# Principles of Safe Autonomy ECE 484 Fall 2023 Lecture 1

Professors: Sayan Mitra

August 22, 2023

https://publish.illinois.edu/safe-autonomy/

https://mitras.ece.illinois.edu/

mitras@Illinois.edu

@Mitrasayn

# Welcome from Safe Autonomy team!

Sayan Mitra (mitras)

Ujjal Bhowmik (ubhowmik)

Yan Miao (yanmiao2)

Li, Hongyi (hli106)

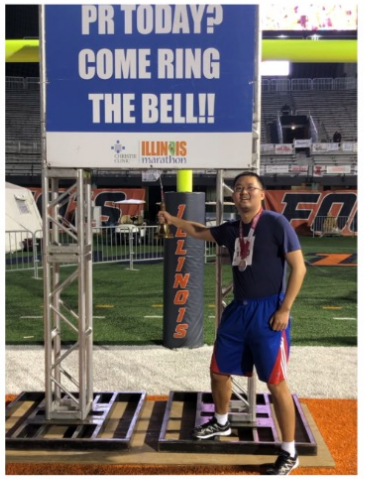
John Pohovey (jpohov2)

Ye-Ji Mun (yejimun2)

Sayan Mitra (mitras)

Ujjal Bhowmik (ubhowmik)


Yan Miao (yanmiao2)




Hongyi Li(hli106)

John Pohovey (jpohov2)

Ye-Ji Mun (yejimun2)

# Plan for today

- What is this course about?
- How will this course work?
- What is the safety verification problem?

# Autonomy *could* improve society provided safety risks are mitigated

Driverless cars will improve productivity

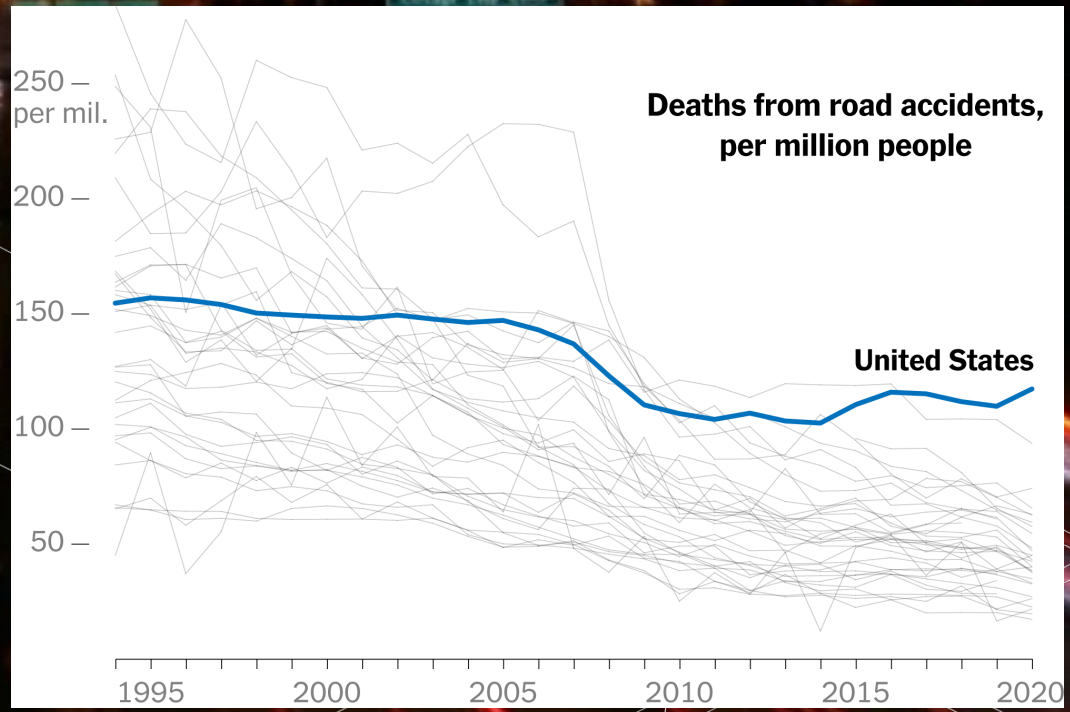
- Americans drives 13,474 miles (300 hrs) per year

Cities will be greener

- 40% of city surface is parking

Will autonomous cars be safer?

- Still 32K+ fatalities and 3M+ injuries every year in the USA



# 100 years of *progress* in *safer roads*

Traffic infrastructure (e.g., lane markings, traffic signals,…)
Police enforcement and traffic regulations
Driver training
Passenger safety (e.g., seatbelts, airbags)
1990's: Improved vehicle design (e.g., crumple zones)
Rear-view and blind spot sensors (e.g., camera)
Advanced Driver Assistance Systems (e.g., ABS, ACC, etc.)
2000's pedestrian and cyclist safety (lower speed limits)

# PREDICTIONS SCORECARD, 2022 JANUARY 01 by Rodney Brooks

http://rodneybrooks.com/predictions-scorecard-2022-january-01/

The years in blue indicate when the industry leaders thought these predictions would come to pass. I have highlighted all the dates up through 2021, now numbering 17 of the 23 predictions. Not one of them has happened or is even close to happening.

FORECASTS: http://www.driverless-future.com/?page_id=384 March 27, 2017

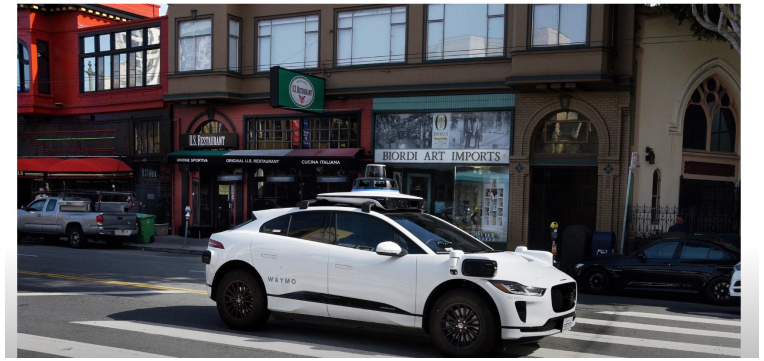
NVIDIA to introduce level-4 enabling system by **2018** *(2017)*
NuTonomy to provide self-driving taxi services in Singapore by **2018**, expand to 10 cities around world by **2020** *(2016)*
Delphi and MobilEye to provide off-the-shelf self-driving system by **2019** *(2016)*
Ford CEO announces fully autonomous vehicles for mobility services by **2021** *(2016)* ←
Volkswagen expects first self driving cars on the market by **2019** *(2016)*
GM: Autonomous cars could be deployed by **2020** or sooner *(2016)* ←
BMW to launch autonomous iNext in **2021** *(2016)* ←
Ford's head of product development: autonomous vehicle on the market by **2020** *(2016)* ←
Baidu's Chief Scientist expects large number of self-driving cars on the road by **2019** *(2016)*
First autonomous Toyota to be available in **2020** *(2015)* ←
Elon Musk now expects first fully autonomous Tesla by **2018**, approved by **2021** *(2015)*
US Sec Trans: Driverless cars will be in use all over the world by **2025** *(2015)*
Uber fleet to be driverless by **2030** *(2015)* ←
Ford CEO expects fully autonomous cars by **2020** *(2015)* ←
Next generation Audi A8 capable of fully autonomous driving in **2017** *(2014)*
Jaguar and Land-Rover to provide fully autonomous cars by **2024** says Director of Research and Technology *(2014)*
Fully autonomous vehicles could be ready by **2025**, predicts Daimler chairman *(2014)* ←
Nissan to provide fully autonomous vehicles by **2020** *(2013)* ←
Truly autonomous cars to populate roads by **2028-2032** estimates insurance think tank executive *(2013)*
Continental to make fully autonomous driving a reality by **2025** *(2012)*

Hubris on a mass delusion scale. Audi fully autonomous by 2017? That is Teslan in its delusion level.

# When will we have autonomous cars?

**Robotaxis Can Now Work the Streets of San Francisco 24/7**

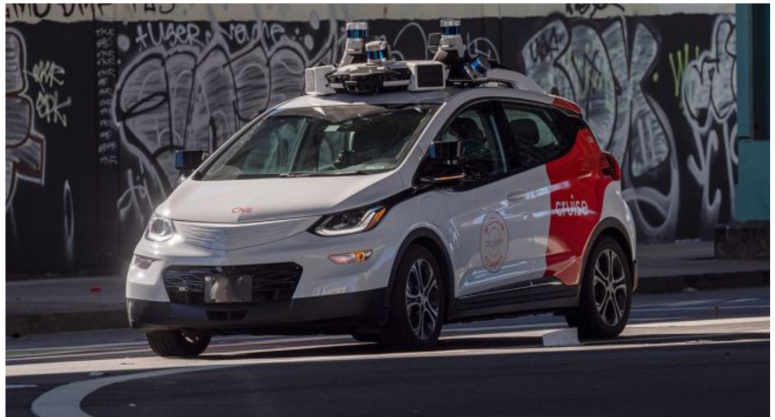
Robotaxis can offer paid rides in San Francisco around the clock after Alphabet's Waymo and GM's Cruise got approval from the California Public Utilities Commission.





**San Francisco Wants Halt to Cruise, Waymo Expansion Ruling**

City Says Expanded Service for Robotaxis Can Cause 'Serious Harm'



Aug. 19, 2023, at 12:32 p.m. General Motors' Cruise autonomous vehicle unit has agreed to cut its fleet of San Francisco robotaxis in half as authorities investigate two recent crashes in the city.

Some of you will be part of the solution for this problem!

# Flying Cars: Urban air-mobility


## Jaunt Journey Roadmap


*Jaunt Tech Demonstrator (JTD) 2020 (Q4)*

*Jaunt Journey 2023 (Q1)*

O'HARE

### Air Taxi To O'Hare Will Allow Chicago Travelers To Skip Traffic On The Kennedy

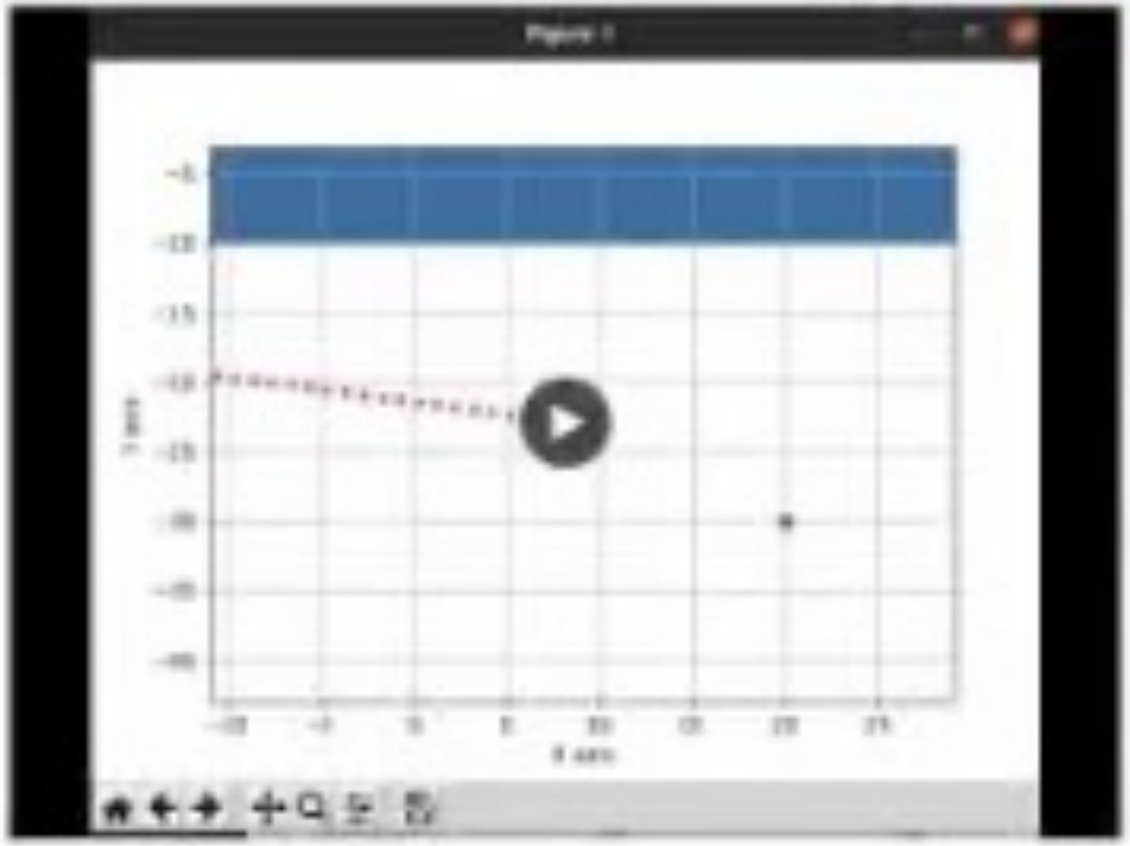
The city's first air taxi plans to launch in 2025. Company officials say the cost will be competitive with a rideshare between Downtown and the airport.

Ariel Parrella-Aureli 7:22 AM CDT on Mar 27, 2023


Credit: Archer Aviation

Some of you will be part of the solution for this problem!

# Videos



Straight Parking without obstacles

# Congratulations to GRAIC 2.0 Head-to-Head Winners!

# Motivating problem

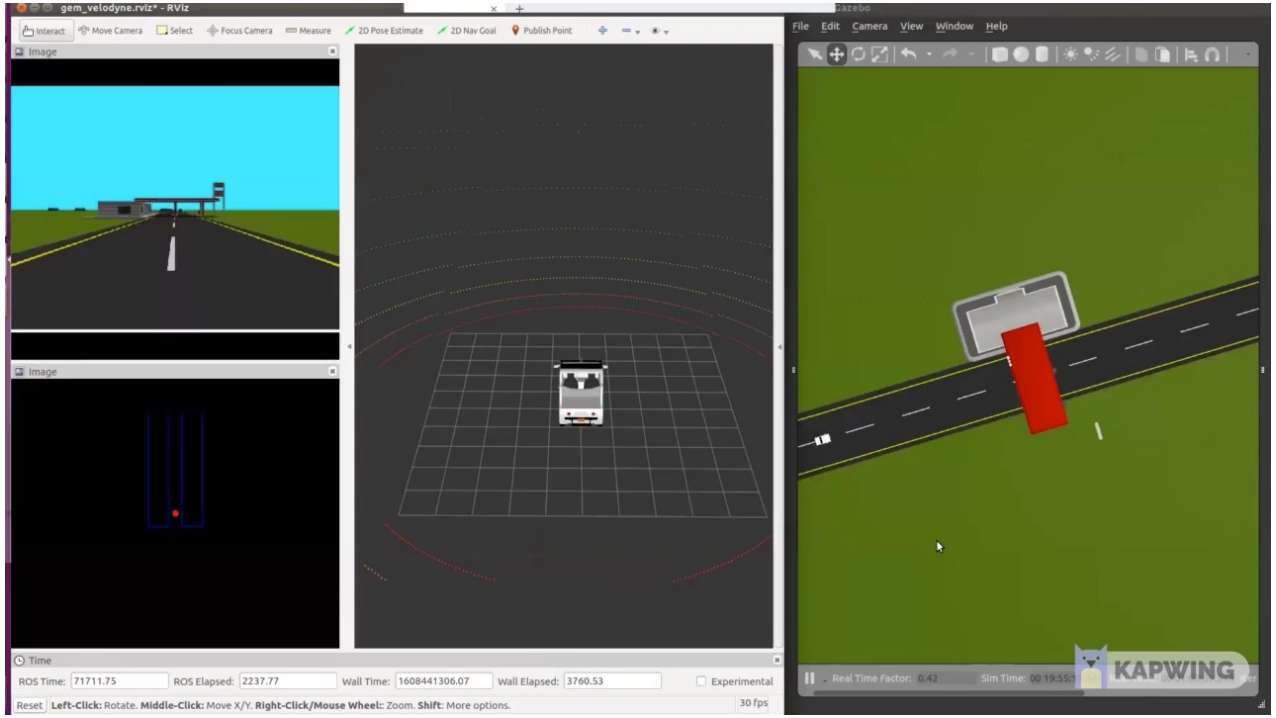
Simulated car on track with Lidar

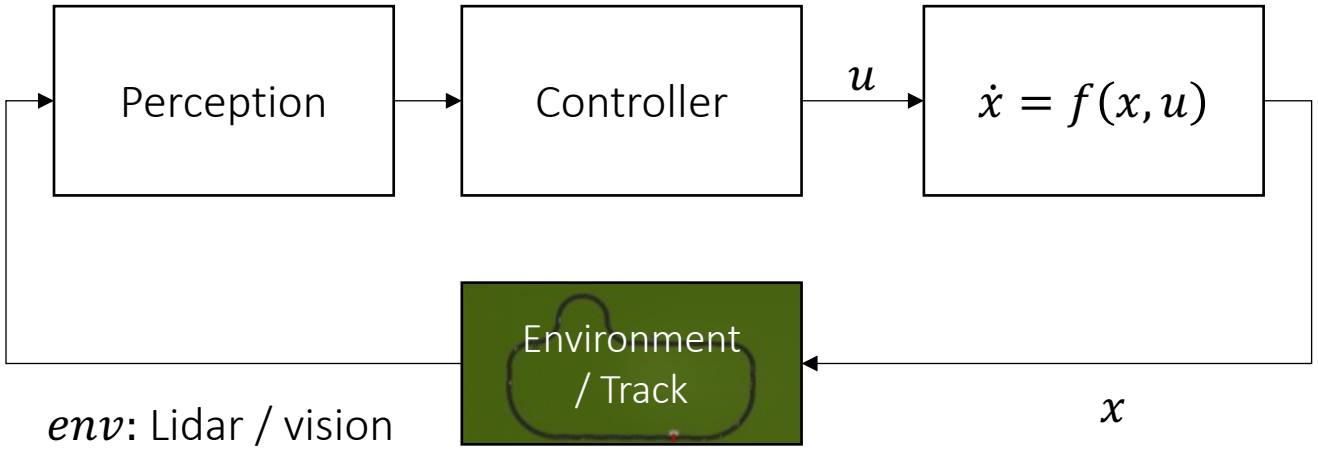
**Problem:** For a given track **check** that the car does not collide and stays in lane

Different speeds, types of obstacles, complexity decision logic and dynamics

Can we check *efficiently*?
Can we *generalize* to *similar* tracks?

What assumptions about perception, physics, computation needed for safety?



“Testing can be used to show the presence of bugs, but never to show their absence!’’ --- Edsger W. Dijkstra

# Naively collecting test driving miles is also not going to work

Probability of a fatal accident per one hour of human driving: $10^{-6}$

Assume* that for AV this has to be $10^{-9}$

Data required to guarantee a probability of $10^{-9}$ fatality per hour of driving is inversely proportional: $10^{9}$ hours, 30 billion miles

Multi-agent, open system, with human interactions => cannot be simulated offline to generate data

Any change is software means tests have to be rerun

To extrapolate from a finite sampling of executions, we need to make some *assumptions*.

A collection of assumptions defines a ***model***

We need models and data to make claims about system safety and correctness

In ECE484 you will learn about concepts and algorithms **and** the assumptions under which they are correct

*On a Formal Model of Safe and Scalable Self-driving Cars* by *Shai Shalev-Shwartz, Shaked Shammah, Amnon Shashua, 2017 (Responsibility Sensitive Safety)*

# Plan for today

- What is this course about?
- How will this course work?
- What is the safety verification problem?

# Course goals

## Know

Components of an autonomous system , safety standards, …

How to use software modules for perception, planning, control, ROS, Yolo, OpenCV, Z3, …

## Do

Code and analyze algorithms for perception clustering, convolution, filtering, edge detection, filtering, localization, planning, formal verification

Plan, propose, organize and execute a team project

## Understand

Models, algorithms, data, biases, assumptions for building trustworthy autonomous systems

Theoretical properties of algorithms and their limitations

## Get inspired

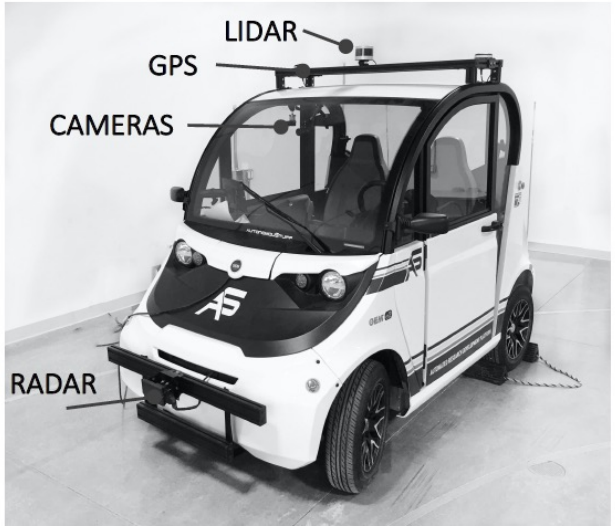
Become the Isaac Newton of Autonomy

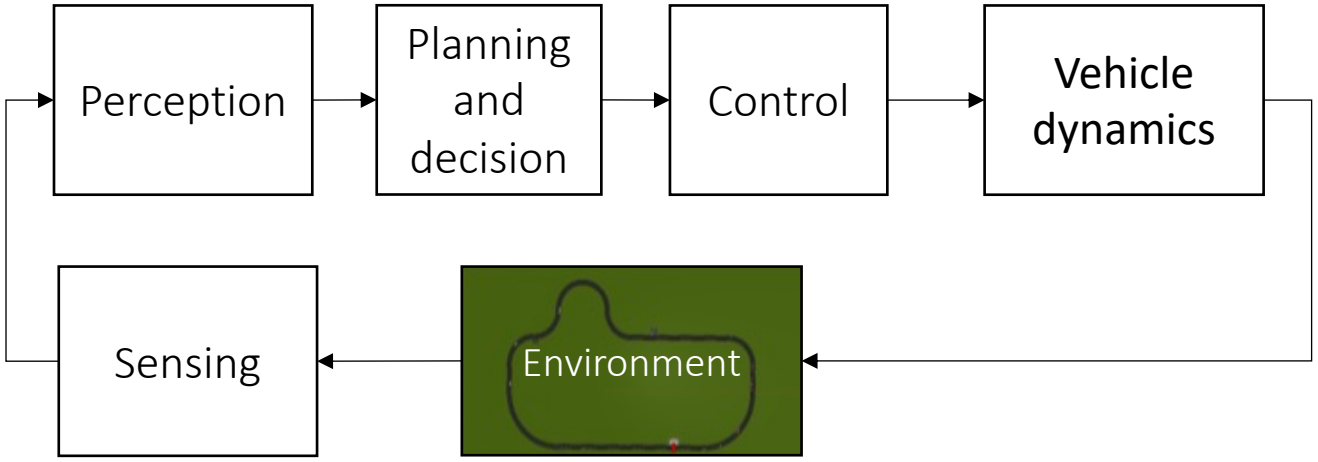
“To do things right, first you need love, then technique.” – Antoni Gaudí

# Why are we here? Course goals

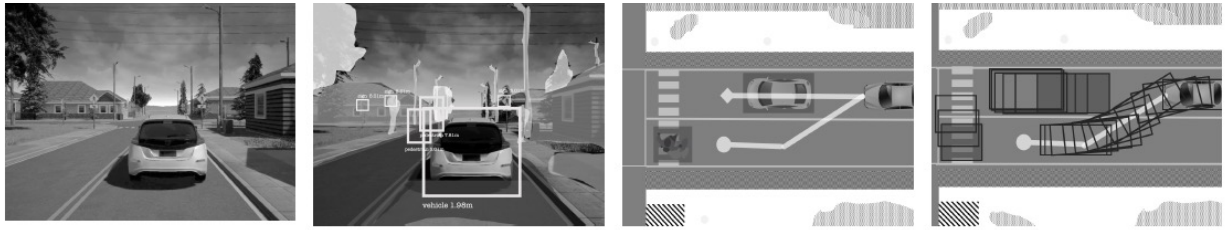
| | | |
|---|---|---|
| Know |  | Lectures, MPs, Homework |
| Do |  | MPs, Homework, Project, Participate |
| Understand |  | Lectures, MP, Homework, Exams |
| Get inspired |  | Project |

# Autonomous GEM vehicle: An example CPS



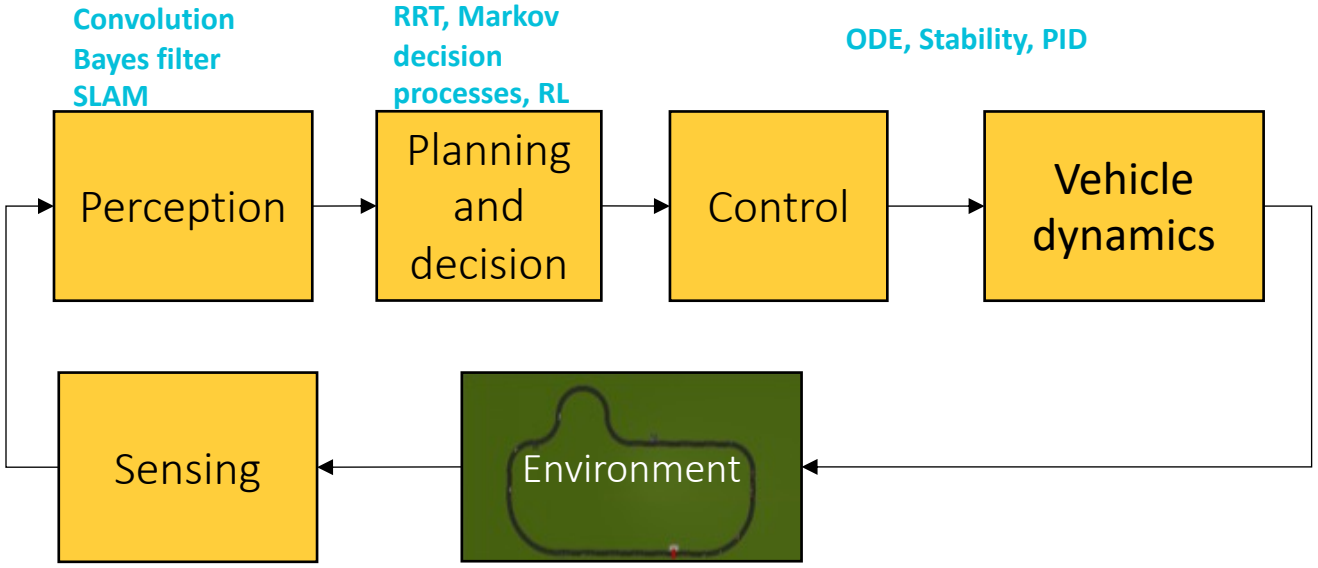

$env$: Lidar / vision



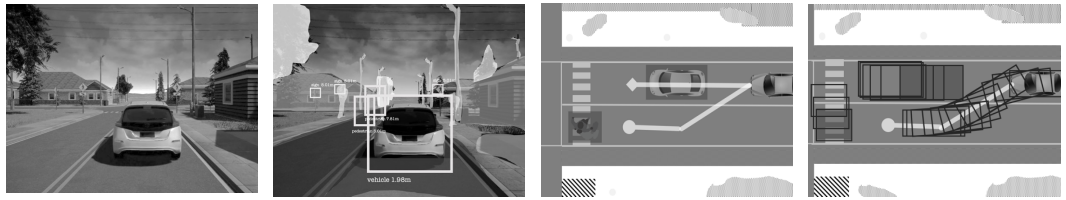
| Sensing | Perception | Decisions and planning | Control |
|---|---|---|---|
| Physics-based models of cameras, LIDAR, radar, GPS, and so on. | Programs for object tracking, scene understanding, and so on. | Programs and multi-agent models of pedestrians, cars, and so on. | Dynamical models of vehicle engine, powertrain, steering, tires, and so on. |

# Course structure


Safety, end-to-end testing, simulation, system integration
MP0, MP5, Project
State machines, model checking, hypothesis testing, ROS




$env$: Lidar / vision



| Sensing | Perception | Decisions and planning | Control |
|---|---|---|---|
| MP3 **Project** | MP1 MP3 **Project** | MP4 **Project** | MP2 **Project** |

# About ECE484

Start here: https://publish.illinois.edu/safe-autonomy/

- Schedule, lab, resources, papers, homework, MP, code, project, gitlab links

Campuswire for announcements, but no SLA, best effort response delay ~2 days.

- Discussions, forming teams, occasional polls, feedback

Canvass for MP release and grades

# Schedule: https://publish.illinois.edu/safe-autonomy/schedule-spring-2022/

- Simple safety (MP0, 2 weeks)
- Perception (MP1 lane detection, 2 weeks)
- Modeling and control (MP2 vehicle control, 2 weeks)
- Oct 3: Midterm 1
- Filtering: localization particle filtering (MP3 localization, 2 weeks)
- Planning (MP4 planning ??, 2 weeks)
- Nov 14: Midterm 2
- Fall Break Nov 21 - 24
- Guest lecture; wrap up

- Group formation
- Lab safety training
- Labs, MPs
- Project pitch

- Fall Break
- Intermediate checking??
- Practice presentation
- Final presentation
- Video

# Course materials

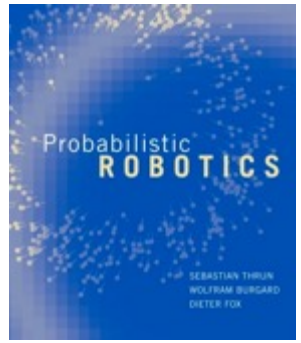
Lecture notes, slides, code, video lectures, lab manuals created and curated from recent research publications

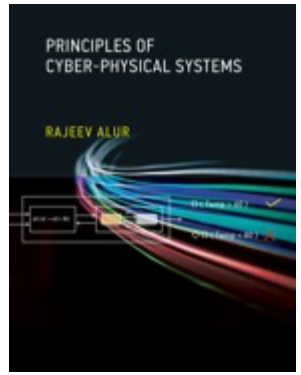
Course reader: Available from webpage

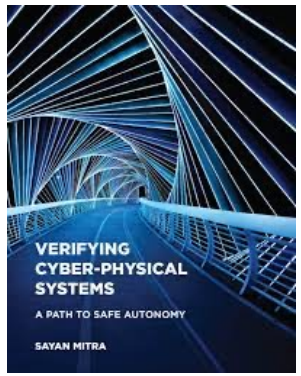
References:

- *Probabilistic robotics, By Sebastian Thrun, Wolfram Burgard and Dieter Fox, 2005*
- *Principles of Cyber-Physical Systems, Rajeev Alur, MIT Press, 2015*
- *Verifying Cyber-physical Systems, Sayan Mitra, MIT Press 2021**

  *(if you are interested in safety verification)*



# Course: components and (tentative) weights

- 3-4 programming assignments or MPs 45% (group)
  - ROS + Python, Ubuntu, VM BYOD or use lab workstations
  - labs (Friday 9am-8 pm starting this Friday)
  - Office hours
- Homework assignments 10% (individual)
  - math, analysis, critical reasoning; preparation for midterms
- Midterms x2  20% (individual)
- Mini project 25% (group): more on this later, 3 tracks:
  - A. Dev and test concepts on GEM
  - B. GRAIC autonomous racing competition / testing
  - C. F1tenth small racing car

| Tentative grade boundaries | |
|---|---|
| A | >90 |
| B | >80 |
| C | >65 |
| D | >55 |

# Homework, participation, & exam: Individual work 35%

- Testing principles, concepts
- Read course notes and slides routinely; exercises are provided
- Homework sets (synchronized with MPs)
- 2 in-class midterms **Oct 3, Nov 14**
- No final exam

# Teamwork: MP, labs, and mini project

- In groups: Form your group of 3 now! Make your group (form), make new friends
  - If you do not have a group by **Sunday (12 midnight AoE)** we will assign you a group
- Each MP will build a significant component of an autonomous system over **2 weeks**
- Use your computer with Ubuntu 20.04 or lab computers (except T2-4:30 W9-11,2-4pm)
- TAs and LAs will run live labs in ECEB 5072
- MP walkthough, setup, bridge the lecture and the assignments
- MP0+HW0 will be release this Friday (8/25), labs starts this Friday
  - Your entire group has to attend 1 lab for the MP walkthrough
  - And 1 lab after the MP is due (to demo your work).

# Mini projects: explore, inspire, and impress

- GEM Track. Build on existing SW, e.g., parallel parking, lane following, and pedestrian avoidance
- GRAIC Track. Participate in an open simulation-based autonomous racing competition
- Outcomes: Write research papers, jumpstart grad research, career in autonomy, incubate startup ideas, sharpen presentation skills
- We provide: Polaris GEM vehicle (camera, LIDAR, RADAR, IMU, GPS, and drive-by-wire system) modules for pedestrian detection, lane tracking, and vehicle control, a vehicle simulator, and testing facility (highbay) with indoor positioning system. GRAIC autonomy software stack
- Expertise (TA, lab and office hours, TBD)
- Timeline: Get started, be a member of IRL from this link
  - High-bay virtual site visit and training (in next 2 weeks)
  - Project pitch
  - Public presentation, demo, awards (End of Semester)

Spring 2022 projects
Spring 2020 projects
Fall 2020 projects