Autonomous Vehicle Driving

Midterm Project – A.Y. 2021/22

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1   Executive Summary

CARLA "perfect" data are used to implement a behavioural planner which allows to manage collisions with other vehicles or pedestrians and it manages the presence of traffic lights.

1.1   ODD

Our behavioral planner is positioned in the following ODD:

- Lateral control is provided, but it only takes care of following the right trajectory. The possibility of overtaking has not been implemented.

- The longitudinal control, which takes care of maintaining speed.

- OEDR: the vehicle is capable of handling dangerous situations, such as pedestrians crossing the road.

- The vehicle is not able to autonomously manage dangerous situations that require a response to the moral experiment. For example, the vehicle is unable to choose whether the lesser evil is crashing into the car in front of it or having several pedestrians injure themselves on it (pedestrian suicide in Carla).

- The vehicle is limited to a situation where the map waypoints are known. Furthermore, data on the position and status of other vehicles, other pedestrians and traffic lights must also be known. It can be assumed that you are on a smart road without non-intelligent vehicles.

- It is assumed that in most cases the other agents comply with the rules of the road, for example that the vehicles all walk in the right direction and in the right lane, and that they do not crash into other vehicles (although this does not always occur in simulations).

2 Progettazione ed implementazione

2.1 Behavioural Planner

The architecture of the behaviour planner is located between the Mission Planner and the Local Planner. You can see them in the following figure.
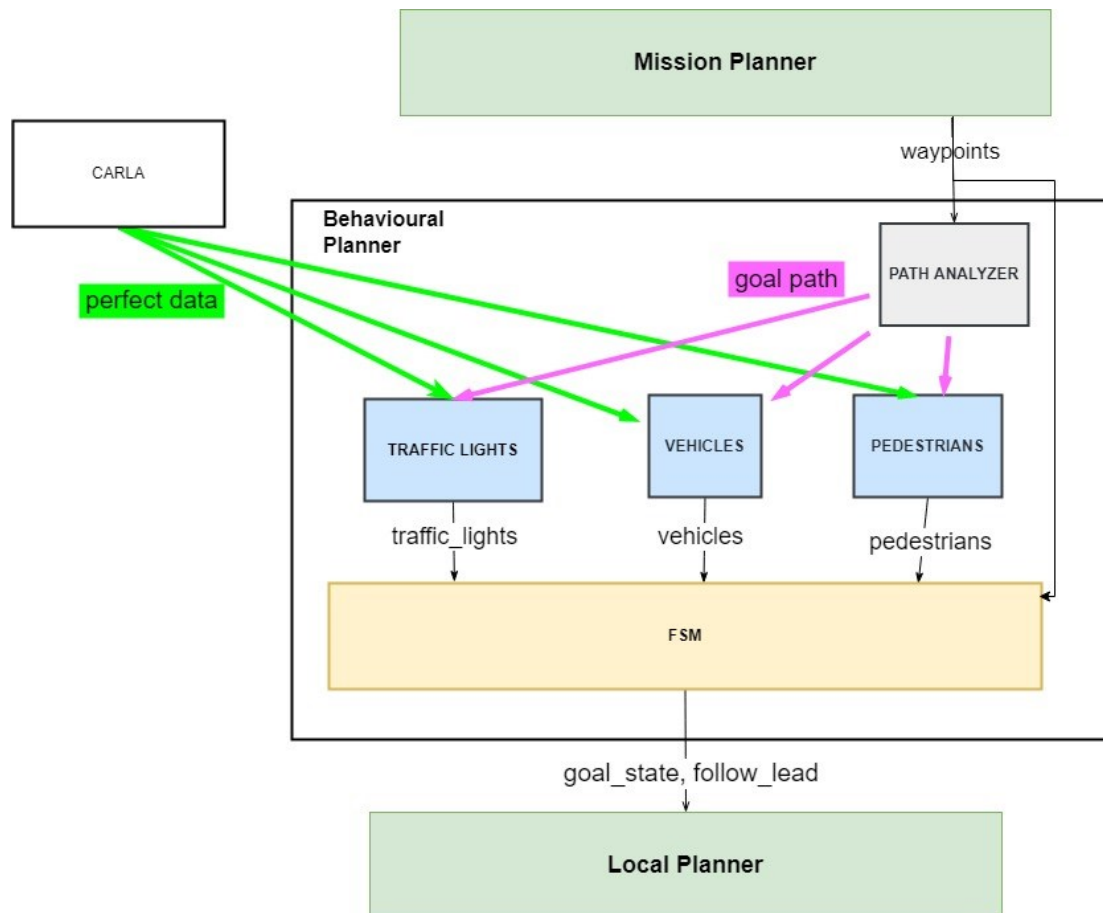
We can see that we receive the path waypoints from the Carla Mission Planner, and the perfect data from Carla as if we were on a smart road where vehicles, pedestrians and traffic lights share position and status.

- The module "*Path Analyzer*" creates the path considering the waypoints to be considered based on the lookahead, directly proportional to the speed.

- The modules "*Pedestrians*", "*Vehicles*" and "*Traffic Lights*" take as input the calculated route and the data of carla and check if some of these objects are present in the route and if they are relevant for the specific scene. As regards vehicles, for example, only those present in the same lane as the car are considered lead vehicles. As far as pedestrians are concerned, both those on the road and those on the pavement are considered obstacles and will arrive on the road in front of the car in at most double the time it will take the car to get to that point.

- The waypoints and the information provided by these other modules are taken as input by the *FSM*, which calculates the outputs to be provided to the local planner, that is the desired state and the eventual vehicle to follow by adapting the trajectory.
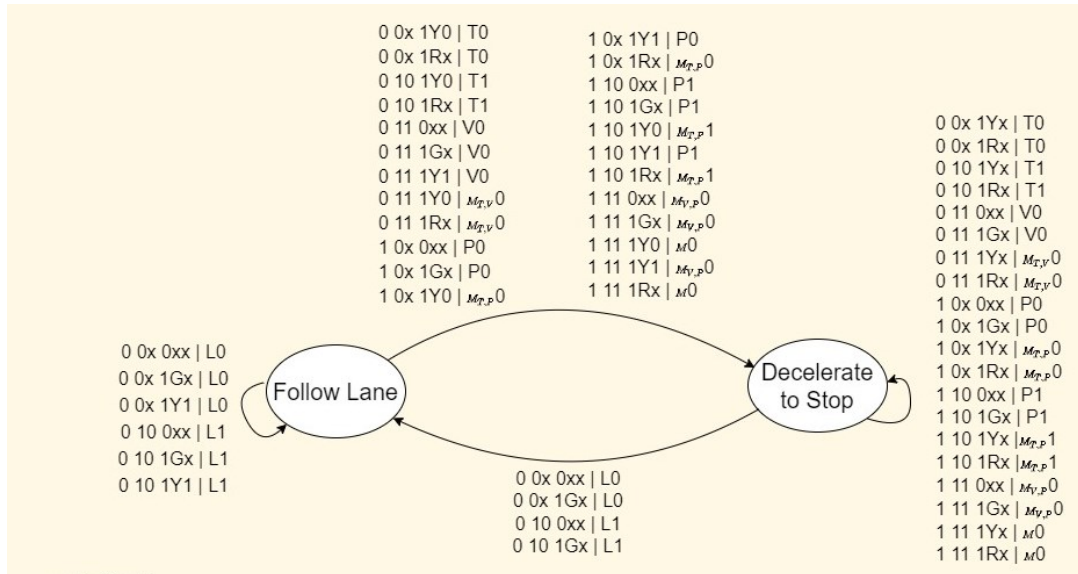
2.2 FSM

Three states are defined in the FSM, with the following meaning:

- **Follow Lane**: In this state the car follows the trajectory in the absence of events that involve having to stop in front of a pedestrian or a traffic light. As for the vehicles, being managed at a lower level (in the local planner) it is only indicated whether or not to follow the lead vehicle and the status of the latter.

- **Decelerate to Stop**: In this state, a pedestrian has been detected who is or will be on the road for which it is necessary to stop, or a traffic light that has been red or yellow (but without the car having yet engaged the intersection).

It can be seen that the transitions cover all combinations of the following possibilities, giving priority to the closest obstacle:

- **Trafficlight**: The favorable occasions to pass the traffic light are those in which it is green or yellow but only if the vehicle has already engaged the intersection. The unfavorable occasions are all the others, that is with a yellow traffic light and without having occupied the intersection or with a red light.
- **Vehicle**: If there is a vehicle in the path of the car, it must adapt its speed to maintain the gap.
- **Pedestrian**: If a pedestrian is in the middle of the road in the lane of the car or if it is expected that it will arrive on the trajectory in at most twice the time it will take the car to arrive at the same point, the car must stop before the pedestrian and until this will not leave the lane.

```
0 0x 1Y0 | T0                1 0x 1Y1 | P0
0 0x 1Rx | T0                1 0x 1Rx | M_{T,P}0               0 0x 1Yx | T0
0 10 1Y0 | T1                1 10 0xx | P1                     0 0x 1Rx | T0
0 10 1Rx | T1                1 10 1Gx | P1                     0 10 1Yx | T1
0 11 0xx | V0                1 10 1Y0 | M_{T,P}1               0 10 1Rx | T1
0 11 1Gx | V0                1 10 1Y1 | P1                      0 11 0xx | V0
0 11 1Y1 | V0                1 10 1Rx | M_{T,P}1               0 11 1Gx | V0
0 11 1Y0 | M_{T,V}0          1 11 0xx | M_{V,P}0               0 11 1Yx | M_{T,V}0
0 11 1Rx | M_{T,V}0          1 11 1Gx | M_{V,P}0               0 11 1Rx | M_{T,V}0
1 0x 0xx | P0                1 11 1Y0 | M0                      1 0x 0xx | P0
1 0x 1Gx | P0                1 11 1Y1 | M_{V,P}0               1 0x 1Gx | P0
1 0x 1Y0 | M_{T,P}0          1 11 1Rx | M0                      1 0x 1Yx | M_{T,P}0
                                                                1 0x 1Rx | M_{T,P}0
                                                                1 10 0xx | P1
0 0x 0xx | L0                                                   1 10 1Gx | P1
0 0x 1Gx | L0                                                   1 10 1Yx | M_{T,P}1
0 0x 1Y1 | L0    ( Follow Lane )      ( Decelerate to Stop )    1 10 1Rx | M_{T,P}1
0 10 0xx | L1                                                   1 11 0xx | M_{V,P}0
0 10 1Gx | L1                                                   1 11 1Gx | M_{V,P}0
0 10 1Y1 | L1                                                   1 11 1Yx | M0
                      0 0x 0xx | L0                             1 11 1Rx | M0
                      0 0x 1Gx | L0
                      0 10 0xx | L1
                      0 10 1Gx | L1
```

control input

$$\text{pedestrian}_{\text{found}} | \text{lead\_vehicle}_{\text{found}} | \text{lead\_vehicle}_{\text{speed}} <= \text{speed}_{TH} | \text{trafficlight}_{\text{found}} | \text{trafficlight}_{\text{state}} | \frac{\text{distance}_{\text{to trafficlight}}}{\text{car}_{\text{velocity}}} < \text{time}_{\text{yellow}}$$

Is 1 if the car can pass the trafficlights before it turns red. This because it's unsafe stop brake too late.

control output

$$\text{goal}_{\text{index}} | \text{lead vehicle}$$

P: pedestrian
V: vehicle
T: trafficlight
L: lookahead
$M_{T,P} = \min(T, P)$
$M_{T,V} = \min(T, V)$
$M_{V,P} = \min(V, P)$
$M = \min(T, V, P)$

3 3. Analisi sperimentale del sistema

3.1 Quantitative Analysis

This section shows the tests carried out and their descriptions. In the repository, however, you can also see the execution of these.

3.1.1 Test 1

Code	Traffic Lights	pedestrians	vehicles	situation passed
9-123-300-1-1-1	2 red	3	0	5/5

In this test there are two red lights. The vehicle waits for these to turn green before setting off. 3 pedestrians are encountered in the path, which are not in the path of the vehicle and which do not seem to have to cross, therefore they are not considered as obstacles

3.1.2 Test 2

26-15-1-1-1-1	1 green, 1 yellow	0	0	2/2

In this test there is a green light, whereby the vehicle passes without stopping. Then the next traffic light is also green. As you pass this traffic light, it turns yellow, but having the car already engaged at the intersection, it continues to pass.

3.1.3 Test 3

118-28-1-1-1-1	1 green, 1 yellow	0	0	1/1

In this test there is a green light, so the vehicle passes without stopping.

3.1.4 Test 4

125-28-1-1-1-1	1 red	0	0	1/1

In this test there is a red light, so the car stops until it turns green, when it restarts.

3.1.5 Test 5

128-24-1-1-1-1	1 green, 1 yellow	0	0	2/2

The vehicle passes a green light and then finds a yellow light that has not yet engaged the intersection, so it stops.

3.1.6 Test 6

53-92-150-150-3-1	1 yellow	1 crossing in the corner, 1 crossing the road	1 lead stopped	4/4

In this test there is initially a pedestrian crossing a bend, so the car stops to let him pass. Then there is a vehicle and a pedestrian parked in the street. When the vehicle restarts the pedestrian is still in front of the car, so we wait for the pedestrian to get out of the trajectory before setting off again. Then a green traffic light is passed which turns yellow when it has practically already been passed.

3.1.7 Test 7

89-119-150-150-3-1	1 green, 1 red	3	1 lead at the trafficlight, 1 bicycle who pass with red, 1 lead	7/8

In this test we follow a vehicle at the green light, then we stop at the red light until it turns green again. With the green light the car continues on its trajectory but collides with a bike that has passed the red one (we consider this a situation not overcome even if it is not managed in the ODD). Later we find some pedestrians who, however, are on the sidewalk and are not considered obstacles. Then follow the new lead vehicle to the end of the path.

3.1.8 Test 8

116-140-300-150-1-1	1 green	5 crossing the way	2 lead	8/8

In this test, a vehicle is initially followed at a green light. Then we slow down to stop at a pedestrian crossing, who soon finishes the crossing and then starts again before we have stopped. Later, when standing behind a stationary vehicle, two pedestrians cross dying on the car and you remain stationary until they disappear. Then you stop behind a stopped vehicle at a green light.

3.1.9 Test 9

123-46-150-150-2-2	1 green, 1 red	4 crossing pedestrians	2 lead, 1 stopped in the middle of the intersection	8/9

In this test you start stationary behind a vehicle stopped at a red traffic light, then you set off again and switch to green. We stop before two pedestrians crossing the street. Afterwards we stop at a red light. THEN again behind the queued vehicles. Later again behind a red light and, while waiting for the green, two pedestrians commit suicide on the car. When restarting with the green, you collide with a vehicle stopped in a curve (waypoints problem, in fact this is on our trajectory and we assume that in our odd there are no reverse vehicles on our trajectory).

3.1.10 Test 10

| 123-46-150-150-3-1 | 2 green | 2 crossing | 2 lead, 1 stopped in the middle of the way | 7/7 |

In this test we follow the same lead vehicle for two different intersections as both are stopped at the red light. In both cases it happens that a pedestrian crosses in front of the stationary vehicle, so we continue to wait behind the vehicle. Eventually we stop as there is a stationary vehicle in the middle of the road (not considered in the ODD)

3.1.11 Test 11

| 123-46-150-300-1-1 | 3 green, 1 yellow | 3 crossing | 5 lead | 12/12 |

In this test, the same lead vehicle is always followed in 2 intersections as it is stopped at a red light. When you restart with the green light you slow down as there is a pedestrian crossing and then you queue up to another vehicle stopped at a red light. A pedestrian crashes into the vehicle in front of us before the traffic lights. Then we stop behind a line of vehicles in columns, and then in front of a vehicle and a red light. In this situation, which is blocked, a pedestrian crashes into the car.

3.1.12 Test 12

| 130-12-100-100-0-0 | 2 red | 2 crossing | 2 lead | 6/6 |

In this test we follow a vehicle on our trajectory. This hits a pedestrian that is crossing and then disappears. The vehicle starts moving forward but our car stops because it is about to cross another pedestrian. After the pedestrian we queue up to the vehicle stopped at the red light. Then there is another red light.

3.1.13 Summary

The tests reported are passed in most cases, in particular 2 situations have reported accidents:

- 123-46-150-150-3-1 : the vehicle collides with a car on the other lane as it continues cornering. However, the error is caused by the arrangement of the waypoints.
- 89-119-150-150-3-1: in this case the vehicle collides with a bicycle at the intersection after a traffic light. However, the bicycle has not respected its red light so it is a case that does not fall within our ODD which assumes that the other vehicles respect the rules of the road code
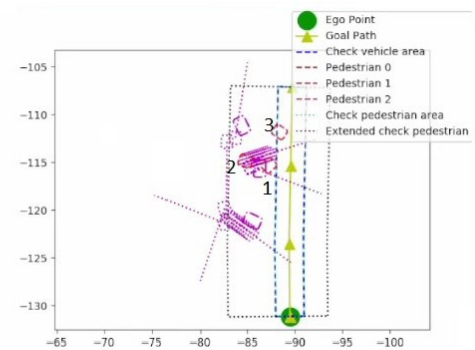
3.2   Qualitative Analysis

In this section some critical cases are reported in order to demonstrate their working.

### 3.2.1   Yellow Traffic Light

In case of yellow light the vehicle pass the traffic light if it has already joined the intersection.

3.2.2 Pedestrian tracking with "perfect" data

In case of pedestrian out of our lane the vehicle keeps tracking them in order to compute an eventually intersection with our trajectory. In particular, we consider pedestrian speed and orientation in order to compute the time he needs to arrive at the intersection point with our trajectory. If it takes at most twice as long as we need to arrive to the intersection point then we decelerate for him. In the following screenshot pedestrians are numbered as the vehicle sees them considering their orientation and speed.

3.2.3 Lead vehicle stopped at traffic light
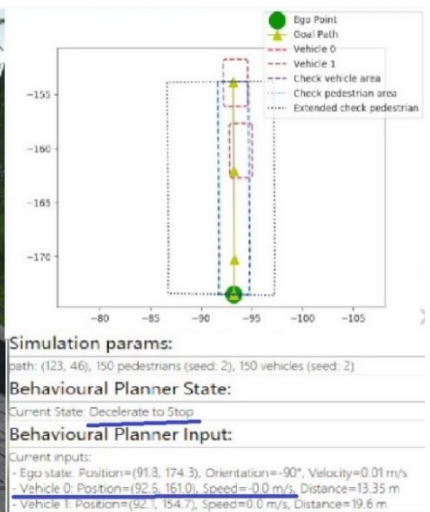
In case of stopped lead vehicle the player agent doesn't follow it but decelerates to stop. This behaviuor allows to avoid cases where the player agent stops too far from the lead vehicle.

3.3 Video demo

Traffic lights : https://www.youtube.com/watch?v=5L9QwT_yl1k

Vehicles : https://www.youtube.com/watch?v=GhraqP6mP30

Pedestrians : https://www.youtube.com/watch?v=UIo7Ag_J8qE