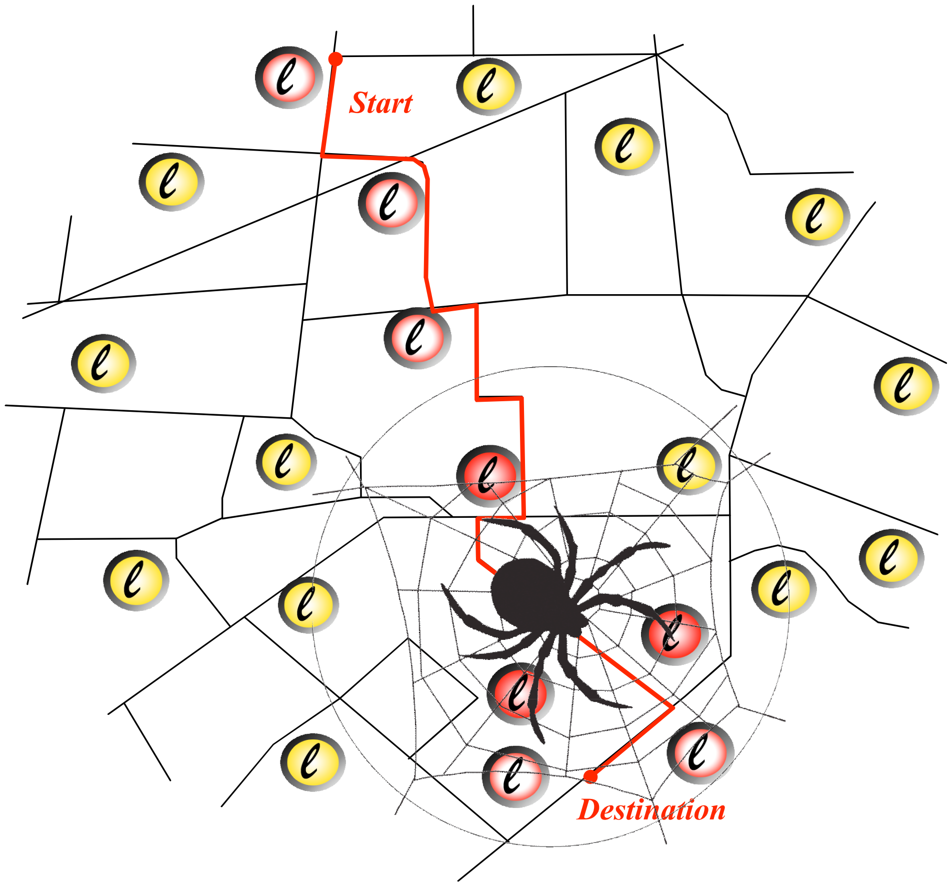


The Landmark Spider: Weaving the Landmark Web

David Caduff, University of Zurich
Sabine Timpf, University of Zurich

Conference paper STRC 2005

STRC **5th Swiss Transport Research Conference**
Monte Verità / Ascona, March 9-11, 2005

The Landmark Spider: Weaving the Landmark Web

David Caduff
University of Zurich
Zurich

Phone: +41 1 635 52 55
Fax: +41 1 635 68 48
email: caduff@geo.unizh.ch

Sabine Timpf
University of Zurich
Zurich

Phone: +41 1 635 51 52
Fax: +41 1 635 68 48
email: timpf@geo.unizh.ch

March 2005

Abstract

Mobile navigation systems are important assets for travelers visiting foreign environments, as they provide instructions on how to find the way to get to a chosen destination. Research has shown that finding ones way in a foreign environment is primarily based on cues in the environment. In this paper, we propose an algorithm that generates the clearest route in terms of spatial references and use the selected landmarks to describe the route. Wayfinding is dynamic in nature and as wayfinders move along, the cues used as reference points change, hence, raising the need for route generation methods that account for motion. Our model generalizes this dynamic task and selects spatial cues based on distance and orientation of the navigator with respect to the landmark, and the salience of spatial objects. The results of this process are represented in a spatio-analogical fashion, which diagrammatically supports wayfinding decisions.

Keywords

Navigation – Wayfinding – Landmark – Clearest Path

1. The Generation of Route Descriptions

Landmarks play an important role when humans navigate through foreign environments (Lynch, 1960; May, Ross, Bayer, & Tarkiainen, 2003). For example, trying to find the way is much easier if the navigator can rely on a description of the route based on well-recognizable objects in the environment, instead of navigating solely on the basis of street names and metric directions (Tom & Denis, 2003). Landmark-based navigation applies knowledge about prominent objects in the environment to guide travelers through foreign environments (Hampe & Elias, 2004; Lee, Tappe, & Klippel, 2002). Therefore, collecting and incorporating landmarks along a route is a crucial task of navigation systems that aim at providing efficient and reliable route instructions. Several proposals have been made on how to automatically extract landmarks from data sets and how such landmarks could be used to enhance wayfinding instructions (Elias, 2003; Nothegger, 2003; Raubal & Winter, 2002). So far, however, the question what routes offer the clearest cues and how to integrate these cues in the route generation process is only poorly understood. We define a cognitive model that assesses the relevance of significant spatial objects based on their features (i.e., saliency), and from a traveler’s perspective (i.e. heading, distance). The model assesses the relevance of landmarks at each node along the route with respect to the traveler, includes the selected landmarks in the route generation process, and dynamically weaves a web of landmarks along the route. These computation forms the basis on which a diagrammatic representation of the route is produced. We will term this model the Landmark Spider.

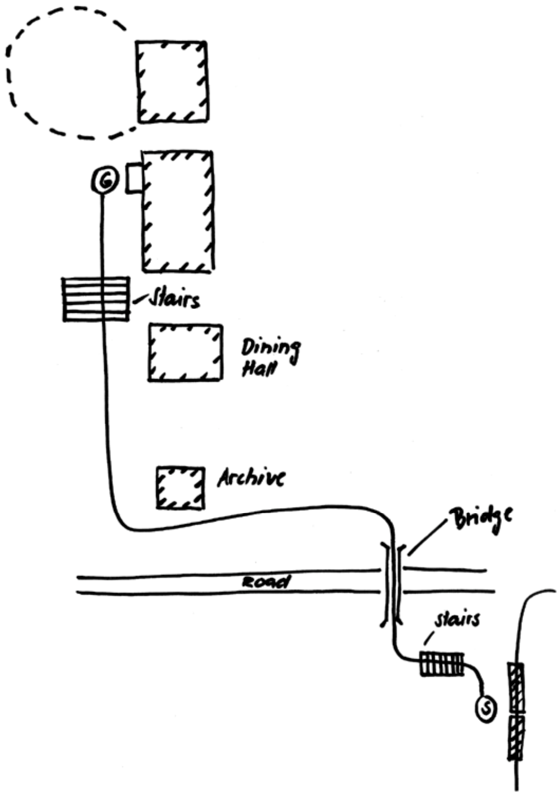
2. Landmark-based Navigation

Cognitive research has shown that the clarity of route instructions may be as important in navigational tasks as the overall length of the route. Streeter and co-authors found that human navigators were prepared to take suboptimal routes in terms of travel time, if these routes were potentially easier to describe and to follow (Streeter & Vitello, 1986; Streeter, Vitello, & Wonsiewicz, 1985). Landmarks are important elements in route instructions as they support clarity of a specific route and therefore ensure efficient and reliable navigation (Denis, Pazzaglia, Cornoldi, & Bertolo, 1999). So far, the typical approach to incorporate landmarks in route descriptions has been to enrich referential route representations with information about landmarks (Denis et al., 1999; Elias, 2003; Nothegger, 2003; Raubal & Winter, 2002; Redish & Touretzky, 1995). Our approach is different in that it uses a subset of all available landmarks, which are most prominent and easy to find, to determine the clearest route. The introduction of landmarks in the route generation process is advantageous, since it enables us to avoid areas of low landmark density and ensures consistent access to landmark information along the complete route.

2.1 Diagrammatic Route Description

Visual representations with overlay of diagrammatic elements are ubiquitous in decision-making (Casakin, Barkowsky, Klippel, & Freksa, 2000; Hegarty, Haarslev, & Narayanan, 2002). For instance, in location-based tasks, information services represent instructions about intended movements and plans, and monitor the progress of action on maps that contain terrain and other relevant information. In many contexts, as for instance in the military, diagrams are deemed so important that manuals have standardized the elements of such representations. Diagrams are often overlaid on top of maps, and they indicate, using a combination of iconic and spatially veridical elements, information such as movements of cars, locations and identities of business units, regions of traffic, points of interest, and so on (Hernandez & Zimmermann, 1993; Werner, 2002). Diagrams abstract away details that are not essential to a reasoning task and highlight those that are, and by means of symbolic elements (such as attached labels and iconic diagrammatic elements), they point to relevant pieces of conceptual information. Figure 1 shows an example of a route sketch as could have been supplied to a tourist asking for directions. The route sketch abstracts the reality in such a way that important cues are preserved and yet the directions are easily understandable and easy to follow.

Figure 1 Example of a route sketch



The whole process is so natural that we often fail to appreciate the complexity of the cognitive activities involved. Nevertheless, understanding and formalizing the perceptual and conceptual processes involved in such apparently effortless reasoning is necessary if we wish to provide effective navigation instructions. Intelligent computer support that, among other things, relieves the traveler by highlighting upcoming cues, attempts to infer the best reference points based on existent route knowledge, and presents the results in such a way that salient information visually stands out, can greatly enhance the usability, reliability, and efficiency of route descriptions.

We attempt to enhance navigation as we exploit the benefits of diagrams for landmark-based navigation. Our goal is to computationally reproduce route descriptions as produced by 'experts' (Figure 1) by assessing the relevance of spatial objects along a route and by considering the traveler's movement. Assessing the relevance of landmarks results in a set of objects by which the route will be described. The result of this process is represented in a spatio-analogical fashion, which diagrammatically supports wayfinding decisions navigators may have to take along the way. Highlighting what landmarks are relevant at each point along a route relieves the cognitive load put on the navigator, and hence, assists in efficiently finding the way.

3. A Framework for Landmark Deduction

In landmark-based navigation, the schematization of landmark knowledge is important for reducing the cognitive effort put on navigators when trying to find a destination. Freksa (1999) has proposed that an appropriate representation tool should include the following processes: 1) identifying and selecting relevant aspects from the physical environment, 2) choosing an appropriate structure for the inferences to be made between the represented world and the representing world, and 3) interpreting the results of the inferences.

In the following sections, we present a framework based on these three processes, which sets the base for deducing relevant landmarks, integrating them in the route generation, and presenting them appropriately. It is to be noted that the main focus of this work is on the integration of landmarks in the route generation process, rather than extracting landmarks from databases. Therefore, we assume that a set of potential landmarks is specified in the area of interest and that positional information and saliencies are known.

3.1 Landmark Support

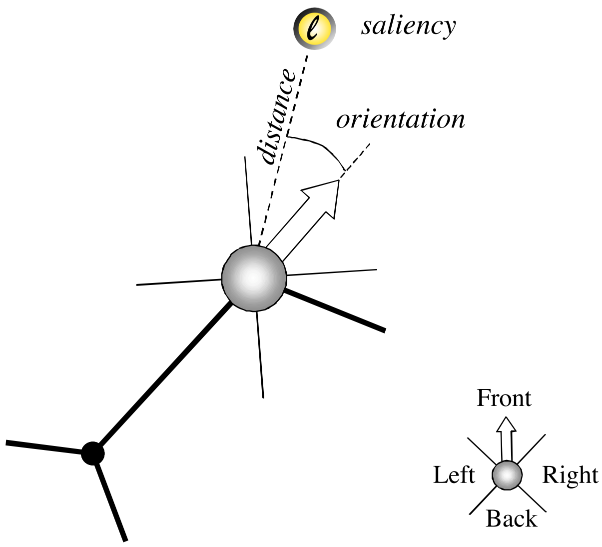
Landmark-based navigation relies on the presence of landmarks at each point along the route where navigators might need assistance. According to Michon and Denis (2001), the three most important reasons why landmarks are required during navigation are: 1) signaling where an action should be executed, 2) creating the link to the next section of the route, and 3) reassuring navigators that they are still on track. These reasons are applied at specific locations along the way, and hence, can be mapped onto any network graph representing routes navigators may take.

Signaling where an action should be taken occurs at places where three or more edges meet. This is typically the case at decision points, with the exception of turning around. Turning around may happen along any given edge, but for the purpose of this study, we neglect this case and assume that any decision taken by the navigator is correct and no turning around is required. Hence, each node needs to have a landmark associated with it. The ideal case would be two connected nodes, where each node is associated with a salient landmark, and the configuration of the landmarks is such, that each is visible from any position along the connecting edge. Typically, however, as travelers move along, one landmark eventually gets out of sight and a gap in terms of spatial reference points results. Therefore, we take for granted that the edge (i.e. the channel that connects two nodes) functions as a sufficient lead for guiding the navigator to the according node. Hence, no landmark information is required along the edge.

3.2 Distance and Orientation

The selection of landmarks that are relevant at nodes along the route is based on the spatial configuration of traveler and landmarks. The Landmark Spider analyzes the binary relation defined by the navigator and each landmark at decision points. This relation is defined by the traveler's position and orientation with respect to the landmark. Landmark objects exist in many shapes and variations. For the sake of simplicity, however, we reduce landmarks to point-like objects. As a result of this abstraction, the relation between navigator and landmark consists of two components, which are distance and orientation, as illustrated in figure 2.

Figure 2 Binary relation between navigator and landmark at decision point



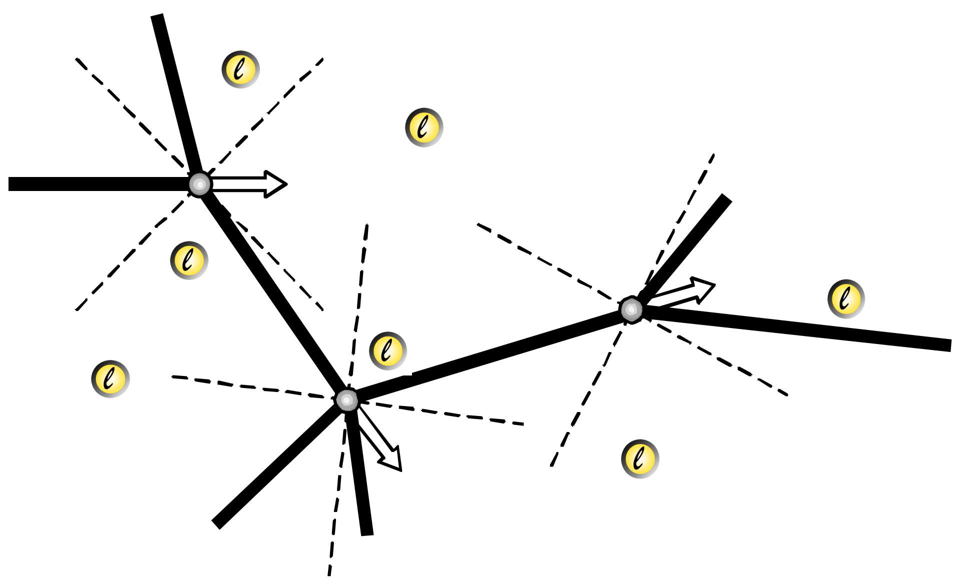
The relative distance between the navigator and the landmark is an important measure as to whether a landmark is to be considered for route generation. Research on landmark configurations for wayfinding has shown that close landmarks are better suited as spatial reference than distant landmarks (Waller, Loomis, Golledge, & Beall, 2000). Orientation is included due to the fact that traveling is a directed process. Hence, the orientation of a landmark with respect to the navigator is important when referring to landmarks (Steck & Mallot, 1997; Wang & Spelke, 2000). Previous research has shown that the orientation of the traveler is dependent on the path traveled. Specifically, the direction of the head, and hence, the field of view, is aligned with the path traveled (Hollands, Patla, & Vickers, 2002). As a result, landmarks that are located in the front of the traveler are more likely to be used as reference than landmarks located in the traveler's back (Zimmermann & Freksa, 1996). To reflect this in our model, we divide the field of view into sections (i.e., front, back, left and right) and assign each section a value that reflects the likeliness that landmarks in the specific sections will be used as navigational cues.

4. Landmark-based Route Generation

The computation of the clearest route is based on a route network and a set of landmarks with their spatial attributes and inherent properties, which are expressed as a saliency value. We assume that these values are known and assign low weights to landmarks with high information content and high weights to less salient landmarks. The algorithm employed to find the optimal path between start and destination node is a revised version of Dijkstra's shortest weighted path algorithm (Algorithm 1). It operates by first initializing all edges connected to the starting node with the weight of the most prominent landmark at the upcoming decision point. For each node connected to the starting node, the weights of the landmarks are calculated assuming that the navigator's heading corresponds to the direction in which the edge is traversed (Figure 3). In the second phase, the algorithm iterates through each node while maximizing the cumulative landmark information, i.e. minimizing the sum of the weights of the traversed edges.

The algorithm iterates until all edges have been visited and the clearest path from the starting node to all nodes in the network are calculated. The computation of the clearest path is based solely only information about landmarks and their individual positions with respect to traveler's orientation at decision points along the route. At no point in the algorithm is any distance information involved in the calculation.

Figure 3 Individual headings for nodes A, B, and C



The graph used in the algorithm consists of nodes and edges, $G=(V,E)$, and is assumed to be a connected, simple, directed graph. The assumption that the graph is directed is essential for our model, since we associate weights with edges based on the direction that the edge is traversed. Further, we define a starting node $s \in V$, $\mathcal{E}$ is the set of outgoing edges at a specific node, $\mathcal{E} = \{((v_i, v_j), (v_j, v_k)) \in E \times E\}$, $w : \mathcal{E} \rightarrow \mathbf{R}^+$ is the graph weighting function, $c_s : E \rightarrow \mathbf{R}^+$ stores the weights of the clearest paths from s to every node in the graph, and $S = \{\}$ is the set of visited edges.

Algorithm 1 The Landmark Spider Algorithm

```
Initialize c_S(e) = ∞ for all e ∈ E
for all (s,v_i) ∈ E do
    set c_s(s,v_i) = Weight of edge with
                     clearest node
while |E \ S| > 0 do
    Find e ∈ E \ S such that c_s(e) is minimized
    Add e to S
    for all e' ∈ E \ S do
        if (e,e') ∈ ℰ then
            set c_s(e') = min(c_s(e'), c_s(e) + w(e,e'))
```

In order to find the path to clearest path to a specific destination d, we must first find the edge where $c_s(v_i, d)$ is minimized, that is, we need to retrieve the node connected to d that contains the lowest cumulative weight from the function c_s that stores the weights. The last step in the process is to reconstruct the path by iterating backwards through the edges while repeatedly retrieving the node associated with the lowest cost. The result is a set of nodes describing the path best suited for landmark-based navigation.

Algorithm 2 Backtracking the path containing the maximum landmark information

```
Initialize t = d, path p = (t)
While t ≠ s do
    Find (v_1,t) ∈ E such that c_s(v_1,t) is minimized
    Prepend vertex v_1 to path p
    Set t = v_1
```

4.1 The Weighting Function

In this section we will have a closer look at the weighting function. Basically, the weight is the sum of the factors that define the binary relation between travelers at decision points on the route and potential landmarks. These factors are 1) the distance between the node (i.e. the traveler's position) and the landmark, 2) the orientation of the traveler with respect to the landmark, and 3) the salience of the landmark itself. The distance is important since close landmarks make better reference points than distant landmarks. The saliency of the landmark indicates its quality, which is in essence a measure of the 'visibility' of the landmark. As a result, the salience is an essential part of the relation between points on the route and the landmark. This configuration ensures that each node along the route is associated with a weight indicating the relevance of potential landmarks with respect to the navigator's heading. Introducing these weights in the weighted shortest path algorithms and summing them up results in the optimal route in terms of landmark coverage. The weighting function is defined as:

$$w_i = a \cdot \text{Distance} + b \cdot \text{Orientation} + c \cdot \text{Salience} \qquad (1)$$

where w_i is the weight of a specific landmark with respect to the navigator's position, a, b, and c refer to the navigator's personal preferences when looking for landmarks, distance and orientation are values given by the spatial configuration, and the saliency is derived from the spatial objects. The total weight of a single route is the sum of the single weights:

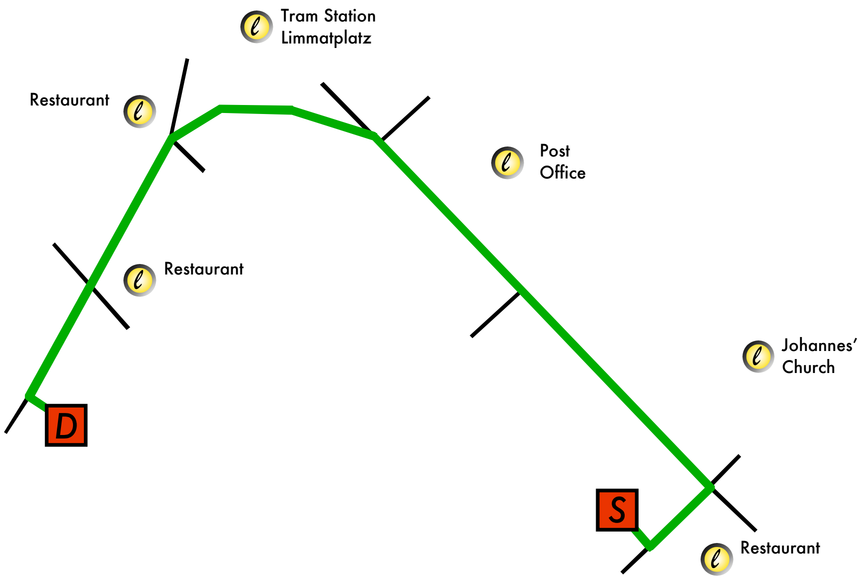
$$W = \sum_{i=1}^{n} w_i \qquad (2)$$

The presentation of the route instructions is based on the results of the route generation. Due to the fact that the generation algorithm assesses the relevance of the available landmarks along the way and includes them in the results, no further processing is required. The final step is to present the routes appropriately to the navigator. The path is presented in a spatio-analogical way, which enhances navigation and decision support as orientation in the field is straightforward and easy to establish.

4.2 Diagrammatic Route Description

The result of the shortest weighted path algorithm is a set of connected nodes that defines the route with the clearest route, that is, the route offering best feedback to the navigator in terms of salient landmarks. Each node in the set is associated with the most prominent landmark for a specific traveling direction. Based on these results, the landmark spider generates a diagrammatic route description that represents the path in a spatio-analogical way (Figure 4).

Figure 4 Example of diagrammatic route presentation



The representation contains both, depictions and descriptions. The route elements (i.e. the start node (S) and destination node (D), the decision points, the connecting edges, and the most prominent landmarks (l)) are depicted as symbols. The landmarks are further described by their name or function, which convey additional information, and hence, complement the depictive representation. To support reorientation of the traveler and hint to the next step of the journey, the description is further enhanced with references to outgoing edges at decision points.

5. Conclusions

The landmark spider model is designed to mimic the characteristics of navigators trying to find their way on the base of landmarks. We established the theoretical framework for landmark-based navigation and analyzed the spatial relations between navigator and landmark. Questions on results analysis and comparison, as well as computational issues and performance are subject of ongoing research. In the best-case scenario, however, we expect that the optimal route computed by the landmark spider will be identical to the shortest path between starting point and destination. The worst-case scenario occurs if the density of available landmarks is too low, in which case parameters of the weighting function may have to be adjusted appropriately.

The landmark spider is a first approach towards the integration of landmarks in the route generation process. Current research activities focus on the refinement of the weighting function, as well as the representation of the results in the form of a dynamic diagrammatic representation that can be used for handheld devices such as PDAs or cellphones.

6. Acknowledgments

The authors wish to acknowledge Urs-Jakob Rüetschi for pointers to the literature and simulating discussions about several issues of this paper. The research is funded by SNSF Project 205120-101631, ‘Problem-solving knowledge for multi-modal wayfinding’. The authors appreciate their financial support.

7. References

Casakin, H., Barkowsky, T., Klippel, A., & Freksa, C. (2000). *Schematic Maps as Wayfinding Aids*. Paper presented at the Spatial Cognition II.

Denis, M., Pazzaglia, F., Cornoldi, C., & Bertolo, L. (1999). Spatial Discourse and Navigation: An Analysis of Route Directions in the City of Venice. *Applied Cognitive Science, 13*(2), 145-174.

Elias, B. (2003). *Extracting Landmarks with Data Mining Methods*. Paper presented at the International Conference on Spatial Information Theory, COSIT 2003, Kartause Ittingen, Switzerland.

Freksa, C. (1999). *Spatial aspects of task-specific wayfinding maps*. Paper presented at the Visual and spatial reasoning in design, University of Sydney: Key Centre of Computing and Cognition.

Hampe, M., & Elias, B. (2004). *Integrating topographic information and lanmdarks for mobile navigation*. Paper presented at the Symposium 2004, Geowissenschaftliche Mitteilungen, Wien, Austria.

Hegarty, M., Haarslev, V., & Narayanan, N. H. (2002). Diagrammatic Reasoning. *Künstliche Intelligenz, 4*, 38-39.

Hernandez, D., & Zimmermann, K. (1993). *Default reasoning and the qualitative representation of spatial knowledge*. Paper presented at the Defaults and Prototypes - Non monotonic Reasoning for Language and Knowledge Processing.

Hollands, M. A., Patla, A. E., & Vickers, J. N. (2002). "Look where you're going!": Gaze Behaviour associated with maintaining and changing the direction of locomotion. *Exp Brain Res, 143*, 221-230.

Lee, P. U., Tappe, H., & Klippel, A. (2002). Acquisition of Landmark Knowledge from Static and Dynamic Presentation of Route Maps. *Künstliche Intelligenz, 4*, 32-34.

Lynch, K. (1960). *The Image of the City*. Boston: The M.I.T. Press.

May, A. J., Ross, T., Bayer, S. H., & Tarkiainen, M. J. (2003). Pedestrian Navigation Aids: Information Requirements and Design Principles. *Personal Ubiquitous Computing, 7*, 331-338.

Michon, P.-E., & Denis, M. (2001). *When and Why Are Visual Landmarks Used in Giving Directions*. Paper presented at the International Conference on Spatial Information Theory, COSIT 2001, Morro Bay, CA, USA.

Nothegger, C. (2003). *Automatic Selection of Landmarks.* Unpublished Diplomarbeit, University of Technology, Vienna.

Raubal, M., & Winter, S. (2002, September 25 - 28, 2002). *Enriching Wayfinding Instructions with Local Landmarks.* Paper presented at the Second International Conference on Geographic Information Science.

Redish, A. D., & Touretzky, D. S. (1995). Navigating with Landmarks: Computing Goal Locations from Place Codes. *Symbolic Visual Learning*.

Steck, S. D., & Mallot, H. A. (1997). *The Role of Global and Local Landmarks in Virtual Environment Navigation* (Technical Report). Tübingen, Germany: Max-Planck-Institut für biologische Kybernetik.

Streeter, L. A., & Vitello, D. (1986). A profile of driver's map-reading abilities. *Human Factors, 28*, 223-239.

Streeter, L. A., Vitello, D., & Wonsiewicz, S. A. (1985). How to Tell People Where to Go: Comparing Navigational Aids. *International Journal of Man-Machine Studies, 22*(5), 549-562.

Tom, A., & Denis, M. (2003). *Referring to Landmark or Street Information in Route Directions: What Difference Does It Make?* Paper presented at the International Conference on Spatial Information Theory, COSIT, Kartause Ittingen, Switzerland.

Waller, D., Loomis, J. M., Golledge, R. G., & Beall, A. (2000). Place learning in humans: The role of distance and direction information. *Spatial Cognition and Computation, 2*, 333-354.

Wang, R. F., & Spelke, E. S. (2000). Updating egocentric representations in human navigation. *Cognition, 77*, 215-250.

Werner, S. (2002). Cognitive Reference Systems and Their Role in Designing Spatial Information Displays. *Künstliche Intelligenz, 4*, 10-13.

Zimmermann, K., & Freksa, C. (1996). Qualitative Spatial Reasoning Using Orientation, Distance, and Path Knowledge. *Applied Intelligence, 6*, 49-58.