Wayfinding and description strategies in an unfamiliar complex building

Thora Tenbrink (tenbrink@uni-bremen.de)
SFB/TR 8 Spatial Cognition, Universität Bremen, Germany

Evelyn Bergmann (e.bergmann@uni-bremen.de)
SFB/TR 8 Spatial Cognition, Universität Bremen, Germany

Lars Konieczny (lars.konieczny@cognition.uni-freiburg.de)
SFB/TR 8 Spatial Cognition, Universität Freiburg, Germany

Abstract

Describing routes is an easy everyday task for people who know the environment well. However, strategies exist also for situations where only incomplete knowledge is available. We present a study eliciting verbalized route plans and think-aloud data from novices and experts who were asked to find and describe routes in a complex building. The spatial descriptions were analyzed relating the level of knowledge to route efficiency, and to occurrences of particular linguistic elements. Results reveal a diversity of wayfinding and description strategies, ranging from generic methods via building specific strategies to classic turn-by-turn directions. Experience with the building predicted the performance in finding efficient paths as well as the extent to which concrete spatial elements and uncertainty or orientation markers occurred in the descriptions. These findings open up the possibility of predicting the expertise of a speaker from the form as well as the contents of a route description.

Keywords: route descriptions; cognitive map; incomplete knowledge; wayfinding strategies.

Introduction

Imagine asking someone for the way, and hearing in response "uhm, well, you could just try walking to the right here, look out for the signs, best search for the main staircase, it must be there somewhere". You would recognize that this person is no expert of the environment – yet this is far from a denial to respond. On the contrary, you might even follow this advice, even though it is just a vague hint. But what exactly is it in this utterance that reveals the speaker's cognitive status? And what is the nature of those hints that speakers with limited spatial knowledge can possibly convey?

Route descriptions can be viewed as a way of accessing speakers' current spatial representation of an environment. Research in this area has mostly centered on typical turn-by-turn directions (Denis, 1997; Lovelace & Montello, 1999). This kind of detailed instruction presupposes a considerable degree of familiarity with the environment. Often, research focuses on pre-defined paths, aiming to elicit those elements that are most crucial for conveying a route efficiently. However, clearly this research only captures description, not planning or wayfinding strategies in relation to variable knowledge. Yet the underlying assumption of (reasonably) complete knowledge represents the exception rather than the rule. Human knowledge of environments is typically limited and in part distorted (Canter, 1977; Tversky, 1981). In order to deal with this limitation, people consult maps or verbal descriptions (with equal benefit, cf. Meilinger & Knauff, 2008), or they draw upon cognitive strategies of wayfinding (Golledge, 1999), with different implications for outdoor (Wiener et al., 2004) versus indoor (Hölscher et al., 2006) environments. In this paper, we will address indoor environments (complex buildings) with a particular focus on the verbalization of routes as well as wayfinding strategies.

Wayfinding and description strategies

Knowledge about a building determines not only how people navigate and find their way around, but also how comfortable they feel in it without the risk of losing orientation (Carlson et al., 2010), and how they will talk about it when describing the setting and guiding others along their way. In spite of the fact that all of these issues belong to everyday experience, surprisingly little is known about how humans actually deal with incomplete knowledge when finding their way around in complex buildings.

Much research has proved the crucial impact of *landmarks* on human understanding of spatial environments – particularly outside of buildings (e.g., Presson & Montello, 1988; Caduff & Timpf, 2008). Humans use landmarks to orient and locate their own position, to retrace a route, to find the correct direction towards a destination, to describe routes to others, and so on. However, the extent to which such findings can be transferred to indoor scenarios remains unclear, except for findings highlighting the particular role of central points (well-known parts of a building) for orientation (Gärling et al., 1983) as well as wayfinding strategies (Hölscher et al., 2006).

Similar observations can be made concerning other route elements, such as hallways or other types of paths within buildings, their names or features, directions or angles, distances, and so on. Some of the available results so far point to systematic effects of particular spatial tasks, goals, or configurational features leading to a difference in the conceived salience of spatial entities of various types (Peponis et al., 1990; Weisman, 1981). However, the role of knowledge of the environment in question remains unclear.

Wayfinding strategies may be based either on rational reasoning processes in relation to a given goal, or on contextual factors that may influence the wayfinders' decisions even without their conscious awareness. Studies have investigated variations in the spatial situation, such as the length of the line of sight or other factors that may impact path selection (Golledge, 1997; Hochmair & Frank, 2002), as well as various kinds of tasks involving more global navigation decisions and strategies (Wiener et al., 2004). Furthermore, a number of studies address speakers' strategies in *describing* spatial environments, such as mentally following a continuous route through the building (Linde & Labov, 1975), and switching perspectives throughout a discourse (e.g., Tversky, 1999).

Taken together, there is much evidence that spatial knowledge, behavior, and description are intricately interrelated in the application of high-level cognitive strategies. It is therefore promising to pursue the investigation of navigation behavior together with language production. Previous work has profited considerably from a close analysis of natural language produced along with spatial tasks (e.g., Soh & Smith-Jackson, 2004; Spiers & Maguire, 2008). Nevertheless, the question of how speakers react when asked to produce descriptions towards a particular spatial goal in an unfamiliar environment remains open so far. To our knowledge, there is no study directly addressing speakers' wayfinding and description strategies in such a task, neither in indoor nor in outdoor scenarios. Therefore, our work presented in the following is predominantly explorative. We elicited verbal descriptions with the expectation that already the *content* of a verbalization should be informative as it reveals conscious thought. Speakers may provide explicit reasons, strategies, and generalizations; and their language may reveal both global strategies and local spatial choices that can be interpreted relative to their level of spatial knowledge. Additionally, we were interested in the particular linguistic structures that might further reflect cognitive patterns, for example via the use of lexical choices (e.g. route elements), deixis, and presuppositions reflecting speakers' expectations.

Wayfinding and Description: Empirical study

Since classic turn-by-turn route directions presuppose a considerable amount of environment-specific spatial knowledge on the part of the speaker, our empirical setup was designed to elicit any type of description that participants might produce spontaneously.

Two groups of participants (30 experts and 60 novices with respect to the building, namely employees with offices in the building, and students in their orientation week; all native speakers of German) described the shortest way to a) the nearest exit and b) the Cafeteria from 5 different starting points distributed on four different levels of the "GW2" building of the University of Bremen (see Figure 1 for an impression of the building's complexity). The order of these two destinations was balanced. A subset of participants (13 experts and 53 novices) additionally walked to the second one of their two goals while thinking aloud. The verbalizations were analyzed linguistically and related to behavioral data (route choice) as well as level of knowledge.

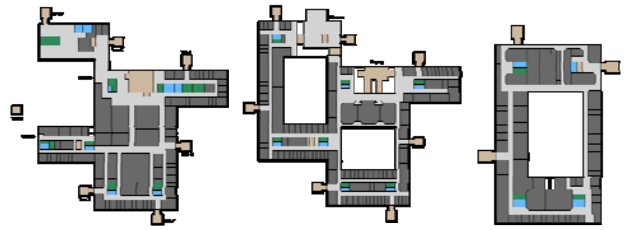

Figure 1: Three floor levels of GW2 (floor plans available at www.fb10.uni-bremen.de, retrieved in 2009).

Procedure

Participation was on a voluntary basis without compensation. The participants were approached by the experimenter either a) in their office (employees) or b) in or in front of a lecture room (students). They were then asked if they agreed to take part in a short wayfinding experiment, which was very simple and would take only about five minutes. The experimenter wrote down the gender and approximate age of the participant, and their current location. Participants were informed that the experiment was recorded. If they consented, they were asked to name their native language and to self-rate their familiarity with the building on a scale between 1 (very well) and 6 (not at all). The experimenter then asked the two experimental questions (in randomized order; all questions and examples are here translated from the German original):

1. Imagine you have to leave this building as quickly as possible. Please explain to me as well as you can how you would do that.
2. Imagine you want to go to the Cafeteria in this building. How do you get there using the shortest route?

After having answered these questions, the participants were further asked if they agreed to take part in the second part of this study. They were informed that this would take a few minutes and that they would be rewarded with candy. Consenting participants were given the following instruction (using the latter one of their previous goals):

"Please walk now to [the nearest exit / the Cafeteria] using the shortest route. It is not important to us whether you walk the same route that you just described or take a route that is even shorter. However, it is important to us that you *think aloud* while you are walking. Please say everything that crosses your mind."

The experimenter followed the participant and plotted their route on a map of the building while walking. If the participant fell silent, they were reminded to think aloud.

Research hypotheses

On the behavioral level, we expected that novices would orient towards salient entities and central points rather than choosing a direct route. Such a strategy would lead to less efficient routes than those found by experts in wayfinding and description. Since there was no operationalizable *a priori* measure for saliency as perceived by individual wayfinders, reasons for choosing particular routes were identified via quantitative and qualitative linguistic analysis. We also expected participants to be able to assess their own level of knowledge reasonably well, leading to a correlation between self-assessment of expertise with route efficiency.

On the linguistic level, we started out with the main aim of exploring the types of language produced in the case of incomplete knowledge (in contrast to expert knowledge), reflecting underlying wayfinding and description strategies via particular linguistic markers. Gradually, operationalizable criteria were developed for a systematic comparison of linguistic features. In particular, we expected that novices should use fewer *concrete spatial elements* than experts, but more *orientation indicators* and *uncertainty markers* (definitions are given below). Additionally we expected situated (think aloud) descriptions to reflect similar patterns as in-advance descriptions generally. However, because of available visual information, think aloud data during situated navigation should lead to the use of more *orientation indicators* and less *uncertainty markers* than in-advance descriptions, and possibly less *concrete spatial elements* because visible objects do not require explicit naming.

Analysis

In order to address the research hypotheses just summarized, we judged the efficiency of the chosen routes in relation to the shortest route. This was done by way of a 4-point scale with the following values: 1=shortest route, 2=minimal detour, 3=large detour, 4=goal not reached. After examining the number of turns and approximate length in meters in comparison to the shortest path, routes were categorized intuitively by two independent coders, who agreed with each other in 90% of the cases. Next, we annotated spatial linguistic categories that are well-known to be crucial for wayfinding (Denis, 1997; Tversky & Lee, 1999), and a variety of linguistic markers of orientation and uncertainty. These markers were identified post-hoc on the basis of the data, as they appeared to be potential indicators of underlying cognitive strategies or prerequisites. Our annotation categories were defined as follows.

Concrete spatial elements

Start & endpoint. Landmark or region presented as start or endpoint; including deixis in obvious linguistic contexts: "von *hier* aus; und dann wären wir schon *da*" (*from* here, *and then we'd already be* there).

Segment. Progression along a leg of the route. Typical segment markers include *durch* (through) [with the exception of doors], *entlang* (along), *runter* (down), *hoch* (up), *bis zum Ende* (to the end).

(Change) of direction. Projective terms and spatial prepositions that signal direction, such as *links* (left), *rechts* (right), *nach oben / rauf* (upwards), *nach unten / runter* (downwards), *geradeaus* (straight on), *zurück* (back), *rein* (into), *raus* (out of).

Landmark. Point-like spatial entities used for orientation that could be seen or heard; these often appear in the context of the prepositions *an* (at) and *(bis) zu* (till / to / up to).

Region. Areas with boundaries; linguistic context: *hinein* (into), *in* (in), *heraus* (out of), *aus* (out)*;* also: *oben*, *unten* (up, down if not used as direction), *vorne* (front).

Distance. Qualitative or quantitative expressions that signal duration (time, spatial distance).

Orientation indicators

References to public orientation aids. These include predominantly the information signs in the building, and emergency maps on the walls.

Deixis: demonstratives such as *dies/e* (this), and *hier* (here), *da* (there), *dort* (over there) (except in their use to refer to the start or destination). A frequent use of deixis can be taken to signal a main orientation towards the (deictic) "here and now", i.e., to information that is currently perceptually available, rather than spatial memory.

Process of orientation. Verbs that mark the process of orientation, such as *sich an etw. orientieren* (orient towards something), *Ausschau halten nach / nach etw. gucken* (look out for), *etw. suchen* (search something), *auf etw. achten* (pay attention to something).

Perception. Full verbs of perception, such as *gucken / schauen / sehen* (see / look / watch).

Exploration particles are utterances using the German construction [PRON VERB (einfach) mal], e.g., *wir gehen einfach mal los*; here translated as "let's just…".

Uncertainty markers

Vagueness markers start with *irgend-: -wie* (somehow), -*was* (something), -*wo* (somewhere), -*wann* (sometime).

Restarts. The word or sentence is left incomplete and a fresh start is attempted, as in *ich gehe nach li- links* (I now go to the le- left); *ich würde jetzt rechts – ich gehe nach rechts* (I would now right – I go to the right).

Referential problems. Reference is made by *dies(e)* together with a noun, and followed by an attribute, such as *in diesem Hauptgebäude wo auch die Asta und so was ist* (in this main building where also the Asta and all that is).

Modals: *könn(t)en* (could), *dürfen* (may), *müss(t)en* (might), *soll(t)en* (should), *wollen / mögen* (would like), *würden* (would).

Hedges. One of the following adverbs is used that signal uncertainty about the truth of the proposition: *eigentlich* (in a sense), *wahrscheinlich* (probably), *möglicherweise* (possibly), *vielleicht / eventuell* (maybe), *quasi* (quasi).

Stance. One of the following verbs is used that signals the speaker's degree of certainty concerning the truth of the proposition: *glauben* (believe), *denken* (think), *wissen* (know), *meinen* (mean).

Annotations were carried out by two independent coders who agreed with each other about the categorization of any linguistic unit in 85% of the cases.

Finally, we analyzed the descriptions and verbal protocols qualitatively in order to gain an intuitive understanding of the wayfinding and description strategies available in the case of incomplete knowledge. Along with this analysis, we established the relation between our qualitative discoveries and the quantitive analysis measures just listed.

Results

Behavioral performance

Experts found more efficient paths than novices, expert mean: 1.08, novices mean: 1.55, Wilcoxon rank sum test: W = 208.5, p<.05). In particular, in contrast to the direct paths chosen by experts, novices' paths typically passed a prominent main staircase (see Figure 2 for an example). Experts assessed their own knowledge to be higher than novices did (Wilcoxon rank sum test: W = 379.5, p<.001). However, the correlation between their self-assessed knowledge and the efficiency of their chosen routes failed to reach significance (Kendall's rank correlation tau: z = 1.3721, p= .17).

Figure 2: Example for paths chosen by novices and experts. The path chosen by the novice leads to the main entrance via the main staircase as a prominent landmark, while the expert's path leads to a minor entrance via the shortest possible path.

Quantitative analysis of verbal data

Our quantitative linguistic feature analysis using the operationalizable criteria described above revealed the following patterns. We fitted mixed-effects logistic regression models (Pinheiro & Bates, 2000) with the fixed factors *expertise* and *task* (*planning* vs. *thinking-aloud*), and *participants* as random factor, using the statistical software package R (R Development Core Team, 2011). The results (Fig. 3) revealed that novices produced fewer *concrete spatial elements* than experts (std.err=.265, z=-3.79, p<.001), but more *orientation indicators* (std.err=.173, z=5.65, p<.001) and more *uncertainty markers* (std.err=.177, z=3.13, p<.01). Moreover, more concrete spatial elements and more uncertainty markers were produced when the task was to explain the route in advance (planning) rather than thinking aloud (*concrete*: std.err=.127, z=-5.534, p<.001; *uncertainty*: std.err=.132, z=-3.82, p<.001). However, fewer orientation indicators were produced in planning, even though the effect was only marginally reliable (std.err=.125, z=1.943, p<.052). Experts produced particularly many concrete spatial elements when they were planning, resulting in a reliably better model fit when the interaction was kept in the model (Chi^2=8.01, p<0.01).

Despite the lack of a significant correlation between (self-assessed) spatial knowledge and expertise, self-assessment had a reliable effect on the utterances produced when added to the models (replacing expertise), such that a better self assessment lead to the production of more concrete elements (std.err=.095, z=-3.51, p<.001), but fewer orientation indicators (std.err=.069, z=2.78, p<.01) and uncertainty markers (std.err=.068, z=2.904, p<.01).

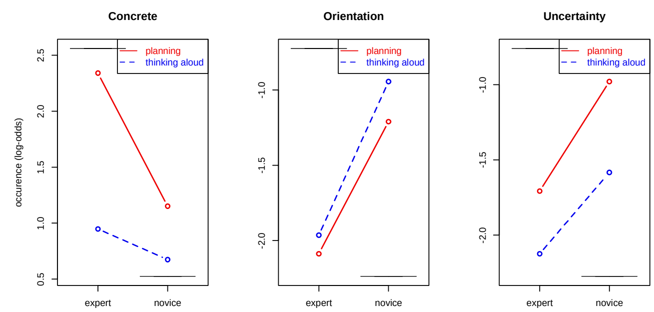

Figure 3: Occurrence (estimates) of concrete spatial elements, orientation indicators, and uncertainty markers as a function of expertise and task.

Qualitative analysis of verbal data

To illustrate the linguistic results of our study, we first provide typical examples of route descriptions given by an expert (example 1) and by a novice (example 2).

1. From my office door to the left and uh at the end of the hallway to the right, and then there is already the exit.
2. Uhm, I would, yes, in principle go back again to the main staircase and then, yes, one must, I think, then there is, you know, the bakery on one side, then one needs to go past it and straight on and then, also in this café, as far as I know, and then there is an exit.

Here are think-aloud protocols elicited from an expert (example 3) and from a novice (example 4):

3. So we go now to the staircase, tower A. But I always walk the stairs. Well, this building is a building to get lost in, really. Only to the exit. Just down the tower A.
4. So, we will now go in here, and let's press the Two. Hm (lift stops). Maybe one further down after all. Uhm, okay, let's go straight on. Okay, let's just go downstairs. And [we] need to get over there. Exactly, down here. Hm, office. Ha, to the left here. Along there. Here are we.

Clearly both of these description types (in-advance route descriptions and think-aloud data) differ between experts and novices with respect to the linguistic features listed above, such as uncertainty markers and orientation indicators. In the following, we focus on the differences concerning spatial knowledge rather than differences in text types. Our qualitative analysis of the verbal data revealed that participants had the following range of options at their disposal. The elicited verbalizations range from *general strategies* via *building specific* and *central point–oriented strategies* to *specific turn-by-turn directions* using the shortest path. In particular, we can characterize the range of options emerging from our data as follows. Note that the given examples are chosen to illustrate how the quantitative linguistic feature analysis maps with the range of strategies proposed here. However, as the examples also illustrate, the linguistic features need to be appreciated as superficial indicators which, if analyzed without context, may appear misleading, as there is no simple one-to-one correspondence between linguistic form and underlying cognitive strategy.

Basic generic strategy

Even without any previous knowledge, people can ask other people, look out for signs, retrace their earlier paths, or use any other generally available strategy that enables them to find the intended destination. Characteristic verbal descriptions of this kind from our data include: "No idea, I search for an info sign and then I continue looking [laughs]"; "Well, either [look] for signs or just ask others who are running around here"; "Well, then I would, uh, take the path that I also used to come in, even if this is not the, maybe not the shortest one, but I already know it, then I would also retrace it". These descriptions contain no concrete spatial elements such as segments, directions, landmarks, and distances. Typical orientation markers for this strategy concern mostly searching (for generically expected items that might or might not be there), references to orientation aids, and modals (*I would*). Apart from that, this basic strategy type may be considered as unfailing, so as to involve relatively little uncertainty (i.e., people do not even try to find their way independently).

Environment specific strategy

With only very little knowledge of the specific building in which people are navigating, they can orient towards particular features of this environment. The building used in our study has the specific features of signs displaying room numbers and other destinations (departments, central points), as well as staircase towers (semi-detached from the building itself). Relevant utterances include "Follow the signs, which are hanging above the doors"; "and then I would hope that I walk directly in the direction of the tower"; "uh, I would search for the nearest staircase down". These utterances contain presuppositions as signaled by the definite articles in *the signs, the tower, the nearest staircase*. Such indicators either reflect rudimentary knowledge about the environment, or specific expectations about it (i.e., there must be a staircase that can be used to get down).

Central point oriented strategy

Previous experience with an environment leads to the memory of landmarks as a first step in acquiring a cognitive map (Siegel & White, 1975). In this building, prominent landmarks included a large hall together with a main staircase, both adjacent to the cafeteria as well as to a main entrance. Novices with some knowledge of this building regularly chose a path via these prominent central points, even if it was not the shortest one (see Figure 2 above). Relevant utterances include "This hall, where the main staircase is as well"; "I would always first go to the main staircase here, and then from there downwards". These utterances contain orientation and uncertainty markers, but also a number of concrete spatial elements, as speakers start to orient towards specific locations within the building.

Specific turn-by-turn directions

With elaborate knowledge of the building, speakers can not only describe a concrete route, but also decide about the shortest path to the destination (cf. behavioral results). Furthermore, they can describe the location of the destination directly. All of this reflects the extent to which speakers can draw on an integrated cognitive map. Relevant utterances of this kind include "When I walk out of my office to the right, then directly left again, keep straight on, uhm, then you would already go directly towards the Cafeteria and there down the stairs. Then onto the first level"; "The shortest path up here to the exit is down tower A". Utterances such as these are characterized heavily by the concrete spatial elements known for route descriptions from the literature as listed above. They contain few orientation or uncertainty markers.

Discussion

We set out in this study to investigate the strategies of wayfinding and description in a complex building in the case of incomplete knowledge. Our study compared the solutions found by experts familiar with the building to those put forward by novices, in our case new students at the university. Results showed that, as expected, routes found by experts were reliably more efficient than those by novices. The degree of expertise was also reflected in the linguistic features of the verbalizations, both with respect to in-advance route descriptions and in the task-concurrent think-aloud protocols. These two discourse types differed with respect to mention of *concrete spatial elements* and *uncertainty markers*, which were most characteristic for planning ahead, as well as *orientation indicators*, which were most characteristic for thinking aloud while navigating. These linguistic features also systematically reflected the range of strategies of dealing with uncertainty in a wayfinding situation, independent of discourse type. Novices used fewer *concrete spatial elements* than experts, but more *orientation indicators* and *uncertainty markers*. This reflects their tendency towards using generic (search) strategies rather than describing specific routes typically described by experts in answer to a route request. Confronted with a spatial task that they could not solve directly, novices could rely on unfailing procedures such as *asking passers-by, looking out for orientation aids,* and *retracing the previous route.* Between these two extremes of complete knowledge and complete ignorance, the participants made use of specific features of the environment that they had already encountered, ranging from general building features (towers, type of signs) to individual central points (specific landmarks such as the main hall and staircase). These environmental features supported navigation (i.e., routes were designed to lead via prominent locations) and were reflected prominently in the verbalizations.

These results are in line with previous findings highlighting the prominent role of previously learned central points within complex buildings (Gärling et al., 1983;

Hölscher et al., 2006). Moreover, they provide a novel context for the investigation of (concrete, turn-by-turn) route descriptions, namely in terms of being situated at one end along a cline of familiarity with the environment in question. Moving towards the other end of the cline, route descriptions gradually become less concrete, although they may still serve as useful wayfinding support as they orient towards prominent locations.

Linguistic markers such as vagueness particles, hedges, modals, and perception and orientation verbs to some extent indicate a lack of expertise on the part of the speaker, whereas references to concrete spatial entities convey spatial certainty. This extends previous, more general findings on speakers' display of their cognitive status, which their dialogue partners can detect and react to (Brennan & Williams, 1995). Presuppositions such as the use of definite articles along with items not directly encountered reveal the wayfinder's expectations about the current environment. Findings such as these can be useful across a range of practical applications. For instance, an automatic dialogue system (e.g., Cuayáhuitl et al., 2010) may be enabled to react to a speaker's uncertainty and expectations, of which they may not be aware, in a supportive way. Furthermore, a well-founded assessment of spatial knowledge, expectations, and wayfinding confidence can be used to improve the compatibility between the spatial environment and the strategies and abilities of its users (Carlson et al., 2010).

Acknowledgments

Funding by the DFG, SFB/TR 8 Spatial Cognition, Strategic Project [NavTalk], is gratefully acknowledged. We thank Christoph Hölscher and Julia Frankenstein for discussions on the topic of this paper, and our student assistants for support in carrying out and analyzing the reported study.

References

Brennan, S.E., & Williams, M. (1995). The feeling of another's knowing: prosody and filled pauses as cues to listeners about the metacognitive states of speakers. *Journal of Memory and Language 34*, 383-398.

Canter, D. (1977). *The Psychology of Place*. London: The Architectural Press Ltd.

Carlson, L.A., Hölscher, C., Shipley, T.F., & Conroy Dalton, R. (2010). Getting lost in buildings. *Current Directions in Psychological Science 19*(5), 284-289.

Cuayáhuitl, H., Dethlefs, N., Richter, K.F.R., Tenbrink, T., & Bateman, J. (2010). A dialogue system for indoor wayfinding using text-based natural language. *International Journal of Computational Linguistics and Applications* 1 (1-2), 285–304.

Denis, M. (1997). The description of routes: A cognitive approach to the production of spatial discourse. *Cahiers de Psychologie Cognitive, 16*(4):409-458.

Gärling, T., Lindberg, E., & Mäntylä, T. (1983). Orientation in buildings: effects of familiarity, visual access, and orientation aids. *Journal of Applied Psychology, 68*(1), 177–186.

Golledge, R.G. (1997). Defining the Criteria Used in Path Selection. In D.F. Ettema & H.J.P. Timmermans (Eds.), *Activity-Based Approaches to Travel Analysis*. Elsevier.

Golledge, R.G. (ed.) (1999). *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*. Johns Hopkins University Press, Baltimore, MD, USA.

Hochmair, H.H. & Frank, A.U. (2002). Influence of estimation errors on wayfinding-decisions in unknown street networks - analyzing the least-angle strategy. *Spatial Cognition and Computation 2* (4): 283-313.

Hölscher, C., Meilinger, T., Vrachliotis, G., Brösamle, M., & Knauff, M. (2006). Up the Down Staircase: Wayfinding Strategies and Multi-Level Buildings. *Journal of Environmental Psychology 26*(4), 284-299.

Linde, C. & Labov, W. (1975). Spatial networks as a site for the study of language and thought. *Language 51*,924-939.

Lovelace, K., Hegarty, M., & Montello, D.R. (1999). Elements of Good Route Directions in Familiar and Unfamiliar Environments. In C. Freksa & D.M. Mark (Eds.), *Spatial Information Theory.* Berlin: Springer.

Meilinger, T. & Knauff, M. 2008. Ask for your way or use a map: a field experiment on spatial orientation and wayfinding in an urban environment. *Spatial Science 53*:2,13-24.

Peponis, J., Zimring, C., & Choi, Y. K. (1990). Finding the building in wayfinding. *Environment and Behavior, 22(5)*, 555–590.

Pinheiro, J. C., & Bates, D. M. (2000). *Mixed-effects models in S and S-PLUS*. New York: Springer.

R Development Core Team. (2011). R: A language and environment for statistical computing [Computer software manual]. Vienna, Austria.

Siegel, A.W., & White, S.H. (1975). The development of spatial representations of large-scale environments. In H.W. Reese (Ed.), *Advances in child development and behavior*. New York: Academic Press.

Soh, B.K. & Smith-Jackson, T.L. (2004). Influence of map design, individual differences, and environmental cues on way finding performance. *Spatial Cognition and Computation*, 4, 137-166.

Spiers, H.J. & Maguire, E.A. (2008). The dynamic nature of cognition during wayfinding. *Journal of Environmental Psychology* 28:3, 232-249.

Tversky, B. (1981). Distortions in memory for maps. *Cognitive Psychology*, 13, 407-433.

Tversky, B. (1999). Spatial Perspective in Descriptions. In P. Bloom, M.A. Peterson, L. Nadel & M.F. Garrett (Eds.), *Language and Space*. Cambridge, MA: MIT Press.

Tversky, B. & Lee, P. (1999). Pictorial and Verbal Tools for Conveying Routes. In C. Freksa & D.M. Mark (Eds.), *Spatial information theory* (COSIT '99). Berlin: Springer.

Weisman, J. (1981). Evaluating architectural legibility: Way-finding in the built environment. *Environment and Behavior*, 13(2), 189–204.

Wiener, J. M., Schnee, A., & Mallot, H. A. (2004). Use and Interaction of Navigation Strategies in Regionalized Environments. *Journal of Environmental Psychology, 24*(4), 475 – 493.