







CSCI 420-02 Robotics

Trey Woodlief
Fall 2026

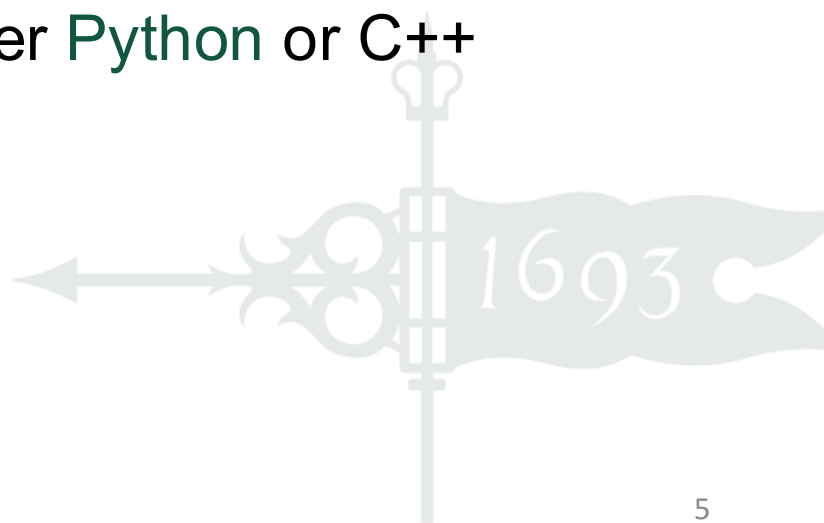


WILLIAM & MARY

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Who is this class for?

- You want to learn robots *from a CS perspective*.
 - Not a course on mechanics, electronics, and only briefly on AI
- You have no prior university-level robotics experience.
- You are very comfortable in either **Python** or C++
- You can debug systems issues

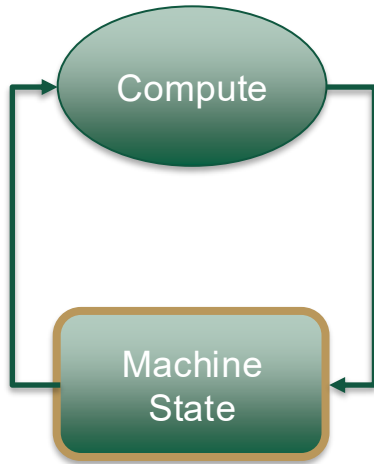


Why robots?

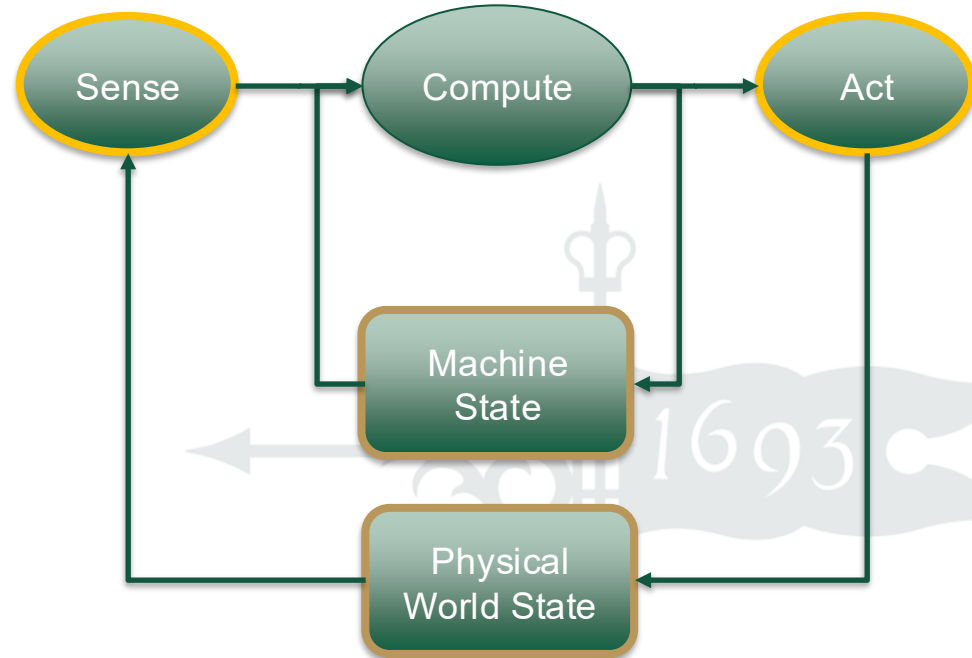
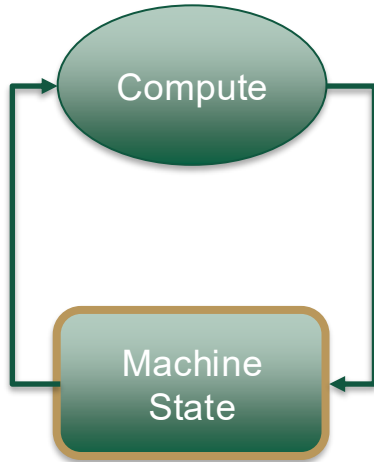
- How do we build systems that can **operate safely** in the **physical world**?



Cyber-only Operation



Cyber-only vs Physical World



Exercise – Groups of 3

- Goal: Stack the 3 cups. Cup with dots on top.
- One person **SENSE**
 - Looking at the cups,
explain to CONTROL what you see *relative to the desk*
- Second person **CONTROL**
 - Looking away from the cups,
instruct ACT how to move/grasp/etc
- Third person **ACT**
 - Looking away from the cups,
follow the instructions from CONTROL
- Repeat



Operating in the Physical World

- What was challenging?



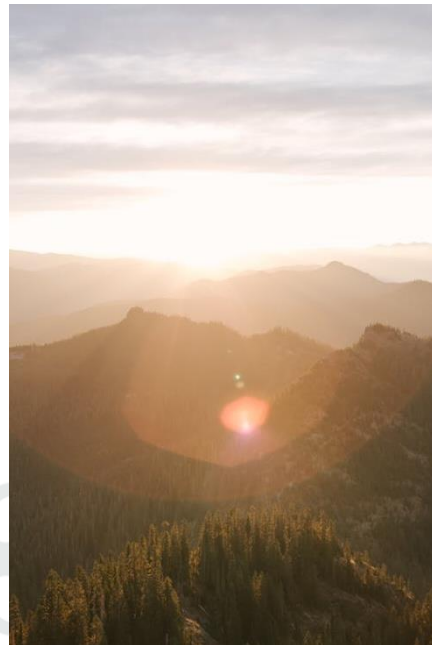
Operating in the Physical World

- What was challenging?
 - Imprecise sensing
 - Uncertain control
 - Frame of reference
 - Incomplete model of the world
 - Misunderstandings/miscommunications

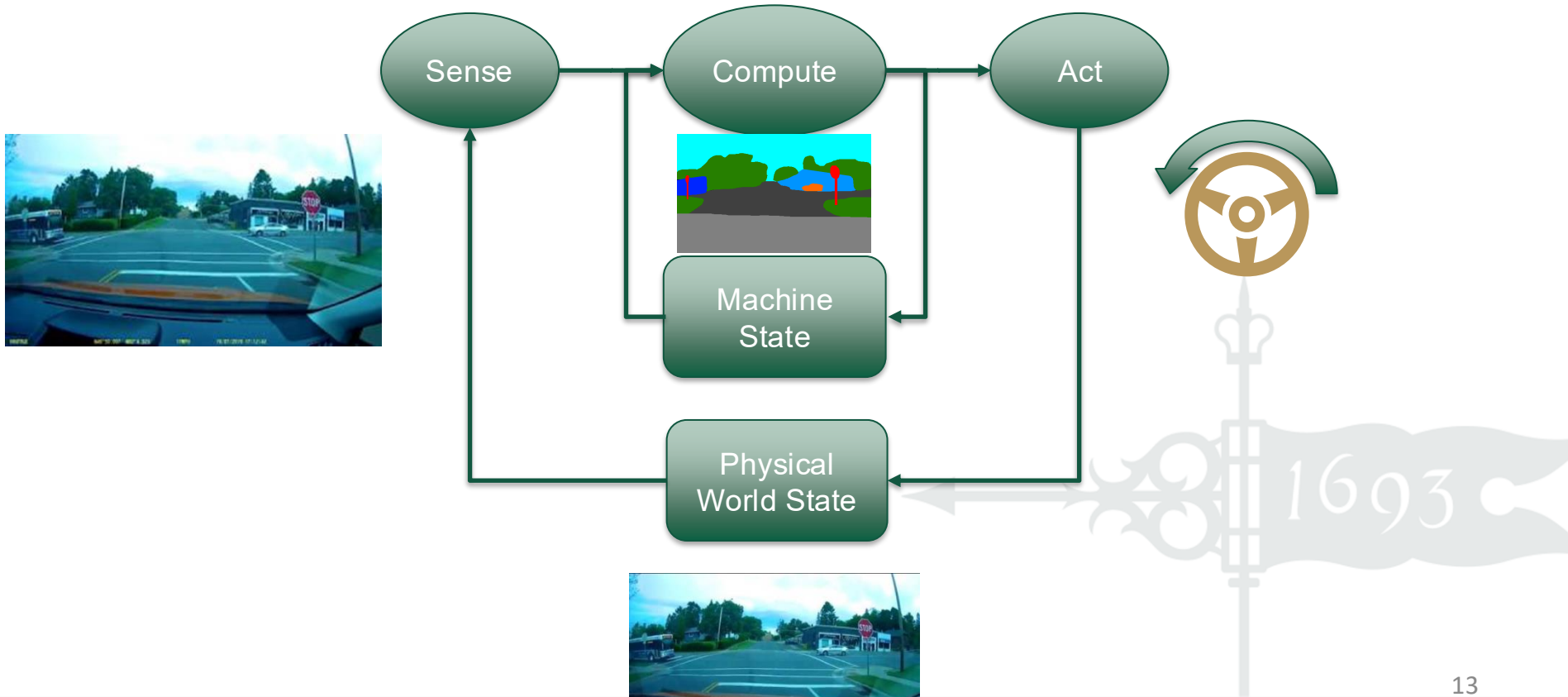


Operating in the World is Hard!

- The world is complicated!
- Sensors are imperfect
- All descriptions are approximate
- Uncertainty at every step
- Timing is important

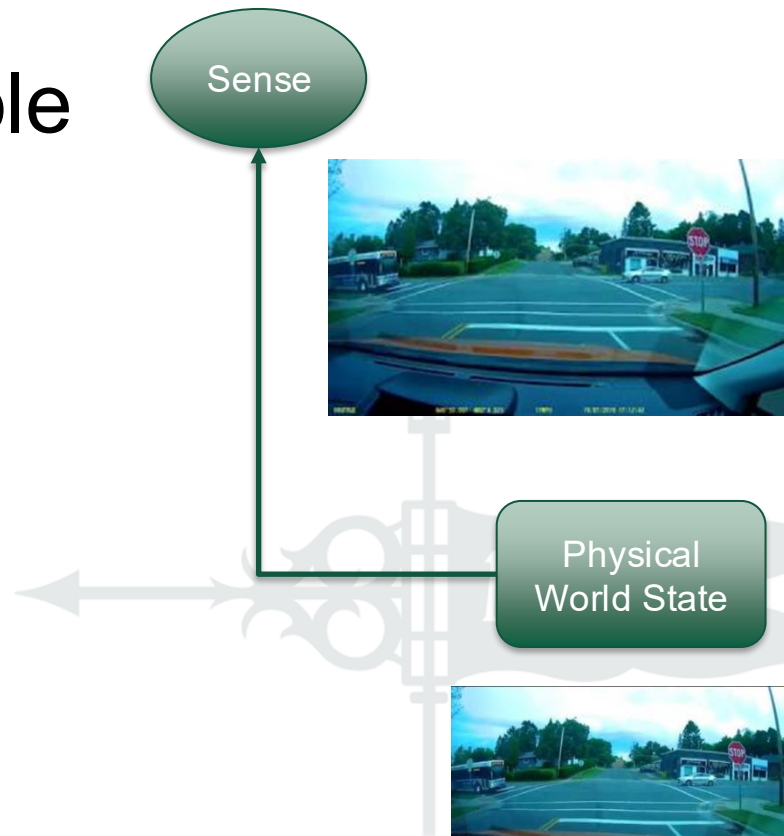


Putting it all Together



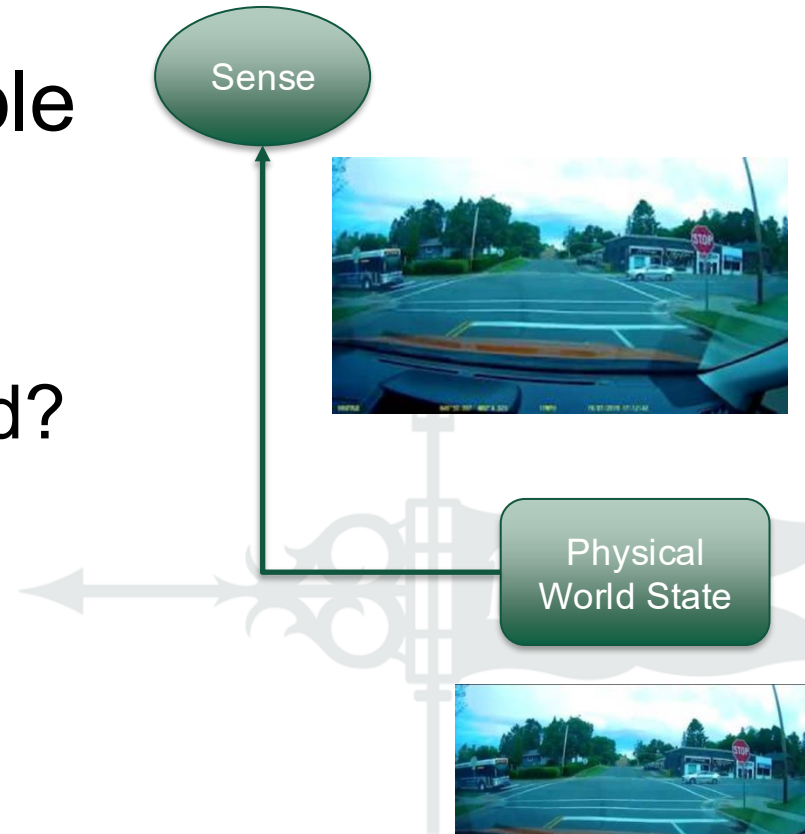
Sensing

- World partially observable



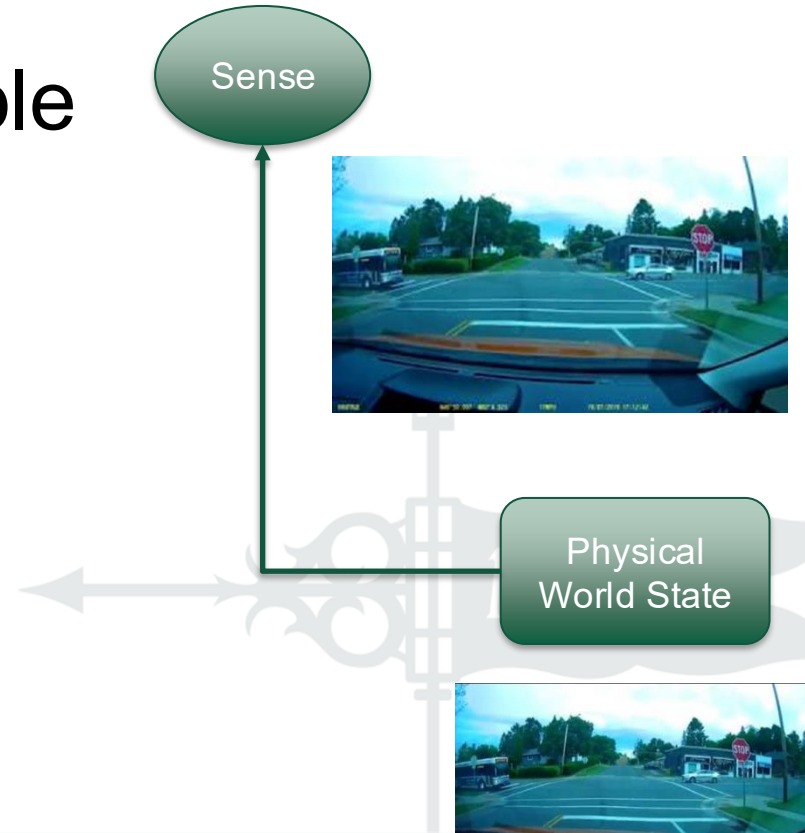
Sensing

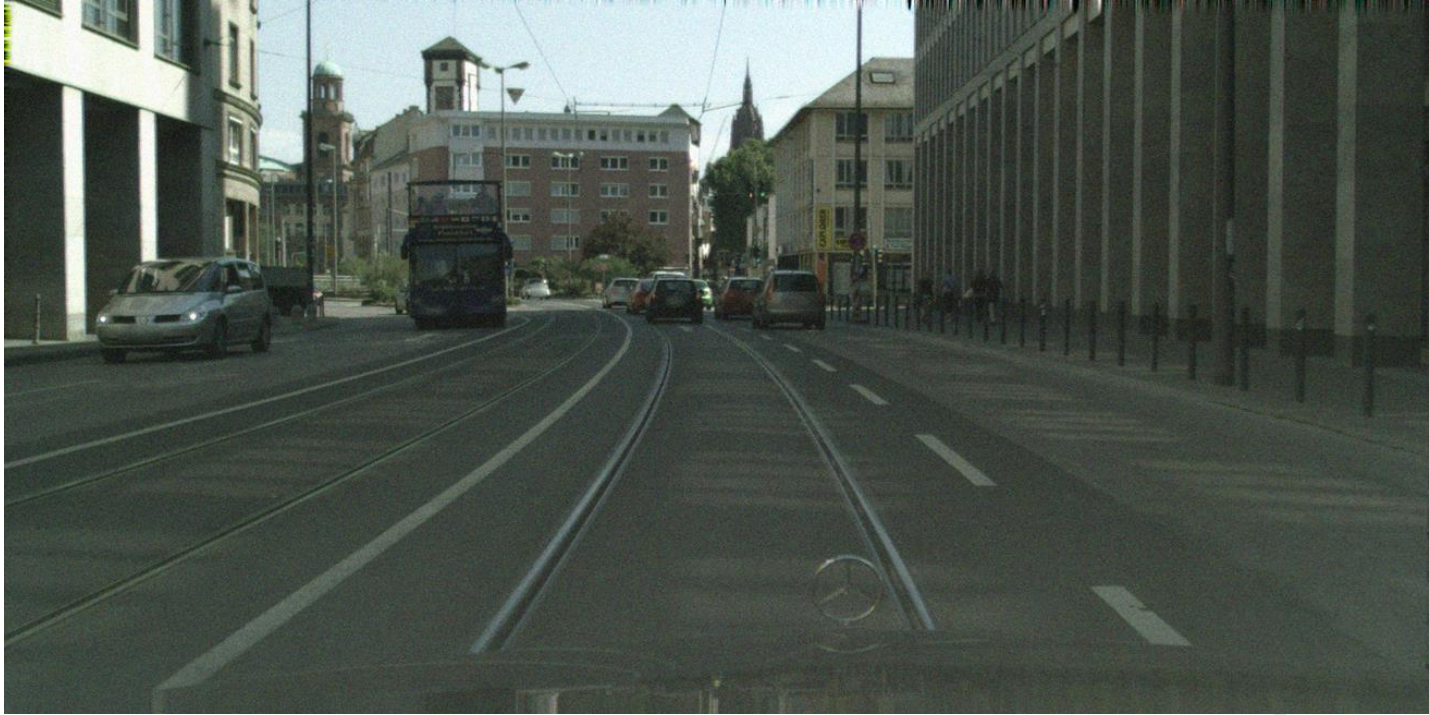
- World partially observable
 - You only "see" what the sensor "sees"
 - What's happening behind?



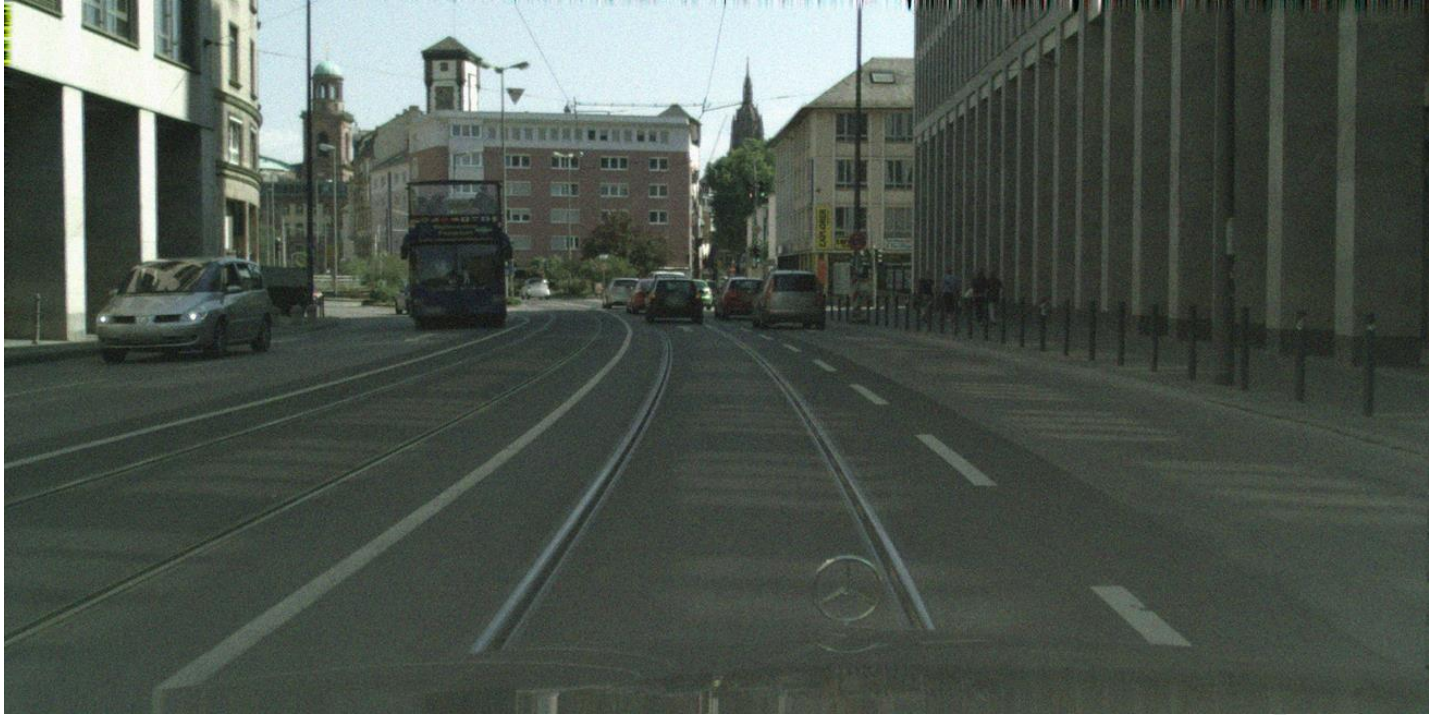
Sensing

- World partially observable
- Sensors are noisy

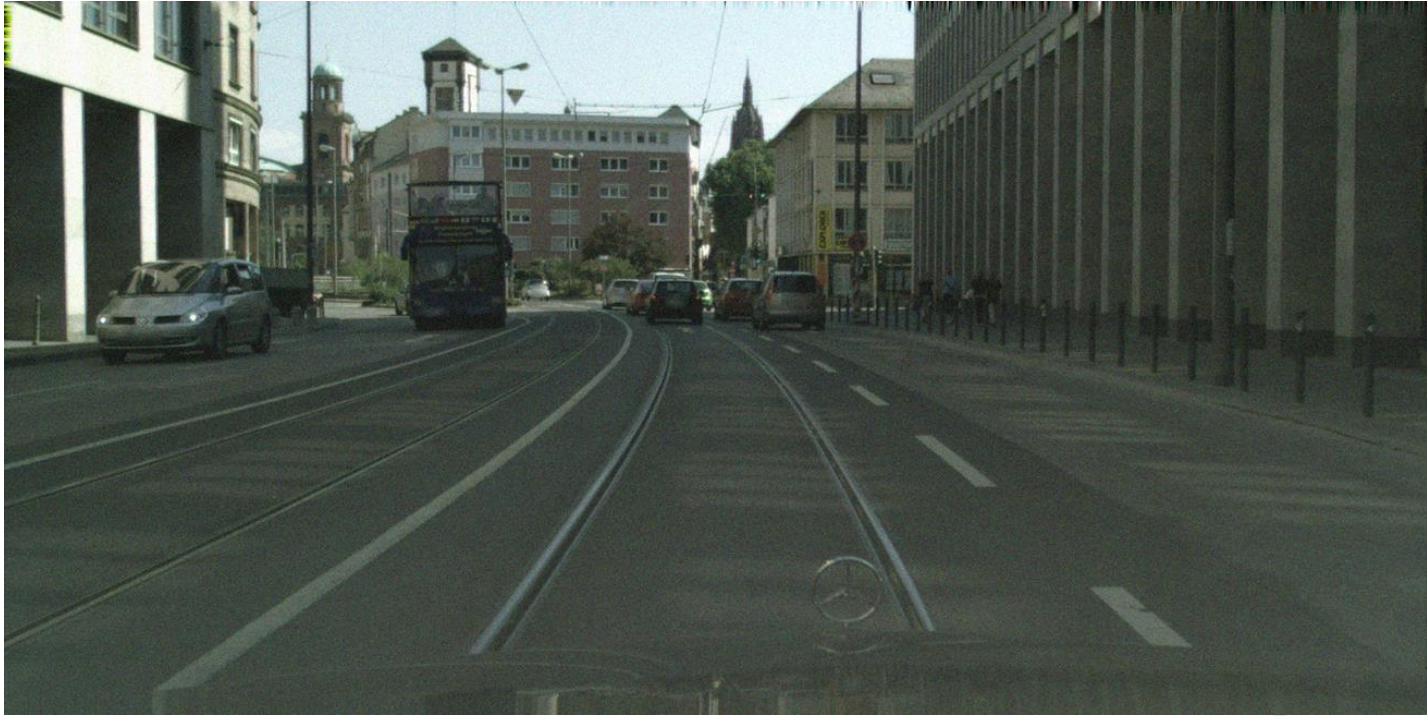




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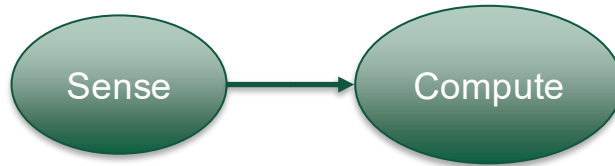




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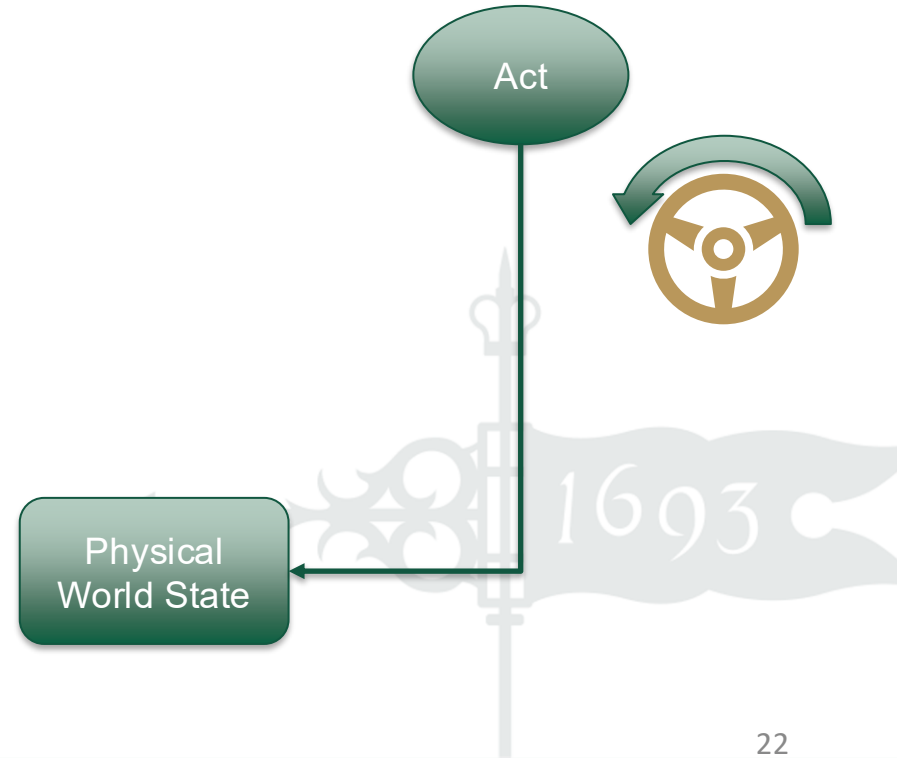
Sensing to Compute

- Inferring world state is approximation/abstraction



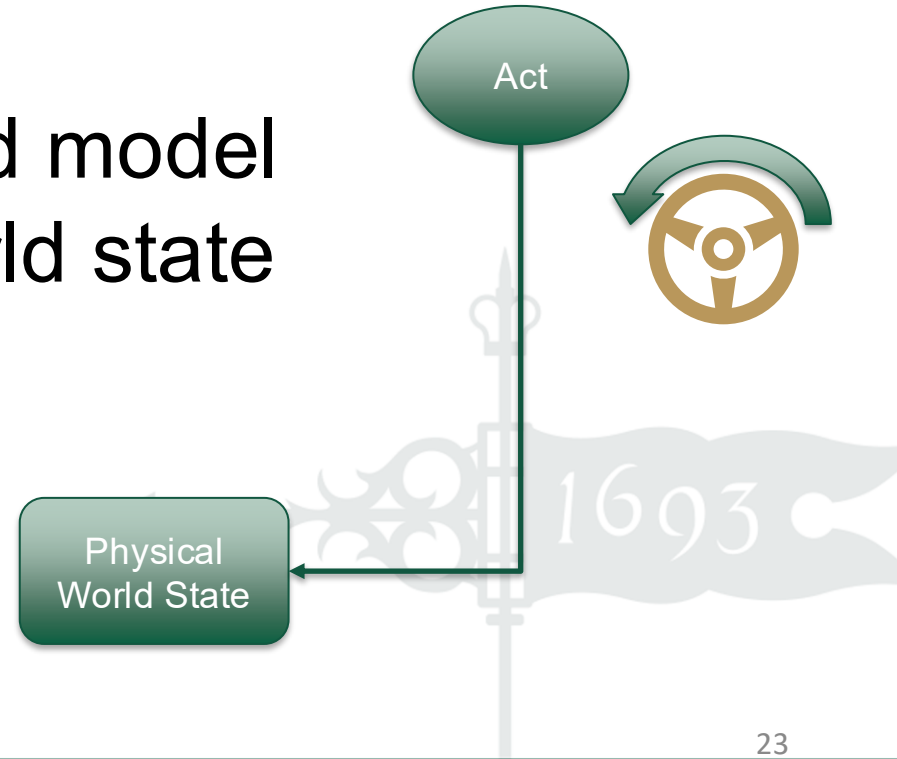
Actuation

- Actuation is noisy



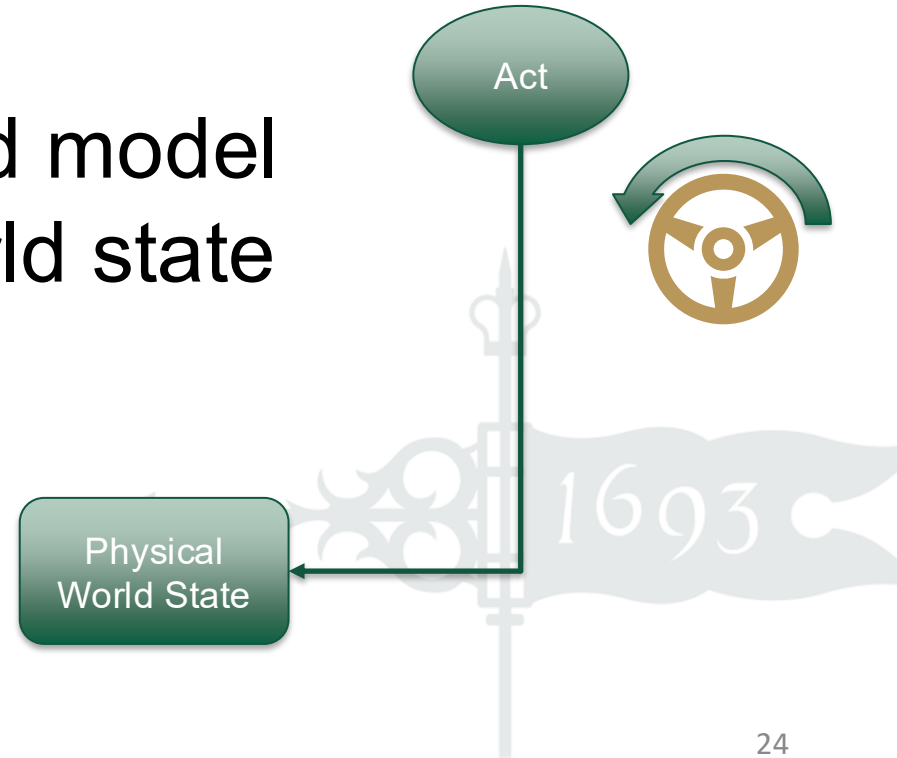
Actuation

- Actuation is noisy
- Inaccurate when world model doesn't match the world state



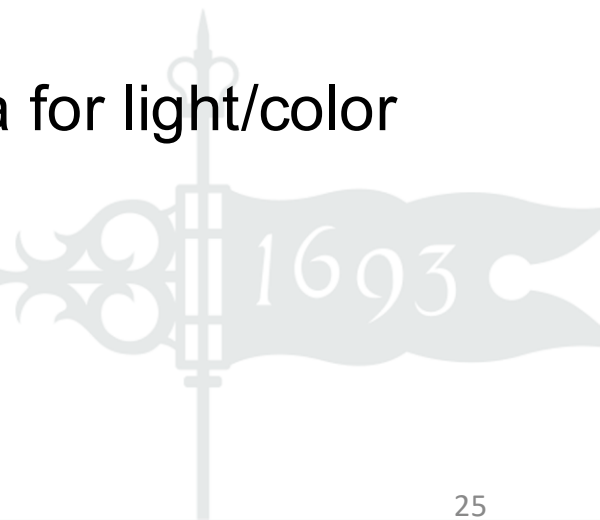
Actuation

- Actuation is noisy
- Inaccurate when world model doesn't match the world state



How do we overcome?

- More and better sensors
 - Higher precision (4K vs 720)
 - Different modalities
 - Radar/LiDAR for distance, camera for light/color
 - Sensor fusion to combine
 - Sensor feedback over time



How do we overcome?

- Better models of the robot and world



(a) image



(b) semantic segmentation



(c) instance segmentation



(d) panoptic segmentation

<https://www.labellerr.com/blog/semantic-vs-instance-vs-panoptic-which-image-segmentation-technique-to-choose/>

How do we overcome?

- More and faster feedback/control loops
 - When is human-in-the-loop needed?
- Exposure to more scenarios
 - Training for AI-components
 - Coverage of relevant pieces in testing
 - Simulation versus real-world

Where are we now?



Where are we now?

The New York Times

U.S. Will Investigate Tesla's Autopilot System Over Crashes With Emergency Vehicles

It will be the broadest look yet at Tesla's assisted-driving technology. The National Highway Traffic Safety Administration has the authority to force a recall or require new safety features.

Share full article



A Tesla Model S crashed into a fire engine on Interstate 405 in Culver City, Calif., in 2018. A government report said the driver of the Tesla had been using the car's Autopilot system. KCBS-TV, via Associated Press

Wired

BACKCHANNEL BUSINESS CULTURE DEAN IDEAS SCIENCE SECURITY MUNCH

AI/ML MANUAL TRANSPORTATION MAR 21, 2018 8:32 PM

Uber Video Shows the Kind of Crash Self-Driving Cars Are Made to Avoid

And that the human safety driver was looking away from the road in the seconds leading up to the fatal impact.



California Bans GM's Cruise Robotaxis After Near-Fatal Pedestrian Accident

Justin Banner - Writer; Getty Images - Photographer | Oct 27, 2023



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EDITOR'S PICK

Tesla In Taiwan Crashes Directly Into Overturned Truck, Ignores Pedestrian, With Autopilot On

Brad Templeton Senior Contributor

I cover robotics technology & previously worked on Google's car team.

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Jun 2, 2020, 06:20pm EDT

Listen to article 8 minutes

This article is more than 3 years old.

Video from Taiwan reveals a disturbing Tesla crash, where the vehicle plows directly into the top of a large truck lying on its side, straddling two lanes of a freeway. The driver states the vehicle was in Autopilot mode. The driver did not hit the brakes himself until far too late, indicating he was probably not paying attention. The road has light traffic and visibility is very good. Nobody was injured.



Why should *you* do robots?

- How do we ~~build~~ *engineer software* so that systems that can *operate safely* in the *physical world*?



Bringing CS & SE to robots

- You are an expert in:
 - Software architecture & design patterns
 - Complex abstraction
 - Algorithms & data structures
 - Requirements
 - Testing & maintenance



Bringing CS & SE to robots

- You are an expert in:

This course will equip you to bring this expertise to the robotics domain.

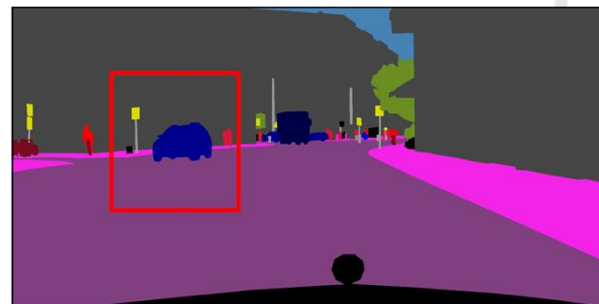
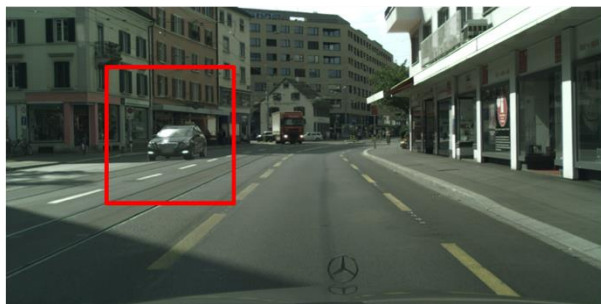
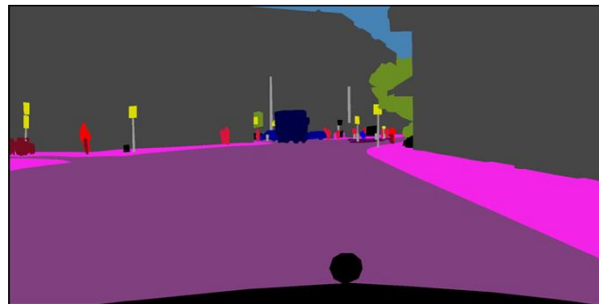
- Testing & maintenance

My Research

- I aim to improve the safety of robots & autonomous systems
- We research ways to:
 - Validate robot perception
 - Connect perception to requirements
 - Validate and Verify against requirements

My Research

- Testing perception systems



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My Research

- Runtime monitoring for AVs

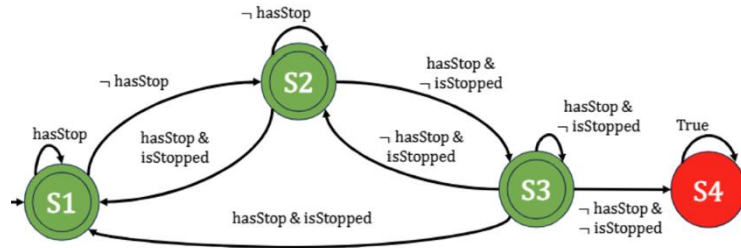
LTL_f Formula for ψ_9 :

$\mathcal{G}((\neg \text{hasStop} \& \mathcal{X} \text{ hasStop}) \rightarrow (\mathcal{X}(\text{hasStop} \mathcal{U} (\text{isStopped} \mid \mathcal{G}(\text{hasStop}))))))$

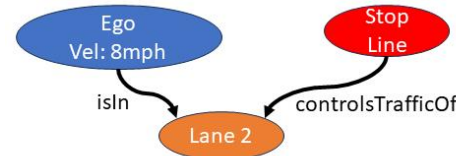
Atomic Propositions:

$\text{hasStop}: \mid \text{relSet}(\text{Ego}, \text{isIn}) \cap \text{relSet}(\text{stopLine}, \text{controlsTrafficOf}) \mid > 0$

$\text{isStopped}: \mid \text{filterByAttr}(\text{Ego}, \text{speed}, \lambda x: x < \epsilon) \mid = 1$



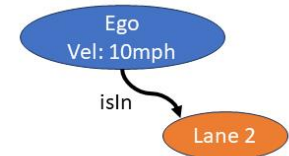
Time: 22s



Atomic Propositions
hasStop, ¬isStopped

State
S3

Time: 23s

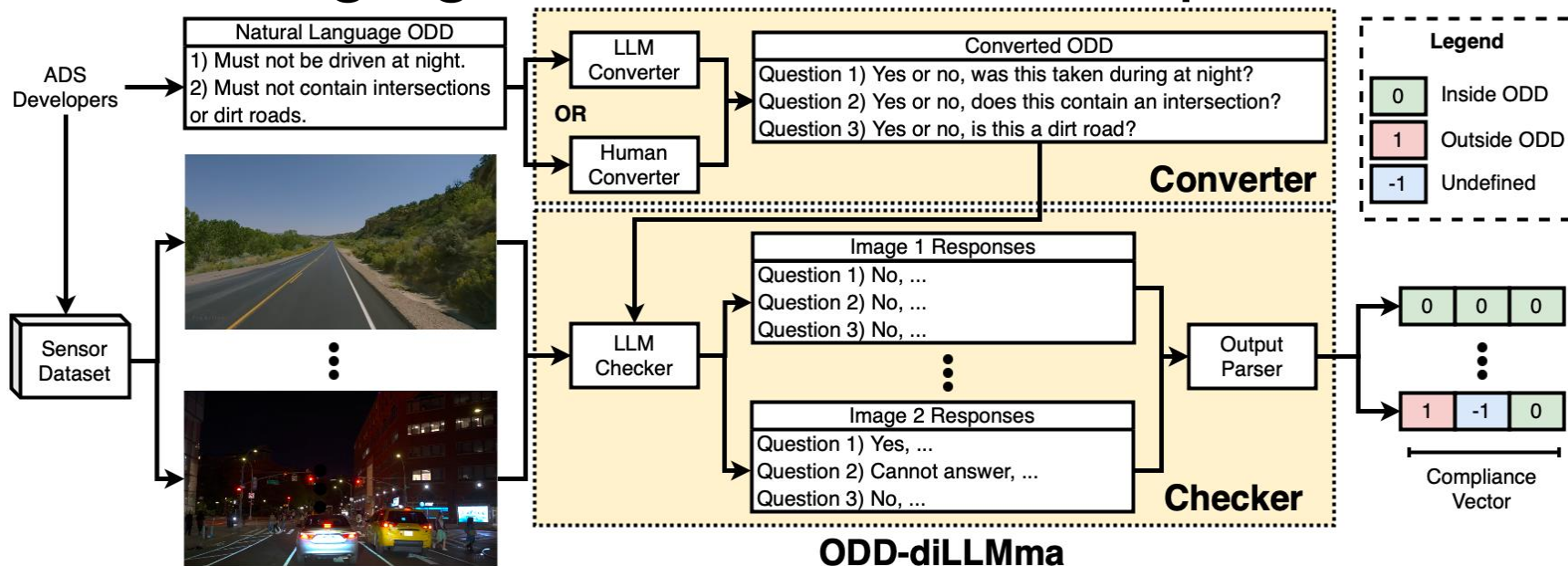


Atomic Propositions
¬hasStop, ¬isStopped

State
S4

My Research

- Leveraging LLMs for difficult requirements



My Research

- Automated testing approaches for robots

