

Running head: PRAGMATIC DESTINATION DESCRIPTIONS

Pragmatic Construction of Destination Descriptions for Urban Environments

Martin Tomko

University of Zurich, Switzerland

Stephan Winter

The University of Melbourne, Australia

Abstract

Destination descriptions are route descriptions focusing on the ‘where’ of the destination instead of the ‘how’ to reach it. They provide first a coarse reference to the destination, and then increasingly more detailed ones as the description proceeds. We introduce a definition of destination descriptions, along with an analysis of the construction and interpretation of destination descriptions grounded in pragmatic communication theory. We present a formal model enabling the selection of references for destination descriptions from models of experiential hierarchies of urban environments. This model generates route directions for people with some knowledge of the environment. Destination descriptions are usually shorter and we conjecture that the cognitive workload required during their use is lower than for equivalent turn-based directions.

Pragmatic Construction of Destination Descriptions for Urban Environments

The ways people convey place descriptions, as answers to where questions, are well investigated (see, e.g., Paraboni et al., 2007; Tversky, 2003). If the situational context allows some shared knowledge about the structure of the environment to be assumed, place descriptions typically have a hierarchical structure, referring to well-known and unambiguous elements:

“Where are the keys? ”

“They are in the living room, on the table.”

Tversky (2003) calls these elements landmarks. The same structure can be found in some route directions. Consider, for example, a passenger instructing a taxi driver in the city of Hannover, Germany:

“To Luisenstrasse, please.”

“? ? ”

“It is in the city center, next to the opera house, off Rathenaustrasse.”

This description is accepted by the taxi driver; he starts driving, finding the way on his own. In fact, the description *is* a place description: it describes the destination of the trip by the same strategy as in the previous example. We will call this form of route directions *destination descriptions*.

Note that destination descriptions do not give any information about *how* to find the destination, as the turn-by-turn directions of classical navigation services would do. Such classical services expect no existing environmental knowledge of the user at all, only relying on their procedural knowledge, and provide, in the sense of the classical communication theory (Shannon and Weaver, 1949), complete information. Turn-by-turn directions, however, are not adequate in the situation above. On one hand, the taxi driver would be overloaded with

information that is excessive to his survey knowledge of the city. On the other hand, the passenger might not know the route but only the location of the destination.

Thus, destination descriptions are a promising way to convey route directions to people with some familiarity with an environment. Destination descriptions apply for the everyday navigation of people in their home urban environment, providing the freedom of choice of the actual route to the wayfinder. They apply in cases such as finding a shop or a friend's place in an area of the city you are not so familiar with. Since these situations occur more frequently than traveling in a completely new environment, we even estimate the need for destination descriptions being greater than for turn-by-turn directions. Accordingly, our goal is to select the references in destination descriptions automatically.

The research presented in this paper addresses the hypothesis that the content of destination descriptions is independent of the length or complexity of the possible routes to the destination. We develop a computational model of selecting references for a destination description that takes as input the current location and the desired destination of the wayfinder. The model is grounded in relevance theory, a branch of pragmatic communication theory. To identify relevant references, the model accesses and navigates in hierarchical conceptualizations of urban environments, and we demonstrate that the number of references is always relatively short, and in fact independent of the properties of the possible routes to the destination.

This paper is structured as follows: in the next section, we introduce our motivation in more detail and provide an overview of the current state of the art in route directions research. In Section 3, we define and discuss the concept of destination descriptions and the selection of relevant references for such directions. In Section 4, we link destination descriptions with hierarchical mental representations of space and introduce ways to structure data in integrated

experiential hierarchies usable for the task of automated selection of references for destination descriptions. Section 5 introduces a computational model for the selection of references for destination descriptions. The functionality of the model is then demonstrated on an example from the city of Hannover in Section 6. The paper concludes in Section 7 with a discussion of the main contributions and future research directions.

Background

The Where and the How in Spatial Communication

Communication about space, such as direction giving, represents an important use of people's spatial mental representations. People familiar with an environment share some spatial knowledge due to similar (direct or indirect) experience of their environment. This knowledge is then exploited in the place and route descriptions they exchange.

Current research in navigation services concentrates on two broad areas in which methods of personalization are studied: route planning and route communication. The latter includes user interfaces, possibly with advanced interaction such as natural language (Dale et al., 2005), and content adaptation (Klippel, 2003; Richter, 2007a). In general, the focus is on wayfinders without previous experience with the environment.

Klippel (2003) focused on conceptualizations of route direction elements. The identified route direction concepts were used by Klippel et al. (2003) and Richter (2007) in an approach to chunking of turn-based route directions based on the structural properties of a route in order to decrease the number of information items in the resulting directions. While providing an important step towards cognitively ergonomic communication of route knowledge, the level of detail of the directions thus provided is determined purely by the route structure and does not consider a-priori environmental knowledge of the wayfinder. Similarly, Dale et al. (2005)

implemented a system providing route descriptions of varying granularity in a city. Road status hierarchies, road lengths and turn structures were used to construct a hierarchy of chunks of instructions. The resulting directions were structured in a hierarchical tree-like representation for use on mobile devices. Note that the use of administrative street hierarchies may not necessarily reflect the hierarchies inherent in the spatial mental representations of the wayfinders, as administrative hierarchies are the result of other structuring principles than the preservation of cognitively plausibility.

Due to at least coarse a-priori knowledge of the environment, locals may often find turn-based directions excessive and patronizing. They only need an unambiguous indication of the destination, and they plan how to get there on their own.

Experiencing Space

People acquire spatial knowledge through interaction with the environment and improve the completeness and accuracy of this knowledge over time (Allen, 1999; Ishikawa and Montello, 2006; Siegel and White, 1975). The mental representations acquired through direct experience of the environment are further supported by indirect spatial learning from maps, sketches, or spatial narratives. Individual movement behavior, experiences, and cognitive responses to specific properties of the environment are the causes of individual distortions in these representations.

Couclelis et al. (1987) suggest a hierarchical relation between spatial cues and their areas of influence and the mental representations. Spatial cues were found to be foci of so called tectonic plates, regions with which the cues tend to be strongly associated. Further research confirms the hierarchical organization of spatial knowledge (Hirtle, 2003; Hirtle and Jonides, 1985; Taylor and Tversky, 1992) and its reflection in spatial reasoning, where dependence

between an entity's membership in a hierarchy and its use in the spatial task has been demonstrated (Plumert et al., 1995; Wiener and Mallot, 2003).

Hierarchical data structures are frequently adopted in computing for efficient retrieval of *exact* information. In contrast, hierarchies in mental conceptualizations emerge to lower the cognitive effort of storing and retrieving information. The formation of chunks of information and their hierarchical organization preserves the information and lowers the cognitive effort while increasing the comprehensibility (Taylor and Tversky, 1992). The information retrieved from memory may often be approximate, as far as it is sufficient to support a given task (e.g., “the address is near the opera house”).

In route directions, the information retrieved from the spatial mental representation of the speaker is communicated to the hearer who relates it to his or her a-priori spatial mental representation, or forms a new one. When communicating to people with a-priori spatial knowledge, the extent of their knowledge of the environment is not known to the speaker and has to be inferred. The research of Fussell and Krauss (1992) and Lau and Chiu (2001) shows that estimates of others' knowledge of landmarks can be highly accurate, although with a bias toward one's own knowledge. Furthermore, the differences between long-term and short-term inhabitants are minor, which aligns with the findings reported by Ishikawa and Montello (2006), pointing to the quick formation of advanced forms of spatial knowledge. Thus, there is strong evidence that common knowledge of the environment can be operationalized in so-called experiential hierarchies (Section 4.1).

Relevance Theory of Communication

While messages exchanged in everyday communication contain only a small part of the information necessary to perform a task required, people receiving this information are able to

interpret the meaning conveyed. Pragmatic information theories have been devised by linguists to explain this observed discrepancy, but remained largely neglected by researchers in the field of spatial communication. Notable exceptions are the works of Frank (2003) and Worboys (2003), grounding their works in the theory presented by Grice (1957). These works point to the importance of a-priori information as an important part of the context in which the hearer interprets the message received. Among pragmatic information theories, relevance theory (Sperber and Wilson, 1986) has recently gained prominence by its ability to explain several shortcomings of the approaches by Grice. The understanding of the implied content requires another reasoning step, which is the inference of the speaker's intentions by the hearer. The inferential communication model uses Grice's concept of relevance in an extended manner, explaining the principles of inferential communication using this concept exclusively.

Communication always happens in a cognitive environment, or context. Cognitive environment is defined by Sperber and Wilson (1986) as the set of assumptions bearing on comprehension available to a cognitive agent, in our case a person. An important part of the cognitive environment consists of knowledge previously acquired, be it in previous utterances (i.e. linguistic context), or by interaction with the physical environment, with all its facets, such as space, sounds, smells, and other people. Relevance theory builds on the assumption that human cognitive processes tend to maximize the efficiency of any action, emphasizing the importance of the cognitive environment to the comprehension of an utterance. In this cognitive environment, communication is the act of construction of a verbal or non-verbal stimulus, meant to achieve cognitive effects.

A stimulus is relevant if it connects with available contextual assumptions to provide a positive cognitive effect. Of course, many stimuli of varying relevance may be perceived by an

individual at any time. The relevance of possible referents is evaluated, and the referent which is evaluated as most relevant in the given situation is selected. The interpretation of the meaning of this stimulus is left to the hearer, who interprets the utterance in a manner most relevant to her or himself. The speaker, on the other hand, makes sure that the stimulus is perceived as relevant, through content of the message or the communication form.

The process of maximizing relevance during interpretation of a stimulus follows a path of minimal effort. This is stated in the principle of relevance (Sperber and Wilson, 1986):

- Everything else being equal, the greater the cognitive effect achieved by the processing of a given piece of information, the greater its relevance for the individual who processes it.

- Everything else being equal, the greater the effort involved in the processing of a given piece of information, the lesser its relevance for the individual who processes it.

Clark and Marshall (1981) mention physical and linguistic co-presence of the communication partners, as well as their community membership among the fundamental factors influencing the the cognitive environment of communication partners. Physical co-presence relates to sharing a location or being aware of the other's location while linguistic co-presence relates to sharing the knowledge of what was said in the communication previously. Physical co-presence may also be projected (Gerrig et al., 2001), as it is the case in a phone communication where one of the communicators refers to her or his location. Community membership relates to the declared or perceivable affiliation of one or both communication partners to a group with shared characteristics—such as drivers, golf players or colleagues. These factors contribute to the inference of the extent of common knowledge shared by the speaker and the hearer or hearers, and influence the comprehension of the meaning of a message by the hearer. Each stimulus

modifies the cognitive environment of the hearer, and has to be considered when interpreting a consecutive stimulus. In the case of a communication about a *where* question, the speaker tries to identify a place, and therefore composes a spatial referring expression (Paraboni et al., 2007; Tomko and Winter, 2006). A referring expression is defined as an expression uniquely identifying a specific entity (Dale, 1992). Human-generated referring expressions share common properties, such as accuracy, brevity, incremental structure and relevance, characteristics applying also to human spatial communication. In this context, table-top scene settings or descriptions of text locations in books (Plumert et al., 1995, 2001) have previously been studied and analyzed.

Destination Descriptions

Definition of Destination Descriptions

Destination descriptions are place descriptions provided in the context of a wayfinding task. As such, destination descriptions represent a specific case of referring expressions (Dale, 1992) and can be defined as follows:

Definition: A destination description is a referring expression uniquely describing a destination of a route in a given urban environment, consisting of a hierarchically ordered set of references to prominent spatial features of various types, provided in the context of inferential communication to a hearer with assumed a-priori spatial knowledge of the environment.

Destination descriptions are provided to wayfinders without prescribing them the detailed route to take, taking advantage of their a-priori spatial knowledge whose extent is only inferred. The route planning process is performed independently by the wayfinder, combining the information contained in the destination description with their own spatial knowledge. Should the speaker have had a route in mind, this route needs not be identical to that taken by the

wayfinder. Furthermore, the brevity of destination descriptions is a significant property lowering the effort necessary to remember them and so allows the wayfinder to concentrate the cognitive effort on other tasks, such as wayfinding or driving.

Structure of Destination Descriptions

Imagine the speaker in the process of route planning, directly preceding the communication of a destination description to a hearer. In this cognitive subtask of the spatial communication process the speaker explores her or his mental representation of the route she or he would take (Wunderlich and Reinelt, 1982) and the mental representation of the destination's and the route's surrounding vista spaces (further called the *route context*). In the destination description the speaker then refers to prominent spatial features that are part of this mental representation. Note that the speaker may not necessarily know the whole route, if his or her spatial knowledge is formed from indirect experience, such as reading a map.

In destination descriptions, references are serialized hierarchically, usually in order from references to the most prominent referents in the wider vicinity of the destination to detailed references to less prominent features closer to the destination. Note that the change in granularity of references selected is due to the narrowing of the space within which the destination has to be singled out, and that the first reference selected is not contained in the vista space of the start of the route, as it is the case in turn-based route directions (Maaß, 1994; Wunderlich and Reinelt, 1982).

As the destination description proceed from general to more detailed references, the certainty of the speaker that the hearer has sufficient spatial knowledge to interpret the references progressively decreases. In human communication, speakers typically switch at the point of their loss in confidence from destination descriptions to turn-based directions for the rest of the route.

The minimum spatial detail communicated in a reference occurring in destination descriptions is that of the first reference. This is the reference with the most distinguishing power at the start of the communication, allowing singling out the majority of distractors and narrowing down the location of the destination. The selection of consecutive references then consists of the task of retrieving a relevant reference within the context area specified by the previous reference.

Any reference provides the most relevant information available in the given context, in order to form a referring expression. This context is largely determined by the previous reference, especially its spatial location and extent. The process of selecting of any consecutive reference is then equivalent to the process of selecting the previous reference, in the context of the newly selected reference. This suggests that the reference selection process performed by the speaker can be modeled as a recursive task, requiring explicit knowledge of the location in the context of which the first reference is selected for the hearer—the start of the route.

Relevance of a reference

The application of the principle of relevance to the selection of references for destination descriptions requires a cognitively plausible operationalization of cognitive effort and cognitive effect in a given cognitive environment. First of all, the cognitive environment in which the communication of destination descriptions occurs determines the selection of references. Modeling context is, however, a non-deterministic problem, and only approximations are possible (Dey, 2000). As noted earlier, physical co-presence, linguistic co-presence and community membership are factors facilitating the inference of common knowledge among communicators. The more assumptions about context we commit to, the less general and adaptive the resulting system will be. The model of destination descriptions presented therefore relies only on the following minimal set of assumptions:

A-priori spatial knowledge The hearer is assumed to have common spatial knowledge formed by experiencing the space during navigation in a finite number of previous trips. The extent of this knowledge is not made explicit to the speaker, and it therefore left unspecified in the model proposed.

Functional perspective A functional perspective on the urban structure is determined by the selection of the means of transport, ostensibly disclosed to the speaker.

Co-presence The reference retrieved is relevant from the perspective of the current location, physically or virtually (as determined by previous reference) shared by the hearer with the speaker at the moment of selecting the reference by the speaker.

The requirement of a functional perspective on the spatial knowledge of the hearer links to the condition of possessing a-priori spatial knowledge. This requirement further assumes that the a-priori spatial knowledge of the hearer is conventional in nature, i.e. the means of transport used to follow the directions provided to the hearer allows the use of the spatial knowledge of the speaker. This requirement allows the elements of the city ((Lynch, 1960) to be classified by their function (also see Section 4). For example, the streets in the street network accessible by car will be used as paths by a taxi-driver, and the canals of Venice will be used as a network of paths in the case of a Venetian gondolier. The model presented is constrained to an urban (anthropomorphic) environment. In natural environments the conceptual elements constituting the structure of space may be different (e.g., mountains and rock formations acting as landmarks).

The co-presence requirement has a fundamental impact on the selection of references in destination descriptions. It allows the speaker to assume the spatial context the hearer will have

on the urban environment when interpreting a given reference. This reference is interpreted by the hearer in the spatial context specified by the previous reference, or in case of the first reference of the destination descriptions in the spatial context of the start of the route.

Community membership is reinforced by the requirement of the hearer to have at least coarse spatial knowledge of the environment, i.e. the hearer may be considered a local. The knowledge of the hearer is acquired by perceiving the environment while navigating in the city. The extent of distortions in the spatial mental representation of the hearer is assumed to preserve the partial order of the elements compatible with that of the speaker. The extent of the spatial knowledge as such may be largely different.

Following relevance theory, the relevance of a reference r to an element, in a given context, is modeled as a function of its prominence and its distance from the current location and the destination, in a hierarchical model of the environment. The start s and destination t of the route $route_{s,t}$ provide the parameters of context (or cognitive environment) required by the principle of relevance. The prominence of a reference serves as a means to estimate the cognitive effect of the reference, while the distance relates to the cognitive effort to process the reference (Equation 1):

$$relevance^{(s,t)} = f(rank_r, distance_r^{-1})^{(s,t)} \quad (1)$$

The more prominent an element of the environment is, the less effort is required from the hearer to relate the reference made by the speaker to her or his mental representation of the element. The assessment of prominence of a reference r in our model is only relative and formalized as a partial order $rank_r$). References less prominent than t are irrelevant, as they would not provide any cognitive effect to the hearer. On the other hand, the subjective judgment of distance from the referent, related to the complexity of the structure of the physical

environment, relates to the hearer's cognitive effort, as the ambiguity of interpretation of the reference increases with the size of the choice set of elements that have to be searched through. As noted by Montello (1997), distance knowledge correlates with a process of summing vista spaces. We consider this finding in our simplified operationalization of distance as the topological distance between reference region of landmarks (for more detail, see (Winter et al., 2008)), as presented in Section 5. The concept of topological distance provides us with a measure enabling the cognitive effort required to process a reference to an element to be approximated.

The transition through granularities in destination descriptions is often accompanied with a change of the type of reference—references to districts alternate with those to paths or landmarks. The selection of the referent adapts to the structure of the space, in order to minimize the total number of references and provide the most relevant one, satisfying the equation above.

Integrated Hierarchical Model of the Environment

The content of destination descriptions is largely defined by the hierarchical structure of the speaker's mental representation of the environment and their assumptions about the hierarchical mental representation of the hearer. Hence, a cognitively motivated hierarchical model of the structure of an urban environment is needed.

Experiential Hierarchies of the Structure of the Environment

The urban environment consists of various spatial features, such as suburbs, prominent landmarks, streets and their junctions, water canals and city walls, to name a few. According to Lynch (1960) people categorize these physical features into five types of elements: nodes, paths, edges, districts and landmarks. Lynch's definitions of these types show that the categories relate to the bodily experience acquired during exploration and traveling through the environment.

Hierarchical mental representations of spatial environments are exploited in navigation. To be prominent, a spatial feature must stand out from other features in the environment. People's individual experiential hierarchies represent one of the fundamental structures on which they base their assumptions about the spatial knowledge of others (Fussell and Krauss, 1992). As it is neither common nor practical to externalize these individual mental representations to one's communication partners, a plausible model of reference selection for destination descriptions cannot rely on an individual's hierarchical mental representation, but only on the hierarchical organization of spatial knowledge commonly shared between people living in a city.

Although peoples' individual experiences of an environment are distorted by their actual movement patterns in the city, over time they experience over time more of the city's general structure (e.g., from media, conversations, maps and ad-hoc journeys to unfamiliar parts of the city). Thus, we can assume that a prominent feature of the environment becomes prominent for the majority of those who have experienced it. Individual experiences are assumed to only increase the perception of some features as being prominent, while the lack of individual experiences will lead to gaps in the individual's collection of objectively prominent features. Hence, the common knowledge of prominent features is largely overlapping with the individuals experiences—the more familiar the person is, the larger is the overlap. What is therefore needed is a generic measure of *prominence* for all types of elements of a city, along with a ranking order or classification in a hierarchy.

Modeling Experiential Hierarchies

For each type of element of the city, the prominence of a feature is the result of its visual, semantic and structural characteristics (Raubal and Winter, 2002). For each of the types, however, the importance of the characteristics is different. *Districts* are difficult to be perceived

from a single view point. They are experienced as a homogeneous environment, sharing characteristics and distinct from the surroundings. The semantic and structural characteristics of districts are therefore comparatively stronger than visual ones. *Streets* may be experienced due to their structural properties, facilitating trips through the city due to their structural embedding. And *landmark buildings* are remembered due to their unique visual or semantic properties, such as the distinct characteristics of their façades or the type of business residing in them.

The intensity of experience of a spatial feature is related to its functional, structural or semantic prominence in a specific environment. This experience of prominence establishes a partial order between the individual spatial features, and an experiential hierarchy emerges. Based on these properties we can develop cognitively motivated hierarchical datasets. In a first step, we build hierarchies for individual types of elements of the city, which is done here for landmarks, paths and districts, and later we discuss their integration. In this way, means are discussed to build and integrate hierarchies for landmarks, paths and districts, as representatives of point-like, linear and areal types of elements of the city. One can expect that similar principles may apply for hierarchies of nodes (point-like) and edges (linear).

However, a major barrier towards the integration of edges and nodes is their more ambiguous definition, posing a major obstacle for their identification and consecutive integration in spatial datasets. Therefore, these types of elements of the city are not discussed further.

Hierarchies for landmarks. A ranking order for landmarks based on their individual salience was first presented by Winter et al. (2008). A landmark forms an anchor of its reference regions (Kettani and Moulin, 1999), the region in which the landmark is unique and dominant, i.e., it is the most prominent element of the region. Reference regions can be constructed based on various motivations, for example, a landmark's vista space, or partitions of the point sets of

all landmarks (Winter et al., 2008). Observing the salience of a landmark, neighboring landmarks can be compared by prominence, and only the most prominent are retained in the next level of the hierarchy. The result is a classified (leveled) hierarchy. *Hierarchies for paths*. Lynch's paths are equated with named streets, since the city is experienced through movement within the street network. The basic element, the named street (further used interchangeably with path), consists of all the street segments sharing the same name. Named streets are identifiable and form to some extent a cognitive unit. Tomko et al. (2008) presented a continuous ranking method for streets, coined experiential rank, where their individual salience depends on their functional role in the path network. Frequently used streets (parts of many shortest paths in the city) are considered more prominent than other streets, as they are more likely to be experienced. Experiential rank values are derived from the network analysis measure of betweenness centrality. While salience is reflected in the relative difference between the rank values, it does not result in a leveled hierarchy.

Hierarchies for districts. In principle, the city can be segmented in any partition of two-dimensional areas sharing some common perceptual characteristics and having a distinct inside and outside. For the purpose of this paper, no special cognitively motivated district hierarchy is suggested. Instead, certain levels of the administrative (political) district hierarchy are employed. We argue, similarly to the case of streets, that names of districts make them cognitively salient, as they are also used in human place descriptions.

Integration of Experiential Hierarchies

To demonstrate the feasibility of integrating different hierarchies, we study the hierarchies of the three types of elements derived so far. These types of elements of the city are organized in hierarchies of very different properties:

Named streets are organized in a rank order, which is a function of their likelihood to be used;

Landmarks are ordered by their visual and semantic salience, but are also linked through the properties of their reference regions, themselves a type of districts, which forms a containment hierarchy with $m:n$ relationships; and

Districts such as administrative regions are organized in a $1:n$ containment hierarchy. They also structurally integrate paths and landmarks.

These types of elements also have relations at the same level, not only across hierarchical levels or granularities. Paths connect districts, while landmarks have a perceptual influence on their reference regions and thus give context to districts. Landmarks are also experienced by wayfinders navigating along paths, as they are *en route*. Figure 1 schematically depicts the elementary relationships between the three types of element, as relevant for our model. Note that by composition, other relationships may be formed: the en-route relationship between a landmark and a path can be derived from the relationship between the landmark and the district best matching the reference region it gives context to, and the relationship between this region and the containment relationship with the path.

These relationships can be explicitly encoded in a dataset containing all three hierarchies. This form of integration is presumed for the navigation through these hierarchies as discussed in the next section. They also will appear in the data set created to test the selection of references for destination descriptions in Section 6.

Model of Destination Descriptions

In destination descriptions, a sequence of references identifies the destination of the route. This section develops the rules governing the selection of relevant references from models

of experiential hierarchies of urban environments. Rules for district based references were first developed in Tomko and Winter (2006), including selection algorithms. They are here summarized and extended for other hierarchies. Tomko (2007) presents the formal specification and computational implementation of the rules in a strictly-typed, purely functional programming language Haskell (Peterson et al., 1997), including a test dataset.

A set of minimal rules allows the selecting of references with a preserved topological distance from the start and the destination in order to avoid trivial references. To select the most relevant reference r in a given spatial context, the topological relation of the spatial context defined by the start of the route s , its destination t , and the distance from the potential references is evaluated in the hierarchical structure of the city (for a step-by-step illustration of the operation of the following algorithm, interested readers are referred to (Tomko, 2007)):

1. If current location or destination are not members of the hierarchy, return error and stop;
2. If current location and destination are identical, stop;
3. If current location and destination are neighbors, stop and switch to turn-based directions;
4. If current location and destination have identical or neighboring direct superordinate elements, return a reference to the destination and stop;
5. If an element is a common ancestor of current location and destination, move down a level;
6. If an element is neighbor with an ancestor element of the current location, move down a level;

7. Otherwise: return a reference and continue. Among possible referents, priority is given to the referents along the route. If multiple references are available, select the landmark closest to the destination; and

8. If a landmark is referred to multiple times, remove all but one reference.

To preserve cognitive plausibility in the operationalization of the principle of relevance, instead of Euclidean metrics used to assess the distance between elements, neighborhood relationships in the hierarchical structure of the environment are considered. This is equivalent to the assessment of the topological distance (following the common definition as a number of adjacent elements) between reference regions of a given granularity level. This is just one of the possible approaches, and more sophisticated methods to estimate the effect of the environment on the speaker's judgment of distance could be made. It is, however, difficult to estimate individual judgments of distance, and given the evidence for a qualitative structure of human spatial mental representations the consideration of neighborhood relationships through topological distance provides a reasonable approximation, as shown later in the results. The retrieval of a landmark or its reference region is an equivalent task, and allows an interchangeable selection of the references. At higher granularity levels where the landmark acts as a global one, the preference is given to references to a district, as long as the name of an administrative region can be attributed. Furthermore, a preference for en-route landmarks allows disambiguating between close landmarks of equal prominence.

The reference selected for inclusion in destination descriptions must balance the requirement to be the most prominent possible, and at the same time topologically close to the current spatial context *s*. Not only the balanced consideration of the two factors allows for the evaluation of the relative relevance of a reference, it also allows for the avoidance of *trivial*

references—references requiring low cognitive effort to process, but which provide low cognitive effect in the given context.

While references to landmarks are included by the speaker at the coarsest granularity possible to minimize cognitive effort, they are interpreted by the hearer at the finest granularity available in the hearer’s spatial mental representation. The preserved identity of a landmark across multiple granularities results in a reduction of the resulting reference set. Thus, references to landmarks may be interpreted at multiple granularities. This property may be the reason why references to landmarks are so frequently made by people, and why route directions and destination descriptions with landmarks are considered useful.

To extend the model, we further consider the hierarchical structure of paths in an integrated manner with districts and landmarks. The paths are ordered by prominence through their experiential rank value and integrated into the hierarchy of districts by relation of containment. Note that the destination descriptions model is independent of the ranking of paths used. Paths can connect distant districts, and a reference to such paths can therefore radically decrease the need for other references, especially if the path is prominent. Only references to paths which connect the districts along the route are selected in the model proposed. A reference to a path can be only made if the path is prominent (i.e., has an experiential rank value above mean), or if it provides direct connection of the current spatial context and the destination of the route, when the speaker can refer to the path directly (e.g.: “follow this path to the destination.”). Thus, two further rules can be added:

1. If the current location is connected to the destination by one or more paths, return reference to the most prominent and stop;

2. If the reference to a landmark is of lower prominence than the prominence of a path connecting the current location with the landmark's reference region, add reference to the most prominent of such paths.

A reference to a path directly connecting the current spatial context with the destination is always the most relevant reference possible. Paths act as linear landmarks (Hansen et al., 2006) and thus allow the speaker to significantly reduce ambiguity from the destination descriptions without increasing their length, by covering an extensive part of the environment through which the wayfinder will navigate. They also reduce the cognitive effort necessary for the interpretation of references to landmarks in the proximity of the destination by allowing for more detailed place descriptions. The inclusion of paths in destination descriptions provides an insight to the transition between destination descriptions and turn-based directions in areas where the speaker cannot assume shared knowledge of the wayfinder. The fundamental property of paths, namely the facilitation of connections between two locations, requires the insertion of a district or landmark reference after or before the insertion of the path referent. A reference to a path can never stand alone; the wayfinder needs to receive information about either the direction, or the extent to which to follow a path. The omission of such reference would include inconsistency and ambiguity in the resulting destination description. If the reference to the district or landmark follows the reference to the landmark, it provides both the information about extent and direction. If the reference to district or landmark precedes the reference to the path, the direction is inferred (away from the district or path). The extent has to be acquired from environmental clues by the hearer. This usually occurs when the reference is made to a prominent path directly leading to the destination. Note that the insertion of references to paths does not change destination descriptions into turn-based route directions. The destination descriptions including

paths are still not binding the wayfinder to a single route or approach direction. Furthermore, as shown in the following section, path references usually occur as the last reference in the destination descriptions before the reference to the destination itself.

The simple combination of the topological distance, the hierarchical rank of a spatial element and the context of the route, combined in a set of rules, provide means for a computational interpretation of the principle of relevance enabling the selection of references for destination descriptions.

Model Testing and Results

The inputs for the reference selection model are represented by the integrated hierarchical dataset and a route, representing the result of the route planning process of the speaker. This route is never communicated to the hearer and is only used internally by the model to allow for the selection of en-route landmarks. This route was specified as an ordered list of finest level districts defining the immediate visual space of the route between the start and the destination, as imagined by the speaker. To verify the model, routes of various lengths and complexities across a test area of central Hannover were constructed. Consecutively, destination descriptions for these routes were generated, and their adherence to the rules specified was verified. The destination descriptions were assessed by comparing the resulting sets of references with the characteristics of human destination descriptions summarized in Section **Error! Reference source not found.3**.

The following principal characteristics of destination descriptions were sought:

Consistency: the resulting combination of references must create an unambiguous specification of the destination, thus resulting in a referring expression;

Well-formedness: the destination descriptions should not have redundant references, and each consecutive reference should provide relevant information in the context of the previous one;

Brevity: the resulting destination descriptions should combine integrated references to heterogeneous types of elements in order to achieve relevance and brevity. The reduction of references in comparison to homogeneous destination descriptions and turn-based directions generated by a Web service was sought; and

Content: The selection of relevant references should be dependent on the hierarchical structure of the environment in the proximity of the destination and not on the route imagined by the speaker. The assessment of the plausibility of the content of the destination descriptions is based on the individual judgment and the consultation with a local expert. Plausibility is desired, but remains subjective.

In the following case study, the process of identification of district and landmark-based referents for a route from the *Universität Hannover* to the *Staatstheater-Oper Hannover* (Figure 2 **Error! Reference source not found.**) is demonstrated. The sets of references retrieved are influenced by the content and quality of the dataset. The dataset had a limited extent, and the assessment of the properties of landmarks followed Winter et al. (2008).

Model Behavior

In a first experiment, the rules for the selection of district and landmark-based references were applied. The following references are retrieved for the route:

```
directions = [Rathaus (landmark), Katasteramt (landmark)]
```

These results could be interpreted in a natural language generation task for example as follows (note that generating natural language is beyond the scope of the model presented):

“Where is the opera house? ”

“In the direction of the Rathaus, by the Katasteramt.”

The destination is found in the district equivalent to the city center of Hannover, a reference region assigned to the landmark *Rathaus* in our dataset. The context of the route is then restricted to the general area specified by the reference region of the landmark, and consecutive references of finer granularity are provided (the building of *Katasteramt*, associated with the prominent region of the town known as *Kröpcke*). Our model allows for interchangeable insertion of references to landmarks or districts. The destination descriptions then proceed from a general reference to a landmark with a reference region covering major parts of the city to a more local region. The route description could be completed with the reference to the destination itself, *Staatstheater-Oper*.

While the resulting sets of district and landmark-based references were assessed by a local expert as plausible, specific routes to destinations in areas of low-prominence may lack environmental clues, and therefore the destination descriptions may result in high cognitive effort for the hearer. In such environments, references to path help reduce the cognitive effort of the wayfinder. Furthermore, the integration of paths in the model improves the consistency of the content by providing spatial context to local landmarks. The integration of references to paths results in a new set of references:

```
directions = [Rathaus (landmark), Katasteramt (landmark),
Staendehausstrasse (path)],
```

which translates in the following destination descriptions:

“ In the direction of the Rathaus, by the Katasteramt, off Ständehausstraße.”

While *Ständehausstraße* is not a prominent street of Hannover, it is the most prominent street directly connecting the *Katasteramt* with the destination of the route, the *Staatstheater-Oper* (Figure 2 **Error! Reference source not found.**). As it is the last reference of the destination description, the speaker relies on environmental clues that this street will be identified. Furthermore, a prominent local landmark, the *Katasteramt*, is at one of its extremities. The resulting destination description leads the wayfinder closer to the destination than the pure district and landmark based set of references. Such an integration of diverse references improves the adaptation to the structure of the environment and reduces the ambiguity of the destination descriptions.

Consider a shorter route between the *Allianz-Hochhaus* and the *Statstheater-Oper*, where both the start and destination are within the reference region of the *Rathaus*:

```
directions = [[Katasteramt (landmark), Karmarchstrasse
(path) ]
```

The reference to the *Rathaus* is omitted, in contrast to the start-destination combination of the *Universität Hannover* and the *Staatstheater-Oper*. It would not provide additional information to the wayfinder.

The structure of the environment around the final parts of the route has the most significant influence on the selection of path references. The inclusion of references to paths provide destination descriptions that are not restrictive or patronizing, but provide added guidance on the approach to the destination, and thus require less cognitive effort from the hearer. The resulting destination description is therefore more relevant than the purely district/landmark based destination description. This is easily verifiable, as the two sets are of equal length, but the integrated set is richer in information.

The context in which destination descriptions are provided (e.g., a driver asking a pedestrian for directions) can alter the speaker's choice of references, especially path references. A route generated by Google Maps for car drivers has been used to simulate a route planning process of the speaker considering the needs of a driver. It has been used as input to the model to select references for destination descriptions. The references to districts and landmarks retrieved are identical to those retrieved for the pedestrian route, despite the fact that the route suggested by Google Maps was more complex and longer than a pedestrian route. It avoids the city center, as the *Staatstheater-Oper* is in the pedestrian zone (Figure 3**Error! Reference source not found.**). The resulting turn-based directions contain eleven references. A driver is guided to approach the *Staatstheater-Oper* from a different direction than a pedestrian, and accordingly, in the destination description the reference to a different path is provided:

```
directions = [Rathaus (landmark), Katasteramt (landmark),
Andreasstrasse (path)]
```

This illustrates how the content of destination descriptions is primarily influenced by the granular structure of the city in the proximity of the destination, instead of the route considered by the speaker or the complexity of the environment around the start of the route. Of course, the preference given to local en-route landmarks influences the content of the resulting destination descriptions, but the primary influence is that of the structure of space proximal to the destination described. This effect is also evident when constructing destination descriptions for routes in the opposite direction (from the *Staatstheater-Oper* to the *Universität Hannover*):

```
directions = [Universität Hannover (landmark), Bremer Damm
(path)]
```

While in turn-based directions the only difference in the references retrieved for opposite routes are the result of driving restrictions (e.g., one way streets), there is no overlap between

references included in destination descriptions. Furthermore, the *Universität Hannover* is one of the most prominent landmarks in our dataset, and thus the resulting destination description is very brief, containing only an additional reference to a prominent path directly connecting the city center with the vicinity of the university. A wayfinder with a partial familiarity with this area will be able to find and follow this path to the destination. Depending on the distribution of prominent paths in the proximity of the destination, the path included in the destination descriptions need not be in direct relation with the destination itself (i.e., the destination may not be en-route), as in the example of the destination description to the *Universität Hannover*, where *Bremer Damm* is a highly prominent path in the larger region of the University.

Observations

To study the model, we composed a series of origin-destination pairs covering the center of Hannover, and generated destination descriptions for the routes there and back. The routes connected hierarchically distant regions in the dataset available, specially the areas covered by the campus of the *Universität Hannover* and the center of the city. The depth of the hierarchical dataset consisted of six levels. In the test cases studied, the destination descriptions generated ranged in length between 2 and 3 (or 4 if the reference to the destination itself is included), and were not related to the distance between the origin and the destination (measured as the number of reference regions of finest granularity landmarks between the origin and destination). The resulting sets of references represent a small proportion of the superordinate elements of the destination. Note that a deeper hierarchical structure need not necessarily lead to longer destination descriptions. The patterns identified in the integrated sets of references for destination descriptions tested are shown in Table 1.

In Pattern 1, the reference to a global landmark or significant part of the city narrows down the search space for the next reference. It assists the hearer to interpret the following reference correctly. The consecutive reference is made to a local (en-route) landmark (or its reference region). The reference to a local path between the local landmark and the destination is made if no prominent path connects the destination with the reference region of the local landmark selected previously. This is the case of the example discussed in the first example of Section 6. If a prominent path can be found in the area specified by the global landmark (Pattern 2), it is used to guide the hearer to the next landmark, in which vicinity the destination is found. The reference to the destination found in the vicinity of the local landmark is optional, as shown in the second example in Section 6.

As the dataset used for testing covered a relatively small region densely clustered with well interconnected landmarks, Patterns 3 and 4 were common. They occur when the destination is in the direct vicinity of a global landmark. Then, the global landmark is en-route and serves as a local landmark as well. A reference to a path (prominent or not) is then inserted to guide the wayfinder toward the destination, as shown in the references retrieved for a route between the *Staatstheater-Oper* and the *Institute of Chemistry* of the University of Hannover:

```
directions = [[Universitaet Hannover (landmark), Im Moore
(path) ]
```

Pattern 5 occurs in cases when the destination is located in proximity (en-route) of a highly prominent path, as is the case of the example of the route between the *Staatstheater-Oper* to the *Universität Hannover*) in Section 6. The reference to the destination is then necessary, to provide the wayfinder with directional information. It is assumed that the hearer will be able to identify the destination.

The only means to alternate the selection of the references in the model is by enlarging or reducing the set of prominent paths (by setting a different threshold of experiential rank value). This does not alter the length of the resulting sets of references, but changes the balance between the district/landmark references and references to paths. If the threshold is lower, the balance shifts from district and landmark references to references to paths, and leads to brief destination descriptions. Patterns 2, 3 and 5 become more frequent. If the number of prominent paths in the city is low, the resulting sets of referents exhibit Patterns 1 and 4.

To summarize, the results generated by the model on a series of origin-destination pairs and alternative routes show the following characteristics:

The number of references is not dependent on the complexity of the route retrieved, but on the complexity of the hierarchical organization of the environment in the proximity of the destination;

The number of references retrieved is small in comparison with turn-based directions, and shows consistent patterns; and

The alteration of the threshold defining the set of prominent paths in the destination descriptions does not influence the overall length of the results significantly, but changes the contents pattern of the results. If the threshold is stricter, references to paths become less common and Patterns 2, 3 and 5 (Table 1) are less likely to occur.

Conclusions

Summary

Spatial information is often communicated in situations where message relevance is paramount to the safety of people. Irrelevant information negatively influences understanding of the message or extends the processing time. In this paper, we introduced an inferential model of

destination descriptions for people with a-priori spatial knowledge of the environment, grounded in relevance theory. We identify principles by which the hierarchical structure of the environment, and the spatial context in which the destination descriptions are communicated, determine the content of destination descriptions without the need to consider individual spatial knowledge.

The main contributions presented in this paper are:

An operationalization of the relevance theory in the domain of spatial communication. The relevance of a spatial element in a given context is defined in terms of its relative prominence, distance, and the spatial context of communication;

A formal definition of destination descriptions as referring expressions that present a special case of place descriptions, communicated in an inferential communication. The interpretation of the references requires the consideration of the context in which they are provided;

An executable, cognitively motivated model of destination descriptions, presenting a formal approach to the selection of references, implemented in Haskell; and

The introduction of the concept of integrated experiential hierarchies. Hierarchical datasets organized as experiential hierarchies provide a cognitively inspired means of ranking spatial elements by the inferred perception of their prominence.

Based on a hierarchically structured dataset, the model selects references for the destination descriptions. The model selects references for destination descriptions that satisfy the characteristics of human-generated destination descriptions by adapting to the structure of the spatial vicinity of the destination. The content of the generated sets of references depends only on the complexity of the environment in the proximity of the destination and is therefore not

proportional to the length or complexity of the route. The resulting sets of references are short, thus contributing to their ergonomics. Furthermore, they allow for the inclusion of different types of referents, selected based on their prominence. Hence, destination descriptions reduce the communication to spatial information relevant for the wayfinder and consecutively reduced their cognitive workload.

Recently, Wu and Winter (2008) have demonstrated that already the simplest type of destination descriptions (based on street names only) results in consistently shorter descriptions than turn-based directions. District and landmark-based destination descriptions will, in the worst case, have a maximum length of the depth of the hierarchical system. The depth of such systems is a fraction of the number of the entities contained, hence also destination descriptions based on districts or landmarks are on average shorter than turn-based directions. The combination of references to districts, landmarks and prominent paths will therefore always produce destination descriptions that outperform turn-based directions in length.

Together with the model of destination descriptions, a novel, cognitively motivated approach to the integration of hierarchical datasets of landmarks, districts and paths is presented. Integrated hierarchical datasets link in a tight structure the experiential hierarchies of heterogeneous spatial elements. The low frequency of prominent referents in experiential hierarchies hints at why individuals' estimates of shared knowledge with others is highly correlated, and allows for a qualified estimate of general familiarity with an element of the city.

Discussion

Cognitive Workload and Destination Descriptions. Destination descriptions are a specific form of spatial communication, combining the properties of route directions and place descriptions. It appears that the length of destination descriptions is related to the depth of the

experiential hierarchies, not the length of the route. While the number of references in turn-based directions grows linearly with the complexity of the route, the number of references in destination descriptions grows only logarithmically, being proportional to the depth of the granular model of the environment. A large number of elements can be contained in a system of a few granularity levels. Furthermore, the recursive selection of references in destination descriptions re-evaluates the changing spatial context in which every consecutive reference is selected and allows for a further reduction of the destination descriptions' length.

Reliability of Inference of Common Spatial Knowledge. As shown, the shared context between the hearer and the speaker in inferential communication is a major influence on the choice of referents. The selection of referents from experiential hierarchies influences the success of communication. As the distribution of prominent spatial features follows a heavy-tailed distribution (Tomko et al., 2008), the likelihood to experience some of the prominent streets and landmarks in the environment is higher by magnitudes to that of experiencing the marginal ones. This is understandable, as prominence is a function of rarity of a phenomenon. Due to the distribution of prominence in experiential hierarchies, a relatively low number of trips through the environment should provide a relatively good spatial knowledge allowing for successful communication at least at a coarse level of granularity. This allows experiential hierarchical datasets to be used to estimate the spatial knowledge of the user. Note that in urban environments that lack landmarks the resulting hierarchical structure of space may be too shallow to construct destination descriptions—indeed, the lack of legibility of such spaces may require the communication using turn-based directions to reduce the ambiguity of the communication.

Experiential Urban Data Structures for Destination Descriptions. The argumentation presented in this paper starts from the position that structural and visual properties of the

elements of the city are paramount in the inference of shared spatial knowledge. The experience of visual and structural prominence is common among the population with similar spatial behavior. The shared experience is further strengthened by secondary experience of these prominent features, through indirect sources such as maps, news articles and Web resources. While these sources also allow some judgments about others' perception of semantic prominence of a spatial feature, these judgments are not necessarily applicable to the same extent as those based on visual or structural properties. For example, the café where one eats lunch every day may be highly prominent in one's spatial mental representation, but without comparatively more extensive background information (derived from e.g., community membership) others are not able to infer the extent of this prominence. First attempts to infer semantic prominence of spatial objects are based on the assessment of the spatial distribution of the category of these objects in space (Tomko and Purves, 2008).

The quality of the dataset influences the estimate of relevance of the referents retrieved by the model. For instance, while cognitively plausible, the construction of landmark hierarchies based exclusively on visibility produced distortions in the dataset, compared to the perception of the centre of Hannover by locals. Local experts indicated that while the references selected by the computational model are usable and satisfactory, more appropriate references are available.

Semantic properties of spatial elements can, however, be used in destination descriptions in an indirect manner. A hearer can be sensitized, or primed, to a specific semantic characteristic of a landmark by the speaker or the navigation system. Once seen, the landmark will be perceived as salient. This mechanism allows hearers to successfully use destination descriptions containing references which may not be usually perceived as prominent by the hearers.

Outlook

The inferential model of selection of references for destination descriptions provides an alternative solution to personalization of route directions through systems relying on user profiles, using historic information for optimized, personalized information provision in the future (Patel et al., 2006). When first initialized, the system has no previous knowledge of the user's knowledge (unless the user explicitly declares some knowledge in their profile). The model presented infers the relevance of references to spatial features without prior explicit personalization. It provides partially adapted information from the very first use. It can, therefore, complement learning agent-based systems, to provide a fully adaptive system.

A navigation service providing destination descriptions will need to externalize the information in a form adapted to the users of the system. Externalization methods, such as natural language generation or schematic visualization interfaces need to be devised to communicate the references selected in an appropriate manner. Furthermore, the user may not be, for various reasons, satisfied by the model's selection of references. Well designed user interfaces should cater for such situations, e.g., through user-initiated dialog.

It is possible that the wayfinder's spatial knowledge is insufficient to supplement destination descriptions with information necessary to reach the destination, e.g., when the route leads through environments with low density of landmarks and prominent streets. Then, the combination of destination descriptions and turn-based directions is a common feature of human-generated navigation instructions. Destination descriptions provided at coarser granularities are coupled with turn-based route directions in the proximity of the destination. The change of the communication mode is based on the speaker's assumption that the hearer's spatial knowledge is not complete enough to be able to identify and reach the destination without the added detail.

The transition to turn-based directions can be enhanced with approaches to further improve the cognitive ergonomics of the resulting directions (Klippel, 2003; Richter, 2007a). Research on the integration of turn-based directions with the model of destination descriptions presented, allowing a smooth transition between destination descriptions and turn-based directions is currently being undertaken (Richter, 2007b; Srinivas and Hirtle, 2008).

Finally, further work is necessary to extend the concept of integrated experiential hierarchies to cater for references to nodes and edges, including prominent complex configurations of multiple spatial elements of different types. It is hypothesized that experiential hierarchies of nodes may be constructed using network analysis approaches similarly to path experiential hierarchies.

References

- Allen, G. L. (1999). Spatial Abilities, Cognitive Maps, and Wayfinding. In R. G. Golledge (Ed.), *Wayfinding Behavior* (pp. 46-80). Baltimore: Johns Hopkins University Press.
- Clark, H. H., & Marshall, C. R. (1981). Definite Reference and Mutual Knowledge. In A. K. Joshi, B. L. Webber & I. A. Sag (Eds.), *Elements of Discourse Understanding* (pp. 10-63). Cambridge: Cambridge University Press.
- Couclelis, H., Golledge, R. G., Gale, N., & Tobler, W. (1987). Exploring the Anchorpoint Hypothesis of Spatial Cognition. *Journal of Environmental Psychology*, 7, 99–122.
- Dale, R. (1992). *Generating Referring Expressions: Constructing Descriptions in a Domain of Objects and Processes.*: MIT Press.
- Dale, R., Geldof, S., & Prost, J.-P. (2005). Using Natural Language Generation in Automatic Route Description. *Journal of Research and Practice in Information Technology*, 37(1), 89-105.
- Dey, A. K. (2000). *Providing Architectural Support for Building Context-Aware Applications*. Unpublished PhD thesis, Georgia Institute of Technology.
- Frank, A. (2003). Pragmatic Information Content: How to Measure the Information in a Route Description. In M. Duckham, M. Goodchild & M. Worboys (Eds.), *Foundations of Geographic Information Science* (pp. 47-68). London and New York: Taylor & Francis.

- Fussell, S. R., & Krauss, R. M. (1992). Coordination of Knowledge in Communication: Effects of Speakers' Assumptions About What Others Know. *Journal of Personality and Social Psychology, 62*(3), 378-391.
- Gerrig, R. J., Brennan, S. E., & Ohaeri, J. O. (2001). What Characters Know: Projected Knowledge and Projected Co-Presence. *Journal of Memory and Language, 44*, 81-95.
- Grice, P. (1957). Meaning. *Philosophical Review, 66*, 377-388.
- Hansen, S., Richter, K.-F., & Klippel, A. (2006). Landmarks in OpenLS: A data structure for cognitive ergonomic route directions. In M. Raubal, H. Miller, A. Frank & M. Goodchild (Eds.), *Geographic Information Science* (Vol. 4197, pp. 128-144). Berlin: Springer-Verlag.
- Hirtle, S. C. (2003). Neighborhoods and Landmarks. In M. Duckham, M. Goodchild & M. Worboys (Eds.), *Foundations of Geographic Information Science* (pp. 191-203). London and New York: Taylor and Francis.
- Hirtle, S. C., & Jonides, J. (1985). Evidence of Hierarchies in Cognitive Maps. *Memory and Cognition, 13*, 208-217.
- Ishikawa, T., & Montello, D. R. (2006). Spatial Knowledge Acquisition from Direct Experience in the Environment: Individual Differences in the Development of Metric Knowledge and the Integration of Separately Learned Places. *Cognitive Psychology, 52*(2), 93-129.
- Kettani, D., & Moulin, B. (1999). A Spatial Model Based on the Notions of Spatial Conceptual Map and of Object's Influence Areas. In C. Freksa & D. M. Mark (Eds.), *Spatial Information Theory. Cognitive and Computational Foundations of Geographic Information Science: International Conference COSIT'99, Stade, Germany, August 1999. Proceedings* (Vol. 1661, pp. 401-416). Berlin, Heidelberg: Springer-Verlag.

- Klippel, A. (2003). *Wayfinding Choremes. Conceptualizing Wayfinding and Route Selection Elements*. Unpublished PhD Thesis, University of Bremen, Bremen.
- Klippel, A., Tappe, H., & Habel, C. (2003). Pictorial Representations of Routes: Chunking Route Segments during Comprehension. In C. Freksa, W. Brauer, C. Habel & K. F. Wender (Eds.), *Spatial Cognition III --- Routes and Navigation, Human Memory and Learning, Spatial Representation and Spatial Learning* (Vol. 2685, pp. 11-33). Berlin: Springer-Verlag.
- Lau, I. Y.-M., & Chiu, C.-y. (2001). I Know What You Know: Assumptions about Others' Knowledge and their Effects on Message Construction. *Social Cognition*, 19(6), 587-600.
- Lynch, K. (1960). *The Image of the City*. Cambridge, Massachusetts, USA: The MIT Press.
- Maaß, W. (1993). A Cognitive Model for the Process of Multimodal, Incremental Route Descriptions. In A. Frank & I. Campari (Eds.), *Spatial information theory: A theoretical basis for GIS* (pp. 1-13). Berlin: Springer-Verlag.
- Montello, D. R. (1997). The Perception and Cognition of Environmental Distance: Direct Sources of Information. In S. C. Hirtle & A. Frank (Eds.), *Spatial Information Theory - A Theoretical Basis for GIS. International Conference COSIT '97 Laurel Highlands, Pennsylvania, USA, October 15-18, 1997 Proceedings* (Vol. 1329, pp. 297-311). Berlin-Heidelberg: Springer-Verlag.
- Paraboni, I., van Deemter, K., & Masthoff, J. (2007). Generating Referring Expressions: Making Referents Easy to Identify. . *Computational Linguistics*, 33(2), 229-254.
- Patel, K., Chen, M. Y., Smith, I., & Landay, J. A. (2006). *Personalizing Routes*. Paper presented at the ACM Symposium on User Interface Software and Technology, Montreux, Switzerland.

Peterson, J., Hammond, K., Augustsson, L., Boutel, B., Burton, W., & Fasel, J., et al. (1997).

Report on the Programming Language Haskell (Yale University Research Report No.

No. YALEU / DCS/ RR-1106): Yale University

Plumert, J. M., Carswell, C., de Vet, K., & Ihrig, D. (1995). The Content and Organization of

Communication about Object Locations. *Journal of Memory and Language*, 37, 477-498.

Plumert, J. M., Spalding, T. L., & Nichols-Whitehead, P. (2001). Preferences for Ascending and

Descending Hierarchical Organization in Spatial Communication. *Memory and*

Cognition, 29(2), 274-284.

Raubal, M., & Winter, S. (2002). Enriching Wayfinding Instructions with Local Landmarks. In

M. J. Egenhofer & D. M. Mark (Eds.), *Geographic Information Science: Second*

International Conference, GIScience 2002, Boulder, CO, USA, September 25-28, 2002.

Proceedings (Vol. 2478, pp. 243-259). Berlin: Springer.

Richter, K.-F. (2007). From Turn-By-Turn Directions to Overview Information on the Way To

Take. In G. Gartner (Ed.), *Location Based Services and TeleCartography* (pp. 205–214).

Berlin, Heidelberg: Springer-Verlag.

Richter, K.-F. (2007). *Context-Specific Route Directions: Generation of Cognitively Motivated*

Wayfinding Instructions. Unpublished PhD, University of Bremen.

Shannon, C. E., & Weaver, W. (1949). *The Mathematical Theory of Communication*. Urbana,

Illinois: The University of Illinois Press.

Siegel, A. W., & White, S. H. (1975). The Development of Spatial Representations of Large-

Scale Environments. *Advances in child development and behavior*, 10, 9-55.

Sperber, D., & Wilson, D. (1986). *Relevance*. Oxford, UK: Basil Blackwell Ltd.

- Srinivas, S., & Hirtle, S. C. (2007). Knowledge Based Schematization of Route Directions. In *Spatial Cognition V: Reasoning, Action, Interaction: International Conference Spatial Cognition 2006, Bremen, Germany*. Berlin, Heidelberg: Springer-Verlag.
- Taylor, H. A., & Tversky, B. (1992). Descriptions and Depictions of Environments. *Memory and Cognition*, 20(5), 483-496.
- Tomko, M. (2007). *Destination Descriptions in Urban Environments*. Unpublished PhD. Thesis, University of Melbourne, Melbourne, Australia. Available at: <http://eprints.infodiv.unimelb.edu.au/archive/00003594/>.
- Tomko, M., & Purves, R. S. (2008). *Categorical Prominence and the Characteristic Description of Regions* Paper presented at the Semantic Web meets Geospatial Applications, held in conjunction with AGILE 2008, Girona, Spain.
- Tomko, M., & Winter, S. (2006). Recursive Construction of Granular Route Directions. *Journal of Spatial Science*, 51(1), 101-115.
- Tomko, M., Winter, S., & Claramunt, C. (2008). Experiential Hierarchies of Streets. *Computers, Environment and Urban Systems*, 32(1), 41-52.
- Tversky, B. (2003). Places, Points, Planes, Paths, and Portions. In E. van der Zee & J. Slack (Eds.), *Representing Direction in Language and Space* (pp. 132-143). Oxford: Oxford University Press.
- Wiener, J. M., & Mallot, H. A. (2003). 'Fine-to-Coarse' Route Planning and Navigation in Regionalized Environments. *Spatial Cognition and Computation*, 3(4), 331-358.
- Winter, S., Tomko, M., Elias, B., & Sester, M. (2008). Landmark Hierarchies in Context. *Environment and Planning B: Planning and Design*, 35(3), 381-398.

- Worboys, M. (2003). Communicating Geographic Information in Context. In M. Duckham, M. Goodchild & M. Worboys (Eds.), *Foundations of Geographic Information Science* (pp. 33-45). London and New York: Taylor & Francis.
- Wu, Y., & Winter, S. (2008, poster). *Communicating with Navigation Systems about Places*. Poster presented at the Spatial Cognition 2008, Freiburg, Germany.
- Wunderlich, D., & Reinelt, R. (1982). How to get There from Here. In R. J. Jarvella & W. Klein (Eds.), *Speech, Place, Action* (pp. 183-201). Chichester, NY: John Wiley & Sons.

Author Note

The research has been supported by the Cooperative Research Centre for Spatial Information, whose activities are funded by the Australian Commonwealth's Cooperative Research Centres Programme. The second author acknowledges a fellowship by the Hanse Institute for Advanced Studies, Germany. The support of the National Mapping Agency of Lower Saxony, Germany (Landesvermessung und Geobasisinformation Niedersachsen) which provided the testing dataset for Hannover (ATKIS Basis DLM (www.atkis.de)) is gratefully acknowledged. We are grateful to three anonymous reviewers for their suggestions and comments. Requests for reprints should be sent to Martin Tomko, Department of Geography, University of Zurich – Irchel, Winterthurerstr. 190, CH-8057 Zurich, Switzerland, Email: martin.tomko@geo.uzh.ch.

Table 1. Patterns observed in sets of references in destination descriptions (D–district, L^G –global landmark, L^L –local landmark, P–path, P^{Prom} –prominent path), t–destination, where \oplus is the exclusive disjunction.

Pattern	1	2	3	4	5
1 st reference	$D \oplus L^G$	$D \oplus L^G$	$L^G = L^L$	$L^G = L^L$	P^{Prom}
2 nd reference	$D \oplus L^L$	P^{Prom}	P^{Prom}	P	
3 rd reference	P	$D \oplus L^L$			
Optional reference	t	t	t	t	t

Figure Captions

Figure 1. Schema of relations between heterogeneous types of elements of the city in integrated hierarchies.

Figure 2. References selected for the destination descriptions. The path network is shown in light gray for illustration. The thick black line symbolizes the coverage of the landmark/districts dataset boundary.

Figure 3. Map of the route between the Universität Hannover and the Staatstheater-Oper (© 2007, Google Maps).





