Scenario Interpretation based on Primary Situations for Automatic Turning at Urban Intersections

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Abstract: Even for a human driver, urban intersections represent probably the most difficult scenarios, in which the driver could be overloaded by understanding the traffic rules, predicting the intention of other objects, etc. The complexity of these scenarios makes the task of automated driving at intersections a very difficult challenge. Thus, we propose an approach that aims to reduce the complexity of the scenario interpretation by breaking down the problem into a set of primary situations linked over time. Based on the combination of four primary situations, the scenario interpretation should enable the corresponding planning that guides the ego vehicle along a driving corridor.

1 INTRODUCTION

Driver assistance and automated driving systems have become a very emerging field of research in the last decades. In (Okuda et al., 2014) the authors review the most promising approaches and techniques used in these kind of systems.

Considering the basic conceptual flowchart in Fig. 1, the automated driving process can be simplified into four main steps: (1) perception, (2) scenario interpretation, (3) planning and (4) control. In this basic representation, the perception module provides the description of the surrounding world to the next module. Then, the scenario interpretation module achieves the comprehension of the relevant information for the following planning and control stages.

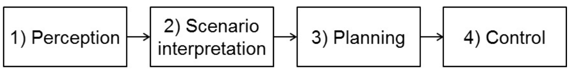

Figure 1: Basic conceptual flowchart for automated driving based on four main steps. The environment perception (1) represents the low level processing of sensors and a priori data (e.g. image processing, object recognition and tracking, localization and mapping, etc.). The scenario interpretation (2) corresponds with the understanding of the processed data. The planning (3) makes the proper decisions and delivers them to the control module (4), which finally provides the adequate signals in terms of steering and acceleration.

Obviously, the more inaccurate the perception is, the more complex is the interpretation of the provided data. But even if the perception provides accurate information about the surrounding of the ego vehicle, the problem is not simple. The large number of possible collisions with other road users at urban intersections makes the problem a very complex challenge. For this reason, the proposed concept aims to enable the decision making for automated turning at urban intersection in a simple manner.

In this paper, we first describe the general concept of *scenario interpretation* for automated driving. Then, section 3 gives an overview of related work at intersections. After that, we address the problem in section 4. Hereafter, the proposed approach is explained in section 5. And finally, section 6 concludes the paper.

1.1 Definition of Scenario Interpretation

Before going into further details, two concepts have to be defined: *scenario* and *interpretation*. The authors in (Geyer et al., 2014) propose a definition for some relevant terms in the automated driving context (situation, scene, scenario, etc.). As can be seen in Fig. 2, the scenery is defined as the combination of all possible single static elements (e.g. road network, number of lanes, crosswalks, position of traffic lights, speed limits, etc.). The scene contains the scenery and the information of all dynamic objects with their cor-

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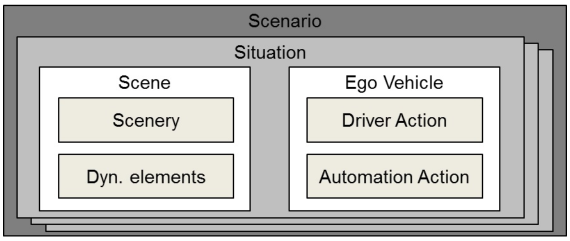

Figure 2: Definition of the term scenario by (Geyer et al., 2014).

responding states. The situation consist of the scene and optional ego vehicle. In this context, the situation describes the current state, which could persist several seconds until some conditions or criteria are filled. On the contrary, the scenario describes different states over the time, so that it contains at least one situation, in which the last situation corresponds to the last relevant situation.

Another definition is used in (Domsch and Negele, 2008). Domsch et al. propose a definition for terms like: driver-situation, traffic situation, scenario, etc.. A driving situation is described with the parameters: static (road network, traffic rules, priority, etc.), dynamic (objects, traffic lights phases, etc.) and diverse (weather, road conditions, etc.). Moreover, Ulbrich et al. (Ulbrich et al., 2015) present a coherent review and comparison of these terms and propose their own definitions.

On the other hand, the term *interpretation* refers to the act of explaining the meaning of something. In this sense, the perception module makes a description of the surrounding of the vehicle and the scenario interpretation module gives a proper meaning to this information. Accordingly, the scenario interpretation at intersection involves the following tasks:

- Filtering relevant information
- Using the information of the road network with corresponding logical correspondences
- Predicting the intention of other vehicles
- Handling occlusions
- Achieving risk assessment
- Considering logical traffic rules
- Handling the right of way
- Handling localization uncertainty
- Etc.

For example, in the first example of Fig. 3 (A) the ego vehicle (in blue) is turning to the left and another vehicle (in red) is approaching the intersection. It becomes obvious that it is crucial to know on which lane the other car is driving to determine a possible collision with the ego vehicle: if the red car is driving on

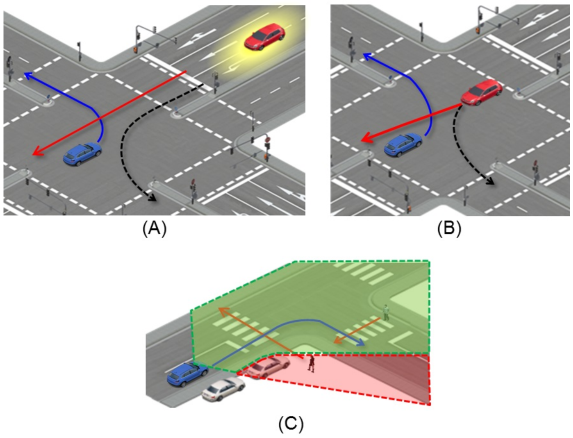

Figure 3: Examples of scenario interpretation at intersections. **(A) Intention prediction of an oncoming vehicle with inaccurate position:** the ego vehicle (in blue) is making a left turn maneuver (blue path) and other vehicle (in red) is approaching the intersection. The yellow blob surrounding the other vehicle represents the uncertainty of its measured position. In case that the other vehicle is driving forward (red path), there is an intersection of both paths. Otherwise (black dotted path), there is no collision between both vehicles. **(B) Intention prediction of an oncoming vehicle with accurate position:** the ego vehicle is turning left and the other vehicle (which is already in the intersection and its position is accurate enough) could drive forward or turn left. **(C) Handling occlusion while approaching an intersection:** the ego vehicle is approaching the intersection and aims to turn to the right. Due to an obstacle (e.g. another vehicle), the occlusion impede to detect a crossing pedestrian at the right side of a zebra crossing. The green and red colored regions indicate the perceptible and non perceptible areas respectively.

its most left lane, it is just allowed to turn to the left, so that a collision with the ego vehicle is not expected. Alternatively, if the other car is not driving on its most left lane, its path has a conflict with the ego's driving corridor. Thus, if the position of other vehicles (or ego vehicle) is not accurate enough (e.g. due to location uncertainty), the scenario interpretation module has to manage the uncertainty of the information in order to understand how critical is the situation.

But even considering a perfect accuracy of the position of both vehicles, a proper intention prediction could be crucial (depending on the road network and its turning possibilities). As shown in 3 (B), the ego vehicle is turning left and the other car could perform two maneuvers: driving forward or turning left. In this case, the accuracy of the state of the other car (e.g. yaw, velocity, etc.) is crucial to achieve a proper intention prediction.

Moreover, an important task of the scenario interpretation module is to handle occlusions. In this way, it is not only important to understand the provided information, but also to take into account which information is missing. For example, in Fig. 3 (C) the ego vehicle (blue) is approaching the intersection and an obstacle (a parked car in white) impede to detect a pedestrian. For this given scenario, the first pedestrian (behind the obstacle) is not detected due to the occlusion, but a proper scenario interpretation should be able to interpret the occlusion as a critical missing information. Consequently, it is unclear if more pedestrians approach the crosswalk or not.

1.2 Scenario Interpretation at Urban Intersections

Due to the complexity of scenarios at urban intersections, it becomes obvious that a proper scenario interpretation is required. In recent years several methods have been proposed to tackle this problem. Vacek et al. (Vacek et al., 2007) present an approach for a case- and rule-based situation interpretation using description logic. The raw data from the sensors is stored and transformed into a higher level representation. The different expected behavior of other vehicles generates the linkage of other cases over time with corresponding probabilities for every different situation. Since the number of different options becomes very large at intersections, the computational cost for the description logic reasoning constitutes the main drawback of this approach. Logic description is also used by Huelsen et al. (Hülsen et al., 2011) to describe an ontology that represents the road networks, objects, their relations and the corresponding traffic rules. The goal is to reason relations, objects, traffic rules (e.g. *hasRightOfWay* or *hasToYield*) using inference services. Even keeping only necessary information for reasoning, the main drawback of this approach are the high computational costs. Therefore, this approach is insufficient for real-time computation.

Geyer et al. (Geyer et al., 2011) present a method based on the cooperation between the driver and the system with the Conduct-By-Wire (CBW) concept. Depending on the current driving situation, and the required information, the so-called gates are identified. A driving situation is described with three types of parameters: Static (road network, traffic rules, priority, etc), dynamic (objects, traffic lights phases, etc.) and diverse (weather, road conditions, etc.). The system analyzes the required information at the gates. Consequently, different automation levels are set to make easier the cooperation between the system and the driver. To determine which information is needed, a occupancy map and entry directions at the intersection are set. The CBW approach was also used by Schreiber and Negele (Schreiber et al., 2010) to develop of a maneuver catalog from the driver point of view. The focus is to analyze what the driver is expected to do. This information is combined with a set of maneuvers that should cover every possible traffic and driving maneuver. The authors in (Alonso et al., 2011)present two methods for priority conflict resolution (priority charts and priority levels) using a vehicle-to-vehicle (V2V) communication system as a requirement. The first method uses vectors to describe the turning possibilities of all vehicles and their corresponding priority signs. Then, an auxiliary table containing all possible vectors associated with Boolean values is used to indicate if the ego vehicle has to move or stop. This table contains 111 different cases without considering the traffic signs combinations (3 for one vehicle, 27 for two vehicles, and 81 for three vehicles). On the other hand, the second proposed method aims to determine whether the ego vehicle can continue or must wait by interpreting the different priority levels (using an auxiliary truth table to detect potential conflicts with other vehicles). The authors propose a flowchart to handle the right of way problem. These two proposed methods depend on an specific topology (in this case a two road intersection). Moreover, V2V communication is required. Although the focus of (Lotz and Winner, 2014) is not to turn automatically at urban intersections, the authors propose a maneuver-based planning for automated vehicles. Based on the desired maneuver (or set of maneuvers over the time) the proposed system plans the proper lane change by approaching the intersection. The approach was tested in a multi-lane road network without other road users.

2 PROBLEM DESCRIPTION

The described problem is focused on understanding the perceived information of the environment at urban intersections. In this sense, the interpretation should enable to plan the proper vehicle motion for turning at urban intersections with different precedence states. Unfortunately, there is no international regulation that controls the traffic flow at intersections in a unique manner for all the possible scenarios all over the world. Therefore, this work considers the regulation described in the Vienna Convention on Road Signs and Signals (for Europe, 2006) and the German regulation (für Straßen und Verkehrswesen (FGSV), 2010) in particular. A coherent way to address the problem is to describe an intersection in a simple manner. Therefore, we try to make a conceptual description of the scenario answering three questions

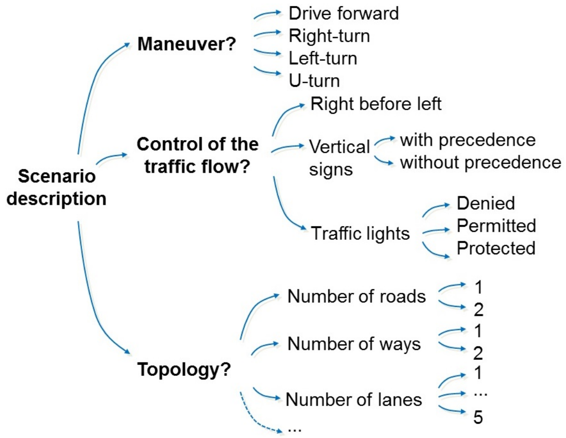

Figure 4: Simple classification to describe an intersection.

(cf. 4):

- Which maneuver is making the ego vehicle?
- In which way is the traffic flow controlled?
- What is the topology of the intersection?

Therefore, the traffic flow at intersections can be controlled in three different ways: by the *right of way* rule, with vertical signs or traffic lights. The ego vehicle intention and the control of the traffic flow, yield different scenarios and potential conflicts with other vehicles or vulnerable road users (VRU). Fig. 5 illustrates the different possible scenarios considering a simple intersection topology. This classification is an improved version of the method proposed by Fastenmeier (Fastenmeier et al., 1995):

In this sense, every possible state of the intersection defines the control of the traffic flow (from an ego perspective, i.e. it indicates how ego vehicle should handle the right of way). The following intersection states are considered:

Denied: a common circular red traffic light has been detected. The ego vehicle has to stop as long as the traffic light color is red.

Permitted: a common circular green light has been detected, so that the ego vehicle is allowed to turn. However, the ego vehicle has to give way to oncoming vehicles while turning left and VRU have priority in parallel conflicts.

Protected: a green arrow traffic light has been detected. According to (für Straßen und Verkehrswesen (FGSV), 2010), the path of the ego vehicle to complete the turning maneuver has no conflicts with other road users.

Permitted on Red: a static sign with a green arrow has been detected beside a red traffic light. Even if the traffic light indicates red, the ego vehicle is allowed to turn if there is no potential collision with other crossing/oncoming vehicles.

Right before Left: a vertical sign indicates that the rule *right before left* has to be applied or no vertical sign controls the traffic flow, and consequently, this rule is applied by default.

With Precedence: a priority road sign has been detected, so that other crossing vehicles are required to give way to the ego vehicle.

Give Way: a give way is used to notify the ego vehicle that it has to give way to other crossing vehicles.

Stop: the detected stop sign implies that the ego vehicle is required to stop (even if any other vehicle is crossing) and give way to other vehicles.

The other possibility to describe an intersection is to consider its topology. Other authors (Gerstenberger, 2015) have analyzed in detail the most common topologies to determine the relation between the different topologies and the traffic accidents. Considering the large number or possible different topologies, we take for granted that a scenario interpretation based on specific topologies is not appropriate. Therefore, the proposed solution aims to achieve a left and right turn maneuver independently on the intersection topology.

3 PROPOSED APPROACH

The proposed approach aims to make the interpretation of the scenario (and further planning) easier by breaking it down into primary situations. Therefore, we first describe in detail how we define a scenario based on primary situations and finally we explain how the ego vehicle is guided to complete the turning maneuver.

3.1 Scenario Interpretation based on Primary Situations

A scenario contains mainly three important concepts: the linkage of the expected primary situations, the ego intention and the information of the intersection state, which defines how the traffic flow is controlled from an ego perspective. In this way, the primary situations are defined by potential conflicts with other road users and further relevant. A single primary situation

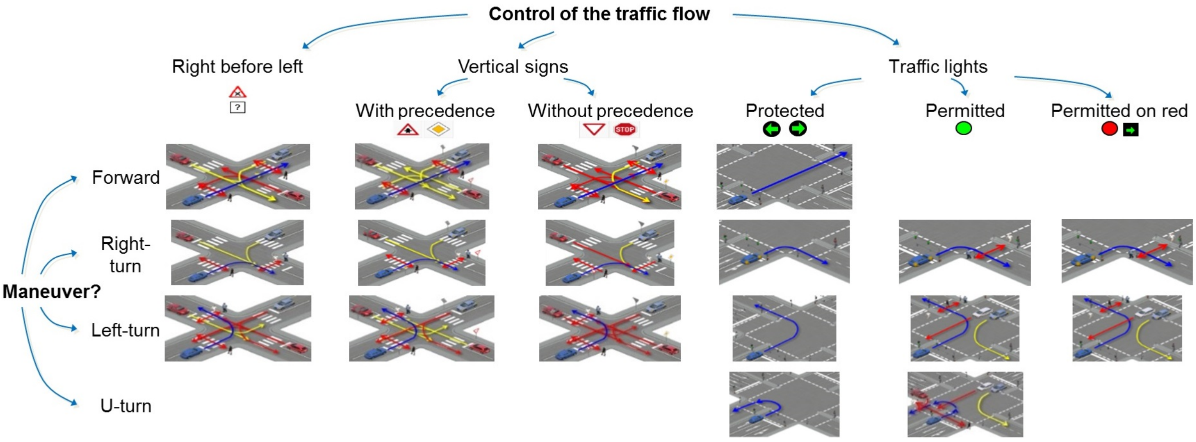

Figure 5: Classification of possible scenarios at a simple intersection topology considering the desired maneuver and right of way. Every column represents a different maneuver of ego vehicle with its path (blue). Every row corresponds to a different manner to control the of right of way. All possible path of other vehicles with a potential collision with ego vehicle is colored depending on its priority. The other vehicles (or VRU) with a red path have priority with respect to ego vehicle. The other vehicles with yellow paths are required to give way to ego. The dotted arrows indicate paths of other vehicles without an intersection with ego's path.

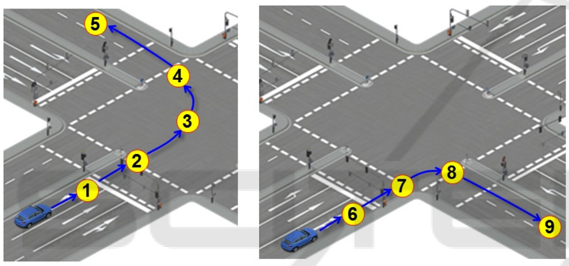

Figure 6: Nine primary target points for automatic turning left or right at intersections.

requires at least a target point, its corresponding region(s) of interest (ROI) and the relevant objects inside this ROI(s). This concepts are explained down bellow. Every target point indicates the position and velocity of the ego vehicle along a determine driving path (or trajectory). It represents the stages where a single primary situation is expected, so that the set of target points defines the maneuver of the vehicle. As shown in Fig. 6, the set of primary target points for turning at intersections can be automatically calculated based on the road network information..

Furthermore, every ROI describes a geometric area (as 2D polygon) that has to be observed for every primary situation. It represents the area where relevant objects are expected. For example, if a zebra crossing was detected in front of the ego vehicle, the ROI for this situation should represent the area where pedestrians could be. In other words, the ROIs indicate the areas where objects (other vehicles or VRU) could appear and produce potential conflicts with the ego vehicle. Therefore, the ROIs can be calculated automatically considering the road network information (i.e. considering the paths intersection of the ego

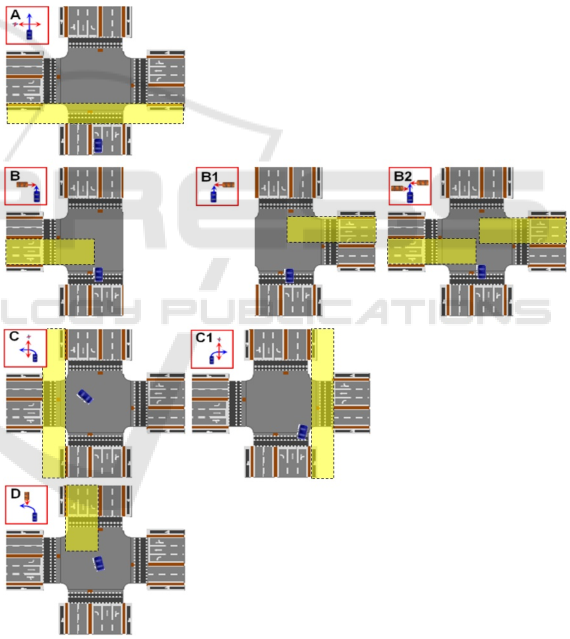

Figure 7: Primary situations (A, B, B1, B2, C, C1, D) with corresponding region of interest (yellow semi-transparent rectangles) for a generic intersection and ego position (colored in blue).

vehicle and other road users).

As it is illustrated in Fig. 7, we propose four primary situations with their corresponding ROIs (*A*, *B*, *C*, *D*):

A: a perpendicular conflict with VRU (e.g. a crosswalk, zebra crossing or bike lane) is in front of the ego vehicle. The corresponding ROI consists of the conflict and its surround area where potential objects are expected. For example, if the ego vehicle is approaching the intersection and there is a perpendicular bike lane in front of it, the ROI is automatically calculated considering the area that the ego vehicle aims to overdrive and the surrounding area along the bike lane where a possible bicycle could be. Obviously, the size of the area along the bike lane is determined by the ego velocity (the faster ego vehicle drives, the larger should be the size of the area along the bike lane).

B: the ego vehicle has a conflict with a left-cross lane (e.g. at a T-form intersection without right-crossing lanes). Here, the ROI is calculated considering the information of the road network along the possible left-cross lanes. $B1$ is not considered a primary situation its own, but a mirrored version of B, in which the cross lane comes from the right side. In addition, $B2$ corresponds to a combination of B and $B1$ (e.g. at a X-form intersection).

C: the ego vehicle has a conflict with a parallel crosswalk, zebra crossing or bike lane. Perpendicular and parallel conflicts with VRUs by turning at intersections have to be handled in a different manner compared to situation A. For example, at an intersection controlled with traffic lights, when the state is permitted, the ego vehicle has precedence with respect to the VRUs crossing a perpendicular crosswalk. On the contrary, the ego vehicle has no precedence with respect to VRUs crossing a parallel crosswalk (this is graphically explained in Fig. 5).

D: the ego vehicle has a conflict with an oncoming vehicle.

The linkage of the primary situations represents the order in which consecutive single primary situations are expected and the relations between them. Accordingly, the situations can be vertically or horizontally linked: a vertical link indicates that the next primary situation is expected at a certain distance (and, depending on the variation of the ego velocity over time). But a horizontal link denotes that another different primary situation could also be expected at the same distance. The level of the vertical and horizontal linkage is denoted by i and j respectively. In this sense, a scenario (S) denotes the connections of primary situations (PS_{ij}):

$$\begin{aligned} S = \{PS_{11}, ..., PS_{1N_1};\\ PS_{21}, ..., PS_{2N_2};\\ ...;\\ PS_{M1}, PS_{MN_M}\}, \end{aligned} \tag{1}$$

where M is the number of different vertical linkage levels and Ni is the number horizontal linkage levels for every corresponding vertical level (i). The concept is illustrated in Fig. 8.

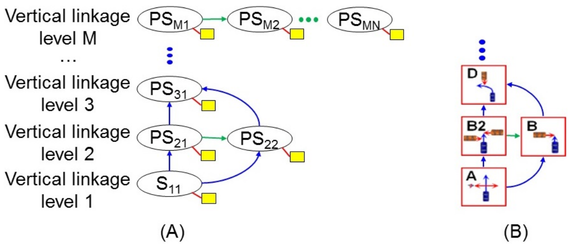

Figure 8: Concept of a scenario based on linkages of primary situations. (A) and (B) illustrates the concept and a given example respectively. Every ellipse (PS_{ij}) represents a primary situation with its corresponding relevant information. The blue and green arrows indicate the vertical (i) and horizontal (j) linkage level respectively. The yellow rectangles represent the information of the ROIs and the detected objects. In this example, the first situation PS_{11} is linked vertically with the primary situations PS_{21} and PS_{22}, which are horizontally linked between them (green arrow) and once again vertically linked with PS_{31}.

For example, the ego vehicle is approaching the intersection with the intention of turning to the left without precedence. Firstly (i.e. vertical linkage level 1), a perpendicular crosswalk is detected, so that the first situation PS_{11} corresponds to the primary situation A. In this case, the yellow rectangle represents the ROI around the crosswalk and the detected objects. Lets say that the information of the road network is not accurate (or trustworthy) enough, and consequently the interpretation module can not guaranty that the intersection has a T- or X-form. In this case two possibilities are expected: $PS_{11} = B$ (left-cross lane) and $PS_{22} = B2$ (left and right-cross lane). Furthermore, independently on which primary situation is the most probable at the vertical linkage 2, the next expected situation (PS_{31}) is D (i.e. we expect oncoming vehicles inside the corresponding ROI). And so on, the scenario is interpreted by generating the linkage of primary situations over time and continuously updating these linkages. For this given example, as ego vehicle is getting closer to the intersection, the road network information becomes more accurate, so that the vertical linkages become also more robust. In other words, the linkages are updated taking into account the information of the perception module and optimizing the connections between the primary situations.

3.2 Planning the Maneuver

Once the scenario is generated, the target points have to be set according to the available information (e.g. relevant objects or intersection state), so that the ego

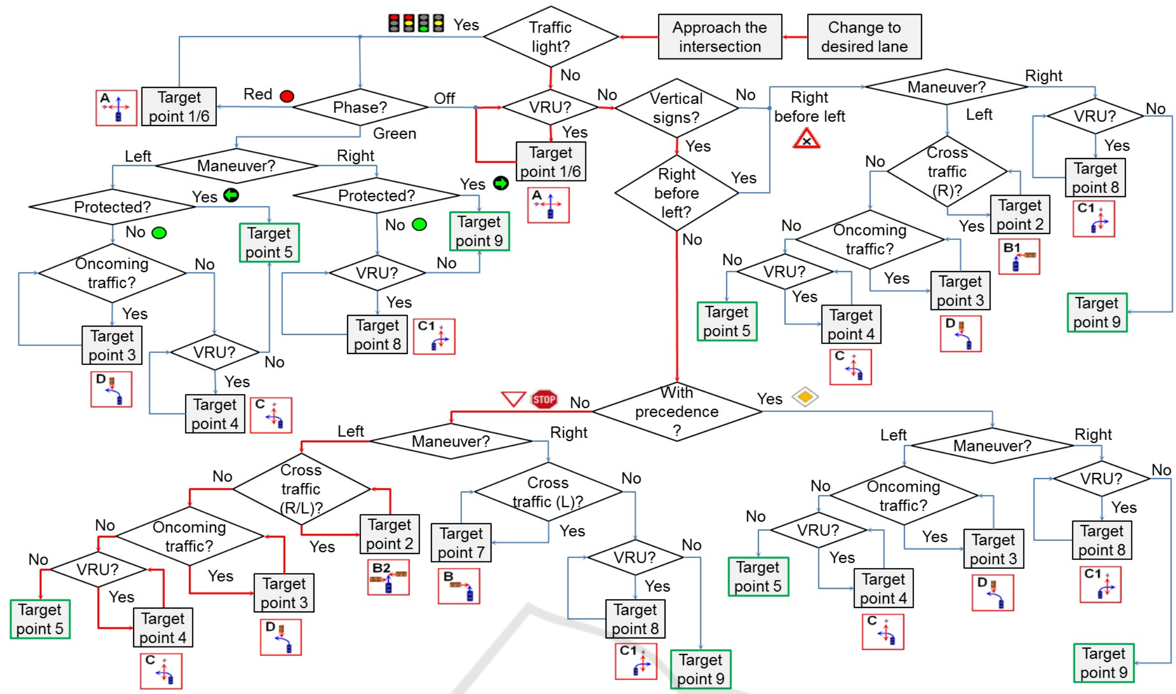

Figure 9: Flowchart for automated turning based on primary situations. It explains step by step the connection of the expected primary situations and their according target points. The last target point guides the ego vehicle to the end of the turning maneuver (rectangles with green border). A given example is highlighted in red (left turn without precedence).

vehicle is guided to achieve the whole turning maneuver. Since the trajectory of the ego vehicle is part of the scenario, the target points are set along a driving path. The flowchart highlighted in Fig. 9 explains which information is needed to set the proper target points for every primary situation. For the sake of clarity, the diagram has been kept simple by considering only a very basic topology. In other words, the consideration of more complex topologies (e.g. handling T- or X-form intersections) is omitted to ease its representation and understanding. Furthermore, the difference between an intersection state *stop* or *give way*, and the intersection state *permitted on red* are also omitted.

Once the ego vehicle approaches the intersection and has done the proper lane change(s), the first required information is how plausible the existence of traffic lights and vertical signs are. This determines the first main branching of the flowchart, which is based on how the traffic flow is controlled, namely by traffic lights, vertical signs or the *right before left* rule. In the given example (highlighted with red arrows in the flowchart 9 any traffic light is detected. Then, a primary situation A is expected depending on the existence of a perpendicular conflict with VRUs. Then, the flowchart is divided into two branches depending how the traffic flow is controlled, i.e., by vertical signs or the *right before left* rule. In the given example a yield sign was detected, and the ego vehicle intends to turn left, so that both left and right possible crossing vehicles have the right of way (primary situation *B*2). Consequently, if the a collision with ego vehicle and some crossing vehicle from both sides inside the corresponding ROIs is predicted, the target point 2 forces ego vehicle to stop in front of the conflict area so long as no collision is expected. Then, the next primary situation *D* implies setting the target point 3, in such a way as to avoid a collision with oncoming vehicles. But in case that any collision is predicted (e.g. because the are no oncoming vehicles in the corresponding ROI), the next target point 4 (primary situation *C*) is set as long as the conflict area is not passable. Otherwise, the left turn maneuver is completed with the target point 5. An important advantage of this concept is that a target point does not only indicate a position, but also a desired velocity. This allows handling occlusions in a simple manner. For example, in case that the ego vehicle is making a right turn (see Fig. 10) and an obstacle (e.g. other car) impedes to observe the ROI completely, the scenario interpretation should not take for granted that the whole ROI is free. In fact, a pedestrian could be in those parts of the ROI that are not perceptible (in this example behind the white car). As human drivers, we would probably reduce the velocity because we are not sure if some pedestrians are crossing.

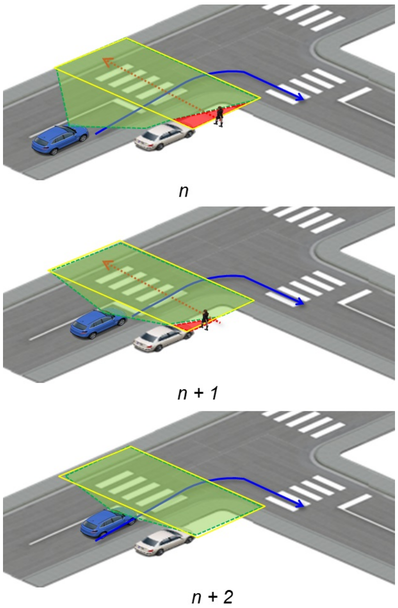

Figure 10: Occlusion example illustrated over the time (n, $n+1$ and $n+2$). The ego vehicle (blue) is making a right turn maneuver (blue path) and other vehicle (white) impedes to observe the ROI (yellow rectangle) completely. The perceptible and not perceptible areas are colored in green and red respectively. The illustrated pedestrian and its path (dotted red arrow) corresponds to a placed virtual object.

The idea is to imitate cognitive human reaction in a very simple way: setting a virtual object. This object is placed representing the worst case (i.e. a pedestrian is crossing so that a collision with the ego vehicle will occur). In the given example, a virtual pedestrian is placed at the time n and $n+1$. This placed object causes that the prediction module set the target point 6 with a very low velocity (e.g. 5 Km/h), because a pedestrian could be behind the white car.

4 CONCLUSIONS

In this paper a scenario interpretation approach for automated driving at intersections has been introduced. The main goal of the proposed method is to make the interpretation of the scenario and the further decision making easier. This has been achieved by breaking down the problem into four primary situations (or combinations of them). After explaining the meaning of the term *scenario interpretation*, an overview of the related work was given. Then, we described the problem taking into account the intention on the ego vehicle and the intersection state that controls the traffic flow. This analysis identified the potential conflicts with other road users in a simple manner. In this way, the scenario consists of linkages of expected primary situation over time, in which just the relevant information is needed. These primary situations are defined by the potential conflicts with other road users and further information (target point, ROI, relevant objects). Moreover, a flowchart to complete the left and right turn maneuver was presented. This diagram represents the combination of primary situations over time facilitating to turn left/right automatically. Compared to state-of-the-art solutions, a very important advantage of our system is that it may be applied independently of the intersections topology. Furthermore, it offers the possibility of handling occlusions in a simple way.

Future research will focus on optimizing the process of predicting the intersection state that controls the right of way at the intersection. Moreover, research work to analyze the computational cost of the proposed approach have to be done. In this sense, a detailed evaluation of the proposed approach and its functionality over the time for real scenarios will be achieved and compared with other techniques. These future validation involves scenarios with different VRUs, weather conditions and topologies.

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