

# TOWARDS AUTOMATED SAFETY COVERAGE AND TESTING FOR AUTONOMOUS VEHICLES

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MS THESIS

COMPUTER SCIENCE

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# MOTIVATION

## BRUTE FORCE

Drive millions of miles in simulation or in the real world; too slow; infinite situations



## Current Attempts To Ensure Safety Of Autonomous Vehicles

*How can we ensure that an autonomous vehicle drives safely upon encountering an unusual (edge) traffic situation ?*

## FORMAL METHODS

Reasoning about scenario specific safety; often too simplistic to generate guarantees

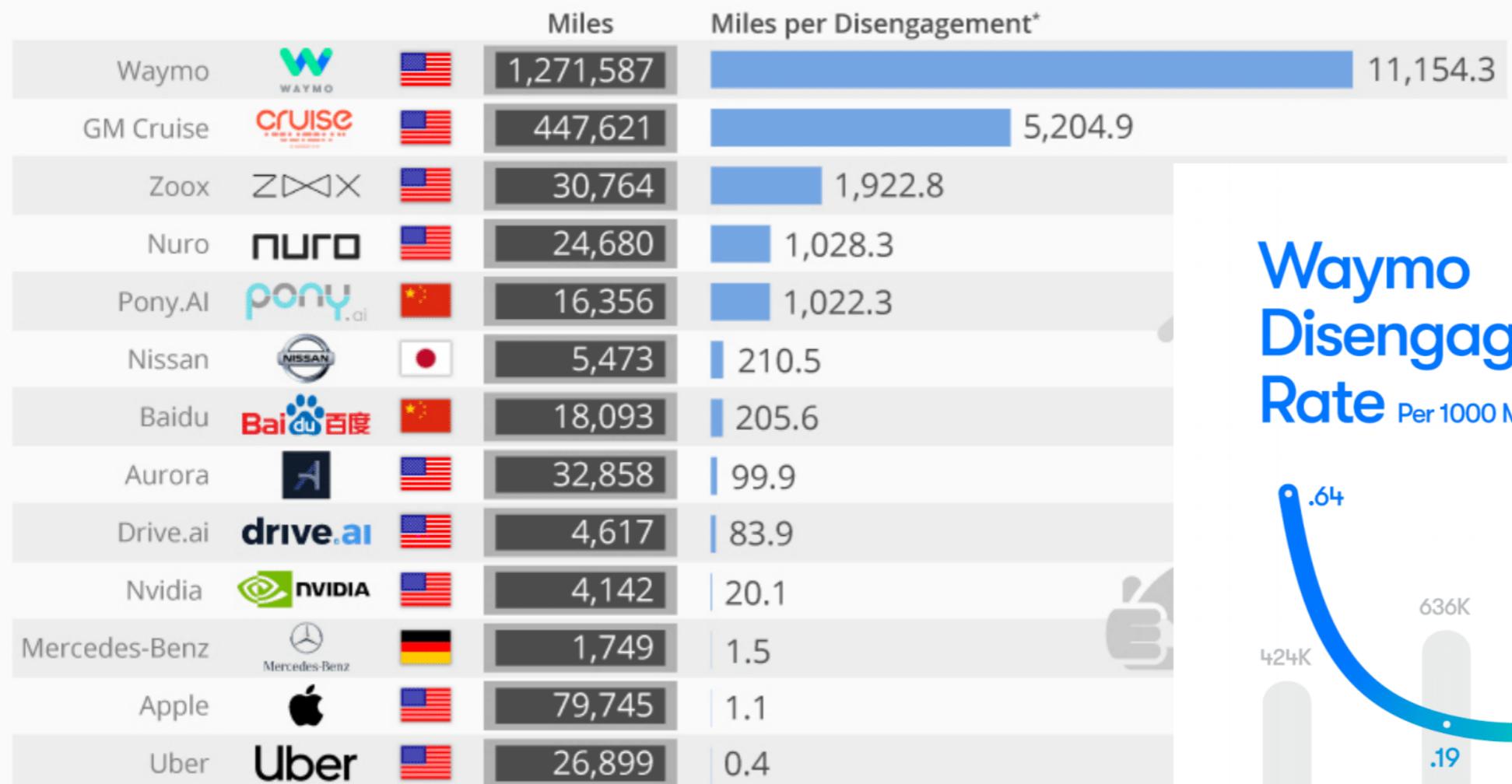


**Lack of standard safety measuring stick!**

# MOTIVATION

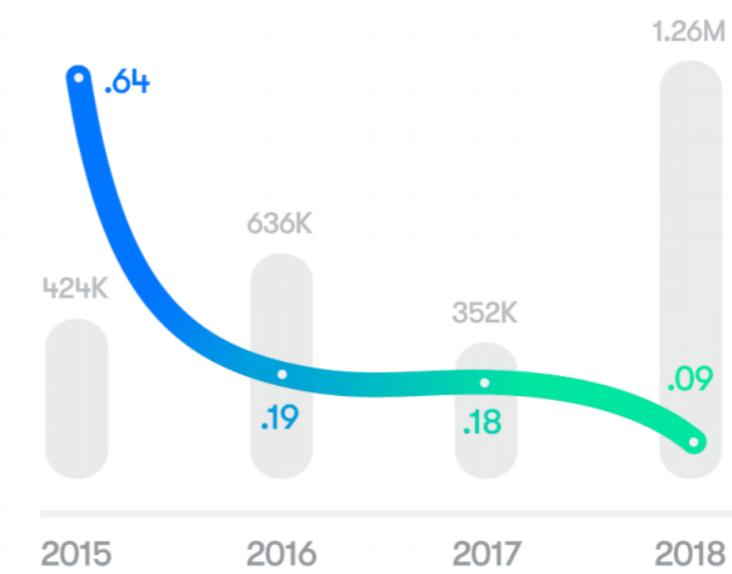
## The Self-Driving Car Companies Going The Distance

Number of test miles and reportable miles per disengagement in California in 2018



\* Cases where a car's software detects a failure or a driver perceived a failure, resulting in control being seized.

Waymo  
Disengagement  
Rate Per 1000 Miles



Miles Driven in California

# MOTIVATION

**No unified method of testing for safety**

The screenshot shows the NHTSA website with a blue header. The header includes the United States Department of Transportation logo, a search bar with a magnifying glass icon, and a 'REPORT A PROBLEM' button. Below the header is the NHTSA logo with the text 'NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION'. The main navigation menu has links for Ratings, Recalls, Risky Driving, Road Safety, Equipment, Technology & Innovation, and MORE INFO. A yellow banner at the top of the page reads '← AUTOMATED DRIVING SYSTEMS' and 'Voluntary Safety Self-Assessment'. Below the banner, there's a 'Share' button with icons for Facebook, Twitter, LinkedIn, and Email. A welcome message about the Voluntary Safety Self-Assessment Disclosure Index is displayed, along with a section titled 'NHTSA Resources' containing links to 'Voluntary Guidance' and 'VSSA Template'.

United States Department of Transportation

SEARCH

REPORT A PROBLEM

NHTSA  
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Ratings    Recalls    Risky Driving    Road Safety    Equipment    Technology & Innovation    MORE INFO ▾

← AUTOMATED DRIVING SYSTEMS

## Voluntary Safety Self-Assessment

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Welcome to NHTSA's Automated Driving Systems (ADSs – SAE International Automation Levels 3-5) Voluntary Safety Self-Assessment (VSSA) Disclosure Index. Inclusion in the index does not constitute Federal endorsement or approval of a company disclosure. NHTSA will do its best to update this site as soon as possible when it becomes aware of new VSSA disclosures.

### NHTSA Resources

- [Voluntary Guidance](#)
- [VSSA Template](#)

# MOTIVATION

All miles are not equal

## Company VSSA Disclosures

- [Apple](#)
- [Aurora](#)
- [AutoX](#)
- [Ford](#)
- [GM](#)
- [Ike](#)
- [Mercedes-Benz/Bosch L4-L5](#)
- [Mercedes Benz L3](#)
- [Navya](#)
- [Nuro](#)
- [Nvidia](#)
- [Robomart](#)
- [Starsky Robotics](#)
- [TuSimple](#)
- [Uber](#)
- [Waymo](#)
- [Zoox](#)

Driving 20 percent better than a human  
requires 11 billion miles of validation!

## PROBLEM STATEMENT

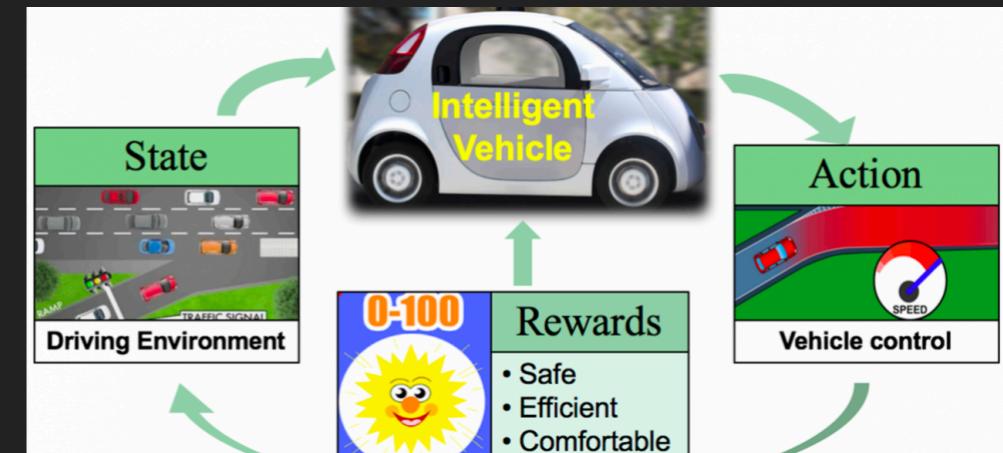
- ▶ Use reinforcement learning to generate unexpected traffic situations on an autonomous driving simulator
- ▶ Intentionally try to cause collisions for autonomous vehicles to discover edge cases where they fail

# REINFORCEMENT LEARNING IN DRIVING

Using RL to park



Using RL to learn correct driving behaviors



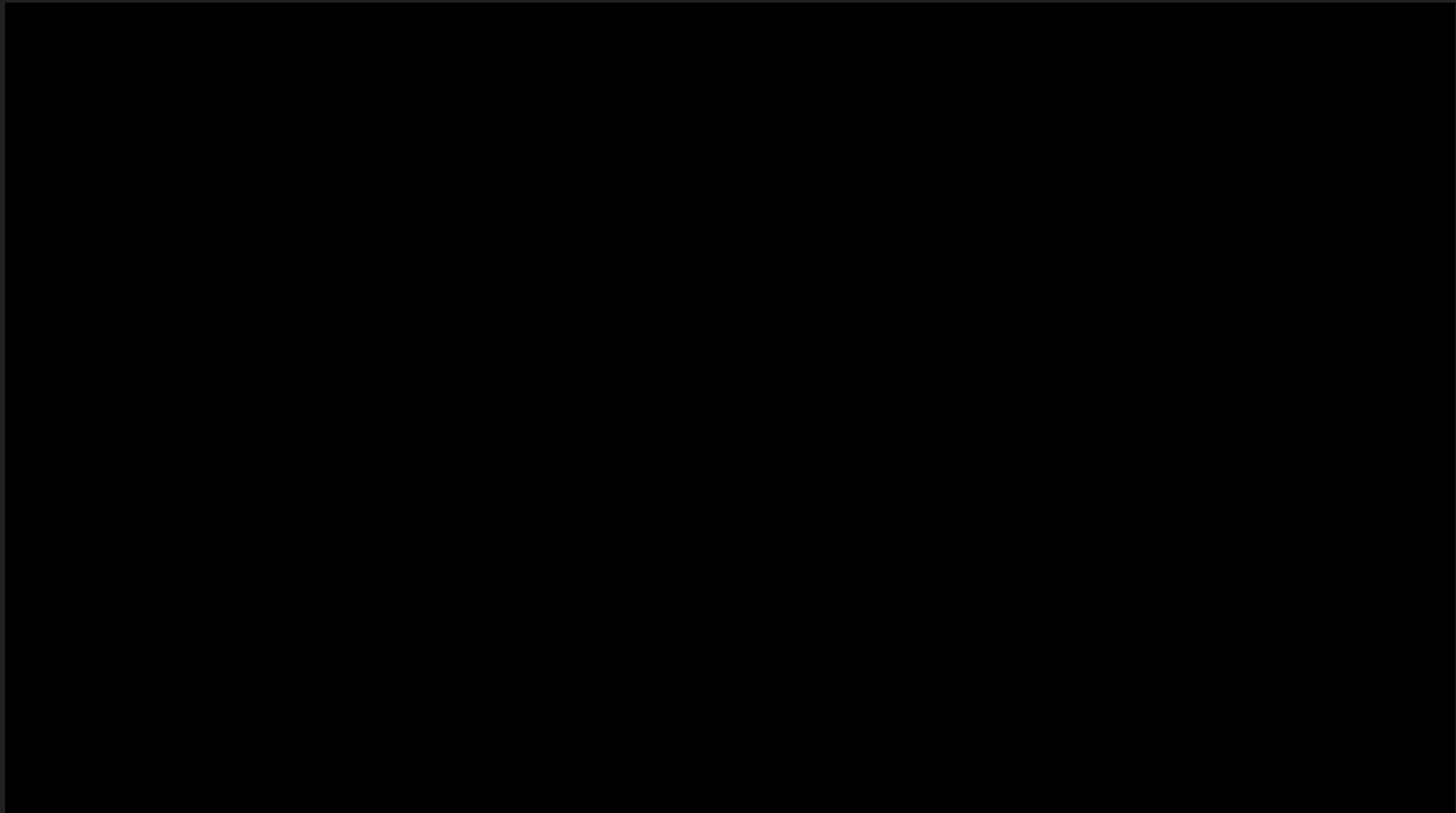
## RELATED WORKS

- ▶ RL for lane changing ([Wang et al. 2018](#))
- ▶ Sampling rare event situations for AVs ([Sarkar et al. 2019](#))
- ▶ Estimating probability of collision in rare event situations for AVs ([O'Kelly et al. 2018](#))

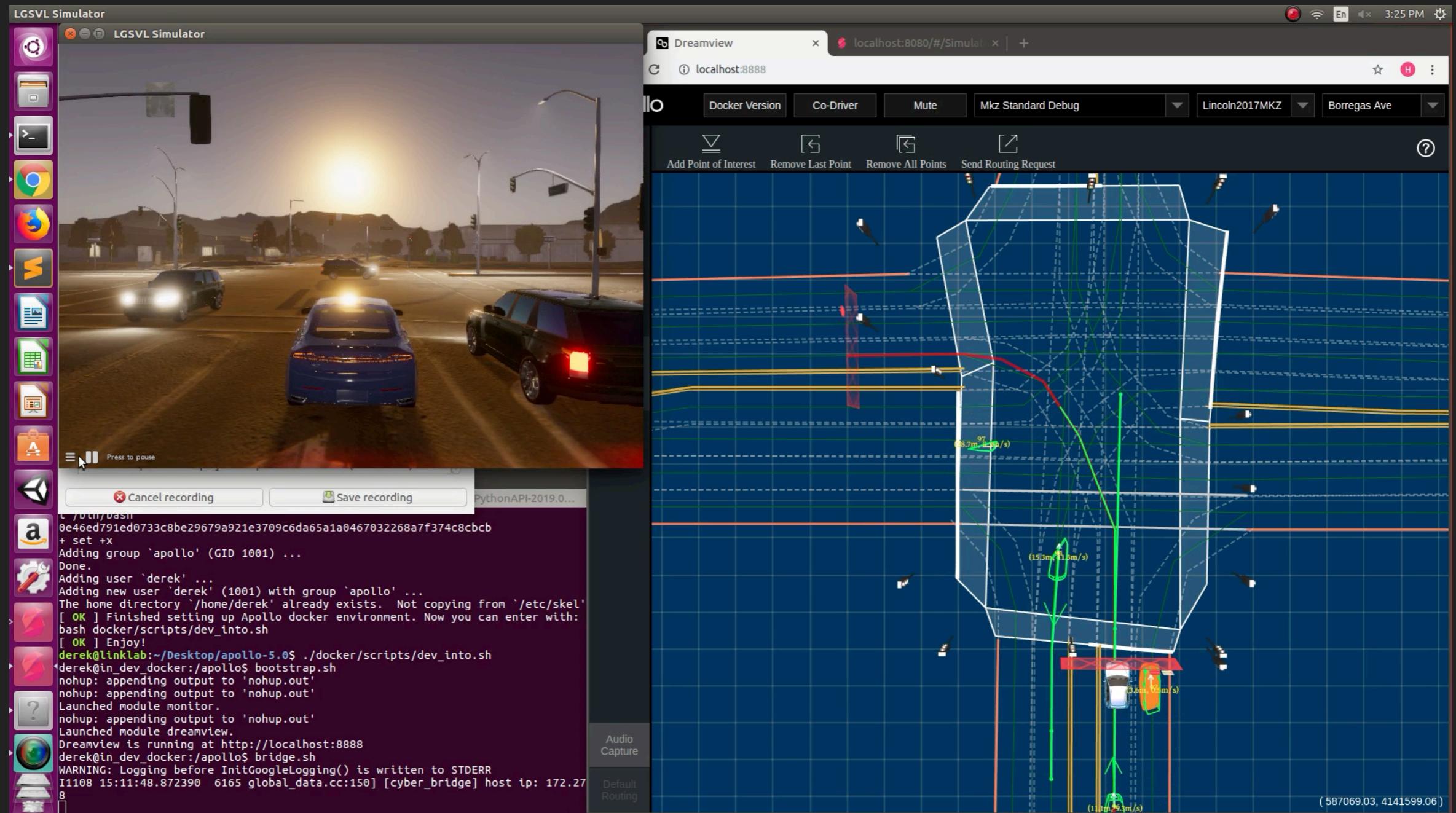
## THE LGSQL SIMULATOR

- ▶ A photo-realistic, HD rendering AD simulator
- ▶ New, well maintained
- ▶ Flexible module selection
- ▶ Integration of Baidu's Apollo AD stack

# THE LGSQL SIMULATOR (DEMO)



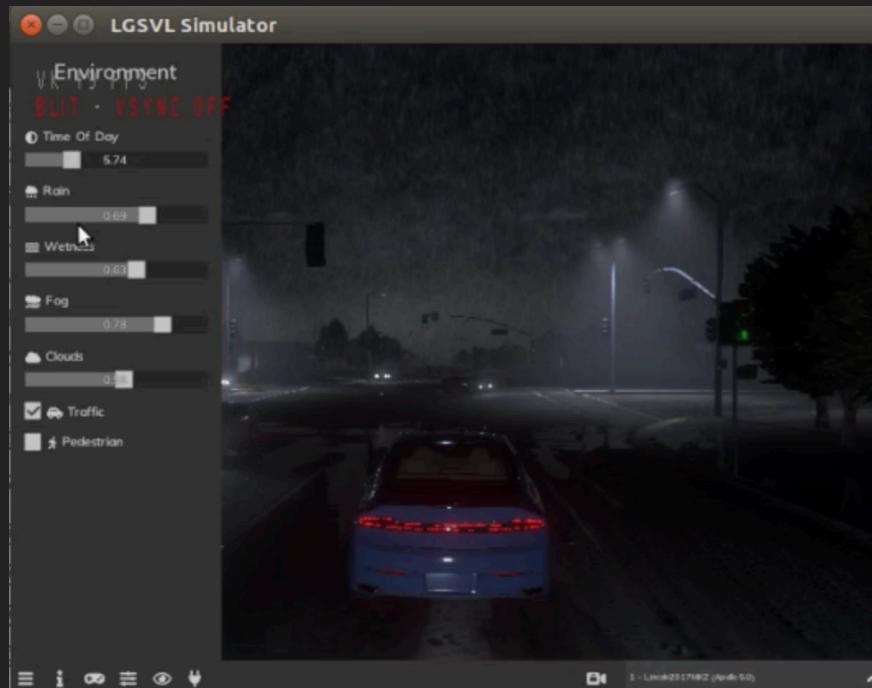
# THE LGSQL SIMULATOR (DEMO)



## LGSVL PYTHON API

- ▶ Input: Scenario parameters  $\Psi$ 
  - ▶ Dynamic ( $\Psi_d$ ): weather (rain, fog, wetness), time of day, position/velocity of NPC vehicles/pedestrians, waypoints for NPC vehicles/pedestrians, state of traffic lights
  - ▶ Static ( $\Psi_s$ ): road geometry, position traffic signs/lights

## LGSVL PYTHON API (EXAMPLE)

 $\Psi_d$ 

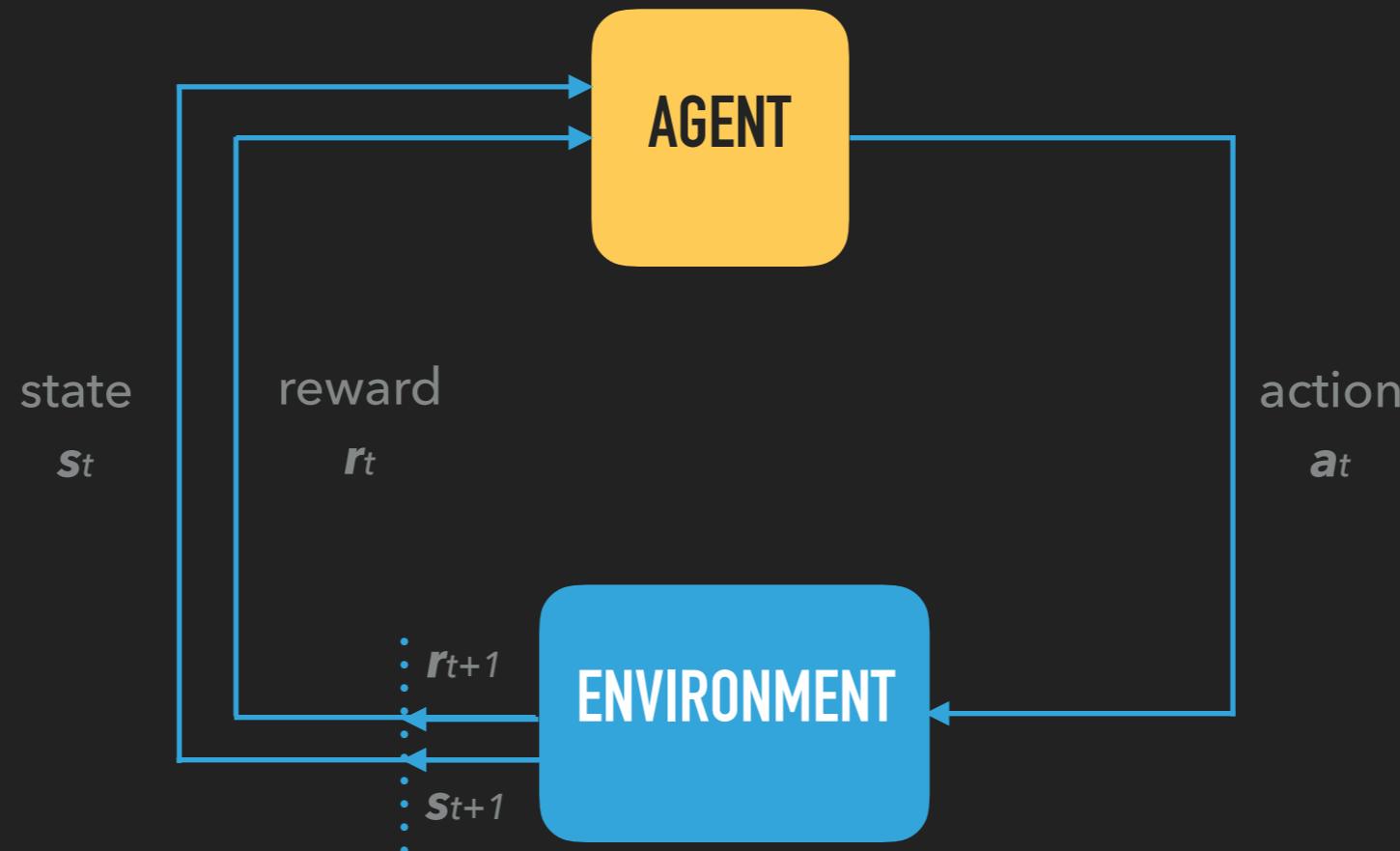
Rain, wetness, fog, NPC vehicles/pedestrians, NPC waypoints, state of traffic lights

 $\Psi_s$ 

Road geometry, position of traffic signs/lights

# REINFORCEMENT LEARNING

- ▶ Agent learns a policy by “exploration and exploitation”
- ▶ Value in each action is determined by the reward function



# ACTOR CRITIC REINFORCEMENT LEARNING

- ▶ Actor learns which action to take in each state
- ▶ Critic estimates the value of actor's action
- ▶ Both Actor and Critic improve in training



## RL - REWARD FUNCTION

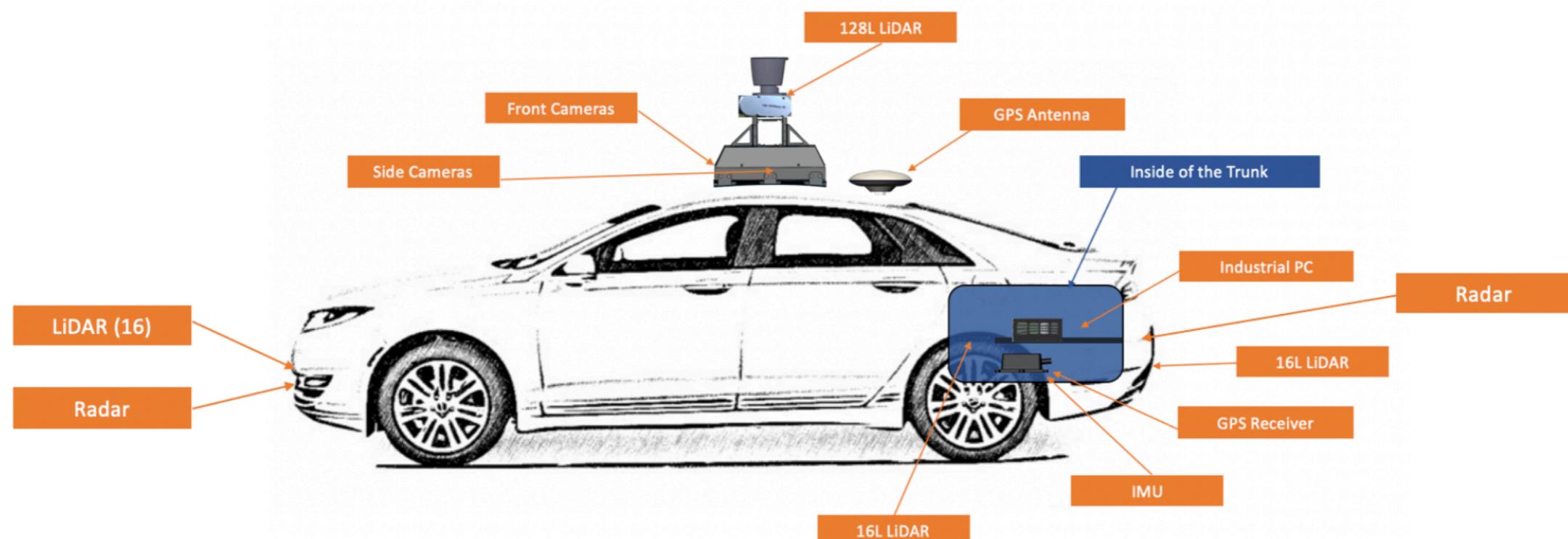
- ▶ Time to collision (TTC) between Apollo and NPC vehicle
  - ▶ Goal: reduce TTC down to 0
  - ▶ Extra reward of 100\* for collision
  - ▶ Room for refinement
- 
- ▶ \*naively chosen value

## BAIDU'S APOLLO

- ▶ Open source AD stack
- ▶ Constantly being updated
- ▶ State-of-the-art hardware and software architecture

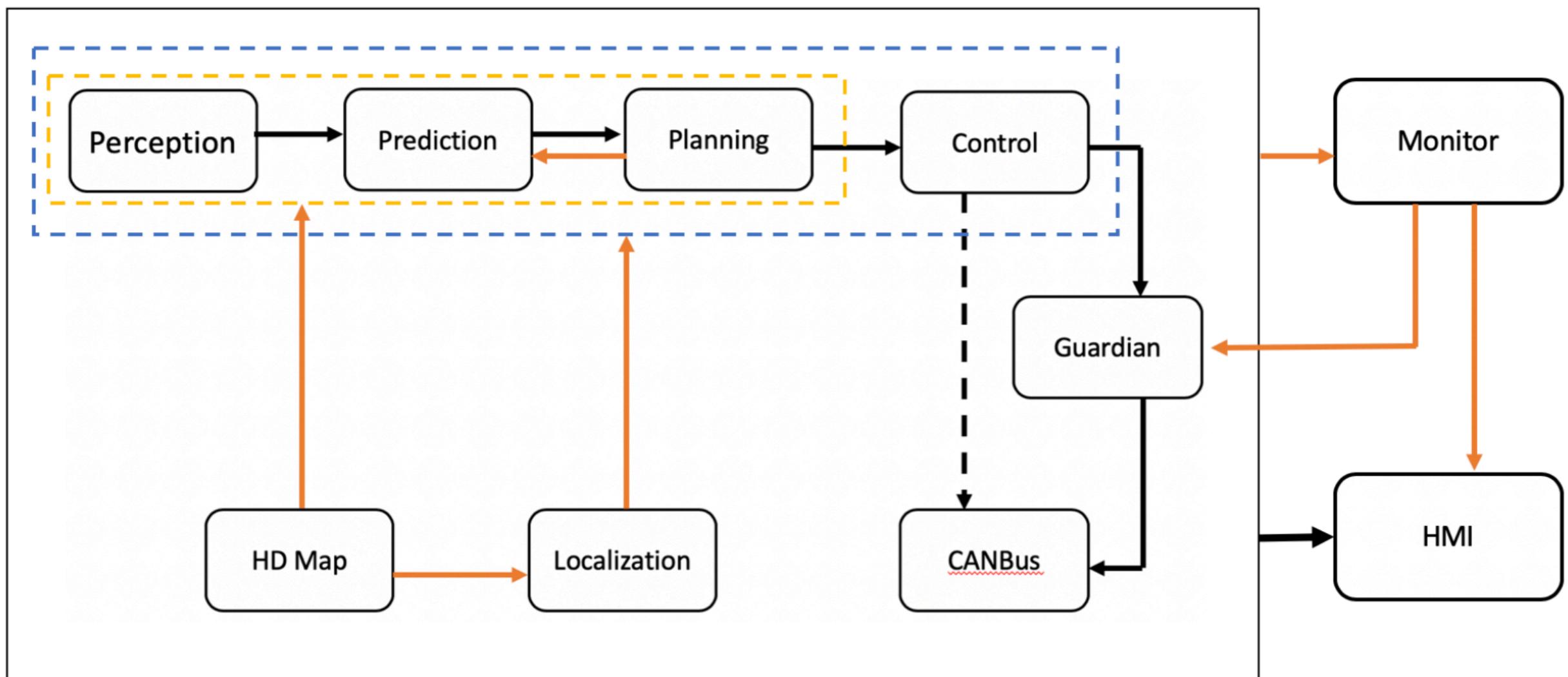
# APOLLO HARDWARE ARCHITECTURE

- Hardware/ Vehicle Overview



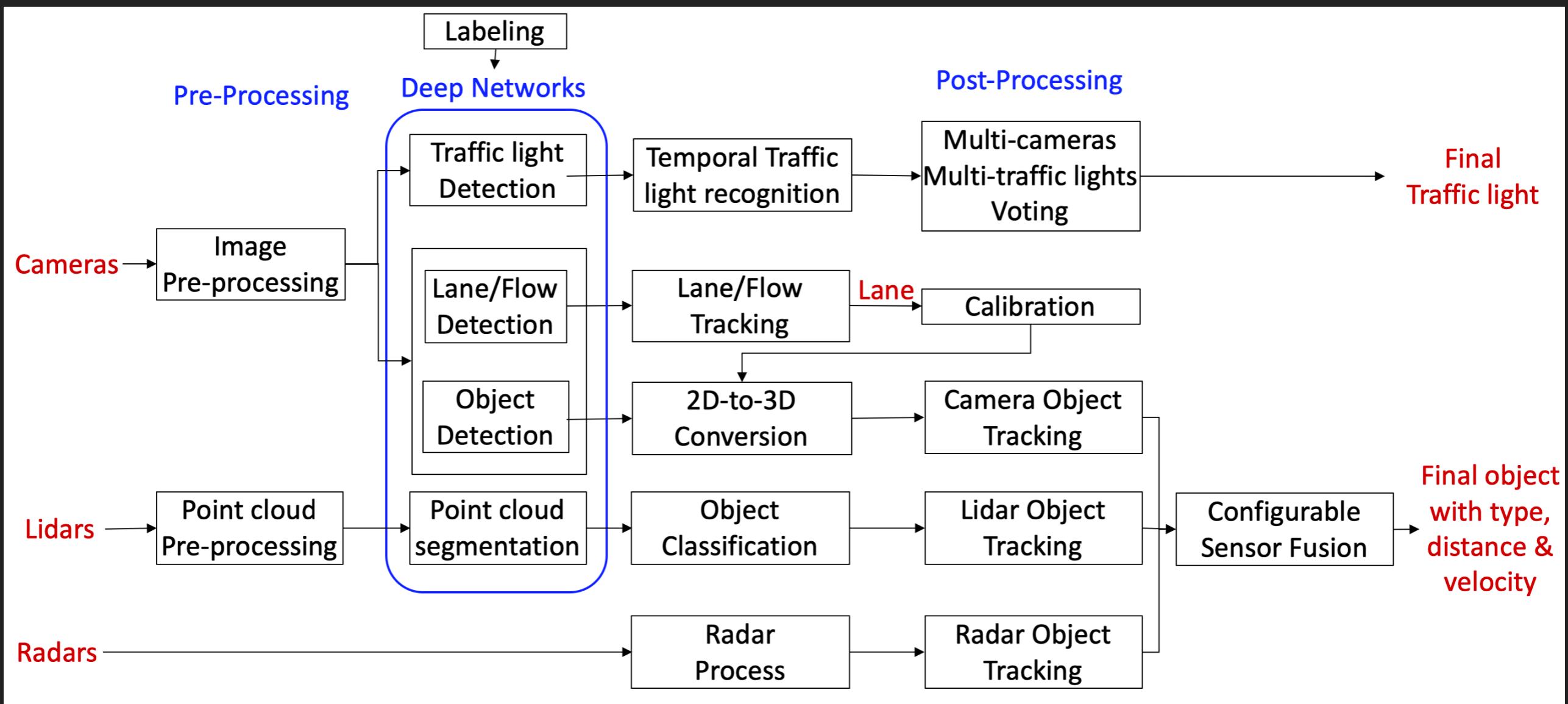
# APOLLO SOFTWARE ARCHITECTURE

- Software Overview - Navigation Mode



Key: Data Lines      Control lines

# APOLLO'S PERCEPTION MODULE



# BMW plans to join Apollo, the open autonomous driving platform by Baidu

News | July 10th, 2018 by Horatiu Boeriu 0 comments

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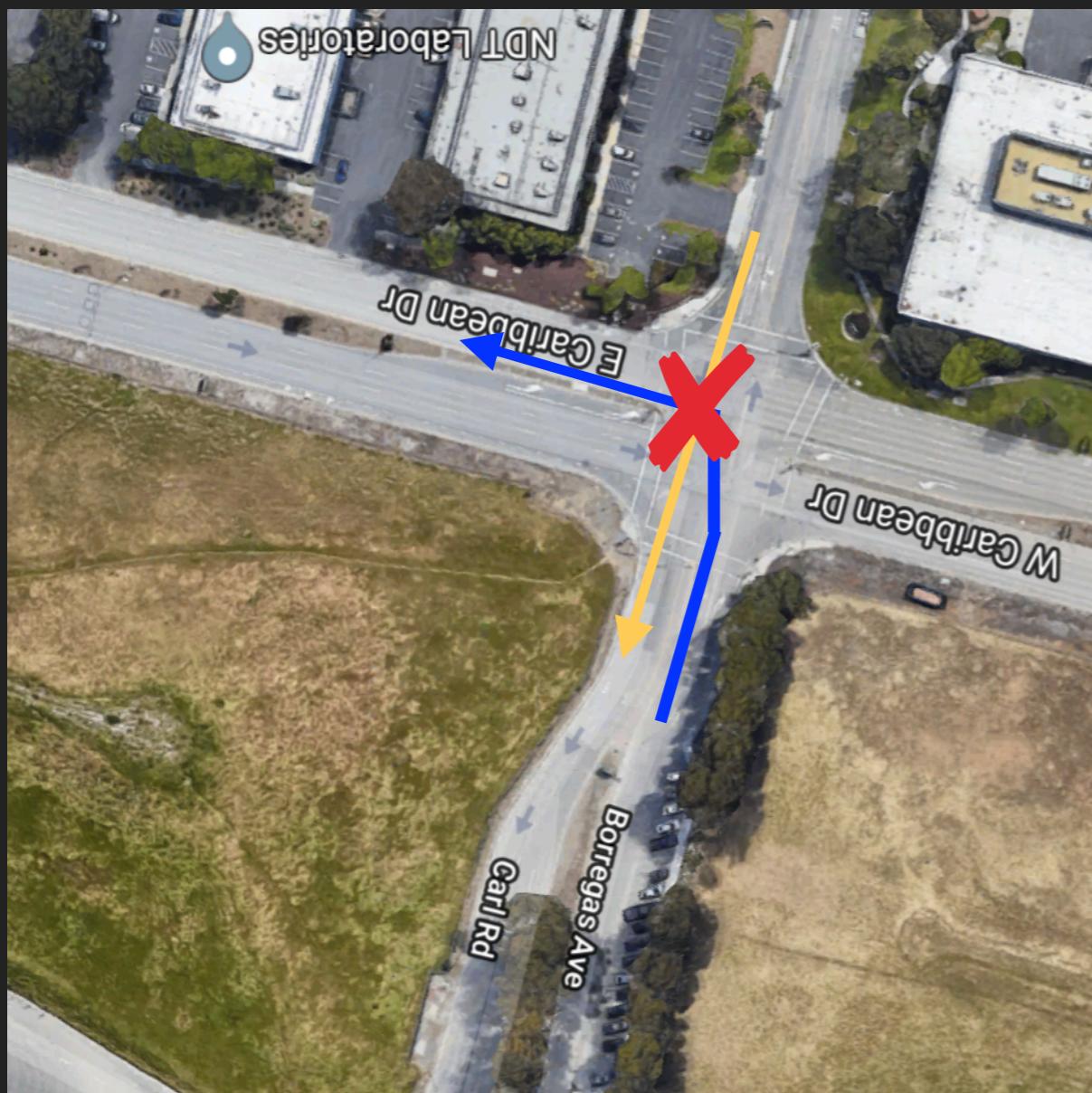


Apollo is recognized as having a robust AD algorithm!

## SIMULATION 1

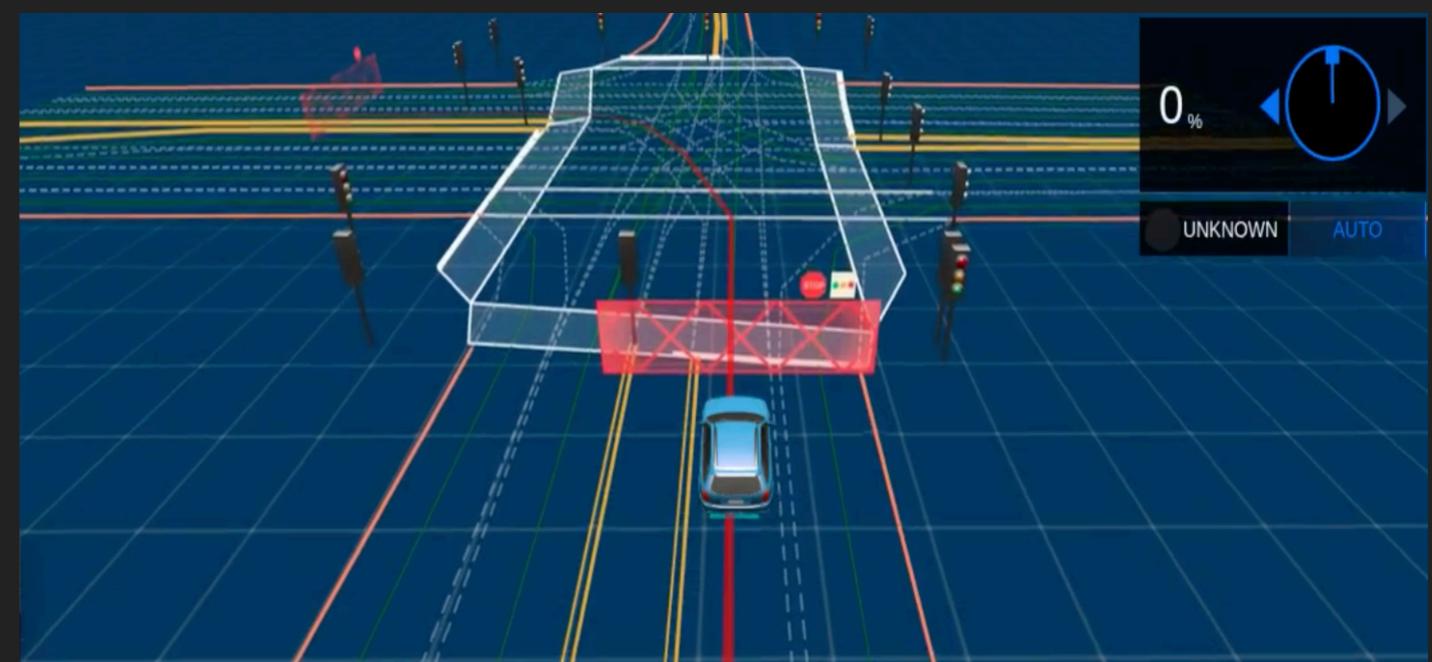
- ▶  $\Psi_d$ : position/velocity of one NPC vehicle, time of day, rain-, fog-, wetness-rates [0, 1], traffic light set to green
- ▶  $\Psi_s$ : Borregas Ave. Sunnyvale, CA

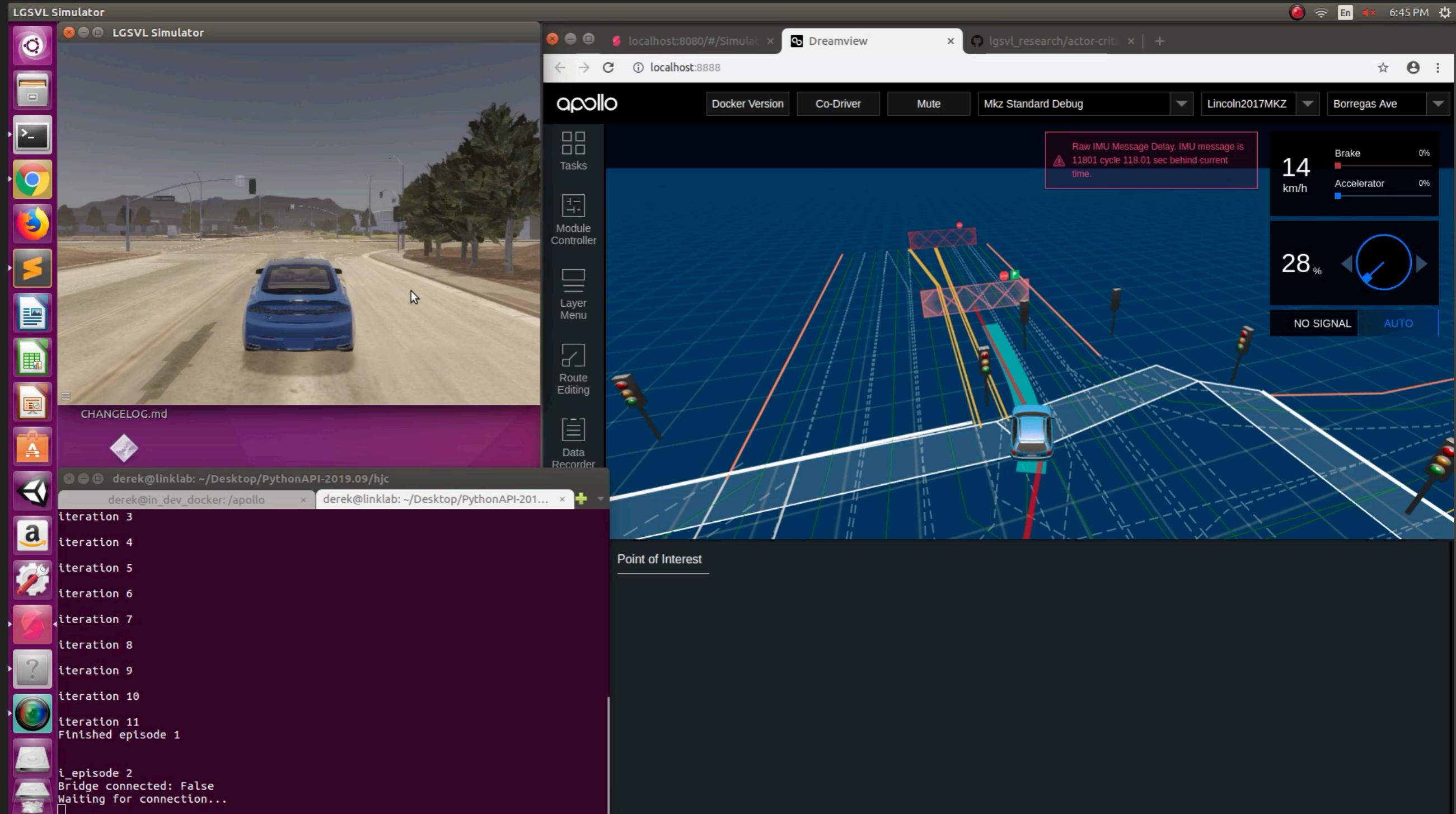
# SIMULATION 1



## RESULT 1

- ▶ RL agent invalidates Apollo's perception module by creating a dense fog.



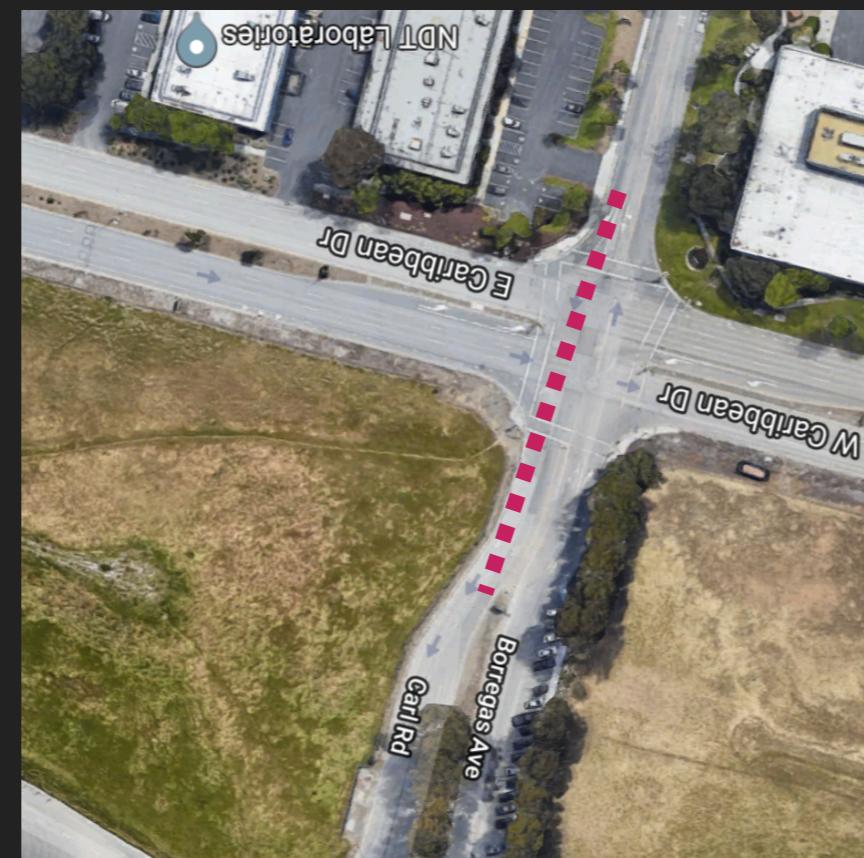


## RESULT 1 - OBSERVATION

- ▶ RL agent is given control over fog => failure in perception
- ▶ Abruptly changing fog unrealistic.
- ▶ Curse of dimensionality. Can we cause a collision?

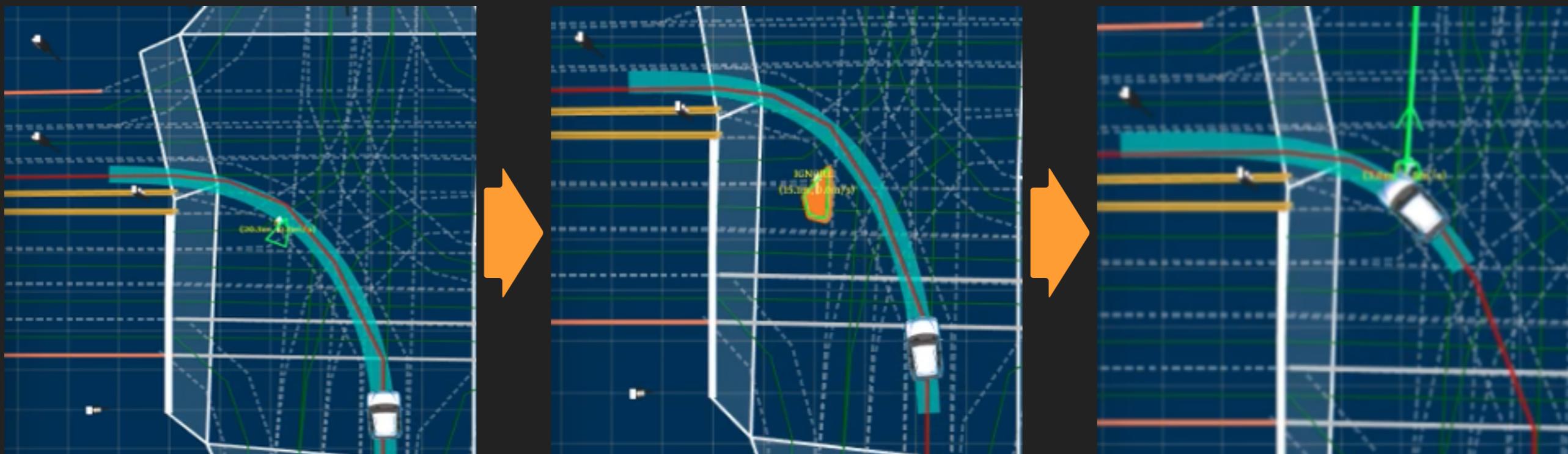
## SIMULATION 2

- ▶  $\Psi_d$ : velocity of one NPC vehicle (rest are fixed). NPC waypoint uniformly sampled from spawn to destination.
- ▶  $\Psi_s$ : Borregas Ave. Sunnyvale, CA



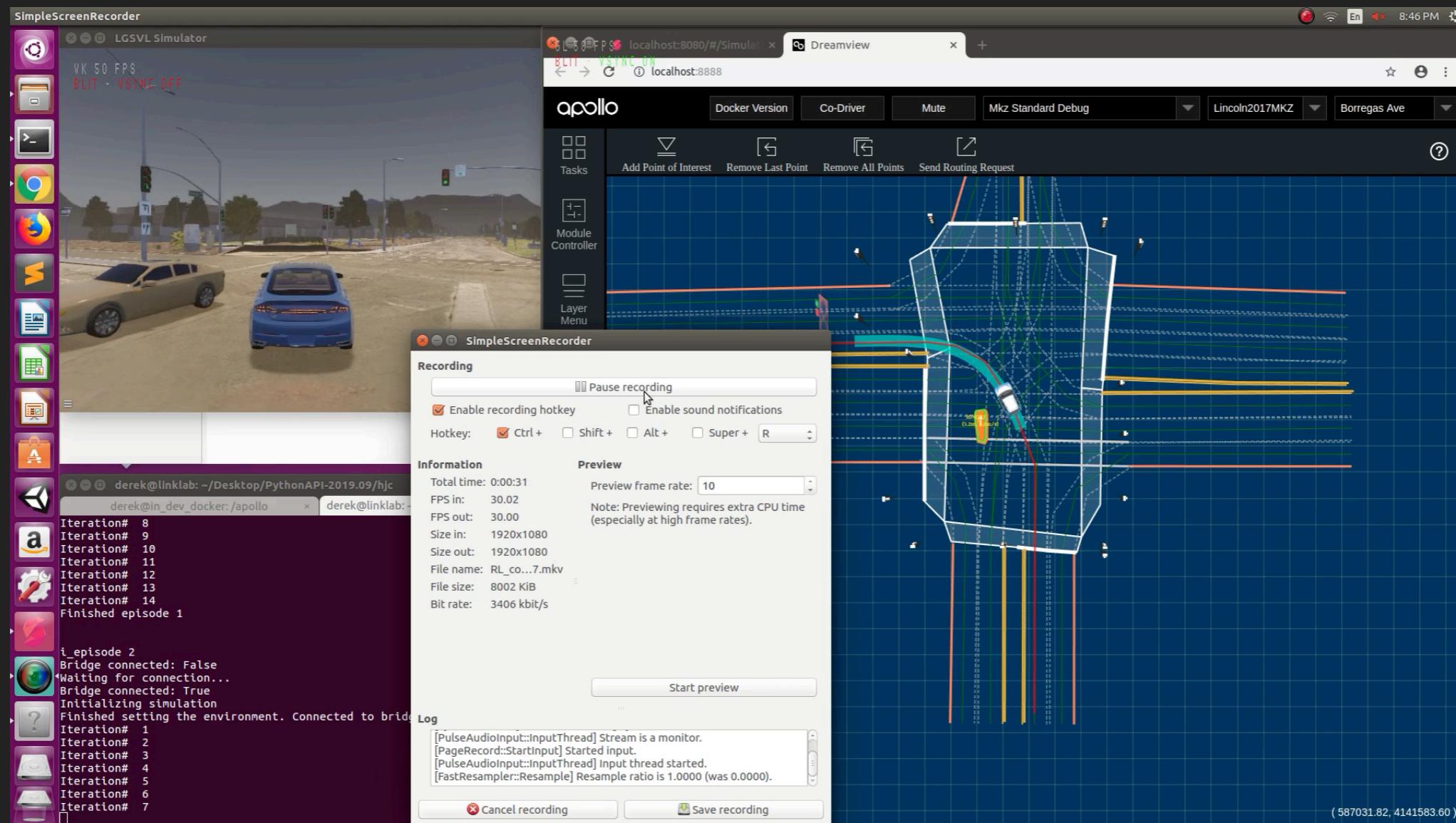
## RESULT 2

- ▶ After training for hundreds of iterations, collision!



## RESULT 2 - OBSERVATION

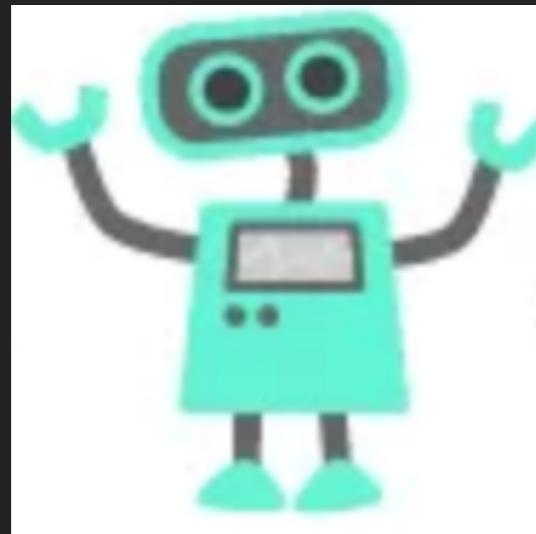
- ▶ Revealed a potential safety vulnerability for Baidu Apollo



## CONTRIBUTION

- ▶ Built the framework for using deep reinforcement learning for automated testing for AVs
- ▶ [https://github.com/hyunjaecho94/lgsvl\\_research/](https://github.com/hyunjaecho94/lgsvl_research/)

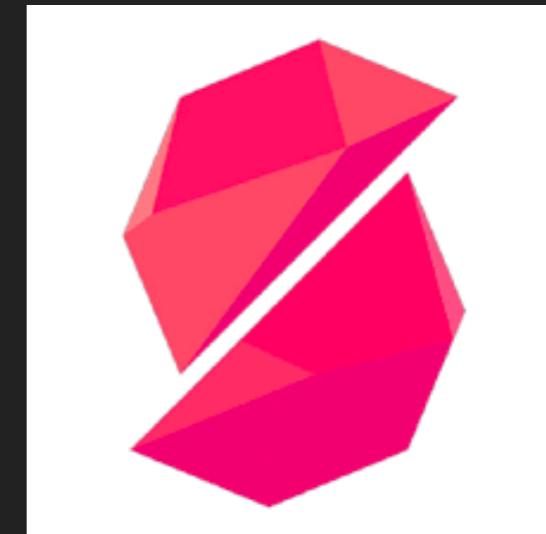
REINFORCEMENT LEARNING



APOLLO



LGSVL SIMULATOR



## LIMITATIONS

- ▶ Computational limitation for training
- ▶ =>Difficulty in exploring more parameters (i.g. pedestrians)
- ▶ Lack of command line method of training

## FUTURE WORK

- Extending the action space of RL agent
- Refining the reward function
- Combined methods with related works
  1. sampling rare scenarios
  2. incorporating crash probability

## CONCLUDING REMARKS

- Workshop at Autonomy in CPS 2020
- I would like to thank the committee members, professor Sebastian Elbaum and professor Matthew Dwyer
- Ph.D. in CS!

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END OF PRESENTATION. THANK YOU.