CONSIDERATIONS FOR EFFICIENT COMMUNICATION OF ROUTE DIRECTIONS

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ABSTRACT:

We can observe that people familiar with an environment give route directions of varying granularity to other locals. Such route directions are typically shorter than the turn based directions of current navigation services, and contain only references of high relevance to the wayfinder. Studying these route directions of varying granularity reveals that they are intended to be memorized, a property that requires a low cognitive workload of the wayfinder during their usage. The short-term memory span of humans imposes a limit on the amount and the structure of information communicated. We argue that route directions of varying granularity provide the means to respect these limits by efficient recoding.

1 INTRODUCTION

Route directions of navigation services are characteristic in their constant level of detail. With increasing length of the route, the route directions are hard to memorize and contain a high proportion of references of low relevance to wayfinders that are familiar with the environment: locals. For that reason, car navigation systems or mobile location-based services communicate their route directions sequentially. Each utterance is given at the time the corresponding wayfinding action has to be undertaken. In this case, the wayfinder has to constantly pay attention to the communication channel, waiting for new messages. The wayfinder also has to assemble the information from the previous and the current utterance to more complex activities. For example, consecutive utterances such as *"Drive straight for three intersections"* and, after some time, *"At the next intersection turn right into the A Street"* require first the action of travelling straight for three intersections, and then at the third intersection to turn right into a street that is named *A Street*. While the wayfinder is counting intersections she has to match *third* and *next*, and to manage the redundant information *into A-Street*. Afterwards, the current direction becomes in short term memory the previous one, and a new one is provided; a longer sequence producing a context or story line is never provided. In this form of communication, cognitive overload is produced by both aspects, the short term memory keeping frequently changing information, and redundancy that overrules relevance and requires conflict resolution.

In contrast, route directions given by people to other locals are typically of varying granularity. We call them *granular route directions* (Tomko and Winter, accepted, Tomko and Winter, 2005). Such route directions are typically shorter than the turn based directions of current navigation services. They refer only to relevant features, if we define relevance by the need of disambiguation. The direction giver infers from the communication situation the wayfinder's knowledge, and chooses an appropriate amount of detail. Granular route directions can integrate references to multiple elements of the city as they were specified by Lynch (1960).

Our hypothesis is that the content and structure of granular route directions is a result of a recoding process aimed at conveying only relevant information in a manner not exceeding the span of the short-term memory of the wayfinder. We will argue that the length of route directions is limited by the human short-term memory span (Miller, 1956), and that by referencing to multiple types of elements of the city, i.e., by producing a context, the cognitive effort of memorizing is reduced. The efficiency of information recoding in granular route directions is demonstrated on a small corpus of survey data provided by wayfinders with high level of familiarity with the city.

The remainder of the paper is structured as follows: We first introduce the concept of granular route directions as a method of lowering the cognitive workload of a local wayfinder. Afterwards, we introduce the hierarchies of the individual elements of the city in an urban environment, as a means to link relevance and prominence. We then introduce our model for the automated generation of granular route directions. The model is compared to a corpus of granular route directions produced by locals in a small experiment. Finally, we generalize the principles of communication of spatial information in circumstances where low cognitive workload is required. The paper ends with conclusions and an outlook.

2 GRANULAR ROUTE DIRECTIONS

Aspects of the adaptation of route directions to human conceptualization of space are an important subject of research. Timpf et al. (1992) developed a hierarchical model of concepts in route planning for wayfinders in a hierarchically structured road network. It uses a single type of element of the city, roads, and builds on the traditional turn-by-turn approach to route directions.

Locals, however, rarely convey route directions in such full detail. For example, imagine the following conversation between a taxi passenger and a driver, which starts at Melbourne Airport:

Passenger:"To Turnbull Alley, please."
Driver:"??"
Passenger:"It is in the city, a small laneway just opposite the Parliament."
Driver:"Very well."

The described route leads from Melbourne Airport to a location in the city center. Interestingly, the passenger describes only the *location* of the target, but not the *route* itself. The passenger assumes that the taxi driver can fill in the route to the referred target, by means of previously acquired knowledge of the street network. Furthermore, the passenger describes the location of the target in a *hierarchical manner*, with increasing amount of detail. These *granular route directions* route directions are the result of an internal information recoding process, creating references to the experiential structure of the environment and at the same time decreasing the number of references to a minimum. For the same route, the turn-by-turn directions of a state-of-the-art navigation service contains directions with 14 references.

3 HIERARCHICAL CITY STRUCTURE

The relevance of a reference to an element of the city in route directions is not only a function of the position of the element with regard to the route and the position of the wayfinder along it, but also depends on the prominence of the element (Klippel and Winter, 2005). An urban environment consists of five classes of elements of the city: paths, nodes, barriers, districts and landmarks (Lynch, 1960). Their prominence, however, is not uniform, and hence, prominence forms hierarchies within the different classes of elements of the city.

Hierarchical conceptualizations are used for fast retrieval of approximate, but sufficient information. Recoding processes of selection and aggregation provide means to transit between detailed information and the more granular information provided at hierarchically higher levels of conceptualization (Timpf and Egenhofer, 1997). The results achieved are optimized, with balance between accuracy and costs of retrieving the information for supporting a given task. Hierarchical conceptualizations of an urban environment (*experiential hierarchies*) are formed by experiencing the city by navigation through the street network. As such they are different from other hierarchies, e.g., administrative ones. For instance, names of administrative districts are used in communication, but their administrative boundaries and hierarchical grouping may be different from the mental representations in experiential hierarchies of locals (Montello et al., 2003).

4 COMPUTATIONAL CONSTRUCTION OF RELEVANCE-BASED GRANULAR ROUTE DIRECTIONS

For the above reasons, urban data structured according to experiential hierarchies are necessary for automatic construction of granular route directions. Previously we have proposed and implemented a computational model for the construction; the model is based on evaluation of the relevance of possible references (Tomko and Winter, accepted, Tomko and Winter, 2005). Here, relevance is expressed in constraints on the hierarchical level of potential references and their topological distance from the previous reference. These constraints are applied recursively to retrieve the whole sequence of references in granular route directions. The result is a referring expression of low ambiguity, if used together with the tacit knowledge of the wayfinder.

So far the proposed and implemented model only applies to district hierarchies, but its extension to other elements of the city is the current focus of our research. Our model shows that the resulting set of references is significantly shorter then the set of references in turn-by-turn directions. Furthermore, theoretically the length of turn-by-turn directions increases linearly with the length of the route, but the length of granular route directions increases only logarithmically due to the hierarchic model.

The model can be demonstrated by an artificial data set of a hierarchic triangular partition of space, each triangle being of the element class *district*. The hierarchy consists of three levels (see Figure 1): $d1$-$d4$, $d11$-$d44$, and $d111$-$d444$. The arbitrarily chosen test route from $d122$ to $d322$ consists of 13 turn-by-turn elements:

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route = [d122, d121, d143, d243, d242, d241,
d224, d214, d212, d213, d341, d324, d322]
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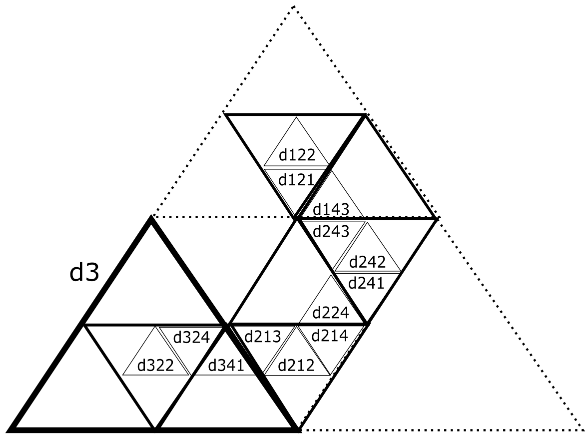

Figure 1: A route from district $d122$ to $d322$ in a hierarchic triangular structure.

In the worst case, a model for granular route directions can return three references, according to the depth of the tree ($d3$, $d32$, $d322$). However, the relevance constraints return only two elements in this case, skipping one level that is not relevant (for details see Tomko and Winter (2005)):

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grd = [d3, d322]
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5 GRANULAR ROUTE DIRECTIONS AND THE CAPACITY OF SHORT-TERM MEMORY

In this section we will collect evidence from two sides to support the hypothesis that granular route directions aim to not exceed the capacity of the human short-term memory. This evidence will come from expected lengths of computational granular route directions, and from observed lengths of granular route directions given by humans.

5.1 Capacity of the short-term memory

Despite differences between various cognitive tasks, the span of short-term memory was reported to equal to approximately seven information items, with a spread of two (Miller, 1956). Consecutive studies indicate even slightly lower numbers (Cowan, 2001). We will demonstrate that granular route directions are in the order of this capacity. Miller also suggests that this capacity can be increased if the items to be remembered are of different types. Thus, diversity helps to increase the short-term memory span, with a lower increase with every added type of item.

5.2 Expected lengths of granular route directions

It appears that the length of granular route directions is related to the depth of the hierarchies, not to the length of the routes. From administrative classifications of districts to road classifications, the number of levels in which the respective domains of man-made phenomena are classified are relatively small. For example, the element class *district* in an urban environment has a greatest element, the city itself, and least elements, parcels at street address level. In between there is a small number of levels, such as building block, quarter, and suburb, which sums up to five levels. In another example, we have investigated the hierarchy of landmarks in a city, and found it consisting of seven levels (Winter et al., in preparation).

When classifying spatial phenomena based on perceptual characteristics instead of administrative parameters, hierarchies of a similar order of depth are built. Locals have concepts of the administrative partition, and they have (experiential) spatial representations of these concepts. Furthermore, there is a cognitive relation between the amalgamation into coarser granularity levels and the phenomena contained. This provides a considerable advantage of purely administrative hierarchies, where the identification of entities and their grouping is not necessarily grounded in the experience of the locals, as it is often the case with suburb boundaries.

Finally, the relation between the hierarchies of the different elements of the city allows for efficient transition between the individual hierarchies of the different types of references. For instance, the association of a district with one of its prominent landmarks can be so strong, that the landmark takes over the identity of the district (Winter et al., in preparation). Relationships like this allow to construct granular route directions of interlinked hierarchies of the elements of a city. For example, the *Tour Eiffel* can interchangeably be associated with Paris' seventh district (or the Champ de Mars, depending on the starting point of a route).

5.3 Observed lengths of granular route directions

An analysis of the structure of granular route directions provided by humans reveals several common characteristics in the communication of routes.

An experiment was performed with 14 graduate students of the same university department while they were attending a workshop at the outskirts of the city of Melbourne, $107km$ from the campus. The participants were asked in an anonymous survey to give directions to a taxi driver to get back to the campus. The number of references in the route directions provided by the participants ranged between three and eleven, with the average of six. In eight cases, references to three classes of elements of the city were used. Five participants used two classes of referents, and one included four. For comparison, a current Web-based navigation service comes up with route directions containing 31 references to elements of the city. Most of its references were street names (i.e., to elements of the class *path*, and one reference of a roundabout was of the class *(structural) landmark*.

The length of provided route directions, measured as number of references, was correlated with the count of types of referents. When only two types were used, the number of references was below or equal to average, and included the shortest set of directions in the set of answers. This corpus of data is limited in size, but few general observations can be made.

The apparent reduction in information conveyed is manifested by the lesser length of the granular route directions, measured by the number of references to spatial elements. All the resulting directions are usable for a local taxi driver, which implies that only irrelevant information was removed. This irrelevant information becomes relevant for actually driving the route, and hence, the local wayfinder has to feed it back based on his knowledge of the street network. Thus, we can say that a considerable recoding process takes place in granular route directions.

The reduction of the number of references in granular route directions may not be the only reason for their lower cognitive complexity when compared to turn-based directions. The inclusion of multiple types of references extends the span of short-term memory (Miller, 1956). The average occurrence of three types of references in the route directions generated in our experiment points to the possibility to encode a complex and lengthy route in an utterance that fits the short-term memory span of the wayfinder. The diversity of references enables to increase this span sufficiently, to accommodate the increased information content. The five types of elements of the city offer a diversity of possible types of referents enabling to construct efficient route directions of considerable length, even in complex urban environments.

Finally, visual or semantic properties of the referents, such as landmarks, were included in granular route directions. The level of detail of such visual descriptions is, however, often simplified. For example, the reference to *'the red building'* provides a simplified reference to the visual appearance of a façade, but omits the specification of texture, size, and other visual properties. Granular route directions are a specific type of referring expression (Dale, 1992), and thus only parameters of the referent with discriminatory power are included. It is unclear whether the memory capacity of the wayfinder would be overloaded if a multitude of attributes was used.

6 CONCLUSIONS AND OUTLOOK

We have discussed the importance of low cognitive workload on short-term memory when providing route directions. The recoding of traditional turn-based route directions into granular route directions reduces the number of references in route descriptions. Thus, relevance based selection grounded in hierarchical granulation, together with the alteration of the type of references, provides efficient means to increase the amount of information to be communicated and retained in the short-term memory of a human agent. The collected evidence from a computational and an experimental perspective shows that typical granular route directions fit into the capacity of the human short-term memory. Similar principles should allow to optimize spatial information communication systems not only for the generation of route directions, but also in related fields of visualization of spatial data. A thorough cognitive testing is, however, needed to definitely prove this hypothesis.

An extension of the current model for automatic generation of granular route directions will enable to integrate multiple hierarchies of different types of references. This will enable the construction of coherent, relevance based route directions with lower cognitive workload of the wayfinder.

We assume that the consideration of the short-term memory span is relevant in visual communication of spatial information as well. It is possible that photo-realistic visualization in immersive 3D environment may have negative effects on performance in tasks where the cognitive workload of the human operator has to be kept low. Further testing is necessary to determine whether such visualization techniques lead to visual clutter and a consequent information overload.

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REFERENCES

Cowan, N., 2001. The Magical Number of 4 in Short-Term Memory: A Reconsideration of Mental Storage Capacity. Behavioral and Brain Sciences.

Dale, R., 1992. Generating Referring Expressions: Constructing Descriptions in a Domain of Objects and Processes. ACL-MIT Series in Natural Language Processing, MIT Press.

Klippel, A. and Winter, S., 2005. Structural Salience of Landmarks for Route Directions. In: A. Cohn and D. Mark (eds), COSIT 2005, Lecture Notes in Computer Science, Vol. 3693, Springer, Berlin, pp. 347–362.

Lynch, K., 1960. The Image of the City. The MIT Press, Cambridge, Massachusetts, USA.

Miller, G., 1956. The Magical Number Seven, Plus or Minus Two. The Psychological Review 63, pp. 81–97.

Montello, D. R., Goodchild, M., Gottsegen, J. and Fohl, P., 2003. Where's Downtown?: Behavioral Methods for Determining Referents of Vague Spatial Queries. Spatial Cognition and Computation 3(2-3), pp. 185–204.

Timpf, S. and Egenhofer, M. J., 1997. Using Hierarchical Spatial Data Structures for Hierarchical Spatial Reasoning. In: S. Hirtle and A. Frank (eds), Spatial Information Theory - A Theoretical Basis for GIS, Lecture Notes in Computer Science, Vol. 1329, Springer-Verlag, Berlin-Heidelberg, pp. 69–83.

Timpf, S., Volta, G., Pollock, D. and Egenhofer, M. J., 1992. A Conceptual Model of Wayfinding Using Multiple Levels of Abstraction. In: A. Frank, I. Campari and U. Formentini (eds), Theory and Methods of Spatio-Temporal Reasoning in Geographic Space, Lecture Notes in Computer Science, Vol. 639, Springer-Verlag, pp. 348–367.

Tomko, M. and Winter, S., 2005. Reconstruction of Scenes from Geo-Referenced Web Resources. In: Spatial Science Conference, Spatial Science Institute, Melbourne, Australia.

Tomko, M. and Winter, S., accepted. Initial Entity Identification for Granular Route Directions. In: W. Kainz, A. Riedl and G. Elmes (eds), 12th International Symposium on Spatial Data Handling 2006, Springer-Verlag, Vienna, Austria.

Winter, S., Tomko, M., Elias, B. and Sester, M., in preparation. Landmark Hierarchies in Context.