Wayfinding Choremes

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Abstract. How can we represent spatial information in maps in a cognitively adequate way? The present article outlines a *cognitive conceptual* approach that proposes primitive conceptual elements from which maps can be constructed. Based on work in geography that starts with abstract models of geographic phenomena, namely *modelisation chorematique* by R. Brunet (1980, 1987), we coin primitive conceptual elements of route directions *wayfinding choremes*. Sketch map drawings were analyzed as they obey the same medial constraints as maps but are constructed in a way that provides insights into human conceptions. A distinction between *structural* and *functional* aspects of wayfinding presents a useful method to gain further knowledge about human conceptualizations and leads to a practicable cognitive conceptual approach to map construction.

Keywords. Conceptual structuring processes, route directions, wayfinding, cognitive conceptual approach to map making, spatial primitives.

1 Schematic Conceptual Representations

All maps are schematic maps. However, there is a category of maps that intentionally violates cartographic design constraints, such as sketch maps that distort, for example, distance information. For the purpose of this paper, we will refer to these maps as "schematic". Schematic maps reveal characteristics of human spatial information processing since certain aspects of space are simplified, omitted, and/or distorted with the assumption that users do not need the altered information. The most useful information is selected and structured to reflect human conceptualizations of the spatial domain (Freksa, Barkowsky, and Klippel, 1999; Tversky, 2000). Schematization approaches usually employ bottom-up—data-driven—methods similar to cartographic generalization. Stepwise they reduce and focus the information content of rich knowledge sources, for example, by shape simplification algorithms and other related research (e.g., Barkowsky, Latecki, and Richter, 2000; Cabello et al., 2001).

Despite findings from the cognitive science community on the positive effects of information reduction by schematization (e.g., Clark, 1989) cartographers continue to speak of 'maps that have to lie' (e.g., Monmonier, 1996) as they cannot represent the world one to one. In our opinion, schematic maps are not the 'bigger liars' but are

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representations that focus on relevant information and, thereby, accomplish valuable support for information processing. Tversky (2003) identified benefits of schematization; we have regrouped them and added further aspects:

- Cognitive and conceptual considerations – Schematization is a prerequisite to deal with the abundance of information available as, for example, the capacity of working memory is restricted. It also fosters the integration of information and thereby speeds decision making.
- Perceptual considerations – Visual complexity has been early on noted as one of the major drawbacks on information processing (e.g., Dobson, 1980; Phillips & Noyes, 1982).
- Informatics and AI perspective – Schematic information qualifies for compact data formats and computational efficiency. Less rich geometries—for example, ordering information and topology—constitute major research fields in qualitative spatial reasoning (e.g., Vieu, 1997).
- Technical aspects – New means for information presentation, for example, small displays, do not allow for great detail.

With the dawn of experimental cartography (Eckert, 1921/1925; Robinson, 1952) and especially since cognitive questions play a greater role in cartography (e.g., Petchenik, 1975; Medyckyj-Scott & Board, 1991; MacEachren, 1995; for an overview see Montello, 2002) map design improved by incorporating a cognitive perspective. However, most cognitively motivated studies focus on the thematic content or the overall design of maps and not on spatial components.

We illustrate this within the theoretical framework of graphic semiotics by Bertin (1974). Bertin grounds his work on visual variables in analyzing information depictable by the properties of the plane. For diagrams these are the horizontal and the vertical axis, which can be used to illustrate all kinds of information, for example, representing the changing amounts of precipitation during a year for a certain place on the earth's surface. While this conveniently visualizes the relation of two kinds of information, maps encounter the problem (or the advantage, see, e.g., Palmer, 1978; Freksa, 1999) that the two dimensions of the plane are reserved for representing *locational spatial information*—the *geographic component* in Bertins terminology. This affords the use of the *third dimension*—Bertin's visual variables, for example, color or hue—for depicting any other information. Whereas cognitive cartographic research focuses often on the third dimension, spatial cognition research is primarily concerned with locational spatial information.

Brunet (1980, 1987) proposed a singular approach that emphasizes conceptual spatial information. Even though he might not have characterized his own work thus, his approach could be viewed as cognitively oriented. Coming from analytical geography (e.g., Wirth, 1979), he established simple models that characterize—according to his theory—every possible spatial situation. Examples for these models are 'meshes' (French *maillage*), indicating the partitioning of a region, or 'contact', characterizing processes at boundaries. In correspondence to his theoretical models Brunet proposed graphical counterparts constituting the basic components of the maps he advocated. Following Bertin (1974) he subdivided every model according to three cartographic primitives in *point-like*, *linear*, and *areal* models. As a fourth synthetic but important primitive he added the *net* (French *reseau*). He chose the term *modelisation chorematique* or chorematic modeling for his theory composing *choreme* of the Greek word for space (*chorus*) and the suffix *–eme*. The basic set of choremes is combinable like the letters of the alphabet, hence, as we communicate 'all' things by combining letters, by combining choremes we cartographically communicate 'all' geographic phenomena. Fig. 1 depicts a part of his choreme table showing three basic models—meshes, attraction, and contact—for the cartographic primitives—point, line, area, and net.

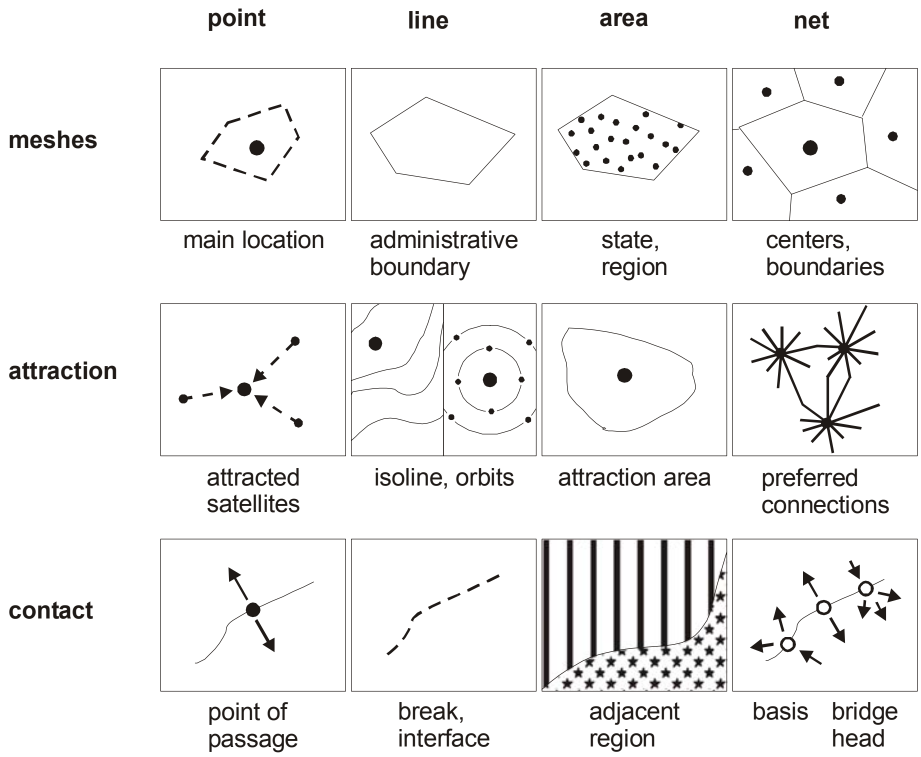

Fig. 1. The table of *choremes* by Brunet (extract, Brunet, 1987, p.191)

Although Brunet motivates his theory not explicitly by cognitive science research, he claims that by applying his graphic models to map making maps speak for themselves "Le langage de la carte est dans la forme, l'arrangement et la signification des distribution qu'elle montre. Les formes élémentaires sont les sémes de ce langage ; la syntaxe est dans leurs relations ; le message entier dans la configuration de la distribution" (Brunet, 1987, p. 190). And indeed, we find correspondences comparing his models with how humans structure environmental information, like, for example, image schemata (Johnson, 1987; Lakoff, 1987), hierarchies (e.g., Hirtle & Heidorn, 1993), or perceptual primitives (e.g., Biederman, 1987).

This—in our terminology—conceptual approach to map making constitutes the starting point for the ideas presented in this paper. Whereas Brunet built a theory for geography and geographic knowledge in general we focus our work on the domain of wayfinding and route directions for three major reasons:

- The present work defines a cognitive adequate way for representing spatial information essential for wayfinding; a domain for which Brunet's choremes are not applicable.
- We aim at automating map making appropriate for a given wayfinding situation. Therefore, the basic conceptual elements should not change from map to map but rather be the invariants. Brunet's choremes provide general means for structuring spatial knowledge but change greatly if represented in maps.
- People's conceptualizations change depending on the given domain and the events that take place in this domain. Hence, to elicit human conceptualizations we have to be as specific as necessary.

Analogous to Brunet's work we coin primitive conceptual elements of wayfinding and route directions *wayfinding choremes*. Combined, wayfinding choremes represent (nearly) all necessary route information in street networks. The conceptual models will be associated with pictorial representations. Hence, the term *wayfinding choremes* is systematically ambiguous as it denotes human conceptual as well as graphical entities.

2 Structure and Function

What is the difference between thinking of an intersection per se and thinking of an intersection at which one has to perform a specific action? Ample research explains how humans schematize spatial information at different scales (see Montello, 1993) from general organizational–structural aspects (e.g., Stevens & Coupe, 1978) to small scale characteristics of it (e.g., Evans, 1980; Moar & Bower, 1983). Schematization can be applied to objects (e.g., an intersection), as well as to actions (e.g., *turn right at the next intersection*). Schematizations of actions were inferred from object schematizations and resemble recent discussions of *events* (cf. e.g., Zacks & Tversky, 2001; Casati & Varzi, 1996). Following Quine (1996), Zacks and Tversky (2001) convincingly argue that events can be treated analogous to objects. Although they differentiate between actions and events—blowing out a candle is categorized as an action whereas a candle blown out on a windy day is an event—the distinction is not pertinent to the present work and the terms will be used interchangeably.

Wayfinding actions take place in environmental spatial structures which consist of objects and relations between objects. Hence, we differentiate conceptualizations of objects and conceptualizations of actions. Moreover, we are concerned with the representation of adequate spatial information in a spatio-analogical medium, therefore, our main focus are spatial aspects of map-like representations. The following terminology will stress these distinctions. With *structure* we refer to the object level, i.e. the spatial structure as physically present in the environment, with *function* we indicate the event/action level, or, to be more precise, the structural aspects demarcated by an action. This—in our opinion important distinction—is also reflected in the differentiation between *path* and *route* (Montello, in press) denoting a behavioral pattern as route, whereas the term path is reserved for a physical structure.

Again, the terms action / function / route build one pillar indicating a behavioral pattern, and object / structure / path group together to form a second pillar denoting the level of the physical reality. Fig. 2 clarifies this distinction for the domain of route directions and wayfinding.

The left side of Fig. 2 depicts a part of a city street network. From a structural perspective this network can be partitioned, for example, according to human spatial concepts, into intersections, i.e. branching points, and path segments. Additionally, the right side of Fig. 2 shows some behavioral patterns within the same network. The actions performed assign a different meaning to the objects identified on the structural level, for example, an intersection becomes a decision point. The route, which—in its character—is isomorphic to a path, demarcates the functionally relevant parts of the intersection within the structural framework.

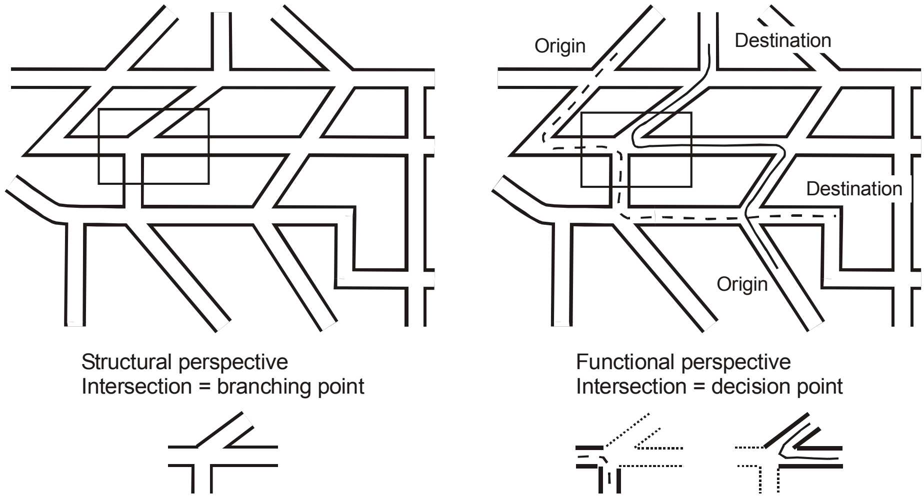

Fig. 2. Distinguishing paths (structural perspective) from routes (functional perspective)

3 Conceptualizing Route Direction Elements

Tversky and her coworkers (1998, 1999, and 2000) proposed that common conceptual structures underlie both, verbal and pictorial route directions. They advocate two toolkits for route directions containing primitive elements that establish a basic set for each of the two forms of external representation. They emphasize that the semantic correspondence of these toolkits can be used to translate between them. On the other hand, the basic elements of route directions in their pictorial toolkit stress structural aspects of intersections—additional arrows complement functional information—while the verbal direction toolkit relies primarily on functional aspects, i.e. most elements in their direction toolkit use verbs of motion. In the following, we focus on decision points as they constitute the most important aspects in route directions (Denis, 1997; Allen, 1997).

In the previous section we have discussed the distinction between structural aspects of a wayfinding situation as opposed to functional aspects of the behavioral pattern of following or planning a route. Rethinking the approach of conceptual elements—especially for pictorial route directions—from this perspective poses the question if the structure, i.e. the configurational information of a branching point, is the primitive element, or if not functional aspects, i.e. the demarcated parts of a decision point activated by a specific action, require more attention.

The structure of *the* prototypical intersection seems to be evident, i.e. two paths meeting at a right angle. However, the concept is invalidated when an uneven number of branches like the case of 5-way intersections occurs, when more branches have to be arranged (6-way intersection), or when the provided concept is underspecific, like in the case of star-shaped intersections.

Thinking about the complications to conceptualize these spatial structures and having in mind the proposed importance of a functional perspective leads to the following questions: First, is more attention necessary on functional aspects? And, second, if the representation of route directions—inherently on the action side—should not seek to identify rather functional than structural prototypes.

In order to gain evidence for the differentiation between structure and function and the corresponding differences in advocating conceptual primitives we examined human conceptualizations of route direction elements in an experimental setting.

Methods

Participants

19 participants volunteered for the study, 8 female and 11 male. They were native German speakers between 20 and 33, most of them holding an academic degree.

Design

Each participant constructed 42 drawings of a list of spatial expressions. Either these spatial expressions were general spatial concepts important for route directions, like ‘intersection’ (*Kreuzung*) or ‘turn right’, or they were actually parts of route directions like ‘at the star shaped intersection you turn right’ (*an der Sternkreuzung biegst Du rechts ab*). The verbal spatial expressions were systematically varied according to different types of intersections and to prototypical directions covering most of the actions required at decision points found in route traveling in outdoor networks on an average level of abstraction. These functional aspects, i.e. the actions to be taken at intersections, were chosen from models of qualitative spatial reasoning (e.g., Frank, 1992; Hernandez, 1994; Raubal, 2001). These are expressions necessary to give directions according to an 8-direction model. The resulting seven—the ‘going back’ direction is not examined here—functional expressions are: sharp right (scharf rechts), right (rechts), half right (schräg rechts), straight (geradeaus), half left (schräg links), left (links), sharp left (scharf links). ‘straight’, ‘right’, and ‘left’ are referred to as *basic (turning) concepts*, if modified by ‘sharp’ or ‘half’ as *specific turning concepts*. The directions were pretested to see if they were understood by participants.

The six concepts that actually require a direction change were tested for every intersection, i.e. 3-way (3-er Kreuzung), 4-way (only referred to as intersection (Kreuzung)), 5-way (5-er Kreuzung), 6-way (6-er Kreuzung), and star shaped (Sternkreuzung). The ‘straight’ (geradeaus) concept was only tested for ‘intersection’ (Kreuzung) and ‘6-way intersection’ (6-er Kreuzung). Additionally, the participants obtained written concepts for, for example, intersection (Kreuzung), turn right (rechts abbiegen), straight (geradeaus), or turn right at the 3rd intersection (an der dritten Kreuzung rechts).

Material

The participants were provided with 44 single pages. The first page carried general instructions. Each of the following pages had a spatial expression printed on the top margin of the page leaving the rest of the page as drawing space. The last page contained a questionnaire on general participant information.

Procedure

Participants provided a graphical representation, i.e. a drawing, for each spatial expression within the space supplied. They could pursue the task in a self-paced manner and were unrestricted regarding orientation and scale.

Results

The main results we will focus on provide evidence for the importance of distinguishing functional and structural aspects of route direction elements and of people’s conceptions of functional route features, i.e. the question what is the basis for wayfinding choremes. Additionally, some general results are reported on as they add further insight into human conceptualizations of route direction elements. First, we will discuss some of the participants’ drawings and then we analyze conceptualizations of turning concepts at decision points.

Fig. 3. Drawing of the concept of an *intersection* as a *structural concept*

The prototypical drawing of an intersection as a *structural concept*—the participants received the expression *intersection*—meets the expectations entirely, i.e. a 4-way intersection where the branches meet at right angle (see Fig. 3). This prototypical concept is also adhered to when the spatial expression included one of the following three *basic (turning) concepts* at a 4-way intersection: *turn right*, *go straight*, and *turn left*. 84.2% of the participants followed this scheme for the turn-right-concepts, 84.2% for the turn-left-concept, and 100% for the go-straight-concept[1].

When the action required at a 4-way intersection became more specific, i.e. the basic turning concepts were modified either by *sharp* or *half*, for example, *turn half left at the intersection*, the prototype of the intersection concept disappeared (see Fig. 4). This resulted in a changing number of branches ranging from three to five and a differing orientation of the branches that were not functionally involved. These differences did not only occur between subjects but also within subjects—then, for different turning concepts.

Fig. 4. The *intersection* concept with a superimposed *specific action*

Hence, the prototypical concept of an intersection holds as long as the action necessary corresponds to one of the three basic turning concepts but disappears if more specific actions are compulsory, i.e. there is no prototypical 4-way intersection if one has to turn half left or half right at this intersection.

Likewise, the missing intersection prototype became apparent when the participants were required to draw intersections that do not match a 90° increment scheme, like the 3-, 5-, or 6-way intersection, or the underspecific star-shaped one (see Fig. 5).

[1] Some exceptions in more detail: Participant 2 used the ‘prototypical’ concept of an intersection throughout his (4-way) intersection drawings without varying it, no matter what kind of action was required at the intersection. Participant 4 ignored the difference between the basic concept, i.e. *left* and *right*, and the *sharp* modification resulting in ‘identical’ depictions. Participant 8 and 9 used 3-way intersections for the basic concepts *left* and *right*. One participant drew only the functional concept.

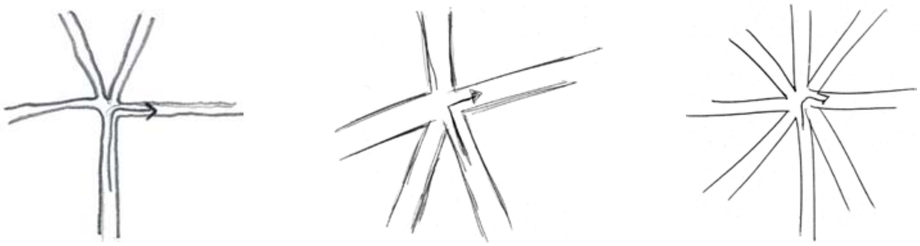

Fig. 5. Drawings for the turning concept *right* at a star-shaped intersection

On the other hand, the examples show that whereas the structure of the intersections changes, the turning concepts, i.e. the functional aspects, seem to be a constant factor of the participants' conceptualization (their drawings).

Hence, we now turn to the analysis of the conceptualization of turning concepts and put forth the following hypotheses: 1) Prototypical turning concepts, i.e. the functional aspect, are a stable factor in people's conceptualization of route direction elements independent of the type of intersection at which they are required. 2) This holds equally for all 6 turning concepts specified according to an 8-direction model.

Table 1 displays the results of the drawings with respect to the intersections' functional aspects, i.e. the question if prototypical conceptual turning concepts exist for the 6 specified direction changes. A participant's drawing was counted as a prototypical turning concept if it matched with a 45° increment according to an 8-direction model.

Table 1. Results (N=19; absolute frequencies and percent values (in brackets)) for the prototypicality of turning concepts (sr (sharp right), r (right), hr (half right), hl (half left), l (left), sl (sharp left)). ‚Pure' in the intersection column denotes turning concepts without the specification of a type of intersection, for example, *turn right*

(N = 19) abs & (%)	**sr**	**r**	**hr**	**hl**	**l**	**sl**
pure	14 (73.68)	19 (100.00)	19 (100.00)	18 (94.74)	19 (100.00)	15 (78.95)
3-way	12 (63.16)	14 (73.68)	18 (94.74)	19 (100.00)	14 (73.68)	16 (84.21)
4-way	15 (78.95)	18 (94.74)	18 (94.74)	18 (94.74)	19 (100.00)	16 (84.21)
5-way	17 (89.47)	17 (89.47)	18 (89.47)	19 (100.00)	16 (84.21)	14 (73.68)
6-way	13 (68.42)	16 (84.21)	16 (84.21)	19 (100.00)	14 (73.68)	17 (89.47)
star	15 (78.95)	13 (68.42)	18 (94.74)	17 (89.47)	14 (73.68)	16 (84.21)
mean	**14,33 (75.44)**	**16,17 (85.09)**	**17,83 (93.86)**	**18,33 (96.49)**	**16 (84.21)**	**15,67 (82.46)**

The data shows that participants greatly agree on the prototypicality of turning concepts, hence, the functional aspects of intersections in route directions seem to be the constant factor. This holds for each of the 5 types of intersections and for the 'pure' turning concepts, i.e. the one not specifying an intersections. And this also holds for each of the 6 turning concepts. The values range from 63.16% for the *sharp right* turning concepts at a 3-way intersection to various 100% agreements, for example, *left* at a 4-way intersection or *half left* at a 6-way intersection. The mean agreement to the six prototypical turning concepts ranges from 14.3 for the *sharp right* turning concept to 18.3 for the *half left* turning concept out of 19 (from 75.44% to 96.49%).

Discussion

The study evidence a distinction between structural and functional aspects in the conceptualization of basic route direction elements, i.e. turning concepts at decision points. This difference is extremely relevant, especially for complex route elements that can be found in many European downtown areas, for example, Trier. From a structural perspective not every intersection can be prototypicalized in the same way, i.e. *the* prototypical intersection as externalized by the participants (see Fig. 3, 4, and 5). Beyond this aspect the data analysis reveals that the required action is of uttermost importance. Functionally relevant aspects play a major role in the conceptualization and prototypicalization of route directions elements. These aspects seem to be important, especially in situations in which a prototypical representation cannot be expected—i.e. intersections with a number of branches that do not allow for a regular 90° division of space—or if the turning concept affords a specific action, like *turn **half** left*. The reported results show a common ground for a functional characterization of turning concepts at decision points according to an 8-direction model, rather than relying strictly on structural prototypes of intersections. This offers a new perspective on schematizing spatial information in maps, i.e. applying prototypical route direction elements obtained from externalizations of conceptualized actions. Hence, if the domain comprises actions, the schematization has to consider them, as they are the focus of the wayfinder while structural information play a secondary role. Prototypical functional elements in route directions are termed *wayfinding choremes*. Their pictorial counterparts are obtained by externalizing conceptualizations of primitive wayfinding actions into a spatio-analogical medium (see Fig. 6).

Furthermore, the data shows some differences within the conformity with prototypical turning concepts which will be looked at in greater detail as they reveal some peculiarities about intersections in interaction with turning concepts. The *half left* and *half right* directions at the 3-way intersection were the most consistently represented. Compared with this result, the basic turning concepts at this type of intersection were rather weak. Even though not significant, this effect can be explained as some participants equated *take the right part of the fork* with *turn right*. Consequently, the intersections were depicted in fork shape which does not allow for a prototypical *turn right* concept, i.e. a 90° angle. The comparatively low values for the basic turning concepts at 6-way and star-shaped intersections can be partially explained by the fact that some participants drew the intersection before they drew the turning concept. As they used the same shape for these intersections during the entire experiment the correct representation of basic turning concepts were not possible.

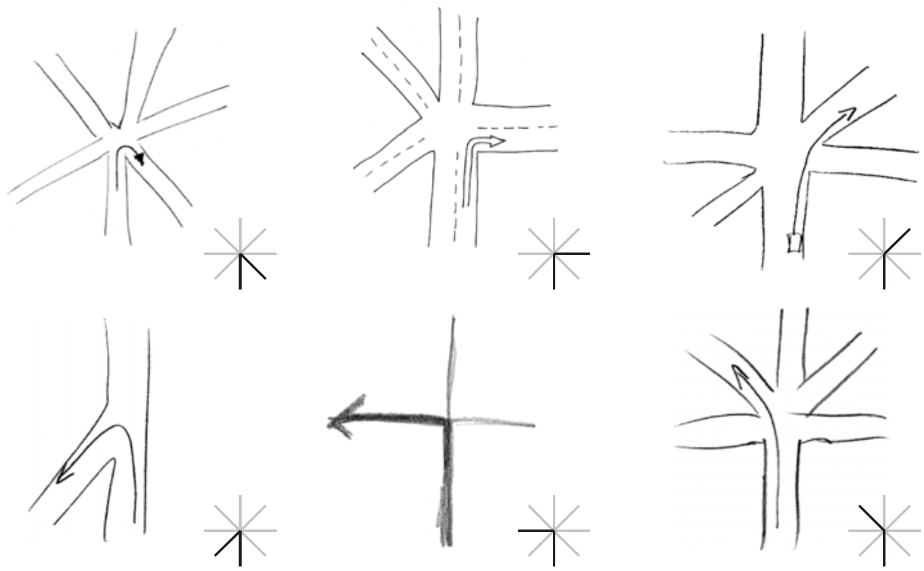

Fig. 6. Prototypical turning concepts (drawings) and identified *wayfinding choremes* (bold lines) within an 8-direction model

4 Applying Wayfinding Choremes to Map Construction

We now sketch our ideas on applying wayfinding choremes to map construction. We will only outline the main ideas, as this is work in progress. General and commonly known aspects of cognitive spatial information processing relevant for the adequate depiction of route information are only briefly mentioned.

The basic procedure consists of three steps. Assume a scenario where we either provide mobile wayfinding assistance or, like in some internet applications, information on parts of the route. The first step *focuses* on the relevant decision point. We have two classes of decision points: those that require a direction change [DP+] and those that do not [DP-]. As shown, for example, in Klippel, Tappe, and Habel (2003) higher order route elements, i.e. superordinate directions like *turn right at the third intersection*, are a strong organizational aspect of route directions. Hence, we apply simple combination rules on wayfinding choremes. Basically, wayfinding choremes of the type *straight*, i.e. [DP-], can be grouped and combined with wayfinding choremes of type [DP+], corresponding to conceptualization of, for example, *turn right at the third intersection*. The focus lies on these combined wayfinding choremes, i.e. higher order route direction elements.

The second step *replaces* functionally relevant parts of intersections with one of the six basic wayfinding choremes for a directional change if the subsequent decision point is of the type [DP+], or it replaces the functional aspects of a higher order structure, i.e. a combination of wayfinding choremes, respectively. The functionally involved branches of an intersection are categorized according to an 8-direction model. Only the functionally relevant parts are replaced as these are the important aspects of a given intersection and they are the ones for which we can advocate a minimal number of primitive prototypical realizations, i.e. the wayfinding choremes.

The last step *aligns* the resulting wayfinding choreme map with the direction of traveling, according to proven benefits of alignment on information processing (e.g., Adeyemi, 1982; Levine, 1982; Warren & Scott, 1993).

Problems of underspecificity are solved by the depiction of the corresponding spatial structure and in the spatio-analogical medium. Whereas verbal route direction elements like *turn right at the intersection* can lead to confusion if the direction matches two alternatives, this problem is solved in a map-like representation by the perseverance of ordering information[2].

5 Conclusions and Outlook

The cognitively adequate representation of spatial information is still an open question. We approached this problem for the domain of wayfinding by setting of from work on graphical primitives, namely the choremes of Brunet and the direction toolkit by Tversky and Lee. Distinguishing functional and structural aspects of the given domain provided valuable insights into human conceptualizations. The study on sketch map drawings led us to advocate a set of six prototypical turning concepts corresponding to a functional conceptualization of route direction elements. For these primitives (plus the concept for *straight*) we dub the term *wayfinding choremes*. The approach can be termed cognitive conceptual or top-down as it does not schematize a rich set of spatial information but starts from abstract spatial conceptualizations.

A combination of conceptual elements and veridical information is possible and desirable as it bears resemblance to human information processing. Some information is conceptualized while other information is used for identification purposes or is simply taken from the environment (e.g., Raubal & Worboys, 1999). Thereby, we stress the conceptualization and identification of the relevant information.

Tversky and Lee (1999) have argued that their two toolkits are transduceable into each other; wayfinding choremes realize the next step as they, as well as the corresponding verbal route direction elements, correspond to human conceptualizations of wayfinding actions, hence, both are functionally determined. Based on wayfinding choremes a grammar for route directions can be specified. Together with rules of their combination, we obtain a simple, yet powerful framework for characterizing routes and route directions. By no means have we claimed that the work is finished yet as it is applicable only to ‘normal’ spatial situations in street networks. Variant spatial structure, like, for example, rotaries, are not specified. On the other hand, unusual spatial structures complicate conceptualization. As wayfinding choremes are based on human conceptualizations they further corroborate, for example, research on route complexity (e.g., Richter & Klippel, 2002).

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[2] The only problem occurs if the categorization according to the 8-direction model results in a violation of this information; this may be solved by further refining the model.

We plan to extend our wayfinding choreme approach to other forms of assistance and to the characterization of further spatial situations, for example, pedestrians using public transportation facilities. Other domains comprise different concepts (see for example, work by Raubal (2002) on wayfinding in built environments; Kuhn, 2001; Timpf, 2002). The current set of wayfinding choremes needs to be complemented, for example, by conceptualizations for ***through*** *the hall* or ***up*** *the stairs*.

The work at hand offers also a new perspective on the characterization of events, or, to be more specific, actions. As the conceptualization study shows, it is possible to represent actions in a static spatio-analogical medium without requiring any animation. We suppose that highlighting the relevant information and providing a cognitive conceptualization, i.e. a wayfinding choreme, makes additional information, like arrows, unnecessary. This leads to a further reduction of visual clutter, which has been noted early as a major drawback on information processing (Phillips & Noyes, 1982).

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