Cognitively Ergonomic Route Directions for Location Based Services

Diploma Thesis

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Abstract

Since ever, people have needed to travel from a place A to a place B. Often this journey leads them through an unfamiliar environments. Even in times where no maps were available, there were always people familiar with that particular area. To help people to reach their desired destinations, route directions by these people are a helpful tool. People familiar with an environment can describe the actions a traveler has to perform at specific places along the route. These places must be identified by the traveler, therefore the attributes that make a place most unique and identifiable are taken for the route directions. In present times, computer based wayfinding assistance systems, like car navigation systems, adopt the task to generate and present route directions. Unfortunately, computer generated route directions have only a few analogies with route instructions given by human beings. The human conceptualization of an environment includes much more, and particularly different, details that help people to identify a place. As one example, a church located at an intersection makes this intersection better identifiable than another, because not at every intersection there is a church. Even the structure of an intersection can serve as attribute that makes that intersection better identifiable in human conceptualization.

Due to the lack of cognitive ergonomics in route directions given by artificial navigation systems and the advantages these ergonomics have, the use of the right modality for the automated generation of route directions by navigation assistance systems on order to enhance conceptualization of environmental information is an interesting and promising area of research with a big field of application. The use of mental conceptualizations in route directions joins multidisciplinary research interests, for example, geographical interests for new ways of map representations, linguistic interests to optimize and ease verbal route directions, and also interest of computer science, to find data structures and algorithms for the automated generation of maps and route directions for artificial wayfinding assistance systems.

This thesis introduces an approach for the abstract representation of route directions in a more cognitively ergonomic way and enhances and performs techniques on that representation to even further enhance cognitive ergonomics by applying concepts of human conceptualization of route directions.

Contents

1 Introduction

To travel in an unfamiliar environment from a place A to a place B is a challenging task. Many helpful tools have been developed and realized till now to support travelers solving this task, from simple maps to modern navigation systems. But since ever, even before navigation assistance systems or just maps were available, most travelers ease routing in an unfamiliar environment by using information provided by external means. A typical today scenario may illustrate the following situation. Daily thousands of people all over the world travel. It does not matter if they are visiting foreign cities for holidays or just have to travel to another city for business reasons. After they have checked-in in their hotel, they have to reach other places in the city, for sightseeing or business meetings. They have just arrived and have not bought a city map yet. Since ever, the easiest way to find an unknown location is to ask local people for so called route directions (Tversky & Lee, 1998). But when we compare typical route directions given by human beings with route directions given by, for example, a car navigation system, it is hard to find similarities. Figure 1-1 shows the city center of Bremen. How would route instructions to travel from the Hilton Hotel to a small coffee shop look like received from a local person or a navigation system respectively?

The following instructions are not complete in all their details, but just the essential differences to directions given by human beings shall be illustrated. Instructions given by a human being would sound like this:

- Turn left at the next intersection onto the market place.
- Cross the market place heading to the town hall.
- Pass the town hall on the left and turn right at the “Bremer Stadtmusikanten”.
- Turn left at the next intersection and you will head to your destination, the coffee shop.

Obviously, this differs completely from any instruction known from automated navigation systems, like car navigation systems. The instructions would maybe sound as follows:

- Turn left after 300 meters to street “Am Markt”.
- Turn half right after 500 meters to street “Böttcherstraße”.
- Turn left after 200 meters and follow the street “Unser Lieben Frauen Kirchhof” for 300 meters.
- You have reached your destination.

The automatically generated instructions of an actual computer based navigation system do not sound human-like and increase the cognitive load for the traveler. That means the traveler has to concentrate more on which intersection is the right one to take. If the navigation instructions provide information about salient objects or attributes of the location the traveler has to perform the next action at, like for example the “Bremer Stadtmusikanten”, the cognitive load would be reduced.

Figure 1-1: Bremen City Center taken from Google Earth

Route directions that take into account the conceptualization processes involved in the human navigation are referred to as cognitive ergonomic route directions. They reduce the cognitive load for the travelers and enhance the travelers' location awareness at the same time (Hansen, Richter, & Klippel, 2006).

Another major keyword which is becoming more important in the design of wayfinding assistance systems and is closely related to cognitive ergonomics is cognitive adequacy. Cognitive adequacy covers the two terms cognitively adequate and cognitively plausible and is used in two ways (Strube, 1992). On the one hand it characterizes an external representation, a representation outside the human mind, which is homomorphous or at least shares aspects with an internal cognitive knowledge representation. On the other hand it identifies external representations that support or enhance cognitive processes.

The use of the knowledge about how people mentally conceptualize route information as input for formal conceptual or ontological models has been determined as suggestive to guide the design of route directions made by artificial systems, like navigation systems, by for example Klippel, Tappe, Kulik and Lee (2005). First of all a cognitive ontological approach leads to a theoretical foundation of user-centered approaches incorporating location-awareness and location conceptualization. Second, the approach offers a big potential for the development of suitable visual languages for geographic knowledge and (computer-generated) maps guided by cognitive considerations. Another goal achievable by using the knowledge about the human conceptualization of route information is the contextualization and personalization of wayfinding assistance systems.

The emergent interest in conceptual and ontological approaches that model route information also arises from a multidisciplinary interest in spatial cognition, besides new information technologies. A linguistic approach is to use human conceptualizations for the generation of verbal route directions; cartography has an interest in research on route maps and identifying the information needs of map users; computer science uses results of cognitive science for the development of formal representations of routes to build, for example, new wayfinding applications.

This is the point where this thesis sets off. A short preview of the parts that will be discussed in the following sections shall be given by a modified version of the typical generation process of routes provided by Hansen, Richter and Klippel (2006). The modifications are caused by turning the main attention to cognitive ergonomics. The following four steps describe the modified process:

1. To generate a route from a point A to a point B a data base is needed, which comprises all objects of the current environment that can potentially function as a point of the route where the traveler has to decide what to do next. This data base is independent from the actual route and can be used for the calculation of any route. This step has to be redone only if the underlying data base, for example, GIS data (Brenner & Elias, 2003) or data extracted from the internet (Tomko & Winter, 2005), has been changed, due to, for example, changes in the street network.

2. The actual route is calculated according to the user’s request. These requests can contain the commonly known navigation features, like shortest or fastest route, but also other criteria, like avoiding highways, ferries or bridges, can be taken into account. Also imaginable are alternative approaches for route calculations, like passing as much sights as possible in a city for tourists or criteria like avoiding steps and heavy increases for disabled users in wheel chairs.

3. The decision points of the route are “rated”, for example, according to their salience in the context of a route. With the aid of these ratings and other methods for improving the cognitive ergonomics of the instructions, like combining several route directions into a single instruction, the route directions will be enhanced.

4. Based on the formal route directions generated in step 2 and improved in step 3 the actual route directions are represented in the desired way, for example, verbal or graphical advices or maps are generated that focus on specific aspects.

In this thesis I will pay attention on the steps number three and four. But the route instructions generated in step two have to be represented in a data structure as input for the following two steps. Therefore section 2 introduces a data structure for routes and its elements. The data structure is based on the approach by Hansen, Richter and Klippel (2006) to represent landmarks. The use of the landmark approach enables the ratability of route elements, which is needed in step three.

For the realization of the third step I will use the approach of the Wayfinding Choreme Theory by Klippel, Tappe, Kulik and Lee (2005) as basis. The theory will be introduced and enhanced in section 3. A major keyword of the Wayfinding Choreme Theory is the term rewriting; it offers the opportunity to combine specific sequences of route directions to a single, more complex one, the so called Higher Order Route Direction Elements (HORDEs). The constraints which single elements are allowed to combine are defined in rule, or productions respectively, sets. These production sets can be modified according to cognitive or personal preferences. Section 3.4 will introduce one specific production set with the goal of cognitive ergonomic as result of the section 3.

The introduced theoretical approaches of section 2 and 3 will be implemented in the programming language Java. Section 4 introduces the Decision Point Data Structure as implementation of the data structure for route elements and the Wayfinhing Choreme Route Parser as realization of the term rewriting process of the Wayfinding Choreme Theory. The above mentioned productions and a tool to generate and modify the sets of productions have also been implemented and will be introduced in section 4.

Section 5 of this thesis introduces a cognitively adequate route direction externalization. It covers the fourth step of the generation process of routes. After the introduction of some already existing approaches to embed cognitive aspects for graphical externalizations of route directions, I will develop the Graphical Wayfinding Choreme Advice Theory. The theory picks up the idea of existing graphical advices generated by current wayfinding assistance systems and enhances them by embedding additional, cognitive aspects provided by the data structure for route elements. Section 6 finally introduces the corresponding Java implementation for the automated generation of cognitively adequate route directions from any direction represented by the data structure for route elements.

2 Route Elements

This section introduces an approach to classify the relevant elements of a route, the so called decision points. For the realization a classification used to represent different kinds of landmarks will be the basis to gain more opportunities to distinguish route elements and make them classifiable according to cognitive aspects. Decision points are functionally relevant points along a route, such as street intersections, that require a decision on which direction to take (Klippel, Tappe, Kulik, & Lee, 2005). Landmarks can be described as salient objects in the environment (Hansen, Richter, & Klippel, 2006). An object is salient, when it is easily recognizable in the environment, because its properties differ from the properties of most other objects. A church, for example, has its typical architecture that is not typical for any other building. Landmarks are getting ratable, according to their salience. Decision points on the other hand also have different attributes that makes them easier to recognize for a traveler. A salient object located at a decision point makes the decision point's salience comparable with the salience of the salient object itself.

The definition of decision points implies a basic salience for any decision point. The traveler must have to have the choice between at least two options. This makes the structure of a decision point or rather the underlying intersection, respectively, more salient than for example a street where the traveler does not have to make a decision because nothing else is possible than following it. Every decision point is salient in the environment somehow, even if, for example, no special building is located at it. Therefore, every decision point contains to a subset of landmarks. With the aid of this definition, decision points can be handled analogous to landmarks. The potential to rate landmarks can be adapted to decision points. And the rating of a decision point is analogous to the identifiability by a traveler.

The degree of salience of a landmark can be classified according to attributes provided by the taxonomy for landmarks developed by Hansen, Richter and Klippel (2006) and personal preferences. The following section will introduce the taxonomy of landmarks and discuss which levels are meaningfully applicable to be used with decision points. Based on that information, a data structure for decision points will be developed where a closer look will be taken on what information is required for representing decision points in a cognitive ergonomic way.

2.1 Landmarks

Landmarks are an element for the structuring of environmental information into cognitive conceptual units. They have the potential to identify uniquely pertinent intersections and disambiguate spatial situations at complex intersections. For example, in a city with many similar-looking intersections it is often difficult to identify the specific searched one. Often a salient object, for example, a special building or an intersection with a special structure like roundabouts, eases the search. Landmarks can help to structure information of the space (Hansen, Richter, & Klippel, 2006).

The described appearance of a landmark is the reason why they are widely used in verbal as well as graphical route directions given by humans. Landmarks ease linking actions during the wayfinding process to the environment, or linking a decision point to the action that needs to be performed there. Not using these advantages is a violation of cognitive ergonomics (Hansen, Richter, & Klippel, 2006).

The question which part of the environment can be used as a landmark also answers the question which parts of the environment are salient in human conceptualization. There are plenty of definitions. One that is still used in many approaches of research is the qualitative description of Lynch (1960) provided in his work on elements of a city that structure knowledge of the environment. Another simple definition of Presson and Montello (1988) says that everything that stands out of the background can be used as a landmark. Analogous, the salience of a landmark describes the pall that highlights the landmark in its context, the environment, and makes it better accessible in human awareness. The grade of salience is defined by a combination of different visual, structural and semantic aspects (Sorrows & Hirtle, 1999) and also depends on the conceptualization of a wayfinding concept (Klippel, Tappe, Kulik, & Lee, 2005).

Actual instructions given by wayfinding applications do not have a differentiation of grades of salience of decision points. Investigations about salience of objects in the environment cited above conclude commonly that generally the more salient an object is, the better it is identifiable by human. Therefore, the classification of decision points according to the salience of landmarks in human conceptualization makes sense when trying to find a cognitive ergonomic way for the representation of route instructions.

2.2 Landmark Taxonomy

Data structures that incorporate the cognitive conceptual functions of route directions gain a big potential. Challenges of such an implementation are the automatic definition and extraction of appropriate salient objects in the environment, which may function as landmarks, from the available data set and the integration of them in automatically generated directions. The approach by Hansen, Richter and Klippel (2006) that is introduced in this section focuses on another challenge, the embedding of landmarks semantically into an appropriate data structure, a process which contained many open questions for research whereas a big field of application was present. A good understanding why and when people are using landmarks in organizing spatial knowledge for the purpose of communication or memory has already been existed, how to formalize this information for artificial navigation systems on the other hand is the major achievement of the approach.

The data structure by Hansen, Richter and Klippel (2006) is based on the OpenLS[1] standard and closes the gap between approaches identifying landmarks and those generating cognitive ergonomic route directions and automatically integrating landmarks. They introduced a classification according to the function of a landmark in route directions. It excludes (visual) information to enable the wayfinder to identify a landmark. It is sufficient to derive the relation between route elements and landmarks and the function of a landmark within an instruction. To this end, an eight-level-taxonomy has been developed; each level of the taxonomy describes different aspects of the function of a landmark within an instruction.

The taxonomy has been developed to describe every possible type of landmark along a route, including landmarks not located at decision points but located along the route between two decision points. For example, one level of the taxonomy provides information whether a landmark is identifying, or is located at a decision point respectively, or not. For the development of a data structure that represents points along the route that need a decision to take and are therefore identifying, this level of information is not useful. I will only introduce the levels useful for achieving the goal of a data structure for decision points.

The next sections introduce the levels of the landmark taxonomy providing data relevant for landmarks that identify decision points. Afterwards, a data structure for decision points will be introduced that uses the introduced levels of the landmark taxonomy for the description of

[1] Server specification for location based services proposed by the Open Geospatial Consortium (http://www.opengeospatial.org/standards/olscore)

decision points. Hence, every decision point provides the relevant information about the salience of itself, no matter if an intersection or a prominent building gains the decision point's salience. All decision points are comparable with each other and therefore classifiable.

2.2.1 Root Level

The root level is the basic concept of the landmark taxonomy and identifies an entity as part of the taxonomy. It is useful to have an abstract level where all possible landmarks, or for the later application decision points, belong to, for operations that affect all elements of the taxonomy.

2.2.2 Functional Level

This level describes the number of decision points a landmark is utilized for. The determination is subjected to 1-element and n-element landmarks. In the manner of decision points the attribute 1-element identifies a decision point located at a 1-element landmark, for example, a salient object, like a church located at an intersection. A decision point that is classified as n-element has an n-element salient object that ranges over several decision points located at it. A river passing next to a street, for example, is a salient object that can be located at several decision points in a row the traveler has to follow until reaching another unmistakably identifiable decision point. Possible applications might be instructions like "Follow the river and turn left at the third intersection" or "Turn half right before entering the forest".

2.2.3 Conceptual Level

Humans generally conceptualize the functional role of the spatial extension of a landmark in three categories: point-like, line-like or area-like. In the geometric sense all objects in a two-dimensional space are an area, a church, a river as well as a forest. But humans internally add a priority to the spatial description ranging over point, line and area. On the one hand, human rate the size of a landmark, a point-like object is smaller than a line-like object, which again is smaller than an area-like object. Therefore a church would be declared as point-like, a river as line-like and a forest as area-like on the conceptual level. On the other hand, the conceptualization of the object depends on spatial relational level of the landmark, which will be described in section 2.2.5. Crossing, for example, a park, it is conceptualized more area-like. When the traveler is driving along a park, some people conceptualize the park more line-like.

2.2.4 Object Class Level

The object class level is only relevant for 1-element landmarks. It distinguishes intersections, route elements uniquely because of their structure and route segments located at outstanding buildings. For the application with decision points, this level describes which aspect of the decision point is the salient one, the aspect that makes the decision point easier to identify by the traveler.

2.2.5 Spatial Relation Level

This level describes the spatial relation of the landmark to the route segment it is located at. The spatial relation between a decision point and its salient object depends on its functional role in the action that has to be performed at the route segment, its geometry, its position in the spatial configuration of the surrounding environment and its object class. This information associates an appropriate spatial relation with the route segment reflecting its conceptualization. For example, the traveler is heading to an intersection with four branches where a church is located at. Depending on the direction the traveler heads to the intersection and the location of the church, the church has the spatial relation before, after, left, right, etc.

2.3 Decision Point Data Structure

Based on their taxonomy for landmarks, Hansen, Richter and Klippel (2006) developed a data structure in XML using the OpenLS standard. Based on this approach, this section describes a data structure for decision points only. Therefore, not all levels of the original taxonomy will be taken into account.

The data structure for decision points will not handle decision points equally to landmarks, but with the help of the landmark taxonomy subgroups of decision points with salient attributes can be generated. Especially the first four levels of the taxonomy introduced in the previous section are interesting. The subsets are ordered in a hierarchical structure. With the aid of these different types for decision points the distinction of decision points according to the salience of landmarks is possible.

The basic group containing all decision points represents the root level of the taxonomy. Based on the conceptual level of the taxonomy accrue three subgroups of decision points. The data structure for decision points also has three classes to distinguish the following groups of decision point: decision points with a line-like landmark located at it, decision points with an area-like landmark located at it and decision points with a point-like decision point located at it. According to the functional level also the distinction between 1-element and n-element decision points is designated. Therefore, the group of n-element decision points acts as upper-level group for decision points located at line- and area-like landmarks. A class for 1-element decision points is not designated in the data structure for decision points, because all decision points that do not belong to the group of n-element decision points belong to the group of 1-element decision points by default.

Based on the object class level of the landmark taxonomy, the group of point-like decision point splits again into two different groups: Decision points where a general salient object (GSO) is located at and decision points being uniquely identifiable due to the salient structure of the intersection branches. The third type designated by the landmark taxonomy contains intersections, points along the route a decision has to be taken. Hence, I develop a data structure for decision points; the root level of the data structure already characterizes this attribute.

The two classes for decision points that outstand from a simple 1-element decision points due to their structure or GSO located at it provide the opportunity to store additional information about the structure or GSO respectively. To prevent conflicts, the case of a decision point that has a special intersection structure and is located at a GSO must be covered. It does not matter for the later use of the data structure where sequences of decision points will be combined to HORDE according to a specific set of term rewriting rules, but the applications that fill the data structure with real data must decide which attribute gains a higher priority.

For the term rewriting process of the Wayfinding Choreme Theory introduced in section 3.3.4 the data structure provides additional information about structures of intersections or GSOs located at decision points. A distinction between different structures, for example, T-intersections and fork-intersections, provides additional alternatives for the prioritization of different rules. It may be possible that for some travelers a fork-intersection is less salient than a T-intersection; in that case rules that handle decision points with a fork-structure has to be prioritized lower. The same scenario fits to GSO. Additional information, for example, about the category of a GSO like churches, parking lots or patrol stations, offers the opportunity to prioritize different groups of GSO differently.

Also needed for the often stated opportunity to combine sequences of decision points to HORDEs is an additional type for the representation of them. At this point the data structure will just be extended by the type “Horde” that also belongs to the root group of decision points, the attributes and data of this type will be introduced in section 4.2, where the implementation of the data structure will be introduced. A second additional type I will introduce at this point is a data structure to represent a whole route, the route string. The route string contains an arbitrary number of decision points in a specific sequence. All decision points the traveler is passing to get from a place A to a place B are stored in a route string.

Figure 2-1 shows the hierarchal dependencies and a schematic overview of the data structure for decision points.

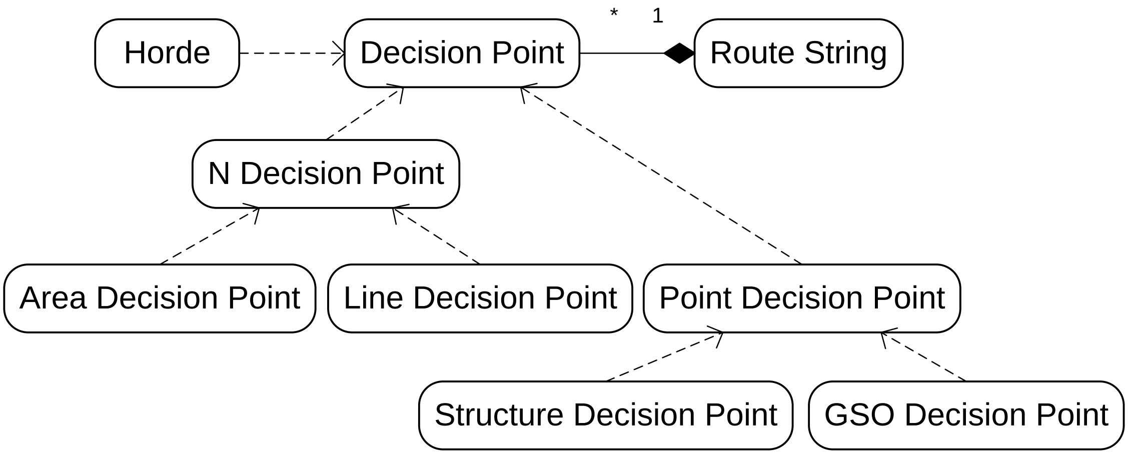

Figure 2-1: Abstract inheritance hierarchy

The approach presented in my thesis introduces just example implementations for additional information available on structures and GSOs. Any application representing routes using this data structure may extend their own version, maybe containing more functionality for the use with other applications than the wayfinding choreme parser.

A description of the implementation of the presented data set can be found in section 4.2.

3 Wayfinding Choreme Theory

Section 112 provides a classification of decision points that allows for distinguishing them by saliency in human conceptualization and contains a conception to represent Higher Order Route Direction Elements (HORDE). As the next step, an appropriate way to model route information is needed. The wayfinding choreme approach (Klippel, 2003) reflects abstract mental concepts in an abstract graphical externalization. This cognitive conceptual approach proposes primitive conceptual elements of route directions, based on work in geography by Brunet, namely “modelisation chorematique” (Brunet, 1987). Cognitive conceptual approaches are contrary to the commonly used data driven approaches. The data driven approach starts with rich representations of spatial environments and derives representations that are more schematic by systematic abstraction, for example, by cartographic generalization. Cognitive conceptual approaches, on the other hand, are characterized by taking conceptual spatial representations as a starting point, and produces richer (more detailed) representations by concretizing, combining and contextualizing them. (Klippel, Lee, Fabrikant, Montello, & Batemann, 2005).

In this thesis I develop an approach for route directions which fits cognitive ergonomics. For this reason the generated route directions have to gain cognitive adequacy. Cognitive adequacy is used as a cover term in this approach, analogous to the approach by Klippel, Tappe, Kulik and Lee (2005), for both expressions, cognitively adequate and cognitively plausible, which has been distinguished in many approaches by several researchers.

3.1 Internal and External Representations

For the understanding of internal and external representations it is necessary to show the differences between both. The comparison of depictions and descriptions by Tversky and Lee (1999) shares many aspects with the comparison of internal and external representations. A depiction, in analogy with an external representation, is appropriate for information that is directly or metaphorical. Descriptions, on the other hand, are more appropriate for abstract information, as are internal representations.

Tversky and Lee describe external representations, depictions like pictures or words, as inventions to promote the human memory thinking. They also refer to Donald (1991), who even claims external representations are analogous to internal representations; they are storage and retrieval devices. Advantages and disadvantages of external representations that an internal one does not have are described by Tversky and Lee and many researchers before them (Larkin & Simon, 1987; Donald, 1991). Human information processing, for example, is limited by the number of items (memory) and the number of operations (processing). External representations on the other hand are virtually unlimited. It is possible to provide tons of information within one representation, which again complicates the search for specific information such that it can be very expensive. Also the aspects consistency and accessibility of information provide different characteristics. While internal devices are fleeting, external devices are floating. The internal representation is private and internal where an external representation is public, transportable and shareable.

A special feature of depictions is the possibility to arrange items in the space in and of itself. Grouping related information spatially proximal minimizes the search and facilitates inferences. Grouping, ordering and distance in space corresponds with grouping, ordering or distance in other dimensions.

But depictions also come with several limitations. The effectiveness of depictions comes from their use of space in meaningful ways and their ease in making inferences. Depictions that force their correctness by overloading itself with information where it may not be meaningful forces wrong inferences. Depictions convey one or maybe more meanings naturally, but do not convey other meanings and relations.

The comparison with depictions shows many advantages and also disadvantages of external representations and which information to reduce or expand must be chosen carefully. The use of externalizations can reduce the cognitive load and ease the reading process, but can also achieve the opposite.

According to Berendt, Barkowsky, Freksa and Kelter (1998) the term map characterizes a type of pictorial representation which has three things in common. First, they have two-dimensional spatial extent. Second, geographic entities, like forests or cities, are symbolized by depictions. Third, the localization of these symbols conveys information about spatial relations in the world. Due to the listed analogies of maps, they have also denoted the term map as useable to denote cognitive or internal representations of external maps in a figurative way.

The last paragraphs have shown positive and negative cognitive effects of externalizations, for example, depictions like maps but also other data structure to transfer information. When developing an external representation of internal knowledge the data to include or omit must be chosen conscientiously, depending on the focus the external representation gains.

3.2 Cognitive Adequacy

Cognitive adequacy has been used on the one hand to characterize an external representation homomorphous to, or at least sharing aspects with, an internal cognitive knowledge representation (Klippel, Tappe, Kulik, & Lee, 2005; Strube, 1992). On the other hand an external representation is a representation outside the human mind. Several different external representations of the internal mental conceptualization of route directions are imaginable, like verbal, written, spoken or graphical advices. Route directions as introduced in the approach of wayfinding choremes (Klippel, 2003) are one example. Tversky and Lee (1998; 1999) analyzed sketch map drawings to elicit elements for a graphical toolkit as well as verbalizations for a verbal toolkit for route directions. They have found a correspondence between both toolkits and an underlying common conceptual structure both originate from. The wayfinding choreme route grammar represents this common conceptual structure. The following sections introduce the approach of the wayfinding choreme route grammar and define concrete suggestions for possible productions needed to combine single wayfinding choremes to HORDEs.

The second meaning used for cognitive adequacy is to identify external representations that support or enhance cognitive processes to aid knowledge acquisition and problem solving. Section 5 will introduce several existing approaches enhancing route maps to ease cognitive processes and an extension of the graphical advices commonly used by car navigation systems, to enhance the cognitive adequacy by using provided cognitive aspects of route directions.

3.3 Wayfinding Choremes

Improving map designs by incorporating a cognitive perspective plays a greater role since the beginning of experimental cartography and cognitive questions are getting more relevant in cartography (for an overview see: Montello, 2002). Wayfinding choremes are a cognitive conceptual approach that proposes primitive conceptual elements from which wayfinding and route instructions can be constructed (Klippel, 2003). The idea is based on the approach of the French geographer Brunet, who emphasized conceptual spatial information in his work to create a language for space (Brunet, 1987).

How to add additional information to an existing externalization has been researched by Bertin (1974). He grounded his work on visual variables in analyzing information describable by the properties of the plane. With a diagram all kinds of information, for example the precipitation in one year at one place of the world's surface, can be represented by its visual variables, the horizontal and vertical axes. This basis raises a problem with maps; the two dimensions of the plane are reserved for representing locational spatial information, called geographic component in Bertin's terminology. To characterize any other information, like colors or hue, the use of a third dimension is required – Bertin's visual variables (Bertin, 1974). Brunet used this third dimension to emphasize the conceptual spatial information.

With the aid of the emphasized conceptual spatial information Brunet's established simple models that characterize - according to his theory - every possible spatial situation (Brunet, 1987). The idea for his basic set of simple models is that all elements are combinable like the symbols of an alphabet. By combining symbols of an alphabet we achieve all possible words, by combining the simple models all geographic phenomena can be represented. The simple models are constructs, like for example 'Meshes', that indicate the partitioning of a region or a 'Contact' that characterizes processes at boundaries. According to these theoretical models Brunet proposed graphical counterparts representing the basic components of maps. Every model is subdivided according to three cartographic primitives, point-like, linear and areal models. As a fourth syntactic primitive he added the net. Brunet named his theory chorematic modeling. Choreme is a made-up word that combines the Greek word for space - chorus - and the suffix –eme, which indicates the relationship to language.

Brunet's theory is not explicitly motivated by cognitive science research, but he claims that by applying his graphic models to mapmaking, maps speak for themselves. Hence, wayfinding choremes describe primitive conceptual elements that claim to create wayfinding and route direction elements speaking for themselves (Klippel, 2003). Analogous to Brunet's approach wayfinding choremes represent all necessary route information in street networks. The conceptual models are associated with graphical representations. So the term wayfinding choreme is ambiguous as it denotes human conceptual as well as graphical entities.

In comparison to Brunet's theory for geography and geographic knowledge, the wayfinding choreme theory focuses on the domain of wayfinding and route directions for three major reasons (Klippel, 2003).

- Wayfinding choremes try to define a cognitively adequate way for representing spatial information essential for wayfinding; a domain Brunet's choremes are not applicable for.
- The basic conceptual elements of Brunet provide general means for structuring spatial knowledge, but change if represented in a map. The wayfinding choremes aim at automating map or instruction making appropriate for a given wayfinding situation. Hence, the basic conceptual elements should be invariants for all representations.
- The conceptualization of humans change depending on the given domain and the event that takes place at the domain. For this reason wayfinding choremes have to be as specific as possible.

3.3.1 Route Direction Elements

Tversky and her coworkers (Tversky & Lee, 1998, 1999; Tversky, 2000) developed two semantically corresponding toolkits for the external representation of route directions, one for verbal and one for pictorial route instructions. Both toolkits contain primitive elements which establish a basic set of elements. The basic elements of the pictorial toolkit highlight the structural aspects of an intersection with additional arrows to illustrate the action to be performed; the verbal direction toolkit accentuates the functional aspects using verbs of motion.

This consideration poses the question whether the structural or the functional aspects require more attention. Hence, we differentiate the terms structure and function in a colloquial but easy way; namely what are the differences between thinking of an intersection itself and thinking of an intersection at which one has to perform a specific action.

The term structure refers to the object level, for example, the spatial structure as physically present in the environment. A function indicates the event/action level and indicates the structural aspects demarcated by the action (Klippel, 2003).

We can picture this by reflecting the distinction between a route and a path (Montello, 2005). A route describes a behavioral pattern on a path; we perform specific way changing actions to get from a place A to a place B. An intersection is a place where to take a specific direction to achieve the goal. A path on the other hand is a physical structure. An intersection, in this case, is only a branching point; the structural view is how many branches in which directions are physically present.

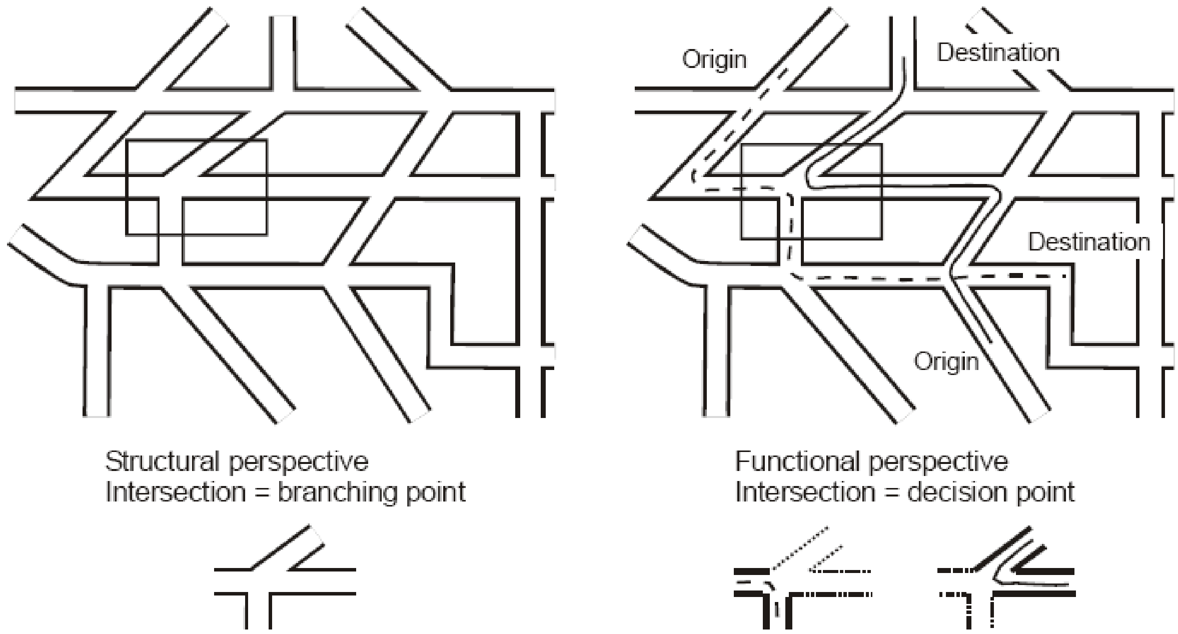

Figure 3-1: Distinguishing paths (structural perspective) from routes (functional perspective) (Klippel, 2003)

The basic set of wayfinding choremes represents actions (for example which direction to take at an intersection) rather than structures or the spatial layout the action is embedded in. Intersections can have an arbitrary number of branches and also branches in every possible direction. It is most unlikely that all branches are orthogonal; especially intersections with an uneven number of branches like 5-ways, with exorbitantly many branches like 6-ways or underspecified structures like star-shaped intersections have to be arranged.

An experimental setting by Klippel (2003) used to examine human conceptualizations of route direction elements clarifies whether the representation of route directions seeks to identify rather functional than structural prototypes.

He provided 19 participants with 42 single pages with a spatial expression printed on the top. Either these expressions were general spatial terms important for route directions, like ‘intersection’ or ‘turn right’, or parts of route directions, like ‘turn left at the star-shaped intersection'. The functional aspects, for example, the actions to be taken at intersections, were chosen from the models of qualitative spatial reasoning (for example, Frank, 1992; Hernández, 1994; Raubal, 2001). These are expressions necessary to give directions according to an 8-direction model, which will be introduced later in this thesis. The participants had to provide a graphical representation, for example a drawing, for each spatial expression.

The results identified by analyzing the experiment provided several aspects for the modulation of the wayfinding choremes. Klippel was able to evidence the importance of the distinction between structural and functional aspects in the conceptualization of basic elements of routes.

Especially for complex route elements, like 5- or 6-way intersections, it has shown that not every intersection can be conceptualized from the structural perspective; several different interpretations of the same intersection have been presented by the participants.

Even though functionally relevant aspects of actions play a major role in human conceptualization, the functional perspective also meets its limits trying to generalize specific actions, like “turn half left at the intersection”. Participants interpreted this in very different ways, especially when performing the action at intersections with branches not in regular 90° angles. Also instructions like “turn left at the next intersection” show the weakness of route directions just based on functional aspects. Many participants interpreted the advice to turn left as taking the most-left positioned branch of an intersection, even if there was a branch with an angle of 90° available at this intersection. Basically, a left turn should correspond with the branch with an angle of 90° and not the next “leftist” street available.

A third observation is based on the evaluation of answers by the participants on different directions to take. It is easier for the human to conceptualize the “standard” turns to the left and right, associating a 90° angle. “Modified” turns, like sharp left or half right, are much harder to conceptualize for human beings and lead to more confusion.

As conclusion of the results Klippel advised, whenever the domain of use comprises actions, the schematization has to consider them, as they are in the focus of the wayfinder. But on the other hand, structural information cannot be ignored even if it plays a secondary role. Route direction elements obtained from the externalizations of conceptualized actions provide a new perspective on schematizing spatial information in maps.

All these aspects have to be considered when modeling prototypical functional elements in route directions, the wayfinding choremes.

3.3.2 General Characteristics of Wayfinding Choremes

Before I can start to introduce and define the basic set of wayfinding choremes, the distinction between two different characteristics has to be introduced, the I- and E-wayfinding choremes (Klippel, Tappe, Kulik, & Lee, 2005).

When characterizing wayfinding choremes, two different types have to be distinguished. Like the Chomskian differentiation of internal and external languages (Chomsky, 1986), we have to account for I- (internal) and E- (external) wayfinding choremes. I-wayfinding choremes are abstract mental concepts underlying route directions and wayfinding in all possible modalities. They are modality neutral. E-wayfinding choremes on the other hand are modality specific external representations of I-wayfinding choremes used for different modalities, for example, a graphical and a verbal representation.

The external wayfinding choremes are not homomorphous to internal wayfinding choremes, because external representations in different modalities vary from one another. A graphical externalization, for example, is spatially specific, because the instantiation requires fixing all configurable parameters (for example, orientation of the branches of an intersection and angles between them). The verbal externalization normally does not need that much spatial information about branches not involved in the action, because they are not externalized in language.

The wayfinding choreme route grammar is an internal wayfinding choreme representation. In section 5 a visualization possibility of this internal representation, so called graphical advices, will be derived.

3.3.3 Set of Wayfinding Choremes

The wayfinding choremes are grounded in an 8-sector-model from which an 8-direction-model can be derived by determining the bisecting lines of each sector. Using an angle of 45° we are getting eight directions from the middle point. This model is a simplification and can be refined further; people may need more than 8 sectors and/or the sectors are not equally sized (Montello & Frank, 1996). But a higher number of sectors will not change the general approach taken by the wayfinding choreme theory; it just increases the number of primitives and therefore the number of possible chunks (Klippel, Tappe, Kulik, & Lee, 2005).

Humans generally do not conceptualize possible directions as vectors that originate from the center of a decision point while navigating. Normally, a reference line is needed, in our case the street or direction the navigator is heading to the decision point. According to the 8-direction-model the navigator has 7 directions for his goal-orientated action. The turning “back” action plays a secondary role because it is most often senseless or even impossible.

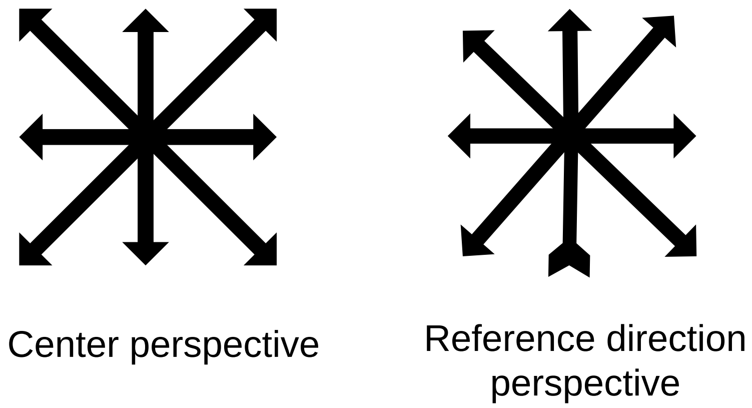

Figure 3-2: 8 Center and Reference Direction Perspective on Decision Points (Klippel, Tappe, Kulik, & Lee, 2005)

To put it in a nutshell, wayfinding choremes are extracted from the (7+1)-direction model based on a reference direction perspective. Seven potential directions conceptualized in combination with the reference direction result in seven wayfinding choremes: SHARP LEFT, LEFT, HALF LEFT, STRAIGHT, HALF RIGHT, RIGHT, SHARP RIGHT.

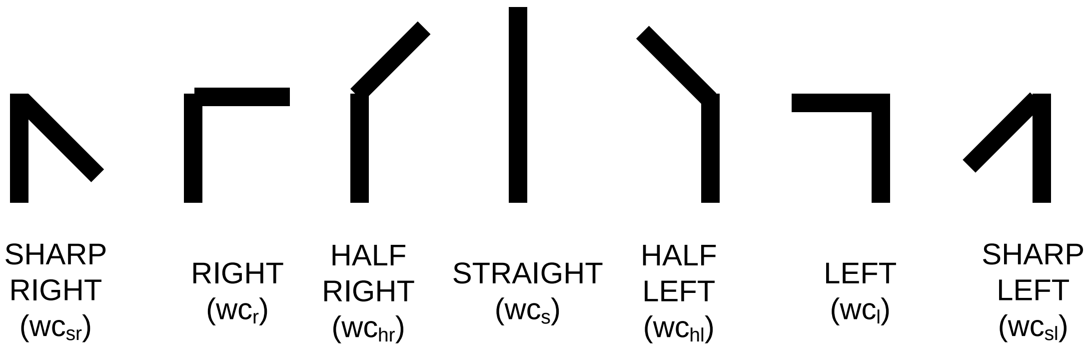

Figure 3-3: Basic Wayfinding Choremes
(Klippel, Tappe, Kulik, & Lee, 2005)

These seven directions are distinguished and categorized in three turning concepts. Based on the experimental work by Klippel I have discussed in section 3.3.2, a hierarchical categorization is possible.

First of all I differentiate between wayfinding choremes that involve and do not involve a change of direction. The category DP- contains all wayfinding choremes the navigator reaches where no change of direction has to be performed. Wayfinding choremes where a change of directions has to be performed shape the second category DP+. A further distinction of non-turning actions is not necessary, the only element of the (7+1)-direction model that does not have a change of direction is STRAIGHT. The extant directions are categorized in two subgroups, standard and modified turns. The standard turns are associated to a standard 90° angle (LEFT, RIGHT) and modified turns are all combinations of the standard turns with the keywords SHARP and HALF.

The three categories Non-Turning Choremes (NTC), Standard-Turning Choremes (STC) and Modified-Turning Choremes (MTC) are called turning concepts.

To recapitulate, we have a basic set of primitives persisting of 7 directions that can be hierarchically classified by three subcategories. Figure 3-4 shows the hierarchical categorization of the primitive wayfinding choremes.

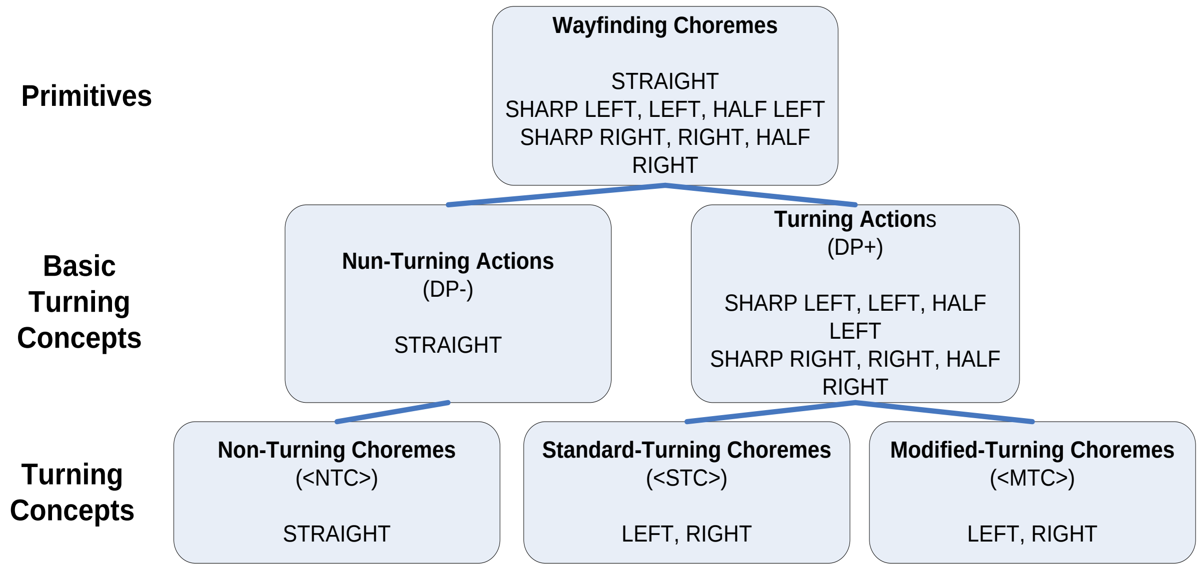

Figure 3-4: Hieratically categorization of wayfinding choremes

3.3.4 Chunking of Wayfinding Choremes

In section 2 I have introduced and developed a data structure for decision points derived from the taxonomy of landmarks. The previous sections gave us an understanding of wayfinding choremes and the importance of structural as well as functional information of route direction elements. One major aspect that is missing for the generation of cognitively ergonomic route directions is the combining of single wayfinding choremes to higher order route direction elements (HORDEs), the so called chunking. For example, in human conceptualization the route direction “turn left at the third intersection” is more appropriate than the sequence of route directions “pass the next intersection, pass the next intersection, turn left at the next intersection”. A feature of the human conceptualization of wayfinding is to chunk functionally related decision points to an advice with a more complex structure but nevertheless reduces the cognitive load for a human traveler.

Wayfinding choremes can be classified according to the basic distinction of turning concepts. The entire route represented by wayfinding choremes, characterized by its origin, destination and the wayfinding choremes connecting the origin and destination, can be considered as the top-level category of a route conceptualization ontology. As described above, the integration of sequences of wayfinding choremes of a route is called chunking. The process of chunking does not replace the present decision points; it tries to ease the decision-making for the traveller. Instructions of chunked wayfinding choremes based on specific patterns often reduce the cognitive load more for the traveller than the sequence of instructions or single decision points. The instructions of chunked wayfinding choremes focus the users’ attention on multiple intersections at the same time and he exactly knows what to do. Single instructions need the users’ attention for every single decision point again.

Different chunked wayfinding choremes of the route are mereologically related to wayfinding choremes. Any sequence of wayfinding choremes of a route can be chunked to a HORDE, even the entire route. Hence, the same route can be organized in a number of ways applying different mental conceptualizations, for example, reflecting personal or maybe cognitive preferences. The rules of the wayfinding choreme route grammar introduced in section 3.3.6 are an application of such a conceptualization which takes a closer look on cognitive aspects for the chunking process.

With the help of HORDEs different descriptions for a given route on the basis of the same wayfinding choremes are possible whereas the formal conceptualization within the route ontology does not change (Klippel, Tappe, Kulik, & Lee, 2005).

Chunking wayfinding choremes results in another positive effect, an increase of efficiency. A very small set of primitives is the basis for a variety of complex structures. The rules to generate HORDEs from the set of primitive wayfinding choremes, or even already chunked primitives, are adaptable to different requirements and are canonical cases to individual preferences. Not just cognitively ergonomic, but rather general and personalized cognitively ergonomic navigation assistance gets possible.

3.3.5 Wayfinding Choreme Route Grammar

Wayfinding choremes give us the opportunity to represent route instructions in a more cognitively adequate way than most wayfinding applications do. To make the instructions cognitively ergonomic, the primitive wayfinding choremes have to be chunked to HORDEs. HORDEs can be created by a functional chunking of wayfinding choremes into more complex expressions. Like the primitive wayfinding choremes, HORDE are route elements defined from the perspective of route directions and wayfinding tasks, rather than path elements, which are defined by the physical and spatial characteristics (see section 3.3.1).

A complete route can be seen as one word of a formal language that is determined by its strings over a finite alphabet, the basic set of wayfinding choremes. A grammar also consists of defined rules to generate well-defined words in a language. A route is described by its corresponding route string R of wayfinding choremes. A HORDE can be defined as a substring of R. Analogous to the approach by Brunet (1987) who introduced a limited set of primitives that suffice for modeling every possible spatial situation, the alphabet or the primitive set of wayfinding choremes is enough for modeling every possible route. The basic set of wayfinding choremes can be characterized as a small number of primitives, whereby term rewriting can be used for modeling route information.

3.3.5.1 Term rewriting

The following definition of term rewriting is based on Dershowitz and Jouannaud (1990). The word term rewriting is used in mathematics, computer science and logic. All potentially non-deterministic methods of replacing a subterm of a term with another subterm are called rewriting processes. Terms can be, for example, a formula for the mathematic use or words of a formal language in theoretical computer science. As long as the rules are non-deterministic, they can be applied in many different ways or more than one rule can be applicable at the same time. To manage this, some kind of algorithm is needed to make the process deterministic.

A rewrite system consists of a set of terms and relations how to transform these terms. A very prominent example is a computer program, a specific set of instructions, operators, variables and keywords can be used to define a computer program. With the help of term rewriting this computer program will be optimized and translated to code closer to machine instructions or even byte code by a compiler. This helps to write computer programs in a language that is easier readable for a human.

3.3.5.2 Existing Approach for Term Rewriting

The approach by Klippel, Tappe, Kulik and Lee (2005) introduces the general process of term rewriting for wayfinding choremes. $R \in L(WCRG)$ denotes a string representing a route, whereas $L(WCRG)$ denotes the language that contains all possible words that can be generated with the rules of the Wayfinding Choreme Route Grammar. Each two wayfinding choremes of R that are not from the same type are functionally different. Respectively, each two wayfinding choremes that are from the same type are functionally equivalent. The string R is processed sequentially and the defined rules of the grammar are processed in their order of definition. Each chosen rule is processed to the whole route string before the next rule is used.

The first set of rules contains rules for the extraction of HORDEs, which chunk different wayfinding choremes, where different means functionally different. Klippel denotes this kind of HORDEs as dwc. The second set contains rules for the extraction of HORDEs chunking functionally equivalent wayfinding choremes, analogous denoted as ewc.

To build up the set of rules to generate functionally different wayfinding choremes, Klippel and his coworkers distinguish two types of constellations of wayfinding choreme sequences. The first type contains strings of one or more STRAIGHT wayfinding choremes (wc_s), followed by a turning wayfinding choreme (tc), either standard (STC) or modified (MTC). The decision point, the action of the turning wayfinding choreme has to be performed at, must be unmistakably identified by either its structure (stc), for example, a T-intersection (T), which makes any further movement impossible, or a landmark ($R+$) located at the decision point. Also the destination ($Destination$) of the traveler can be emanated as salient for the traveler and therefore unmistakably identifiable. Figure 3-5 shows example intersections that meet the conditions.

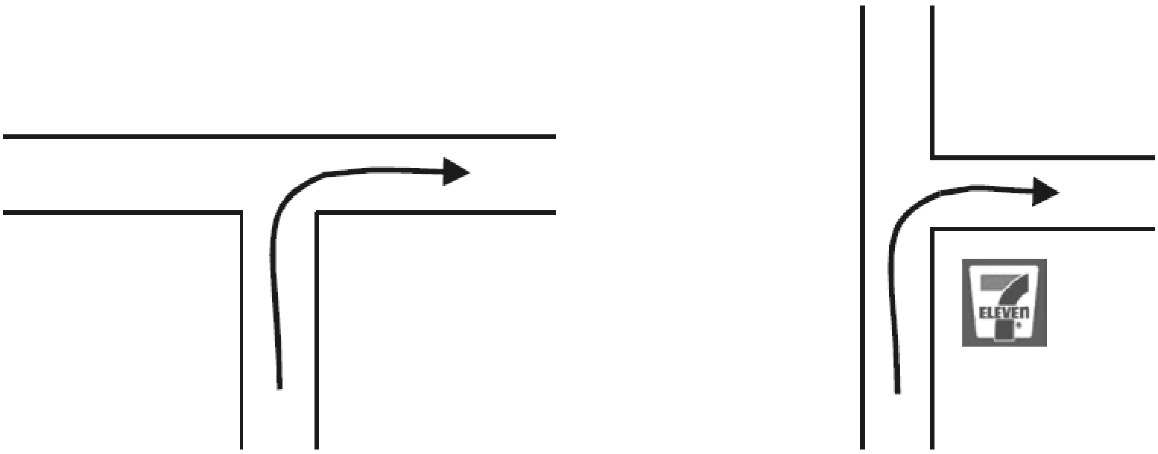

Figure 3-5: Unambiguous function segmentation; TURNING wayfinding choreme with T-Intersection or salient landmark (Klippel, Tappe, Kulik, & Lee, 2005)

These spatial situations offer the opportunity to form large chunks, theoretically there is no restriction on the number of STRAIGHT wayfinding choremes to combine because the turn is unmistakably identifiable.

The second type of functionally different wayfinding choremes contains sequences that end with a turning wayfinding choreme without any salient feature. Due to this lack of identification, a restriction of the number of precedent STRAIGHT wayfinding choremes is necessary. Klippel has chosen only 2 or 3 foregoing STRAIGHT wayfinding choremes as sensible.

The following four rules describe the rules to chunk functionally different wayfinding choremes. They are divided by an arrow into a right hand and left hand side, if the left hand side fits to a sequence of wayfinding choremes of the route, they will be replaced by the right hand side of the rule. All symbols of the rules needed to read them have been placed in brackets in the paragraphs above, after they have been explained in the text.

$$\underbrace{(wc_s wc_s \ldots wc_s)}_{n-times}\, tc^{R+} \rightarrow\ dwc^{R+}; n \in \mathbb{N}, tc^{R+} \in \{STC^{R+}, MTC^{R+}, Destination\}$$

$$\underbrace{(wc_s wc_s \dots wc_s)}_{n-times} stc^T \rightarrow dwc^T; n \in \mathbb{N}, stc^T \in \{wc_r^T, wc_l^T\}$$

$$wc_s wc_s tc \rightarrow dwc^{3tc}; tc \in \{STC, MTC\}$$

$$wc_s tc \rightarrow dwc^{2tc}; tc \in \{STC, MTC\}$$

The set of rules combining functionally equivalent sequences of wayfinding choremes to HORDEs contains rules to combine two or three functionally equivalent wayfinding choremes. For instructions handling modified turning concept the maximum number of chunked wayfinding choremes is restricted to two.

A third set of rules introduced by Klippel et. al. chunks so called special concepts, spatially interesting situations that, for example, often occur in grid-shaped street networks in North America. The P-Turn, for example, is the spatial situation where a left turn is prohibited but an alternative is given by driving "around the block". Conveyed with wayfinding choremes this means one wc_s, followed by three times wc_r, followed by another wc_s.

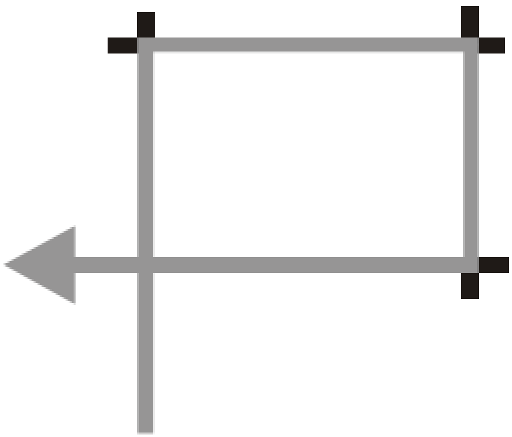

Figure 3-6: P-Turn - $wc_s wc_r wc_r wc_r wc_s$
(Klippel, Tappe, Kulik, & Lee, 2005)

These spatial situations are easy to identify by using wayfinding choremes, but the external representation is often complicated. The instruction "Make a P-turn" will probably not be understood by everybody.

Never the less, the approach gives a good entry point for improvement. The next sections will combine the approach with my data structure for decision points based on the data structure introduced in section 2.3.

3.3.6 Formal Representation

To ensure the correctness of term rewriting and have an abstract basis for an implementation, a formal representation of all possible spatial situations with the help of wayfinding choremes is reasonable. Therefore I will first adapt the wayfinding choreme theory to be a context-free and deterministic formal grammar that produces a language containing all possible strings composed of wayfinding choremes.

In the first step, a basic grammar useable to generate any string composed of the basic set of wayfinding choremes is introduced. Afterwards the set of productions will be extended by rules to generate functional equivalent and different wayfinding choremes according to the approach introduced in section Existing Approach for Term Rewriting3.3.5.2. Section 3.3.6.4 modifies these productions to realize the representation of decision points in the taxonomy of landmarks. Finally an extension of the rules to special concepts will be presented.

3.3.6.1 Basic Grammar

The importance of a modality-independent representation of wayfinding choremes has already been discussed. A representation providing the basis for modality-specific externalizations (for example graphical or verbal route directions) is needed.

The formal grammar $WCRG = (N, T, P, S)$ is a 4-tupel representing wayfinding choremes containing

- A finite set N of non-terminal symbols
- The alphabet T with terminal symbols, for the wayfinding choreme grammar in its very basic form. In our case this is the basic set of wayfinding choremes $T = \{wc_{sr}, wc_r, wc_{hr}, wc_s, wc_{hl}, wc_l, wc_{sl}\}$
- A finite set P of term-rewriting rules
- A subset of the set of non-terminals representing the start symbols.

The next step is to define the set of non-terminal symbols and a basic set of productions to convert non-terminal symbols to terminal symbols for getting a valid string. In the very basic version of my grammar I will not allow the chunking of wayfinding choremes to have an easy entry point for the further development. Later I will include the chunking based on the existing grammar. For every terminal symbol I define a corresponding non-terminal symbol and a rule to convert this non-terminal symbol to the corresponding terminal symbol.

$$N = \{S, WC_{SR}, WC_R, WC_{HR}, WC_S, WC_{HL}, WC_L, WC_{SL}\}$$

$$P = \{WC_{SR} \to wc_{sr}, WC_R \to wc_r, WC_{HR} \to wc_{hr}, WC_S \to wc_s,$$

$$WC_{HL} \to wc_{hl}, WC_L \to wc_l, WC_{SL} \to wc_{sl}\}$$

Finally, we need the set of starting symbols. We have to add the additional non-terminal symbol S to the set of non-terminal symbols, because the set of starting symbols must be a subset of the set of non-terminal symbols. To be able to generate every possible route, we also need the following rules:

$$S \to \lambda | WC_{SR}S | WC_R S | WC_{HR}S | WC_S S | WC_{HL}S | WC_L S | WC_{SL}S$$

The term λ represents the so called empty term. The definition of a basic version of the wayfinding choreme route grammar is completed and it is possible to generate every possible route consisting of the basic wayfinding choremes.

$$L(WCRG) = T^*$$

The proof is trivial. The first step is to proof that for every word $u \in L$ a derivation $S \to uS$ exists. A mathematical induction over the structure of the word u will serve as proof.

Base case:
Consider $u = \lambda$. The word λS is creatable by the empty derivation.

$$S = \lambda S$$

Inductive hypothesis:
For the word $u \in L(WCRG)$, uS is creatable by processing the rules of the rule set P.

$$S \overset{*}{\rightarrow} uS$$

Inductive step:
For all $x \in T$, uxS is creatable by processing the rules of the rule set P.

$$S \overset{*}{\rightarrow} uxS$$

According to the rule set there exist derivations for every $x \in T$:

$$\text{For } x = wc_{sr}: uS \rightarrow \mathrm{uWC_{SR}\,S} \rightarrow \mathrm{uwc_{sr}\,S}$$

$$\text{For } x = wc_{r}: uS \rightarrow \mathrm{uWC_{R}\,S} \rightarrow \mathrm{uwc_{r}\,S}$$

$$\text{For } x = wc_{hr}: uS \rightarrow \mathrm{uWC_{HR}\,S} \rightarrow \mathrm{uwc_{hr}\,S}$$

$$For\ x = wc_{s}: uS \rightarrow \mathrm{uWC_{S}\,S} \rightarrow \mathrm{uwc_{s}\,S}$$

$$For\ x = wc_{hl}: uS \rightarrow \mathrm{uWC_{HL}\,S} \rightarrow \mathrm{uwc_{hl}\,S}$$

$$For\ x = wc_{l}: uS \rightarrow \mathrm{uWC_{L}\,S} \rightarrow \mathrm{uwc_{l}\,S}$$

$$For\ x = wc_{sl}: uS \rightarrow \mathrm{uWC_{SL}\,S} \rightarrow \mathrm{uwc_{sl}\,S}$$

This proves that there exists a derivation $uS \overset{*}{\rightarrow} uxS$. According to the hypothesis, there exists a derivation $S \overset{*}{\rightarrow} uS$.

Therefore, a derivation $S \overset{*}{\rightarrow} uxS$ exists.

Every word $u \in L(WCRG)$ can be created by deriving the word uS and applying the derivation $S \rightarrow \lambda$.

3.3.6.2 Productions for Functionally Equivalent Wayfinding Choremes

The chunking of functionally equivalent wayfinding choremes was introduced in the approach by Klippel et al (2005) and will be the first step to improve the formal route grammar introduced in this thesis.

To represent a HORDE that contains chunked functionally equivalent subterms, the grammar will turn context-sensitive. A context-free grammar is defined as having only productions with one non-terminal symbol on the left-hand side of a rule. The rules to combine a sequence of wayfinding choremes to a HORDE have to define more than one non-terminal symbol on the left-hand side. Also attributes for non-terminal symbols have to be added, which are not possible in a formal grammar, whereby the grammar is not really formal anymore, but still a good way to declare the limits of proper words of the language produced by the grammar.

The new terminal symbol named ewc^{nt} has to be created, that represents an equivalent wayfinding choreme of n elements of type t. The type t defines a specific direction; the number n represents the number of chunked terms of the defined type. At this point we do not consider any other criteria, for example, the maximum or minimum number of elements that can be chunked, even if these are important aspects for the cognitive adequacy, as shown in the approach by Klippel et al.

In section 3.3.7 I will introduce the chunking of HORDEs. Therefore a non-terminal symbol as well as a terminal symbol is required for every type of HORDE I will introduce in the next sections. Also an additional rule to transform the non-terminal symbol for the HORDE type to the terminal symbol has to be added to the set of productions. I will not mention this step for every new non-terminal I will introduce in the next sections.

The definition of a new production turns out to be more difficult than the definition of the symbols. Theoretically we have to define one production for every type of wayfinding choreme and every possible number of symbols on the left hand side as well as one terminal symbol ewc^{nt} and non-terminal symbol EWC^{nt} on the right hand side where n shows the number of non-terminal symbols on the left hand side. To make it more concise, the following more abstract rule that is normally not possible in a formal grammar has been defined:

$$\underbrace{(WC_T \ldots WC_T)}_{n} \rightarrow EWC^{nT}, WC_T \in N\backslash\{S\}; n \in \mathbb{N}$$

This rule represents all possible sequences of functionally equivalent wayfinding choremes on the left hand side and transforms them to the according HORDE.

3.3.6.3 Productions for Functionally Different Wayfinding Choremes

Next we will chunk functionally different wayfinding choremes according to the approach by Klippel et al. To illustrate the chunking of functionally different wayfinding choremes we use the already illustrated example chosen for the introduction to this section as cognitively ergonomic route instruction “Turn left at the third junction”. To achieve this instruction as the result of chunking wayfinding choremes, the substring WC_S, WC_S, WC_L has to be transformed to a HORDE. Analogous to the chunking of functionally equivalent wayfinding choremes, the formal productions to chunk functionally different wayfinding choremes are initially made without taking cognitive adequacy into account.

According to the rules introduced by Klippel, an arbitrary number of wayfinding choremes of the same turning direction must be followed by a wayfinding choreme of another turning direction. The turning directions are not fixed as STRAIGHT. Thereby the formal definition is not restricted to combining just STRAIGHT wayfinding choremes with another direction. Sense or nonsense of this option from a cognitive perspective does not matter at this point and will be discussed later.

The new non-terminal symbol DWC_u^{nt} represents a HORDE combining functionally different wayfinding choremes, whereas n wayfinding choremes of turning direction t are combined before reaching a decision point with the turning direction u.

The production is defined analogous to the production for equivalent wayfinding choremes:

$$\underbrace{(WC_T \ldots WC_T)}_{n} WC_U \rightarrow DWC_U^{nT}; WC_T, WC_U \in N\backslash\{S\}; WC_T \neq WC_U; n \in \mathbb{N}$$

The representation of HORDEs combining functionally different wayfinding choremes with an unmistakably identifiable decision point as destination will not be attached in this section; the next section will granulate the resulting HORDEs according to the opportunities given by distinguishing several different types of salient decision points based on the taxonomy of landmarks.

3.3.6.4 Productions for Wayfinding Choremes as Landmarks

In the development of the wayfinding choremes route grammar the next step is to combine the grammar introduced in the previous sections with the data structure of decision points described in section 2. Some of the described decision point types are already covered by the work I have done so far, for example, the point-like decision points without any further saliency. The structure does not vary from functional different wayfinding choremes as introduced in section 3.3.6.3.

Decision points that are more conspicuous because of salient objects like buildings — General Salient Objects (GSO) in the landmark's taxonomy — must have one additional attribute compared to decision points without any salient attribute. They have to provide information that the last decision point is located at a GSO. Due to the fact that decision points heading to this landmark do not have to have the direction STRAIGHT, instructions like "Keep turning half left until you reach the stadium" are imaginable. I will add the new non-terminal symbol LWC_{ul}^{t}, whereas the $l \in L_{GSO}$ is just a placeholder for semantic information about the landmark. The set L will be defined as the set containing all possible landmarks. The set $L_{GSO} \subseteq L$ defines all possible GSO landmarks.

$$\underbrace{(WC_T \ldots WC_T)}_{n} WC_U^{l} \rightarrow LWC_{Ul}^{T}; WC_T, WC_U \in N \backslash \{S\}; l \in L_{GSO}; n \in \mathbb{N}$$

To fulfill all categories of 1-element decision points, decision points with a special structure have to be handled. For HORDE identified by a prominent structure, the set of non-terminal symbols is extended by the new symbol SWC_{us}^{t}. This wayfinding choreme combines decision points with the turning direction t until reaching a wayfinding choreme with the special structure s that turns to the direction u. The symbol $s \in ST$ is a placeholder to store semantic information about the structure. The set ST will be defined as the set containing all possible structures.

A structure $s \in ST$ is defined as set of sets of possible branch configurations. The structure for a T-intersection, for example, would be defined as follows:

$$s = \{\{WC_L, WC_R\}, \{WC_{SL}, WC_{HR}\}, \{WC_{HL}, WC_{SR}\}\}$$

For a T-intersection the structure must contain all sets of each two directions that have an angle of approximately 180° to each other, because of the definition of a T-intersection in human conceptualization. For other structures, for example a roundabout, the set of possible directions depends on the branches the roundabout has.

The new production equals the production for wayfinding choremes at GSOs.

$$\underbrace{(WC_T \ldots WC_T)}_{n} WC_U^{s} \rightarrow SWC_{Us}^{T}; WC_T, WC_U \in X; X \in s, s \in ST; n \in \mathbb{N}$$

Now the productions for n-element decision points are missing, but they are also very similar to the productions for the definition of GSO decision points. The major differences are that all decision points have to be located at a specific line- or area-like shaped landmark, e.g. a river or a forest, but the turning concept is irrelevant. For clarity, a new non-terminal symbol will be introduced to represent this kind of HORDEs. $NLWC_{ul}^{m}$ represents an n-element landmark decision point located along, inside etc a landmark $l \in L_{Area} \cap L_{Line}$, until reaching a wayfinding choreme unmistakably identifiable by $m \in L_{GSO} \cap ST$. The sets $L_{Area} \subseteq L$ and $L_{Line} \subseteq L$ represent the subset of line-like landmarks and area-like landmarks respectively.

$$\underbrace{(WC^{l} \ldots WC^{l})}_{n} WC_U^{m} \rightarrow NLWC_{Ul}^{m}; WC, WC_U \in N \backslash \{S\};$$
$$l \in L_{Area} \cap L_{Line}; m \in L_{GSO} \cap ST; n \in \mathbb{N}$$

3.3.6.5 Productions for Special Concepts of Wayfinding Choremes

The formal definition of terminal symbols and productions to enable special concepts are not simple, because a special concept can have an arbitrary structure. To put it in a nutshell, everything must be possible. The formal definition for the production to generate HORDEs representing special concepts allows everything, because currently cognitive adequacy is not taking into account. The new non-terminal symbol $SPWC$ does not have any specific attributes, every special concept must have their own attributes and descriptions what it does and is.

$$WC^* \rightarrow SPWC; WC = N \backslash \{S\}$$

3.3.7 Chunking of HORDEs

The previous section developed a formal representation to chunk wayfinding choremes contained in the basic set of wayfinding choremes. By an explicit definition of a production set that takes cognitive adequacy into account based on the formal representation, it is possible to reduce the number of instructions and replace them by more cognitive instructions that reduce the cognitive load for travelers. But not only the wayfinding choremes of the basic set shall be chunkable, also the already chunked wayfinding choremes, the HORDEs, can be chunked themselves to more complex HORDEs.

Chunking of already complex instructions might seem to be not effective and even confusing for the traveler. A reasonable application for the chunking of HORDEs is the improvement of the cognitive ergonomy for verbal instructions. For example, a route string contains a sequence of the instructions: “Turn left at the third intersection”. The second instruction could be cognitively enhanced by changing it to “Turn left at the third intersection again”. The small word “again” might not change the sentence enormous, but reduces the cognitive load of the traveler because performing an already known action is easier. The small word “again” reminds the traveler that the instruction has been performed already before.

Nevertheless, the chunking of HORDEs does not make sense for every sequence of HORDEs and not even for every kind of HORDEs. HORDEs should be the most complex elements and generated in the first step out of the basic set of wayfinding choremes. But chunking the repetition of the same HORDE appears to be useful.

I will not survey more recursions of chunking HORDEs, even if it is probably possible to find use cases where it would make sense and even improve the cognitive ergonomic of wayfinding choremes.

Functionally equivalent and functionally different chunking of HORDEs will be separately embedded to the formal grammar. The definition of functionally equivalent and different HORDEs goes along with the definition for basic wayfinding choremes.

Functionally equivalent chunked HORDEs are represented by the terminal symbol $hewc^{nt}$, whereas n represents the number of chunked HORDEs and t the type of chunked HORDE. Functionally different chunked HORDEs are represented analogous to functionally different wayfinding choremes as $hdwc_u^{nt}$. The productions are defined analogous to the production to chunk wayfinding choremes contained in the basic set.

$$\underbrace{(WC_T \ \ldots WC_T)}_{n} \rightarrow hewc_T^n; WC_T \in \{EWC, DWC, LWC, SWC, NLWC, SPWC\}; n \in \mathbb{N}$$

$$\underbrace{(WC_T \ \ldots WC_T)}_{n} WC_U \rightarrow hdwc_U^{nT};$$

$$WC_T, WC_U \in \{EWC, DWC, LWC, SWC, NLWC, SPWC\};\ n \in \mathbb{N}$$

3.3.8 Prioritization of Productions

The definition of the formal grammar for wayfinding choremes is complete. The rules for term rewriting are the productions of this formal grammar. Unfortunately, the productions of a formal grammar are defined in a set and a set does not have an order and therefore the production to be performed is chosen randomly. A prioritization to prefer certain rules is not possible without losing properties of a formal grammar.

A prioritization is important to fulfill one of the major aspects of this approach, cognitive adequacy. Productions that chunk, for example, functionally different wayfinding choremes should be favored over chunking functionally equivalent wayfinding choremes. A small example shows the importance of this prioritization to achieve cognitive adequacy. Let $R = WC_S WC_S WC_S WC_L$ be a string of wayfinding choremes representing a route. A rule would match to chunk $WC_S WC_S WC_S$ as functionally equivalent wayfinding choreme as well as another rule matches $WC_S WC_S WC_S WC_L$ as functionally different wayfinding choreme. It is desirable that the second case is favored and the string R would be transformed to $R = DWC_L^{3S}$ instead of $R = EWC^{3S} WC_L$.

One way of prioritization is to take the order of definition. The single rules would be executed on the route string in the order of definition. Many problems are already solved by this simple approach. To offer the highest flexibility, a specific and individual prioritization for every single rule must be possible. With this procedure more than one rule can have the same priority, in the case of a wanted equalization of rules.

Every rule gets an individual rating. The rating consists of a number. The rule with the highest number will be favored. If there is more than one rule with the same rating, the applied rule will be chosen randomly. The priority of a rule will be displayed above the production arrow as a symbolic barrier. Only the arrow with the highest number can be passed.

$$n \overset{p}{\rightarrow} t \,; n \in N, t \in T, p \in \mathbb{N}$$

3.4 Production Sets

The Wayfinding Choreme Grammar consists of one set of productions with term rewriting rules. In the formal representation the set of rules is defined very abstract and thousands of different configurations are possible. Different configured sets can be defined for different purposes. Also different E-wayfinding choremes of the same I-wayfinding choremes may need different rules for term rewriting. But executing the rules does still generate representations based on the I-wayfinding choreme route grammar. Each different transformation of the route string is striving different purposes.

The approach of cognitive ergonomic route instructions targets the transformation of route strings to become as cognitive ergonomic as possible. Cognitive ergonomy can be interpreted in as much different ways as sets of productions are generable. Whether a set of productions is cognitively ergonomic strongly depends on personal affectations of the creator. A more detailed description of my understanding of cognitive ergonomy will be given in the next section. Based on this information one set of productions will be introduced to transform any route string to become as cognitive ergonomic as possible.

3.4.1 Cognitive Ergonomy

What is a cognitively ergonomic route string? This is the first question the developer of a production set for the wayfinding choreme route grammar should ask himself. Cognitive ergonomy strongly depends on personal influences and understandings. Many small and apparently unimportant aspects have to be considered in any decision for every rule. Some examples shall illustrate which questions and decisions can be important.

Cognitively ergonomic route instructions are imaginable as human descriptions of reaching a point B from a point A. The goal when modeling the rules for the wayfinding choreme grammar have to be to transform single wayfinding choremes to as large chunks a human would use for his description of a route.

The first example is the generation of rules to chunk functionally equivalent wayfinding choremes. There is a correlation between type and number of wayfinding choremes that shall be chunked. The number of decision points to chunk to one functionally equivalent wayfinding choreme for the turning direction STRAIGHT obviously differs from the number of decision points with other turning directions. To chunk 4 or more LEFT or RIGHT decision points, for example, does not make much sense in human conceptualization. After turning left the fourth time, in human conceptualization the traveler reaches the same point again. Chunking four or more STRAIGHT decision points on the other hand generates cognitively reasonable chunks. Still, even the maximum number of STRAIGHT chunks is arguable. How cognitive it is to chunk 10 or more wayfinding choremes is questionable.

If a decision point is unambiguously identifiable, for example the next T-intersection on the route, the STRAIGHT decision points should not be chunked to functionally equivalent wayfinding choremes. This is the point where the prioritization of rules has to take place. The prioritization must be deliberated to avoid the opportunity of more cognitive ergonomic results but also try to avoid single decision points that may have been combined when using another order of rule execution.

These are just two aspects worth considering when developing production sets. More aspects will be introduced while introducing one complete set of productions in the next section.

3.4.2 Productions

This section will give an example for a set of productions that transforms strings consisting of the basic set of wayfinding choremes to HORDEs to make the route instructions more cognitively ergonomic. The rules are defined according to the formal definitions in section 3.3.6. The order of definitions is according to the prioritization of the rules described in section 3.3.8.

The first pair of rules chunks two or three wayfinding choremes of any direction of the turning concepts STC, MTC or NTC to an according functionally equivalent wayfinding choreme. These rules have the lowest prioritization, whereas chunking three basic wayfinding choremes is favored over chunking two wayfinding choremes.

$$\underbrace{(WC_T \ldots WC_T)}_{n} \xrightarrow{n-2} EWC_T^n, WC_T \in \{WC_{SR}, WC_R, WC_{HR}, WC_S, WC_{HL}, WC_L, WC_{SL}\}, n \in \{2,3\}$$

A further chunking of wayfinding choremes containing the turning concepts STC and MTC does not make sense anymore to improve cognitive ergonomy in my opinion. Chunking sequences of wayfinding choremes representing straight on the other hand should be handled by further rules. Therefore two more rules to build HORDEs from sequences of 4 or 5 wayfinding choremes heading straight are defined with corresponding priorities to prefer the chunking five over four primitives. To compress more than 5 instructions into one single instruction does not make sense anymore in my opinion. It is cognitively plausible to let a traveler count from 2 or up to 5 intersections, but more will confuse the traveler more than helping him.

$$\underbrace{(WC_S \ldots WC_S)}_{n} \xrightarrow{n-2} EWC_S^n, n \in \{4,5\}$$

The next four rules combine between one and four wayfinding choremes which leads the traveler straight, before reaching a decision point where a turning action has to be performed. The prioritization goes along with the prioritization rules for generating functionally equivalent wayfinding choremes, as the more STRAIGHT wayfinding choremes lead the turning wayfinding choreme, the higher is their priority. But all rules are ranked higher than any rule introduced before.

$$\underbrace{(WC_S \dots WC_S)}_{n} WC_T \xrightarrow{n+3} DWC_T^{nS}; WC_T \in \{WC_{SR}, WC_R, WC_{HR}, WC_{HL}, WC_L, WC_{SL}\}, n \in \{1..4\}$$

The next higher ranked and, therefore, higher prioritized rules are reserved for combinations of leading STRAIGHT wayfinding choremes followed by a decision point located at a landmark. Here the number of leading STRAIGHT wayfinding choremes has been increased to 6, because the number will not be used in the resulting instructions anymore. It is completely satisfactory for the traveler to get the instruction “Turn left after the church on the right side”, how many intersections he has to pass in the mean time is irrelevant. Anyway I define a limit of 6 leading straight wayfinding choremes, because the traveler might get impatient when he gets an instruction and no church appears for 10 intersections. In the case of landmarks the last decision point can also direct straight, the instruction “Follow the road until you have reached the church on the left side” is more cognitively adequate than the instruction “Follow the road for the next three intersections”.

$$\underbrace{(WC_S \dots WC_S)}_{n} WC_T^l \xrightarrow{n+7} LWC_{Tl}^S; WC_T \in \{WC_{SR}, WC_R, WC_{HR}, WC_S, WC_{HL}, WC_L, WC_{SL}\},$$
$$l \in L_{GSO}, n \in \{1..6\}$$

For decision points that stand out because of their shape, like for example roundabouts or T-intersections, I need to define the possible turn direction configurations of the corresponding structure. For T-intersections I have to distinguish three cases, characterized by an angle of approximately 180° of its two branches: left and right, sharp left and half right as well as sharp right and half left. The argumentation for the maximum number of decision points with a turning direction STRAIGHT leading to this special shaped junction is the same as for decision points located at a landmark.

$$s_T = \{\{WC_L, WC_R\}, \{WC_{SL}, WC_{HR}\}, \{WC_{HL}, WC_{SR}\}\}$$
$$\underbrace{(WC_S \dots WC_S)}_{n} WC_U^{s_T} \xrightarrow{n+7} SWC_{Us_T}^S; WC_U \in X, X \in s_T; n \in \{1..6\}$$

This set of productions will also declare the shapes roundabout and fork as salient structures. The rules do not differ from the rules for T-intersections. For a fork-shaped intersection I obtain the same restrictions for possible turning directions. A fork intersection is defined as an intersection with two branches, one directs half left and one directs half right. Due to that, these are the only possible turning directions for the last decision point.

$$s_{Fork} = \{\{WC_{HL}, WC_{HR}\}\}$$
$$\underbrace{(WC_S \dots WC_S)}_{n} WC_U^{s_{Fork}} \xrightarrow{n+7} SWC_{Us_{Fork}}^S; WC_U \in X, X \in s_{Fork}; n \in \{1..6\}$$

The rule for roundabout structures is analogous, but they depend on the roundabout. Different structures representing roundabout can be defined. The possible branch configurations depend on the branches the roundabout is leaving.

The last type of landmarks is the n-element landmark. This means, a sequence of decision points is located along, inside, etc. a landmark that has an area- or line-like appearance. The turning directions of the chunked wayfinding choremes do not matter in this case, because the traveler has to follow the course of the landmark. The last decision point where the route directs away from the landmark must be unambiguously identifiable by its structure or by another landmark located at it.

$$(WC^l \dots WC^l)WC_U^m \overset{14}{\rightarrow} NLWC_{Ul}^m; WC, WC_U \in \{WC_{SR}, WC_R, WC_{HR}, WC_S, WC_{HL}, WC_L, WC_{SL}\};$$
$$l \in L_{Area} \cap L_{Line}; m \in L_{GSO} \cap ST$$

As special concepts I have decided to pick the so called p or q-turn, also introduced by Klippel and his coworkers (Klippel, Tappe, Kulik, & Lee, 2005). This turn has to be performed whenever the traveler is not allowed to turn left or turn right respectively. In this case the traveler has to go straight and turn three times to the opposite direction to go straight over the junction he was not allowed to turn at. Figure 3-6 shows a p-turn, whereas the shape of this part of a route can be seen as a p. The q-turn on the other hand is when the traveler is not allowed to turn right.

$$WC_S WC_T WC_T WC_T WC_S \overset{22}{\rightarrow} SPWC; WC_T \in \{WC_L, WC_R\}$$

My last rule handles the chunking of HORDEs. Any sequence of functionally equivalent HORDEs will be chunked. I have limited the maximum length of the sequence to seven, because the chunking of HORDEs just enables for the output to add words like “again” to the instructions to ease them in a cognitive manner. The priority is very low and increases with the number of HORDEs in a sequence. The priorities are all lower than the priorities of chunking functionally different wayfinding choremes. This assures that the biggest sequences of functionally equivalent HORDEs have been created before the HORDEs are chunked.

$$\underbrace{(WC_T \;\dots WC_T)}_{n} \xrightarrow{2-n} HEWC_T^n; T \in \{EWC, DWC, LWC, SWC, NLWC, SPWC\}, n \in \{2..7\}$$

4 Implementation Data Structure and Choreme Parser

The approaches of the wayfinding choreme route grammar and of a decision point structure based on the taxonomy of landmarks offer a good basis for the representation and optimization of cognitively ergonomic route directions. Now both theoretical approaches have to be implemented.

For the implementation the Sun Java[2] Toolkit for Connected Device Configuration (CDC) 1.0[3] has been chosen due to the following two major reasons. First, Java is a platform independent language and therefore executable on various systems. Second, CDC is designed for both mobile and consumer devices that have faster CPUs and more memory than typical wireless devices. It is a slimmed version of the Java Standard Edition 1.4.2 and is executable on desktop PCs as well. Hence, the implementation of the approaches is usable on mobile devices as well as desktop PCs.

This section will also introduce an editor to generate and modify production sets that can be used for a user-specific execution of the term rewriting for the optimization of wayfinding choremes. The editor is runnable on normal desktop PCs and uses the latest Java Standard Edition 1.6.0[4]. User of the term rewriting module can generate or modify the production sets according to their personal preferences and later upload them to the appropriate device the term rewriting shall be executed.

In the section 4.1 I will give a short overview about the architecture used for the interaction of the different modules of the data structure of decision points, the term rewriting of the wayfinding choreme route grammar and the editor for the generation and modification of production sets for the term rewriting. Algorithms and details of the implementation of the data structure for decision points is introduced in section 4.2 followed by the presentation of the term rewriting module in section 4.3. The final section of this chapter will introduce the basic ideas and highlights of the editor for production sets.

4.1 Architecture

All compontents that are developed for this thesis are supposed to reach one goal, the representation, support and optimization of route instructions based on the wayfinding choreme route grammar. The single packages introduced in this chapter will be independent packages inside a workspace, a library that provides a data structure for decision points, a library that provides the option to customizely optimize a route string and an executable editor for the generation and modification of production sets for the term rewriting library. As a fourth executable module the test module contains runable tests for both libraries. Figure 4-1 shows the basic overview of the single modules and their dependencies.

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[2] Java programming language by Sun Microsystems (http://java.sun.com/)

[3] Sun Java Toolkit for CDC (http://java.sun.com/products/cdctoolkit/)

[4] Sun Java Standard Edition 1.6 (http://java.sun.com/javase/6/)

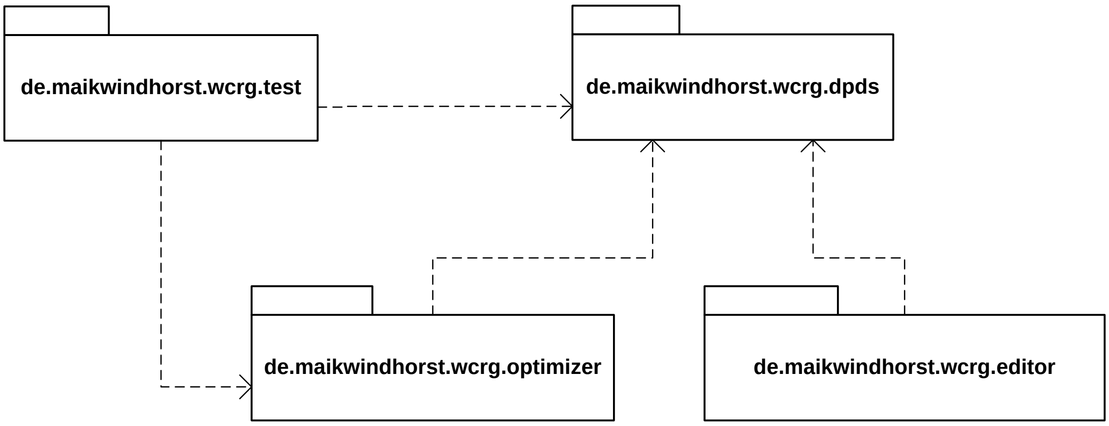


Figure 4-1: Overview package de.maikwindhorst.wcrg and its dependencies

4.2 Implementation of Decision Points

The implementation of the data structure is straight-forwardly done according to the introduced data types in section 2.3. Figure 4-2 shows an overview of the classes of the package of the decision point data structure (dpds).

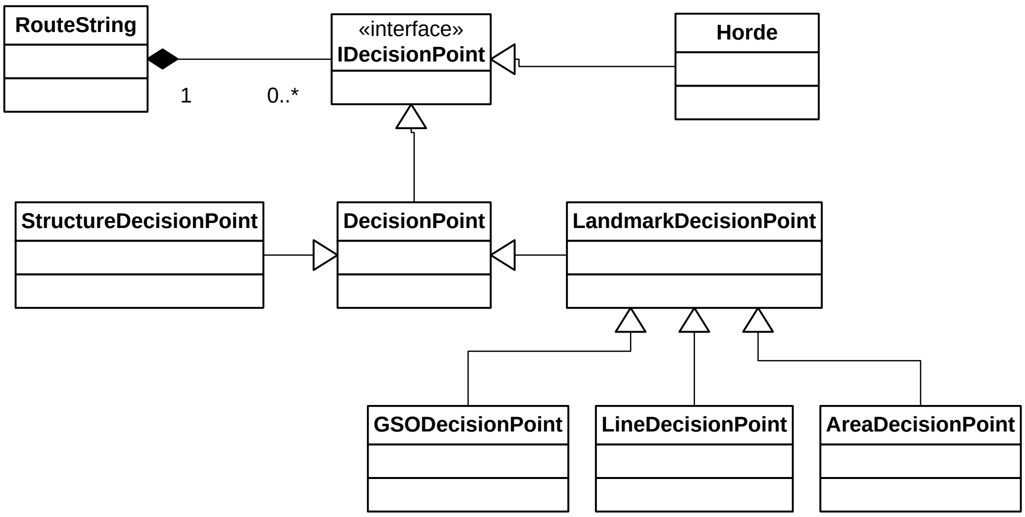


Figure 4-2: Overview package DPDS (decision point data structure)

As we can see, the hierarchical structure shown in Figure 2-1 is not directly translated to a Java class hierarchy. This is caused by the needed information the single classes representing the different types of decision points need. The interface *IDecisionPoint*, for example, represents the root level and the class *DecisionPoint* represents intersections without any other saliency. Also the distinction between decision points with a point-, line- or area-like structure seems to be missing in this structure. For that reason, I have defined additional interfaces; Figure 4-3 shows the complete structure including the interfaces. The reason for this hierarchy is, some types share the same information as others. A decision point, for example, contains all information about the intersection and the direction the traveler has to take at this direction. Landmark decision points also need all this information, but additionally the spatial relation of the object. The same information is needed by GSO decision points, but not for structure decision points. Even both originate from the 1-element decision point in the introduction of the data structure; they cannot derive from the same objects. The structure has to be modeled independent with the aid of interfaces.

The whole data structure holds its information in a generic way. There are no objects with a special structure dictated to use the data structure. Hence, a decision point just stores an object that implements the interface *IIntersection*. This interface constrains the implementation to provide certain methods and constants needed for the use of this data structure to run the optimizer package. For example, a method to get the streets branching from the intersection and their angles according a specific direction is needed. The angles of the branches must be declared in degree of the angle, where 0° stands for back, 90° for left etc. When creating a decision point object, the directions will be converted to the corresponding turn directions and the mapping between angle and turn directions will be stored. This is necessary, because the wayfinding choreme parser only works on turn directions, externalizations like the graphical route direction advices introduced in section 5 will offer the user the opportunity to display the branches of the intersection in turn directions as well as the exact angle. For the conversion, branches with, for example, an angle between 68 and 112 will be mapped to the turn direction left. When two angles are mapped on the same turn direction, the closer branch to the direction will be chosen and the other will be mapped on the next nearest turn direction.

This kind of interface has also been used to realize the ideas introduced in section 2.3. To distinguish decision points located at a GSO on the basis of the category of the GSO. Therefore, the interface *IGsoLandmark* requires a certain method to retrieve the category. Hence, the specific structure of the objects stored in the data structure is completely customizable by the user of the framework.

Due to the fact that the categories of the GSOs and also structures that are denoted as salient must store certain information and must be comparable for the optimization process, the two special interfaces *ICategory* and *IStructure* must be implemented by categories and structures. A category must be unmistakably identifiable and must therefore provide an ID. A structure on the other hand is more complex, it must provide its possible branch configurations. A T-intersection, for example, only allows the branch configurations left and right, half left and sharp right and half right and sharp left. A structure must implement the appropriate interface and provide this kind of information.

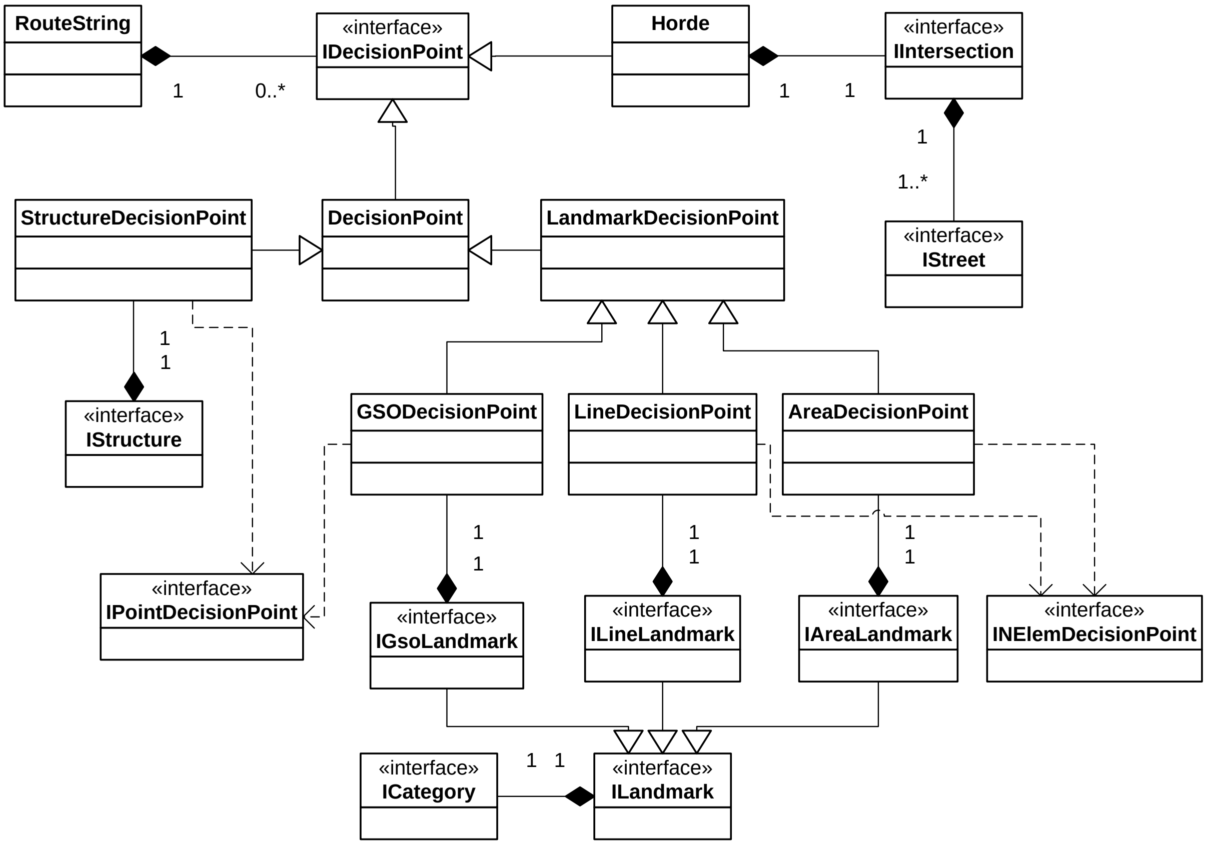
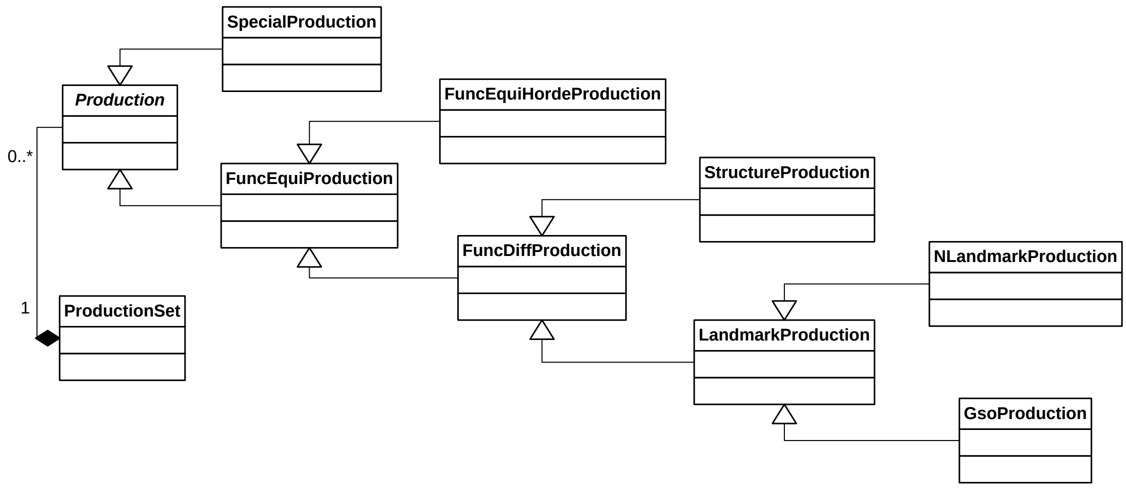


Figure 4-3: Overview of the package DPDS with Interfaces

One of the users of structures and categories and therefore provider of implementations of the interfaces is the optimization package introduced in section 4.3. All possible types of structures and categories are provided in an external XML file which contains the production set that is used to perform the term rewriting process. This is necessary, because user specific production sets can only contain rules that are pointed to specific categories or structures, when these structures are also defined in the specific production set. Otherwise, categories and structures cannot be unmistakably identifiable.

4.3 Implementation Term Rewriting

The package *optimization* that contains the data structure and execution of the term rewriting process is split into two sub-packages. The package *productions* contains a data structure for all types of rules introduced in the formal grammar in section 3.3.6. Figute 4-4 shows an overview of this package and its hierarchy.



Figute 4-4: Hierachical overview of the *productions* package

By taking a closer look on the algorithm of the rule execution the hierarchical structure of the package offers many advantages. A *ProductionSet* contains an arbitrary number of productions. A method call starts the execution of the term rewriting process based on the rules in the production set. The passed string will be parsed in the sequence of the priorities of the rules. Each production class itself contains a method named *perform*, which overrides the method of the parent class. To perform the rule of a specific class often contains exactly the same steps as to perform a rule of the parent class. For example, if a functionally different rule shall be executed, the first step is to search for a sequence of functionally equivalent wayfinding choremes and this sequence must be followed by a choreme of another turn direction. The functionality to identify a sequence of functionally equivalent wayfinding choremes already exists in the functionally equivalent production and can be used. The functionally different production only has to implement the steps of the functionally different part.

This chain can be continued through the whole inheritance hierarchy. A landmark production, for example, has to find a functionally different sequence and a landmark has to be located at the last decision point of the found sequence.

The inheritance structure is not only useful for the execution chain of the production; it is also well suited for the information needed to be stored in a production. The class *Production* stores the common information every production has to have, like the priority, the minimum and maximum count of choremes to chunk and the turn directions that are allowed to chunk. This also shows the abstractness of the rule implementation. For example, the user wants to define rules that chunk up to five and at least three straight, left or right choremes and all of them have the same priority. The abstractness of the rules allows covering all 9 cases with one rule. All productions only add the information needed that is not provided by the parent class.

The second package of the *optimize* package is named *parser* which contains an XML parser to read production set specifications of a XML file. Since not every user of the WCRG framework might be capable of coding Java and it is also not very comfortable to change the source code to change production sets, I have developed a XML format for productions. It is possible to define any kind of rules within this XML format in a normal text editor or with the aid of the production set editor introduced in section 4.4.

Obviously, a parser is needed to read the information saved in the XML file that generates the appropriate executable production set. Unfortunately, the CDC toolkit used for the implementation does not have any XML support as the Java standard edition does. Hence, I use the

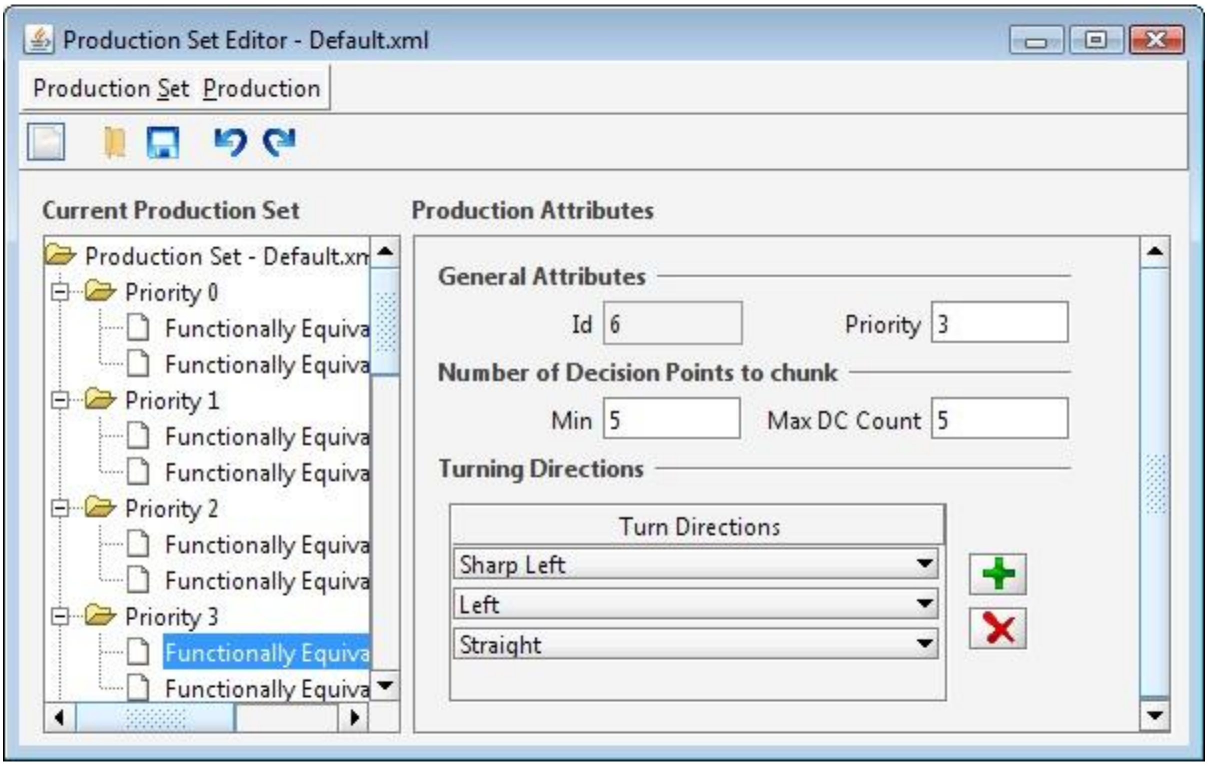
XmlPull parser provided by the kXML project[5], a free Java library developed for the use on mobile devices.

Section 4.2 already mentioned the need of gaining information about used structures and categories of GSOs of the same source as production sets. Therefore, the additional type parser based on the XMLPull parser is provided by this package. The type parser is a kind of preparser to the production set parser. It reads the information about the used structures and GSO categories from the XML file and provides this information for the production parser.

4.4 Implementation of the Production Editor

For the personalized use of the term rewriting tool as described in section 4.3 customized for different user groups according to their preferences of which decision points shall be chunked, different sets of productions are necessary. The production sets are stored and provided for the use with the term rewriting library in a XML format. Even XML is a very simple format it might not be understood by everybody who wants to generate production sets. To edit the XML files in a standard text editor tool is also not very comfortable and does not prevent errors within the structure of the XML file. Errors in the XML structure might cause errors while executing the term rewriting library.

Therefore I have implemented a production editor. The production editor is an application for desktop PCs that allow the user to create new production sets or load and edit existing production sets. Picture 4-5 shows a screenshot of the production editor.



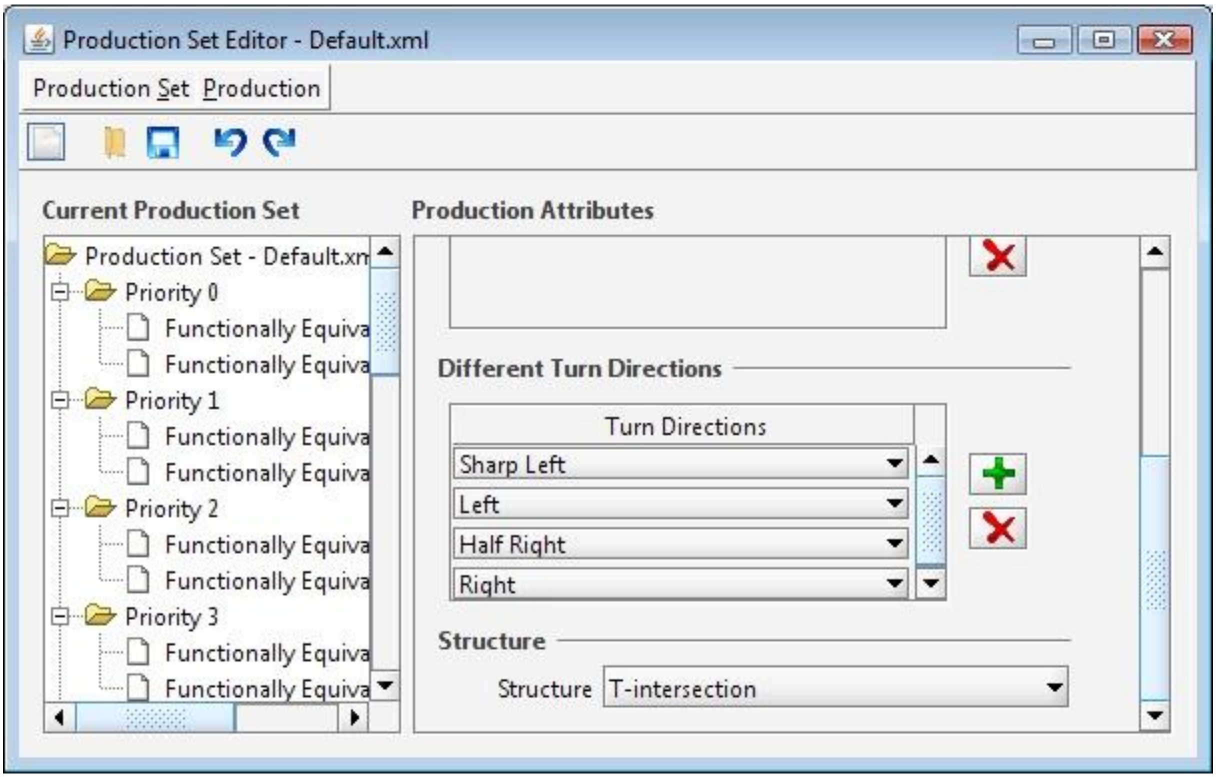
Picture 4-5: Screenshot Production Set Editor

The screenshot shows the loaded production set *Default.xml*. On the left side all productions sorted by its priorities are listed in a tree view. On the right side the selected production with the id 6 is shown. As visible in the tree view the production has the priority 3. When changing the priority, the tree view is updated automatically. The selected production is a functionally

[5] kXML Porject (http://kobjects.org/kxml/)

equivalent production. All other attributes of a production of type functionally equivalent as described in section 3.3.6.2 are also displayed and are changeable.

All attributes which can have more than one value, for example the turn direction, are displayed in small tables filled with drop down boxes. A add and delete button offer to add an additional direction or remove the selected one respectively. Picture 4-6 shows a screenshot of the production editor and the additional attributes that are needed for a structure production as described in section 3.3.6.4. A structure drop down button is available where the structure can be chosen. Only structures which are defined in the type's file of the production set as described in section 4.3 can be chosen. Every structure allows only particular different turn directions according to the possible branch configurations the structure describes. Therefore, only the possible directions can be chosen with the drop down buttons. If the user removes one particular direction, all other directions will be removed that does not fit the possible branch combinations of the structure anymore. If a direction is added, all additional directions will be added automatically that are needed to have a complete branch configuration.



Picture 4-6: Screenshot Production Set Editor with selected structure production

The screenshot shows an example where the selected structure is looking for decision points with the structure *T-intersection*. The turn directions Sharp Left, Left, Half Right and Right are selected as turn directions. When changing one of the directions, the drop down menu will only show the direction Half Left and Sharp Right, because the combination of these two directions is the last possible combination of branches representing a T-intersection. If the user selects Half Left for the drop down button where Left is selected now, the direction Right will be removed and the direction Sharp Right will be added automatically. All these mechanisms predict unwanted mistakes within the production set.

Two other features worth mentioning are the undo and redo functionality as well as a functionality to prevent an unwanted loss of data when the user has forgotten to save his production set. The undo functionality offers the user to undo his last 22 actions. The redo functionality offers to redo all undone activities on the current production set respectively. To prevent the user from losing data because he has forgotten to save before, for example, creating a new production set or closing the application, the save status of a production set is stored and a reminder to save or discard the changes is given to the user before the production set will be closed.

To put it in a nutshell, the production set editor is a useful tool to create or change production sets with the security for the user to get a valid production set usable with the term rewriting library.

5 Cognitively Adequate Route Information Externalizations

With the wayfinding choreme route grammar I have introduced a conceptual structure from which arbitrary external representations of route information originate. This section introduces some existing approaches of cognitively adequate externalizations. First, I will discuss the advantages of schematic maps for external representations of route information in section 5.1. Afterwards, section 5.2 takes a closer look at the toolkit approach by Tversky and Lee (1999) and the approach of aspect maps by Berendt, Barkowsky, Freksa and Kelter (1998) in section 5.3 will give a short overview about another existing approach to externalize route information. A comparison of these approaches with the approach of the wayfinding choremes by Klippel (2003) in section 5.4 shows the differences between focusing on structural and functional aspects. The approach of chorematic focus maps by Klippel and Richter (2004) will introduce in section 5.5 one way to use wayfinding choremes for an externalization of route information.

In section 5.6 I will discuss the different modalities usable to present route information on different devices and argue for my choice of the graphical wayfinding choreme advice theory which will be introduced in section 5.7.

5.1 Topographic vs. Schematic Maps

Topographic maps are designed to show the primary geographic characteristics of an environment (for example, shapes of land and water areas) as precisely as possible (Berendt, Barkowsky, Freksa, & Kelter, 1998). Schematic maps on the other hand intentionally distort spatial knowledge. Examples for schematic maps are sketch maps. Sketch maps reflect the knowledge stored in the human mind, for example, a mental conceptualization.

The distortion of spatial knowledge gains an emergent interest because it enhances many aspects of cognitive science, like the reduction of the cognitive load or enhancing cognitive ergonomy. This fact in turn eases the map reading process especially for people who are not trained in the interaction with maps.

Two major aspects can explain the attractiveness of schematic maps and the interest of cognitive science in them. First, many maps are cluttered with irrelevant information, schematic maps which omit selected data eases the perceptual comprehension. Less visual clutter also intensifies the focus on specific information that is needed to perform specific tasks, like an action that has to be performed at a decision point. Therefore, Freksa (1999) refers to schematic maps as task-specific maps. Second, schematic maps are reflections of human mental concepts. To put it in a nutshell, a schematic map corresponds to human spatial knowledge (internal) as well as to a task-specifically reduced representation of the real world (external). Matching internal and external representations of the environment are much easier for people, especially when they are not trained in interactions with maps, what therefore eases the map reading process (Klippel & Richter, 2004).

5.2 Toolkit Approach

Tversky and Lee (1999) developed the toolkit approach. Section 3.1 has already introduced some of their ideas, for example, that externalizations have a common conceptual ground.

The toolkit approach tries to find the ideal elements for toolkits for verbal and pictorial route directions. The toolkits contain all elements needed to construct route directions, like verbal descriptions or sketch maps.

The idea is based on the work of Denis who designated several components of ideal route directions by analyzing the structure of verbal route directions (Denis, 1997; Denis & Briffault, 1997; Denis, Pazzaglia, Cornoldi, & Bertolo, 1998). Both the traveler and the instructor are located at a designated start point. The following progression starts iteratively. A landmark has to be found, at this landmark the traveler has to perform an action, for example, a change of direction or the continuation in the same direction, which starts the progression again until he reaches the final destination. These three steps do not fit to verbal directions only, they fit to both, pictorial and verbal directions. Both are also composed of the same components: landmarks, orientations and actions. The semantic content of elements of both is similar because the same conceptual information serves as a basis.

Tversky and Lee discovered differences between the pictorial and verbal direction elements. For the different types of components, there were always more verbal than pictorial options. Language allows several different ways to express the same action compared to the iconic character of a map. The mapping of a more or less straight line in the real world to a more or less straight line on the paper is natural (Tversky, 1995). Also one depiction often aggregates several meanings which would differ in language, for example, a crossed pair of lines indicates an intersection, a start point and an end point.

The field test by Tversky and Lee (1999, pp. 56-60) has also shown that an incomplete depiction of route directions is sufficient to reach a destination. Even though, much of the necessary information was missing, travelers were able to reach their destination because most of the missing information was implicit, for example, the missing labeling of start and end points. Tversky and Lee based this on the inference rules. The rule of continuity, for example, says, if the start point is missing, it will be the same as the previous end point. Or the rule of forward progression describes situations if two reorientations occur successively, a forward movement will be implied between these two reorientations.

5.3 Aspect Maps

The approach of aspect maps by Berendt, Barkowsky, Freksa and Kelter (1998) originates in the field of artificial intelligence. Aspect maps represent specific knowledge, so called aspects, that is needed for a task in a cognitively motivated level of abstraction. These aspects are extracted from the existing data and grouped in three different types. The distinction contains remaining unchanged knowledge, knowledge that needs to be represented but can be altered in some way and knowledge that can be omitted.

The aspects that are to be depicted are ranked in a depictional precedence (Barkowsky & Freksa, 1997). Therefore, some of the aspects get depicted in a way such that they are not readable literally from the map anymore. A good example for aspect maps are subway-maps. The direction and distance relations between stations can be distorted. The directions may be hold, for example, in an 8-sector model. The ordering between the different lines on the other hand needs to be preserved, because the map is supposed to provide the user the information about the stations the traveler can reach and how many stations he has to stay in the subway to reach his desired destination. To put it in a nutshell, specific maps need to emphasize information needed to fulfill its disposition.

The criteria described in section 3.1 that characterize a pictorial representation as a map applies to a large variety of representations of spatial information. Two types of geographic maps fall into this class in particular: Topographic maps and thematic maps. As described in section 5.1, topographic maps are designed to show the primary geographic characteristics of an environment. A thematic map on the other hand is designed to show data that is attached to the topographic basis (e.g. demographic information). Obviously, both representations are based on the same data, but different aspects are emphasized or omitted respectively to fulfill their purpose.

Another example for aspect maps are sketch maps as described in section 5.1. All data is omitted that is not needed to serve a certain specific ad hoc purpose. Even though only a few spatial characteristics of the environment are represented which are imprecise to only represent the features they are supposed to show, sketched maps have the same origin of data, whereas the aspects have been chosen to just depict relevant information for a specific task.

5.4 Structural vs. Functional Aspects

When we talk about aspects, an external representation shall emphasize or omit respectively, we can distinguish between structural and functional aspects. The last sections have mostly handled structural aspects.

Most approaches concerning visualization of route information focus on structural aspects, for example, the conceptualization or depiction of objects. The wayfinding choreme theory introduced in section 3 in contrast concentrates on the functional characterization of route information, for example, focuses on actions that demarcate only parts of the physical spatial structure of decision points. Section 3.3.1 illustrated the distinction of structural and functional aspects.

And also aspects to omit or emphasize in maps, such as in sketch maps, have structural and functional intentions. A sketch map that depicts a route from a point A to a point B can omit the correct number of branches a decision point actually has, when the branches that are relevant for the action to perform are illustrated in the map. From the structural perspective, deciding which branches of a decision point are important to sketch is impossible, whereas the functional perspective opens this possibility. The correctness of omitting specific structural aspects when they are used in a functional manner has been shown by field tests for the toolkit approach by Tversky and her coworkers (Tversky & Lee, 1999). They have shown that maps with missing structural information are still useful with the aid of inference rules as described in section 5.2.

5.5 Chorematic Focus Maps

The chorematic focus maps are an approach by Klippel and Richter (2004) that combines two existing approaches of providing graphical route information in a cognitively adequate way. The first approach is the approach of wayfinding choremes by Klippel (2003) that is based on the wayfinding choreme theory presented in section 3. Section 5.5.1 will give a short overview about the aspects used for chorematic focus maps.

The second approach used by chorematic focus maps are focus maps as presented by Zipf and Richter (2002) which will be introduced in section 5.5.2.

Chorematic focus maps are well suited as wayfinding assistance and are generated in four steps. In the first step the route is calculated where also the area is determined that should be most prominent on the map. This step determines which area of the map is needed to depict the route. The second step selects the aspects that are relevant for the given task. The term aspect in chorematic focus maps has the same meaning as in the approach of aspect maps.

After the needed information has been found, a focus map (section 5.5.2) can be constructed to depict them. This is the third step and leads to the final fourth step of replacing functional relevant branches with the corresponding wayfinding choremes (section 5.5.1).

Both, wayfinding choremes and focus maps, supplement each other perfectly. With the aid of focus maps the attention of the user is drawn to the region of interest on the map. Graphical wayfinding choremes on the other hand emphasize the functionally relevant parts of decision points.

5.5.1 Wayfinding Choremes in Maps

Wayfinding choremes are defined as mental conceptualization of primitive functional wayfinding and route direction elements and as the definition shows, the focus is on functional aspects. The major difference, especially of graphical wayfinding choremes, to the toolkit approach (section 5.2) and aspect maps (section 5.3) is the reflection of procedural knowledge, the knowledge about how to interact with the world, and not structural aspects.

The important goal of graphical wayfinding choremes is the combination of prototypical functional and veridical aspects. The action that has to be performed at a decision point is communicated by a prototypical graphical instantiation, which is embedded in veridical spatial situations. Branches that are relevant for performing an action are emphasized whereas irrelevant branches in the veridical structure are deemphasized. Figure 5-1 shows an example for a graphical wayfindning choreme.

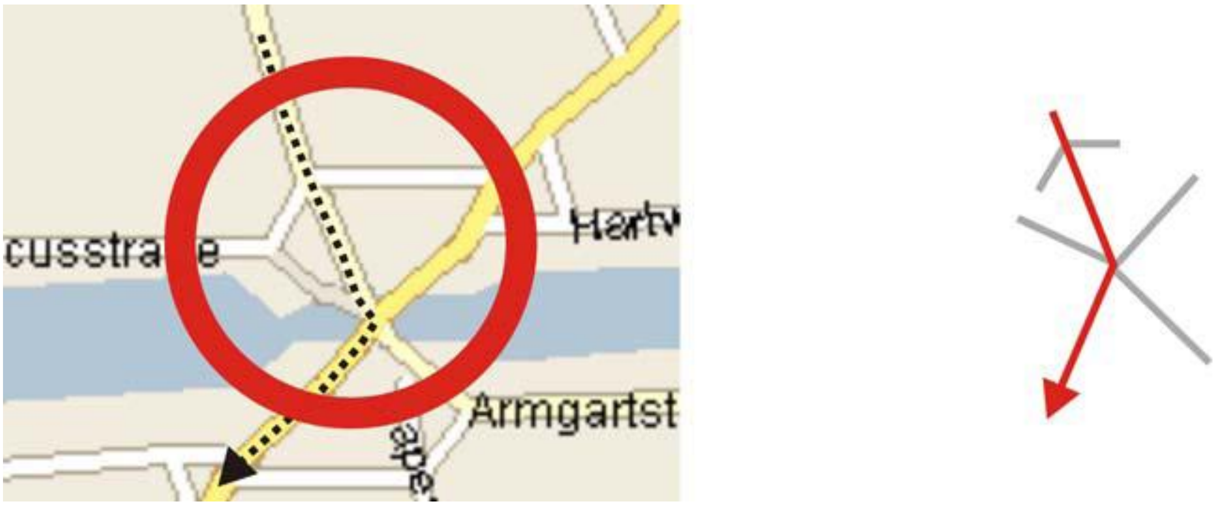


Figure 5-1: Combining prototypical information (wayfinding choremes) and veridical information at decision point (Klippel & Richter, 2004)

5.5.2 Focus Maps

Focus maps are an approach that draws the users' attention towards the regions of interest in a map. Zipf and Richter (2002) use different degrees of generalization and the effect of fading colors to reach this goal. Generalization is a simple but very effective tool; the shapes of objects far off the regions of interest are simplified. Whereas streets, houses or other objects near the region of interest are displayed in full detail, the shapes of buildings or streets far off the region of interest are displayed in a simplified geometry. Additionally, with the fading of colors the attention of the user is funneled to the knowledge needed for a specific task. Figure 5-2 shows an example of a focus map. The focus of the map reader is funneled to the center of the map. The geometry of buildings and other areas around the center of the map are simplified and colors get lighter.

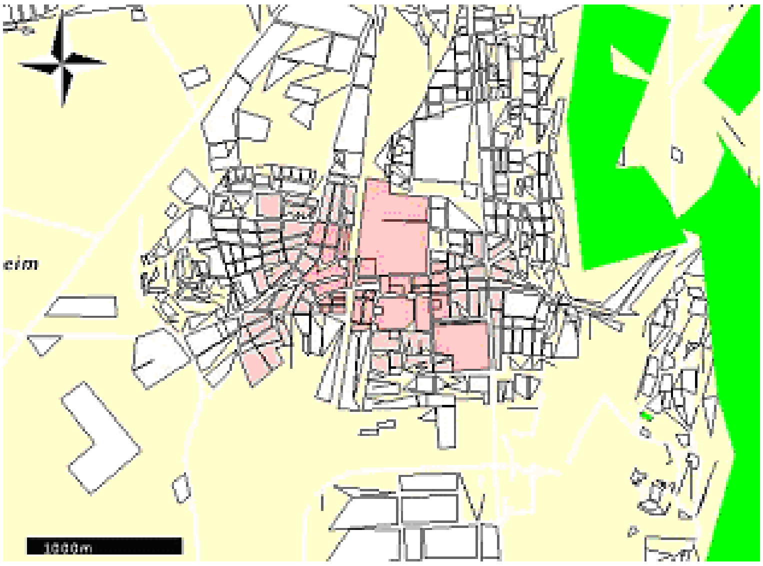


Figure 5-2: Example of focus map (Zipf & Richter, 2002)

With focus maps the users' interpretation process gets focused on the region of interest, which reduces the amount of information to be processed, whereas the rest of the data is still present, for example, for the help of orientation.

Another imaginable application for focus maps is the combination with the approach by Berendt, Barkowsky, Freksa and Kelter (1998). Each map represents entities pictorially or symbolically, it depends on the map type and scale which is predominant. Berendt gives the example of generating a survey map at a smaller scale on the basis of a detailed reference map. Geographic features often have to be grouped and replaced symbolically and that is what focus maps are doing. The amount of symbolic information depends on the prominence of an area. The more focus a specific area shall have, the more pictorial information is used for the representation of this part of the map.

5.6 Modality Selection

Since I want to develop wayfinding assistance for mobile devices, the selection of modality shall be well reviewed. Elting, Zwickel and Malaka (2002) analyzed presentations of information using multiple modalities. They discovered that it has great influence on users' perception, their comfort and their performance using a computer-based information system. For this thesis only the usability of mobile devices matters. They distinguished three types of output, verbal textual, verbal spoken and information shown in pictures. During their empirical study they have detected that the use of a combination of spoken text and pictures is the best for representations on mobile devices, like PDAs. The participants of their empirical study were able to memorize the most information over a long period of time compared with all other combinations (see Figure 5-3). Only the combination of written text and a picture has a better value in one of five timeslots. Also the degree of overload of information was rated better by the users of PDAs for the combination of verbal textual and pictorial information than for the other combinations.

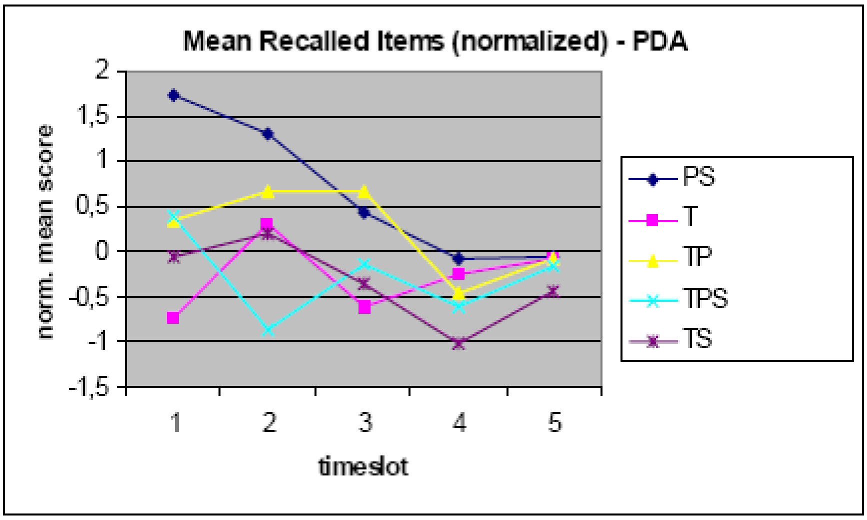


Figure 5-3: Normalized recalled items curves PDA. (P = Picture; S = Speech; T = Text) (Elting, Zwickel, & Malaka, 2002)

These results lead to the choice of a combination of spoken instructions and illustrative figures. Also research work by Freksa (1999) about customized wayfinding support supports the choice of this modality. Verbal descriptions only make sense when the information has to be processed immediately. A written or graphical description, like a sketch map, on the other hand makes more sense when the given information is needed for a longer time and the actions do not have to be performed immediately. Due to the fact that this thesis shall provide tools useable for mobile wayfinding assistance system, a written or depictional description in combination with a verbal, spoken description makes good sense. Pictorial advices give the user an overview about the information needed for the upcoming task; it is displayed after the previous action has been performed. Spoken advices support the focus on new information the moment it is available as well as immediately before a specific action has to be performed. The same tactics is used in actual car navigation systems. A map with highlighted streets of the route is shown next to a small pictorial advice that describes the current action to proceed. Spoken advices are given after the previous action has been performed and before the new decision point is reached.

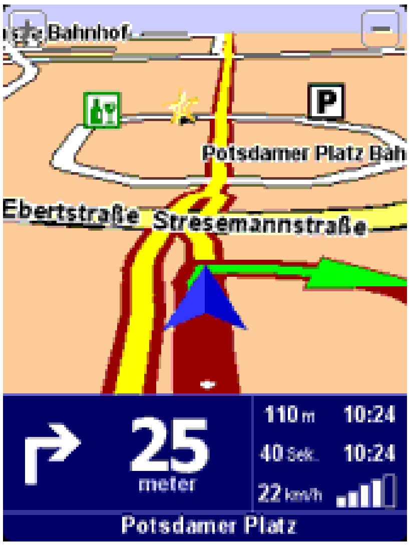


Figure 5-4: Screenshot Tom-Tom Car Navigation System

Figure 5-4 shows a typical example for advices of a car navigation system. The route is highlighted on the map, in the lower left corner a pictorial advice shows a generalized illustration of the action that has to be performed.

5.7 Graphical Wayfinding Choreme Advice Theory

After I have introduced some existing approaches for the graphical representation of route information, this section introduces a theory to provide the user with information about a route based on the wayfinding choreme theory.

Based on the knowledge of the previous section about modalities suitable for mobile information systems, I will develop a theory for graphical advices. It is a common tool in existing wayfinding assistance systems to use a generalized depiction of the directions to follow with the help of arrows. The screenshot in Figure 5-4 shows in its lower left corner a typical advice given by actual wayfinding assistance systems. So far, these advices do not consider many cognitive aspects. The only information that is provided by the advice is to turn right. The graphical advice alone does not provide any information about the decision point this turn has to be performed at. The cognitive load for the traveler would be significantly lowered when the device would provide more information about the decision point, like other streets branching from it. Maybe the shape of the intersection itself is very significant such that it would be easier to identify, like T-intersections. Or a prominent building is located at the decision point and has a specific spatial relation to it. According to all this cognitive easements pointed out during the past sections, I will upgrade current graphical advices by including the aspects of the wayfinding choreme theory.

However, the presented approach of cognitively ergonomic graphical route direction advices should not be used alone for navigation assistance. As described in section 5.6, most useful for mobile assistance systems is the combination of graphical advices and textual spoken advices. This section only describes the approach of graphical advices. The generation of textual advices according to the route direction instructions generated by the wayfinding choreme theory is left for future research.

Due to the fact that the advices will not stand alone, I will give examples during the introduction of the graphical advices where data will be omitted which is supposed to be handled with verbal advices. For example, specific categories of landmarks cannot be included in graphical advices, because of the limited space for the advices. Only a separation between different shapes and a qualitatively correct spatial location of this landmark are relevant for graphical advices. Point-like landmarks should not have the same graphical depiction as line-like or area-like landmarks. A landmark that is located left of a decision point should also be located on the left side in a graphical advice to not confuse the traveler when reading the advice. This, for example, is information transferred with the verbal advice as well; the correct spatial location of the landmark makes sense to be mentioned in both externalizations. Other sttributes, like the shape of a landmark, are transferred in verbal spoken advices indirectly by mentioning the category of the landmark. The category church, for example, implies a point-like landmark; a river on the other hand implies a line-like landmark.

5.7.1 Wayfinding Choreme Advices

The first step is to automatically generate graphical advices for any possible single wayfinding choreme. We have to have the ability to represent single decision points before we can display chunked decision points (HORDEs).

Graphical advices in actual wayfinding choremes only display the turn the driver has to do. Branches that are not involved in the action that has to be performed are not displayed; the user has no information about the real spatial structure of the intersection. Especially for special intersection structures, like T-intersections, this is a loss of information useful for the wayfinder to reduce the cognitive load. Extra information that makes an intersection easier to identify, like landmarks near the decision point, are also not attended in current graphical advises, even a generalized representation of landmarks located at decision points is very useful for a traveler.

For the use of the graphical advices introduced in this paper, the wayfinding application has the choice between a realistic and generalized representation of decision points. The generalized version is restricted to the 8-direction model as the wayfinding choreme theory in this thesis provides. Figure 3-3: Basic Wayfinding Choremes shows the possible directions. Any possible combination of directions describes every possible intersection a framework to display graphical advices must be able to generate. The realistic representation of intersections displays the branches with their real angle.

The graphical advice of a decision point is always oriented according to the direction the traveler is traveling to. The branch the traveler is heading to the decision point is always pointing north.

The next step is to differentiate branches involved in the action that has to be performed at the decision point and branches that are not involved. The focus map approach introduces a simple but effective method, the fading of colors. Therefore, active branches will be printed in black, for inactive a lighter gray has been chosen to gain a big contrast. Also arrowheads will be placed at the end of the branches the traveler has to follow. Figure 5-5 shows a possible representation for an advice of an intersection with 4 branches, for which the corresponding textual advice is “Turn half right at the next intersection”.

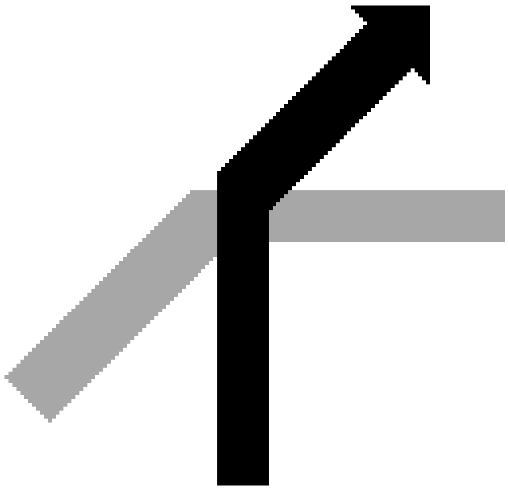


Figure 5-5: „Turn half right at the next intersection“

Now the actual spatial structure is included in the information readable from the advice. The next important step is to integrate the different types of landmarks at the correct spatial location. Figure 5-6 and Figure 5-7 show examples for a point landmark and a line landmark next to a decision point. For area-like landmarks where the decision point has the spatial relation “inside”, the background color will be colored lightly with an identifying color.

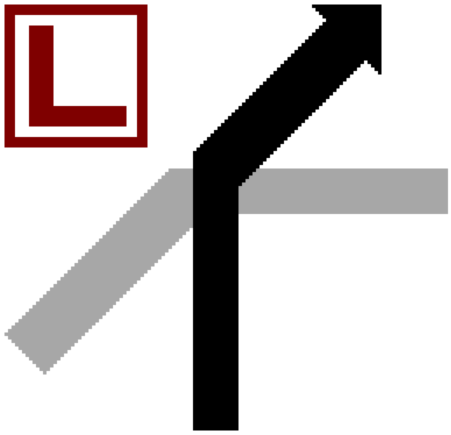


Figure 5-6: Point landmark at decision point

Figure 5-7: Line landmark at decision point

With the described technique a graphical advice can be generated for every possible single decision point. According to the wayfinding choreme theory a wayfinding choreme must not consist of only one decision point. The next section will introduce graphical advices for combined decision points, the HORDEs.

5.7.2 HORDE Advices

As described in section 3.3.4, HORDEs are chunked decision points. Indeed, I have a suitable graphical representation for every single decision point, but there are several things to be observed when combining two or more decision points. The distance between two intersections can vary a lot. Imagine a route on a highway compared with a route in a city center street network. The differences between the distances must be represented somehow. Another problem occurs when a route is following a line- or area-like landmark for a sequence of decision points. The spatial location has to fit for all decision points in this sequence, even if the street, for example, crosses the landmark object.

A third problem occurs with the differences between the realistic and generalized form of representation. For a route string, for example, that contains a sequence of one straight direction, 3 right turns followed by another straight direction. The generalized output of the graphical advices would display a p-turn situation where the streets will cross each other (Figure 3-6). But, as described in 2, internally the turn directions are matching an interval of angles and there also exist angle combinations that would be matched to three times turn right, where the streets would cross at a different location or even not at all. This problem will not be solved in this thesis, because algorithms for the identification of such situations on real world data are required. Also the wayfinding choreme approach introduced in section 3 has to be improved in a very large scale.

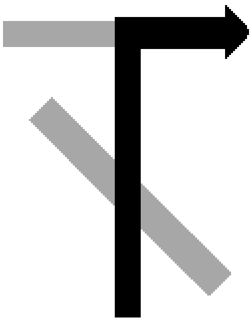
The following section introduces first an approach to realize the distance problem and presents some examples for graphical advices representing a HORDE without or with point-like landmarks. Second, line- and area-like landmarks will be added to the depictions of HORDEs as graphical advises.

5.7.2.1 Distance Problem

For graphical advices the depiction of the distance between the single decision points of a HORDE is not very important. Every single decision point on the route is displayed, no other route segments are displayed and the user has to count the number of decision points or wait until he reaches a landmark or intersection with a special structure respectively. Therefore, generally I will disregard the distances between decision points by taking the same pictorial representation for every situation.

However, for some people the distance they have to follow a road might be important, even if they know the number of decision points they have to pass. Therefore, an additional advice stating the distance to the next decision point using a metric unit shall be possible. Another imaginable add-on to decrease the cognitive load for the traveler is an advice starting the names of the street the traveler is following and the street the traveler has to follow after successfully performing an action. This is also a tactic very common in actual wayfinding assistance systems.

Figure 5-8: Examples for graphical advices for HORDEs shows two examples of graphical advices for HORDEs with and without additional information about the distance of the whole HORDE and the single decision points.



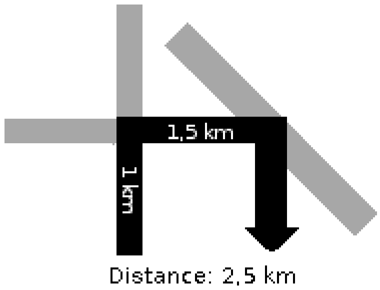


Figure 5-8: Examples for graphical advices for HORDEs

The pictures illustrate the graphical advice for the textual HORDE “Turn right at the second intersection” and “Turn right the next two intersections”.

5.7.2.2 Line- and Area-like Landmarks

The greatest problems occur for graphical advices for HORDEs located at an n-element landmark. The landmark has to be always in the right spatial location relative to the decision point and the graphical representation must be connected across all concerned decision points, even if a street, for example, crosses a line-like shaped landmark. To solve this problem, during the painting process of the single decision points specific coordinates depending on the spatial location are stored. According to the information about the spatial relation of the current decision point and the spatial relation of the landmark at the last decision point, the location of the line-like or area-like landmark can be modified.

Sequences of decision points located at area-like landmarks can change the spatial relation between, for example, inside and next to the landmark. The same technique as described for line-like landmarks will be adopted to area-like landmarks. In the case of area-like landmarks I have to store the position of the area of the last decision point of the sequence instead of the coordinates of the line. Due to the fact, that it is most unlikely, or in human conceptualization even impossible (see section 2.2.3), that an area-like landmark will change its spatial relation between two decision points from, for example, left to right, the realization for area-like landmarks is much easier.

Figure 5-9 shows two examples for a line like and an area-like landmark located at HORDEs.

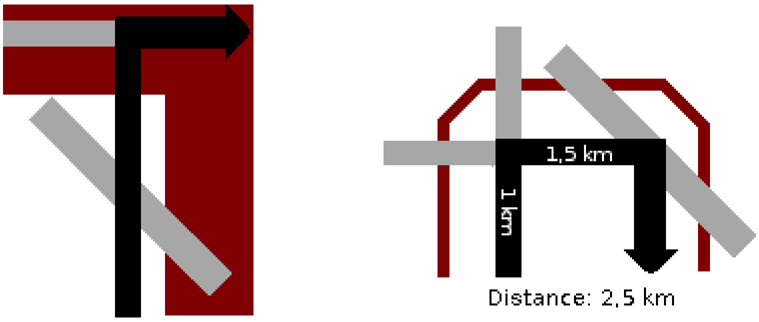


Figure 5-9: Graphical advices with n-element landmarks. The left figure shows an example for an area-like landmark, the right figure for a line-like landmark respectively.

6 Implementation of the Graphical Advices

Many different approaches about externalizations of cognitive ergonomic route instructions have been presented in section 5. Section 5.7 has introduced my approach of the graphical wayfinding choreme advice theory as an externalization for the wayfinding choreme route grammar as introduced in section 3.3.5. This section will describe a library for the automated generation of graphical wayfinding choreme advices. The library is able to generate graphical advices for every object available in the data structure for decision points as described in section 4.2, also HORDEs can be chosen as input which has been generated by executing the term rewriting library described in section 4.3.

The graphical wayfinding choreme advices are supposed to be applicable on mobile devices, same as the term rewriting library. Hence, for the same reasons the Java version for CDC has been chosen for the implementation of the graphical advices.

Figure 6-1 illustrates the basic idea behind the algorithm I have chosen to generate graphical advices for a decision point. The single components like lines for the branches of an intersection, arrows to highlight the directions, GSOs with a specific spatial relation and/or line landmarks also with a particular spatial relation are printed individually. The combination of the single elements constructs every possible single decision point. Obviously, the area-like landmarks are missing in this illustration, but my current implementation of the data structure does not allow an area-like and a line-like landmark at the same decision point. This is a topic for future research.

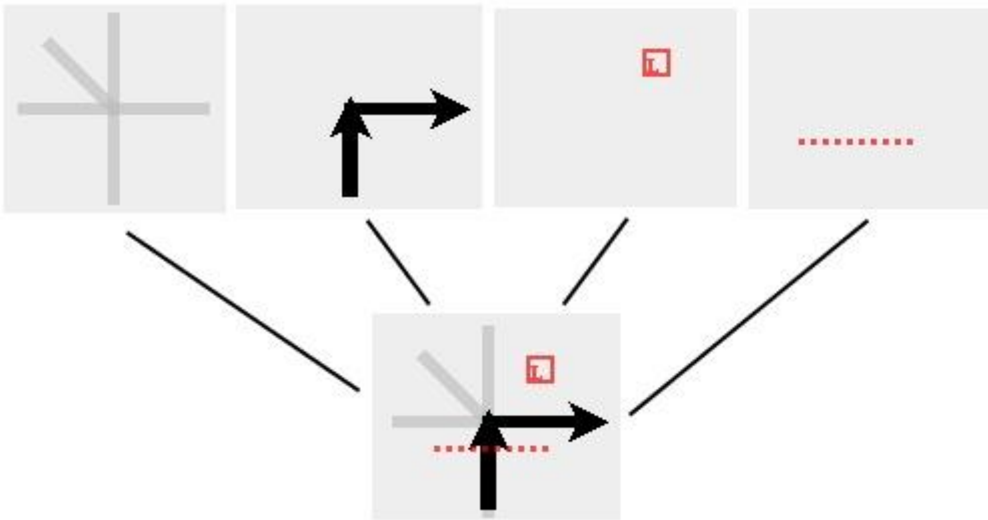


Figure 6-1: Combine simple elements to complex decision points

Section 6.1 introduces the generation steps for the single components available for a single decision point. Afterwards, section 6.2 provides an overview about the anomalies to handle for the generation of graphical advices for a chunked sequence of decision points.

6.1 Generation of Graphical Advices for single Decision Points

The generation process for graphical advices of decision points can be split into several small steps as shown in Figure 6-1. The first step that is necessary for any kind of decision point is to paint the structure of the intersection the action of the decision point has to be performed. As mentioned in section 5.7.1 one step to enhance the cognitive ergonomics of the graphical advices is to display all branches of the intersection, no matter if they are involved in the particular action. The structure can be a useful attribute of an intersection to identify it, sometimes even unmistakably, as introduced in section 2.3 as structure decision points. In section

2.3 I have described, that the decision point objects provide information about the real angle of their branches, whereas 0° means backwards, as well as the turn directions according to the wayfinding choreme theory. The user of the library for the generation of graphical advices has the choice whether the angles of the branches are painted exactly or generalized to the 8-direction model.

The advices are generated and returned as a Java *JComponent* object. This can simply be included into a standard user interface written in Java. The function *paint* of the object has been overwritten to realize the painting of the graphical advice components. The branches of the intersections are painted in a light gray color to reduce the user's attention to less relevant details for the action to perform, according to the approach of aspect maps as introduced in section 5.3.

The next step in the process of generating graphical advices for wayfinding choremes is to highlight the branches of the intersection that are involved in the action to perform. Black arrows with a thicker line overprint the branches of the intersection as shown in Figure 6-1.

These two steps are already enough to cover many subgroups of the introduced decision points in section 2.3. To cover all possible decision points, three addition steps are necessary to display the different kinds of landmarks. First, I have to position and paint GSOs correctly according to their spatial relation. If a decision point is located at a GSO, a red square with an L inside will be placed according to the spatial relation the GSO has. Of course, the implementation shall be able to handle any possible situation. Due to the fact that the spatial relations of landmarks are also generalized to the 8-direction model, a branch might exist with the same turn direction. For example, a GSO is located half left of a decision point and a street branch of the decision point with an angle of 110°. 110° internally matches the turn direction HALF LEFT. In this case an algorithm calculates the best position of the landmark. Depending on the angle of the street, the landmark will be moved left or right of the street. Figure 6-2 shows an example of a moved landmark depending on the angle of the branch. Unfortunately, this could cause graphical advices that do not represent the exact real world situation; the landmark might be on the wrong side. But this problem can be solved in future research by improving the approach with a data structure containing real world coordinates.

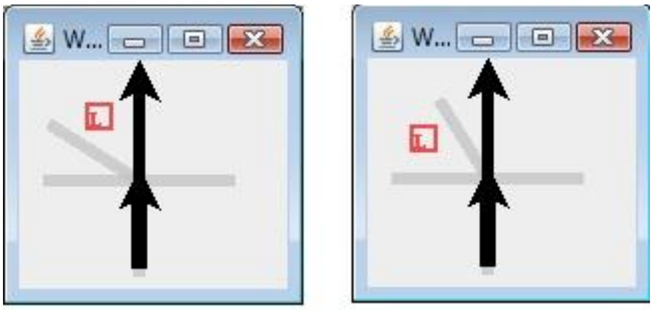


Figure 6-2: The landmark moves depending the angle of branch

Line-like and area-like landmarks are easy to realize for single decision points. Streets branching off the same direction simply cross the line-like landmark or enter the area-like landmark respectively. Line-like landmarks are represented as a red, dotted line and area-like landmarks as a green, dotted square covering a particular area depending on the spatial relation of the landmark.

6.2 Generation of Graphical Advices for HORDEs

Basically, the generation of graphical advices for HORDEs does not differ from the generation of graphical advices for single decision points. But some aspects complicate the whole process immense.

First of all, the graphical advice shall be located in the top left corner of the *JComponent* object and the size of the object shall fit to the size of the advice. For a single decision point the calculation is very simple, because every device has a default maximum size, which can also be defined by the user of the library when designated. But for HORDEs, a sequence of decision points, it is much more complicated. The starting point of the first advice depends on the course of the following decision points of the sequence. Figure 6-4 and Figure 6-6 show two example advices for HORDEs. In the first case, the coordinates for the first advice have to be moved 3 times to the right, in the second case 4 times to the right. The same problem is adaptable to the size problem of the advices. The size depends on the same constraints. The problem gets even worth, when the angles of the streets are not normalized as shown in Figure 6-3.

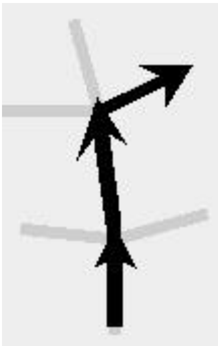


Figure 6-3: Example of a HORDE not normalized to 8-direction model

To predict the coordinates and the size of the advice in Figure 6-3 is nearly impossible without access to real world data. Hence, only a proximate position of the first advice and the size is given by the library for not normalized HORDEs. The size and coordinates of the first advice for HORDEs with branches according to the 8-direction model are given precisely.

After the coordinates for the first advice has been found, the first advice can be drawn like a single decision point. But the directions and spatial relations of the next decision point in the sequence depends on the turn direction of the previous one. Figure 6-4 shows an example for this problem. The spatial relation of the GSO and line-like landmark and the turn directions of the decision points have to be rotated according to the direction of the previous decision point. For example, the turn direction of the second decision point is denoted as STRAIGHT. Hence, the previous decision point heads LEFT, the directions of all branches and also the turn direction has to be painted rotated, in that case also left. Figure 6-3 shows the rotation of all branches depending on the angle of the branches of the previous turn direction when the angle is not generalized according to the 8-direction model

The rotation of angles or spatial relations depending on another angle is an easy to solve mathematical problem. Much more problems occur when line landmarks shall be painted in one piece and also still matching the correct spatial relation. Figure 6-4 shows an example for locating a line-like landmark along a HORDE.

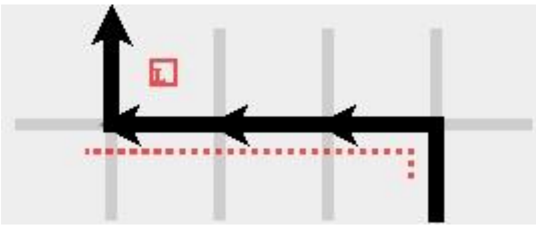


Figure 6-4: Exmple of a HORDE located at a line-like landmark

But, for example, it is also possible that the street is crossing the line-like landmark and a landmark that has been located on the left side is located on the right side at the next decision point. Figure 6-5 shows an example how I have realized this situation. As described in section 5.7.2.2 the coordinates of the landmark of the last and the actual advice are stored and compared to display line-like landmarks correctly.

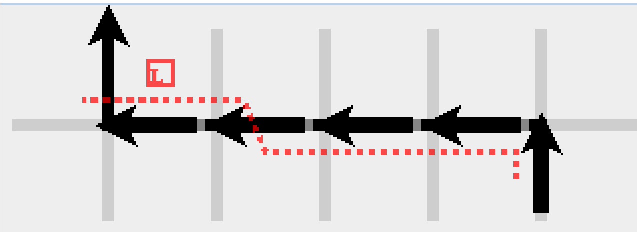


Figure 6-5: HORDE crossing a line-like landmark

The same problems are adaptable to area-like landmarks. Figure 6-6 shows a picture of a HORDE located at an area-like landmark. The algorithm behind my implementation of drawing line- and area-like landmarks along a sequence of single decision points is to paint them after the intersections has been painted. While the sequence of decision points is iterated and the intersections painted, according to the spatial relation of the landmark, the required start- and endpoints are stored. For example, a line-landmark has the spatial relation left, the corrdinates in the lower and upper left sector of the advice are stored. After all decision points have been iterated, the points will be connected with a red, dotted line. Additionally, the sequence of the stored points depends on the direction the route is heading to and away from the decision point. A line-like landmark, for example, is located in the lower left corner. If the route heads to this decision point from the back and turns left, the point next to the heading street has to be added first before adding the point next to the leaving drection. Figure 6-4 contains an example for this problem. If the points of the line-like landmark of the first advice would be added in the opposide sequence, an additional, unwanted line with an angle of 45° would appear, because the points of the line landmark are connected by an red, dotted line in the sequence they are stored.

The same procedure as described for line-like landmarks also works for area-like landmarks. In this case the algorithm does not calculate coordinates, it connects different squares with each other. Figure 6-6 displays a typical example of a area-like landmark located along a HORDE.

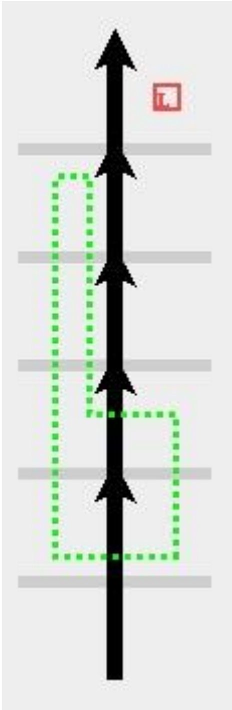


Figure 6-6: Example of a HORDE located at a area-like landmark

7 Conclusion

7.1 Summary

This thesis has introduced processes that increase cognitive ergonomics for the automated generation of route directions and provides an implementation of an appropriate externalization of them. To this end, the approach of wayfinding choremes by Klippel and his coworkers (Klippel, Tappe, Kulik, & Lee, 2005) has been analyzed and enhanced according to the following aspects.

First, a data structure has been developed to serve as input and output for the term rewriting process described in the wayfinding approach. For the optimization and personalization of the term rewriting process the background for a rating and consequently distinguishability of wayfinding choremes has been integrated. By deriving a data structure for decision points from the taxonomy of landmarks by Hansen et. al. (Hansen, Richter, & Klippel, 2006), decision points can be distinguished according to their saliency, where saliency is a good indicator for cognitive relevance in human conceptualization and also personal preferences.

The second aspect affects the term rewriting process of the wayfinding choreme approach. This process for the optimization of cognitive ergonomics by chunking single wayfinding choremes to higher order route direction elements has been incorporated and formalized with the aid of a formal grammar. Step by step the formal grammar has been build up from generating route strings composed of the basic set of wayfinding choremes up to the generation of complex route strings containing HORDEs of all kinds introduced in the approach of wayfinding choremes. Afterwards, the lack of prioritization of certain rules has been disposed by attaching a priority to each a rule based on its saliency, this way reflecting cognitive relevance or personal preferences of the user respectively.

Thirdly one set of term rewriting rules has been developed and introduced to produce as cognitively ergonomic route strings as possible. The choice of the rules is grounded in the aspects introduced during the whole thesis about cognitive ergonomics. Furthermore, additional considerations based on common sense reasoning have influenced choosing the rules. Especially the prioritization has been routed by latter preferences.

The last theoretical step of the thesis introduced one way of externalizing wayfinding choremes represented in the data structure for decision points. An analysis of existing approaches and also of research about modalitiy selection for mobile devices resulted in an approach to enhance graphical route direction advices known from present wayfinding assistance systems by applying specific changes to reduce the cognitive load of the user. Influences from several approaches, like aspect maps by Berendt et. al. (Berendt, Barkowsky, Freksa, & Kelter, 1998) or chorematic focus maps by Klippel and Richter (2004), has lead to the Graphical Wayfinding Choreme Advice Theory.

Finally, my work ends in an implementation of all introduced modules for the execution on mobile devices as well as desktop PCs. A data model of the data structure has been developed and filled with test data to execute a library for proceeding term rewriting according to a user-defined set of productions. For the user-defined use of the term rewriting library, production sets can be stored in an XML format and be passed as basis for the term rewriting process. To ease the generation and modification and also to avoid mistakes in the format structure, an editor for production sets has been implemented as well.

7.2 Evaluation and Outlook

With this thesis I have developed an approach for the generation of cognitively ergonomic route instructions. The ideas of several existing approaches have been used, combined and enhanced for the realization. Next to the graphical wayfinding choreme advice theory the developed theoretical framework provides the background for dozens of further externalizations which can work on the same basis. The already increased attention for the use of mobile devices, the integration of the developed theories and implementations in already existing or new wayfinding assistance systems is imaginable. Due to the volitional abstractness of all theoretical approaches and implementations, the further development in several directions is easy to realize.

There are very interesting open questions left by my thesis on purpose. As already mentioned in my introduction, the thesis does not handle the collection of data to fill the suggested data structure. One interesting further enhancement of my approach is the mapping of the decision point data structure to real geometric positional data, like in the approach of route graphs by Krieg-Brückner and his coworkers (Krieg-Brückner, Frese, Lüttich, Mandel, Mossakowski, & Ross, 2005) where the nodes of route graphs are annotated with additional enviromental information, like landmarks. As already mentioned in the previous sections, the use of real world data would also offer new possibilities to the described problems, such as the positioning of landmarks.

Another aspect for the enhancement of my approach is the attachment of more possible turn directions for the wayfinding choreme theory. As already mentioned in section 3.3.3, this would not change the basic concepts I have introduced with my approach, but offer more and more complex opportunities for new rules and externalizations.

The development of the verbal textual externalization lend itself as further research, due to the insights of section 5.6. But since the performance and memory of mobile devices increases continually, also other externalizations are imaginable. Many approaches have been introduced to emphasize particular purposes in the last sections: the generation of whole new maps based on cognitive principles for mobile devices is a challenging task. This thesis offers big potential for further research and serves a good basis for it.

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9 Table of Figures

Eidesstaatliche Erklärung

Hiermit versichere ich, dass ich diese Diplomarbeit selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe. Die Stellen meiner Arbeit, die dem Wortlaut oder dem Sinn nach anderen Werken entnommen sind, habe ich in jedem Fall unter Angabe der Quelle als Entlehnung kenntlich gemacht. Dasselbe gilt sinngemäß für Tabellen, Karten und Abbildungen. Diese Arbeit hat in dieser oder einer ähnlichen Form noch nicht im Rahmen einer anderen Prüfung vorgelegen.