Landmarks in OpenLS — A Data Structure for Cognitive Ergonomic Route Directions

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Abstract. Landmarks support the structuring of environmental information into cognitive conceptual units, they have the potential to identify uniquely pertinent intersections for route following, and they disambiguate spatial situations at complex intersections. Not using them in automatically generated route directions is a violation of cognitive ergonomics. While we have made great progress on the one hand in characterizing and on the other hand in mining potential landmarks, viable data structures that incorporate their cognitive conceptual functions in route directions are poorly developed. The present article closes this gap by providing a representation based on the OpenLS standard that allows for capturing the semantics of landmarks. In this data structure, the cognitive conceptual essence of a landmark is represented allowing for generating route directions automatically and imbuing street network data with cognitively meaningful elements.

1 Introduction

Traveling from place A to place B in an unfamiliar environment is a challenging task. To ease this task, human beings often rely on route information provided by external means, i.e. route directions [27, 6]. Route directions that regard mental conceptualization processes involved in the human navigation are referred to as *cognitive ergonomic* route directions in this article. They try to reduce the cognitive load for the travelers and to enhance the travellers location awareness at the same time. Manifold research has been carried out on what constitutes good route directions, how to formalize cognitive aspects, and how route directions can be generated automatically.

A recurring theme in this research are landmarks: they turn out to be one of the most important environmental features in wayfinding and route following (e.g., [23, 20, 5]). They are a prime means to structure space; and they are widely used in route directions given by humans, as they easily allow linking actions during wayfinding to the environment. Many aspects of landmarks have been

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examined in the past, but the main challenges for wayfinding assistance systems are the automatic definition and extraction of appropriate salient objects, which may function as landmarks, from the available data sets and their integration in automatically generated directions. In other words, how can the data that is available through various sources these days be transferred into meaningful units that allow for communicating knowledge rather than information?

Mining landmarks and attaching measures to saliency are well advanced research topics, but the semantic embedding of landmarks into data structures is yet unsolved. While a good understanding exists why and when people use landmarks in organizing spatial knowledge for the purpose of communication or memory, our abilities to formalize this knowledge and to integrate landmarks in current information technology, such as PDA navigation assistants, is still limited. A major difficulty is to sufficiently formalize the concept of a landmark itself; this is a necessary step to enable a service providing route directions to integrate landmarks into the generated instructions.

This paper closes the gap between approaches identifying landmarks and those generating cognitive ergonomic route directions that automatically integrate landmarks. It proposes a data model that allows to capture the required information for generating route directions. It relates the different parts of the information, which are communicated in the route directions, to each other and constrains their use in order to avoid generating instructions that are inadequate for humans. The corresponding data structure is used to extend the OpenLS standard [17, 1], a server specification for location based services proposed by the Open Geospatial Consortium (OGC); the data structure is defined in a XML markup-language as used in the OpenLS specification. This standard enables a straight-forward integration of our data structure in concrete OpenLS-based applications. The data structure itself is not constrained by any limitations or requirements of a specific application and also independent from the underlying data set. Hence, it is well-suited to be the integrating brace for different approaches.

The paper is structured as follows: first we provide some pertinent details on landmarks in route following and route directions, and their integration in the automatic generation of route directions. Then we introduce a classification of landmarks which is used as formal basis of the data structure (Section 3), and the OpenLS standard, which is used to define the data structure (Section 4). In Section 5 we present our data structure and how it may be used to integrate landmarks into OpenLS. The paper concludes with an outlook on future work in Section 6.

2 Landmarks in route directions

Landmarks structure environments [8], for example, as anchor points for spatial knowledge [3]. In acquiring knowledge on a previously unknown environment, they are learned early on [23]. Accordingly, landmarks are important features of route directions [6]. They may be used for identifying origin and destination and distinguishing decision points [19], and they are especially useful to link actions to be performed within the environment, i.e. with the decision point the action needs to be performed at [5]. In that, they work better than street signs [25]. Not surprisingly, humans use landmarks to communicate route knowledge in both verbal and graphical instructions [5, 28].

Given that landmarks are so important, the idea of integrating them in automatically generated route directions is straightforward. But here the question arises which parts of our environment can be used as landmarks? It exists a plethora of definitions of "landmark", with Lynch's qualitative description provided in his seminal work on elements of a city that structure knowledge of the environment being one of the first that still has great impact on today's research [15]. According to Presson and Montello [20], for example, everything that stands out of the background may serve as a landmark. In the context of route following even road intersections are possible landmarks [12, 18]. Its salience determines whether an object may serve as landmark. The more salient an object is, the better it is identifyable by a human, i.e. the more it differs from the background. A combination of different visual, structural, and semantic aspects determines salience [24]. It also depends on the conceptualization of a wayfinding event (cf., [13, 22]).

The work presented in this article is embeded in the endeavour of generating route directions automatically. There are approaches to identify objects suitable as landmarks, i.e. to extract salient objects from geographic data sets (e.g., [21, 7]). And several approaches aim at automatically generating route directions that take cognitive aspects including landmarks into account (e.g., [22, 4, 16]). Integration of these two kinds of approaches is still an open issue.

The representation proposed in this paper, which builds on open standards and is based on cognitive considerations, aims on narrowing the gap between them. The following are the necessary steps of the generation process with special focus on the integration of landmarks (cf. [7]).

1. The first step is to create a data base, which comprises all objects in the current environment that can potentially function as a landmark. This step is idenpendent from an actual route and can be done once before route calculation, and then be used for any route. It only has to be redone if the underlying data changes. GIS data [2] or even data extracted from the internet [26] may be used as underlying data set.
2. The actual route is calculated according to the user's request (e.g., shortest route, quickest route, via locations) and all potential landmarks for that route are identified.
3. The identified landmarks are rated, for example, according to their salience in the context of the route [30] and the most useful are selected to be integrated in the route directions [7].
4. Based on these landmarks other methods for improving the cognitive ergonomics of the instructions, like combining instructions for several decision points into a single instruction (termed *chunking* by Klippel et al. [10] or *segmentation* by Dale et al. [4]), can be applied to the data generated so far.

➡ At this point all necessary data for generating route directions is collected and the route is already structured according to the instructions to be generated later.

5. In a final step the actual route directions are produced. If the results of step four are applicable, these instructions can be personalized regarding user–specific requirements and preferences (e.g., mode of presentation).

In this article we focus on a representation used for encoding the results of the fourth step above. The information processed and collected in step 4 needs to be stored in order to be usable in step 5. The data structure preferably correlates the single parts of the data set according to their future use in route directions; the information is represented independent from the modality of the route directions to be used in step 5. The generation process of step 5 may produce route instructions which adapt to the specific needs and personal preferences of a user; such personalization may require adaptation of the previous steps. However, in this paper we focus on the integration of landmarks as an aspect of cognitive ergonomic route directions and leave the personalization aspect as future work.

3 Classification of landmarks

We need a formal specification of how landmarks function in route directions in order to integrate them in automatically generated route instructions. This specification needs to identify all required information for referring to a landmark in route directions.

Therefore, we propose a classification of landmarks according to their function in route directions [14]. While this classification excludes a detailed discussion of which (visual) information to communicate in order to enable a wayfinder to identify a landmark, it is sufficient to derive the relation between route elements and landmarks and the function of landmarks within an instruction; this way it reflects cognitive ergonomic aspects of using landmarks. Hence, it is used as the basis for the data structure presented in this paper.

Landmarks are classified according to an eight–level taxonomy. Each level describes a different aspect of a landmark's function within an instruction; the first four levels of the taxonomy are shown in Figure 1. Note that not each level provides new information for each type of landmark. The core aspects of this taxonomy presented in [14] are outlined in the following.

Root Level The basic concept addressed in this taxonomy is *landmark*. Accordingly, it is listed at the *root level*.

Functional Level Landmarks used in route directions may serve different purposes which are reflected in different conceptualizations. Among other things, the function of a landmark depends on the number of route elements the landmark is utilized for. Route elements are either decision points or route segments: a route consist of a sequence of alternating decision points and route segments [9, 5]. On this level, two different groups of landmarks are

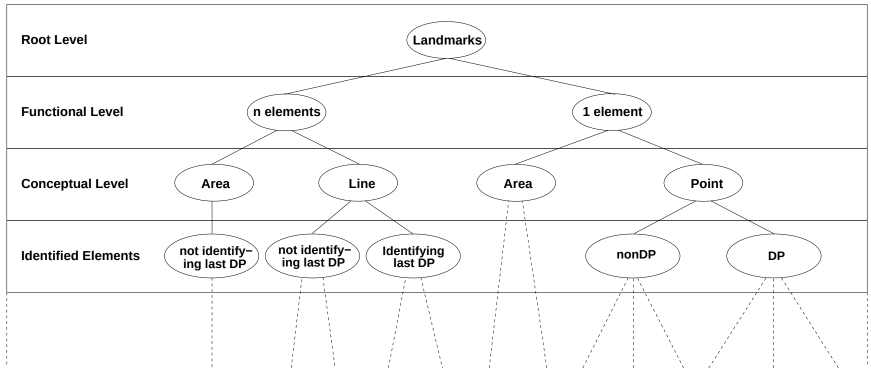

Fig. 1. The first four levels of the taxonomy of landmarks.

distinguished. The distinctive feature is whether the landmark is relevant for one single route element (*1 Element*) or for a sequence of more than one route element (*n Elements*).

Conceptual Level On the *Conceptual level* landmarks are categorised by the way humans conceptualize the functional role of their spatial extension. In the mental conceptualization they may function either as point–like (*Point*), line-like (*Line*) or area-like (*Area*) entity depending on their usage in the route following process. That means, geometrically higher–order landmarks (with $area \rightarrow line \rightarrow point$) can be conceptualized as a landmark of a lower geometrical order. For example, an areal or linear landmark can be referred to in an instruction as a point–like landmark (cf. Fig. 2).

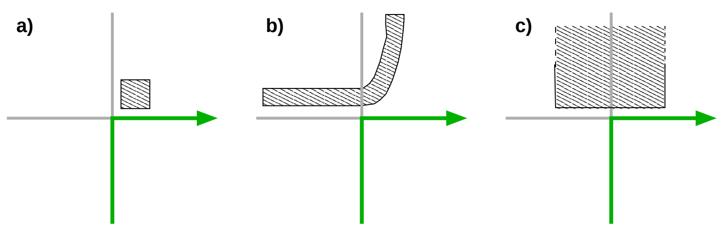

Fig. 2. Landmarks conceptualized as point–like with a) a point-like, b) a linear, and c) an areal geometry; the corresponding instruction is "turn right at the landmark".

Identified Elements On the *Identified Elements level* landmarks are distinguished by the type of route element they relate to; landmarks can be used either to identify a route–segment or a decision point. 1–Element–landmarks located at decision points can be used either to identify the decision point or to more specifically describe the action the traveller has to perform at the corresponding intersection. The latter landmarks are categorised as *DP*; the former as *nonDP*. n–Elements–landmarks are distinguished by whether they identifiy the last decision point they are utilized for (*identifying last DP*, e.g. "follow the tram tracks till they end.", or *not identifying last DP*, e.g. "follow the river until you reach the town hall.", respectively).

Object Class This level is only relevant for point-landmarks located at decision points. Here, we distinguish between different categories of landmarks with a point-like function: *Street Name*, *Structure*, and general salient object (*GSO*). The category *Street Name* comprises the branches of an intersection identifiable by their name (e.g., by a street sign), which may serve as a landmark. The category *Structure* denotes intersections that are referred to because of their salient structure (e.g., a T–intersection). All other objects that may function as a point–landmark are grouped in the category *GSO*. It is necessary to distinguish between these three categories as their integration in route directions depends on different requirements for describing the landmark.

Turn The *Turn level* refers to landmarks which relate to one particular decision point. In the case of n–Elements–landmarks, this decision point is the last the landmark is applicable for, but only if it is identified by the landmark itself (see *Identified Elements*). At this decision point, the traveller has either to perform a directional change or to go straight. Hence, we further distinguish between the categories DP^{+}, where a directional change is required, and DP^{-}, where the traveller has to go straight.

Geometrical Level On the *Geometrical level*, landmarks are categorised according to their geometry. We distinguish *point–like*, *linear–like* and *area–like* landmarks. These categories are not based on the exact mathematical definition of the terms, but are used according to their common colloquial understanding.

In a 2–dimensional projection of the route and its surrounding environment, in a truly mathematical sense all landmarks would geometrically be areas. But humans conceptualize some as point–like (e.g., buildings), some as line–like (e.g., rivers), and others as area–like entities (e.g., forests)[3]—independent of their use in route directions. The categorization of a landmark's geometry depends, therefore, on the ratio of its width and its length and on its size proportional to the route itself.

The transition between these categories is vague and cannot be easily defined in a formal way: it is often not unambiguously clear whether a landmark is *point–like*, *linear–like* or *area-like*. Heuristics need to be applied in order to resolve this vagueness.

Spatial Relational Level The last, most fine-grained level of the taxonomy is the *Spatial Relational Level*. Here, we differentiate the spatial relations that hold between landmarks and actions. Depending on the functional role of the landmark in that action, its geometry, and its position in the spatial

[3] The question whether a landmark is point–like or area–like is also often dependent on scale.

configuration of the surrounding environment, we associate an appropriate spatial relation with the landmark reflecting its conceptualization. These conceptualizations are identified by spatial terms (e.g., *before*, *after*, *at*, *in*, *around*, *along* as shown in Fig. 3 and 5) (cf. [9, 22]).

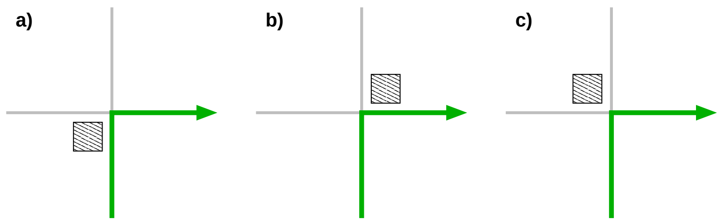

Fig. 3. a) Landmark located *before* the turning point, b) *after* the turning point, and c) not located at functional relevant branch (*at*).

We use this classification as basis to represent different types of landmarks in a system's internal, abstract data structure. This way, a landmark's function is already specified and we can constrain the final generation of instructions in order to adapt the directions to the users' requirements.

4 OpenLS

We use XML for Location Services (XLS), a XML based markup–language defined in the OpenLS specification, for defining a data structure capturing the classification of landmarks presented in the last section [17]. OpenLS describes the so called GeoMobility Server (GMS), an open platform for location-based services and its core services (directory service, gateway service, location utility service, presentation service, route service). It consists of a set of specifications of interfaces and (XML–)schemas, which define the access to the core services of such a server and the abstract data types used in the documents exchanged between server and client. OpenLS specifies primarily the interaction between client and server (request and response schemas) and the format in which the transfered data is encoded.

4.1 The Navigation Service

Additionally to the five core services, a sixth service, the Navigation Service, has been defined [1]. It is based on the Route Service and comprises the same functionality plus the option to provide the client with all information necessary to generate more elaborate route directions.

Answers to a navigation request do not contain complete route directions; instead the information necessary to generate them is transferred encoded in a special data structure defined by XLS. This then allows the client to produce route directions specific to its abilities. The data structure is supposed to capture the information after the fourth processing step as described in Section 2. Thus, our focus of research is on this part of the generation process of route directions. Accordingly, XLS was chosen as basis for specifying the data structure proposed in this article.

The OpenLS data structure basically consists of a sequence of instructions. Each instruction describes the action the traveller has to perform at a decision point combined with information on the next route segment. The data structure originally used in OpenLS Navigation does not allow to store all information that is needed to generate cognitive ergonomic route directions. For example, even though landmarks may be integrated in the instructions, this is only possible in a very simple and restricted way, which is insufficient to describe all possible functions of landmarks within route directions.

4.2 Landmarks in OpenLS

Landmarks play an important role in the navigation process of humans and are ominpresent in human generated route directions. Therefore, it would be desirable to integrate them in a standard such as OpenLS.

The data structure for route directions in OpenLS explicitly provides an attribute for describing a landmark within an instruction. Each direction can be enriched by an advisory, that can serve different purposes, among others also describing a landmark. The offered attributes allow providing the name of the landmark and its location along the route (left or right side of the route or on both sides). Other infromation about the landmark cannot be encoded, i.e. the available data types do not allow for encoding information about a landmark in an extent necessary for the cognitive ergonomic use of landmarks. Therefore, the integration of additional data types into XLS is necessary in order to provide all information required for the use of landmarks within route directions.

5 Extending OpenLS to include landmarks

Our work aims at extending the data structure of the Navigation Service with several features necessary for generating cognitive ergonomic route directions. We introduce encoding of angular turning information and of the spatial structure of an intersection in order to enable the generation of precise route directions (cf. [11]); we extend the original data types with respect to spatial chunking [10] and hierarchical structuring of route directions [13]; and we enable integration of landmarks based on our classification of landmarks (see Section 3). Therefore, large parts of the original data types are replaced by new elements regarding the functionality required to generate cognitive ergonomic route directions. In the following, we describe how this integration of landmarks is implemented.

5.1 Data type representing landmarks

All types of landmarks defined in our data structure are derived from an abstract parent type comprising all basic information about a landmark. With this basic parent type we can use the different types of landmarks in a polymorphic way, i.e. use any type of landmark at the same place in an instruction without the need of specifing which concrete type of landmark to use beforehand.

A landmark type specification captures all information needed to identify the particular object: its geographical position, the spatial relation to the relevant route element, and, if needed, specific information necessary for the type of landmark at hand. Based on the abstract parent type, all other types are developed according to the classification presented in Section 3. Figure 4 shows the class-tree of the types of landmarks used.

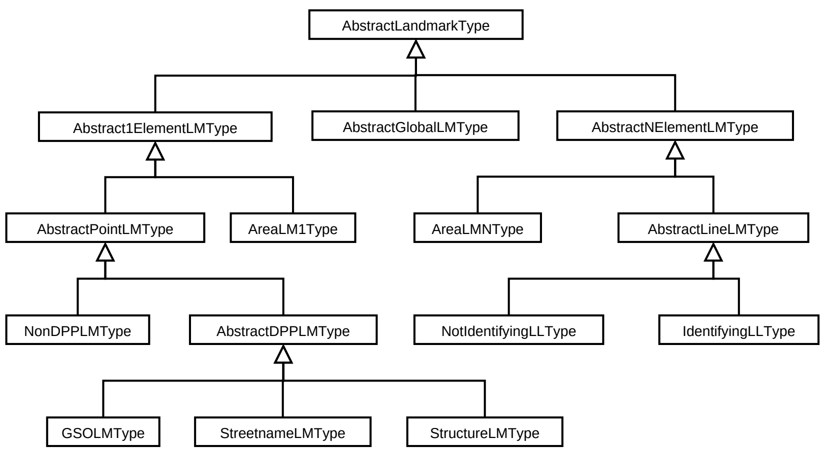

Fig. 4. Class diagram of landmarks defined in the OpenLS extension.

Abstract1ElementLMType
The category of landmarks related to a single element of the route is divided into two subcategories: point-landmarks and area–landmarks. The proposed data structure contains a class for the category *1 element* with two child–classes for the two subcategories.

AbstractPointLMType Landmarks of this type are categorised into landmarks located at a decision point and landmarks located at a route–segment. Since we distinguish three different kinds of salient objects, which all require a special and unique description to be used as a landmark at a decision point, again three sub–classes have to be defined.

StreetnameLMType Streets indentifiable by their names may function as landmarks to identify an intersection and to mark the further direction to take. The type *StreetnameLMType* indicates explicitly that a street is used as a landmark. Since the location of such a landmark is already defined by the street's position in the intersection's spatial configuration, a further spatial relation describing its location relative to the decision point is not necessary. In the route's specification, it is sufficient to indicate the street's appearance by its name and position.

StructureLMType Intersections can potentially be identified by their spatial structure. Salient intersections like roundabouts or T–intersections can be used as landmarks [12, 18]. Similar to streets functioning as landmarks, intersections require a specific description: a specification of the intersection's spatial configuration is usually sufficient for its identification. Our data structure supports the most salient categories of intersections (roundabouts, complex intersections, T– and fork–intersections). A further spatial relation does not need to be provided, since it describes the spatial struture of the decision point itself.

GSOLMType The appearance of general salient objects along a route needs to be specified by their position and the spatial relation used to describe their location relative to the route. This is required for generating an instruction referring to such an object.

Landmarks at a route segment (*NonDPPLMType*) do not require a further categorization in sub-classes. The provided information comprises a description, their geographic location, and the spatial relation used to refer to them.

AreaLM1Type This type of landmarks does not require a further division in sub–types and, therefore, the class representing this kind of landmarks has no child–classes. Since for this type no additional information is required, an object of this type contains only the common class–variables like geographic location and a landmark's description. The spatial relation used with these landmarks is always IN, which is not explicitely represented in the XLS definition of this class.

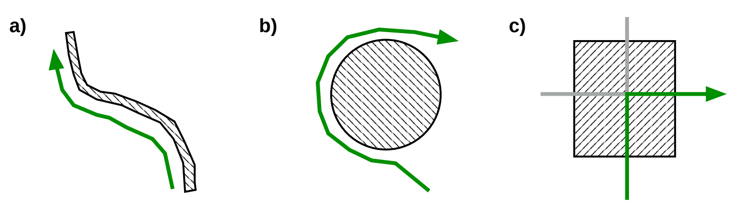

Fig. 5. a) A linear landmark located *along* the the route, b) *around* an areal landmark, and c) a decision point located *in* an areal landmark.

AbstractNElementLMType
Landmarks related to more than one route element are represented by the abstract class *AbstractNElementLMType*. Similar to the class *Abstract1Element-LMType* two child-classes for the two required sub-categories are introduced. *AbstractLineLMType* stores information on landmarks conceptualized as linear and *AreaLMNType* those conceptualized as area-like.

AbstractLineLMType landmarks are divided into two different sub–classes. One comprises all landmarks that themselves identify the point where the course of the route ceases following the landmark (*IdentifyingLLType*), and the other comprises all landmarks which require additional information in form of a point–like landmark to identify this point (*NotIdentifyingLLType*).

AreaLMNType landmarks are represented by a non-abstract class since there exists no further categorization which requires child–classes. The provided information is the same as for area-landmarks identifying a single decision point. Again, there is only one possible spatial relation (AROUND), which is implicitly represented with this type.

5.2 Integration of landmarks with other features of a route

As mentioned above, route directions encoded in the proposed data structure consist in its simplest form of a sequence of route elements. In OpenLS, these are termed *maneuvers*; they describe the required action at a decision point and the previous route segment. Extending this, route directions can contain higher-order route elements subsuming other route elements; this way structuring the instructions. All these elements (decision points, segments and chunks) may be related to landmarks. Additionally, n-Elements-landmarks can be combined with other landmarks, as well. Figure 6 shows the structure of an example route. This route consists of a start- and an end-maneuver (which is common to all routes), a chunk that subsumes three elementary maneuvers, and two additional elementary maneuvers. The segment of *Maneuver 1*, the decision point of *Maneuver 5* and the *Chunk* are all related to landmarks. The implementation of these relations and of other possible relations between route elements and landmarks are explained in the following.

Landmarks at. . .

. . . chunks Chunks combine several instructions for single decision points into one single higher–order route element comprising a sequence of several decision points (cf. [10, 4]). Landmarks often are the structuring element of chunks. This purpose can be served by either line-like or point-like landmarks. Therefore, each chunk can contain an element of the type *AbstractLineLMType* or *AbstractPointLMType*.

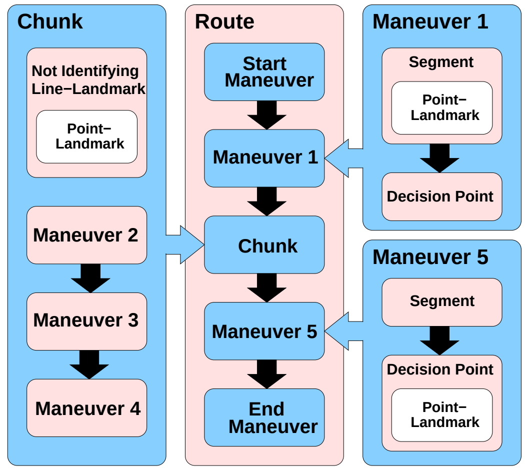

Fig. 6. Structure of an example route.

. . . linear landmarks In the context of chunking route directions it is distinguished between line–like landmarks that are sufficient to specify the end of a chunk or line–like landmarks that are not. The latter type of landmarks requires additional information, which can be given in form of another landmark. Therefore, n-Elments-landmarks of type *NotIdentifyingLLType* or *AreaLMNType* contain an additional element that specifies the decision point where the route stops following the landmark. This can be marked by an element of type *Abstract1ElementLMType*.

. . . segments Objects used as a landmark at route segments need to be of category 1-Element-landmark. Elements representing a segment can contain objects of the type *Abstract1ElementLMType*. In principle, the number of landmarks related to a segment is not limited. If a segment contains more than one landmark, the decsion which one is used in the instructions is made in step 3 of the generation process for route directions described in Section 2, and may depend on a user's needs and preferences.

. . . decision points Intersections may be identified by landmarks with a point–like or an area–like function. Therefore, objects representing an instruction at a decision point may contain landmark objects of the three according types (*StreetNameLMType*, *StructureLMType*, *GSOLMType*). The number of landmarks related to an instruction at an intersection is not constrained, since several objects salient enough to function as a landmark may be located at an intersection. The most appropriate needs to be identified in the rating step of the generation process (step 3).

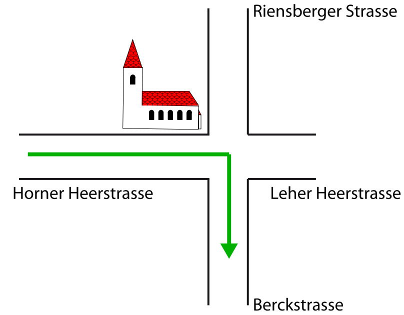

Fig. 7. Sketch of the spatial situation at the intersection used in the example.

Figure 7 shows an example of a decision point identified by a point–landmark—a church—where the traveller has to perform the action of "*turn right*". The XLS–code encoding the corresponding maneuver for this example is shown in Figure 8. It contains information about the route segment leading to the decision point and about the decision point itself, including the landmark. An intersection is represented by its geographic position and by the streets crossing at this point, which are identified by their names and their angle relative to current movement direction. The landmark located at the decision point is a church, which functions as a general salient object used as a point landmark. It is, therefore, represented by an element of type *GSOLMType*. Since the traveller has to turn right *after* she passed the church, the spatial relation used here is termed AFTER.

Based on this XLS–code an OpenLS-based client is able to generate a verbal instruction for this example that specifies the required action and uses the landmark to identify the intersection; for example, "turn right after the church". A pictorial representation, i.e., the sketch shown in 7, may also be reproduced with the provided information.

6 Conclusion and outlook

Landmarks are omnipresent in any route following and wayfinding activity. They are very important in structuring spatial knowledge and a prime means to link actions in wayfinding to the environment. They are widely used in route directions given by human beings; not using them in automatically generated route directions is a violation of cognitive ergonomics.

In this article, we propose a representation of landmarks that may be used by systems generating route directions. Underlying this representation is a taxonomy that classifies landmarks according to their function in route following and their conceptualized geometric properties. This taxonomy is reflected in a corresponding data structure that captures all information requrired to integrate landmarks in route directions. The data structure is based on the OGC

```
<xls:XManeuver xsi:type="xls:XManeuverType" actionType="
    Turn" id="mn1" directionOfTurn="Right" junctionType="
    Intersection" >
  <xls:ManeuverPoint>
    <gml:pos>14.0 4.0</gml:pos>
  </xls:ManeuverPoint>
  <xls:JunctionCategory xsi:type="
      xls:StandardIntersectionType" TurnDirection="right"
      >
       <xls:RouteBranch Streetname="Berckstrasse">
         <xls:Angle uom="degree">90</xls:Angle>
       </xls:RouteBranch>
       <xls:NoRouteBranch Streetname="Riensberger Strasse
           ">
         <xls:Angle uom="degree">270</xls:Angle>
       </xls:NoRouteBranch>
       <xls:NoRouteBranch Streetname="Leher Heerstrasse">
         <xls:Angle uom="degree">0</xls:Angle>
       </xls:NoRouteBranch>
  </xls:JunctionCategory>
  <xls:OneElementLandmark xsi:type="xls:GSOLMType" Name=
      "Horner Kirche" SpatialRelation="after" >
    <xls:Description xsi:type="
        xls:LMDescriptionExampleType"></xls:Description>
    <xls:PointPosition>
      <gml:pos>12.0 2.0</gml:pos>
    </xls:PointPosition>
  </xls:OneElementLandmark>
  <xls:PreviousSegment Streetname="Horner Heerstrasse">
    <xls:Distance value="10"></xls:Distance>
    <xls:TravelTime>P0Y0M0DT0H0M2.3S</xls:TravelTime>
    <xls:BoundingBox>
      <gml:pos>2.0 4.0</gml:pos>
      <gml:pos>14.0 4.0</gml:pos>
    </xls:BoundingBox>
  </xls:PreviousSegment>
</xls:XManeuver>
```

Fig. 8. Specification of the maneuver depicted in Fig. 7.

OpenLS standard and provides a XML-based specification of actions to be performed in route following along with the structure these actions are performed in. This integration of landmarks in a well-defined standard that specifies route information independent from a concrete implementation or underlying data set is a well-suited brace between different approaches to deal with landmarks automatically. Hence, our approach closes the gap between approaches mining landmarks in data sets on the one hand and approaches employing landmarks in the automatic generation of route directions on the other hand. Furthermore, the function of landmarks is defined on the abstract, internal system's level. Thus, we can easily constrain their usage in an externalization presented to a user such that the instructions adapt to the users' requirements.

There are some desirable extensions left for future work. For example, landmarks used for orientating the traveller at the beginning of a route and for identifying the destination of a route require additional information (cf. [19]), which is not yet sufficiently covered by the proposed data structure. To easily and reliably identify the objects used as visual landmarks, a description of those features determining the saliency of the landmark has to be provided. While the data types already offer means to store information for this purpose, determining exactly which information to store and how to organize it is an open question.

Other aspects of cognitive ergonomic route directions have to be regarded in the data structure, as well. We are currently finishing methods to perform chunking, i.e. subsuming instructions for several decision points into a single instruction (cf. [10, 4]) on the proposed data structure. This allows a more ergonomic, human-like structuring of route directions. Reducing the underspecification of cognitive situation models [31] (as instantiated by verbal route directions) by naming the spatial structures in which actions are embedded is an ongoing research effort.

Finally, our approach may be extended to include aspects of personalized route directions. This step would allow to regard a user's personal preferences (e.g., mode of presentation or familiarity with the environment) into the generation process, and, thus, to produce route directions that are truly adequate for an individual person.

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