F1TENTH Autonomous Racing

Course Introduction

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F1 TENTH

Safe Autonomy Lab
University of Pennsylvania

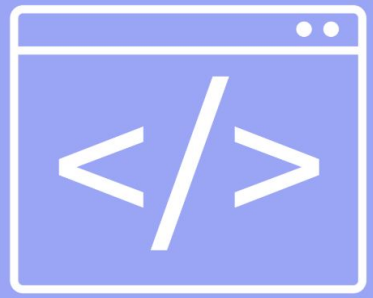
Penn Engineering

Overview

- Introduction to the course
  - Logistics, grading criteria, policies
- Course Support
  - TAs, Canvas, Piazza, Github
- Expectations
- Brief introduction to autonomous racing cars

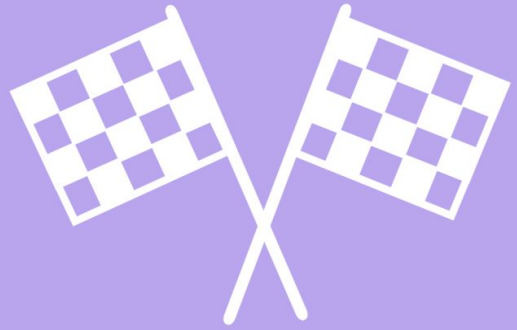
BUILD

Construct your vehicle using our starter kit.



CODE

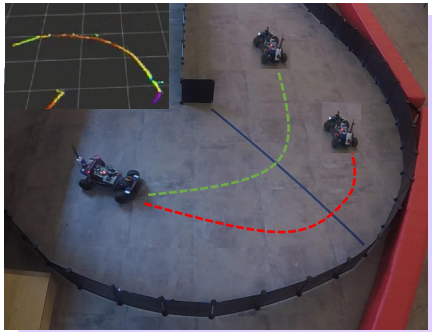
Learn to drive your vehicle autonomously.



RACE

Register to Compete

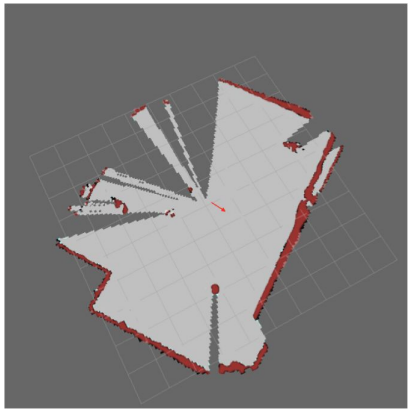
FROM GAP FINDING ...

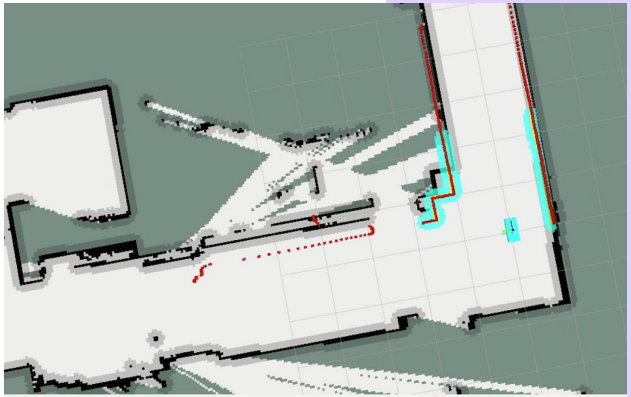


PERCEPTION

Progress to more advanced algorithms

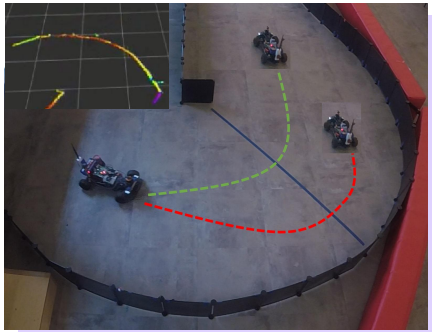
... TO SLAM





F1 TENTH

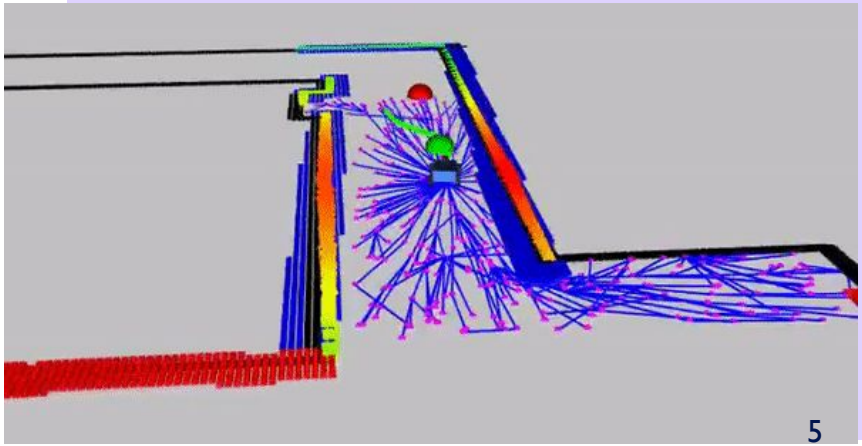
FROM FOLLOW-THE-GAP ...



PLANNING

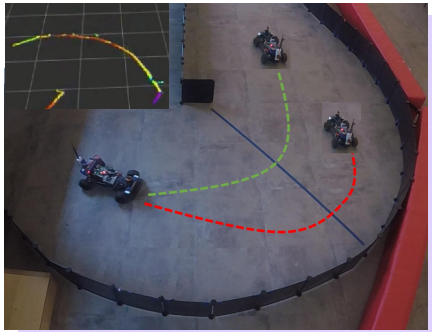
Progress to more advanced algorithms

... TO RRT



F1 TENTH

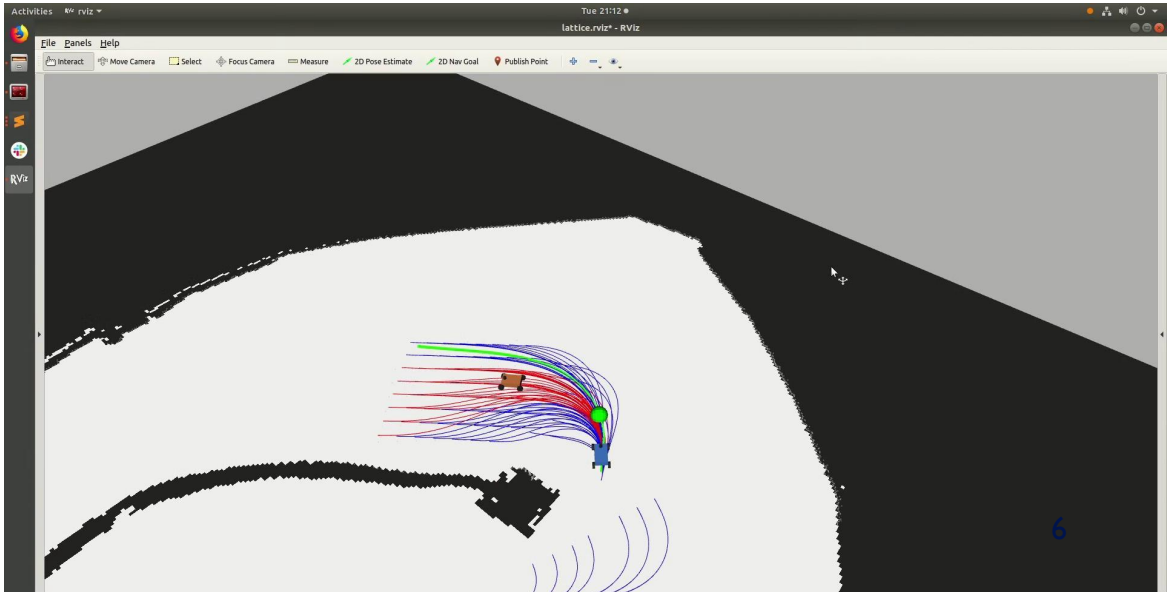
FROM PID ...



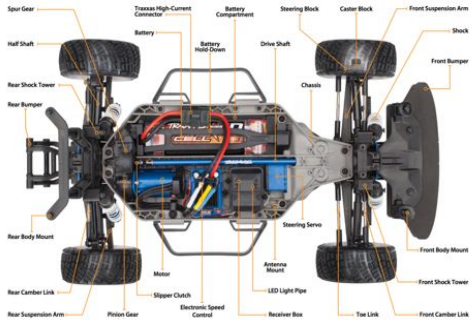
CONTROL

Progress to more advanced algorithms

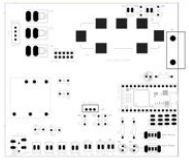
... TO MODEL PREDICTIVE CONTROL



F1 TENTH



Chassis Design



F1/10 Powerboard

2D Lidar

Stereo Camera

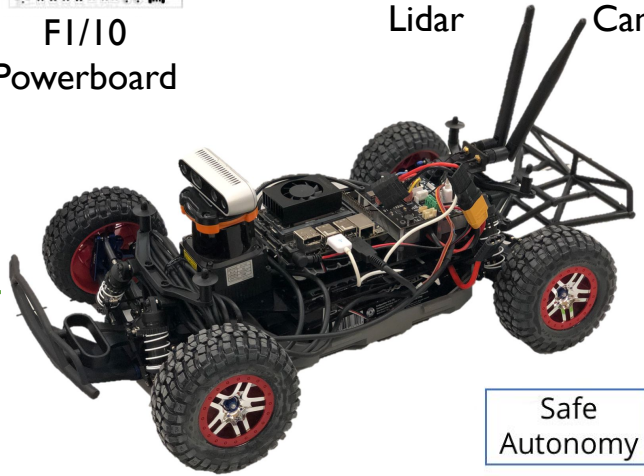
Mono Camera

VESC Controller

Wifi

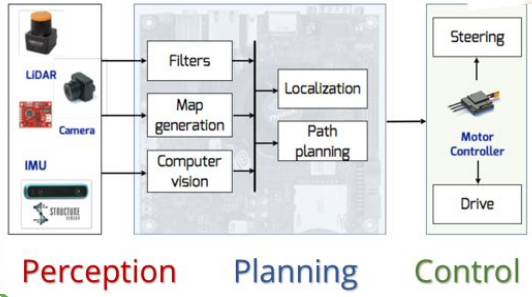
NVIDIA Jetson NX GPU Compute Platform

System Integration

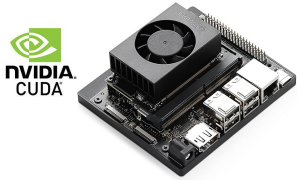


Software Architecture

ROS2



GPU Acceleration



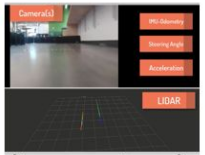
Research Enabled

Safe Autonomy	Secure Autonomy	Coordinated Autonomy	Efficient Autonomy

Lane Keeping Assist

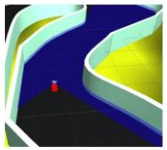
Model-Predictive Control

AV Data Collection



Simultaneous Localization And Mapping (SLAM)

F1/10 Simulator



DNN Racing

Penn Engineering F1 TENTH

Course Mechanics & Expectations

Instructor

Prof. Rahul Mangharam

Associate Professor in ESE and CIS
Director, xLAB :: Safe Autonomous Systems Laboratory
Penn Director, Safety21 - Department of Transportation National Center
Director, Autoware Center of Excellence for Autonomous Driving at Pennovation

Safe + Ethical + Agile Autonomy

How can we provide guarantees of safety & performance for closed-loop life-critical systems?

How to reach me:

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Penn Engineering

Course Team

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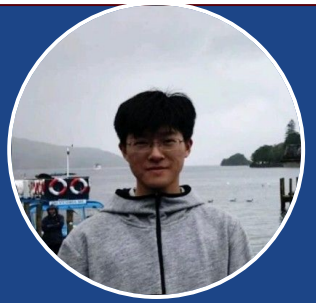
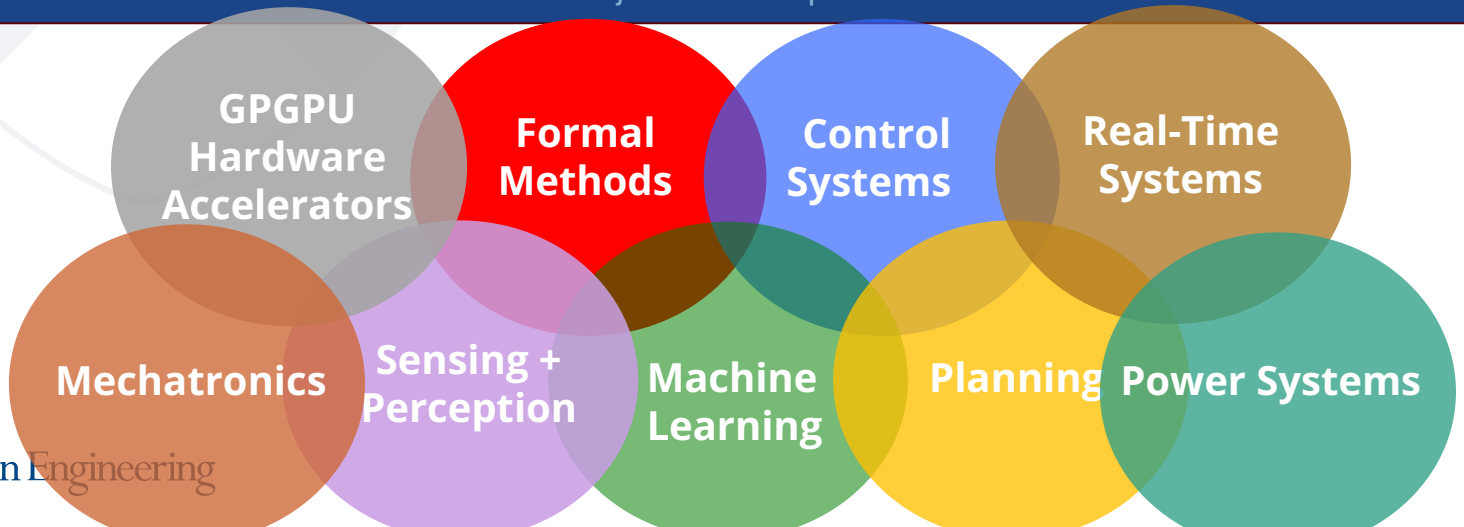


Derek Zhou
derekzmy@seas.upenn.edu



Penn Engineering

Course Logistics

Syllabus	https://tinyurl.com/F1TENTH-24Syllabus
Discussions	Ed
Schedule	https://tinyurl.com/F1TENTH-24Schedule
Canvas	http://tinyurl.com/F1TENTH24-Canvas

Lecture + Tutorials + Lab Format

Mon and Wed for 1.5hrs (12:00pm-1:30pm)

1. Lecture - First 50mins
2. Tutorial - Next 20mins
3. Hands-on Lab and Office Hours

Fridays: 12-1pm: Recitation + Teamwork Time in KLAB

This way we meet for a substantial amount of time so you get the guidance to succeed.

Lesson Plan

Part I: Learn to Drive

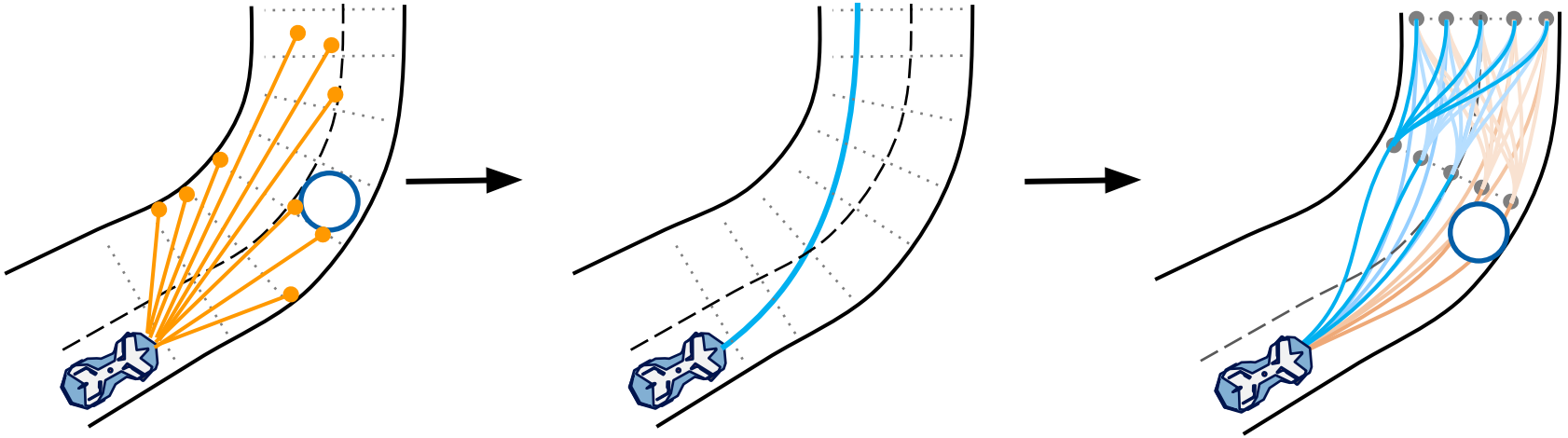
Autonomous Driving w/ F1TENTH

Avoid the crash - Reactive Planning

Part II: Learn to Race

Follow the Raceline - Pure Pursuit

Race & Overtake - Graph Planner



1. Follow The Gap
2. Follow The Raceline
3. Race

Course Schedule

A. Robotics and ROS basics
- a. Sensors and Mechanics
- b. Simulator
- c. Safe AV control basics

B. Navigation
- a. Reactive planning
- b. Mapping and Localization
- c. Pure Pursuit planning
- d. AV Ethics

C. AV Race Planning
- a. Raceline optimization
- b. RRT Planner
- c. Model Predictive Control

D. Vision and Learning
- a. Detection and Pose Estimation
- b. RL

E. Hands-on Project
- a. Drive till you MHz!

Lecture	Lecture Topic	Tutorial	Assignments Out
	Module A: Introduction to ROS, F110 & the Simulator		
1	Introduction to Autonomous Driving: Perception, Planning Control	T1: Intro to Docker & ROS 2	Lab 1: ROS 2 (individual)
2	Automatic Emergency Braking	T2: Intro to F1Tenth Sim	Lab 2: Automatic Emergency Braking
3	Rigid Body Transforms	T3: ROS2 and tf2	
	Module B: Reactive Methods & *RACE!*		
4	Wall Following	T4: Race car hands-on	Lab 3: Wall Following
5	Follow the Gap: Obstacle Avoidance		Lab 4: Follow the Gap
6	Vehicle State and Dynamics		
7	Scan matching		Lab 5. Scan Matching
8	Race Preparation		
9	**Race 1: Reactive**		
	Module C: Mapping & Localization		
10	Localization: Particle Filter	T5: Running Particle Filter	
11	SLAM: Cartographer	T6: Cartographer/HectorSLAM	Lab 6: Carto & Pure Pursuit
12	Pure Pursuit		
	Module D: Planning & Control		
13	Global Planning: Maps, A*, Djikstra		
14	Local Planning: RRT, Spline Based Planner		Lab 7: Motion Planning
	SPRING BREAK		
15	Path Tracking: MPC		
	Module E: Vision		
16	Classical Perception and Vision - Lane Detection & Optical Flow		Lab 8: Perception & Vision
17	ML Perception and Vision - Object Detection and Tracking		Lab 9: Ethics for AVs
18	Race Prep		
19	**Race 2: With Map**		
20	Final Project Overviews		Final Project Proposal
21	Ethics		
	Module F: Special Topics		
22	Raceline Optimization: Minimum Curvature, Minimum Time, Tunercar		Final Project
23	Theme 1: Autonomous Racing in the Real World		
24	Theme 2: AV Perception		
25	Theme 3: AV Middleware, OS		
	Flex		
	Module G: F1TENTH Grand Prix!!		
26	Project Demos		
27	Race Prep		
28	**Final Race Day**		
29	Final Project Documentation Submission Deadline		

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D. Vision and Learning
- a. Detection and Pose Estimation
- b. RL

E. Hands-on Project
- a. Drive till you MHz!

Date	#	Lecture Topic	Tutorial	Assignments Out	Due
		Module A: Introduction to ROS, F110 & the Simulator			
1/11	1	**Introduction to Autonomous Driving and Racing**	T1: Intro to ROS 2	Lab 1: ROS 2	
1/18	2	**Automatic Emergency Braking**	T2: Intro to F1Tenth Sim	Lab 2: AEB	Lab 1
1/23	3	**Rigid Body Transforms**	T3: ROS2 and tf2		
		Module B: Reactive Methods			
1/25	4	**Wall Following**	T4: Hands-on with race car	Lab 3: Wall Following	
1/30	5	**Vehicle States, Vehicle Dynamics and Maps**	T4 continued		Lab 2
2/1	6	**Follow the Gap: Obstacle Avoidance**	T4 continued	Lab 4: Follow the Gap	
		Module C: Mapping & Localization			
2/6	7	**Filtering**	Race Preparation Office Hours (OH)		Lab 3
2/8	8	**Localization: Particle Filter**	T5: Running Particle Filter		
2/13	9	**Race 1: Reactive Racing**			Lab 4
2/15	10	**Scan matching**	Office Hours (OH)		
2/20	11	**Introduction to Graph-based SLAM**	T6: Running slam_toolbox	Lab 5: SLAM & Pure Pursuit	
		Module D: Planning & Control			
2/22	12	**Pure Pursuit**			
2/27	13	**Intro to Optimization**	OH		Lab 5
3/1	14	**Local Planning: RRT, Spline Based Planner**		Lab 6: Motion Planning	
		Spring Break			
3/13	15	**Path Tracking: Model Predictive Control**	OH		
		Module E: Vision			
3/15	16	**Classical Perception**		Lab 7: MPC	
3/20	17	**Machine Learning Perception**	OH	Debate: Ethics for AVs	Lab 6
3/22	18	**Final Project Overviews**	Race Prep	Lab 8: Perception & Vision	
3/27	19	**Race 2: Racing with map**			
3/29	20	Final Project Discussions			Lab 7
4/3	21	Ethics: Moral Decision Making in AVs			Debate
		Module F: Special Topics			
4/5	22	**Raceline Optimization**		Final Project	Lab 8
4/10	23	**Special Topic 1: Reinforcement Learning**		Final Project	Proposal
4/12	24	**Special Topic 2: Game-Theoretic Planning**		Final Project	
4/17	25	**Special Topic 3: Assured Autonomy**		Final Project	
4/19		**Race Prep**		Final Project	
		Module G: F1TENTH Grand Prix!!			
4/24	26	**Final Race Day**			
4/26	27	**Special Topic 4: Guest**			
5/3	28	**Project Demos**			Final Demo
5/3	29	**Final Project Documentation Submission Deadline**		Project report	

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- b. Mapping and Localization
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C. AV Race Planning
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D. Vision and Learning
- a. Detection and Pose Estimation
- b. RL

E. Hands-on Project
- a. Drive till you MHz!

Date	Day	Lecture	Lecture Topic	Tutorial	Assignments Out	Assignments Due
			Module A: Introduction to ROS, F110 & the Simulator			
1/22	M	1	Introduction to Autonomous Driving: Perception, Planning Control [Slides] [Video]	T1: Intro to ROS 2 [Slides] [Video]	Lab 1: ROS 2 (individual)	
1/24	W	2	Automatic Emergency Braking [Slides] [Video]	T2: Intro to F1Tenth Sim [Repo][Video]	Lab 2: Automatic Emergency Braking	
1/29	M	3	Rigid Body Transforms [Slides] [Video]	T3: ROS2 and tf2 [Slides]		Lab1
			Module B: Reactive Methods			
1/31	W	4	PID for Wall Following [Slides] [Video]	T4: Getting to know the car, odom tuning, battery safety, running containers on the car, remote desktop, network setup [Slides]	Lab 3: Wall Following	
2/5	M	5	Vehicle States and Vehicle Dynamics [Slides] [Video]	T4 continued, cars hands on		Lab 2
2/7	W	6	Follow the Gap: Obstacle Avoidance [Slides] [Video]	T4 continued	Lab 4: Follow the Gap	
			Module C: Mapping & Localization			
2/12	M	7	Filtering [Slides] [Video]	Race Preparation Office Hours (OH)		Lab 3
2/14	W	8	Localization: Particle Filter [Slides] [Video]	Race Preparation Office Hours (OH)		
2/19	M		Race 1 prepare	Race Preparation Office Hours (OH)		
2/21	W		**Race 1: Reactive Racing**			Lab 4
2/26	M	9	Introduction to Graph-based SLAM [Slides] [Video]	T5: Running slam_toolbox and pf [Slides]	Lab 5: SLAM & Pure Pursuit	
			Module D: Planning & Control			
2/28	W	10	Pure Pursuit [Slides] [Video]			
3/4						
3/6				Spring Break		
3/11	M	11	Local Planning: RRT, Spline Based Planner [Slides] [Video]	OH	Lab 6: Motion Planning	
3/13	W	12	Optimization & Control I: Optimization Basics and LQR			Lab 5
3/18	M	13	Optimization & Control II: Model Predictive Control [Slides] [Video]	OH	Lab 7: MPC	
			Module E: Vision			
3/20	W	14	Classical Perception [Slides] [Video]		Lab 8: Perception & Vision	
3/25	M	15	Machine Learning Perception [Slides] [Video]	OH	Debate: Ethics for AVs	Lab 6
3/27	W		Final Project Overviews [Slides]	Race Prep		
4/1	M		Final Project Discussions			Lab 7
4/3	W		**Race 2: Racing with map**			
4/8	M	16	Ethics [Slides]	T6: F1Tenth on Foxglove		Debate (before lecture) +
			Module F: Special Topics			
4/10	W	17	Raceline Optimization [Slides]		Final Project	Lab 8
4/15	M	18	Reinforcement Learning and Imitation Learning [RL slides, IL slides]		Final Project	
4/17	W	19	Special Topic 1:		Final Project	
4/22	M	20	Special Topic 2:		Final Project	
4/24	W		Race 3 prepare		Final Project	
			Module G: F1TENTH Grand Prix!!			
4/29	M		**Final Race Day**			
5/1	W	21	AV4EV Autonomous Electric Go-Kart Project in Pennovation [Slides]			
5/9	M		Project Demos			Final Project Demo
5/12	T		Final Project Documentation Submission Deadline			Project report submission
			Note: Demos and Final project dates are firm. No extensions.			

Teams

→ **4 students per team**

→ **Diverse teams**

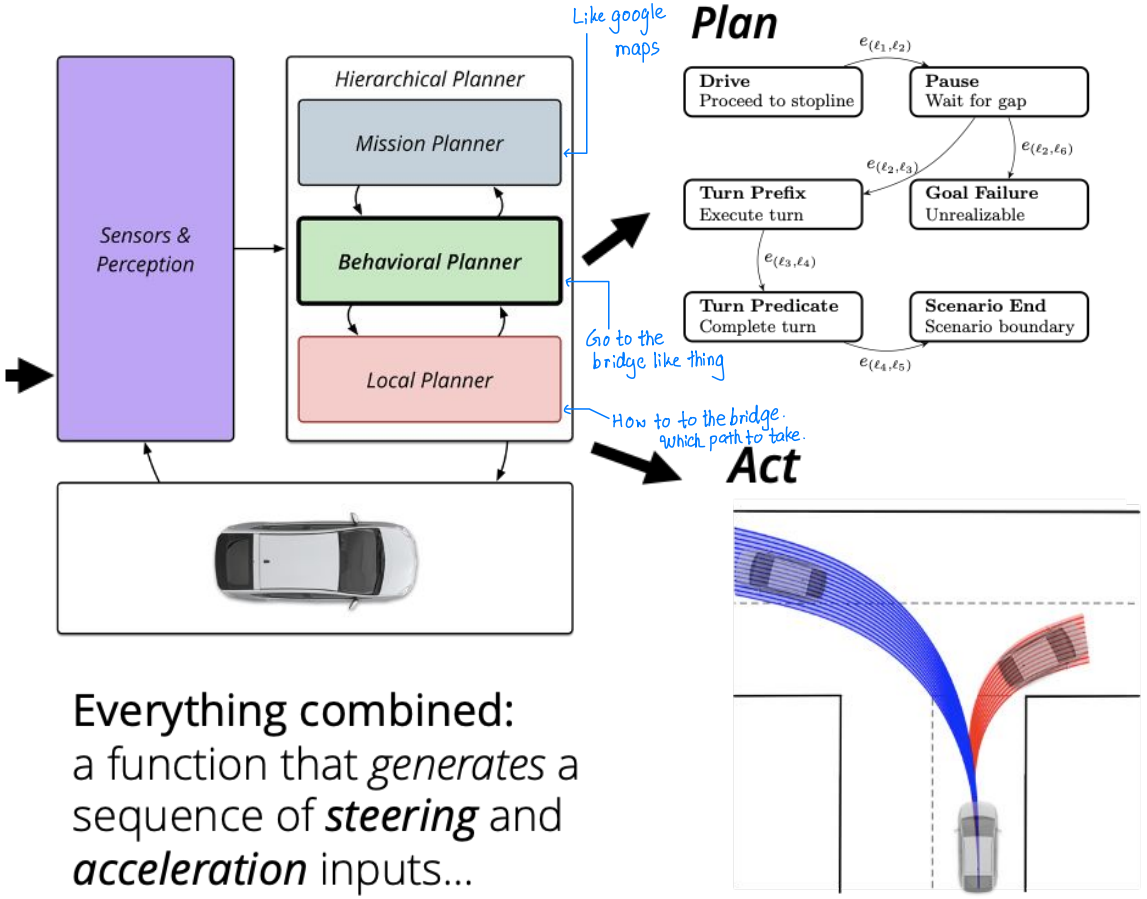
- Mix of Majors (only one per team): MEAM, EE, ROBO, CIS
- Mix of Geography
- Mix of programming expertise (py, C++)

→ **We will assign teams**

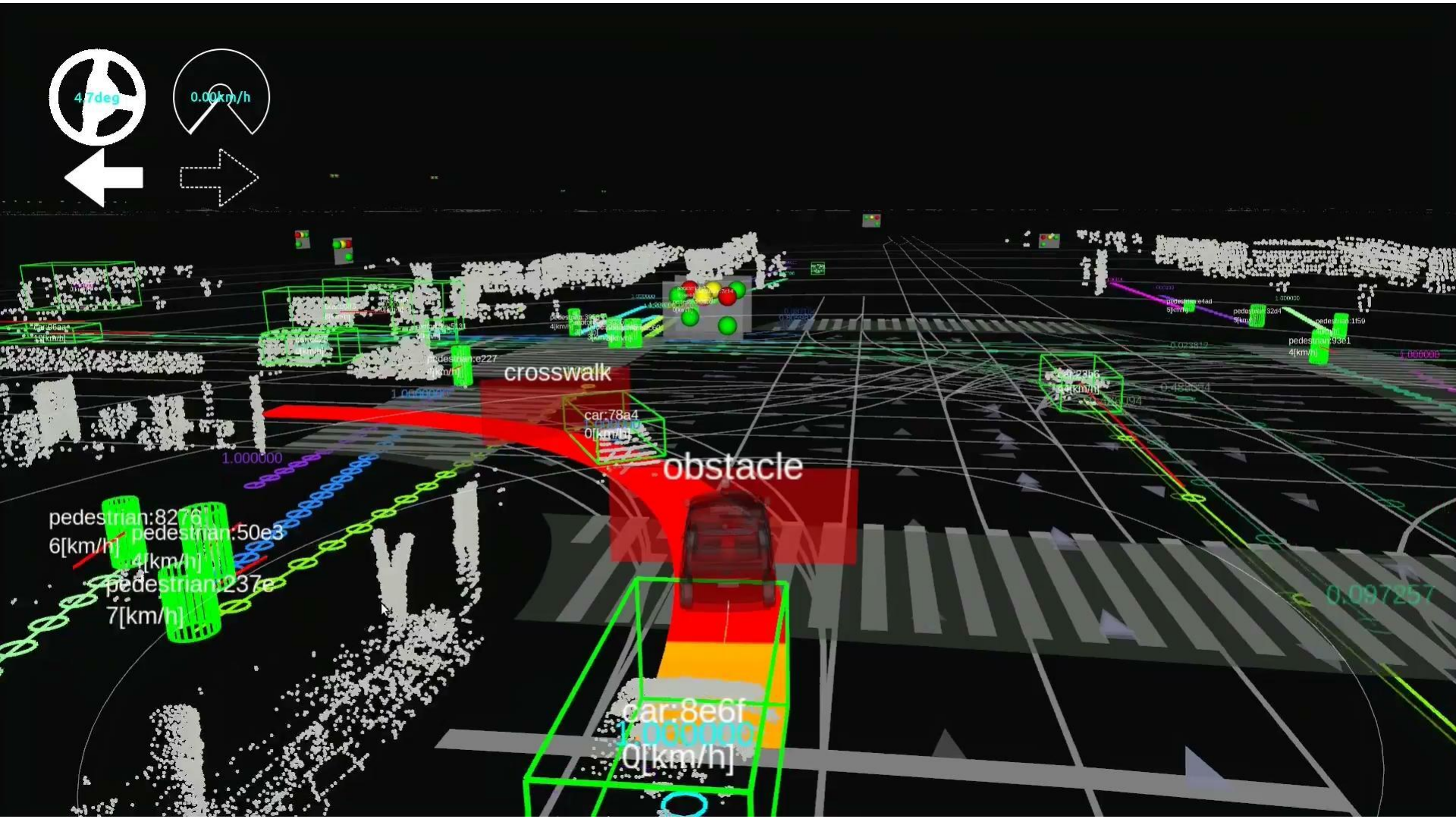
I. Autonomous Cars today

AV Perception, Planning, Control pipeline

Sense



Everything combined:
a function that *generates* a sequence of ***steering*** and ***acceleration*** inputs...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pedestrian:8276
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PREFECT
Winterthur
Ohringen
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Polizei
71
2016-05-19 07:04:02 --- km/h
DR650GW-2CH/FHD-HD

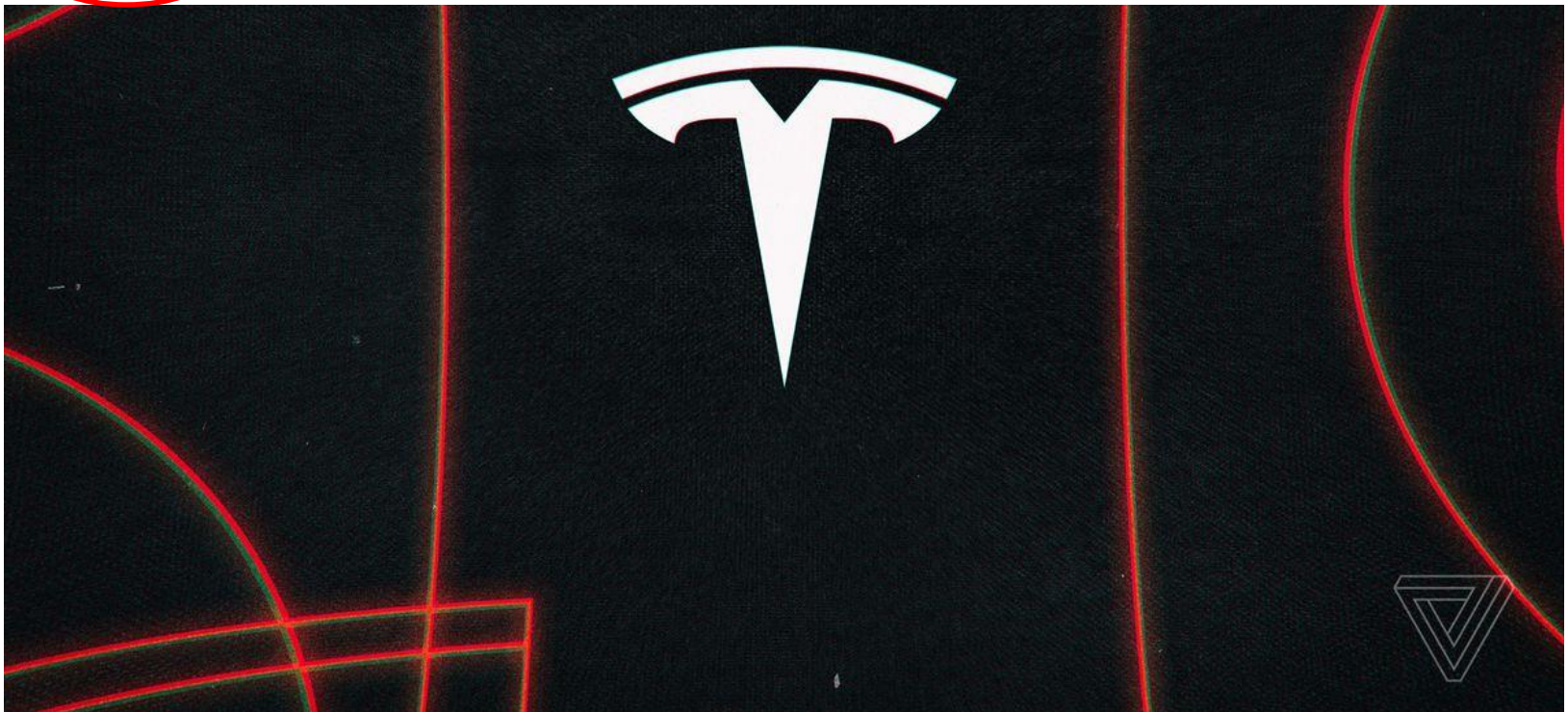

gb
cctv


2018/11/17 12:17:04
2018 Tesla crash – these failures are real!

Tesla ‘recalls’ more than 285,000 vehicles in China over cruise control safety concerns

Most of the affected vehicles were made in China at Tesla’s Shanghai plant

By Kim Lyons | Jun 26, 2021, 9:02am EDT



Balancing Performance and Safety

Current AV technology still struggles in non-cooperative scenarios like merging due to competing objectives:

- **Maximize performance:** negotiate the merge without delay or hesitation
- **Maintain safety:** avoid catastrophic failures and crashes

Racing (autonomously) highlights this performance safety tradeoff.

Videos: Mobileye and Formula 1

Autonomous Driving: Why racing ?

1

Detecting the vehicle limits

Unstructured Environment

Different Tracks and Conditions

Different vehicle setups

2

Decision making at the vehicle limits

High prediction uncertainty

Strategy, Energy, Overtaking

3

Handling at the vehicle limits

High speeds, High accelerations

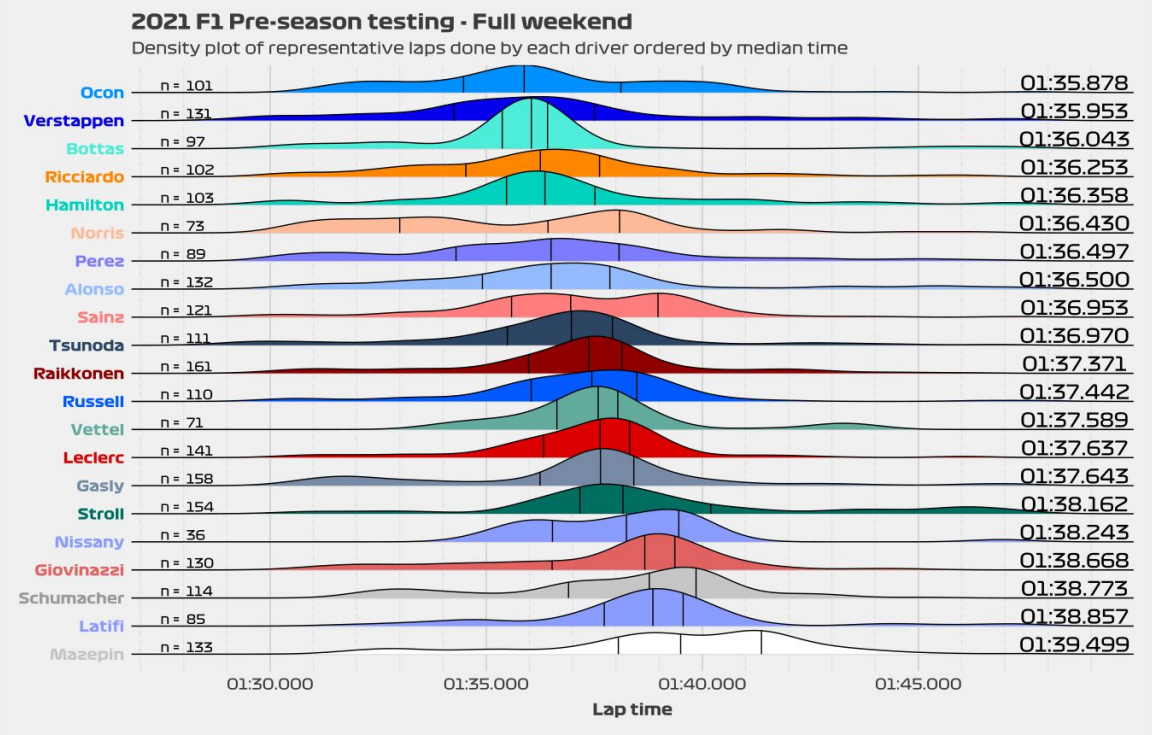
High planning horizon necessary

Small reaction times

Penn Engineering F1TENTH

F1 Fun Fact #1 Lap-time matters

½ second slower and
you are out of the Top 10

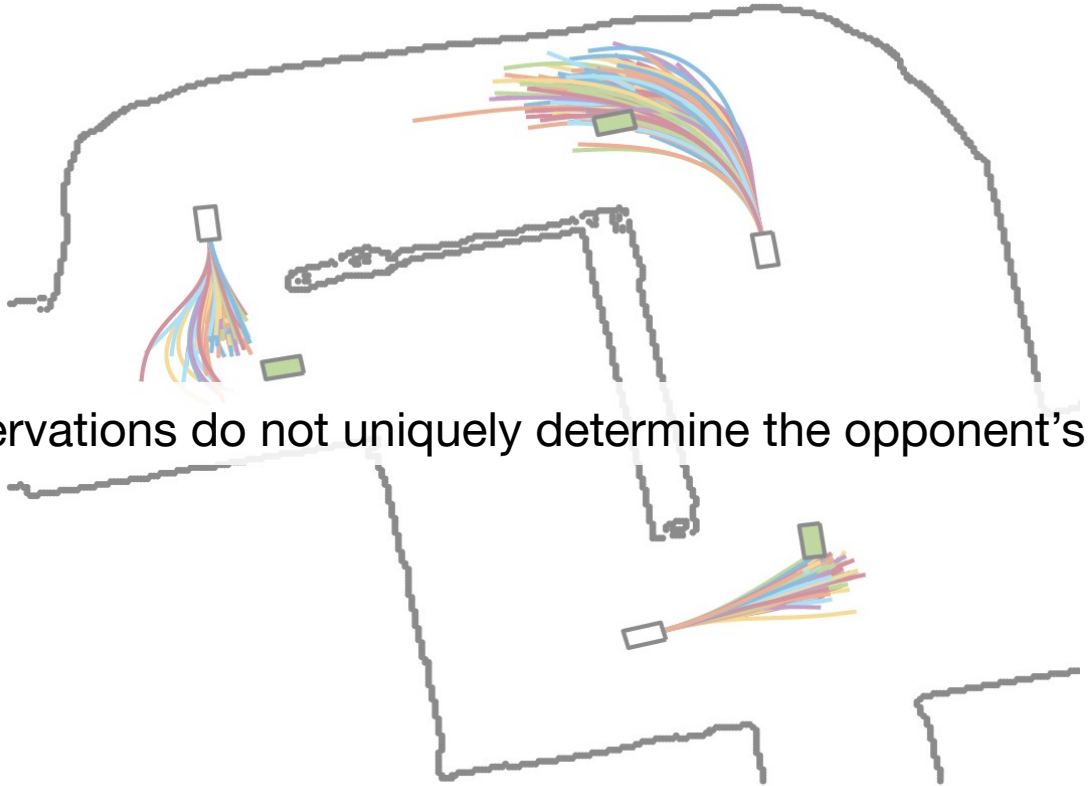


F1 Fun Fact #2 Lap-time matters but….

F1 1950-2022, race winner achieved fastest lap-time in only 40.2% of races

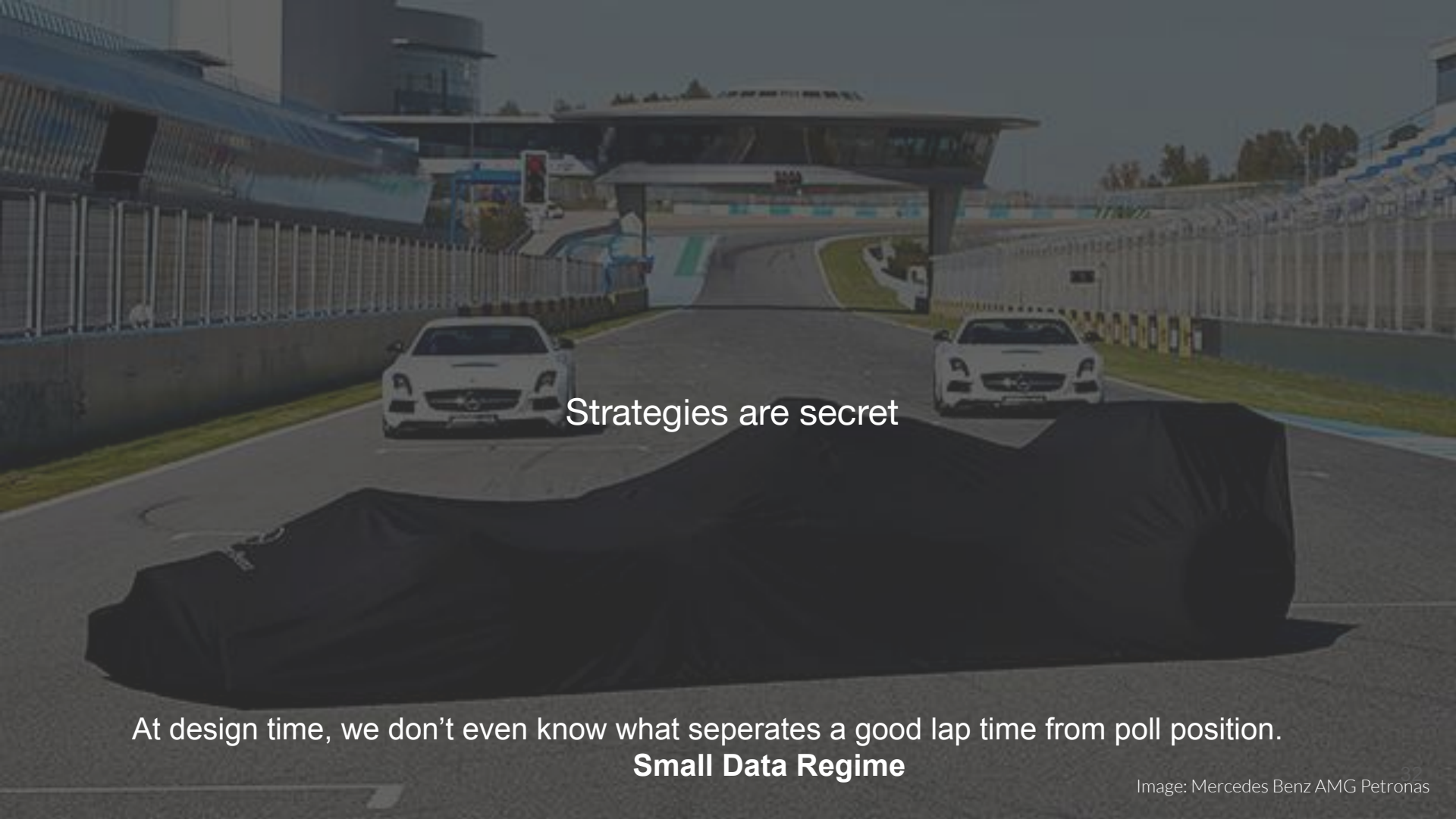
Consistency and achieving the right balance between
aggressiveness and restraint
are crucial to success in racing

Image: Formula 1



Sensor observations do not uniquely determine the opponent's behavior

The actions of elite policies (given identical sensor observations) are strongly multi-modal.



At design time, we don’t even know what seperates a good lap time from poll position.

Small Data Regime

Image: Mercedes Benz AMG Petronas

Autonomous Racing 2022-23

F1TENTH

Roborace

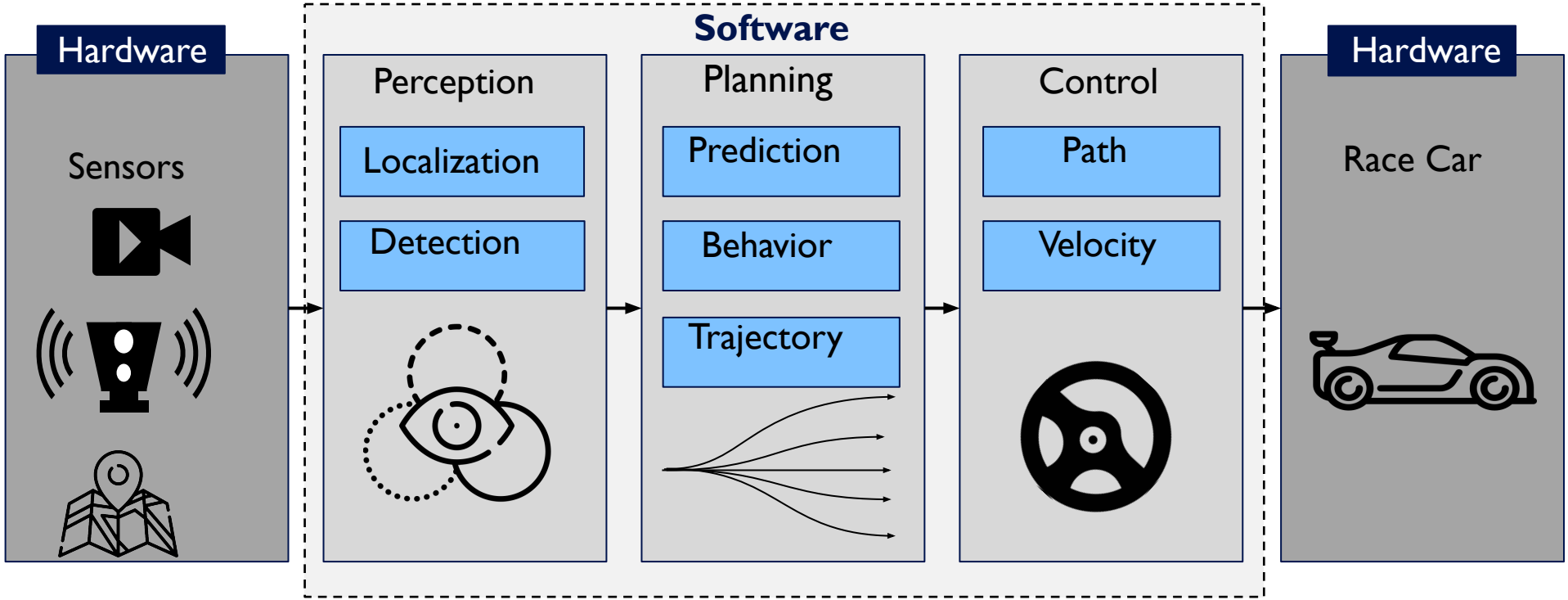
Formula Student

Indy Autonomous Challenge

Indy 2023 - just last weekend

Penn

Autonomous Driving - The Pipeline



Low-Cost Open-Source Platform for Machine Learning engineering on **Perception, Planning & Control**

F1 TENTH

Lecture Snapshots

Penn Engineering X F1 TENTH

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D. Vision and Learning
- a. Detection and Pose Estimation
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Module A: AV Driving Basics

Penn Engineering X F1 TENTH

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- b. Mapping and Localization
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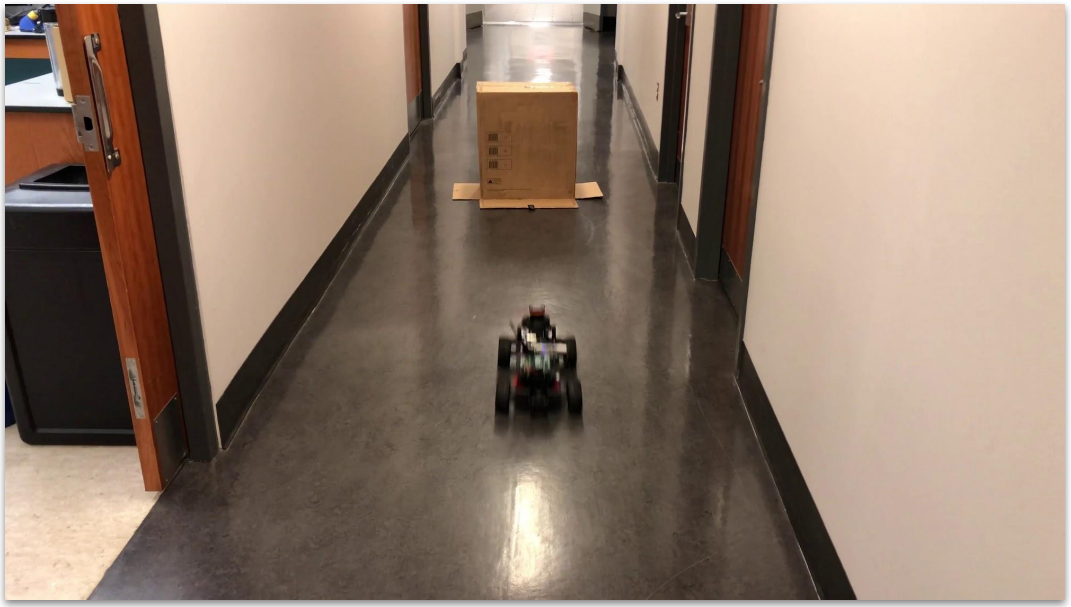
Automatic Emergency Braking

Challenge:
Prevent the car from crashing while trying new algorithms.

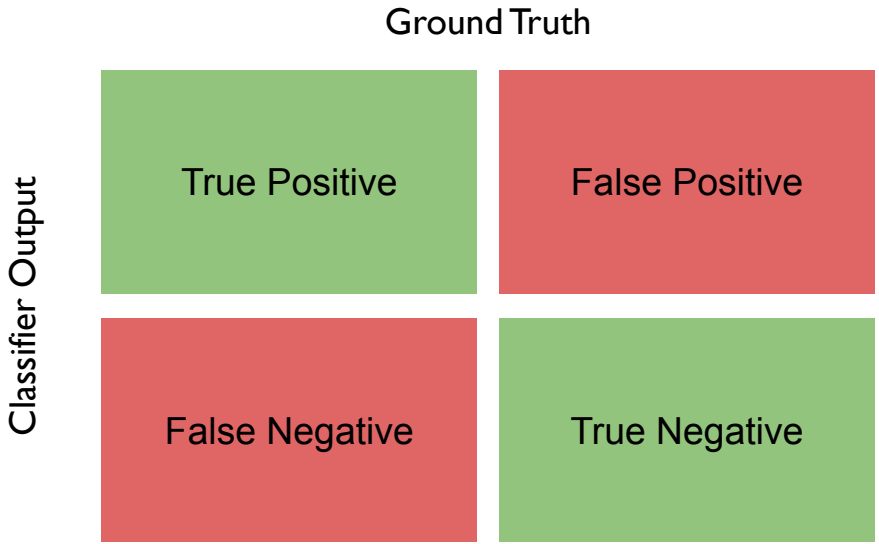
Learning outcome:
Real-life implementations, sensors, failure modes.

Assignment:
Time-to-collision based braking



Types of Failures

Which one of these is a serious problem?



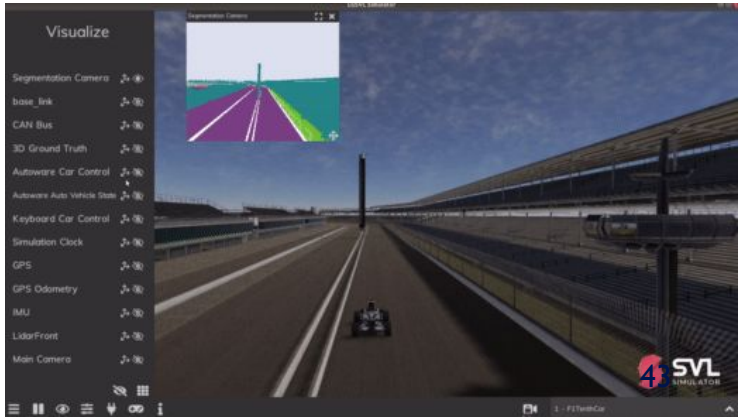
F1Tenth Simulation Environments

F1TENTH Gym:

- Lightweight 2D simulator built in Python
- Asynchronous
- Faster than real-time execution (30x realtime)
- Realistic vehicle simulation and collision
- Runs multiple vehicle instances
- Publishes laser scan and odometry data
- Built for fast prototyping

LG SVL Simulator:

- 3D Simulator with Unity based Environments
- Distributed Cloud Simulation
- Bridges: ROS, ROS2, Apollo, Autoware, Python
- Sophisticated Physics Simulation
- Sensor Integration



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F1Tenth Simulator Tutorial

F1TENTH Gym:

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- Asynchronous
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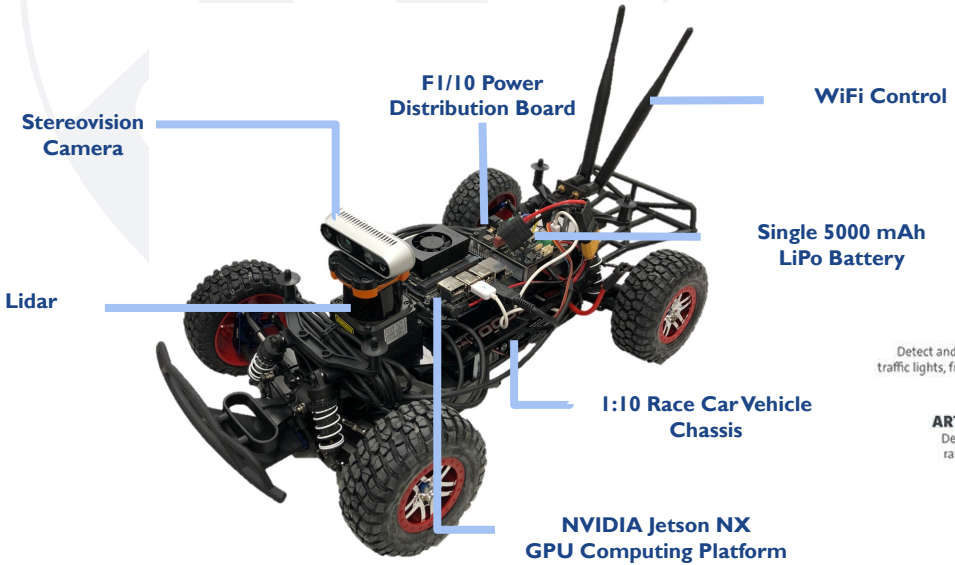
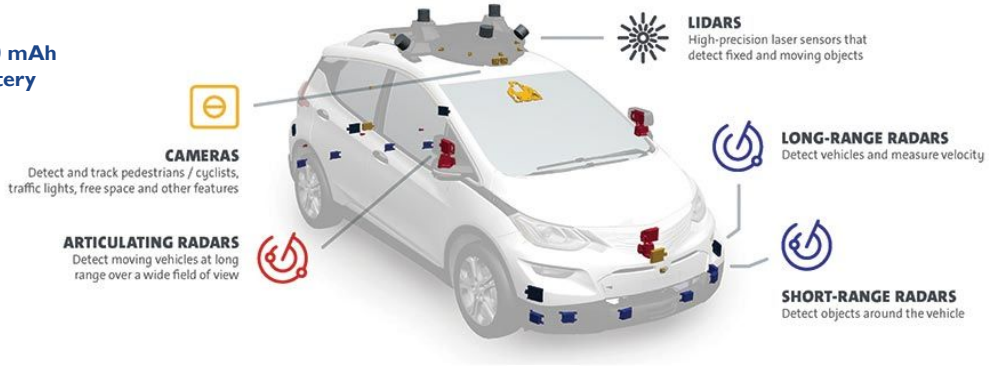
Pose Representation and Transforms

Each sensor provides measurements in the frame of reference specific to that sensor





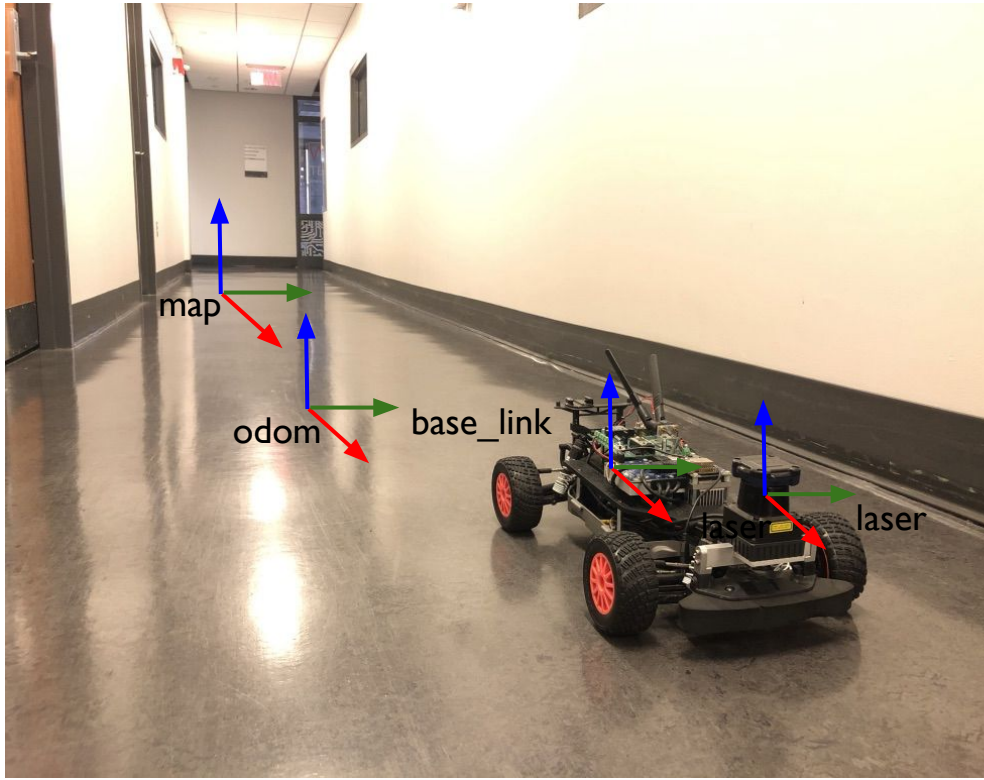
www.autonomousvehicletech.com

Pose Representation and Transforms

Challenge:
Sensors in different reference frames

Learning outcome:
Coordinate frames, Rigid body transforms

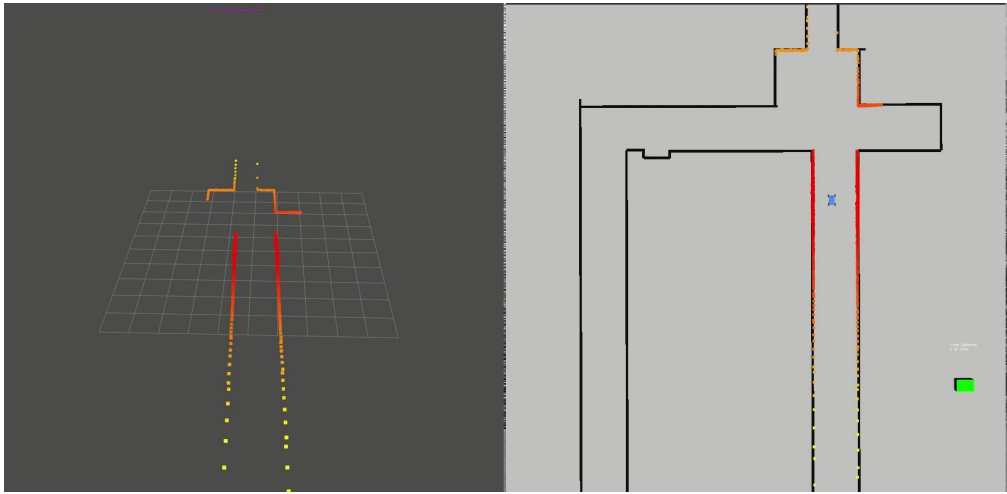
Assignment:
Pose transformations in ROS



Multiple Reference Frames

- The world makes more sense if we put the laser scans in the global map frame instead of the **laser frame.**

- More information available when planning in a **global frame** instead of extracting information in the observation frame.



Electronic Speed Control

Challenge:
Actuate vehicle via commands in physics units

Learning Outcome:
PID, motor control, etc.

Assignment:
Motor controller tuning and related parameters

Module B: Reactive Methods

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Wall-following

Challenge:
How can we drive the car around the track

Learning Outcome:
Basics of PID, how to compute error, failure modes.

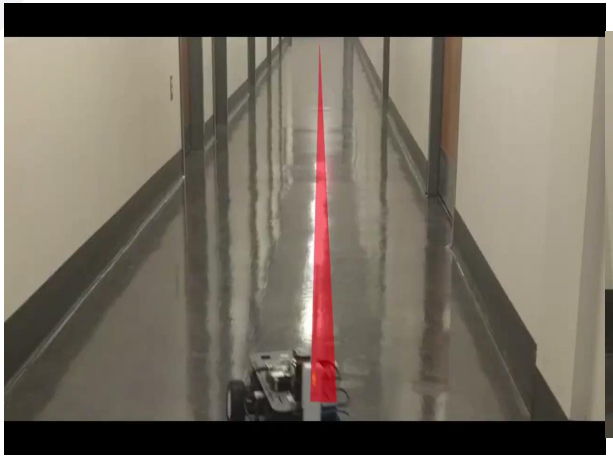
Assignment:
Wall following in simulation and on the vehicle.

PID

Effective tuning of the gains is crucial to good performance.

K_P=14, K_i=0.01, K_D=0

K_P=5, K_i=0, K_D=0.09



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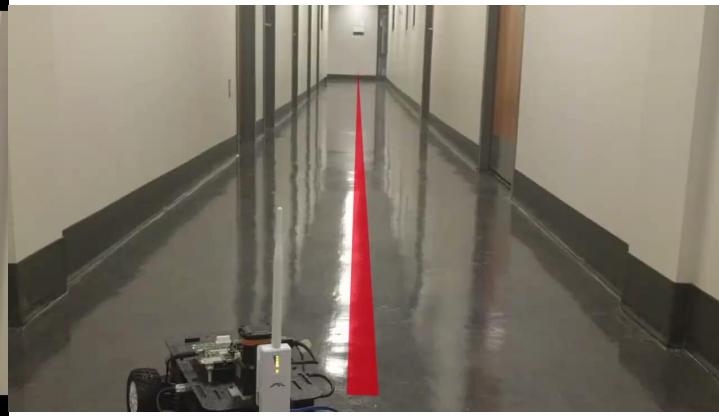
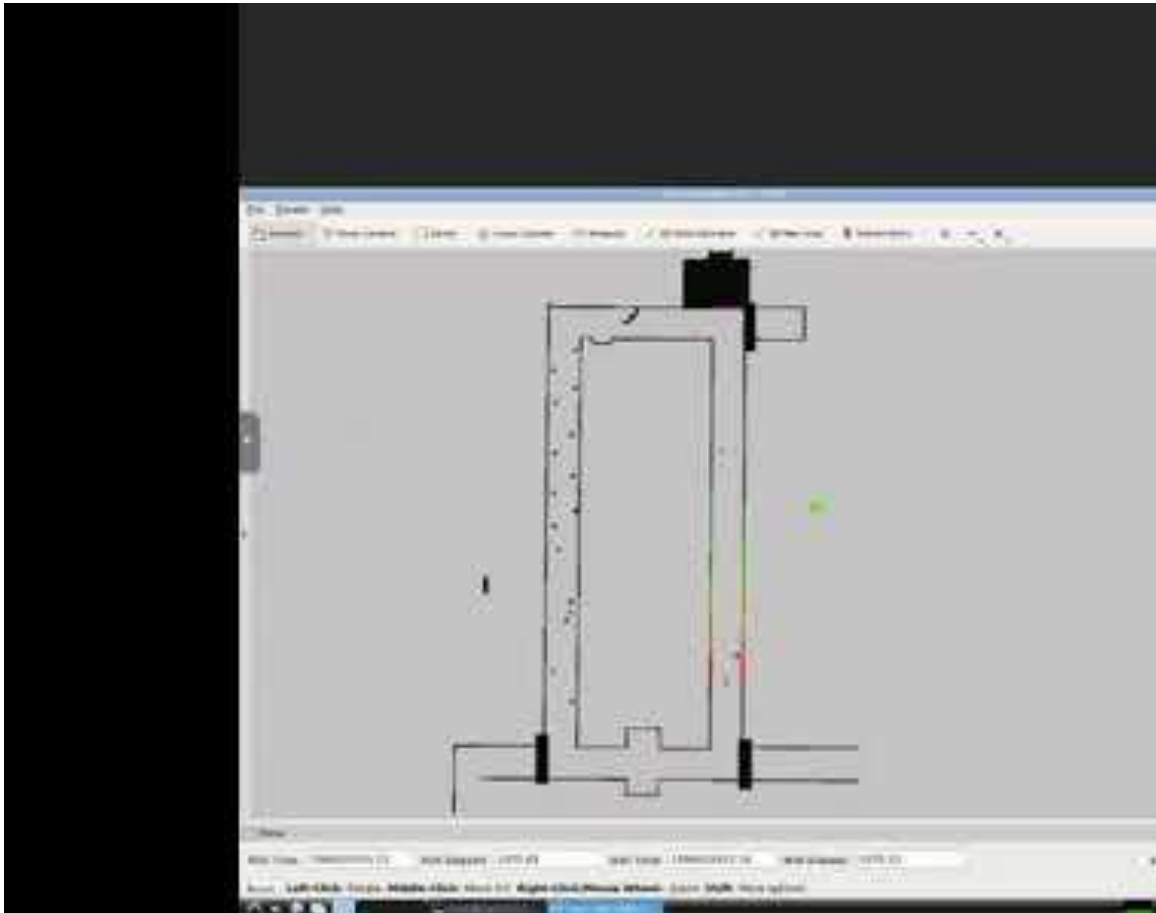


Obstacle Avoidance: Follow the Gap

Challenge:
How can we avoid obstacles

Learning Outcome:
Basics of reactive navigation, avoidance on both static and dynamic obstacles

Assignment:
Follow the gap in simulation and on the vehicle.



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Obstacle Avoidance: Follow the Gap

Challenge:
How can we avoid obstacles

Learning Outcome:
Basics of reactive navigation, avoidance on both static and dynamic obstacles

Assignment:
Follow the gap in simulation and on the vehicle.

Race 1: Reactive Methods

- **Race Format:** Time attack, single car
- **Penalties:** Crashing
- **Baseline:** Complete 5 laps without crashing
- **Example Video:** Follow the Gap in CPSWeek Grand Prix'18

Module C: Map-based Methods

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Localization: Scan Matching

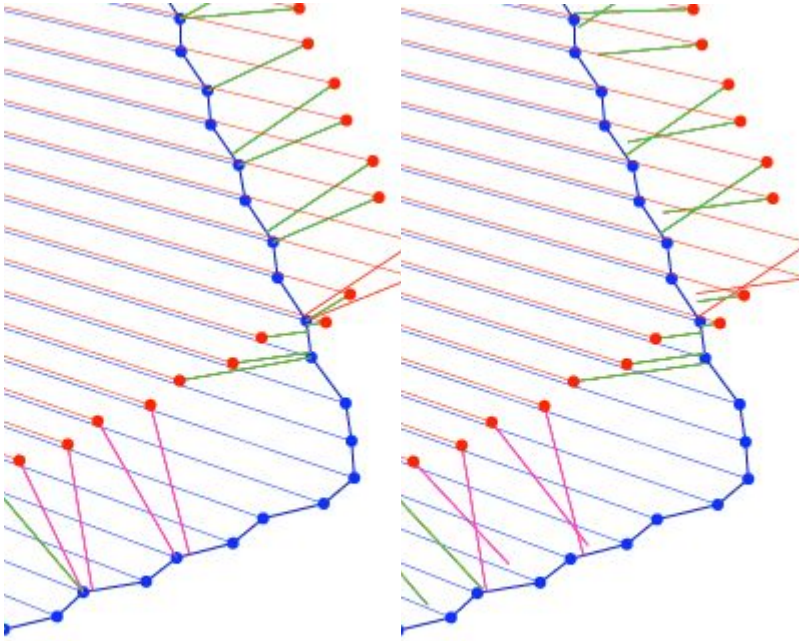
Challenge:
Where is the robot with respect to the previous frame

Learning Outcome:
Iterative closest point algorithm, implementing a real research paper

Understand:
Scan matching using iterative closest point in the simulator

Localization: Scan Matching

- Scan matching is a fundamental localization algorithm, and is used in most of the modern SLAM algorithms.
- Students implement different metrics (point-to-point vs. point-to-line, shown on the right) for ICP from a research paper.
- Students implement fast correspondence search to make ICP practical for a moving robot.

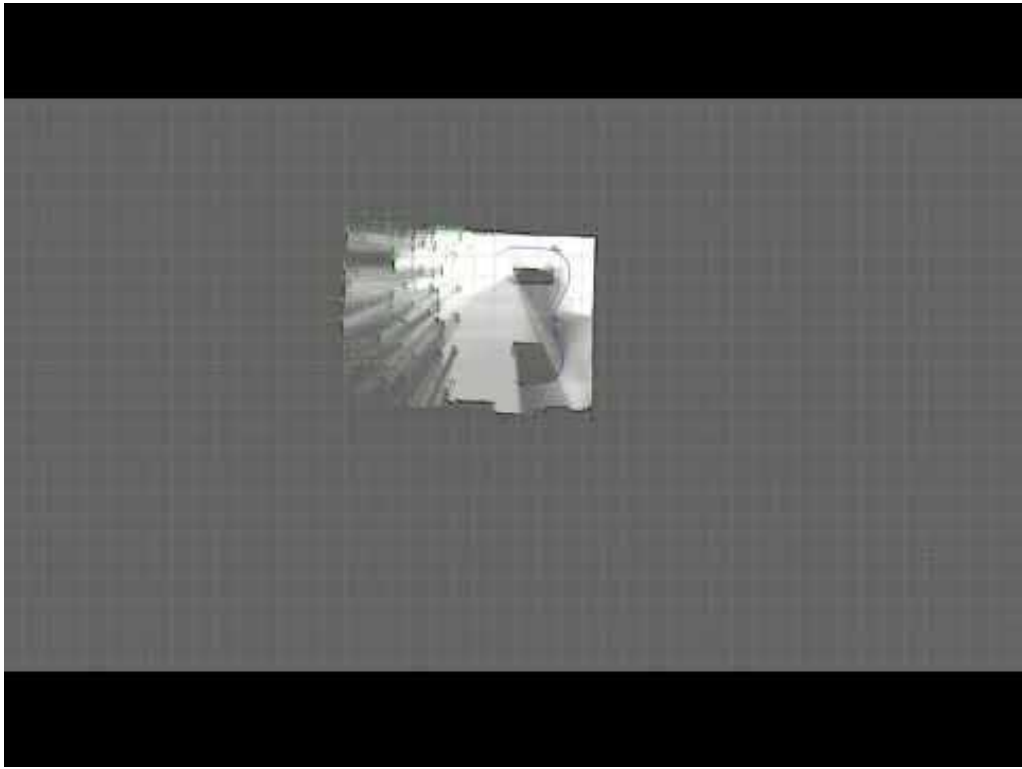


Simultaneous Localization and Mapping with Graph SLAM

Challenge:
How to use state-of-the-art tools for map building.

Learning Outcome:
Understanding the Graph SLAM and how it relates to scan matching.

Assignment:
Build maps with Graph SLAM of race track on the car.

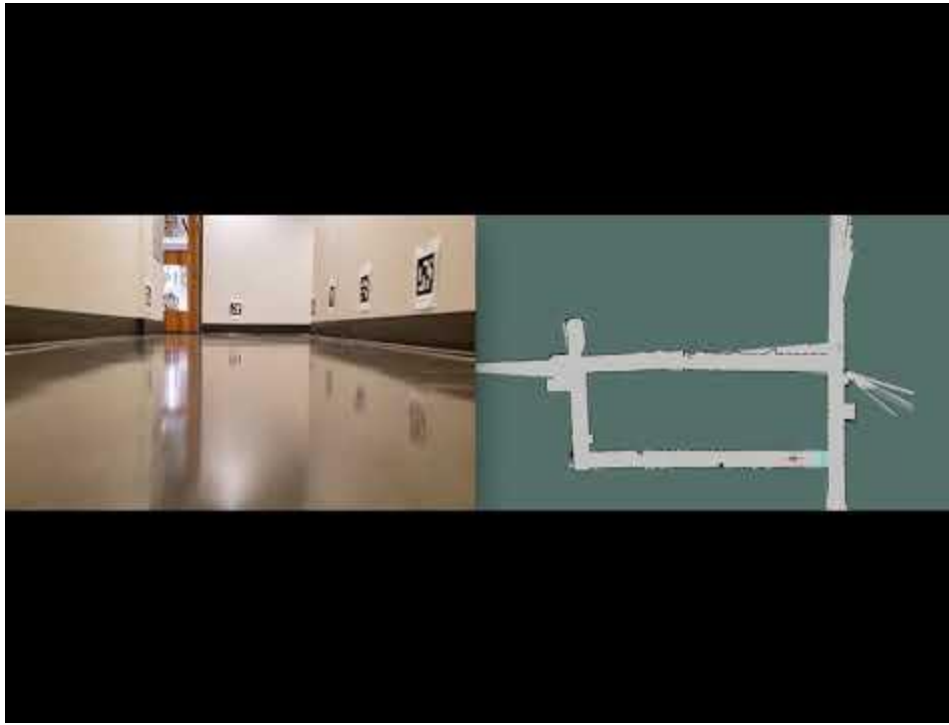


Localization: Particle Filter

Challenge:
Given a map of the world and multiple sensor observations, what is the pose of my robot?

Learning Outcome:
Understanding particle filter, which is a version of a bayesian filter

Assignment:
Running Particle Filter to localize in the world

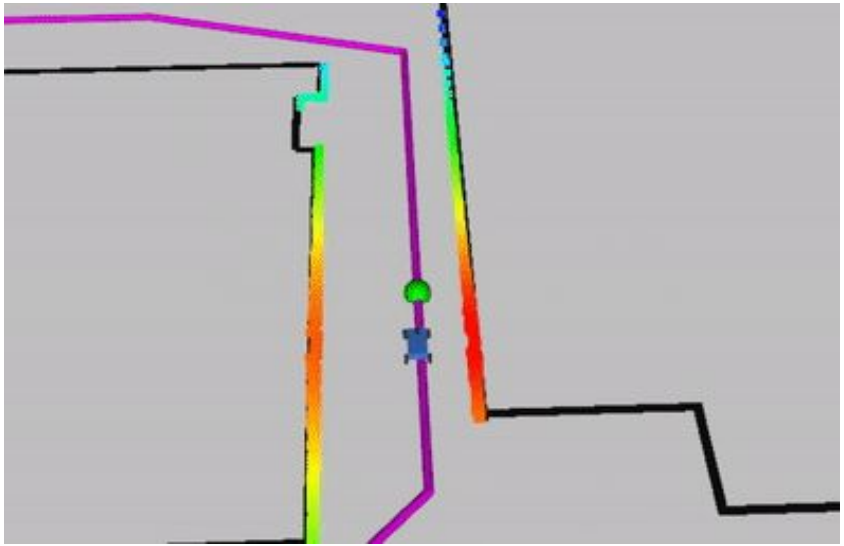


Pure Pursuit

Challenge:
How to track a reference trajectory given a map the ability to localize?

Learning Outcome:
Closed form geometric approach and alternatives.

Assignment:
Implement pure pursuit waypoint tracker in the simulator and on the car.



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Race 2: Map-based Methods

Race Format:
Time attack, single car

Penalties:
Crashing

Baseline:
Complete 5 laps without crashing

Example Video:
Pure Pursuit CPSWeek 2019

Module D: Motion Planning

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Motion Planning

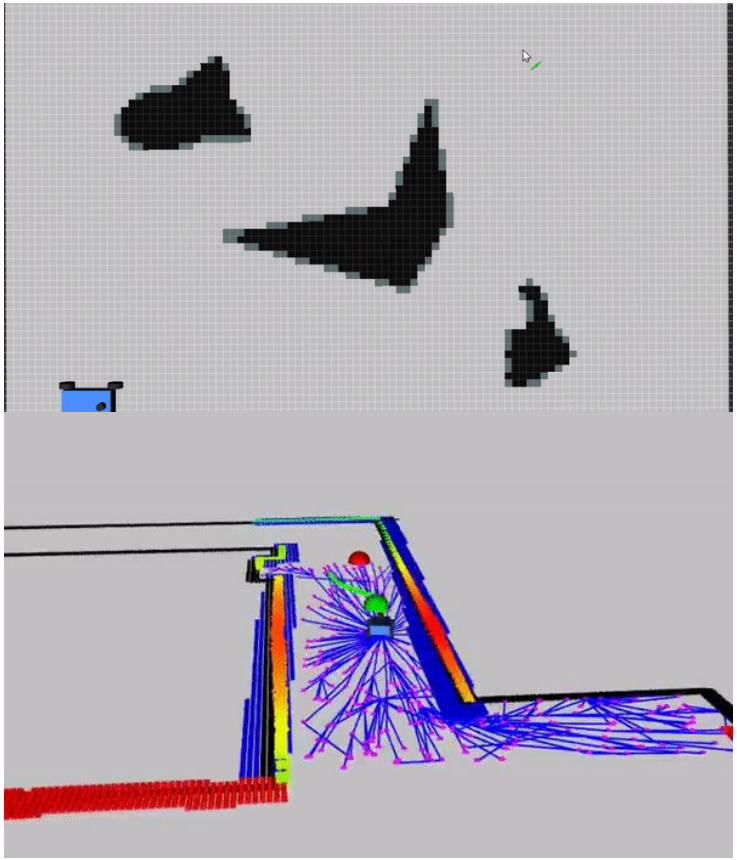
Challenge:
How do we combine the capabilities of map based methods while being able to avoid obstacles

Learning Outcome:
Understanding search-based motion planning, probabilistic planning methods, RRT and its variants

Assignment:
Implement RRT in the simulator and on the car.

Motion Planning

- **Occupancy grid:** approximating the real world with a discrete representation, also relates back to the SLAM lecture
- **Planning in discrete space** with search-based planning methods (A*, Dijkstra's)
- **Planning in continuous space** with probabilistic planning methods (RRT, RRT*)

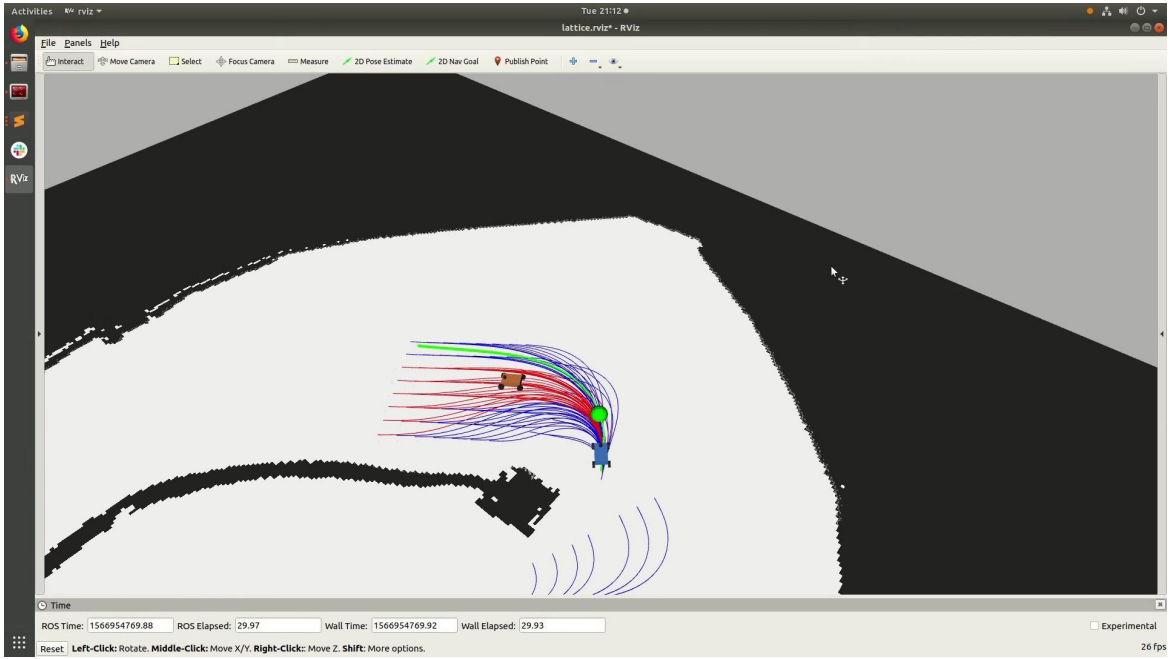


Model Predictive Control

Challenge:
Create dynamically feasible trajectories for overtaking

Learning Outcome:
Trajectory optimization & sampling based MPC

Assignment:
As a project option



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Classic Computer Vision: Detection and Pose Estimation

Challenge:

Where is the other car?

Learning Outcome:

Understanding camera model, single view geometry, Homography, detecting features, and prediction.

Assignment:

Camera calibration, detecting poses of AprilTags, predicting the trajectory of adversarial vehicle.

Learning-based Computer Vision: Detection and Pose Estimation

Challenge:

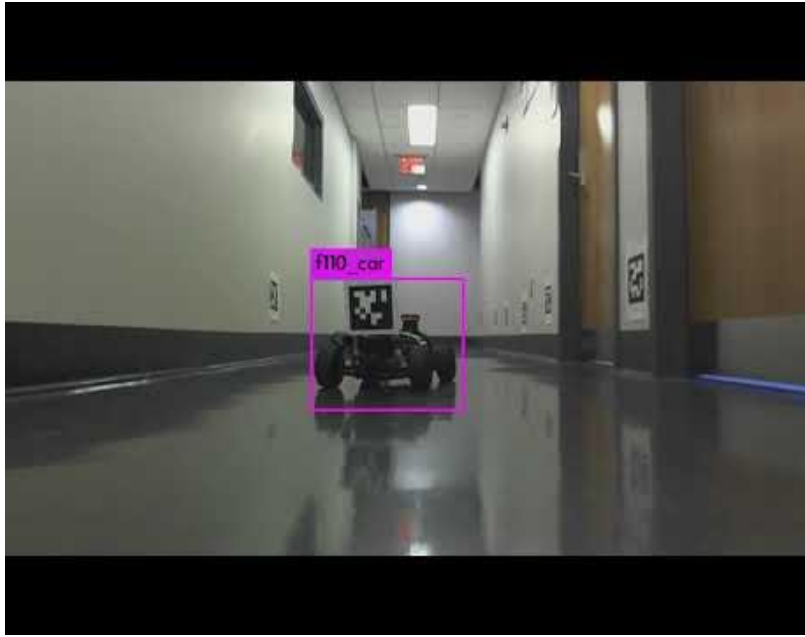
Where is the other car without using fiducial markers?

Learning outcomes:

Understanding multi-view geometry, the epipolar constraint, stereo vision, and using Convolution Neural Network detectors.

Assignment:

Making the detection pipeline fast



Reinforcement Learning

Challenge:

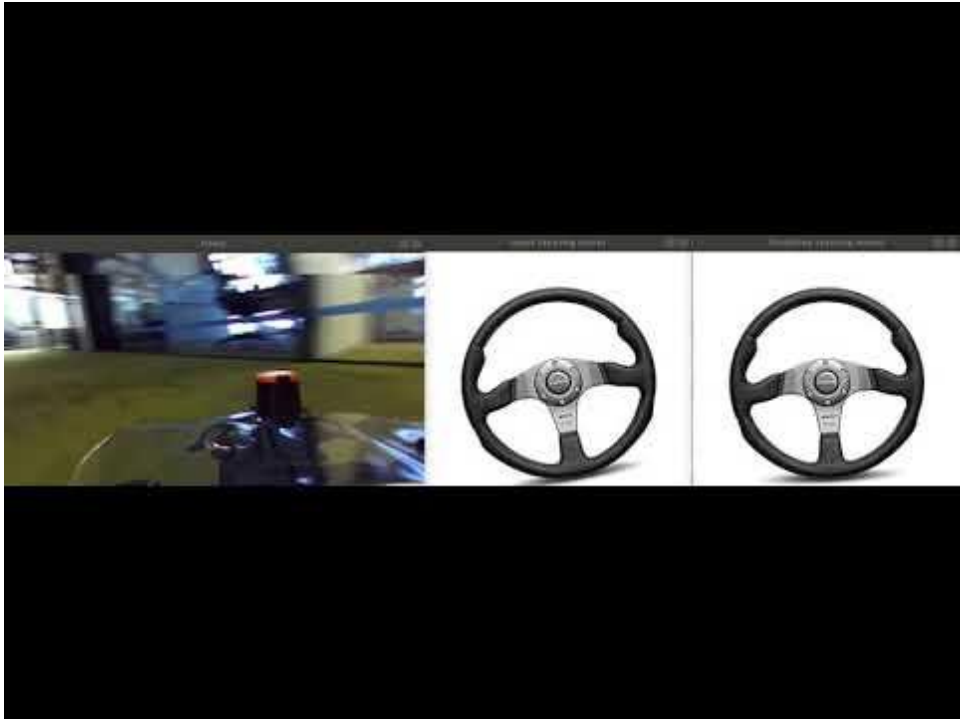
How to learn from human drivers?

Learning outcomes:

Understand imitation learning and implement it

Assignment:

RL as a project option.



Module F: Grand Prix

Penn Engineering × F1TENTH

Course Schedule

A. Robotics and ROS basics
- a. Sensors and Mechanics
- b. Simulator
- c. Safe AV control basics

B. Navigation
- a. Reactive planning
- b. Mapping and Localization
- c. Pure Pursuit planning
- d. AV Ethics

C. AV Race Planning
- a. Raceline optimization
- b. RRT Planner
- c. Model Predictive Control

D. Vision and Learning
- a. Detection and Pose Estimation
- b. RL

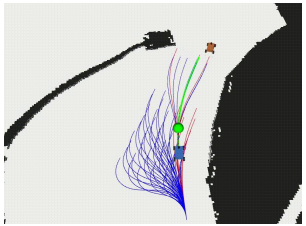
E. Hands-on Project
- a. Drive till you MHz!

Lecture	Lecture Topic	Tutorial	Assignments Out
	Module A: Introduction to ROS, F110 & the Simulator		
1	Introduction to Autonomous Driving: Perception, Planning Control	T1: Intro to Docker & ROS 2	Lab 1: ROS 2 (individual)
2	Automatic Emergency Braking	T2: Intro to F1Tenth Sim	Lab 2: Automatic Emergency Braking
3	Rigid Body Transforms	T3: ROS2 and tf2	
	Module B: Reactive Methods & *RACE!*		
4	Wall Following	T4: Race car hands-on	Lab 3: Wall Following
5	Follow the Gap: Obstacle Avoidance		Lab 4: Follow the Gap
6	Vehicle State and Dynamics		
7	Scan matching		Lab 5. Scan Matching
8	Race Preparation		
9	**Race 1: Reactive**		
	Module C: Mapping & Localization		
10	Localization: Particle Filter	T5: Running Particle Filter	
11	SLAM: Cartographer	T6: Cartographer/HectorSLAM	Lab 6: Carto & Pure Pursuit
12	Pure Pursuit		
	Module D: Planning & Control		
13	Global Planning: Maps, A*, Djikstra		
14	Local Planning: RRT, Spline Based Planner		Lab 7: Motion Planning
	SPRING BREAK		
15	Path Tracking: MPC		
	Module E: Vision		
16	Classical Perception and Vision - Lane Detection & Optical Flow		Lab 8: Perception & Vision
17	ML Perception and Vision - Object Detection and Tracking		Lab 9: Ethics for AVs
18	Race Prep		
19	**Race 2: With Map**		
20	Final Project Overviews		Final Project Proposal
21	Ethics		
	Module F: Special Topics		
22	Raceline Optimization: Minimum Curvature, Minimum Time, Tunercar		Final Project
23	Theme 1: Autonomous Racing in the Real World		
24	Theme 2: AV Perception		
25	Theme 3: AV Middleware, OS		
	Flex		
	Module G: F1TENTH Grand Prix!!		
26	Project Demos		
27	Race Prep		
28	**Final Race Day**		
29	Final Project Documentation Submission Deadline		

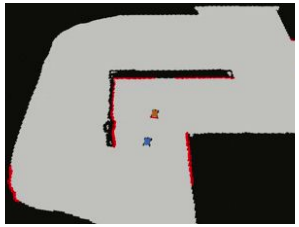
Race 3: Head-to-Head

- **Race Format:** Round-robin, two cars
- **Penalties:** Crashing
- **Baseline:** Avoid static obstacles
- **Example Video:** Follow-the-gap CPSWeek'19

F1TENTH: Research projects for students

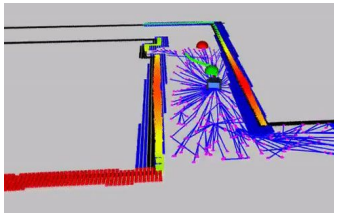


MPC Racing Stack

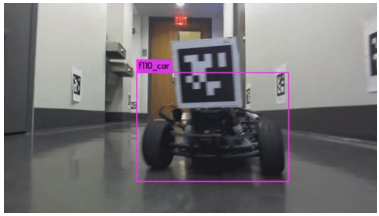


Overtaking & Improvisation

F1TENTH Hardware 2.0

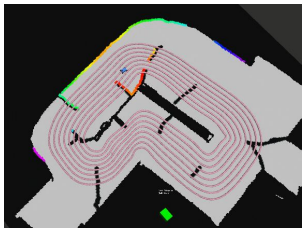


Multi-Vehicle Coordination



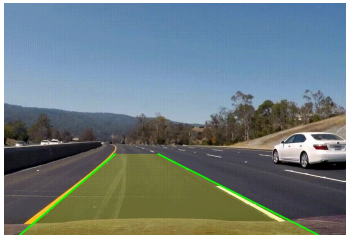
Object Detection

TUNERCAR*



Virtual Racing Front End

Visual Slam

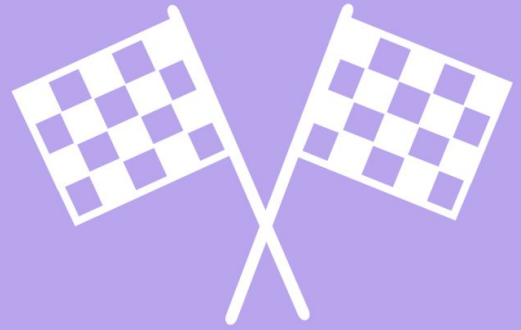


Vision-based Navigation

CAD2CAV

Penn Engineering F1 TENTH

AUTONOMOUS RACING



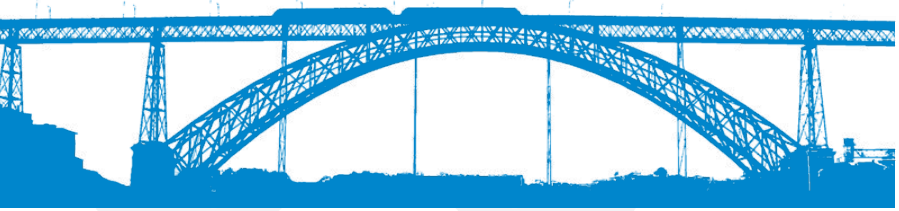
RACE

Register to Compete

International Competitions

2017 Embedded Networked Sensor Systems [SenSys], **Seoul**

2018 Cyber-Physical Systems Week [CPS-Week], **Portugal**



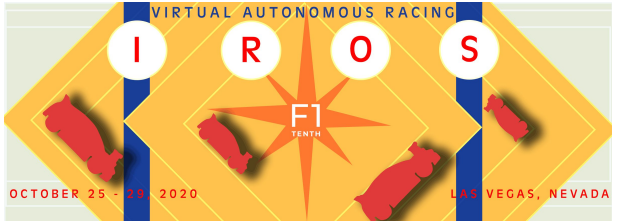
2018 Embedded Systems Week [ESweek], Torino, **Italy**

2019 Cyber-Physical Systems Week [CPSweek], **Montreal**, Canada

2019 Embedded Systems Week [ESweek], **New York City**

2020 IFAC World Congress, **Berlin**, Germany

2020 IROS International Conf. on Intelligent Robots & Systems



2021 IROS International Conf. on Intelligent Robots & Systems


NVIDIA

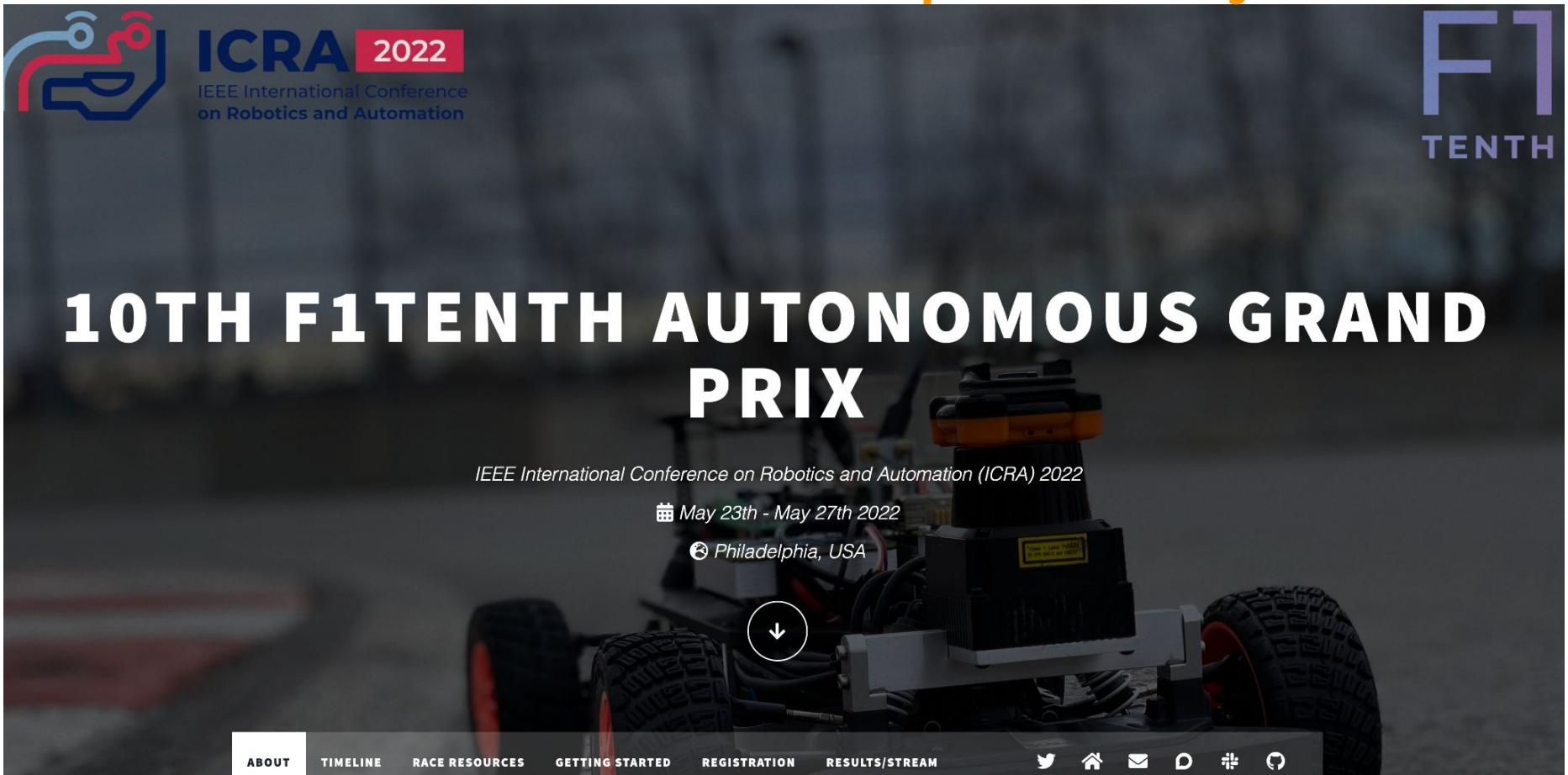
2022 F1Tenth Autonomous Racing Competition

ICRA 2022
IEEE International Conference on Robotics and Automation

May 22-27, 2022 in Philadelphia!

https://icra2022-race.f1tenth.org/

10th F1Tenth Autonomous Racing Competition At ICRA 2022 in Phialdelphia this May



10th F1Tenth Autonomous Racing Competition
At ICRA 2022 in Phialdelphia this May

Winner!

Zhijun Zhang

ing

10th F1Tenth Autonomous Racing Competition
At ICRA 2022 in Phialdelphia this May

F1TENTH Race Participants

- University of Pennsylvania
- Technische Universität Wien (Vienna University of Technology)
- Lehigh University
- Drexel University
- University at Buffalo
- Stony Brook University
- University of Central Florida
- ETH zürich
- Università degli Studi di Modena e Reggio Emilia (UNIMORE)
- The University of Texas at Austin
- Rice University
- UC San Diego
- The Autoware Foundation
- Alma Mater Studiorum A.D. 1088
- Polish Academy of Sciences
- Carnegie Mellon University


Control
Debug
we also measure accelerations

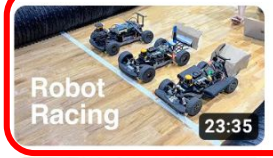
F1Tenth is going viral :)

Building the FASTEST Self Driving RC Car

Steven Gong
27.2K subscribers
Subscribe

23K | Share | Save

614K views 6 months ago WATERLOO
I built a self-driving RC Car that can follow racing lines and then tried to race it as fast as possible without crashing it. This time, it is WAY faster than anything you've seen in the previous video.

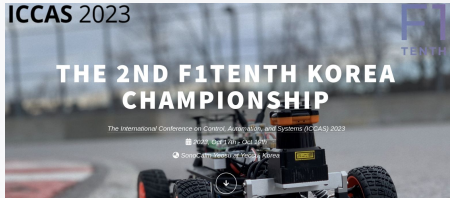


I RACED My Self-Driving RC Car
Steven Gong
387K views • 2 months ago

Building the FASTEST LEGO Car
ProjectAir

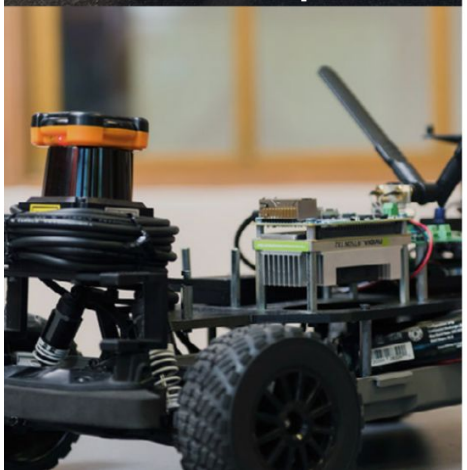
F1Tenth Autonomous Racing Competitions

1. CPSweek, San Antonio - RACE 11 (May'23)
2. ICRA, London - RACE 12 (June'23)
3. IEEE IV, Alaska - RACE 13 (June'23)
4. IROS, Detroit - RACE 14 (Oct'23)
5. ICCAS, 2nd Korean GPX - RACE 15 (Oct'23)
6. CPSweek, Hong Kong - RACE 16 (May'24)
7. ICRA, Japan - RACE 17 (June'24)
8. IEEE IV, Korea - RACE 18 (June'24)
9. IEEE ISTC, Canada - RACE 19 (Sept'24)
10. ICCAS, 3rd Korean GPX - RACE 20 (Oct'24)



2nd Workshop on Opportunities and Challenges with Autonomous Racing at ICRA 2022

200+ Participants



INVITED SPEAKERS

Bryn Balcombe
Chief Strategy Officer
Roborace

Marko Bertogna
Full Professor
University of Modena

Sergio Savaresi
Full Professor
Politecnico di Milano

Alexander Wischnewski
CTO
driveblocks

Mauro Salazar
Assistant Professor
TU Eindhoven

Evangelos Theodorou
Associate Professor
Georgia Institute of Technology

Mac Schwager
Full Professor
Stanford University

Jonathan Goh
Research Scientist
Toyota Research Institute

Srikanth Saripalli
Full Professor
Texas A&M University

Peter Wurman
Director
Sony AI America

10 invited speakers
16 contributed talks

1ST WORKSHOP ON

MAD-GAMES: MULTI-AGENT DYNAMIC GAMES

IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) 2023

October 1, 2023

OCTOBER 1 - 5, 2023

IEEE/RSJ International Conference on Intelligent Robots and Systems

9 exciting invited speakers
+
13 interesting contributed papers

ORGANIZERS:

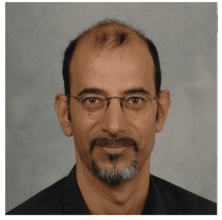
Rahul Mangharam
ASSOCIATE PROFESSOR
DEPARTMENT OF ELECTRICAL AND SYSTEMS ENGINEERING
UNIVERSITY OF PENNSYLVANIA

Johannes Betz
ASSISTANT PROFESSOR
DEPARTMENT OF MOBILITY SYSTEMS ENGINEERING
TECHNICAL UNIVERSITY OF MUNICH

Venkat Krovi
MICHELIN CHAIR PROFESSOR
DEPARTMENT OF AUTOMOTIVE ENGINEERING
CLEMSON UNIVERSITY

Hongrui Zheng
PH.D. CANDIDATE
DEPARTMENT OF ELECTRICAL AND SYSTEMS ENGINEERING
UNIVERSITY OF PENNSYLVANIA

INVITED SPEAKERS



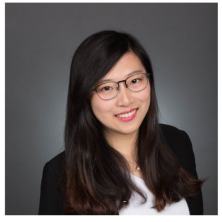
Panagiotis Tsiotras
DAVID & ANDREW LEWIS CHAIR PROFESSOR
GEORGIA TECH

Jana Tumova
ASSOCIATE PROFESSOR
KTH ROYAL INSTITUTE OF TECHNOLOGY

Peter Stone
PROFESSOR
UNIVERSITY OF TEXAS AT AUSTIN

Abolfazl Hashemi
ASSISTANT PROFESSOR
PURDUE

Eric Mazumdar
ASSISTANT PROFESSOR
CALTECH



Manxi Wu
ASSISTANT PROFESSOR
CORNELL

Roberto Valenti
SENIOR ROBOTICS RESEARCH SCIENTIST

Roya Firoozi
POSTDOCTORAL RESEARCHER
STANFORD UNIVERSITY

F1/10 COMMUNITY PARTNERS 60+

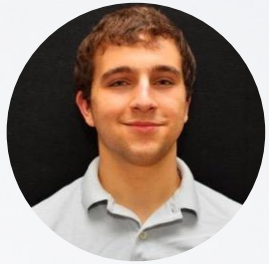
The F1Tenth Racing Crew Alumni

2017

Paril Jain
TESLA

Nischal KN
NVIDIA

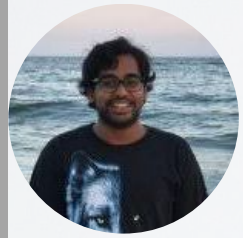
Paritosh Kelkar
HONDA



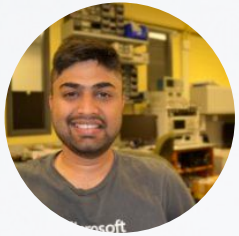
Matt Brady
AMAZON ROBOTICS

Carter Sharer
Youtube Star

2018



Nitesh Singh
RIVIAN



Thejas Kesari
RIVIAN Automotive

Jalaj Maheshwari
Crash Engineer, CHOP

Dr. Madhur Behl
University of Virginia

Dr. Houssam Abbas
Oregon State U

2019

Jack Harkins
Nvidia GPU Firmware

Thejas Kesari
ML Engineer, Universal Logic

You?

Christopher Kao
Built Robotics

Akarsh Varre
Drone Racing League

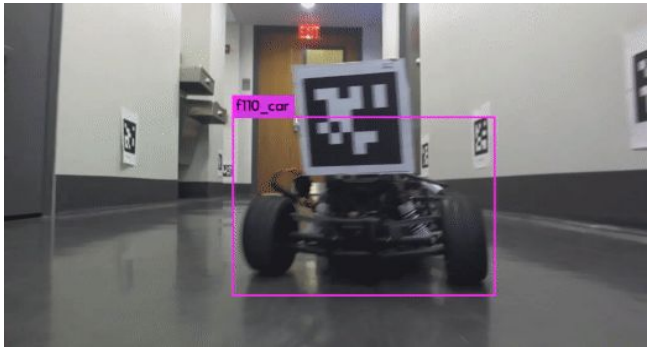
Do you have what it takes to be the

Best Autonomous Driver?

Penn Engineering


f1tenth.org
F1
TENTH

F1TENTH in action



Perception

Planning

Control

RACE !