Core Ontologies for Safe Autonomous Driving

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Abstract. Representing the knowledge of driving environments in a structured machine-readable format is necessary for safe autonomous driving. We use ontologies to represent the knowledge of maps, driving paths, and driving environments to improve safety for smart vehicles. In this paper, we introduce core ontologies that are used for developing Advanced Driver Assistance Systems. The ontologies can be reused and extended for constructing Knowledge Base for smart vehicles as well as for implementing different types of Advanced Driver Assistance Systems.

Keywords: Ontology, Dataset, Advanced Driver Assistance System (ADAS).

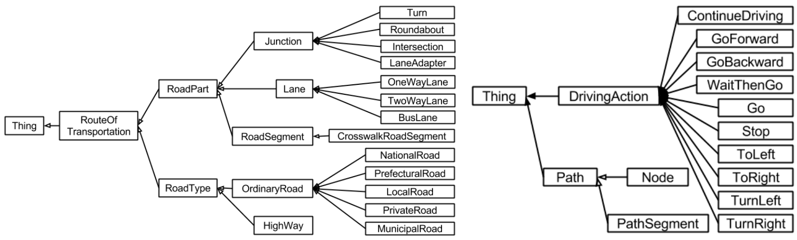
1 Introduction

Autonomous driving is one of the most promising and challenging research topics among IT companies and automobile industries. Current autonomous vehicles under development are equipped with several highly sensitive sensors such as camera, stereo camera, Lidar, and Radar. Although objects and lanes can be detected using these sensors, the vehicles cannot understand the meaning of driving environments without knowledge representation of the data. Therefore, a machine understandable knowledge representation method is necessary to fill the gap between perceived driving environments and knowledge processing.

Ontologies are the structural frameworks for knowledge representation about the world or some part of it, which mainly consists of concepts (classes) and the relationships (properties) among them [2]. We constructed ontologies to enable smart vehicles to understand the driving environments. The ontologies can represent knowledge of sophisticated maps, paths and driving control concepts that are necessary for autonomous driving.

2 Ontology-based Dataset

The dataset is a machine-understandable Knowledge Base for smart vehicles, which is constructed using core ontologies: map ontology, control ontology, and car ontology. Based on these core ontologies, we constructed instances about maps, paths, and cars. The dataset contains 36424 RDF triples, 147 classes, 84 properties, and 1218 entities. The repository of the dataset is available on http://www.toyota-ti.ac.jp/Lab/Denshi/COIN/Ontology/TTICore-0.03/.



(a) Classes of map ontology. (b) Classes of control ontology.

Fig. 1: Main classes of map ontology and control ontology.

2.1 Ontologies

Map Ontology: A sophisticated machine understandable map is required for autonomous cars to perceive driving environments. Therefore, we construct a map ontology to describe road networks such as road, intersection, lane, and traffic light information, etc. The map ontology contains 80 classes, 17 object properties, and 32 datatype properties. Figure 1a shows the main classes of the map ontology. A road consists of junctions and road segments, where a road segment consists of an arbitrary number of lanes.

Object properties map:goStraightTo[3], map:turnLeftTo, and map:turnRightTo are used to identify the driving directions when a car drives from one road part to another. We use map:relatedTrafficLight to link the related traffic lights that a driver should observe on a lane.

Control Ontology: The concepts in Fig. 1b show the main classes of the control ontology, which are used to represent driving actions and paths of autonomous vehicles. This control ontology contains 35 classes, 15 object properties, and 2 datatype properties. To represent a path, we use instances of control:PathSegment instead of a collection of GPS points of a trajectory. A path segment can be an intersection, a lane, a crosswalk, or a turn. The Node class contains "startNode" and "endNode", which are the start and end GPS positions of a path. The object property control:nextPathSegment[4] is used to link connected path segments and the datatype property control:pathSegmentID is used to index path segments.

Car Ontology: The car ontology contains concepts of different types of vehicles and devices which are installed on a car such as sensors and engines. It includes 32 classes, 3 object properties, and 15 datatype properties. The object property car:isRunningOn[5] is used to assert the current location of a car and the datatype properties such as "car_ID", "car_length", and "velocity" are used to describe a car.

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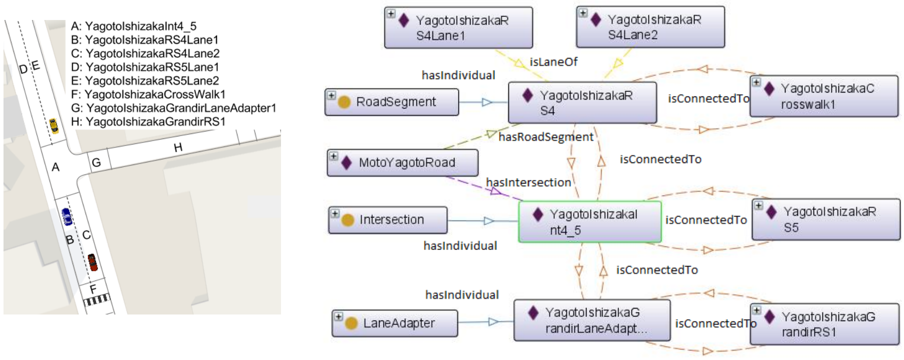
[3] map: <http://www.toyota-ti.ac.jp/Lab/Denshi/COIN/Map#>.
[4] control: <http://www.toyota-ti.ac.jp/Lab/Denshi/COIN/Control#>.
[5] car: <http://www.toyota-ti.ac.jp/Lab/Denshi/COIN/Car#>.



(a) Map. (b) Visualization.

Fig. 2: Example of a Road.

2.2 Instances

Instances are also known as individuals that model abstract or concrete objects based on the ontologies. With the core ontologies, we model instances such as maps, paths, and cars. We constructed map data in Tempaku ward of Nagoya Japan based on the map ontology and control ontology. The map dataset includes 111 intersections, 127 road segments, 4 crosswalks, 302 one-way lanes, 6 two-way lanes, 23 bus lanes, and 330 traffic lights with accurate GPS positions.

Here, we show some instances of a road part in Fig. 2. Figure 2a shows how these individuals are assigned on a map. Figure 2b illustrates the relations among the individuals of road parts: a road (MotoYagotoRoad), an intersection (YagotoIshizakaInt4_5), four road segments (YagotoIshizakaRS4, YagotoIshizakaRS5, YagotoIshizakaCrossWalk1, YagotoIshizakaGrandirRS1), two lanes (YagotoIshizakaRS4Lane1, YagotoIshizakaRS4Lane2), and a lane adapter (YagotoIshizakaGrandirLaneAdapter1). We use the object properties map:hasIntersection and map:hasRoadSegment to link a road with an intersection and a road segment, respectively. We use the object property map:isConnectedTo to link different parts of a road and use map:isLaneOf to relate lanes with road segments as shown in Fig. 2b.

A vehicle has a path instance, which contains connected path segments and their index numbers. We constructed a path starts from TTI campus and ends at the parking place of an apartment near Yagoto station, which contains 140 path segments (about 4.4km). This path is constructed based on the map dataset and each path segment is assigned an integer number starting from zero.

3 ADAS for Smart Vehicles

We developed an Intelligent Decision Making system to improve safety in driving, which belongs to *Advanced Driver Assistance Systems* (ADAS) [3]. The decision making system can assist autonomous vehicles to make appropriate decisions at uncontrolled intersections (without traffic lights) and on two-way narrow roads, which are common in urban areas of Japan. The core ontologies and the instances of map and path are used as the Knowledge Base for our smart vehicle. In addition to the dataset, we added Right-of-Way traffic regulations written in *Semantic Web Rule Language* (SWRL), which is used to express rules as well as logics in Semantic Web applications [1].

The decision making system mainly consists of a sensor data receiver, an ontology-based Knowledge Base, a SPARQL query engine, and a SWRL rule reasoner. We can retrieve the current road, speed limit, and next lane information using SPARQL queries. The system makes decisions such as "Stop", "Go", "ToLeft", or "Give Way" in compliance with traffic regulations when it detects other nearby vehicles. Using the detected vehicle's information such as velocity, position, and heading angle, we add the driving situation to the knowledge base to make a decision. The average execution time for making a decision is about 150ms including ontology reasoning and decision result retrieval. The decisions are sent to a path planning system to change the route or stop to avoid collisions.

4 Conclusion and Future Work

Knowledge about driving environments is considered as an essential component which enables smart vehicles to perceive driving environments. We use machine-readable ontologies to describe maps and driving situations to help smart vehicles understand semantic meaning of the driving environments. In this paper, we described the ontology-based dataset for safe autonomous driving that can be used for developing *Advanced Driver Assistance Systems* (ADAS). The dataset is based on three core ontologies: map ontology, control ontology, and car ontology. We provide map instances and sample path files that can be used for experiments. This dataset is used to develop real-time ADAS that can improve safety in autonomous driving.

In the future, we plan to apply machine learning methods to learn driving situations and automatically construct traffic regulations based on previous driving data. Moreover, various types of intersections will be considered for evaluation.

References

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