F1/10 Autonomous Racing
Course Introduction

Madhur Behl

Computer Science | Engineering Systems and Environment | UVA Link Lab

CS 4501 -003 | 14th January 2020

F1 TENTH

UNIVERSITY of VIRGINIA

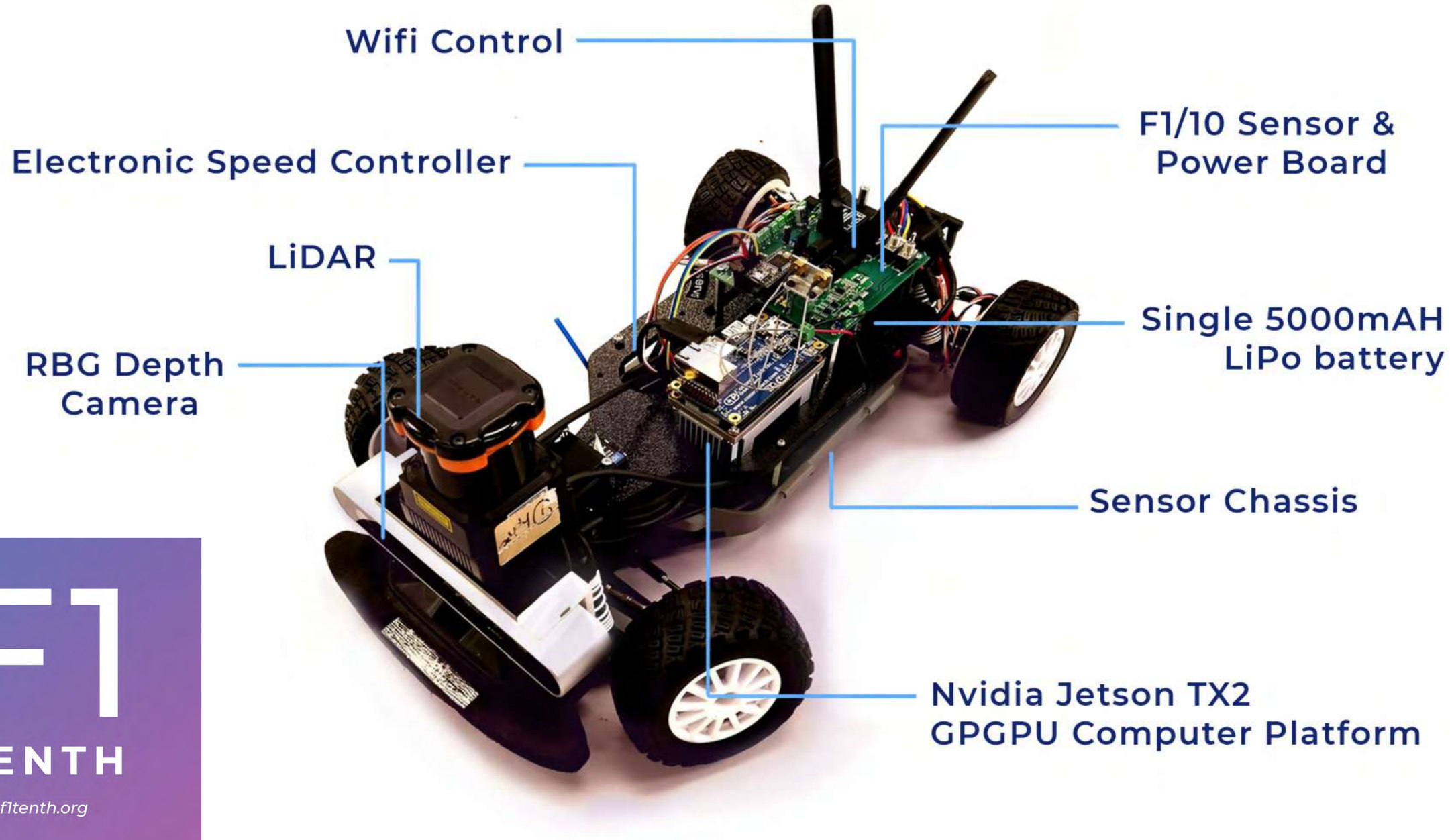
UVA LINK LAB

Overview

- Introduction to the Course and What is F1/10 ?
  - Logistics, grading, policies
- Course Support
  - Website, TAs, Piazza, Github
- Expectations

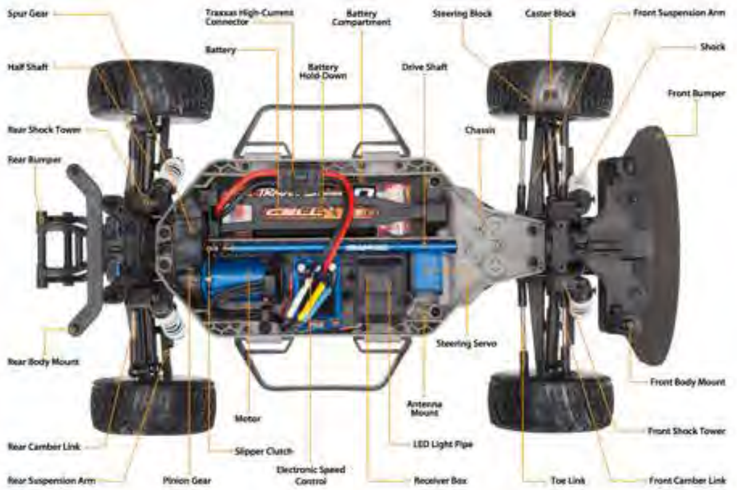
- Brief Introduction to Autonomous Racing topics
- Autonomous Racing Research @ UVA

F1 TENTH

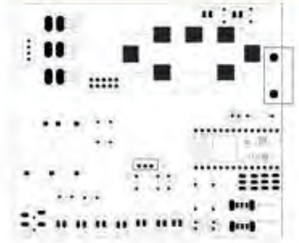


F1 TENTH

f1tenth.org



Chassis Design



F1/10 Platform Board

Hokuyo LiDAR

Zed Depth Camera

FLIR Flea Camera

Electronic Speed Controller

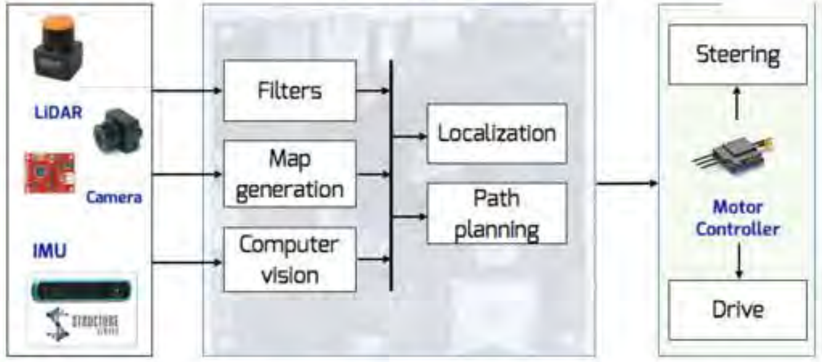
WiFi Telemetry

GPGPU Compute Platform NVIDIA Jetson TX1/TX2

System Integration

Software Architecture

ROS



GPU Accelerated Libraries

NVIDIA CUDA

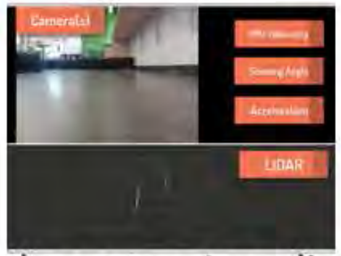
Research Enabled

Safe Autonomy	Secure Autonomy	Coordinated Autonomy	Efficient Autonomy

Lane Keeping Assist

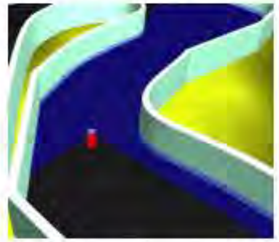
Model-Predictive Control

AV Data Collection



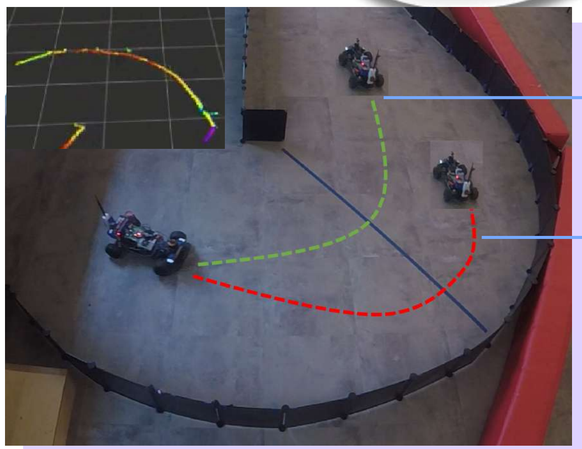
Simultaneous Localization And Mapping (SLAM)

F1/10 Simulator



DNN Racing

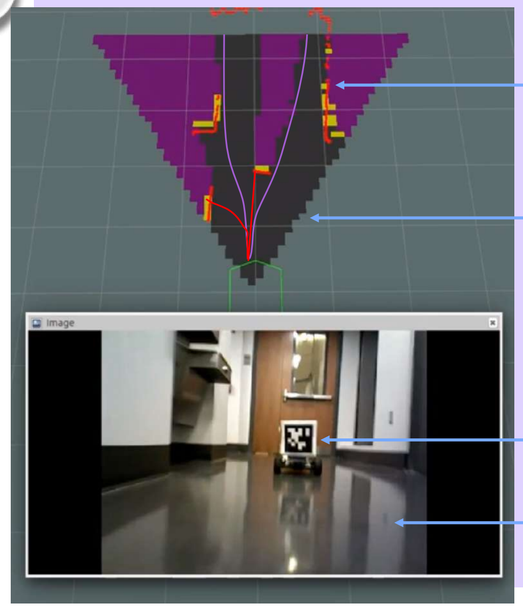
FOLLOW THE GAP METHOD



Follow the gap method

Simple obstacle avoidance

MODEL PREDICTIVE CONTROL



Generated paths

Drivable region

Dynamic obstacle

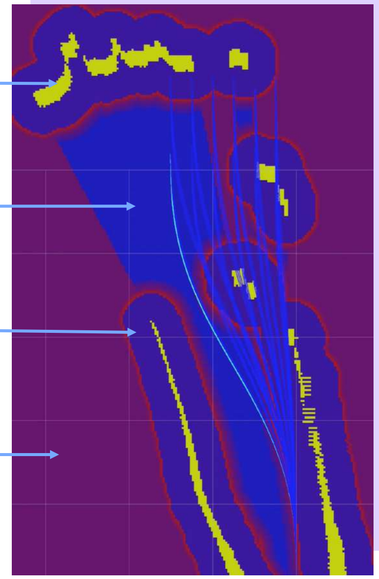
F1/10 RGB FPV

Max. cost (obstacle)

Drivable region

Medium cost

Unexplored space

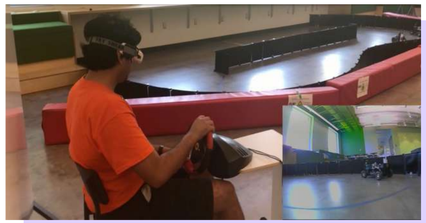


Cost Map Legend

F1 TENTH

END-TO-END DNN

FPV data annotation

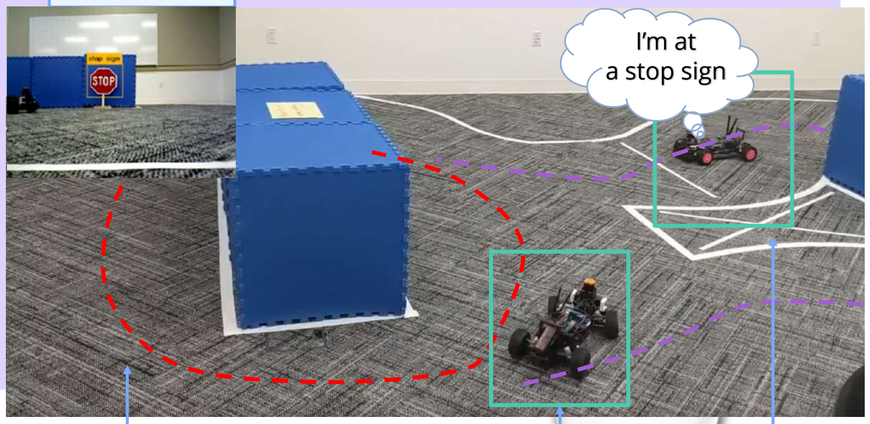


Conv,5x5,stride=2
Conv,3x3
BatchNorm
ReLU
RNN Cell

Predicted steering (blue)
Ground Truth (green)

V2V COLLABORATION

F1/10 FPV

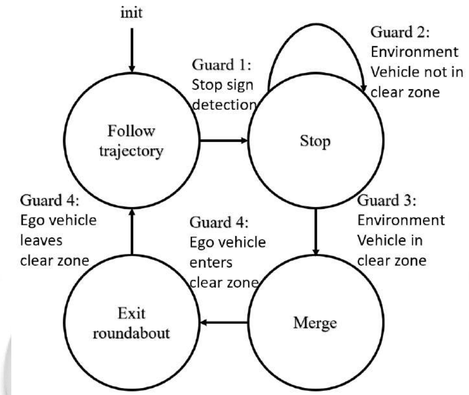


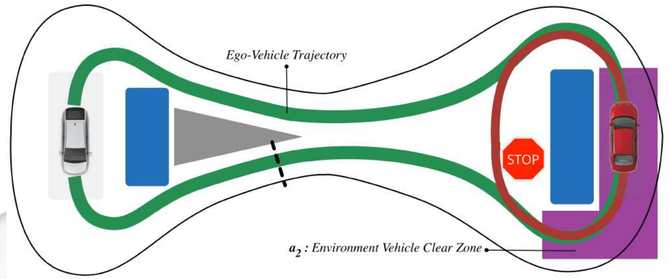
Env. Vehicle Path

Environment vehicle

Ego vehicle

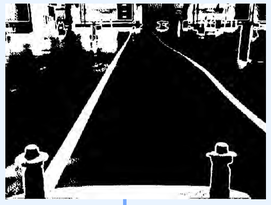
Collaborative behavior automaton



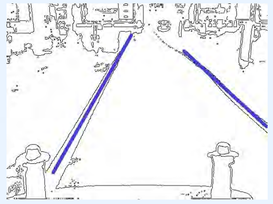


LANE KEEPING ASSIST

Original image



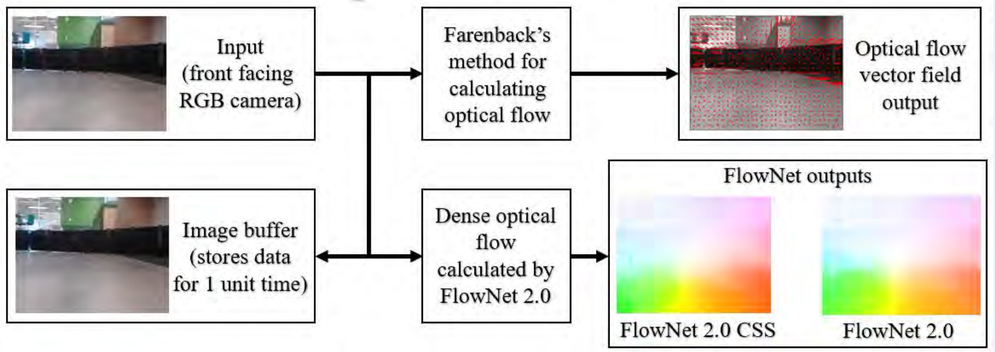
Threshold masking



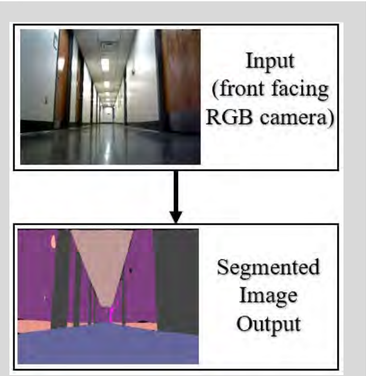
Hough transform

Lane detection pipeline

COMPUTER VISION EXAMPLE



Optical flow



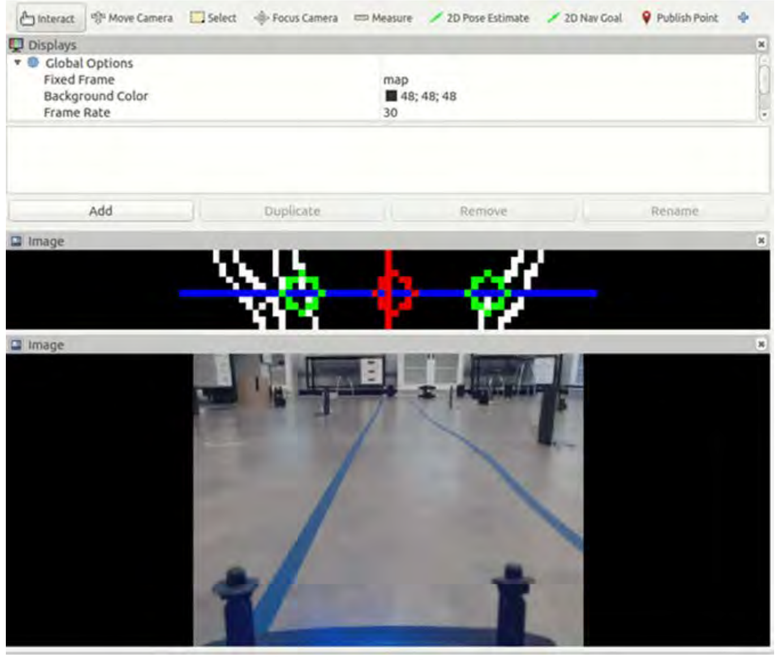
F1/10 online semantic segmentation

F1 TENTH

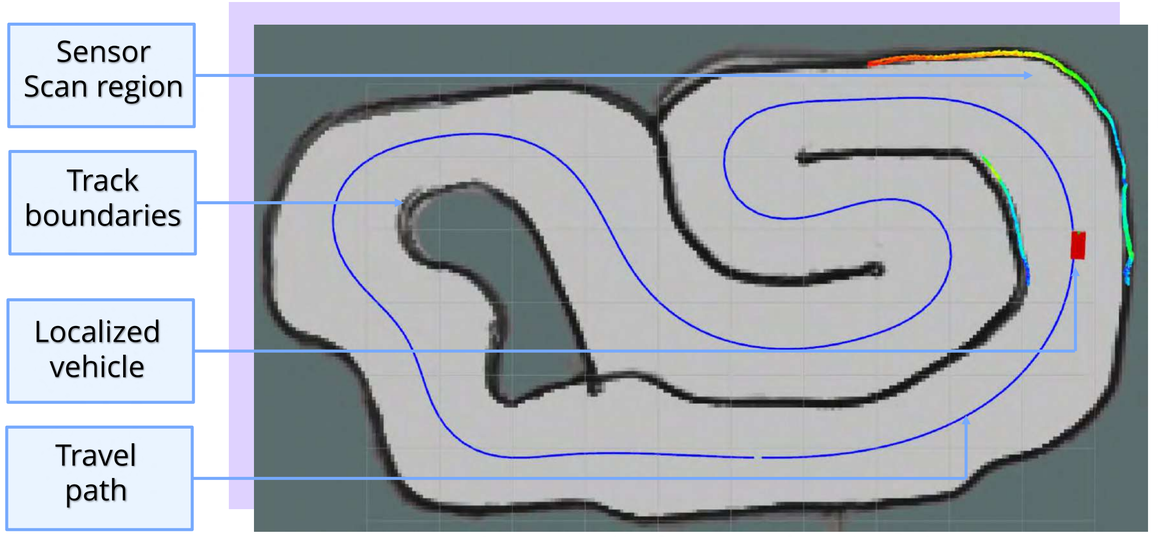
LOCALIZATION AND MAPPING

Currently tested On F1/10

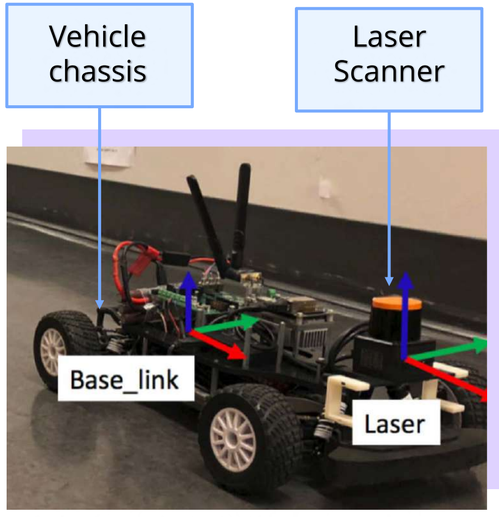
Hector SLAM	AMCL	Google Cartographer	ORB-SLAM



rviz visualization



Global planning using *rviz*



ROS transform frame

F1TENTH GAZEBO SIMULATOR

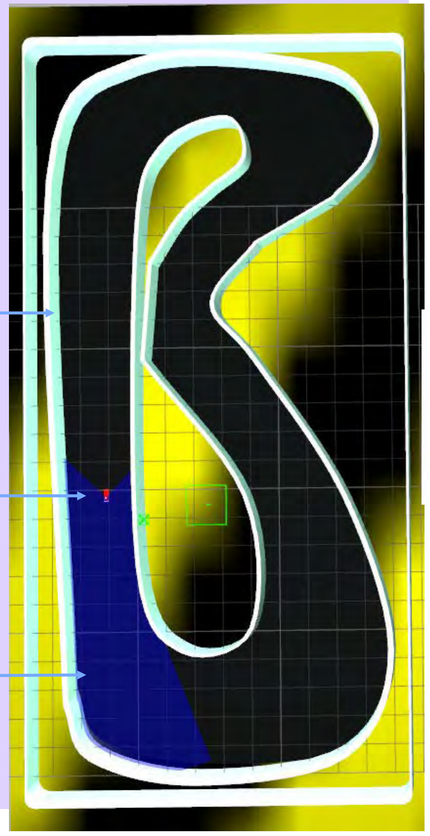
Test algorithm → ROS → GAZEBO → F1/10 simulator

F1/10 ROS URDF model

Track boundaries

Simulated F1/10 car

Sensor Scan region

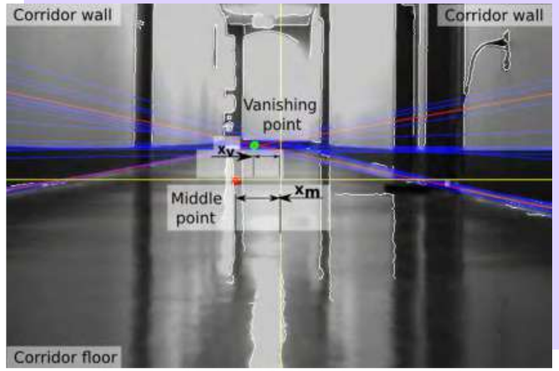


Overhead view of CPS week track in Porto → ROSbag logs LiDAR and Odometry data → Porto track in Gazebo built using ROSbag data

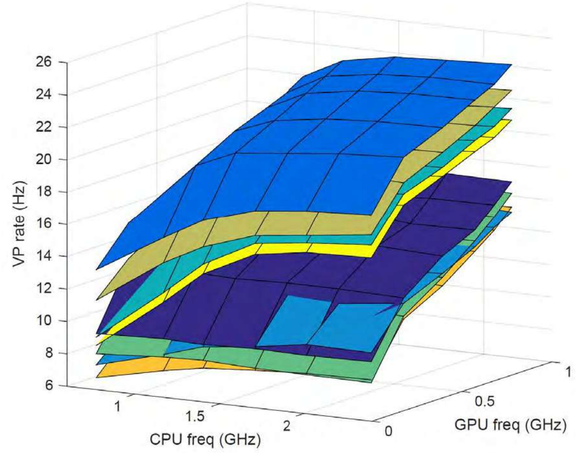
F1 TENTH

REAL TIME SCHEDULING

Vanishing point (VP) algorithm implemented on F1/10

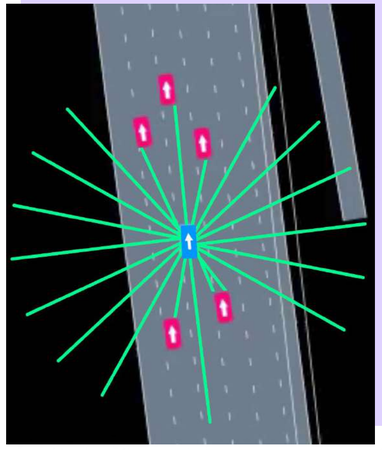


Green dot (vanishing point)
Red dot (middle point)



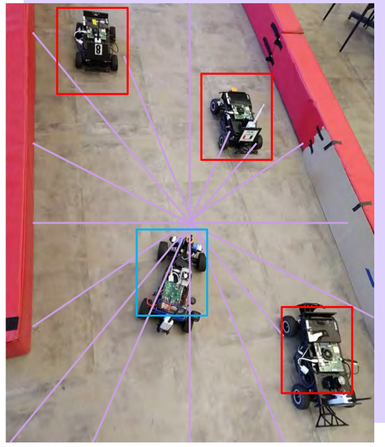
VP throughput based on CPU & GPU frequencies

TESTING & VERIFICATION



GAIL model: Outputs include mean & variance of steering & throttle

Data captured from traffic on I-80



F1/10 helps recreate traffic scenarios to verify model

Course logistics

Instructor

Prof. Madhur Behl

Assistant Professor

Computer Science

Engineering Systems and Environment

Founder: F1/10 International Autonomous Racing Competition

Director: Cavalier Autonomous Racing

How to reach me:

Office: Olsson 265 (Link Lab)

Office Hours: Every Monday 2-3pm in my office (or by appt.)

Webpage: http://www.madhurbehl.com/

Email: madhur.behl@virginia.edu

Teaching Assistants

Varundev SureshBabu

PhD Candidate: Computer Engineering

vss8sm@virginia.edu

Sandesh Banskota

Mechanical Engineering Major & Computer Science Minor

sb3vf@virginia.edu

Mert Karakas

Computer Engineering Major

mmk2nh@virginia.edu

Course logistics

Lectures:

3:30-4:45p Tuesday & Thursday

Rice 120

Lab Demos and Practice:

Rice 242

Course Website:

https://linklab-uva.github.io/autonomousracing/

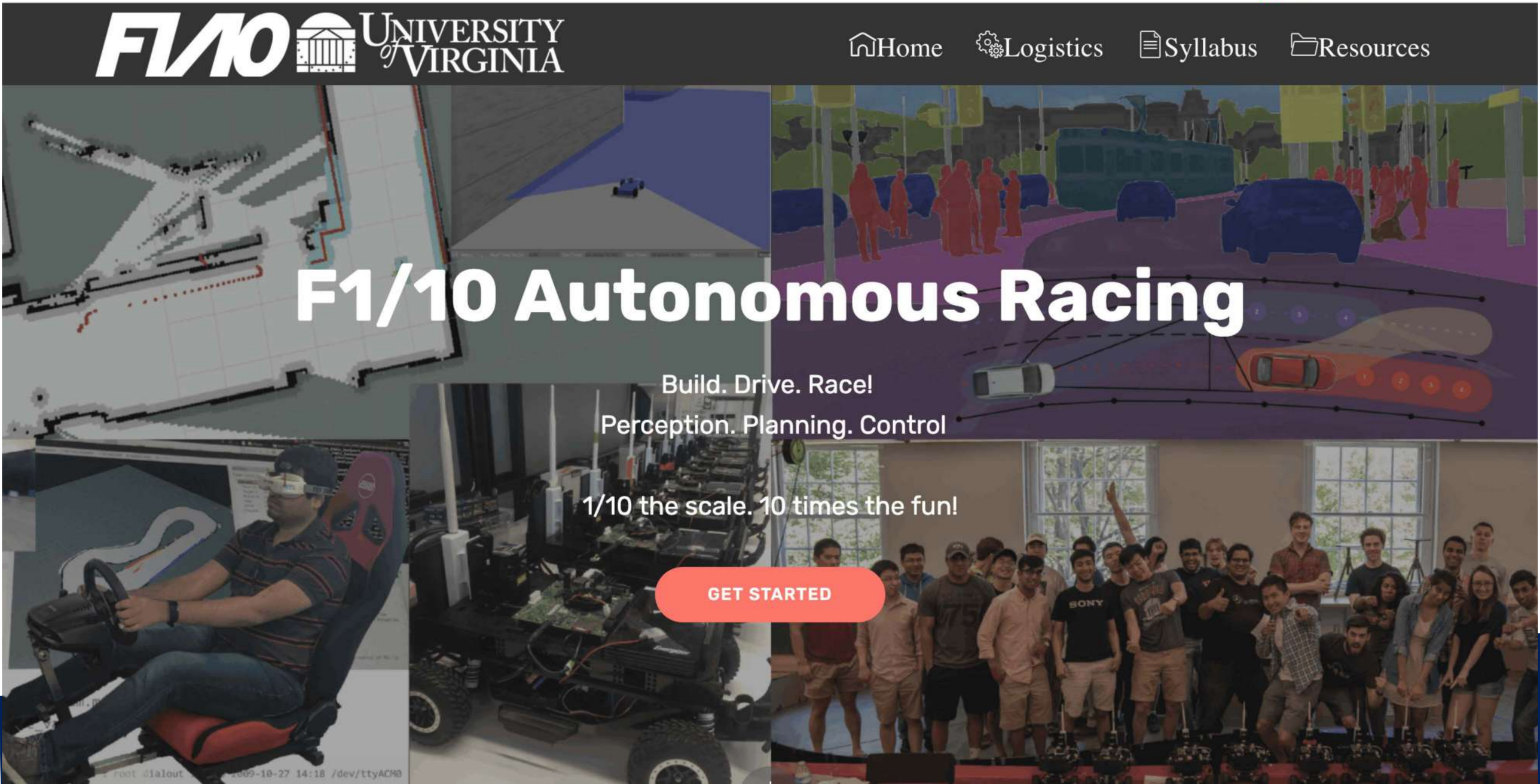
UVA Collab for assignment submission

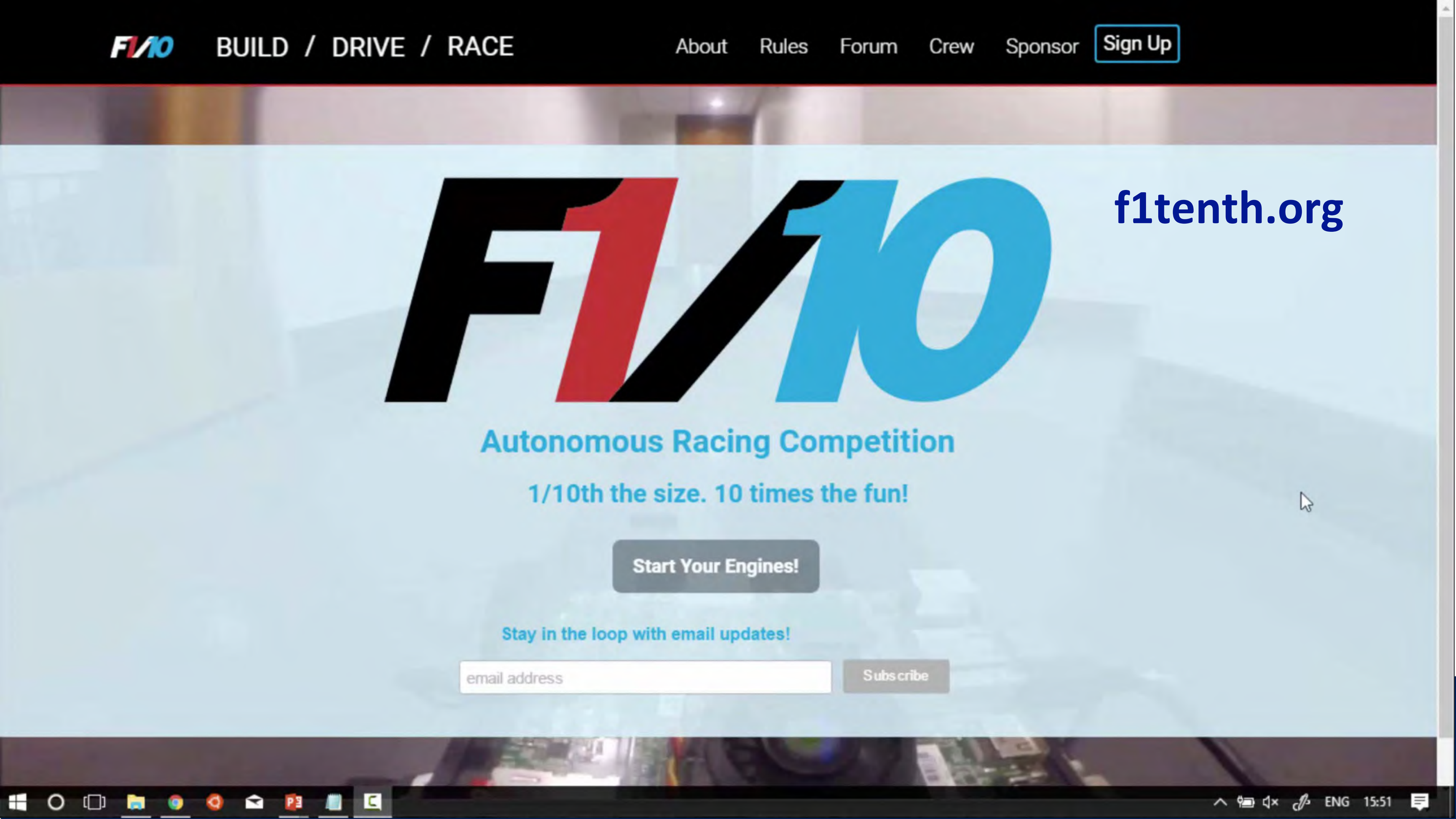
Piazza: TBD

Textbooks: None you have to buy

Github: You will have access to template code for labs and assignments via Git

https://linklab-uva.github.io/autonomousracing/




BUILD / DRIVE / RACE
About
Rules
Forum
Crew
Sponsor
Sign Up
f1tenth.org
Autonomous Racing Competition
1/10th the size. 10 times the fun!
Start Your Engines!
Stay in the loop with email updates!
email address
Subscribe
ENG
15:51

Topics to be covered

Week 1	Course Introduction
Week 2	Introduction to Robot Operating Systems
Week 3	ROS deep dive + TurtleSim
Week 4	Pulse Width Modulation - Teensy
Week 5	Perception – Sensing your surroundings
Week 6	PID Control and path following
Week 7	Wall following, boundary detection

Topics to be covered

Spring Break	
Week 8	Basics of Navigation - Localization
Week 9	Mapping - SLAM
Week 10	Trajectory planning
Week 11	Open CV, Visual Odometry
Week 12	Advanced topics in scene understanding
Week 13	Racing strategy

Lab exercises

Practice Session 1:

Understanding ROS | Setting up the Car

Practice Session 2:

Perception/Sensing | Driving Straight

Practice Session 3:

Driving in a loop | Visual Odometry

Practice Session 3:

Race | Time trials | Head-to-head racing

Grading Criteria

This course does not have a midterm or a final exam.

The final grade will be determined on the basis of:

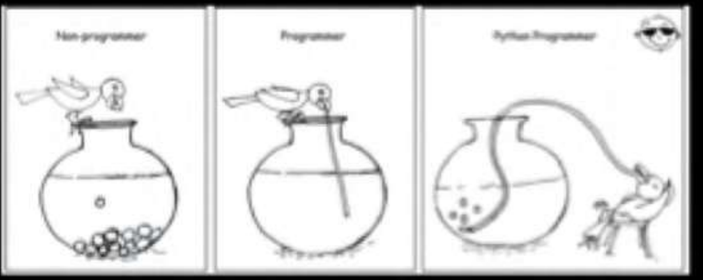
- Weekly assignments
- Lab exercises
- Short project
- Final race performance

Students will be graded individually and in teams.

This is an *advanced* special topics class. Which means, that although, we will cover everything which is required to build, drive, and race the cars; it is assumed that students have some familiarity with the topics highlighted below.

To succeed in this course, you need to have some experience with the following topics:

- Calculus and linear algebra:
  - Single variable calculus and differential equations.
  - Matrix operations- transformations and rotations.
- Basic statistics and probability:
  - What is a probability distribution ?
  - What is sampling ? Mean, and variance of samples.
- Intermediate Python:
  - Function calls, conditional statements, loops and recursion
- Unix/linux command line/shell basics
  - File commands/file permissions: *ls, cd, pwd, mkdir, rm, cp,mv, touch, chmod, tar*
  - Process management: *ps, top, kill pid*
  - *ssh user@host.., grep, locate, echo*
  - Installation: *./configure, make, make install*
  - Ports: */dev/ttyACM**
- Basic physics (Newtonian mechanics)



```
int getRandomNumber()
{
    return 4;  // chosen by fair dice roll.
               // guaranteed to be random.
}
```

Background in the following is recommended, but not required:

- Intermediate C++
- ROS programming
- Integrating sensors with microcontrollers (master/slave configurations)
- Machine learning

If upon, looking at these topics, your conclusion is: *I'm qualified, but not* **that** *qualified.* Then it is likely that you are qualified.
If you are still unsure, feel free to email the instructor for permission to register.

Expectations

- Maturity in programming, linear algebra, calculus, and statistics
- Proficiency in Linux, command line, Github,
- Familiarity with computer vision, and robotics is a plus.
- If you don’t have the background, come back another semester. This course is offered in each Spring semester.
- Course is listed as a specials topics course – we may make adjustments along the way

What this course is not

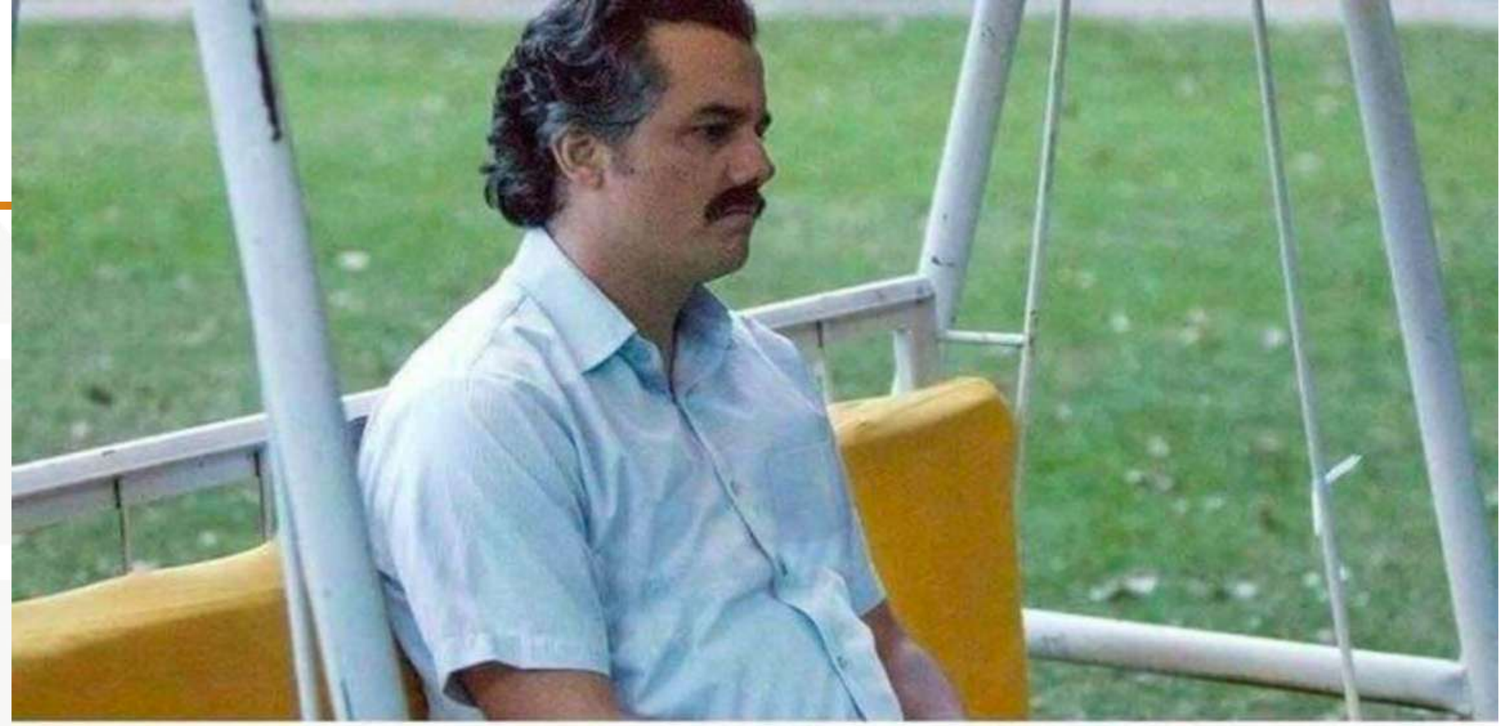
- Mechatronics
- Mechanical Design
- Deep Learning
- Computer Vision
- Your first/second programming, and statistics course
- A replacement for semester long courses in the topics we cover
- **Easy**

Waiting List

Enrolment is restricted to:

48 students

- Hardware/autonomous cars available
- Max capacity of Rice 120



We will use Ubuntu 16.04 LTS on the F1/10 car

Everyone must have access to Ubuntu **16.04 (Xenial)** or **18.04 (Bionic)**

Options:

- Install an Ubuntu virtual machine on any OS.
  - Windows: VirtualBox
  - OS X: Parallels (paid software)
- Dual boot your laptop. (careful)

No lab session this week.

Bring your laptop to the lab session next Thursday.

So what is 

?

Everything that moves will go autonomous

Cars

Trucks

Carts

Drones


WAYMO
7XJT313
Google
WAYMO
WAYMO

THE 6 LEVELS OF AUTONOMOUS DRIVING

L0	L1	L2	L3	L4	L5
No Automation	Driver Assistance	Partial Automation	Conditional Automation	High Automation	Full Automation

SOCIETY OF AUTOMOTIVE ENGINEERS (SAE) AUTOMATION LEVELS

Full Automation

0	1	2	3	4	5
No Automation	**Driver Assistance**	**Partial Automation**	**Conditional Automation**	**High Automation**	**Full Automation**
Zero autonomy; the driver performs all driving tasks.	Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.	Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.	Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.	The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.	The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.

1.35 million deaths worldwide due to vehicle crashes

94% of crashes involve human choice or error in the US.

3 million

Americans age 40 and older are blind or have low vision

79%

of seniors age 65 and older living in car-dependent communities

42 hours

wasted in traffic each year per person

Localization and Mapping

Where am I ?

Scene Understanding

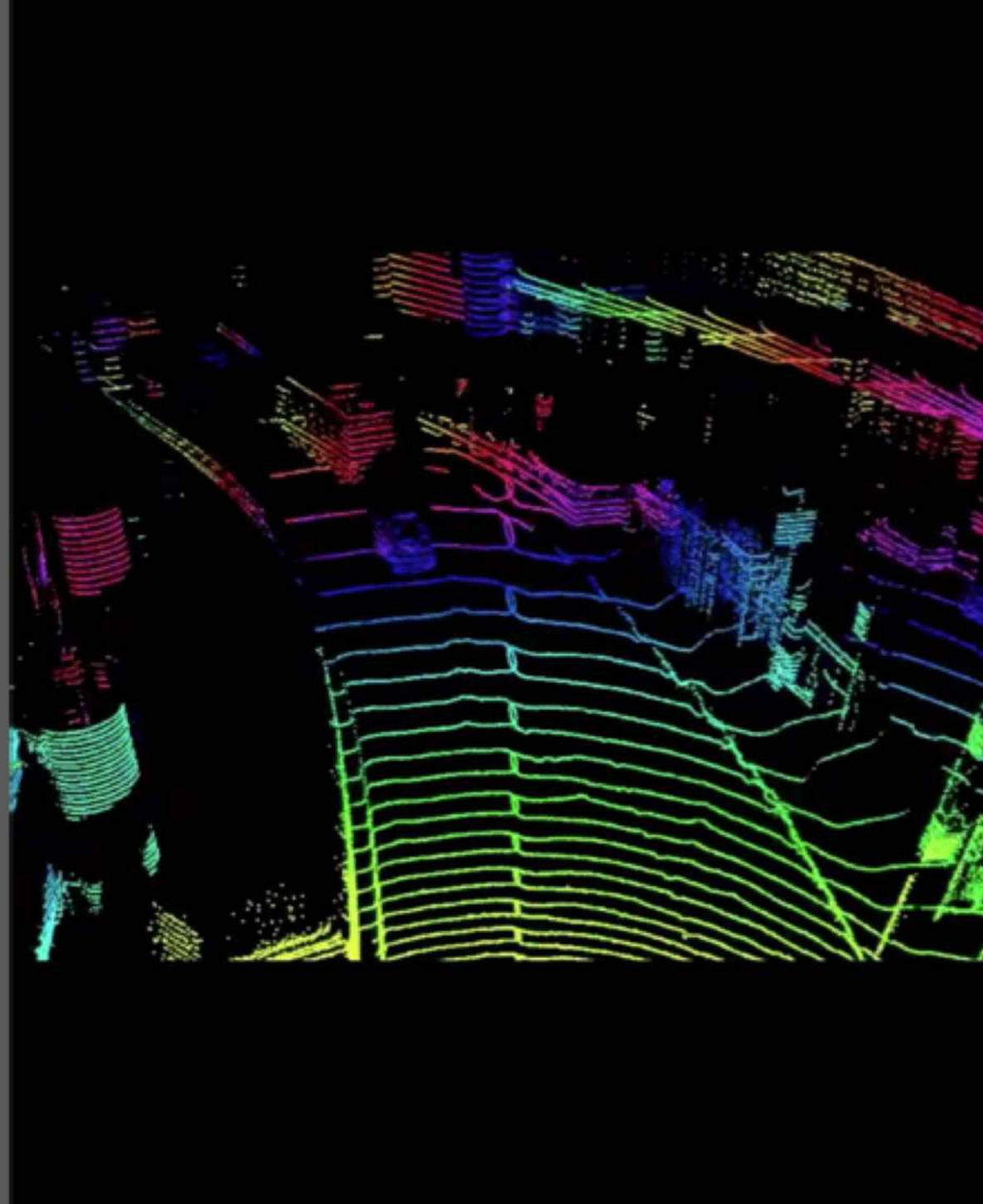
Where/who/what/why of
everyone/everything else ?

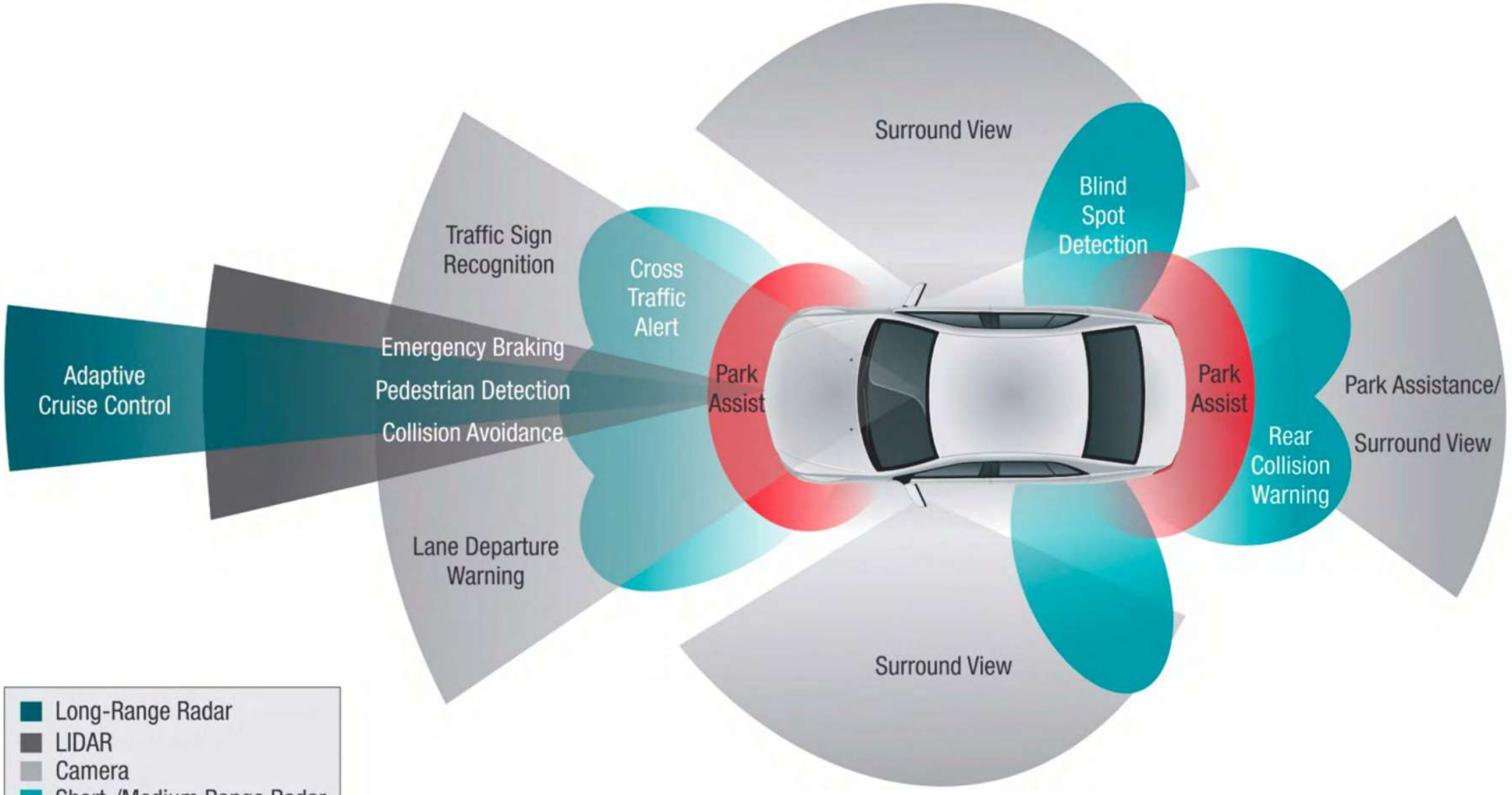
Trajectory Planning and Control

Where should I go next ?
How do I steer and accelerate ?

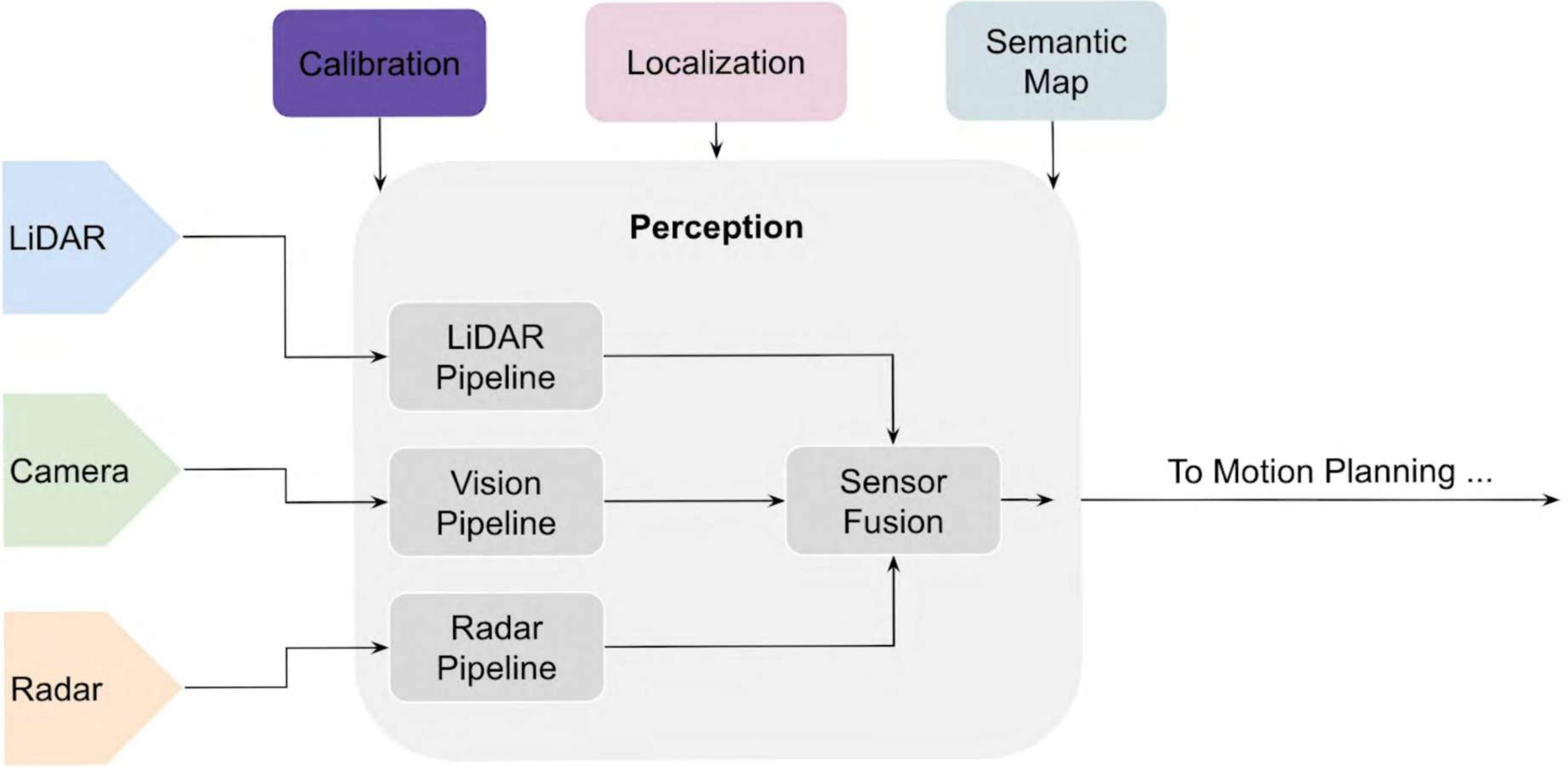
Human Interaction

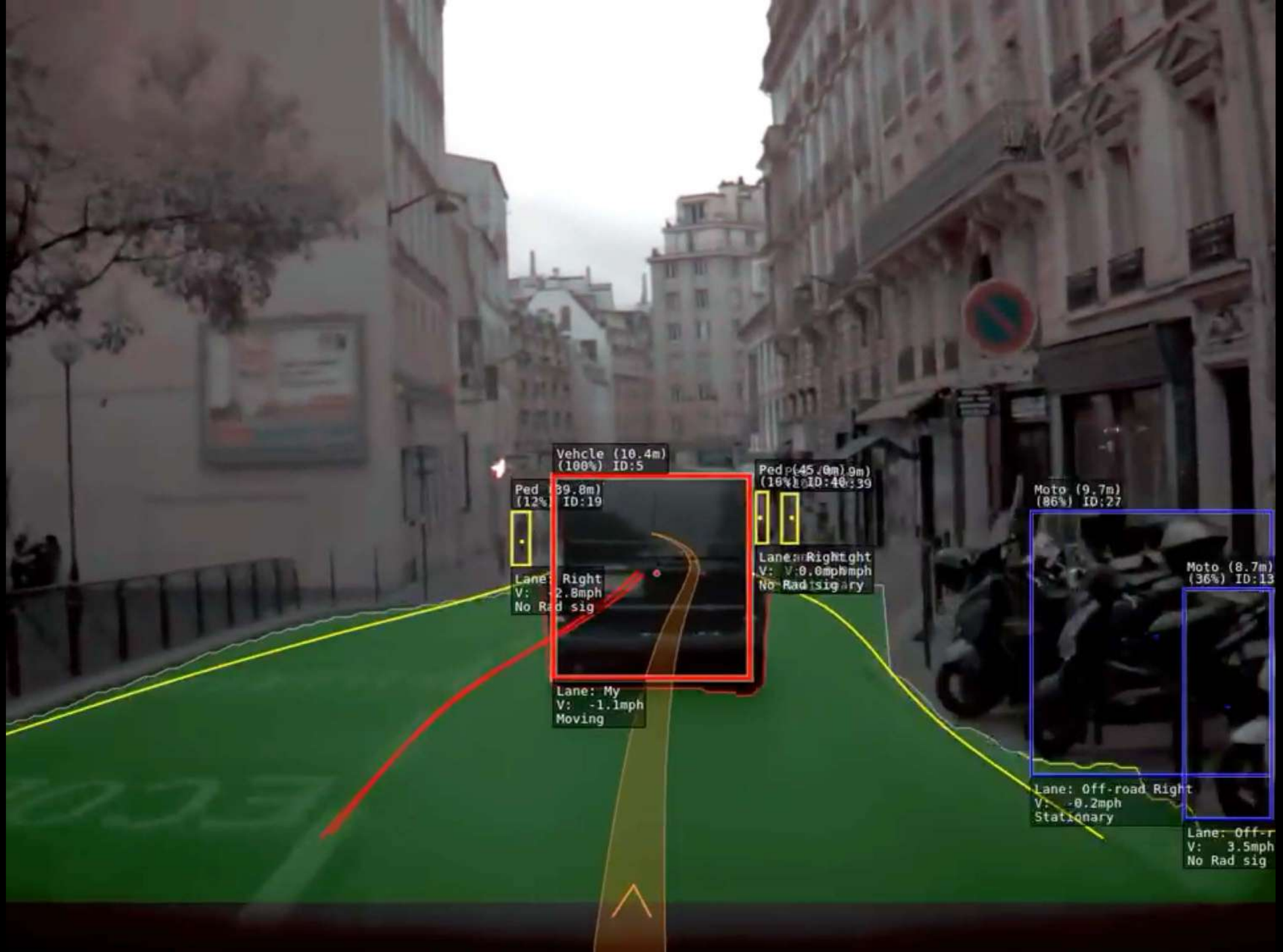
How do I convey my intent to the
passenger and everyone else ?




Surround View
Blind Spot Detection
Traffic Sign Recognition
Cross Traffic Alert
Adaptive Cruise Control
Emergency Braking
Pedestrian Detection
Collision Avoidance
Park Assist
Park Assist
Park Assistance/ Surround View
Rear Collision Warning
Lane Departure Warning
Surround View
Long-Range Radar
LIDAR
Camera
Short-/Medium Range Radar
Ultrasound

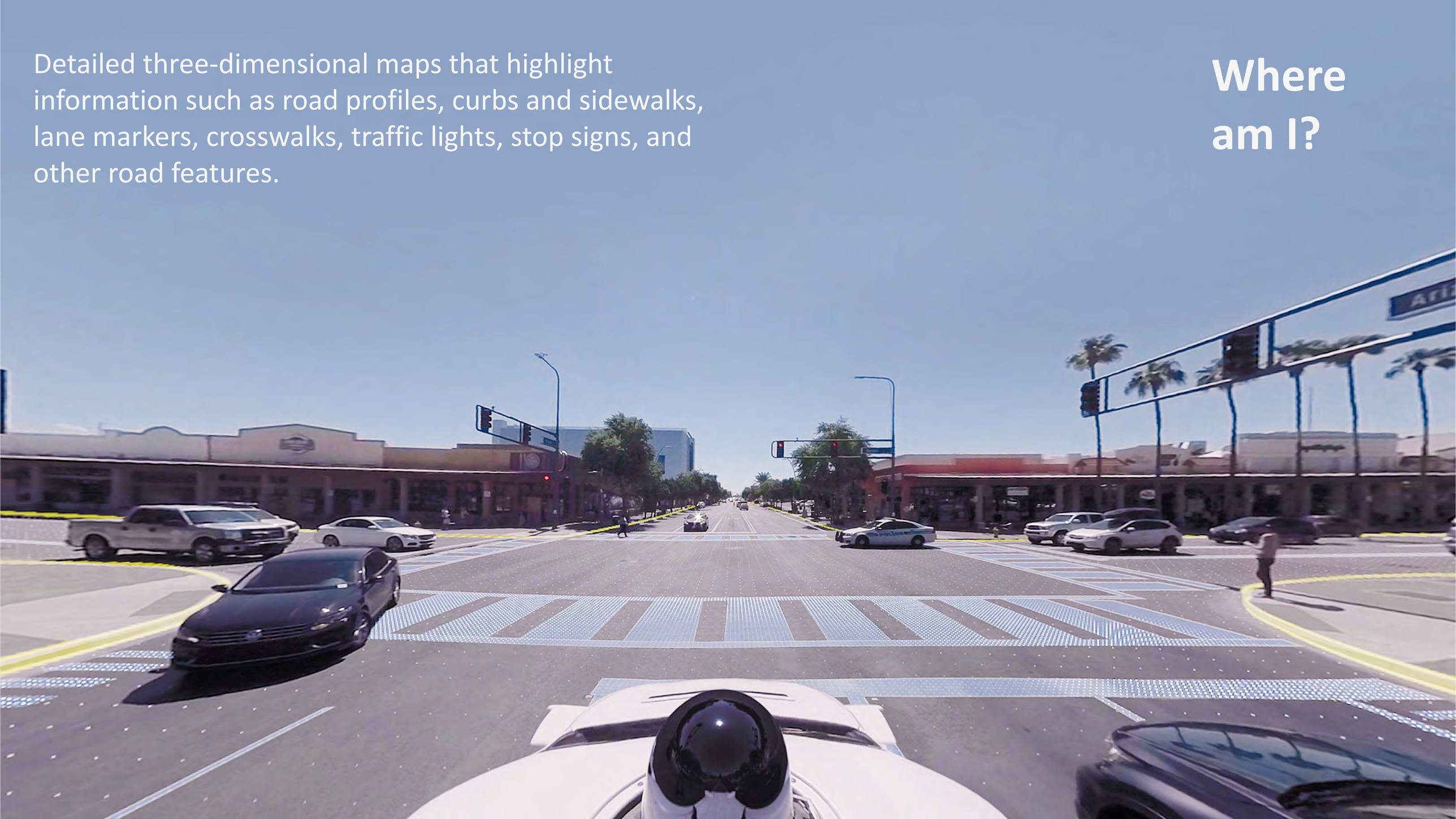
Perception in AV Stack




Vehcle (10.4m)
(100%) ID:5
Ped (12% ID:19
Lane: Right
V: 2.8mph
No Rad sig
Lane: My
V: -1.1mph
Moving
Ped (45.0m) 9m)
(10% ID:40 39
Lane: Right ght
V: V:0.0mph mph
No Rad sig ary
Moto (9.7m)
(86%) ID:27
Moto (8.7m)
(36%) ID:13
Lane: Off-road Right
V: -0.2mph
Stationary
Lane: Off-r
V: 3.5mph
No Rad sig

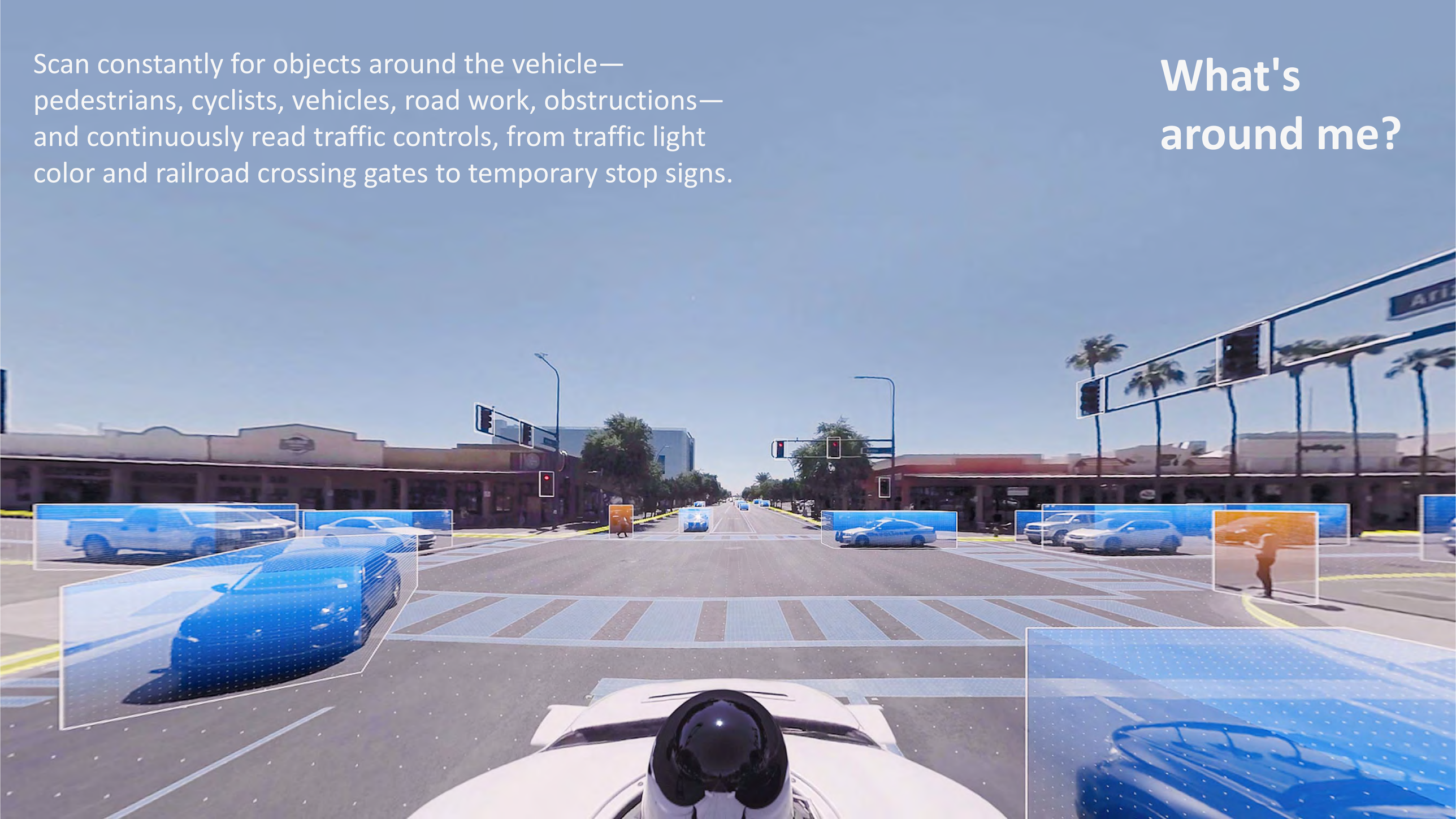
Detailed three-dimensional maps that highlight information such as road profiles, curbs and sidewalks, lane markers, crosswalks, traffic lights, stop signs, and other road features.

Where am I?



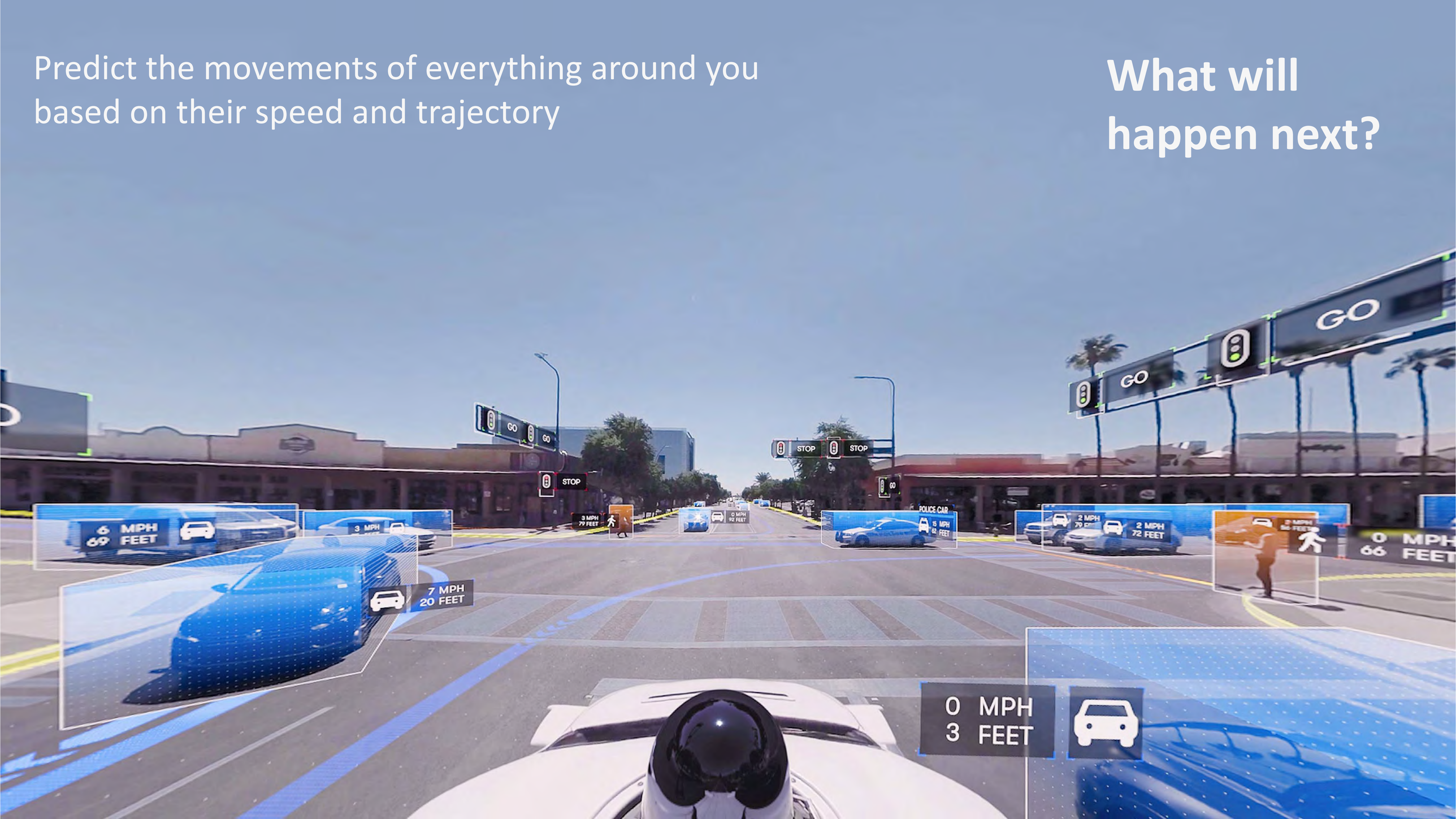
Scan constantly for objects around the vehicle—pedestrians, cyclists, vehicles, road work, obstructions—and continuously read traffic controls, from traffic light color and railroad crossing gates to temporary stop signs.

What's around me?



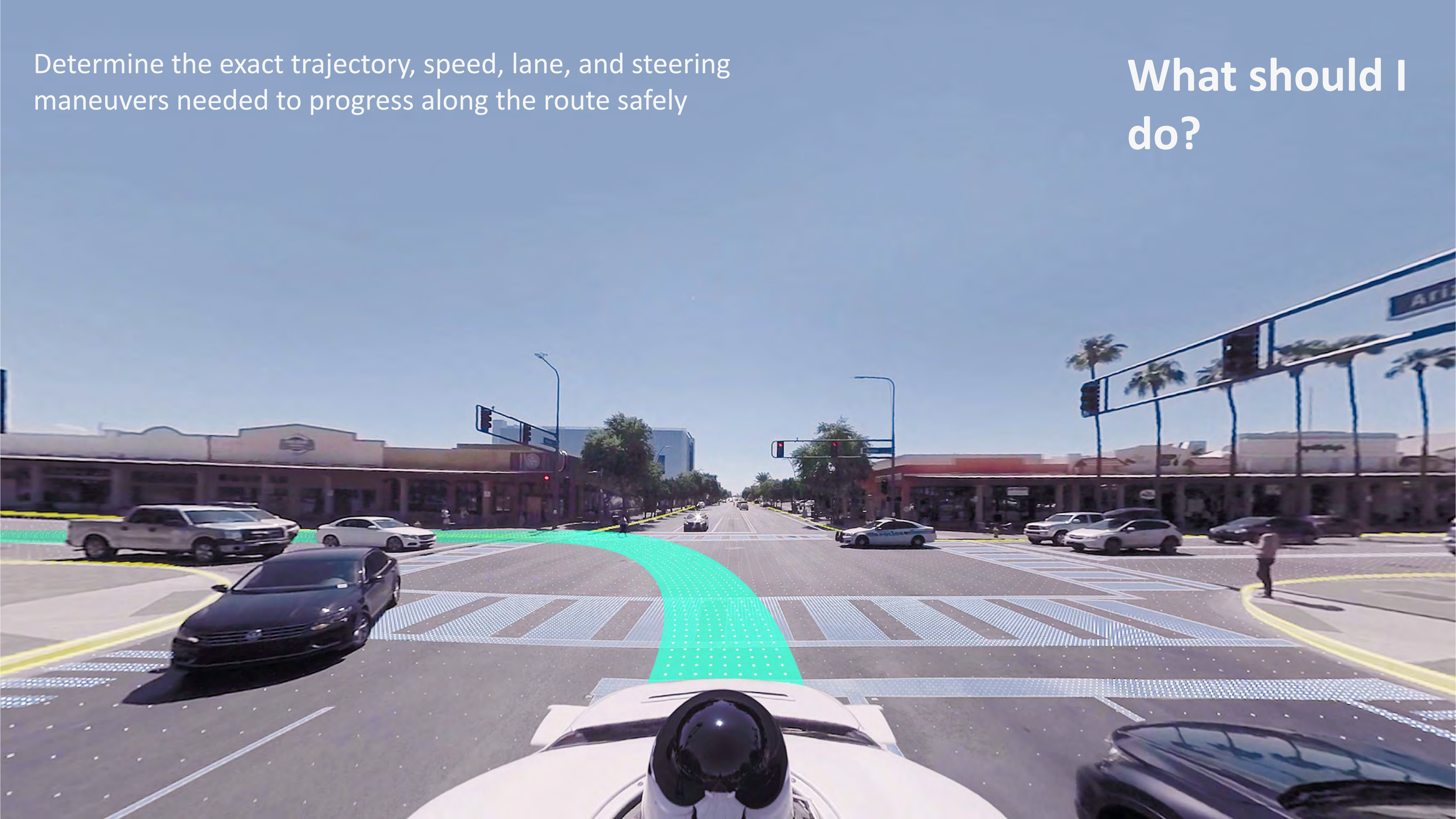
Predict the movements of everything around you based on their speed and trajectory

What will happen next?



Determine the exact trajectory, speed, lane, and steering maneuvers needed to progress along the route safely

What should I do?

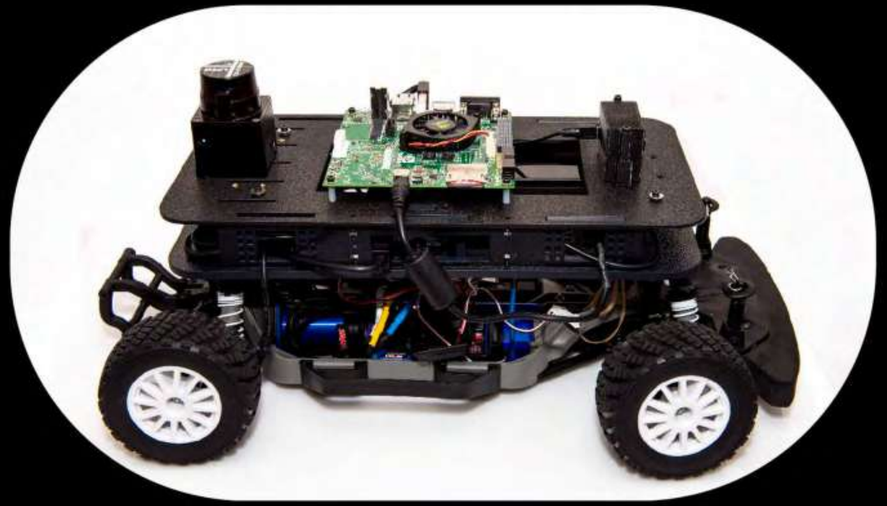


F1/10

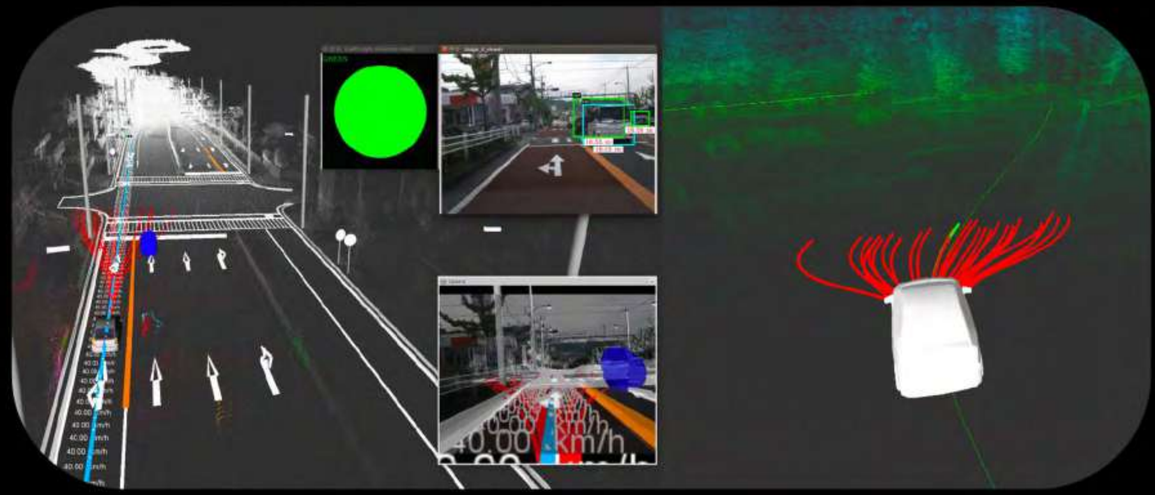
Autonomous Racing

1/10 the scale. 10 times the fun!

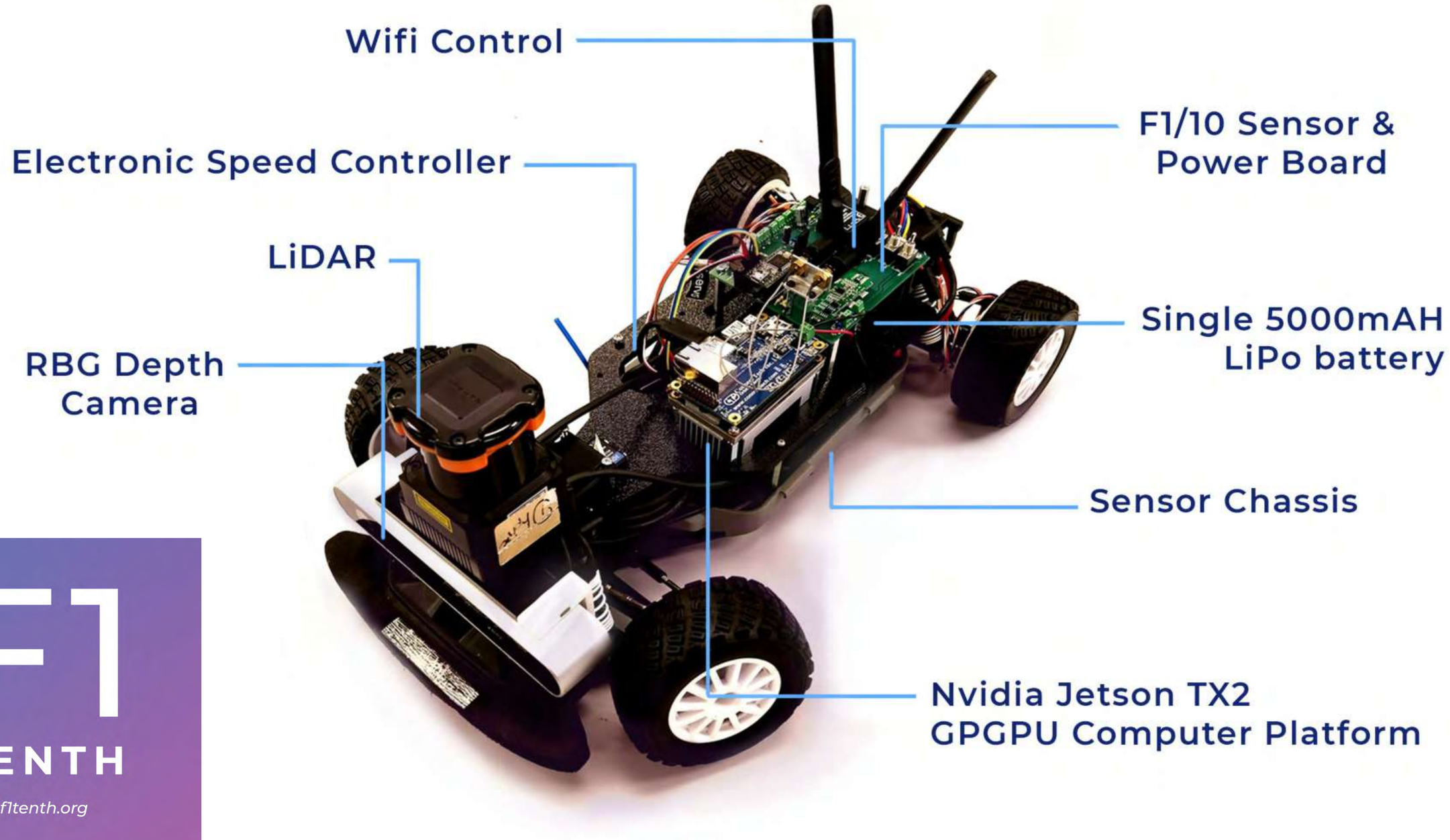
Build. Drive. Race.



Perception. Planning. Control



Build



F1 TENTH

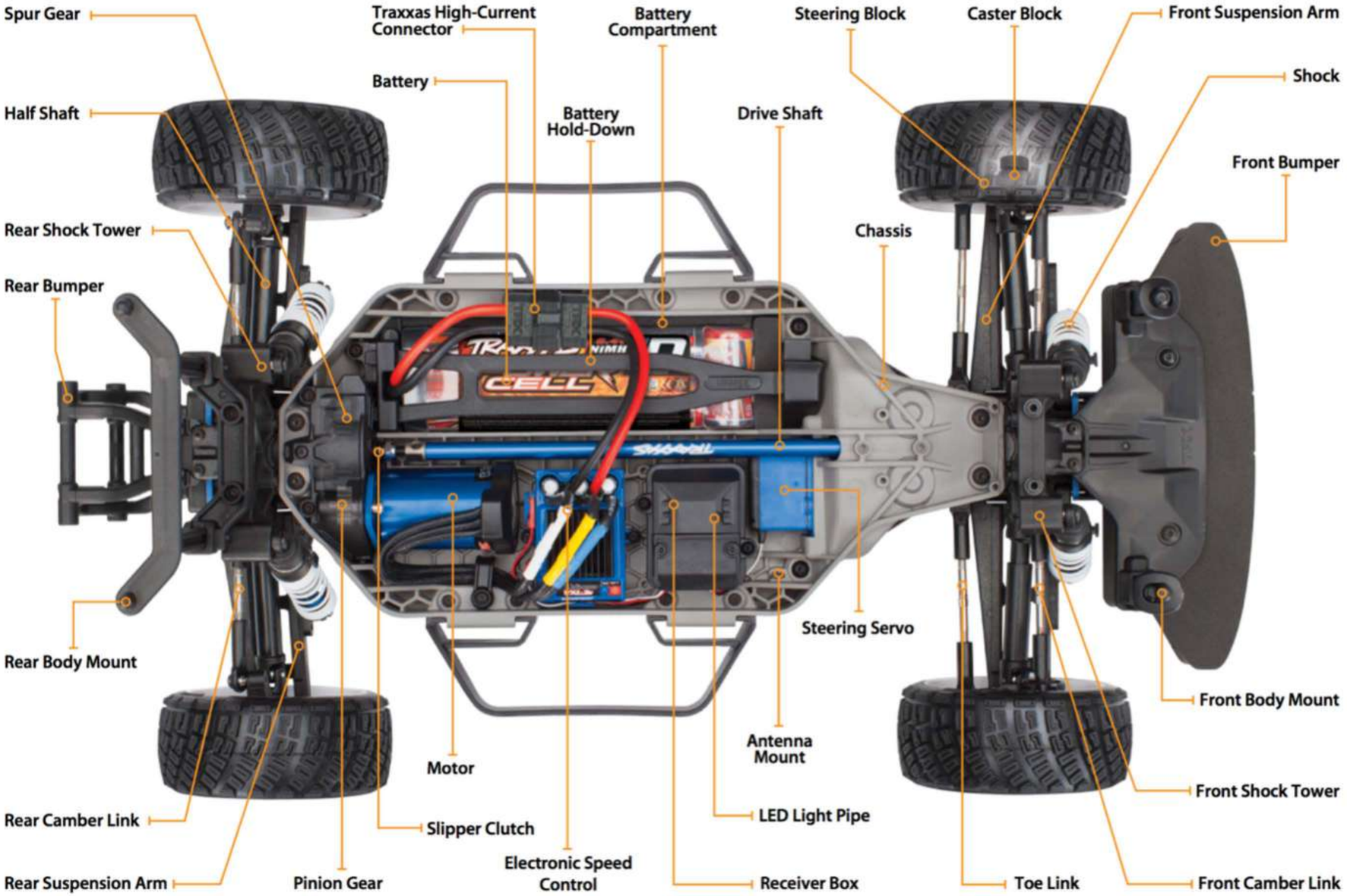
f1tenth.org

Similar dynamics, different parameters

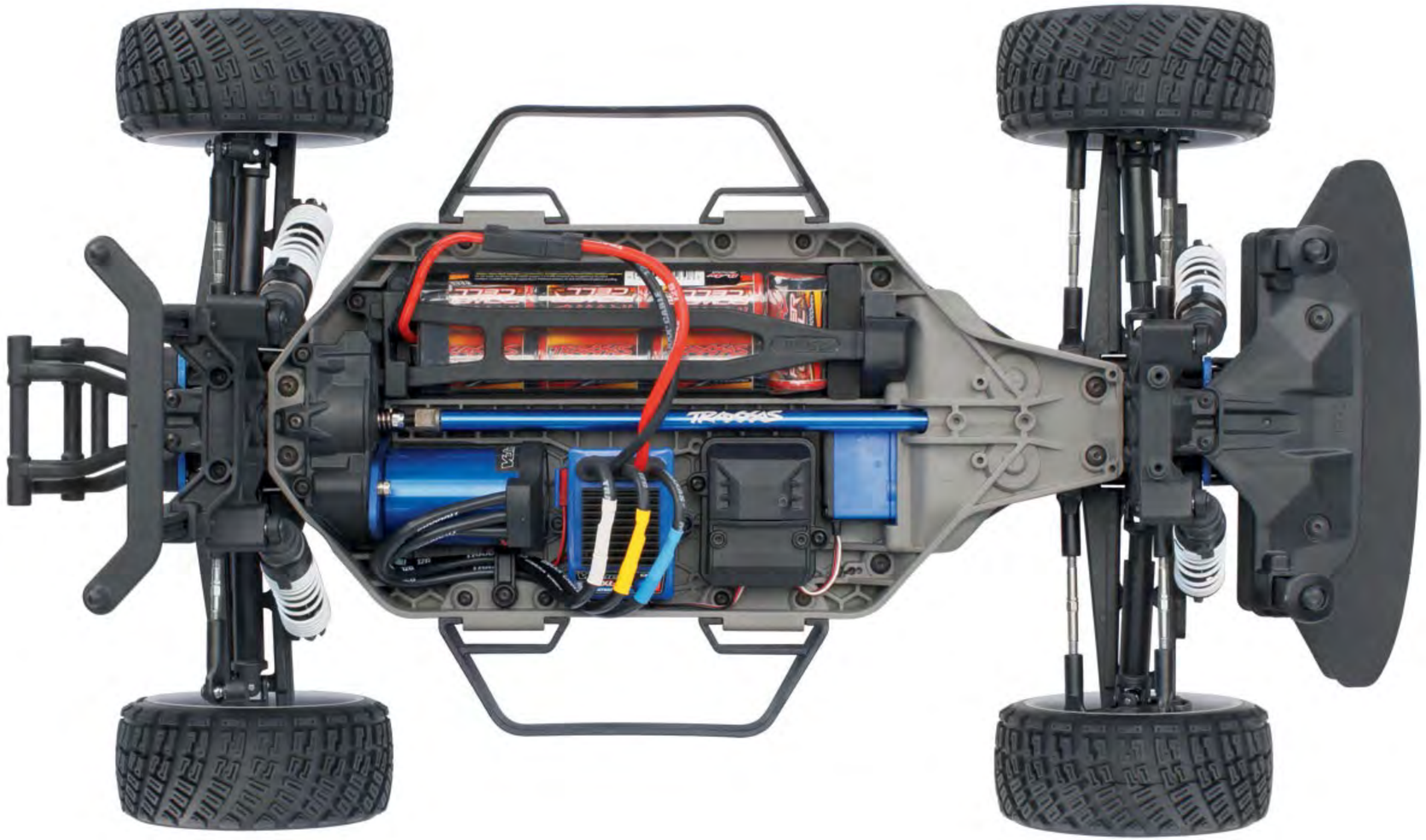
TRAXXAS XO-1 **vs** **Tesla Model S**

Similar sensors,
different scale

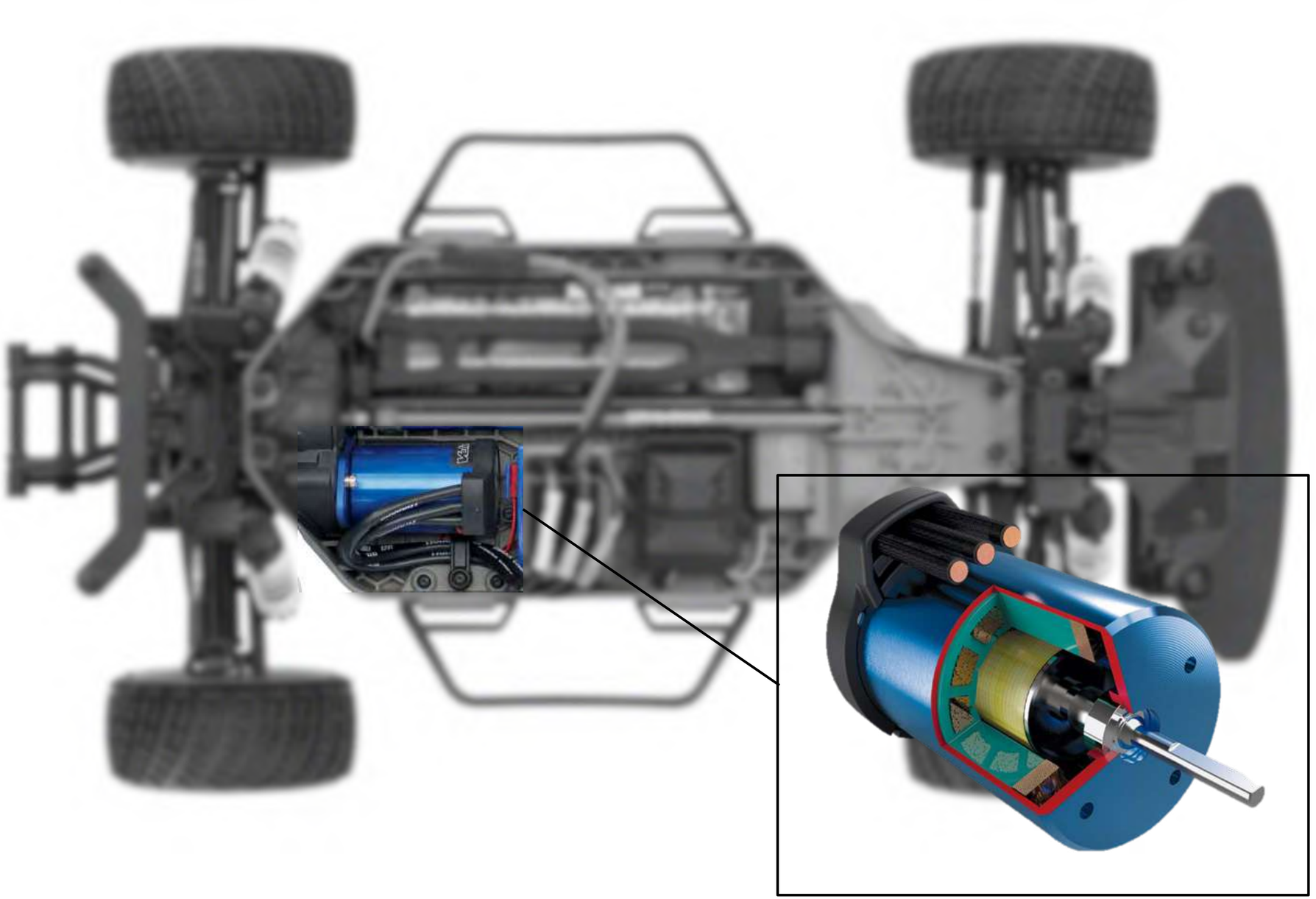
Traxxas 1/10 scale RC race car



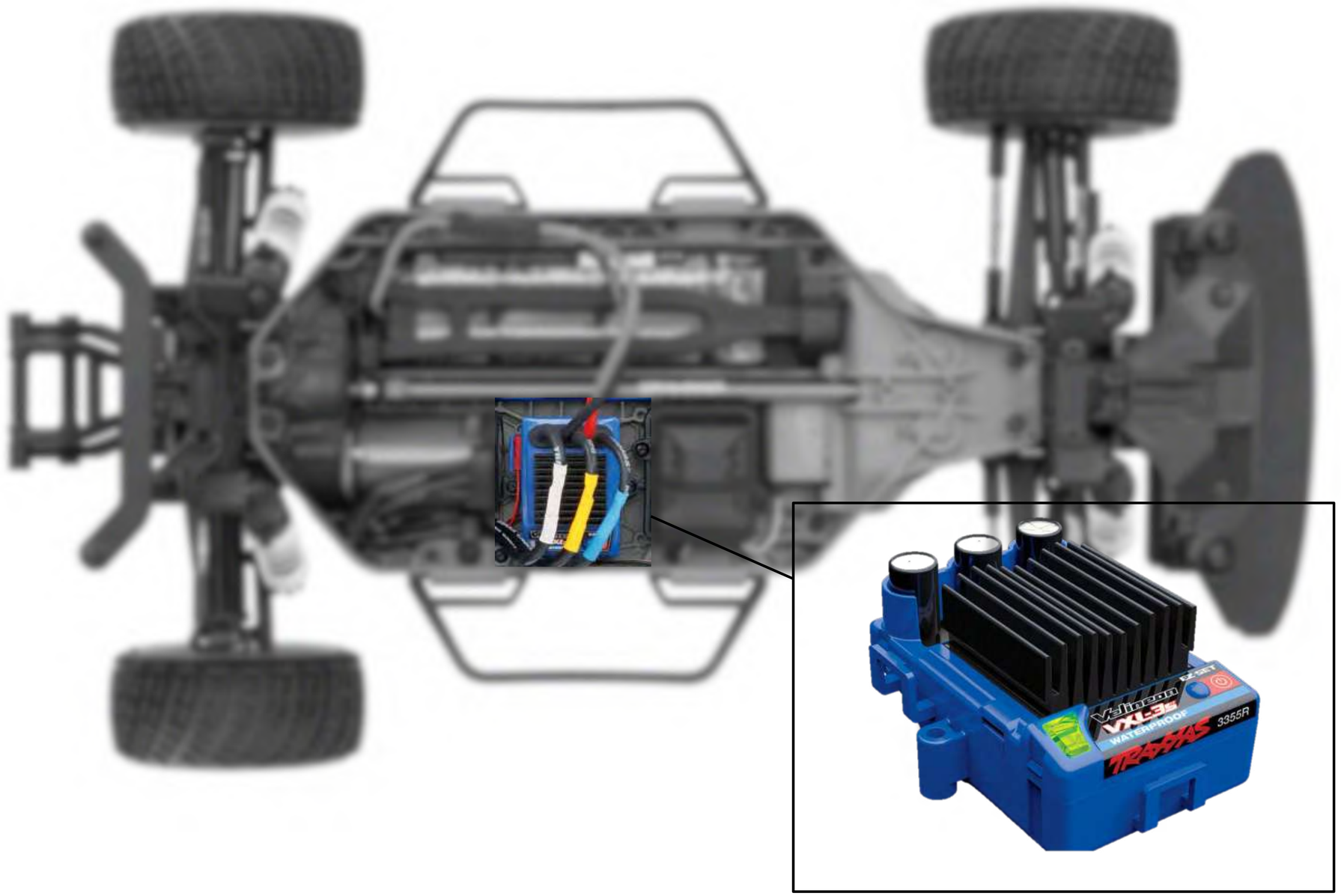
Traxxas 1/10 scale RC race car



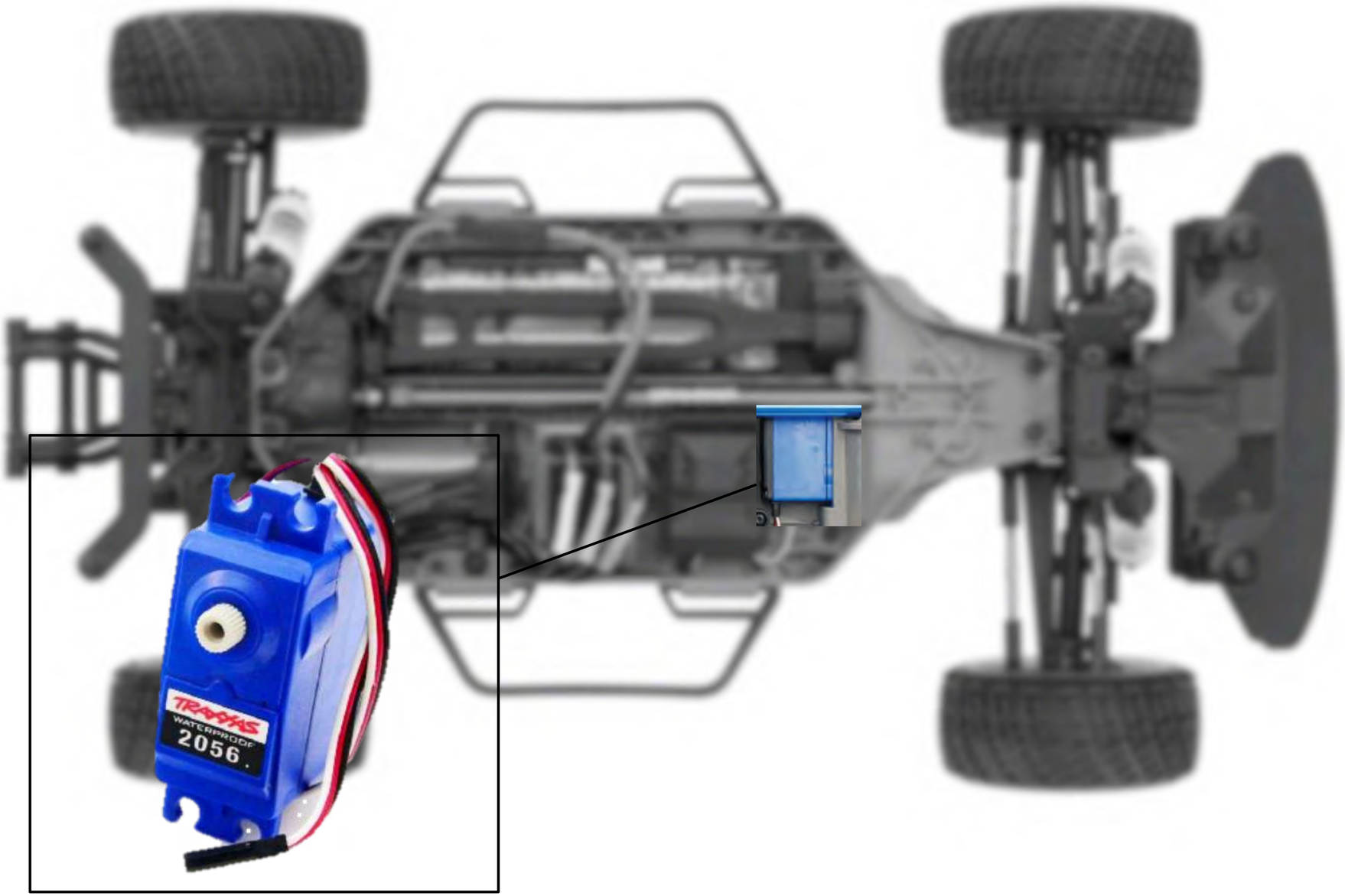
Brushless DC motor



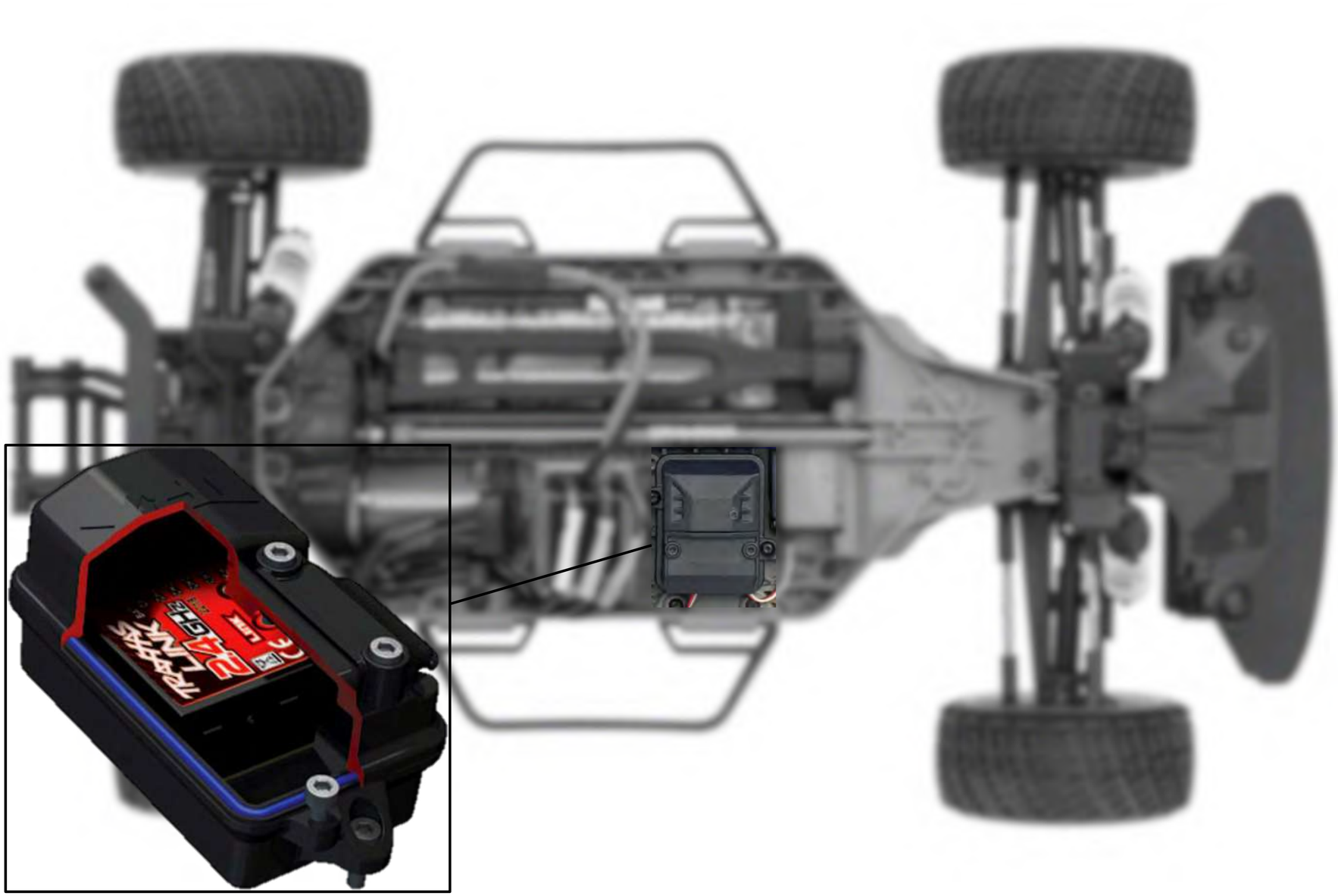
Electronic Speed Control (ESC)



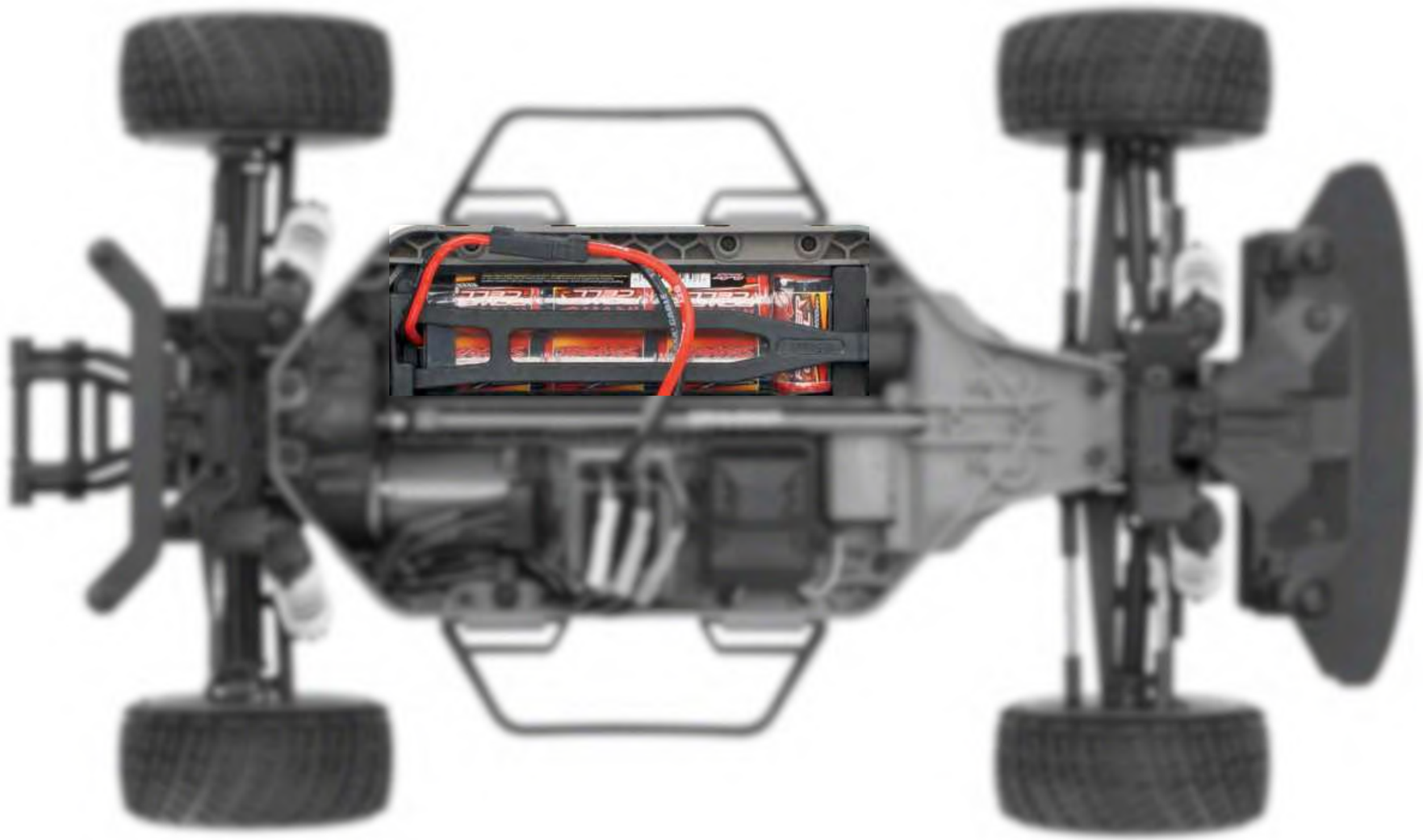
Servo motor for steering



Radio receiver



Battery pack



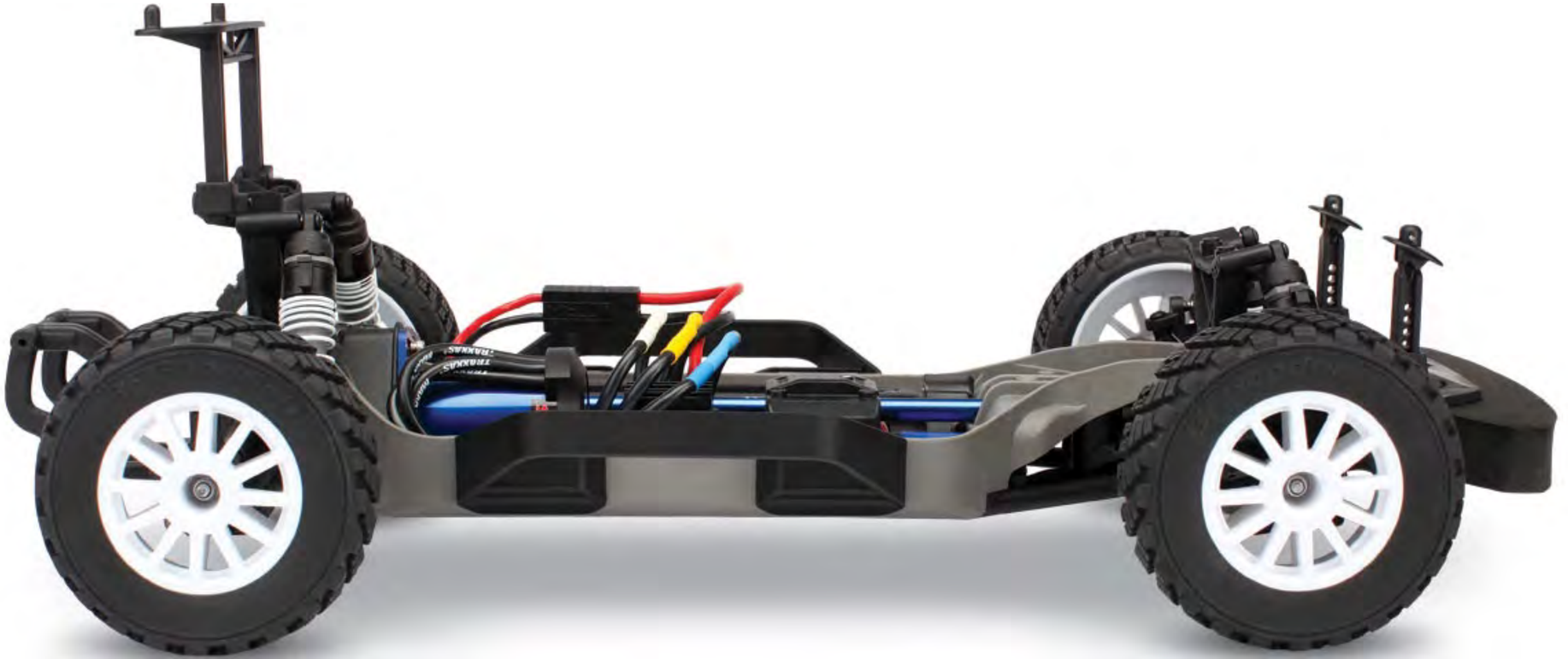
Sensor Integration

LiDAR

Camera

IMU

IR Depth Cameras



Sensor Integration

LiDAR

Camera

IMU

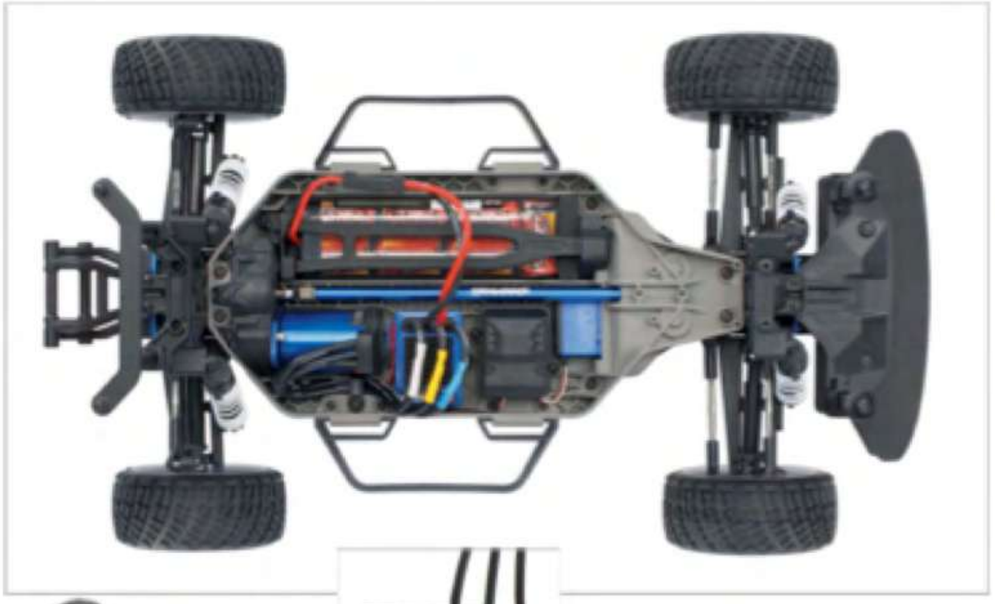
IR Depth Cameras

Wi-fi Telemetry

Onboard Computer

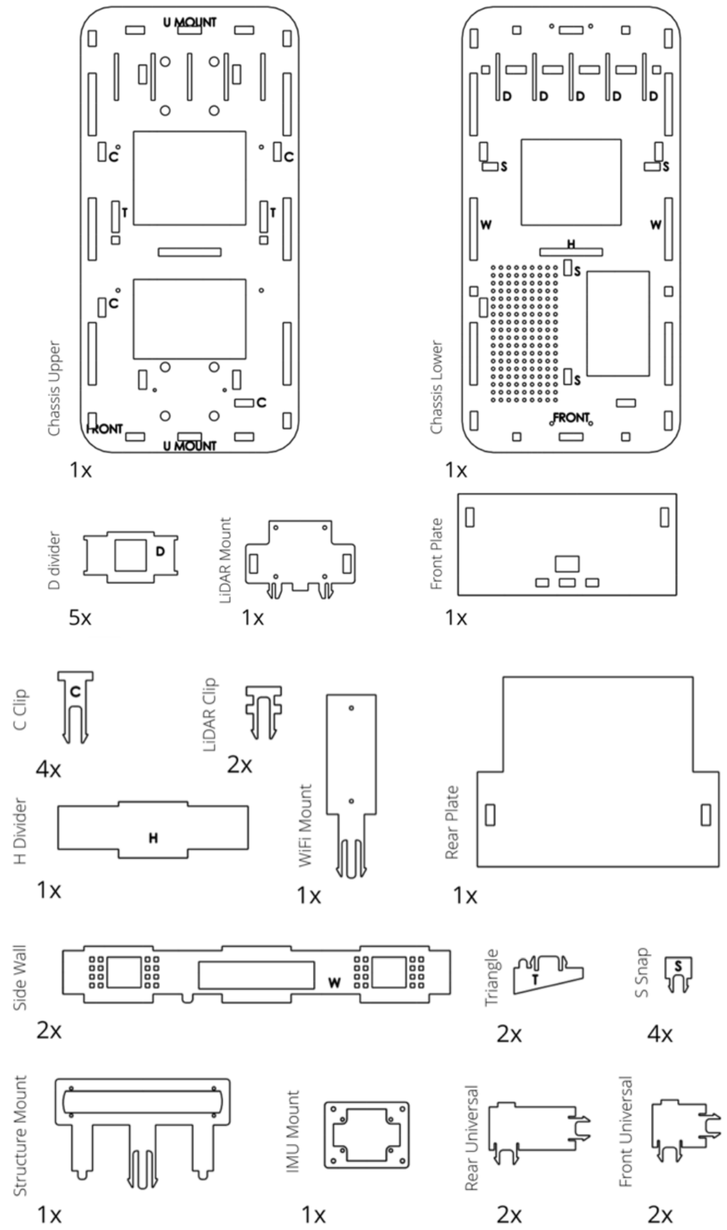
Motor Controller

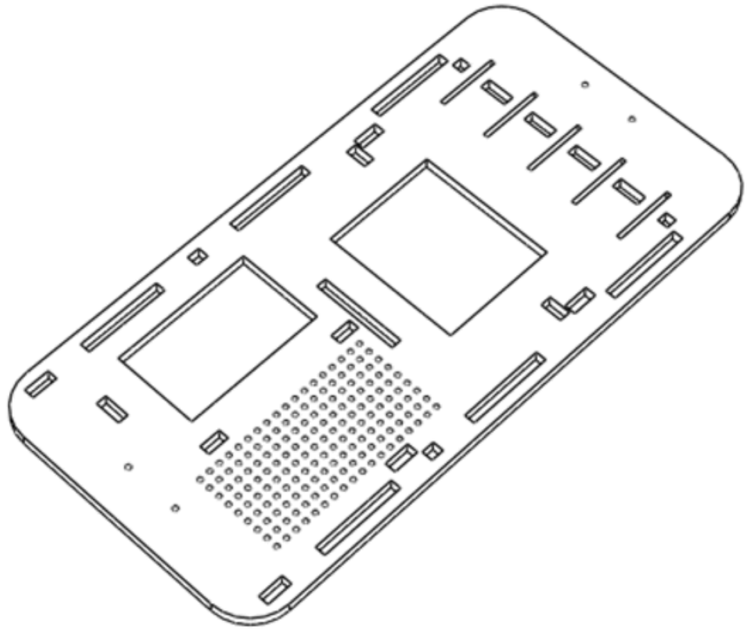
Fastware



Approximately $2,700

With simple IKEA style instructions:





F1/10 Race Car Assembly (Time Lapse)

Electronic Speed Control

Problem:

Actuate vehicle via commands in physical units

Understand:

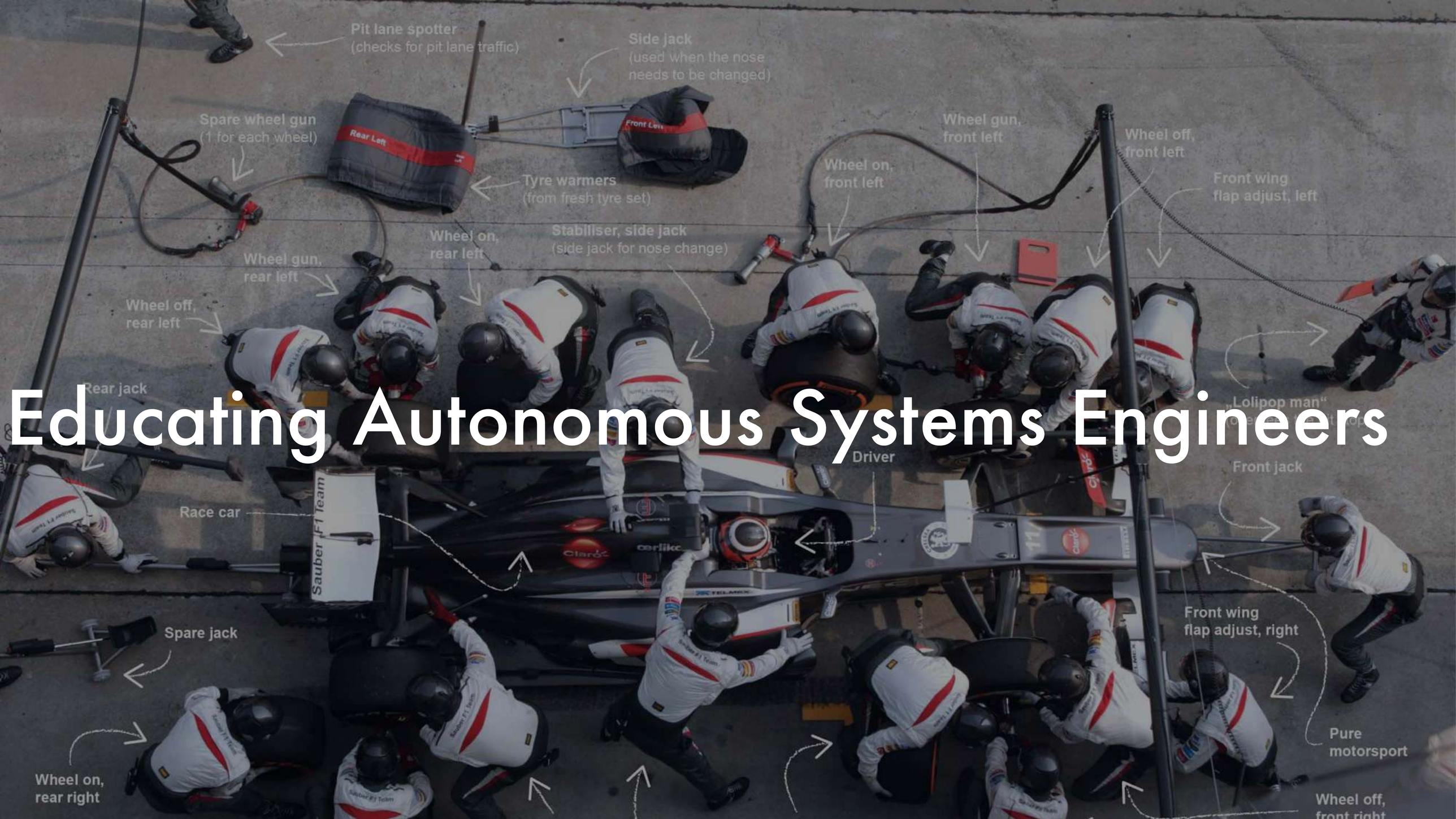
PID, motor control, etc.

Implement:

Motor controller, encoder, PID.

Drive

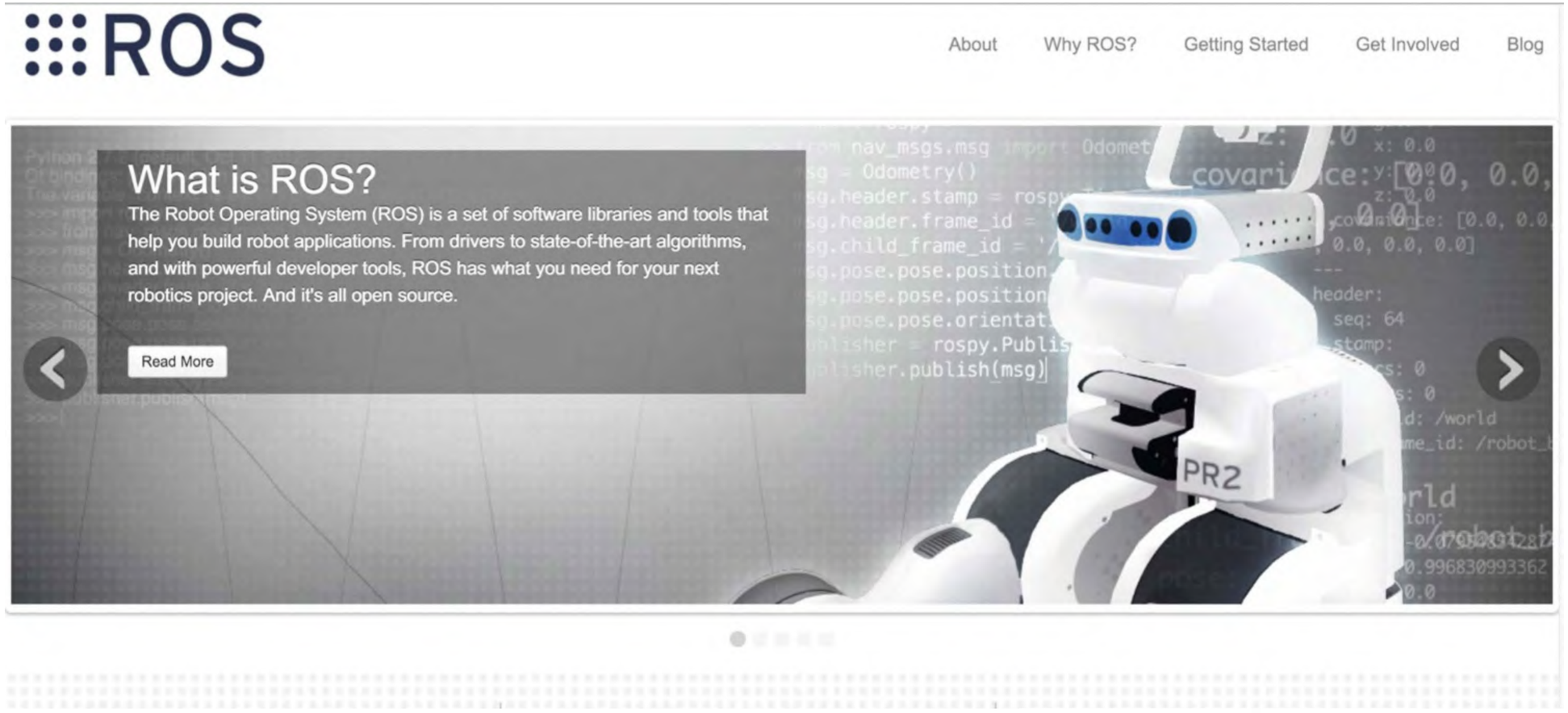
Perception. Planning. Control



Educating Autonomous Systems Engineers

Future racing teams will look like this

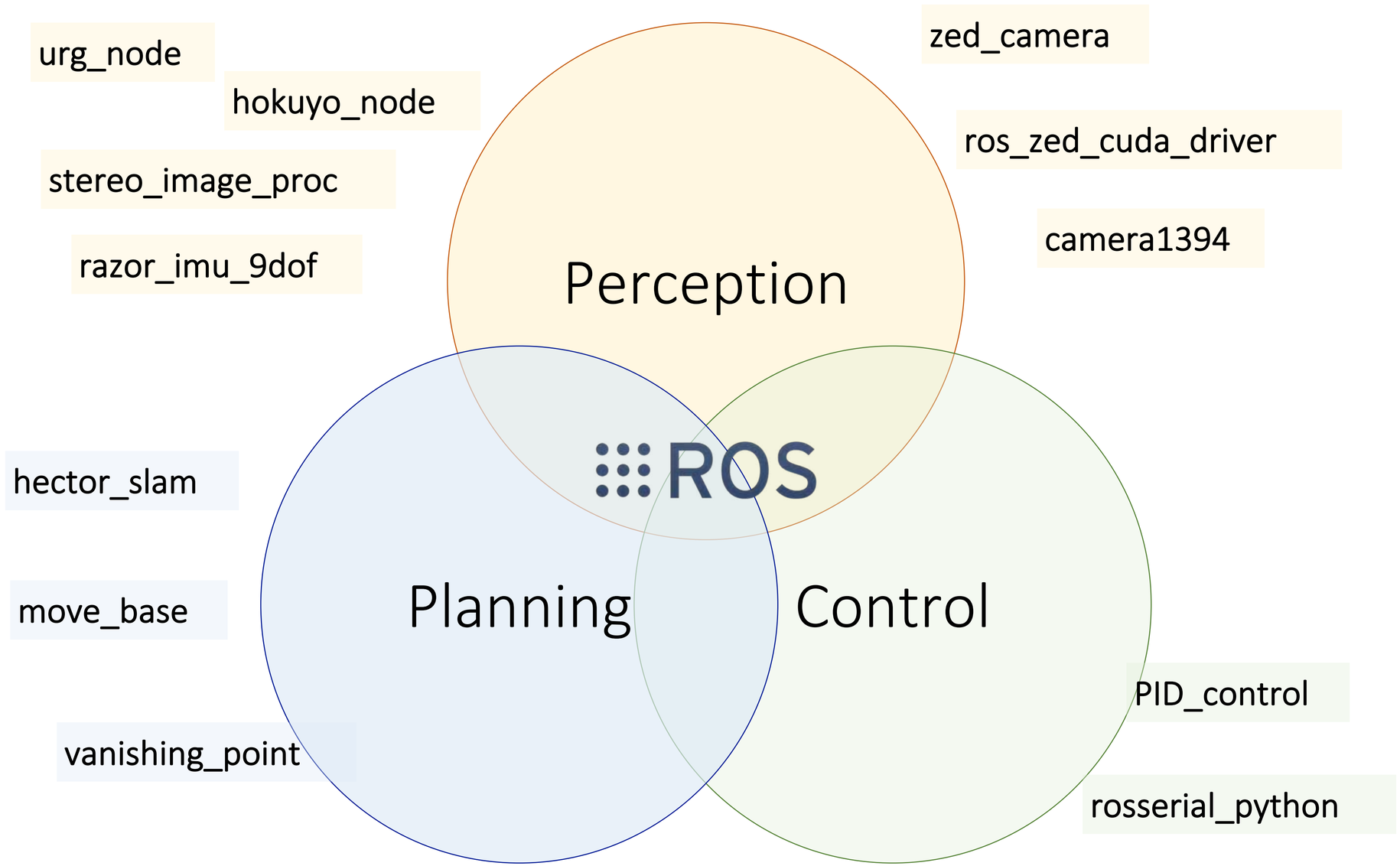
ROS: Robot Operating System



ROS.org

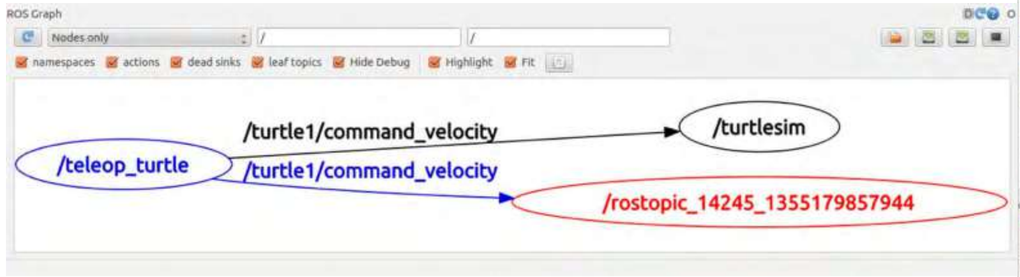
Open Source Robotics Foundation

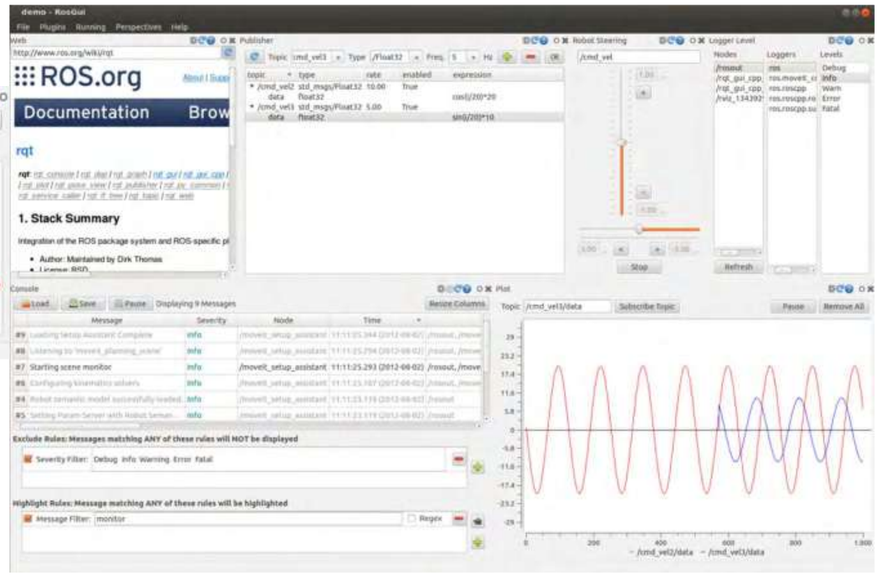
ROS Capabilities

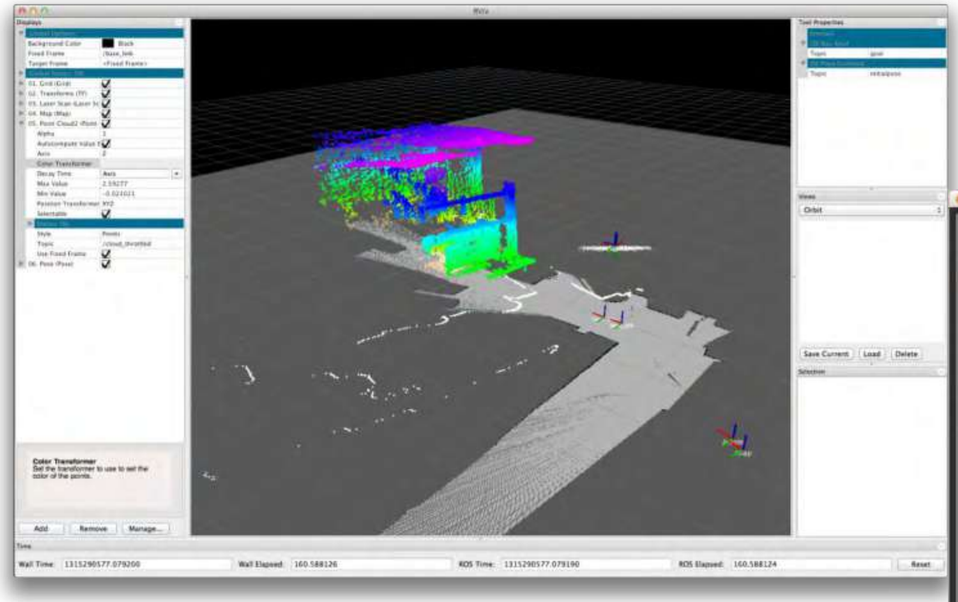


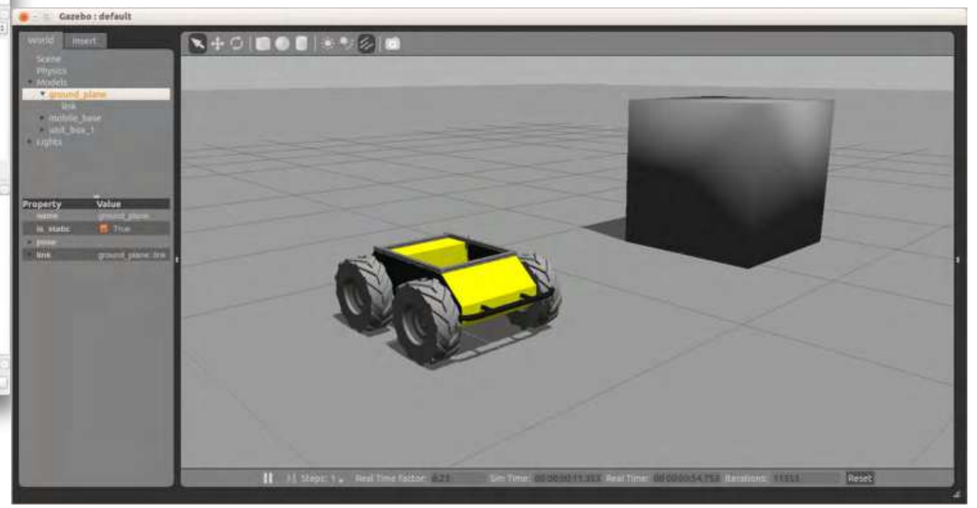
ROS Tools

Visualization, debugging and diagnostics, logging, and simulation





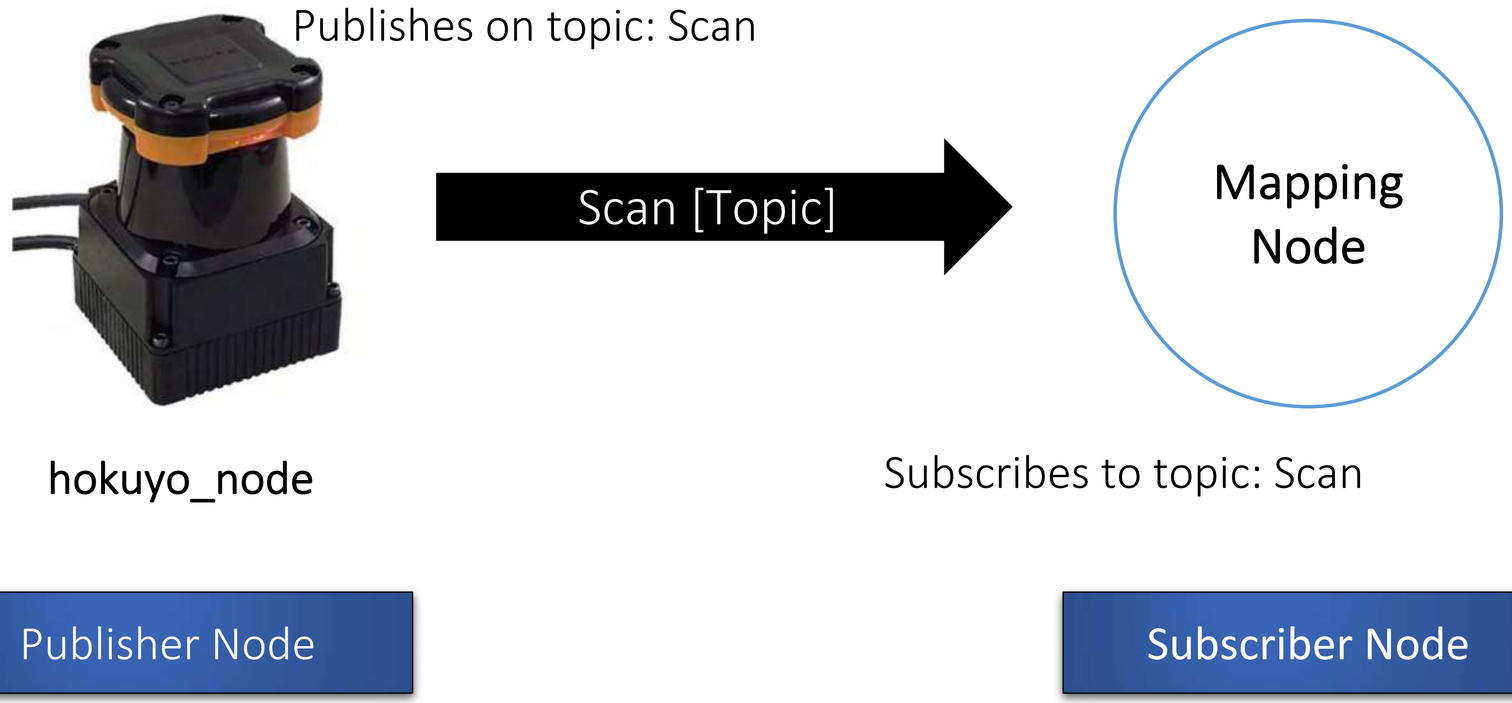




ROS: Topics

Topics are channels over which nodes exchange messages.

They are for streaming data



The entire course is organized as a long Formula 1 race weekend

Lab exercises

Practice Session 1:

Understanding ROS | Setting up the Car

Practice Session 2:

Perception/Sensing | Driving Straight

Practice Session 3:

Driving in a loop | Visual Odometry

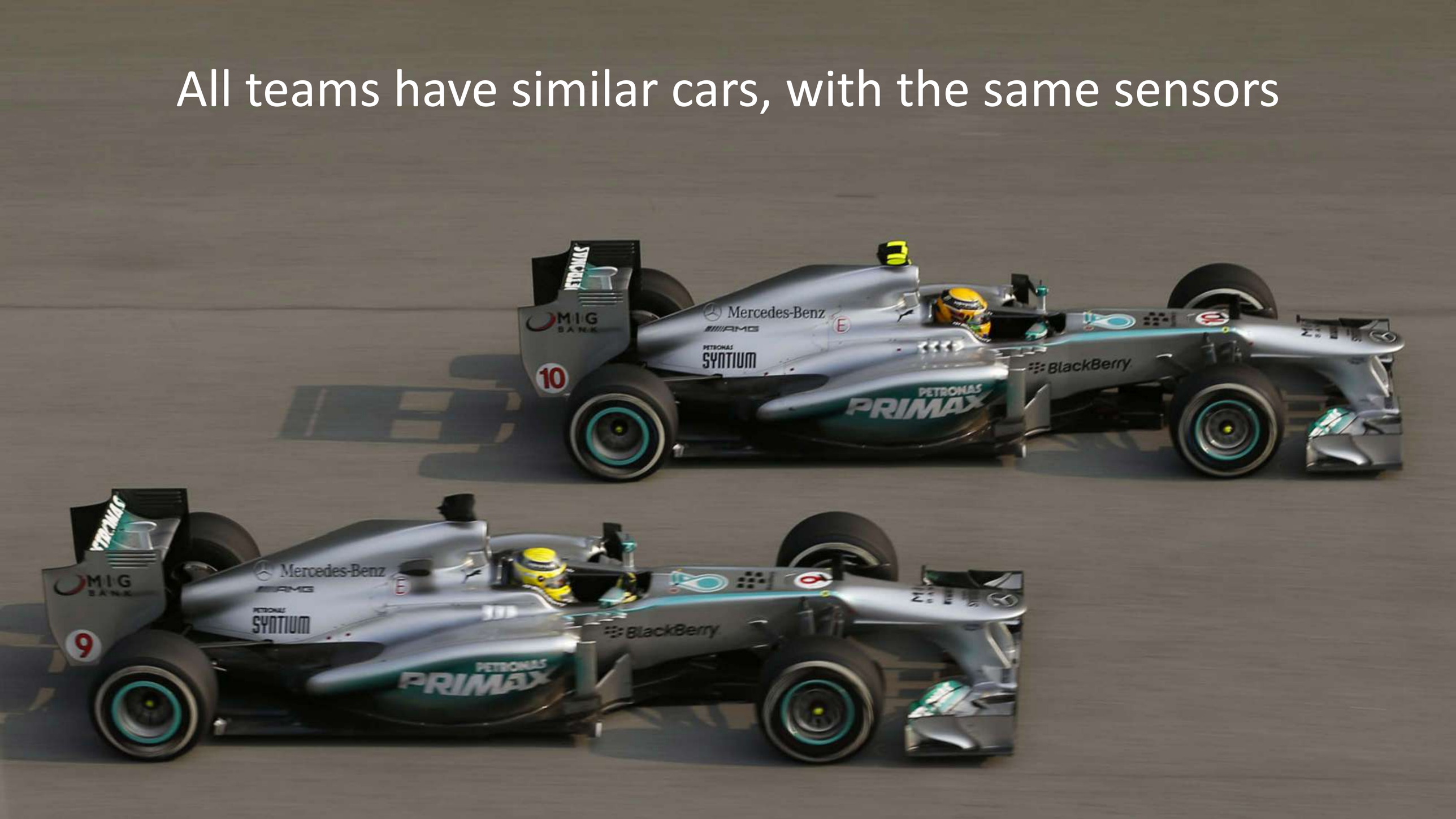
Practice Session 3:

Race | Time trials | Head-to-head racing

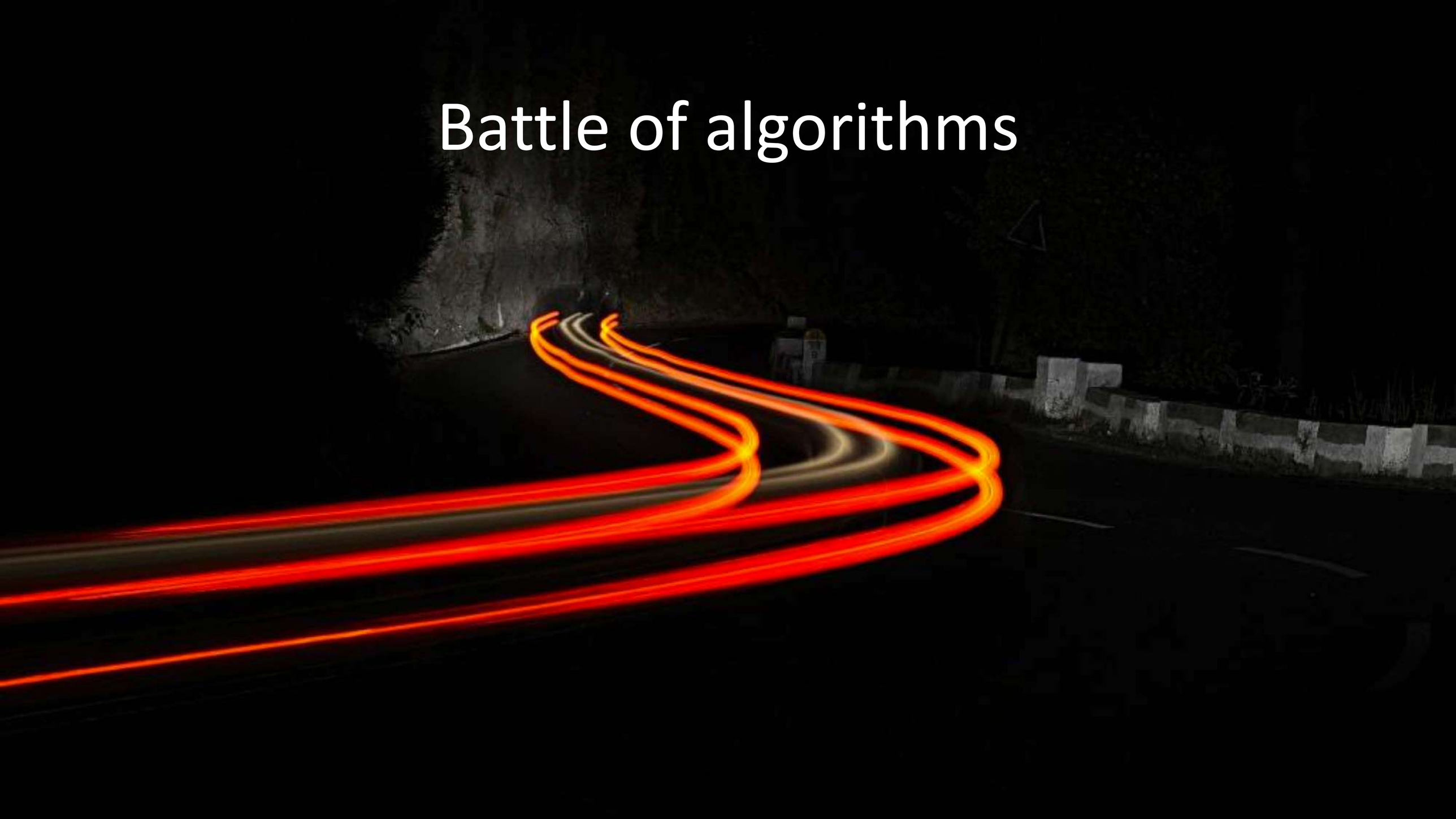

BISMO

Race

All teams have similar cars, with the same sensors



Battle of algorithms



1st F1/10 Race: Oct 2016, Pittsburg, ES-Week

2nd F1/10 Race: Apr 2018, Porto, CPS-Week

3rd F1/10 Race: Oct 2018, Torino, ES-Week

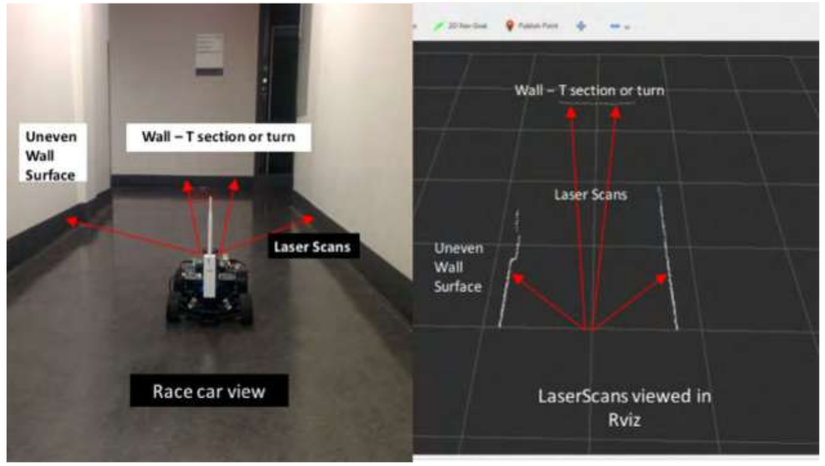
4th F1/10 Race: Apr 2019, Montreal, CPS-Week

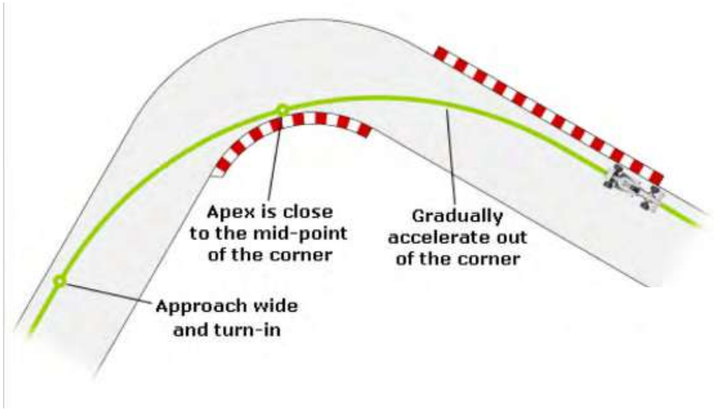

Head-to-head Autonomous Racing
4th F1/10 International Autonomous Racing Competition
F1
TENTH
f1tenth.org

Perception. Planning. Control.

Perception. Planning. Control

Making sense of the surroundings

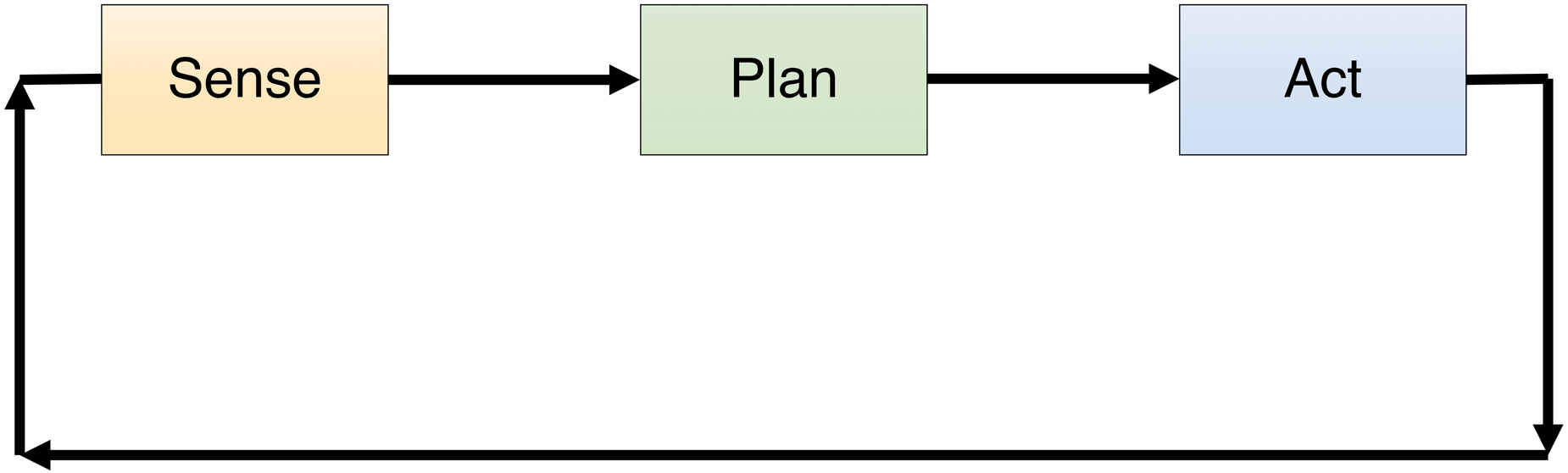


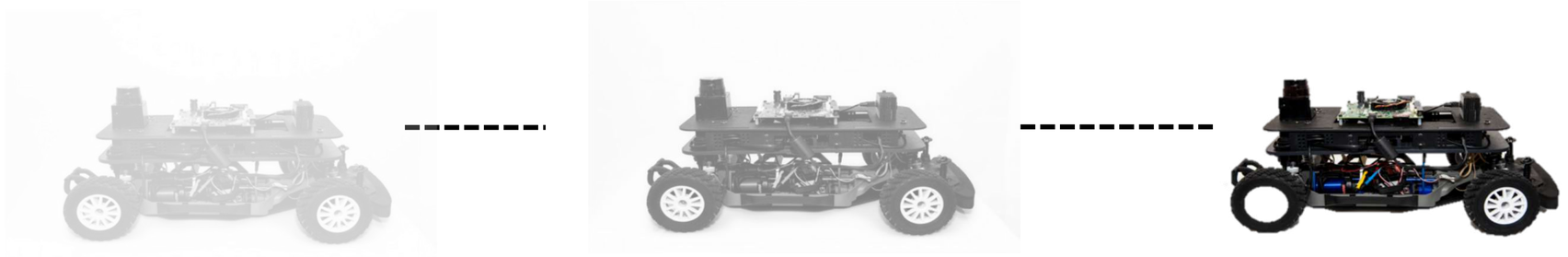


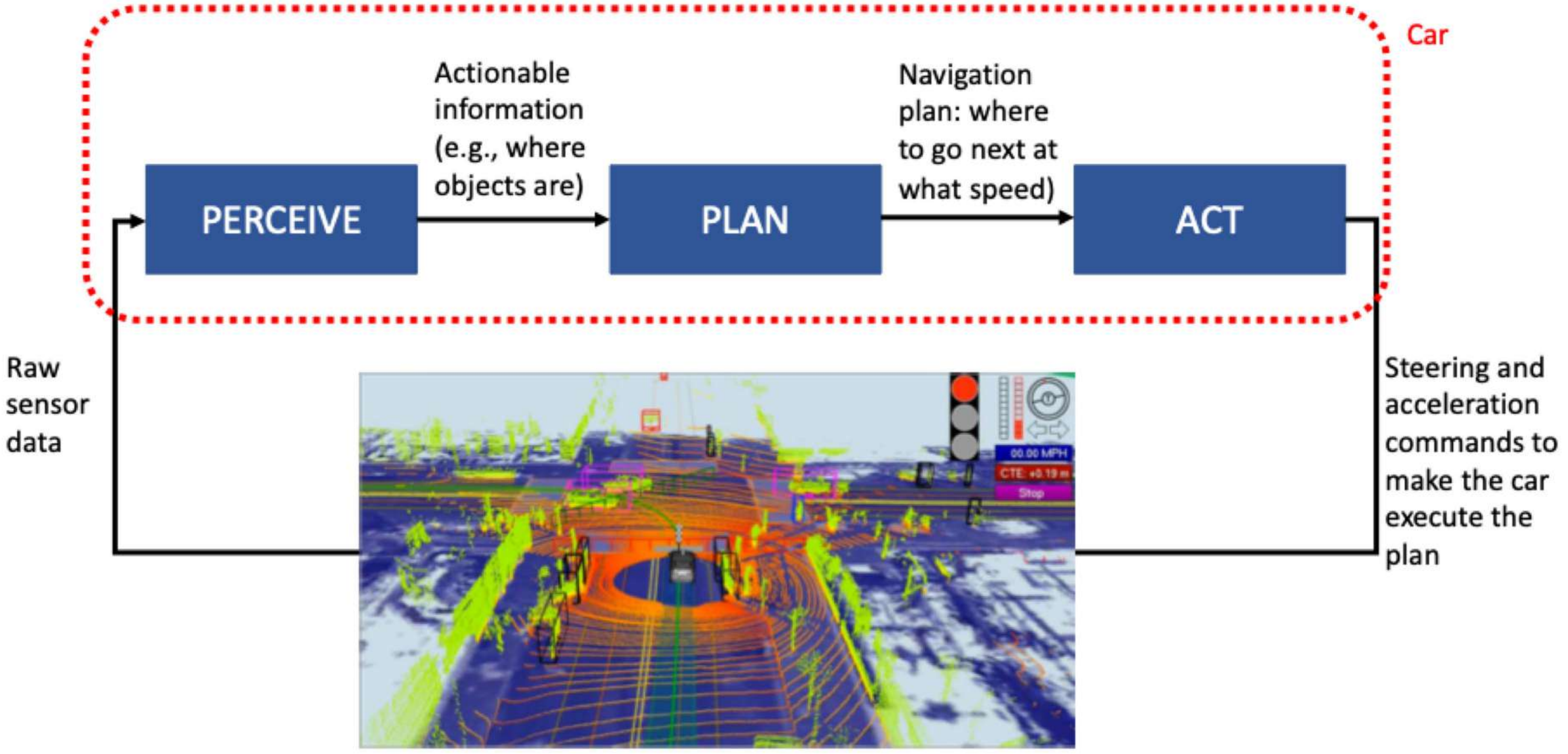
Planning the fastest racing line

Controlling the car to follow the planned path

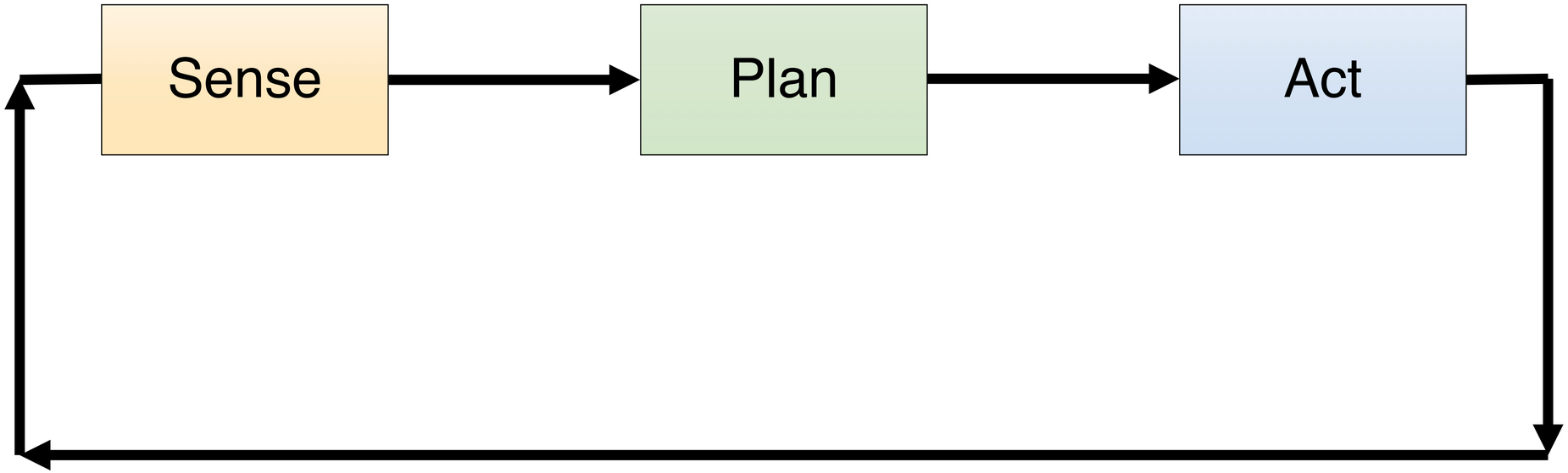
Closing the loop

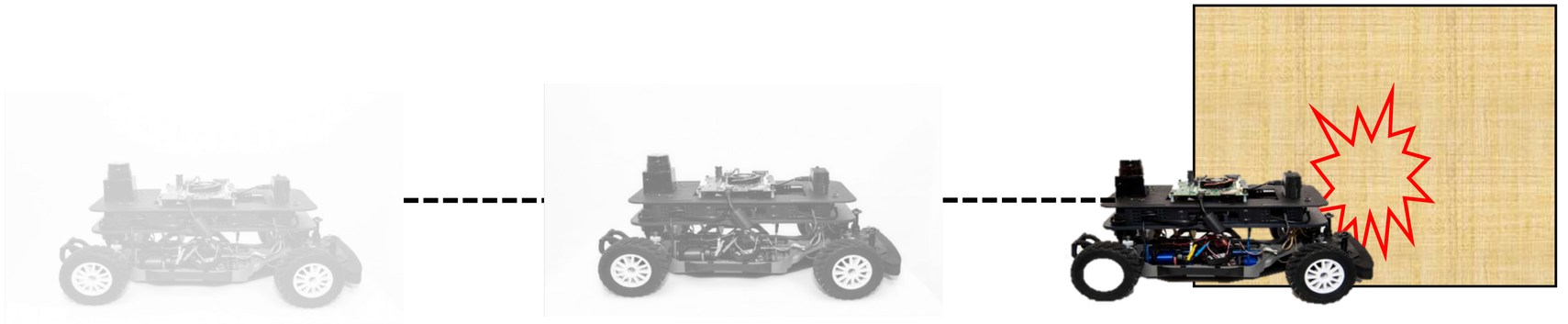




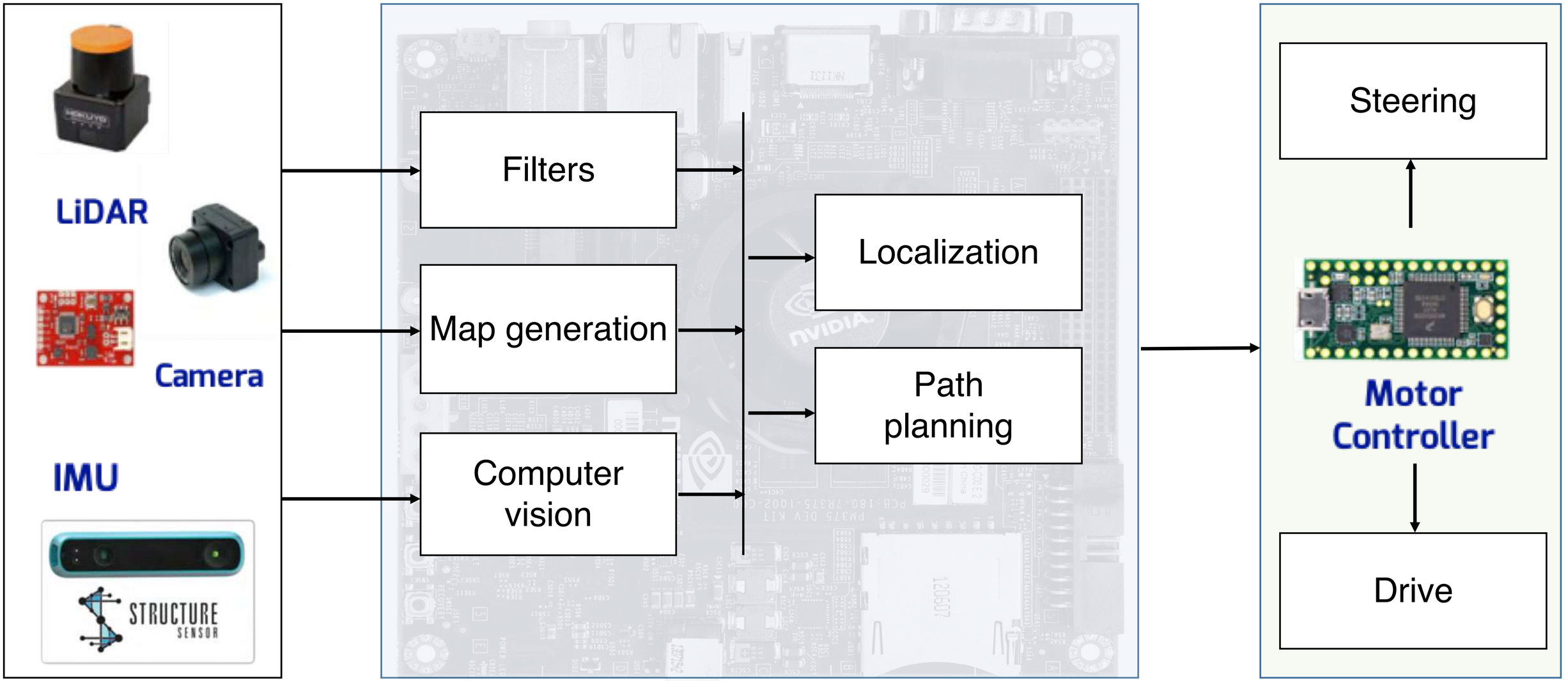

Car
Actionable information (e.g., where objects are)
Navigation plan: where to go next at what speed)
PERCEIVE
PLAN
ACT
Raw sensor data
Steering and acceleration commands to make the car execute the plan
00.00 MPH
Stop
Big Bad World

Closing the loop fast

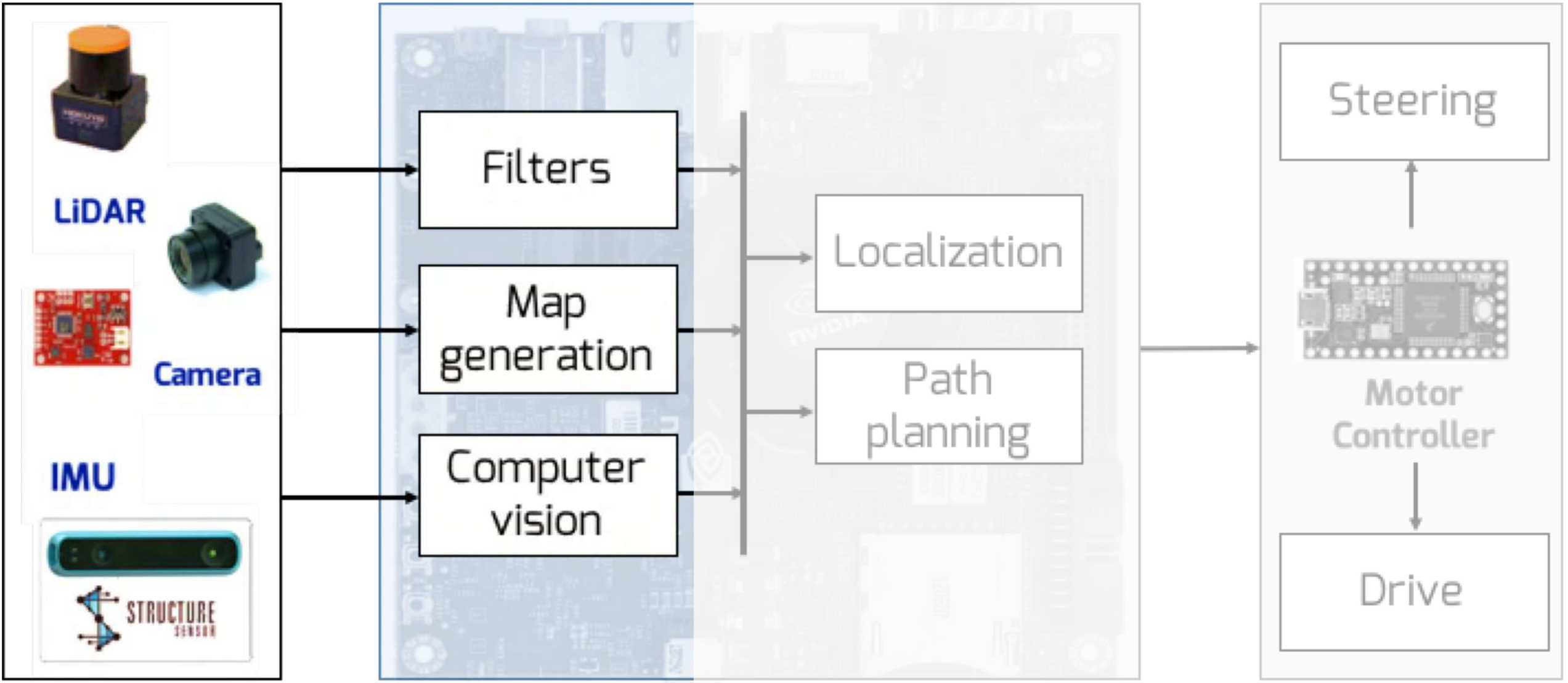




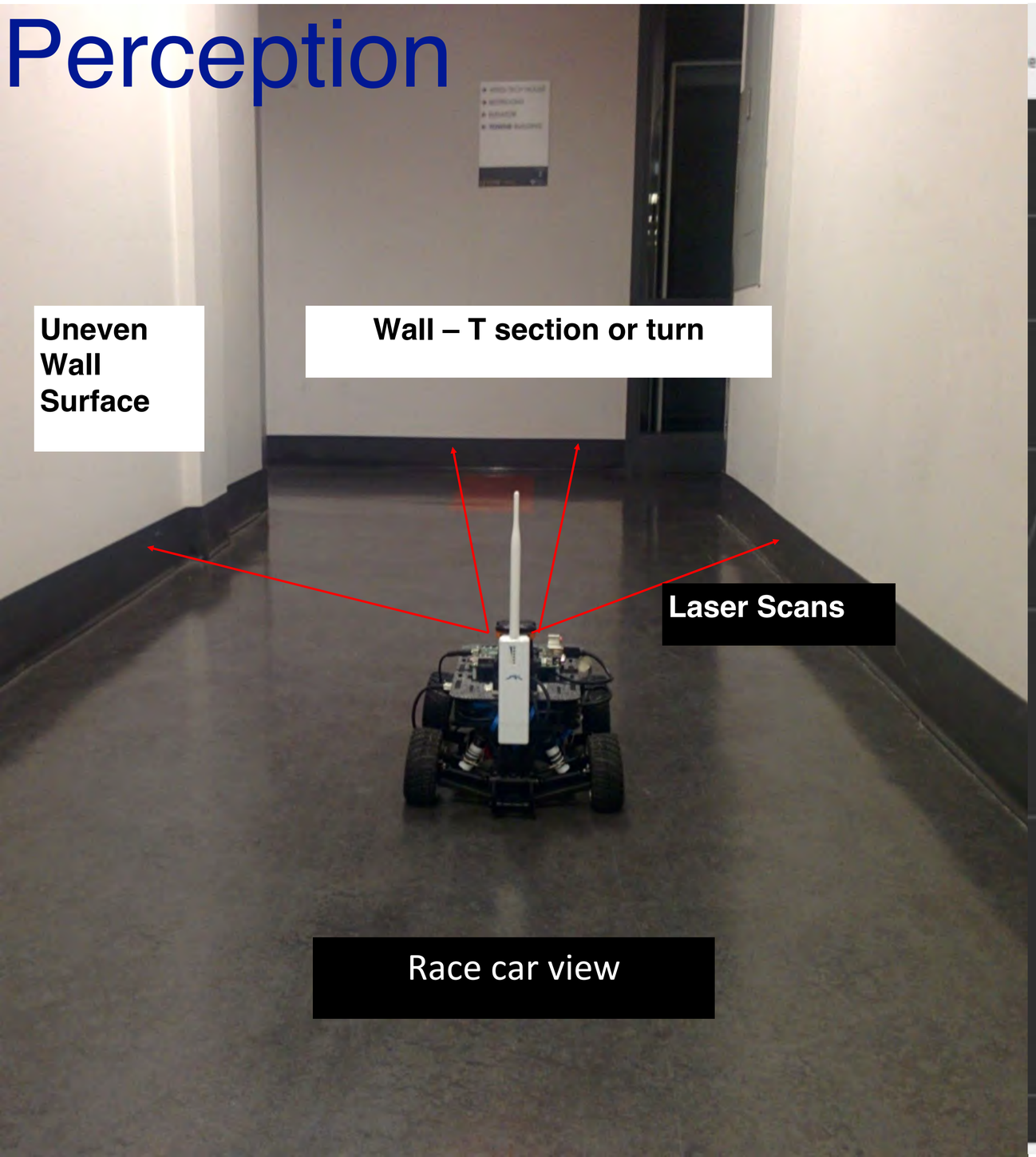
System Architecture

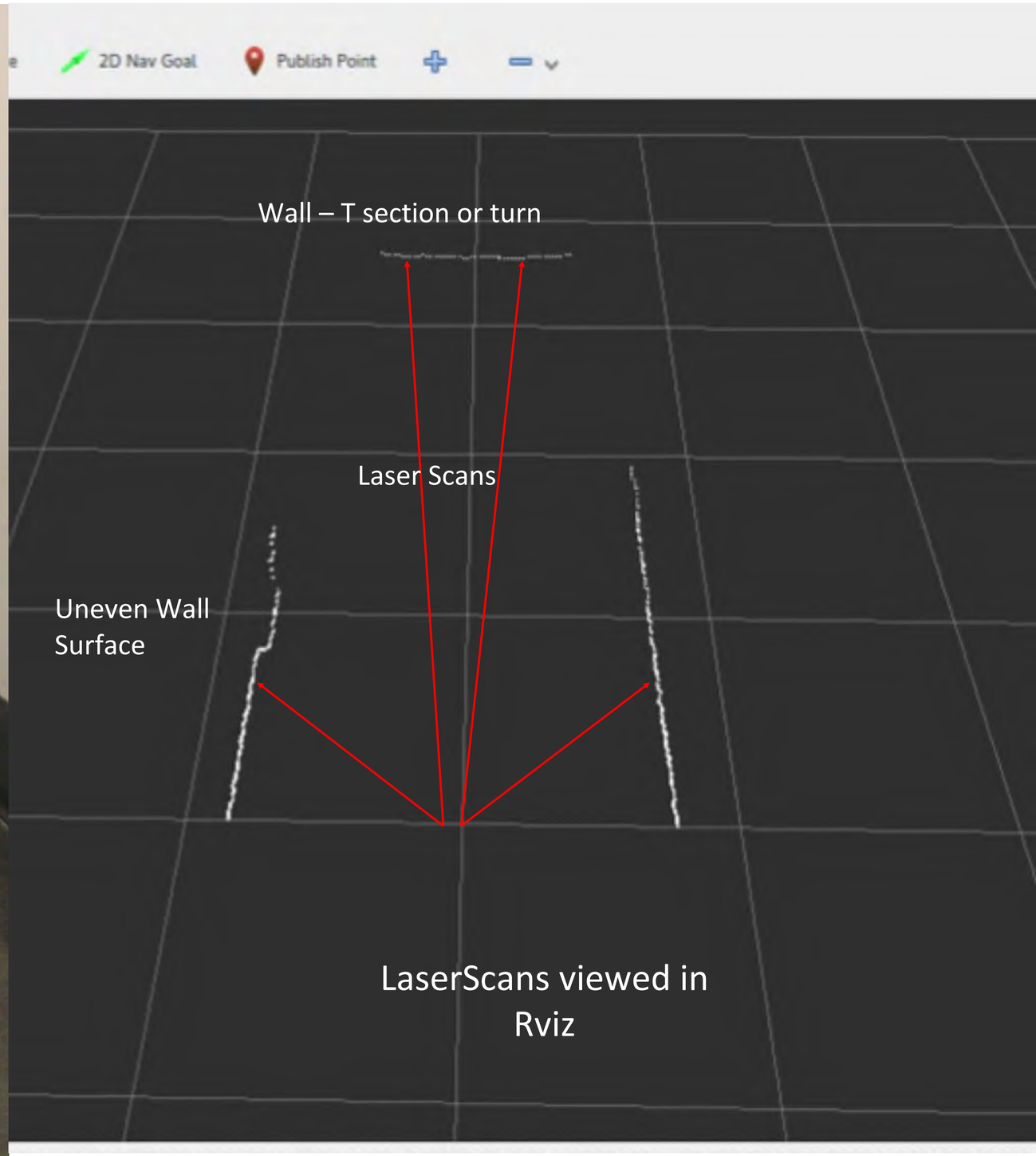


Perception


LiDAR
Camera
IMU
STRUCTURE
SENSOR
Filters
Map generation
Computer vision
Localization
Path planning
Steering
Motor Controller
Drive

Perception


Uneven Wall Surface
Wall – T section or turn
Laser Scans
Race car view


2D Nav Goal
Publish Point
Wall – T section or turn
Laser Scans
Uneven Wall Surface
LaserScans viewed in Rviz

Pose Representations and Transformations

Problem:

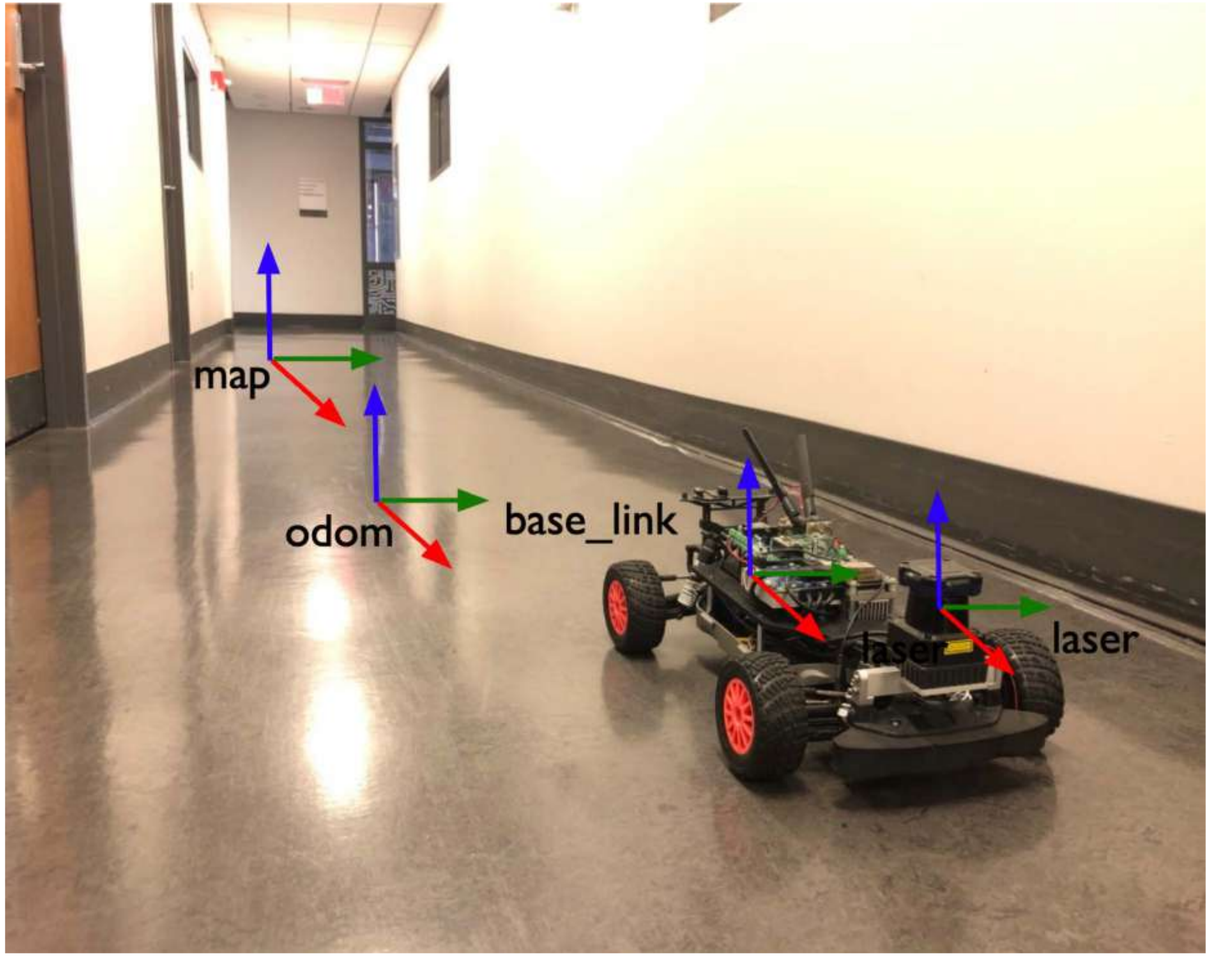
Sensors in different reference frames

Understand:

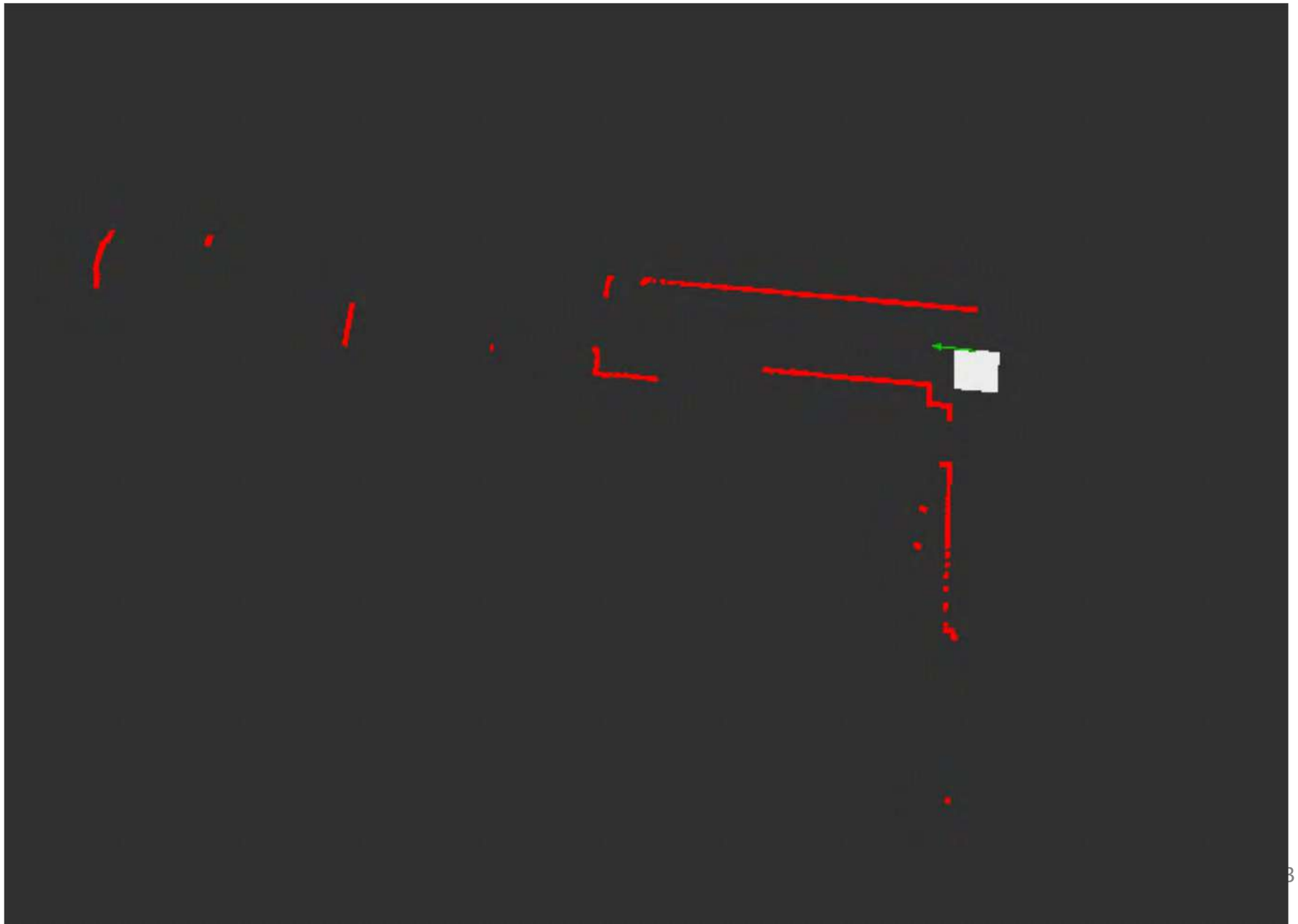
Rigid Body Transformations

Implement:

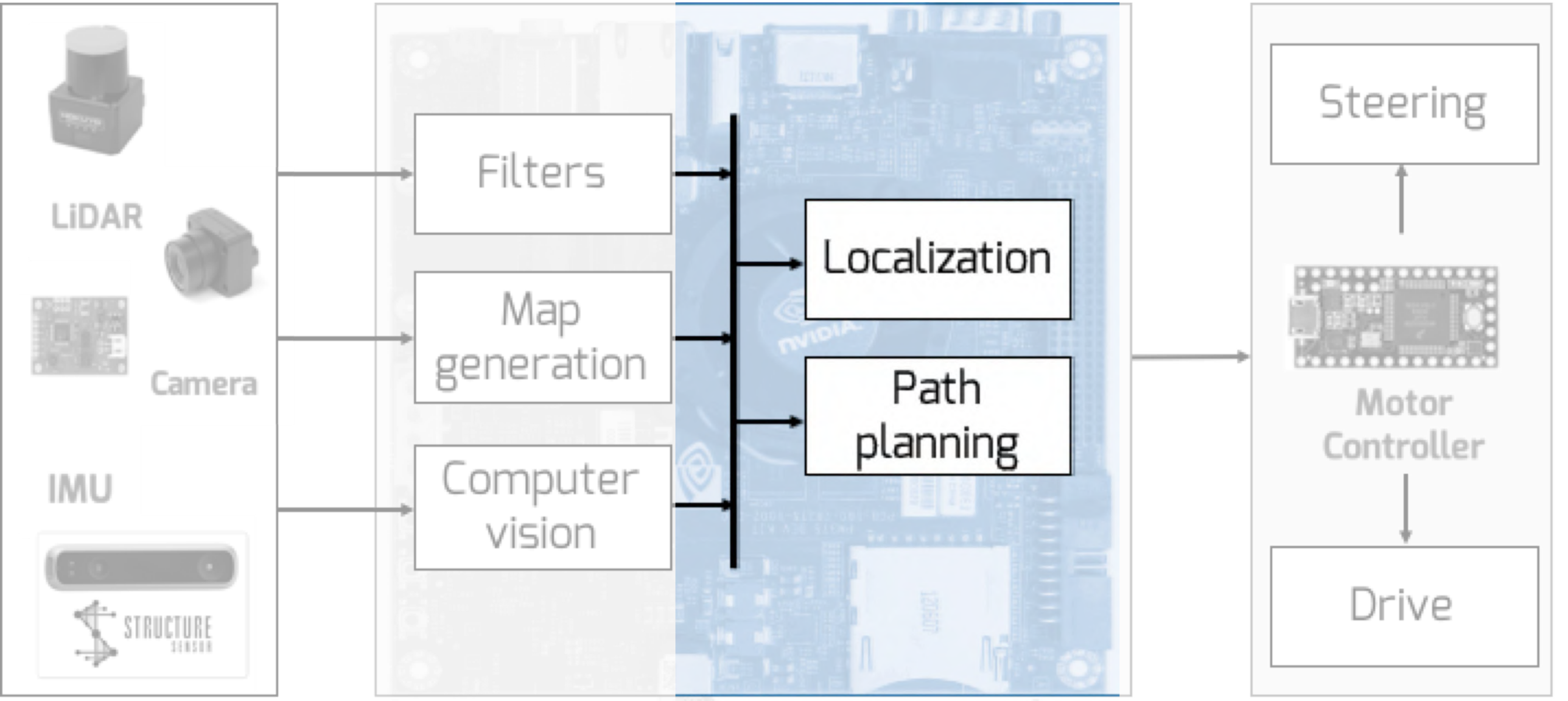
Tf tree, pose transformations in ROS



Registering a LIDAR Scan



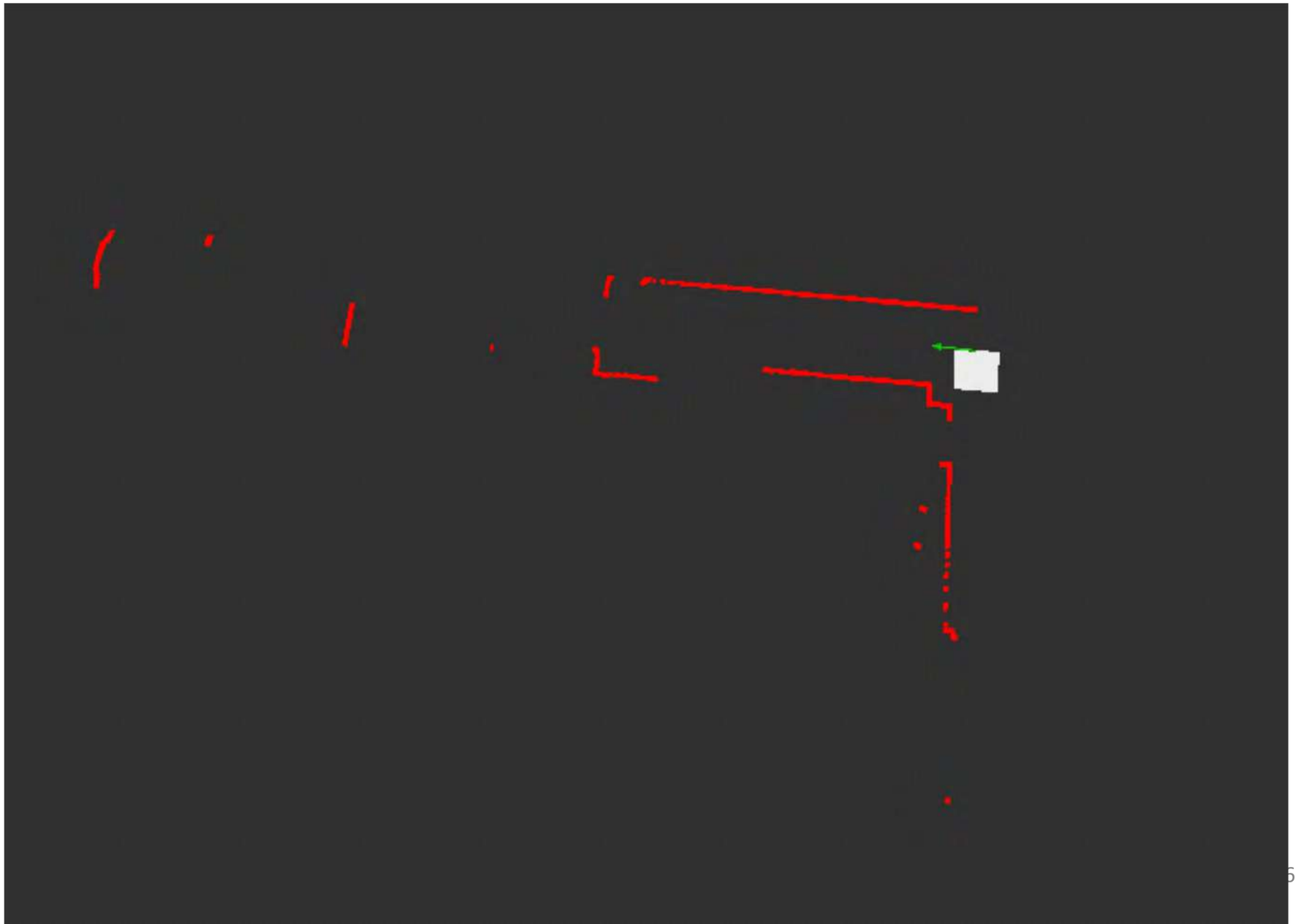
Planning


LiDAR
Camera
IMU
STRUCTURE
Filters
Map generation
Computer vision
Localization
Path planning
Steering
Motor Controller
Drive

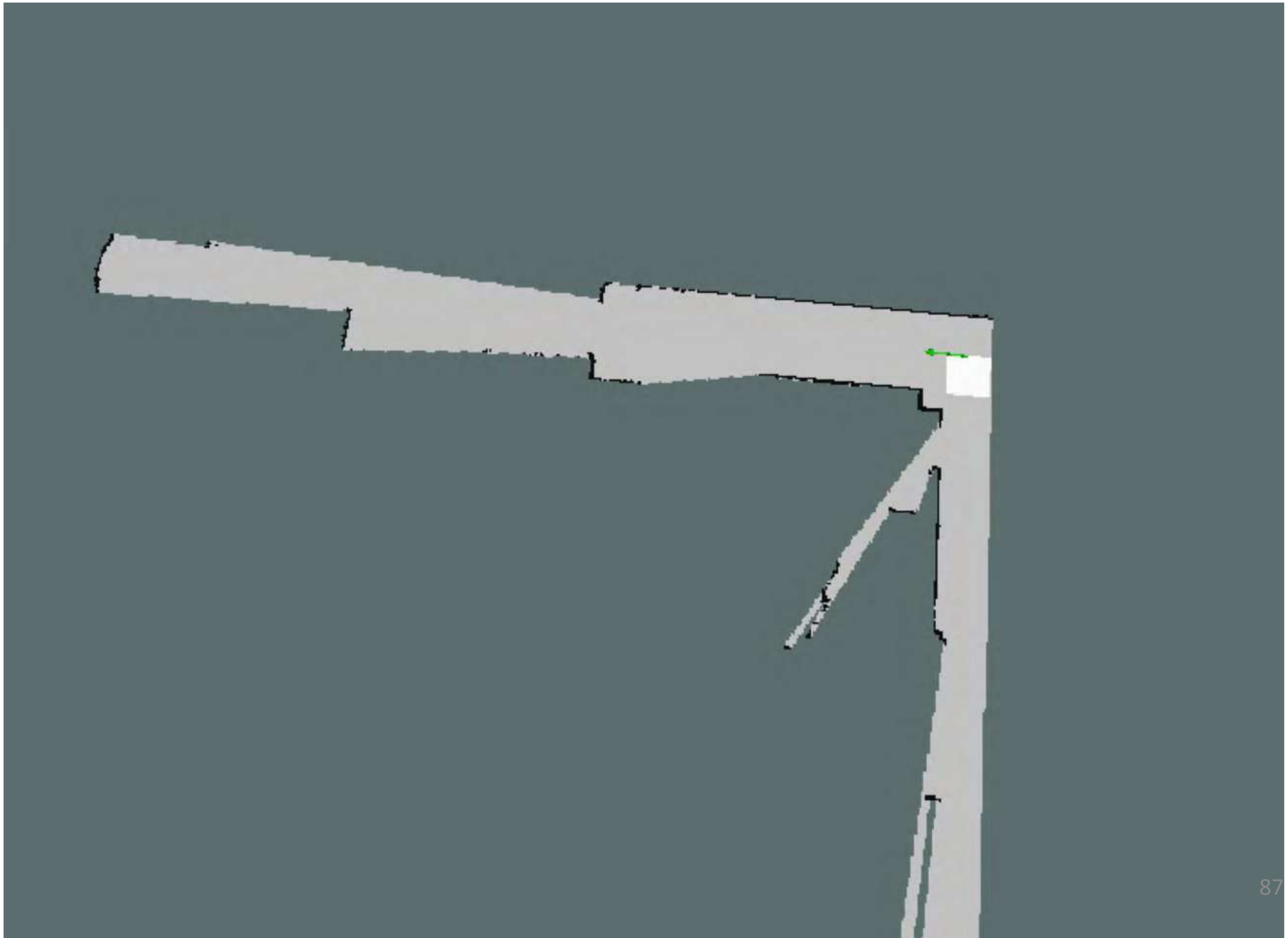
Planning

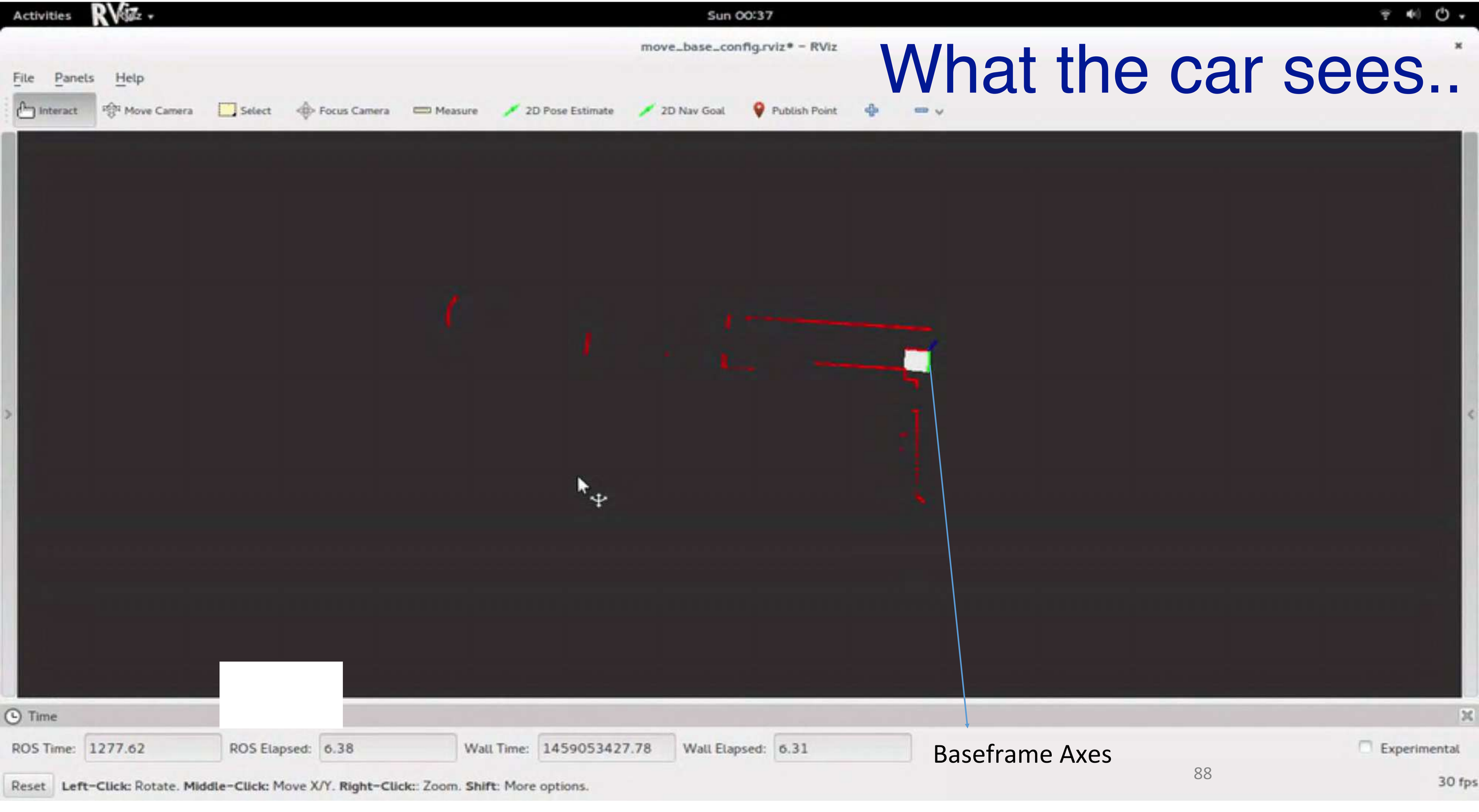

Cost Maps path planning
Time
ROS Time: 1453072851.57
ROS Elapsed: 30.29
Wall Time: 1454341978.42
Wall Elapsed: 68.81
Experimental
Reset
Left-Click: Rotate. Middle-Click: Move X/Y. Right-Click:: Move Z. Shift: More options.
30 fps

Registering a LIDAR Scan

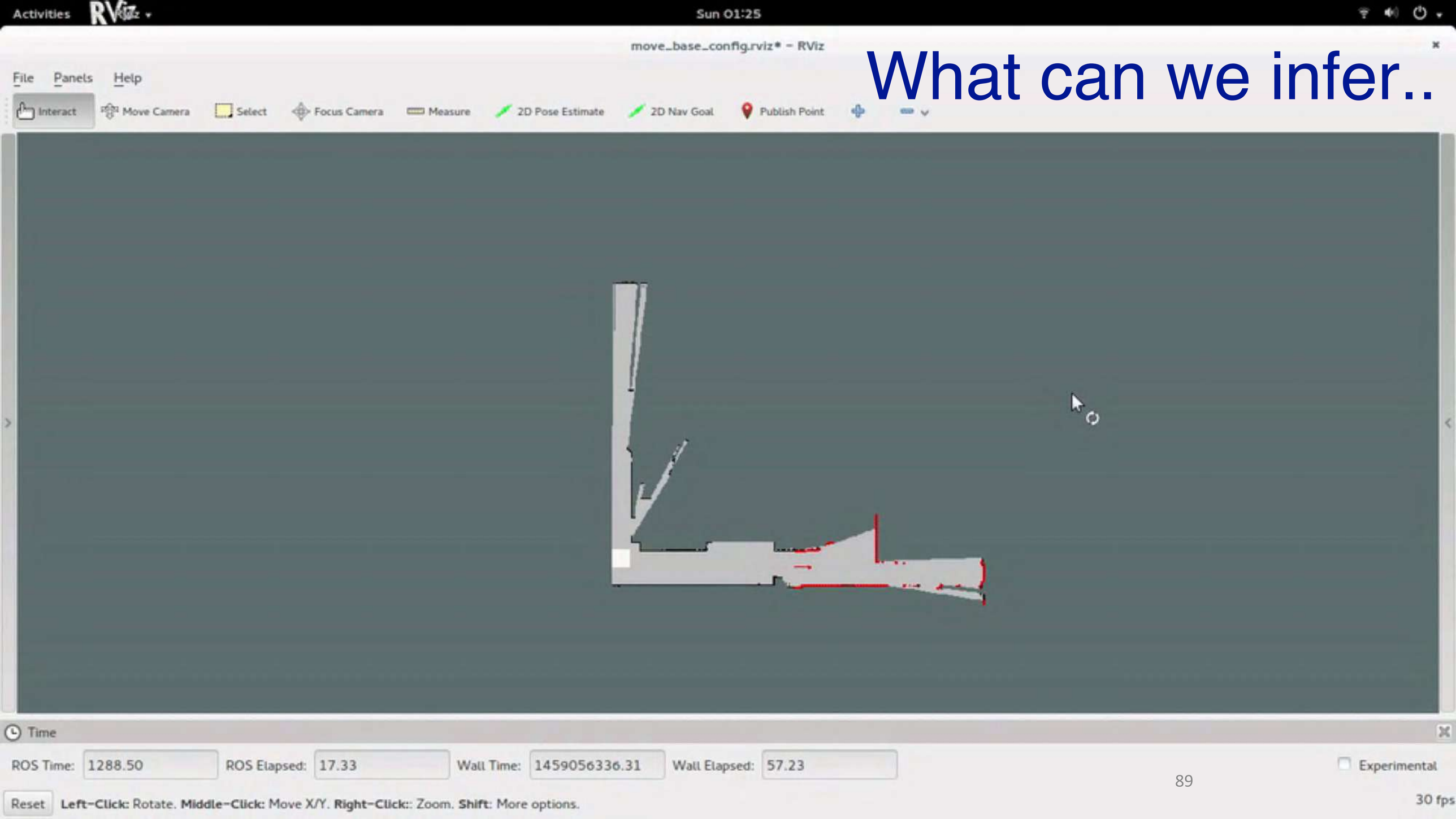


Registering a LIDAR Scan




Activities
RViz
Sun 00:37
move_base_config.rviz* - RViz
File
Panels
Help
Interact
Move Camera
Select
Focus Camera
Measure
2D Pose Estimate
2D Nav Goal
Publish Point
What the car sees..
Time
ROS Time: 1277.62
ROS Elapsed: 6.38
Wall Time: 1459053427.78
Wall Elapsed: 6.31
Experimental
Reset
Left-Click: Rotate. Middle-Click: Move X/Y. Right-Click:: Zoom. Shift: More options.
30 fps
Baseframe Axes

What can we infer..



SLAM

Activities RViz Wed 19:48

mapping_demo.rviz* – RViz

File

se Estimate 2D Nav Goal Publish Point

Topic	/map
Alpha	0.7
Color Scheme	map
Draw Behind	
Resolution	0.05
Width	2048
Height	2048
Position	-51.225; -51.225; 0
Orientation	0; 0; 0; 1
Path	
Status: Ok	

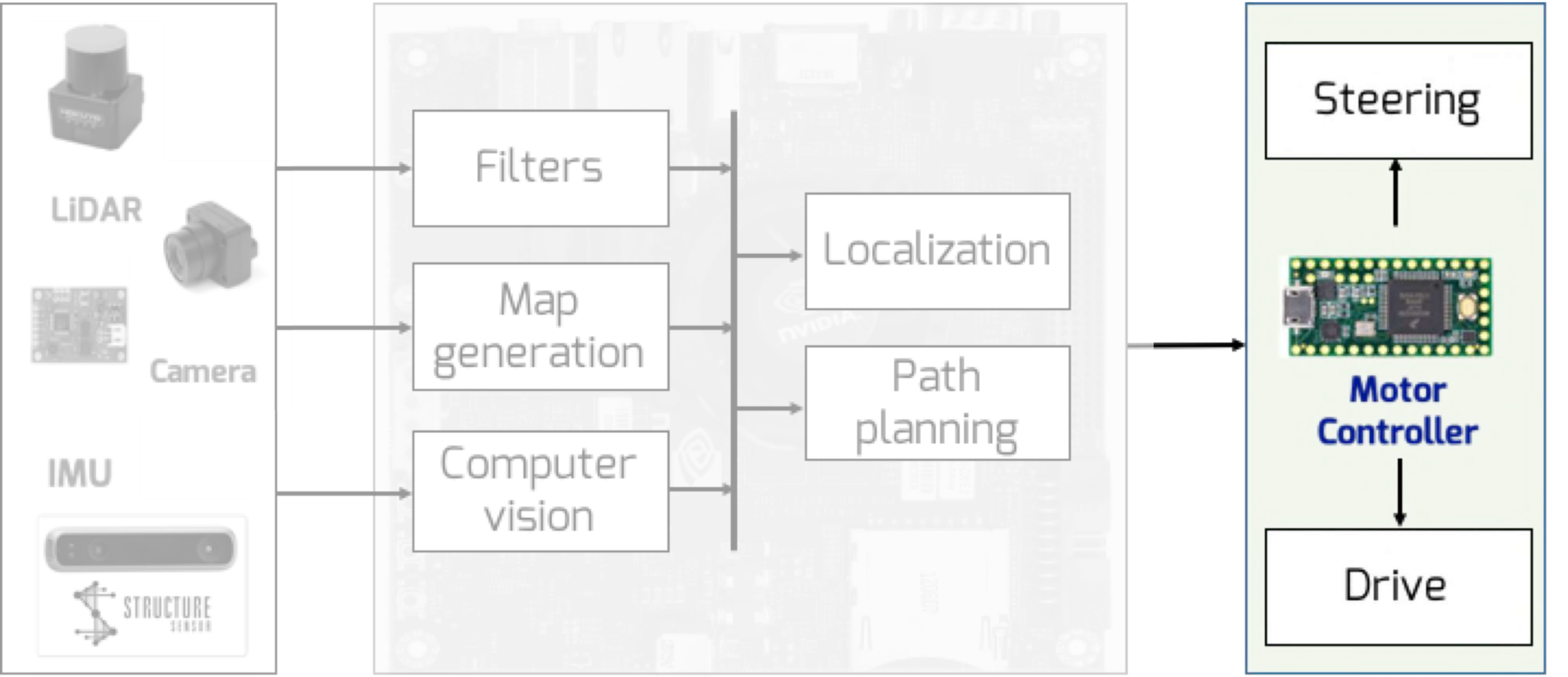
Add Remove Rename

Time

ROS Time: 1458504023.35 ROS Elapsed: 2.01 Wall Time: 1460591289.42 Wall Elapsed: 22.83 Experimental

Reset **Left-Click:** Rotate. **Middle-Click:** Move X/Y. **Right-Click:**: Zoom. **Shift**: More options. 30 fps

Control

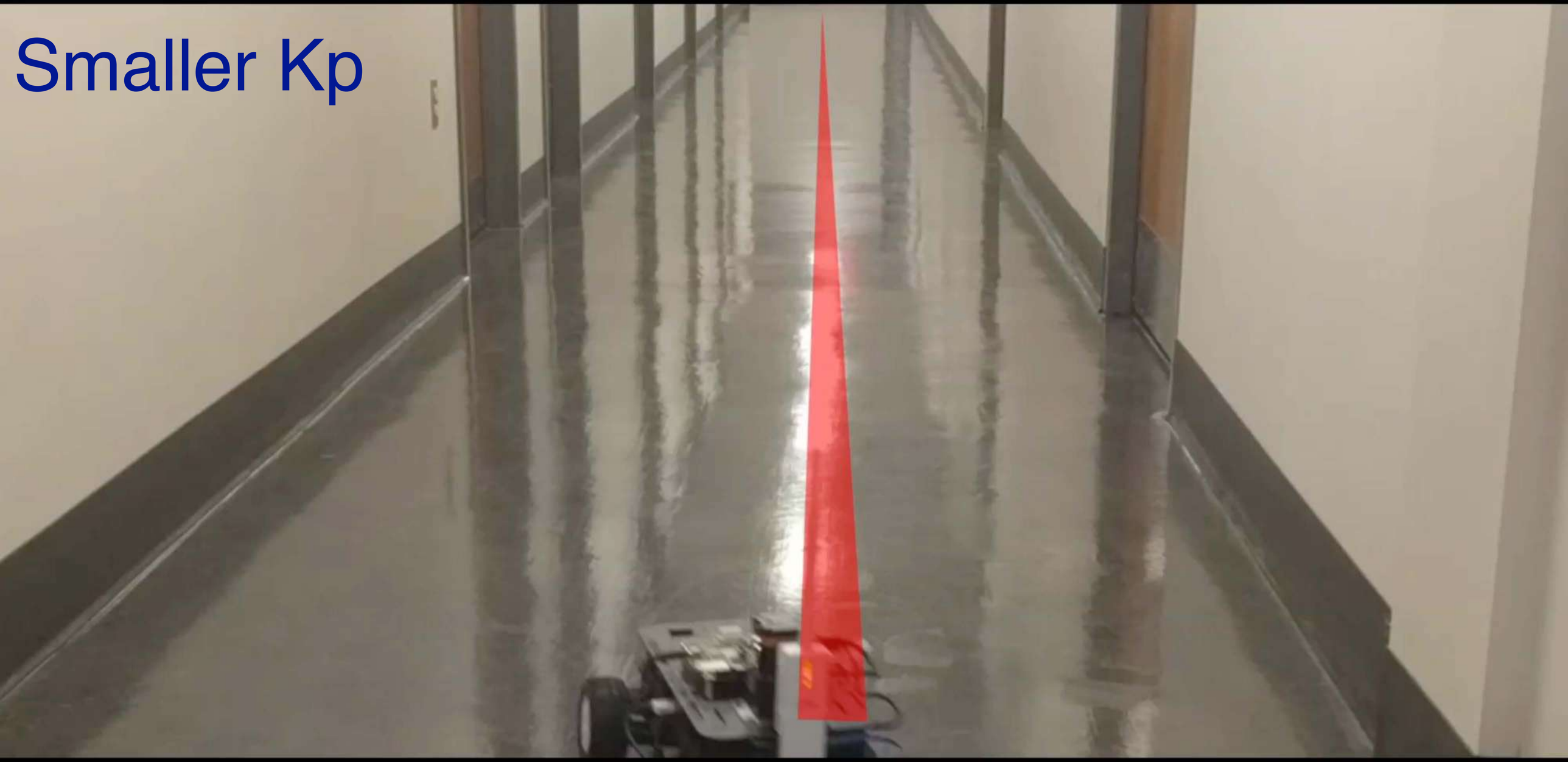

LiDAR
Camera
IMU
STRUCTURE
Filters
Map generation
Computer vision
Localization
Path planning
Steering
Motor Controller
Drive

Control

Proportional, **I**ntegral, **D**erivative control

Nominal gains

Smaller Kp



AMCL- Adaptive Monte Carlo Localization

amcl_config.rviz* - RViz

2D Pose Estimate | 2D Nav Goal | Publish Point

Grid
Odometry
Status: Warn
Topic /amclOdom
Color 15; 31; 255
Position Tolerance 0.1
Angle Tolerance 0.1
Keep 1
Length 1
Map
Map
Pose
PoseArray
Odometry

Keep
Number of arrows to keep before removing the oldest. 0 means keep all of them.

Add | Remove | Rename

Time

ROS Time: 1458504970.57 ROS Elapsed: 7.28 Wall Time: 1460587807.26 Wall Elapsed: 153.93 Experimental

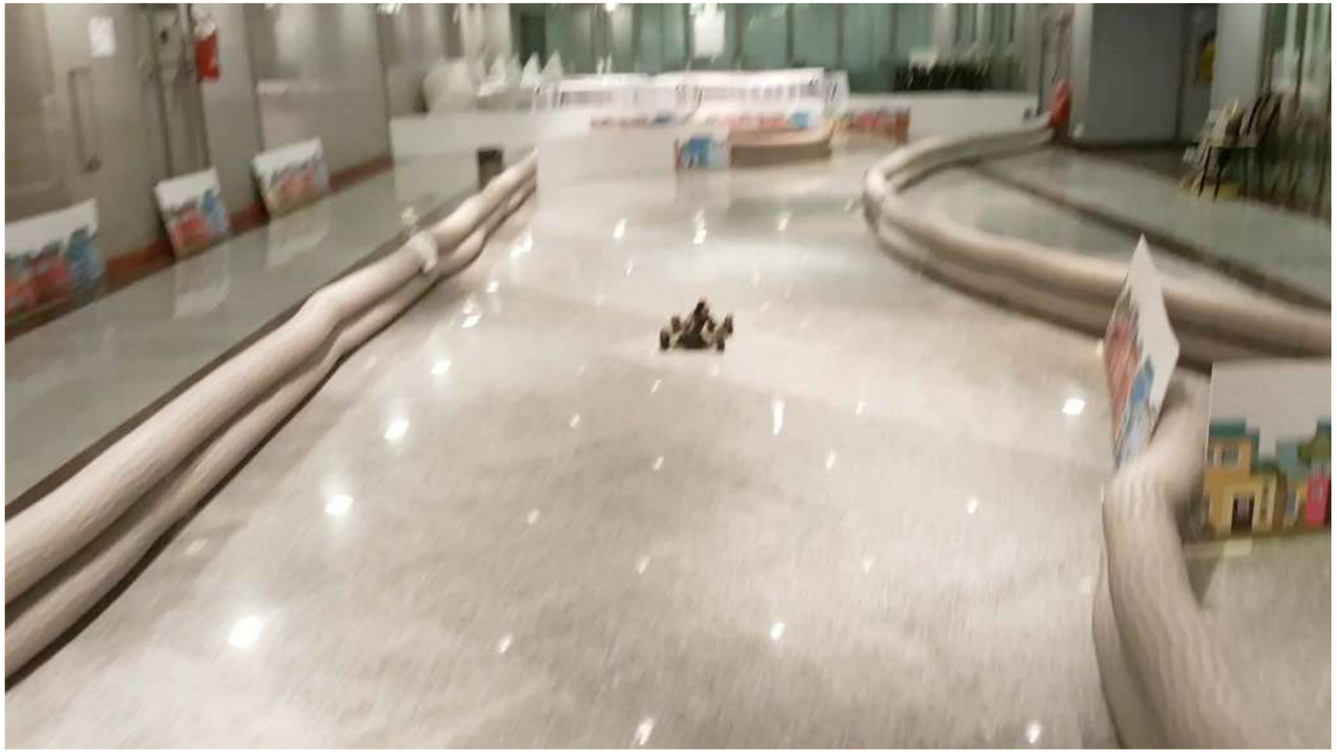
Reset **Left-Click:** Rotate. **Middle-Click:** Move X/Y. **Right-Click/Mouse Wheel:** Zoom. **Shift:** More options. 30 fps

Wall Following

Problem:
Drive around the track using a LIDAR

Understand:
LIAR rays, PID, cross track error

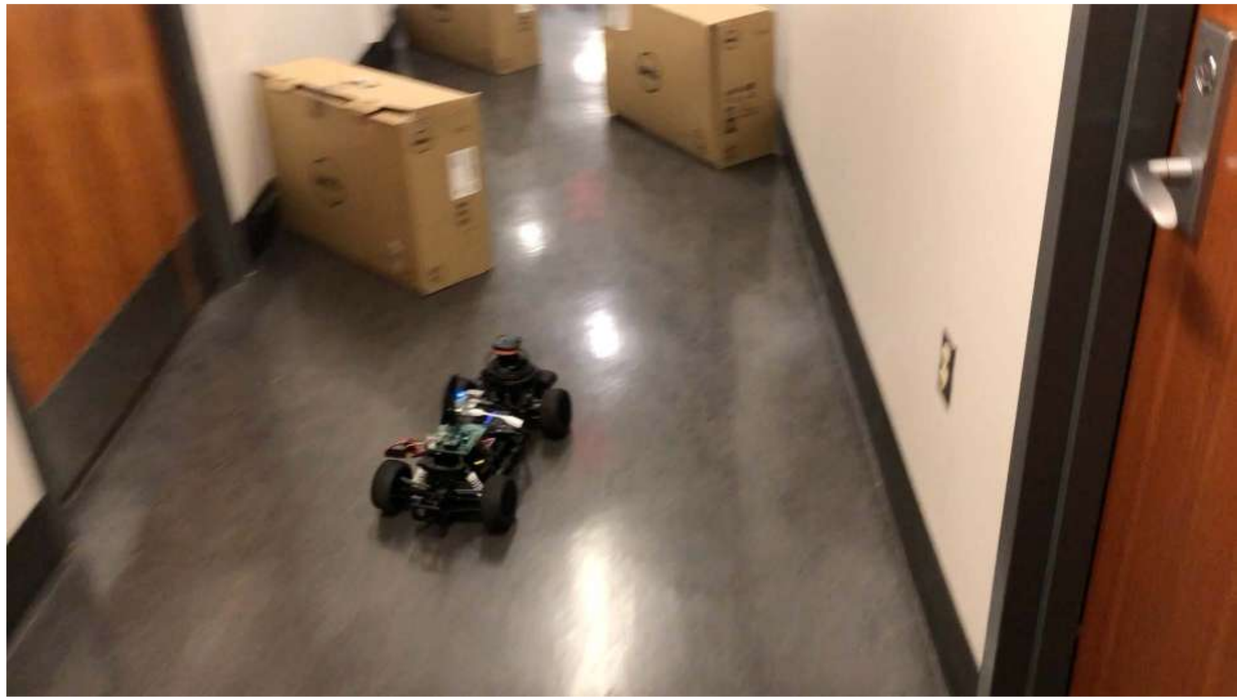
Implement:
Wall following ROS controller



Obstacle Avoidance: Follow the gap

Reactive Navigation:
Use immediate sensor input to decide driving command

Planning for obstacle avoidance:
Use LIDAR for both static and dynamic obstacle avoidance



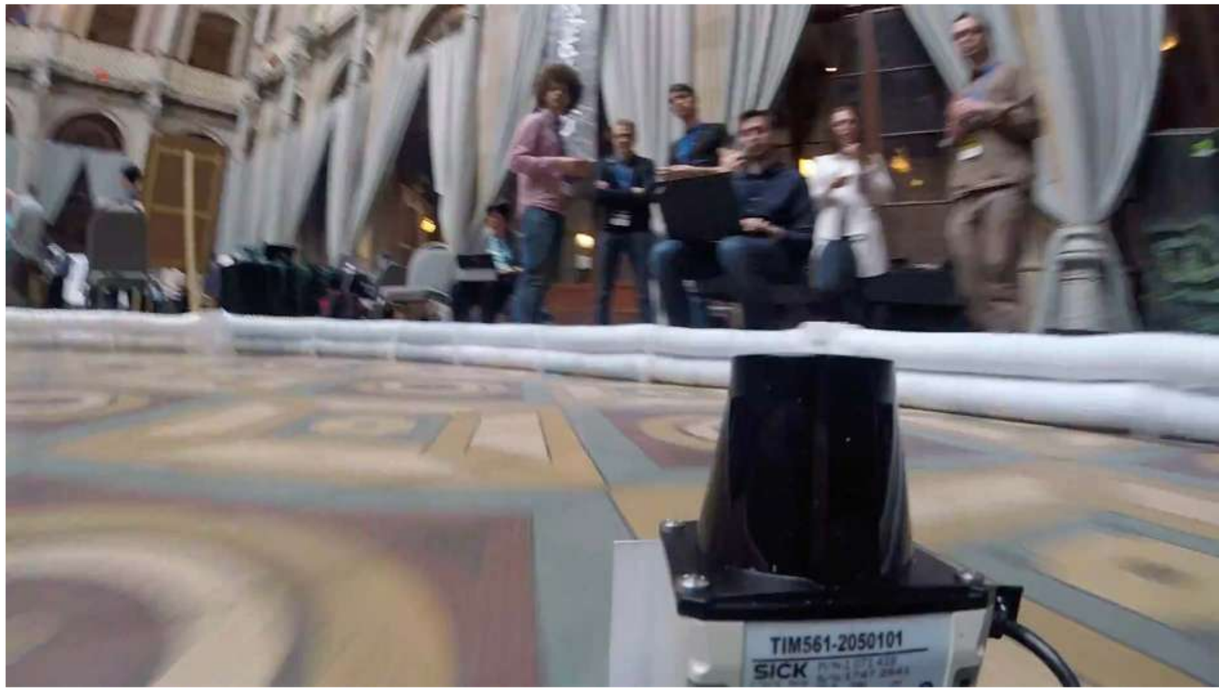
Race: Reactive Methods

Race Format:
Time-trial; single car on track

Penalties: Crashing

Baseline: Complete 5 laps without crashing

Example Video: CPS Week 2018

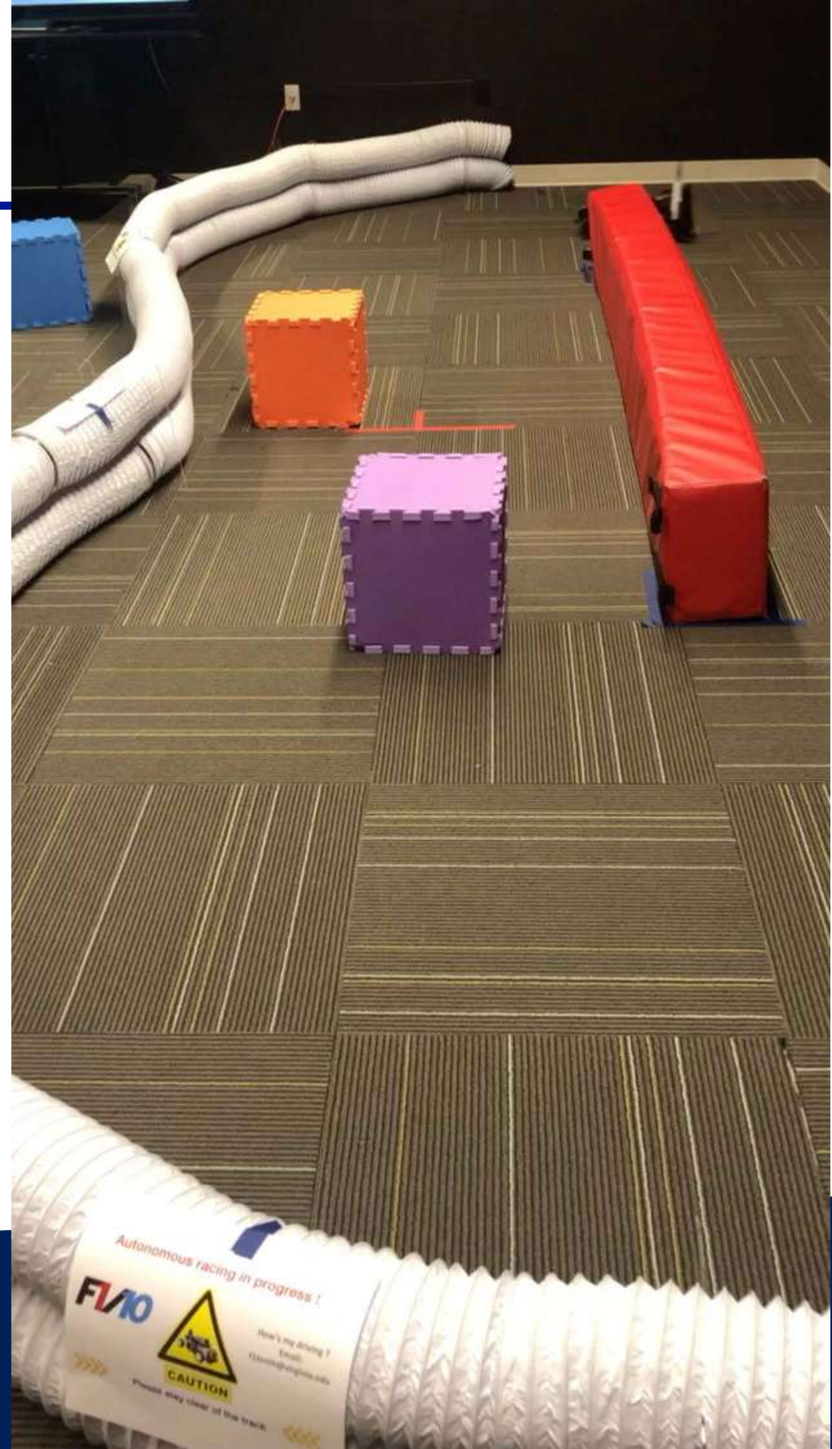


Motion Planning

Problem:

How to find a path between two nodes on a graph, how to navigate collision free through a cluttered space.

1. Search based motion planning
2. RRT
3. Time-Elastic Band Navigation
4. Potential Fields
5. Overtaking and race line planning

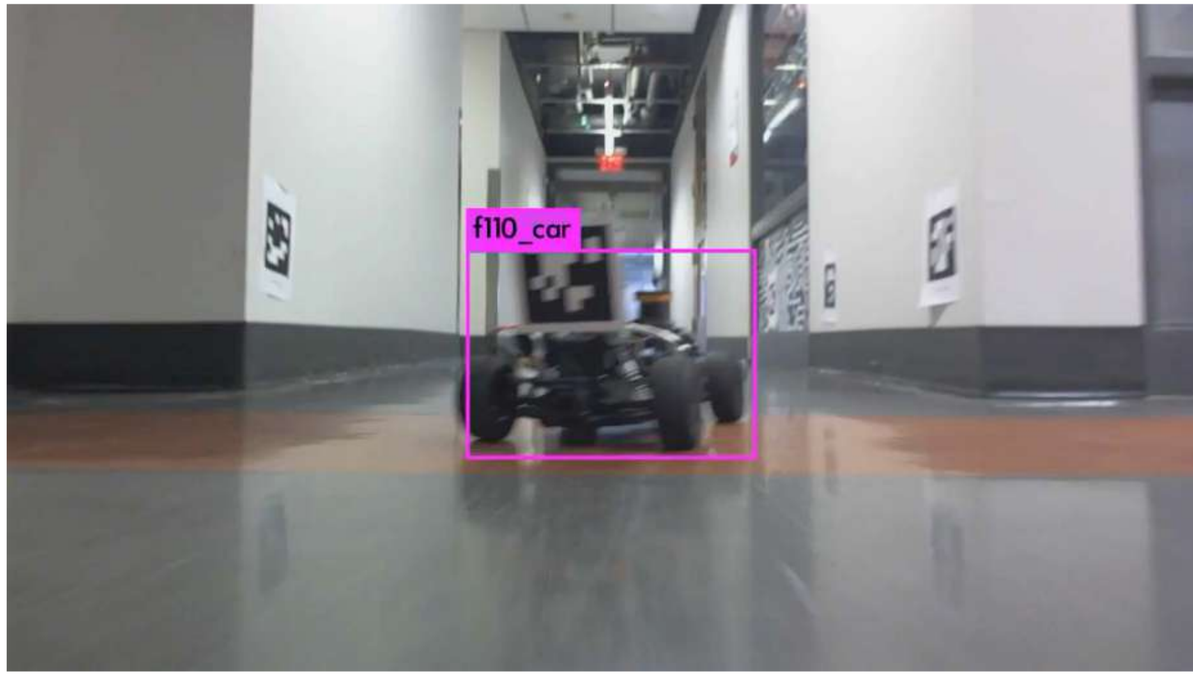


Vision: Detection and Pose Estimation

Problem:

Detect other F1/10 cars and estimate their pose and velocity

1. Deep Learning :YOLO
2. Geometrical vision

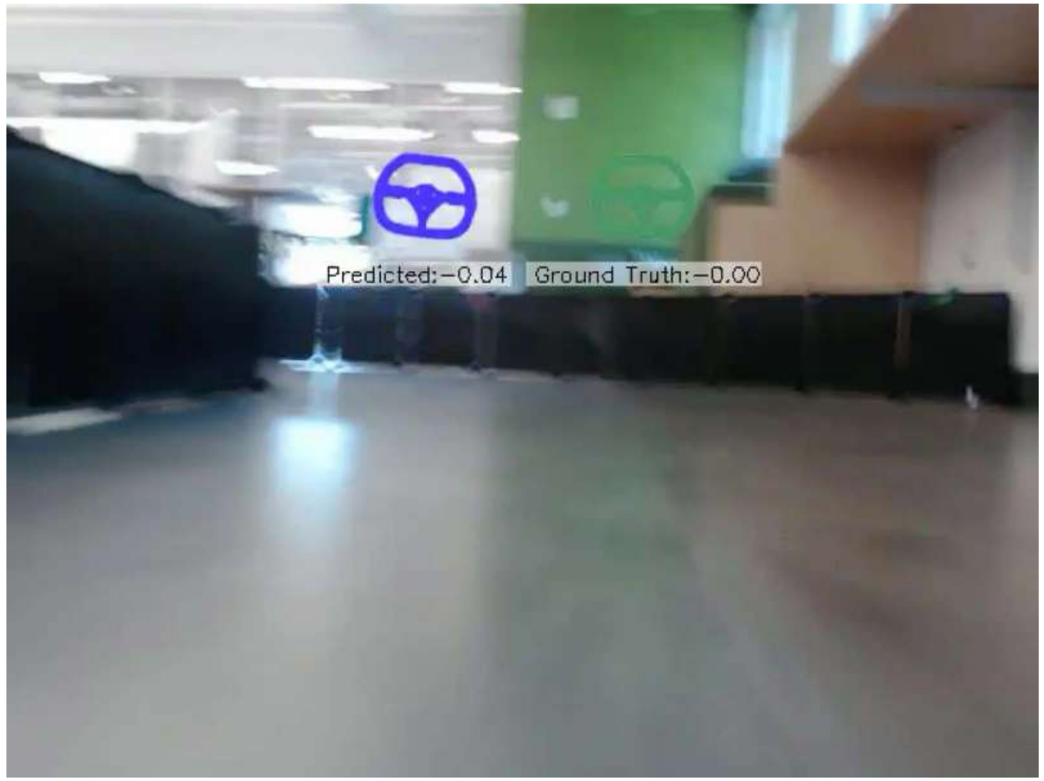


End-to-End Driving

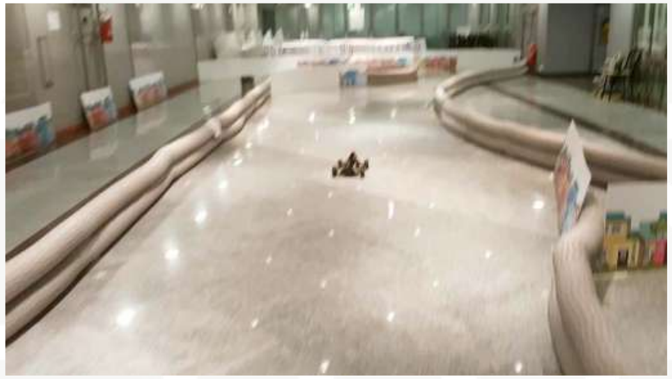
Problem:

End-to-End driving with imitation learning.

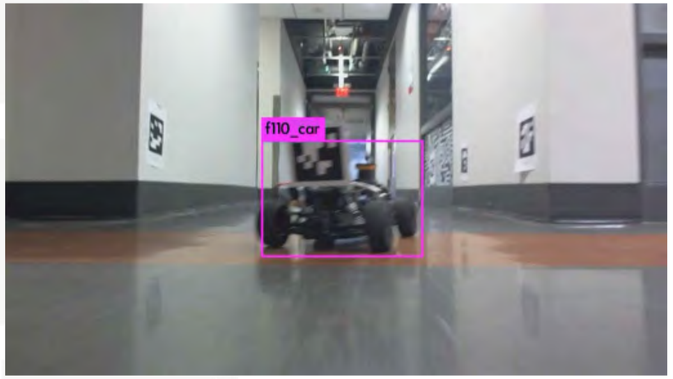
1. Train a network to map pixels to steering angle
2. Pixels to trajectory



Examples

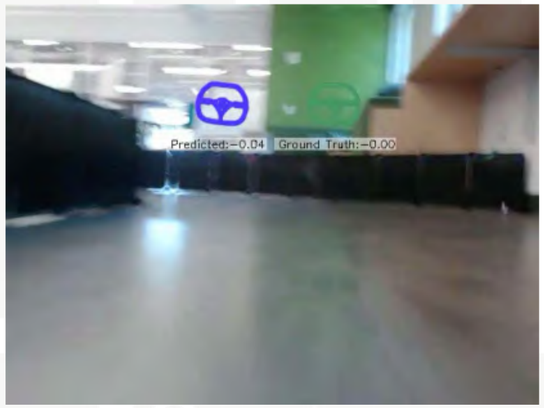


Wall Following



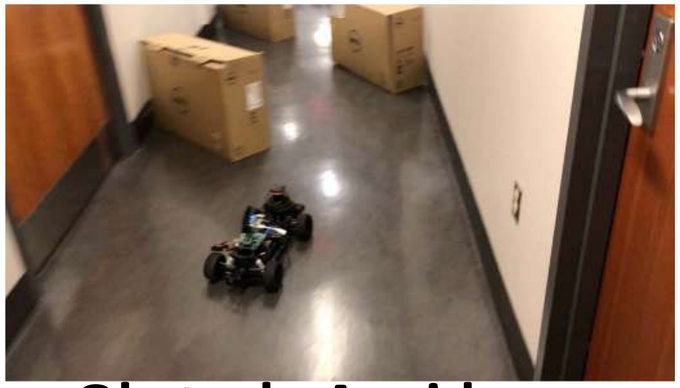
Object Detection and Tracking

Follow the gap



Deep Learning

Your Project



Obstacle Avoidance

ROS F1/10 Autonomous Racing Simulator

f1tenth.dev

Varundev SureshBabu

Prof. Madhur Behl

Computer Science | Link Lab | University of Virginia

F1 TENTH

ROS

University of Virginia

Research

Localization and Mapping

Where am I ?

Scene Understanding

Where/who/what/why of
everyone/everything else ?

Trajectory Planning and Control

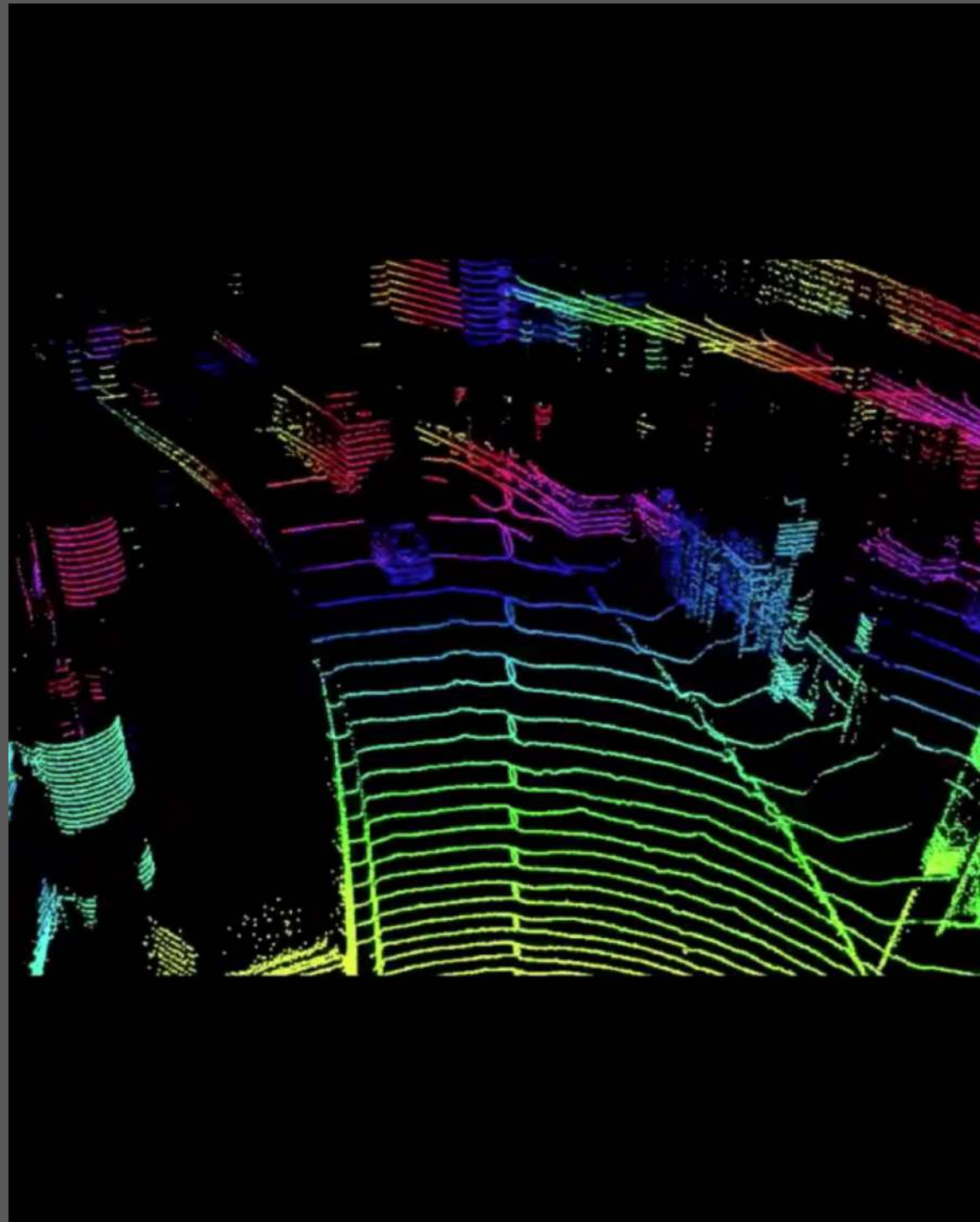
Where should I go next ?
How do I steer and accelerate ?

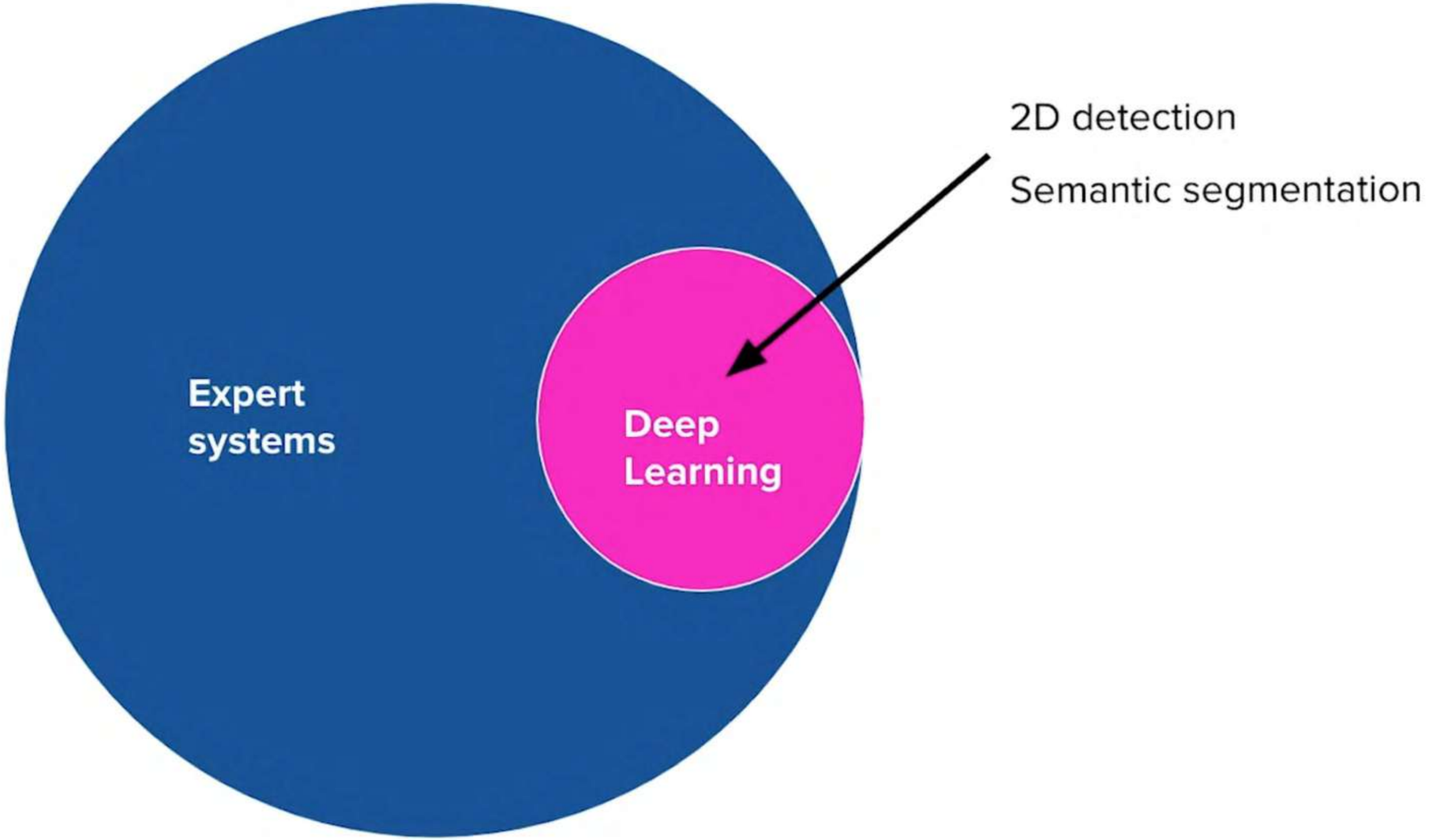
Human Interaction

How do I convey my intent to the
passenger and everyone else ?

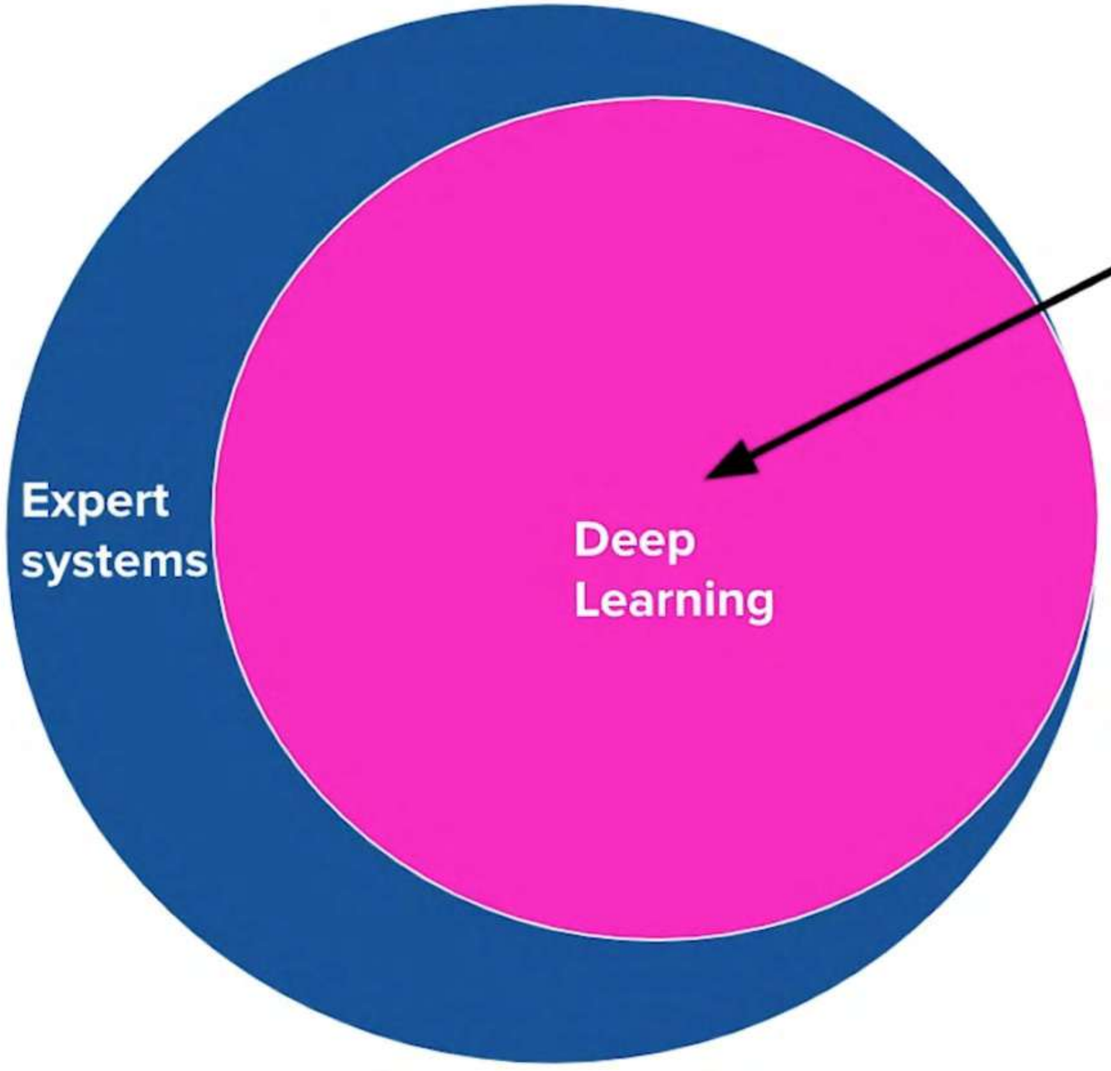
Deep Neural Networks

End-to-end learnable





AV Perception in 2015



2D detection

Instance segmentation

Point cloud segmentation

Tracking

Intent prediction

Monocular depth estimation

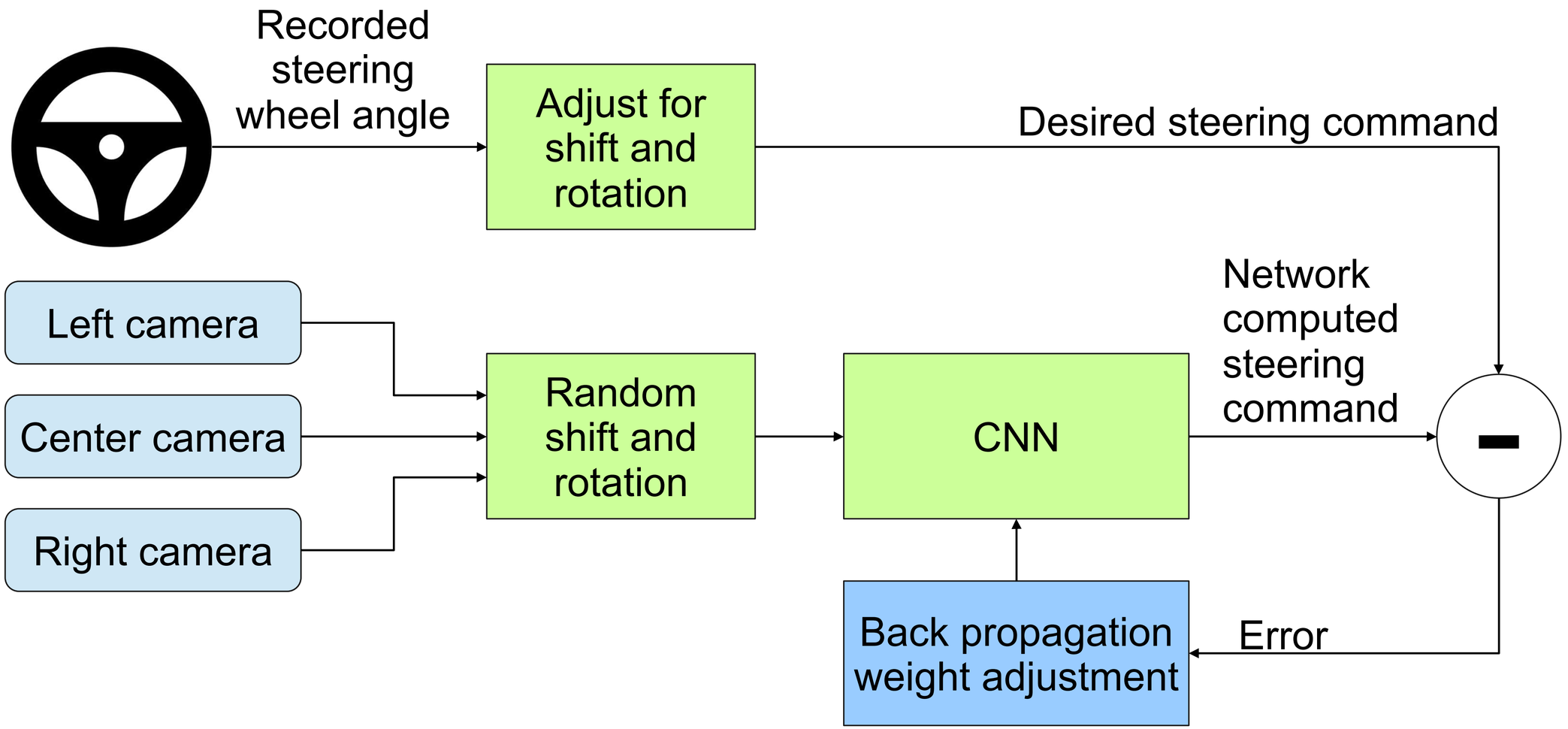
Scene flow

Anomaly detection

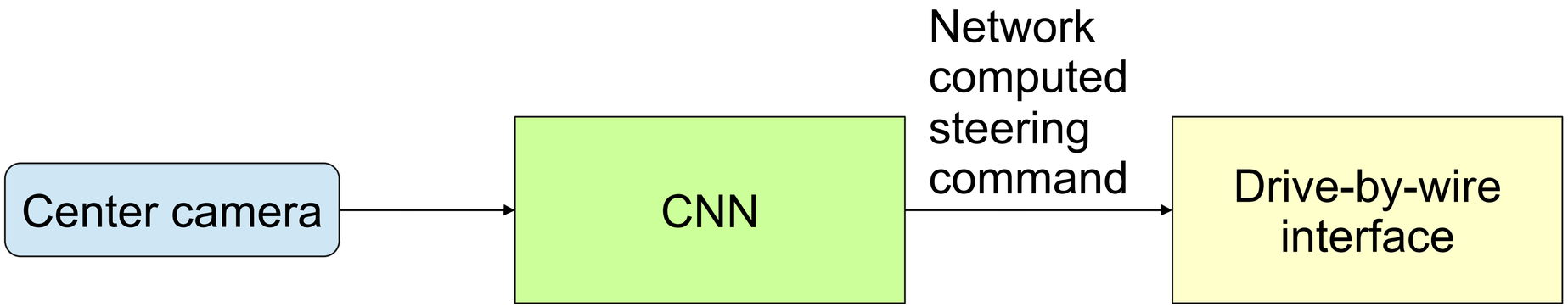
.....

AV Perception today

End-to-End Driving: PilotNET

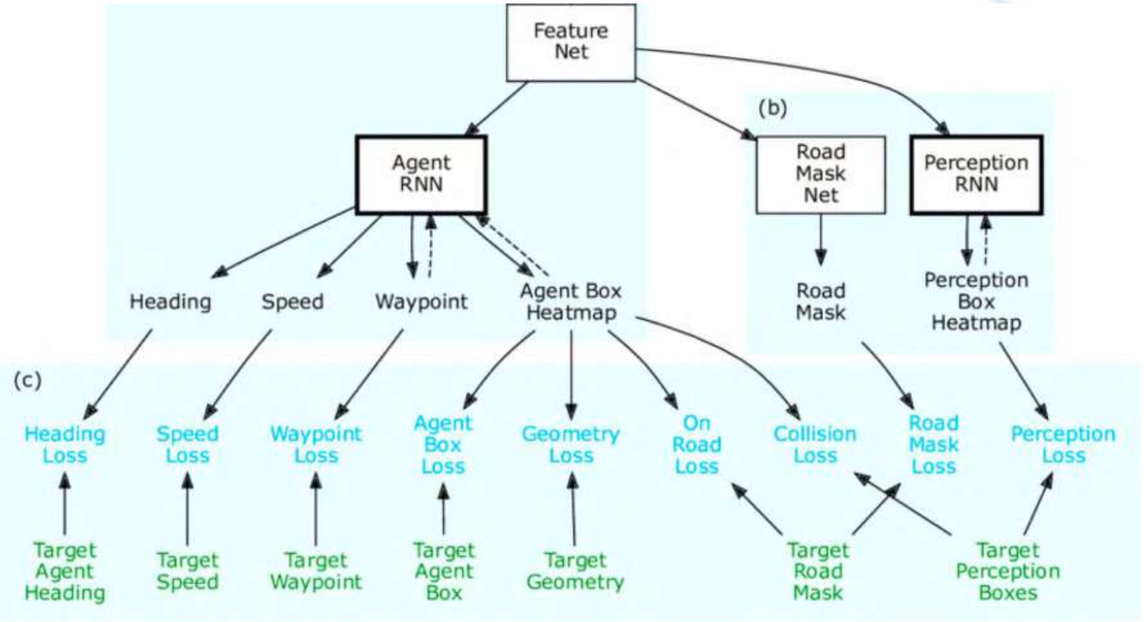


With a single front-facing camera



ChauffeurNet

A Deep Learned Driving Network



WAYMO

WAYVE

ABOUT BLOG CAREERS

Machine intelligence is largely about training data.

When’s a pedestrian not a pedestrian? When it’s a decal.

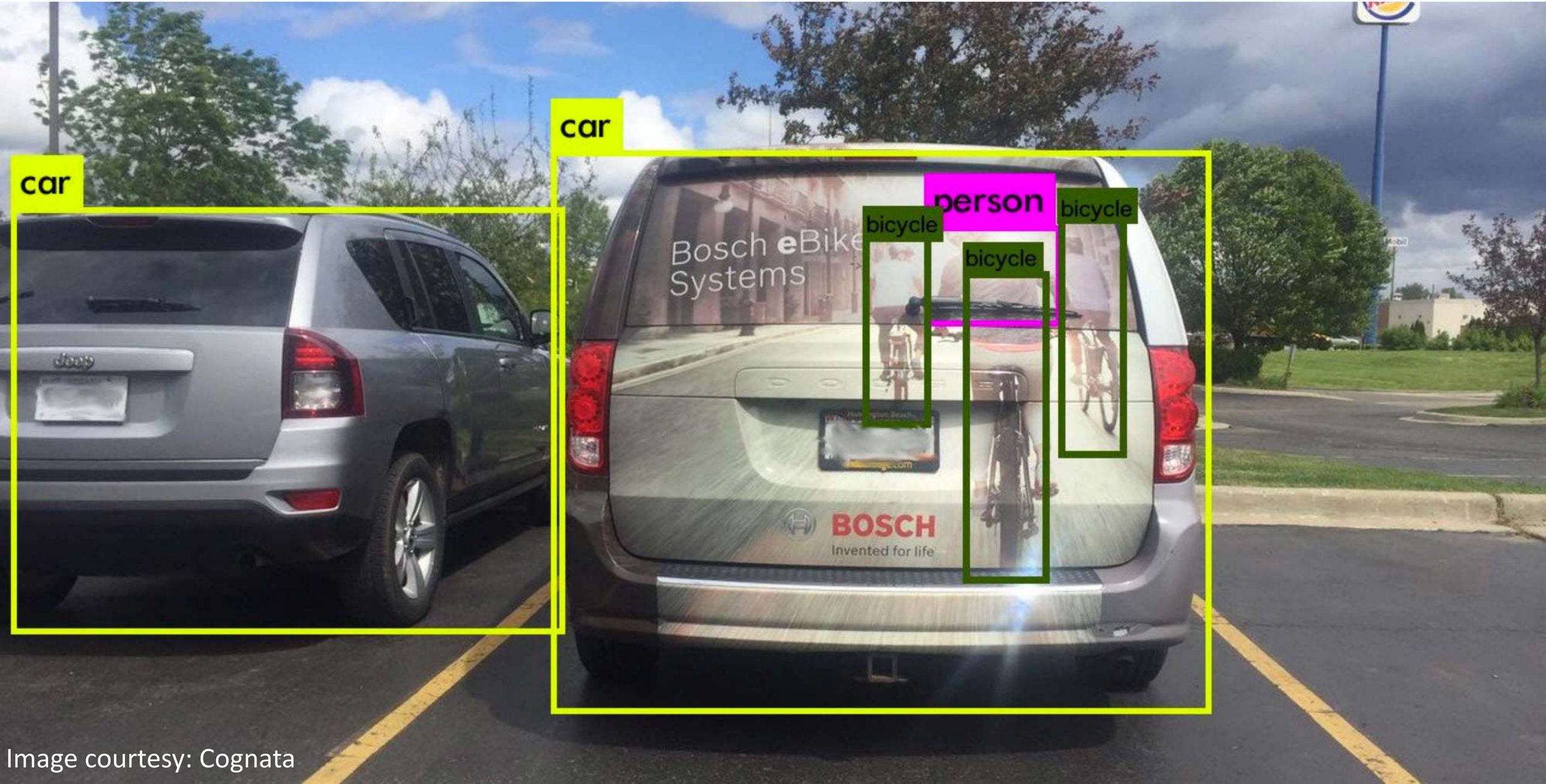


Image courtesy: Cognata

One car ? or Multiple cars ?

Ramen Noodle place or Do Not Enter Sign ?


下鳥羽城ノ越町 付近
20m
MENU
現在地
AUDIO
今日
明日
16:10
現在地
気温(℃)
降水確率(%)
12/5
60
9/3
40
12℃
A 77.5km
000160km
50
x1000 r/min
E
F
km/h


今日
明日
16:10
現在地
気温(℃)
12/5
9/3
降水確率
(%)
60
40
50
12℃
A 77.5km
000160km

There is a bus right next to you!!

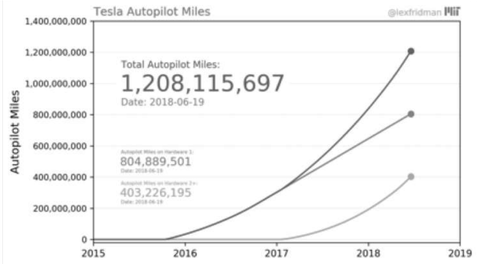
How can we ensure that an autonomous vehicle drives safety upon encountering an unusual traffic situation ?

DeepRacing AI

UVA ENGINEERING
LINK LAB

Brute Force

Drive millions of miles in simulation or in the real world; too slow; infinite situations

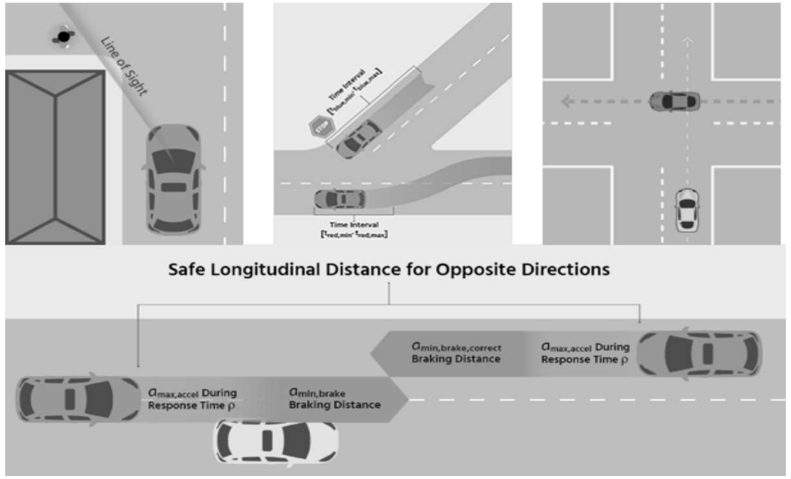


Current Attempts To Ensure Safety Of Autonomous Vehicles

How can we ensure that an autonomous vehicle drives safety upon encountering an unusual (edge) traffic situation ?

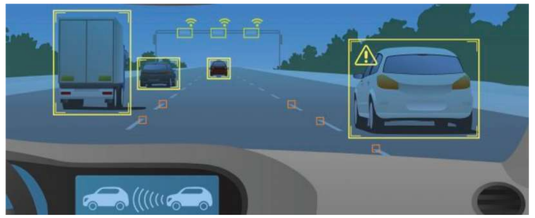
Formal Methods

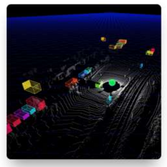
Reasoning about scenario specific safety; often too simplistic to generate guarantees



Safety Through Agility

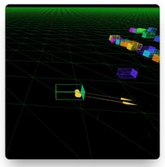
Autonomous vehicles get trained on mostly structured traffic data-sets.





LiDAR

Camera



Radar

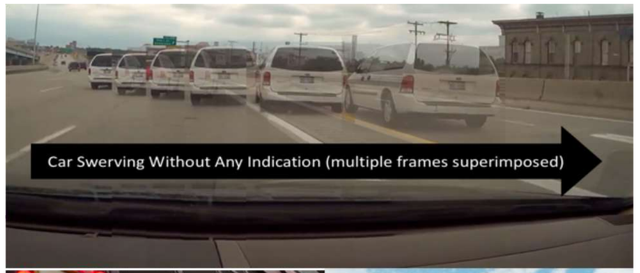
End-to-end DNN for autonomous driving

AV: A

AV: B

DeepRacing
Agile Controller

AV: B is safer overall.

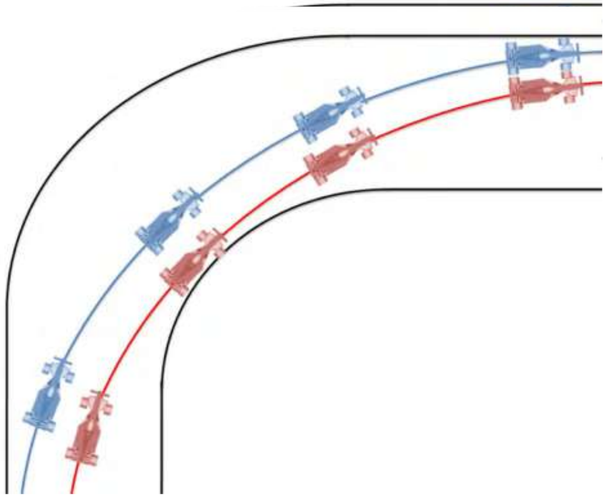


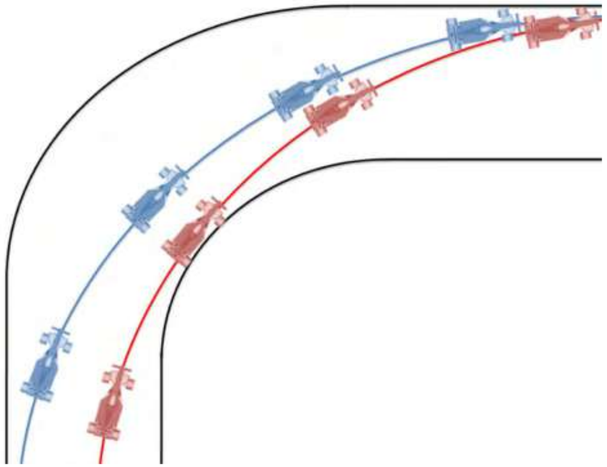
Teaching autonomous vehicles to be agile by autonomously
racing them against each other.

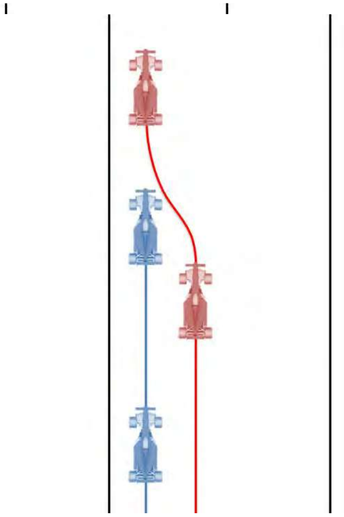

REPLAY
UVA ENGINEERING
LINK LAB
tororosso.com
@tororosso
Pierre GASLY
Toro Rosso
10
GAS

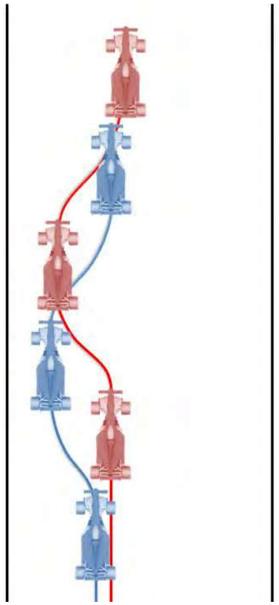

“If everything seems under control,
then you are not going fast enough”

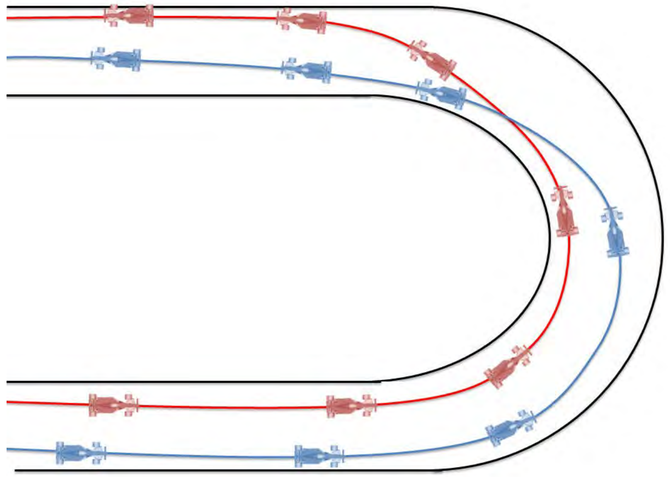
Racing offers more frequent edge cases

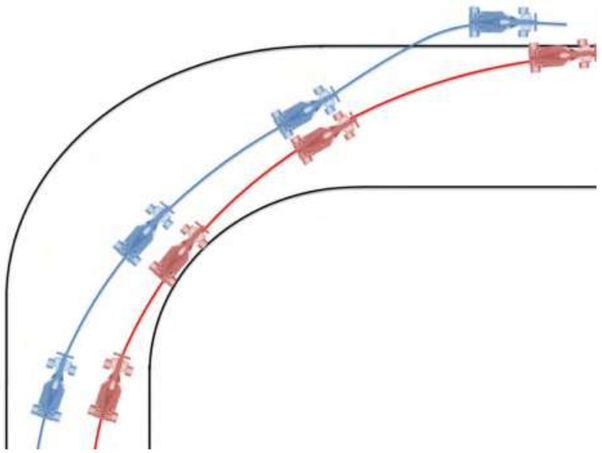






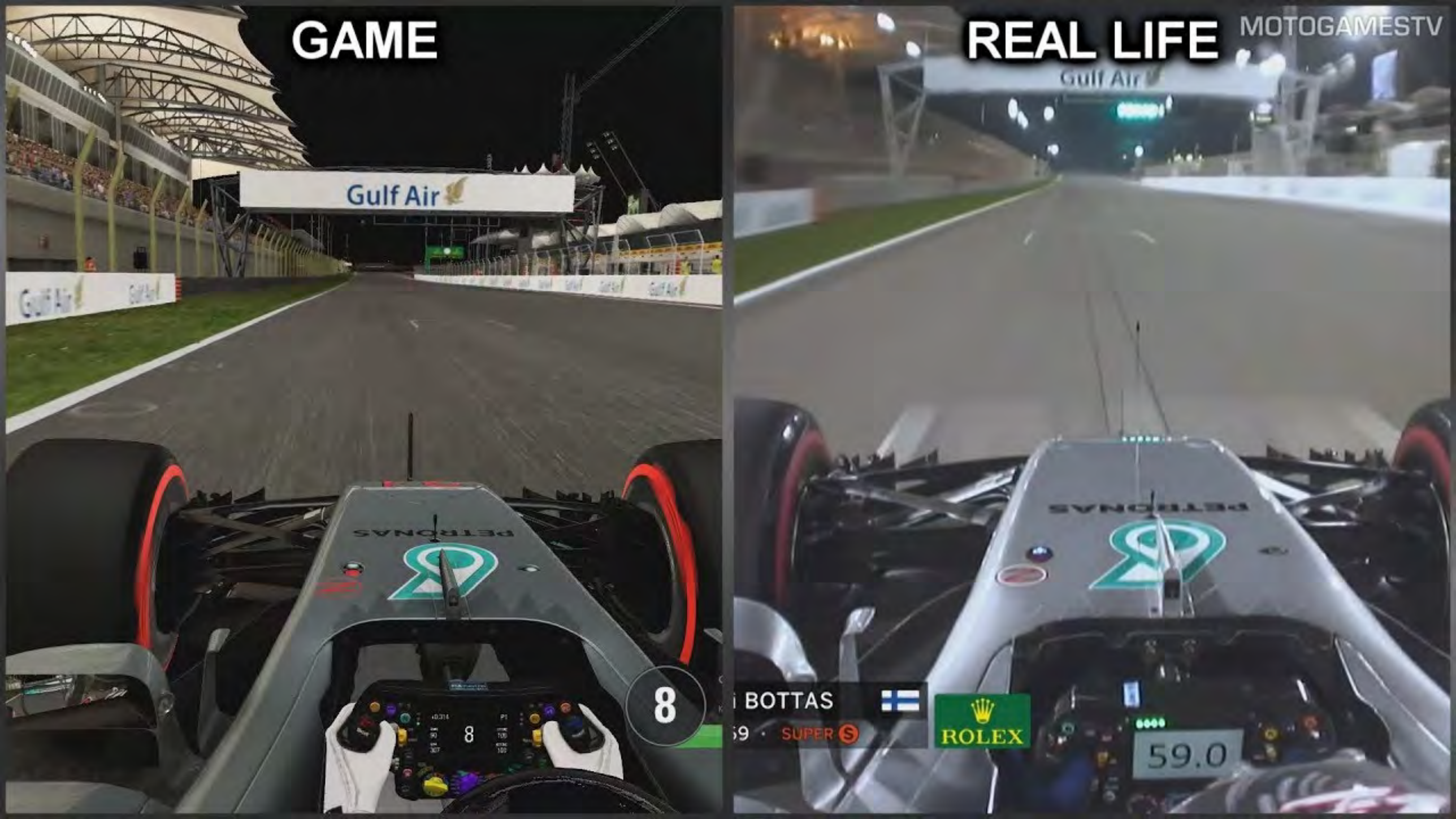




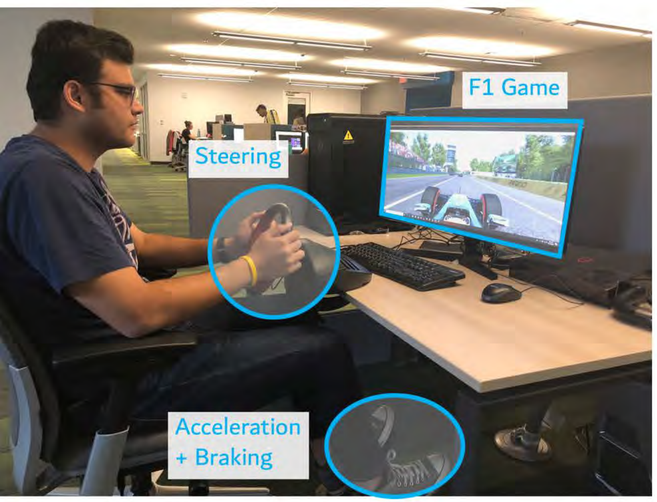


1894… the world's first "horseless carriages" race,
Paris to Rouen.

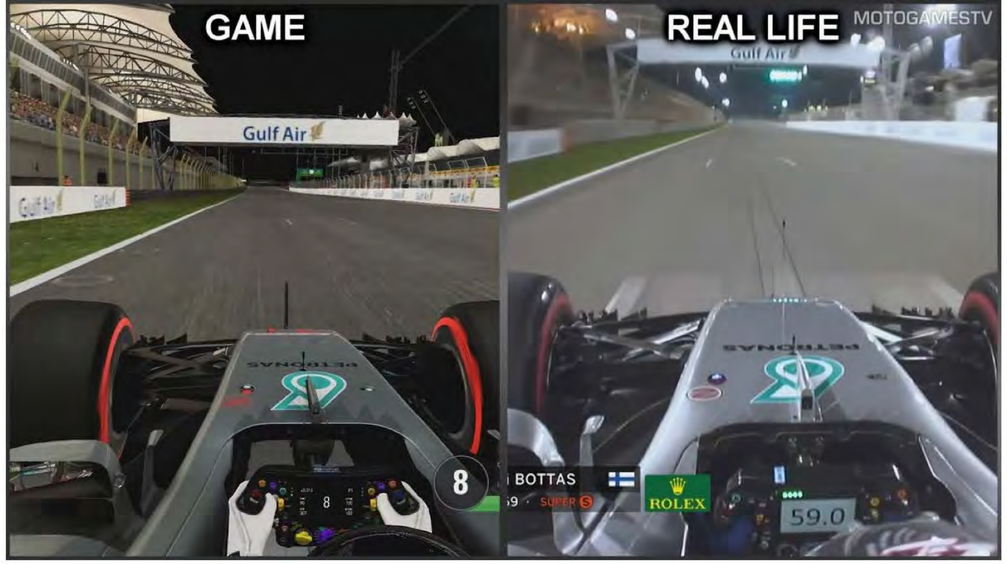

1/12 LAPS
13B


GAME
REAL LIFE
MOTOGAMESTV
Gulf Air
PETRONAS
8
BOTTAS
SUPER
ROLEX
59.0

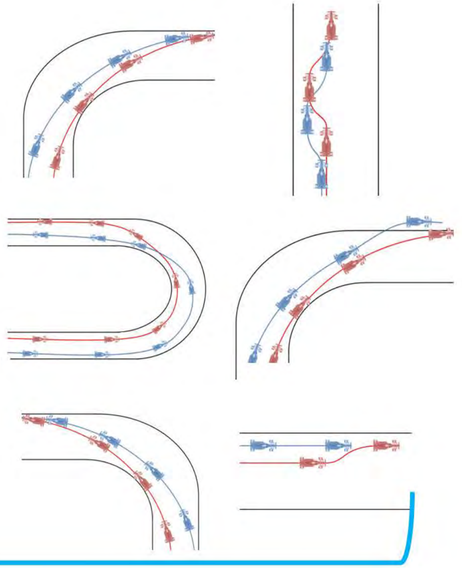

F1 2019
THE OFFICIAL VIDEOGAME
RENAULT
Castrol
E-TECH
6
F1
RENAULT
Castrol
E-TECH
6



Manual Driving Inputs



Racing creates frequent edge cases at high speeds



Autonomous Driving Inputs

F1 2017 Formula 1 | codemasters

Photorealistic + Accurate Physics

vjoy virtual joystick

Closed Loop Testing

UDP stream to log Steering + Accl. i/p

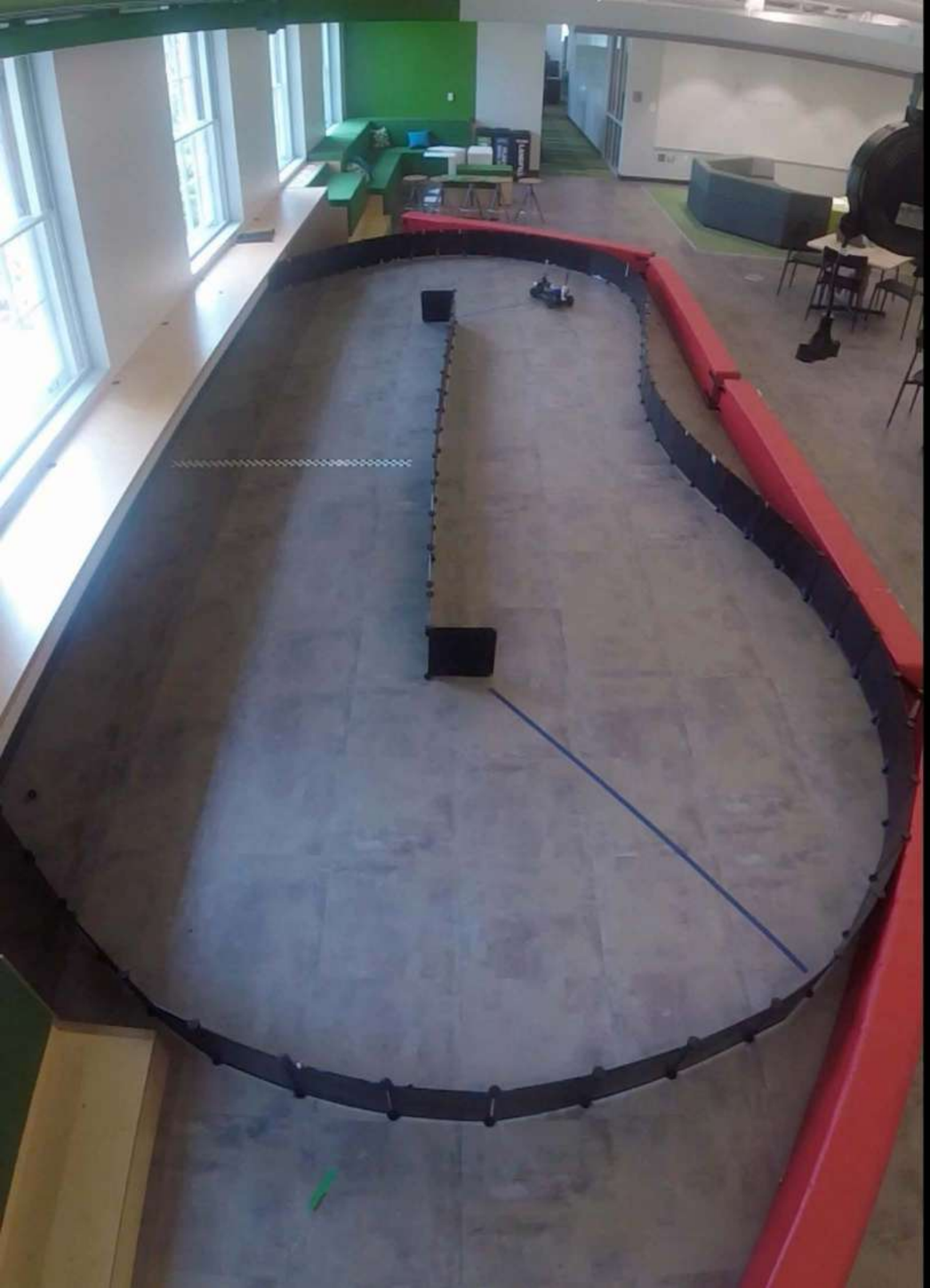
Synchronized screen capture

Each image is labeled with steering and acceleration data

end-to-end learning

DeepRacing Agile Controller

predicted steering + acceleration

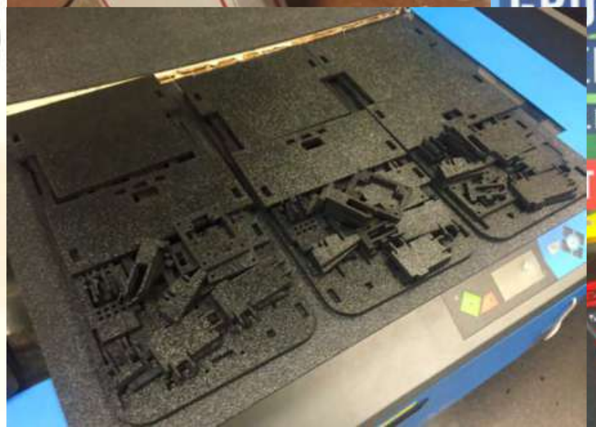


F1/10 FPV Driving


Autonomous racing in progress !
FV10
CAUTION

Fun!


Energizer




TOTAL
RedBull

From F1/10 To F1

Autonomous Indy Racing Challenge

HOOS Racing !!

BEFORE THE COURSE

I know programming

AFTER THE COURSE

ROS, knows I

No drivers were harmed
during the making of this video.

madhur.behl@virginia.edu