CSCI 420-04 Robotics

Trey Woodlief

Fall 2025

WILLIAM & MARY

CHARTERED 1693


DRAGON X DRONES

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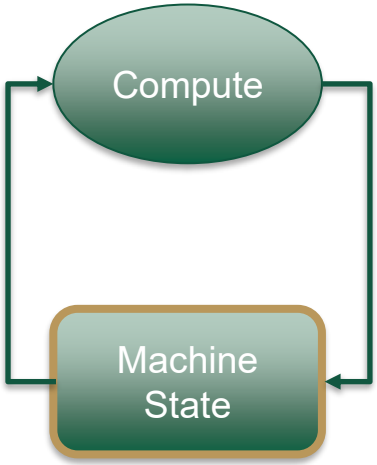
Who is this class for?

- 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
- Poll: comfortable with multi-threaded/asynchronous code

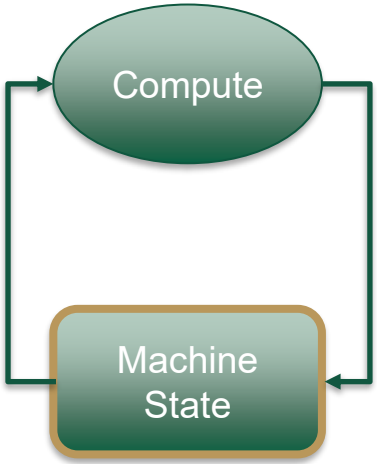
Why robots?

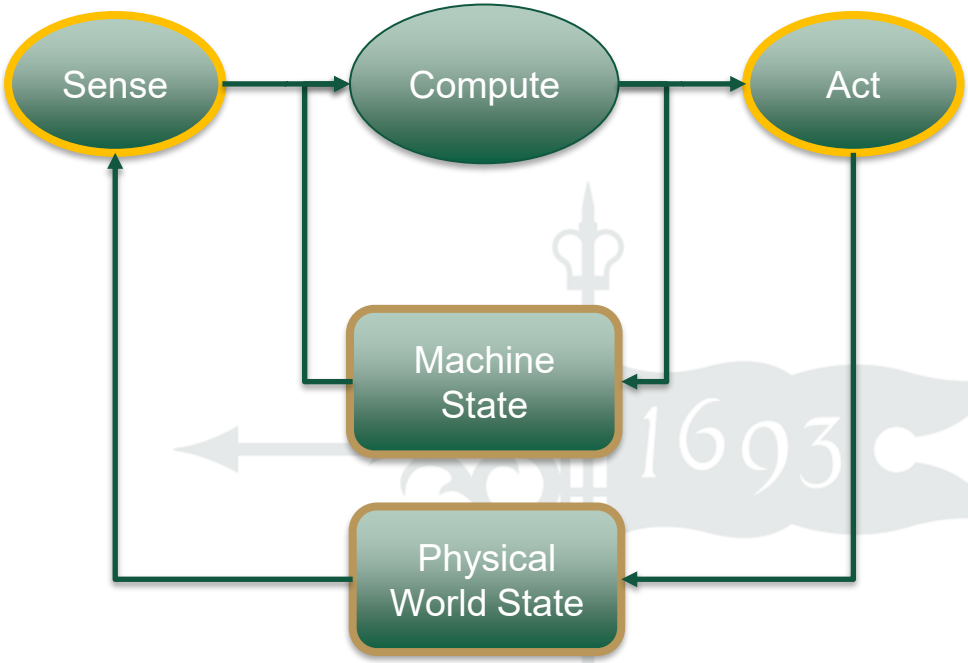
- How do we build systems that can operate safely in the physical world?

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

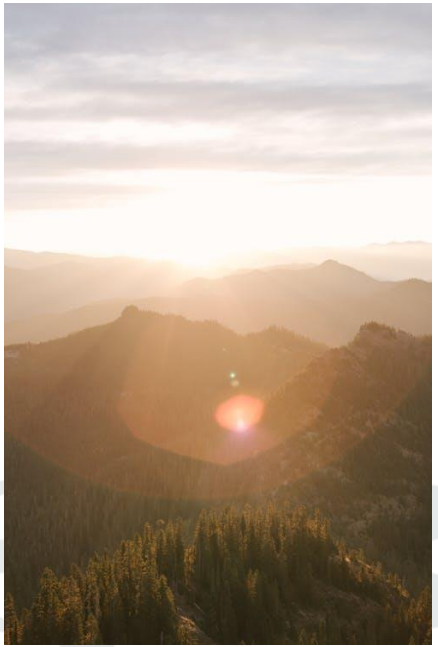
- What was challenging?

Operating in the Physical World

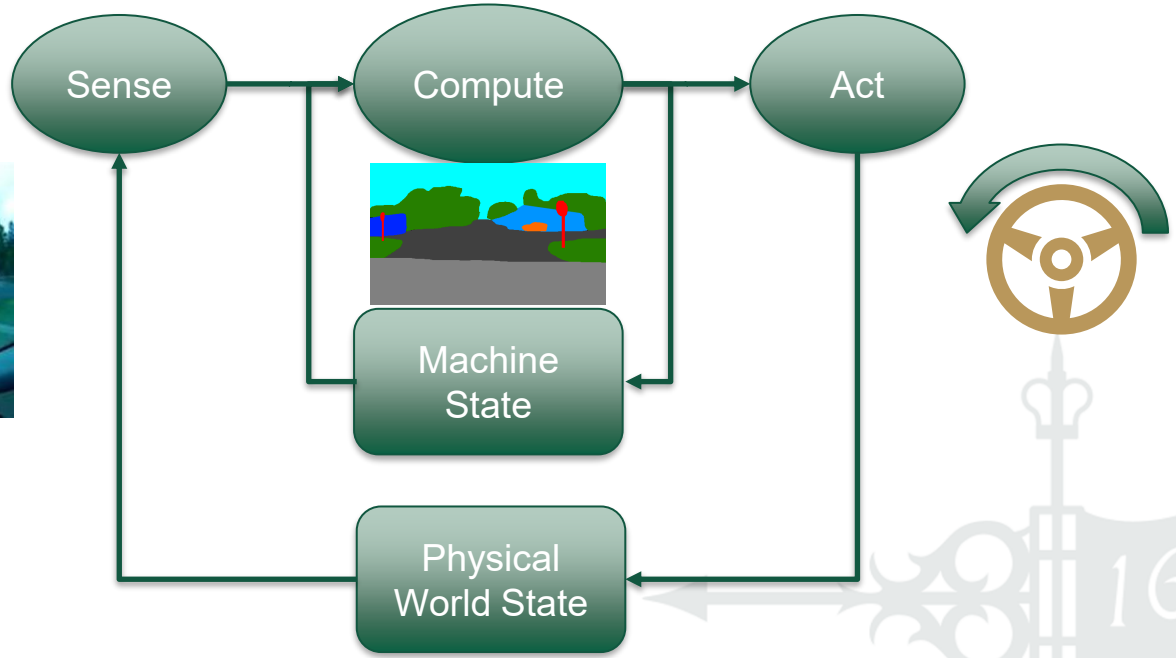
- What was challenging?
  - Imprecise sensing
  - Uncertain control
  - Frame of reference
  - Incomplete model of the world
  - Misunderstandings/miscommunications

Operating in the World is Hard!

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

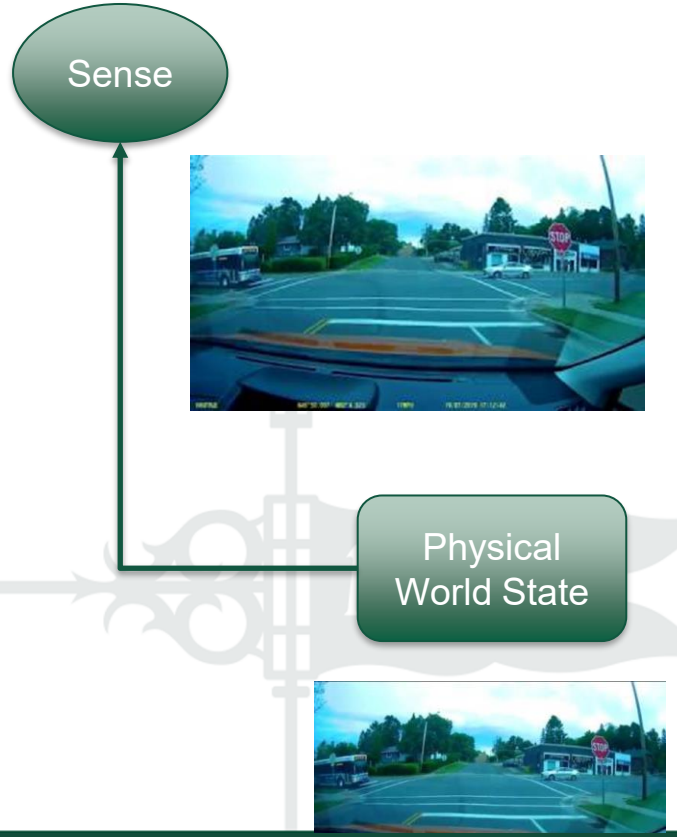


Putting it all Together



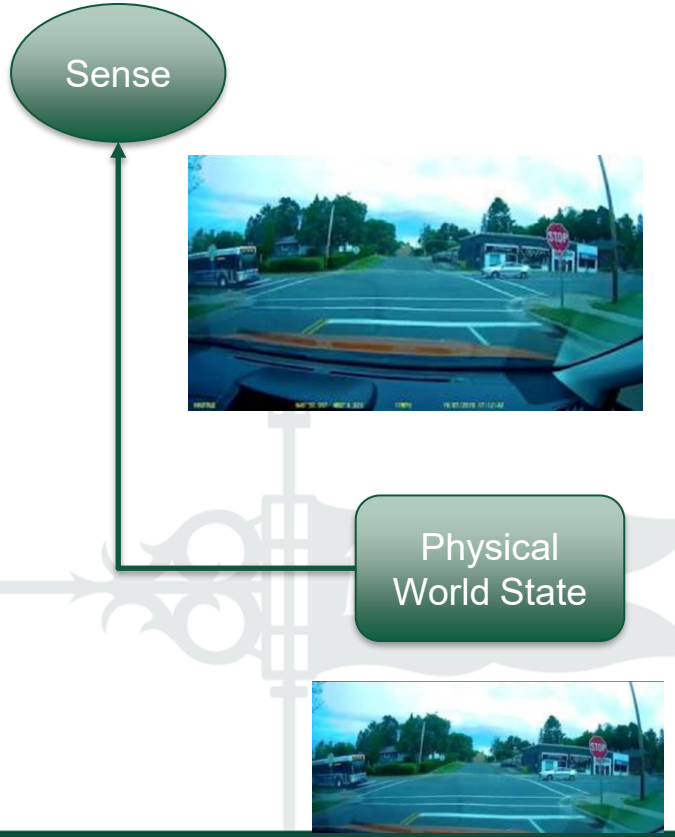
Sensing

- World partially observable



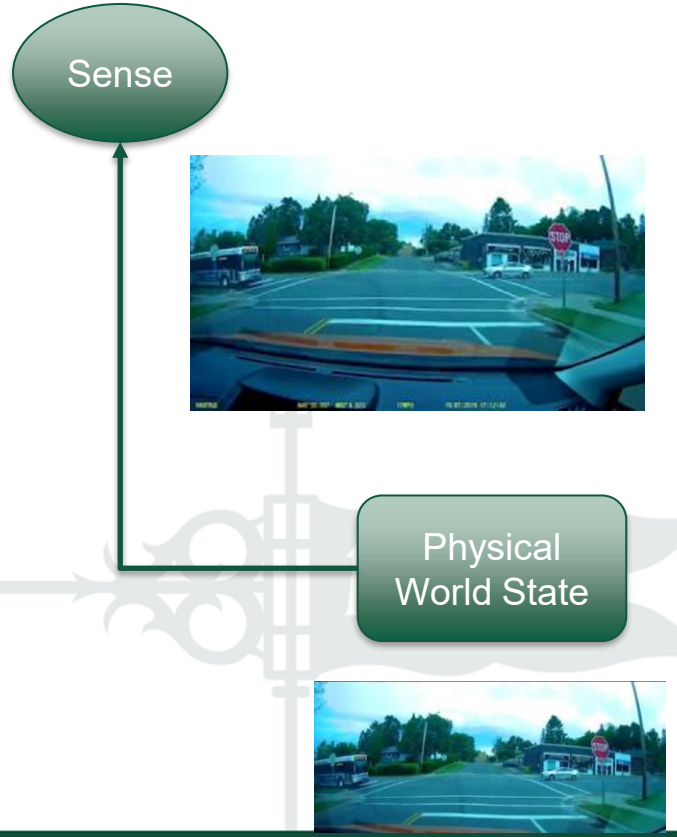
Sensing

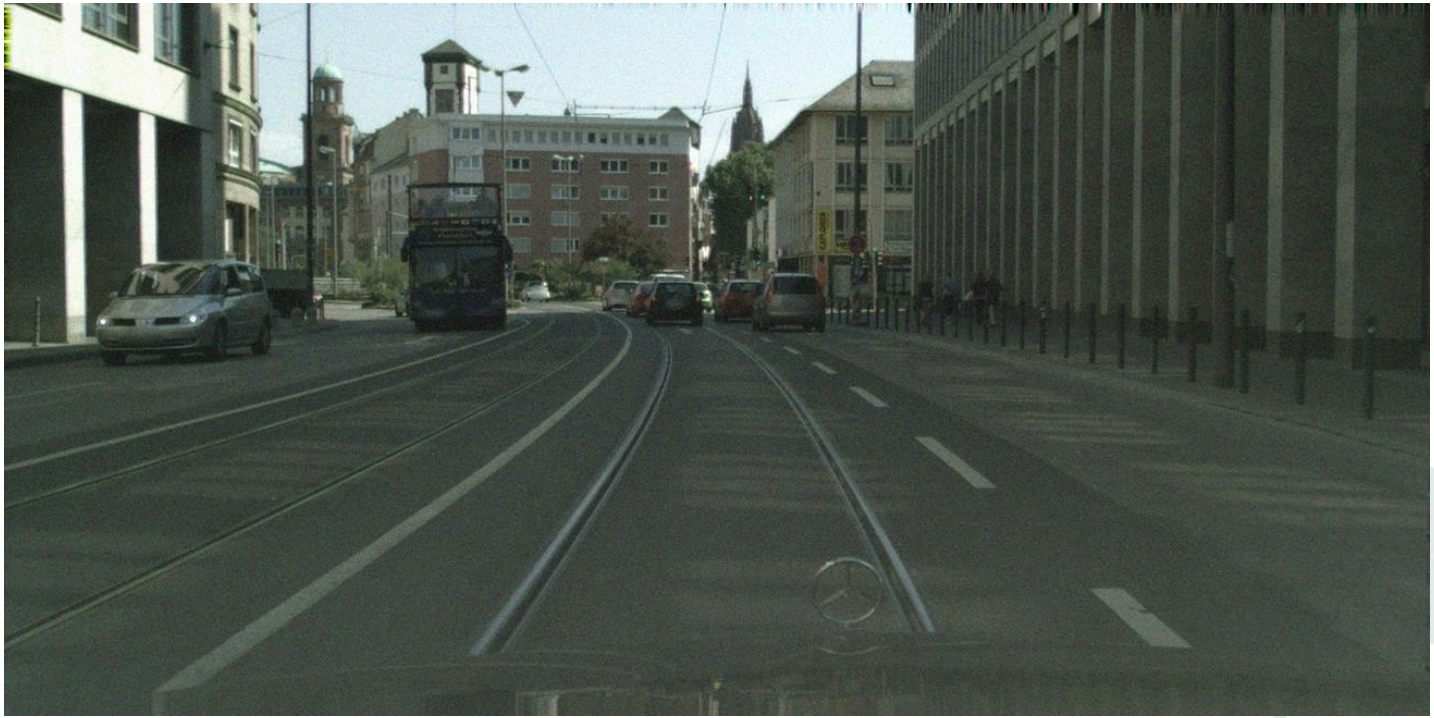
- World partially observable
  - You only "see" what the sensor "sees"
  - What's happening behind?

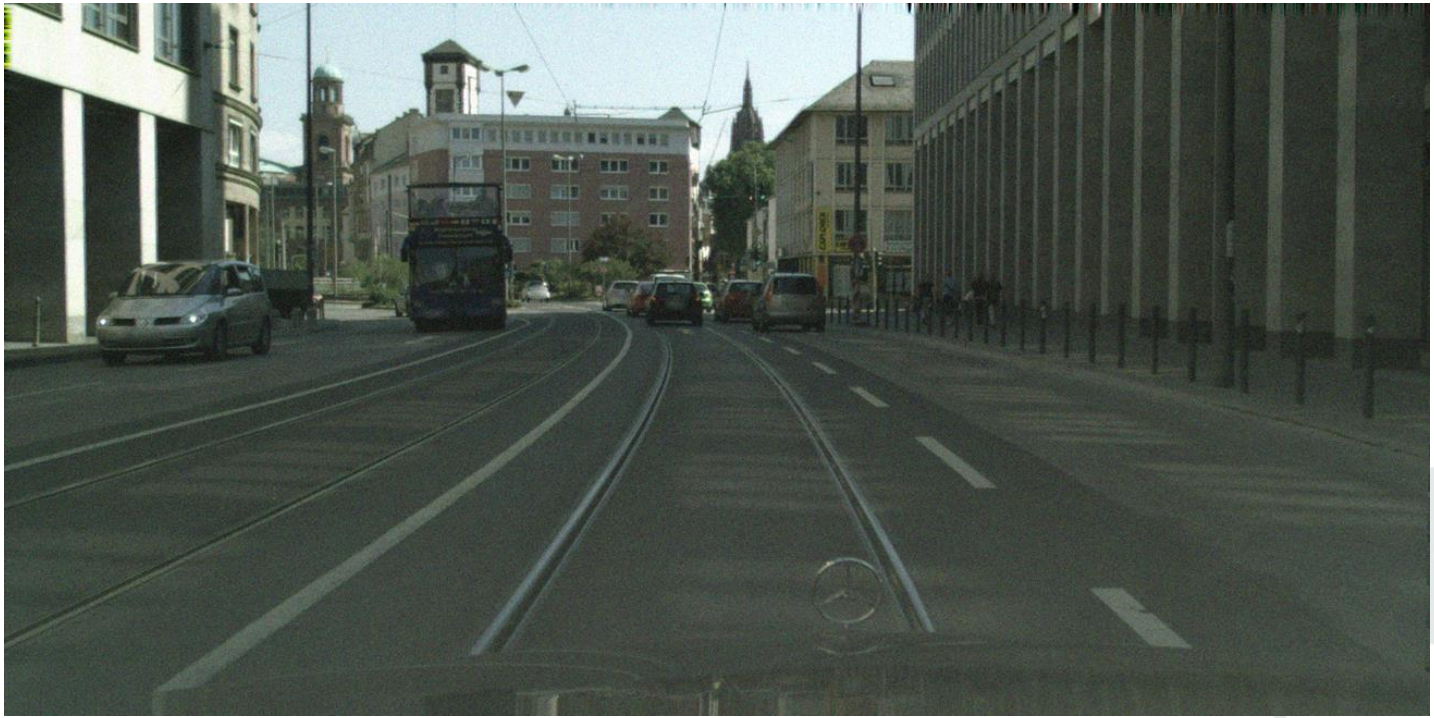


Sensing

- World partially observable
- Sensors are noisy

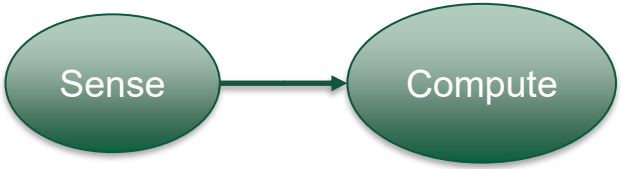






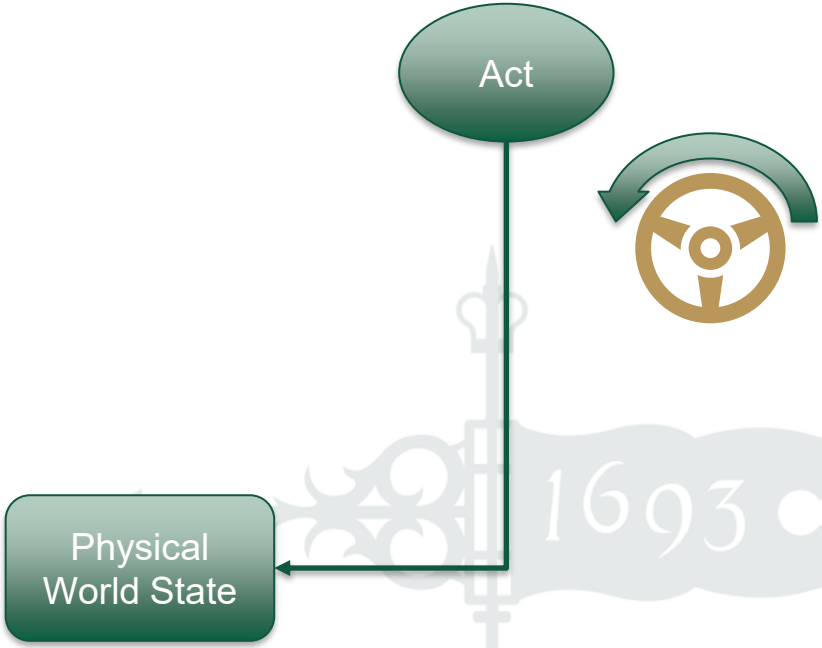
Sensing to Compute

- Inferring world state is approximation/abstraction



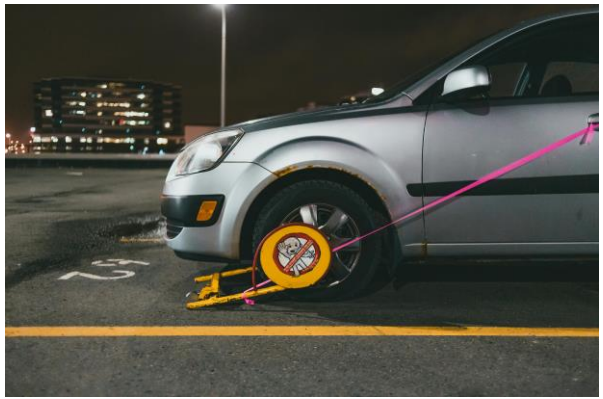
Actuation

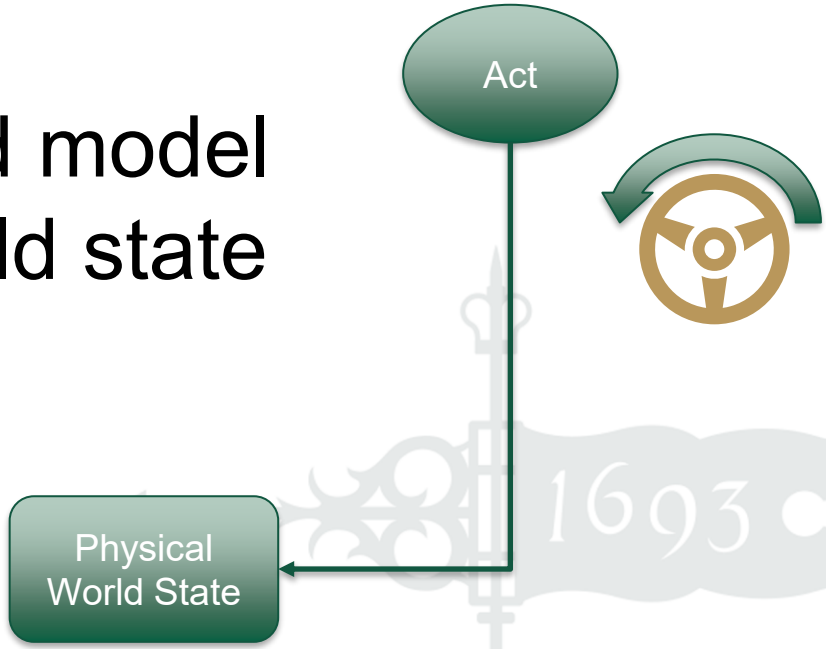
- Actuation is noisy



Actuation

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





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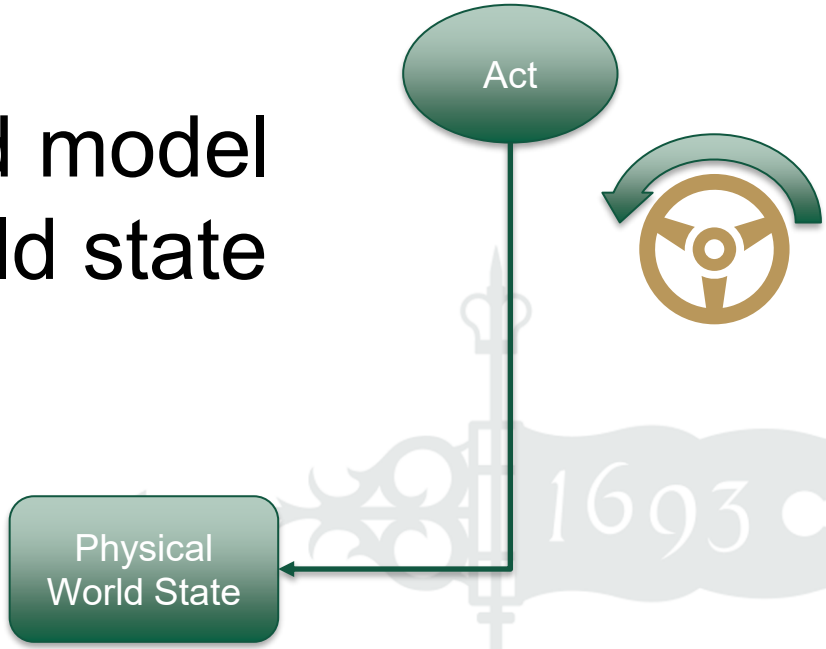
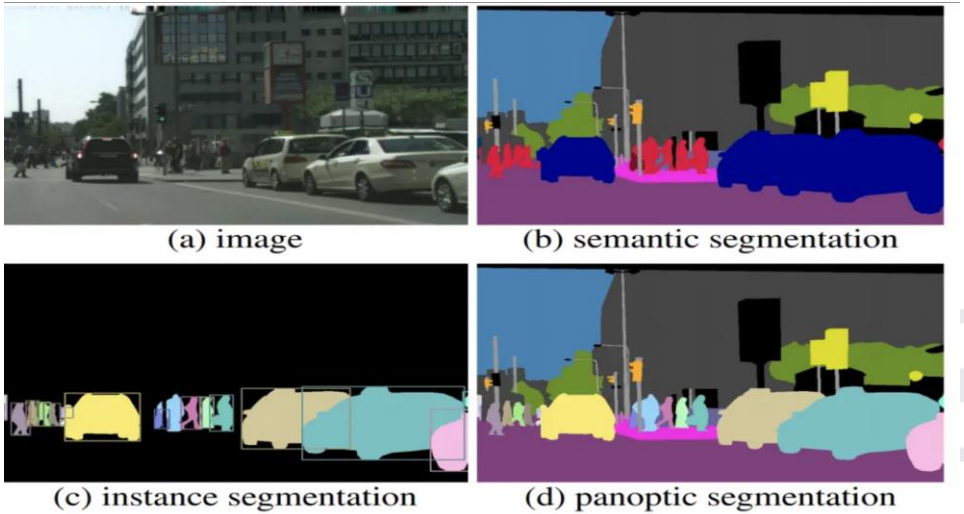


How do we overcome?

- 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



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 123

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

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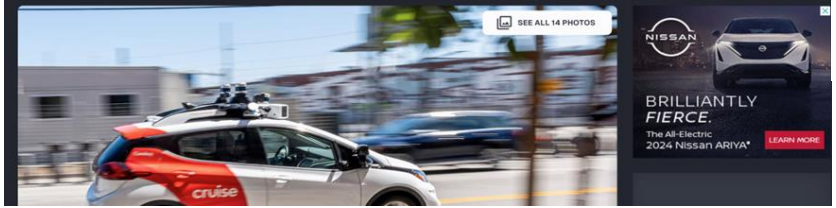
AARIAN MARSHALL TRANSPORTATION MAR 21, 2018 8:32 PM

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



Forbes

FORBES > INNOVATION > TRANSPORTATION

EDITORS' PICK

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

Brad Templeton Senior Contributor
I cover robocar 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 TSLA -0.2% 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:
  - Testing & maintenance

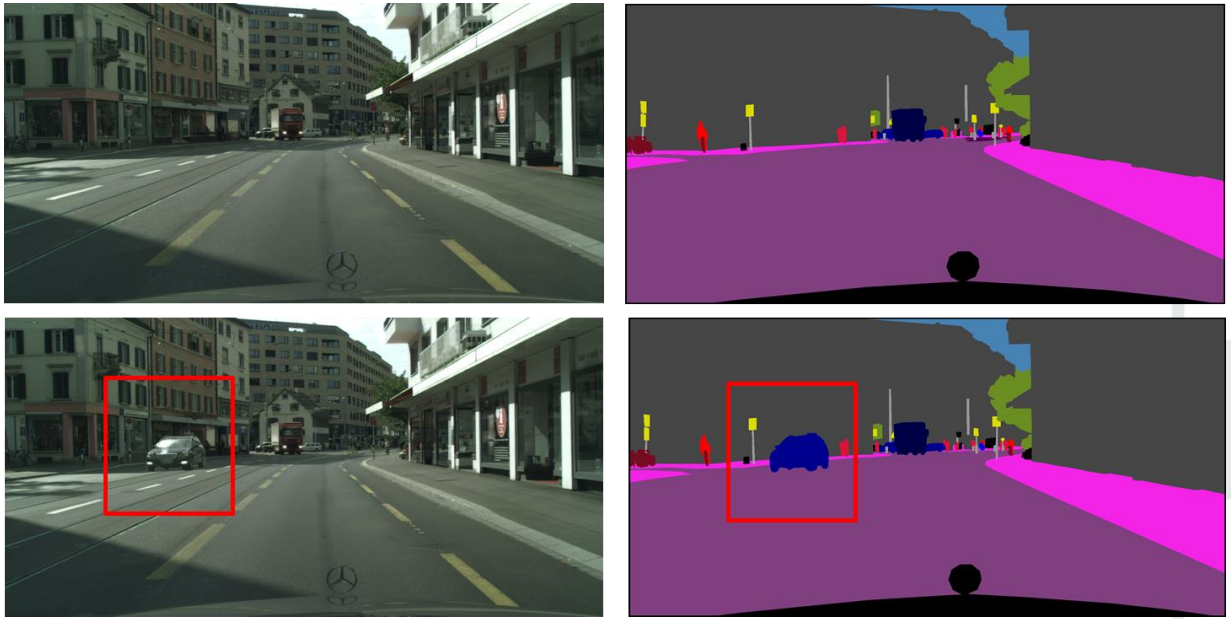
This course will equip you to bring this expertise to the robotics domain.

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



My Research

- Runtime monitoring for AVs

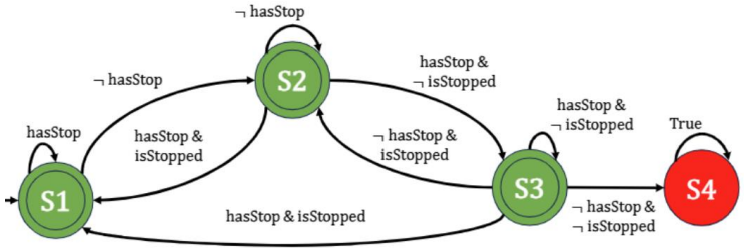
LTL$_f$ Formula for ψ_9:

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

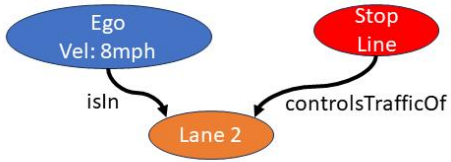
Atomic Propositions:

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

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

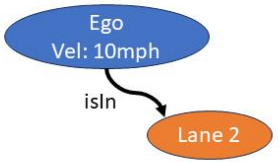


Time: 22s



Atomic Propositions	State
hasStop, ¬isStopped	S3

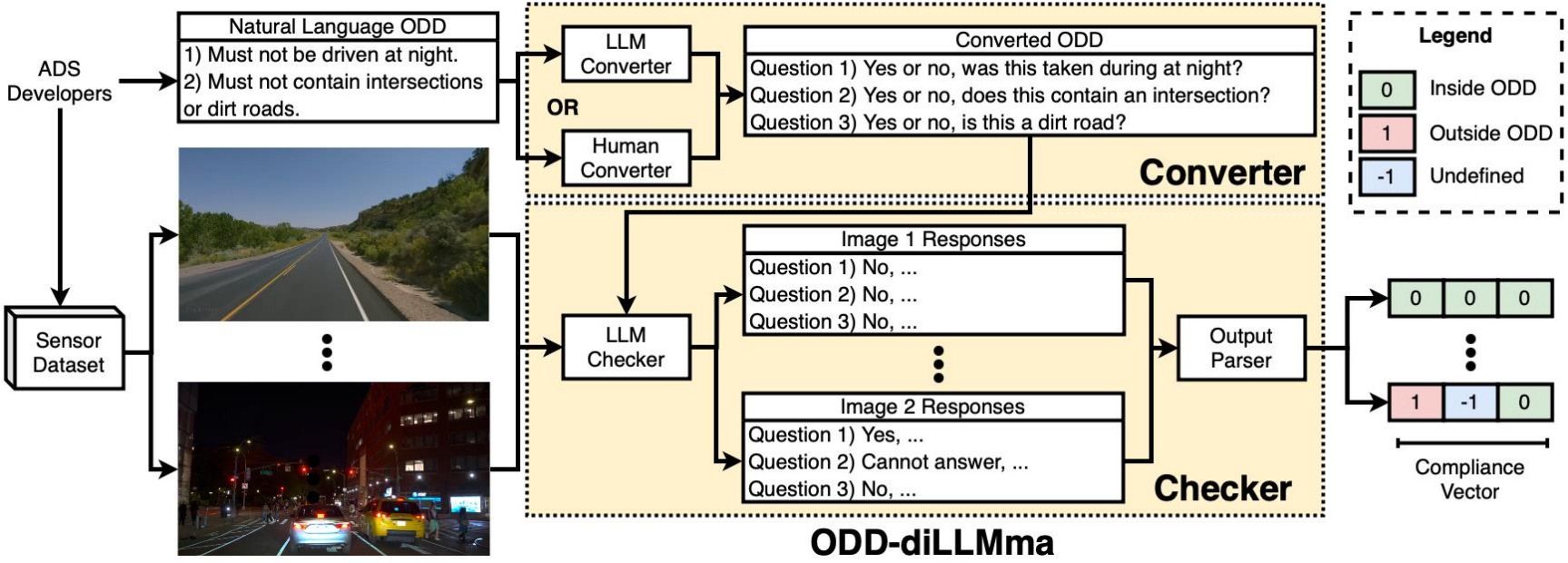
Time: 23s



Atomic Propositions	State
¬hasStop, ¬isStopped	S4

My Research

- Leveraging LLMs for difficult requirements



My Research

- Automated testing approaches for robots

Syllabus & Course Materials

https://treywoodlief.com/CSCI_420_Robotics_Fall_2025/