Self Driving Car - Learning

Module 1

Week 1

Lessons 1 : Practice Quiz

1. Which of the following are components of **longitudinal control**? (Select all that apply) 1 / 1 point

- [x] Accelerating

  Correct
  Correct, accelerating is a component of longitudinal control.

- [x] Braking

  Correct
  Correct, braking is a component of longitudinal control.

- [ ] Planning
- [ ] Steering

2. Which of the following is **not** an example of OEDR? 1 / 1 point

- ○ Slowing down when seeing a construction zone ahead
- ○ Stopping at a red light
- ◉ Finding a route from your current location to a goal location
- ○ Pulling over upon hearing sirens

  Correct
  Correct, finding routes between locations is a long term planning problem and not OEDR.

3. Which of the following tasks would you expect a **Level 2 system** to perform? (Select all that apply)

1 / 1 point

- [x] Maintain constant speed

Correct
Correct, maintaining speed is part of longitudinal control for the level 2 system.

- [x] Stay within a lane

Correct
Correct, maintaining speed is part of lateral control for the level 2 system.

- [x] Change lanes

Correct
Correct, changing lanes is part of lateral control for the level 2 system.

- [ ] Swerve and slow down to avoid a pedestrian

4. What is the **distinction** between Level 3 autonomy and Level 4 autonomy?

1 / 1 point

- ○ Level 3 systems cannot perform OEDR, Level 4 systems can
- ○ Level 3 systems only have lateral or longitudinal control, Level 4 systems have both
- ○ Level 3 systems cannot drive on highways, Level 4 systems can
- ◉ Level 3 systems require full user alertness, Level 4 systems do not

Correct
Correct, level 3 systems cannot handle emergencies automatically and as a result require full user alertness.

5. What distinguishes Level 5 Autonomy from Level 4?

1 / 1 point

- ○ Level 5 autonomy can operate on any road surface and road type, while Level 4 cannot.
- ○ Level 5 has OEDR capability, while Level 4 does not.
- ◉ Level 4 has a restricted operational design domain, whereas Level 5 is unrestricted.
- ○ Level 5 autonomy can operate on any weather condition, while Level 4 cannot.

Correct
Correct, level 5 systems can operate in any weather condition, on any road type or surface and in any scenario and remain safe.

Lessons 2 : Practice Quiz

1. Which of the following tasks are associated with perception? (Select all that apply) **1 / 1 point**

- [x] Identifying road signs

  Correct
  Correct, perception deals with object identification.

- [x] Estimating the motion of other vehicles

  Correct
  Correct, perception deals with position and motion estimation.

- [ ] Responding to traffic light state changes
- [ ] Planning routes on a map

2. Which of the following can be on road objects? (Select all that apply) **1 / 1 point**

- [x] Potholes

  Correct
  Correct, potholes in the drivable surface are on road objects.

- [x] Vehicles

  Correct
  Correct, vehicles can be on road objects. They can also be off road.

- [ ] Stop signs
- [ ] Sidewalks

3. Which of the following tasks pose challenges to perception? (Select all that apply) **1 / 1 point**

- [x] Detecting, tracking and predicting dynamic object motions

  Correct

- [x] Handling sensor uncertainty

  Correct

- [x] Handling sensor occlusion and reflection

  Correct

- [x] Having sensors work in adverse weather conditions

  Correct

4. Which of the following sensors are used for ego localization? (Select all that apply)

1 / 1 point

- [x] Inertial Measurement Unit (IMU)

Correct
Correct, an IMU provide acceleration and rotation rate measurements from accelerometers and gyroscopes, and can be used to estimate vehicle orientation and aid in localization in general.

- [x] Global Navigation Satellite System (GNSS)

Correct
Correct, a GNSS sensor provides position and velocity measurements, and can be used to estimate vehicle position and orientation for localization.

- [ ] Radar
- [ ] Barometers

5. Which of the following objects would be relevant for perception in adaptive cruise control?

1 / 1 point

- ○ Lane markings
- ◉ Other vehicles
- ○ Road signs
- ○ Traffic lights

Correct
Correct, adaptive cruise control detects vehicles ahead to control speed and to maintain safe driving distances.

Module 1 : Graded Quiz

1. **Scenario 1: You're at home and need to drive to work**

1 / 1 point

During the trip, you will be performing OEDR tasks. Of the tasks below, which of the following is **not** an example of OEDR?

- ○ Slowing down when seeing a construction zone ahead
- ◉ Maintaining a distance to a vehicle ahead
- ○ Stopping at a red light
- ○ Pulling over upon hearing sirens

Correct
Correct! Maintaining distance is not a detection and reaction procedure, it is a normal driving behavior.

2. Which of the following tasks are associated with **perception**?

1 / 1 point

- [x] Estimating the motion of other vehicles

Correct
Correct! Estimating the motion of other vehicles is associated with perception

- [x] Identifying road signs

Correct
Correct! Identifying road signs are associated with perception

- [ ] Responding to traffic lights
- [ ] Planning routes on a map

3. Before leaving, you decide to check the weather. The forecast states that over the next few days there will be both sun and rain along with some fog. Assuming your vehicle exhibits Level 5 autonomy, which of the following **weather conditions** can your vehicle operate?

1 / 1 point

- ○ Clear and sunny
- ○ Windy heavy rainfall
- ○ Heavy Fog
- ○ Light rainfall
- ◉ All of the above

Correct
Correct! Level 5 autonomy can operate in any weather condition.

4. You enter your autonomous vehicle and it drives your usual route to work. While the vehicle is driving, you decide to take a nap. For **which levels of autonomy** is this safe? (Select all that apply)

1 / 1 point

- ☐ 1
- ☐ 2
- ☐ 3
- ☑ 4

Correct
Correct! Only level 4 and 5 autonomy can handle emergencies autonomously.

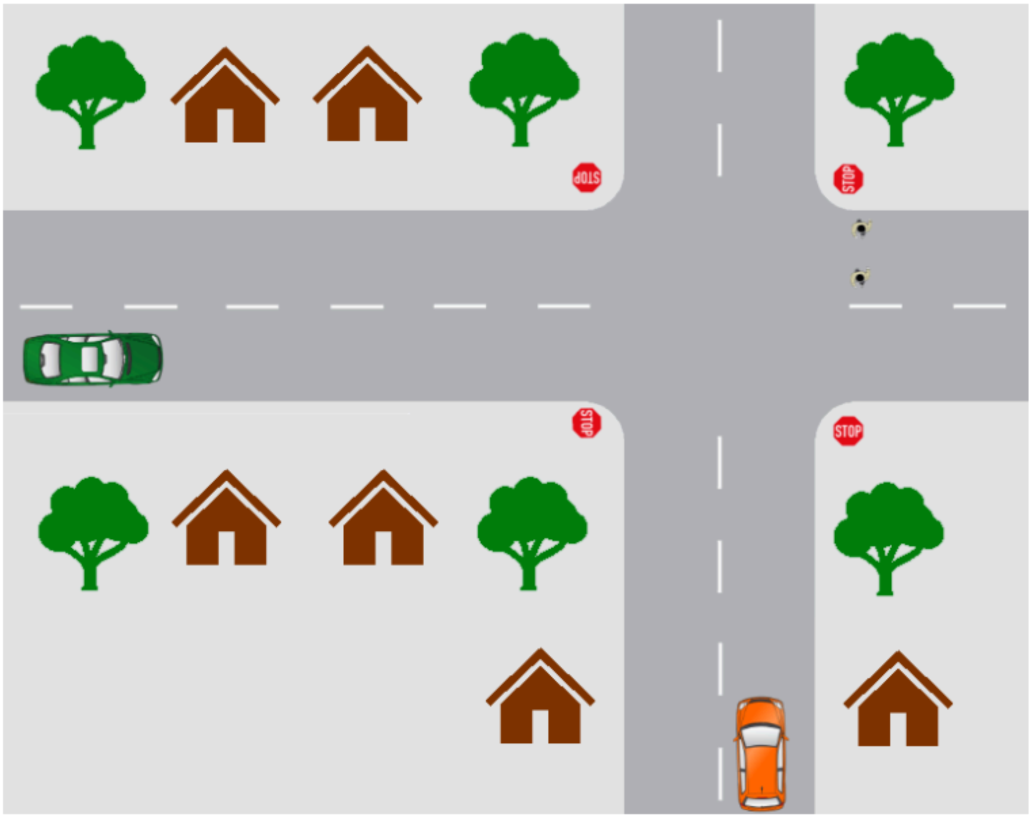
- ☑ 5

Correct
Correct! Only level 4 and 5 autonomy can handle emergencies autonomously.

5. **Scenario 2:** (Assume the car is driving on the right-hand side of the road) .

1 / 1 point

You're approaching an all ways stop sign and you want to make a right turn. Your vehicle is denoted in orange. There are 2 pedestrians currently crossing and another vehicle (denoted in green) approaching the stop sign from the left.



This task involves multiple considerations, which of them are **predictive planning**? Select all that apply.

- [x] The green car arrives at the stop sign after you and plans to travel straight through the intersection. You choose to move first.

Correct
Correct! Predictive planning deals with planning based on predictions of the actions of others.

- [x] Wait for the pedestrians to finish crossing before turning

Correct
Correct! Predictive planning deals with planning based on predictions of the actions of others.

- [ ] Gradually decelerate while reaching the stop sign
- [ ] At a stop sign, stop and look both ways before proceeding

6. Here are some rules for driving at a stop sign. Which of the following is an appropriate **priority ranking**?

1 / 1 point

1) For non all-way stop signs, stop at a point where you can see oncoming traffic without blocking the intersection

2) If there are pedestrians crossing, stop until they have crossed

3) If you reach a stop sign before another vehicle, you should move first if safe

- ○ 1, 2, 3
- ○ 3, 2, 1
- ◉ 2, 1, 3
- ○ 3, 1, 2
- ○ 1, 3, 2

Correct
Correct! Prioritize safety.

7. Which of the following are **off-road objects**? (Select all that apply)

0.6 / 1 point

- ☐ Curbs
- ☑ Trees

Correct
Correct! These are examples of off road objects.

- ☐ Pedestrians
- ☑ Road markings

This should not be selected
Incorrect. Please review off road objects in lecture 2 on Requirements for Perception.

- ☑ Stop signs

Correct
Correct! These are examples of off road objects.

8. Suppose your vehicle has **lane keeping assistance**, which of these objects are relevant for its performance? (Select all that apply)

1 / 1 point

- [ ] Pedestrians
- [ ] Stop signs
- [ ] Trees
- [x] Road markings

Correct
Correct! Detecting road markings and curbs are needed for lane keeping.

- [x] Curbs

Correct
Correct! Detecting road marks and curbs are needed for lane keeping.

9. Which of the following sensors are used for the **lane keeping assistance**? (Select all that apply)

1 / 1 point

- [x] Cameras

Correct
Correct! Detection and localization is needed for lane keeping.

- [ ] Barometers
- [x] GPS

Correct
Correct! Detection and localization is needed for lane keeping.

- [x] LIDAR

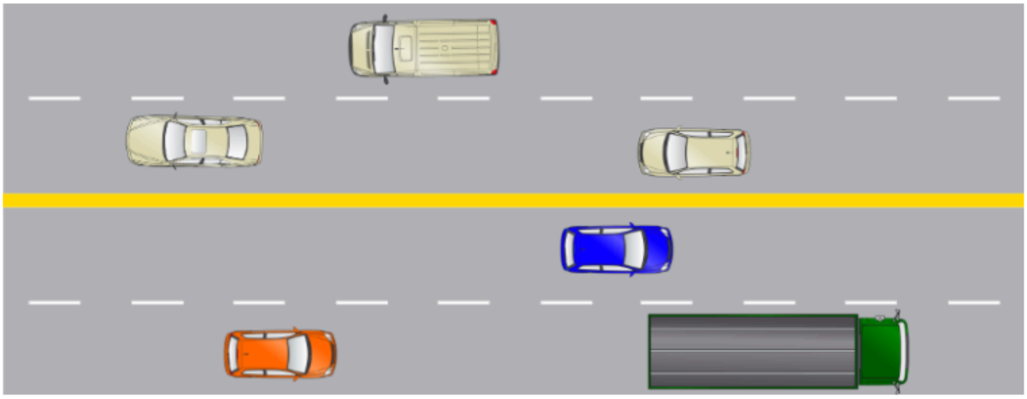
Correct
Correct! Detection and localization is needed for lane keeping.

- [x] IMU

Correct
Correct! Detection and localization is needed for lane keeping.

10. **Scenario 3:** You are on the highway and you see a truck in front of you. Assume the car is driving on the right-hand side of the road. There is also a blue car beside the truck in the other lane.

1 / 1 point



Your vehicle follows the truck and maintains a constant distance away. What kind of **control** is this?

- ○ OEDR
- ○ Lateral
- ◉ Longitudinal
- ○ Fallback

Correct
Correct! Distance keeping is a longitudinal control problem.

11. You decide to **change lanes** to pass a truck. What kind of decision is this?

1 / 1 point

- ◉ Short term planning
- ○ Rule-based planning
- ○ Long term planning
- ○ Immediate
- ○ Reactive

Correct
Correct! Lane changing is a short term task.

12. Which of the following tasks are **rule-based planning**? (Select all that apply)

1 / 1 point

- [ ] If the vehicle in front is going to slow down sharply, then avoid performing a lane change.
- [x] During a lane change, maintain our current speed or accelerate slightly

Correct
Correct! Rule based planning only considers the present state, not what vehicles will do next.

- [x] If there are vehicles directly beside us on the lane, it is unsafe to lane change.

Correct
Correct! Rule based planning only considers the present state, not what vehicles will do next.

13. Suppose the blue vehicle suddenly brakes and you decide to abort the lane change. If your vehicle can **respond automatically and remain in its own lane**, what is the minimum level of autonomy of your vehicle?

1 / 1 point

- ( ) 1
- ( ) 4
- (•) 3
- ( ) 2
- ( ) 5

Correct
Correct! Level 3 autonomy can perform OEDR.

14. The blue vehicle returns to normal speed and you can now safely change lanes. Your car is **performing the lane change**, what kind of control is this?

1 / 1 point

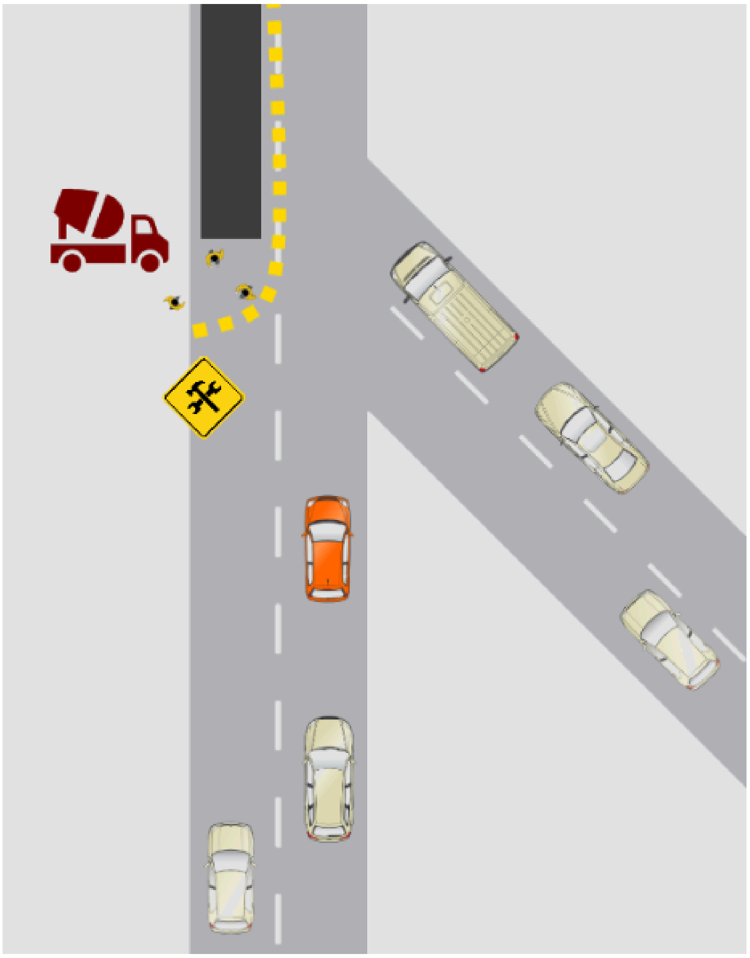
- (•) Lateral
- ( ) Fallback
- ( ) OEDR
- ( ) Longitudinal

Correct
Correct! Lane changing is a lateral control problem.

15. **Scenario 4:** You are almost at work but encounter a construction site.

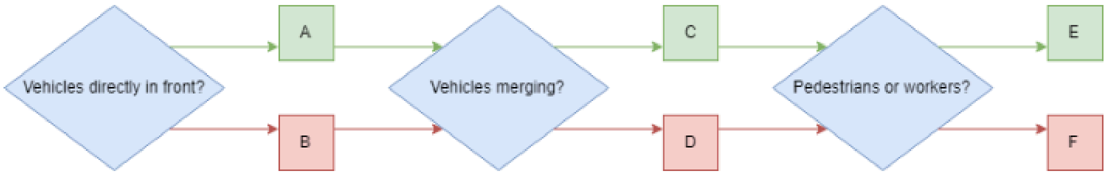
1 / 1 point

Assume the car is driving on the right-hand side of the road. Your vehicle is denoted in orange.



You see a construction site where the workers are repaving a road full of potholes. They are using jackhammers which can cause dust clouds.

You create the following decision tree for getting through the construction site. From the diagram, which of the following decisions should you make? **(green is true, red is false)**



- [ ] A (True)
- [x] B (False)

Correct
Correct!

- [x] C (True)

Correct
Correct!

- [ ] D (False)
- [x] E (True)

Correct
Correct!

- [ ] F (False)

16. Here are a set of rules for making these decisions, **arrange them in an appropriate prioritization**.

1/1 point

1) If there are no vehicles ahead, accelerate to the speed limit

2) Drive slowly in construction zones

3) If there are pedestrians or workers directly ahead in the current lane, stop

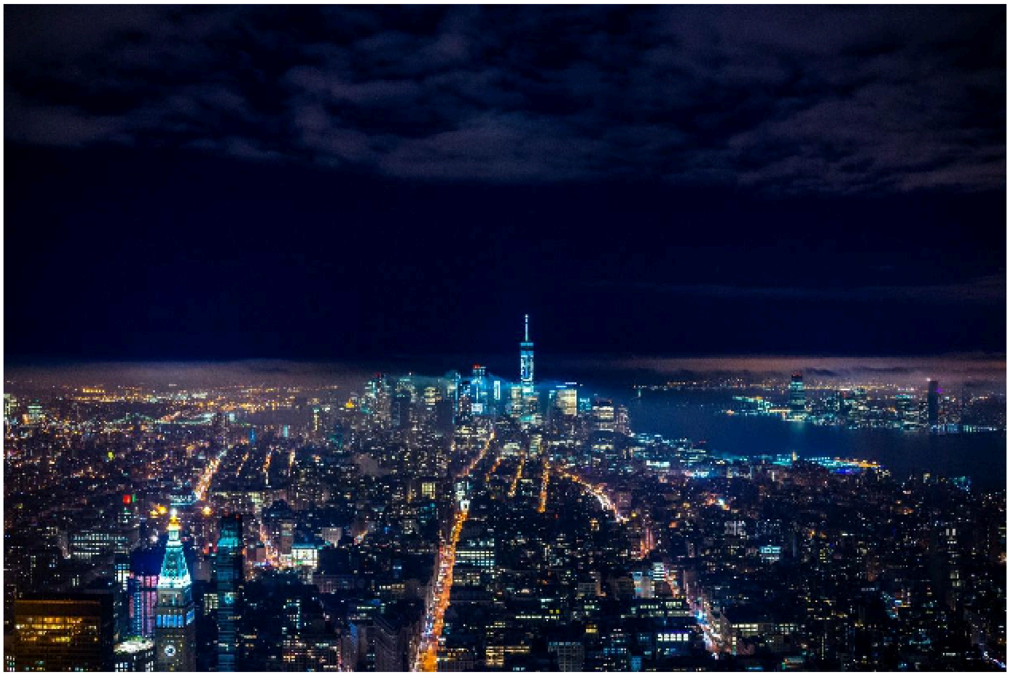
4) Yield to merging vehicles, if necessary

- ○ 1, 2, 3, 4
- ○ 2, 3, 4, 1
- ○ 3, 4, 1, 2
- ◉ 3, 4, 2, 1

Correct
Correct! Prioritize safety in each case, yielding to pedestrians and then vehicles first, before defining acceptable travel speed.

17. **Scenario 5:** You're finished work and need to drive back home, but it's nighttime.

1 / 1 point



You plan a new path home on your GPS application to avoid the construction site, **what type of planning is this**?

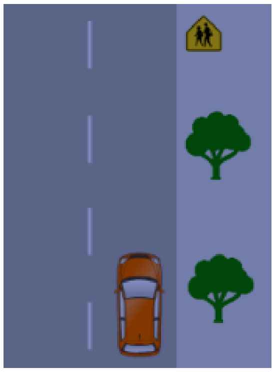
- ○ Reactive
- ◉ Long term planning
- ○ Immediate
- ○ Rule based planning
- ○ Short term planning

Correct

Correct! Setting a path before driving is long term planning.

18. Your new path goes through a school zone and you see the school zone sign. You decide to slow down despite there being no pedestrians or children (it's nighttime). What sort of **planning** is this?

1 / 1 point



- (selected) Rule based planning
- Short term planning
- Immediate planning
- Long term planning
- Reactive planning

Correct

Correct! The rule to slow down in school zones is being followed.

Week 2

Module 2 : Graded Quiz

1. What are the differences between **exteroceptive sensors** and **proprioceptive sensors**? (Select all that apply)

0.6 / 1 point

- [ ] Proprioceptive sensors can determine distance traveled by the vehicle, whereas exteroceptive sensors cannot.
- [x] Exteroceptive sensors can determine obstacle size and distance away, whereas proprioceptive sensors cannot.

Correct
Proprioceptive sensors do not observe nor measure environment surroundings.

- [ ] Exteroceptive sensors can determine distance traveled by the vehicle, whereas proprioceptive sensors cannot.
- [x] Proprioceptive sensors are used to determine vehicle position, whereas exteroceptive sensors are used for sensing the environment.

This should not be selected
Please review types of sensors in lecture 1 on Sensors and Computing Hardware. Hint: exteroceptive sensors can be used for mapping as well.

- [ ] Proprioceptive sensors do not interact with the environment, whereas exteroceptive sensors do.

2. Which of the following exteroceptive sensors would you use in **harsh sunlight**?

1 / 1 point

- [ ] Cameras
- [x] Radar

Correct
Radar is unaffected by harsh sunlight.

- [x] Sonar

Correct
Sonar is unaffected by harsh sunlight.

- [ ] Lidar

3. Why is synchronization and timing accuracy important in the self driving system? **Choose the primary reason.**

1 / 1 point

- ◯ Synchronization is important to ensure that sensors measure the environment at the same time.
- ◯ Synchronization is important to ensure organized computation.
- ◉ Synchronization is important to ensure correct sensor fusion.
- ◯ Synchronization is important to check sensor failure.

Correct
Correct!

4. Your autonomous vehicle is driving on the German autobahn at 150 km/h and you wish to maintain safe following distances with other vehicles. Assuming a safe following distance of 2s, **what is the distance (in m) required between vehicles**? Round your answer to **2 decimal places**.

1 / 1 point

83.33

Correct
150*2/3.6

5. Using the same speed of 150 km/h, **what is the braking distance (in m) required for emergency stops**? Assume an aggressive deceleration of 5 m/s^2. Round your answer to **2 decimal places**.

1 / 1 point

173.64

Correct
(150/3.6)^2/(2*5)

6. Suppose your vehicle was using long range cameras for sensing forward distance, but it is now nighttime and the images captured are too dark. **Which of the following sensors can be used to compensate**?

1 / 1 point

- [ ] IMU
- [x] Radar

Correct
Radar can be configured for long range detection and can also operate in darkness.

- [x] Lidar

Correct
Lidar can be configured for long range detection and can also operate in darkness.

- [ ] Sonar

7. What are the differences between an **occupancy grid** and a **localization map**? (Select all that apply)

1 / 1 point

- [x] An occupancy grid uses a dense representation of the environment, whereas a localization map does not need to be dense.

Correct
Since localization mapping is only concerned with identifying the vehicle pose in the environment, it can use point features or object locations and does not need to densely cover the entire environment, whereas occupancy grid mapping must capture the locations of all obstacles to be avoided and must therefore be dense.

- [x] The localization map is primarily used to estimate the vehicle position, whereas the occupancy grid is primarily used to plan collision free paths.

Correct
Correct. The vehicle position is a critical measurement to estimate how the ego vehicle is moving through the environment, and relies on matching sensor measurements at the current time to the localization map. The occupancy grid map stores live collision avoidance data in the form of occupied and unoccupied cells around the vehicle.

- [ ] The localization map uses only lidar data, whereas the occupancy grid can use both lidar and camera data.
- [ ] The occupancy grid only contains static objects, while the localization map contains only dynamic objects.

8. The vehicle steps through the software architecture and arrives at the controller stage. What information is required for the **controller** to output its commands to the vehicle?

1 / 1 point

- [x] Planned paths

Correct
The controller commands the vehicle to follow the planned paths.

- [x] Vehicle state

Correct
The controller requires the vehicle position and velocity to determine the appropriate amount of steering, throttle, and brake.

- [ ] Environment maps
- [ ] Locations of obstacles and other vehicles

9. What is (are) the role(s) of the **system supervisor**? (Select all that apply)

1 / 1 point

- [x] To ensure that the sensors are working correctly

Correct
The system supervisor is responsible for monitoring hardware and ensuring that the sensors are not broken.

- [ ] To ensure that the planned paths are collision free
- [x] To ensure that the maps update at the correct frequencies

Correct
The system software is responsible for monitoring software and ensuring operation at correct frequencies.

- [ ] To ensure that the controller outputs are within operating range

10. Which of the following tasks should be assigned to the **local planner**?

1 / 1 point

- ( ) Planning a lane change to turn left
- (•) Planning to avoid a parked car in the ego vehicle's lane
- ( ) Planning a merge onto the highway
- ( ) Planning a route to a destination

Correct
This is a reactive planning task, so it should be designated to the local planner.

11. What common objects in the environment appear in the **occupancy grid**?

1 / 1 point

- (•) Parked vehicles
- ( ) Traffic lights
- ( ) Other moving vehicles
- ( ) Lane boundaries

Correct
The occupancy grid contains static obstacles which block vehicle movement.

12. Which of the following maps contain **roadway speed limits**?

1 / 1 point

- ( ) Occupancy grid
- ( ) Localization map
- (•) Detailed roadmap

Correct

The detailed roadmap contains traffic regulations.

Week 3

Module 3 : Graded Quiz

1. Which from the below options is the most **ACCURATE** and **COMPLETE** definition of **risk** in terms of self-driving vehicles?

1 / 1 point

- ○ Risk is any exposure to possible loss or injury
- ○ Risk is a probability or threat of damage, injury, liability, loss, or any other negative occurrence that is caused by external or internal factors
- ◉ Risk is a probability that an event occurs combined with the severity of the harm that the event can cause
- ○ Risk is a condition in which there is a possibility of an adverse deviation from the desired or expected outcome
- ○ None of the above

Correct
Correct! Any autonomous driving team should focus on the most likely and the most severe events first.

2. Which of the following are **major components** of an autonomous driving system? (Select all that apply)

1 / 1 point

- [ ] Adaptation
- [ ] Configuration
- [x] Planning

Correct
Correct! This aspect of the autonomous driving system is extremely important. A mistake in this component can lead to failures and crashes.

- [x] Control

Correct
Correct! This aspect of the autonomous driving system is extremely important. A mistake in this component can lead to failures and crashes.

- [x] Perception

Correct
Correct! This aspect of the autonomous driving system is extremely important. A mistake in this component can lead to failures and crashes.

3. What are the most common categories of autonomous vehicle **hazard sources**? (Select all that apply)

0.8 / 1 point

- [x] Malicious software

Correct
Correct! This is a major hazard source.

- [x] Perception and planning

Correct
Correct! This is a major hazard source.

- [ ] Driver fallback
- [x] Hardware and software

Correct
Correct! This is a major hazard source.

- [x] Electrical and mechanical

Correct
Correct! This is a major hazard source.

4. Is the following statement TRUE or FALSE?

1 / 1 point

The safety framework to structure safety assessment for autonomous driving defined by NHTSA is **MANDATORY** to follow.

- ○ TRUE
- ◉ FALSE

Correct
Correct! NHTSA safety framework was released as a suggestion, and it is not mandatory to follow. The main objective of the NHTSA is to guide companies building self-driving cars without overly restricting innovation or pre-selecting technologies.

5. Which categories are included in the **safety framework** to structure safety assessment for autonomous driving defined by NHTSA? (Select all that apply)

1 / 1 point

- [x] Testing and crash mitigation

Correct
Correct! This is what any autonomous driving company should focus on according to NHTSA.

- [x] Autonomy design

Correct
Correct! This is what any autonomous driving company should focus on according to NHTSA.

- [x] Well-organized software development process

Correct
Correct! This is what any autonomous driving company should focus on according to NHTSA.

- [ ] Digital vehicle model design

6. Which actions are needed to be performed **in the event of an accident** by an autonomous vehicle? (Select all that apply)

1 / 1 point

- [x] Alerting first responders

Correct
Correct! An autonomous vehicle should quickly alert first responders in the event of an accident.

- [x] Returning car to a safe state

Correct
Correct! An autonomous vehicle's post crash behavior should include returning the car to a safe state, for example, stopping.

- [ ] Locking all doors
- [x] Securing fuel pumps

Correct
Correct! Securing fuel pumps in the event of a crash is critical for preventing further potentially dangerous situations.

- [x] Data recording to a black box

Correct
Correct! An autonomous vehicle needs to have an automated data recording function or black box recorder. It is very helpful to have this crash data to analyze and design systems that can avoid this specific kind of crash in the future.

7. What are the **most common** accident scenarios? (Select all that apply)

0.8333333333333334 / 1 point

- [ ] Rollover
- [x] Rear-end

Correct
Correct! All the correct accident scenarios from this question account for over 84% of all crashes.

- [ ] Road departure
- [x] Intersection

Correct
Correct! All the correct accident scenarios from this question account for over 84% of all crashes.

- [x] Lane change

Correct
Correct! All the correct accident scenarios from this question account for over 84% of all crashes.

- [ ] Crosswalk

You didn't select all the correct answers

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8. What kind of **safety system** is described by the following definition? This system can be analyzed to define quantifiable safety performance based on critical assessment of various scenarios.

1 / 1 point

- ( ) Data driven safety
- ( ) Test driven safety
- (•) Analytical safety
- ( ) None of the above

Correct
Correct! Analytical safety can provide strong guidance on which aspects of a system are the biggest contributors to overall safety.

9. According to the report by Rand Corporation, autonomous driving of 8.8 billion miles is required to demonstrate human-level fatality rate of an autonomous vehicle fleet using a 95% Confidence Interval. **How many years** is required to perform this testing with a fleet of 100 vehicles running 24 hours a day, 7 days a week at an average of 25 miles per hour? Your answer should be an integer.

1 / 1 point

402

Correct

Correct!

8,800,000,000 miles / 100 vehicles = 88,000,000 miles per vehicle

88,000,000 miles / 25 miles per hr = 3,520,000 hrs per vehicle

24 hours * 365 days = 8,760 hrs in a year

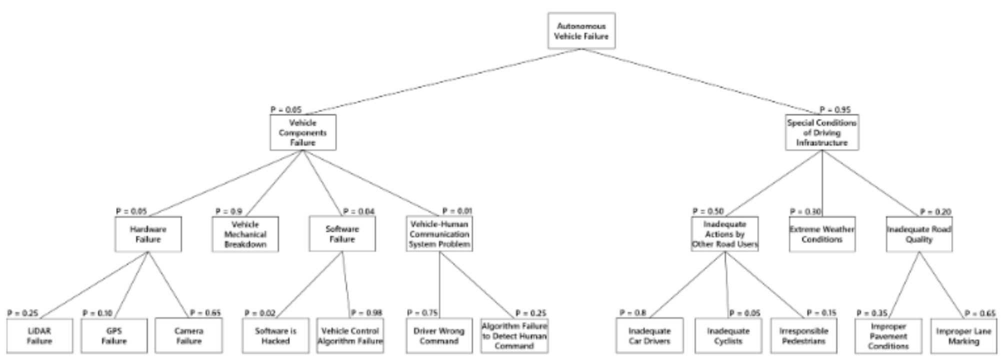
3,520,000 hrs / 8,760 hrs in a year = 401.8 years

It would take at least 400 years to validate the required level of safety with a fleet of 100 vehicles traveling 24x7. That's why testing is being done today on thousands of vehicles simultaneously.

10. Given that an autonomous vehicle failure has happened and based on this tree, **what is the probability** that the failure happened because of Vehicle Control Algorithm Failure OR Inadequate Car Drivers? Please give your answer with the precision of 3 decimal places.

1 / 1 point

Please use this probabilistic fault tree for your computation:



0.382

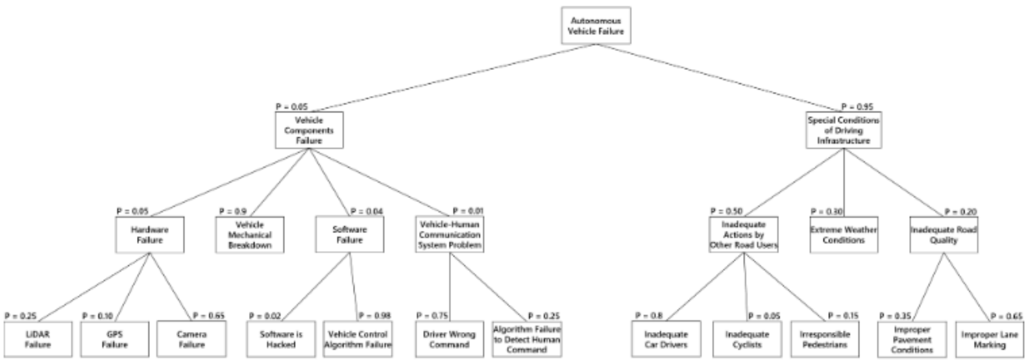
Correct

Correct! The operations used to propagate the probabilities on probabilistic fault trees upwards are the same as the rules of probability when events follow set theory. So, the OR probabilities would be the sum of children node probabilities, assuming independence of the events.

11. Given that the autonomous vehicle failure has happened, and based on this tree**, what is the probability** that the failure happened because of Software Failure AND Extreme Weather Conditions at the same time? Please give your answer with the precision of 3 decimal places.

1 / 1 point

Please use the probabilistic fault tree from the previous question for your computation:



0.001

Correct

Correct! The operations used to propagate the probabilities on probabilistic fault trees upwards are the same as the rules of probability when events follow set theory. So, the AND probabilities would be the product of children node probabilities, assuming independence of the events

12. A computer vision algorithm is responsible for extracting meaningful data from the onboard camera. A computer vision failure restricts the vehicle's ability to navigate the environment around it, hence a problem with this system is a serious failure. However, LiDAR and radar sense similar environment data, so a computer vision failure does not leave the vehicle completely blind. A Computer vision algorithm failure can be considered a somewhat severe failure as it decreases vehicle sensing ability and it gets a severity score of 5. This could happen regularly in low light situations, hence the occurrence number is assigned 4. Computer vision algorithm failure is fairly detectable in majority of the situations, so the detectability score is 3.

1 / 1 point

What is the risk priority number for a Computer vision algorithm failure according to FMEA and based on the description above? Your answer should be an integer.

60

Correct

Correct! The risk priority number is a product of the severity, frequency and detectability of an event. Each feature of the risk priority number is assessed on the scale from 1 to 10, where 10 is being the most severe, the most frequent and the most difficult to detect.

13. There are failures listed below. Which failures should we focus on **solving first** according to FMEA?

1 / 1 point

- ○ Vehicle motion prediction failure (risk priority score of 150)
- ○ Computer vision algorithm failure (risk priority score of 60)
- ○ GPS synchronization failure (risk priority score of 300)
- ◉ Vehicle driving onto a gravel road (risk priority score of 400)

Correct
Correct! The higher the risk priority score is, the higher priority of this failure is.

14. Which of the following options is the most **ACCURATE** and **COMPLETE** definition of **functional safety** in terms of self-driving vehicles?

1 / 1 point

- ○ Functional safety is the process of avoiding unreasonable risk of harm to a living thing.
- ◉ Functional safety is the detection of a potentially dangerous condition resulting in the activation of a protective or corrective device or mechanism to prevent hazardous events arising or providing mitigation to reduce the consequence of the hazardous event
- ○ Functional safety is a deterministic algorithm outlining the procedures that are carried out to prevent hazardous events from happening or minimizing the harm caused by hazardous events to the vehicle passengers and third parties involved in the situation
- ○ Functional safety is a part of the vehicle operation management aimed to minimizing hazards, risks, accidents and near misses
- ○ None of the above

Correct
Correct!

15. Which of the following standards defines **functional safety terms** and **activities for electrical and electronic systems** within motor vehicles?

1 / 1 point

- ○ ISO/TC 204
- ○ ISO 39001
- ○ ISO/PAS 21448
- ◉ ISO 26262
- ○ None of the above

Correct
Correct! The ISO 26262 standard defines functional safety terms and activities for electrical and electronic systems within motor vehicles, and as such addresses the hardware and software hazards that can affect autonomous vehicle safety.

Week 4

All assignments are in this github repository: https://github.com/adeirman46/Self-Driving-Car

Module 4 Programming Exercise: Kinematic Bicycle Model

```
class Bicycle(Bicycle):
    def step(self, v, w):
        # ==================================
        #  Implement kinematic model here
        # ==================================
        xc_dot = v * np.cos(self.theta + self.beta)

        yc_dot = v * np.sin(self.theta + self.beta)

        theta_dot = (v * np.cos(self.beta) * np.tan(self.delta))/self.L

        if w > self.w_max:
            delta_dot = self.w_max
        else:
            delta_dot = w

        self.beta = np.arctan((self.lr * np.tan(self.delta))/self.L)

        self.xc = xc_dot * self.sample_time + self.xc
        self.yc = yc_dot * self.sample_time + self.yc
        self.theta = theta_dot * self.sample_time + self.theta
        self.delta = delta_dot * self.sample_time + self.delta

        pass
```

```
sample_time = 0.01
time_end = 30
model.reset()

t_data = np.arange(0,time_end,sample_time)
x_data = np.zeros_like(t_data)
y_data = np.zeros_like(t_data)
v_data = np.zeros_like(t_data)
w_data = np.zeros_like(t_data)

R = 8
delta = np.arctan(2/8) * 0.995
v_data[:] = 2 * np.pi * R * 2 / 30

for i in range(t_data.shape[0]):
    x_data[i] = model.xc
    y_data[i] = model.yc
```

```
    if i <= t_data.shape[0]/8:
        if model.delta < delta:
            model.step(v_data[i], model.w_max)
            w_data[i] = model.w_max
        else:
            model.step(v_data[i], 0)

    elif i <= 5.08*t_data.shape[0]/8:
        if model.delta > -delta:
            model.step(v_data[i], -model.w_max)
            w_data[i] = -model.w_max
        else:
            model.step(v_data[i], 0)
    else:
        if model.delta < delta:
            model.step(v_data[i], model.w_max)
            w_data[i] = model.w_max
        else:
            model.step(v_data[i], 0)

plt.axis('equal')
plt.plot(x_data, y_data)
plt.show()
```

Module 4 Programming Exercise: Longitudinal Vehicle Model

```
class Vehicle(Vehicle):
    def step(self, throttle, alpha):

        # Engine torque
        Te = throttle * (self.a_0 + self.a_1 * self.w_e + self.a_2 * self.w_e**2)

        # F load
        Faero = self.c_a * self.v**2
        Fg = self.m * self.g * np.sin(alpha)
        Rx = self.c_r1 * self.v
        Fload = Faero + Fg + Rx

        # Wheel angular speed
        w_w = self.GR * self.w_e
        s = ((w_w * self.r_e) - self.v)/self.v
        if abs(s) < 1:
            Fx = self.c * s
        else:
            Fx = self.F_max

        # w_e dot
        self.w_e_dot = (Te - self.GR*self.r_e*Fload)/self.J_e

        # acceleration
```

```
        self.a = (Fx - Fload)/self.m

        # get pos and vel
        self.v += self.a * self.sample_time
        self.x += self.v * self.sample_time - 1/2*self.a*self.sample_time**2

        # get w_e
        self.w_e += self.w_e_dot * self.sample_time

        pass
```

```
time_end = 20
t_data = np.arange(0,time_end,sample_time)
x_data = np.zeros_like(t_data)

# reset the states
model.reset()

# incline angle (in radians)
alpha_1 = np.arctan(3/60)
alpha_2 = np.arctan(9/90)

for i in range(t_data.shape[0]):
    if i <= t_data.shape[0]/4:
        v_data[i] = model.v
        model.step(0.2 + 0.3/5*t_data[i], alpha_1)
        x_data[i] = model.x
    elif i <= t_data.shape[0]*3/4:
        v_data[i] = model.v
        model.step(0.5, alpha_2)
        x_data[i] = model.x
    else:
        v_data[i] = model.v
        model.step(2 - 0.1*t_data[i], 0)
        x_data[i] = model.x

# Plot x vs t for visualization
plt.plot(t_data, x_data)
plt.show()
```

Week 5

Module 5 : Graded Quiz

1. What is the **order** of the following transfer function?

1 / 1 point

$$G(s) = \frac{s-10}{s^2+2s+1}$$

- ○ This is the first order transfer function
- ◉ This is the second order transfer function
- ○ This is the third order transfer function
- ○ This is the fifth order transfer function
- ○ None of the above

Correct
Correct! This transfer function contains a first order numerator and a second order denominator. The order of the function is the highest exponent in the transfer function, so that this is the second order transfer function.

2. What are the **poles and zeros** of the following transfer function?

1 / 1 point

$$G(s) = \frac{s^2+3s-10}{s^2-s-12}$$

- ◉ The poles are -3 and 4; the zeros are 2 and -5
- ○ The poles are -4 and 3; the zeros are 5 and -2
- ○ The poles are 2 and -5; the zeros are -3 and 4
- ○ The poles are 5 and -2; the zeros are -4 and 3
- ○ None of the above

Correct
Correct! The zeros of a system are the roots of the numerator, and the poles of a system are the roots of its denominator.

3. What might be your action as a system control engineer if you need to **increase the overshoot** of a control loop system? (Select all that apply)

1 / 1 point

- [ ] Decrease K_P
- [x] Decrease K_D

Correct
Correct! Decreasing derivative gain leads to an increase of overshoot.

- [x] Increase K_I

Correct
Correct! Increasing integral gain leads to an increase of the overshoot.

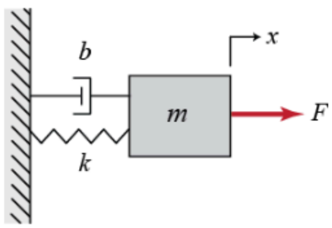
- [ ] Decrease K_I
- [x] Increase K_P

Correct
Correct! Increasing proportional gain leads to an increase of the overshoot.

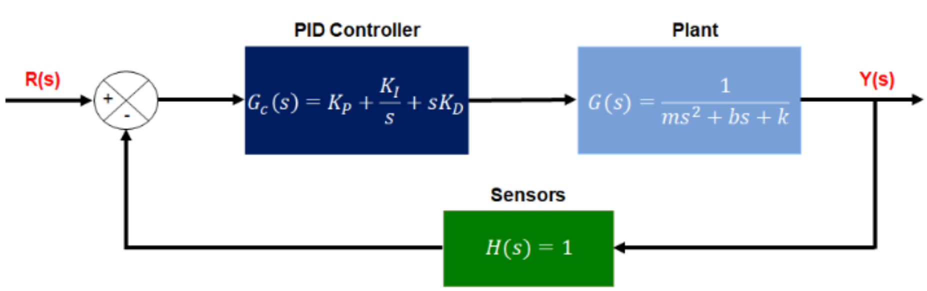
- [ ] Increase K_D

4. Recall the Mass-Spring-Damper System example form the video on PID Control. This system is shown in the figure below.

1 / 1 point



As a system control engineer, you constructed the following closed loop transfer function to represent the Mass-Spring-Damper System. What is the **correct transfer function** for this closed loop?



- [ ] Transformation function 1

$$G(s) = \frac{K_D s^2 + sK_P + K_I}{K_P + \frac{K_I}{s} + K_D s}$$

- [ ] Transformation function 2

$$G(s) = \frac{K_P + \frac{K_I}{s} + K_D s}{K_D s^2 + sK_P + K_I}$$

- [ ] Transformation function 3

$$G(s) = \frac{ms^2 + bs + k + K_P + \frac{K_I}{s} + K_D s}{K_P + \frac{K_I}{s} + K_D s}$$

- [x] Transformation function 4

$$G(s) = \frac{K_D s^2 + sK_P + K_I}{ms^3 + (b + K_D)s^2 + (k + K_P)s + K_I}$$

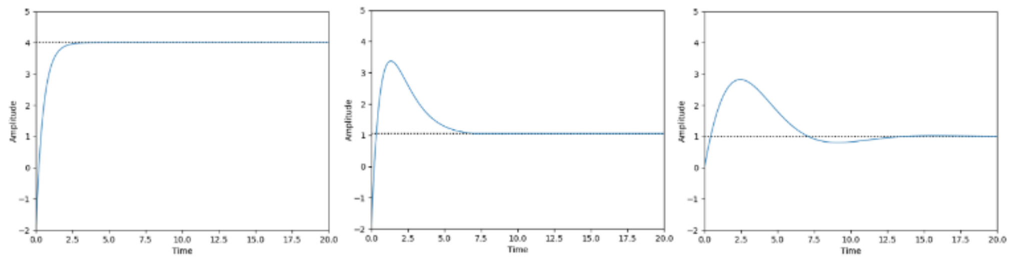
- [ ] None of the above

Correct

Correct!

5. You are given the step response of a few different PID controllers using the same gains for the same first order transfer function. **Determine a possible set of controllers** that generated these step responses:

1 / 1 point



- ○ 1st response by PI; 2nd response by PD; 3rd response by PID
- ○ 1st response by PD; 2nd response by PI; 3rd response by PID
- ○ 1st response by PI; 2nd response by PID; 3rd response by PD
- ◉ 1st response by PD; 2nd response by PID; 3rd response by PI
- ○ None of the above

Correct

Correct! Adding derivative control improves the step response in terms of overshoot and settling time, but slows down the rise time. Adding the integral term instead maintains a short rise time, and is able to reduce oscillation and overshoot, leading to a fast settling time as well. Adding both derivative and integral control terms brings the advantages of both these approaches.

6. What is the output of a typical output of a Longitudinal control module? (Select all that apply)

1 / 1 point

- [ ] Reference velocity
- [x] Throttle angle

Correct

Correct! A longitudinal control module takes a reference velocity as an input and outputs throttle angle and brake pedal position.

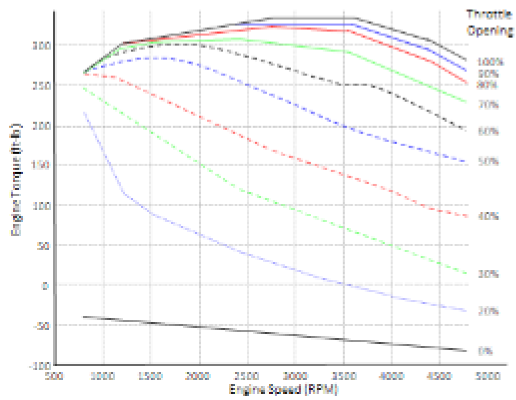
- [ ] Steering angle
- [x] Brake position

Correct

Correct! A longitudinal control module takes reverence velocity as an input and outputs throttle angle and brake pedal position.

7. Based on the engine map in the figure below, **determine the throttle angle** needed to produce 250 ft-lb of torque given that the current engine speed is 3500 RPM.

1 / 1 point

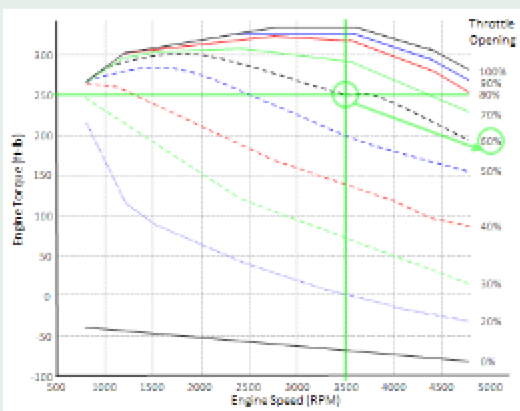


If you need help formatting math functions, [read this article](#).

0.6

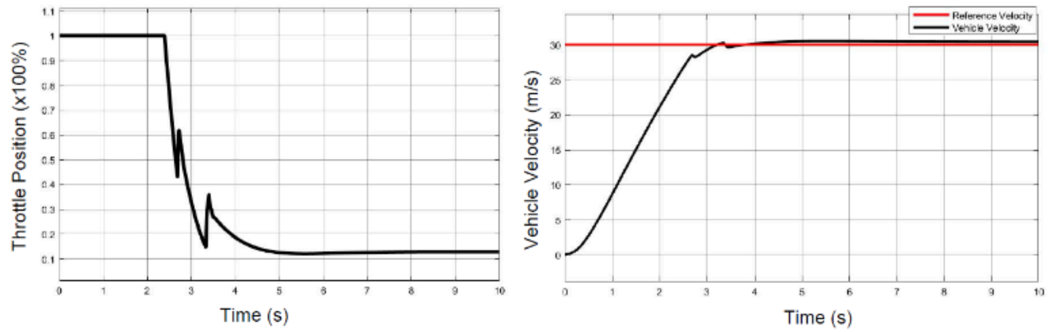
Correct

Correct!



8. The results of a simulation of the control response to a step change in desired speed of a dynamic vehicle model with a PID controller are shown in the figures below. There are two spikes on these figures: one spike is between 2 and 3 seconds, another spike is between 3 and 4 seconds. **What is the reason of these spikes?**

1 / 1 point

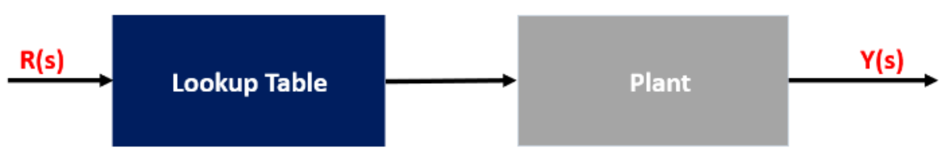


- ○ Engine-transmission torque loss
- ○ Tire slip
- ◉ Nonlinear engine map
- ○ High level controller simplification: changing the integral to a summation over fixed length time steps in the Integral term
- ○ None of the above

Correct
Correct! These artefacts are caused by the engine map nonlinearities.

9. What type of **control system** is shown in the figure below?

1 / 1 point



- ○ Feedback control
- ◉ Feedforward control
- ○ Feedback-feedforward control
- ○ None of the above

Correct
Correct! This diagram represents a feedforward controller. It show an open loop structure, where the reference signal is directly fed into the feedforward controller, which generates the inputs to the plant.

10. What types of inaccuracies are corrected by a feedback controller?

1 / 1 point

- [x] Disturbances

Correct
Correct! The feedback controller corrects for errors that result from disturbances.

- [ ] Nonlinear engine map
- [x] Errors in the plant model

Correct
Correct! The feedback controller corrects for errors that result from inaccuracies in the plant model.

- [ ] High level controller simplification: changing the integral to a summation over fixed length time steps in the Integral term

11. What assumptions are essential for creation of a **longitudinal feedforward input**? (Select all that apply)

1 / 1 point

- [ ] The tire slip angle and ratio are negligible
- [x] The vehicle is at steady state

Correct
Correct! Modelling feedforward block requires converting the entire longitudinal dynamics model into a fixed lookup table or reference map, that maps the reference velocity to the corresponding actuator signals assuming the vehicle is at steady state.

- [ ] The plant system is linear
- [ ] Torque from the engine passes directly to the transmission without loss

12. What are the sources of the load torque considered for a **longitudinal feedforward look-up table computation**? (Select all that apply)

1 / 1 point

- [ ] Static friction
- [ ] Cornering force
- [x] Rolling resistance

Correct
Correct! Rolling resistance is a force acting opposite to the relative motion, so that it is a part of the load torque acting on the vehicle.

- [x] Aerodynamic resistance

Correct
Correct! Aerodynamic resistance is a force acting opposite to the relative motion, so that it is a part of the load torque acting on the vehicle.

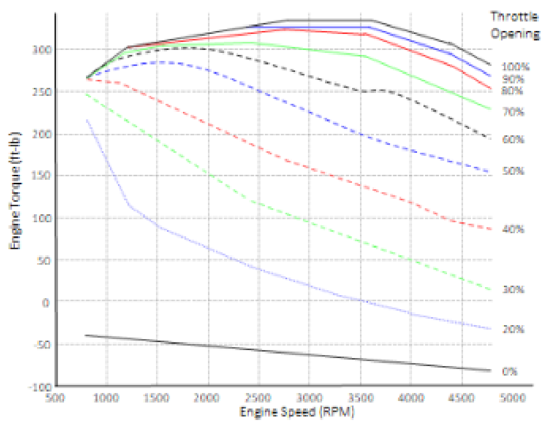
- [ ] Sliding resistance
- [x] Gravitational resistance

Correct
Correct! Gravitational resistance is a force acting opposite to the relative motion, so that it is a part of the load torque acting on the vehicle.

13. A vehicle is being operated on a highway with the reference velocity of 126 km/h (35 m/s) in gear 4 and it overcomes the total load torque of 300 ft-lb. This vehicle specification includes effective wheel radius of 0.35 m and 4th gear ratio of 2. **What throttle angle** is required for maintaining the the current speed of the vehicle?

1 / 1 point

Please use the below engine map for your computation.



If you need help formatting math functions, [read this article](#).

0.7

Correct

Correct!

$$\omega_w = \frac{V_ref}{r_eff} = \frac{35[m/s]}{0.35[m]} = 100[1/s] = 100[hertz]$$

$$\omega_e = \frac{\omega_w}{GR} = \frac{100[hertz]}{2} = 50[hertz]$$

$$\omega_e = 50[1/s] \cdot 60[s/min] = 3000RPM$$

An intersection of $\omega_e = 3000[RPM]$ and $T_{engine} = 300$[ft-lb] falls on the green line on the chart, where the green line defines the throttle angle of 70%.

Week 6

Module 6 : Graded Quiz

1. Which reference path is the **most compact** and **easy to construct**?

1 / 1 point

- (•) Track straight line segment
- ( ) Track waypoints
- ( ) Track parameterized curves
- ( ) None of the above

Correct

Correct! The easiest approach is to define a sequence of straight line segments, by requiring a sequence of endpoint vertices that are connected linearly. This path definition can be very compact and easy to construct, assuming points are well spaced and the environment allows for mostly straight line motion.

2. What is the most **ACCURATE** and **PRECISE** definition of the crosstrack error?

1 / 1 point

- ( ) The crosstrack error is the difference between path heading and the vehicle heading at a reference point along the path
- (•) The crosstrack error is the distance between the vehicle reference point and the closest point on the reference path
- ( ) The crosstrack error is the sum of the absolute difference between each coordinate of the vehicle reference point and the corresponding closest point on the desired path
- ( ) None of the above

Correct

Correct! It is the principle measure of how close the vehicle's position is to the desired position along the path.

3. What vehicle reference frame is used in a **pure pursuit controller**?

1 / 1 point

- ○ Center of gravity
- ○ Center of the front axle
- ◉ Center of the rear axle
- ○ None of the above

Correct

Correct! In this method, the centre of the rear axle is used as the vehicle reference frame. Also, recall that we define the line that connects the centre of the rear axle to the target reference point as the lookahead distance.

4. **Compute the radius** from the instantaneous center of rotation to the center of the vehicle rear axle (in m) required for an autonomous vehicle to follow the desired path based on the information below.

1 / 1 point

The lookahead distance is 10 m; the car length is 4 m; the angle between the vehicle's body heading and the lookahead line is 30°. Your answer should be an integer.

10

Correct

Correct!

$$R = \frac{l_d}{2sin\alpha} = \frac{10}{2sin30^\circ} = \frac{10}{2 \cdot 1/2} = 10$$

5. **Compute the steering angle (in degrees)** required for an autonomous vehicle with pure pursuit lateral control for following the desired path based on the information below.

1 / 1 point

The lookahead distance is 15 m; the car length is 5 m; the angle between the vehicle's body heading and the lookahead line is 60°.

If you need help formatting math functions, read this article.

30

Correct

Correct!

$$\delta = arctan(\frac{2Lsin\alpha}{l_d}) = arctan(\frac{2 \cdot 5 \cdot sin60^\circ}{15}) = arctan(\frac{2 \cdot \sqrt{3}/2}{3}) = arctan(\frac{1}{\sqrt{3}}) = 30^\circ$$

6. Consider a situation in which a vehicle traveling speed has decreased from 100 km/h to 50 km/h. This vehicle lateral control is implemented with a pure pursuit controller where l_d is assigned as a function of vehicle speed. **How should l_d change in this situation?**

1 / 1 point

- ○ l_d should increase
- ◉ l_d should decrease
- ○ l_d should stay the same
- ○ l_d can increase or decrease depending on how the controller is tuned
- ○ None of the above

Correct

Correct! The pursuit controller with a fixed value of ld does not take into account the vehicle speed. This means that the selected steering angle would be the same regardless of whether the vehicle is going 10 km/h or 100 km/h, leading to very different lateral accelerations. A controller tuned for high speed would be far to sluggish at low speed, and one tuned for low speed would be dangerously aggressive at high speed. To overcome this limitation, we define the lookahead distance to increase proportional to vehicle forward speed.

7. What are **major components** of the Stanley controller? (Select all that apply)

1 / 1 point

- [x] Proportional control is introduced for minimizing the crosstrack error

Correct

Correct! This is a major component of the Stanley controller that differs it from the pure pursuit controller.

- [x] Steering angle is set equal to the heading direction to eliminate heading error relative to the path

Correct

Correct! This is a major component of the Stanley controller that differs it from the pure pursuit controller.

- [ ] Derivative control is introduced for minimizing the heading error
- [ ] Crosstrack error is eliminated
- [ ] Integral control is added for both the heading and the crosstrack errors optimization
- [x] Steering angle command is restricted to the min and max steering angles

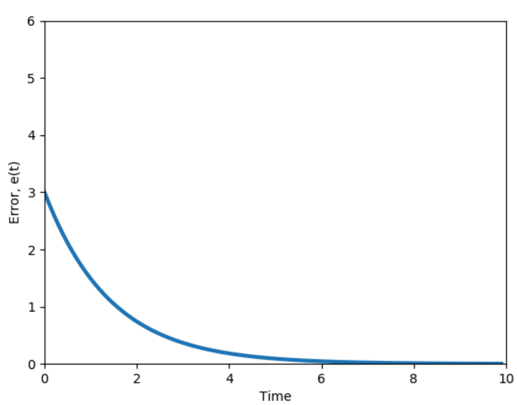
Correct

Correct! This is a major component of the Stanley controller that differs it from the pure pursuit controller.

8. **What is the correct figure** of the crosstrack error dynamics for a small error value(where $e'(t) = -ke(t)$)?

1 / 1 point

(•) Figure 3:



Correct

Correct! Solving the differential equation of the crosstrack error dynamic results in the following function $e(t) = e(0)e^{-kt}$ and this function is plotted above

9. **What is the value of the crosstrack error**, governed by the ODE $e'(t) = -ke(t)$, at $t = 2$ given that $e(0) = 4$ and $k = 1$?

Please give your answer with the precision of 2 decimal places.

0.54

Correct

Correct! Solving the differential equation of the crosstrack error results in the following function:

$$e(t) = e^{-kt} \cdot e(0)$$

Next, using the given values we get:

$$e(2) = e^{-2} \cdot 4 = 0.54$$

10. Which of the statements below about Model Predictive Control (MPC) are **TRUE**? (Select all that apply)

0.75 / 1 point

- [x] MPC works for both linear and nonlinear models

Correct

Correct! The controller can be explicitly applied to the linear or nonlinear models of the vehicle and its subsystems, meaning that we can use the same approach even as our models change or improve over time.

- [x] MPC can impose constraints on the states and the input simultaneously

Correct

Correct! The states and control signals in MPC can be constrained to stay within safe operating bounds, and controls can be selected to maximize multiple objectives simultaneously. Both hard constraints and soft penalties can be employed, leading to a rich set of solutions for constrained control problems.

- [ ] The formulation of an MPC controller is straightforward
- [ ] MPC is an optimized version of Receding Horizon Control

You didn't select all the correct answers

11. What is the typical way of finding the solution for a **nonlinear vehicle dynamics model** given an input function?

1 / 1 point

- ○ Laplace transform
- ◉ Numerical optimization
- ○ Using existing closed form solution
- ○ None of the above

Correct
Correct! No closed form solution exists for a nonlinear dynamic model, and so we rely on numerical optimization to find a solution.

12. What is the output of the **Model Predictive Controller** described in this course? (Select all that apply)

1 / 1 point

- [ ] Throttling/braking
- [ ] Steering angle
- [x] Longitudinal forces

Correct
Correct! The Model Predictive Control takes the reference path, velocity and the vehicle states at each time step as an input and outputs the longitudinal force needed to follow the desired trajectory.

- [x] Lateral forces

Correct
Correct! The Model Predictive Control takes the reference path, velocity and the vehicle states at each time step as an input and outputs the lateral force needed to follow the desired trajectory.

- [ ] None of the above

Week 7

Module 7 : Carla - How to Run

1. **Loading the Simulator with the Race Track Map**

```
\> CarlaUE4.exe [ /Game/Maps/<map_name> ] [ <args> ]
```

```
\> C:
\> cd \Coursera\CarlaSimulator
\> CarlaUE4.exe /Game/Maps/RaceTrack -windowed -carla-no-networking
```

2. **Loading the Simulator with a Fixed Time-Step (20 fps)**

```
\> C:
\> cd \Coursera\CarlaSimulator
\> CarlaUE4.exe /Game/Maps/RaceTrack -windowed -carla-no-networking
-benchmark -fps=20
atau
./CarlaUE4.sh -windowed -carla-no-networking
```

3. **Testing CARLA in Server-Client Mode**

```
\> C:
\> cd \Coursera\CarlaSimulator
\> CarlaUE4.exe /Game/Maps/RaceTrack -windowed -carla-server
-carla-world-port=2003
```

```
\> C:
\> cd \Coursera\CarlaSimulator\PythonClient
\> python manual_control.py --port=2003
atau
\> python module_7.py --port=2003
```

4. **Longitudinal Control**

```
self.vars.create_var('v_previous', 0.0)
self.vars.create_var('t_previous', 0.0)
```

```
self.vars.create_var('error_previous', 0.0)
self.vars.create_var('integral_error_previous', 0.0)
self.vars.create_var('throttle_previous', 0.0)
```

```
kp = 2.0
ki = 0.4
kd = 0.1

# compute error
error = v_desired - v
dt = t - self.vars.t_previous
integral_error = self.vars.integral_error_previous + error * dt
derivative_error = (error - self.vars.error_previous) / dt

# compute PID
a_desired = kp * error + ki * integral_error + kd * derivative_error

throttle_output = 0
brake_output    = 0

if a_desired > 0:
    #relationship between acceleration and throttle follows tanh characteristics
    throttle_output = np.tanh(a_desired)
else:
    throttle_output = 0
```

5. **Lateral Control**

```
# Change the steer output with the lateral controller.
steer_output    = 0

# stanley controller
k_e = 0.1

# yaw path
yaw_path = np.arctan2(waypoints[-1][1] - waypoints[0][1], waypoints[-1][0] -
waypoints[0][0])

# heading error
yaw_diff_heading = yaw_path - yaw
# if heading error greater than 180 degrees, then turn the other way
if yaw_diff_heading > np.pi:
    yaw_diff_heading -= 2 * np.pi
```

```
if yaw_diff_heading < -np.pi:
    yaw_diff_heading += 2 * np.pi

# cross track error
current_xy = np.array([x, y])
crosstrack_error = np.min(np.sum((current_xy - np.array(waypoints)[:, :2])**2, axis=1))
yaw_cross_track = np.arctan2(y-waypoints[0][1], x-waypoints[0][0])
yaw_path_to_crosstrack = yaw_path - yaw_cross_track
# if yaw_path_to_crosstrack greater than 180 degrees, then turn the other way
if yaw_path_to_crosstrack > np.pi:
    yaw_path_to_crosstrack -= 2 * np.pi
if yaw_path_to_crosstrack < -np.pi:
    yaw_path_to_crosstrack += 2 * np.pi
# sign of crosstrack error
 if yaw_path_to_crosstrack > 0:
    crosstrack_error = abs(crosstrack_error)
else:
    crosstrack_error = -abs(crosstrack_error)
# yaw cross track
yaw_cross_track = np.arctan(k_e * crosstrack_error / v)

# steering angle
steer_angle = yaw_diff_heading + yaw_cross_track
# if steering angle greater than 180 degrees, then turn the other way
if steer_angle > np.pi:
    steer_angle -= 2 * np.pi
if steer_angle < -np.pi:
    steer_angle += 2 * np.pi
steer_output = np.clip(steer_angle, -1.22, 1.22)
```

```
self.vars.v_previous = v  # Store forward speed to be used in next step
self.vars.t_previous = t
self.vars.error_previous = error
self.vars.integral_error_previous = integral_error
self.vars.throttle_previous = throttle_output
```

6. Grading

```
python grade_c1m7.py racetrack_waypoints.txt trajectory.txt
```

Module 2

Week 1

Lessons 1 : Practice Quiz

1. In order to apply the method of least squares, it is necessary to know the measurement noise variances. **1 / 1 point**

- ( ) True
- (•) False

Correct
Correct! Least squares can be applied to minimize a squared error criterion, without necessarily knowing the noise characteristics of the measurements.

2. For the method of least squares, select any/all that apply. **1 / 1 point**

- [ ] The squared error criterion and least squares method can be applied directly to nonlinear measurement models.
- [x] Given a linear observation model, the parameters that minimize the squared error criterion can be found by solving the normal equations.

Correct
Correct! However, there is an additional criterion required for the solution to be valid. For more details, review the "Squared Error Criterion and the Method of Least Squares" lecture in this module.

- [x] The method was pioneered by Carl Friedrich Gauss.

Correct
Correct! The least-squares method is usually credited to Carl Friedrich Gauss (1795).

3. Lesson 1 referred to the Jacobian matrix, $\mathbf{H}$, which relates the parameters of the linear model to the measurements. Assume that, for a particular problem, our model has three parameters and we obtain ten measurements - what size should the Jacobian matrix be? **1 / 1 point**

- (•) The matrix $\mathbf{H}$ should be 10×3 in size.
- ( ) The matrix $\mathbf{H}$ should be 3×10 in size.

Correct
Right! There is one row in the matrix for each measurement and one column for each parameter.

4. According to the weighted squared error criterion, the error term corresponding to a measurement with a noise variance of 10 units will be weighted more highly than that of a measurement with a noise variance of 1 unit.

1 / 1 point

- ○ True
- ◉ False

Correct

Correct! A larger noise covariance means a lower weight (i.e., a less trustworthy measurement).

5. In which of these cases would the method of weighted least squares produce valid solutions. Select any/all that apply.

1 / 1 point

- [x] Five measurements, five unknown parameters, and two different noise variances.

Correct

Correct! We have an equal number of measurements and unknowns, which means the five parameters can be estimated correctly. The non-zero noise variances affect the estimator accuracy, but not the validity of the solution.

- [ ] Five measurements, six unknown parameters.
- [x] Ten measurements, two unknown parameters.

Correct

Correct! We have more measurements than unknowns, which means the two parameters can be estimated reliably.

- [ ] Ten measurements, two unknown parameters, and two different noise variances, one of which is exactly zero.

6. You are measuring the voltage drop V across an electrical component using two different multimeters; one of the meters is known to be more reliable than the other. Which method would you use to estimate the best voltage value from noisy measurements?

1 / 1 point

- ◉ Weighted Least Squares
- ○ Least Squares

Correct

Correct! WLS can handle the possibility of the measurements having different noise levels (variances).

Lesson 1 Practice Notebook : Least Squares

```
# Define the H matrix - what does it contain?
H = np.array([[1], [1], [1], [1], [1]])

# Now estimate the resistance parameter.
R = inv(H.T @ H) @ H.T @ (V/I)
```

```
print('The slope parameter of the best-fit line (i.e., the resistance) is:')
print(R[0, 0])
```

or

```
H = np.ones((5, 2))
H[:, 0] = I.ravel()
R = inv(H.T.dot(H)).dot(H.T.dot(V))

print('The slope parameter of the best-fit line (i.e., the resistance) is:')
print(R[0, 0])

I_line = np.arange(0, 0.8, 0.1).reshape(8, 1)
V_line = R[0]*I_line

plt.scatter(I, V)
plt.plot(I_line, V_line)
plt.xlabel('Current (A)')
plt.ylabel('Voltage (V)')
plt.grid(True)
plt.show()
```

Lesson 2 Practice Notebook : Recursive Least Squares

```
## Recursive Solution

# Initialize the 2x1 parameter vector x (i.e., x_0).
x_k = np.array([[4], [0]])

# Initialize the 2x2 covariance matrix (i.e., P_0). Ensure proper shape.
P_k = np.array([[9, 0], [0, 0.2]])

# Our voltage measurement variance (denoted by R, don't confuse with resistance).
R_k = np.array([[0.0225]])

# Pre allocate space to save our estimates at every step.
num_meas = I.shape[0]
x_hist = np.zeros((num_meas + 1, 2, 1))
P_hist = np.zeros((num_meas + 1, 2, 2))

x_hist[0] = x_k
P_hist[0] = P_k

# Iterate over all the available measurements.
for k in range(num_meas):
    # Construct H_k (Jacobian).
    H_k = np.array([[I[k, 0], 1]])
```

```
    # Construct K_k (gain matrix).
    K_k = P_k.dot(H_k.T).dot(inv(H_k.dot(P_k).dot(H_k.T) + R_k))

    # Update our estimate.
    x_k = x_k + K_k.dot(V[k] - H_k.dot(x_k))

    # Update our uncertainty (covariance)
    P_k = (np.eye(2) - K_k.dot(H_k)).dot(P_k)

    # Keep track of our history.
    P_hist[k + 1] = P_k
    x_hist[k + 1] = x_k

print('The slope and offset parameters of the best-fit line (i.e., the resistance and offset) are [R, b]:')
print(x_k[0, 0])
print(x_k[1, 0])
```

Lesson 2 : Practice Quiz

1. The method of maximum likelihood gives the same parameter estimates as the method of least squares for any measurement noise distribution. **1 / 1 point**

- ○ True
- ◉ False

Correct
Correct! The noise must be from the Gaussian family.

2. The product of several Gaussian PDFs with identical variances is also Gaussian. **1 / 1 point**

- ◉ True
- ○ False

Correct
Correct! We used this fact to derive the connection between maximum likelihood and least squares.

3. The least squares criterion is robust to outliers. **1 / 1 point**

- ○ True
- ◉ False

Correct
Correct! Least squares is particularly sensitive to outliers due to the use of squared errors!

4. For a scalar Gaussian random variable, what is the form of the full log likelihood function?

1 / 1 point

- (selected) $-\frac{1}{2}\log(2\pi) - \frac{1}{2}\log\left(\sigma^2\right) - \frac{1}{2\sigma^2}\left(x-\mu\right)^2$
- $-\frac{1}{2}\log(2\pi) + \frac{1}{2}\log\left(\sigma\right) - \frac{1}{2\sigma^2}\left(x-\mu\right)^2$

Correct
Correct!

5. True or False, $\operatorname{argmin}_x f(x) = \operatorname{argmax}_x f(-x)$.

1 / 1 point

- True
- (selected) False

Correct
Correct! $\operatorname{argmin}_x f(x) = \operatorname{argmax}_x - f(x)$.

Module 1 : Graded Quiz

1. Measurements are drawn from a Gaussian distribution with variance σ^2. Which of the estimators below will provide the 'best' estimate of the true value of a parameter? Select any/all that apply:

1 / 1 point

- [x] Least Squares

Correct
Correct! Since all of the variances are identical, ordinary least squares can be used.

- [x] Maximum Likelihood

Correct
Correct! By definition, a maximum likelihood estimator will find the parameter value with the greatest likelihood of being the 'true' value. ML and LS estimators are equivalent in this case.

- [x] Weighed Least Squares

Correct
Correct! Even when all variances are identical, weighted least squares can be applied.

2. Which of the following statements are correct? Select any/all that apply:

2 / 2 points

- [x] When measurement noise comes from a large number of independent sources, a least squares estimator can be used.

Correct
Correct! The Central Limit Theorem states that when a noise comes from a large number of independent sources, the noise distribution will tend towards a Gaussian distribution.

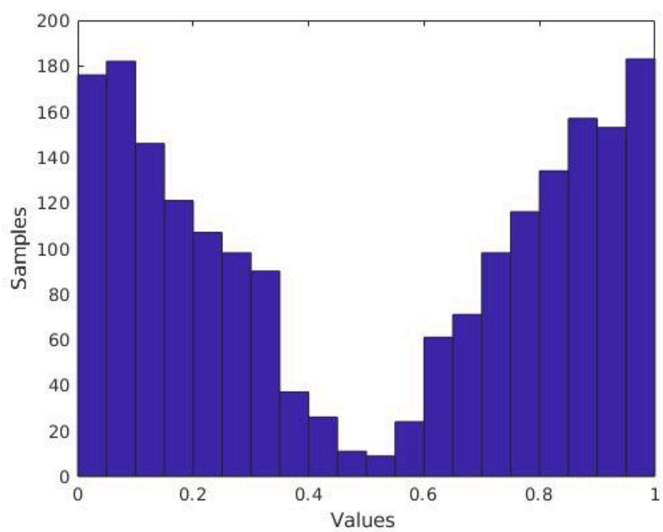
- [x] Least squares estimators are significantly affected by outliers.

Correct
Correct! Outliers are not well handled by least squares estimators, since these estimators minimize the sum of *squared* errors.

- [ ] When measurements are drawn from a non-Gaussian distribution, a maximum likelihood estimator produces the same values as weighted least squares.

3.

1 / 1 point



Given the above histogram of noisy measurements, it is appropriate to use a LS estimator?

○ True

◉ False

Correct
Correct! The distribution of the measurements is clearly not Gaussian, which suggests that least squares will do a poor job.

4. Looking at the histogram in the previous question, what could be the reason for such a distribution of measurements? Select any/all that apply:

1 / 1 point

- [x] There is an outside disturbance affecting the sensor.

Correct
Correct! Even if the measured value is static, a disturbance affecting the sensor (e.g., unmodeled vibrations or someone moving the sensor) might cause significantly different measurements to be produced.

- [ ] The measurement is affected by zero mean Gaussian noise.
- [x] The measured value might be changing.

Correct
Correct! If the measured value is changing (e.g., perhaps switching between two discrete values), the histogram will have multiple peaks.

Week 2

Programming Assignment: Module 2 Graded Notebook (Submission): Estimating a Vehicle Trajectory

```
from numpy.linalg import inv
from math import atan2, cos, sin, sqrt
v_var = 0.01  # translation velocity variance
om_var = 0.01  # rotational velocity variance
r_var = 0.001  # range measurements variance
b_var = 0.001 # bearing measurement variance
```

```
def measurement_update(lk, rk, bk, P_check, x_check):
    x_check[2] = wraptopi(x_check[2])
    x = x_check
    P = P_check
    # get x,y,theta
    x_k = x[0]
    y_k = x[1]
    theta_k = x[2]
    # get xl, yl
    x_l = lk[0]
    y_l = lk[1]
    # simplify
    dx = x_l - x_k - d*cos(theta_k)
    dy = y_l - y_k - d*sin(theta_k)
    r = sqrt(dx**2 + dy**2)
    # phi
    phi = atan2(dy, dx) - theta_k
    y = np.vstack([r, wraptopi(phi)])
    y_meas = np.vstack([rk, wraptopi(bk)])

    # 1. Compute measurement Jacobian
    M = np.eye(2)
    H = np.ones([2, 3])
    H[0, 0] = -dx/r
    H[0, 1] = -dy/r
    H[0, 2] = (dx*d*sin(theta_k) + dy*(-d*cos(theta_k)))/r
    H[1, 0] = dy/r**2
    H[1, 1] = -dx/r**2
    H[1, 2] = -(dy*d*sin(theta_k) + dx*(d*cos(theta_k)))/r**2

    # 2. Compute Kalman Gain
    K = P.dot(H.T).dot(inv(H.dot(P).dot(H.T) + M.dot(cov_y).dot(M.T)))

    # 3. Correct predicted state (remember to wrap the angles to [-pi,pi])
```

```
    x_check = x + K.dot(y_meas - y)
    x_check[2] = wraptopi(x_check[2])

    # 4. Correct covariance
    P_check = (np.eye(3) - K.dot(H)).dot(P)

    return x_check, P_check
```

```
#### 5. Main Filter Loop
#######################################################################
x_check = x_est[0, :].reshape([3, 1])
P_check = P_est[0]
for k in range(1, len(t)):  # start at 1 because we've set the initial prediciton

    delta_t = t[k] - t[k - 1]  # time step (difference between timestamps)
    x_check[2] = wraptopi(x_check[2])
    theta = x_check[2]

    # 1. Update state with odometry readings (remember to wrap the angles to [-pi,pi])
    x_check[0] += v[k-1] * np.cos(theta) * delta_t
    x_check[1] += v[k-1] * np.sin(theta) * delta_t
    x_check[2] += om[k-1] * delta_t
    x_check[2] = wraptopi(x_check[2])

    # 2. Motion model jacobian with respect to last state
    F_km = np.array([[1, 0, -v[k-1]*sin(theta)*delta_t],
                     [0, 1, v[k-1]*cos(theta)*delta_t],
                     [0, 0, 1]])

    # 3. Motion model jacobian with respect to noise
    L_km = np.array([[cos(theta)* delta_t, 0],
                     [sin(theta)* delta_t, 0],
                     [0, delta_t]])

    # 4. Propagate uncertainty
    P_check = F_km.dot(P_check).dot(F_km.T) + L_km.dot(Q_km).dot(L_km.T)

    # 5. Update state estimate using available landmark measurements
    for i in range(len(r[k])):
        x_check, P_check = measurement_update(l[i], r[k, i], b[k, i], P_check, x_check)

    # Set final state predictions for timestep
    x_est[k, 0] = x_check[0]
    x_est[k, 1] = x_check[1]
    x_est[k, 2] = x_check[2]
    P_est[k, :, :] = P_check
```

Week 3

Module 3: Graded Quiz

1. Which of these statements are true? Select any/all that apply:

1 / 1 point

- [ ] Every 3x3 matrix represents a 3D rotation.
- [x] Every set of Euler angles corresponds to a unit quaternion.

Correct
Correct! Any set of Euler angles represents a rotation which can also be represented by a unit quaternion.

- [x] Every unit quaternion has an associated 3x3 rotation matrix.

Correct
Correct! Every quaternion corresponds to a 3x3 rotation matrix.

2. Which of these are valid rotation matrices? Select any/all that apply:

2 / 2 points

- [x] $C_2 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} \\ 0 & -\frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} \end{bmatrix}$

Correct
Correct! $C_2 C_2^T = \mathbf{I}$ holds and $\det C_2 = 1$.

- [ ] $C_3 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} \\ 0 & \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} \end{bmatrix}$

- [ ] $C_4 = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 1 \\ 1 & 0 & 0 \end{bmatrix}$

- [x] $C_1 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$

Correct
Correct! Since C_1 is an identity matrix, it is equivalent to performing "zero" rotation.

3. Localization can be performed on board a vehicle by integrating the rotational velocities and linear accelerations measured by an IMU. Assuming that the IMU measurement noise is drawn from a normal distribution, what will the pose estimation error look like?

1 / 1 point

- (●) The vehicle pose estimation error will grow with time.
- ( ) The vehicle pose estimate error will remain within a bounded interval.
- ( ) The vehicle pose estimate error will decrease with time.

Correct
Correct! Since we are integrating noisy measurements, the error will build up over time.

4. Each GPS satellite transmits a signal that encodes:

1 / 1 point

- (●) The satellite's position and time of signal transmission.
- ( ) The receiver's position and time of signal transmission

Correct
Correct! This information can be used to calculate the vehicle's position.

5. Which of these systems provides the most accurate positioning measurement?

1 / 1 point

- (●) RTK GPS
- ( ) GPS
- ( ) DGPS

Correct
Correct! RTK uses phase of the GPS carrier signal to provide centimetre-level accuracy.

6. What is the minimum number of GPS satellites required to estimate the 3D position of a vehicle through trilateration?

2 / 2 points

4

Correct
Correct! A minimum of four satellites is required to unambiguously calculate the vehicle's 3D position.

Week 4

Module 4: Graded Quiz

1. A single 3D LIDAR reading consists of elevation, azimuth and range measurements $(\epsilon, \alpha, r) = (5^\circ, 10^\circ, 4\ \mathrm{m})$. Assuming that the measurements are noiseless, calculate the position of this point in the Cartesian sensor frame. Note that the elevation and azimuth angles are given in degrees (for convenience) - you will need to convert these values to radians for use with most trigonometric functions.

2 / 2 points

Enter your result in the area below as comma separated list of values, in the (x, y, z) format, e.g (1.22, 2.33, 3.44).

(3.92, 0.69, 0.35)

Correct
Correct!

2.

```
from numpy import *

def sph_to_cart(epsilon, alpha, r):
    """
    Transform sensor readings to Cartesian coordinates in the sensor
    frame. The values of epsilon and alpha are given in radians, while
    r is in metres. Epsilon is the elevation angle and alpha is the
    azimuth angle (i.e., in the x,y plane).
    """
    p = zeros(3)  # Position vector

    # Calculate the Cartesian coordinates
    p[0] = r * cos(epsilon) * cos(alpha)
    p[1] = r * cos(epsilon) * sin(alpha)
    p[2] = r * sin(epsilon)

    return p

def estimate_params(P):
    """
    Estimate parameters from sensor readings in the Cartesian frame.
    Each row in the P matrix contains a single 3D point measurement;
    the matrix P has size n x 3 (for n points). The format is:

    P = [[x1, y1, z1],
         [x2, x2, z2], ...]

    where all coordinate values are in metres. Three parameters are
    required to fit the plane, a, b, and c, according to the equation
```

```
z = a + bx + cy

The function should return the parameters as a NumPy array of size
three, in the order [a, b, c].
"""
# Number of points
n = P.shape[0]

# Construct matrix A and vector b
A = ones((n, 3))
A[:, 1] = P[:, 0]  # x values
A[:, 2] = P[:, 1]  # y values
b = P[:, 2]        # z values

# Solve for the parameters using the normal equation
# (A.T * A) * param_est = A.T * b
param_est = linalg.inv(A.T.dot(A)).dot(A.T).dot(b)

return param_est
```

3. Which of the following statements are true? Select any/all that apply.

1 / 1 point

- [x] ICP is sensitive to outliers caused by moving objects.

> **Correct**
> Correct! Moving objects in the environment can cause incorrect matches between LIDAR scan points.

- [ ] Because the points in a 3D point cloud are defined in Euclidean space, estimating the transformation between two point clouds is possible using simple trigonometry.
- [ ] Point-to-plane ICP is often used in environments that lack structure.

4. You are testing an algorithm for LIDAR-based localization on a vehicle in a controlled environment. What are some of the things you need to take into account? Select any/all that apply.

1 / 1 point

- [ ] We need to make sure the environment is well lit.
- [ ] The LIDAR always needs to be positioned horizontally, as even a small tilt will cause measurement errors.
- [x] It is important to identify shiny and highly reflective objects in the environment, as LIDAR measurements of those objects may be invalid.

> **Correct**
> Correct! Shiny and polished surfaces may dramatically reduce the amount of light reflected back along the original beam direction. For example, if the surface is very shiny, like a mirror, the laser pulse might be scattered completely away from the original pulse direction.

- [x] When the vehicle is moving quickly, it is important to account for the time differences between individual LIDAR pulses.

> **Correct**
> Correct! This means that every single point in a LIDAR sweep is taken from a slightly different position and a slightly different orientation, and this can cause artifacts such as duplicated objects to appear in the LIDAR scans.

5. To estimate the motion of a self-driving car, it is necessary to transform LIDAR scan points from the sensor frame to the vehicle frame. The rotation of the vehicle frame with respect to the LIDAR frame is represented by the rotation matrix $\mathbf{C}_{vl}$. Given any point $\mathbf{p}_l^{(i)}$ in the LIDAR frame, and considering rotation only, which of these expressions correctly transforms the point into the vehicle frame?

1 / 1 point

- (●) $\mathbf{p}_v^{(i)} = \mathbf{C}_{vl}\,\mathbf{p}_l^{(i)}$
- ( ) $\mathbf{p}_v^{(i)} = \left(\mathbf{p}_l^{(i)}\right)^T \mathbf{C}_{vl}$
- ( ) $\mathbf{p}_v^{(i)} = \mathbf{C}_{vl}^T\,\mathbf{p}_l^{(i)}$

> **Correct**
> Correct! The rotation matrix $\mathbf{C}_{vl}$ represents the transform from the LIDAR fo the vehicle frame. Since our points are in the LIDAR frame, the transform needs to be applied on the left.

Week 5

Programming Assignment: Final Project: Vehicle State Estimation on a Roadway

Task 1

```
C_li = np.array([
   [ 0.99376, -0.09722,  0.05466],
   [ 0.09971,  0.99401, -0.04475],
   [-0.04998,  0.04992,  0.9975 ]
])

var_imu_f = 0.10
var_imu_w = 0.10
var_gnss  = 0.01
var_lidar = 1.00

p1_indices = [9000, 9400, 9800, 10200, 10600]
p1_str = ''
for val in p1_indices:
    for i in range(3):
        p1_str += '%.3f ' % (p_est[val, i])
with open('pt1_submission.txt', 'w') as file:
    file.write(p1_str)
```

Task 2

```
C_li = np.array([
     [ 0.9975 , -0.04742,  0.05235],
     [ 0.04992,  0.99763, -0.04742],
     [-0.04998,  0.04992,  0.9975 ]
])

var_imu_f = 0.10
var_imu_w = 0.1
var_gnss  = 0.01
var_lidar = 1000.00

p2_indices = [9000, 9400, 9800, 10200, 10600]
p2_str = ''
for val in p2_indices:
    for i in range(3):
        p2_str += '%.3f ' % (p_est[val, i])
with open('pt2_submission.txt', 'w') as file:
    file.write(p2_str)
```

Task 3

```
C_li = np.array([
   [ 0.99376, -0.09722,  0.05466],
   [ 0.09971,  0.99401, -0.04475],
   [-0.04998,  0.04992,  0.9975 ]
])

var_imu_f = 0.01
var_imu_w = 0.01
var_gnss  = 10.00
var_lidar = 1.00

p3_indices = [6800, 7600, 8400, 9200, 10000]
p3_str = ''
for val in p3_indices:
    for i in range(3):
        p3_str += '%.3f ' % (p_est[val, i])
with open('pt3_submission.txt', 'w') as file:
    file.write(p3_str)
```

Code

```
#### 4. Measurement Update ####
def measurement_update(sensor_var, p_cov_check, y_k, p_check, v_check, q_check):
    # 3.1 Compute Kalman Gain
    I = np.eye(3)
    R = I * sensor_var
    K = p_cov_check @ h_jac.T @ np.linalg.inv(h_jac @ p_cov_check @ h_jac.T + R)

    # 3.2 Compute error state
    delta_k = K @ (y_k - p_check)

    # 3.3 Correct predicted state
    p_hat = p_check + delta_k[:3]
    v_hat = v_check + delta_k[3:6]
    q_hat = Quaternion(euler=delta_k[6:]).quat_mult_right(q_check)

    # 3.4 Compute corrected covariance
    p_cov_hat = (np.eye(9) - K @ h_jac) @ p_cov_check

    return p_hat, v_hat, q_hat, p_cov_hat

#### 5. Main Filter Loop #####
for k in range(1, imu_f.data.shape[0]):  # start at 1 b/c we have initial prediction from gt
    delta_t = imu_f.t[k] - imu_f.t[k - 1]
```

```
    # 1. Update state with IMU inputs
    Cns = Quaternion(*q_est[k-1]).to_mat()

    # 1.1 Linearize the motion model and compute Jacobians
    p_est[k] = p_est[k-1] + delta_t * v_est[k-1] + 0.5 * delta_t ** 2 * (Cns @ imu_f.data[k-1] + g)
    v_est[k] = v_est[k-1] + delta_t * (Cns @ imu_f.data[k-1] + g)
    q_est[k] = Quaternion(axis_angle=imu_w.data[k-1] * delta_t).quat_mult_right(q_est[k-1])

    # 2. Propagate uncertainty
    F = np.eye(9)
    F[:3, 3:6] = delta_t * np.eye(3)
    F[3:6, 6:] = -skew_symmetric(Cns @ imu_f.data[k-1]) * delta_t
    Q = np.eye(6)
    Q[:3, :3] *= var_imu_f * delta_t ** 2
    Q[3:, 3:] *= var_imu_w * delta_t ** 2
    p_cov[k] = F @ p_cov[k-1] @ F.T + l_jac @ Q @ l_jac.T

    # 3. Check availability of GNSS and LIDAR measurements
    if gnss_i < gnss.data.shape[0] and gnss.t[gnss_i] == imu_f.t[k-1]:
        p_est[k], v_est[k], q_est[k], p_cov[k] = measurement_update(var_gnss, p_cov[k],
gnss.data[gnss_i], p_est[k], v_est[k], q_est[k])
        gnss_i += 1
    if lidar_i < lidar.data.shape[0] and lidar.t[lidar_i] == imu_f.t[k-1]:
        p_est[k], v_est[k], q_est[k], p_cov[k] = measurement_update(var_lidar, p_cov[k],
lidar.data[lidar_i], p_est[k], v_est[k], q_est[k])
        lidar_i += 1
```

How to Run

```
python es_ekf.py
```

Module 3

Week 1

Practice Programming Assignment: (Submission) Applying Stereo Depth to a Driving Scenario

```
def compute_left_disparity_map(img_left, img_right):

    # parameter
    num_disparities = 6*16
    block_size = 11
    min_disparity = 0
    window_size = 6

    matcher = cv2.StereoSGBM_create(
        minDisparity = min_disparity,
        numDisparities = num_disparities,
        blockSize = block_size,
        P1 = 8 * 3 * window_size**2,
        P2 = 32 * 3 * window_size**2,
        mode = cv2.STEREO_SGBM_MODE_SGBM_3WAY
    )

    img_left_g = cv2.cvtColor(img_left, cv2.COLOR_BGR2GRAY)
    img_right_g = cv2.cvtColor(img_right, cv2.COLOR_BGR2GRAY)
    disp_left = matcher.compute(img_left_g, img_right_g).astype(np.float32)/16

    return disp_left
```

```
def decompose_projection_matrix(p):

    # decompose P
    k, r, t, _, _, _, _= cv2.decomposeProjectionMatrix(p)
    # normalize t
    t = t / t[3]

    return k, r, t
```

```
def calc_depth_map(disp_left, k_left, t_left, t_right):

    # focal length
    f = k_left[0, 0]
    # baseline b
    b = t_left[1] - t_right[1]
    # replace all instances (0 or -1) in disparity with small value
    disp_left[disp_left == 0] = 0.1
    disp_left[disp_left == -1] = 0.1
    # depth
    depth_map = (f * b)/disp_left

    return depth_map
```

```
def locate_obstacle_in_image(image, obstacle_image):

    # template matching
    cross_corr_map = cv2.matchTemplate(image, obstacle_image, method=cv2.TM_CCOEFF)
    # locate the position
    _, _, _, obstacle_location = cv2.minMaxLoc(cross_corr_map)

    return cross_corr_map, obstacle_location
```

```
def calculate_nearest_point(depth_map, obstacle_location, obstacle_img):

    obs_width = obstacle_img.shape[0]
    obs_height = obstacle_img.shape[1]
    obs_min_x_pos = obstacle_location[1]
    obs_max_x_pos = obstacle_location[1] + obs_width
    obs_min_y_pos = obstacle_location[0]
    obs_max_y_pos = obstacle_location[0] + obs_height

    #get depth
    obs_depth = depth_map[obs_min_x_pos:obs_max_x_pos,
obs_min_y_pos:obs_max_y_pos]
    closest_point_depth = obs_depth.min()

    # create bbox
    obstacle_bbox = patches.Rectangle((obs_min_y_pos, obs_min_x_pos), obs_height,
obs_width, linewidth=1,
                                 edgecolor='r', facecolor='none')

    return closest_point_depth, obstacle_bbox
```

Module 1 Graded Quiz

1. What is the most **ACCURATE** and **PRECISE** definition of the camera obscura?

1 / 1 point

- ○ A passive exteroceptive sensor
- ○ A mathematical model that describes relationship between world coordinates of a point and its projection onto the image plane
- ◉ A box or room with a pinhole aperture in front of an imaging surface
- ○ A tiny hole in a barrier through which light travels
- ○ None of the above

> **Correct**
> Correct! Camera obscura, which translates to Dark Room Camera in English, is a simple construction with a pinhole aperture in front of an imaging surface.

2. Which of the following statements are **TRUE**? Select all that apply.

1 / 1 point

- ☑ Camera extrinsic parameters include a rotation matrix.

> **Correct**
> Correct! Camera extrinsic parameters encompass both a rotation matrix and translation vector.

- ☐ Camera intrinsic parameters include a translation vector.
- ☐ Camera intrinsic parameters define the transformations from 3D camera coordinates to 3D world coordinates
- ☐ Camera extrinsic parameters include the focal length.
- ☑ Camera extrinsic parameters define the transformations from 3D world coordinates to 3D camera coordinates

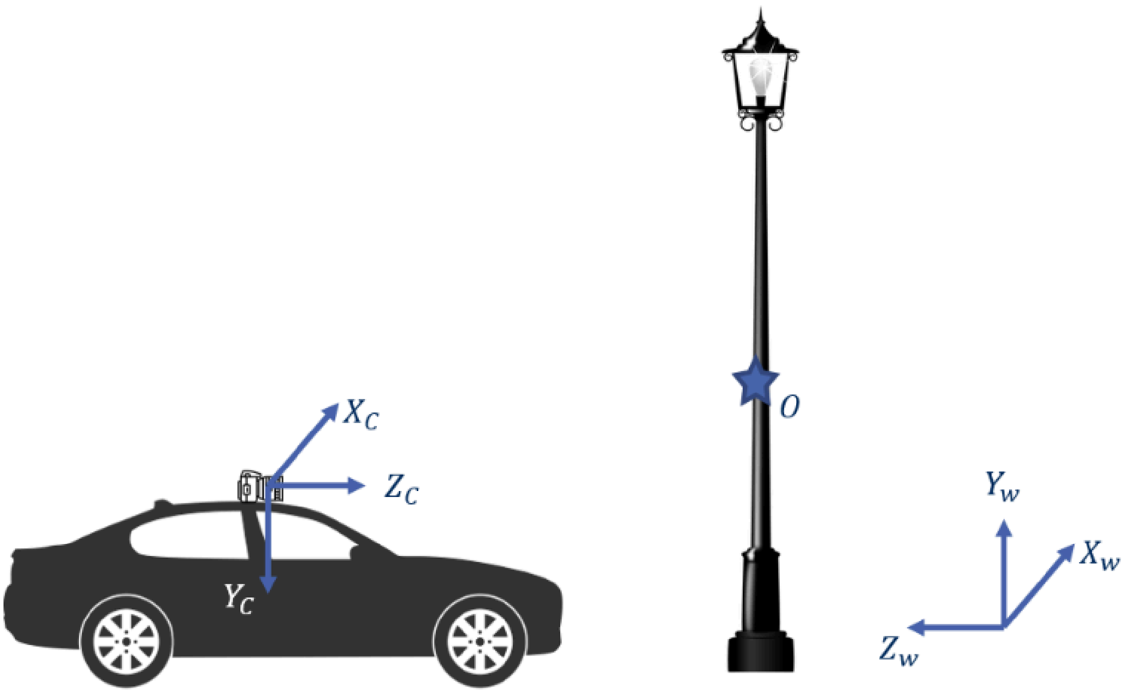
> **Correct**
> Correct! Camera extrinsic parameters indeed define the transformations from 3D world coordinates to 3D camera coordinates.

3. Imagine a situation in which a camera mounted on a car sees a point O on a signpost. The location of this point in world coordinate system is $O = \begin{bmatrix} -0.5 \\ 1.5 \\ 9 \end{bmatrix}$ meters. The location of the center of the world coordinate system relatively to the camera optical center in camera frame coordinates is defined by the translation vector $t = \begin{bmatrix} 1 \\ 2 \\ 10 \end{bmatrix}$ meters and 180° rotation around the X_C axis. The camera intrinsic parameter matrix is $K = \begin{bmatrix} 640 & 0 & 640 \\ 0 & 480 & 480 \\ 0 & 0 & 1 \end{bmatrix}$ and the image resolution is 1280×960 pixels. You can check out the image below to help you visualize the problem.

0 / 1 point

What is the position of this point in the camera coordinate system?

Please write your answer as a string with three comma-separated numbers without spaces (x and y and z), e.g. **"1,2,3"**



"960,720,1"

Incorrect
Incorrect, double check your calculation. You can also review Lesson 1 Part 2: Camera projective geometry.

4. Variation 1

1 / 1 point

Based on the problem presented in the above question, what is the pixel location of the 2D projection of the point O on the image plane?

Please write your answer as a string with two comma-separated numbers without spaces (u and v), e.g. "**100,100**"

"960,720"

Correct
Correct! Recall that this point is located in the left bottom quarter of the image.

5. Why is camera calibration important in the self-driving car domain? Select all that apply.

1 / 1 point

- [ ] Computed camera parameters can be used to determine the camera model
- [x] Computed camera parameters can be used to measure the size of a 2D object in 3D world units

Correct
Correct! Camera intrinsic and extrinsic parameters can be used for locating 3D points on a 2D image coordinate frame as well as locating 2D points in a 3D world coordinate system.

- [x] Computed camera parameters can be used to correct for lens distortion

Correct
Correct! Some complex camera calibration methods allow modeling and estimation of various sophisticated camera parameters such as radial distortion.

- [x] Camera calibration estimates the parameters of the lens and image sensor of a camera

Correct
Correct! Camera calibration is used to compute camera parameters whether in form of projection matrix or in form of intrinsic and extrinsic matrices.

- [x] Computed camera parameters can be used to determine the camera location relative to the scene

Correct
Correct! Determining the camera location using its intrinsic and extrinsic parameters is extensively used in the self-driving car domain, for visual odometry for example.

6. Recall the camera calibration problem formulation, which has the following mathematical representation.

1 / 1 point

What methods from linear algebra can we use for solving this problem? Select all that apply.

$$\begin{bmatrix} X_1 & Y_1 & Z_1 & 1 & 0 & 0 & 0 & 0 & -u_1X_1 & -u_1Y_1 & -u_1Z_1 & -u_1 \\ 0 & 0 & 0 & 0 & X_1 & Y_1 & Z_1 & 1 & -v_1X_1 & -v_1Y_1 & -v_1Z_1 & -v_1 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ X_N & Y_N & Z_N & 1 & 0 & 0 & 0 & 0 & -u_NX_N & -u_NY_N & -u_NX_N & -u_N \\ 0 & 0 & 0 & 0 & X_N & Y_N & Z_N & X_1 & -v_NX_N & -v_NY_N & -v_NY_N & -u_N \end{bmatrix} \begin{bmatrix} p_{11} \\ p_{12} \\ p_{13} \\ p_{14} \\ p_{21} \\ p_{22} \\ p_{23} \\ p_{24} \\ p_{31} \\ p_{32} \\ p_{33} \\ p_{34} \end{bmatrix} = 0$$

- [ ] Gaussian Elimination
- [ ] Method of Complements
- [ ] Eigen Decomposition
- [x] Singular Value Decomposition

> **Correct**
> Correct! Singular Value Decomposition is the way to go. This problem might also be solved with RQ factorization.

- [ ] None of the above

7. Let's continue with the camera calibration formulation from the previous question.

1 / 1 point

What are some DISADVANTAGES of this linear calibration model? Select all that apply.

- [x] The linear model mixes the intrinsic and extrinsic camera parameters

> **Correct**
> Correct! Linear calibration model does not directly provide the intrinsic and extrinsic camera parameters.

- [ ] The linear model is computationally expensive
- [x] The linear model does not allow for the incorporation of parameter constraints

> **Correct**
> Correct! The linear calibration model does not allow us to impose constraints on the solution, such as requiring the focal length to be non-negative.

- [x] Does not model radial distortion and other complex phenomena

> **Correct**
> Correct! The linear calibration model does not take into account complex phenomena such as radial and tangential distortion.

- [ ] None of the above

8. If the baseline between camera centers is known for a stereo rig, what limitation of monocular vision can be avoided?

1 / 1 point

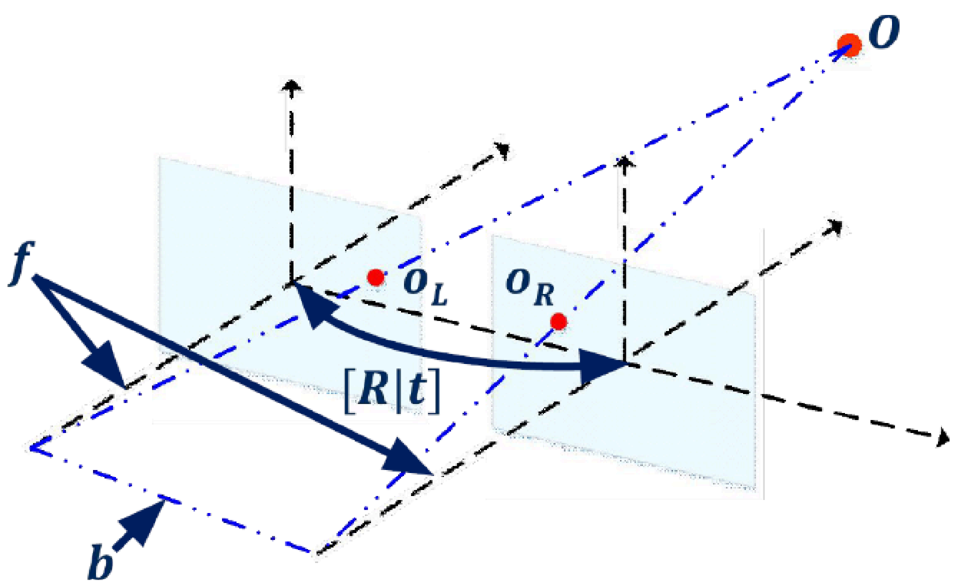
- ( ) Motion blur
- (•) Inability to measure depth to a point
- ( ) Over exposure in bright lighting conditions
- ( ) Inability to measure angle to a point
- ( ) None of the above

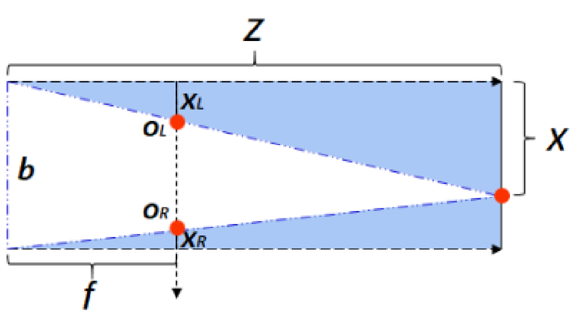
✓ Correct
Correct. Knowledge of the baseline between two camera centers allows the measurements of the same point in each image to be triangulated to identify depth, in the process known as Stereopsis.

9. Consider a stereo camera setup in the figures below, similar to what you saw in the course slides.

0.6 / 1 point

Which of the statement about this configuration are correct? Select all that apply.





- [x] $\frac{x_R}{f} = \frac{b-X}{Z}$

> Correct
> Correct! This equation is constructed by two similar triangles formed by the right camera.

- [ ] $\frac{Z}{X} = \frac{f}{x_R}$
- [x] $\frac{Z}{X} = \frac{f}{x_L}$

> Correct
> Correct! This equation is constructed by two similar triangles formed by the left camera.

- [ ] $\frac{x_R}{f} = \frac{X-b}{Z}$
- [ ] $\frac{x_L}{f} = \frac{b-X}{Z}$

10. What parameters and computations are needed to perform depth calculations from disparity measurements? Select all that apply.

1 / 1 point

- [ ] Need to find the extrinsic transformation between the stereo cameras and the world reference frame
- [x] Need to compute the baseline, and the x and y offsets for the image center

> Correct
> Correct! The baseline, and the x and y offsets are needed to calibrate the stereo camera system.

- [x] Need to compute/know the focal length

> Correct
> Correct! The focal length is needed to calibrate the stereo camera system.

- [ ] No further information is needed. Depth can be computed directly from the pixel disparity.

11. A naive solution for the stereo correspondence problem is an exhaustive search, where we search the whole right image for a match to every pixel in the left image. Why is this a bad approach? Select all that apply.

1 / 1 point

- [x] The naive approach results in a large number of incorrect matches due to similar pixels in different parts of the image

> Correct
> Correct! An exhaustive search for a stereo correspondence finds too many matches, which means that this strategy is unlikely to succeed.

- [x] This approach generally could not run in real time

> Correct
> Correct! An exhaustive search for the stereo correspondence takes considerable amount of computation time.

- [ ] Radial and tangential distortion make it difficult to match corresponding pixels with this approach because it distorts each image differently
- [ ] It is a good approach, and none of the concerns above is valid
- [ ] An exhaustive search can be performed only when the left and right images are taken with the same camera model. Otherwise, the images are too different and cannot be compared

12. What is the definition of an epipolar line for stereo cameras?

0 / 1 point

- ○ A straight line connecting the left and right camera centers in a stereo setup
- ◉ A straight line connecting the optical center of a camera and a point in the scene
- ○ A straight line that passes through the center of the lens and the camera sensor
- ○ A line produced in one camera as a point in 3D space is moved along a single ray emanating from the other camera's optical center
- ○ None of the above

Incorrect
Incorrect, this line indeed lies on the corresponding epipolar plane, however it is not the epipolar line. Please review Lesson 3 Part 2: Visual Depth Perception.

13. Recall that the first basic stereo algorithm which you saw in this module has four necessary steps. These steps are given to you below. Your task is to put them into correct order

1 / 1 point

(A) Compute disparity

(B) Pick the pixel that has minimum cost

(C) Consider each pixel on the epipolar line in the left image

(D) Compare the chosen pixels from the left image to every pixel in the right image on the same epipolar line

- ○ (D), (C), (B), (A)
- ○ (C), (D), (A), (B)
- ◉ (C), (D), (B), (A)
- ○ (C), (B), (D), (A)

Correct
Correct! This is correct order for computing disparity in a pair of stereo images.

14. Which of the below statements about correlation and convolution are correct?

0.8 / 1 point

- [ ] Template matching can only be performed with a convolution filter and not with a cross-correlation filter
- [ ] A convolution filter and a cross-correlation filter are the same if the kernel is symmetric
- [x] A convolution kernel is a 180 degrees rotated cross-correlation kernel

Correct
Correct! You can see this from the convolution and cross-correlation equations.

- [x] The order of multiplication of convolution kernels does not matter

Correct
Correct! Convolution is associative.

- [ ] Cross-correlation is associative

You didn't select all the correct answers

15. Which of these 3X3 image filters is a Gaussian filter?

1 / 1 point

( ) Filter 1:

$$\frac{1}{9}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

(•) Filter 2:

$$\frac{1}{16}\begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix}$$

( ) Filter 3:

$$\frac{1}{10}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 2 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

( ) Filter 4:

$$\begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$$

( ) None of the above

Correct
Incorrect, this is a Gaussian filter. Please review Lesson 4: Image Filtering.

Week 2

Programming Assignment: Visual Odometry for Localization in Autonomous Driving

Feature Extraction

```
def extract_features(image):
    surf = cv2.xfeatures2d.SURF_create(500)
    kp, des = surf.detectAndCompute(image,None)

    return kp, des
```

Extract Feature Dataset

```
def extract_features_dataset(images, extract_features_function):
    kp_list = []
    des_list = []

    for i in range(len(images)):
        kp, des = extract_features_function(images[i])
        kp_list.append(kp)
        des_list.append(des)

    return kp_list, des_list
```

Match Feature

```
def match_features(des1, des2):
    FLANN_INDEX_KDTREE = 1
    index_params = dict(algorithm = FLANN_INDEX_KDTREE, trees=5)
    search_params = dict(checks=50)

    flann = cv2.FlannBasedMatcher(index_params, search_params)
    match = flann.knnMatch(des1, des2, k=2)

    return match
```

Filter Matches Distance

```
def filter_matches_distance(match, dist_threshold):
    filtered_match = []

    for i, (m, n) in enumerate(match):
        if m.distance < dist_threshold * n.distance:
            filtered_match.append(m)
```

```
    return filtered_match
```

Match Features Dataset

```
def match_features_dataset(des_list, match_features):
    matches = []

    for i in range(len(des_list)-1):
        match = match_features(des_list[i], des_list[i+1])
        matches.append(match)

    return matches
```

Filter Matches Dataset

```
def filter_matches_dataset(filter_matches_distance, matches, dist_threshold):
    filtered_matches = []

    for m in matches:
        match = filter_matches_distance(m, dist_threshold)
        filtered_matches.append(match)

    return filtered_matches
```

Estimate Motion

```
def estimate_motion(match, kp1, kp2, k, depth1=None):
    rmat = np.eye(3)
    tvec = np.zeros((3, 1))
    image1_points = []
    image2_points = []

    for m in match:
        train_idx = m.trainIdx
        query_idx = m.queryIdx

        p1x, p1y = kp1[query_idx].pt
        image1_points.append([p1x, p1y])

        p2x, p2y = kp2[train_idx].pt
        image2_points.append([p2x, p2y])

    E, mask = cv2.findEssentialMat(np.array(image1_points), np.array(image2_points), k)
    retval, rmat, tvec, mask = cv2.recoverPose(E, np.array(image1_points),
np.array(image2_points), k)

    return rmat, tvec, image1_points, image2_points
```

Estimate Trajectory

```
def estimate_trajectory(estimate_motion, matches, kp_list, k, depth_maps=[]):
    trajectory = [np.zeros((3,))]  # Start with the initial position at the origin

    R = np.eye(3)
    T = np.zeros((3, 1))
    RT = np.hstack([R, T])
    RT = np.vstack([RT, np.zeros((1, 4))])
    RT[-1, -1] = 1

    for i in range(len(matches)):
        match = matches[i]
        kp1 = kp_list[i]
        kp2 = kp_list[i+1]

        if depth_maps:
            depth = depth_maps[i]
            rmat, tvec, image1_points, image2_points = estimate_motion(match, kp1, kp2, k,
depth1=depth)
        else:
            rmat, tvec, image1_points, image2_points = estimate_motion(match, kp1, kp2, k)

        rt_mat = np.hstack([rmat, tvec])
        rt_mat = np.vstack([rt_mat, np.zeros((1, 4))])
        rt_mat[-1, -1] = 1

        rt_mat_inv = np.linalg.inv(rt_mat)

        RT = np.dot(RT, rt_mat_inv)
        new_trajectory = RT[:3, 3]
        trajectory.append(new_trajectory)

    trajectory = np.array(trajectory).T

    return trajectory
```

Week 3

Quiz: Feed-Forward Neural Networks

1. A feedforward neural network has an input layer, 5 hidden layers and an output layer. What is the **depth** of this neural network?

1 / 1 point

6

Correct

2. During training, the training data specifies the exact form of the hidden layers of a neural network.

1 / 1 point

- ○ True
- ◉ False

Correct

3. Implement the ReLU activation function using numpy by replacing **None** in the code bellow.

0 / 2 points

```
1   import numpy as np
2
3   def ReLU(x):
4
5     y = np.max([0, x])
6
7     return y
```

Run

Reset

No Output

Incorrect

RuntimeErrorElement(RuntimeError,Error on line 5:
y = np.max([0, x]))

4. The main building blocks of a machine learning system are: (Check all that apply.)

1 / 1 point

- [ ] Output Layers
- [x] An Optimization Procedure

Correct
Correct!

- [ ] Hidden layers
- [x] A loss function

Correct
Correct!

- [x] A Model

Correct
Correct!

5. Which output unit/loss function pair is usually used for regression tasks that use neural networks?

1 / 1 point

- (●) Linear output units with Mean Squared Error Loss
- ( ) Softmax output units with Cross-Entropy Loss
- ( ) Sigmoid output units with Mean Squared Error Loss
- ( ) Linear output units with Cross-Entropy Loss

Correct
Correct!

6. The softmax output layer with cross-entropy loss is used to model the mean of a Gaussian distribution.

1 / 1 point

- ( ) True
- (●) False

Correct
Correct!

7. Which of the following might be used as a stopping condition for gradient descent. (Check all that apply.)

1 / 1 point

- [x] The number of iterations or epochs

Correct
Correct!

- [x] The magnitude of change in loss function value

Correct
Correct!

- [x] The magnitude of the change in parameter values

Correct
Correct!

- [ ] The value of the training loss

8. How are neural network **bias** parameters usually initialized at the beginning of training?

1 / 1 point

- (●) Initialized to 0.
- ( ) Initialized to samples from a standard normal distribution.
- ( ) Initialized to -1.
- ( ) Initialized to samples from a standard uniform distribution.

Correct

9. Using all samples to estimate the gradient of the loss function with respect to the parameter results in less than linear return in accuracy of this estimate.

1 / 1 point

- (●) True
- ( ) False

Correct
Correct!

10. You are working on a self-driving car project and want to train a neural network to perform traffic sign classification. You collect images with corresponding traffic sign labels, and want to determine the number of frames you will use for training. Given that you have around **one million** images with labels, what training/validation/testing data split would you use?

1 / 1 point

- ○ 100% training, 0% validation, 0% testing.
- ○ 20% training, 40% validation, 40% testing.
- ○ 60% training, 20% validation, 20% testing.
- ◉ 96% training, 2% validation, 2% testing.

Correct
Correct!

11. You finish training your traffic sign classifier, and want to evaluate its performance. You compute the classification accuracy on the training, validation, and testing data splits and get the following results:

2 / 2 points

Data Split	**Training**	**Validation**	**Testing**
Accuracy	70%	68%	67%

You know that a human has an accuracy of around 98% on the traffic sign classification task. What are things you might try to achieve human level performance? (Check all that apply.)

- [ ] Add regularization to your neural network.
- [ ] Collect more training data.
- [x] Add more layers to your neural network.

Correct
Correct!

- [x] Train your neural network longer.

Correct
Correct!

12. When a neural network overfits the training data, the generalization gap is usually very small.

1 / 1 point

- ○ True
- ◉ False

Correct
Correct!

13. Which of the following strategies are used for regularization in neural networks? (Check all that apply.)

1 / 1 point

- [x] Early Stopping

Correct
Correct!

- [ ] Increasing the number of parameters in the neural network architecture
- [ ] Training the neural network longer
- [x] Norm Penalties

Correct
Correct!

- [x] Dropout

Correct
Correct!

14. Dropout significantly limit the type of neural network models that can be used, and hence is usually used for specific architectures.

1 / 1 point

- ( ) True
- (•) False

Correct
Correct!

15. The name convolutional neural networks comes from the fact that these neural networks use a **convolution operation** instead of general matrix multiplication.

1 / 1 point

- ( ) True
- (•) False

Correct
Correct!

16. The input to a pooling layer has a **width, height and depth** of 224x224x3 respectively. The pooling layer has the following properties:

2 / 2 points

- **Kernel shape:** 2x2
- **Stride**: 2

What is the width of the output of this pooling layer?

112

Correct
Correct!

17. Using convolutions might reduce overfitting, as the number of parameters in convolutional layers is **less** than the number of parameters in fully connected layers.

1 / 1 point

- (selected) True
- False

Correct
Correct!

Week 4

Quiz: Object Detection For Self-Driving Cars

1. The object detection problem is defined as the locating objects in the scene, as well as classifying the objects' category.

   1 / 1 point

   - (x) True
   - ( ) False

   Correct
   Correct!

2. The problem of object detection is non-trivial. Which of the following statements describe reasons for the difficulty in performing object detection? (Check all that apply.)

   1 / 1 point

   - [x] Object size gets smaller as objects move farther away in a road scene.

     Correct
     Correct!

   - [ ] The objects that are usually of interest to detect are highly variable in shape and color.
   - [x] Extent of objects is not fully observed.

     Correct
     Correct!

   - [ ] Cameras are not reliable to perform detection in outdoor environments.
   - [x] Scene illumination is highly variable on road scenes.

     Correct
     Correct!

3. You are a self-driving car perception engineer developing an object detector for your self-driving car. You know that for your object detector to be reliable enough to deploy on a self-driving car, it should have a **minimum precision of** 0.99 and a **minimum recall of** 0.9. The precision and recall are to be computed at a **score threshold** of 0.9 and at an **IOU threshold** of 0.7.

2 / 2 points

You compute the IOU of your detector on a frame with ground truth to find out the following:

S_{car}	0.99	0.95	0.90	0.78	0.74
IOU	0.95	0.69	0.75	0.45	0

Assuming that the single frame shown above is sufficient to characterize the performance of the object detector, is your system reliable to be used on a self-driving car?

- ○ Yes
- ◉ No

Correct
Correct!

4. The **width and height** of the output of a convolutional feature extractor are usually an order of magnitude higher than those of its input.

1 / 1 point

- ○ True
- ◉ False

Correct
Correct!

5. The input to a convolutional layer has a **width, height and depth** of 224x224x3 respectively. The convolutional layer has the following properties:

1 / 1 point

- **Kernel shape:** 3x3x256
- **Stride**: 2
- **Padding**: 3

What is the depth of the output of this convolutional layer?

256

Correct
Correct!

6. When designing convolutional architectures for object detection, max pooling layers are usually placed in which of the following building blocks:

1 / 1 point

- ○ Prior anchor boxes
- ○ Loss function
- ○ Output fully connected layers
- ◉ Convolutional feature extractor

Correct
Correct!

7. 1. What type of output layer is most commonly used in the regression head of a convolutional object detector?

1 / 1 point

- ○ Softmax Layer
- ◉ Linear Layer
- ○ Sigmoidal Layer
- ○ Absolute Value Layer

Correct
Correct!

8. Prior anchor boxes are usually sampled at random in image space before being used in the output layers of an object detector.

1 / 1 point

- ○ True
- ◉ False

Correct
Correct!

9. While training an object detector, the cross entropy is calculated for the negative anchors **only.**

1 / 1 point

- ◉ True
- ○ False

Correct
Correct!

10. When training an object detection model, the regression loss has the form:

1 / 1 point

$$L_{reg} = \frac{1}{N_p} \sum_i p_i L_2(b_i, b_i^*)$$

where the L2 norm is computed for every member in the minibatch. For a **positive** minibatch members, the value of P_i is:

1

Correct
Correct!

11. During non-maximum suppression, the output bounding box list is sorted based on the value of every member's:

0 / 1 point

- (●) Regression loss
- ( ) IOU with ground truth
- ( ) Softmax output score
- ( ) Position in image space

Incorrect
This answer is incorrect. Please refer back to Lesson 3 in this module to review this material.

12. In context of self-driving cars, the output of object detectors can be used as a prior to perform which of the following tasks? (Check all that apply.)

1 / 1 point

- [x] 3D object detection

Correct
Correct!

- [x] Object tracking

Correct
Correct!

- [x] Traffic light state estimation

Correct
Correct!

- [ ] Drivable space estimation

13. One of the main advantages of using the output of 2D object detectors as a prior to 3D object detection is their ability to easily handle occlusion and truncation.

1 / 1 point

- ○ True
- ◉ False

Correct
Correct!

14. Sudden camera motion is detrimental to the performance of object trackers. This is because tracking usually assumes gradual change in the camera's pose relative to the scene.

1 / 1 point

- ◉ True
- ○ False

Correct
Correct!

Week 5

Quiz: Semantic Segmentation For Self-Driving Cars

1. Achieving smooth category boundaries is a major difficulty to take into account while designing semantic segmentation models. Which of the following statements describe the origins of this problem? (Check all that apply.)

1 / 1 point

- [ ] Objects within the same category having variable appearances. An example being multiple color and models for cars on the road.
- [x] Thin objects such as poles, tree trunks, and lane separators.

  Correct
  Correct!

- [x] The similarity in appearance between some categories such as road, curb, and sidewalk.

  Correct
  Correct!

2. When comparing the results of a semantic segmentation model to the ground truth, you found out that for the car category, its **class IOU** is **0.75**. Knowing that the number of false positives **(FP)** is **17**, and the number of false negatives **(FN)** is **3**, what is the number of true positives achieved by this model?

2 / 2 points

60

Correct
Correct!

3. To measure the performance of a semantic segmentation model over all classes, a good idea would be to average the class IOU.

1 / 1 point

- ( ) True
- (•) False

Correct
Correct!

4. Which of the following do you typically see in a Semantic Segmentation Model? (Check all that apply.)

0 / 1 point

- [x] Multiple Convolutional layers followed by an up-sampling layer.

Correct
Correct!

- [ ] Up-sampling layers in the encoder stage of the architecture.
- [x] Multiple Convolutional layers followed by a Pool layer.

Correct
Correct!

- [ ] Up-sampling layers in the decoder stage of the architecture.

You didn't select all the correct answers

5. Anchor boxes are an essential component of any semantic segmentation neural network architecture.

1 / 1 point

- ○ True
- ● False

Correct
Correct!

6. In your semantic segmentation model an input feature map is passed through a nearest neighbor up-sampling layer. The output feature map's depth is equal to that of the input feature map.

1 / 1 point

- ● True
- ○ False

Correct

7. A standard semantic segmentation architecture that uses a softmax output layer is allowed to associate multiple categories to a single pixel in the input image.

1 / 1 point

- ○ True
- ● False

Correct
Correct!

8. Which of the bellow loss functions is usually used to train semantic segmentation models?

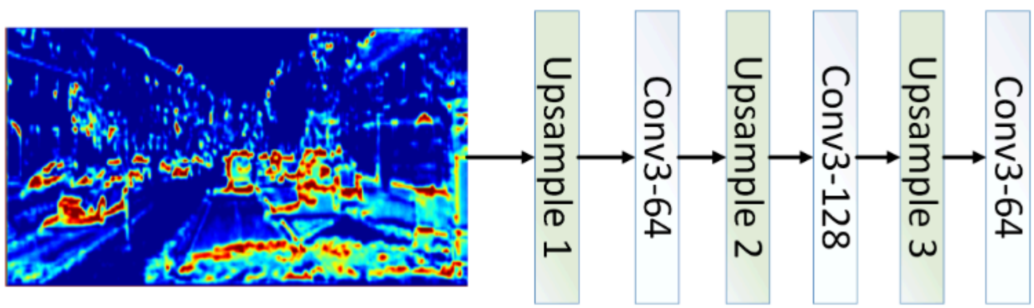
1 / 1 point

- ○ Mean Square Error (L2-Loss)
- ◉ Cross-Entropy Loss
- ○ 0-1 Loss
- ○ Mean Absolute Error (L1-Loss)

Correct
Correct!

9. A semantic segmentation model uses the following decoder architecture. The convolutions are all 3x3, have a padding size of 1, and have a number of filters shown in the figure. The up-sampling multiplier S is 2 for all upsampling layers.

2 / 2 point



If you pass an input of dimensions MxNxD through this decoder, what are the expected output dimensions?

Note: M is the width, N is the height, and D is the depth of the input.

- ◉ 8*M, 8*N, 64*D
- ○ 6*M, 6*N, 64*D
- ○ 8*M, 8*N, 128*D
- ○ M/8, N/8, 64*D

Correct
Correct!

10. In context of self-driving cars, semantic segmentation can be used to perform: (Check all that apply.) **1 / 1 point**

- [x] Drivable space estimation.

  Correct
  Correct!

- [ ] Velocity estimation of dynamic obstacles in the scene.
- [ ] Localization in a predefined 3D map.
- [x] Constrain the image space used to perform 2D object detection.

  Correct
  Correct!

- [x] Lane boundary estimation.

  Correct
  Correct!

11. Which of the following categories in a semantic segmentation output map would be useful to determine lane boundaries? **1 / 1 point**

- [ ] Road
- [x] Lane Separator

  Correct
  Correct!

- [x] Curb

  Correct
  Correct!

- [ ] Pedestrian
- [x] Sidewalk

  Correct
  Correct!

12. To estimate a plane model, an algorithm would require a minimum of:

1 / 1 point

- ( ) Five points, chosen at random.
- (x) Three points, chosen to be non-collinear.
- ( ) Three points, chosen to be collinear.
- ( ) Five points, chosen to be non-collinear.

Correct

13. To estimate lines that could belong to lanes in a post-processed output image from semantic segmentation, containing only relevant categories, one would:

1 / 1 point

- ( ) First apply Hough transform line estimation followed by Canny edge detection.
- ( ) First apply Canny edge detection followed by a Kalman Filter to estimate lines.
- ( ) Use RANSAC to estimate the road plane, then fit lines to its boundary.
- (x) First apply Canny edge detection followed by Hough transform line estimation.

Correct
Correct!

Week 6

Quiz: Semantic Segmentation For Self-Driving Cars

Module 4

Week 1

Module 1 Graded Quiz

1. Which are examples of common scenarios in the autonomous driving motion planning problem? **1 / 1 point**

- ○ A. Left and right turns
- ○ B. Driving up a hill
- ○ C. Lane changes
- ◉ D. A & C

Correct
Correct, left turns, right turns, and lane changes are all examples of common driving scenarios for the autonomous driving motion planning problem.

2. What are some examples of dynamic obstacles? **1 / 1 point**

- ○ A. Trees
- ○ B. Cyclists
- ○ C. Cars
- ○ D. Boulevards
- ◉ E. B & C

Correct
Correct, cyclists and cars are examples of dynamic obstacles.

3. True or false, the autonomous driving mission takes pedestrian behaviour into consideration.

0 / 1 point

- (x) True
- ( ) False

Incorrect
Incorrect. Please refer to Lesson 1 of Module 1 on Driving, Missions, Scenarios, and Behaviour to review this material.

4. True or false, "Staying Stopped" is a maneuver that is useful for handling traffic light controlled intersections.

1 / 1 point

- (x) True
- ( ) False

Correct
Correct, we require the car to stay stopped at a red light, so it is useful for traffic light controlled intersections.

5. Which of these are reasons for decomposing motion planning into a hierarchy of optimization problems?

1 / 1 point

- [x] A. More computationally efficient

Correct
Correct, breaking it into smaller problems helps efficiency.

- [x] B. Can tailor each optimization problem to specific level of abstraction

Correct
Correct, different levels of abstraction are appropriate for different sub-problems.

- [ ] C. Generates higher-quality solutions than solving the problem in its entirety
- [ ] D. None of the above

6. True or false, instantaneous curvature is the inverse of the instantaneous turning radius at a point on a curve.

1 / 1 point

- (•) True
- ( ) False

Correct
Correct, these two values are inversely related.

7. Static obstacles constrain...

1 / 1 point

- ( ) The car's lateral velocity
- ( ) The car's longitudinal velocity
- ( ) The turning radius of the car
- (•) The locations the car can occupy

Correct
Correct, for the car's path to remain collision free, the positions along its path cannot come into contact with the static obstacles surrounding it.

8. A leading vehicle in the ego vehicle's lane constrains...

1 / 1 point

- (•) The car's longitudinal velocity
- ( ) The turning radius of the car
- ( ) The car's lateral velocity
- ( ) The car's maximum jerk

Correct
Correct, we must regulate our speed relative to the speed of a leading vehicle to prevent a collision.

9. True or false, the time gap is the amount of time that it would take for the ego vehicle to reach the current position of its leading vehicle.

1 / 1 point

- (x) True
- ( ) False

Correct

Correct, the time gap is defined as the amount of time that it would take for the ego vehicle to reach the current position of its leading vehicle.

10. True or false, the friction ellipse is always a tighter constraint than the comfort rectangle.

1 / 1 point

- ( ) True
- (x) False

Correct

Correct, in general, the friction ellipse is a looser constraint than the comfort rectangle.

11. To generate the shortest path to a point, we need to minimize...

1 / 1 point

- ( ) Curvature
- ( ) Angular velocity
- (x) Arc length

Correct

Correct, the length of a path is given by its arc length.

12. The integral of difference (IOD) term in a planning objective function can be used to...

1 / 1 point

- A. Improve path smoothness
- B. Track a reference velocity profile
- C. Track a reference path
- D. B & C

Correct

Correct, it is useful for tracking both a reference velocity profile as well as a reference path.

13. True or false, jerk is the derivative of acceleration with respect to time.

1 / 1 point

- True
- False

Correct

Correct, this is the definition of jerk.

14. True or false, maximizing jerk increases the comfort of our planned trajectory.

1 / 1 point

- True
- False

Correct

Correct, maximizing jerk will make the ride less comfortable for our passengers.

15. The ______ at each point in the path constrains the velocity that can be driven at that point, due to the lateral acceleration constraints.

1 / 1 point

- (●) Curvature
- ( ) X position
- ( ) Y position
- ( ) Heading

Correct
Correct, the curvature of the path is what constrains our maximum velocity, due to our lateral acceleration constraints.

16. True or false, mission planning focuses on map-level navigation from the ego vehicle's current position to a final destination.

1 / 1 point

- (●) True
- ( ) False

Correct
Correct, mission planning is a higher-level planning sub-problem.

17. What are some examples of the inputs a finite state machine might take in the context of behaviour planning for autonomous driving?

1 / 1 point

- [x] Traffic light transitions

Correct
Correct, this is an important regulatory element that needs to be handled.

- [ ] The number of passengers in the ego vehicle
- [x] Vehicle positions

Correct
Correct, this is critical for determining ego vehicle behaviour.

- [x] Pedestrian locations

Correct
Correct, pedestrians are important agents in the driving task space.

18. True or false, reinforcement learning relies on interacting with an environment during the learning process.

1 / 1 point

- (•) True
- ( ) False

Correct
Correct, learning by interaction is critical for reinforcement learning.

19. What is a drawback of using a sampling-based method for path planning?

1 / 1 point

- (•) A. If run for a minimal number of iterations, it can generate poor quality paths
- ( ) B. It is often slow at exploring the workspace compared to other methods
- ( ) C. Sampling based methods are often computationally intractable
- ( ) D. None of the above

Correct
Correct, with two few iterations, even an asymptotically optimal sampling-based planner can produce low quality paths to the goal region.

20. True or false, a conformal lattice planner selects goal points ahead of the car that are laterally offset from the centerline of the road, plans paths to each goal point, then selects the best collision-free path according to some objective function.

0 / 1 point

- ○ True
- ◉ False

Incorrect

Incorrect. Please refer to Lesson 4 of Module 1 on Hierarchical Motion Planning to review this material.

Week 2

Programming Assignment: Occupancy Grid Generation

```
def inverse_scanner(num_rows, num_cols, x, y, theta, meas_phi, meas_r, rmax, alpha, beta):
    m = np.zeros((M, N))
    for i in range(num_rows):
        for j in range(num_cols):
            # Find range and bearing relative to the input state (x, y, theta).
            r = math.sqrt((i - x)**2 + (j - y)**2)
            phi = (math.atan2(j - y, i - x) - theta + math.pi) % (2 * math.pi) - math.pi

            # Find the range measurement associated with the relative bearing.
            k = np.argmin(np.abs(np.subtract(phi, meas_phi)))

            # If the range is greater than the maximum sensor range, or behind our range
            # measurement, or is outside of the field of view of the sensor, then no
            # new information is available.
            if (r > min(rmax, meas_r[k] + alpha / 2.0)) or (abs(phi - meas_phi[k]) > beta / 2.0):
                m[i, j] = 0.5

            # If the range measurement lied within this cell, it is likely to be an object.
            elif (meas_r[k] < rmax) and (abs(r - meas_r[k]) < alpha / 2.0):
                m[i, j] = 0.7

            # If the cell is in front of the range measurement, it is likely to be empty.
            elif r < meas_r[k]:
                m[i, j] = 0.3

    return m
```

```
def get_ranges(true_map, X, meas_phi, rmax):
    (M, N) = np.shape(true_map)
    x = X[0]
    y = X[1]
    theta = X[2]
    meas_r = rmax * np.ones(meas_phi.shape)

    # Iterate for each measurement bearing.
    for i in range(len(meas_phi)):
        # Iterate over each unit step up to and including rmax.
        for r in range(1, rmax+1):
            # Determine the coordinates of the cell.
            xi = int(round(x + r * math.cos(theta + meas_phi[i])))
            yi = int(round(y + r * math.sin(theta + meas_phi[i])))
```

```
        # If not in the map, set measurement there and stop going further.
        if (xi <= 0 or xi >= M-1 or yi <= 0 or yi >= N-1):
            meas_r[i] = r
            break
        # If in the map, but hitting an obstacle, set the measurement range
        # and stop ray tracing.
        elif true_map[int(round(xi)), int(round(yi))] == 1:
            meas_r[i] = r
            break

    return meas_r
```

Week 3

Practice Assignment: Road Network Shortest Path Search

```
# For a given graph, origin vertex key, and goal vertex key,
# computes the shortest path in the graph from the origin vertex
# to the goal vertex using Dijkstra's algorithm.
# Returns the shortest path as a list of vertex keys.
def dijkstras_search(origin_key, goal_key, graph):

    # The priority queue of open vertices we've reached.
    # Keys are the vertex keys, vals are the distances.
    open_queue = priority_dict.priority_dict({})

    # The dictionary of closed vertices we've processed.
    closed_dict = {}

    # The dictionary of predecessors for each vertex.
    predecessors = {}

    # Add the origin to the open queue.
    open_queue[origin_key] = 0.0

    # Iterate through the open queue, until we find the goal.
    # Each time, perform a Dijkstra's update on the queue.
    # TODO: Implement the Dijstra update loop.
    goal_found = False
    while (open_queue):
        u, ucost = open_queue.pop_smallest()
        if u == goal_key:
            goal_found = True
            break
        for edge_dict in graph.out_edges([u], data=True):
            v = edge_dict[1]
            if v in closed_dict:
                continue
            uvcost = edge_dict[2]['length']
            if v in open_queue:
                vcost = open_queue[v]
                if ucost + uvcost < vcost:
                    open_queue[v] = ucost + uvcost
                    predecessors[v] = u
            else:
                open_queue[v] = ucost + uvcost
                predecessors[v] = u
        closed_dict[u] = 1

    # If we get through entire priority queue without finding the goal,
```

```
    # something is wrong.
    if not goal_found:
        raise ValueError("Goal not found in search.")

    # Construct the path from the predecessors dictionary.
    return get_path(origin_key, goal_key, predecessors)
```

```
# For a given graph, origin vertex key, and goal vertex key,
# computes the shortest path in the graph from the origin vertex
# to the goal vertex using A* search.
# Returns the shortest path as a list of vertex keys.
def a_star_search(origin_key, goal_key, graph):
    # The priority queue of open vertices we've reached.
    # Keys are the vertex keys, vals are the accumulated
    # distances plus the heuristic estimates of the distance
    # to go.
    open_queue = priority_dict.priority_dict({})

    # The dictionary of closed vertices we've processed.
    closed_dict = {}

    # The dictionary of predecessors for each vertex.
    predecessors = {}

    # The dictionary that stores the best cost to reach each
    # vertex found so far.
    costs = {}

    # Get the spatial data for each vertex as a dictionary.
    node_data = graph.nodes(True)

    # Add the origin to the open queue and the costs dictionary.
    costs[origin_key] = 0.0
    open_queue[origin_key] = distance_heuristic(origin_key, goal_key, node_data)

    # Iterate through the open queue, until we find the goal.
    # Each time, perform an A* update on the queue.
    # TODO: Implement the A* update loop.
    goal_found = False
    while (open_queue):
        u, uheuristic = open_queue.pop_smallest()
        ucost = costs[u]
        if u == goal_key:
            goal_found = True
            break
        for edge_dict in graph.out_edges([u], data=True):
            v = edge_dict[1]
            if v in closed_dict:
```

```
            continue
        uvcost = edge_dict[2]['length']
        if v in open_queue:
            vcost = costs[v]
            if ucost + uvcost + distance_heuristic(v, goal_key, node_data) < open_queue[v]:
                open_queue[v] = ucost + uvcost + distance_heuristic(v, goal_key, node_data)
                costs[v] = ucost + uvcost
                predecessors[v] = u
        else:
            costs[v] = ucost + uvcost
            open_queue[v] = ucost + uvcost + distance_heuristic(v, goal_key, node_data)
            predecessors[v] = u
    closed_dict[u] = 1


# If we get through entire priority queue without finding the goal,
# something is wrong.
if not goal_found:
    raise ValueError("Goal not found in search.")

# Construct the path from the predecessors dictionary.
return get_path(origin_key, goal_key, predecessors)
```

Module 3 Graded Quiz

1. Which best describes the mission underlying an autonomous vehicle's mission planner?

1 / 1 point

- ○ Compute the optimal vehicle behaviour for a given driving scenario
- ○ Generate an optimal, collision-free path to the required destination
- ◉ Navigate a road network to the desired destination from the ego vehicle's position

Correct
Correct, this is the underlying goal of mission planning.

2. Which of these are examples of good values to optimize in a mission planner's objective function?

1 / 1 point

- [ ] Distance from obstacles
- [x] Distance travelled

Correct
Correct, this is a good measure of the efficiency of a global path.

- [ ] Deviation from the speed limit
- [x] Time to destination

Correct
Correct, this is a good measure of the efficiency of a global path.

3. What is a graph in the mission planning context?

1 / 1 point

- ( ) A plot of the car's throttle and steering actuation while executing a driving mission
- ( ) A chart of the different speeds reached during different road segments in a road network
- (•) A discrete mathematical structure used for representing the road network
- ( ) None of the above

Correct
Correct, we are referring to the graph commonly used in discrete math.

4. True or false, Breadth-First Search (BFS) will explore the graph using a "last-in-first-out" data structure known as a stack.

0 / 1 point

- (•) True
- ( ) False

Incorrect
Incorrect. Please refer to Lesson 1 of Module 3 on Creating a Road Network Graph to review this material.

5. True or false, Breadth-First Search (BFS) will always find the optimal (shortest) path in an unweighted graph.

1 / 1 point

- (selected) True
- False

Correct
Correct, BFS will explore all possible predecessors before reaching the goal node in an unweighted graph, and as a result will find the shortest path to the goal.

6. True or false, Breadth-First Search (BFS) will always find the optimal (shortest) path in a weighted graph.

1 / 1 point

- True
- (selected) False

Correct
Correct, BFS will not always be able to find the shortest path if the graph edges have weights.

7. In these graph search algorithms, what is the main purpose of keeping track of a "closed" set of graph vertices?

0 / 1 point

- It helps us keep track of which vertices we still need to search
- (selected) It allows us to know how much of the graph has been searched
- It allows us to avoid getting stuck in cycles

Incorrect
Incorrect. Please refer to Lesson 2 of Module 3 on Dijkstra's Shortest Path Search to review this material.

8. What is a min heap data structure?

1 / 1 point

- ( ) A data structure that stores keys and values, and sorts the keys in terms of their associated values, from largest to smallest.
- ( ) A sorted list of autonomous driving mission priorities for a given driving scenario
- (•) A data structure that stores keys and values, and sorts the keys in terms of their associated values, from smallest to largest.
- ( ) A block of memory useful for dynamic memory allocation

Correct
Correct, this is the definition of a min heap.

9. True or false, in a min heap, the root of the heap (the first element) contains the node with the smallest value.

1 / 1 point

- (•) True
- ( ) False

Correct
Correct, a min heap contains the node with the smallest value at the root.

10. In Dijkstra's algorithm, suppose during the process of adding vertices to the open set, we come across a vertex that has already been added to the open set. However, this time we have found a lower cost to reach this vertex than is presently stored in the open set's min heap. What should be done?

1 / 1 point

- ( ) Close the vertex, as we have now seen it twice during exploration
- ( ) Nothing, as this is impossible under Dijkstra's algorithm
- ( ) Nothing, as the vertex is already in the open set
- (•) Update the cost of that vertex in the open set's min heap

Correct
Correct, we will need to update the min heap to reflect the new path that we have found to that vertex for Dijkstra's algorithm to remain correct.

11. What is a search heuristic in the context of mission planning?

1 / 1 point

- (selected) An estimate of the remaining cost to reach the destination
- Something that helps the autonomous vehicle efficiently change the autonomus driving mission depending on the situation
- A method that allows the autonomous vehicle to quickly identify obstacles in its surroundings
- A tool that autonomous vehicle's use for quickly identifying traffic congestion at a given intersection

Correct
Correct, this cost-to-go helps guide our search to improve speed.

12. Suppose I have a vertex at location (2.0, 3.0) and another at location (4.0, 5.0). What is the Euclidean distance between these two points (to three decimal places)?

1 / 1 point

2.828

Correct
Correct

13. True or false, an admissable heuristic to the A* search algorithm will never underestimate the cost to reach the goal vertex.

1 / 1 point

- True
- (selected) False

Correct
Correct, an admissable heuristic is required to never overestimate the cost to reach the goal vertex.

14. Is the heuristic function h(v) = 0 an admissible heuristic?

1 / 1 point

- ○ No, as in this case A* degenerates into Dijkstra's
- ○ Yes, and in this case A* degenerates into BFS
- ○ No, as in this case A* degenerates into BFS
- ◉ Yes, and in this case A* degenerates in DIjkstra's

Correct
Correct, a zero-valued heuristic is admissible, and in this case A* is the same as Dijkstra's.

15. True or false, the min heap in A* contains the sum of the cost to reach each vertex plus the estimate of the cost to reach the destination from said vertex, according to the search heuristic.

1 / 1 point

- ◉ True
- ○ False

Correct
Correct, this is required to take advantage of the search heuristic.

Week 4

Module 4 Graded Quiz

1. Which of the following best describes an example of a maneuver-based prediction assumption for motion prediction? 1 / 1 point

   - ○ The kinodynamic constraints on a vehicle restricts its potential set of motions
   - ◉ The operating domain of a vehicle restricts the number of feasible or probable maneuvers it can take
   - ○ Certain vehicle models restrict vehicle maneuverability, reducing the prediction space
   - ○ The behaviour of other agents on the road reduces the space of potential actions

   Correct
   Correct, the operating domain restricts which maneuvers are feasible depending on the conditions of the scenario.

2. Which of the following best describes an example of an interactions-aware prediction assumption for motion prediction? 1 / 1 point

   - ○ Engine dynamics are affected by pedestrian motion, restricing the space of potential actions
   - ○ The kinodynamic constraints on a vehicle restricts its potential set of motions
   - ◉ The behaviour of other agents on the road reduces the space of potential actions
   - ○ The operating domain of a vehicle restricts the number of feasible or probable maneuvers it can take

   Correct
   Correct, the behaviour of other agents results in interactions with the ego vehicle that restricts the ego vehicle's behaviour.

3. Which of the following are aspects of pedestrian motion?

1 / 1 point

- [x] Low top speed, but rapid changes in direction and speed are possible

Correct
Correct, pedestrians move slowly but with a high variance in direction.

- [ ] High top speed, but must obey the rules of the road
- [x] Potential to leave designated areas unpredictably

Correct
Correct, pedestrian behaviour can be unpredictable.

- [ ] They often have designated lanes on roads due to their slower speed

4. Which of the following are scenarios for which constant velocity estimation provides a useful estimate?

0 / 1 point

- [ ] Roundabouts
- [x] Straight roads

Correct
Correct - Straight roads are the only situation where constant velocity assumptions can be true.

- [ ] Turns and curved roads
- [x] Traffic light controlled intersections

This should not be selected
Incorrect. Please refer to Lesson 1 of Module 4 on Motion Prediction to review this material.

5. Which of the following are issues with constant velocity prediction?

1 / 1 point

- [x] Doesn't fully account for vehicle kinodynamics

> Correct
> Correct, constant velocity assumptions ignore potential acceleration of the vehicle.

- [ ] Computationally expensive
- [x] Ignores the shape of the road

> Correct
> Correct, the road shape does not affect a constant velocity prediction.

- [x] Ignores regulatory elements

> Correct
> Correct, a constant velocity prediction is unaware of regulatory elements.

6. Which of the following are position-based assumptions for map-aware prediction algorithms?

1 / 1 point

- [x] Vehicles driving down a lane are likely to follow that lane

> Correct
> Correct, vehicles are likely to follow their current lane based on their position in the map.

- [ ] Stop signs will cause vehicles to decelerate to a complete stop
- [x] Lane changes can be predicted based on the state of the blinker light of a vehicle

> Correct
> Correct, this is possible if the other vehicle is in a position to perform a lane change in the map.

- [ ] A high-curvature road segment necessitates a slower vehicle speed

7. Which of the following are velocity-based assumptions for map-aware prediction algorithms? **1 / 1 point**

- [x] A yellow light will cause vehicles to reduce their velocity as they approach an intersection

Correct
Correct, this is a necessity for other vehicles to drive safely.

- [x] Stop signs will cause vehicles to decelerate to a complete stop

Correct
Correct, this is required by law.

- [ ] Lane markings enforce constraints on the location of vehicles in the road
- [x] A high-curvature road segment necessitates a slower vehicle speed

Correct
Correct, high curvature results in high lateral forces, restricting speed.

8. True or false, the more constraints added to our prediction model, the less generalizable it is to all possible traffic scenarios. **1 / 1 point**

- (●) True
- ( ) False

Correct
Correct, it can become too specialized to specific scenarios.

9. True or false, in the case of the multi-hypothesis prediction approach, the most likely nominal behaviour of a dynamic obstacle based on its state, appearance, and track information is taken as the object's predicted motion. **1 / 1 point**

- ( ) True
- (●) False

Correct
Correct, the multi-hypothesis approach instead assigns probabilities to each of the nominal maneuvers available to the dynamic obstacle.

10. Which of the following are properties of multi-hypothesis prediction approaches?

0.75 / 1 point

- [x] Provides a probability distribution over nominal predictions based on the state of the environment.

Correct
Correct, each hypothesis has an associated probability.

- [x] Offers alternative predictions, allowing for fast replanning in case new information arises

Correct
Correct, there are multiple predictions available.

- [ ] Can result in ambiguous predictions
- [ ] Provides a maximum likelihood estimate based on the information present in the current traffic scenario

You didn't select all the correct answers

11. At a high level, what best describes the two fundamental steps in computing time to collision?

1 / 1 point

- ( ) Estimating the first vehicle position, then estimating the other vehicle's velocity
- ( ) Running trajectory rollout to generate potential paths, then checking each path for intersection points
- (•) Compute the location of a collision point along the predicted paths of the dynamic objects, then compute the amount of time to reach said collision point
- ( ) None of the above

Correct
Correct, this outlines the general process of computing time to collision.

12. True or false, the simulation based approach propogates the movement of every vehicle in the scene over a given time horizon into the future, where the state is computed at multiple time steps along the horizon.

1 / 1 point

- (●) True
- ( ) False

Correct
Correct, with this method we are forward simulating the entire scenario.

13. In estimation-based approaches, which of the following are some of the common simplifying assumptions used in the swath intersection computation?

0.75 / 1 point

- [x] Estimating spatial occupancy using simple geometric primitives

Correct
Correct, these can allow for efficient computation.

- [x] Identifying collision points based on path intersection points

Correct
Correct, these are often easy to compute.

- [ ] Assuming the objects ignore regulatory elements
- [ ] Assuming a constant speed profile along an object's predicted path

You didn't select all the correct answers

14. Suppose two vehicles are approximated with a single circle each. The center of one circle is at (1.0 m, 3.0 m) and the other is at (4.0 m, 2.0 m). If the radius of both collision checking circles is 1.5 m, will a collision be detected?

1 / 1 point

- ○ Yes
- ◉ No

Correct
Correct, the distance between the circle centers is greater than the sum of the collision circle radii.

15. Suppose two vehicles, a leading vehicle and a following vehicle, are moving along a straight line. The center of the leading vehicle is 20 m ahead of the center of the following vehicle. The leading vehicle is moving at 15 m/s, and the following vehicle is moving at 20 m/s. The distance from the center to the front bumper of both vehicles is 2.5 m, and the distance from the center to the rear bumper of both vehicles is 2.5 m. What is the time to collision in this scenario?

1 / 1 point

3

Correct
Correct

Week 5

Module 5 Graded Quiz

1. True or false, behavioural planning does not need to take dynamic obstacles into consideration, as it is too low level and should be handled by the local planner.

1 / 1 point

- True
- (selected) False

Correct
Correct, dynamic obstacles are at the correct level of abstraction for behavioral planning and therefore are taken into consideration during the behavioural planning process.

2. As an autonomous vehicle approaches an intersection, which of the following best describes the role of a behavioural planner?

1 / 1 point

- Navigate through the map to find the most efficient path to the required destination.
- (selected) Plan when and where to stop, how long to stay stopped for, and when to proceed through the intersection
- Determine the throttle angle, brake, and steering angle required to track the reference path through the intersection
- Plan a path to the required goal state subject to static/dynamic obstacles and kinodynamic constraints

Correct
Correct, these steps are crucial for safe behaviour in an intersection.

3. What is the primary output of a behavioural planning module?

1 / 1 point

- (selected) The driving maneuver to be executed in the current environment
- A sequence of waypoints that correspond to a feasible, collision-free trajectory
- The throttle, brake, and steering angle values required for tracking the reference trajectory
- The sequence of road segments to be traversed to reach the destination

Correct
Correct, this is how the planner outputs the desired behaviour.

4. Which of the following are common inputs to the behavioural planner?

0.75 / 1 point

- [x] Localization information

Correct
Correct, this lets us know where we are in the map.

- [ ] A default path in the current lane to follow
- [ ] A mission plan
- [x] High definition roadmap

Correct
Correct, this is helpful for localizing other agents, and for map-aware prediction.

You didn't select all the correct answers

5. Which of the following are a disadvantage of using finite state machines for behavioural planning?

1 / 1 point

- ○ As the number of states decreases, it becomes more computationally complex to evaluate state transitions
- ● As the number of states increases, it becomes increasingly complicated to define all possible transition conditions
- ○ Finite state machines can only handle uncertainty when there are many states available
- ○ None of the above

Correct
Correct, this grows exponentially as we add more states.

6. Which portion of the intersection best describes when the ego vehicle is on the intersection?

1 / 1 point

- (●) The interior of the intersection
- ( ) The lane exiting the intersection
- ( ) The lane preceding the intersection
- ( ) None of the above

Correct
Correct, by our definitions in Lesson 2 of Module 5 on Handling an Intersection Scenario Without Dynamic Objects.

7. Which of the following can increase the size of the "approaching", "at", and "on" zones of an intersection?

0.5 / 1 point

- [ ] The speed of the ego vehicle
- [x] The number of dynamic obstacles present

This should not be selected
Incorrect. Please refer to Lesson 2 of Module 5 on Handling an Intersection Scenario Without Dynamic Objects to review this material.

- [ ] The size of the ego vehicle
- [x] The size of the intersection

Correct
Correct, as the size of the intersection increases, the size of the intersection zones increases accordingly.

8. For a 2-lane, 4-way intersection, which of the following maneuvers are absolutely required?

1 / 1 point

- [x] Decelerate to stop

Correct
Correct, this behaviour is required for any intersection.

- [x] Stop

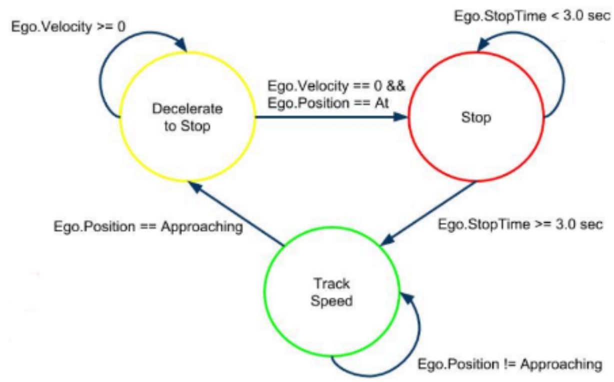
Correct
Correct, this behaviour is necessary for any intersection.

- [ ] Merge to lane
- [x] Track speed

Correct
Correct, this behaviour is required to make forward progress.

9. For this question, let us use our finite state machine discussed in Module 5 Lesson 2. Suppose the car has entered the "Stop" state while at the intersection. Which of the following is the correct transition condition for the vehicle to enter the "Track Speed" state?

1 / 1 point

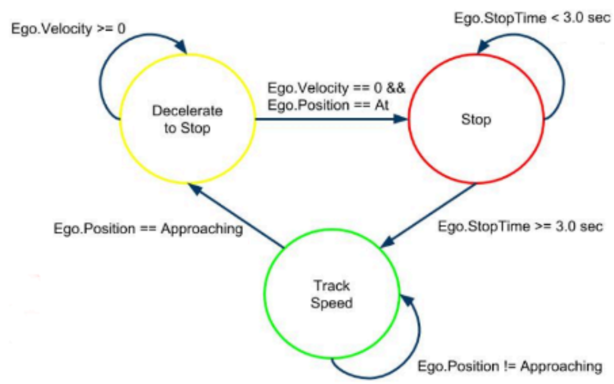


- ○ Ego.StopTime < 3.0 sec
- ○ Ego.Velocity >= 0
- ○ Ego.Position == Approaching
- ◉ Ego.StopTime >= 3.0 sec

Correct
Corrrect, we are required to remain at a complete stop before moving again.

10. For this question, let us use our finite state machine discussed in Module 5 Lesson 2. Suppose the car has entered the "Track speed" state before reaching any zone of the intersection. Which of the following is the correct transition condition for the vehicle to enter the "Decelerate to Stop" state?

1 / 1 point



- ( ) Ego.Position != Approaching
- (•) Ego.Position == Approaching
- ( ) Ego.StopTime < 3.0 sec
- ( ) Ego.Velocity >= 0

Correct
Correct, if we are approaching an intersection we need to decelerate.

11. Which of the following are the key aspects of dynamic objects that we focus upon in behavioural planning?

0.75 / 1 point

- [ ] Maximum velocity
- [x] Time to collision

Correct
Correct, this influences our behaviour with the dynamic object.

- [x] Distance to dynamic object

Correct
Correct, this is useful for determining the relevance of a dynamic object.

- [ ] Distance to collision point

You didn't select all the correct answers

12. Which of the following best describes the "Follow Leader" maneuver?

1 / 1 point

- (•) Follow the speed of, and maintain a safe distance from the lead vehicle
- ( ) In a safe and comfortable manner, decelerate to a complete stop to avoid the leading vehicle
- ( ) Accelerate to the speed of the lead vehicle, passing the lead vehicle if they are below our reference speed
- ( ) When a lead vehicle is performing a lane change, we wait until it is safe and follow them into the adjacent lane

Correct
Correct, this is according to our definition in Lesson 3 of Module 5 on Handling an Intersection Scenario With Dynamic Objects.

13. True or false, using the state machine developed in L3, when the ego vehicle is in the "Stop" state when in the presence of dynamic obstacles, it should transition to the "Track Speed" state after 3 seconds have elapsed.

0 / 1 point

- (•) True
- ( ) False

Incorrect
Incorrect. Please refer to Lesson 3 of Module 5 on Handling an Intersection Scenario With Dynamic Objects to review this material.

14. True or false, using the state machine developed in L3, suppose the ego vehicle is "at" the intersection, and is currently in the "Stop" state and 3 seconds have elapsed. Suppose the only dynamic obstacle is "on" the intersection has a heading of 180 degrees relative to the ego heading, and suppose the ego vehicle intends to drive straight. Which state will the state machine transition to?

1 / 1 point

- ○ Decelerate to Stop
- ○ Stop
- ○ Follow Leader
- ◉ Track Speed

Correct
Correct, the dynamic obstacle is heading in the opposite direction of the ego vehicle, and thus does not interfere with the ego vehicle's desire to proceed straight. Since 3 seconds have elapsed, it will transition to "Track Speed".

15. True or false, using the state machine developed in L3, suppose the ego vehicle is "at" the intersection, and is currently in the "Stop" state and 3 seconds have elapsed. Suppose the only dynamic obstacle is "on" the intersection has a heading of 180 degrees relative to the ego heading, and suppose the ego vehicle intends to turn left. Which state will the state machine transition to?

0 / 1 point

- ○ Track Speed
- ○ Stop
- ○ Decelerate to Stop
- ◉ Follow Leader

Incorrect
Incorrect. Please refer to Lesson 3 of Module 5 on Handling an Intersection Scenario With Dynamic Objects to review this material.

16. Which of the following are disadvantages of using a single state machine to handle multiple scenarios?

0.75 / 1 point

- [ ] Not able to handle a small set of scenarios
- [x] Rule explosion when adding new scenarios to the state machine

Correct
Correct, transition rules grow exponentially with the number of states.

- [ ] Complicated to create and maintain all possible cases
- [x] The amount of computation time required at each step

Correct
Correct, many different conditions will need to be checked at each step.

You didn't select all the correct answers

17. True or false, an example of a hierarchical state machine in the behavioural planning context involves superstates representing each potential scenario and substates representing the maneuvers to be handled in each scenario.

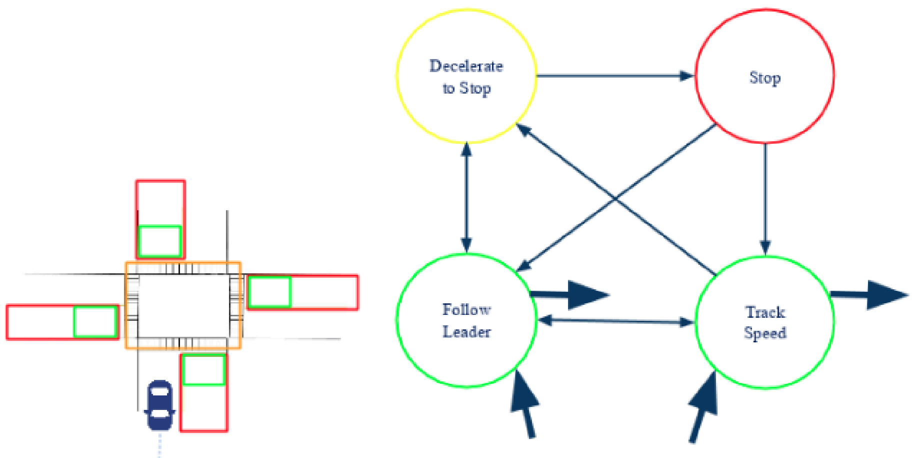
1 / 1 point

- (●) True
- ( ) False

Correct
Correct

18. Following the hierarchical state machine introduced in Module 5 Lesson 4, if we are exiting the intersection and we are currently in the "Intersection Scenario" superstate, which substates of the "Intersection Scenario" will allow us to change to a different superstate?

1 / 1 point



- [ ] Declerate to Stop
- [ ] Stop
- [x] Follow Leader

Correct
Correct, while performing lead vehicle speed tracking we can transition to a different super state.

- [x] Track Speed

Correct
Correct, while performing nominal speed tracking we can transition to a different super state.

19. True or false, the hierarchical state machine is immune to the effects of rule explosion.

1 / 1 point

- ( ) True
- (•) False

Correct
Correct, while the hierarchical state machine can allow for its designer to add more complexity to the system, it is still affected by rule explosion as there are many duplicative transitions in each superstate's state machine.

20. True or false, the hierarchical state machine limits the amount of computation time at each time step by restructuring the search space more efficiently.

0 / 1 point

- ○ True
- ◉ False

Incorrect
Incorrect. Please refer to Lesson 4 of Module 5 on Handling Multiple Scenarios to review this material.

21. Which of the following are some issues with the state machine approaches presented in Lessons 1-4?

0.75 / 1 point

- ☐ There is no method to handle multiple scenarios when using state machines
- ☑ The number of hyperparameters required increases as the behaviours get more complex, and inputs get more noisy

Correct
Correct, the complexity of computation grows quickly as the number of desired behaviours increases.

- ☐ The state machines discussed are only able to handle noise in very limited situations
- ☑ State machines are unlikely to handle situations that have not been explicitly programmed

Correct
Correct, they do not generalize well to unforeseen scenarios.

You didn't select all the correct answers

22. What is an advantage of rule based systems over state machines?

1 / 1 point

- ○ Rule based systems can handle multiple scenarios
- ◉ Rule based systems do not duplicate transitions, as rules can apply throughout significant portions (or all of) the ODD
- ○ Rule based systems do not require as much attention as state machines do, as rules do not impact one another
- ○ None of the above

Correct
Correct, this results in higher planning efficiency.

23. True or false, fuzzy logic systems are more robust to environmental noise than traditional discrete systems, such as a finite state machine.

1 / 1 point

- (●) True
- ( ) False

Correct
Correct, they can handle a wider range of inputs and as a result are more robust to noise.

24. True or false, reinforcement learning involves clustering unlabeled data to inform the behavioural planner on the best course of action in each scenario.

1 / 1 point

- ( ) True
- (●) False

Correct
Correct, reinforcement learning is a form of machine learning in which an agent learns how to interact with a given environment by taking action and receiving continuous rewards.

25. Which of the following are some of the shortcomings of reinforcement learning approaches for behavioural planning?

1 / 1 point

- [ ] Reinforcement learning do not generalize well to scenarios that weren't explicitly programmed
- [x] The model simplicity used for reinforcement learning means the results transfer poorly to real-world scenarios

Correct
Correct, to remain tractable reinforcement learning models are often too simple for what is required in the real world.

- [ ] Reinforcement learning is unable to handle continuous variables, such as the distance to a dynamic obstacle, and these are commonly used in behavioural planning
- [x] It is challenging to perform rigorous safety assessment or safety guarantees of learned systems, as they are largely black boxes

Correct
Correct, the policies learned by reinforcement learning are often not human-interpretable

Week 6

Module 6 Graded Quiz

1. True or false, a kinematic model gives the equations of motion for our robot, while disregarding the impacts of mass and inertia.

1 / 1 point

- (●) True
- ( ) False

Correct
Correct, kinematic models focus on motion and not mass or inertia.

2. True or false, a dynamic model is a model used exclusively for rotating robots.

0 / 1 point

- (●) True
- ( ) False

Incorrect
Incorrect. Please refer to Lesson 1 of Module 6 on Trajectory Propagation to review this material.

3. For the bicycle model, the state of the robot contains which of the following values?

1 / 1 point

- [x] X Position

Correct
Correct, the position and heading form the state in the bicycle model.

- [x] Heading

Correct
Correct, the position and heading form the state in the bicycle model.

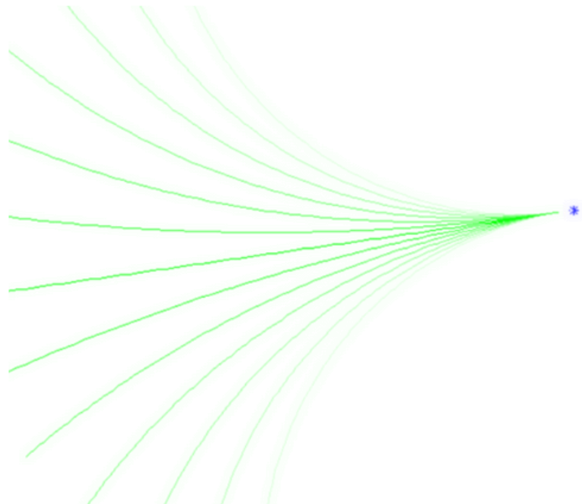
- [x] Y Position

Correct
Correct, the position and heading form the state in the bicycle model.

- [ ] Curvature

4. For this image, assuming each path is of equal length, what input parameter to the bicycle model is being varied across each path?

1 / 1 point



- (selected) Steering Angle
- Velocity

Correct
Correct, each path is of equal length in the same time horizon, so they must have the same velocity. Each path corresponds to an arc of different curvature, so the steering angle must vary across each path.

5. True or false, implementing trajectory propagation recursively is slower than computing the entire sum at each step.

1 / 1 point

- True
- (selected) False

Correct
Correct, implementing trajectory propagation recursively is much more efficient than re-computing the entire sum at each step.

6. Why is collision checking computationally challenging in exact form?

1 / 1 point

- [ ] It requires perfect information about the surroundings
- [ ] It requires heavy geometric computation in a continuous domain
- [ ] The problem scales with the number of obstacles in a given scene
- [x] All of the above

Correct
Correct, all of these contribute to the challenge of collision checking.

7. What is the swath of an autonomous vehicle as it drives along a path?

1 / 1 point

- [ ] The entire region surrounding an autonomous vehicle that is safe for traversal in a given driving situation
- [x] The union of all sets of space occupied by the autonomous vehicle as it traverses the path
- [ ] The region surrounding an autonomous vehicle that is occupied by static obstacles in a given driving situation

Correct
Correct, this is the space the car occupies along the path.

8. Suppose the ego vehicle is currently at the origin, (0.0, 0.0, 0.0), and one of the points in its footprint is at (0.5, 0.5).
One point along the ego vehicle's path is (3.0, 2.0, pi/4).
After performing rotation and translation on this footprint point relative to this path point, what is the footprint point's corresponding position?

1 / 1 point

- [ ] (3.0, 3.0)
- [x] (3.0, 2.707)
- [ ] (3.707, 3.0)
- [ ] (3.707, 2.0)

Correct
Correct, this comes from rotating the point about the origin by pi/4 and then translating it by (3.0, 2.0).

9. True or false, swath-based collision checking sweeps the ego vehicle's footprint along its path, and checks to see if any obstacles lie within this set of space.

1 / 1 point

- (●) True
- ( ) False

Correct
Correct, swath-based collision checking computes the union of all footprints along the ego vehicle's path, then checks if obstacles lie within the region given by the swath.

10. Which of the following is not true about circle based collision checking?

0 / 1 point

- ( ) It conservatively approximates the vehicle footprint using multiple circles
- (●) It uses circles to quickly estimate collision points by checking if the distance to an obstacle is less than any circle radius
- ( ) It uses the friction circle to estimate how close the ego vehicle can be to nearby obstacles
- ( ) It relies on discretizing the path into a sequence of points that the circles can be rotated and translated to

Incorrect
Incorrect. Please refer to Lesson 2 of Module 6 on Collision Checking to review this material.

11. To generate a set of arcs in the trajectory rollout algorithm, which input needs to be varied in our bicycle model?

1 / 1 point

- (●) Steering Angle
- ( ) Velocity
- ( ) Angular Acceleration
- ( ) Heading

Correct
Correct, by varying the steering angle we get a set of arcs of varying curvature.

12. What is the objective function used in the trajectory rollout algorithm for determining which trajectory to select from the trajectory set?

1 / 1 point

- ○ Maximize the distance from obstacles along the path
- ○ Minimize the integral of heading changes along the path
- ◉ Minimize the distance from end of trajectory to goal
- ○ Minimize the total absolute jerk along the path

Correct
Correct, by minimizing the distance from the end of the trajectory to the goal region, we greedily search for the goal region.

13. True or false, for a fixed velocity, larger steering angles will result in larger curvatures in our bicycle model.

1 / 1 point

- ◉ True
- ○ False

Correct
Correct

14. True or false, the trajectory rollout algorithm finds an optimal path to the goal state according to the kinematic model.

1 / 1 point

- ○ True
- ◉ False

Correct
Correct, the trajectory planner is myopic, and as a result only searches for locally optimal solutions at each planning step.

15. True or false, the trajectory rollout planner is always able to find a path to the goal state, if one exists.

1 / 1 point

- ○ True
- ◉ False

Correct
Correct, because the trajectory rollout planner is a receding-horizon planner, it is possible for it to get stuck in certain situations. It can therefore only handle "simple" obstacles in a given scenario.

16. True or false, linear velocity is a higher-order term in the kinematic bicycle model.

1 / 1 point

- ○ True
- ◉ False

Correct
Correct, the linear velocity is an input to the bicycle model, not a higher-order term.

17. What is the purpose of dynamic windowing?

1 / 1 point

- ○ To allow the trajectory rollout algorithm to see farther ahead into the planning process.
- ○ To improve the maneuverability of the vehicle when performing trajectory rollout.
- ◉ To ensure the angular acceleration and linear acceleration lie below a set threshold

Correct
Correct, we use dynamic windowing to filter out paths that would result in too much acceleration applied to the vehicle.

18. Suppose we have a bicycle model travelling at constant velocity v = 1.0 m/s, and length L = 1.0 m. If the time between planning cycles is 0.1 seconds, the previous steering angle delta_ 1 was 0.0 rad, and the current steering angle is 0.5 rad, what is the approximate angular acceleration?

1 / 1 point

5.46

Correct
Correct

19. Suppose we have a bicycle model travelling at constant velocity v = 1.0 m/s, and length L = 1.0 m. If the time between planning cycles is 0.1 seconds, and the previous steering angle delta_ 1 was 0.0 rad. If the maximum angular acceleration is 2.5 rad/s^2, can a path with delta_2 = 0.2 rad be selected this iteration?

1 / 1 point

A. Yes
B. No

- [x] Yes
- [ ] No

Correct
Correct, this gives us an angular acceleration of 2.027, which is below our threshold.

20. Suppose we have a bicycle model travelling at constant steering angle delta = 0.0 rad, and length L = 1.0 m. If the time between planning cycles is 0.1 seconds, the previous velocity was 20.0 m/s, and the current velocity is 20.5 m/s, what is the approximate linear acceleration?

1 / 1 point

5

Correct
Correct

Week 7

Programming Assignment: Course 4 Final Project

```
./CarlaUE4.sh /Game/Maps/Course4 -windowed -carla-server -benchmark -fps=30
```

```
python module_7.py
```

behavioral_planner.py

```
    def transition_state(self, waypoints, ego_state, closed_loop_speed):
        if self._state == FOLLOW_LANE:
            closest_len, closest_index = get_closest_index(waypoints, ego_state)

            goal_index = self.get_goal_index(waypoints, ego_state, closest_len, closest_index)

            updated_index, stop_sign_found = self.check_for_stop_signs(waypoints,
closest_index, goal_index)
            self._goal_index = updated_index if stop_sign_found else goal_index
            self._goal_state = waypoints[self._goal_index]

            if stop_sign_found:
                self._goal_state[2] = 0.0
                self._state = DECELERATE_TO_STOP
            pass

        elif self._state == DECELERATE_TO_STOP:
            if closed_loop_speed > STOP_THRESHOLD:
                self._state = DECELERATE_TO_STOP
            else:
                self._state = STAY_STOPPED
            pass

            if self._stop_count == STOP_COUNTS:
                closest_len, closest_index = get_closest_index(waypoints, ego_state)
                goal_index = self.get_goal_index(waypoints, ego_state, closest_len, closest_index)
                stop_sign_found = self.check_for_stop_signs(waypoints, closest_index,
goal_index)[1]

                self._goal_index = goal_index
                self._goal_state = waypoints[self._goal_index]

                if not stop_sign_found:
                    self._state = FOLLOW_LANE

                pass
```

```
        else:
            self._stop_count += 1

            pass
    else:
        raise ValueError('Invalid state value.')
```

```
def get_goal_index(self, waypoints, ego_state, closest_len, closest_index):

        arc_length = closest_len
        wp_index = closest_index

        if arc_length > self._lookahead:
            return wp_index

        if wp_index == len(waypoints) - 1:
            return wp_index

        while wp_index < len(waypoints) - 1:
          arc_length += math.sqrt((waypoints[wp_index][0] - waypoints[wp_index + 1][0])**2 +
(waypoints[wp_index][1] - waypoints[wp_index + 1][1])**2)
          if arc_length >= self._lookahead:
                wp_index += 1
                break
          else:
                wp_index += 1

        return wp_index
```

```
def get_closest_index(waypoints, ego_state):
    closest_len = float('Inf')
    closest_index = 0

    for i in range(len(waypoints)):
        dist = math.sqrt((ego_state[0] - waypoints[i][0])**2 + (ego_state[1] - waypoints[i][1])**2)
        if dist < closest_len:
            closest_len = dist
            closest_index = i

    return closest_len, closest_index
```

collision_checker.py

```
def collision_check(self, paths, obstacles):

        collision_check_array = np.zeros(len(paths), dtype=bool)
        for i in range(len(paths)):
            collision_free = True
            path           = paths[i]

            for j in range(len(path[0])):

                circle_locations = np.zeros((len(self._circle_offsets), 2))

                circle_locations[:, 0] = [i * int(cos(path[2][j])) for i in self._circle_offsets]  + path[0][j]
                circle_locations[:, 1] = [i * int(sin(path[2][j])) for i in self._circle_offsets]  + path[1][j]

                for k in range(len(obstacles)):
                    collision_dists = \
                        scipy.spatial.distance.cdist(obstacles[k],
                                                     circle_locations)
                    collision_dists = np.subtract(collision_dists,
                                                  self._circle_radii)
                    collision_free = collision_free and \
                                     not np.any(collision_dists < 0)

                    if not collision_free:
                        break
                if not collision_free:
                    break

            collision_check_array[i] = collision_free

        return collision_check_array
```

```
def select_best_path_index(self, paths, collision_check_array, goal_state):

        best_index = None
        best_score = float('Inf')
        for i in range(len(paths)):

            if collision_check_array[i]:

                score = np.sqrt((goal_state[0] - paths[i][0][-1])**2 + (goal_state[1] -
paths[i][1][-1])**2)

                for j in range(len(paths)):
                    if j == i:
                        continue
```

```
            else:
                if not collision_check_array[j]:
                    score += self._weight * np.sqrt((paths[i][0][-1] - paths[j][0][-1])**2 +
(paths[i][1][-1] - paths[j][1][-1])**2)

                    pass

        else:
            score = float('Inf')

        if score < best_score:
            best_score = score
            best_index = i

    return best_index
```

local_planner.py

```
def get_goal_state_set(self, goal_index, goal_state, waypoints, ego_state):

    if goal_index < len(waypoints) - 1:
        delta_x = waypoints[goal_index + 1][0] - waypoints[goal_index][0]
        delta_y = waypoints[goal_index + 1][1] - waypoints[goal_index][1]
    else:
        delta_x = waypoints[goal_index][0] - waypoints[goal_index - 1][0]
        delta_y = waypoints[goal_index][1] - waypoints[goal_index - 1][1]
    heading = np.arctan2(delta_y, delta_x)

    goal_state_local = copy.copy(goal_state)

    goal_state_local[0] -= ego_state[0]
    goal_state_local[1] -= ego_state[1]

    goal_x = goal_state_local[0]*cos(-ego_state[2]) - goal_state_local[1]*sin(-ego_state[2])
    goal_y = goal_state_local[0]*sin(-ego_state[2]) + goal_state_local[1]*cos(-ego_state[2])

    goal_t = heading - ego_state[2]

    goal_v = goal_state[2]

    if goal_t > pi:
        goal_t -= 2*pi
    elif goal_t < -pi:
        goal_t += 2*pi

    goal_state_set = []
    for i in range(self._num_paths):

        offset = (i - self._num_paths // 2) * self._path_offset
```

```
        x_offset = offset*cos(goal_t + pi/2)
        y_offset = offset*sin(goal_t + pi/2)

        goal_state_set.append([goal_x + x_offset,
                               goal_y + y_offset,
                               goal_t,
                               goal_v])

    return goal_state_set
```

path_optimizer.py

```
  def optimize_spiral(self, xf, yf, tf):

    self._xf = xf
    self._yf = yf
    self._tf = tf

    sf_0 = np.linalg.norm([xf, yf])

    p0 = [0.0, 0.0, sf_0]

    bounds = scipy.optimize.Bounds([-0.5, -0.5, sf_0], [0.5, 0.5, np.inf])
    res = scipy.optimize.minimize(self.objective, p0, jac=self.objective_grad,
bounds=bounds, method='L-BFGS-B')

    spiral = self.sample_spiral(res.x)
    return spiral
```

```
  def thetaf(self, a, b, c, d, s):
    pass

    thetas = [a *x + b/2 * x**2 + c/3 * x**3 + d/4 * x**4 for x in s]
    return thetas
```

velocity_planner.py

```
def get_open_loop_speed(self, timestep):

    time_delta = distance_step / (velocity + 1e-6)
```

```
def decelerate_profile(self, path, start_speed):

    if brake_distance + decel_distance + stop_line_buffer > path_length:
        speeds = []
        vf = 0.0
```

```
        for i in reversed(range(stop_index)):
            vi = calc_final_speed(vf, self._a_max, dist)
```

```
def calc_distance(v_i, v_f, a):

    pass

    d = (v_f**2 - v_i**2) / (2 * a)
    return d
```

```
def calc_final_speed(v_i, a, d):

    pass

    dist = v_i**2 + 2 * a * d
    v_f = sqrt(dist) if dist >= 0 else 0
    return v_f
```