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Towards Semantic Modeling for Assisted Driving: BFO-Compliant Ontology to Represent Ride Quality Knowledge

Abstract: - A BFO-Compliant Ontology to Represent Ride Quality Knowledge is a step toward semantic modeling for assisted driving. Semantic reasoning helps to create knowledge from sensor data that is published in RDF using domain ontology. The fundamental requirements for the collection, publishing, and reasoning of knowledge to assist in such a scenario are presented here. This paper proposes ontology to represent the ride quality of a vehicle through semantic knowledge. To support interoperability among multiple domains, we propose an ontology that follows the standard basic formal ontology. The domains addressed are road infrastructure and assisted driving. Taking the example of mapping road quality by estimating degraded roads, bumps, potholes, and hazardous turns, an assisted driving application can guide a driver to slow down for a bump ahead or a sharp turns ahead enabling it to slow down based on geo-mapping the quality through sensors. The same knowledge can be exploited for automated vehicles and other domains related to vehicles, manufacturing, and road infrastructure. The ontology design is intended to support semantic reasoning at the edge.

Keywords: Semantic Modeling, Ontology Development, Basic Formal Ontology, Edge Computing, Assisted Driving, Semantic Web of Things, Knowledge Representation, Vehicular Networks

I. INTRODUCTION

The stored data becomes knowledge when it is compared, reasoned, and presented in an expected manner. Information is valuable when it becomes searchable. The interoperability of knowledge across domains is the game changer. We can search for directions-related information on the internet, as the tools are available based on formal methods and algorithms. Better interoperability among information domains will provide results from the yet-uncharted territory. The term ride quality in our approach intends to capture the perspective of vehicles. The requirement is to capture road and driving conditions. Apart from the time span to cover one point to another by road, assisted driving becomes helpful when the driver or the self-driving system gets a warning regarding bumps, potholes, sharp turns, and potentially hazardous sections of road prone to accidents. The context of the term "assisted driving" in our approach is to provide online support to the driver of a vehicle while driving on the road, for which knowledge regarding ride conditions is already acquired by vehicles. Vehicles can exchange this preventative knowledge in the automated vehicle-to-vehicle communication environment for assisted driving. Our goal is to achieve assisted driving and automated driving. The search engine can provide search results within its boundaries. These boundaries get ex-tended with the inclusion of the Web of Things. The requirement soon will be to publish knowledge on resources made available. An example scenario for functional interoperability can be imagined where a vehicle manufacturing company deploys vehicles that collect ride quality data. The data helps in the preventive maintenance of vehicles and the timely replacement of vehicle parts. Along with this, it can also help in determining how vehicles perform in generally good or bad road conditions. The same data is also useful to authorities of road infrastructure to capture deteriorating roads and roads with hazardous driving conditions. The knowledge source being one and its applicability to different domains requires knowledge exchange at the machine level without human intervention. This is where the common language of interpretation plays a role as a plat-form for knowledge interchange. The semantic model provides this meaning and interpretation information for different domains. The example is described in Figure 1, where our current domain of interest is depicted as sensor-enabled vehicles moving on roads. The ride-quality knowledge, i.e., the effects on the vehicle while being driven on that road, is captured and exchanged. The knowledge is published on the cloud while being open to be queried by other domains like road infrastructure authorities, vehicle manufacturers, and insurance companies. Different domains interpret the knowledge they are capturing from one domain in accordance with their intended queries. It is only when common knowledge is represented with semantics, i.e., its meaning, that we can query it even with search engines that can translate questions in general language to a given language model.

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A. Ontology

The goal of having ontology is sharing a common understanding of the structure of information that is exchanged between machines and which is also human readable. Ontologies define a common vocabulary that helps sharing information in common domain. Primary usages of ontology are fast and flexible data modeling and efficient automated reasoning. In the world of information technology, we deal with loosely coupled systems which are heterogeneous and still need to interoperate with shared semantic and increasing semantic precision; this is where we need the semantic explicitness that ontologies provide [1]. Ontologies have been proposed and standardized for multiple domains from where information must be extracted. Transport related ontologies are developed, and data can be queried from ontology-based information-retrieval systems [2]. The main benefit of ontologies is exchange of data among systems, providing interoperability among systems, designing knowledge, sharing knowledge, and simplifying operations. Ontology explains a concept. When multiple concepts are merged, a common understanding of the structure of information becomes sharable.

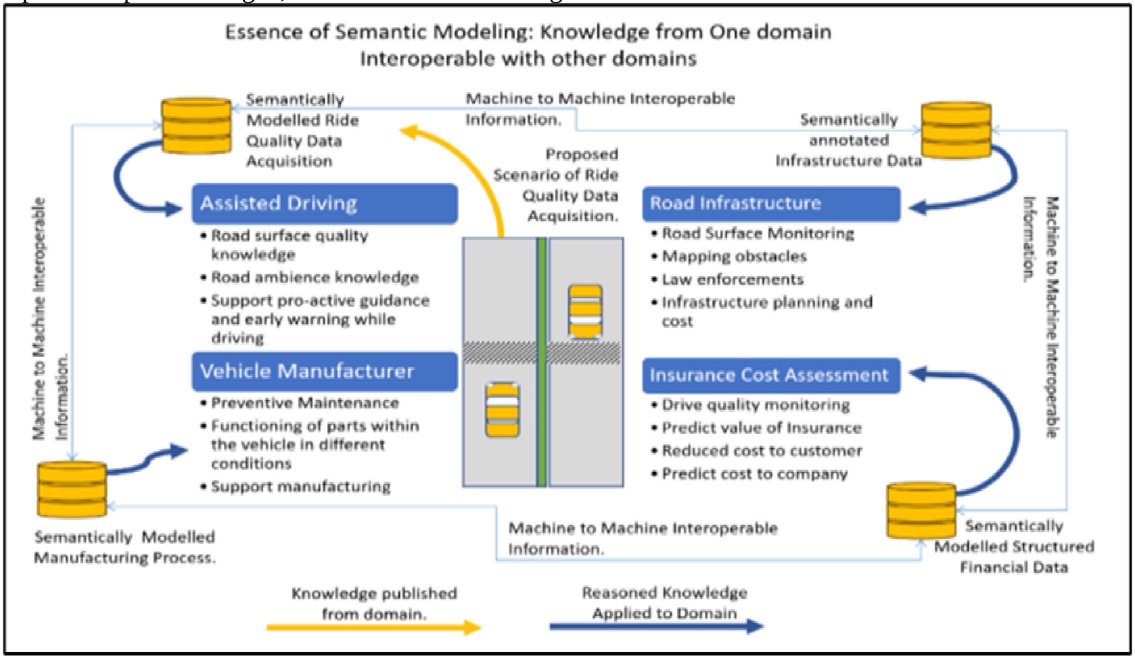

Fig. 1 Essence of Semantic Modeling with an example scenario.

B. Ontology for Internet of Things

There is a plethora of ontologies developed specifically for IoT networks in the last decade. Ontologies are effective tools used to achieve interoperability in IoT [3]. W3C recommended a specific ontology for modeling data from IoT networks with deployed sensors. Challenges for Semantics for IoT include interpretation of sensor data coming from sensors. Sensor ontologies like SOSA have contributions from many research bodies that make it powerful for the representation of data from sensor networks. The Semantic Sensor Network Ontology is significant work that intends to map sensor data to domain ontologies yet does not model the entire system of IoT. Integration of sensor data with SSN ontology is a multi-agent environment is discussed in [4].

C. Semantic Web

The Semantic Web, which is also known as Web 3.0 is a standard with a goal to make the internet data machine-readable. The machine-readable data is required to be published in specific languages like Resource Description Framework (RDF), Web On-tology Language (OWL) and Extensible Markup Language (XML). The work related to semantic web in the past decades includes proposal for IoT architectures [5], [6], [7], [8], [9], smart city architectures [10], models [11] [12], applications [13] usage and development of tools [14] for deployment of such modes and architectures. [15] Presents the relevance of semantic web technologies and linked data in multiple domains. A Machine Learning based approach for classification of ontologies is used for resource discovery in pervasive environments [16]. The W3C-suggested languages list OWL, RDF, SPARQL, SWRL and XML languages are the most used semantic web technologies [3]. The Semantic Web of Things (SWoT) framework [17], calls for common access to information embedded into semantic-enhanced micro-devices populating a smart pervasive environment. This must be enabled using semantic micro-layer for each of communication, identification, and sensing technology. Semantic Web technologies will become the de facto standard on the Internet for representing physical world phenomena and activities accessed from IoT nodes [18]. Increase in deployment of IoT systems in public domain will collect Existing IoT search system do not provide automated and scalable indexing of time-series data [19]. Inference is the process of discovering new facts from given data. It may be based on rules that are pre-defined or those that keep changing.

D. Semantic Modeling for IoT Edge

Edge computing refers to the paradigm where small computers on IoT devices can be exploited to partially process the data collected and save the computation of cloud. Se-mantic reasoning at edge is one of the challenges in IoT. Edge computing can work for scenarios like cloud offloading, smart home, smart city, and collaborative edge [20]. It is envisioned that human intervention should be minimized at the level of data collection. Data Abstraction, reliability and battery usage are the main concerns for edge computing. Services at edge layer must be able to pre-process data at edge layer to reduce cloud load. Semantic reasoning on edge nodes reduces 9.3% of network band-width in experiments done on mobile devices where RDF data is reasoned at both edge level and cloud [21]. Experiments with Android phones as edge nodes are carried out which conclude that EN format consumes the shortest time [22]. Addressing the challenge of heterogeneity in the IoT data, a two-layer model for processing and annotating that data at IoT level is proposed in [23]. A model proposed [24] encompass complex event processing (CEP) and semantic web techniques to be implemented at IoT gateways. Applying semantic reasoning frameworks at the edge and developing distributed reasoning applications can support high level of interoperability. An extensive analysis of semantic reasoning of IoT data using Android phones as edge node and data generated by multiple threads running on desktop PC emulating IoT nodes is carried out in [25]. An extensive work in [18] discusses approaches to add semantics to IoT data and evaluates computational requirements compared to different data representations used. Federated learning at edge IoT is discussed in [26].

E. Vehicular Networks

The number of vehicles which are enabled with sensors to support proactive maintenance, driving assistance and diagnostic data has increased. The parallel advancement in Internet of Things has led to emerging research field of Internet of Vehicles (IoV). The IoV concept enables vehicles as intelligent devices that not only capture data but can pre-process it, communicating it to higher level network and to the other vehicles. The internet of vehicles architecture proposed in [27] suggests data acquisition layer where intra vehicular and inter-vehicular communications can be made. Above this layer, the communication management layer is where the filtering and pre-processing functions are suggested. High resolution GPS data is crucial in diversified applications for which solutions to derive trajectories is proposed from time to time [28]. All the information thus collected and be made machine interpretable only when common understanding of such knowledge is established. This again calls for semantic modeling of such communication frameworks.

F. Assisted Driving

Work on Ontological Modeling for assisted driving is presented in [29] with conceptual ontology diagrams for Vehicles, Vehicle behavior and contexts for assisted driving scenario are represented in SWRL2. Annotations based on ontology of voice messages from vehicle driver to report obstacles on roads are proposed in [30]. The research area of assisted driving has most work done in semantically annotating the images captured by vehicle or the signals captured by various high precision sensors. A scenario of road and traffic analysis is demonstrated for semantic enhanced machine leaning based approach to classify events [16] from heterogeneous data streams.

G. Single Board Computers at Edge

A broad range of applications based on Single Board Architectures are being developed in the areas of industrial automation, engineering, healthcare, entertainment, logistics, transportation, and communications. The single board microcontrollers (SBM), single board computers (SBC) and FPGA (Field Programmable Gate Arrays) based single board architectures (SBA) have seen exponential usage in low-cost integration of sensors in IoT networks [31]. The study of some of main features and possibilities with different architectures is done in [32] where testing is carried out for various parameters like power consumption, processing capability and programming flexibility. In the area of knowledge representation, there is a wide scope of the use of Small Board Computers for annotations and reasoning at edge.

II. MOTIVATION

Road infrastructure has been the backbone for sustaining economic growth world-wide. Governments have been trying to maximize road coverage, and thus maintaining it becomes a greater challenge day by day. The National and State Highways of India have millions of vehicles moving over them in a single day. The quality of the road surface degrades depending on weather conditions and usage. The deteriorated condition then becomes the cause of traffic, accidents, and waterlogged potholes, leading again to traffic and accidents related to it. The public being the major stakeholder, the authorities responsible for timely and precautionary maintenance need to develop an infrastructural setup for collecting crowd-sourced data on the quality of roads at any given time. A dashboard representing major roads and road sections semantically annotated with problematic ride behavior can be developed based on such collective knowledge. Users and vehicular networks can both make use of the same knowledge in assisted driving scenarios.

Considering the significantly large and complex network of roads in the country, it would require all the possible support from technology to monitor and maintain it. Currently, only the national highways in India cover a length of 136,440 km (https://morth.nic.in/annual-report). This does not count state highways and internal roads between villages. The maintenance requires monitoring, which is not yet automated based on data collection from sensing devices. Our intention is to support a system where a generalized idea of the condition of roads can be obtained on a single dash-board. It is necessary that this knowledge be not just human-readable but also interpret-able by humans and machines. This requires semantic modeling of the data, which re-quires us to develop ontology for the domain. Data collection and annotations can be carried out at the edge of vehicular networks.

A recent study suggests that improvements related to scalability, complexity, ease of implementation, consistency in terms of results, and justification for industry are required in ontology development for IoT [3]. Semantic models are developed to capture data from multiple IoT scenarios. In all cases, a dedicated ontology must be developed that supports a semantic model. This ontology may then keep evolving or later become a standard. However, currently, a few upper-level ontologies like DOLCE and SSN are standards. So, there is an adequate gap to develop a semantic model for the ride quality scenario. Apart from vision-based approaches, there is work done based on sensor-based approaches to collect road surface quality information. The work on classifying road surface disruptions is carried out in [33], where a supervised learning approach is used to classify data collected through smartphone sensors. There are attempts to record road quality solely based on sensor readings without adding semantics or making the data available for use by various domains [34]. A semantically enhanced approach for road quality with a modified ontology that can rep-resent low-level semantic interpretation of the statistical distribution of information using on-board diagnostics (OBD-II) and users' smart phones has been presented in [16]. The vehicle industry bodies and researchers have shown interest in developing the IoV (Internet of Vehicles). IoV refers to networks that are ad hoc, dynamic, and dedicated to the exchange of data among vehicles and between vehicles and manufacturers [27]. Such networks would strive to organize data collected by sensors from vehicles. Extensive review and comparative work are done to map road anomalies using smartphone-based sensors [33]. Their work focuses on comparing road anomaly detection problems where data is based on sensors within smartphones. Vehicular network technologies (V2V) and cellular V2V (C-V2V) are still yet to become popular. Such a setup can assist in edge computing and reduce the burden on cloud infrastructure. Author of [35] discusses ontology for scenario definition for the assessment of automated vehicles with an object-oriented framework.

We intend to pre-process the generated data and reason it at the edge level before publishing the data to the cloud. Progressively, we also intend to make our distributed edge reasoning work for off-loading the cloud. The need to optimize reasoning efficiency based on the different requirements of IoT systems is stressed in [21]. Public transport systems are the best means to utilize such ontologies, where the road environment can be monitored and stakeholders can get relevant information via published data [36]. Interoperability can be enhanced if such information is published in RDF. The work in [29] discusses ontology and rules with-out for collecting data, and publishing it for public use. There are discussions for mapping road surface quality; an approach for annotation of road quality knowledge can be found in previous proposals where bicycle-mounted smartphones [37] are proposed to be utilized for sensing roads through inbuilt gyro sensors. The majority of the observations lead us to believe that the straightforward readings from accelerometers and gyro sensors are sufficient to map the effects of road traffic on moving vehicles. One such approach discussed in [34] employs accelerometers for the detection of road anomalies.

III. PROPOSED APPROACH

We suggest a semantic approach to encourage the interoperability of such knowledge to represent the knowledge regarding the quality of rides on roads based on data gathered by vehicles. The approach involves IoT-enabled vehicles to publish semantic knowledge. We consider a vehicle an object of interest in the realm of machine-to-machine communication. This object generates knowledge by processing data from its sensors. The object also consumes the established knowledge. This happens when the vehicle can reason with the acquired knowledge. Thus, independently, without human interaction, the object can communicate with other objects in the same realm in a language that is interpretable and be able to make this knowledge available to be published on the World Wide Web. Assuming the edge device installed on the vehicle is at least as powerful as a mobile phone, the reasoning task can be carried out and distributed among such devices. The vehicle may perform the conversion from raw data to semantic data while it is in a stationary position.

The proposed vehicular network scenario presented in Fig 2 shows road lanes, vehicles, and public points for data aggregation like toll booths. The aggregation points can be public places like bus stops and public buildings. The vehicles are equipped with single-board computers that can annotate the data and publish it in

RDF format. The devices then can represent the knowledge ride quality and transfer it to only the concerned devices and vehicles that are about to use the road.

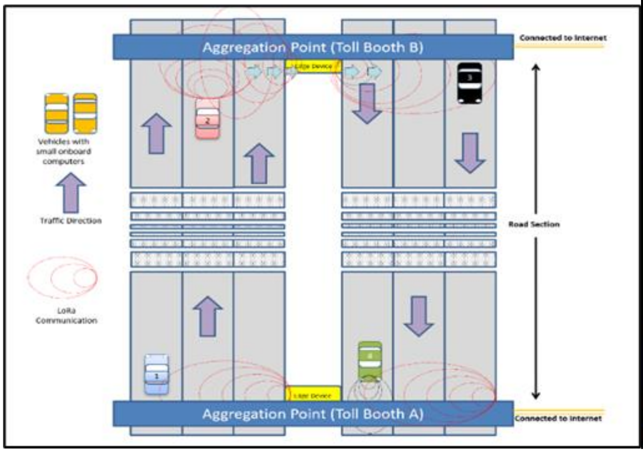

Fig. 2. Example scenario

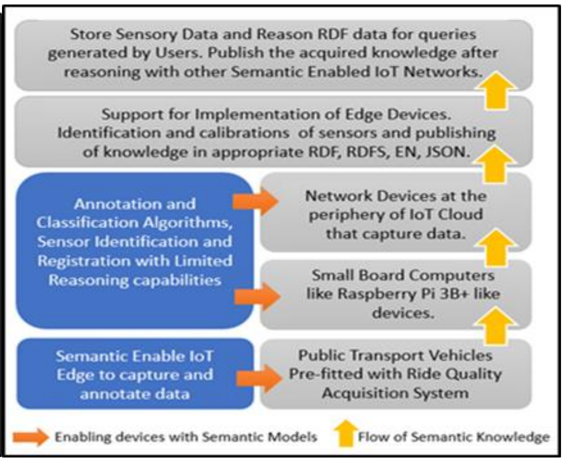

Fig.3. Layers of proposed model

The overall reasoned knowledge is published on the cloud for decision-making on the development and maintenance of infrastructure. Vehicles' ride-quality knowledge would aid them in assisted driving, and again, the knowledge they gain while driving will confirm the knowledge acquired for the same road. It is understood from the perspective of road that at any point, assisted driving only requires a certain fixed window of geo-location. These geo-location bounded patches are the smallest unit of interest for which knowledge must be collect-ed. To represent the knowledge collected, we are required to develop ontology. Populate the ontology with the captured data and publish the data. Fig. 3 provides an overview of the concept from a network level perspective.

The approach requires devices at the edge to be able to annotate the data. This is necessary, as we want the carriers of data to be capable of carrying interoperable knowledge. In the scenario proposed, the vehicle itself is required to communicate with another vehicle. Knowledge interchange thus needs to happen with a common under-standing of information exchange; this is where the edge device needs to be aware of the semantic model to be adapted. The approach applies not only to road surface quality scenarios, but it is also appropriate for all the IoT systems that are implemented in the public domain. The specific sensors may be deployed to sense data relevant to a scenario, but the physical network that they utilize, the edge-gateway layer devices that are used as data sinks, and the information repository where data is cleaned, aggregated, and then published work on devices sharing different semantic models to recognize knowledge generated from different devices. The published knowledge is stored in RDF or XML syntax in the cloud.

IV. ONTOLOGY DEVELOPMENT

Ontology for a specific domain should be able to describe all the concepts within that domain. The reference ontologies are not specific to domain but are built to encompass knowledge from a large set of domains like medical science, biology, environment, and engineering. BFO is one such reference ontology that provides a specific demarcation of what entity should be what in any underlying ontology. Our approach to developing ontology is a classic method to first gather knowledge about the domain and form the classes that. To develop ontology certain principles have been established. This is necessary because developing ontologies for isolated environments will not serve the purpose of interoperability. Thus, it is necessary that the ontologies share a common upper layer, like the Basic Formal Ontology (BFO). BFO is a top-level ontology, as it describes top-level classes that can be used to build other ontologies. Figure 4 explains the concept of BFO as TLO.

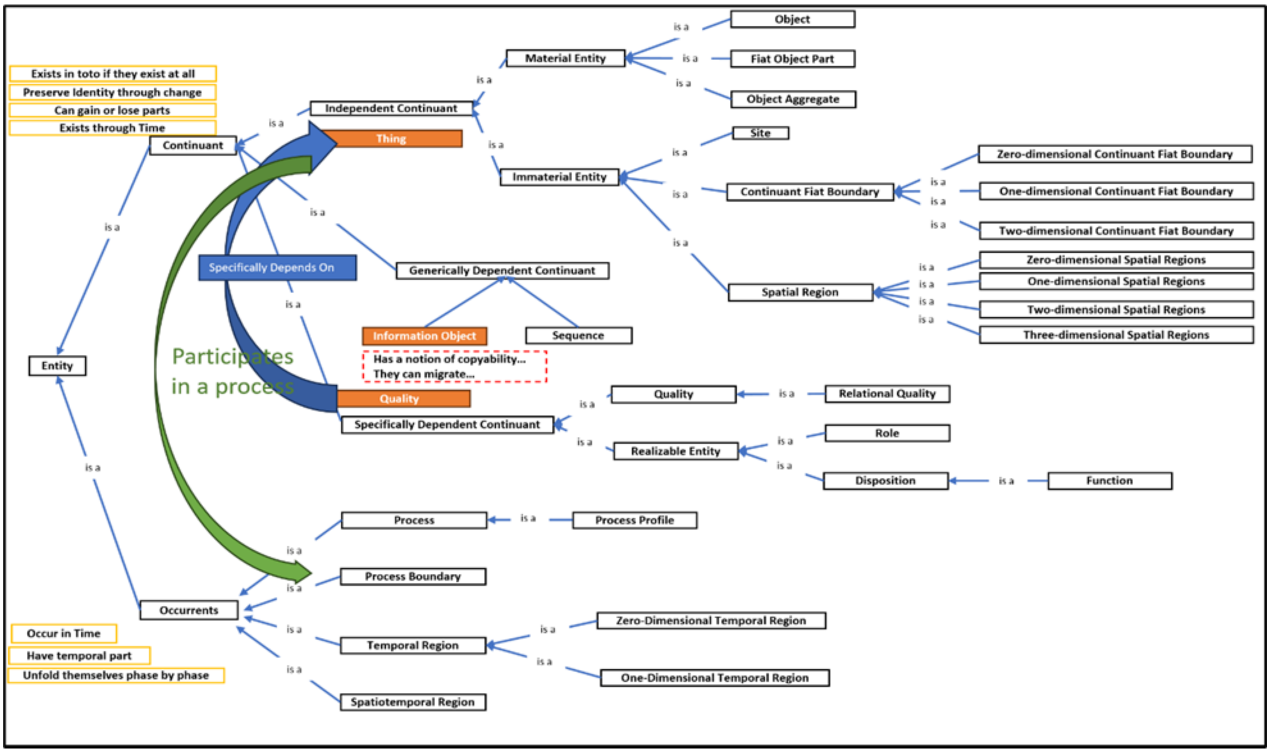

Fig. 4. Understanding BFO

A. Ontology Development Methodology

The initial development starts with identifying what entities the ontology is required to address. These entities can be physical objects like a person or a vehicle, and they can also be processes. We intend to extend the Basic Formal Ontology 2.0 [38] to support interoperability and navigability. A road is defined as a path leading from source to destination that is made appropriate for vehicles to drive and people to commute. The ontology classes are rearranged based on the BFO 2.0 specification [39]. We have used BFO, which is an international standard (https://www.iso.org/standard/74572.html) now. The BFO defines a category as a general class or type that is shared across many different domains and is represented by a domain-neutral term. Top Level Ontology (TLO) was created to represent the categories that are shared across a broad range of domains. Examples of independent continuants are planets, people, and objects in the universe, and examples of specifically dependent continuants are those that exist because things (continuants) exist.

Every term should have at most one parent. The terms in the ontology should be singular nouns. When the knowledge is published in RDF, it should be machine-interpretable. What information do we provide through this ontology? We generate knowledge on the ride quality of vehicles on roads starting and ending at a specific location. The ride quality must be graded. This is followed by the knowledge about vehicles, which requires us to collect knowledge of what kind of vehicle it was along with all the specifications of that vehicle. After this, we need to represent our knowledge about roads. The roads must be defined with two-dimensional parameters. What time of the day and what day of the season was it? The ride quality of the vehicle depends on the ambience of the road, which changes at different times during the day. The temporal data, there-fore, is also required. The provisions made in ontology can allow weather conditions, traffic conditions, and other ambient conditions to be recorded with respect to geographical locations where the road sections are marked. The ride knowledge encompasses the classification of events like sudden braking, sudden turn, and sudden bounce, braking and bump crossing patterns, acceleration, and steady speed.

The steps of ontology development follow a common thought process that includes discussing its domain and scope, listing of classes and their properties, and having competency questions.

The domain and scope of ontology: The scenario for assisted driving needs to address the domain of instructing the automated vehicle or a human driving the vehicle. The semantic model is to be developed for capturing and classifying vehicle movements. Hence, the ontology design discusses terms related to the quality of ride while vehicles traverse the road, thereby addressing every section of the road by aggregating the experience of vehicles passing over them.

Develop competency questions: competency questions address the reason for which ontology exists. The questions are formed in natural language to examine if such information will be available from the designed ontology once it is populated. The list of some of the competency questions is:

- *What is the longest sequence of road sections in bad condition?*
- *Which road sections have a minimum lane change with safe driving conditions?*
- *Which of the bumps detected reduced the vehicle speed to near zero?*
- *Which road section allows the fastest thoroughfares for all the vehicles?*
- *Which road sections need examination for maintenance and repair?*

Develop class hierarchy and description of classes: The BFO standard class hierarchy requires classifying entities in the domain based on continuants and occurrents. This classification mechanism is considered standard for all the entities that are either objects or processes in the domain and is placed appropriately at various levels. An artifact is the data that sensory devices produce. The information artifacts can be copied to and transferred from other devices; hence, they are classified as generically dependent continuants. Physical objects like vehicles, roads, and sensor devices are material entities that exist in the domain as independent continuants. The processes of the domain, like vehicles traversing the road or sensor devices processing data, are occurring at some point in time or within a time interval. The locations and surfaces fall under the entity types of sites and fiat boundaries. The boundaries are again in zero to three dimensional spaces.

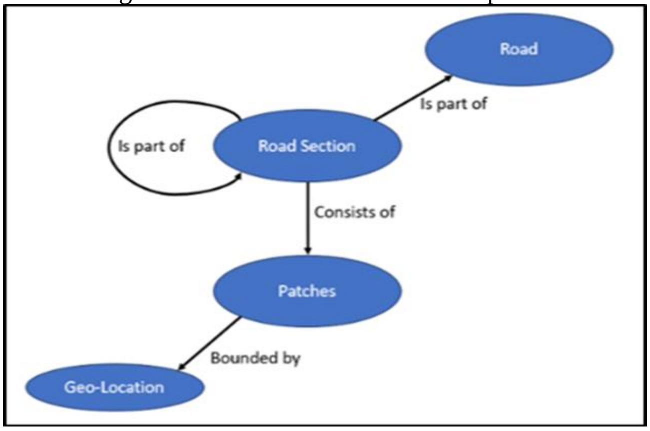

Fig. 5. Concept of road-section in ontology

The fiat boundaries cover all the classes and objects that represent geographical boundaries. The processes occur within these temporal boundaries. Hence, the objects, i.e., continuants, participate in processes. The existence of processes depends on continuants. In our domain, vehicles traversing the road are a process that requires vehicles to exist and roads to exist. Entities that we want to map are vehicles, roads, road sections, and ride quality. A brief description of how we have related each of these entities to BFO is in Table 1.

Assuming that the vehicle is stationary, it is not going to be able to measure any data related to moving on the road. Hence, the geo-location may be part of the road but is not relevant to measuring road quality or ride quality. We therefore introduce the “RoadSection” class. The geo-locations that are closest to one another can divide the components of this class. RoadSection elements thus automatically become parts of larger and larger "RoadSections," some of which can be roads that are clearly defined using names and other attributes. The BFO standards provide guidelines for all the entities, functions, and processes to be mapped. RoadSection is formed of a consecutive sequence of patches, which are the smallest records our data set holds for mapping ride quality. As shown in Fig. 5, we have closely followed the BFO guidelines.

At a time, the vehicle is concerned about the road condition upcoming in the next road section. The road section becomes a section of interest only when there is an event detected. This event can be a combination of several parameters, like a sudden deceleration or a sharp turn. This requires us to fix the problem of heterogeneous devices, which are small board computers, reading sensor data and agreeing to publish data for the same geo-location. The road section thus becomes a section of interest when there are anomalies or disruptions detected and recorded until it becomes normal again. The road section can become a section of interest for a continuous 10 kilometers if it encounters continuous bumps and crests as the vehicle treads on at low speed.

The same section of interest can have sub-sections for each road anomaly that is identifiable, and similarly, the section of interest is part of a larger road section. The most important factor for assisting with driving is the direction of the car. In the majority of road conditions, it is known that lanes in one direction of the road are not in the same condition as lanes in the opposite direction; overall, their conditions may deteriorate in sync with each other. Potholes and erosion may occur at random places. The reasoning thus needs to be done for overlapping road sections. We intend to capture the motion of the vehicle. All the knowledge collected regarding road health is only through the motion of a vehicle. If the same task is to be carried out with any different method, it would still require a monitoring device mounted on a certain type of vehicle. Figure 6 and 7 are screenshots from Protégé tool. Figure 6 show the top level classes and Figure 7 shows the detailed subclasses on specifically dependent continuant.

While the vehicle and its properties, like type, power, length, width, and height, are defined by the manufacturer, these details go into the properties of the vehicle. The geo-spatial incubator group took concrete action to update the W3C GEO vocabulary. The group laid the groundwork for more comprehensive geospatial ontology and formulated a proposal for a W3C Working Group to develop recommendations to further the Web representation of physical location and geography. (https://www.w3.org/2005/Incubator/geo/XGR-geo/).

The ontology needs more refinement by adding more classes to engage maximum entities and their object properties. It is still difficult to find reliable entities dedicated to one domain. The ontology repositories have higher-level ontologies, and the domain-specific ones are updated from time to time. A substantial amount of knowledge is required to be published with each one of the domain-specific ontologies, which can boost their usability through interoperability. Figure 8 is the screen shot of RDF/XML generated to represent the ride quality data. The location of roads and the smallest patch that we intend to address requires addressing geo-locations. We reuse the existing ontology for geo-location. Similar reuse of available ontologies for maintenance and continuous objects like vehicles can increase the interoperability of this model.

Table 1. Example of full page table

Sr. No	Entity Name	BFO equivalent classification	Description
1	Road	BFO: Continuant Fiat Boundary (Fiat Surface)	Immaterial Entity bounded by two-dimensional fiat boundary
2	Road-Section	BFO: Continuant Fiat Boundary (Fiat Surface)	Immaterial Entity bounded by two-dimensional fiat boundary
3	Vehicle	BFO: Material Entity BFO: Object	Material entity that exists independently.
4	Vehicle mounted SBC	BFO: Fiat Object Part	
5	Ride	BFO: Process	BFO occurrent that happens at certain time.
6	RideQuality	BFO: Relational Quality (Can be graded)	BFO: a gradable quality specifically dependent on the Vehicle, Road and its location which are BFO: Continuants.
7	DataOfSBC	BFO: Information Object	BFO: Generically dependent continuant that depends on the existence of continuant. Here SBC. The data file in any format generate by SBC on the vehicle can be represented by this entity.
8	VehicleStarts	BFO: Function	A Function is a disposition which is a realizable entity that is specifically dependent on the existence of independent entity.
9	VehicleStops	BFO: Function	
10	VehicleMoves	BFO: Function	
11	VehicleTurns	BFO: Function	
12	VehicleAccelerates	BFO: Function	
13	VehicleBrakes	BFO: Function	
14	VehicleBounces	BFO: Capability	Vehicle Bounces on Road, which is not a function, but it is an action on vehicle that happens and marked by sensors.
15	RoadSurfaceQuality	BFO: Specifically Dependent Continuant	Road Surface Specifically depends on the existence of Road-Section which is part of Road.
16	BumpOnPatch	BFO: Continuant Fiat Boundary (Fiat Surface)	Bump is physical entity made up of materials, but in mapping ride quality knowledge, it is a location marked by two-dimensional boundaries.
17	PotholedPatch	BFO: Continuant Fiat Boundary (Fiat Surface)	A location marked by two-dimensional boundaries.
18	DriveCautionPatch	BFO: Continuant Fiat Boundary (Fiat Surface)	A location marked by two-dimensional boundaries.
19	SensorSetUp	BFO: Fiat Object Part	Considered as a part of vehicle.
20	ComputeData	BFO: Process	Process is a BFO: Occurrent in which the independent continuant participates.
21	GoodToGoPatch	BFO: Continuant Fiat Boundary (Fiat Surface)	Location marked by two-dimensional boundaries.

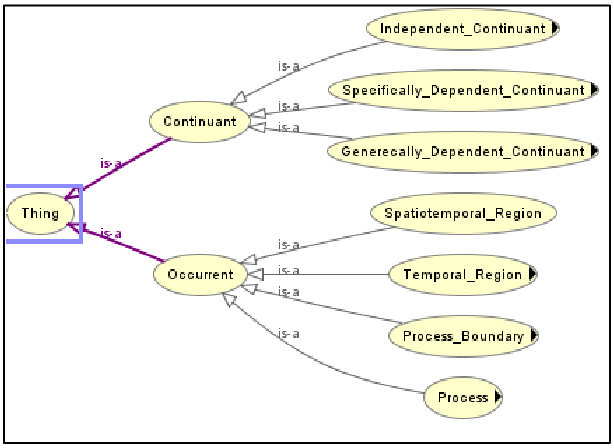

Fig. 6. First level of classes in our ontology

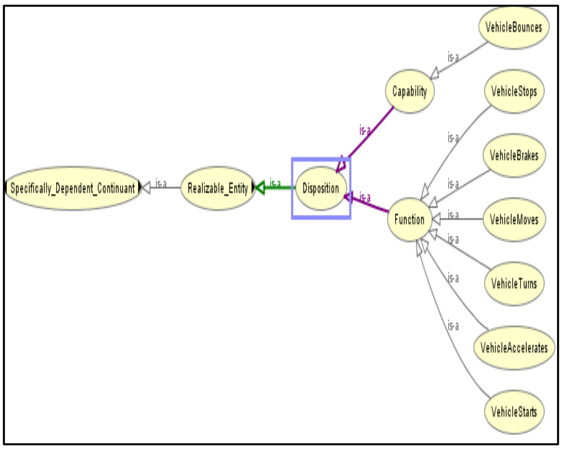

Fig. 7. Protégé classes for Specifically

Dependent Continuants

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<!-- http://www.semanticweb.org/viren/ontologies/2024/0/RideQuality#PatchWithPotholes -->

<owl:Class rdf:about="http://www.semanticweb.org/viren/ontologies/2024/0/RideQuality#PatchWithPotholes">
    <rdfs:subClassOf rdf:resource="http://www.semanticweb.org/viren/ontologies/2024/0/RideQuality#Two-Dim"/>
</owl:Class>



<!-- http://www.semanticweb.org/viren/ontologies/2024/0/RideQuality#Person -->

<owl:Class rdf:about="http://www.semanticweb.org/viren/ontologies/2024/0/RideQuality#Person">
    <rdfs:subClassOf rdf:resource="http://www.semanticweb.org/viren/ontologies/2024/0/RideQuality#Object"/>
</owl:Class>



<!-- http://www.semanticweb.org/viren/ontologies/2024/0/RideQuality#PrivateVehicles -->

<owl:Class rdf:about="http://www.semanticweb.org/viren/ontologies/2024/0/RideQuality#PrivateVehicles">
    <rdfs:subClassOf rdf:resource="http://www.semanticweb.org/viren/ontologies/2024/0/RideQuality#Vehicles"/>
    <owl:disjointWith rdf:resource="http://www.semanticweb.org/viren/ontologies/2024/0/RideQuality#PublicVehicles"/>
</owl:Class>



<!-- http://www.semanticweb.org/viren/ontologies/2024/0/RideQuality#Process -->

<owl:Class rdf:about="http://www.semanticweb.org/viren/ontologies/2024/0/RideQuality#Process">
    <rdfs:subClassOf rdf:resource="http://www.semanticweb.org/viren/ontologies/2024/0/RideQuality#Occurrent"/>
</owl:Class>
```

Fig. 8. RDF XML rendering of part of the ontology

CONCLUSION AND DISCUSSION ON FUTURE WORK

In the partial fulfillment of the proposed approach, this paper shows the development of ontology with the Protégé tool. The ontology is published at https://www .gecdahod.ac.in/ ontologies/ ridequality.owl. The BFO standard is followed to design the ontology. Based on the provided ontology, small-board computers on vehicles will annotate the sensor data they read. This data is in RDF syntax and can be queried for knowledge extraction. The use of semantically annotated data allows us to reason the generated knowledge at the edge level. In IoT scenarios where the point of information collection is moving in and out of the network, the semantic reasoning at the edge gateway can save communication load on networks by publishing annotated information. A fully functional application that annotates data gathered by vehicles and publishes it in RDF/XML format so that other semantic models can query it will be necessary for our future work to complete the application. Our future work also involves vehicle-to-vehicle semantic knowledge interchange.

Author contributions

Viren Patel: Conceptualization, Methodology, Software, Field study, writing Original draft preparation **Kaushik Rana:** Software, Validation. Field study **Viral Borisagar:** Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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