Reinforcement Learning for Autonomous Vehicle Merging Using Highway-Env

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1 Brief description of the problem to be modelled

The objective of this project is to utilize the Highway-Env framework to train an autonomous vehicle model using reinforcement learning to perform highway merging maneuvers safely and efficiently. The model must learn to merge into highway traffic while adapting its behaviour when encountering other vehicles and vice versa. The reinforcement learning approach will focus on optimizing both safety and traffic flow in dynamic highway environments

2 Goals of the simulation project

The primary goals are to ensure successful integration into traffic without collisions and to minimize disruptive behaviour, such as unnecessary lane changes or causing other vehicles to alter their behaviours significantly.

3 Main entities of the system

The system consists of several key entities, including vehicles and the road. The agents can be divided into two types:

- The **ego-vehicle** which is the primary vehicle controlled by the reinforcement learning agent. This is trained in order to achieve the refereed goals.
- The **other vehicles** which represent surrounding traffic on the highway. These vehicles follow predefined behaviour patterns and act as dynamic obstacles for the ego-vehicle to navigate around.

The **road** serves as the environment in which the agents operate. It can vary in the number of lanes and layout. For this project, we chose a highway with two lanes plus a merging one.

4 Variables of the system

The variables used in this project can be divided into two groups, the system variables, which control everything related to the background and all elements present on the simulation, and the ego-vehicle variables, which are responsible for controlling the vehicle's behaviour. Regarding the system we have:

- The **observation** specifies the type of observation the agent receives from the environment
- The **action** defines the type of actions the agent can take. In case of a discrete action space the agent's actions can be turning left or right, accelerate and brake
- The **lanes_count** represents the number of highway lanes in the environment that will be used by cars.
- The **vehicles_count** gives us the number of vehicles present in the simulation including the ego-vehicle. This variable influences the traffic present in the simulation.
- The **duration** show us the total time duration of each simulation
- The **initial_spacing** determine the distance between cars at the start of the simulation. This variable influences the density of traffic.
- The **rewards** can be divided in two different ones. Collision reward with a negative value that is activated when the ego-vehicle collide with other vehicles and speed range reward that reward the ego-vehicle if a certain speed interval is reach.

- Lastly, the **other_vehicles_type** define the behaviour model for the other vehicles during the simulation

Regarding the ego-vehicle we have:

- The **position** of each vehicle (both the ego-vehicle and other vehicles) helps determine safe distances for driving and avoiding collisions.
- **Speed** is a critical variable, as it directly affects vehicle movement and plays a key role in collision avoidance.
- **Acceleration** is also important because it influences how quickly the ego-vehicle can respond to traffic conditions, allowing it to adjust speed smoothly and drive safely.
- Lastly, the **lane index** represents which lane each vehicle occupies on the road and it helps the ego-vehicle make decisions about lane changes in a multi-lane environment.
- The **input** represents the decision that the ego-vehicle makes based on the observations it receives from the environment. These decisions affect the behaviour of all vehicles in the simulation and may include actions such as changing lanes, speeding up or braking.
- The **output** provides us the information we want to evaluate regarding the ego-vehicle behaviour. These metrics may include the number of collisions, the number of episodes involving dangerous driving or the number of successful highway merges by the ego-vehicle.

5 Operation policies to be tested (scenarios)

In this project we will test at least three different operational scenarios:

1. Determining the best action to minimize the impact on the ego-vehicle's velocity when another car is merging onto the highway.
2. Determining the best action to minimize the impact on the behaviour of other vehicles when the ego is merging onto the highway.
3. Identifying the ideal speed for safely merging onto the highway.

6 Key performance indicators and decision criteria

To evaluate the operational scenarios we will implement reward shaping to determine the optimal reward function for each scenario outlined earlier. Additionally certain priority criteria will be establish to ensure a consistent decision-making framework.

The most important scenario is **Scenario 3** where we aim to identify the optimal speed interval, varying in 10 m/s, for merging safely onto the highway. Once the best interval is found, we will attempt to refine it by reducing its amplitude. This scenario applies when the ego-vehicle is merging onto the highway.

The second priority is **Scenario 1** where we evaluate the best action for the ego-vehicle when another vehicle is merging. Possible actions include braking abruptly when very close to the entrance of the merging lane, braking earlier, or, in the last case, changing lanes. This scenario is relevant when the ego-vehicle is already on the highway, and another vehicle is merging.

Lastly, we have **Scenario 2** which could occur when the ego-vehicle is either on the highway or in the merging lane. In terms of priority, we consider highway entry the most important. The ego-vehicle could either brake and wait for an opportunity to merge or accelerate and attempt to merge. For the second priority, if the ego-vehicle is on the highway, it could either brake to allow another vehicle to merge, accelerate, or change lanes to facilitate the merging.

7 Data requirements

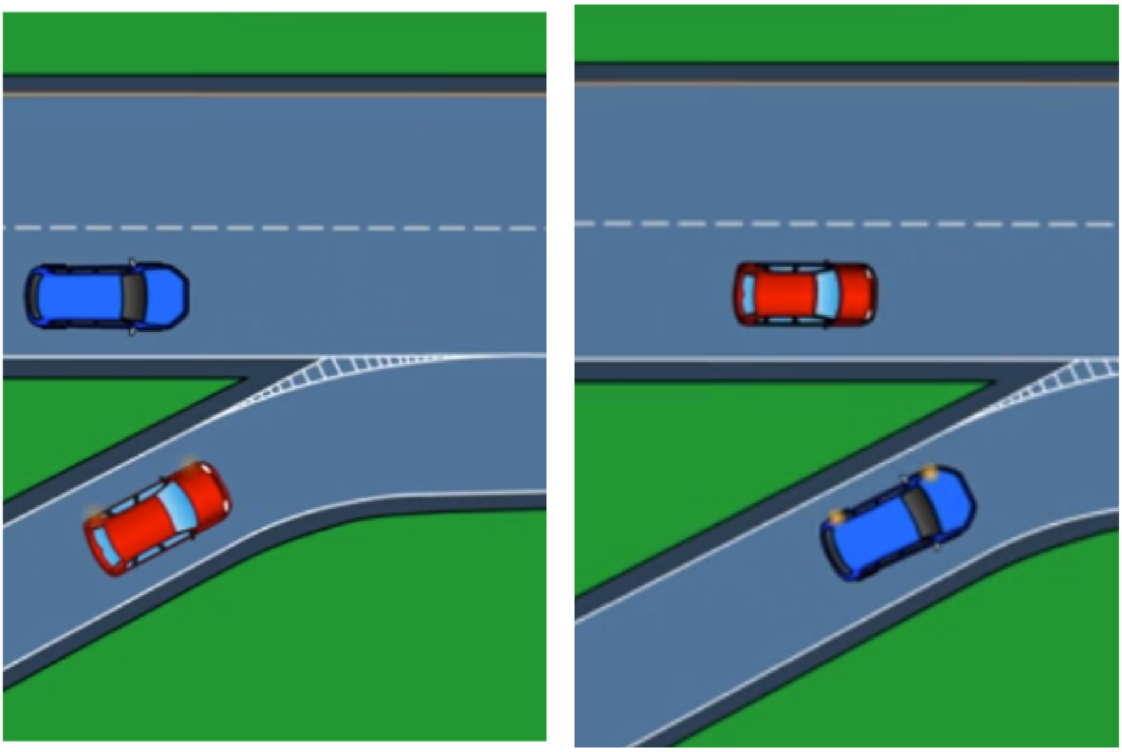
The project's data will be generated throughout the training, but, in order to make the study more realistic, some restrictions were applied such as maximum speed and others. All the aforementioned restrictions will be based on real life Portuguese traffic laws.

8 Simulation tools, environments, languages

On this project the Highway-Env framework to simulate all the scenarios outlined and Python will be used as the code language.

9 Other information the group may find appropriate to describe the problem

We will begin this project with two reference situations for the ego-vehicle's position. The ego-vehicle either starts in the merging lane or already on highway, approaching the merging lane. The highway will have characteristics similar to those of a typical Portuguese one, consisting of two lanes plus a merging one.



(a) Ego Merging

(b) Ego on the highway

Fig. 1. Reference Situations [1]

References

[1] Contributors, W.: Merge onto the highway without crashing. https://www.wikihow.com/Merge-Onto-the-Highway-Without-Crashing (2023), accessed: 2024-10-02