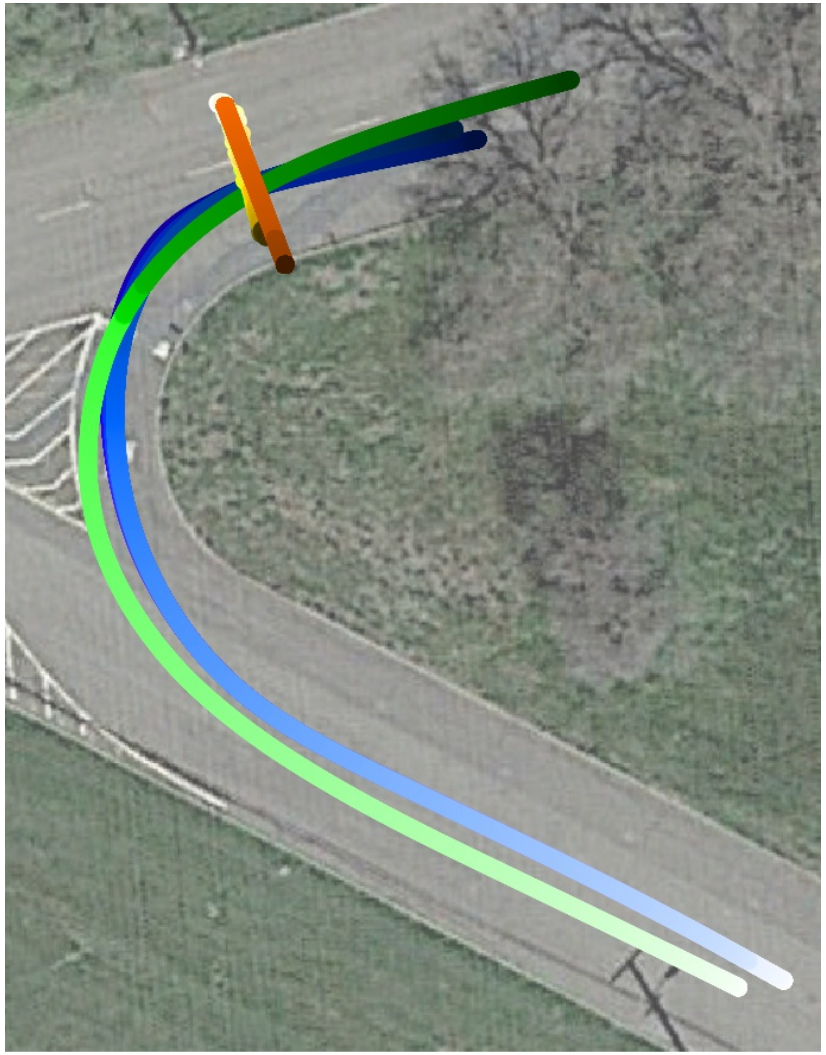
Safe in simulation → safe on the road: **93.5% (no collision)**

Results: Why did the AV Fail?

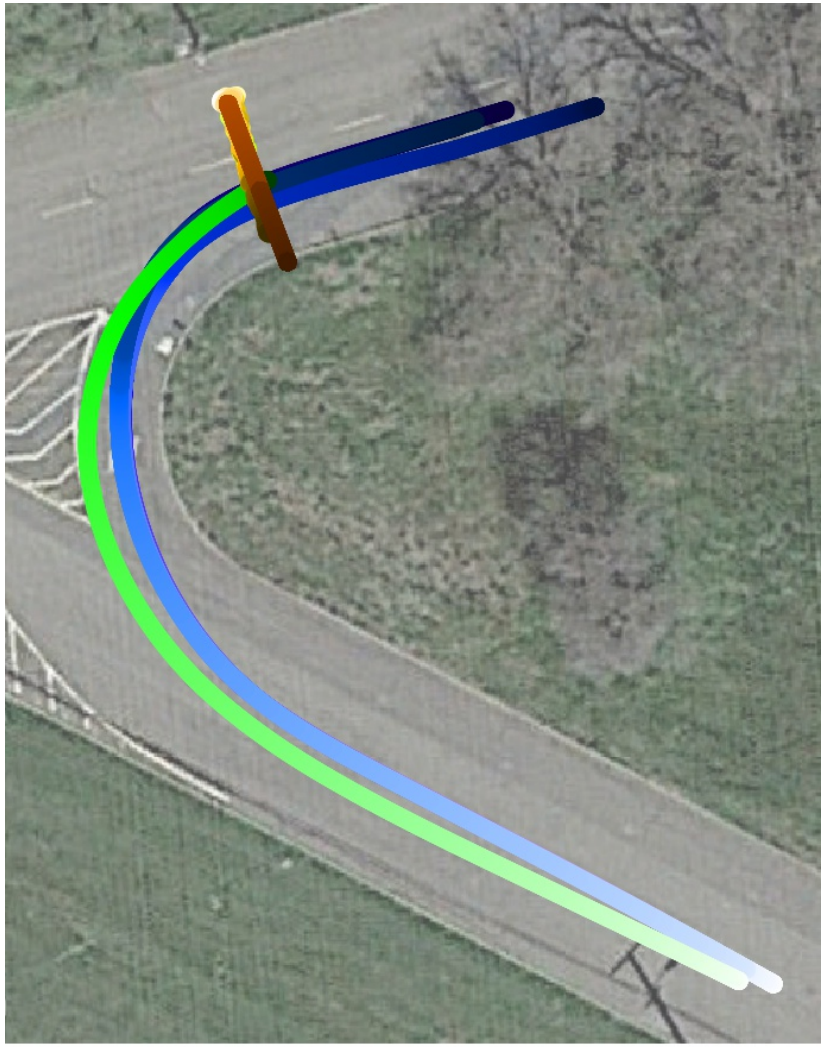
Perception Failure: Apollo 3.5 lost track of the pedestrian several times



Results: How well do the trajectories match?



S1 Run 2



F1 Run 1

Green – AV real
Blue – AV sim

Orange – Ped real
Yellow – Ped sim

Conclusion

- Scenic allows easy modeling of complex AV driving scenarios and associated data generation
- VerifAI covers range of design, verification, and debugging tasks for AI based autonomous systems
- Scenic+VerifAI can be used to bridge the sim-to-real gap
  - Concrete evidence for effectiveness of formally-guided simulation
  - Reduce expense of real-world testing with systematic test generation
- Future Work:
  - More detailed automated analysis of failure cases
  - Evaluation on more complex, higher-dimensional scenarios
  - Improvements in track testing equipment and their connection to simulation

https://github.com/BerkeleyLearnVerify/VerifAI
https://github.com/BerkeleyLearnVerify/Scenic/