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# Wayfinding Choreme Maps

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**Abstract.** This contribution details how conceptual characterizations of route knowledge can provide the basis for graphical route information in a cognitively adequate way. The approach is based on the theory of *wayfinding choremes* that originated from the leitmotif to reflect mental conceptualization processes—as a canonical representation—in different modes of externalization, primarily graphical and verbal. The approach is therefore termed *cognitive conceptual approach to map design*; it stands in opposition to more frequently used data driven approaches. Possibilities and requirements of the conceptual approach are explored and related to information system requirements such as the semantic specification of data structures and their relation to visual output. The wayfinding choreme approach has been implemented in a basic version; its requirements are illustrated and future lines of research are discussed. The focus is placed on organizational aspects of route knowledge, i.e. how they can be modeled and how they can be accounted for in the visualization of modern navigation assistance systems.

## 1 Introduction

Every map reflects a conceptualizing activity put forth by a map maker or a group of map makers. The map maker, nowadays aided by all kinds of technical equipment or even 'himself' an artificial agent, has to make sense of the information available. Yet, the degree to which maps reflect mental conceptualizations varies. A topographic map or an automatically generated internet route map are not necessarily meant to reflect the qualitative abstractions and imprecision of the world in our heads. Rather they are meant to provide an exact depiction of the information that is available about the environment—within, apparently, the limits put forth by the representational medium. In contrast, sketch maps are reflections of knowledge in our heads rather than precise depictions of the environment. In between these classes of representations lies a spectrum of different kinds of maps, some more veridical, some more abstract (cf. e.g., MacEachren, 1994). One important kind of maps are schematic maps, which are crafted as maps but intentionally distort spatial knowledge—just like sketch maps or like human knowledge is (e.g., Klippel, Richter, Barkowsky, & Freksa, 2005; Tversky, 2000). The attractiveness of these maps—and the interest of cognitive science and the visualization community in them—is twofold: schematic maps are perceptually easier to comprehend as they contain less visual clutter (e.g., Phillips &

Noyes, 1982) and have a stronger focus on a specific task at hand. Therefore, they are also referred to as task-specific maps or special purpose maps (Freksa, 1999; Muehrke & Muehrke, 1986). Second, they are able to reflect mental conceptualization processes, or to be more precise, the results thereof. This becomes obvious as we find similar knowledge representation characteristics in schematic maps and in naïve human spatial knowledge (e.g., Tversky, 2000). Matching internal and external representations should therefore be easier with positive effects on the map reading process, especially for map users not trained in the interaction with maps. There are detailed explanations why it is important to define appropriate schematizations, that schematization is an unavoidable necessity for information processing systems and what the positive effects of schematic representations are (see, e.g., Clark, 1989; Tversky et al., 2003). The remaining question, therefore, is not if we should schematize, but how.

Several approaches exist that aim to specify representation theoretic aspects of schematic maps in order to achieve such appropriate schematizations. We will briefly acknowledge two of them: one from cognitive psychology and one from artificial intelligence. The first is the toolkit approach by Tversky and Lee (Tversky & Lee, 1998, 1999). They analyzed sketch map drawings to elicit elements of a graphical toolkit for route directions as well as verbalizations for a corresponding verbal route direction toolkit. They propose a correspondence relation between these two toolkits and an underlying common conceptual structure from which elements in both toolkits originate: verbal and graphical route directions are two different externalizations of the same mental conceptualization process. The elements in their toolkits have the character of prototypes (see Figure 1). This approach and the assumption that a conceptual representation underlies different forms of externalizations reflect common theories in linguistics on how the human brain translates, for example, between different modalities: how can we see a tree and then speak about a tree? The mediating element is, for example, referred to as *conceptual structure* (cf., Jackendoff, 1997)[1]. This assumption is also the basis for the wayfinding choreme approach, discussed in the next section.

The second approach—from artificial intelligence—is called *aspectmaps* (Berendt, Barkowsky, Freksa, & Kelter, 1998): The basic idea of this approach is to construct maps that represent specific knowledge needed for a task at hand. This knowledge, the so-called *aspects*, is extracted from existing data and is represented in a cognitively motivated level of abstraction[2]. The aspectmap approach specifies different types of (spatial) knowledge: knowledge that needs to remain unchanged, knowledge that needs to be present but can be altered, and knowledge that can be omitted in the map. Accordingly, the aspects to be depicted are ranked in a depictional

[1] The authors are aware of the current debate in cognitive science on the question of the modality / amodality of mental representations; for example, in Freksa, Barkowsky, & Klippel (1999) we argue for a more modality specific correspondence between schematic maps and their representations in the brain. However, with respect to the combination/transformation of different modalities (the current line of thought) an amodal representation structure, which reflects a more linguistically oriented approach, bears the greater clarity without loss of validity.

[2] For a cartographic perspective on schematization / generalization see, for example, Brassel and Weibel (1988).

precedence (Barkowsky & Freksa, 1997) and, as a consequence, some aspects may get depicted such that they cannot be read off the map literally any more. To correctly use the map, the map reader's assumption about this depictional precedence, i.e. whether some information is depicted veridical or not, needs to match the actual precedence used in map construction. Otherwise, map reading may lead to overinterpretation, i.e. some aspect is taken for being represented veridical while it is not. Subway maps are a good example for this approach. While the direction and distance relations between stations along a line can be distorted, for example, to fit in a qualitative eight sector direction model and therefore cannot be read off the map literally, the ordering information within and between different subway lines needs to be preserved in order to keep the maps usable, and hence can be seen to be veridical.

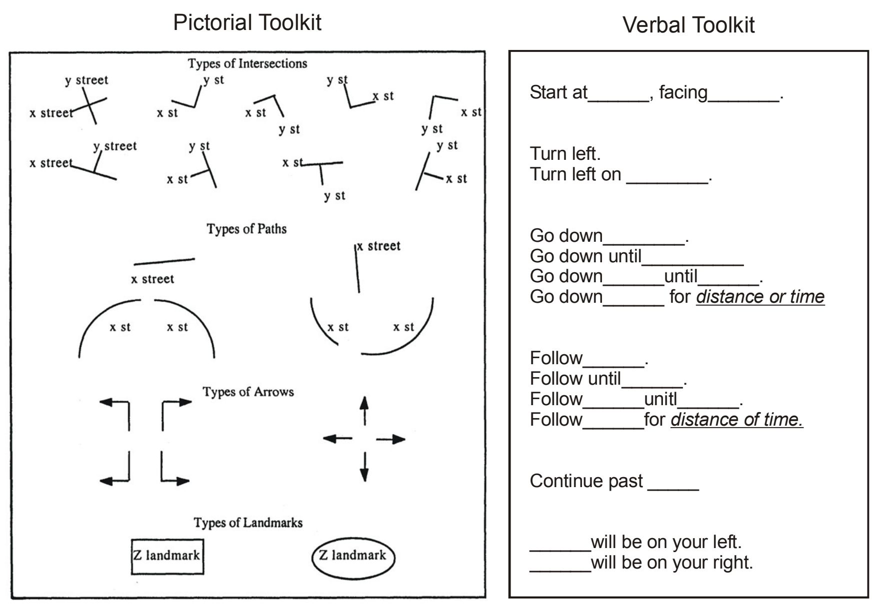


**Fig. 1.** Graphic and verbal direction toolkit by Tversky and Lee (1999, modified).

## 2 The Wayfinding Choreme Approach

The wayfinding choreme theory is inspired by the idea of chorematic modeling, detailed by the French Geographer R. Brunet (e.g., 1987). The term choreme is a composition of the root of the Greek word for space (*chor-*) and the suffix *–eme*; thereby, a close correlation to language is made explicit. Wayfinding choremes—as a domain specific extension—are defined as mental conceptualizations of primitive functional wayfinding and route direction elements (Klippel 2003); their focus is on the actions that take place in environmental structures. Wayfinding choremes reflect procedural knowledge, i.e. knowledge about how to interact with the world and which actions to perform at a decision point. In this sense, wayfinding choremes are schemata and do not as such concern categorical knowledge about physical spatial objects (Aristotle, 1941; Neisser, 1976)[3]. Wayfinding choremes can be externalized, for example, graphically or verbally. To this end, the theory corresponds to the Chomskian differentiation in I-language and E-language in his explanations on language and grammar (Chomsky, 1986). 'I' stands for internal and denotes an abstract part that underlies the observable behavioral aspects of language. 'E' stands for external and refers to these observable behaviors. Correspondingly, we refer to mental conceptual primitives, i.e. abstract mental concepts of basic route direction elements, as *I-wayfinding choremes*. The (graphical and verbal) externalizations of I-wayfinding choremes are termed *E-wayfinding choremes*. In contrast to the toolkit approach by Tversky and Lee (1998; 1999) as well as the aspectmap approach, the wayfinding choreme theory focuses on functional aspects (cf. Klippel, 2003). This focus simplifies the integration of findings from cognitive psychology and artificial intelligence by formally characterizing them such that they are applicable to the generation of graphical and verbal route directions as well as the translation from one modality into the other.

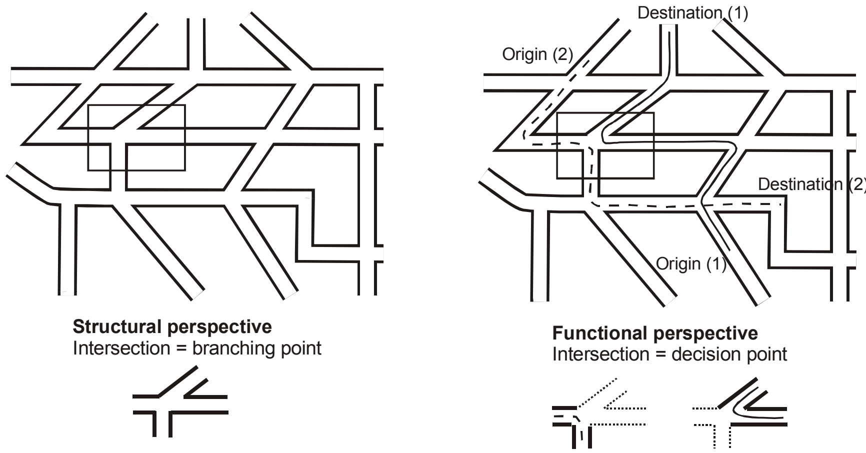


**Fig. 2.** Distinguishing between structural and functional aspects of route information. Without any action taking place, an intersection is referred to as a branching point (left part). In the course of route following an intersection becomes a decision point and the action to take place demarcates functional relevant parts (right part).

Most pertinent for following a route is direction information at decision points (e.g., Daniel & Denis, 1998) on which the research efforts are therefore placed. In Klippel (2003) the empirical basis for wayfinding choremes, i.e. the mental conceptualization of functional primitives of route direction elements, is detailed. One major

[3] For a discussion of the relations of object and event conceptualization see, for example, Zacks and Tversky (2001).

achievement is a clearer distinction between structural and functional elements of route information and how this distinction contributes to a better understanding of conceptualization processes. Most approaches concerned with the visualization of route information focus on structural aspects, i.e. they are concerned with the conceptualization or depiction of objects. In contrast, the wayfinding choreme theory aims to functionally characterize route information, i.e. it focuses on actions that demarcate only the relevant parts of a physical spatial structure. The distinction is reflected in the following definitions and is clarified in Figure 2:

**Structure –** denotes the layout of elements physically present in the spatial environment that are relevant for route directions and wayfinding. This comprises, for example, the number of branches at an intersection and the angles between those branches.

**Function –** denotes the conceptualization of actions that take place in spatial environments. The functional conceptualizations demarcate parts of the environment, i.e. those parts of the structure necessary for the specification of the action to be performed.

An important goal of the wayfinding choreme theory is the combination of prototypical functional and veridical (structural) information. The action that is required at a decision point is communicated by a prototypical graphical instantiation. This prototypical action representation is embedded in a veridical spatial situation. These theoretical remarks will be explained in the following according to their graphical implications.

Figure 3 shows the results for prototypical turning directions at decision points explicated in Klippel (2003). Participants adhere to the prototypicality of the turning actions, i.e. the functional aspects of decision points. It is important to note that they do not adhere to the prototypicality of the intersections' structure. A right turn is a right turn independent of the number of branches at an intersection. In contrast, an intersection with 5 branches has no prototypical graphic realization. A seven direction model for turning actions has been confirmed by these experiments and is taken as a basis for the graphical representation of turning actions at decision points. The seven resulting wayfinding choremes are employed to schematically depict route information.

Given the set of wayfinding choremes for the functional parts of decision points, we will now turn to the remaining information at a decision point. The considerations underlying a wayfinding chorematic depiction are twofold: First, the action that has to be performed at a decision point has to be communicated clearly. This is achieved by representing the turning action by a graphic wayfinding choreme. Second, over-schematization can lead to wrong inferences. Therefore, the following strategy is chosen: veridical information, for recognition and pattern matching, and prototypical information, for the communication of the required action, is combined. Figure 4 shows an example of a decision point. At this decision point the functional relevant parts are replaced by a wayfinding choreme (see Figure 3), whereas the remaining branches are kept veridical, i.e. their angular information is left unchanged with respect to the incoming route segment.

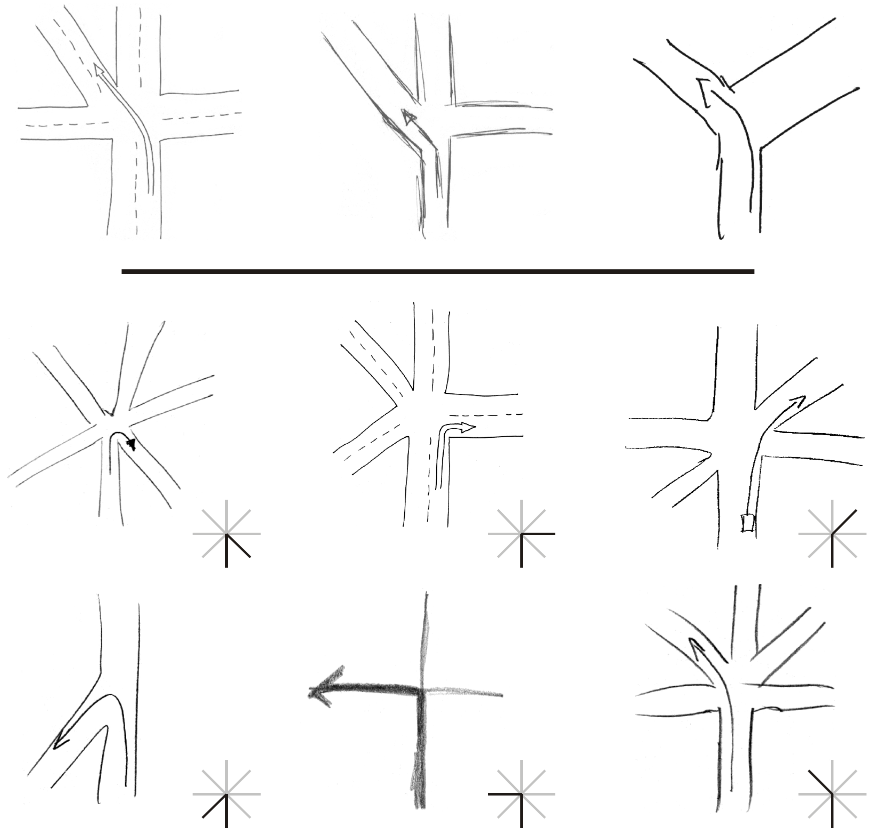

**Fig. 3.** The behavioral basis of wayfinding choremes (Klippel, 2003). The upper part demonstrates that participants adhere to a prototypical concept for, for example, 'veer left' in different types of intersections. The lower part shows the seven basic wayfinding choremes derived from the experimental data.

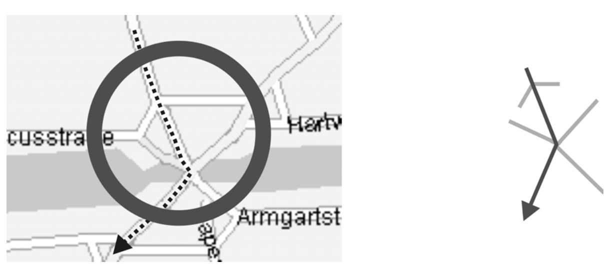


**Fig. 4.** Combining prototypical information (wayfinding choremes, functional aspect) and veridical information (structural aspect) at decision points.

Different to existing solutions (e.g., in navigation systems) a wayfinding choreme based navigation assistance system focuses on the functional information for which prototypical graphical concepts can be determined. The conceptualization of an action that takes place at a decision point demarcates branches that are emphasized; branches that are not functionally involved are deemphasized, however, kept veridical with respect to their number and angle to ensure that the corresponding intersection can be easily identified.

## 3 Relations of Language and Graphics

With the advent of multimodal communication systems the transduction between different external forms of communication—the externalization of conceptual structures—became a prominent research question in several communities (e.g., Allen, 2003; Wahlster, 1998). We focus here on the interplay of language and graphics and their relation to the underlying conceptual structure.

The wayfinding choreme theory provides the basis to relate 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 (I-wayfinding choremes) and the *representing world*, the external representation as route maps or verbal route directions (E-wayfinding choremes) (cf., Palmer, 1978): The linearity of routes enables the ('direct') application of a formal language. Hence, we use a grammatical notation based on wayfinding choremes as terminals, the wayfinding choreme route grammar (WCRG), to specify valid combinations (Klippel, Tappe, Kulik, & Lee, forthcoming 2005). In case of a graphical representation and the two-dimensional character of the representational medium involved we can still speak of pseudo-linearity. The wayfinding choremes become the representation vocabulary that characterizes route knowledge and that is based on mental conceptualizations of directions at decision points. In this sense, the wayfinding choreme theory can also be used for a route knowledge ontology (Chandrasekaran, Josephson, & Benjamins, 1999; see also Przytula-Machrouh, Ligozat, & Denis, 2004)[4]. As the conceptual level is linked to graphical representations we could also speak of an ontology of visualizations. Establishing explicit links between different levels, i.e. the conceptual level (I-wayfinding choremes) and different forms of externalizations (E-wayfinding choremes), allows for the specification of representation-theoretic relations and provides a basis for transducing one externalization into another. Additionally, once a theory is established that allows for specifying which representation to use in which situation (e.g., Meilinger, 2005), a choice can be made.

For mobile cartography, for example, it is essential to define generalization rules that often need a higher level of abstraction (i.e. a coarser granularity) due to the requirements of the representational medium, for instance, a handheld device (Baus, Butz, Krüger, & Lohse, 2001). Likewise, the cognitive requirements change

[4] In Guarino's (1998) terminology such an ontology might primarily be characterized as a domain ontology.

depending on the given (spatial) context. On a conceptual level it is possible to model these requirements and guide the adequate depiction of the corresponding parts of the environment.

We integrated knowledge from different approaches into the wayfinding choreme route grammar, for example, on modeling route directions (Duckham & Kulik, 2003; Klippel, Tappe, & Habel, 2003; Mark, 1985). These approaches provide insights and valuable information on how to structure route knowledge and how to formalize it. Again, as these rules and the grammar operate on a conceptual level, it is possible to 'externalize' them in different modalities, given that the requirements of each representational medium are sufficiently modeled, too.

One of the most detailed researched examples are T-intersections: They provide a fail-safe structure and can therefore be employed to obtain simple route directions. Instructions like 'turn right when the route dead ends' bear little ambiguity. Current research focuses on extending means to structure route knowledge, especially landmarks (e.g., Raubal & Winter, 2002; Richter & Klippel, 2005; Winter, Raubal, & Nothegger, 2004).

For the realization of conceptual knowledge in a representational format that requires the instantiation of exactly one out of many alternatives—as is the case with maps—we need to carefully advise which alternative is chosen. In our case, we propose the distinction between structure and function to allow for the design of maps (see section 2); the conceptualization focuses on the functional level, and functionally prototypical elements are used to represent the conceptualization. Nevertheless, the conceptualization is integrated in structural aspects, which are important, especially in the task of wayfinding and due to the characteristics of the representational medium.

Whilst the distinction of structure and function solves several problems for graphic representations, linguistic externalizations may require a more detailed specification of the conceptualization. A good example is a situation that could be linguistically expressed as 'fork right'. Whilst the 'pure' direction concept could be likewise characterized as 'bear right', participants rather decide for a combination of a coarse direction concept ('right') and additionally specify the structure ('fork'). The graphic representation offers this 'concept' without additional costs, but for a conceptual specification and the externalization in an underspecified modality the conceptualization needs to be more explicit. A disambiguation may also be required in case of ambiguous situations where more than one alternative is available (cf., Tenbrink, 2005).

## 4 Implementing the Wayfinding Choreme Approach

Taken a veridical graphical representation of an environment, as it can be generated from, for example, land use data, we need to replace the functionally relevant parts, i.e. the route segments at decision points, with prototypical graphical representations—the graphic E-wayfinding choremes (Figure 3). We aim to emphasize the action to take at a decision point (see Figure 4), while preserving the configuration of the intersection. A straightforward approach would be to replace the route segment on which a wayfinder leaves a decision point (*outgoing route-segment*) such that the angle between this route segment and the route segment the wayfinder entered the decision point on (*incoming route-segment*) corresponds to the prototypical turning angle of the relevant wayfinding choreme. However, this replacement of a single route segment has consequences for the complete graphic representation of the route: as the replaced route segment needs to end in the next decision point, this decision point's position must be shifted as well. This results in further shifts of its additional branches and all following decision points. The distortions end up towards the end of the route and are dependent, for example, on the length of the route. Changing the positions of decision points and thereby changing their absolute reference would result in a subway-map-like map design with consequences on the interpretability of the information displayed.

Therefore, we keep the positions of all intersections fixed in the map (cf. the schematization approach based on discrete curve evolution by Barkowsky; Latecki, and Richter, (2000). To introduce the prototypical turn, we replace part of the outgoing route segment such that incoming and outgoing route segment adhere to the prototypical angle of the graphic E–wayfinding choreme. The implementation operates on a map consisting of a set of objects, each one standing for a single street, and a graph, which nodes represent the intersections of the streets. A route is composed of a sequence of connected nodes. To replace the intersections at a decision point by the appropriate wayfinding choreme each node is classified: the angle between the incoming and the outgoing route segment of the node is calculated and, based on this angle, the node is assigned to one of the wayfinding choremes.

Subsequently, part of the outgoing route segment is altered so that the angle it spans with incoming route segment corresponds to the prototypical turning angle specified by the E–wayfinding choreme. These operations are performed iteratively for each decision point of the route, with the exception of the nodes at the beginning and the end of the route as there is no incoming or outgoing route-segment, respectively.

We keep part of the incoming route-segment at a decision point veridical, as well. The rest of the route-segment is replaced by a cubic Bézier curve, which connects the two parts of the route-segment kept straight that form the prototypical instantiation of a wayfinding choreme.

The starting point of the Bézier curve is calculated such that the angle enclosed by this new point, the node itself and the last coordinate of the incoming route segment corresponds to the wayfinding choreme. The end point preserves the direction of the replaced route segment from which a wayfinder enters the next intersection. The first control point needs to lie on the line through the current node and the starting point of the Bézier curve and the second on the line through the end point and the next node. This way, the Bézier curve proceeds on both ends tangential to the direction of the route segment's parts.

This replacement emphasizes the action to take by introducing the wayfinding choreme as functional relevant part, but keeps everything else veridical for recognition[5]. Additionally—by introducing the curved line—we provide a sketch-like character to the changed information, visually indicating that here something has been changed and cannot be taken as veridical anymore.

[5] For a different approach that likewise aims at sketch-map like route directions see Agrawala and Stolte (2000).

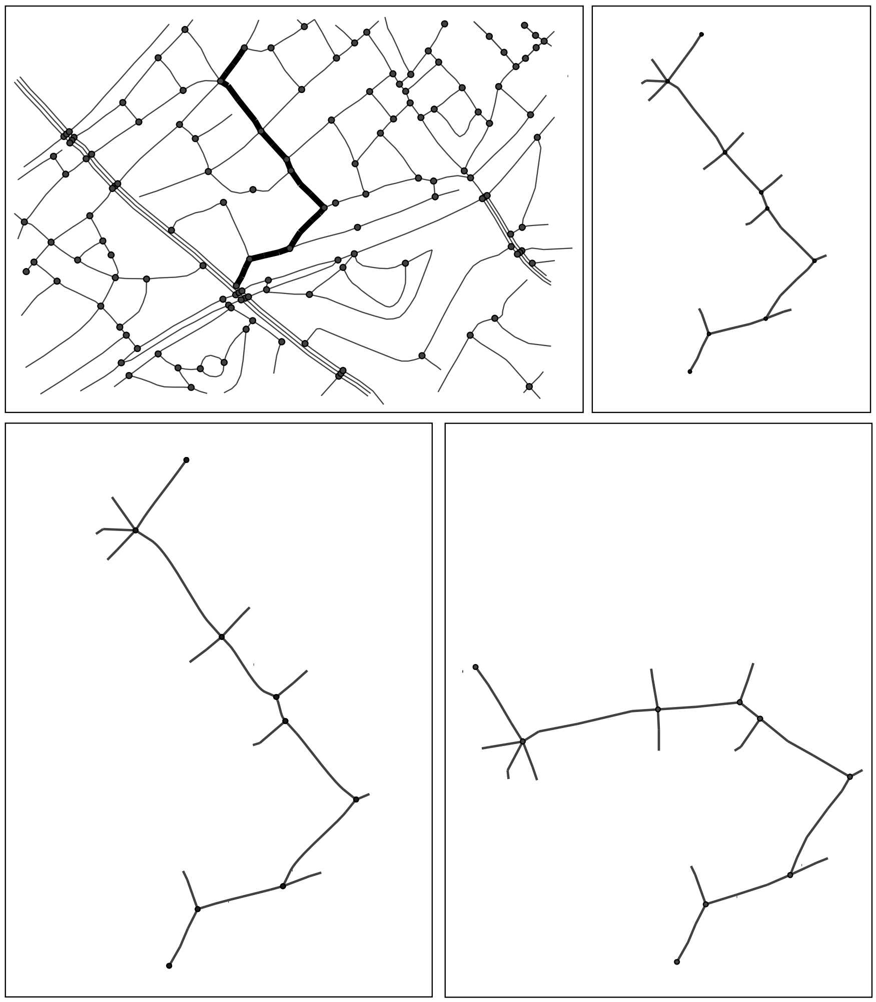

**Fig. 5.** The upper part is a representation of the available data set (left) and a specific route (right). The lower left part is a wayfinding choreme map in its basic version. The wayfinding choremes are embedded in the structure of the decision points; route segments are connected by Bézier curves and the position of the decision points is fixed. The lower right part depicts the same route without curves and adjusted positions of decision points.

## 5 Future Research Directions

In its basic instantiations, wayfinding choreme maps display the requested route in total—or at least a significant part of it—and focus on the schematization of the turning angles at decision points according to results of behavioral experiments. Conceivable, and theoretically and behaviorally partially established, cognitively inspired modifications of the first implementations comprise:

- The organization of route information into meaningful chunks, so called HORDE—Higher Order Route Direction Elements—and the depiction of these chunks as (meta-) annotations to the basic route.
- The clipping of route parts according to HORDE for providing cognitively adequate route directions; this enhances the step-by-step instructions provided by internet route planners or by mobile devices.
- The refinement of the existing theoretical model by additional research on the conceptualization of route elements: a) the basic model of direction concepts, b) the analysis of context and personalization effects. This allows for a better translation performance between different modalities.

### 5.1 HORDE

In an electronic navigation system the approach can be extended to just present the next decision due, i.e. the next decision point, to further ease chorematic wayfinding maps' usage. As discussed, however, by several authors (Dale, Geldof, & Prost, 2003; Denis, 1997; Klippel et al., 2003), several decisions are often chunked into a single conceptualization, for example 'turn left at the third intersection'. This new concept comprises three subsequent decision points: two straight movements followed by a left turn. These higher order route direction elements (HORDE) reflect an omnipresent characteristic in spatial cognition, i.e. the grouping of basic elements into chunks (e.g., Allen & Kirasic, 1985; Miller, 1956). The wayfinding choreme theory allows for a straightforward specification of HORDE on a conceptual level by employing a grammatical notation, the wayfinding choremes route grammar (WCRG) (Klippel et al., forthcoming 2005). Yet, graphically, HORDE need special treatment. Either several decision points need to be focused on at once, or a decision point further ahead, one that, for example, requires the turn, must be in focus. A detailed examination of HORDE and possibilities to adequately depict them are ongoing research.

### 5.2 Refinement

Another future direction of research aims to refine the direction model that is used for assigning wayfinding choremes to turning angles. By employing psychological methods for the elicitation of conceptual knowledge (Klippel et al., 2004), we found that directions are best represented as a combination of sectors and axis. Additionally, the refinement of the conceptualization and the ontological organization within the wayfinding choreme theory allow for changes in *granularity* to model a core aspect of human cognition (e.g., Hobbs, 1985).

Some spatial situations, for example, a fork in the road, require to render the conceptualization of the action performed more precise by a mixed concept of structure and function. In case of a fork the conceptualization changes from a pure direction concept, that could be characterized as veer left/right, to a mixed concept that employs a coarser level of granularity characterized by the two half planes of the egocentric reference system (left/right) plus a reference to the structure, i.e. a fork in the road. The result could be a verbalization like *fork right*. In contrast, the graphic representation requires no changes. For both representations, however, a fork in the road represents a natural means for creating a chunk (HORDE).

## 6 Conclusions

The advantage of constructing maps based on a conceptual specification is that only those elements are depicted that are conceptually relevant. The resulting benefits are twofold: first, the conceptualization of the represented domain is supported (cognitive aspect), second, we aim to fulfill the basic requirements of communication specified by Grice (1989) by only using relevant elements (communicative aspect). In doing so, we also avoid the drawbacks of visual clutter (perceptual aspect). Consider, for example, landmarks as being critical at complex intersections (Michon & Denis, 2001) and at decision points with a direction change (Lee, Klippel, & Tappe, 2003). These landmarks are identified on the conceptual level and only the relevant ones are depicted avoiding cluttering, which would result from showing all possible landmarks.

Several criteria that are specified in the wayfinding choreme theory might shed more light on the general leitmotif of using a cognitive conceptual approach for map design (e.g., Klippel, Lee, Fabrikant, Montello, & Bateman, 2005). Among the most pertinent is *conceptual embedding*, which is the distinction between structure and function. This distinction is also the basis for fusing pictorial and non-pictorial information: some information that is available in the abstract data structure is not represented graphically or is inherent to the representational medium. It becomes explicitly available on the conceptual level and therefore provides insights in the transduction of different modalities and for the design of multimodal systems.

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