Generation of Meaningful Location References for Referencing Traffic Information to Road Networks Using Qualitative Spatial Concepts

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Abstract Location referencing systems (LRS) are a crucial requisite for referencing traffic information to a road network. In the past, several methods and standards for static or dynamic location referencing have been proposed. All of them support machine-interpretable location references but only some of them include human-interpretable concepts. If included, these references are based on pre-defined locations (e.g. as location catalogue) and often miss meaningful interlinking with road network models (e.g. locations being simply mapped to geographic coordinates). In a parallel research strand, ontological concepts for structuring road networks based on human conceptualizations of space have been proposed. So far, both methods have not been integrated. The current work closes this gap and proposes a generation process for meaningful location references on top of road networks based on qualitative spatial concepts. A prototypical implementation using OWL, Neo4J graph database and a standardized nationwide road network graph shows the practical applicability of the approach. Results indicate that the proposed approach is able to bridge the gap between existing road network models and human conceptualizations on multiple levels of abstraction.

Keywords Digital road networks · Location referencing · Qualitative spatial concepts

1 Introduction

One of the crucial aspects of digital road information such as traffic events, real-time traffic information or road condition information is concerned with the referencing of information entities to a digital representation of a road network. Usually this is accomplished by using GIS-based location referencing methods (Hackeloeer et al. 2014). In the past, several different methods and data models for

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location referencing have been proposed (Hackeloeer et al. 2014; Nyerges 1990; Scarponcini 2002; Vonderohe et al. 1997; Zhou et al. 2000). In general, the different methods and data models can be categorized into three approaches: the first approach uses shared road network models (e.g. each information processing system has to use the same road network model), the second approach is based on dynamic location referencing (e.g. information processing systems code location references in a way that these references can be mapped on different road network models) and the third approach uses shared catalogues of pre-defined locations (e.g. a standard set of well-known locations is defined which is then used by different information processing systems). All approaches have in common that they primarily support machine-interpretable locations. Examples of the first approach are Geographic Data Files (GDF) (ISO 14825 2011) or Austria's National Transport Graph GIP.at (Mandl-Mair 2012). OpenLR[1] or TPEG-ULR (Ernst et al. 2012) are examples of the second approach. The third approach also provides human-interpretable location references. In the past, two standard formats for expressing human-interpretable location references have been proposed, namely TMC location tables (ISO 14819-3 2013) and TPEG-Loc by the Transport Protocol Expert Group (TPEG).[2] These location referencing systems provide human- as well as machine-interpretable location references based on a catalogue of pre-defined locations such as road junctions, road sections or points of interest. However, pre-defined location catalogues are typically not interlinked with digital road network models, but are simply mapped to geographic references such as WGS84. Moreover, the location tables often have to be derived through a time-consuming manual process which hinders frequent updates. In another research strand, authors have proposed qualitative concepts for structuring road networks based on human conceptualizations of space for supporting human-interpretability of road information (Car and Frank 1994; Timpf et al. 1992; Wang and Meng 2009). These approaches model a road network on multiple levels of abstraction and therefore provide valuable contributions for cognitively adequate location references which can be read and interpreted by human beings as well. So far, these approaches have not been integrated into location referencing systems. Furthermore, a process for generating such information automatically on top of digital road network models is missing.

In this work we propose an integrated process for enhancing digital road network models with qualitative spatial concepts on multiple levels of abstraction. Therefore, cognitively adequate abstraction levels and qualitative spatial concepts are derived from natural language traffic messages and formally defined by a multi-level ontology. The main contribution of the work is the description of a process for generating individuals of the ontology (location references) on top of arbitrary road network graphs. A prototypical implementation based on the ontology modelling language OWL and Neo4J graph database shows the practical

[1] http://www.openlr.org/.

[2] http://tisa.org/technologies/tpeg/.

applicability of the approach. The proposed ontology and the generation process are tested with data from Austria's National Transport Graph (GIP.at). Results show that the proposed approach is able to enhance digital road networks with qualitative spatial location references on multiple levels of abstraction to enable meaningful location referencing.

The remainder of the work is structured as follows: Sect. 2 discusses related work with respect to location referencing approaches. Section 3 proposes the ontology classes as well as their relationships. In Sect. 4 a prototypical implementation based on OWL and Neo4J graph database is presented. Section 5 discusses results from applying the approach to a nationwide road network graph and Sect. 6 concludes the work.

2 Related Work

GIS-based modelling of road networks for referencing road or traffic information has been addressed by several research strands. One of the first proposals came from Nyerges (1990). Nyerges proposed three different locational reference strategies for highways, namely (1) road name and milage, (2) control sections with equidistant or variable lengths and (3) link (chain) and node. Although the proposal solely addresses highways, it can be adapted to other roads as well. Vonderohe et al. (1997) proposed a generic data model for linear referencing systems which may be considered the foundation of most location referencing systems. The authors proposed anchor points (e.g. intersections) and anchor sections (e.g. links between intersections) as natural segmentations of road networks and proposed road segmentation strategies as linear references. Scarponcini (2002) extended this approach with a generalized model for linear referencing in transport which takes into account different linear referencing methods. Curtin (2007) proposed a comprehensive process for linear referencing based on the generalized model by Scarponcini. In another noticeable work Curtin et al. (2007) took this model into account for discussing general principles of network analysis in geographic information science. Nowadays, most standard formats for describing static or dynamic road network references such as GDF, TMC, TPEG-Loc, TPEG-ULR or OpenLR use similar models with some form of linear referencing. However, most of these models are designed with respect to data exchange between systems, not taking cognitive spatial concepts into account. TMC, TPEG-Loc and TPEG-ULR also provide human-interpretable formats, but have to be either manually maintained and are limited to catalogues of pre-defined locations without providing the possibility to link concepts with existing road network models.

Beside the technical approaches, authors proposed conceptual modelling approaches of road networks taking human conceptualizations of space into account. Timpf et al. (1992) proposed a conceptual model for highway navigation with three levels of abstraction, namely *planning*, *instruction* and *driver* level. For each of the different abstraction levels, spatial concepts for describing a road network are defined. Car and Frank (1994) proposed a hierarchical algorithm for path search in large road networks based on human conceptualizations. More recent works also proposed ontological modelling approaches of road networks: Timpf (2002) presented an ontology of wayfinding from a traveler's perspective. The most recent approach with respect to our work comes from Wang and Meng (2009). The authors proposed a hierarchical ontology for modelling road networks on multiple scales. However, they did not consider the conceptualization of road networks from a traffic information perspective—their concepts are tailored to navigation and routing. Moreover, their approach does not take existing road network models into account.

Our approach of generating meaningful location references on top of digital road network models is placed somewhere in the middle of the presented previous approaches and tries to integrate them: On the one hand it takes into account the perspective of human conceptualizations of road networks, as proposed by Timpf and other authors, and on the other hand, it considers the more technically-oriented approaches, as anchor point theory, static and dynamic linear referencing. The approach bridges the gap between purely static and purely dynamic location referencing systems by proposing a process for automatic generation of meaningful location references as enhancement of digital road network models. Therefore, qualitative spatial concepts modelled with the standardized web ontology language OWL (Bechhofer 2009) are used. This enables the management and query of location references by using standard tools from the semantic web community like graph databases or query languages such as Cypher or SPARQL.

3 Qualitative Spatial Concepts for Road Network Referencing

For generating meaningful location references on top of digital road network models, we firstly define cognitive spatial concepts which are commonly used by road users in their everyday language. As starting point, we analyzed spatial references being used in traffic messages. For example, a natural language traffic message could be composed as follows: "On motorway A1 in travel direction Salzburg between exit Mondsee and Thalgau at kilometer 231 be aware of a broken vehicle". From this and similar examples, we derive the following structure of human-interpretable spatial references in the context of traffic messages: (1) the message uniquely identifies a road by its reference number or a well-known name, (2) the message identifies the driving direction by using qualitative spatial direction concepts, (3) the message identifies the relevant road section (this can be optional if the message is related to the whole road) and (4) if available and necessary, the message identifies a more detailed linear reference of the event (e.g. mileage point). From this example it gets obvious, that human-interpretable descriptions of traffic-related events contain spatial concepts on at least three cognitive levels, namely road, section and optionally a more detailed segmentation such as a road segment or a linear reference such as a single location or a dynamic segment. For separating sections the cognitive spatial concept of a junction (including interchanges and intersections) is used and for identifying driving directions we propose qualitative direction concepts.

Therefore, our conceptual modelling approach resulted in six concepts for representing road networks on different conceptual levels, namely **Road**, **Section**, **Junction**, **Segment**, **LinearReference** and **Direction**. For the definition of the concepts and the relationships we integrated results from previous approaches discussed in the related work section. As proposed by Guarino (1998), we define these concepts and relationships as ontology.

3.1 Spatial Concepts

Road: On the most abstract cognitive level we define **Road** as the basic concept. A road is determined by its (at least locally) **unique name** or **reference number**. The concept of a road is used in different levels of abstraction since a national road, for example, could cover long distances but may also include different local roads. Higher level roads are typically designed to connect prominent places such as cities or villages and local roads are designed to connect city districts. Due to their prominent nature in any road network and due to their specific characteristics (e.g. separate driving directions, on/off ramps, etc.) we define **Motorway** as a sub-concept of Road. Prominent examples of roads in Austria are the federal road "B1—Wiener Bundesstraße" or the motorway "A1—Westautobahn". It is worth to mention that the ontology could contain several other sub-concepts of roads, but in our case we keep it simple and for most traffic messages both concepts are sufficient to distinguish. If necessary, the ontology can be easily extended with additional sub-concepts (Fig. 1).

Section: On the next cognitive level we define the concept **Section**. A **Section** is defined as part of a road with start and end point at prominent junctions with other roads. This concept has been defined in analogy to anchor points and anchor sections as proposed by Vonderohe et al. (1997). For example, the part of "A1—Westautobahn" motorway in Austria between the exits "Mondsee" and "Thalgau" is modelled as a **Section**. In case that a road starts or ends without a junction, than start or end node of the road is selected as section start or end. As sub-concept of **Section** we define the concept **Ramp** for representing sections connecting sections of different roads.

Segment: On the lowest cognitive level we define the concept of a **Segment**. A **Segment** separates a section in more detailed parts, being characterized by equal attributes (e.g. form, lanes, width) or more detailed anchor nodes (e.g. minor roads being connected to the road). For example, the part of a road section between two non-prominent nodes can be characterized as a road segment. This concept may be used for linking the higher-level concepts with any other road network model being

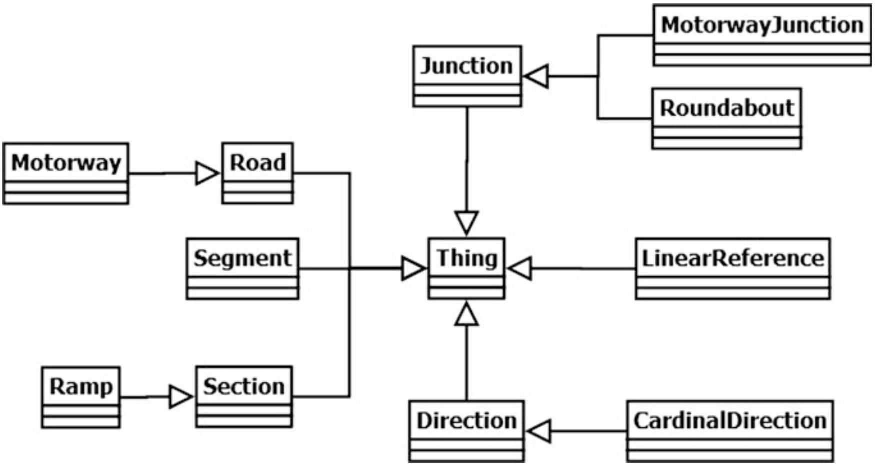

Fig. 1 The basic ontology of spatial concepts and selected sub-concepts

typically modelled on the abstraction level of segments only (sometimes also called links).

Junction: In our conceptual modelling approach, sections are the result of structuring the road network with respect to road interchanges and intersections. Therefore, we define **Junction** as central cognitive concept for structuring road networks. Accordingly, we defined two sub-concepts, namely **MotorwayJunction** (including all ramps as well as the road segments between the ramps) and **Roundabout** (including all segments of a roundabout) since both junctions have special characteristics and thus play a major role in mental models. It is worth to mention that a junction may be composed of several ramps and segments, e.g. in case that the junction is a motorway interchange or any other complex junction.

Direction: Until now we are able to model roads on different cognitive levels, but we are not able to indicate directions in a qualitative way. With respect to traffic information, each information entity has to be related to a unique driving direction. Thus, we complete our road ontology with the concept **Direction**. Similar to the LinearReference concept, the concept may be used on each cognitive level, representing the direction of a road, a section or a segment. From a technical perspective, directions of roads, sections or segments are represented by defining start and end node of the corresponding entity. While this approach is well-suited for systems, human beings are used to express directions with qualitative spatial concepts. One of the simplest qualitative concepts is the **Cardinal Direction** concept (e.g. 4- or 8-sector model) which classifies driving directions as cardinal directions (Frank 1996). However, depending on the cultural background, people more likely use other or additional qualitative direction concepts on different cognitive levels: (1) on a city level inbound or outbound direction in relation to the city center or names of prominent city districts, points of interest or junctions, (2) on a regional level names of prominent towns and villages or junctions, (3) on a

Table 1 The six concepts of the proposed ontology

Concept	Description
Road	A road describes a continuous infrastructure for driving with the same reference number or name
Section	A section splits a road according to well-known anchor points (e.g. junctions). The sub-concept Ramp connects a road or road section with another road or road section
Segment	A segment splits a section into several parts with equidistant or variable length. The segmentation of a road section is usually disjoint and complete
Junction	A junction is used to model the connection of two or more roads. A junction subsumes all sections that are part of the junction. This includes all ramps and deceleration/acceleration lanes but also the parts of the connected roads between the outer ramps
Direction	The directions is used to qualitatively express driving directions in a human-interpretable way
LinearReference	A LinearReference may be used to linearly reference arbitrary parts (single position or part) of a road, road section or road segment with a relative start and end offset relation to the entering point of the corresponding road, road section or road segment. LinearReferences may be point or line references

national level names of prominent cities and prominent junctions and (4) on an international level national borders or prominent cities. Since such qualitative direction concepts need further modelling effort, for now we limit our ontology to the concept of cardinal directions and postpone the definition of more detailed qualitative direction concepts to future work.

LinearReference: For referencing road information to arbitrary road parts (on each cognitive level), the literature proposes linear reference methods (LRM) as commonly agreed approach (Hackeloeer et al. 2014). A linear reference can be either static (e.g. pre-defined mileage points) or dynamic (e.g. dynamically referenced traffic events) and either a point reference (e.g. mileage point, traffic event at a single location) or a line reference (e.g. 100 m segments, traffic event of a certain length). For our road ontology, we propose a generic concept **LinearReference**. It is defined with relative start and end offsets in driving directions on each cognitive level (e.g. as offset to a road, section or segment). We propose to define more detailed linear reference concepts (e.g. MilageLocation, 100MeterLinearReference or EventLocation) as sub-concepts of LinearReference if needed (Table 1).

3.2 Relationships

Until now, we have defined the spatial concepts but we excluded the relationships between these concepts. From a cognitive perspective, road-related spatial references are typically derived from three hierarchical spatial reference frames, namely (1) an international reference frame (e.g. international reference numbers for motorways), (2) a national reference frame (e.g. nationwide names or references for national roads) and (3) a local reference frame (e.g. local names for regional or national roads within a city). For example, for messages within a city center people use local road names, whereas outside the city center nationwide road names are used. Accordingly, on long distance travels people switch to an international reference frame. Since we conceptualize roads according to their name or reference, the same physical road may be conceptualized twice or threefold in our ontology. For example, a road may be conceptualized by its local name (e.g. "Ignaz-Harrer-Straße") and by its national name (e.g. "B1—Wiener Bundesstraße"). Now, one could argue that the relationship between both road conceptualizations has to be modelled as is-part-of-relationship, but this is not generally valid. For example, in the city of Salzburg, only parts of the local road "Ignaz-Harrer-Straße" belong to the national road "B1—Wiener Bundesstraße". Other parts belong to the national road "B155—Münchner Bundesstraße". Therefore, we decided to model this relationship not on the road-level, but on the section-level since both parts of the "Ignaz-Harrer-Straße" are modelled as separate sections anyway. Furthermore, since sections may vary between local and national roads (due to different naming strategies), we model the section-to-section-relationship as hierarchical relationship (*isSubSectionOf*). Consequently, a section may have several relationships, namely being part of different roads (a local and a national road) but also being part of other sections. This modelling strategy allows us to express the cognitive hierarchical relationship of changing spatial reference frames between local and national frames seamlessly.

4 Implementation

4.1 Overall Process

From an implementation perspective, we propose the following 3-step approach for describing the ontology as well as generating the individuals of the ontology on top of a road network model:

1. The proposed qualitative spatial concepts have to be defined using a standardized ontology language. Due to its broad acceptance, we decided to use the Web Ontology Language (OWL). We modelled the OWL structure by using the Protégé editor. Figure 2 shows the resulting OWL ontology as OntoGraf[3] visualization (Protégé plugin). This ontology is the foundation for all further processing steps.
2. We expect an arbitrary road network to be modelled as directed road network graph with road segments as vertices and connections between the segments as

[3] http://protegewiki.stanford.edu/wiki/OntoGraf.

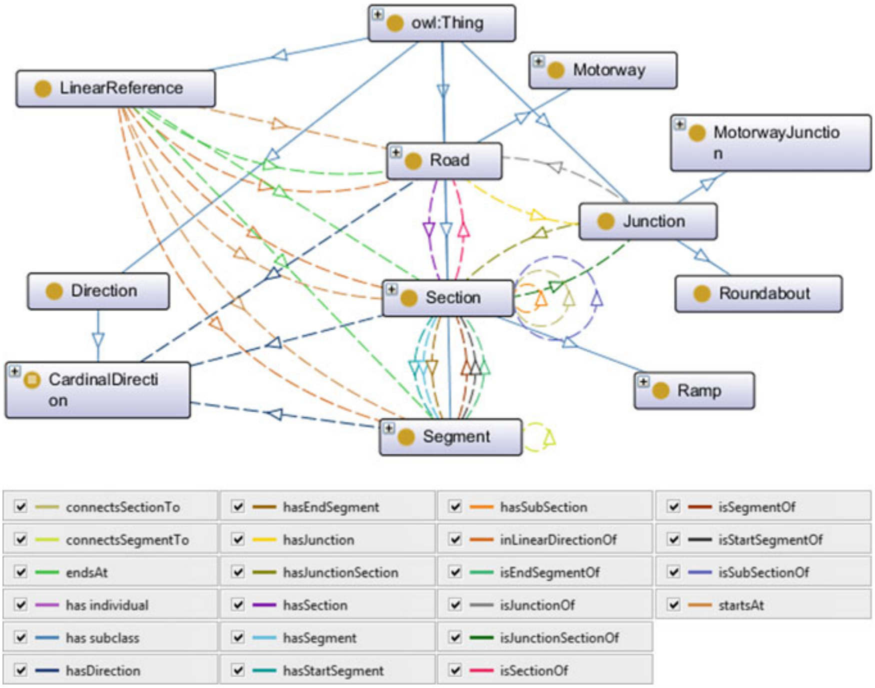

Fig. 2 OWL classes and relationships visualized with OntoGraf

edges. Attributes such as geometries, road names and road class hierarchies have to be attributed to the directed road segments. In our implementation approach we used the standardized format for modelling transport networks in Austria (GIP.at) and imported the road model into a Neo4J graph database.

3. The generation process for individuals of the ontology takes the OWL ontology and the road network graph as input and generates the individuals. The overall process is listed in the next subsection. The process has been implemented as Neo4J Plugin. This plugin accesses the OWL ontology using the OWL API[4] and stores the OWL ontology together with the generated individuals in the Neo4J graph database following the method described in the Neo4J Blog.[5] Storing the ontology in Neo4J instead of a triple store has the benefit that it can be accessed and queried using the graph query language Cypher.[6] Furthermore, it is possible to traverse the individuals of the ontology using standard graph algorithms.

[4]http://owlapi.sourceforge.net/.

[5]http://neo4j.com/blog/using-owl-with-neo4j/.

[6]http://neo4j.com/docs/developer-manual/current/#cypher-query-lang.

Table 2 Relationships between the six concepts of the ontology

Concept	Relationship	Concept
Road	►hasSection, ◄isSectionOf	Section
Section	►hasSegment, ◄isSegmentOf, ◄isStartSegmentOf, ◄isEndSegmentOf	Segment
Section	►connectsSectionTo ►isSubSectionOf, ◄hasSubSectionOf	Section
Segment	►connectsSegmentTo	Segment
Junction	◄hasJunction, ►isJunctionOf	Road
Junction	◄hasJunctionSection, ►isJunctionSectionOf	Section
Road, Section, Segment	►hasDirection,	Direction
LinearReference	►startsAt, ►endsAt, ►inLinearDirectionOf	Road, Section, Segment

Figure 2 shows the basic OWL classes of the ontology and its relationships. In OWL the latter are modelled as directed relations using object properties (cf. Table 2).

4.2 Generation Process for Individuals

To generate the individuals of the ontology on top of a road network, the following four steps have to be executed:

1. The road segments and connections have to be read from a file or database. Properties have to include at least the segment id, the road name and/or reference number, the start and end node identification number, the road type and connections to neighbor segments at both ends. In order to derive junctions and sections, all topological connections between segments must be known or determinable. Road graphs often include drivable connections only, which would yield incomplete or unrecognized junctions, e.g., at junctions with one or more one-way streets. In this case, it depends on the data model, if the complete topological connection information can be extracted from the road network model in an efficient way. For the proposed algorithm the missing information is derived by comparing the start and end node ids of the segments.
2. *Sections* and *roads* can now be derived from the chain of road segments. A *section* is composed of an ordered list of segments being located between two road junctions or between a road junction and the end of a road. The proposed extraction algorithm starts at an arbitrary segment (i.e. a segment which occurs first in the database) and proceeds in both directions by following the topological connections to other segments. The section grows as long as a segment has exactly one topological connection to another segment. This strategy is repeated until each segment has been processed. Next, sections are divided into

sub-sections where the road name changes. Each sub-set of segments with a unique road name becomes its own section which is a child of the original section. Complex junctions are composed of *Sections* which have been identified as *Ramps* as well as the road sections of the intersecting roads enclosed by the ramps (compare with Fig. 6). A property is used to differentiate between on- and off-ramps. In case of a motorway junction, all sections of a junction are merged into a *MotorwayJunction,* which inherits from the general *Junction* concept. Similarly, sections of a roundabout belong to one *Roundabout* individual which also inherits from the *Junction* class.

3. *Roads* are modelled as sequences of sections with the same road name. In analogy to segments, road sections are interlinked via the relation *connectsSectionTo*. If a *Segment* contains a local and national road name, individual roads are created. In case of minor road name errors (e.g. small segments with missing road names), the algorithm detects these errors and merges nearby road parts. Due to their special characteristics, motorways are mapped to the *Motorway* class.
4. *Cardinal Directions* are derived by comparing the first and the last coordinate of the start and end node of a segment, the start and end segment of a section or the start and end section of a road. The concept *LinearReference* provides the possibility to extract a part of a road, section or segment (e.g. between 10.4 and 12.3 km of a road). It can be used for dynamic referencing of traffic messages on multiple abstraction levels.

5 Results

5.1 Test Data

For testing our approach we generated individuals of the ontology on top of Austria's National Transport Graph (GIP.at)[7] which is a geo-referenced dataset of a nationwide transport network published under the Creative Commons 3.0 license.[8] We imported the road network data (47,236 km) from the provided CSV-format into a generic road graph model using Neo4J graph database. In the GIP.at format (CSV file), the road network is modelled on the abstraction level of topologically connected road segments (so called links). In our approach, each link from the CSV file is represented as individual of the *Segment* class. We filtered the data using the functional road class (FRC) attribute (which is used to express the hierarchy of roads in the network) in order to apply the ontology generation process to the strategic road network only. The filter range was from FRC 0 (which stands for motorways) to FRC 4 (which stands for roads connecting villages or city districts).

[7] https://www.data.gv.at/katalog/dataset/3fefc838-791d-4dde-975b-a4131a54e7c5.

[8] https://creativecommons.org/licenses/by/3.0/at/.

The generation process resulted in a total count of 223.328 road segments. After import of the road segments in a Neo4J database, we executed our generation process (Neo4J Plugin) for deriving the individuals according to the proposed ontology. The generation process finished and resulted in 25.072 roads and 66.987 sections.

5.2 Examples and Queries

To test the ontology and the generated individuals, we implemented several Cypher queries. With the Cypher queries we tried to answer the following questions:

- Q1: Are roads and sections adequately represented on different levels of abstraction?
- Q2: How well does the modelling of junctions work?
- Q3: How can we use junctions as selector for between-sections?
- Q4: Does the qualitative direction concept proof useful?

For answering these four questions we present three example queries and visualize the results. Figure 3 shows the locations of the three examples on a map of the Western provinces of Austria (including parts of Bavaria).

To answer the first **question Q1**, we have chosen the Fernpassstraße (~75 km) which is an important national transit highway in the province of Tyrol and crosses

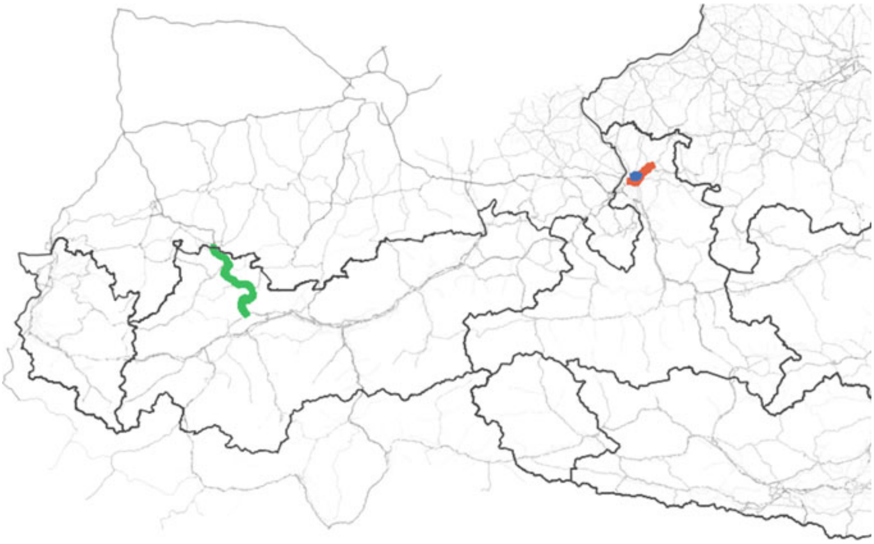

Fig. 3 Location of roads and sections from the examples (*green* B179—Fernpassstraße; *red* B1—Wiener Straße; *blue* motorway junction Salzburg Nord)

several villages with different/additional local names—hence a prominent example of a road with different levels of abstraction, junctions and ramps.

Example 1 Cypher query to retrieve all sections of “B179—Fernpassstraße”.

```
MATCH (r:Road {roadRef:‘B179’})-[:hasSection]-(sec)
OPTIONAL MATCH (sec)-[:hasSubSection]-(ssec)
RETURN r,sec, ssec
```

Results of the query are shown in Fig. 4. It contains the individuals of the road “B179—Fernpassstraße” (in the center) surrounded by 30 *Sections* (green). The arrows show the *isSectionOf*- and *hasSection*-relations. The remaining 22 (blue) individuals show ramps.

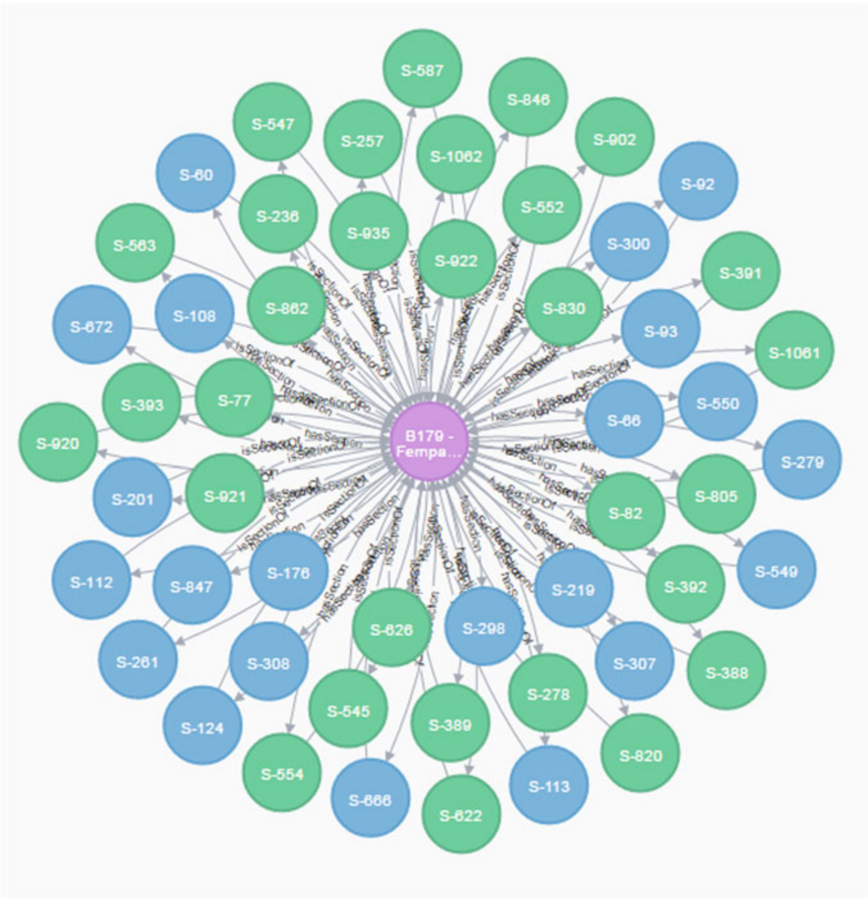

Fig. 4 Automatically derived road sections of the B179—Fernpassstraße in Austria (federal highway); visualized with Neo4j Browser

Another aspect of the ontology is presented in Fig. 5. Figure 5 shows a map of a long road section of ‘B179—Fernpassstraße’ (blue) and two small sub-sections representing local roads (orange and green). The long section does not contain any intersections with other roads but the two sub-sections are attributed with local

Fig. 5 Local roads ‘Fernpaß’ and ‘Fernstein’ as sub-sections (*orange, green*) of a national road section (*blue*)

Fig. 6 Sections of junction “A1—Westautobahn—Anschlussstelle Salzburg Nord”. Each section is illustrated in a unique colour, and *Ramps* are marked with a *black solid* outline

names. This example nicely visualizes the relationship between national and local abstraction levels. While non-local road users with distant destinations will primarily conceptualize the national road (‘B179—Fernpassstraße’) and most likely conceptualize this section as one section, local road users will most likely conceptualize the local names (‘Fernstein’ and ‘Fernpaß’) and therefore conceptualize the section in a more granular way. With the concept of sub-sections we are able to model each of the granularities accordingly.

To address **question Q2** concerning the modelling of junctions, the next query retrieves a complex motorway junction. As Fig. 6 shows, the junction has on- and off-ramps, acceleration and deceleration lanes.

Example 2 Cypher query to retrieve all sections of junction “Anschlussstelle Salzburg Nord” (federal highway × motorway).

```
MATCH (j: MotorwayJunction
      {junctionName: ‘ Anschlussstelle SalzburgNord’})
      -[:hasJunctionSection]- > (sec)-[:hasSegment]-
      > (seg)
RETURN sec.section_id,seg.segment_id,labels(sec)[0]
```

The Cypher query presented in Example 2 selects all road sections of the *Junction* ‘Anschlussstelle Salzburg Nord’ connecting the motorway ‘A1—Westautobahn’ with the roads ‘B150’ and ‘B156’. As visible from Fig. 6, the two motorway sections (in the middle from east to west) and the intersecting roads (from south to north) are also part of the junction, which is intuitively expected. From this example we conclude, that the ontology and the generation process are able to model complex motorway junctions in a cognitively adequate way. Since junctions are an important mental concept, this is a necessary step for human interpretability of traffic messages. Furthermore, the *Sections* which are part of the *Junction* can be used to reference fine-granular traffic information, e.g., problems on the on-ramp or on the side roads.

Question Q3 addresses the challenge of selecting sections between two junctions and **question Q4** deals with driving directions. As example, a 12 km long diverse road section of the federal highway ‘B1—Wiener Bundesstraße’ has been chosen. Two roundabouts delimit the section, one close to a motorway junction, the other in the city center of Salzburg. This road section has features of an urban main road but also of an arterial road and highway.

Example 3 Cypher query to retrieve all sections sections of “B1—Wiener Straße” (federal highway) between roundabout “Kreisel Eugendorf A1” and roundabout “B1—KV Hans Schmid Platz”.

```
MATCH (j:Roundabout {name: ‘Kreisel Eugendorf A1’})-
      [:hasJunctionSection]- > (n:Section)
WITH startSec LIMIT 1
MATCH (j:Roundabout {name: ‘B1 - KV Hans Schmid Platz’})-
      [:hasJunctionSection]- > (n:Section)
```

```
WITH endSec LIMIT 1
MATCH (r:Road {roadName: 'B1 – Wiener Straße'})-[:hasSection]-
      > (sec)
WITH sec
MATCH p = shortestPath((startSec)-[:connectsSectionTo*0..
      9999]- > (endSec))
WHERE p IN sec
WITH p
MATCH (p)- [:hasDirection]->
      (d:CardinalDirection)
RETURN p, d
```

The query selects the *Road* 'B1—Wiener Straße' and retrieves all sections between the *Junctions* 'Kreisel Eugendorf A1' and 'B1—KV Hans Schmid Platz'. First, the starting *Section* at the first *Junction* and the end *Section at* the last *Junction* are derived (relationships *hasJunctionSection*). The shortest path method finds the sequence of *Sections* connecting both *Junctions* via the *connectsSectionTo*-relationships. The resulting *Sections* and the driving directions as *Cardinal Directions* are visualized in Fig. 5 (Fig. 7).

Fig. 7 Sections of the road 'B1—Wiener Straße' between junction to 'Kreisel Eugendorf A1' and junction to 'B1—KV Hans Schmid Platz'. The different colors represent the different *Sections*. The short *grey lines* reveal the *Segments*. The *black arrows* and letters indicate the driving direction of the sections as *Cardinal Direction*

6 Conclusions

In this work we proposed an integrated process for generating meaningful location references for enhancing road network models based on an ontology with six qualitative spatial concepts (*Road*, *Section*, *Segment*, *Junction*, *Direction*, *LinearReference*) and their relationships. This approach is on the one hand intended to bridge the gap between technically-oriented and human-interpretable location referencing systems and on the other hand to bridge the gap between static and dynamic referencing systems. We presented a prototypical implementation of an automatic process for generating the individuals of the ontology on top of a standardized, nationwide road network graph using a standardized ontology description language (OWL) and an open source graph database (Neo4J) for storing the ontology as well as the individuals. From the conceptualization and implementation approach we derived the following conclusions:

1. The proposed approach has demonstrated the use of qualitative spatial concepts for enhancing digital road networks with for the purpose of locational referencing on different levels of abstraction. This may be considered as clear benefit in comparison to previous static (e.g. TMC location table) as well as dynamic (e.g. OpenLR) approaches.
2. The proposed approach was tested with a nationwide road network graph. This goes beyond previous conceptual modelling approaches and demonstrates practical applicability. Although the approach has only been tested with one road network data model, due to the similar modelling concepts (e.g. road segments, topological connections, attributes) it may be easily adapted to other data models as well.
3. The quality of the resulting ontology instances heavily depends on the quality of the underlying road network graph, e.g. correctness of topological connectivity, road names, and hierarchical structure. Before generating the individuals of the ontology, a thorough quality evaluation process by taking into account standardized quality measures (ISO 19157 2013) has to be considered.
4. The use of cardinal directions as qualitative spatial direction concepts satisfies human-readability, applicability and interpretability only partly. The need for an automated process of deriving more expressive spatial direction concepts, which are closer to the everyday language, has been identified. However, the proposed ontology can be taken as foundation for a more detailed ontology by integrating additional qualitative spatial concepts.
5. So far an empirical evaluation of the proposed spatial concepts is missing. We have only demonstrated a plausibilisation for some challenging road network parts. However, since the basic spatial concepts have been derived from natural language and existing human-interpretable location referencing techniques, the overall ontology has a good empirical foundation.

In the future we plan to address the question of extending the ontology with more detailed qualitative direction concepts which are closer to everyday language.

Furthermore, we are planning to apply the ontology for different application scenarios to further evaluate adequacy and applicability empirically.

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