Automated Enrichment of Routing Instructions

Oskar Wage
Leibniz Universität Hannover/Institute of Cartography and Geoinformatics
Appelstraße 9a
Hannover, Germany
wage@ikg.uni-hannover.de

Udo Feuerhake
Leibniz Universität Hannover/Institute of Cartography and Geoinformatics
Appelstraße 9a
Hannover, Germany
feuerhake@ikg.uni-hannover.de

Monika Sester
Leibniz Universität Hannover/Institute of Cartography and Geoinformatics
Appelstraße 9a
Hannover, Germany
sester@ikg.uni-hannover.de

Abstract

Commonly used navigation instructions are based on metric turn descriptions (e.g. “turn left onto Nienburger Straße in 100 m”). For the user it is easy to follow the route, but later it is typically hard to remember how s/he got there. Orientation is based on remarkable objects or locations called landmarks. They are then linked and combined to so-called survey knowledge in the psychological model of a cognitive map. Some of today’s navigation systems also contain landmarks – they are, however, only used at decision points of the route. The goal of this research is to enhance the user's own sense of orientation by enriching common routing instructions with relational hints to landmarks.

First, potential landmark objects are defined, extracted from OpenStreetMap and assigned an importance weight. The landmarks are then used to enrich the given routes: In the enrichment process, the influence of the landmarks is modeled as a decline of the weight by distance. Afterwards the most influential landmark is selected for each route segment. The 9-Intersection-Model and an adapted Direction-Relation-Matrix are the core methods that are used to analyse and determine the relations between the route and the chosen landmarks.

The automatic description of relevant landmarks along a route is implemented as an interactive web-map. The main goal of this paper is the development of the system. Still, a first evaluation was conducted, in order to test the users’ ability of orientation after using enriched instructions compared to users using the classic ones.

Keywords: routing, cognitive map, landmark, orientation, navigation

1 Introduction

Today’s navigation systems commonly provide routing instructions in terms of turn-by-turn actions. They usually consist of a direction to move in a certain distance. As mentioned in Sester & Dalyot (2015), it is easy for the user to follow the given sequence of instructions, even in an unknown environment. Nevertheless, it is hard to remember later how s/he reached the destination. Thus, the user will have to rely on the support of a navigation system also on future rides through a previously visited region. Münzer et al. (2006) showed that passively following navigation instructions leads to a deteriorated spatial survey knowledge of the environment. Human communication of spatial information is done by describing names and relations of known objects. The mental representation of space is based on memorable places or objects, called landmarks. There is no unified definition of landmarks in the literature, but based on Lynch (1960), this term is commonly used for objects or places which have a singular characteristic (e.g. visual or functional) in their neighborhood. They are categorized roughly into local and global landmarks, depending on their sphere of influence (see Sorrows & Hirtle, 1999).

The combination of multiple landmarks to form a cognitive map, first mentioned in Tolman (1948), allows to navigate without external tools and to discuss e.g. meeting points with other people. Gärling, Böök & Lindberg (1984) describe the human spatial long-term memory as a cognitive map, which is represented as a graph structure. The landmarks can be understood as nodes, connected by known routes and actions between them. For that reason, the overall importance of landmarks as anchor points in spatial cognition is clear. However, common navigation systems do not explicitly support the training of their user’s cognitive map. Even if in current systems also landmarks are getting popular, they are mainly used at decision points to ensure the user to be still on track – not for forming a mental map. Accordingly, this work’s aim is to develop an automatic enrichment process for routing instructions by landmark hints.

There is a rich literature dealing with the use of landmarks for navigation. E.g. using landmarks for the improvement of the orientation during the navigation process as in Raubal & Winter (2002). They include visually significant landmarks at decision points to improve the user’s certainty in difficult situations.

This research, in contrast, aims at medium- and long-acting improvements of the user’s cognitive map by providing dedicated hints to landmarks and by observing the latter from different perspectives. So objects with merely local influence will mostly be neglected and only those with a micro-regional to global relevance are used.

Sester & Dalyot (2015) give an overview of possible concepts for designing spatial operators describing relative relations of objects in the context of a route and landmarks.

This work focuses on qualifying the relation of surrounding landmarks to a route, but not selecting and scoring them, as done in Schwering, Li & Anacta (2013) or Tezuka et al. (2004).

2 Analysis of Spatial Relations

The core task of describing a landmark's position from a driver's perspective is to analyze and categorize the spatial relation between a line string (route geometry) and a polygon (landmark object), as in our approach, even point landmarks are assigned a minimum extent. Peuquet and Ci-Xiang (1987) present a concept to detect whether a target object is on the left or right side of a reference object. In our context, more detailed and comprehensive possibilities for describing relations is desirable, thus, in the following sections will introduce two fundamental concepts to describe the relevant relationships.

2.1 Topological: 9-Intersection-Model

The topology of two geometric objects describes their spatial connection.

$$R(A,B) = \begin{bmatrix} A^\circ \cap B^\circ & A^\circ \cap \partial B & A^\circ \cap B^- \\ \partial A \cap B^\circ & \partial A \cap \partial B & \partial A \cap B^- \\ A^- \cap B^\circ & A^- \cap \partial B & A^- \cap B^- \end{bmatrix} \quad (1)$$

Introduced by Egenhofer & Herring (1990), the 9-Intersection-Model is the most common concept of topologic two dimensional relation analysis in GIS. It looks at the two input geometries separated into their exterior, boundary and interior. These sets are intersected and the nine resulting intersections are inspected and structured according to equation (1). This way different geometric primitives can be processed equally, by only taking their different dimensions and resulting definitions of boundary and interior into account.

2.2 Directional: Direction-Relation-Matrix

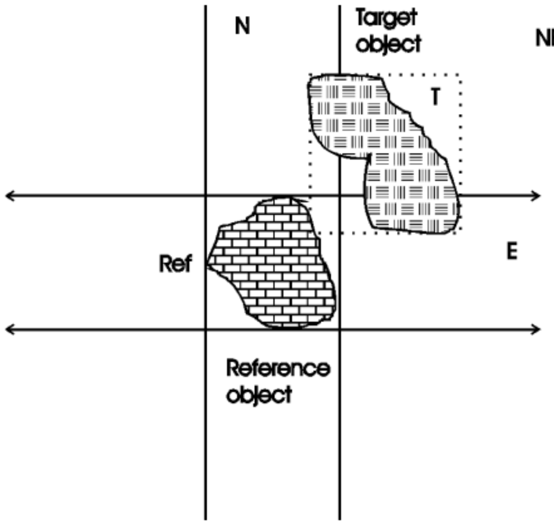
In figure 1 the Direction-Relation-Matrix's concept, published by Goyal & Egenhofer (1997), is visualized. Similar to the 9-Intersection-Matrix, it interprets two planar geometries, but in this case in regard to their direction relation.

The center object is considered as reference. It defines a grid frame by its minimum bounding box with extended edges (in direction of the coordinate axes).

$$DRM(Ref,T) = \begin{bmatrix} 0 & 0.1 & 0.65 \\ 0 & 0 & 0.25 \\ 0 & 0 & 0 \end{bmatrix} \quad (2)$$

Each of the resulting cells defines a cardinal direction in relation to the reference object. The second (target) object is checked for intersections with these cells. The results are organized in a binary 3x3 matrix. For a more detailed description of the object configuration, the areas of the intersection are set in relation to the object's total extent. By this, not only the fact that there is an intersection is registered, but also its relative size. As an example, the resulting matrix

Figure 1: Setup of the Direction Relation Matrix.



Source: Goyal & Egenhofer (1997)

from figure 1 is given in equation (2). It demonstrates a gain of information to determine the targets main area in northeast.

3 Enrichment Process

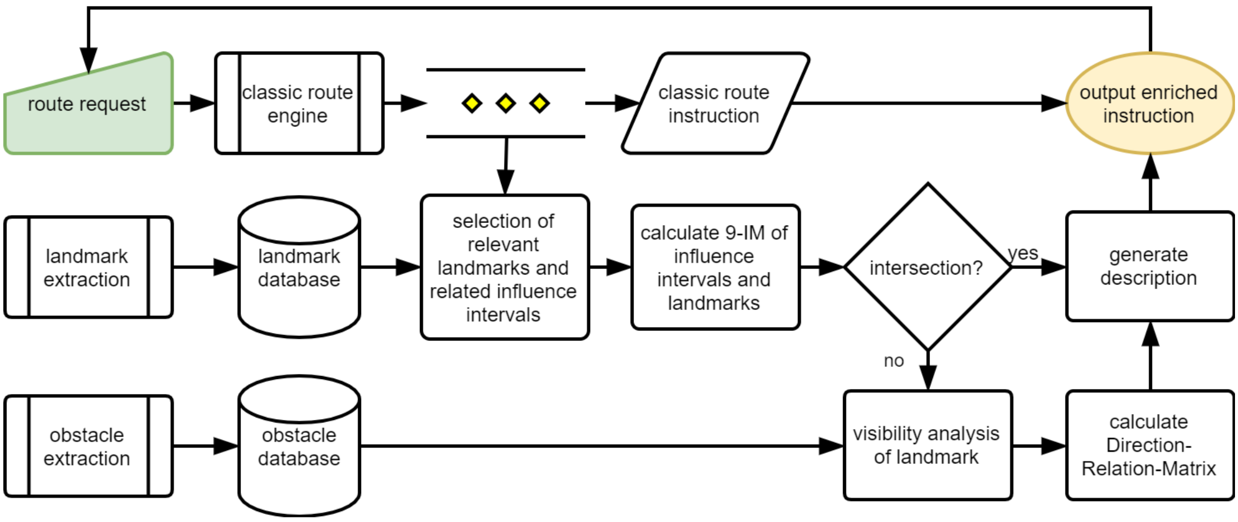
Figure 2 shows the flow diagram of the whole enrichment process. As a first step, a pool of possible landmarks needs to be prepared. In addition, important regions, such as administrative districts (like state, town and city-district) are extracted from OpenStreetMap[1]. Subsequently, the interesting landmarks (based on given criteria) can be selected for a requested route. Only the spatial relation of these relative to the route needs to be analyzed and described. Thus, the resulting route description consists of a sequence of describing elements of important objects relative to the route. In addition, an overall route summary is generated, to provide the user a general introduction of the route in the beginning.

3.1 Data Preparation

As the focus of this work is not on mining and rating landmarks, a simple test set for the city of Hanover was extracted from OpenStreetMap. Based on assigned tags, common objects in the public urban space like churches, parks, sport stadiums, lakes, forests, train/tram stations and

[1] https://openstreetmap.org

Figure 2: Flow diagram of the enrichment process.



rivers were used. These objects were assigned an empirically determined weight according to these categories, e.g. churches get a high value, bus stops a low one.

To enable a simplified check of the landmarks' visibility from the current user's position, built-up areas are identified in OpenStreetMap by the *building* tag. Independent from their height, the resulting geometries are assumed to block the direct view on the landmarks and are stored for a later visibility analysis.

3.2 Identification of Relevant Landmarks

In case of a route request, the first step is to select relevant landmarks. This is done by modeling the stored landmark ratings depending on their distance to the route's geometry. For this, equation (3) was developed as model of a landmark's aura (modeled influence of a landmark in a certain distance), similar to Arampatzis et al. (2006). Given the weight ω, the aura decreases exponentially by the distance d and a decay factor f (a value of 100 is used for our experiments).

$$aura = \omega \cdot \exp\left(\frac{-d}{f}\right) \tag{3}$$

In this way, a natural representation of the landmark influence behavior is generated, balancing rank and distance. For instance, a very dominant object in a larger distance, e.g. a famous church, can have a higher aura than a close bus stop.

A route consists of several line segments. For each of them the auras of the surrounding landmarks are determined and the landmark with the highest influence at the individual segments are selected.

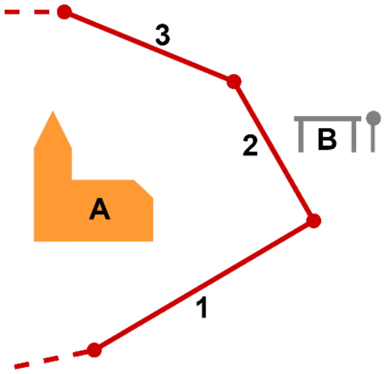
3.3 Analysis and Decription of Spatial Relations

Several subsequent segments can be assigned the same landmark. In order to avoid a repetition of mentioning the same landmark, segments with the same landmarks are aggregated from the first appearance to the last. In the example of figure 3 a set of route segments and landmarks are sketched. Imagine landmark A as a strong weighted church and B as a low weighted bus stop. The church has the biggest aura at segments 1 and 3, but at segment 2 the bus stop might reach the largest aura, due to its closeness. As a result, the church would be assigned to all three segments as aggregated interval and the bus stop to segment 2 for further processing.

In the next step, each of the landmark geometries is projected to their interval. To ensure a natural behavior, also for complex shapes, the projection is not done directly by the shortest distance. The corner points of the landmark's minimal enclosing rectangle are projected to their closest point on the landmark's convex hull. The resulting four points are transferred to the closest ones one the landmark's interest interval of the route. This ensures a limited range of interest, even for geometrically extended landmarks. Otherwise, a long river would reach an interval over the complete route, although it has only a high aura at a crossing point.

To appropriately link route and corresponding landmark and create the hint, the relation between the resulting influence

Figure 3: Sketch of route segments and surrounding landmarks for explanation of influence aggregation.



intervals and their landmarks is analyzed. It starts by inspecting the topology based on the 9-Intersection-Matrix using the route influence interval and the landmark polygon as input. The first element of the intersection matrix element (1,1) is used to check if there is an intersection at all. In case of a false, the process continues with the visibility check, which is described in the following paragraph. If there is an intersection of the interior of the two geometries, element (1,2) is used to check if the interval starts and ends inside the polygon. If there also is no intersection with the polygon borders (element (2,2)), the interval is inside or above the landmark. Otherwise, it has to enter, leave or cross the landmark. Depending on the type of the landmark (e.g. forest, subway station or lake) the proper relation is determined (e.g. "over" or "through").

For non-intersecting objects, a simplified visibility analysis checks whether the landmark is visible from the corresponding point on the route. A single line of sight is enough for a positive feedback.

If there is no topologic intersection, the goal is to identify a relative direction. This is determined by a modified Direction-Relation-Matrix. The modifications consists of aligning the object w.r.t. to the start and the end of the interval, instead of south to north. This leads to a direction analysis relative to the user's route. The resulting matrix is first checked for a single outstanding element. If the maximum value is at least 0.5 higher than the second highest, its cell is assumed as main direction. The following list shows the patterns of the matrix together with verbal descriptions of the landmark position:

 Over there on the left is (*) the *landmark*.
 Straight ahead is (*) the *landmark*.
 Over there on the right is (*) the *landmark*.
 Left hand is (*) the *landmark*.
 You are passing the *landmark* (*).
 Right hand is (*) the *landmark*.
 In the left back is (*) the *landmark*.
 In the back is (*) the *landmark*.
 In the right back is (*) the *landmark*.

If there is no significant cell, the best fitting template from the following set is chosen:

 In the front is (*) the *landmark*.
 In the back is (*) the *landmark*.
 You are moving along the *landmark* (*) on the right.
 You are moving along the *landmark* (*) on the left.
 You are moving around the *landmark* (*) on the left.
 You are moving around the *landmark* (*) on the right.
 You are moving through the (*) *landmark*.

Each of these binary templates is multiplied elementwise with the Direction-Relation-Matrix and summed up. The template with highest sum is selected. In the text patterns *landmark* is replaced by its name.

In addition to the topologic and directional relations, also visibility is used as additional characteristic. The building data from OpenStreetMap is used to detect, if there might be obstructing objects in front of landmarks. In such a case, a *hidden* is included at (*), if the view on the landmark is blocked.

3.4 Route Summary

In addition to the route hints, a summary is generated to be presented at the start of a routing procedure. It consists of highlighting the most important and global landmarks along the route and describing its general course. The first one is done by selecting the landmark with highest aura and highest rank of the whole route. The second one is gained by extracting the routes main cardinal direction. Additionally, the administrative areas, passed by the route, are analyzed. All this information is used to create a text block.

4 Implementation and Evaluation

The previously introduced concept has been implemented as a web-map to give a practical impression of its behavior. Further, the generated results are used to perform an evaluation of the output.

4.1 Implementation

A prototype for the evaluation of the enrichment process has been implemented as a web-map based on the following common technologies: a PostgreSQL[2] database system with PostGIS[3] (extension with spatial geometries and functions) is used for data processing and storing, the well-known Leaflet[4] library as map framework. The Graphhopper[5] Routing API serves as classic routing engine and provides the route geometry between origin and destination together with the classic instructions.

4.2 Results

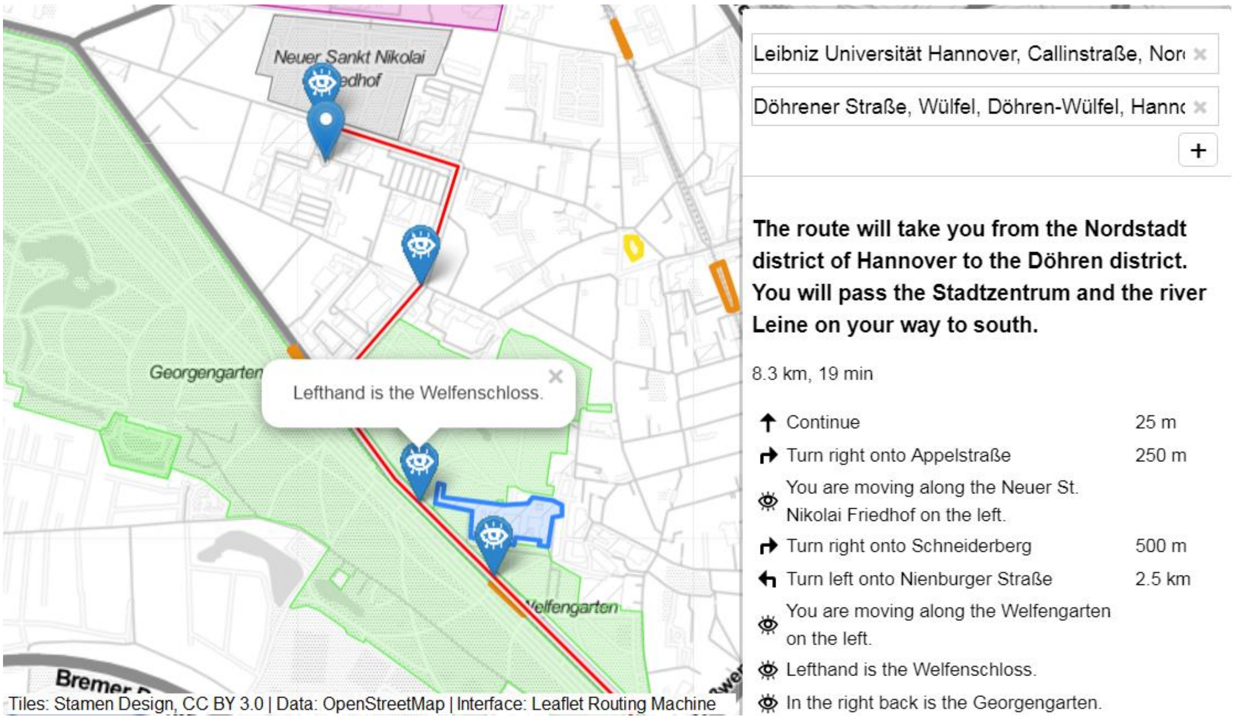
Figure 4 shows the result of the fully automatic process of routing enrichment. The textual description consists of the normal instructions from the Routing API ("continue", "turn right"), enriched by the new landmark hints created along the route. They are marked with an eye-symbol, which is also presented in the visual interface. The route summary gives the general context concerning the city districts of starting and end point, as well as the main landmarks passed by, namely the city center ("Stadtzentrum") and the river Leine.

4.3 Evaluation

A first evaluation was conducted to investigate if users, who get an enriched route description, will be able to find their way back more efficient than with classic turn-by-turn

[2] https://www.postgresql.org
[3] https://postgis.net
[4] http://leafletjs.com
[5] https://graphhopper.com/api/1/docs/routing/

Figure 4: Implemented web-interface to present enriched routing instructions like in common tools.



instructions. Since a test to determine the improvements in orientation in a real environment is difficult, it was investigated in a simulation, in some way similar to the test in Burnett & Lee (2005). Real, about 2 km long routes were chosen in an urban area of Hamburg, which was unknown to all candidates. The basic idea is to compare the needed distance of candidates to "walk" the previously shown route virtually back in Google Streetview[6]. The routes included a small detour, so candidates with an acquired overview knowledge are able to shorten it. A reference group was shown videos with classic turn-by-turn instructions, whereas the test group's videos were augmented with enriched instructions. The candidates' age varied between 21 and 55 years. Each group (test and reference) consisted of five candidates with a similar gender and age distribution. The test group chose on average 14-17 % shorter tracks than the reference group. By this, it can be concluded an improvement of route awareness through enriched navigation instructions, even on the first run.

5 Conclusion and Outlook

This work investigated possibilities of automatically enriching routing instructions in order to support the creation of a mental map of the environment. An automatic process to augment classic navigation instructions by hints to nearby landmarks was successfully developed and tested.

The usage of the 9-Intersection- and Direction-Relation-Matrix concepts showed up as very generic, allowing very natural relation descriptions. The evaluation of generated descriptions confirmed the basic assumption of a positive influence of the users' orientation.

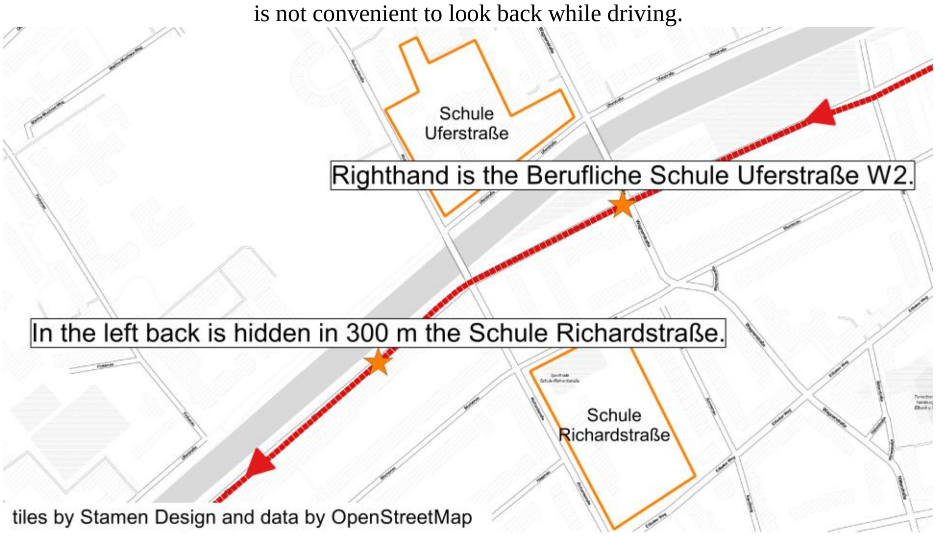
This proof of concept shows the potential of the approach. In order to turn it into a professional navigation application, there are several options for future work. Firstly, the definition of the set of rich and meaningful landmarks and their weights should be refined.

Furthermore, in the current version, there are sometimes ambiguous instructions at turns, as well as hints to landmarks in the back (see figure 5), which users tend to experience as disturbing. An optimization process for optimally placing the instructions would help to avoid these deficiencies. For this, it would have to score different positions within the area of influence and select the best one. As described, the visibility check is very simple, and requires a more refined calculation – also possibly taking a 3D model into account. In general, user tests have to investigate in detail the role of invisible ("hidden") landmarks, which also include landmarks in the back, which the user has not perceived while passing by.

User profiles might be introduced, to allow personalized selections of landmarks and descriptions, by responding to user experiences and preferences, assuming that users might memorize such instructions more easily. Finally, routes could be varied slightly depending on previously traveled ones in order to create a more complete "mental picture".

[6] https://www.google.com/streetview

Figure 5: Example snipped from route with driving direction from top-right to bottom-left. The star icons mark positions of landmark hints. The hint to Schule Uferstraße is to the right and in front, thus fits well. The other one to Schule Richardstraße ("In the left back is hidden in 300 m the Schule Richardstraße.") was considered as not helpful by the test candidates, because it is not convenient to look back while driving.



References

Arampatzis, A., van Kreveld, M., Reinbacher, I., Jones, C. B., Vaid, S., Clough, P., Joho, H. & Sanderson. M. (2006). Web-based delineation of imprecise regions. In: *Computers, Environment and Urban Systems*, 30(4), 436–459.

Burnett, G. E. & Lee, K. (2005). The Effect of Vehicle Navigation Systems on the Formation of Cognitive Maps. In: *International conference of traffic and transport psychology*, p. 407-418.

Egenhofer, M. J. & Herring, J. (1990). Categorizing Binary Topological Relations between Regions, Lines, and Points in Geographic Databases. In: *Santa Barbara CA National Center for Geographic Information and Analysis Technical Report*, p. 94 ff.

Gärling, T., Böök, A. & Lindberg, E. (1984). Cognitive mapping of large-scale environments: The interrelationship of action plans, acquisition, and orientation. *Environment and behavior*, 16(1), 3-34.

Goyal, R. K. & Egenhofer, M. J. (1997). The Direction-Relation Matrix: A Representation for Directions Relations Between Extended Spatial Objects. In: *the annual assembly and the summer retreat of University Consortium for Geographic Information Systems Science 3*, pp. 95–102.

Lynch, K. (1960). The image of the city. The Technology Press & Harvard University Press, Cambridge.

Münzer, S., Zimmer, H. D., Schwalm, M., Baus, J. & Aslan, I. (2006). Computer-assisted navigation assistance and the acquisition of route and survey knowledge. *Journal of Environmental Psychology 26(4)*, pp. 300-308.

Peuquet, D. J. & Ci-Xiang, Z. (1987). An Algorithm to Determine the Directional Relationship between Arbitrarily-Shaped Polygons in the Plane. In: *Pattern Recognition 20*, No. 1, pp. 65–74.

Raubal, M. & Winter, S. (2002). Enriching Wayfinding Instructions with Local Landmarks. In: *International Conference on Geographic Information Science* Springer, pp. 243–259.

Schwering, A., Li, R. & Anacta, V. J. A. (2013). Orientation Information in Different Forms of Route Instructions. In: *Short Paper Proceedings of the 16th AGILE Conference on Geographic Information Science*, Leuven, Belgium.

Sester, M. & Dalyot, S. (2015). Enriching Navigation Instructions to Support the Formation of Mental Maps. In: *Advances in Spatial Data Handling and Analysis*. Springer, pp. 15–33.

Sorrows, M. E. & Hirtle, S. C. (1999). The Nature of Landmarks for Real and Electronic Spaces. In: *International Conference on Spatial Information Theory*, pp. 37-50, Springer, Berlin, Heidelberg.

Tezuka, T., Yokota, Y., Iwaihara, M. & Tana-Ka, K. (2004). Extraction of Cognitively-Significant Place Names and Regions from Web-Based Physical Proximity Co-occurrences. In: *International Conference on Web Information Systems Engineering.* Springer, Berlin, Heidelberg, pp. 113–124.

Tolman, E. C. (1948). Cognitive maps in rats and men. *Psychological review*, 55(4), 189.