Cognitively Ergonomic Route Directions

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COGNITIVE ASPECTS OF ROUTE DIRECTIONS

Route directions fascinate researchers in several fields. Since the 70s linguists and cognitive scientists have used verbal route directions as a window to cognition to learn about cognitive processes that reflect structuring principles of environmental knowledge (e.g., Klein, 1978). Over the last decade, the number of publications on various aspects of route directions has increased. Next to the general aspects of how to provide route directions and how to identify principles that allow us to define what makes route directions cognitively ergonomic, technical aspects of navigation support systems have become an additional focus. The question required from the latter perspective is part of a broader approach that aims to formally characterize the meaning (semantics) of spatial relations. In other words, if we want to bridge the gap between information systems and behavioral analysis we have to answer how we perform the transition from data to knowledge.

Several key elements can be identified based on psychological and linguistic literature on route directions that are pertinent for cognitively ergonomic route directions (Denis, 1997; Lovelace, Hegarty, & Montello, 1999; Tversky & Lee, 1999). These comprise the conceptualization of directions at decision points, the spatial chunking of route direction elements to obtain hierarchies and to change the level of granularity, the role of landmarks, the communication in different modalities, the traveling in different modes, and aspects of personalization (see Table 1). Most research on routes and route directions deals with navigation in urban structures such as street networks. The results discussed in this article focus on this domain.

Table 1: Cognitive Ergonomics of Route Directions

Cognitively ergonomic route directions

- are qualitative, not quantitative,
- allow for different levels of granularity and organize spatial knowledge hierarchically,
- reflect cognitive conceptualizations of directions at decision points,
- chunk route direction elements into larger units to reduce cognitive load,
- use landmarks to:
  - disambiguate spatial situations,
  - anchor turning actions,
  - and to confirm that the right actions have been taken,
- present information in multimodal communication systems allowing for an interplay of language and graphics, but respecting for the underlying conceptual structure,
- allow for an adaptation to the user's familiarity with an environment, as well as personal styles and different languages.

APPROACHES TO REPRESENTING ROUTE KNOWLEDGE

Behavioral studies have substantiated key elements of cognitively ergonomic route directions. To implement these aspects in information systems detailed formal characterizations of route knowledge are required. The approaches discussed below are a representative vocabulary that allows for the characterization of mental conceptualization processes reflecting the results from behavioral studies (see Table 1). In this sense we can refer to them as *Ontologies of Route Knowledge* (Chandrasekaran, Josephson, & Benjamins, 1999; Gruber, 1993). In Guarino's terminology these approaches would most likely be called *domain ontologies* (Guarino, 1998).

One of the earliest approaches is the *TOUR* model by Kuipers (Kuipers, 1978) that later developed into the *Spatial Semantic Hierarchy* (SSH) (Kuipers, 2000). Kuipers and his collaborators developed this approach to add the qualitativeness that can be found in the organization of a cognitive agent's spatial knowledge to approaches in robotics. The latter classically relied more on quantitative spatial descriptions. The SSH allows for modeling cognitive representations of space as well as for building a framework for robot navigation, i.e. qualitative and quantitative aspects are combined. The SSH especially reflects the aspect of hierarchical organization of spatial knowledge by providing different levels of information representation: the sensory, control, causal, topological, and metrical level. Ontological characterizations are developed for each level to match human cognitive processes.

The *Route Graph* model (Werner, Krieg-Brückner, & Herrmann, 2000) describes key elements for route based navigation. Similar to the SSH, it allows representing knowledge on different levels of granularity. However, it is much more abstract and does not provide any processes for acquiring this knowledge. It is intended to provide a formalism expressing key notions of route knowledge independent of a particular implementation, agent, or domain. Its focus is on a sound formal specification of basic elements and operations, like the transition from route knowledge to survey knowledge by merging routes into a graph-like structure.

A linguistically grounded approach with the aim to generate verbal route directions is the *CORAL* project by Dale and coworkers (e.g., Dale, Geldof, & Prost, 2005). One of the central aspects of their approach is the organization of parts of a route into meaningful units, a process they call segmentation. Instead of providing turn-by-turn directions, this approach allows for a small number of instructions that capture the most important aspects of a route. The employed modeling language is called Route Planning Markup Language (RPML).

Formalisms that model route knowledge on the conceptual level can be found in the theory of *wayfinding choremes* (Klippel, Tappe, Kulik, & Lee, 2005) and *context-specific route directions* (Richter & Klippel, 2005). These approaches model route knowledge modality-independent on the conceptual level. The wayfinding choreme theory employs conceptual primitives—as the result of conceptualization processes of a cognitive agent incorporating functional as well as geometrical environmental aspects—to define basic as well as super-ordinate valid expressions on different levels of granularity. The approach to context-specific route directions builds on this theory. A systematics of route direction elements determines which, and how, entities may be referred to in route directions. Accordingly, abstract relational specifications are inferred by optimization processes that adapt route directions to environmental characteristics and inherent route properties.

Human wayfinding, however, may not be restricted to a single mode of transportation. A typical example is public transport, where travelers frequently switch between pedestrian movement and passive transportation (trains, buses, etc.). Timpf (2002) analyzed route directions for multi-modal wayfinding and developed two different ontologies of route knowledge: one representing knowledge from the perspective of the traveler and one taking the perspective of the transportation system. The former focuses on movement along a single route, i.e., actions to perform to reach the destination, while the latter provides concepts referring to the complete transportation network.

An industry approach for formalizing route knowledge can be found in Part 6: Navigation Service of the *OpenLS* specification. The OpenGIS Location Services (OpenLS) Implementation Specification (Mabrouk, 2005) describes 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 *Navigation Service* described in Part 6 of the OpenLS specification provides the accessing client, amongst other services, with preprocessed data that is required for the generation of route directions. Based on XML specifications, it defines a data structure that allows clients to generate their own route directions which may accord more to a user's preferences. The used data model structures the route in maneuvers (descriptions combining a turn at a decision point and proceeding on the following route segment) and enhances them with additional information about route elements.

CORE ASPECTS OF COGNITIVELY ERGONOMIC ROUTE DIRECTIONS

In the following, three aspects that are at the core of cognitively ergonomic route directions will be discussed in greater detail: cognitively adequate direction concepts, the use of landmarks, and spatial chunking to obtain hierarchies and change the level of granularity.

Conceptualization of directions at decision points

The specification of direction changes is the most pertinent information in route directions. While current route information systems heavily rely on street names to identify the proper direction to take, behavioral research (Tom & Denis, 2003) has shown that from a cognitive perspective, street names are not the preferred means to reorient oneself. People rather rely on landmarks (as discussed in the next section) and appropriate direction concepts. On the most basic level we have to specify the correspondence between a direction change (in terms of the angle) and a direction concept. For example, which sector is applicable to a concept like "turn right"? On a more elaborate level, we have to specify alternative direction concepts and detail their scope of application. Figure 1 shows some examples of how the same direction change can result in different direction concepts (and corresponding verbalizations) depending, among other things, on the spatial structure in which the change occurs. We need this level of specificity for two reasons. First, a qualitative but precise direction model allows for verbally instantiating a situation model (Zwaan & Radvansky, 1998) of the encountered intersections. Second, intersections can function as landmarks. Just like classical examples of landmarks, such as the Eiffel Tower, in the context of a specific route, a salient intersection can be used to organize spatial knowledge. This aspect has not yet gained much attention.

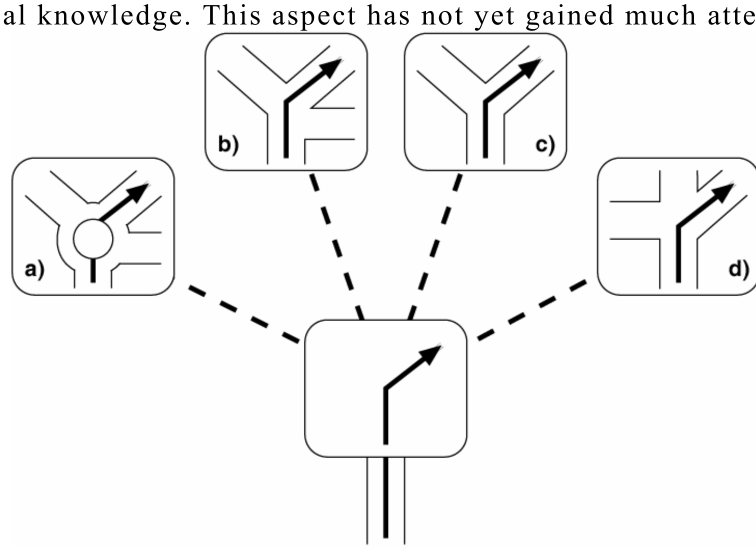

Figure 1. A change of a direction is associated with different conceptualizations according to the intersection at which it takes place. The 'pure' change may be linguistically characterized as *take*

the second exit at the roundabout (a). At intersection (b) it might change to the *second right*; at intersection (c) it may change to *fork right*, and at (d) it becomes *veer right*.

Enriching route directions with landmarks

Analyzing human route directions shows how prominently landmarks are used to structure the respective spatial knowledge, to give the instructed the possibility to assure that they are still following the correct route, and to anchor required turning actions. Since landmarks seem to be such an important part of human-generated route directions their integration is pertinent for automatically generating cognitively ergonomic instructions.

Several classifications of landmarks and their characteristics have been discussed in the literature. One of the first assessments is presented by Lynch (1960) who distinguishes Landmarks as one of five elements that structure urban knowledge: path, edges, districts, nodes, and landmarks. It is commonly agreed that the landmark account should comprise all five elements, as according to Presson and Montello (1988) everything that stands out of the background may serve as a landmark. That is, given the right spatial context different features of an environment may serve as landmarks. Sorrows and Hirtle (1999) distinguish three characteristics important for making an object a landmark: its *visual*, *semantic*, and *structural* characteristics. Additionally, landmarks can be categorized according to their cognitive function within route directions, their geometry, and their spatial relation to the route. Humans conceptualize landmarks either as point-like, linear, or area-like entities. However, these conceptualizations do not necessarily correspond to the geometric characteristics of objects but reflect the schematization processes cognitive agents apply (Herskovits, 1986). A detailed description of the different roles of landmarks is necessary to allow for their integration in an automatic generation process. For example, a simple, yet as of today unexplored way to enrich route directions with landmarks is to include references to salient intersections, like T-intersections or roundabouts, which are easy to identify automatically. This also reflects the direction concepts humans employ with such structures (see also Fig. 1).

Spatial Chunking: Hierarchies and levels of granularity

The hierarchical organization of spatial information and flexibly changing between levels of granularity are omnipresent in the cognitive organization of spatial knowledge (Hobbs, 1985; Kuipers, 2000). Chunking elementary wayfinding actions (such as turns at intersections) in order to impose a hierarchical structure and to change the level of granularity reflects not only cognitive conceptualization processes but organizes route knowledge in a cognitively ergonomic way. Especially users who are familiar with an environment can profit from such an approach. In general, providing a user with too much detail violates findings of cognitive science, as for example formulated in Clark's *007 Principle*: "In general, evolved creatures will neither store nor process information in costly ways when they can use the structure of the environment and their operations upon it as a convenient stand-in for the information-processing operations concerned. That is, know only as much as you need to know to get the job done." (Clark, 1989, p. 64)

Structuring route descriptions by subsuming instructions gives users a coarse overview over a route, which is easier to perceive and quite often sufficient for successful wayfinding, especially if the user is familiar with the environment. Of course, the subsumed information still has to be accessible in case the user needs it (or, as discussions on positioning technologies in this volume show, the user may simply re-query a new route from his new position). This may either be possible by zoom-in operations, i.e., by accessing the next, more detailed level of the hierarchy, or by (mental) inference processes. Such inferences, for example, extract from an instruction like "turn left at the dead end" information on which action to perform at all intersections before the dead end, namely to continue straight (e.g., Duckham & Kulik, 2003). The following cognitive strategies for spatial chunking are discussed in the literature (Dale et al., 2005; Klippel, Tappe, & Habel, 2003): numerical chunking, structure chunking, landmark chunking, and chunking using the street level hierarchy.

THE MULTIMODAL PRESENTATION OF ROUTE KNOWLEDGE

The *multimodal communication* of spatial information is a core aspect of human cognition: linguistic expressions, graphical representations such as sketch maps, and gestures are channels along which humans naturally communicate (Oviatt, 2003). Each representational medium—each channel—has advantages in specific contexts but may fail in other situations (Kray, Laakso, Elting, & Coors, 2003). For example, natural language expressions are inherently underspecified: a term like *turn right* is applicable to a range of different turning angles at an intersection and therefore may be sufficient in many situations. Fig. 2, however, shows a situation that requires a complex explanation if a description is provided in linguistic terms. In this case, a graphic representation is more suitable to communicate the situation at hand. Communication channels also differ with respect to their suitability in the identification of *landmarks*. A salient object at an intersection might be visually easily identifiable and recognisable, but hard to describe linguistically. An expression like *follow the road to the dead end* on the other hand, may chunk a large part within a route linguistically and therefore, communicate the spatial situation more efficiently if the dead end is a long way away and hard to depict on a small screen.

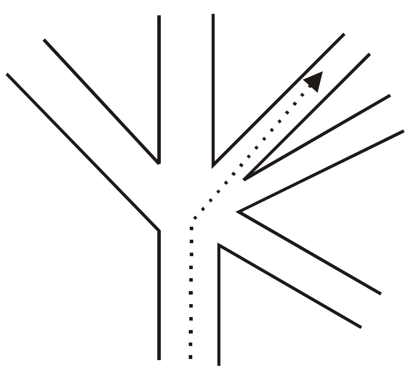

Figure 2. Complex Intersection.

The communication of route information, whether visually, linguistically, or in any other modality, has to follow the same guidelines as established for the structuring of route knowledge. Cluttering any communication process has shown to violate cognitive ergonomics and to slow down information processing. This confinement to sparseness has been shown for visual route directions, for example, by Agrawala and Stolte (2000), who based their route direction tool on results obtained from sketch maps (Tversky & Lee, 1999).

SUMMARY

In the last decades, research on route directions in linguistics and cognitive science revealed many underlying principles and processes of human route direction production and comprehension, and, thus, provides us with an understanding of what constitutes cognitively ergonomic route directions. However, this understanding has to be formally specified to be implemented in information systems for wayfinding assistance, like internet route-planners. In essence, three cognitive principles need to be implemented in wayfinding assistance systems to generate cognitively ergonomic route directions: adequate direction concepts, the enrichment of route directions with landmarks, and spatial chunking which allows for a hierarchical structuring of route knowledge and representations on different levels of granularity. To this end, we need a thorough understanding of which direction concept humans apply in which situation, a detailed ontology of the different kinds of landmarks and the role they may take in route directions, as well as formal characterizations that model hierarchical structures and guide the changes of granularity.

Terms and Definitions

Cognitive Ergonomics: The design of information systems that places a strong emphasis on cognitive aspects. In the case of route directions the design aims for a lower cognitive load and enhanced location awareness at the same time.

Landmark: Any entity in the environment that sticks out from the background.

OpenLS: Specification of an open platform for location-based services defining their core functionality (directory service, gateway service, location utility service, presentation service, route service).

Personalization: Adaptation of information presentation and interaction with a device / software to the needs and preferences of a specific, individual user.

Route Directions: A set of instructions that allow a wayfinder in known or unknown environments to follow a route from a start point to a destination.

Granularity – Here, it refers to the detail in route directions; from coarse levels for general planning to finer levels to provide context-specific information, for example at decision points.

Spatial Semantic Hierarchy (SSH): A computational model defining acquisition and representation of spatial knowledge on different levels of abstraction ranging from sensory information to topological knowledge.

Wayfinding: The cognitive conceptual activity of planning and finding ones way.

Wayfinding Choremes: Mental conceptualizations of functional wayfinding and route direction elements.

References

Agrawala, M., & Stolte, C. (2000). A design and implementation for effective computer-generated route maps. In *AAAI Symposium on Smart Graphics, March 2000*. Stanford.

Chandrasekaran, B., Josephson, J. R., & Benjamins, V. R. (1999). What are ontologies, and why do we need them? *IEEE Intelligent Systems and Their Applications, 14*(1), 20-26.

Clark, A. (1989). *Microcognition: Philosophy, cognitive science, and parallel distributed processing.* Cambridge, MA: MIT Press.

Dale, R., Geldof, S., & Prost, J.-P. (2005). Using natural language generation in automatic route description. *Journal of Research and practice in Information Technology, 37*(1), 89-105.

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

Duckham, M., & Kulik, L. (2003). "Simples" paths: Automated route selection for navigation. In W. Kuhn, M. Worboys & S. Timpf (Eds.), *Spatial Information Theory: Foundations of Geographic Information Science. Conference on Spatial Information Theory (COSIT) 2003.* (pp. 182-199). Berlin: Springer.

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

Guarino, N. (1998). Formal ontology and information systems. In N. Guarino (Ed.), *Formal Ontology in Information Systems. Proceedings of FOIS'98, Trento, Italy, 6-8 June 1998.* (pp. 3-15). Amsterdam: IOS Press.

Herskovits, A. (1986). *Language and Spatial Cognition: An Interdisciplinary Study of the Representation of the Prepositions in English*. Cambridge, UK: Cambridge University Press.

Hobbs, J. R. (1985). Granularity. In A. Joshi (Ed.), *Proceedings of the 9th International Joint Conference on Artificial Intelligence. Los Angeles, CA* (pp. 432-435). San Francisco, CA: Morgan Kaufmann.

Klein, W. (1978). Wegauskuenfte. *Zeitschrift für Literaturwissenschaft und Linguistik, 33*, 9-57.

Klippel, A., Tappe, T., & Habel, C. (2003). Pictorial representations of routes: Chunking route segments during comprehension. In C. Freksa, W. Brauer, C. Habel & K. F. Wender (Eds.), *Spatial Cognition III. Routes and Navigation, Human Memory and Learning, Spatial Representation and Spatial Learning.* (pp. 11-33). Berlin: Springer.

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.

Kray, C., Laakso, K., Elting, C., & Coors, V. (2003). *Presenting route instructions on mobile devices.* Paper presented at the IUI'03, January 12-15, 2003, miami, Florida, USA.

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

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

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

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

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

Oviatt, S. L. (2003). Multimodal interfaces. In J. Jacko & A. Sears (Eds.), *The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications.* (pp. 286-304). Mahwah, NJ: Lawrence Erlbaum.

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.

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

Sorrows, M., & Hirtle, S. C. (1999). The nature of landmarks for real and electronic spaces. In C. Freksa & D. M. Mark (Eds.), *Spatial information theory. Cognitive and computational foundations of geographic information science* (pp. 37-50). Berlin: Springer.

Timpf, S. (2002). Ontologies of wayfinding: A traveler's perspective. *Networks and Spatial Environments, 2*, 3-33.

Tom, A., & Denis, M. (2003). Referring to landmark or street iniformation in route directions: What difference does it make? In W. Kuhn, M. Worboys & S. Timpf (Eds.), *Spatial information theory.*

Foundations of geogrpahic information science. International conference, COSIT 2003, Kartause Ittingen, Switzerland, September 2003. (pp. 362-374). Berlin: Springer.

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

Werner, S., Krieg-Brückner, B., & Herrmann, T. (2000). Modeling navigational knowledge by route graphs. In C. Freksa, W. Brauer, C. Habel & K. F. Wender (Eds.), *Spatial cognition II. Integrating abstract theories, empirical studies, formal methods, and practical applications.* (pp. 295-316). Berlin: Springer.

Zwaan, R. A., & Radvansky, G. A. (1998). Situation models in language comprehension and memory. *Psychological Bulletin, 123*(2), 162-185.