Alexander Klippel, Stefan Hansen, Jessica Davies and Stephan Winter. A High-Level Cognitive Framework for Route Directions.
Proceedings of SSC 2005 Spatial Intelligence, Innovation and Praxis: The national biennial Conference of the Spatial Science Institute, September 2005. Melbourne: Spatial Sciences Institute. ISBN 0-9581366-2-9

A HIGH-LEVEL COGNITIVE FRAMEWORK FOR ROUTE DIRECTIONS

KLIPPEL, A.[1], HANSEN, S.[2], DAVIES, J.[3], WINTER, S.[4]

[1]Cooperative Research Centre for Spatial Information, Department of Geomatics, The University of Melbourne, Australia
[2]Transregional Collaborative Research Center for Spatial Cognition (SFB/TR 8), University of Bremen, Germany
[3]LISAsoft, Melbourne, Australia
[4]Department of Geomatics, The University of Melbourne, Australia
aklippel@unimelb.edu.au

KEYWORDS: route directions, spatial cognition, location based services, standardisation (OpenLS).

ABSTRACT

This paper introduces a framework for route directions based on research results from cognitive science. Contrary to existing route planning systems this approach focuses on cognitive aspects to improve the communication of route knowledge. In order to achieve cognitively adequate communication we need to (a) organise data according to the cognitive model of the wayfinder and (b) specify this organisation in a format that is usable by information systems. These requirements are reflected in the structure of this article.

First we provide an overview of results of research on cognitively adequate route directions and detail which aspects of good route directions have already been implemented and where additional work is needed. The question of what makes a route direction cognitively adequate is answered from the perspective of basic research. In this context we discuss approaches to formalise route knowledge: as a kind of spatial ontology, the conceptualisation of directions at decision points, the chunking of route direction elements, the enrichment of route directions with landmarks, the disambiguation of spatial situations and the interplay of language and graphics in multimodal communication systems and their relation to the underlying conceptual structure.

A developing standard for location based services is the OpenGIS Location Services (OpenLS) specification. We describe briefly the functionality of the services and their technical basis. The focus is placed on the structure of the navigation service revealing where—from a cognitive perspective—improvements can be made. Based on this analysis we propose to modify the OpenLS standard and to extend its functionality. This modification is exemplarily discussed for direction concepts at different intersections; the final specification is a work in progress. In conclusion we discuss remaining problems and missing research topics necessary to make route directions cognitively adequate.

BIOGRAPHY

Dr. Alexander Klippel is a Research Fellow at the CRC for Spatial Information, Department of Geomatics, The University of Melbourne. He received his Ph.D. in Informatics from the Universität Bremen with emphasis on cognitive science.

INTRODUCTION

Route planning and navigation assistance systems can efficiently calculate routes between two locations, for example, the fastest or the shortest route. The technical means for accomplishing this task are well established and constantly under refinement [Meng et al. 2005]. At present, however, there is a paucity of understanding of the communication processes with human users, both verbally and graphically. For the design of automated information services that provide information to a user it is essential to specify a formal theory that allows for the transition of raw data, such as routes in street networks, to knowledge, i.e. the cognitively adequate communication of the data (see Fig. 1). In other words, the question remains, what is the best way to organise data in order to communicate it to the user via appropriate interfaces?

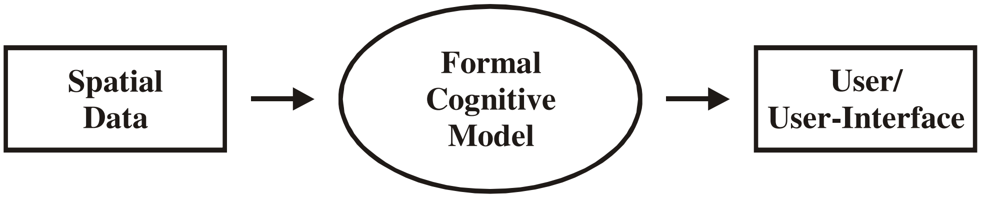

Figure 1. Processing spatial data by formal cognitive models for modern information systems.

The approach taken in this paper is twofold: First, knowledge on the cognitively adequate communication or route directions is discussed (Section 2). Second, advantage is taken of developing standardisations for route directions (Section 3) and means to specify route directions by a standard are investigated to allow for restructuring of the route according to cognitive principles and to enrich route directions with cognitively adequate features such as landmarks.

This approach does not aim to generate route directions in a specific modality, for example, language or graphics. The goal is rather a general specification of the underlying conceptual structure that will allow for presenting route information in both, language and graphics.

SOME APPROACHES TO ROUTE FORMALISM AND COGNITIVELY ADEQUATE ROUTE DIRECTIONS

The cognitive literature on route directions provides a rich source of aspects that can and should be used in route information systems [e.g., Denis 1997; Lovelace et al. 1999; Tversky and Lee 1999; Klippel et al. 2005]. A short overview of this research and of corresponding formalisms is outlined below. It reveals which aspects of good route directions have already been implemented and where additional work is needed. In general, the question 'what makes a route direction cognitively adequate?' is answered from the perspective of basic research.

Ontologies of Route Knowledge

Several approaches aim to formalise route knowledge and specify underlying conceptualizations. The results of these explications are referred to as ontologies [Gruber 1993]. Due to space restrictions, only a brief overview of some of these approaches is provided:

The TOUR model and the Spatial Semantic Hierarchy (SSH) [Kuipers 1978; Kuipers 2000] Kuipers and collaborators developed this approach to add qualitativeness—as it can be found in human wayfinding—to robotics and formal characterizations of spatial knowledge. The SSH serves as a model for human mental representations as well as a framework for robots gathering knowledge on their environment and the format of the representation they aubsequently build. A core element of the SSH is the hierarchical organization of spatial knowledge. Each level within the hierarchy establishes its own ontology to match the complexity of human cognition.

The RouteGraph [Werner et al. 2000] The RouteGraph theory is an abstract formalism to express the key concepts of route based navigation; these concepts group around *places* and *route segments* and are specified in great detail to formally represent complex navigation knowledge. The RouteGraph theory builds on interdisciplinary research on wayfinding and navigation and is not restricted to one species. The main assumptions behind this general approach are that on an abstract level the tasks of planning routes and of executing the correct actions along the way are the same for most species and equally for artificial agents such as robots.

CORAL / RPML [Dale et al. 2003; Dale et al. 2005] The CORAL project aims to generate verbal route directions automatically as a specific application of natural language generation (NLG). Some of the principles for cognitively adequate route directions (see the following Sections) are integrated or discussed within this approach, especially the ideas on providing aggregated rather then turn-by-turn directions. The route information is represented in a format called Route Planning Markup Language (RPML) to allow for a device independent realisation.

Wayfinding Choremes and Abstract Route Directions (ARD) [Klippel 2003b; Klippel et al. 2005; Richter and Klippel 2005] These approaches are specifically designed as a modality independent representation for both graphical and verbal route directions and to incorporate findings from cognitive psychology and behavioural studies. While the wayfinding choremes theory employs conceptual primitives to model route knowledge and to allow for the criteria specified in the following Sections (2.2 – 2.6) as well as personalization of route directions, ARD extends the general approach by focussing specifically on the structure of an environment and its elements that need to be, or can be, considered for generating context specific route directions.

The Conceptualization of Directions at Decision Points

The processing and representation of angular (direction) information is essential for wayfinding and route planning [Golledge 1999; Waller et al. 2002]. Experimental results [Denis 1997] and several formalisms (see Section 2.1) show that route directions and wayfinding basically consist of making direction choices at decision points. Pursuing this line of thought, wayfinding can be characterized as following a route segment up to a decision point, making a directional choice, following the next route segment up to the next decision point, making a directional choice, and so on. Decision points can be operationalized as belonging to two main categories: decision points with a direction change (DP+) and decision points without a direction change (DP-). The question arises, how do humans conceptualize directions at decision points, especially at DP+? What are prototypical direction (turning) concepts and how can their graphical and verbal externalizations be specified?

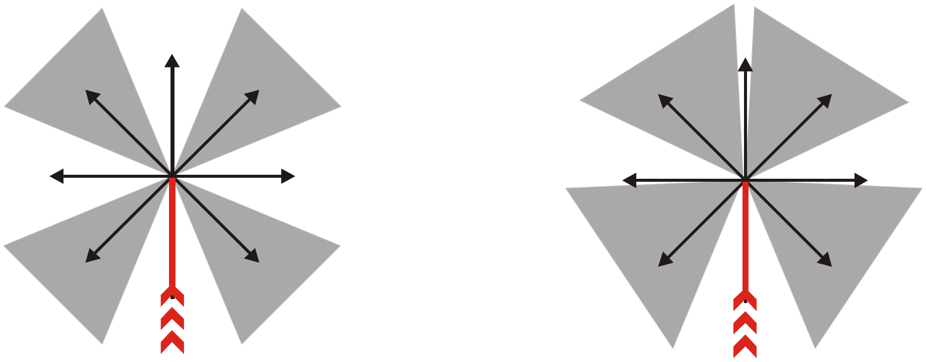

Figure 2. Original (left part) and revised (right part) direction model for the generation of verbal route directions and the schematization of maps [Klippel 2003a; Klippel et al. 2004].

Several experiments were conducted on the conceptualization of directions at decision points and their representation in verbal and graphical route directions [e.g., Tversky and Lee 1999]. One experimental finding was that direction concepts can best be represented as a combination of axes and sectors [Klippel et al. 2004]. Figure 2 shows results of these experiments: While a straightforward approach would assume eight equally sized sectors for the 8 main directions (left part of Figure 2) the experiment [Klippel et al. 2004] revealed that participants conceptualise directions at decision points differently. The results show 8 groups; one of them, however, is an axis. The left and the right plane are symmetric, but the front and the back plane are not. Front and Back plane are clearly separated by '90' degree left and right turns which marks them as prominent directions, too. The individual sectors differ in size (right part Figure 2). While these experiments were designed to shed light on the conceptualization of direction concepts at intersections without competing branches, ongoing research shows that the context in which a direction turn takes place plays a major role in the conceptualization of the action (see Section 3).

HORDE – Combining Route Direction Elements

Route directions provide instructions on how to proceed for every decision point, yet, not every decision point and the accompanying action need to be mentioned explicitly. Often, it is possible to combine actions for several decision points into one route direction; this combination is an important mechanism for cognitively adequate route directions and the conceptualization of routes. This process is called *spatial chunking* [Klippel et al. 2003], or referred to as *segmentation and aggregation* [Dale et al. 2003].

Spatial chunking groups several decision point / action pairs into a single segment; these segments are called higher order route direction elements (HORDE) [Klippel 2003b]. Dale et al. [2003] identified two segmentation principles: landmark-based and path-based segmentation. In landmark-based segmentation, landmarks at decision points delimit a part of the route to be followed; the route is decomposed into segments, each leading to such a landmark. Path-based segmentation is based on three features of paths—road status, i.e. the road level hierarchy (highways, main roads, etc.), path length, and turn saliency (e.g., T-intersections). By employing any of these features or a combination thereof, routes can be segmented.
Klippel et al. [2003] differentiate three kinds of spatial chunking: (1) Numerical chunking, which is realized by counting the decision points until a direction change occurs, for example ‘turn left at the third intersection’. Additionally, a sequence of decision points with equal direction changes can be chunked, for example ‘twice right’. (2) Landmark chunking denotes the use of an unambiguous landmark that identifies the decision points with a direction change (DP+) to mark the point where a direction change occurs. An example for such a HORDE is ‘turn right at the gas station’. The number of intermediate decision points is not specified in this kind of chunking. (3) Structure chunking where spatial structures that are unique in a given local environment are exploited. For example, the dead end of a T-intersection unequivocally marks the need for a direction change, for example, ‘at the dead end make a right‘. An instruction like ‘follow the river’ also rests upon structure chunking as it combines actions for several decision points that are located along the river into a single one [Richter and Klippel 2005].

Landmarks

Lynch's [1960] paper on elements that structure our knowledge of our spatial environment, inspired multiple research papers on the meaning of landmarks. Klippel and Winter [to appear] summarized some basic facts:

- Everything that stands out from the background can be a landmark [Presson and Montello 1988].
- In certain contexts, e.g., route following, even road intersections can be landmarks [Klippel 2003b].
- Landmarks structure environmental knowledge, for example, as anchor points [Couclelis et al. 1987].
- Landmarks are used to communicate route knowledge verbally and graphically [Denis 1997; Tversky and Lee 1999].
- Landmarks are integrated in route directions to varying degrees, increasingly at origins, destinations, and distinguished decision points [Michon and Denis 2001].
- Landmarks at decision points are more pertinent when a change in direction is required [Lee et al. 2002].
- Landmarks generally work better than street signs in wayfinding [Tom and Denis 2003].

We understand why and when people use landmarks to organize their spatial knowledge or to communicate spatial information. In contrast, our knowledge to formalize this knowledge and to integrate landmarks in current information technology, such as PDA navigation assistants, is still limited. One difficulty is to formalize the concept of a landmark, such that a service can automatically identify features that could potentially be a landmark. According to a recent proposal visual, semantic and structural qualities of features determine their salience; salient features are considered as landmarks, i.e., they differ from the background [Raubal and Winter 2002]. This approach has been related to work on data mining by Elias

[2003]. The measure of salience can be adapted to context [Winter et al. 2005], and can be weighted with advanced visibility along a route [Winter 2003] to become route specific. To this end, automatically identified landmarks show good compliance with landmarks selected by human participants, although measures exist only for visual and semantic qualities. Structural qualities have not been included in the characterization so far. An approach orthogonal to the work on the saliency of landmarks aims to define the saliency of landmarks based on the conceptualization of a wayfinding event [e.g., Klippel et al. 2005; Richter and Klippel 2005]. The turning at intersections (decision points) are regarded as event primitives, and conceptual primitives derived thereof (see Section 2.1). In Klippel and Winter [to appear], the conceptual approach is elaborated and the integration of landmarks, specifically, their structural salience induced by the conceptualization of a wayfinding action is detailed. Based on their characterization, the rules specified for HORDE [Dale et al. 2005; Klippel et al. 2005] have been extended to allow for different levels of granularity in conceptual route directions (see also Section 2.3).

Disambiguating Spatial Situations

In Klippel [2003a] the empirical basis for graphic realizations of prototypical direction concepts is detailed as part of the wayfinding choreme theory, i.e. the mental conceptualization of functional primitives of route direction elements (see also Figure 2). In contrast to graphic externalizations of mental conceptualization verbal externalizations may require a different level of detail depending on the spatial situation, as language often leaves many aspects underspecified. Analyses of utterances that indicate the direction change at decision points are leading to a systematic specification [Tenbrink and Klippel 2005] of a) the structure of an intersection, b) the action to be performed at an intersection, c) the conceptualization of this action, and c) the unambiguous verbal reference to it as part of a route direction.

These first experimental results indicate the following strategies. There are standard intersections, like a 4-way intersection, and standard actions, like ‘left’, ‘right’, and ‘straight’. If standard actions occur at standard intersections, unmodified projective terms are appropriate, for example, ‘turn right (at the intersection)’. Additionally, people tend to adopt a direction model that comprises axes and sectors, expressed for instance, by modifications of the projective terms if the angle of the intended direction departs from the prototypical axis. For example, ‘turn right’ may change to ‘turn sharp right’ and may be modified to ‘turn very sharp right’. While these directions allow for some flexibility, since they relate to sectors, the concept for straight is an axis.

The strategies participants adopted in the experiments changed depending on whether the action to be instructed a) took place at a complex intersection or b) if competing branches required a disambiguation of the situation. For the identification of object locations Tenbrink [2005] provides results on how the contrast of competing objects can be enhanced. Some ideas on how contrastive reference can be achieved in route directions were presented by Klippel and Montello [2004]. Besides rendering the direction concept precise (for example, by providing detailed descriptions according to the direction model, and possibly relying on clock directions or an absolute reference system), participants adopted the following strategies: naming the structure in which the actions take place and using this name in conjunction with a coarse direction concept (‘fork right’), comparing the possibilities to take (‘furthest right’), conceptually changing to ordering information in conjunction with a coarse direction concept (‘the third on your left’), describing a competing direction not to take (‘not straight but slightly to the left‘), or combining any of these strategies. The presence of a landmark (see Section 2.4) again changes the strategies used.

Multi-Modality

With the advent of multimodal communication systems, the translation between different external forms of communication—the externalization of conceptual structures—became a prominent research question in several communities [Wahlster 1998; Allen 2003]. Focus here is placed on the interplay of language and graphics and their relation to the underlying conceptual structure. The wayfinding choreme theory, for instance, provides the basis for relating different kinds of external representations, for example, language and graphics, on a conceptual level. The domain of wayfinding and route directions allows for taking advantage of a homomorphism between the represented world, i.e. the mental conceptualization of route information and the representing world, the external representation as route maps or verbal route directions [Palmer 1978]. The linearity of routes enables the ('direct') application of a formal language as, for example, proposed in the wayfinding choreme theory, to specify basic elements of route knowledge and their valid combinations

[Klippel et al. 2005]. The method of specifying route knowledge on a conceptual level can be found in other approaches dealing with graphic and verbal directions [Tversky and Lee 1999; Ligozat 2000; Richter and Klippel 2005].

THE OPENLS STANDARD

The OpenGIS Location Services (OpenLS) [Mabrouk 2005] Implementation Specification is the description of an open platform for location-based application services, the so called GeoMobility Server (GMS), proposed by the Open Geospatial Consortium (OGC). It offers a framework for the interoperable use of mobile devices, services and location-related data. The specification defines access to the services provided by a GMS as request and response pairs, and the associated abstract data types (ADT).

The specification of a GMS includes five core services: the Directory Service, the Gateway Service, the Location Utility Service, the Presentation Service and the Route Service. The Directory Service offers access to an online directory (such as the Yellow Pages). It allows for finding a specific or a nearest place, a requested product or service. The Gateway Service is an interface between a GMS and a Location Server for requesting the location of one or more mobile devices. The Location Utility Service (Geocoder/Reverse Geocoder) returns to a given position the complete normalized description of a feature location (place name, street address, postal code) or given a feature location (place, street or postal code) it provides the position and the complete normalized description. The Presentation Service portrays a map based on any geographic information for display on a mobile terminal and finally the Route Service determines travel routes and navigation information between two or more points.

In addition to these five core services a GMS can also implement a Navigation Service [Bychowski 2003]. This is an enhanced version of the Route Service, which supports the same parameters as the Route Service as well as additional parameters for navigation purposes. Thereby the main focus is placed on extending the description of turn-by-turn directions. The access to the server is specified as request and response pairs. The method of encoding these request and response pairs is defined by a XML-based markup language, called XML for Location Services (XLS). XLS, which is defined as a XML schema, describes the appearance of the documents exchanged between the client and the GMS (incorporating associated ADTs). The response of a GMS to a service request consists of a XLS-document which provides the requested information. If a navigation service is requested the returned document can contain information about a route's overall characteristics (estimated travel time, distance, etc.), its geometry, a map of the route and instructions for travelling the route.

The OpenLS specification of the navigation service offers two different possibilities for describing route instructions. The first consists of a list of turn-by-turn instructions and information about distance and travel time. Thereby a single route instruction is a simple string. Since this is the only constraint, an instruction is completely arbitrary. The second possibility contains a list of elements of the complex type AbstractManeuverType (see Figure 3), which provides more elaborate turn-by-turn directions with predefined content.

Besides providing information about the next route segment, such as estimated travel time and distance, a travel manoeuvre describes the current decision point and the action that has to be taken by the traveller. A decision point can be classified by the attribute JunctionType, which can take as a value one element of a set of predefined categories (e.g. “Intersection”, “Roundabout” or “EntranceRamp”). Furthermore the geometry coordinate of the decision point encoded according to the Geographic Markup Language (GML, an ISO standard) and its name are given. The action the traveller has to take is specified by the attribute ActionType, values for which also belong to a predefined category (e.g. “Turn”, “ProceedTo” or “Stop”). If the action at the decision point is “Turn”, a travel manoeuvre can also provide the direction of the turn, which belongs to a predefined class. If the current intersection is a roundabout or a complex intersection, the attribute numberExitsToPass can be used for specifying the instruction for the traveller more accurately. Since the use of numberExitsToPass and DirectionOfTurn is only constrained by the documentation within the schema definitions, arbitrary combinations of attributes (e.g. the DirectionOfTurn=SlightLeft with the ActionType=Stop) are possible.

We are in the process of investigating the ways OpenLS can express route directions. In particular we are focusing on the concepts developed in Section 2, which would lead to cognitively adequate route directions. We will propose ways to express these concepts by means of the OpenLS specification, or, where OpenLS is not capable of expressing them, extensions to OpenLS will be recommended.

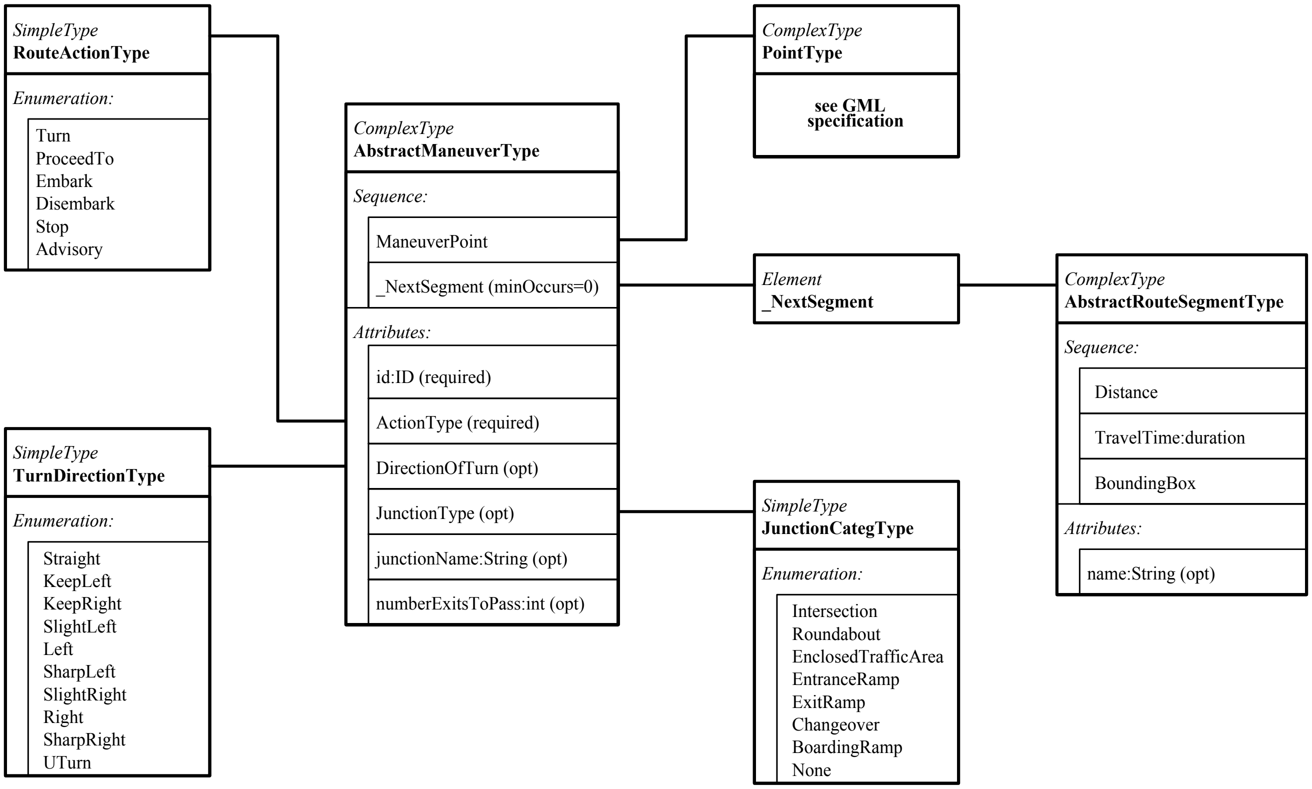

Figure 3. OpenLS, part 6, navigation service. Partial specification for "AbstractManeuverType".

ON MODIFYING THE OPENLS STANDARD

The OpenLS standards provide several features to implement the requirements identified in section 2. It is, for example, possible to use different alternatives to encode direction concepts (see Section 2.2). The direction concepts as such can be modified according to the specifications in the TurnDirectionType (see Figure 3), and a turning direction can be characterized according to an eight direction model (see also Figure 2; the ‘back’ concept is furthermore characterized as a ‘UTurn’). Additionally, however, supplementary direction values can be found in this enumeration, for example, ‘KeepLeft’. The semantic differences between ‘KeepLeft’ and ‘SlightLeft’ cannot be explained based on the absolute change in direction but only if the spatial structure determined by the type of intersection in which the action takes place, is also considered (see Figure 4). This may also comprise differences in the street level hierarchy.

A sensible extension to the pure direction concepts is the entry for the numberExitsToPass attribute that can be found in the AbstractManeuverType. The advice provided for the use of this attribute is “Number of exits or intersections to pass before turning off a roundabout or complex intersection.” [Bychowski 2003, p. 20]. This attribute can be used to mirror results obtained from natural language analysis on how human navigators disambiguate spatial situations (see Section 2.5). For example at roundabouts, instead of providing a direction concept the exit to take is specified on the basis of its numerical ordering (see Figure 4). In contrast to the results from behavioural data, however, changes of directions at complex intersections are not sufficiently characterized by pure ordering concepts. Rather, participants disambiguate a complex spatial situation as depicted in Figure 4 by combining a coarse direction concept in combination with an ordering concept. This means, while a numberExitsToPass concept is applicable to a full circle at a roundabout, at a complex intersection it is only applicable to one of the half planes (left or right) resulting in verbalization/conceptualization like “take the third street on your left”. Figure 4 illustrates these problems by depicting the ‘same’ (in terms of angular) change of direction at different intersections. This problem also indicates the general problem of mixing the conceptual level with the level of verbal characterizations.

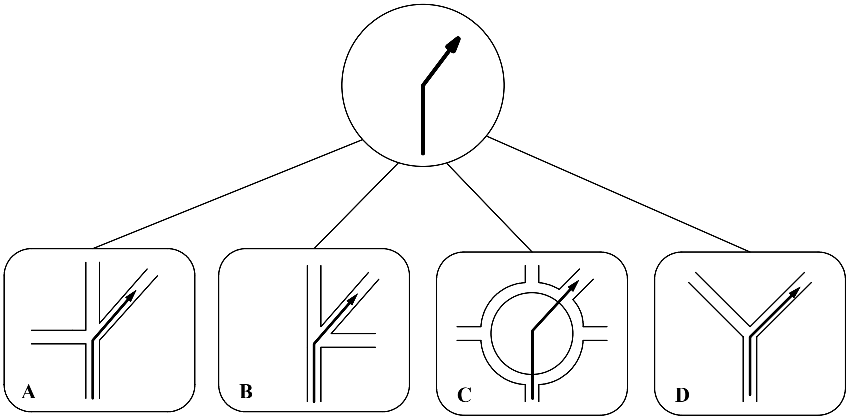

Figure 4. A change of a direction is imbued with different meanings according to the intersection in which it takes place. The 'pure' change may be characterized as 'veer right' at intersection (a). At intersection (b) it might change to 'the second right'; at the roundabout (c) it changes to 'the third (or second) exit', and at (d) it becomes 'fork right'.

The discussion in the preceding paragraphs shows the two main directions of modification this paper proposes: First, the extension of the OpenLS standard by adding classes (like intersection) to allow for a more detailed characterization of route information. Second, a clearer structure of the different levels of classes and subclasses to sensibly allow for combinations according to criteria of good route directions without restricting the general applicability.

To sum up the discussed example and the aspects detailed in section 2, we aim to modify the standard to allow for the integration of the following features:

- A detailed specification of types of intersections to allow for (a) providing the necessary basis to characterize the conceptualizations that result from the combination of the structure of an intersection and the action that takes place; and (b) to use salient intersections as landmarks in route directions to generate HORDE.
- The TurnDirectionType should be constrained by the type of the intersection.
- The possibility to chunk route elements (decision points) into HORDE by rules provided in Section 2.3, i.e. landmark, structure and numerical chunking.
- A specific class for landmarks as one of the most important structural elements in route directions. This class should be able to incorporate results discussed in Section 2.4. Especially the taxonomy of landmark locations and the integration of different types of landmarks.

CONCLUSIONS AND PERSPECTIVES

Although the general awareness of characteristics of cognitively adequate route directions has increased in recent approaches and several aspects are theoretically established, a general framework for cognitively adequate route directions and especially their realisation in information systems is still missing. The focus on a standard like OpenLS therefore, should allow for a widespread applicability of the identified problems and their solutions. The current status of OpenLS is not yet sufficient for incorporating all aspects of cognitively adequate route directions. The extension of the standard is therefore within the focus of our work. Whether it will be possible to integrate it into the standard as such or as a separate specification based, at least, on the general approach is undecided at this stage. The work is an ongoing research effort and while theoretical aspects have been established, the standardization and in particular the focus on OpenLS is a more recent enterprise.

Although several results have been obtained recently by behavioural studies and the interdisciplinary approach to route directions—cognitive psychology, linguistics, informatics, GIScience—all of which have greatly enhanced the provision of route information, the specific aspect of generating cognitively adequate characterisations of route information requires further research. The necessary research can be classified into the following categories:

- the identification of spatial structures and (a) their applicability in the creation of HORDE, i.e. the chunking or segmentation of route information to obtain fewer, but more meaningful subparts on appropriate levels of granularity, and (b) the disambiguation of spatial information in complex situations.

- the relation of language and graphics to create multimodal route directions that, instead of two independent representations as it can be found today, seamlessly integrate to take advantage of the representational characteristics of each medium [Meilinger 2005].
- the design of cognitively adequate interfaces which make it necessary to extend the research from the more cognitive aspects to perceptual factors.

Additionally, the OpenLS standard seems to focus primarily on navigation in motorized vehicles. This means that special requirements for other modes of transportation are not sufficiently framed.

ACKNOWLEDGEMENTS

This work has been supported by the Cooperative Research Centre for Spatial Information, whose activities are funded by the Australian Commonwealth's Cooperative Research Centres Programme. We thank two anonymous reviewers for valuable comments.

REFERENCES

Allen, G.L., (2003), "Gestures accompanying verbal route directions: Do they point to a new avenue for examining spatial representations?" **Spatial Cognition and Computation**, 3, 259-268.

Bychowski, T., (2003), **OpenGis Location Services (OpenLS): Part 6 - Navigation Service. OGC Implementation Specification 03-007r1, Version 0.5.0, Open Gis Consortium Inc.**

Couclelis, H.; Golledge, R.G.; Gale, N.; Tobler, W., (1987), "Exploring the anchor-point hypothesis of spatial cognition." **Journal of Environmental Psychology**, 7 (2), 99-122.

Dale, R.; Geldof, S.; Prost, J.-P., (2003), CORAL: Using Natural Language Generation for Navigational Assistance. In: Oudshoorn, M. (Ed.), Proceedings of the 26th Australasian Computer Science Conference (ACSC2003), **Adelaide, Australia**.

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.

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

Elias, B., (2003), "Extracting Landmarks with Data Mining Methods". In: Kuhn, W.; Worboys, M.F.; Timpf, S. (Eds.), **Spatial Information Theory**. Lecture Notes in Computer Science, 2825. Springer, Berlin, pp. 398-412.

Golledge, R.G. (Ed.), (1999), **Wayfinding behavior. Cognitive mapping and other spatial processes**. Johns Hopkins University Press, Baltimore.

Gruber, T.R., (1993), "A translation approach to portable ontologies". **Knowledge Acquisition**, 5 (2), 199-220.

Klippel, A., (2003a), "Wayfinding Choremes." In: Kuhn, W.; Worboys, M.; Timpf, S. (Eds.), **Spatial Information Theory: Foundations of Geographic Information Science. Conference on Spatial Information Theory (COSIT) 2003.**, Springer, Berlin, pp. 320-334.

Klippel, A., (2003b), **Wayfinding Choremes. Conceptualizing Wayfinding and Route Direction Elements.** Universität Bremen: Bremen.

Klippel, A.; Dewey, C.; Knauff, M.; Richter, K.-F.; Montello, D.R.; Freksa, C.; Loeliger, E.-A., (2004), "Direction concepts in wayfinding assistance." In: Baus, J.; Kray, C.; Porzel, R. (Eds.), **Workshop on Artificial Intelligence in Mobile Systems 2004 (AIMS'04)**, SFB 378 Memo 84, Saarbrücken, pp. 1-8.

Klippel, A.; Montello, D.R., (2004), "On the robustness of mental conceptualizations of turn direction concepts." In: Egenhofer, M.J.; Freksa, C.; Miller, H. (Eds.), **GIScience 2004. The Thrid International Conference on Geogrpahic Information Science, October 20-23, 2004, University of Maryland (Extended Abstract).** Regents of the University of California, Adelphi, Maryland, U.S.A., pp. 139-141.

Klippel, A.; Tappe, T.; Habel, C., (2003), "Pictorial Representations of Routes: Chunking Route Segments during Comprehension." In: Freksa, C. et al. (Eds.), **Spatial Cognition III. Routes and Navigation, Human Memory and Learning, Spatial Representation and Spatial Learning.**, Springer, Berlin, pp. 11-33.

Klippel, A.; Tappe, T.; Kulik, L.; Lee, P.U., (2005), "Wayfinding choremes - A language for modeling conceptual route knowledge." **Journal of Visual Languages and Computing**, 16 (4), 311-329.

Klippel, A.; Winter, S., (to appear), "Structural salience of landmarks for route directions", **Conference on Spatial Information Theory - COSIT 2005**.

Kuipers, B., (1978), "Modelling spatial knowledge". **Cognitive Science**, 2 (2), 129-154.

Kuipers, B., (2000), "The spatial semantic hierarchy". **Artificial Intelligence**, 119, 191-233.

Lee, P.U.; Tappe, T.; Klippel, A., (2002), "Acquisition of landmark knowledge from static and dynamic presentation of route maps." **KI (Themenheft Spatial Cognition)**, 32-34.

Ligozat, G., (2000), "From language to motion, and back: Generating and using route descriptions". In: Christodoulakis, D.N. (Ed.), **Natural Language Processing - NLP 2000: Second International Conference, Patras, Greece, June 2000. Proceedings**, Springer, Berlin.

Lovelace, K.; Hegarty, M.; Montello, D.R., (1999), "Elements of good route directions in familiar and unfamiliar environments". In: Freksa, C.; Mark, D.M. (Eds.), **Spatial information theory. Cognitive and computational foundations of geographic information science**, Springer, Belin, pp. 65-82.

Lynch, K., (1960), **The image of the city.** MIT Press: Cambridge, MA.

Mabrouk, M., (2005), **OpenGis Location Services (OpenLS): Core Services. OGC Implementation Specification 05-016 Version 1.1 Open Gis Consortium Inc.**

Meilinger, T., (2005), "Wayfinding with maps and verbal directions", **CogSci 2005, XXVII Annual Meeting of the Cognitive Science Society, July 21-23 Stresa, Italy**.

Meng, L.; Zipf, A.; Reichenbacher, T., (2005), **Map-based Mobile Services. Theories, Methods and Implementations**. Springer: Berlin.

Michon, P.-E.; Denis, M., (2001), "When and why are visual landmarks used in giving directions?" In: Montello, D.R. (Ed.), **Spatial Information Theory. Foundations of geographic information science. International Conference, COSIT 2001, Morro Bay, CA, USA, September 2001.**, Springer, Berlin, pp. 292-305.

Palmer, S.E., (1978), "Fundamental aspects of cognitive representation." In: Rosch, E.; Lloyd, B.B. (Eds.), **Cognition and categorization**, Lawrence Erlbaum, Hillsdale, NJ, pp. 259-303.

Presson, C.C.; Montello, D.R., (1988), "Points of reference in spatial cognition: Stalking the elusive landmark." **British Journal of Developmental Psychology**, 6, 378-381.

Raubal, M.; Winter, S., (2002), "Enriching wayfinding instructions with local landmarks." In: Egenhofer, M.J.; Mark, D.M. (Eds.), **Geographic Information Science. Lecture Notes in Computer Science, Vol. 2478.**, Springer, Berlin, pp. 243-259.

Richter, K.-F.; Klippel, A., (2005), "A model for context-specific route directions." In: Freksa, C.; Knauff, M.; Krieg-Brueckner, B. (Eds.), **Spatial Cognition IV. Reasoning, Action, and Interaction: International Conference Spatial Cognition 2004, Frauenchiemsee, Germany, October 11-13, 2004, Revised Selected Papers**, Lecture Notes in Computer Science, Volume 3343. Springer, Berlin, pp. 58-78.

Tenbrink, T., (2005), "Identifying objects on the basis of spatial contrast: An empirical study". In: Freksa, C.; Knauff, M.; Krieg-Brueckner, B. (Eds.), **Spatial Cognition IV. Reasoning, Action, and Interaction: International Conference Spatial Cognition 2004, Frauenchiemsee, Germany, October 11-13, 2004, Revised Selected Papers**, Lecture Notes in Computer Science, Volume 3343. Springer, Berlin, pp. 124-146.

Tenbrink, T.; Klippel, A., (2005), Achieving reference via contrast in route descriptions and spatial object identification, 21st Scandinavian Conference of Linguistics, NTNU, Trondheim, June 1-4, 2005 (abstract).

Tom, A.; Denis, M., (2003), "Referring to landmark or street iniformation in route directions: What difference does it make?" In: Kuhn, W.; Worboys, M.; Timpf, S. (Eds.), **Spatial information theory. Foundations of geogrpahic information science. International conference, COSIT 2003, Kartause Ittingen, Switzerland, September 2003.**, Springer, Berlin, pp. 362-374.

Tversky, B.; Lee, P.U., (1999), "Pictorial and verbal tools for conveying routes". In: Freksa, C.; Mark, D.M. (Eds.), **Spatial information theory. Cognitive and computational foundations of geographic information science**, Springer, Berlin, pp. 51-64.

Wahlster, W., (1998), "User and discourse models for multimodal communication". In: Maybury, M.; Wahlster, W. (Eds.), **Intelligent user interfaces**, Morgan Kaufmann Press, San Mateo, CA, pp. 359-370.

Waller, D.; Montello, D.R.; Richardson, A.E.; Hegarty, M., (2002), "Orientation specificity and spatial updating of memories for layouts." **Journal of Experimental Psychology: Learning, Memory, & Cognition**, 28, 1051 - 1063.

Werner, S.; Krieg-Brückner, B.; Herrmann, T., (2000), "Modeling navigational knowledge by route graphs." In: Freksa, C. et al. (Eds.), **Spatial cognition II. Integrating abstract theories, empirical studies, formal methods, and practical applications.**, Springer, Berlin, pp. 295-316.

Winter, S., (2003), "Route Adaptive Selection of Salient Features". In: Kuhn, W.; Worboys, M.F.; Timpf, S. (Eds.), **Spatial Information Theory**. Lecture Notes in Computer Science, 2825. Springer, Berlin, pp. 320-334.

Winter, S.; Raubal, M.; Nothegger, C., (2005), "Focalizing Measures of Salience for Wayfinding". In: Meng, L.; Zipf, A.; Reichenbacher, T. (Eds.), **Map-based Mobile Services - Theories, Methods and Implementations**, Springer Geosciences, Berlin, pp. 127-142.