Part 1: AV Development and Architecture

All solution notes here are exemplary to support the virtual review process, due to the nature of the questions. Alternative answers are possible and were corrected accordingly.

1.1. Your company decided to use ROS for the development of a commercial self-driving vehicle. You are supposed to present the advantages and disadvantages of this design decision to your team. List and explain two advantages and two disadvantages.

Advantage 1:
High amount of open source packages for prototyping to speed up the development

Advantage 2:
Provides debugging, logging, visualization and basic simulation tools out of the box

Downside 1:
Limited real-time capabilities

Downside 2:
No safety guarantees

Answers must be significant and correct. +1 for each answer.

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1.2. Your management is trying to decide if they want to have teleoperation (remote control) for the self-driving car. List and explain one pro and one contra argument for the teleoperation. Which communication channels would you use for the V2X and why?

Pro remote control:
Remote operator can take over in situations that the self-driving car cannot resolve on its own

Contra remote control:
Adding an interface for teleoperation poses a security risk

Communication channel:
5G due to its low latency and high bandwidth

Answers must be significant for teleoperation and communication channel has to be explained. +1 for each answer.

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1.3. Your system architects are trying to figure out how to achieve functional independence in their self-driving car design, and they have asked you for your thoughts. What impact does functional independence have on ADAS development for vehicles with regards to combinatorial optimization and vendor optimization? How is this different for self-driving car development?

Combinatorial optimization:
Functional independence enables the vendor to sell a combination of functionalities to the customer according to the customer's needs.

Vendor optimization:
Functional independence enables you to employ various suppliers for the independent modules.

Difference ADAS vs Self-driving car:
For ADAS functional independence can be achieved easier as the assistance modules do not need to be highly interconnected. In contrast a self-driving car requires a high amount of interconnectivity and thus, functional independence is harder to achieve.

Answers must be significant for functional independence. +1 for each answer.

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1.4. The developers read that one of the design principles in Robinos would be polymorphism. Now they are wondering how they can apply this concept to their self-driving car software. You have been asked to explain how you could apply polymorphism to your collision avoidance. Provide the explanation, using two concrete traffic objects that you want to avoid a collision with for the example. Provide pseudo-code for the example.

Polymorphism is the idea of a shared interface to objects of different types that need to implement similar functionalities.

Concrete traffic objects: Pedestrian, Car

```
Abstract class trafficObject{
    boolean checkCollision(){};
}

Class pedestrian extends trafficObject{
    boolean checkCollision(){ // provide concrete implementation for Pedestrian
    };
}

Classcar extends trafficObject{
    boolean checkCollision(){ // provide concrete implementation for Car
```

```
    };
}

List<trafficObject> trafficObjects;

...

For each obj in trafficObjects {
    obj.checkCollision();
}
```

+2 for explanation of Polymorphism
+1 for each concrete traffic objects (max 2)
+2 for polymorphism related Pseudocode (1 for basic, 1 for quality)

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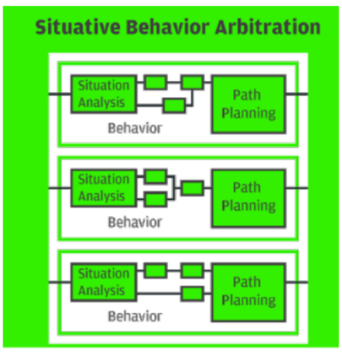
1.5. Another principle the developers liked to read about was situative behavior arbitration. The management has been complaining that the self-driving vehicle "does not understand pedestrians". When pedestrians are standing on the sidewalk very close to the road, sometimes the vehicle does not stop fast enough when they suddenly cross in front of the car, and sometimes the car waits forever in front of them, even though the pedestrians do not want to cross the road. You are tasked with developing a situative behavior arbitration block to handle these situations. Provide high level pseudo code for situation assessment and path planning expressing the interaction between these two modules and how they are specialized for this scenario. You are allowed to abstract the low level algorithms, as long as the specializations to the scenario and the interfaces and exchanged information between the modules become clear.

- The answer should express the modular structure of the situative behavior arbitration
- The answer should make use of the related properties, such as comfort and risk
- The pseudo code must implement these principles
- The solution must be specialized to the scenario, and show this for both the situation assessment and the path planning. Must be significant for the scenario use case.

- **Situative behavior arbitration block**, which can be thought of as a "plugin container" for the behavior (or function) modules and decides execution based on the following factors:
- **Applicability**: The ability of the function to operate, expressed in percent. E.g. a lane change assist that sees clear lane markings, road side boundaries, and convoy tracks, and an empty left lane, might set this to 100%; if it only sees convoy tracks and lane markings are unclear (e.g. in a construction site), it might set this to 30%; if the left lane is occupied, it will always set this to 0%.
- **Desire**: The desire of the function to operate, in percent. E.g. an adaptive cruise control function set to 130km/h on an empty highway might set this to 100%; if it finds itself behind a truck going 80km/h it might set this to 50%.
- **Risk**: A scalar, expressed in percent, giving an assessment of the risk involved when performing the behavior. A lane changing assistant that sees a perfectly clear left lane might set this to 20% (since visibility from the ego vehicle will always be obstructed), one that sees a slowly-approaching vehicle to the rear in the left lane might set this to 50%, one that sees a vehicle arriving with high difference velocity might set it to 90%.
- **Comfort**: A scalar, expressed in percent, giving an assessment of the comfort to the driver that performing a certain motion will entail; expected high lateral or longitudinal acceleration or deceleration will result in a low comfort level, gentle motions in a high one.



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1.6. You are supposed to design a sensor-set for a self-driving car. You are told that the self-driving function will only be used for highway driving in Germany. How does this restriction to highway driving change the requirements for your sensor-set design, as opposed to city driving? List 4 specific properties of this scenario and how they impact the sensor-set design.

1: Increased speed on highways -> sensors need a higher detection range to detect other vehicles early enough

2: No intersection on German highways -> sensor field of view does not need to cover crossing width of intersections.

3: No parking scenarios on a highway -> No need for distance sensors that are precise to low cm range

4: No traffic lights -> Color detection of the lights with a camera not necessary

Answers must state 4 highway specific properties and impact on sensors. +1 for each complete answer.

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Part 2: Path Planning

2.1. One of the students in your team came to you, asking for help with understanding holonomic and non-holonomic constraints. Are the following constraints each holonomic or non-holonomic? Why?

$\dot{y} = \cos(\theta), \dot{x} = \sin(\theta), \dot{\theta} = u$

Non-Holonomic – The constraints depend on derivatives of state variables

$0 \leq x \leq 20 \wedge 0 \leq y \leq 15$

Holonomic – The constraints can be written without using derivatives

+1 for each correct answer with meaningful explanation.

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2.2. Due to your valuable input, the student has made great progress with his work. He was given the task to implement a good path planning algorithm to enable the self-driving car to plan a high level navigation route from Munich to Hamburg. For this the student decided to implement the Dubins Car planning approach, combining multiple words, such as LSR, SLR etc. into a route from Munich to Hamburg. Now the student nervously awaits the feedback from the management and asks you for your thoughts. Do you think the described Dubins Car planning is the right tool for the task? Which algorithm would you instead suggest to the student and why?

Dubins car planning is not an appropriate approach for the high-level navigation task as Dubins car is more appropriate for low-level navigation.

Instead the A* algorithm can be used with a graph consisting of the cities as nodes and the edges representing the streets as a heuristic can be applied well to this scenario.

+2 for rejecting Dubins car and explanation
+2 for correct suggestion of other algorithm and explanation

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2.3. After listening to your explanation, the student left and went back to implementing. A week later the student has come back and present the result of his work. The student now implemented the Reeds and Shepp approach instead of the Dubins approach for planning the high level navigation route from Munich to Hamburg. What are the differences between the Dubins car approach and the Reeds and Shepp car approach?

The Reeds and Shepp car model may additionally drive backwards. This results in 48 possible words instead of 6 words as for Dubins car.

+1 for backwards
+1 for number of possible words

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2.4. After the recent results, management decided to give the student a new task. The student is supposed to prototype the collision checking. You are supposed to explain the Minkowski sum to the student. What is the Minkowski sum and how can it be used for collision checking? What impact does the orientation of a robot, which is checking for collisions with its environment, have on the utilization of the Minkowski sum?

Definition:
The Minkowski sum of two sets of vectors A and D is formed by adding each vector in A to each vector in B:

$$A + B = \{\mathbf{a} + \mathbf{b} \,|\, \mathbf{a} \in A,\ \mathbf{b} \in B\}.$$

Collision Checking:
The shape of the robot can be added to the Obstacle map using the Minkowski sum. For collision checking it is only necessary to check the position of the robot in this Minkowski sum.

Orientation:
For non-circular robots the Minkowski sum has to be calculated for every orientation

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+1 for each correct answer.

2.5 The end of the student's internship is approaching and management decided to give him a test to solve. By solving the test, the student will get the chance to apply for a fulltime position. After a lot of studying, the differences between different path planning concepts still remain unclear to the student and the student asks you for help. Explain the differences between combinatorial, behavior-based, random sampling and search methods for path planning. When would you prefer a search based approach over a random sampling based approach?

Combinatorial:
Directly solve the path planning problem based on the geometry of the configuration space

Behavior-based:
A reactive motion strategy for the whole configuration space

Random sampling:
Explore the configuration space with random samples and create a graph in the configuration space with connects the start and goal

Search:
Search algorithms explore an existing graph consisting of nodes and transition edges

Search is preferred if a search graph does already exist or if the problem is well suited for a heuristic

+1 for each explanation.
+1 for Search vs Random sampling argument

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Part 3: Detection and Fusion

3.1 You are given responsibility for a team of 6 multi-sensor-data-fusion experts. Management wants you to define requirements and tasks for the team in order to achieve good results for the self-driving car. Because management has just given you this responsibility, they still want you to explain your resulting requirements and tasks to them. Following, you find a number of design options. The self-driving car is supposed to drive autonomously on highways in Germany only. Choose one design option for each (What?), explain your choice (Why?), and list an advantage and a disadvantage for your choice.

Occupancy grid map vs Polygon based map (expressing occupancy through a variety of polygons instead of rectangular grids):

Occupancy grid map:
Advantage: Easy to compute independent of object shape variety
Disadvantage: Constant grid cell size leads to precision optimization issues with near and far range detections or high computational cost

Deep learning based end-to-end object tracking vs Kalman filter:

Kalman Filter:
Advantage: light on memory , computationally inexpensive and easily explainable results
Disadvantage: limited to linear behaviors and doesn't take specific traffic interactions into concern

Only front wheels can steer vs front wheels and back wheels can steer (2 wheel steering vs 4 wheel steering):

Front wheel steering as it is sufficient for the task.
Advantage: Less cost
Disadvantage: Decreased maneuverability

Choice for one required: +1 for explanation of choice or advantange
+1 for disadvantage

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3.2 The management heard at a conference that Kalman filters are important. They want more information from you. How is the Kalman filter used for object tracking? How does the measurement noise affect the Kalman gain? Which situations are well suited for the Kalman filter? In a scenario with multiple traffic particpants, how are the relations between the different traffic participants usually modelled with the standard Kalman filter? How could the Kalman Filter be applied to handle inputs from multiple sensors with different sensor models simultaneously?

1. The Kalman filter can be used to predict the state of an object using a linear motion model of the object and correct prediction errors using measurements in an update step.
2. High sensor noise leads to a lower Kalman gain and thus, the filter is relying more on the underlying process model and less on the measurements.
3. Kalman filters are generally well suited for linear problems.
4. Relations between different traffic participants are usually not modelled.
5. The update step can be performed multiple times to include each sensor model.

+1 for each answer.

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3.3 Management is asking why you need such a big budget for your fusion team. Somebody brought up using the ROC curve to explain the situation to the management. How can the Receiver Operating Characteristic curve be used to assess the reliability and performance of object detection algorithms for self-driving cars? Which would be the best spot in the diagram to reach and is this spot typically reached/achieved?

1. The ROC curve can be used to illustrate the rate of true and false-positives whilst varying the sensitivity of the detection algorithm
2. The optimal position in the ROC curve is the top-left corner with no false-positives and no false-negatives.
3. This point usually cannot be reached in a real-world application.

+1 for each answer.

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3.4 Your car is having issues during strong sunlight after it rained. The engineers believe this is due to reflections blinding the cameras. Could this be due to specular reflections? Which target and signal properties decide if the reflections are specular or diffuse? Are combinations of the two types possible? Which model can be used to compute these reflections?

1. Yes
2. Wave length and surface roughness
3. Combinations are possible
4. BRDF models

+1 for each answer.

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3.5. To save costs, 3 of the engineers on your team have been replaced with the student who proposed the Dubins car approach to navigate from Munich to Hamburg. The student insists that the more it rains, the longer the maximum detection range of the lidar scanner would become, because the student read on the internet that the emitted light would jump from droplet to droplet, having strong rain effectively increase the sensor detection range due to the bouncing effect. Using the lidar range equation and its channel models, explain the impact of rain on the lidar object detection. Which lidar and rain parameters are relevant for calculating the impact of the rain?

- Use the lidar range equation to argue your case (+1)
- Provide parameters that impact the effect the rain has on the detection, such as the droplet diameter distribution (+2)
- The detection range is reduced (+1)

$$P_R(R) = C_A \int_{t'=0}^{2R/c} P_T(t')\, H(R - ct'/2)\, dt'$$

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3.6. You heard that the student is more familiar with deep neural networks than with physics and you consider giving a related task to the student. Unfortunately, the only neural network architecture the student is familiar with is the Autoencoder. Describe the Autoencoder and define a task in autonomous driving that is well handled by Autoencoders and explain why this is the case.

The Autoencoder is a neural network consisting of input and output layers with n nodes and a hidden layer with p<n nodes. The data are compressed to these information rich nodes before reconstructing the original image from them. The goal is to learn a reduced and efficient encoding of the data in an unsupervised fashion.

In autonomous driving one could use an AE to remove noise from camera data that originates from snow. The Autoencoder's unsupervised learning is easily applied to this problem, using pictures with and without snow. An alternative would be GANs, but they are harder to train and verify.

+2 for explanation of autoencoder (1 partial, 1 quality)
+2 for specific, significant autonomous driving task and AE specific explanation explanation

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3.7. Your other 3 team members have made good progress with the detection algorithms while the student was studying autoencoders. The self-driving car software now detects a variety of things. After studying the detections, you want to fuse the resulting outputs. You have decided to use the JDL model for this. Which JDL level would you sort the following detections into and why?

Driver attention: Level 1 or 3 – Threat intent estimation

Radar return signal strength amplitude over time: Level 0 – For example signal level

Loss of road friction / wheel slipping: Level 1 or 2 or 3 – For example Threat intent estimation

Bicycles: Level 1 or 2 – For example Object classification

+1 for each correct answer with an explanation. Level and argument must match.

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3.8. To perform the multi-sensor-data-fusion in your vehicle, you are supposed to choose between centralized, decentralized and distributed fusion architectures. Choose one of these for your high-way driving self-driving car, explain it and describe one advantage and one disadvantage of your choice. Finally, you are supposed to give related requirement to the E/E-architects. Which hardware do you suggest to run the fusion with as part of the E/E-architecture, which bus systems and general network architecture do you suggest to use? Explain each choice and requirement.

In a distributed fusion architecture, the data from each sensor are processed independently before the information is sent to the fusion node. Several intermediate fusion nodes are also possible.

Advantage: Less Bandwidth required after preprocessing as no raw data needs to be sent

Disadvantage: Not the complete information is available in the fusion node and thus, the scheme is not theoretically optimal

Run Software on any CPU/GPU combination or embedded hardware. Ethernet: provides sufficient bandwidth for the information. Ring topology: as only preprocessed information is sent the ring can realize the required bandwidth.

+1 for each answer. Choices and explanations must be consistent with each other, practical and significant for autonomous vehicle fusion architectures. _/6