Principles of Safe Autonomy
ECE 498 SM
Lecture 1: Overview

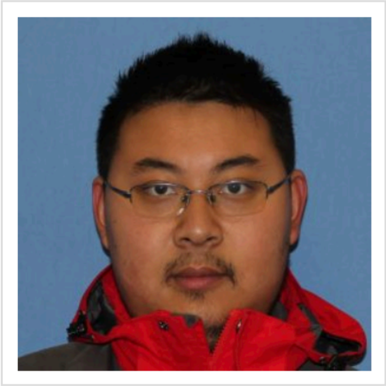
Professors: Sayan Mitra

Graduate Teaching Assistants: Yangge Li and Minghao Jiang

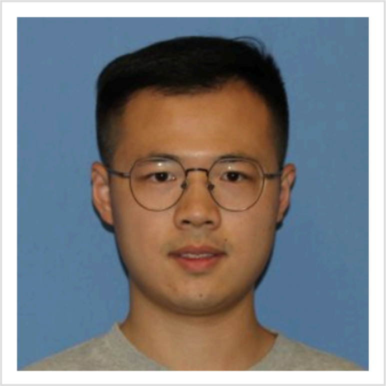
Undergraduate Assistants: Qichao Gao and Hebron Taylor

Welcome from SafeAuto Team!

Sayan Mitra (mitras)



Yangge Li (li213)



Minghao Jiang (mjiang24)

- Professor Sayan Mitra
- CEO: Yangge Li
- CTO: Minghao Jiang

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

Plan for today

- What is this course about?
- Why is this approach to autonomous systems important?
- How will this course work? (Administrivia)
- Technical content:
  - What would it take to assure safety of an autonomous system?

Autonomous systems *will* be awesome

Driverless cars will make us more productive

Average American drives 300 hours per each

Our cities will be greener

40 % of city surface is parking

Travel and deliveries will be safer

32K+ fatalities every year

THE TOP 263

Gartner Hype Cycle for Emerging Technologies, 2019

COMET LABS

PREDICTIONS SCORECARD, 2020 JANUARY 01 by Rodney Brooks

http://rodneybrooks.com/predictions-scorecard-2020-january-01/

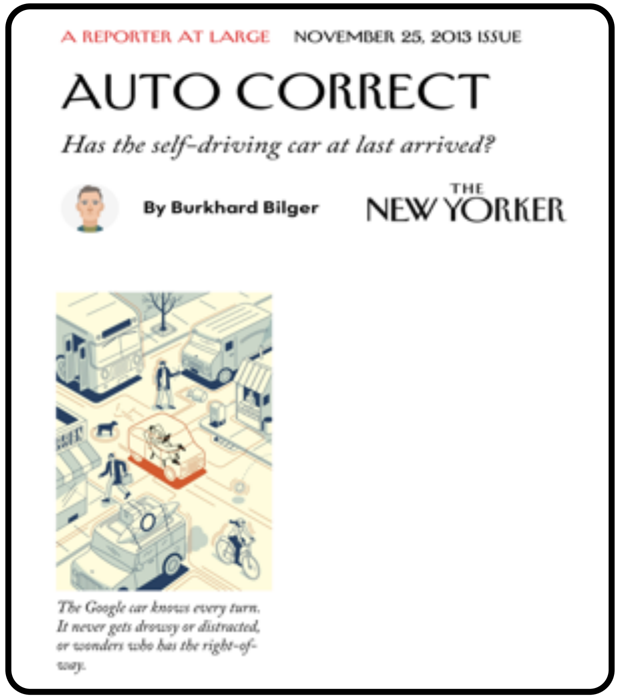
FORECASTS: http://www.driverless-future.com/?page_id=384 March 27, 2017

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)*

Recently I had added some arrows to this slide. The skinny red arrows point to dates that have passed without the prediction coming to pass. The fatter orange arrows point to cases where company executives have since come out with

Building autonomous cars will be like going to the Moon---or harder

Demonstrations of driverless cars date back to the 80s/90s in the Eureka/ Prometheus Pro



A REPORTER AT LARGE NOVEMBER 25, 2013 ISSUE

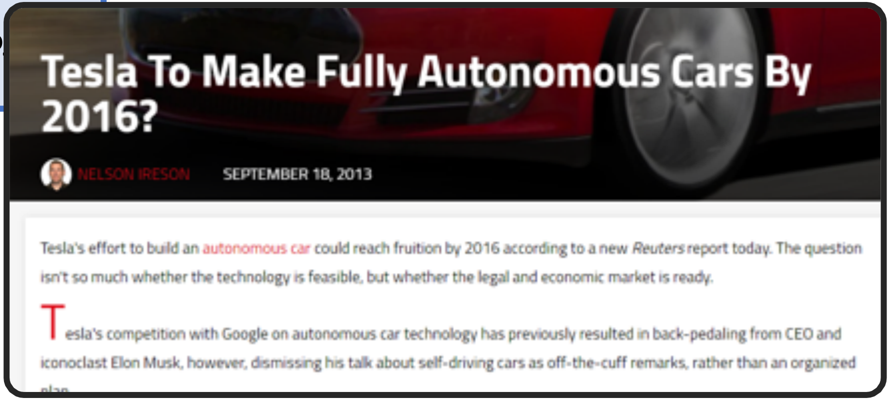
AUTO CORRECT

Has the self-driving car at last arrived?

By Burkhard Bilger

THE NEW YORKER

The Google car knows every turn. It never gets drowsy or distracted, or wonders who has the right-of-way.



Tesla To Make Fully Autonomous Cars By 2016?

NELSON IRESON SEPTEMBER 18, 2013

Tesla's effort to build an autonomous car could reach fruition by 2016 according to a new *Reuters* report today. The question isn't so much whether the technology is feasible, but whether the legal and economic market is ready.

Tesla's competition with Google on autonomous car technology has previously resulted in back-pedaling from CEO and iconoclast Elon Musk, however, dismissing his talk about self-driving cars as off-the-cuff remarks, rather than an organized plan.

TECH \ AMAZON \ DRONES

Delivery drones are coming: Jeff Bezos promises half-hour shipping with Amazon Prime Air

By David Pierce | Dec 1, 2013, 8:10pm EST

SHARE

TECH

Uber's Self-Driving Car Detected Pedestrian Before Fatal Crash, But "Decided" Not to Stop

VICTOR TANGERMANN, FUTURISM

8 MAY 2018

When a self-driving car is involved in a fatal accident, who is at fault? Is it the "safety-driver," the company behind the car, or the lawmakers that allowed

Drone Causes Aircraft Crash for First Time in the US: Report

FEB 16, 2018 MICHAEL ZHANG

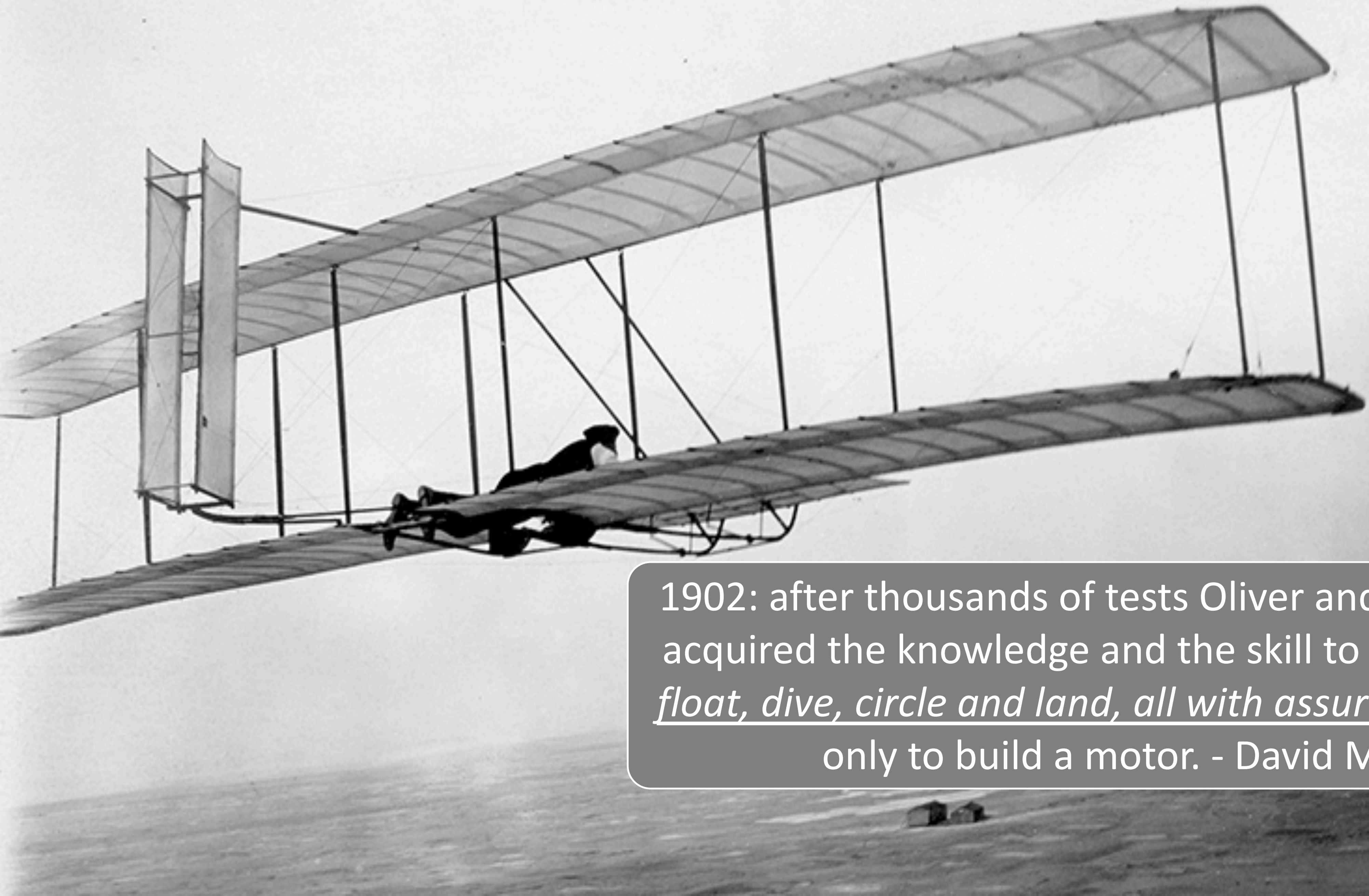
Share 2.3K Tweet

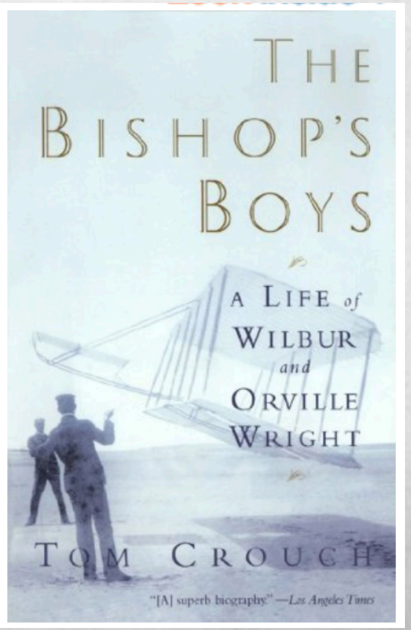
150 COMMENTS

Some of you will be working on this problem!

A different race a century later


TheFilmGate@aol.com
FIRST
ROCKET
MAIL
02:47:16:22

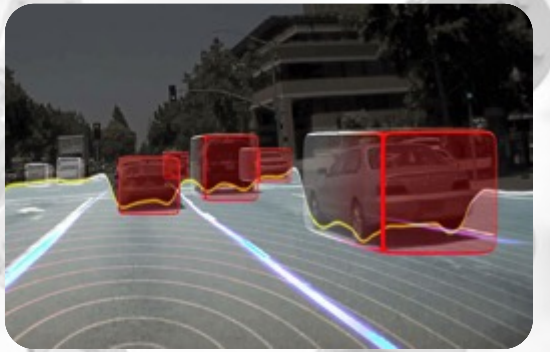




1902: after thousands of tests Oliver and Wilbur Wright had acquired the knowledge and the skill to fly. *They could soar, float, dive, circle and land, all with assurance*. Now they had only to build a motor. - David McCullough

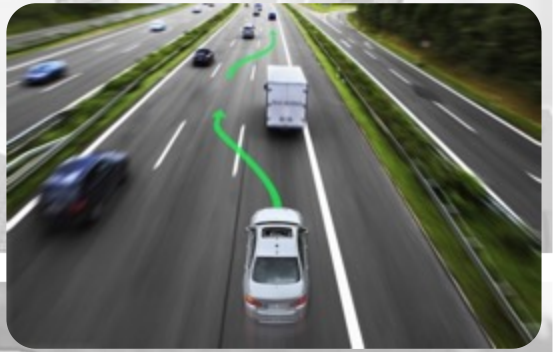
Sense

camera, LIDAR, GPS, computer vision, machine learning, neural networks, data



Decide and Control

navigation, path planning, physics, code



Act

computers, networks, engine, steering, brake

What are the key missing pieces?

Checking safety against low probability, high risk events --- hard problem

Hazardous Event Frequencies	
Disengagement Rate	0.12 per 1000 km
Collision Rate	12.5 per 100 million km
Fatality Rate	0.70 per 100 million km

“30 billion miles of test driving necessary to attain the level of assurance necessary to make autonomous vehicles acceptable to society”

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

An honest scientific approach

1. Create detailed *mathema*tical *models* of the autonomous systems and its environment
2. Enumerate the precise *requirements* of the system and the conditions on the environment under which it is supposed to work
3. Analyze the system to either
   - *prove* that all behaviors meet the requirement (perhaps with high probability)
   - find counter-examples, corner cases, etc., debug and repeat

- Currently there are fundamental flaws in making this work for autonomous systems
- Why study this approach?
  - Careful reasoning can expose flawed assumptions, bad design choices
  - The approach has been successful in other industries: microprocessors, aviation, cloud computing, nuclear, ..
  - Big strides in the last few years
  - Working deliberately towards a more perfect understanding is a worthwhile intellectual struggle

Why are we here? 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

Plan for today

- What is this course about?
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Administrivia

How will the course work?

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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

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

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Why are we here? Course goals

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

About the course

Everything starts here: https://publish.illinois.edu/safe-autonomy/

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

Piazza for announcements, but no SLA

- Use it for forming teams, your own discussions
- Do not expect to get answers to HW and exam related questions on piazza in the last minute.

Compass for grades

Schedule

https://publish.illinois.edu/safe-autonomy/fall-2020-schedule/

- Simple safety
- Perception (vision)
- Modeling and control --- Project proposal
- Planning and decision making --- Midterm 1
- Filtering: localization particle filtering
- Safety analysis --- Midterm 2
- Fall break
- Project presentations

Course materials

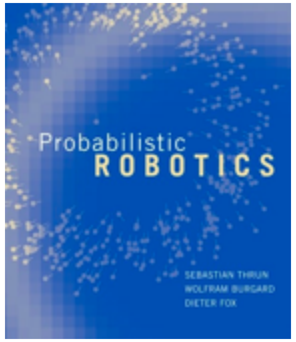
No textbook

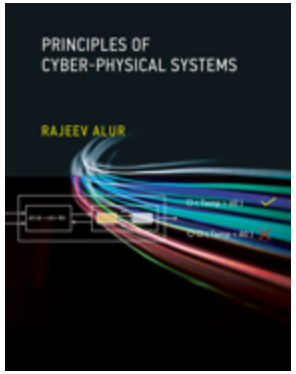
Lecture notes, slides, code, video lectures, lab manuals created and curated from recent research publications

Reference books:

Probabilistic robotics, By Sebastian Thrun, Wolfram Burgard and Dieter Fox, 2005

Principles of Cyber-Physical Systems, Rajeev Alur, MIT Press, 2015





Course: components and weights

- 6 programming assignments or MPs 40% (group)
  - ROS + Python, Ubuntu, BYOD or use lab workstations
  - Office hours, evening labs
- 4 homework assignments 15% (individual)
  - Math, analysis, some proofs, reasoning
- participation 5%
  - Ask questions in class; there will be live quizzes, polls
- 2 midterms + 1 project 40%
  - 15 + 25 OR 25 + 15

Homework and exams

- Individual work, testing concepts covered in lectures and MPs
- homework sets (synchronized with MPs)
- 2 in-class midterms (Oct 7 and Nov 18)
- No final exam

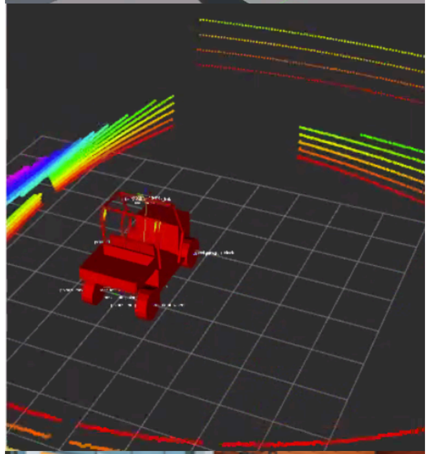
MP, labs, and project 1

- In groups: Form your group of 3-4 now! Try to make your group diverse, make new friends
- In each MP you. will build a significant component of an autonomous system over ~**2 weeks**: E.g. camera-based lane detection, vehicle modeling control, pedestrian detection, etc.
- You will need your own computer with Ubuntu 16.04 OR broadband internet connection to remote login to our lab computers (there may be AWS option available)
- To help you, TAs and UGA will run live labs over zoom
  - get you started with the MPs, cover topics the bridge the lecture and the assignments
- MP0+HW0 will be release this Friday (8/28), labs start next week
- Your entire group has to attend 1 lab after a new MP is released,
- And 1 lab after the MP is due (to demo your work). For the other weeks, at least one representative from the group should discuss progress with MPs and projects

Projects: 2 tracks:

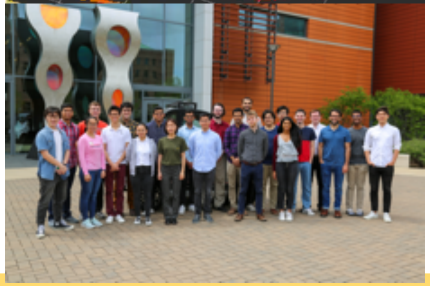
- Semester-long group project to explore, inspire, and impress
- GEM Track. Build on existing SW to live demo at Highbay
  - Reliable parallel parking, lane following and pedestrian avoidance outdoor track, biker intent estimation and reaction
  - COVID related uncertainty about highbay access; Frontload the work

- SIM Track. Build significant feature in simulator and make safety claims
  - Build Unity-based photorealistic renderer connected with Gazebo; advanced decision module with high-level decision making around pedestrians and other vehicles; enable multi-agent interactive simulations



- Outcomes: Technical papers, jumpstart grad research, incubate startup ideas, new course materials
- We will 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.
- 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 (next week)
  - Project pitch (next 3 weeks)
  - Public presentation, demo, awards (last 2 classes)

See last semester's projects



Grade boundaries from last semester*

A+	>94
A	>88
A-	>85
B-, B, B+	70-84
C	<70

*May change because of big disruptions

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  1. Create a *model* of the autonomous system
  2. Identify the *requirements* and *assumptions*
  3. Analyze model to show that it meets the requirements under the assumptions

A “simple” safety scenario

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

Automatic Emergency Braking

Not a trivial requirement

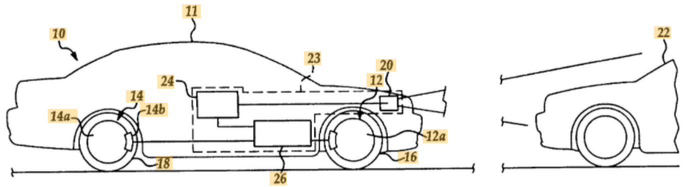


Figure 1

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 ...

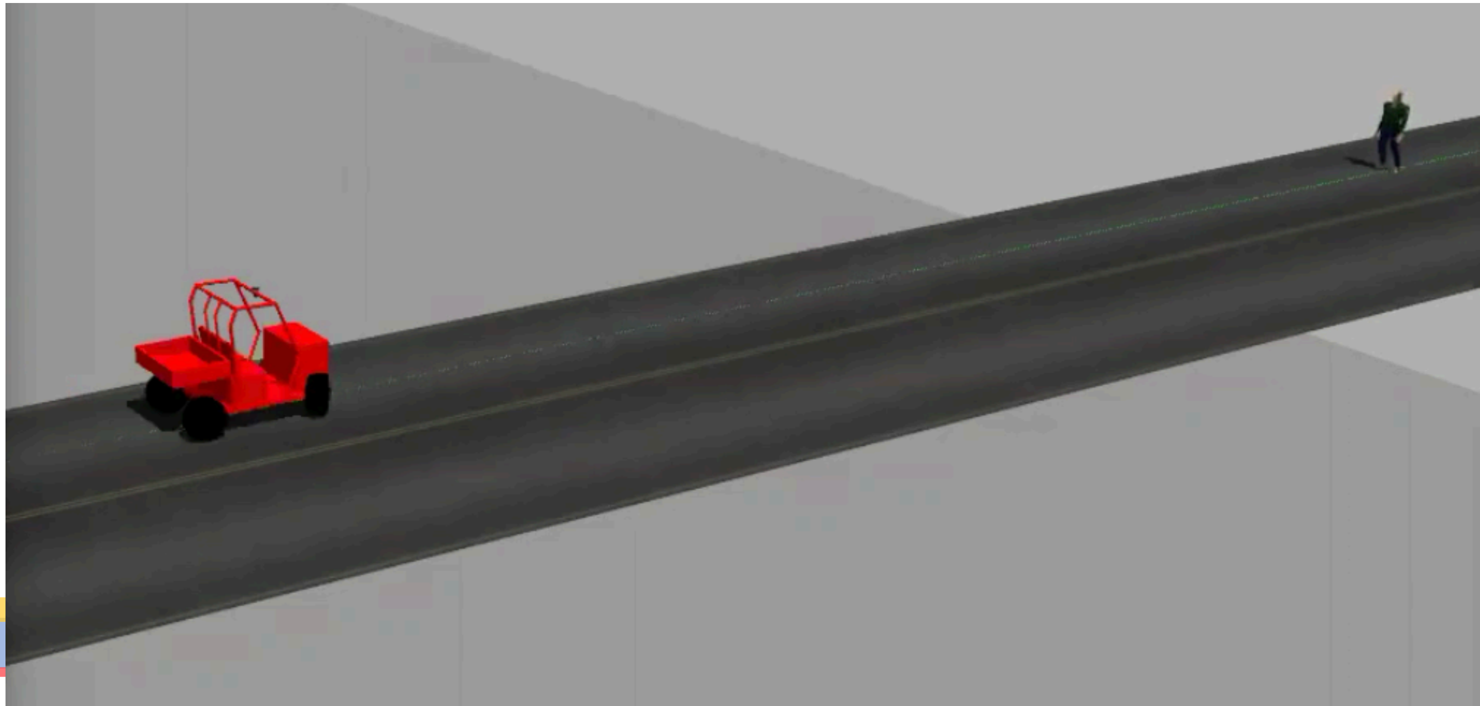
insurancenewsnet.com › oarticle › patent-application-tit...
Patent Application Titled “Multiple-Stage Collision Avoidance ...
Apr 3, 2019 - No assignee for this **patent** application has been made. ... **Automatic emergency braking** systems will similarly, also, soon be required for tractor ...


LiveLeak

Modeling the scenario

- What is a model of a system?
- A *mathematical model* describes how a system behaves.
  - What are the key parameters and states?
  - How are the parameters selected by nature?
  - What are the initial conditions of the state?
  - How do the state change over time? …
  - What parts of the model are available for observation/analysis?
- Models include the implicit and explicit assumptions (biases) we are making about the system

A model



A model as a program

SimpleCar$(D_{sense}, v_0, x_{10}, x_{20}, a_b)$, $x_{20} > x_{10}$

initially: $x_1 = x_{10}, v_1 = v_0, x_2 = x_{20}, v_2 = 0$

  $s = 0$, $timer = 0$

if $d \leq D_{sense}$

  $s = 1$

  if $v_1 \geq a_b$

    $v_1 = v_1 - a_b$

    $timer = timer + 1$

  else

    $v_1 = 0$

$x_1 = x_1 + v_1$

Behaviors of the system model

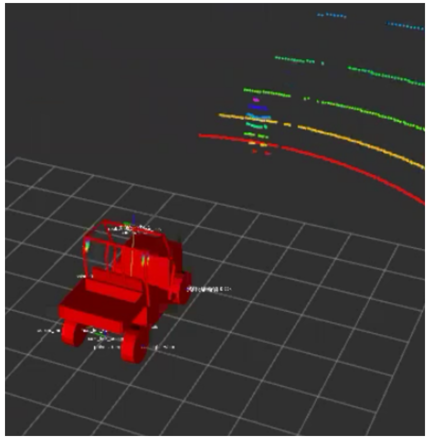
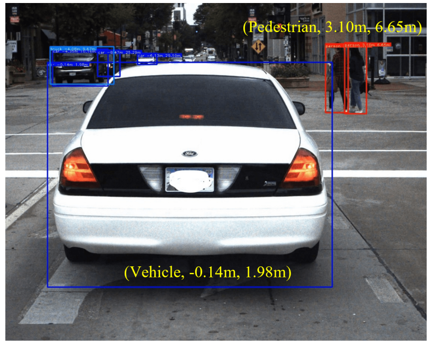
SimpleCar$(D_{sense}, v_0, x_{10}, x_{20}, a_b)$, $x_{20} > x_{10}$
initially: $x_1 = x_{10}, v_1 = v_0, x_2 = x_{20}, v_2 = 0$
  $s = 0, timer = 0$
if $d \leq D_{sense}$
  $s = 1$
  if $v_1 \geq a_b$
    $v_1 = v_1 - a_b$
    $timer = timer + 1$
  else
    $v_1 = 0$
$x_1 = x_1 + v_1$

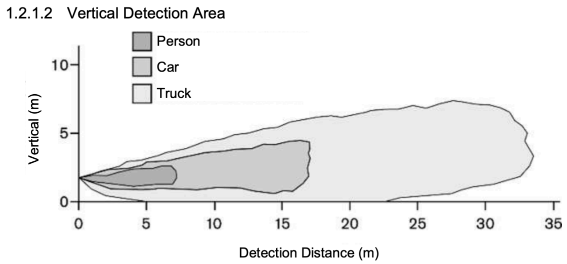
- An execution of the model captures a single run or behavior
- An execution α is a sequence $\boldsymbol{x(0)}, \boldsymbol{x(1)}$, ... such that
  - $\boldsymbol{x(0)}$ satisfies the **initially** clause, and
  - **for each t,** $\boldsymbol{x(t)}$ goes to or **transitions** to $\boldsymbol{x(t+1)}$ **by** executing SimpleCar

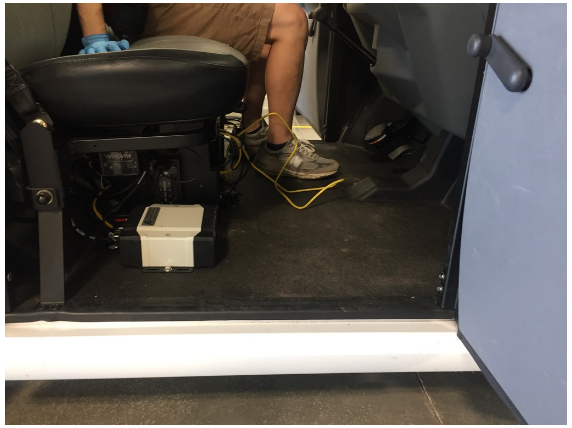
“All models are wrong, some are useful.”

Baked-in Assumptions

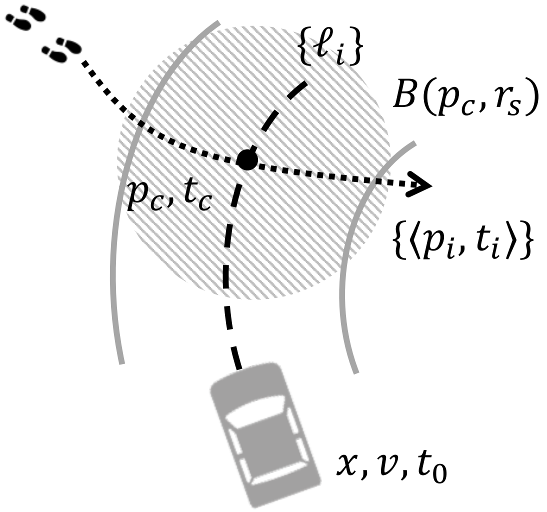
- Perception.
  - Sensor detects obstacle **iff** distance $d \leq D_{sense}$
  - very idealized
  - Pedestrian is known to be moving with constant velocity from initial position. This will be used in the safety analysis, but not in the vehicle's automatic braking algorithm
- No sensing-computation-actuation delay.
  - The time step in which $d \leq D_{sense}$ becomes smaller is exactly when the velocity starts to decrease






Baked-in Assumptions (continued)



- Mechanical or Dynamical assumptions
  - Vehicle and pedestrian moving in 1-D lane.
  - Does not go backwards.
  - Perfect discrete kinematic model for velocity and acceleration.
- Nature of time
  - Discrete steps. Each execution of the above function models advancement of time by 1 step. If 1 step = 1 second, $x_1(t+1) = x_1(t) + v_1(t).1$
    - We cannot talk about what happens between [t, t+1]
  - Atomic steps. 1 step = complete (atomic) execution of the program.
    - We cannot directly talk about the states visited after partial execution of program

Identifying requirements: Define safety

- A *requirement* is a precise statement about what the behaviors of the system should and should not do.

Writing the model more explicitly

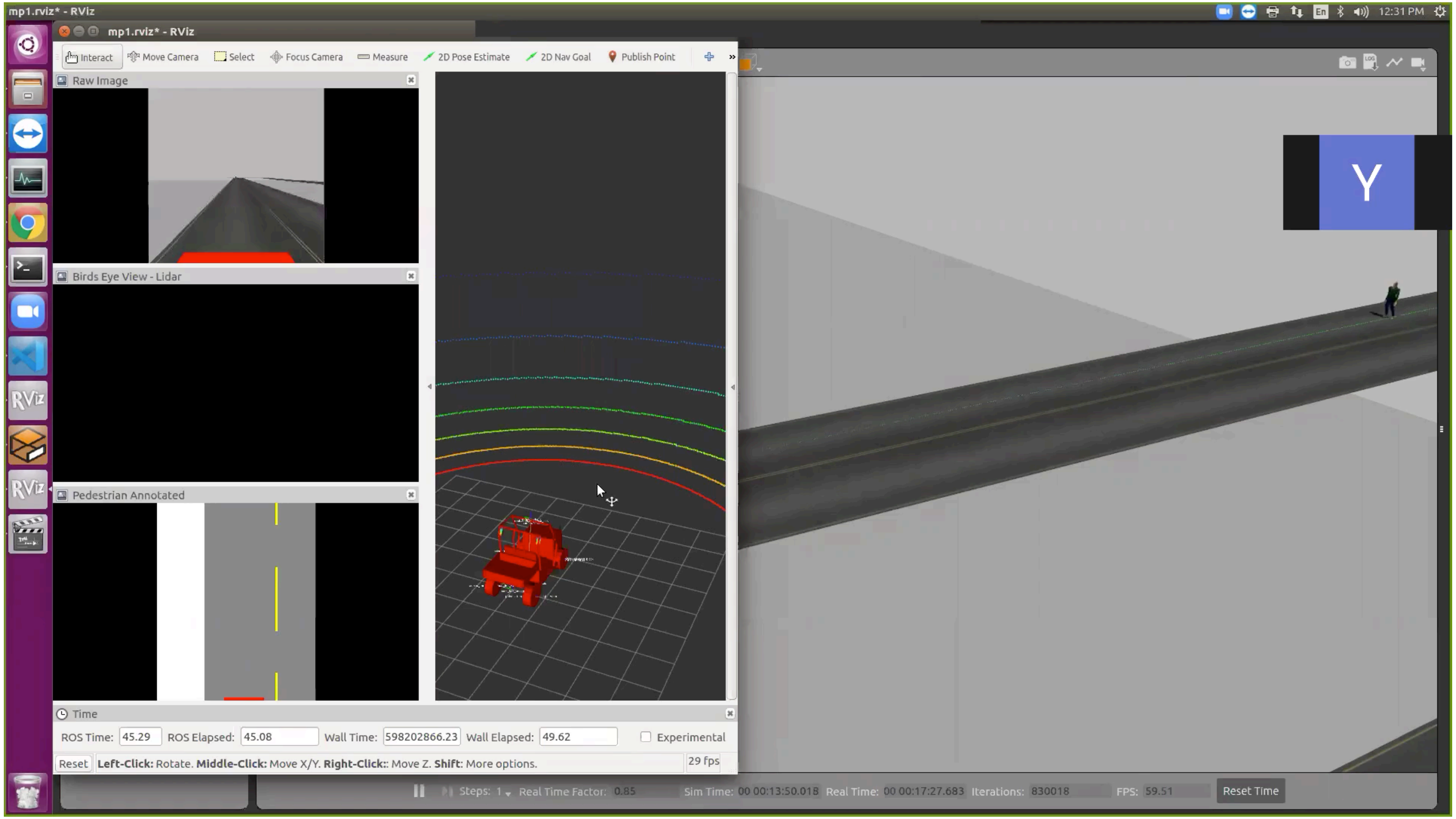
SimpleCar$(D_{sense}, v_0, x_{10}, x_{20}, a_b), x_{20} > x_{10}$
initially: $x_1 = x_{10}, v_1 = v_0, x_2 = x_{20}, v_2 = 0$
  $s = 0, timer = 0$
if $d \leq D_{sense}$
  $s = 1$
  if $v_1 \geq a_b$
    $v_1 = v_1 - a_b$
    $timer = timer + 1$
  else
    $v_1 = 0$
$x_1 = x_1 + v_1$

SimpleCar$(D_{sense}, v_0, x_{10}, x_{20}, a_b), x_{20} > x_{10}$
initially: $x_1(0) = x_{10}, v_1(0) = v_0, x_2(0) = x_{20}, v_2(0) = 0$
  $s(0) = 0, timer(0) = 0$
$d(t) = x_2(t) - x_1(t)$
if $d(t) \leq D_{sense}$
  $s(t+1) = 1$
  if $v_1(t) \geq a_b$
    $v_1(t+1) = v_1(t) - a_b$
    $timer(t+1) = timer(t) + 1$
  else
    $v_1(t+1) = 0$
    $timer(t+1) = timer(t)$
else

Proving safety (next time)

- Invariant (candidate).

MP0: Simulate model for testing



Summary

- Form your team. Decide track. Sign-up to be member of IRL
- Careful modeling and reasoning can expose flawed assumptions, bad design bugs, make the system explainable
- Baked-in assumptions and discovered assumptions
- Discrete time model: states, initial states, transition function
- Requirements, e.g., safety