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Pragmatic Construction of Destination Descriptions for Urban Environments

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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. In this paper, 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 allows for a provision of 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 the equivalent turn-based directions.
Keywords: relevance, spatial communication, destination descriptions, experiential hierarchies

1 Introduction

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

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"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 services expect no familiarity of the user with the environment at all, regardless of the users actual familiarity. 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 of some familiarity with an environment. This means, destination descriptions apply for the everyday navigation of people in their home urban environment. They apply for cases such as finding a shop or a friends 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 larger than for turn-by-turn directions. Accordingly, our goal is to generate the references in destination descriptions automatically.

The research presented in this paper addresses the hypothesis that the content of destination descriptions is determined by the structure of the urban environment in the proximity of the destination. Consequently, we have to address the hierarchical conceptualizations of urban environments, and a way to navigate in these hierarchies for the selection of appropriate, i.e., relevant and unambiguous references. As a result, we present an executable reference selection model grounded in relevance theory, a branch of pragmatic communication theory.

This paper is structured as follows: in the next Section, we introduce our motivation in more details 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 how to structure data in integrated experiential hierarchies usable for the task of automated selection of references for destination descriptions. Section 5 introduces in more detail 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.

2 Background

2.1 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 a 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) and Richter (2007a) focused on chunking of turn-based route directions based on the structural properties of the route described, in order to decrease the number of information items in the resulting directions. The level of detail of the directions provided is therefore 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. The use of administrative street hierarchies may not necessarily be always cognitively plausible.

Due to at least coarse a-priori knowledge of the environment, locals may often find turn-based directions excessive and patronizing. They only need the information about where to get, and they substitute the information about how to do so on their own.

2.2 Experiencing Space

People store their spatial knowledge in mental representations of space. This environmental knowledge is acquired through interaction with the environment and improves in completeness and accuracy over time (Allen, 1999; Ishikawa and Montello, 2006; Siegel and White, 1975). Mental representations acquired through direct experience of the environment is 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 this hierarchical organization of spatial knowledge (Hirtle, 2003; Hirtle and Jonides, 1985; Taylor and Tversky, 1992). This hierarchical organization is further reflected in spatial reasoning, where dependence between an entitys membership in a hierarchy and its use in the spatial task was 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, common knowledge of the environment can be operationalized in so-called experiential hierarchies (Section 4.1).

2.3 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. Among notable exceptions are the works of Frank (2003) and Worboys (2003), grounding their works on 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. 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 environment. 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. Cognitive environment is then defined as a set of assumptions bearing on comprehension available to a cognitive agent. In this environment, the act of communication presents 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. Thus, cognitive agents pick the most relevant stimulus in a given communication situation. 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 a stimulus is therefore left to the hearer, trying to interpret 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 or form.

The process of maximization of 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 co-presence, linguistic co-presence and community membership among the fundamental factors of the cognitive environment influencing comprehension and the inference of the extent of common knowledge, available to all communication partners. 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 in (Dale, 1992) as an expression uniquely identifying a specific entity. 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.

3 Destination Descriptions

3.1 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, profiting of their a-priori spatial knowledge, which extent is only inferred. The route planning process is performed independently by the wayfinder, combining the information contained in the destination description with 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.

3.2 Structure of Destination Descriptions

Imagine the speaker, mentally traveling through the mental representation of the route and its surrounding vista spaces (further called the *route context*), and referring to prominent entities which are part of this mental representation. 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 (Figure 1). 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.

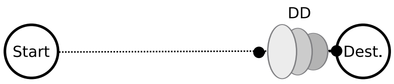

Figure 1.: Structure of destination descriptions.

As the directions proceed from general to more detailed references, the certainty of the speaker that the hearer has sufficient spatial knowledge 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 to single out the majority of distractors and narrow 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 by the previous reference. The process of selection of any consecutive reference is then equivalent to the process of selection of the first reference, in the new context. This suggests that the process can be modeled as a recursive task of selection of the most relevant reference in the context specified by the previous reference. This also requires explicit knowledge of the the location providing the context in which the first reference is selected—the start of the route.

3.3 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. 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 explicitly known 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, ostensively 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 selection of the reference by the speaker.

The requirement of a functional perspective on the spatial knowledge of the hearer links to the condition of possession of a-priori spatial knowledge. It 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 to classify the elements of the city ((Lynch, 1960), also see Section 4) by their function. 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 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).

Co-presence allows the speaker to assume the spatial context the hearer will have on the urban environment when interpreting a given reference. This co-presence need not be physical, but can be projected (Gerrig et al., 2001). Projected co-presence allows the speaker to infer the spatial context of the hearer at the moment of interpretation of a reference provided in the destination descriptions. A reference is interpreted by a hearer in the spatial context specified by the previous reference, or in case of the first reference of the destination descriptions in the context of the start of the route. Co-presence requirement has a fundamental impact on the selection of references in destination descriptions.

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:

$$relevance_r^{(s,t)} = \left(\frac{rank_r}{distance_r}\right)^{(s,t)} \tag{1}$$

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. References less prominent then t are irrelevant, as they would not provide any cognitive effect to the hearer. On the other hand, distance from the referent increases the hearer's cognitive effort, as the ambiguity of interpretation of the reference increases with the size of the choice set of elements that has to be searched through. Distance is thus a measure enabling the cognitive effort required to process a reference to an element to be estimated.

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 and 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.

4 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.

4.1 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 features into five kinds of elements: places, paths, barriers, districts and landmarks. Lynch's definitions of these terms show that they stand for mental conceptualizations related to the bodily experience of exploring or 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. While 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), it is impossible to externalize individual mental representations. In fact, a model even should not reflect an individual person's hierarchical mental representation, but only 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, 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 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 indiviidual experiences—the more familiar the person is the larger is the overlap. What is therefore needed is a generic measures of *prominence* for all types of elements of a city, along with a ranking order or classification in a hierarchy.

4.2 Modelling Experiential Hierarchies

For each type of elements 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 these types, however, the relevance of these 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 surrounding. The semantic and structural characteristics of districts are therefore comparatively stronger then 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 a 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. Later we discuss their integration.

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.

4.3 Integration of Experiential Hierarchies

To demonstrate the feasibility of integrating different hierarchies, we will 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, which forms a containment hierarchy with $m : n$ relationships;
- administrative districts are organized in a $1 : n$ containment hierarchy. They also structurally integrate paths and landmarks.

These types of elements have also 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, they are *en route*. Figure 2 schematically depicts these possible relationships.

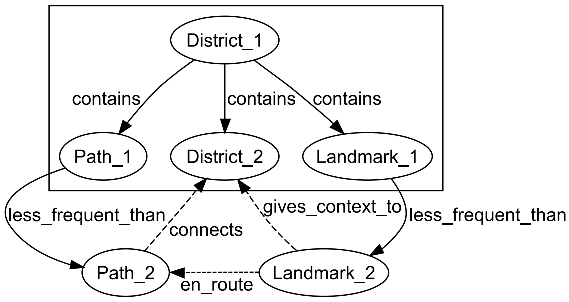

Figure 2.: Schema of relations between heterogeneous types of elements of the city in integrated hierarchies.

These relationships can be added to a dataset containing the three hierarchies. Such an integration is presumed when in the next section the navigation through these hierarchies is discussed. They also will appear in the data set created to test the selection of references for destination descriptions in Section 6.

5 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.

A set of minimal rules allows selecting references with a preserved topological distance form 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:

1. If current location or destination are not members of the hierarchy, throw exception.
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.
8. If a landmark is referred to multiple times, remove all but one reference.

To preserve cognitive plausibility, the metrics used to assess the distance is not Euclidean, but topological, and it operates in the hierarchical structure of the environment considered. A preference for en-route landmarks allows to disambiguate between close landmarks of equal prominence. 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.

The reference selected for inclusion in destination descriptions must balance the requirement to be the most prominent possible, and at ther 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 landmarks 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. 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 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 then 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. This property provides an insight to the transition between destination descriptions and turn-based directions. Furthermore, structuraly prominent paths allow reduce cognitive effort in the interpretation of references to landmarks and regions in the proximity of the destination.

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 directions. 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.

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 to select references for destination descriptions.

6 Model Testing and Results

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 content of the destination descriptions was assessed by comparing the resulting sets of references with the characteristics of destination descriptions summarized in Section 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.
- 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 *Staatsoper Hannover* (Figure 3) 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).

6.1 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, Kroepcke]
```

These results can be interpreted as the following destination descriptions generated by a local:

> "Where is the opera house?"
> "In the direction of the Rathaus, next to the Kroepcke. "

The destination is found in the proximity of the first landmark specified, the global landmark *Rathaus*. 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 *Kröpcke*). The destination descriptions proceed from a general reference to a landmark with a reference regions covering major parts of the city to a more local landmark. The route description could be completed with the reference to the destination itself, Staatsoper.

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 resulting destination descriptions may result in high cognitive effort of the hearer. The integration of paths in the model reduces further improves the consistency of the content of the references retrieved by matching references to local landmarks with references to paths. The integration of references to paths results in a new set of references:

```
directions = [Rathaus, Kroepcke, Staendehausstrasse]
```

which translates in the following destination descriptions:

> *" In the direction of the Rathaus, close to the Kröpcke, take the Ständehausstraße."*

While Ständehausstraße is not a prominent street of Hannover, it is the most prominent street directly connecting the Kröpcke with the destination of the route, the Staatsoper (Figure 3). 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 Kröpcke, 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 ambiguity of the destination descriptions.

In general, only the structure of the environment arount the final parts of the route influences the selection of path references. The inclusion of references to paths provide destination descriptions that are not patronizing, but provide added guidance on the approach to the destination, and thus require less 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 more information rich.

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. A different

Figure 3.: References selected for the destination description for the route from Universität Hannover to the Staatsoper. The route is shown in gray shading. The references retrieved: Rathaus, Kröpcke and the Ständehausstraße are labeled.

functional perspective on the path network influence the selection of references due to the preference of en-route landmarks. For example, the route suggested by Google Maps is complex and avoids the city center, as the Staatsoper is in the pedestrian zone (Figure 4). The resulting turn-based directions contain eleven references. A driver is guided to approach the Staatsoper from a different direction than a pedestrian.

The route generated by Google Maps has been used as input to generate destination descriptions. The references retrieved are identical to those retrieved for the direct, pedestrian route. 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. 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 overall structure of space.

6.2 Observations

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

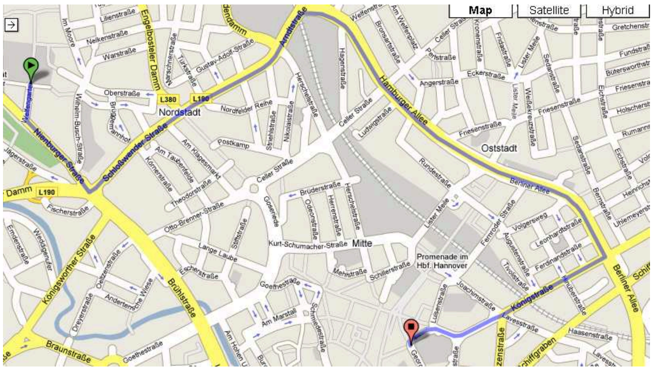

Figure 4.: Map of the route between the Universität Hannover and the Staatsoper (© 2007, Google Maps).

- 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 and shows similar patterns;
- The alteration of the threshold defining the set of prominent paths in the destination descriptionsdoes not influence the overall length of the results significantly, but changes the contents pattern of the results.

In the test cases studied, the length of generated sets of references in the integrated hierarchical spatial data structure of Hannover ranged 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. The depth of the hierarchical dataset consisted of six levels. Thus, 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 descriptionstested 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. If such a path can be found in the area specified by the global landmark (Pattern 2), it is used to guide the hearer to the local landmark, in which vicinity the destination is found. The reference to the destination found in the vicinity of the local landmark is optional.

Table 1:
: Patterns in sets of references in destination descriptions(D–district, L^G–global landmark, L^L–local landmark, P–path, P^{Prom}–prominent path).

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

Patterns 3 and 4 occur when the destination is in the direct vicinity of the 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. Pattern 5 occurs in cases when the destination is located in proximity (en-route) of a prominent path. 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 3, 4 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 2.

7 Conclusions

7.1 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.
- 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 outputs of the model satisfy the characteristics of human-generated destination descriptions: the generated sets of references are short, and are not proportional to the length or complexity of the route; the inclusion of different types of referents adapts to the structure of space and reduces the cognitive workload of the wayfinder.

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.

7.2 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.

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. The inference of semantic prominence of an element, on the other hand, is problematic and highly subjective (i.e., individual to a person).

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.

7.3 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., trough 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 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 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 barriers, 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.

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