ECE 484: Principles of Safe Autonomy
Fall 2025 Lecture 1: Course Overview

Professor: Huan Zhang

Aug 26, 2025

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

https://huan-zhang.com

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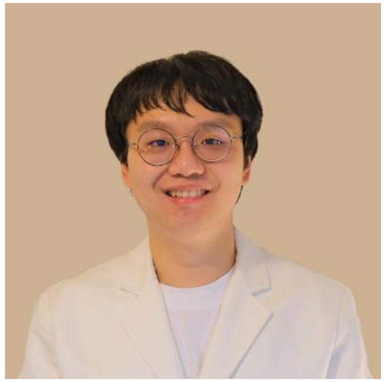
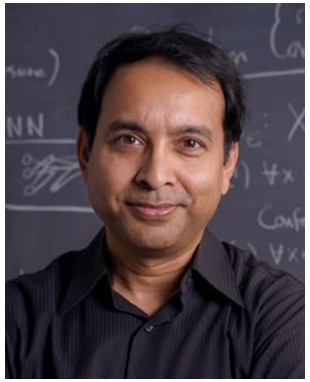
Welcome from Safe Autonomy Fall 2025 team!



Prof. Huan Zhang (huanz)



Prof. Sayan Mitra (mitras)
(Chicago section)

Grad TAs

Hanna Chen (hannac4)

Will Chen (hongyuc5)

Han Wang (hanw14)

James Menezes
(jamesdm4)

Xiangru Zhong (xiangru4)

Fatemeh Cheraghi
(fatemeh5)

Undergrad CAs

Hyoungju
Lim (hl89)

Tanvi
Kulkarni

Shreya Patil
)

Yanhao
Yang
(yanhaoy2)

Bach
Hoang
(bachh2)

Plan for today

- What is this course about?
- How will this course work?
- What is safety and how to check it?

Principles of Safe Autonomy

Significant accomplishments in autonomy

- NASA’s Perseverance rover performed autonomous science operations on Mars; the Ingenuity helicopter performed the first powered, controlled flights on another planet (2021-22).
- Waymo now has 22% market share of taxi journeys in San Francisco, and now exceeds human-driver taxi company Lyft.
- Zipline, Wing, Amazon Prime Air have launched commercial deliveries. Air taxis are on the horizon.


How Microbes Become Frenemies | A Twist on Quantum Holograms

ScienceNews

Messages from Mars

The Perseverance rover reveals a rocky surprise


Doing Business

Rwanda to the world: Now Zipline enters Japan market


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

Autonomy *could* improve society provided safety risks are mitigated

Driverless cars will improve productivity

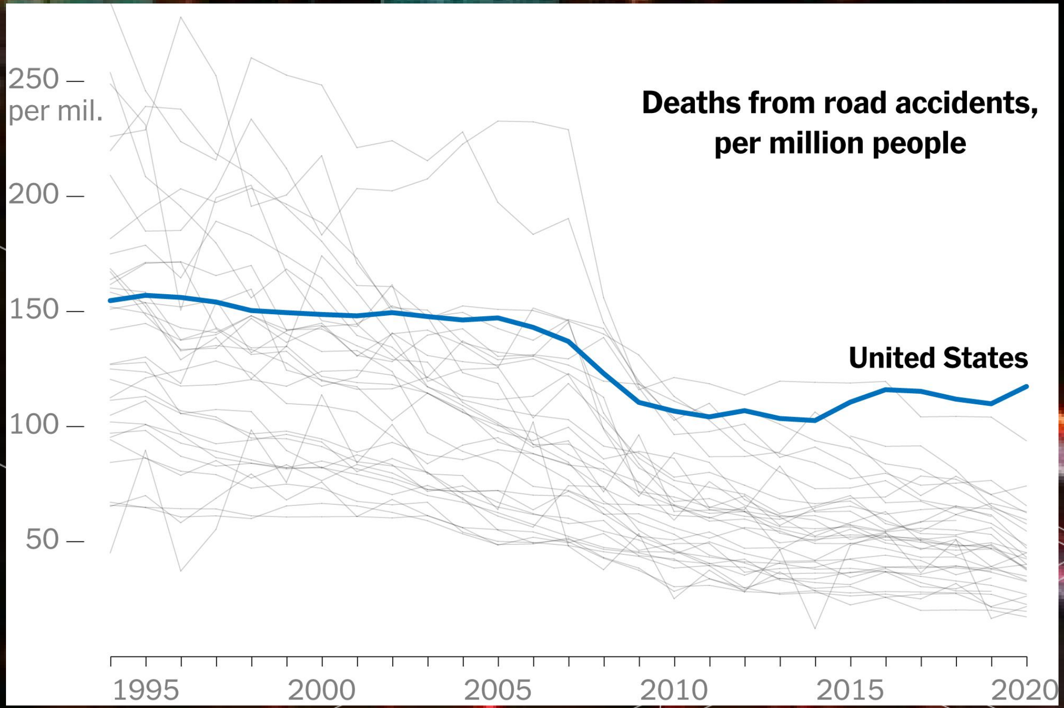
- Americans drives 13,474 miles (300 hrs) per year

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



Challenges and opportunities in autonomy

- Cost
- Reliability
- Energy

New products

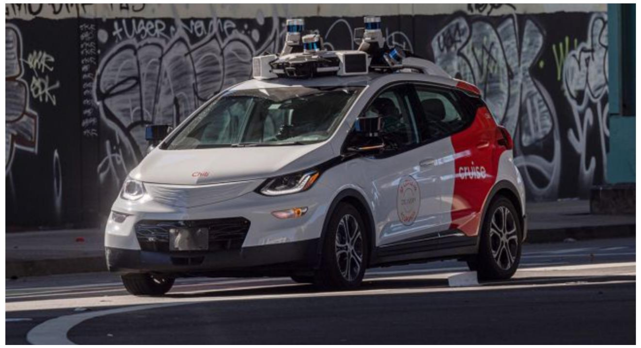
- Hospital and elderly care
- Home robot assistant

Autonomy is a **frontier** of engineering

YOU will build, found, join the coming autonomy transformation!

San Francisco Wants Halt to Cruise, Waymo Expansion Ruling

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



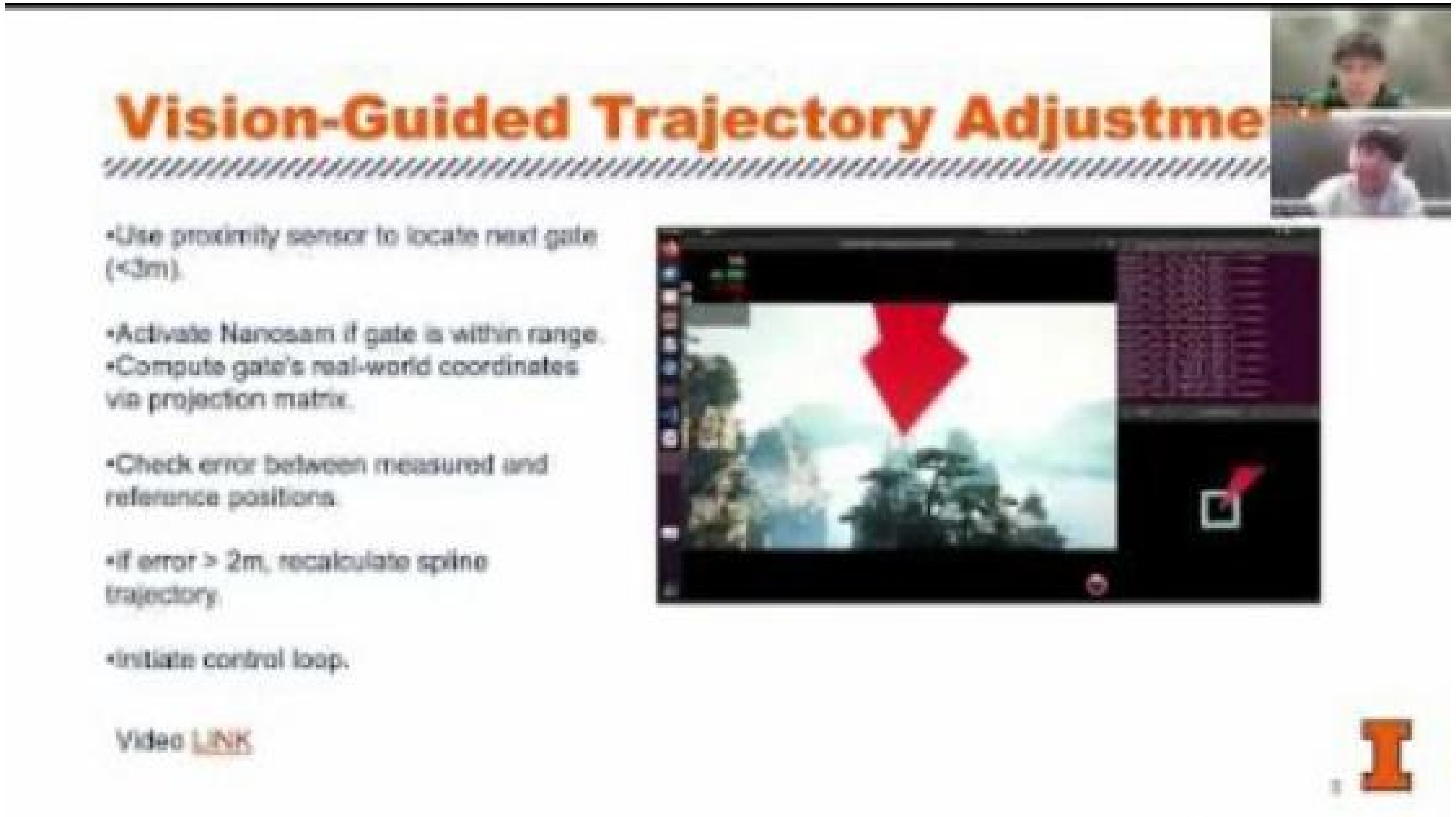
Aug. 19, 2023, at 12:32 p.m. General Motors' Cruise autonomous vehicle unit has agreed to cut its fleet of San Francisco robotaxis in half as authorities investigate two recent crashes in the city.

Example of what you will build in 484

https://youtu.be/J0_EZeZfXWk

Another example: Drone racing project

https://youtu.be/Ij09vzV7xkI?t=207



Plan for today

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

Course Objectives

Learn

- Algorithms and math concepts for perception, planning, control, filtering, verification
- Software tools like ROS, Yolo, OpenCV, Z3, Verse

Build

- modules for lane detection, localization, planning, verification
- an autonomous system

Understand

- models for capturing uncertainty: automata, ODEs, Markov chains
- algorithms---assumptions and guarantees and limits

Get inspired to build the future of autonomy and uncover the scientific principles

Course Details

Learn

- Algorithms and math concepts for perception, planning, control, filtering, verification [HW, midterms]
- Software tools like ROS, Yolo, OpenCV, Z3, Verse [MPs, project]

Build

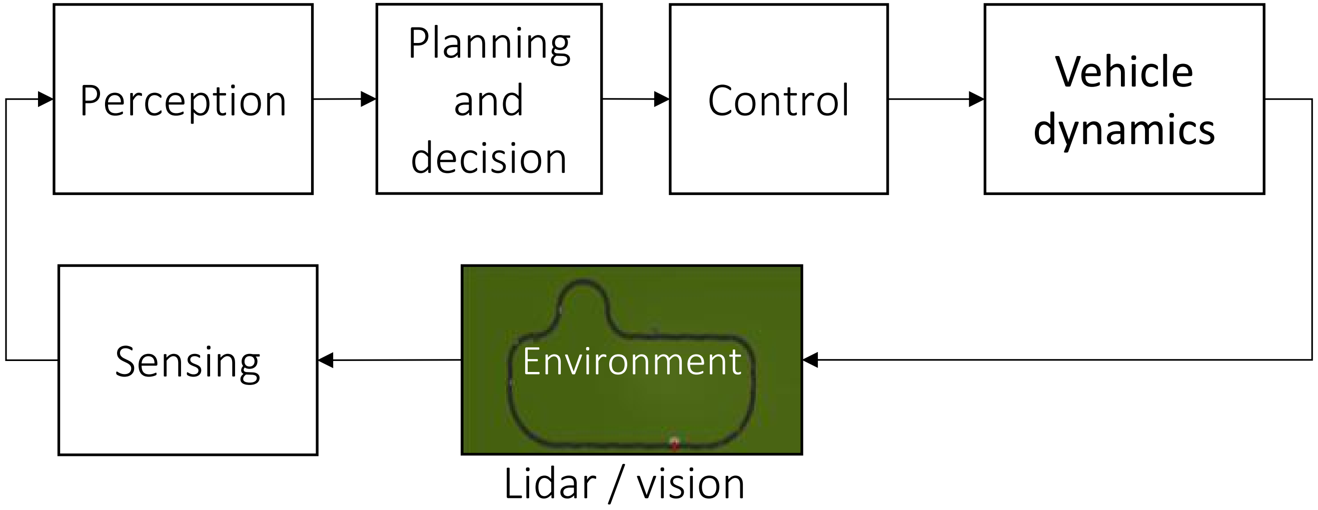
- modules for lane detection, localization, planning, verification [MPs]
- an autonomous system [project]

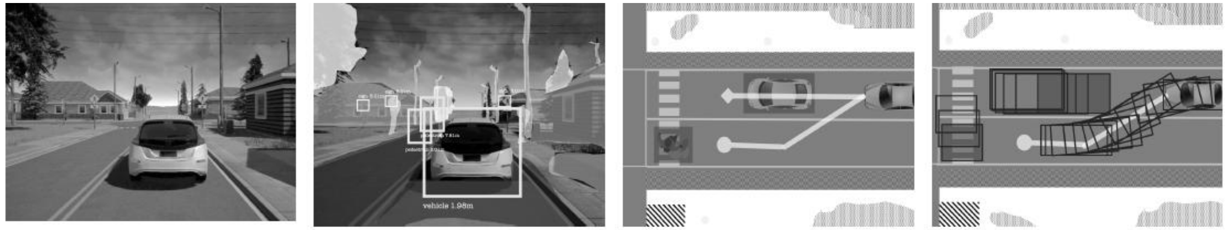
Understand

- models for capturing uncertainty: automata, ODEs, Markov chains [HW, midterms]
- algorithms---assumptions and guarantees and limits [HW, midterms]

Get inspired to build the future of autonomy and uncover the scientific principles [project]

Autonomous GEM vehicle





Sensing

Physics-based models of cameras, LIDAR, radar, GPS, and so on.

Perception

Programs for object tracking, scene understanding, and so on.

Decisions and planning

Programs and multi-agent models of pedestrians, cars, and so on.

Control

Dynamical models of vehicle engine, powertrain, steering, tires, and so on.

Course structure

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

Convolution
Bayes filter
SLAM

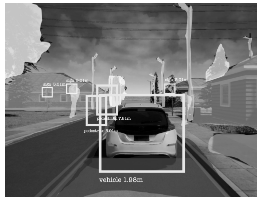
RRT, Markov decision processes, RL

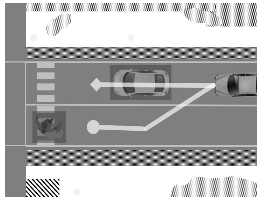
ODE, Stability, PID

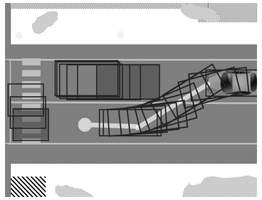
Perception → Planning and decision → Control → Vehicle dynamics → Environment → Sensing → Perception

Environment

Lidar / vision







Sensing	Perception	Decisions and planning	Control
MP1	MP1 MP3	MP2	MP2
Project	**Project**	**Project**	**Project**

Administrivia

Course Website: 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. https://campuswire.com/c/G687F3C20/feed

Discussions, forming teams, occasional polls, feedback

Gradescope/Canvas for submitting homework

Course materials

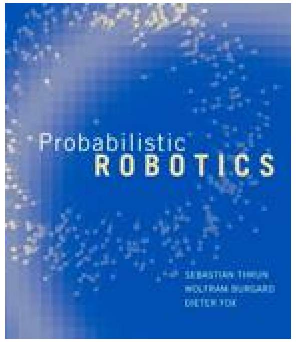
Lecture notes, slides, code, video lectures, lab manuals created and curated from recent research publications

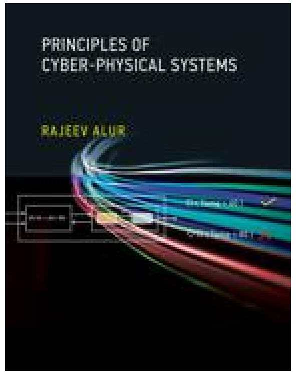
Course reader: Available from: https://publish.illinois.edu/safe-autonomy/files/2023/08/Safe_Autonomy_Course_Reader.pdf

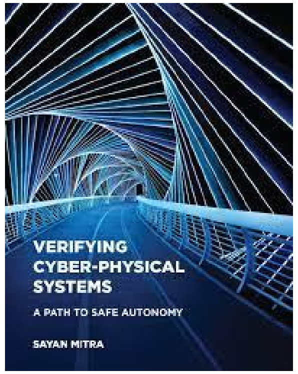
Lecture recording on MediaSpace

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*







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, 4 tracks:
  - A. Dev and test concepts on GEM
  - B. GRAIC autonomous racing competition / testing
  - C. F1tenth small racing car
  - D. Drone racing

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

Teamwork: MP, labs, and mini project

- In groups: Form your group of 3-4 **now**! Create groups by this Friday (more details on Campuswire)
- Each MP will build a significant component of an autonomous system over **2 weeks**
- Use your computer with **Ubuntu 22.04** or ECEB5072 lab computers
- TAs and LAs will run live labs in ECEB 5072
- MP walkthough, setup, bridge the lecture and the assignments
- MP0+HW0 will be released this Friday (8/29), labs starts this Friday
  - Your entire group has to attend one lab for the MP walkthrough
  - And 1 lab after the MP is due (to demo your work).

Course schedule

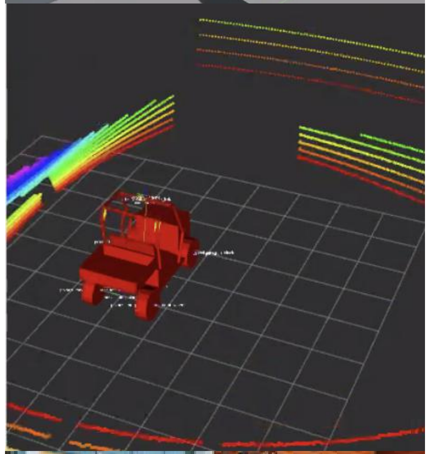
https://publish.illinois.edu/safe-autonomy/schedule-fall-2025/

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
- Timeline:
    - High-bay virtual site visit and training (check Campuswire!)
    - Project pitch (around the mid of semester)
    - Public presentation, demo, awards (End of Semester)

Spring 2024 projects
Spring 2022 projects
Spring 2020 projects
Fall 2020 projects






Office hours

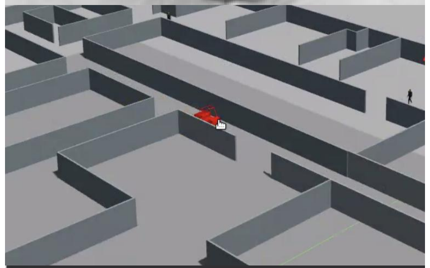
Office Hours

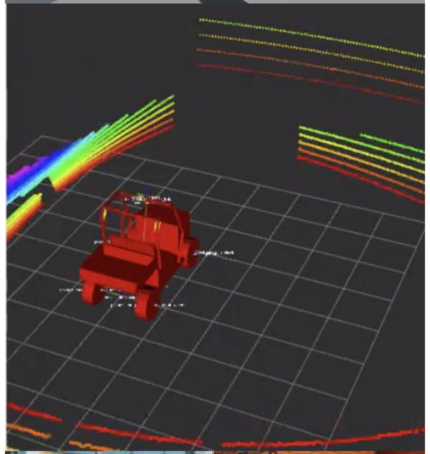
TA	Day/Time	Location
Hanna	Thursday 4PM	ECEB 5072
Fatemeh	Thursday 11AM	ECEB 5072
Xiangru	Wednesday 4PM	ECEB 5072
Han	Wednesday 1PM	ECEB 5072
James	Wednesday 2PM	ECEB 5072

Lead TA: Hanna Chen (hannac4@illinois.edu)

Instructor (Prof. Huan Zhang) office hours: 2 - 4 slots per week, book here for in-person and here for online

Spring 2024 projects
Spring 2022 projects
Spring 2020 projects
Fall 2020 projects





Principles of Autonomy ECE 484
Fall 2025
Lecture 1-3: Checking Safety

Professor: Huan Zhang

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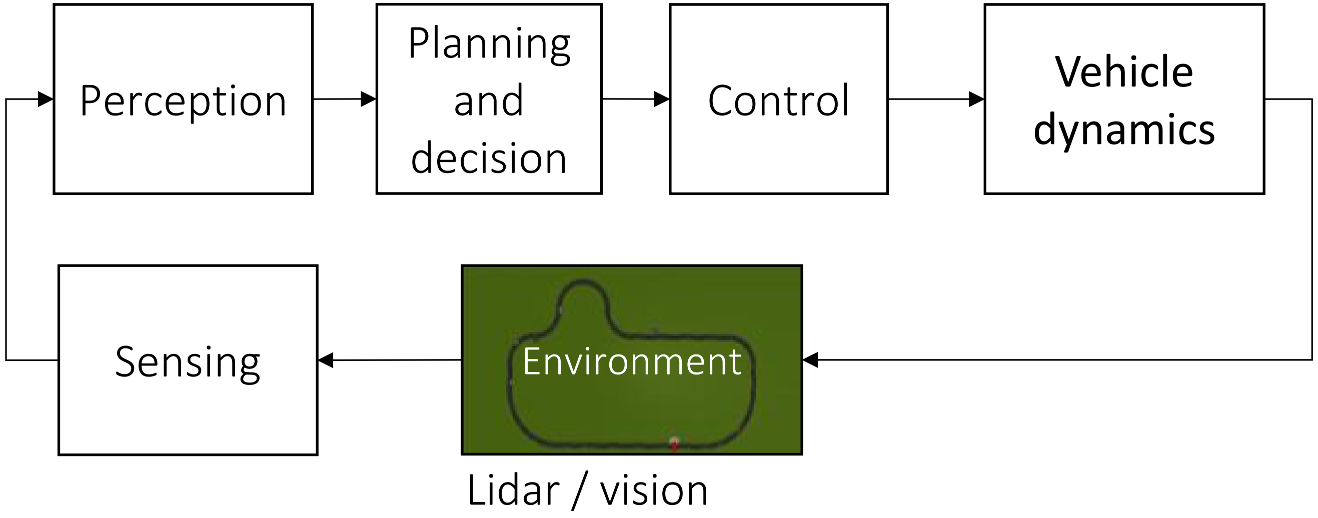
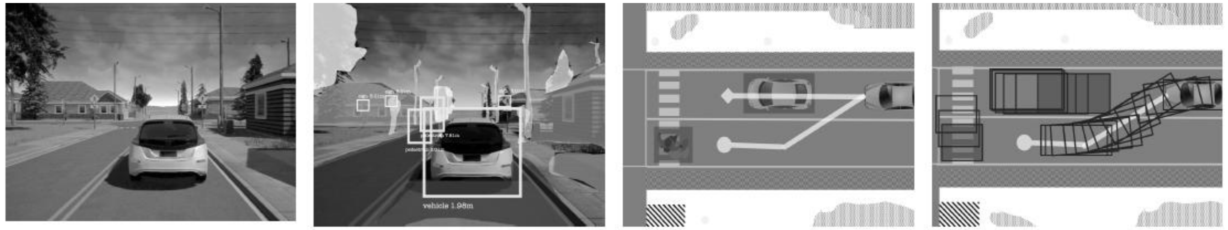
Architecture of a typical autonomous system

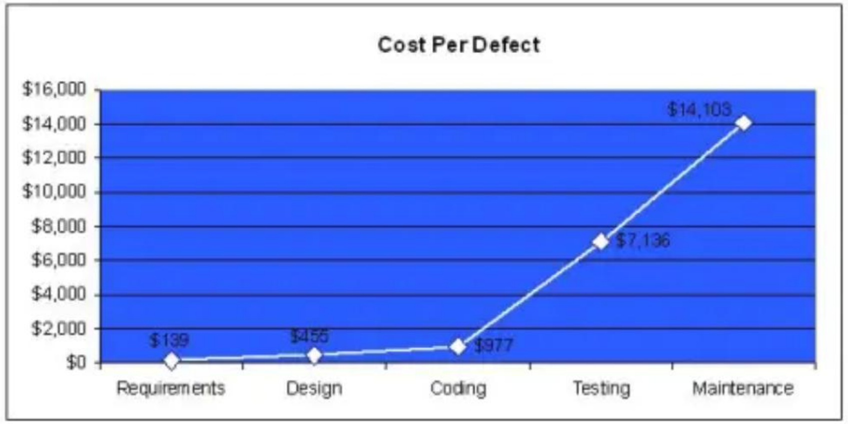




Sensing	**Perception**	**Decisions and planning**	**Control**
Physics-based models of cameras, LIDAR, radar, GPS, and so on.	Programs for object tracking, scene understanding, and so on.	Programs and multi-agent models of pedestrians, cars, and so on.	Dynamical models of vehicle engine, powertrain, steering,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

Cost of unreliability in autonomous systems

- Therac-25 radiation therapy machine delivered overdoses because of software bug which resulted in 6 fatalities (1985 - 1987).
- Elaine Herzberg was killed by selfdriving Uber prototype in Tempe, Arizona in March 2018.
- A simple data conversion error (overflow) caused the **$500M Ariane 5 rocket** to veer off course and explode shortly after launch (June 4, 1996).
- GM's Cruise autonomous vehicle unit shut down parts of its San Francisco robotaxi fleet after crashes in 2023.
- Cost of defects grow exponentially with the time of discovery



Capers Jones, Software Assessments, Benchmarks, and Best Practices, Addison-Wesley, 2000

Checking truthfulness of statements about reliability and safety

- A popular method for checking truth: Statistical testing
- "Testing can be used to show the presence of bugs, but never to show their absence!"
- --- Edsger W. Dijkstra
- Amount of testing required for autonomous systems can be prohibitive
  - Probability of a fatality caused by an **accident per one hour of human driving** is known to be 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 proportional to its inverse, **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

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

Checking truthfulness of statements

The ultimate standard for truth: A theorem with a proof

Formal verification: The science of proving or disproving truth of statements asserting correctness of systems

Proofs are being used at scale in Amazon, Meta, Microsoft, NASA, …

"In 2017 alone the security team used deductive theorem provers or model checking tools to reason about cryptographic protocols/systems, hypervisors, boot-loaders/BIOS/firmware, garbage collectors, and network designs." Byron Cook, Amazon

Byron Cook's talk at FLoC 2018
https://www.youtube.com/watch?v=JfjLKBO27nw

Formal Verification in Software: an example

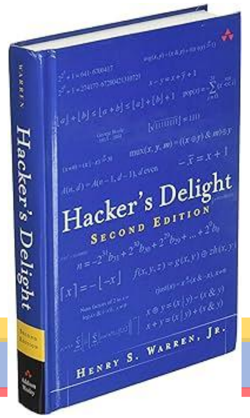
Simple programming task: given a 32-bit unsigned integer, calculate how many bits are set to 1 (“population count”)

Naive implementation

```
int popcount(uint32_t x) {
  int c = 0;
  for (int i = 0; i < 32; i++) {
    c += x & 1;
    x >>= 1;
  }
  return c;
}
```

Clever implementation

```
int popcount (uint32_t x) {
    x = x - ((x >> 1) & 0x55555555);
    x = (x & 0x33333333) + ((x >> 2) & 0x33333333);
    x = ((x + (x >> 4) & 0xf0f0f0f) * 0x1010101) >> 24;
    return x;
}
```



Example source: Marijn J.H. Heule, “SAT and SMT Solvers in Practice”

Formal Verification in Software: an example

Can we trust this “clever implementation” of the same function?

What would you do to ensure this clever implementation is correct? Brute-force?

Naive implementation **?=** **Clever implementation**

```
int popcount(uint32_t x) {
  int c = 0;
  for (int i = 0; i < 32; i++) {
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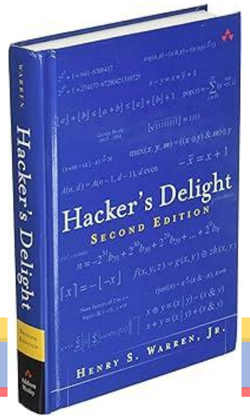

Formal Verification in Software: Specification

Formal verification aims to prove that **for all possible inputs,** the results of the two functions are the same (mathematically, same integer is returned)

Verification **specification**:

Naive implementation **==** Clever implementation

```
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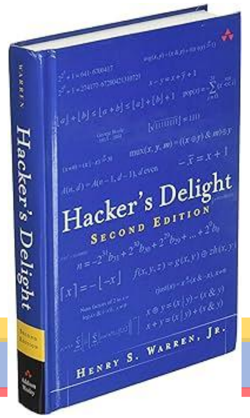

Example: Automatic Emergency Braking (AEB)

A car moving down a straight road has to detect any pedestrian (or another car) in front and stop before it collides.

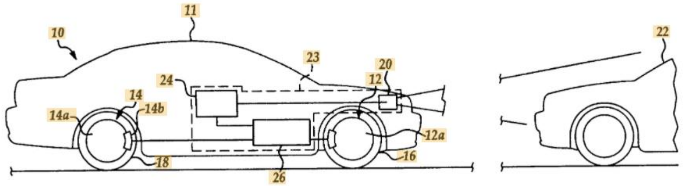

Figure 1

Today: There is no standard for checking correctness of AEB systems

Future: Every time an AEB engineer commits code in github, a theorem proves safety of the system under appropriate assumptions, or finds an unsafe scenario

www.google.com › patents
US20110168504A1 - Emergency braking system - Google ...
Jump to **Patent** citations (18) - US4053026A * 1975-12-09 1977-10-11 Nissan Motor Co., Ltd. Logic circuit for an **automatic braking** system for a motor ...

www.google.com › patents
US5170858A - Automatic braking apparatus with ultrasonic ...
An automatic braking apparatus includes: an ultrasonic wave emitter provided in a ... Info: **Patent** citations (13); Cited by (7); Legal events; Similar documents; Priority and ... US6523912B1 2003-02-25 **Autonomous emergency braking** system.

www.google.com › patents
DE102004030994A1 - Brake assistant for motor vehicles ...
B60T7/22 **Brake**-action initiating means for **automatic** initiation; for initiation not ... Info: **Patent** citations (3); Cited by (9); Legal events; Similar documents ... data from the environment sensor and then **automatically** initiates **emergency braking**.

www.google.com.pg › patents
Braking control system for vehicle - Google Patents
An **automatic emergency braking** system for a vehicle includes a forward viewing camera and a control. At least in part responsive to processing of captured ...

www.automotiveworld.com › news-releases › toyota-ip...
Toyota IP Solutions and IUPUI issue first commercial license ...
Jul 22, 2020 - ... and validation of automotive **automatic emergency braking** (AEB) ... and Director of **Patent** Licensing for Toyota Motor North America. "We are ...

insurancenewsnet.com › oarticle › patent-application-tit...
Patent Application Titled "Multiple-Stage Collision Avoidance ...
Apr 3, 2019 - No assignee for this **patent** application has been made. ... **Automatic emergency braking** systems will similarly, also, soon be required for tractor ...

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