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# Before or After: Prepositions in Spatially Constrained Systems

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**Abstract.** Cognitive agents use different strategies to identify relevant spatial information in communication. The chosen strategy depends on the agents' conceptualization of the spatial situation at hand. This situation is determined by structural and functional aspects that are induced by the environment and the actions performed or intended therein. In this paper, we are interested in conceptualizations in the context of route directions. We focus on the meaning of prepositions used to characterize movements (actions) in spatially constrained systems such as street networks. We report on different strategies employed by people to disambiguate turning actions at intersections and demonstrate how these can be reflected in automatically generated route directions, again concentrating on the assignment of prepositions for anchoring movement. Including methods that focus on the most successful strategies people use in computational systems is a prerequisite for route directions that respect for human conceptualizations of spatial situations and that become, thus, cognitively ergonomic route directions.

## 1 Introduction

Cognitive agents communicate about space through various modalities [1]. Each modality, such as natural language expressions or sketch maps, has their own representational characteristics. While the problem of graphic, map-like representations is their commitment to one out of potentially many instantiations of a spatial situations [2], the problem of linguistic expressions is to determine their meaning as they are inherently underspecified. This problem manifests itself in the large body of research literature on spatial prepositions (e.g., [3]). Prepositions are still not well handled in formal systems as a limited number of prepositions can have manifold meanings; the semantics of a preposition changes with the context in which the preposition is used [4, 5]. This makes prepositions a highly challenging research topic.

In this paper, we focus on the semantics of prepositions in the context of route directions. More specifically, we are interested in assigning a preposition to anchor movements in a spatially constrained system, i.e. a city street network.

Most studies on the semantics of spatial prepositions take place in unconstrained, or better naturally constrained, environments, in that, for example, they rely on the influence of gravity and the characteristics of the objects in question. In contrast, we focus on the influence of structural aspects of an environment on the semantics of spatial prepositions. This approach is part of a larger research effort investigating the role of structure and function in the conceptualization of events.

We proceed with a short overview on route directions and landmarks introducing the key concepts used in this work and clarifying the distinction between *structure* and *function* in the next section. We continue discussing some empirical findings on how people's choices depend on a decision point's structure and on the action that has to be performed (Section 3). We then present a computational approach that takes these findings into account and selects spatial prepositions based on configurational knowledge and neighborhood relations of the involved functionally relevant entities (Section 5). Modeling these entities is explained in Section 4.

## 2 Route Directions and Landmarks

Route directions provide a wayfinder with information on how to reach her current destination; they are task-oriented specifications of the actions to be carried out [6, 7]. Route directions are not merely a description of what a wayfinder will encounter along the route; they include references to actions at decision points, to landmarks, and confirmative information whether the correct route is still followed. Since they focus on the actions to be performed, verbal route directions are procedural discourse [8]. Routes are inherently linear; therefore, the linearization problem, i.e. the problem of choosing among many possible sequences when organizing spatial information that extends over two or three dimensions, does not apply here. With routes, the sequence of spatial information is determined by the spatial sequence of locations encountered during route following (see also Section 2.1). On the other hand, the linearization problem exists in a modified form [9]: structuring route knowledge comprises the spatial chunking of individual decision points into larger units. This is a process on the conceptual level to organize spatial knowledge. In that, it differs from and precedes the linguistic process of aggregation as explained, for example, in [10], which is used to form sentences that communicate several pieces of information at once.

The core of route directions is a sequential description of actions, like "walk" or "turn [left]" [11]. These actions are termed *route-following actions* in the following. The core is enhanced with descriptions of the spatial situations that will be encountered during route following, especially references to landmarks [12]. Landmarks foster the identification of decision points, the origin and destination of a route, provide verification of route progress, provide orientation cues for homing vectors, and suggest regional differentiating features. Landmarks are pertinent for route directions [8, 13]. They are especially useful when anchoring actions in space, i.e. if the action that has to be performed at a decision point is anchored by the reference to a landmark, such as "turn right after the post office".

For the inclusion of landmarks in automatically generated route directions the spatial relation between the landmark and the action performed at a decision point has to be determined to provide anchoring in space. The parameters taken into account are the decision point itself, the route-following action performed at the decision point (i.e., the angle of the change in direction), and the position of a landmark (Fig. 1).

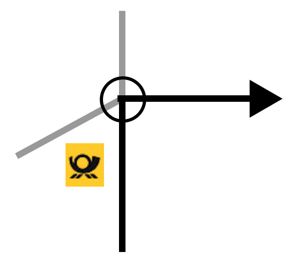

**Fig. 1.** Parameters determining assignment of a spatial preposition: the encircled decision point, a route-following action (right turn) indicated by the bold arrow-lines, and a landmark (a post office) positioned in proximity to the decision point.

### 2.1 Structure and Function

Klippel's distinction of *structure* and *function* [14] is based on Montello's differentiation between the environment and the actions or movement that is performed in that environment [15][3]. This distinction is reflected terminologically by *path* and *route*.

*Structure* denotes the layout of elements physically present in the spatial environment. This comprises, for example, the number of branches at an intersection, the angles between those branches, and a landmark's position (relative to the action performed at an intersection). *Function* is related to the actions that take place in spatial environments. The functional characterization demarcates parts of the environment, i.e. those parts of the structure that are necessary for the specification of the action to be performed (see Fig. 2). Structure has an impact on the conceptualization of an action, in our case the change of direction at a decision point, and in return on the assignment of a *spatial projective term*, its modification, and the choice of a *spatial preposition* (see next section).

A trajectory, such as the movement of an agent, can be discretized by focusing on the direction changes the agent makes. Considering route following,

[3] Montello's book chapter has been available as 'in press' for several years on his homepage before publication; this explains the seemingly contradicting publication dates.

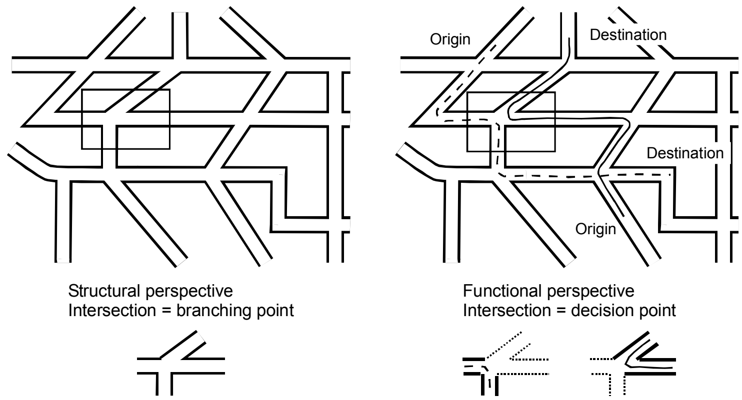


**Fig. 2.** Distinction of structural and functional aspects of route information (from [14]).

the critical points of direction change are the decision points: here, a wayfinder needs to decide on the further way to take. Consequently, they are pertinent for route following [13]—even if no change of direction occurs, i.e., the agent is going straight at an intersection. A route may be represented as a sequence of decision points. Depending on the structure in which these direction changes take place, the conceptualization of the same change of direction as a discrete step in a route can differ. Accordingly, describing the turn at a decision point, for example, linguistically, may differ depending on the structure and action to be performed. In the next section, we outline some strategies people employ in giving directions at decision points. These strategies depend both on structural and functional aspects.

## 3 Strategies for Describing Route-Following Actions

Klippel, Tenbrink, and Montello [16] propose a characterization of aspects that influence the specification of spatial relations in the context of route directions. These aspects include the structure of an intersection, the route-following action to be performed at an intersection that demarcates functionally relevant parts, the availability of additional features that can be used to anchor the action to be performed, like landmarks, and the conceptualization of this action as a result of structure and function and the features available. For example, Figure 3 illustrates how an intersection's structure may change the linguistic characterization of a change of direction.

An analysis of a route direction corpus, sampled as reported in [9], reveals several options to communicate which branch to take at an intersection. The following categories reflect the conceptualization of turns at decision points and, thereby, correspond to different kinds of spatial knowledge: qualitative direction concepts expressed by projective terms, references to absolute directions,

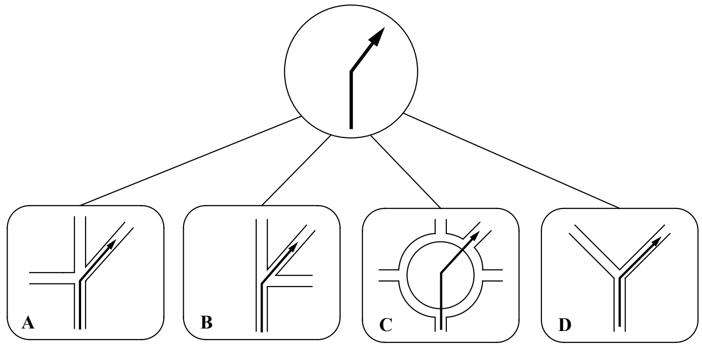


**Fig. 3.** According to the intersection in which it takes place, a change of direction is associated with different meaning. While the 'pure' change may be characterized as "veer right" at the intersection (A), at intersection (B) it may change to "the second right"; at the roundabout (C) it becomes "the third (or second) exit"; and at (D) "fork right" (from [17]).

and direction-indicating verbs, for example, "turn right", "go west", "veer left"; qualitative modifications (hedges) specifying the direction [18, 19], as in "slightly right", quantitative measures of directions in degrees, for instance, "turn exactly 90 degrees"; clock directions ("turn three o'clock"); references to the structure, for example, "dead end", "fork"; ordering concepts, like "the first exit"; reliance on landmarks to indicate a direction, as in "where the statue is".

In this paper, we concentrate on the aspect of relying on landmarks to indicate directions. Depending on their geometry and size in relation to the environment, landmarks can be considered point-like, linear, or area-like (cf. [20, 21]). Here, we discuss landmarks conceptualized as being point-like, i.e. those located in a small, restricted area of an environment, that are functionally relevant only for a small part of the route, usually a single decision point. These landmarks may be located at a decision point or in-between two decision points.

Landmarks in-between two decision points may either be related to the decision point passed after them or to the one just passed. Those related to the decision point after them may be used to identify this decision point ("you'll pass a gas station; after that, turn right at the next intersection"). A landmark related to a decision point just passed can be used to confirm that the correct direction has been chosen ("if you pass the church, you picked the correct turn."). In the following, we focus on landmarks being conceptualized at a position *at* a decision point. These landmarks are frequently used to identify the intersection, especially if other intersections are nearby and, more importantly in the context of this paper, they are frequently used to anchor the direction change to be performed at an intersection [8]. Linguistically, the anchoring is encoded as *turn [right, left] [before, after, at]*$\{$*landmark X*$\}$. The different prepositions correspond to different relations of landmark $X$ relative to the action to be performed at the decision point: the landmark is either passed before or after the route-following action, or not directly passed at all (cf. Section 5.2). These possible spatial relations between landmark and decision point are represented as $lm^{<}$ (landmark passed *before* decision point), $lm^{>}$ (landmark passed *after* decision point), $lm^{-}$ (landmark *at* decision point, but not directly passed) (cf. also [22]).

Clearly, the preposition *at* is less constrained than *before* or *after*, i.e. its semantic scope is larger. In the context of this paper it potentially incorporates the other two. Still, we choose *before* or *after* if applicable, since they relate the position of a landmark directly to the action performed at the respective decision point and are, thus, more specific. The rational for this is rooted in considerations of cognitive ergonomics that strive to provide as much detail as possible with as little information as necessary. From the perspective of cognitive science we could say that the situation model [23] that is instantiated, for example, by a linguistic instruction, has to be rendered as precise as possible by using a preposition with a smaller semantic scope. We take a Griceian perspective [24] in generating references.

Function determines which structural aspects are relevant for the situation at hand. That is, the actions performed in route following induce spatial configurations and the sequence in which entities are encountered along the route. Thus, even if we consider static configurations of intersections in the following to determine the spatial relation between landmark $X$ and the decision point, these result from performing an (imagined) action at this intersection, i.e. the entities can be considered events in this case.

## 4 Modeling Routes

As stated in Section 2.1, we consider decision points most pertinent for route directions. Following a route comprises two basic processes: getting to a decision point and, there, determining the further direction to take [25]. Accordingly, routes are represented as sequence of decision point/action pairs; each pair representing the route-following action required at a given decision point. We represent the environment, which in our work is a spatially constrained system, like a street network, as a graph reflecting its layout. The graph is annotated with additional information, for example, the geometry and position of landmarks.

Even though we model the structural aspects of wayfinding in an environment as a graph decision points are not merely a node in the graph, i.e. not just a point-like entity. Instead, a decision point denotes a certain area around an intersection, which contains not only the point where the branches meet but also parts of the branches itself (see Section 5.1). This way, it represents the configuration of path-segments at a branching point. The two functionally relevant path-segments, the route-segments, are part of the decision point, which corresponds to human mental conceptualization. This modeling also reflects another action-oriented aspect: people usually do not turn on the spot like some robots do, but rather in an extended process with deciding on the direction to turn and then changing

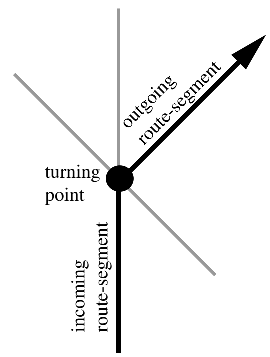


**Fig. 4.** A decision point with the two functionally relevant branches: the *incoming* and *outgoing* route-segment. The branches' meeting point is the *turning point*.

direction gradually while keeping their forward movement [14, 26]; especially when traveling by bike or car.

For the purpose of assigning a preposition to describe the spatial configuration, we abstract from this gradual direction change and model decision points such that all path-segments of the decision point meet in a single point, which we denote with the technical term *turning point* in the following (Fig. 4). This way, at the turning point the area around an intersection gets divided into a *region before action* and a *region after action* as a wayfinder's direction of motion induces a directedness of the functionally relevant branches. Landmarks located at a decision point are represented as a point inside the decision point's area whose position relative to the turning point can be determined based on a shared local or global coordinate system.

## 5 Determining References to Landmarks

In this section, we present a computational method to determine the spatial relation of a landmark relative to an action performed at a decision point. Thereby, we provide a formal characterization of a possible resulting mental conceptualization. Based on this relation, we can anchor the action performed at that decision point with the landmark. This method is based on configurational knowledge and neighborhood relations. It is employed in our model for generating *context-specific route directions* [20, 27]. This model explicitly adapts the generated directions to the context, i.e. to the current action to take in the current surrounding environment (see Section 6).

Linear or circular orderings represent information about the sequence and neighborhood of entities without specifying any further metric information, such as distances between these entities (e.g., [28]). This kind of information is a powerful structuring means; it is also easy to determine as it only requires knowledge about a neighborhood relation between the relevant entities. This holds especially for routes: routes are linear and directed entities; the movement direction of the wayfinder induces an orientation on the point-like entities along the route, like decision points or landmarks. This orientation, in turn, induces an ordering on these entities [28].

We exploit ordering information to compute a landmark's position at a decision point. In the following, we explain how to determine the neighborhood relation of functionally relevant entities at decision points and how to generate references to landmarks based on this information.

### 5.1 Landmarks at a Decision Point

To determine references to landmarks at decision points, first of all those landmarks located at that decision point need to be identified. Whether a landmark can be considered to be at a decision point depends on its distance to the decision point. Distance can be based on different kinds of information: most typical, metric information is used, i.e. calculating distance between two entities based on coordinates. However, in the context of our work, the crucial information for referencing a landmark is what will be encountered between passing a landmark and a decision point (or vice versa). Therefore, next to metric distance between decision point and landmark, we also rely on ordering information.

In a first step, landmark candidates are identified. To this end, we determine which landmarks are within a decision point's region. The size of this region depends on different parameters, like a wayfinder's travel mode. Most importantly, we choose a decision point's region such that no other decision point falls within this region. This way, we prevent conflicting association of landmarks with decision points. This may, however, lead to different sizes of this region for different decision points (e.g., smaller regions for decision points that are close together). Additional information, like a landmark's saliency can be taken into account to further restrict the set of landmark candidates (see Section 6; cf. also, e.g., [29]).

From these landmark candidates, we check which landmarks actually are applicable as reference to a landmark at a decision point, i.e. we need to decide which of the landmarks from the candidate set is to be used in the instructions. For a landmark to be *at* a decision point, no other landmark candidate may be between the entity used as landmark and the decision point. For example, a post office may be referenced as a landmark at a decision point if no other building referable as landmark is passed between post office and decision point (see Fig. 5). That is, in the linear ordering of landmarks and decision point, decision point and landmark *at* the decision point need to be neighbors. This way, we achieve the (spatially) closest possible coupling of landmark and decision point, which fosters identification of the place where to perform the required action.

### 5.2 References to Landmarks at a Decision Point

Landmarks located at a decision point can either be passed before the route-following action takes place, after the action, or may not be located at a func-

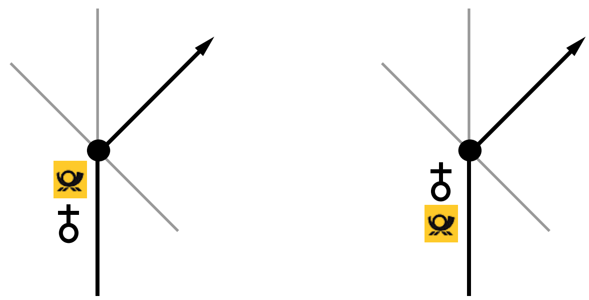


**Fig. 5.** Distance of a landmark—the post office—based on ordering information: a) landmark at a decision point: the post office is directly passed before the turning point; b) landmark not at a decision point: the church is passed after the post office, but before the turning point.

tionally relevant branch. In order to determine which relation between landmark and action holds and, consequently, which preposition to use preferably, we need to know a landmark's position relative to the functionally relevant branches. We distinguish three relations—$lm^<$, $lm^>$, $lm^-$—to denote a landmark's position. They are termed *reference relations*. If relation $lm^<$ holds, i.e. if a landmark is passed before performing an action at a turning point, the landmark must be *next to* the incoming route-segment. If the relation $lm^>$ holds the landmark is passed after the route-following action took place and is next to the outgoing route-segment. If a landmark is neither next to the incoming nor the outgoing route-segment, it is not at a functionally relevant branch. We use the relation $lm^-$ to describe this situation where a landmark is at a decision point which position with respect to the route-segments cannot be further specified.

But what does *next to* mean in this context? It refers to the neighborhood relation that underlies the ordering information of the entities at a decision point. For locating a landmark, the *next to* relation describes a region of a landmark's possible locations. These locations are chosen such that the landmark is located before or after the turning point and no other branch is between the functionally relevant branch and the landmark (see Fig. 6). For the incoming route-segment the region that satisfies these conditions is termed *before-region*, for the outgoing route-segment it is termed *after-region*. The landmark needs to be located in the before-region for the relation $lm^<$ to hold and in the after-region for the relation $lm^>$. To determine whether a landmark is in the before- or after-region of a decision point, we can exploit ordering information. The branches of a decision point form a circular ordering as they are neighbored according to their bearing—with the last branch in the ordering being neighbored to the first one (see Fig. 7a).

The ordering can be calculated by determining the angle of a branch relative to some reference direction, for example north representing a bearing of 0, and

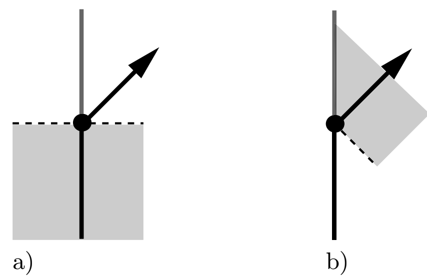

**Fig. 6.** Regions of a landmark's possible location relative to the functionally relevant branches: a) *before*, b) *after*.

then sorting all branches according to their direction angle. By creating a new virtual branch ranging from the turning point to the landmark in consideration, we can introduce the landmark's location to the branches' ordering (see Fig. 7b). We recompute the ordering and can, this way, determine the landmark's position with respect to the newly established ordering. Since for the reference relations $lm^<$ or $lm^>$ to hold the neighborhood relation *next to* needs to hold, and for *next to* to hold no other branch may be between a route-segment and a landmark, we check whether the newly introduced virtual branch is a direct neighbor of either of the functionally relevant branches in the ordering.

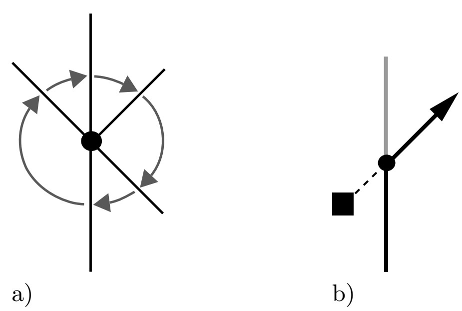

**Fig. 7.** a) An intersection with five branches. The arrows indicate the neighborhood relation between the branches; the branch pointed at is a neighbor of the branch the arrow starts from. This relation is symmetric. b) Virtual branch (dotted line) introducing a landmark's location to the branches' ordering.

This allows determining the reference relation to use for a landmark at a decision point. If the virtual branch is a neighbor of the incoming route-segment, $lm^<$ holds, if it is a neighbor of the outgoing route-segment, $lm^>$ holds. This procedure is very simple, but does not cover all cases: consider, for example, the configuration shown in Figure 8. Here, the landmark's virtual branch is next

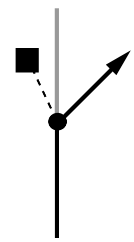

**Fig. 8.** Example for a situation in which a landmark's virtual branch (the dotted line) is next to the incoming route-segment, but the landmark is located after the turning point. Here, $lm^<$ is not a valid result.

to the incoming route-segment in the branches' ordering, but located after the turning point. This violates the second condition of our definition of the before-region, namely that a landmark needs to be before the turning point. Therefore, calculating the neighborhood relation yields $lm^<$, but it is not a valid result in this case.

To account for this case, we introduce two additional virtual branches. These virtual branches originate at the turning point and head perpendicularly to the functionally relevant branch to the left and right (Fig. 9). That is, to create the before-region, we introduce two virtual branches perpendicular to the incoming route-segment; their calculation is straightforward. For the after-region we apply the same procedure with the outgoing route-segment.

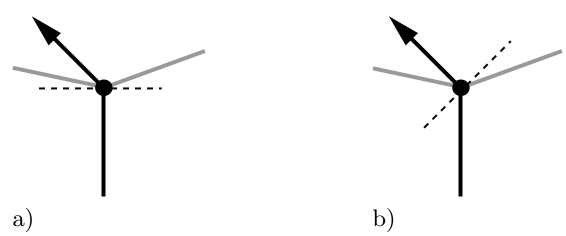


**Fig. 9.** Virtual branches (dotted lines) deliminating (a) the before-region and (b) the after-region, respectively.

This way, we ensure that the functionally relevant branch and a landmark's virtual branch cannot be direct neighbors if the landmark is not located in the correct region. Put differently, if they are direct neighbors, route-segment and landmark are on the same side of the turning point, as required in the definition of before- and after-region. Figure 10 shows examples for determining a landmark's position at a decision point using this approach. Note that we cannot introduce both sets of virtual branches—for the before- and after-region—to the ordering

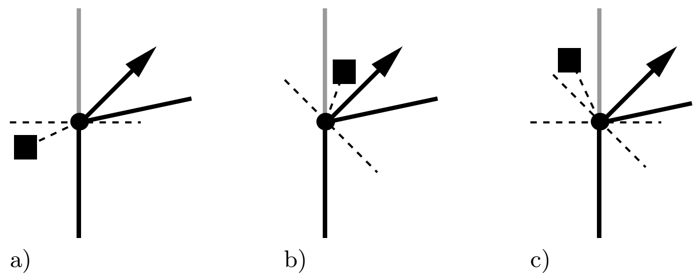

**Fig. 10.** Examples of a decision point's configuration and the resulting landmark's reference relation: a) $lm^{<}$, b) $lm^{>}$, c) $lm^{-}$.

at the same time. This would result in overlaps in certain cases and, hence, unwanted restrictions of the two regions (cf. Fig. 10c).

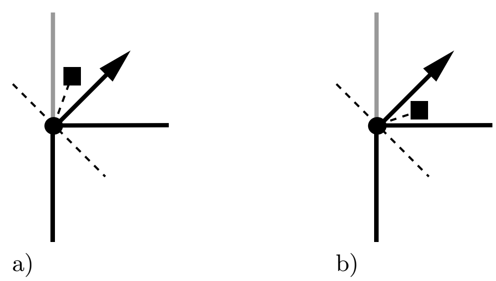

**Fig. 11.** "Turn right *before* landmark": a) landmark correctly indicating outgoing branch; b) ambiguous situation where landmark may mislead wayfinder.

For relation $lm^{>}$ we need to consider a further restriction. The corresponding preposition *before* is the most restricted in its semantic scope, i.e. it underlies the most constraints for being applicable to identify the branch to take. To indicate the correct branch, the landmark needs to be left of the outgoing branch when turning into the right half-plane and right of the outgoing branch for turning left (see Fig. 11). Otherwise, references to a landmark will lead to wrong references: in Figure 11b the default assumption would be to take the branch heading off 90 degrees to the right as this branch is directly in front of the landmark as seen from the direction of movement. However, the intended branch is the one heading off 45 degrees to the right. The order of branches and the landmark is calculated relative to some reference bearing. Accordingly, determining whether a landmark is left (or right) of the outgoing branch is straightforward: in this case it is directly before (or after) this branch in the order, i.e. the landmark

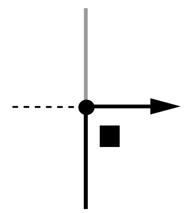

**Fig. 12.** Neighbored incoming and outgoing route-segment. Here, before- and after-region may overlap.

is predecessor (or successor) of the outgoing branch in the ordered sequence of entities under consideration.

Finally, if incoming and outgoing route-segment are neighbors in the branches' circular ordering, the before- and after-region possibly overlap. In this case, both $lm^<$ and $lm^>$ are in principle valid results of determining the landmark's position at the decision point. However, in configurations as shown in Figure 12 the preposition *before* is not applicable, i.e. conceptually does not cover the situation model and is, therefore, never used. Hence, $lm^<$ represents this configuration; $lm^>$ is excluded ($lm^-$ would be applicable, as well, as it incorporates $lm^<$ and $lm^>$, but is not chosen as it is less specific; see Section 3).

## 6 References to Landmarks in Instructions

With the presented method we are able to determine a landmark's relation to the route-following action to be performed at a decision point, and, hence, to suggest a corresponding preposition. These prepositions are used in generating descriptions of spatial situations to be communicated to a human user. We employ them in our computational model generating route directions that explicitly considers a route's properties and environmental characteristics. Accordingly, the resulting directions are termed *context-specific* as they adapt to the current action to take in the current surrounding environment [20].

The model generates abstract, modality-free specifications of the actions to be performed at decision points. It is based on a systematics of elements that can be used in route directions. According to the systematics, the model generates for each decision point all possible instructions that unambiguously describe the action to be performed there. Each such instruction represents a decision point and the action as a relational term, for example `(DP`$_1$`,left)`. The direction relations correspond to the route-following actions a wayfinder needs to perform, for example, *left* corresponds to "turn left", *north* to "head north", etc. Generating directions for the complete route, then, is realized as an optimization process. This process decides for each decision point which instruction of a set of possible instructions to use; in that, it relies on spatial chunking, i.e. on mechanisms to combine a sequence of instructions for single decision points into a single instruction for several consecutive decision points [9, 10]. With that, it accounts for another important principle of cognitively ergonomic route directions.

To generate instructions that link a landmark to the action to be performed, we annotate the direction relation with the landmark's identifier and corresponding reference relation determined as explained above. For example, this may result in a specification like $\texttt{(DP}_1\texttt{,left/church lm}^{<}\texttt{)}$. This notation focuses on the most relevant information, i.e. which action to perform at which decision point (here, turning left at decision point 1). The action can then be further specified by, for example, linking it with a landmark present at the decision point (here, a church located before the decision point). This way, the general structure of our abstract route directions is always the same with the crucial information coming first; this is independent of whether the instruction is annotated or which type of annotation is to be used.

The specification does not need (and is not intended) to be externalized as it is. For example, literally, the specification given above corresponds to an instruction like "pass the church *before* you turn left". However, usually instructions focus on the route-following action to be performed at a decision point, not the landmark's location; i.e. the focus is on "turn left" in this example. Accordingly, an appropriate verbalization would be "turn left *after* the church". Thus, the relation between spatial relation and preposition to use is as follows: $lm^{<}$ corresponds to the preposition *after*, $lm^{>}$ to the preposition *before*, and $lm^{-}$ to the preposition *at*.

There might be several landmarks present at a decision point. This results in several options for anchoring movement in space by reference to a landmark. In such cases, the computational system needs to decide on which reference to use. One possibility is to integrate preference rules in the model on which preposition, and accordingly landmark, to choose: a simple rule may, for example, state to prefer determinate references (*before*, *after*) over indeterminate (*at*) to adhere to the Gricean principles called for above. A more elaborate approach is to take a landmark's saliency into account. Existing approaches determine saliency, for example, with data mining methods [30], or based on visual, semantic, and structural features of an environment's enitities [29]; the latter approach has been extended to also account for the structure of the street network wayfinding takes place in [22]. These approaches allow for calculating a landmark's saliency value, which can then be used to determine the most salient landmark at a decision point in order to refer to this one in the instructions.

Furthermore, the model implements additional strategies for disambiguating references in direction giving (see Section 3). It employs ordering concepts in situations where several branches head in the same direction, like in "take the second left". Also, it analyses an intersection's structure based on the geometric configuration of its branches and the movement direction of the wayfinder. This reveals salient intersections, like T-intersections, that may be referred to in an instruction and, consequently, may function as a landmark [31]. Such references to the structure, which can be found in human direction giving, restrict which direction relations are applicable. For example, an angular direction change that maps to *veer right* in the employed direction model is coarsened to *right* when used in combination with a reference to a fork-intersection, as in "fork right".

## 7 Conclusions and Outlook

To disambiguate and to identify relevant information in a route direction task, people employ different strategies in describing spatial situations. The strategy used depends on the conceptualization of the situation, which in turn is determined by structural and functional aspects. In the context of route directions, the actions to be performed at decision points are the focus of interest. We report results of a linguistic analysis that reveals several strategies used by speakers to communicate which branch to take at an intersection. Choice of the strategy depends on several aspects including the action to be performed, the conceptualization of this action as a result of structure and function, and the availability of landmarks. In this paper, we especially focused on landmarks used to identify intersections.

Such landmarks are a powerful means to anchor the direction change to be performed at an intersection. The position of the landmark relative to the decision point determines how this anchoring can be done. We presented a computational approach to determine the proper spatial relation between landmark and decision point; this approach exploits qualitative knowledge at an intersection. The structure of an intersection, i.e. the configuration of its branches, constraints possible landmark's positions and, hence, the spatial relation that is applicable. Applicability of a relation can be determined by ordering information and neighborhood relations of an intersection's branches. Depending on a landmark's position in the branches' order, the landmark is either passed before ($lm^<$) or after ($lm^>$) the route-following action or not directly passed at all ($lm^-$). Based on the spatial relation that holds, a preposition can be determined that reflects the relation between landmark and the action to be performed at the decision point: in case of $lm^<$ the action is performed *after* the landmark; with $lm^>$ it is performed *before* the landmark. $lm^-$ denotes a configuration with an action performed *at* a landmark. Our computational method allows for generating appropriate references to landmarks and, this way, anchoring actions in route following with a landmark. Thus, it implements an important principle of cognitive ergonomics for route directions.

The presented approach is part of a larger research effort investigating the role of structure and function in the conceptualization of events, and to develop a model that generates cognitively ergonomic route directions. Including such methods, which are similar to people's strategies to describe spatial situations, in a computational system is a prerequisite for automatically generated route directions that respect for human conceptualizations of spatial situations. This way, users' confidence is increased, and the route directions become easier to understand. This holds especially for the actions to be performed at complex intersections.

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## References

1. Wahlster, W., Reithinger, N., Blocher, A.: SmartKom: Towards multimodal dialogues with anthropomorphic interface agents. In Wolf, G., Klein, G., eds.: Proceedings of the International Status Conference "Human-Computer Interaction", DLR, Berlin (2001) 22–34
2. Habel, C.: Representational commitment in maps. In Duckham, M., Goodchild, M., Worboys, M., eds.: Foundations of Geographic Information Science, London, Taylor and Francis (2003)
3. Retz-Schmidt, G.: Various views on spatial prepositions. AI Magazine **9**(2) (1988) 95–105
4. Regier, T.: The Human Semantic Potential: Spatial Language and Constrained Connectionism. The MIT Press, Cambridge, MA (1996)
5. Coventry, K.R., Garrod, S.C.: Saying, seeing and acting. The psychological semantics of spatial prepositions. In: Essays in Cognitive Psychology Series. Psychology Press, Hove and New York (2004) 201
6. Schweizer, K., Katz, S., Janzen, G.: Orientierung im Raum — kognitive Grundlagen und sprachliche Realisierung. Tourismus Journal **4**(1) (2000) 79–104
7. Tversky, B., Lee, P.U.: How space structures language. In Freksa, C., Habel, C., Wender, K.F., eds.: Spatial Cognition. Springer, Berlin (1998) 157–175
8. Denis, M.: The description of routes: A cognitive approach to the production of spatial discourse. Cahiers Psychologie Cognitive **16**(4) (1997) 409–458
9. Klippel, A., Tappe, H., Habel, C.: Pictorial representations of routes: Chunking route segments during comprehension. In Freksa, C., Brauer, W., Habel, C., Wender, K.F., eds.: Spatial Cognition III, Berlin, Springer (2003)
10. Dale, R., Geldof, S., Prost, J.P.: Using natural language generation in automatic route description. Journal of Research and Practice in Information Technology **37**(1) (2005) 89–105
11. Lovelace, K.L., Hegarty, M., Montello, D.R.: 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 Geopraphic Information Science. International Conference COSIT, Berlin, Springer (1999) 65–82
12. Golledge, R.G.: Human wayfinding and cognitive maps. In Golledge, R.G., ed.: Wayfinding Behavior — Cognitive Mapping and Other Spatial Processes. John Hopkins University Press, Baltimore, USA (1999) 5–46
13. Michon, P.E., Denis, M.: When and why are visual landmarks used in giving directions? In Montello, D.R., ed.: Spatial Information Theory, Berlin, Springer (2001) 400–414

14. Klippel, A.: Wayfinding Choremes — Conceptualizing Wayfinding and Route Direction Elements. PhD thesis, Universität Bremen (2003)
15. Montello, D.R.: Navigation. In Shah, P., Miyake, A., eds.: Handbook of Visuospatial Thinking. Cambridge University Press, Cambridge (2005) 257–294
16. Klippel, A., Tenbrink, T., Montello, D.R.: The role of structure and function in conceptualization of directions. (submitted)
17. Klippel, A., Hansen, S., Davies, J., Winter, S.: A high-level cognitive framework for route directions. In: Proceedings of the SSC 2005 Spatial Intelligence, Innovation and Praxis: The National Bienneal Conference of the Spatial Science Institute. (2005)
18. Lakoff, G.: Hedges: A study in meaning criteria and the logic of fuzzy concepts. Journal of Philosophical Logic **2**(4) (1973) 458–508
19. Vorwerg, C.: Raumrelationen in Wahrnehmung und Sprache. Deutscher Universitäts-Verlag, Wiesbaden (2001)
20. Richter, K.F., Klippel, A.: A model for context-specific route directions. In Freksa, C., Knauff, M., Krieg-Brückner, B., Nebel, B., Barkowsky, T., eds.: Spatial Cognition IV. Reasoning, Action, Interaction: International Conference Spatial Cognition 2004, Berlin, Springer (2005) 58–78
21. Hansen, S., Richter, K.F., Klippel, A.: Landmarks in OpenLS - a data structure for cognitive ergonomic route directions. In Raubal, M., Miller, H., Frank, A.U., Goodchild, M.F., eds.: Geographic Information Science - Fourth International Conference, GIScience 2006, Berlin, Springer (to appear)
22. Klippel, A., Winter, S.: Structural salience of landmarks for route directions. In Cohn, A., Mark, D., eds.: Spatial Information Theory. International Conference COSIT, Berlin, Springer (2005) 347–362
23. Zwaan, R.A., Radvansky, G.A.: Situation models in language comprehension and memory. Psychological Bulletin **123**(2) (1998) 162–185
24. Grice, H.P.: Logic and conversation. In Cole, P., Morgan, J.L., eds.: Speech Acts. Volume 3 of Syntax and Semantics. Academic Press, New York (1975) 41–58
25. Daniel, M.P., Denis, M.: Spatial descriptions as navigational aids: A cognitive analysis of route directions. Kognitionswissenschaft **7** (1998) 45–52
26. Tversky, B., Lee, P.U.: Pictorial and verbal tools for conveying routes. In Freksa, C., Mark, D.M., eds.: Spatial Information Theory - Cognitive and Computational Foundations of Geopraphic Information Science. International Conference COSIT, Berlin, Springer (1999) 51–64
27. Richter, K.F., Klippel, A., Freksa, C.: Shortest, fastest, - but what next? A different approach to route directions. In Raubal, M., Sliwinski, A., Kuhn, W., eds.: Beiträge zu den Münsteraner GI-Tagen 2004, Münster, IfGIprints (2004) 205–217
28. Schlieder, C.: Reasoning about ordering. In Frank, A.U., Kuhn, W., eds.: Spatial Information Theory, Berlin, Springer (1995)
29. Raubal, M., Winter, S.: Enriching wayfinding instructions with local landmarks. In Egenhofer, M., Mark, D., eds.: Geographic Information Science - Second International Conference GIScience 2002, Berlin, Springer (2002) 243–259
30. Elias, B.: Extracting landmarks with data mining methods. In Kuhn, W., Worboys, M., Timpf, S., eds.: Spatial Information Theory: Foundations of Geographic Information Science. Conference on Spatial Information Theory (COSIT), Berlin, Springer (2003) 375–389
31. Klippel, A., Richter, K.F., Hansen, S.: Structural salience as a landmark. In: Workshop Mobile Maps 2005, Salzburg, Austria (2005)