An Ontology-based Approach to Generate the Advanced Driver Assistance Use Cases of Highway Traffic

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Abstract: Autonomous vehicles perceive the environment with different kinds of sensors (camera, radar, lidar...). They must evolve in an unpredictable environment and a wide context of dynamic execution, with strong interactions. In order to generate the safety of the autonomous vehicle, its occupants and the others road users, it is necessary to validate the decisions of the algorithms for all the situations that will be met. These situations are described and generated as different use cases of automated vehicles. In this work, we propose an approach to generate automatically use cases of autonomous vehicle for highway. This approach is based on a three layers hierarchy, which exploits static and mobile concepts we have defined in the context of three ontologies: highway, weather and vehicle. The highway ontology and the weather ontology conceptualize the environment in which evolves the autonomous vehicle, and the vehicle ontology consists of the vehicle devices and the control actions. To apply our approach, we consider a running example about the insertion of a vehicle by the right entrance lane of a highway.

1 INTRODUCTION

Autonomous vehicles must evolve in an unpredictable environment and a wide context of dynamic execution, with strong interactions. Since the 1970s, the research on autonomous vehicle became a tentancy in the industry. After years of exploration, certain progress has been made. In early 2018, Audi expanded Traffic Light Information Vehicle-to-Infrastructure (V2I) system to Washington (Krok, 2018). Nissan plans to continue the collaboration with NASA to adapt NASA technology for use in their Seamless Autonomous Mobility platform (Bartosiak, 2018). Not only is the traditional auto industry dedicated to this research domain, but other companies, such as Google and Intel, have also participated to the development of the autonomous vehicles. Waymo, which started as Google's self-driving car project, canceled the design of the steering wheel and pedals (Gain, 2017), which completely overturns the design of traditional cars.

Recently, the world's first driverless taxi was put into use in Dubai (Caughill, 2017). Tesla has made the first delivery of fifty (50) out of two hundreds (200) vehicles to Dubai. The goal is for the cars to evolve into a fully autonomous taxi service. Autonomous vehicles are no longer just in the scenes of science fiction movies. They come to real life and will become more commonplace as ordinary cars. However, at the same time, autonomous vehicles brought new problems to our lives, for example, the issue of accident liability determination, and most importantly, the issue of safety.

The recent fatal crash in California of Tesla's Autopilot System shows that safety assessment of intelligent systems is a high-priority topic in the automated vehicle industry. The driver's hands were not detected on the wheel for six seconds prior to the collision (BBC, 2018) while the owners guide specifies that the driver must keep the hands on the steering wheel at all times (Tesla, 2018). The autopilot is not smart enough to hold all the situations it meets. Human driver needs to be involved at critical moments, but its attention cannot be focused for a long time since most of the time the driver has nothing to do in such vehicles.

To ensure the safety of the autonomous vehicle, its occupants and the other road users, when autonomous vehicles evolve in the dynamic environment, it is necessary to simulate all possible situations to test and validate the decisions of the algorithms of the Advanced Driver-Assistance Systems (ADAS) inside the vehicle. These situations are described and genera-

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ted as different use cases of automated vehicles. A use case is defined as one or several scenarios applied to functional ranges and behaviors to simulate the ADAS. A scenario describes the temporal development between several scenes in a sequence of scenes.

In this work, we propose an approach to generate automatically use cases of autonomous vehicle in the context of highway. This approach is based on a three layers hierarchy, which exploits static and mobile concepts we have defined in the context of three ontologies: highway, weather and vehicle. We consider a running example: "*Insertion of vehicle by the right entrance lane of a highway*", to show the concepts and their relationships in the ontologies. We introduce the approach of use cases generation with different scenarios constructed using several scenes and we show how to apply this approach on the running example.

Structure of the paper: Section 2 is dedicated to Related Works. In Section 3, we describe our running example. The three ontologies are presented in Section 4. Our approach of use cases generation is presented in Section 5. Finally, we conclude our work in Section 6.

2 RELATED WORKS

Several researchers have used ontologies for the conceptualization of the ADAS or the control of the autonomous vehicle.

An ontology of recognition for the ADAS system is presented in (Armand et al., 2014). The authors define an ontology composed of concepts and their instances. This ontology includes contextual concepts and context parameters. It is able to process human-like reasoning on global road contexts. Another ontology is proposed by Pollard et al. (Pollard et al., 2013) for situation assessment for automated ground vehicles. It includes the sensors/actuators state, environmental conditions and driver's state. However, as the classes of both ontologies are highly generalized, they are not enough to describe use cases to simulate and validate ADAS.

To build a knowledge base for smart vehicles and implement different types of ADAS, Zhao et al. (Zhao et al., 2015) proposed three ontologies: map ontology, control ontology and car ontology. They focus on algorithms for rapid decision making for autonomous vehicle systems. They provide an ontology-based knowledge base and decision-making system that can make safe decisions about uncontrolled intersections and narrow roads. However, the authors did not consider the equipment of the road infrastructure in their map ontology, for example the traffic signs which are an important part for use cases construction.

Morignot et al. (Morignot and Nashashibi, 2012) propose an ontology to relax traffic regulation in unusual but practical situations, in order to assist drivers. Their ontology represents the vehicles, the infrastructure and the traffic regulation for the general road. It is based on the experience of the members of the lab with driving license, not based on a texts corpus. That may be useful for modelling the concepts involved in traffic regulation relaxation, but we need more rigorous ontologies for modelling the concepts involved in general situations.

In (Bagschik et al., 2017), the authors propose, using ontology, to create scenarios for development of automated driving functions. They propose a process for an ontology based scene creation and a model for knowledge representation with 5 layers: road-level, traffic infrastructure, temporary manipulation of the first two levels, objects and environment. A scene is created from first layer to fifth layer. This ontology has modelled German motorways with 284 classes, 762 logical axioms and 75 semantic web rules. A number of scenes could be automatically generated in natural language. However, the natural language is not a machine-understandable knowledge and the transformation of natural language based scenes to simulation data formats with such a huge ontology is a tremendous work.

In (Hülsen et al., 2011) and in (Hummel et al., 2008) use a description logic to describe the scenes. The first work provides a generic description of road intersections using the concepts *Car*, *Crossing*, *RoadConnection* and *SignAtCrossing*. They use description logic to reason about the relations between cars and describe how a traffic intersection situation is set up in this ontology and define its semantics. The results are presented for an intersection with 5 roads, 11 lanes and 6 cars driving towards the intersection. Hummel et al. (Hummel et al., 2008) also propose an ontology to understand road infrastructures at intersections. This approach focuses on the geometrical details related to the multilevel topological information. It presents scene comprehension frameworks based on the description logic, which can identify unreasonable sensor data by checking for consistency. All these ontologies are limited to the situation of intersection which is not enough to simulate an environment and validate the ADAS.

3 RUNNING EXAMPLE

We consider the situation “*Insertion of vehicle by the right entrance lane of a highway*” as the running example. It is in daylight and the temperature is c °C. The humidity is h % and the pressure is p mPa. The wind speed is v_w km/h and its direction is d_w ° (from 0 to 360 °, 180 ° refers to a southerly wind).

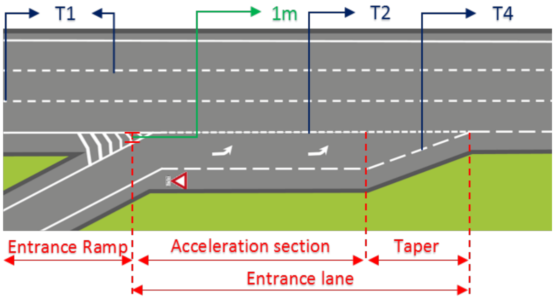

Figure 1: Scenography of the running example.

The highway is separated into two carriageways by median. In the scenography of this running example (Figure 1), a portion of one carriageway is selected. The left hard shoulder is located on the immediate outside of the median. The edge of the left hard shoulder is marked by two single solid white lines. This carriageway has three main lanes and an entrance lane. There is a chevrons marking placed between the outside lane and the entrance lane. The entrance lane is composed of an acceleration section and a taper. An entrance ramp is connected with the entrance lane at the point where the width of the chevrons reduces to one meter ($1m$). The right soft shoulder is located on the immediate outside of the right hard shoulder. In the beginning of the acceleration section, a give way sign is placed on the right soft shoulder. There are two deflection arrows marking on the acceleration section. The types of dashed lines are provided on Figure 1. Their definitions are those provided in the official French document for road symbols (Minist ère de l'écologie, 1988).

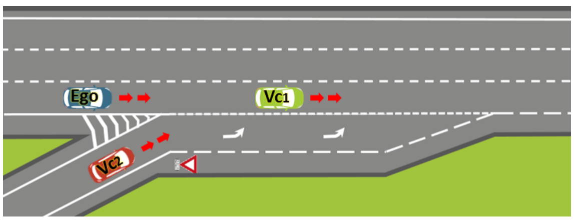

Figure 2: Initial scene of the running example.

In the initial scene (Figure 2) of running example, the Ego vehicle (blue) rolls on the right lane of a separated lane road. The speed of Ego is given by v_e km/h on the portion which speed is limited to 130 km/h. The System Traffic Jam Chauffeur (TJC) is active and regulates the speed of Ego with respect to a target vehicle Vc_1 (green) that is located d_1 m in front of Ego. A third vehicle Vc_2 (red) arrives on the entrance lane and wants to insert the highway. Vc_1 and Vc_2 roll at a speed equal to v_1 km/h and v_2 km/h, respectively.

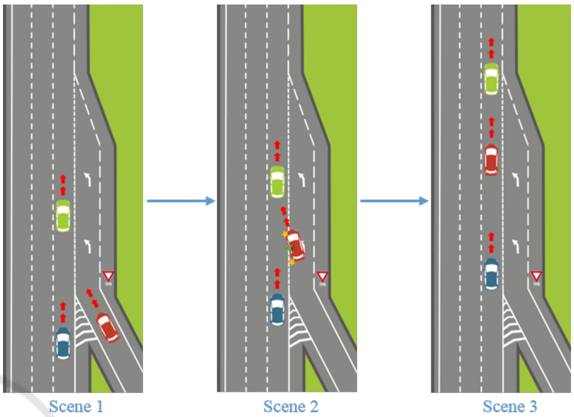

Figure 3: Vehicle insertion before Ego.

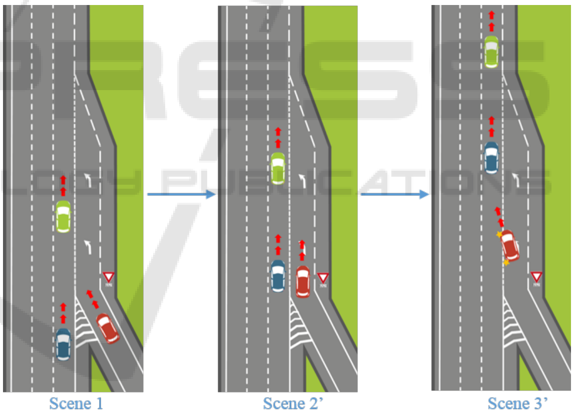

Figure 4: Vehicle insertion after Ego.

We suppose that $v_e = v_1 = v_2$ in this running example. From the initial scene, there are two possibilities: Vc_2 inserts before or after Ego. In the first case (Figure 3), Ego decelerates and Vc_2 turns on the left direction lights and begins to insert before Ego. It follows that the radar of Ego detects this vehicle which becomes the new target vehicle. Ego follows Vc_2. In the second case, if Ego makes the decision to accelerate, obviously this action will lead to another scene and influence the whole scenario as showed in Figure 4. Of course Ego may do nothing and continue driving. In this case, it is the turn of Vc_2 to make decision to decelerate or accelerate. There are also situations where both Ego and Vc_2 do the same actions. For example, they accelerate. But eventually all these situations will render in either of two possibilities: Vc_2 inserts before or after Ego. Note that Ego cannot change to the left lane because on that lane, there is no vehicle and thus no possible target vehicle to follow.

4 ONTOLOGIES

An ontology is a structural framework for the representation of knowledge about a domain. It is often conceived as a set of concepts with their definitions and relationships (Uschold and Gruninger, 1996). In this work, we define three ontologies: highway ontology and weather ontology to specify the environment in which evolves the autonomous vehicle, and the vehicle ontology which consists of the vehicle devices and control actions. The ontologies we have defined have been edited in Protege (protege.stanford.edu, 2012).

4.1 The Concepts

In the following, we describe the concepts of the three (3) ontologies.

Highway Ontology: The highway infrastructure consists of the physical components of highway system providing facilities essential to allow the vehicle driving on the highway. We have built highway ontology based on the French official documents (Minist ère de l'écologie, 1988) (Ministère de l'équipement, 2000). This ontology involves four main concepts: $RoadPart$, $Roadway$, $Zone$ and $Equipment$. The concept $RoadPart$ refers to the long profile of the highway. We consider that the highway is composed of connected segments and interchanges. There are two types of interchanges on highway: $Branch$ and $Ramp$. The branch connects to another highway and the ramp connects to other types of roads. The concept $Roadway$ refers to the longitudinal profile of the highway. The special areas on the highway ($Toll$, $SafetyArea$, $RestArea$, etc.) are classified in the concept $Zone$. The concept $Equipment$ refers to the facilities that guarantee the normal operation of highways. It could be $Barrier$, $Fence$, $TrafficSymbol$, $Lighting$ or $EmergencyTelephone$.

The concepts of this ontology are defined in terms of entity, sub-entities and properties. For example, the concept $EntranceLane$ is defined as in Table 1. In the running example, the ID of $EntranceLane$ is $EnLane_1$.

Table 1: Definition of the concept $EntranceLane$.

Concept	$EntranceLane$
Entity	entrance_lane
Definition	A lane which allows vehicles accessing a highway to accelerate until integrating the highway flow.
Properties	ID, Alignment (Horizontal & Vertical), Length, Width, SpeedLimit
Sub-entities	Acceleration Section, Taper

Figure 5 shows all the fifty-four (54) concepts we have defined for highway ontology. The framed concepts are the concepts that can be used for the running example.

Weather Ontology: The weather describes the state of the atmosphere at a particular place and time. Some phenomena influence the visibility of captors

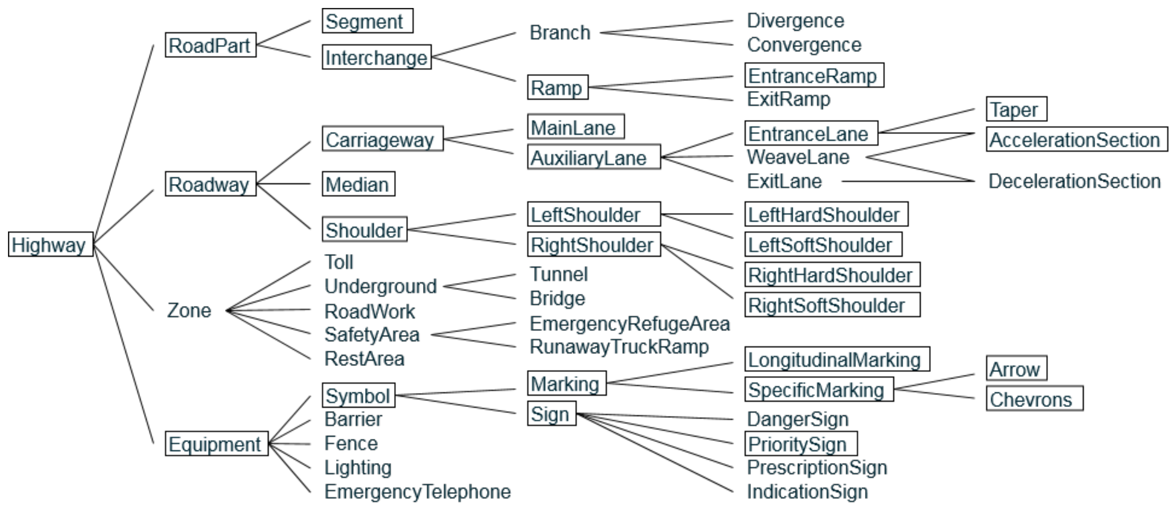

Figure 5: Concepts of highway ontology (framed concepts for running example).

on the autonomous vehicle, for exemple the concepts *Daylight*, *Precipitation*, *Fog* and *Haze*. As the properties of the concept *Daylight* presented in Table 2, the visibility of the autonomous vehicle is reflected by the distance at which an infrastructure or a vehicle can be clearly discerned. Some concepts have their properties to show the physical quantity, such as the concepts *Temperature*, *Pressure* and *Humidity*.

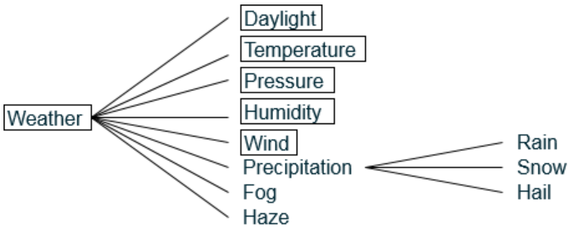

Figure 7: Concepts of Weather ontology.

Table 2: Definition of the concept *Daylight*

Concept	*Daylight*
Entity	daylight
Definition	The combination of all direct and indirect sunlight during the daytime.
Properties	Direction (from 0 to 360 °, 180 ° refers to south light), Visibility (*m*)

We have defined twelve (12) concepts for the weather ontology (Figure 7). The framed concepts are those that can be used for the running example.

Table 3: Properties of concept *Vehicle*.

ID	Ego	Vc_1	Vc_2
Role	$EgoCar$	$TargetCar$	$OtherCar$
Category	$Class1$	$Class1$	$Class1$
Height	H_e	H_1	H_2
Width	W_e	W_1	W_2
Length	L_e	L_1	L_2
Weight	m_e	m_1	m_2
Color	$Blue$	$Green$	Red
Speed	v_e	v_1	v_2

Vehicle Ontology: This ontology describes the performance of a vehicle with nine (9) properties. Table 3 shows the properties of three vehicles in the initial scene of running example. All roles (*EgoCar*, *TargetCar* and *OtherCar*) of vehicles can be represented. There are five classes of vehicle category provided in (Ministère de l'équipement, 2000), where $Class1$ refers to light vehicles whose hight is less than or equal to $2m$ and GVWR (Gross Vehicle Weight Rating) is less than or equal to $3,5t$. The concept *Vehicle* consists of two main sub-entities: *Device* and *Action*. *Device* refers to the devices actionable during the performance of the vehicle, such as the *WindscreenWiper* and the *Light*. *Action* refers to the control actions that could be made by pilot, such as action *ChangeLane* defined in Table 4.

Table 4: Definition of the concept *ChangeLane*.

Concept	*ChangeLane*
Entity	change_lane
Definition	An action indicating a lane change to enter or exit the highway or overtaking another vehicle.
Properties	Direction (Left/right)

Figure 6 shows the twenty-six (26) concepts we have defined for vehicle ontology. The framed concepts are those that can be used for the running example.

4.2 The Relationships and Rules

In order to represent the complex and intricate relationships between the entities, we consider three kinds of relationships (Figure 8): the relationships between the highway entities, the relationships between the vehicle entities, and the relationships between the entities of highway and vehicle. Moreover, the traffic regulation and the interactions between the concepts are written as rules to simulate the environment of autonomous vehicle. We use first-order logic to repre-

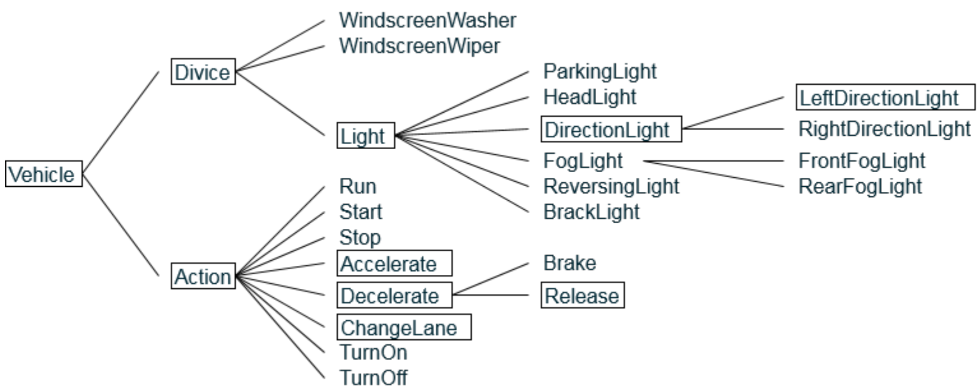

Figure 6: Concepts of vehicle ontology.

sent these relationships and rules. Note that we use the ID of concepts as the variables in the relationship formulas.

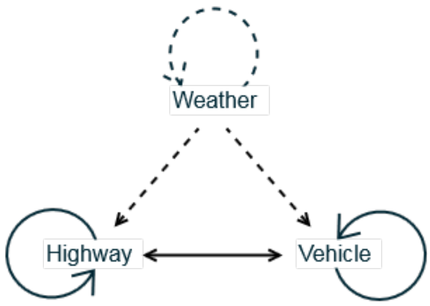

Figure 8: Relationships (solid lines) and effects (dashed lines).

a. Relationships between Highway Entities

There are three types of relationships between the entities of the highway ontology:

– inheritance relationship (unary). For example the relationship $isShoulder(RightSoftShoulder_1)$ means that $RightSoftShoulder_1$ is a sub-entity of $Shoulder$.

– composition relationship (binary). For example $hasCarriageway(Roadway_1, RightSoftShoulder_1)$ means that $Roadway_1$ is composed of $RightSoftShoulder_1$.

– position relationship (binary) which consists of the longitudinal position, the transverse position and the vertical position. For example the vertical position relationship $hasPrioritySign(RightSoftShoulder_1, PrioritySign_1)$ means that $PrioritySign_1$ is located on $RightSoftShoulder_1$.

Combining the three previous types of relationships, we can infer more complex relationships. For example, combining relationships $isShoulder$, $hasCarriageway$, $hasPrioritySign$ with $isPrioritySign$ and $isRoadway$ relationships, we can infer the following one (Formula (1)).

$$\begin{aligned} & isRoadway(Roadway_1) \bigwedge \\ & isShoulder(RightSoftShoulder_1) \bigwedge \\ & isPrioritySign(PrioritySign_1) \bigwedge \\ & hasCarriageway(Roadway_1, RightSoftShoulder_1) \bigwedge \\ & hasPrioritySign(RightSoftShoulder_1, PrioritySign_1) \\ & \rightarrow hasPrioritySign(Roadway_1, PrioritySign_1) \end{aligned} \quad (1)$$

Where $\bigwedge$ is the conjunction logical connector and $\rightarrow$ is the implication logical connector.

Table 5 lists out all relationships between the entities of highway for running example. We note that the relationships $hasRightHardShoulder(Median_1, Lefthardshoulder_1)$ means that there is $Lefthardshoulder_1$ at the right hand of $Median_1$. $Lefthardshoulder_1$ is the ID of entity $left\_hard\_shoulder$. This entity is different from $right\_hard\_shoulder$ which refers to the hard shoulder at the edges of the highway.

Table 5: Relationships between highway entities for running example.

Type	Relationship
Inheritance	$isHighway$, $isInterchange$, $isRamp$, $isShoulder$, $isEquipment$, $isSymbol$, $isMarking$, $isSpecificMarking$, $isSign$, $isPrioritySign$
Composition	$hasSegment$, $hasInterchange$, $hasRoadway$, $hasMedian$, $hasCarriageway$, $hasShoulder$, $hasLane$, $hasMainLane$, $hasAuxilaryLane$, $hasAccelerationSection$, $hasTaper$
Position	Longitudinal position: $connecteToSegment$, $connecteToAccelerationSection$, $connecteToTaper$ Transverse position: $hasLeftMedian$, $hasLeftShoulder$, $hasRightShoulder$, $hasLeftLine$, $hasRightLine$, $hasLeftChevronMarking$, $hasRightChevronMarking$, $hasLeftSoftShoulder$, $hasRightSoftShoulder$ Vertical position: $hasSignCedezlepassage$, $hasDeflectionArrowMarking$

b. Relationships between Vehicle Entities

There are eight (8) binary relationships between $EgoCar$ and the other cars ($TargetCar$ and $OtherCar$). We consider that the $EgoCar$ position is the origin point as shown in Figure 9.

The $EgoCar$ can have a $TargetCar$ in front, which is conceptualised using relationship $hasAheadVehicle$ and each $OtherCar$ around it is considered using the

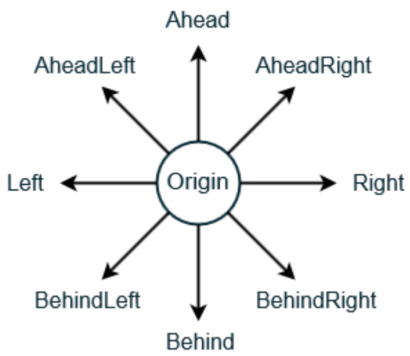

Figure 9: Vehicles around the $EgoCar$.

following relationships:

- hasAheadLeftVehicle
- hasLeftVehicle
- hasBehindLeftVehicle
- hasBehindVehicle
- hasBehindRightVehicle
- hasRightVehicle
- hasAheadRightVehicle

In the first scene of our running example, the relationship between $EgoCar$ and $TargetCar$ can be described using Formula (2), and the relationship between $EgoCar$ and $OtherCar$ can be described using Formula (3).

$$hasAheadVehicle(Ego, Vc_1) \tag{2}$$

$$hasRightVehicle(Ego, Vc_2) \tag{3}$$

Where Ego, Vc_1 and Vc_2 are the ID of $EgoCar$, $TargetCar$ and $OtherCar$, perspectively.

c. Relationships between Highway and Vehicle Entities

In this study, we consider that all vehicles obey the traffic rules. Therefore, the binary relationships between vehicle and highway entities are the followings:

- enters
- leaves
- on

The formulas of these relationships have two variables, the ID of concept $Vehicle$ and the ID of a concept which can be any of $Lane$, $Shoulder$ or $SafetyArea$. For example, in the first scene, the relationships between the entities of vehicle and highway can be described as:

$$on(Ego, Lane_3) \tag{4}$$

$$on(Vc_1, Lane_3) \tag{5}$$

$$on(Vc_2, EnLane_1) \tag{6}$$

Where $Lane_3$ is the ID of $Lane$ and $EnLane_1$ is the ID of $EntranceLane$.

We consider the traffic regulation as rules to define the features and significance of highway infrastructure, and regulate the behavior of vehicles. In the running example, the speed on $Carriageway_1$, which is the ID of $Carriageway$, is limited to 130 km/h. This rule limits the speed of $EgoCar$ and this can be specified as:

$$Speed(Ego) \leq SpeedLimit(Carriageway_1) \tag{7}$$

Where $Speed$ is a function to generate the speed of vehicles and $SpeedLimit$ is a function to show the speed limit on a portion of highway. Note that $v_e \leq 130km/h$ can be derived from Formula (7).

The weather phenomena can have an effect on the highway, the vehicle and on itself (Figure 8). These effects are also written as rules. For example, the $Snow$ phenomenon can only appear at very low temperatures, and it can make the vehicle make action $TurnOn$ the $FogLight$ to increase the visibility of Ego for the other cars. And the $Snow$ phenomenon can affect the visibility of the $Equipment$ of highway. In this work, we assign values directly to the function $Visibility$ because there is not enough available data to build the model which simulates the effects of weather phenomena.

5 USE CASES GENERATION

Simon Ulbrich et al. (Ulbrich et al., 2015) present a definition of interfaces for the design and test of functional modules of an automated vehicle. Based on that, we define the *scene* as a snapshot of the vehicle environment including the static and mobile elements, and the relationships among those elements. A *scenario* describes the temporal development between several scenes in a sequence of scenes (Figure 10). These scenes are developped by the actions made by $EgoCar$ or the events occuring due to the actions made by other vehicles, and this from the point of view of $EgoCar$. A *use case* describes one or several scenarios applied to some ranges and behaviors to simulate the ADAS.

In order to generate use cases based on the ontologies we have defined, we define a three-layers approach. This approach follows a bottom-up hierarchy of an ontology with three layers for semantic expression of dynamic events in dynamic traffic scenes (Yun and Kai, 2015). Our approach consists of the following three layers:

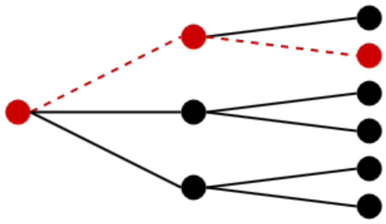

Figure 10: A scenario (red dashed line) made by actions/events (edges) and scenes (nodes).

Basic Layer: The basic layer includes the static concepts and the mobile concepts of the highway, the weather and the vehicle ontologies. The entities that do not change position are considered as static. The infrastructure and the weather are considered as the static concepts, while *EgoCar* and the traffic are considered as the mobile ones. Some of the static concepts, such as the lighting and the weather, can change state but not their position. We call them dynamic concepts, in order to distinguish them from the mobile ones. All the concepts that appear in the running example are framed in Figure 5, Figure 6 and Figure 7.

Interaction Layer: The static concepts and the mobile concepts of the basic layer are defined in terms of entity, sub-entities and properties. The interaction layer describes the interaction relationships, between on the one hand the static entities, and on the other hand the mobile ones. Moreover this layer describes the relationships between static and mobile entities. With the first order logic, we describe the relationships between the entities using formulas such as those used for the running example in Subsection 4.2. Then the scene generated is described as the logic formulas with the concepts in the basic layer and the relationships in the interaction layer. For example, in the first scene of the running example, the vehicles part can be described as follows:

$$on(Ego, Lane_3) \tag{8}$$

$$on(Vc_1, Lane_3) \tag{9}$$

$$on(Vc_2, EnLane_1) \tag{10}$$

$$hasAheadVehicle(Ego, Vc_1) \tag{11}$$

$$Distance(Ego, Vc_1) = d_1 \tag{12}$$

$$hasRightVehicle(Ego, Vc_2) \tag{13}$$

$$Distance(Ego, Vc_2) = d_2 \tag{14}$$

Generation Layer: The task of the generation layer is to build use cases which include one or several scenarios. In the beginning of this section, the scenario is defined as a sequence of scenes, associated with the goals, values and actions of *EgoCar*, the values and events from the other actors, and the values of the properties defined in the static concepts. In the running example, the objective is the insertion of Vc_2 (*OtherCar*) by the right entrance lane of the highway. The actions which can possibly be made by *Ego* (*EgoCar*) are *Decelerate*, *Accelerate* and *Run*. The actions possibly made by other vehicles, which are considered as events from *Ego*'s point of view, are *Decelerate*, *Accelerate*, *Run*, *ChangeLane* and *TurnOn* (Figure 6).

With the same initial scene, it is evident that different actions or events lead to different scenes, and make different scenarios. In the running example, we describe two of several possibilities. The scenario in the first case (Figure 11) can be generated as:

$$Scene1 = \{Concepts\} \vee \{Relationships\} \tag{15}$$

$$Scene2 = (Scene1, Decelerate) \tag{16}$$

$$Scene3 = (Scene2, Event_1) \tag{17}$$

Where

$$Event_1 \equiv (Vc_2, ChangeLane(Left)) \tag{18}$$

In Scene 2, Vc_2 is on $EnLane_1$ which is presented in formula (6) and the relationship between $EnLane_1$ and $Lane_3$ is $hasLeftLane(EnLane_1, Lane_3)$. Therefore, $Event_1$ means that Vc_2 makes action *ChangeLane* from $Enlane_1$ to $Lane_3$.

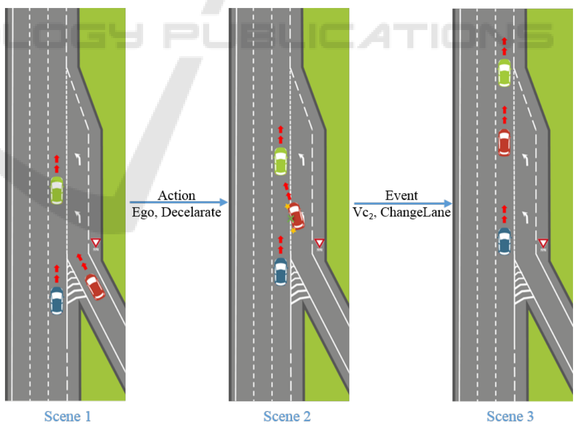

Figure 11: Scenario "Insertion before *Ego*".

One scenario is one possibility of a use case (Figure 10). A use case includes one or several scenarios. The use case of autonomous vehicle is the simulation of the driving environment, the traffic and the pilot. As the role of the pilot, system ADAS limits to a set of decisions that will be made by *EgoCar*. For example, the existence of a target vehicle is necessary for the *EgoCar* to activate the system TJC. Therefore, the *EgoCar* cannot make the action *ChangeLane* to the left lane because there is no target vehicle. These ranges and behaviors are presented as rules to make sure that only reasonable use cases will be generated.

6 CONCLUSIONS

In this article, we propose an ontology-based approach for the generation of use cases with a hierarchy in three layers: basic layer, interaction layer and generation layer. We built three ontologies for the conceptualization and characterization of the components of use cases: a highway ontology and a weather ontology to specify the environment in which evolves the autonomous vehicle, and a vehicle ontology which consists of the vehicle devices and the control actions. Relationships and rules, such as traffic regulation, are expressed using a first-order logic.

An autonomous vehicle is a safety-critical system for which all behaviors must be predictable. Therefore, the generated use cases need to be modelled with a semantically explicit formal language to improve their reliability and robustness. In the future, we are interested in the formalisation of these use cases considering also the time factor.

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