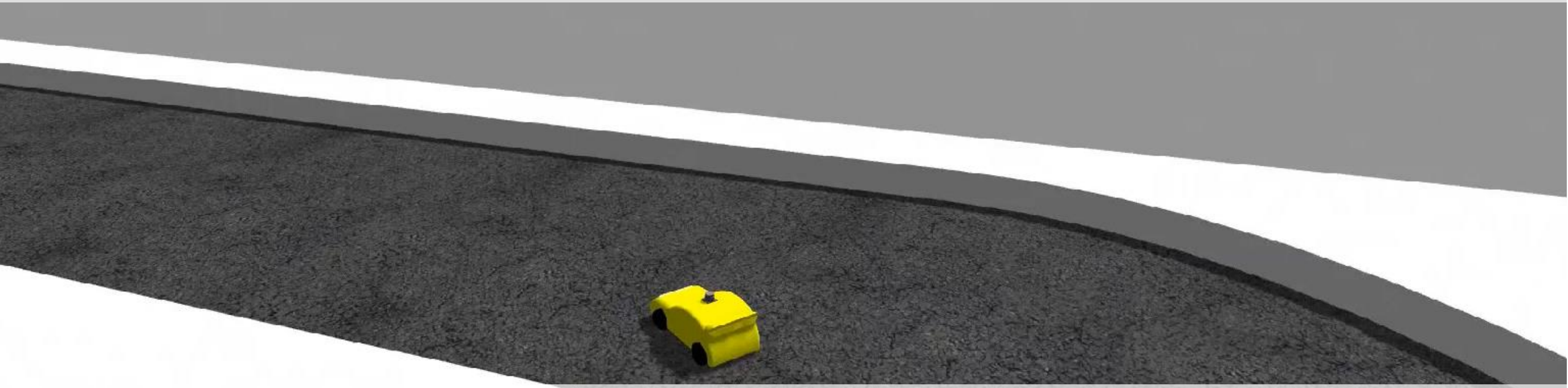
ROS F1/10 Autonomous Racing Simulator



Varundev Suresh Babu and Prof. Madhur Behl
Computer Science | Link Lab | University of Virginia

F1 TENTH
f1tenth.org

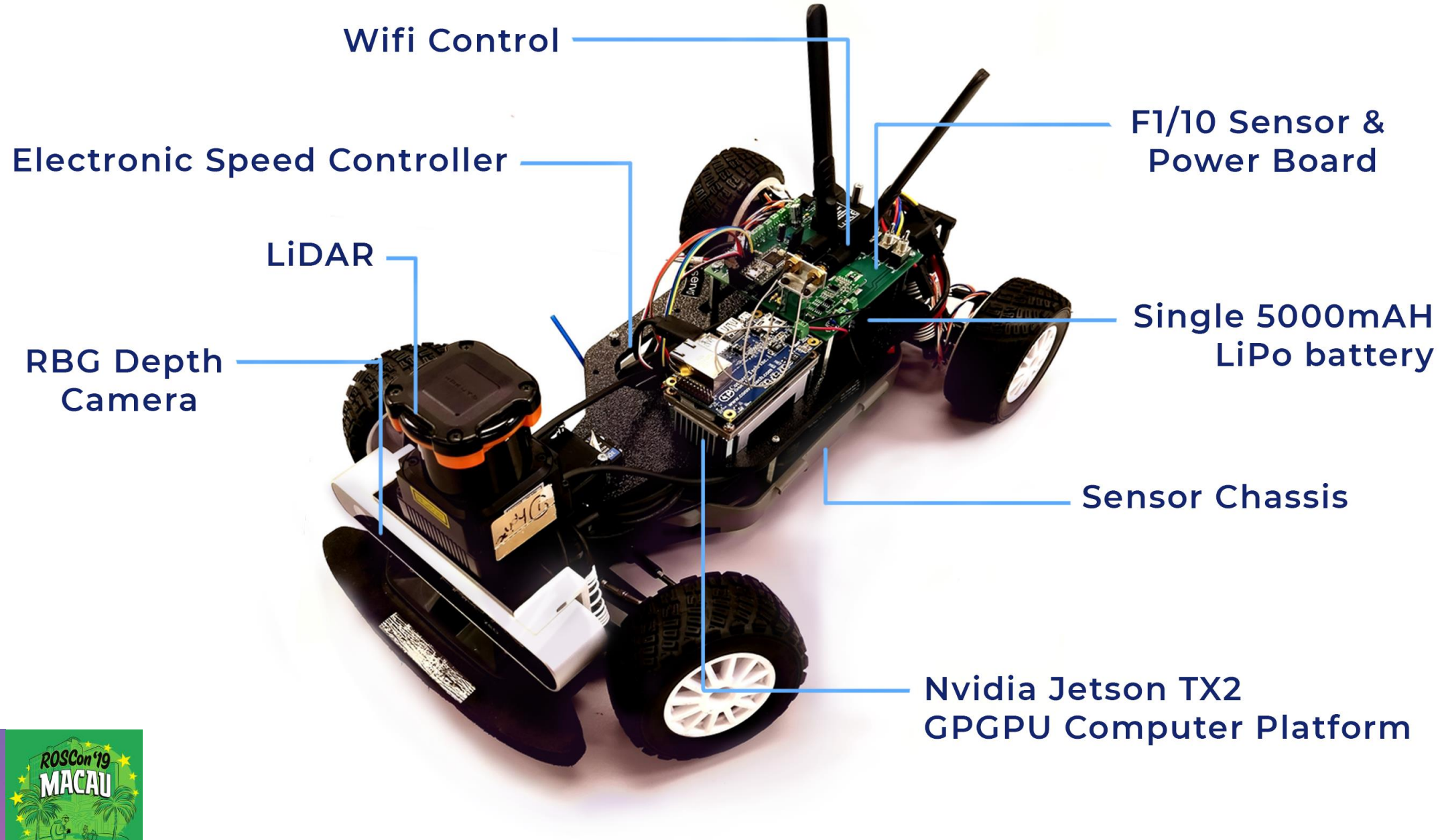
ROS

Varundev Suresh Babu

Ph.D. Candidate
Computer Engineering
University of Virginia

Email: varundev@virginia.edu

What is F1/10 [f1tenth] ?



F1 TENTH
f1tenth.org

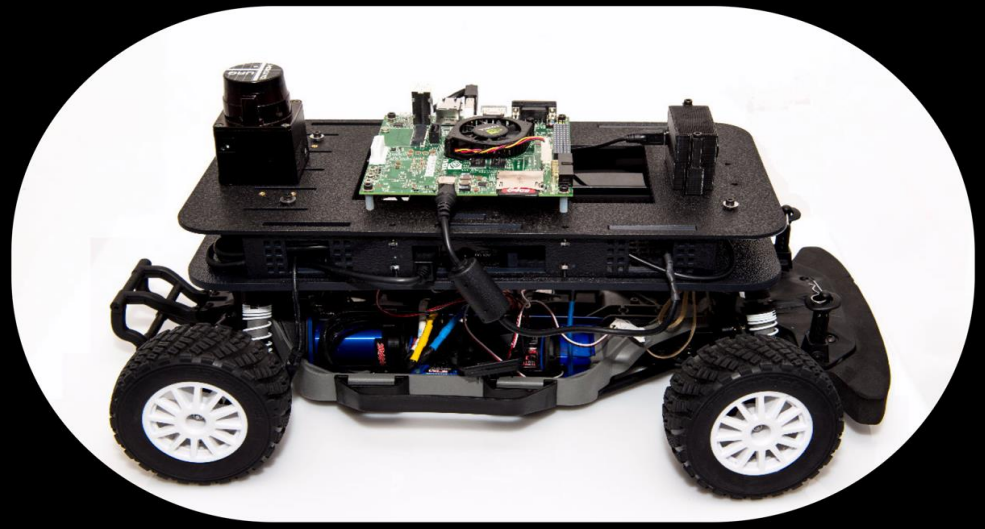
ROSCon '19 MACAU

F1/10

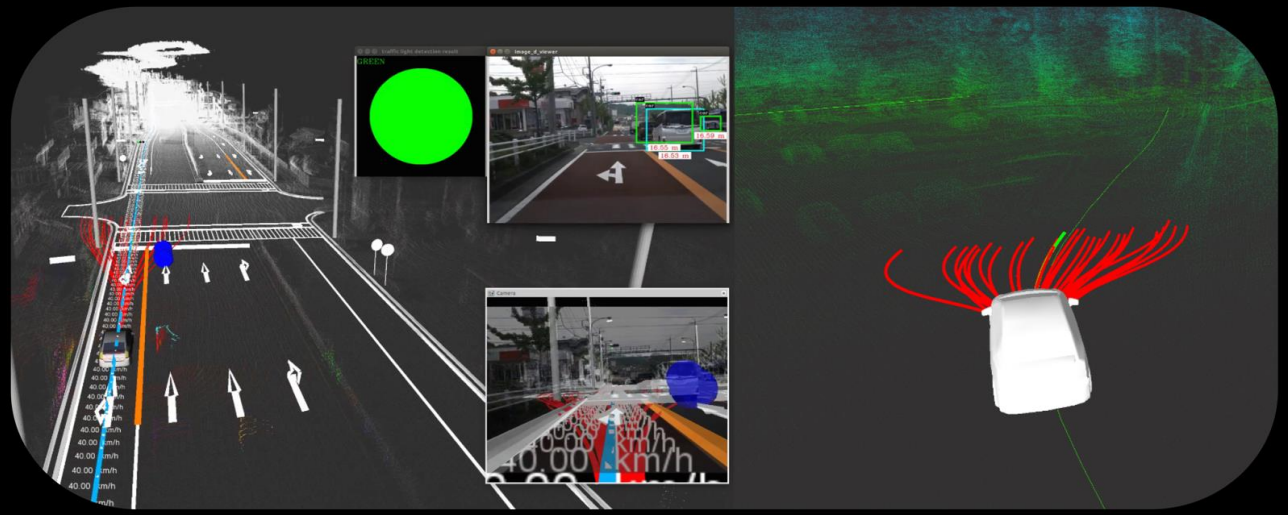
Autonomous Racing

1/10 the scale. 10 times the fun!

Build. Drive. Race.



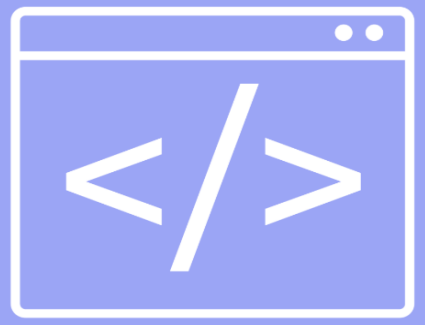
Perception. Planning. Control



f1tenth.org

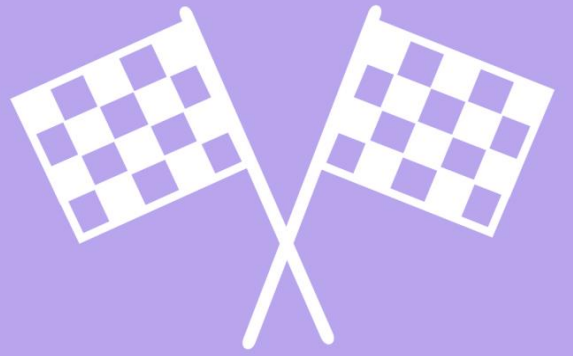
BUILD

Construct your vehicle using our starter kit.



CODE

Learn to drive your vehicle autonomously.



RACE

Register to Compete

Similar dynamics, different parameters

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

Similar sensors,
different scale

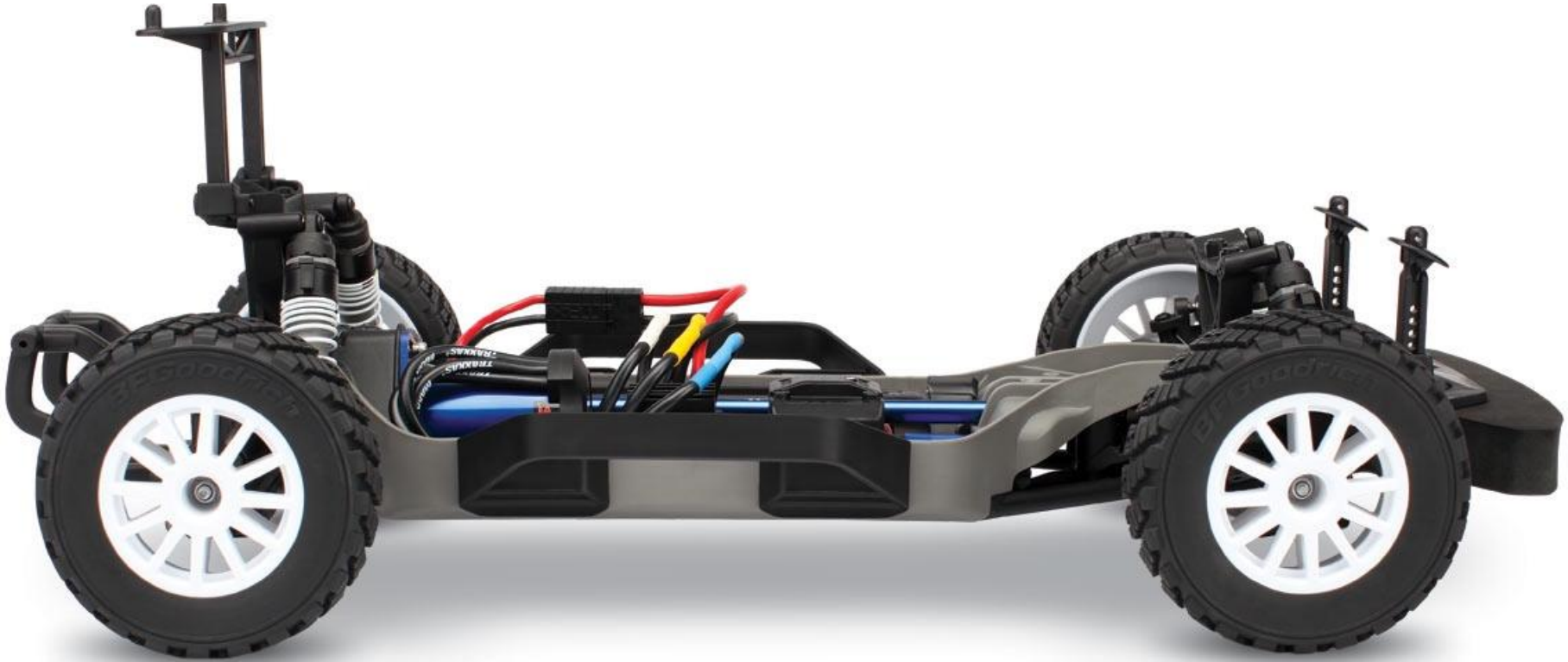
Sensor Integration

LiDAR

Camera

IMU

IR Depth Cameras



Sensor Integration

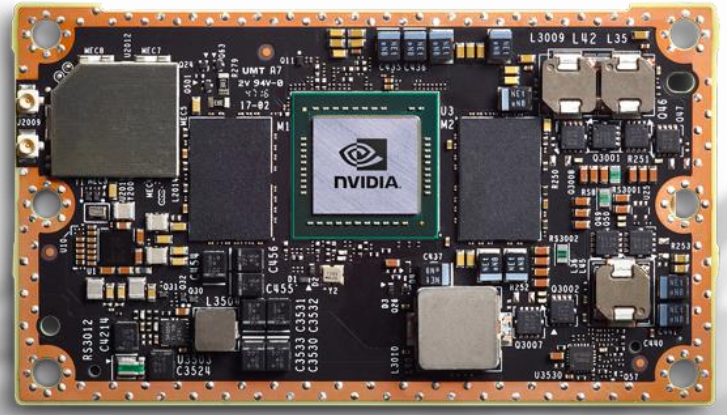
LiDAR

Camera

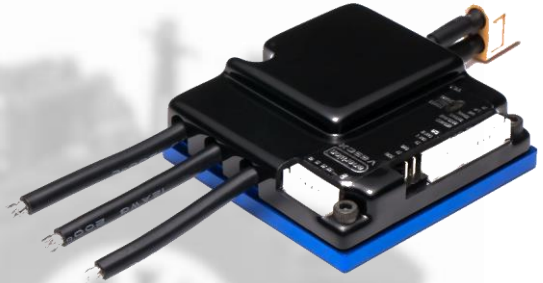
IMU

IR Depth Cameras

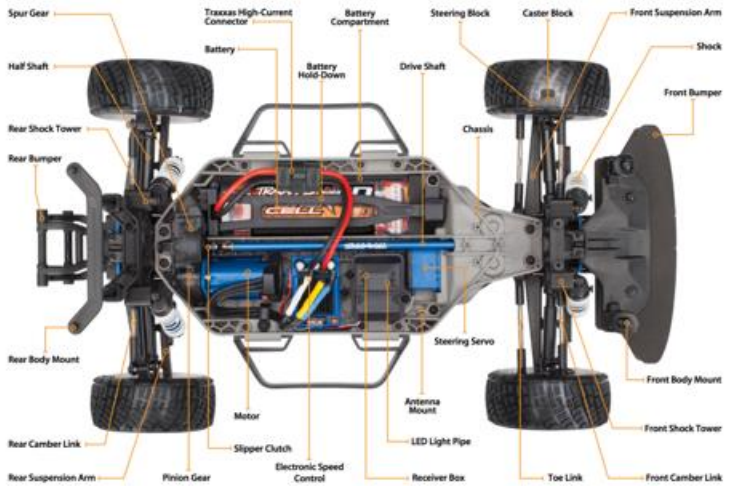
Wi-fi Telemetry



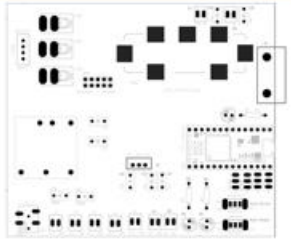
Onboard Computer



Motor Controller



Chassis Design



F1/10 Platform Board

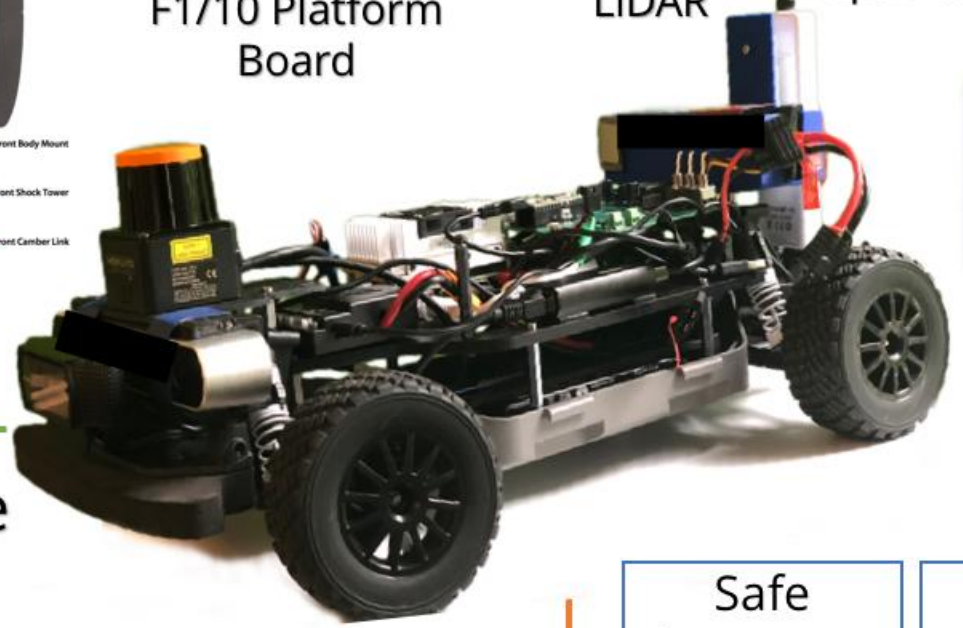
Hokuyo LiDAR

Zed Depth Camera

FLIR Flea Camera

Electronic Speed Controller

WiFi Telemetry

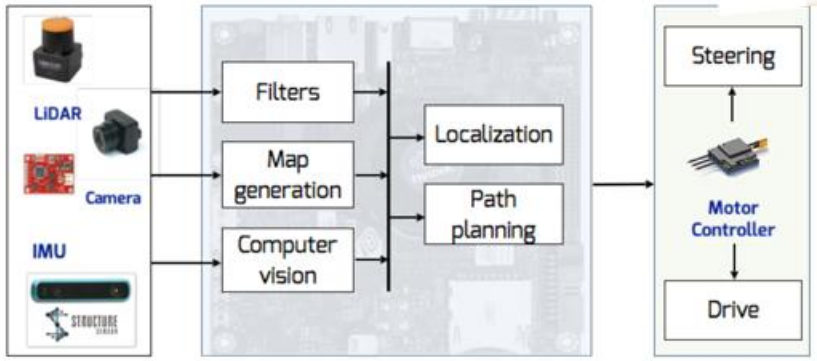


GPGPU Compute Platform NVIDIA Jetson TX1/TX2

System Integration

Software Architecture

ROS



Perception Planning Control

GPU Accelerated Libraries

NVIDIA CUDA

Research Enabled

Safe Autonomy	Secure Autonomy	Coordinated Autonomy	Efficient Autonomy

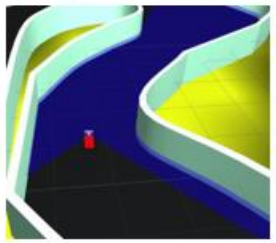
Lane Keeping Assist

Model-Predictive Control

AV Data Collection

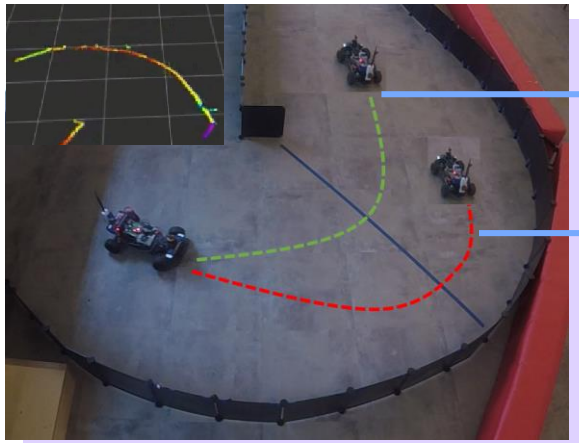
Simultaneous Localization And Mapping (SLAM)

F1/10 Simulator



DNN Racing

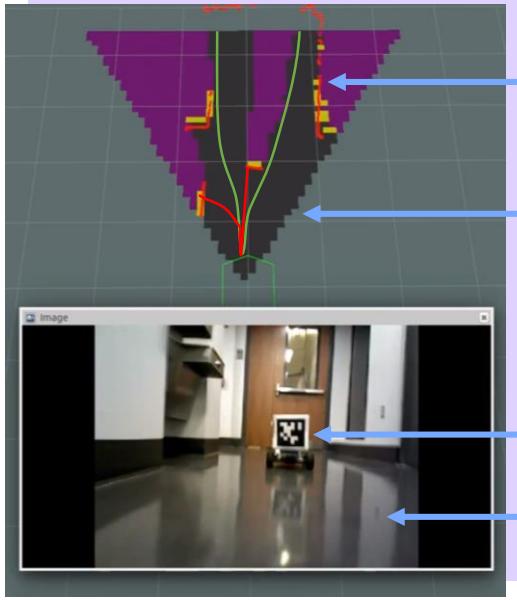
FOLLOW THE GAP METHOD



Follow the gap method

Simple obstacle avoidance

MODEL PREDICTIVE CONTROL



Generated paths

Drivable region

Dynamic obstacle

F1/10 RGB FPV

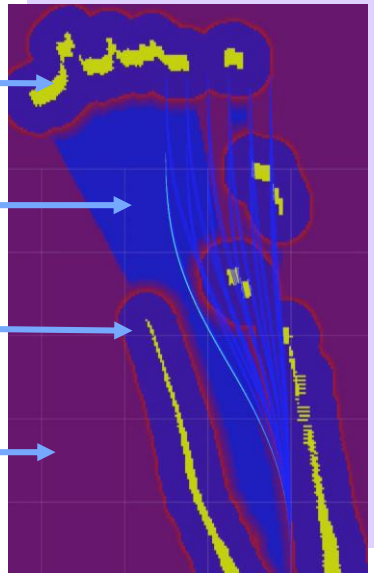
Max. cost (obstacle)

Drivable region

Medium cost

Unexplored space

Cost Map Legend



F1 TENTH

END-TO-END DNN

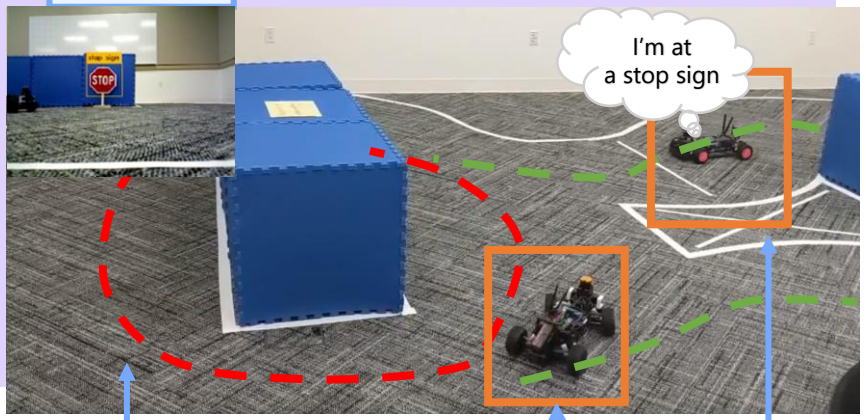
FPV data annotation

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

Predicted steering (blue)
Ground Truth (green)

V2V COLLABORATION

F1/10 FPV

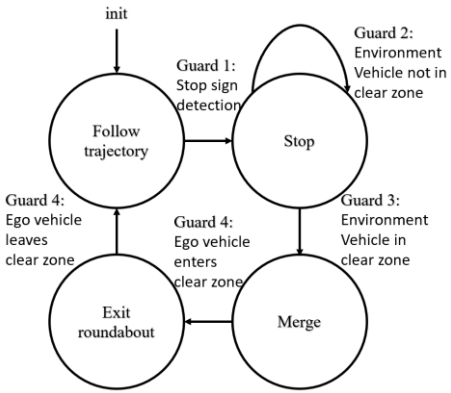


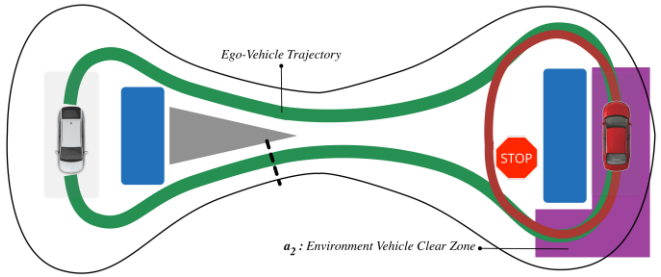
Env. Vehicle Path

Environment vehicle

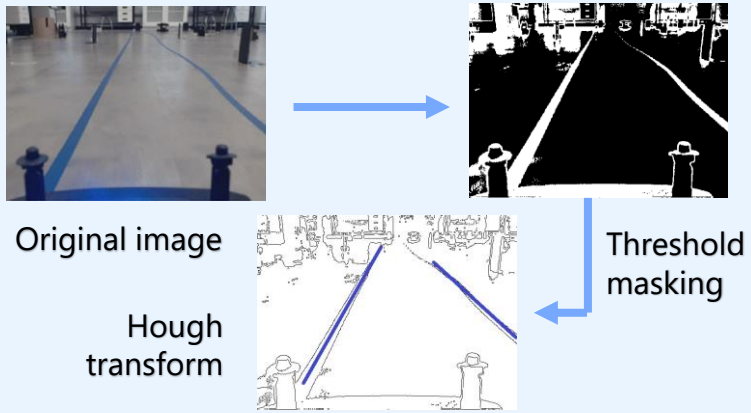
Ego vehicle

Collaborative behavior automaton



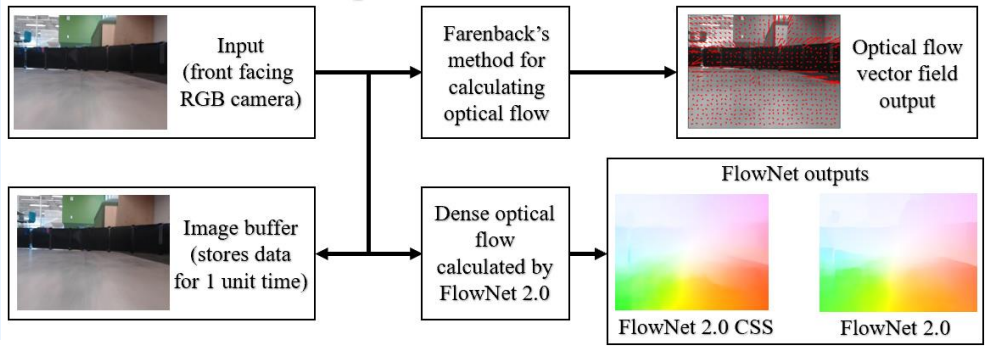


LANE KEEPING ASSIST

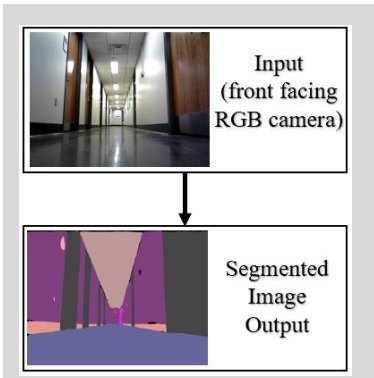


Lane detection pipeline

COMPUTER VISION EXAMPLE



Optical flow



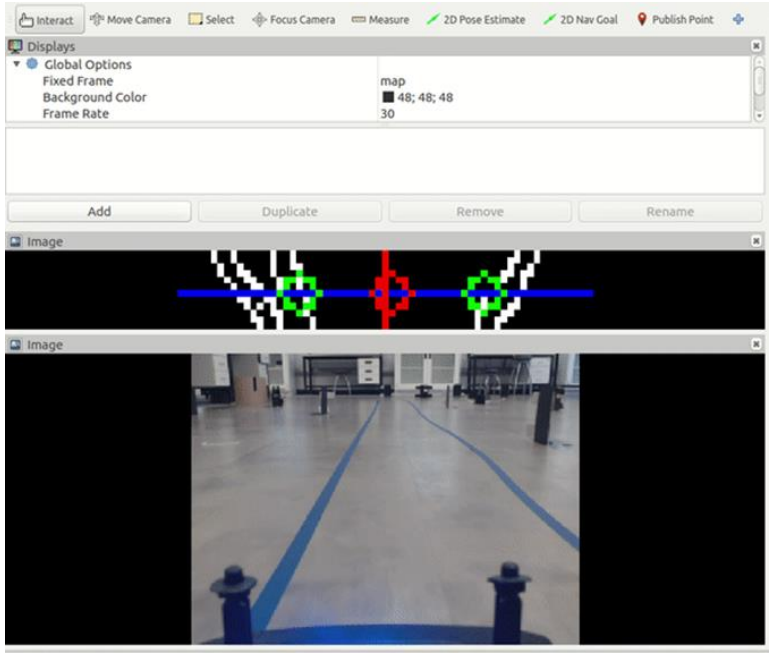
F1/10 online semantic segmentation

F1 TENTH

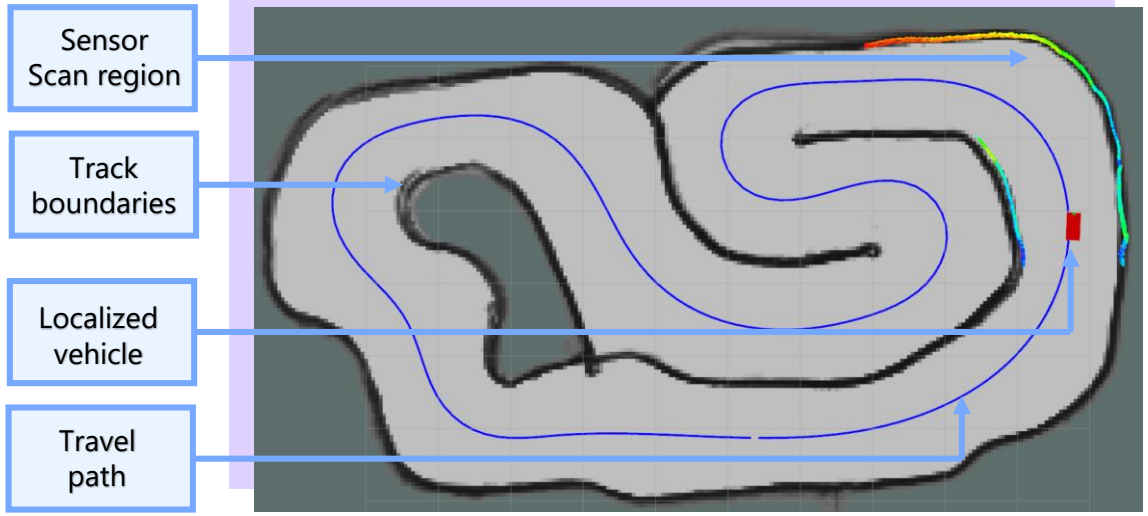
LOCALIZATION AND MAPPING

Currently tested On F1/10

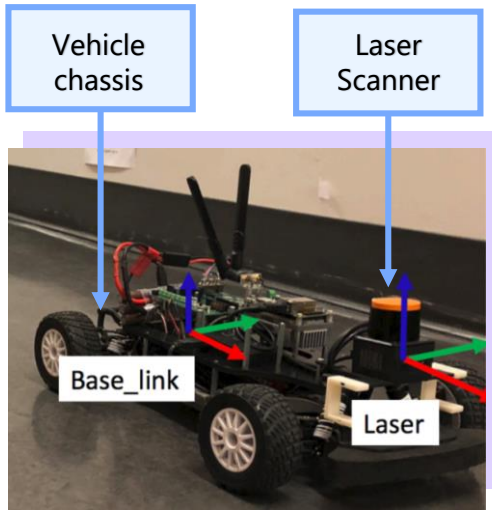
Hector SLAM	AMCL	Google Cartographer	ORB-SLAM



rviz visualization



Global planning using *rviz*



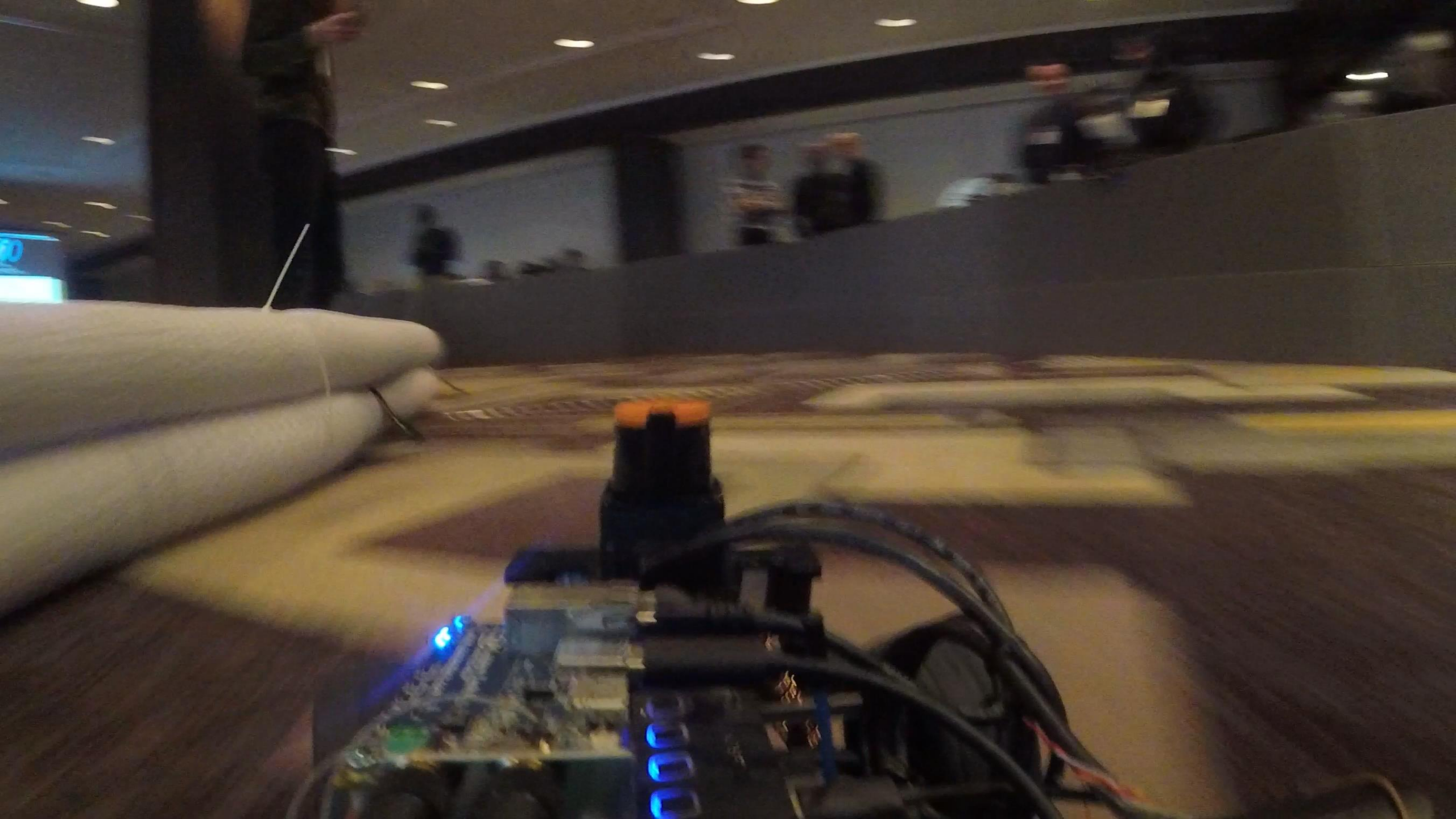
ROS transform frame

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

America

F1/10 COMMUNITY PARTNERS

F1/10 COMMUNITY PARTNERS

Europe & Asia

UNIMORE
UNIVERSITÀ DEGLI STUDI DI
MODENA E REGGIO EMILIA

UNIWERSYTET
WARSZAWSKI

SEOULTECH
SEOUL NATIONAL UNIVERSITY OF SCIENCE & TECHNOLOGY

서울대학교
SEOUL NATIONAL UNIVERSITY

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

국민대학교
KOOKMIN UNIVERSITY

daftcode

Limitations

Hardware cost - $ 3000

Slow Algorithm Development

From design to hardware implementation

ROS F1/10 Autonomous Racing Simulator

f1tenth.dev

GitHub docker ROS

Simulator Requirements

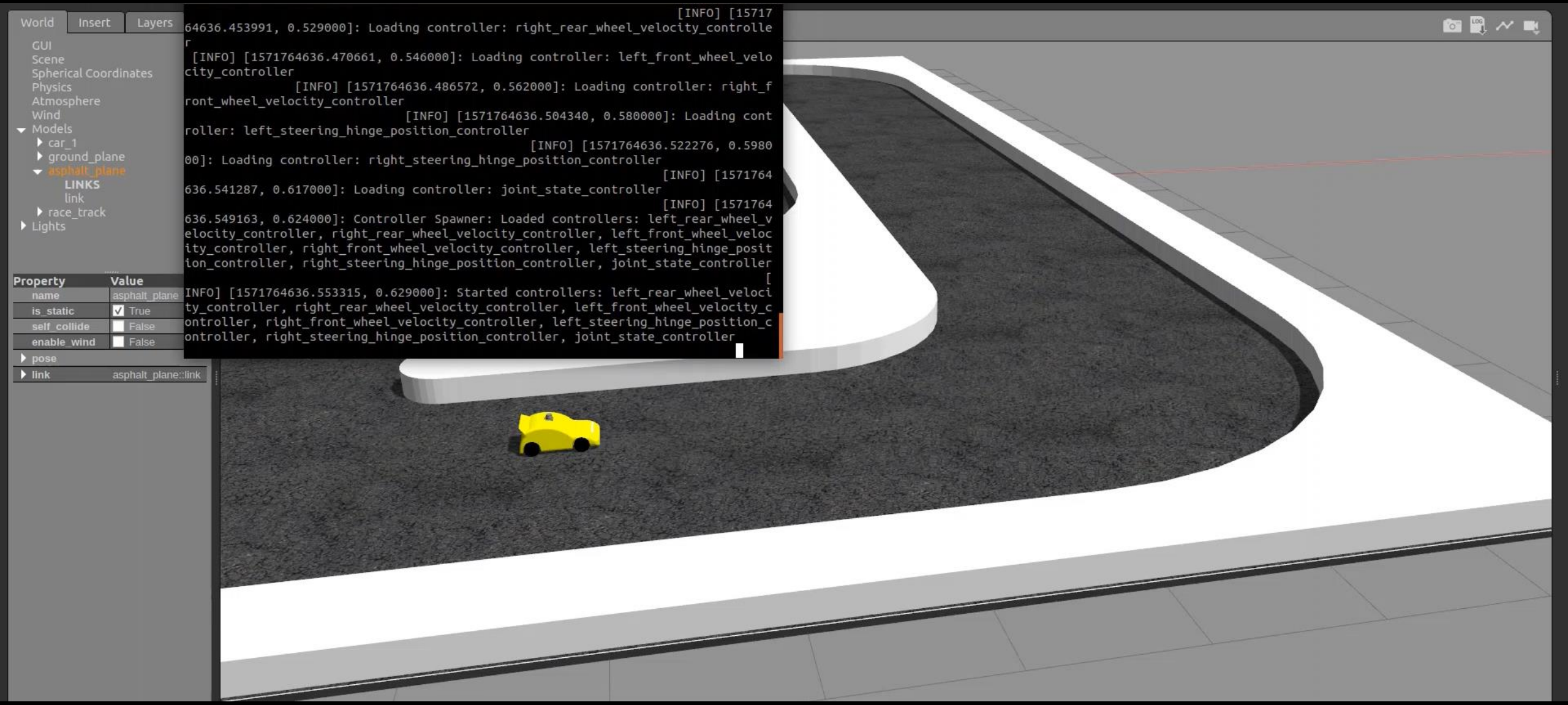
18.04 (bionic)

+

Melodic

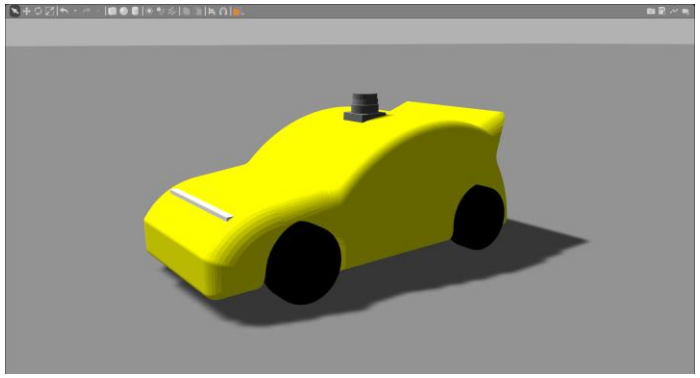
+

Instructions on f1tenth.dev



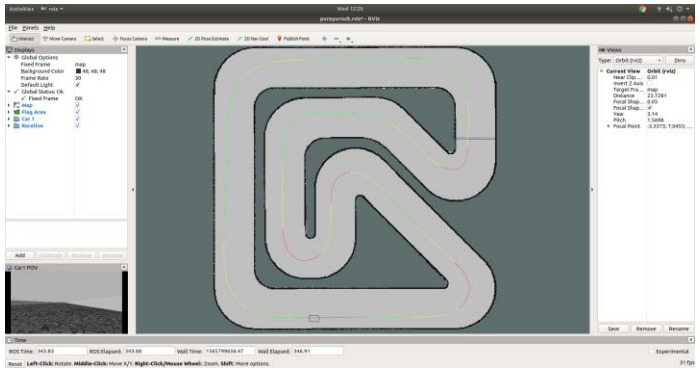

```
roslaunch f1tenth-sim simulator.launch
```

Simulator Elements



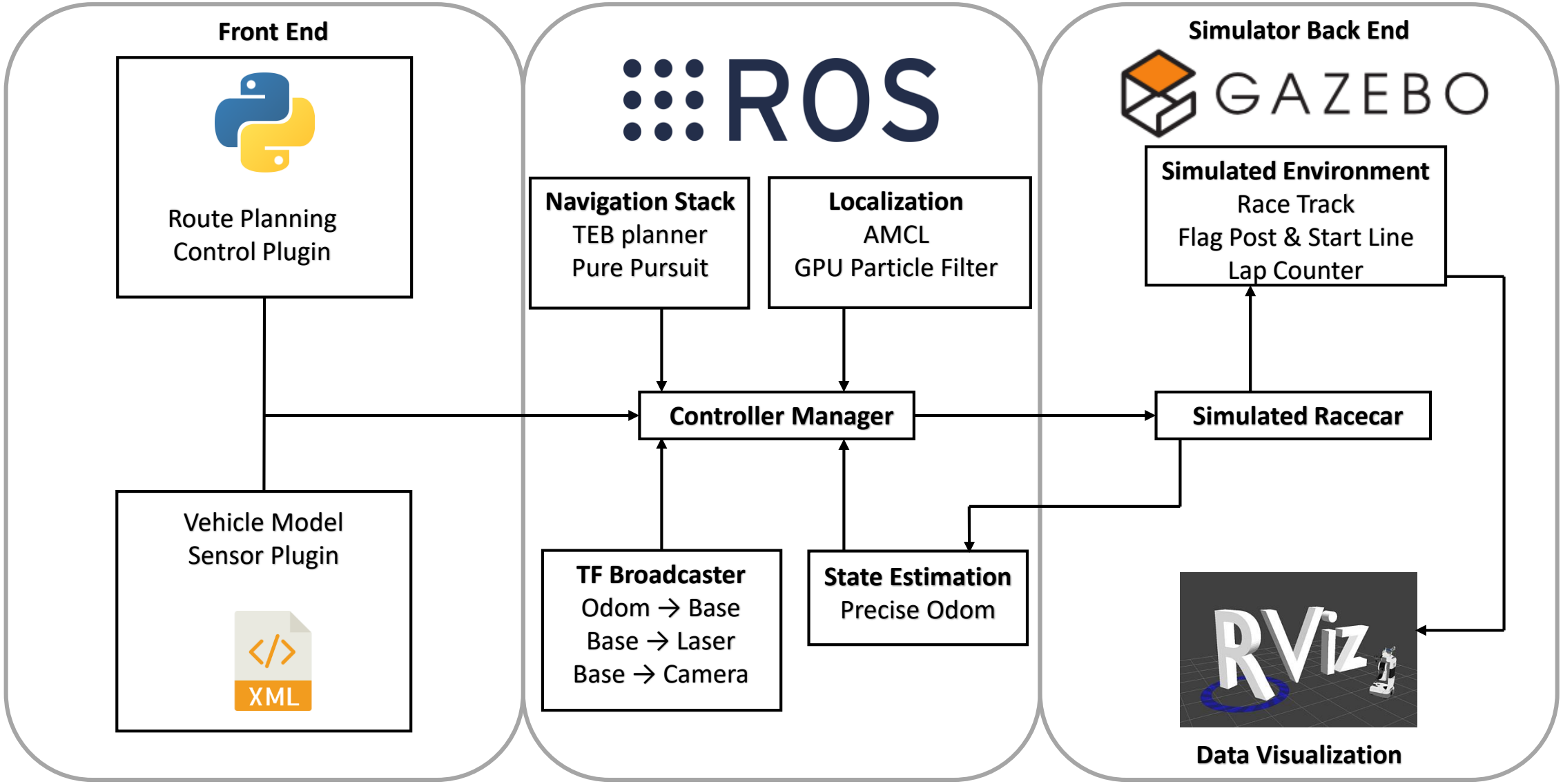
Racecar

Race Track

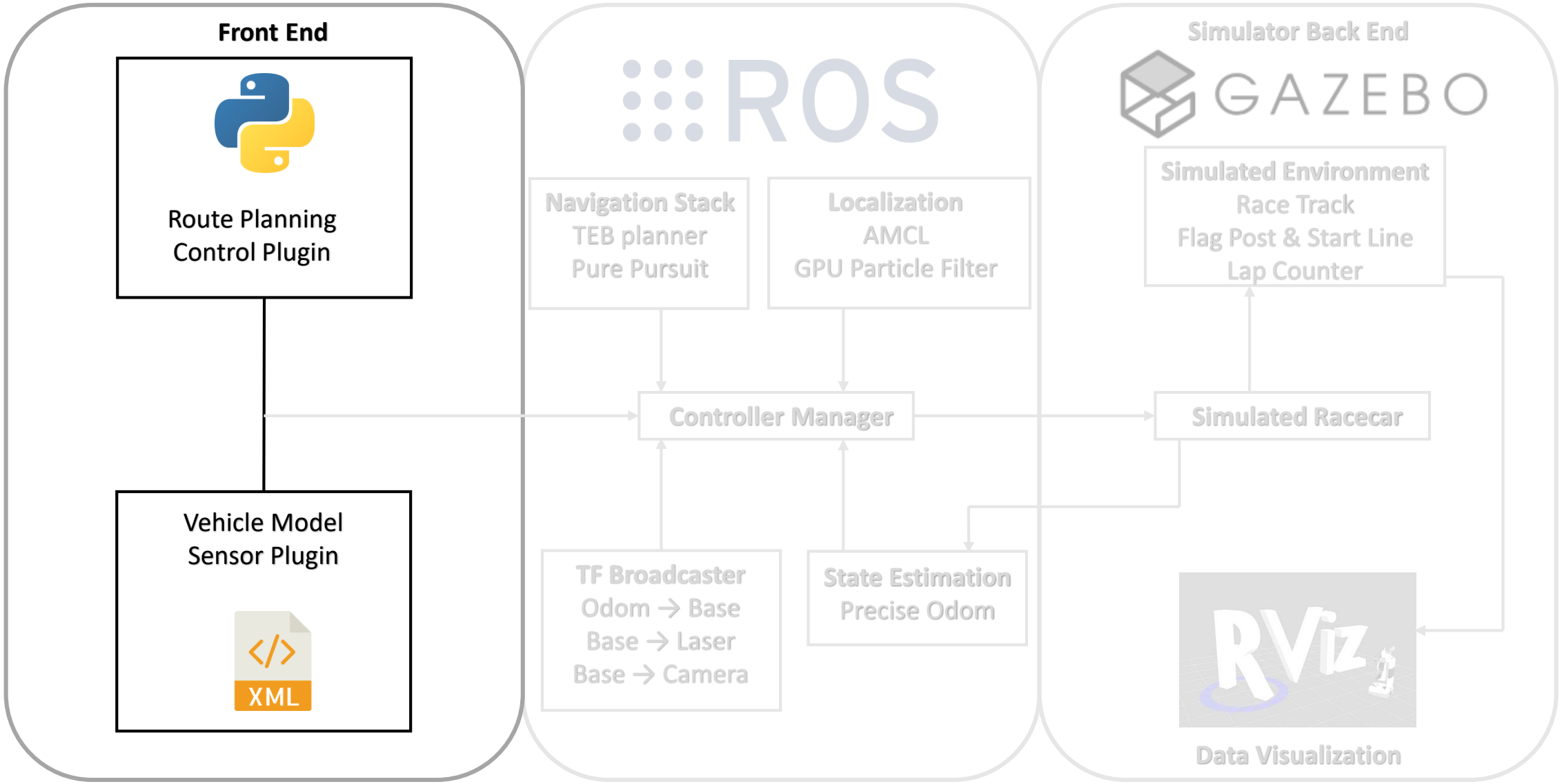


Algorithms

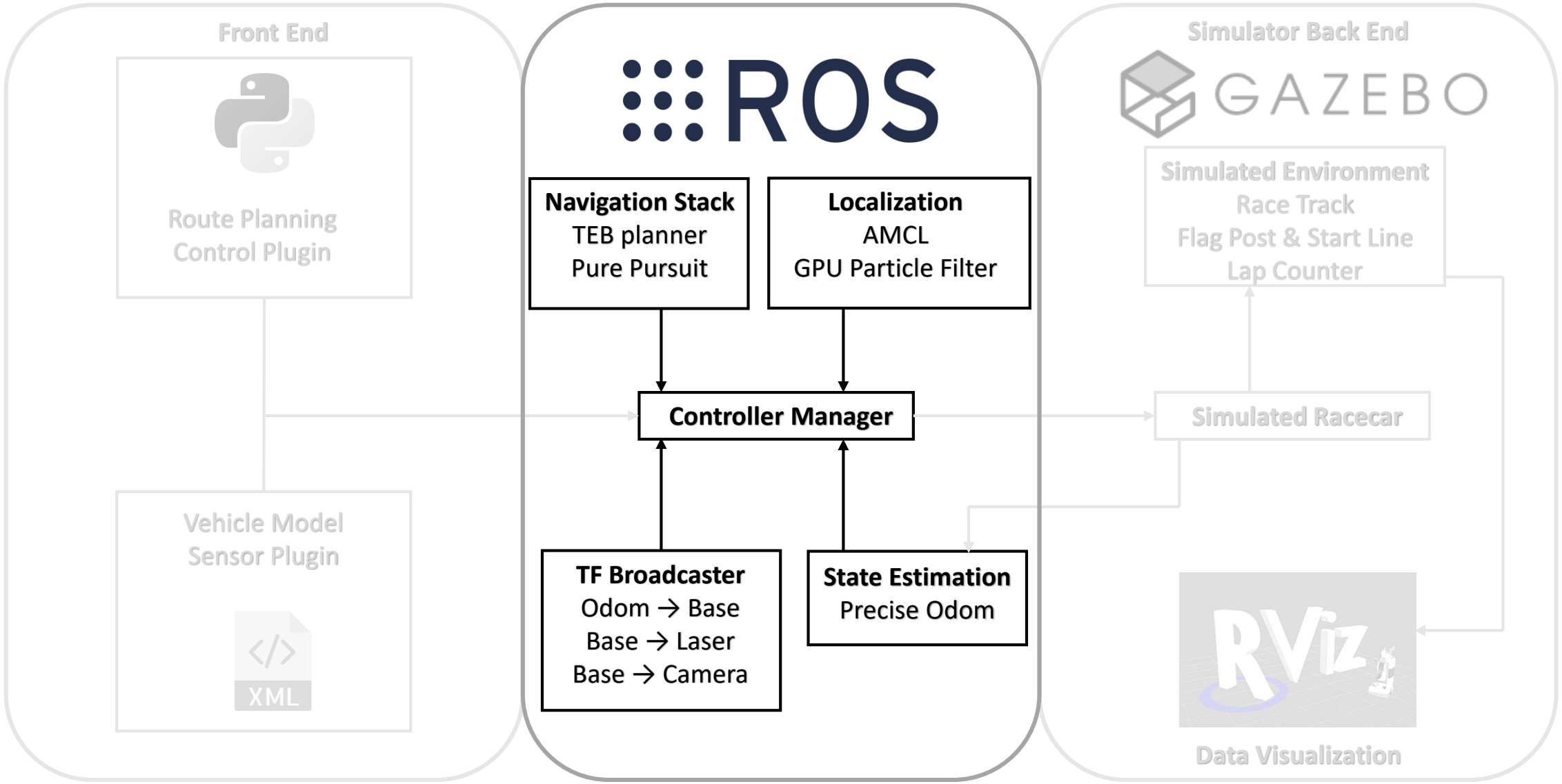
Simulator Architecture



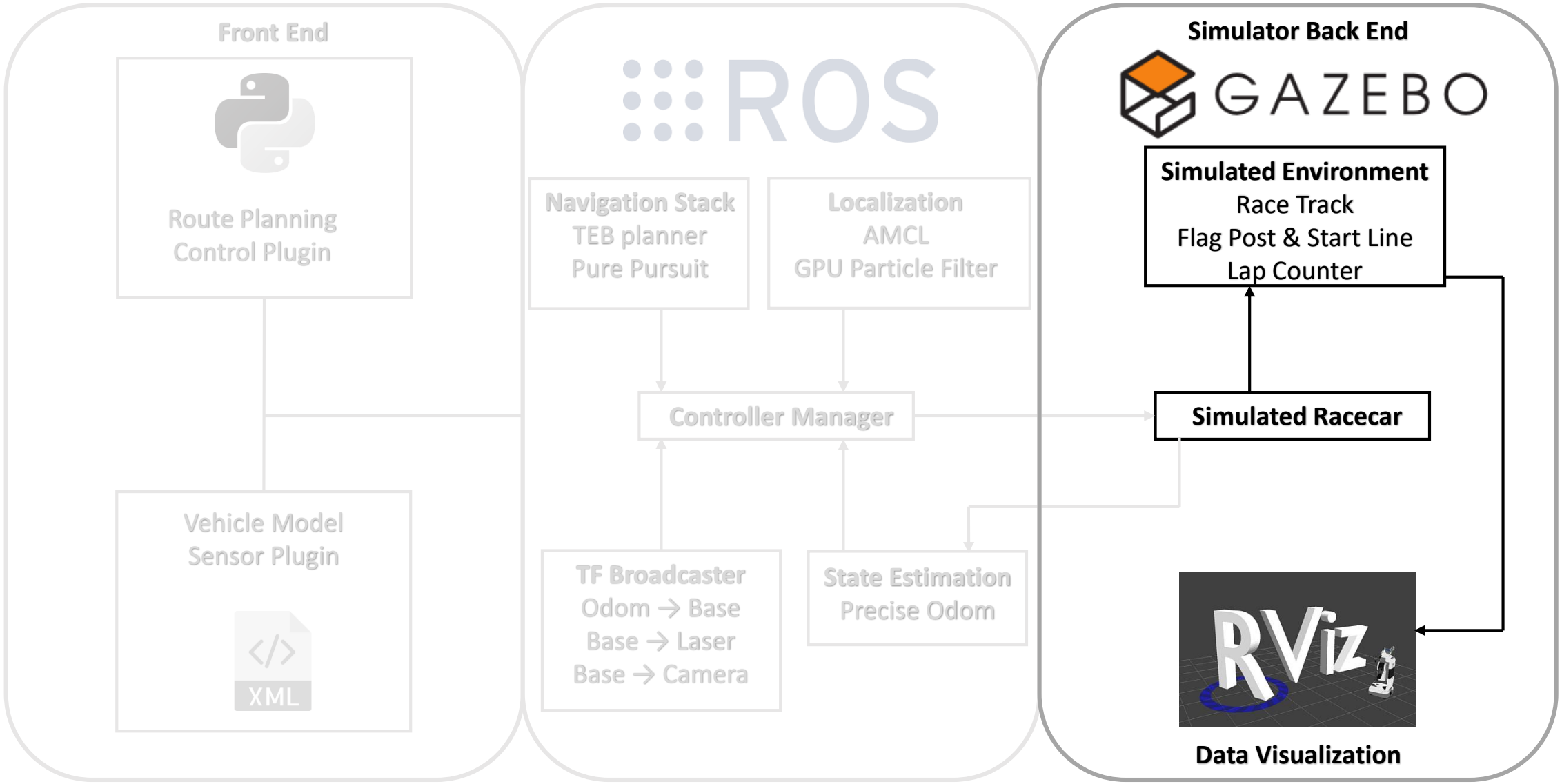
Front End


Front End
Route Planning
Control Plugin
Vehicle Model
Sensor Plugin
XML
ROS
Navigation Stack
TEB planner
Pure Pursuit
Localization
AMCL
GPU Particle Filter
Controller Manager
TF Broadcaster
Odom → Base
Base → Laser
Base → Camera
State Estimation
Precise Odom
Simulator Back End
GAZEBO
Simulated Environment
Race Track
Flag Post & Start Line
Lap Counter
Simulated Racecar
RViz
Data Visualization

Navigation and Control Algorithms



Gazebo and Visualization

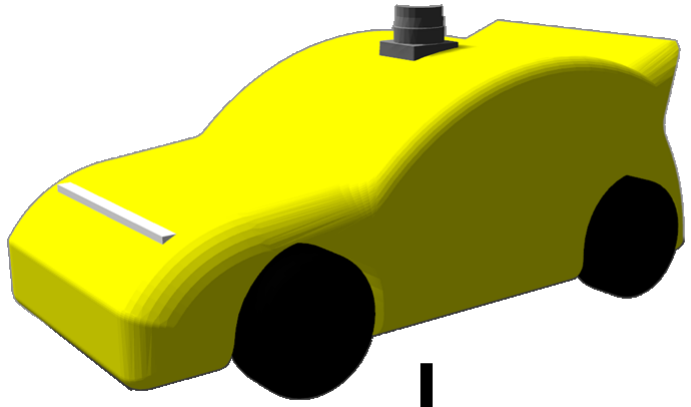


Racecar Model

F1/10 Autonomous
Racecar Platform

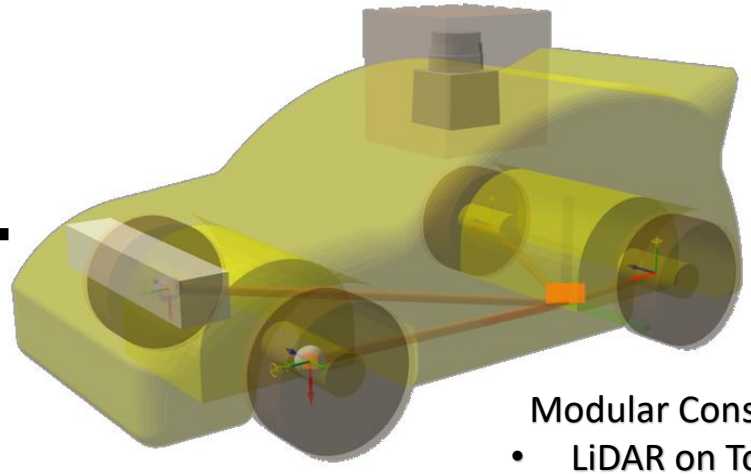
Size & Performance
Replicated

CAD, xacro, urdf



Simulated F1/10 Racecar
- Customizable color
- Multiple sensors

Gazebo
Sensor Plugins

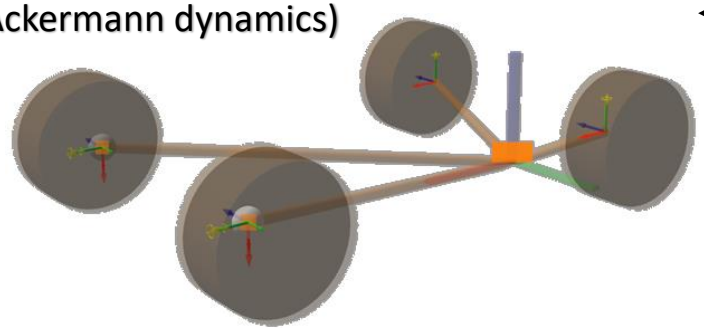


Modular Construction
- LiDAR on Top
- Camera on the hood

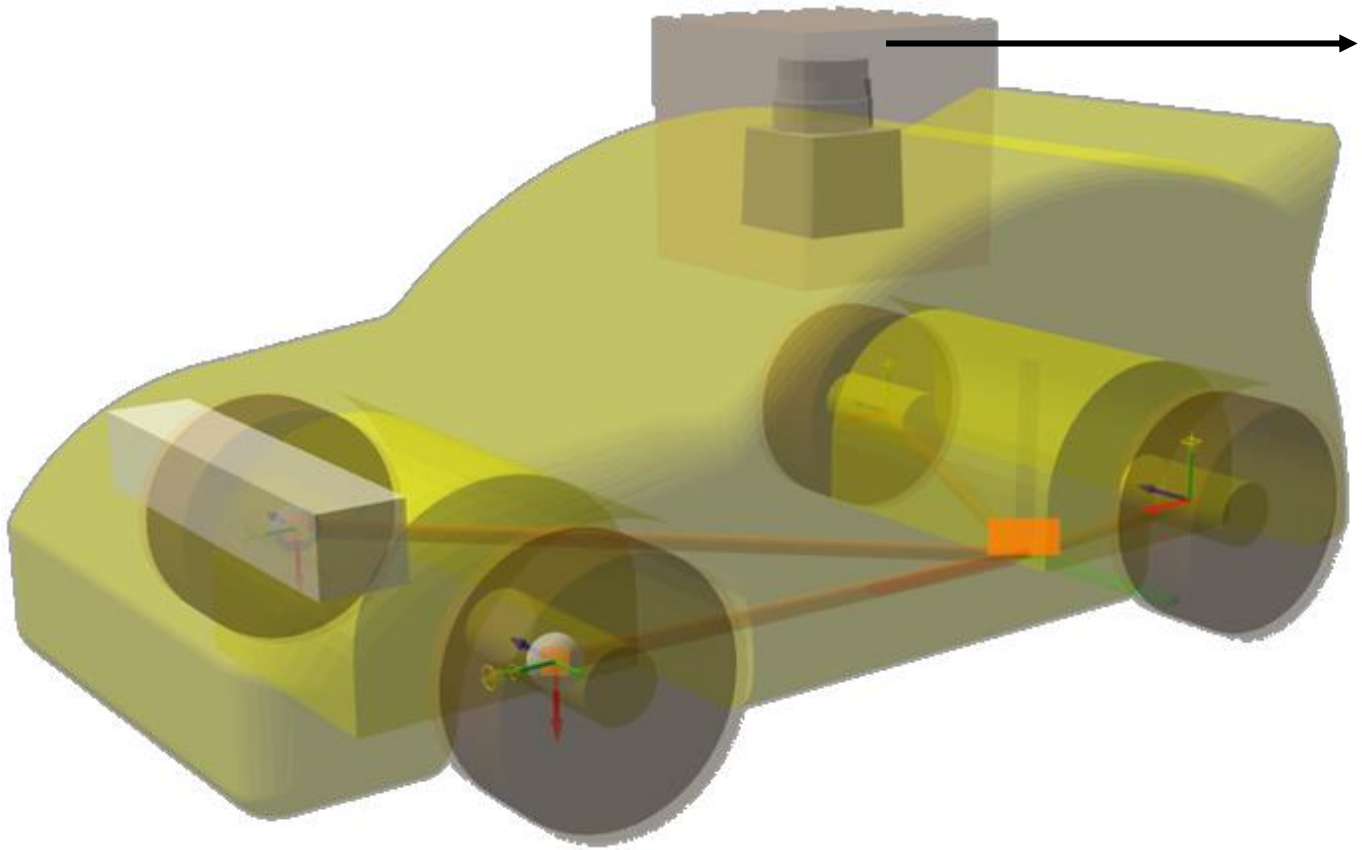
4 Wheel Independent Drive

(with hard differential constraints
enforced by control plugin)

Powertrain
(with Ackermann dynamics)



Modular Design



Primary Navigation Sensor

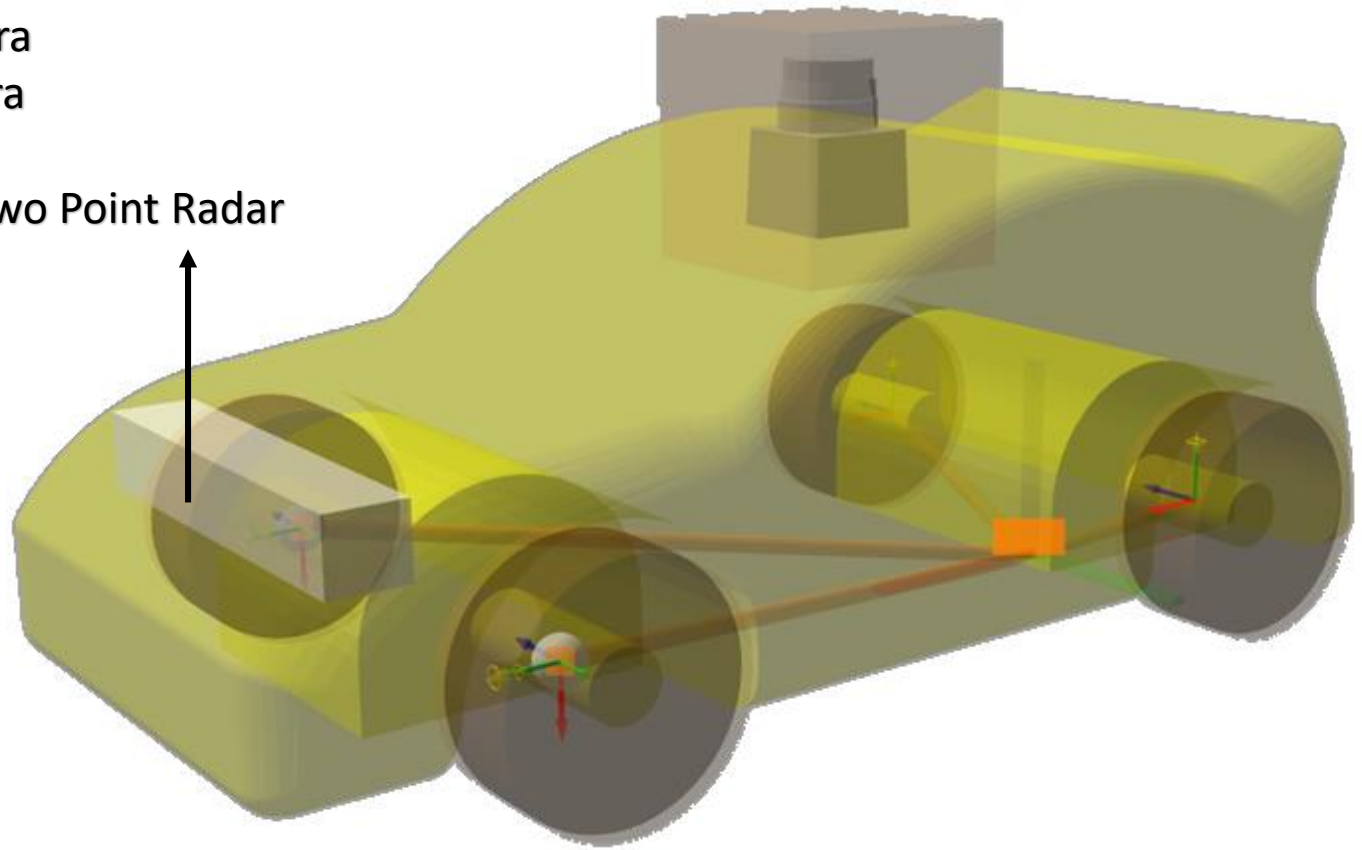
2D Scanning LiDAR

- Hokuyo sensor plugin
- *LaserScan.msg* message type
- Range (4.0m to 30.0m)
- Scan Angle (180 to 360 degrees)
- Position changed in URDF

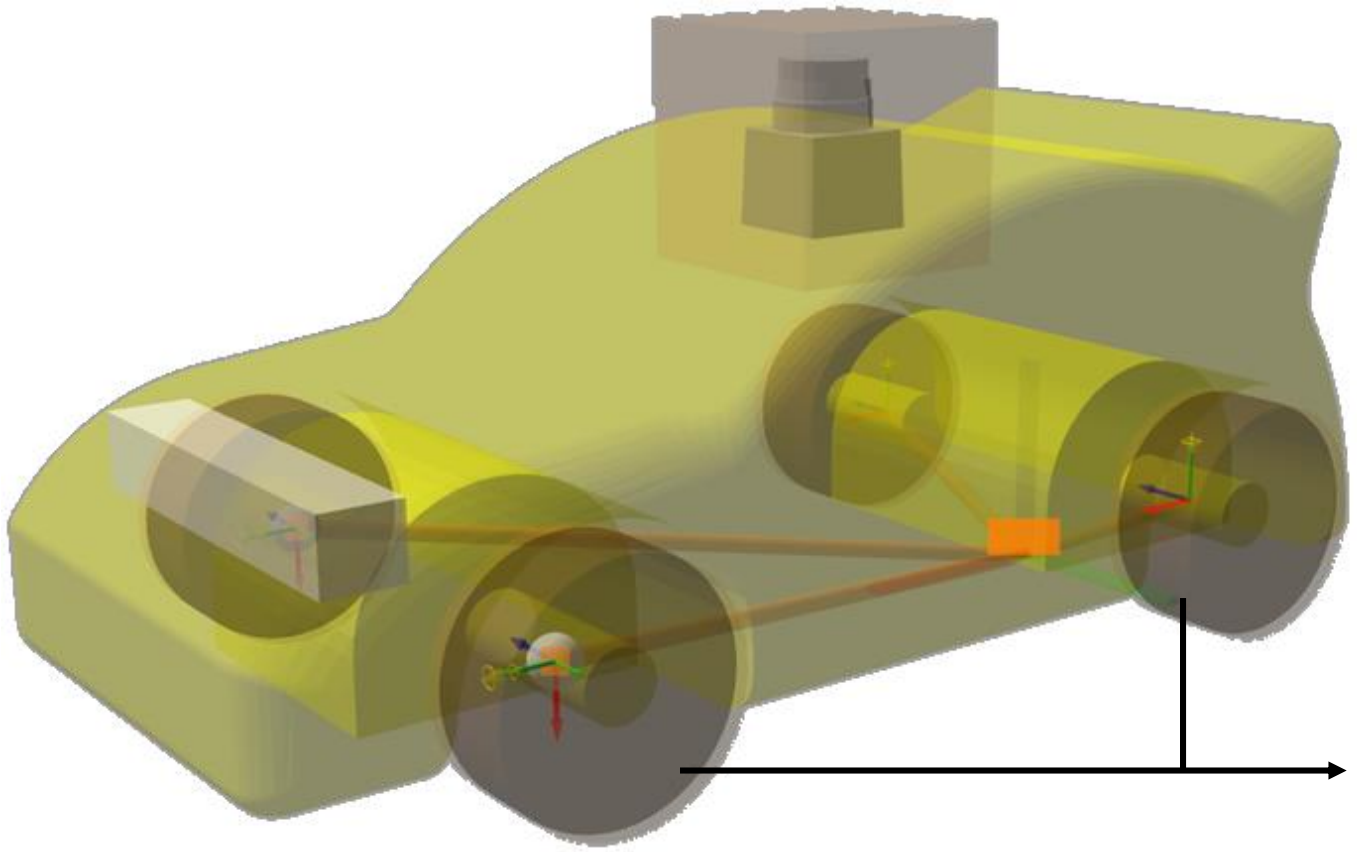
Modular Design

Secondary Navigation Sensors

- Stereo Camera
- Depth Camera
- IMU
- Front/Rear Two Point Radar



Modular Design



Racecar Chassis
(Shell, powertrain,
Collision sensor, controller)

- Collision sensor
- Rear Wheel/ All wheel drive
- Speed set as RPM or m/s
- Differential enable/disable
- Energy meter and bank with boost

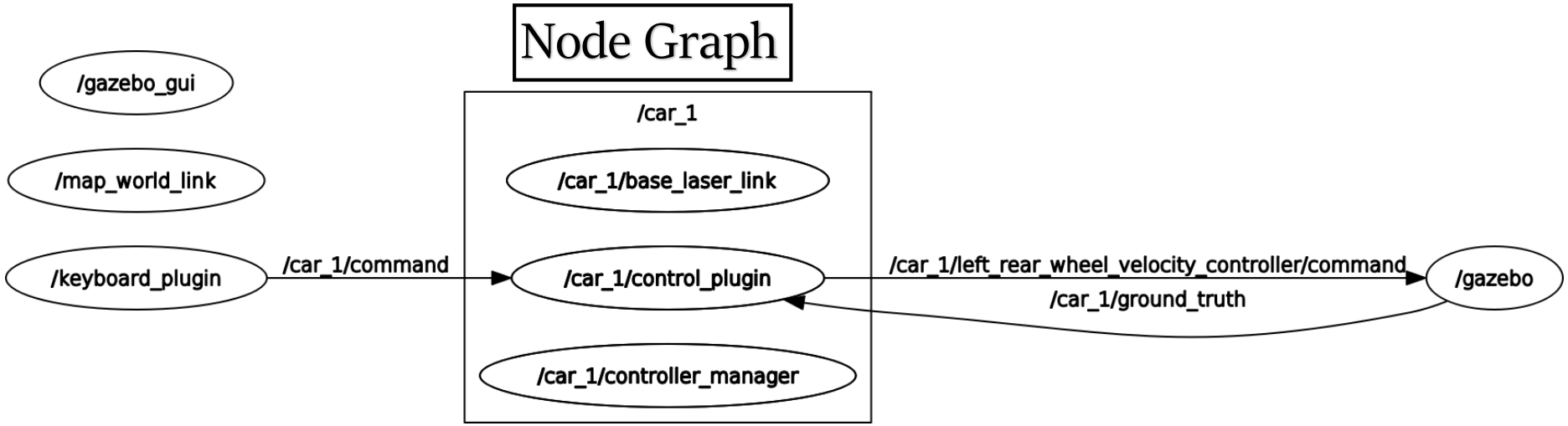
Racecar Control Nodes

tf Nodes (static & dynamic)

`/car_name/base_laser_link`
`/car_name/base_odom_link`

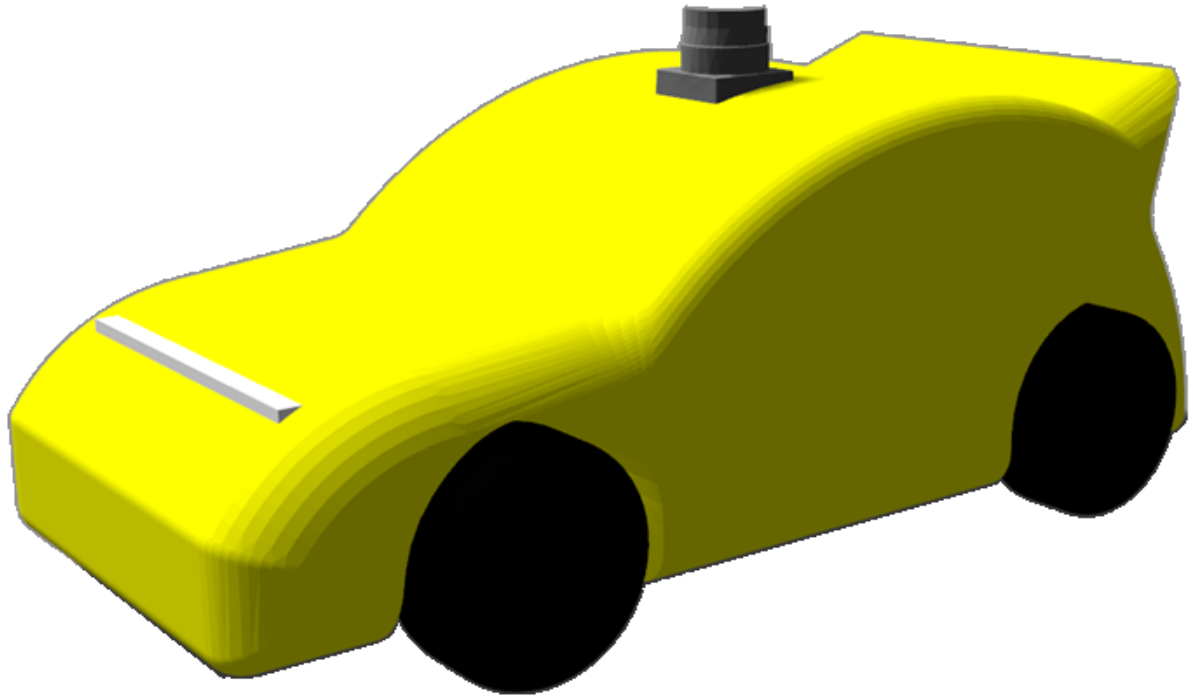
Command, Control & Feedback Node

`/car_name/control_plugin`



Control Plugin

Command & Control



Message Type:

`AckermannDrive.msg`

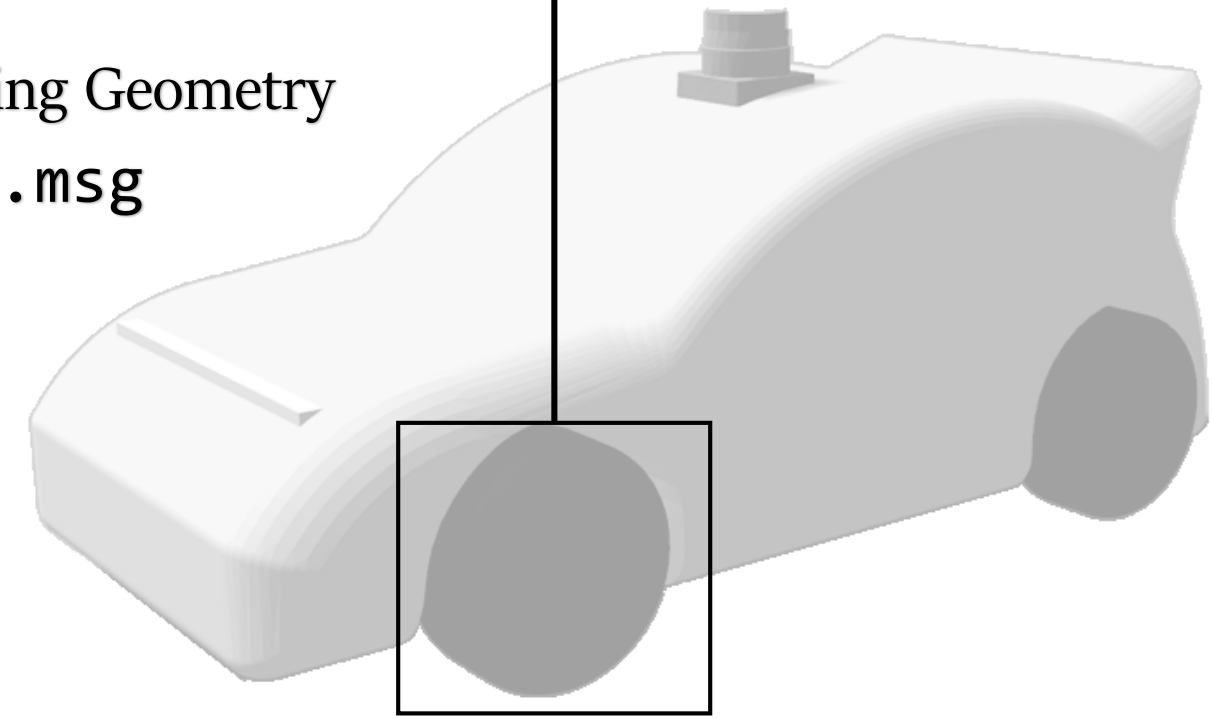
Control Plugin

Command & Control

Steering Column Controller

Ackermann Steering Geometry

`Float64.msg`

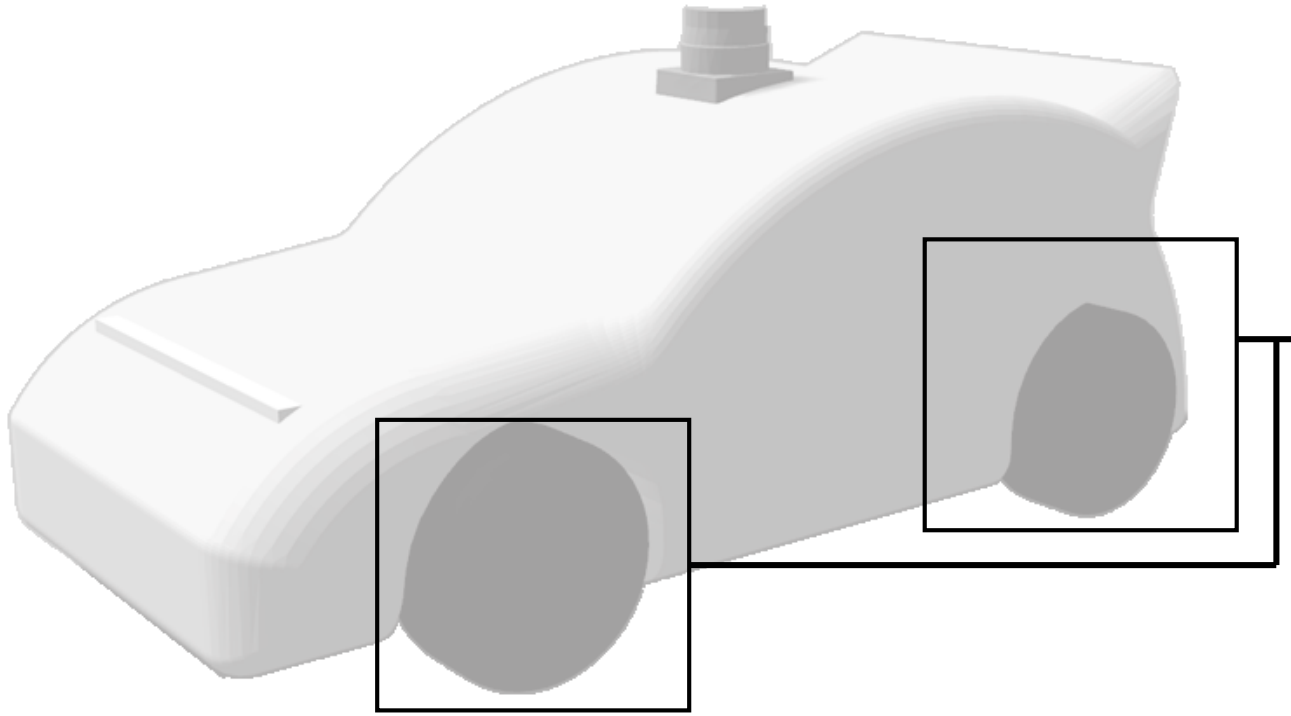


Message Type:

`AckermannDrive.msg`

Control Plugin

Command & Control



Wheel RPM Controller

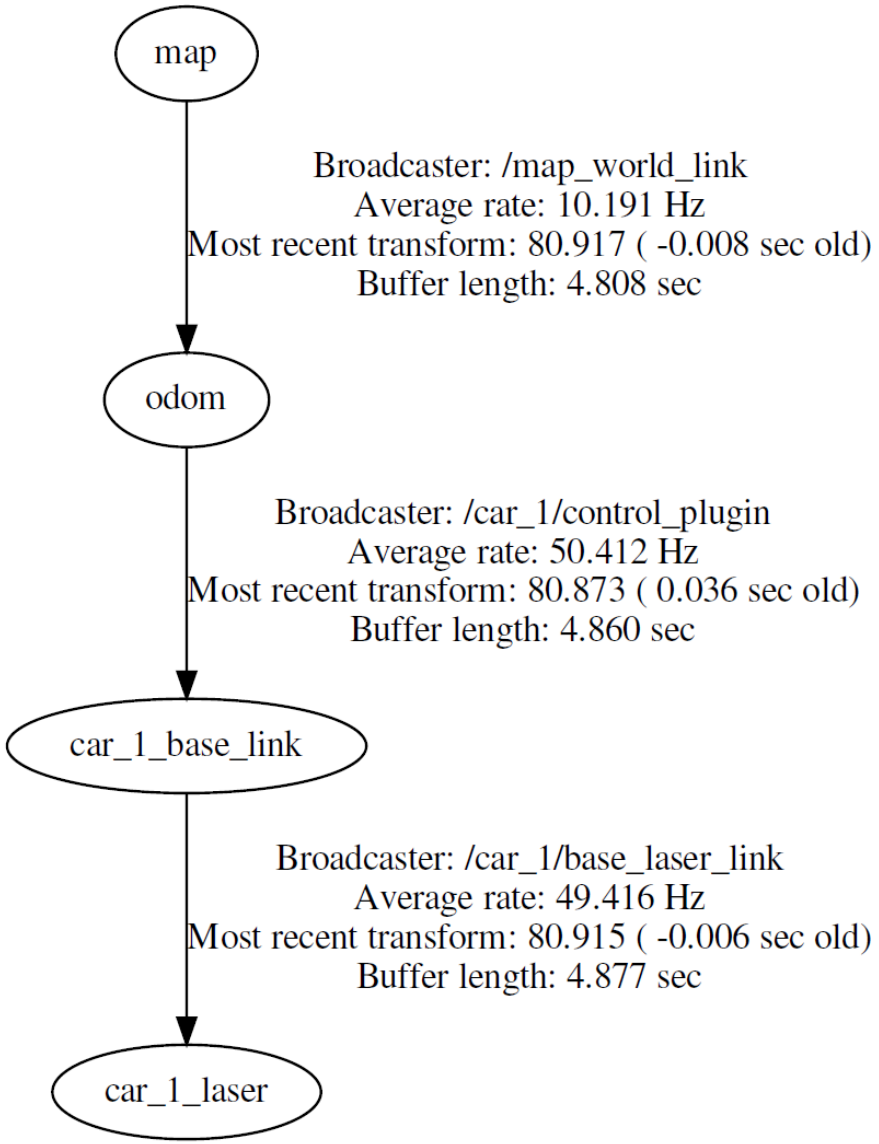
PID Speed Control

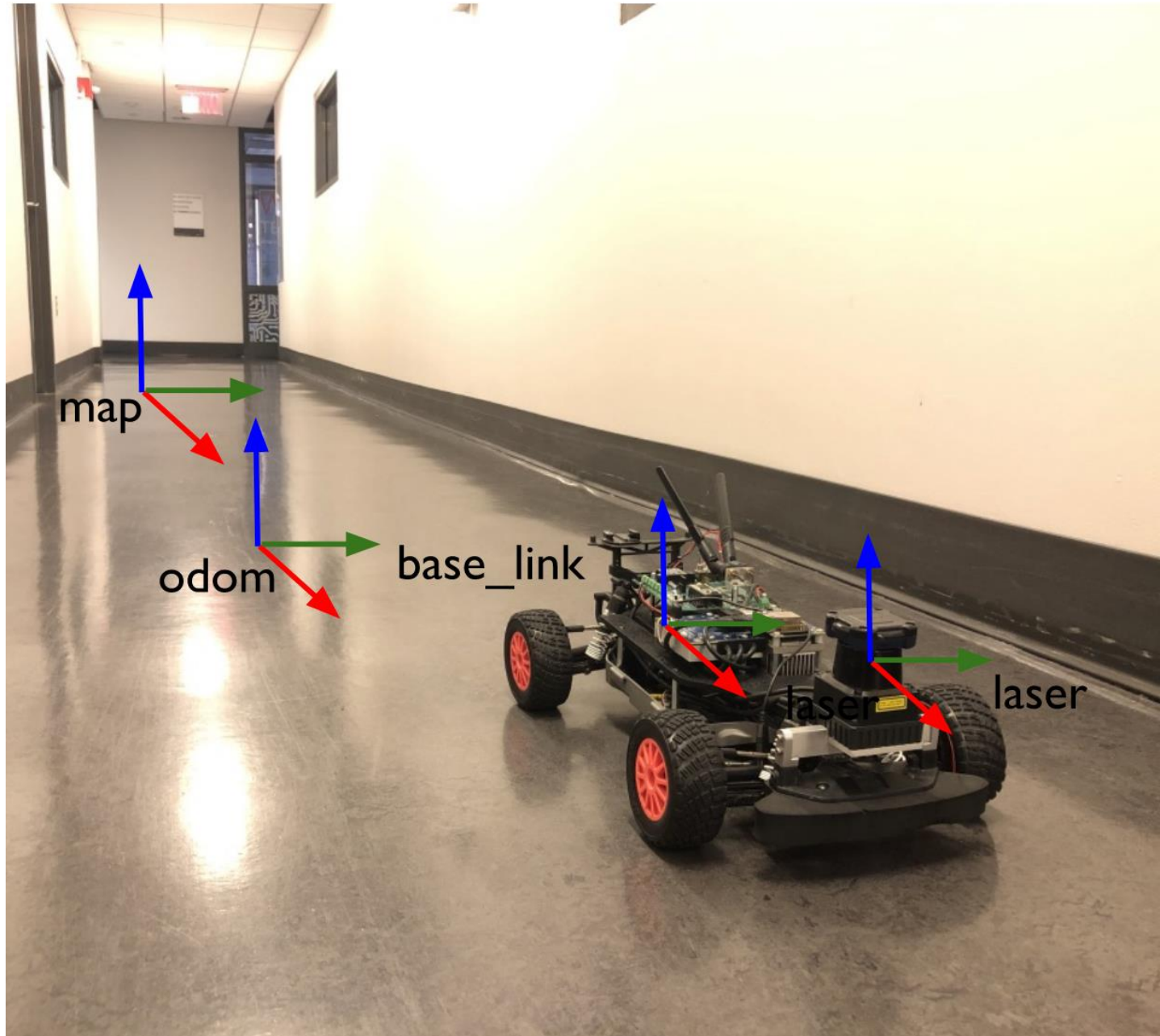
`Float64.msg`

Message Type:

`AckermannDrive.msg`

tf-Tree


map
Broadcaster: /map_world_link
Average rate: 10.191 Hz
Most recent transform: 80.917 (-0.008 sec old)
Buffer length: 4.808 sec
odom
Broadcaster: /car_1/control_plugin
Average rate: 50.412 Hz
Most recent transform: 80.873 (0.036 sec old)
Buffer length: 4.860 sec
car_1_base_link
Broadcaster: /car_1/base_laser_link
Average rate: 49.416 Hz
Most recent transform: 80.915 (-0.006 sec old)
Buffer length: 4.877 sec
car_1_laser


map
odom
base_link
laser
laser

Racecar Object Creation

```
<!-- spawn car using the set global parameters -->
<include      file              = '$(find f1tenth-sim)/launch/simulator.launch'>
<arg          name              = 'car_name'
              value             = '$(arg car_name)'/>
<arg          name              = 'paint'
              value             = '$(arg car_paint)'/>
<arg          name              = 'run_gazebo'
              value             = '$(arg run_gazebo)'/>
<arg          name              = 'x_pos'
              value             = '$(arg x_pos)'/>
<arg          name              = 'y_pos'
              value             = '$(arg y_pos)'/> </include>
```

Racecar Object Creation

```
<!-- spawn car using the set global parameters -->
<include      file          = '$(find f1tenth-sim)/launch/simulator.launch'>
<arg          name          = 'car_name'
              value         = '$(arg car_name)'/>
<arg          name          = 'paint'
              value         = '$(arg car_paint)'/>
<arg          name          = 'run_gazebo'
              value         = '$(arg run_gazebo)'/>
<arg          name          = 'x_pos'
              value         = '$(arg x_pos)'/>
<arg          name          = 'y_pos'
              value         = '$(arg y_pos)'/> </include>
```

Unique namespace

Racecar Object Creation

```
<!-- spawn car using the set global parameters -->
<include      file          = '$(find f1tenth-sim)/launch/simulator.launch'>
<arg          name          = 'car_name'
              value         = '$(arg car_name)'/>
<arg          name          = 'paint'
              value         = '$(arg car_paint)'/>
<arg          name          = 'run_gazebo'
              value         = '$(arg run_gazebo)'/>
<arg          name          = 'x_pos'
              value         = '$(arg x_pos)'/>
<arg          name          = 'y_pos'
              value         = '$(arg y_pos)'/> </include>
```

Visual paint scheme

Racecar Object Creation

```
<!-- spawn car using the set global parameters -->
<include      file          = '$(find f1tenth-sim)/launch/simulator.launch'>
<arg          name          = 'car_name'
              value         = '$(arg car_name)'/>
<arg          name          = 'paint'
              value         = '$(arg car_paint)'/>
<arg          name          = 'run_gazebo'
              value         = '$(arg run_gazebo)'/>
<arg          name          = 'x_pos'
              value         = '$(arg x_pos)'/>
<arg          name          = 'y_pos'
              value         = '$(arg y_pos)'/> </include>
```

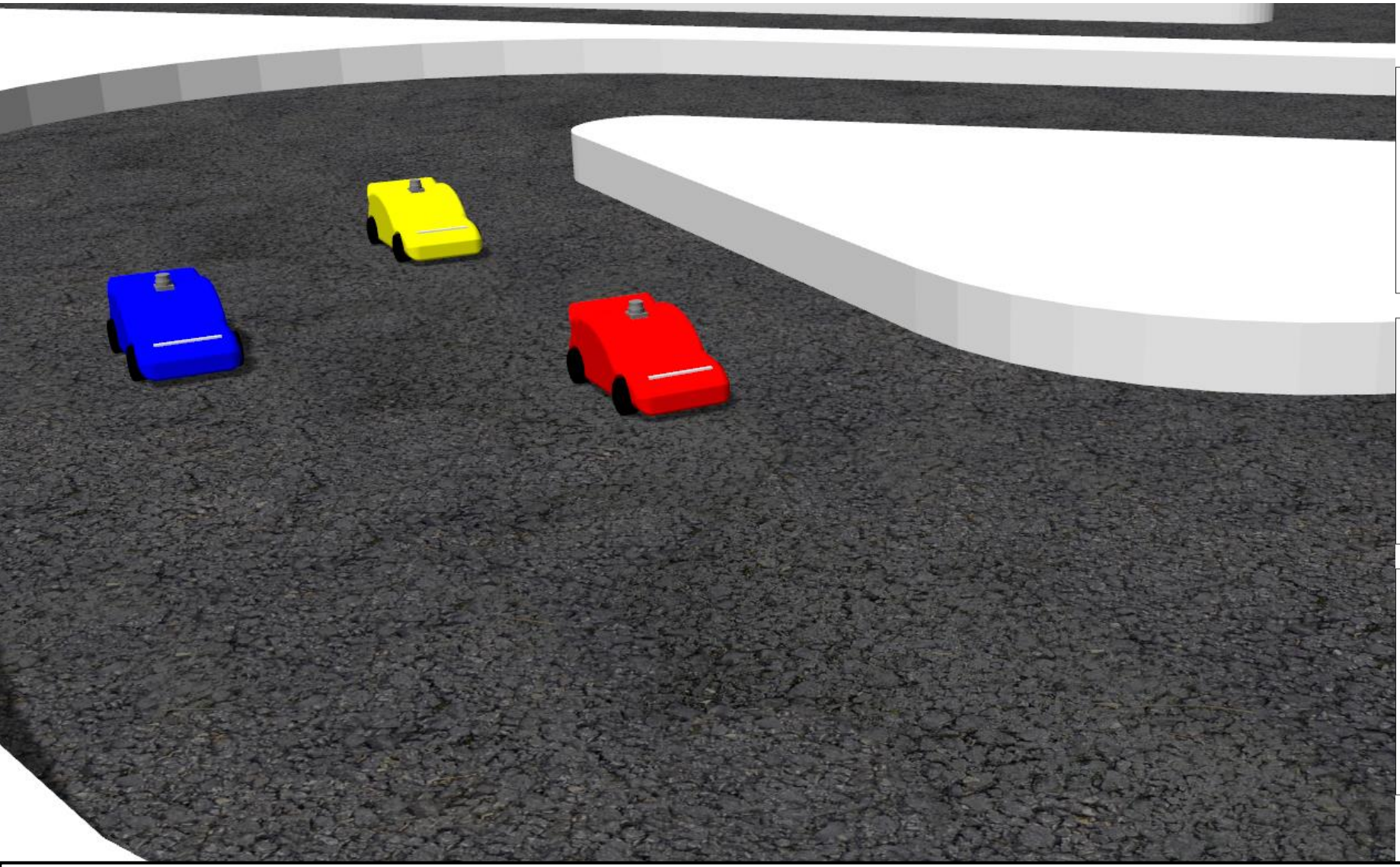
Circuit-Breaker (keeps only one session active)

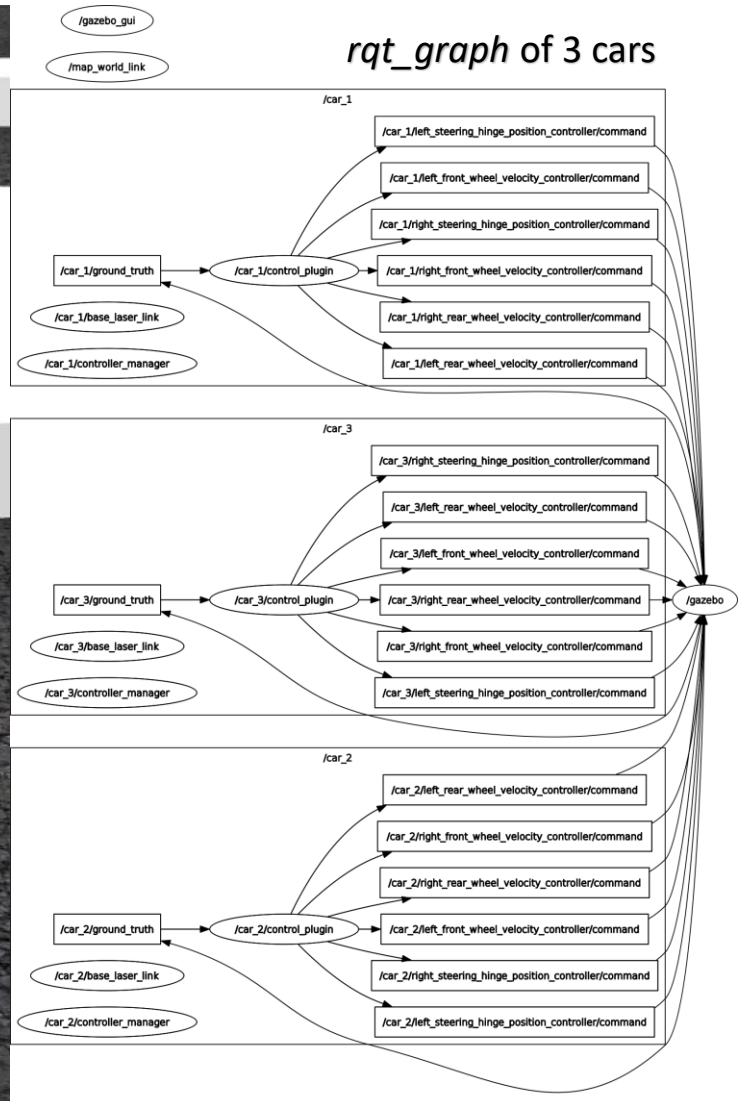
Racecar Object Creation

```
<!-- spawn car using the set global parameters -->
<include      file          = '$(find f1tenth-sim)/launch/simulator.launch'>
<arg          name          = 'car_name'
              value         = '$(arg car_name)'/>
<arg          name          = 'paint'
              value         = '$(arg car_paint)'/>
<arg          name          = 'run_gazebo'
              value         = '$(arg run_gazebo)'/>
<arg          name          = 'x_pos'
              value         = '$(arg x_pos)'/>
<arg          name          = 'y_pos'
              value         = '$(arg y_pos)'/> </include>
```

Racecar spawn location

Spawn Multiple Racecars



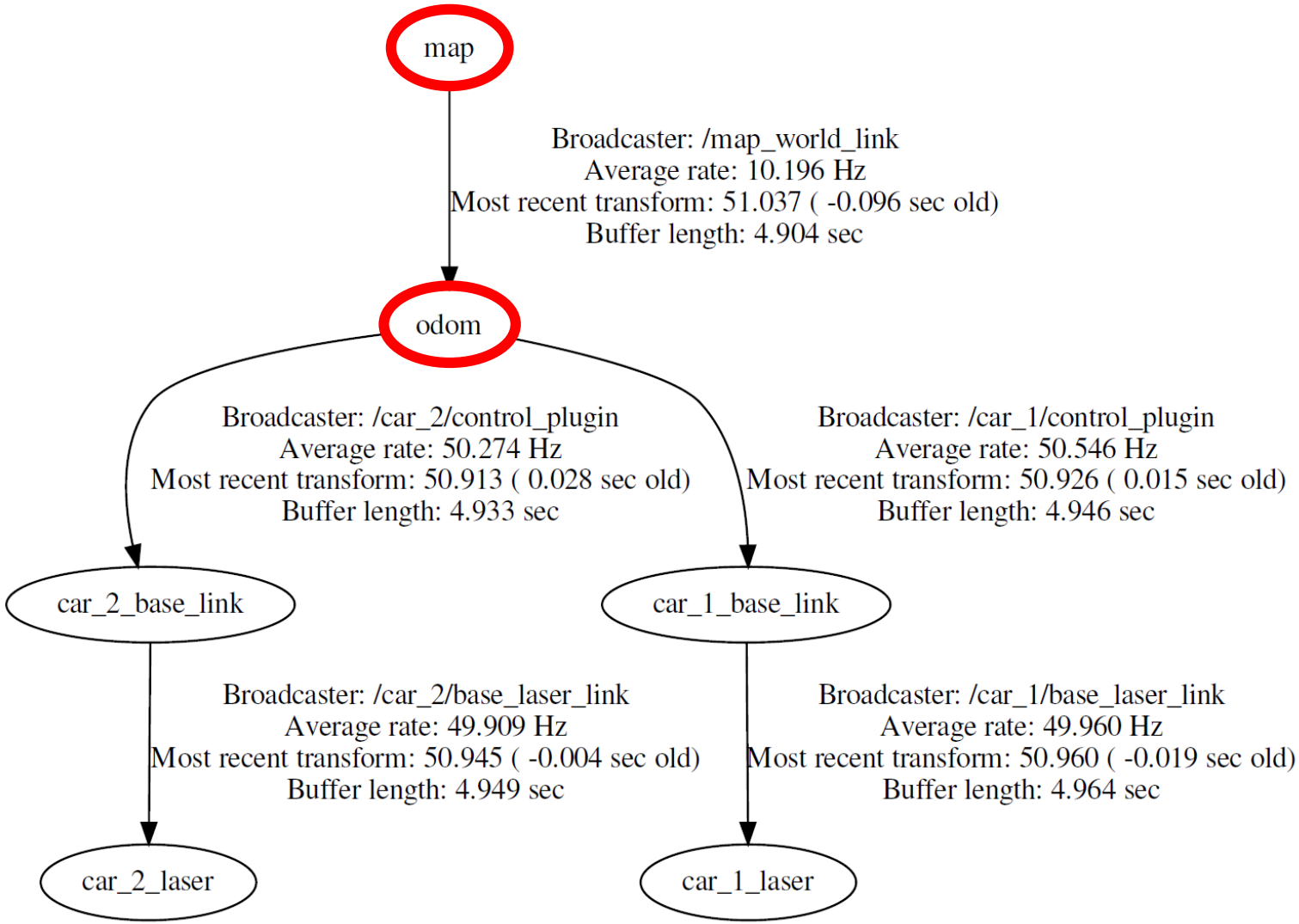


rqt_graph of 3 cars

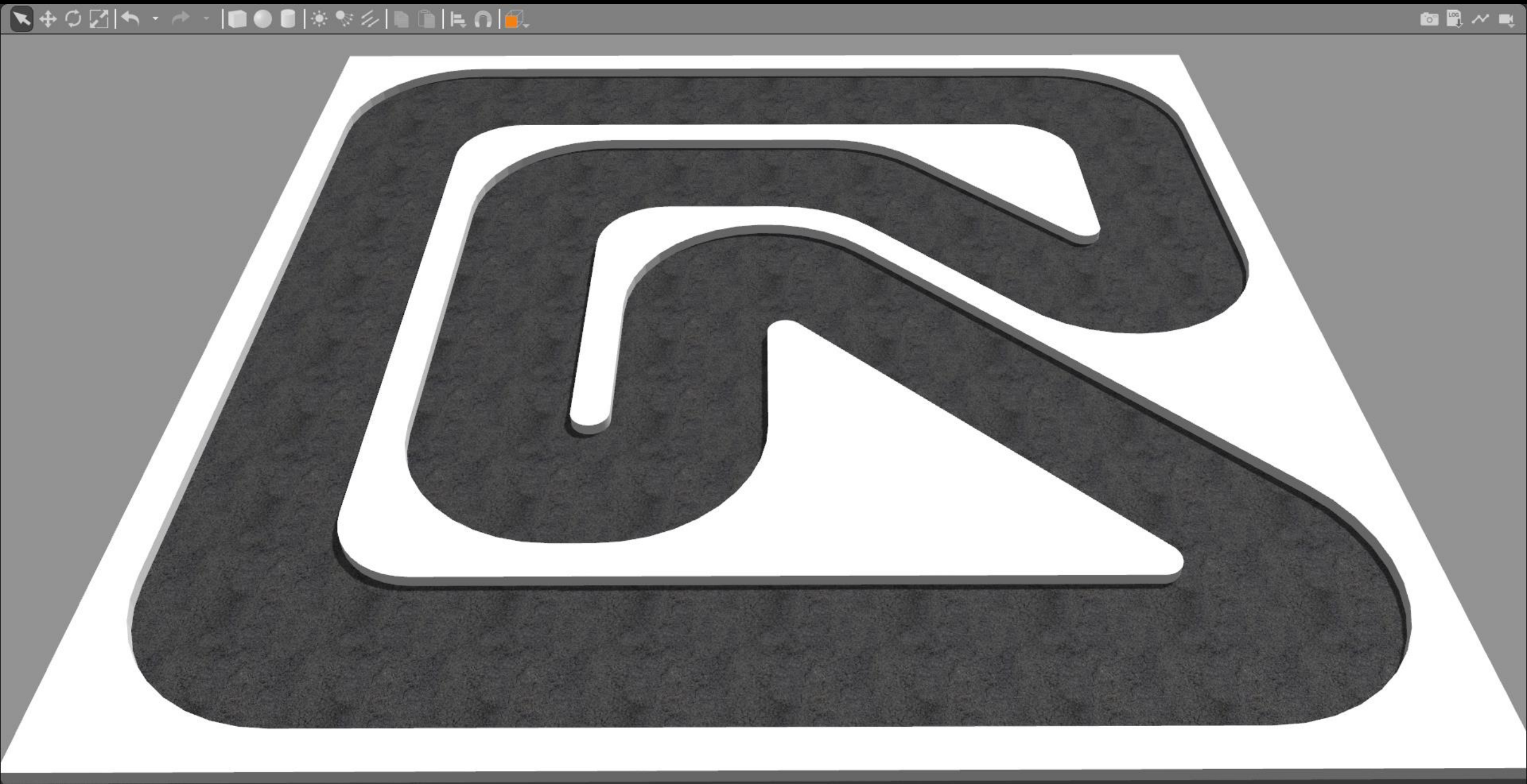
Namespace resolution handled by ROS

Capable of implementing different controllers

Multiple Racecars (tf-frames)



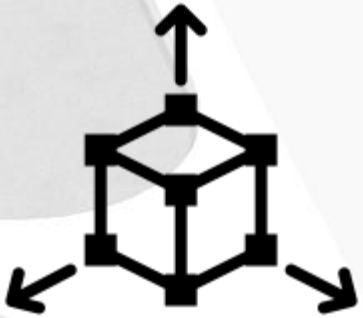
Simulated Race Track



Race Track creation process

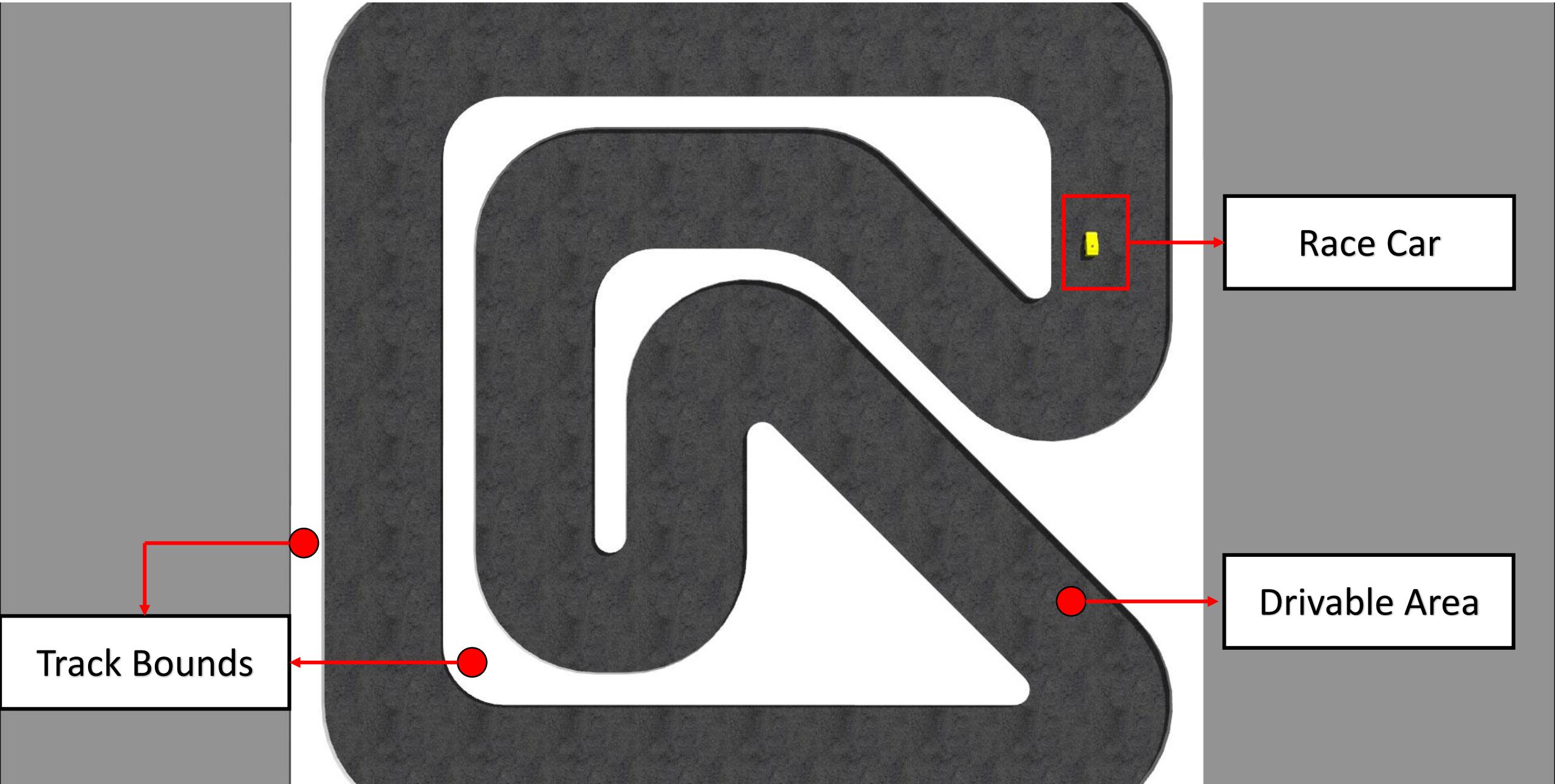
Sketch a 2D track

Convert to 3D mesh

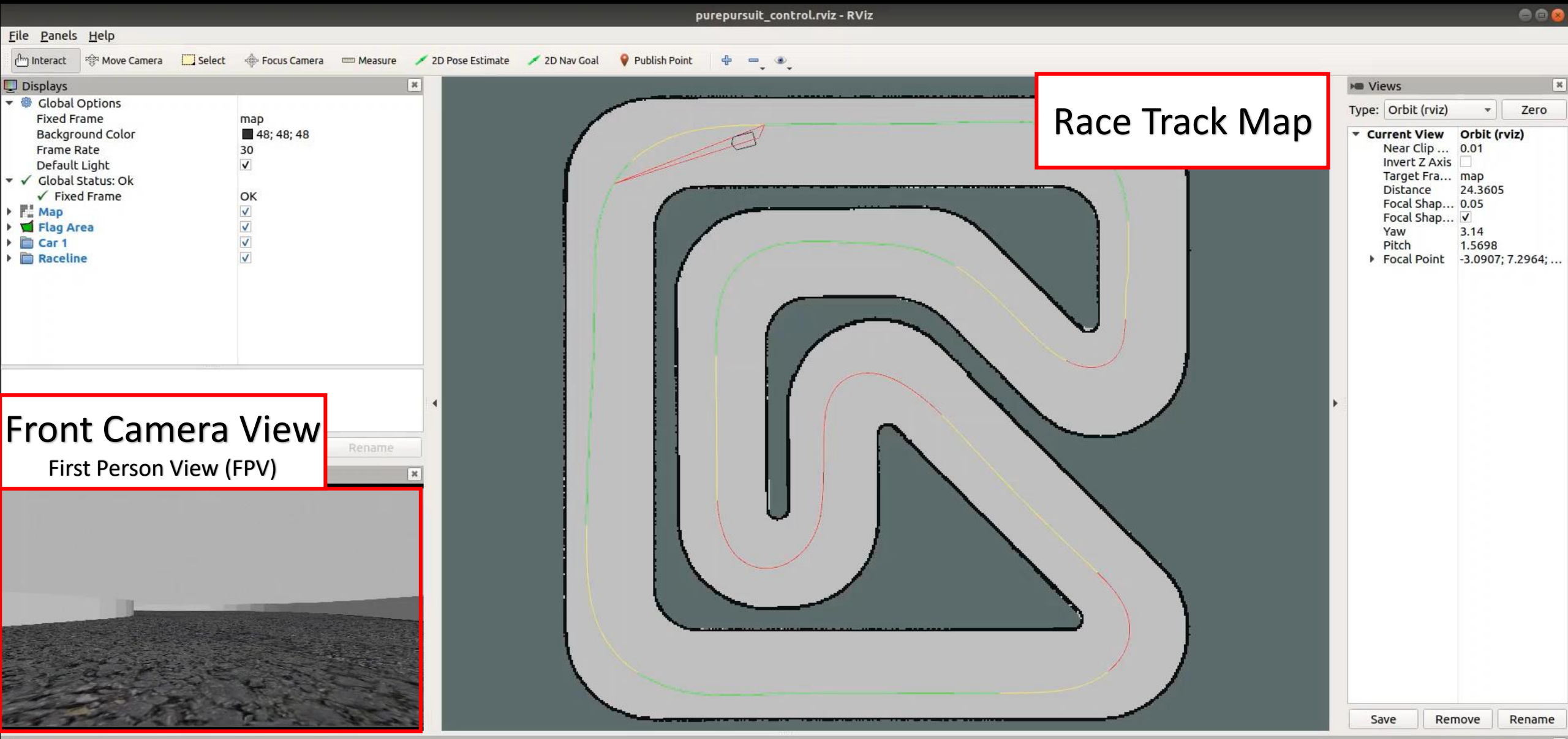


Export as STL/DAE

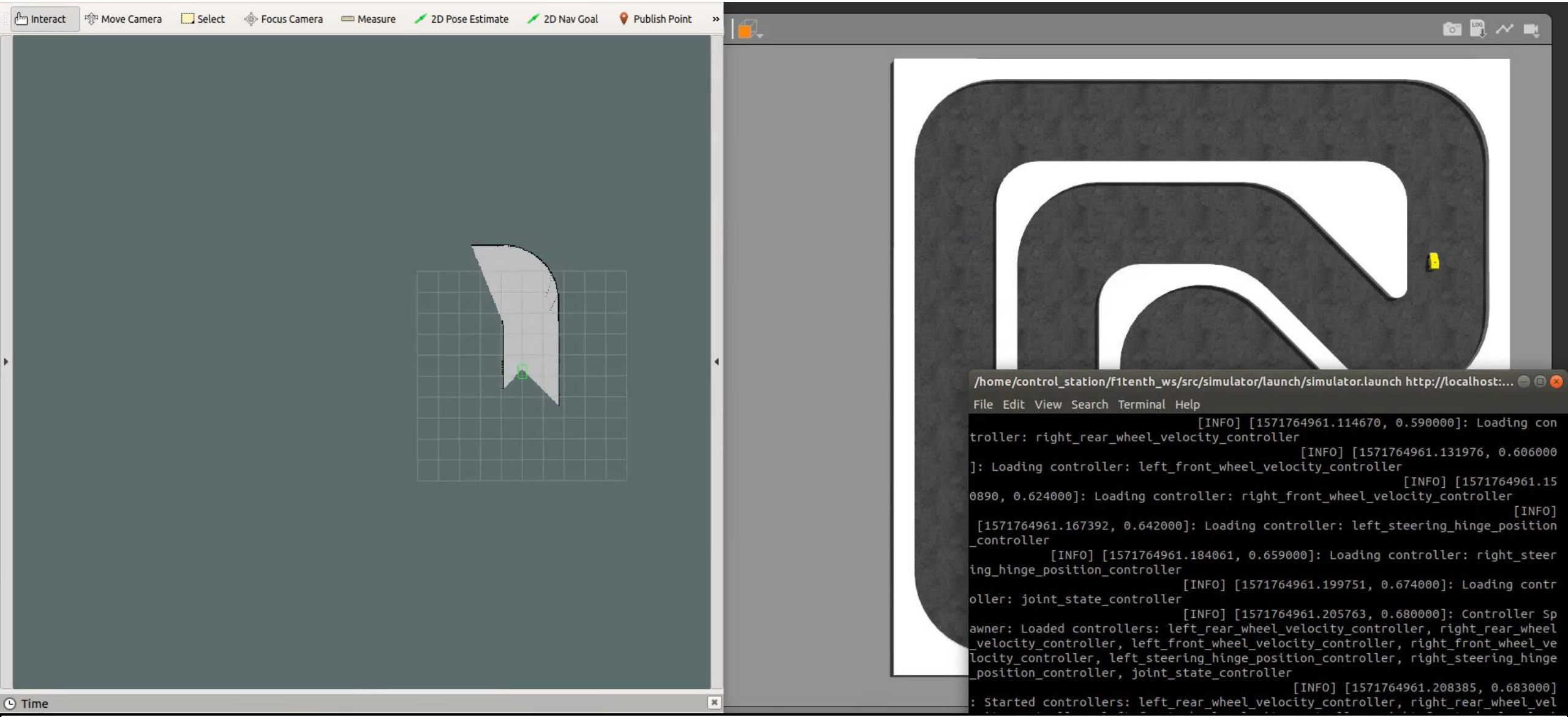
Race-Track Setup (Gazebo View)



Race-Track Setup (*rviz* View)

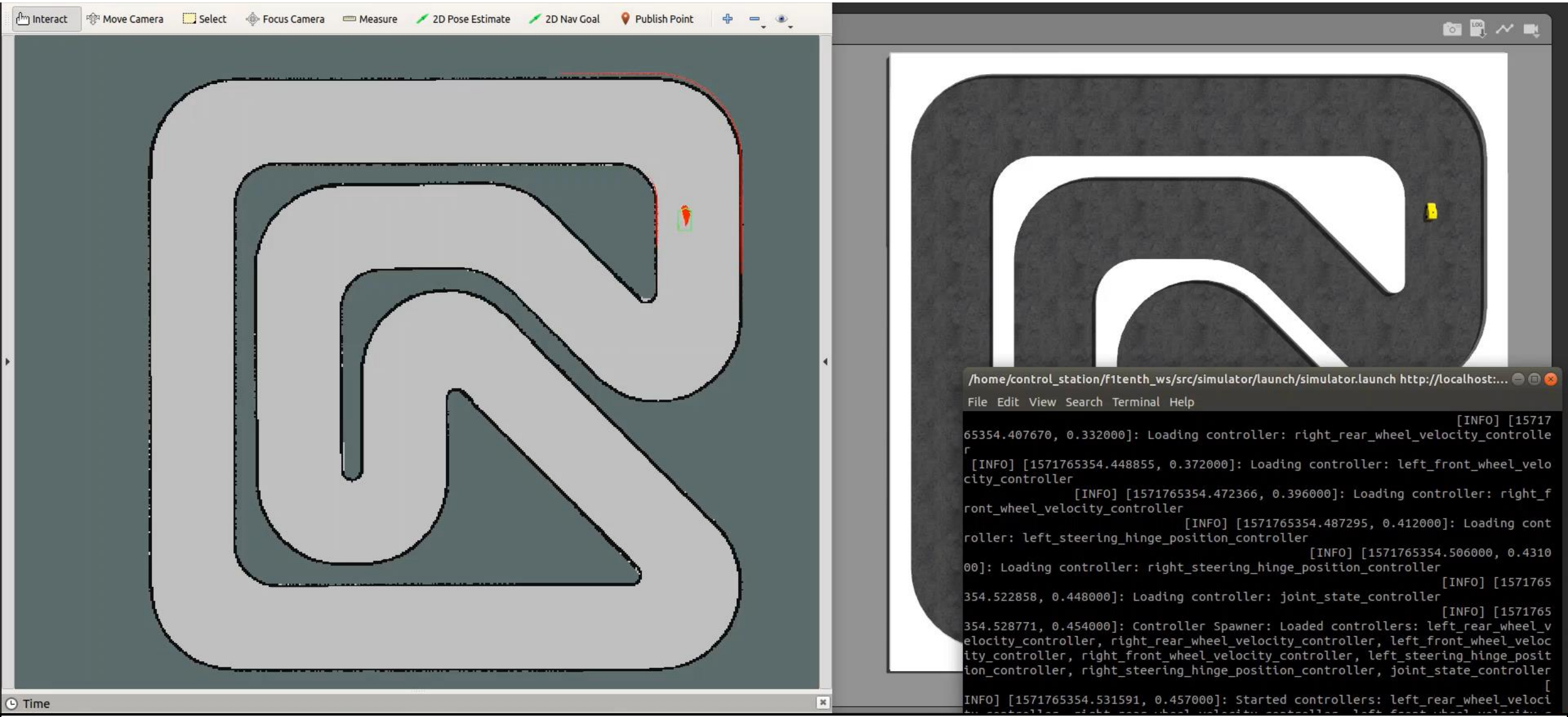


Mapping – Hector SLAM




```
roslaunch f1tenth-sim simulator.launch
roslaunch f1tenth-sim mapping.launch
```

Localization – GPU Particle Filter




```
roslaunch f1tenth-sim simulator.launch
roslaunch f1tenth-sim localization.launch
```

Localization

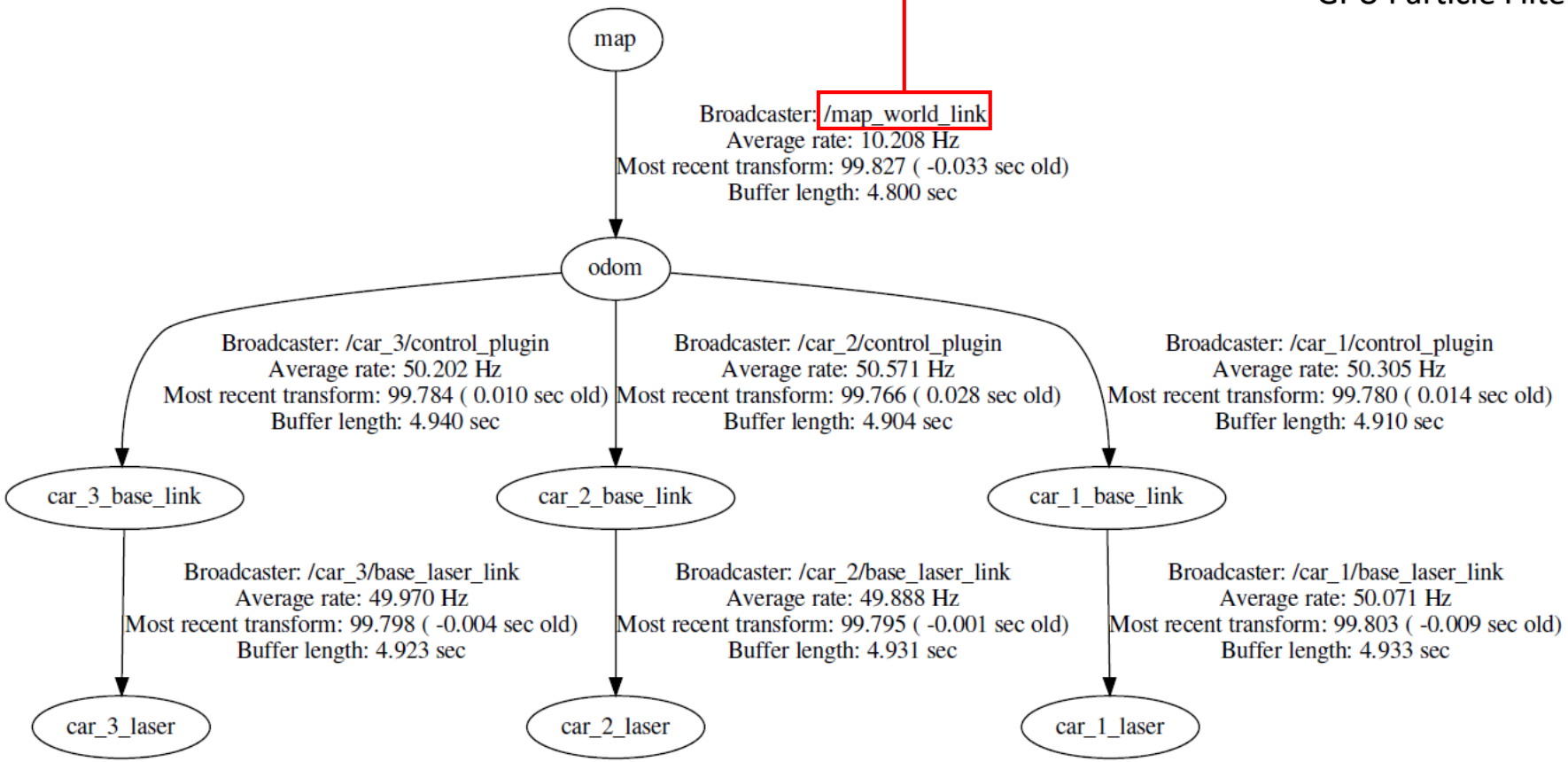
(Implemented for multiple vehicles)

Odometry sources

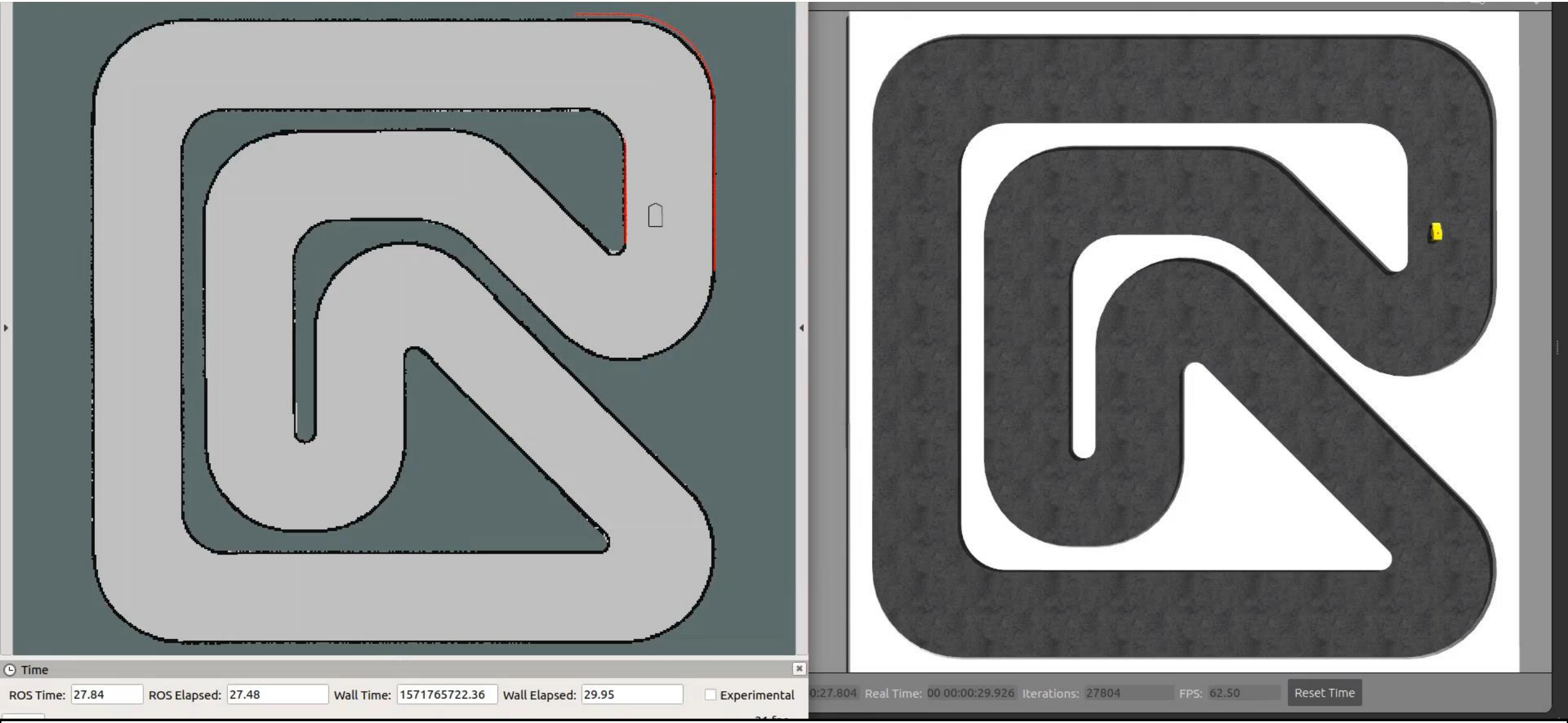
- Gazebo (available, default option)
- Laser Scanmatcher (available, implemented)
- Virtual Wheel Encoders (work in progress)

Provided by

- AMCL (default, implemented)
- GPU Particle Filter (available, tested)

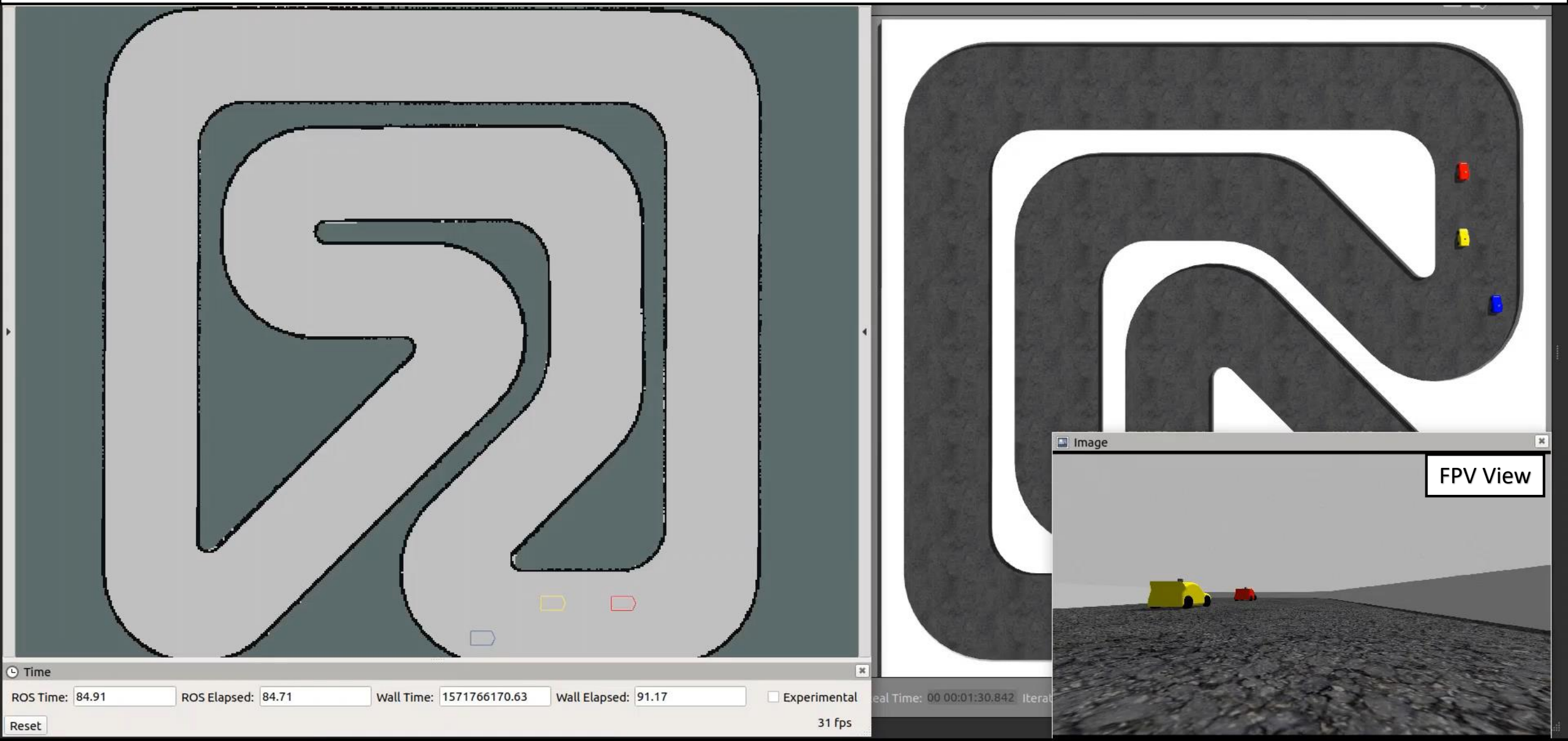


Motion Planning – ROS Navigation with TEB Planner

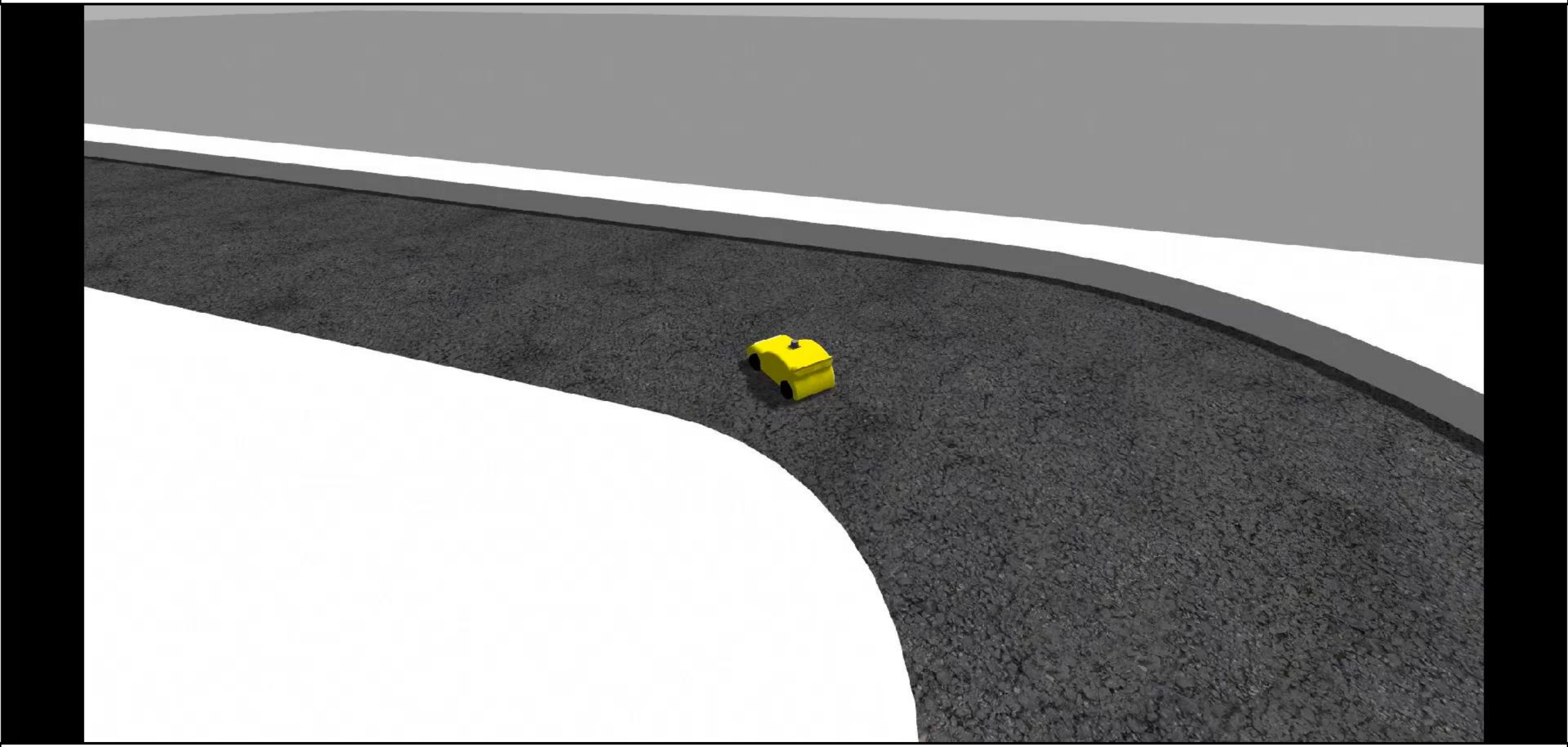



```
roslaunch f1tenth-sim navigation.launch
```

Multiple Independent Navigation

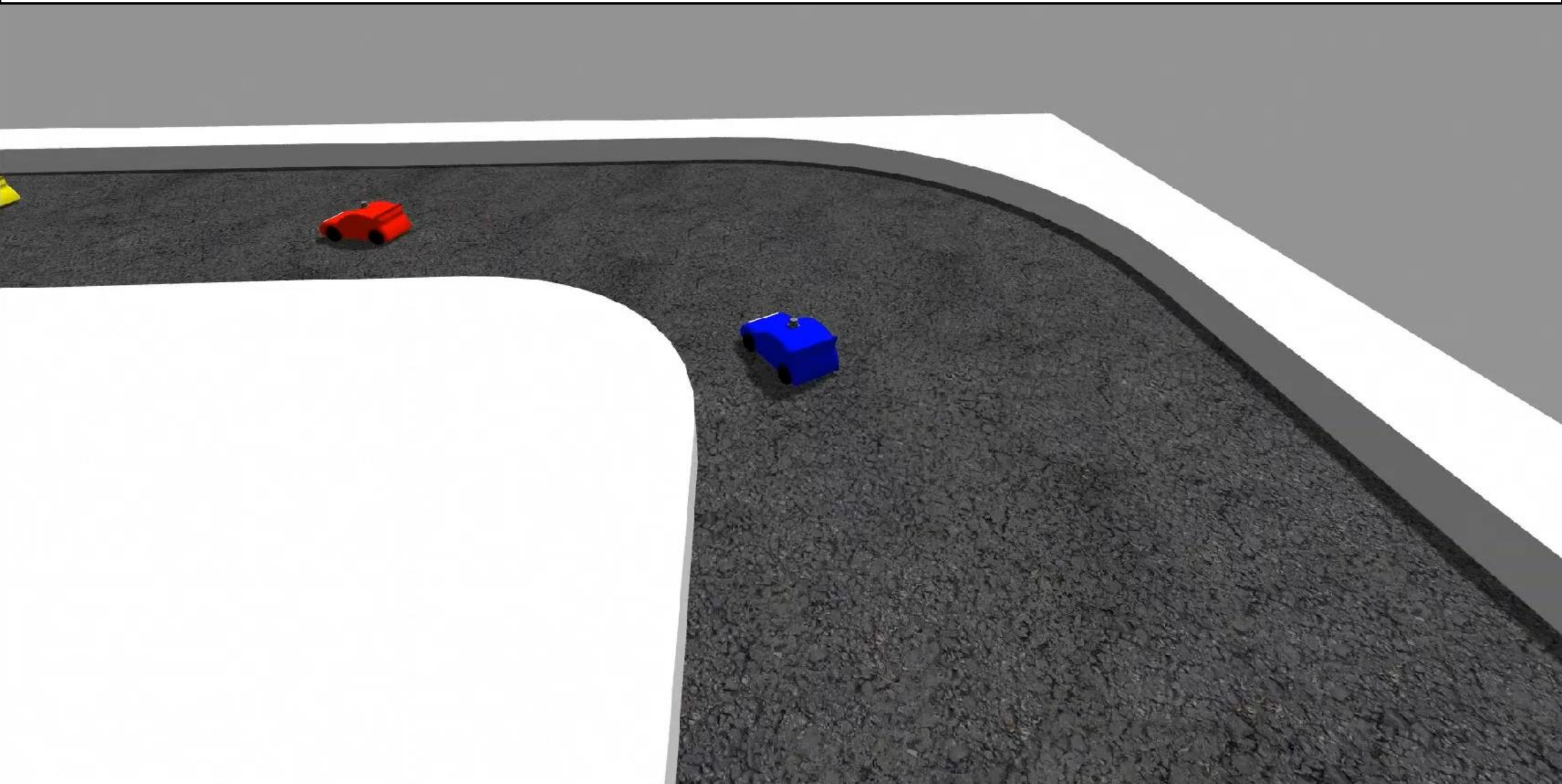


Racing Algorithms (Single Racecar)



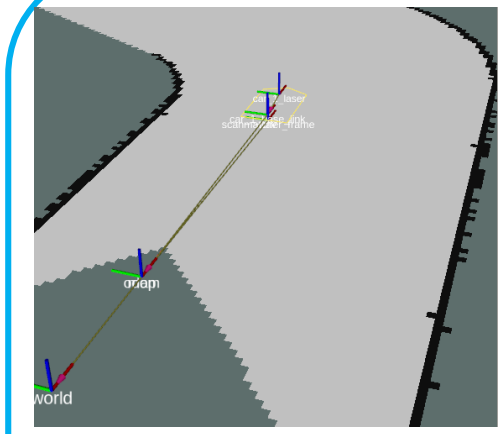
```
roslaunch f1tenth-sim purepursuit_one_car.launch
```

Racing Algorithms (Multiple Racecars)



f1tenth.dev

Algorithms



Mapping
Hector, Cartographer

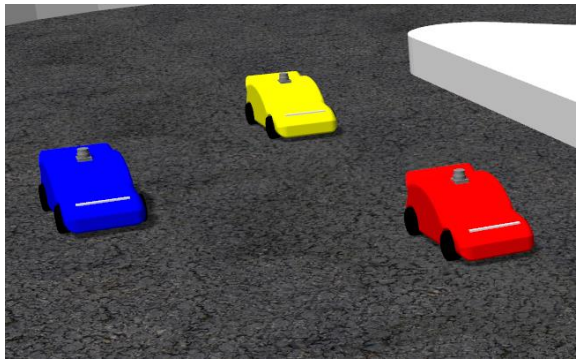
Localization
AMCL, GPU Particle Filter

Motion Planning
ROS Navigation
TEB Planner

Modularity

Sensors
Hokuyo 2D LiDAR
RGBD Camera
Collision Sensor

Control
Ackermann Steering
Traction Control
Realistic dynamics



Open Source

GitHub

docker

aws *

* Planned

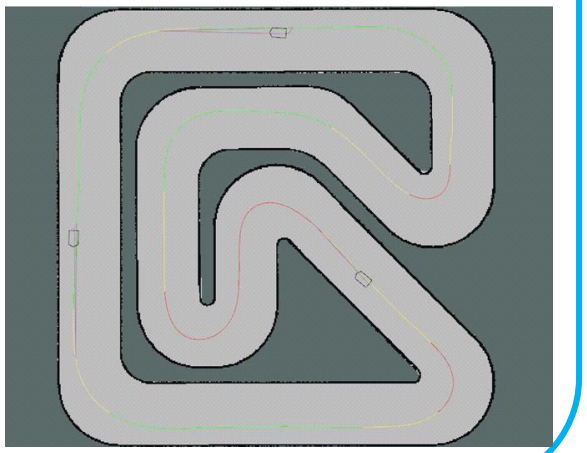
Autonomous Racing Research

Advanced Pure-Pursuit
With Adaptive Lookahead

Autonomous Overtake

Head-to-Head Racing

Dynamic Obstacle Avoidance



Get Started

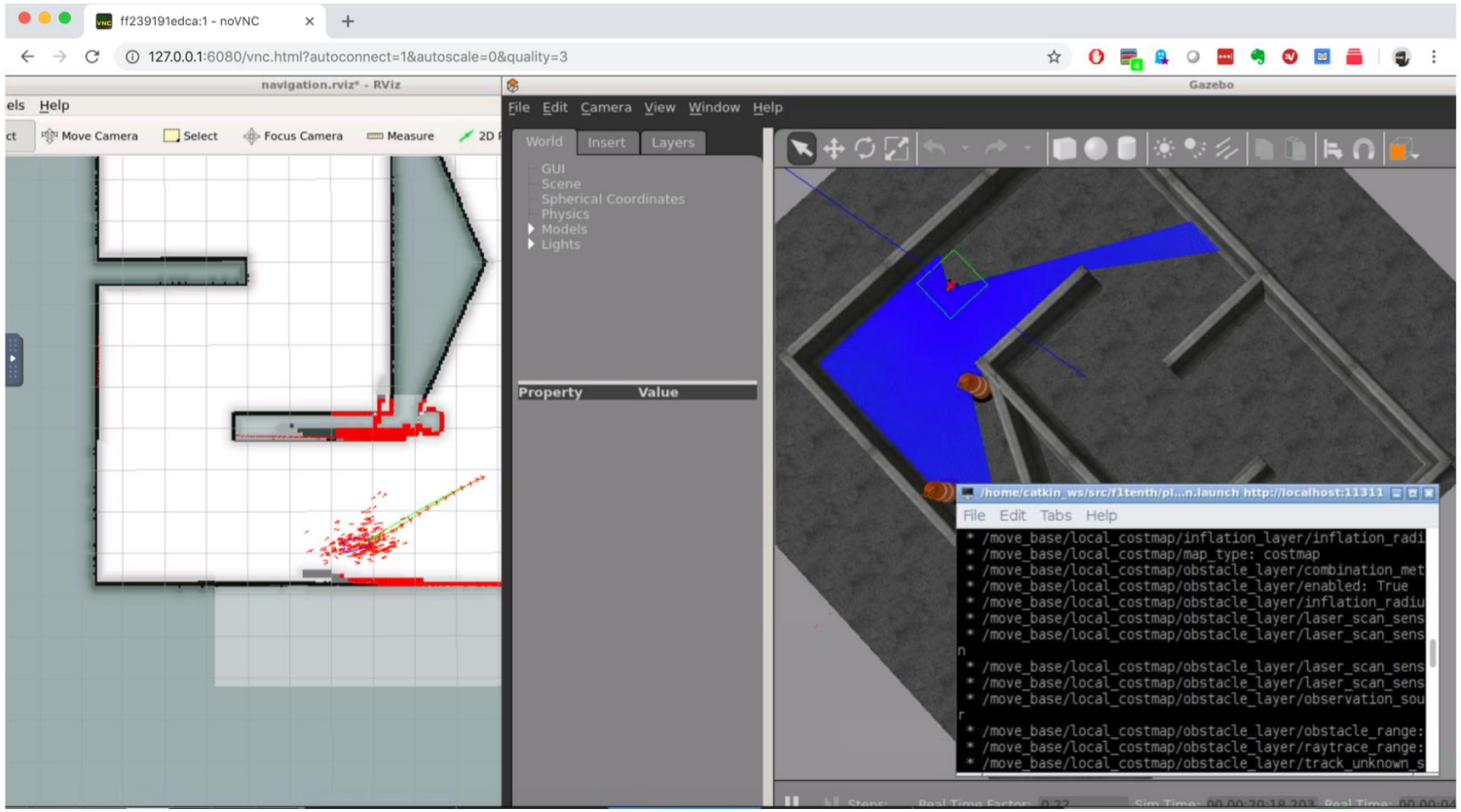
f1tenth.dev

varundev@virginia.edu

F1/10 Autonomous Racing Simulator is now open-source and available!

Step 1) `docker run -it --rm -p 6080:80 madhurbehl/f1tenth`

Step 2) Visit 127.0.0.1:6080 in your favorite browser



Algorithms Supported:

Follow-the-gap planner
Hector-SLAM mapping
Adaptive Monte Carlo Localization
Time-Elastic Band Local Planner

Visit madhurbehl/f1tenth
on DockerHub or click on the icons below

docker

GitHub