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Taking off to the Third Dimension — Schematization of Virtual Environments* —

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Abstract
Virtual environments are increasingly popular in different areas in both research and industry. However, interaction with these environments is challenging, posing a variety of difficulties to human users. In this paper, we explore how well known principles of abstraction and information reduction for 2D spatial representations, which we term *schematization*, can be transferred to the 3D representations of virtual environments in order to increase their utility.

Keywords: Schematization, Virtual Environments, 3D, Wayfinding

1. INTRODUCTION

The importance of virtual environments has been growing over the last few years. Virtual environments (VEs) are utilized in many areas such as entertainment, industrial and architectural design, training, and medicine among others (Brooks 1999). Moreover virtual environments as simulations are a valuable tool for environmental psychology. Their advantages are reproducibility of studies, the minimization of interferences, and the accurate recordings of subjects' behavior and performance (Nash et al., 2000). Many studies in the area of spatial cognition are eased or only made possible by the usage of VEs. Moreover, in the area of geovisualization, virtual reality is increasingly used as medium to visualize geospatial data (Slocum et al., 2001). In this context, there is one major research area to consider, namely geospatial virtual environments. On the one hand, these environments can remodel real environments such as cities, for example, in Google Earth. On the other hand, they can be used to provide additional geospatial information such as, for example, the visualization of three-dimensional water circulation (Slocum et al., 2001). This kind of visualization of spatial information can be used not only for entertainment, but also for new forms

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of tourism and training approaches, for example, in rescue scenarios. In our approach, we focus on virtual cities (VCs), which are 3D models of usually existing cities. Virtual cities are large, complex virtual environments with definite structural features.

Many studies show that VEs can be used to acquire spatial knowledge of an environment. However, there are also many navigational problems characteristic of virtual environments. Navigation in virtual environments is a difficult task; the difficulties increase with increasing size of the environment. People not only have severe problems in orienting in a virtual environment, also the survey knowledge they acquire is poorer compared to navigation in the real world. These problems can be partly attributed to the absence of vestibular and proprioceptive stimuli. However, many navigation difficulties and spatial behavior issues within virtual environments are still poorly understood (Nash et al., 2000). There has been a lot of work on improving people's navigation performance in VEs (e.g., Darken & Siebert, 1993, 1996) by, for example, providing maps to ease orientation. Still, these studies show contradicting performance results, attributing these results, among others, to exposure time, level of expertise of the participants, and size and level of detail of the environments (e.g., Goerger et al., 1998; Richardson et al., 1999).

At the same time, for traditional representations of space, namely maps (diagrams) and verbal descriptions, abundant work exists on their effects on navigation performance and the acquisition of route and survey knowledge (e.g., Lloyd & Cammack, 1996; Richardson et al., 1999; Daniel et al., 2003; Meilinger, 2005). Also, several approaches aim at easing the use of navigation assistance and, consequently, at increasing people's navigation performance (e.g., Tversky & Lee, 1999; Barkowsky et al., 2000; Agrawala & Stolte, 2001; Klippel et al, 2005a). Most of these approaches apply principles of abstraction and information reduction, a process we term *schematization* (Klippel et al., 2005b).

In this paper, we address the question whether and how these existing methods of schematization may be transferred to virtual environments. Schematization is a sensible method to enhance the legibility of a virtual environment; a legible environment eases acquiring spatial knowledge. When using virtual environments for solving spatial tasks we have to know which cognitive processes are involved in order to develop adequate support. Schematization is an adequate way of supporting these processes as will be argued for in the next section. The aim of this approach is to develop visualizations for VEs that create a navigable virtual world without presenting any additional tools, such as virtual maps or beacons, to get a more naturalistic way of acquiring spatial knowledge by VEs.

It is important to note that in this paper we do not address questions of how to implement the transferred schematization principles. These questions are well answered within the area of computer graphics that offers different suitable approaches and methods for creating the discussed graphical effects (e.g., Strothotte & Schlechtweg, 2002). Instead, our focus is on questions of why this transfer is cognitively beneficial, i.e., eases navigation and interaction with 3D virtual environments. These questions drive the discussion throughout this paper.

We firstly introduce the concept of *schematization* in more detail (Section 2). We also provide a categorization of different schematization principles, allowing for classifying and evaluating approaches according to this categorization. We then argue for ways to transfer the schematization principles to virtual environments in Section 3, thereby addressing the key differences and difficulties and explaining expected effects.

2. SCHEMATIZATION

Representations of spatial (geographical) information necessarily distort real world information. Certain aspects may be simplified, some exaggerated, some even omitted. This loss of information may be due to the representational medium, for example, (cartographic) maps that depict an environment on a scale much smaller than 1:1. However, this *abstraction* is also a pertinent aspect of human perception and cognition; by reducing the amount of incoming information to that relevant for the current situation. Reasoning and interacting with these representations is often easier than with the represented world itself (cf. Palmer, 1978). In cognitive science, this information reduction is often termed *schematization*.

2.1 What is Schematization?

In cognitive science, especially linguistics, schematization is discussed from an information processing point of view. According to Herskovits, schematization involves three distinguishable processes: abstraction, idealization, and selection (Herskovits, 1998; cf. also Talmy, 1983). We define schematization to be the process of intentionally simplifying a representation beyond technical needs to achieve cognitive adequacy (Klippel et al., 2005b). Cognitive adequacy may either refer to representations that resemble mental knowledge representation, or representations of cognitive processes (Strube, 1992). Schematic representations often aim at matching both these meanings.

In computer science and artificial intelligence, Berendt et al. (1998) present a framework for constructing schematic representations, which focuses on the identification and extraction of the information relevant for a given task (cf. also Freksa, 1999). Three different types of knowledge are distinguished: knowledge that needs to be represented unaltered; knowledge that can be distorted but needs to be present; and knowledge that can be omitted. This distinction may refer to different kinds of spatial knowledge (e.g., topology, distance, direction) and to different objects in a space. Additionally, different approaches may be used to generate schematic representations. In the following, we will disentangle these distinctions and approaches in a categorization of schematization principles.

2.2 A Categorization of Schematization

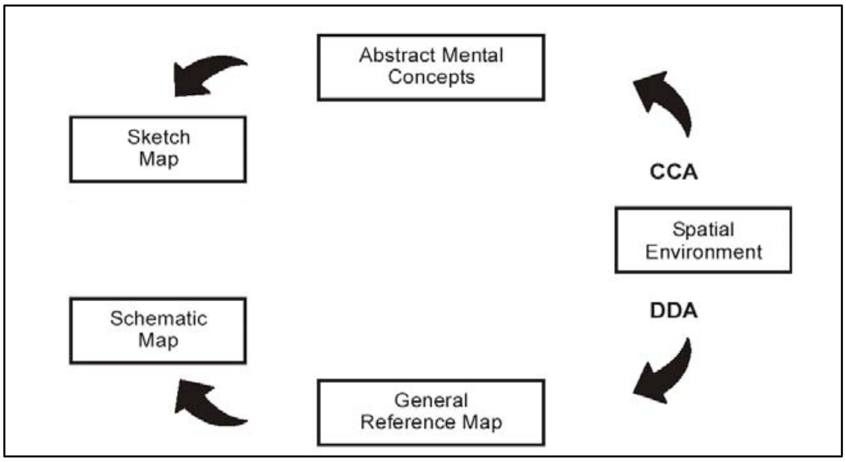
To define a categorization of schematization, first we need to define the borders of our categorization. As stated above, in different research areas, schematization has different connotations. There are many synonyms for schematization or similarities to related concepts, such as generalization, conceptualization, abstraction, idealization, or selection (e.g., Herskovits 1998). Each of these synonyms emphasizes different concepts and functions in schematization. We will focus in our categorization on schematic maps and arrange concepts, functions, structure and primitives according to the task of wayfinding.

Schematic maps are designed to be cognitively adequate. In this context, the term schematic map has been used to denote diagrammatic artifacts used to bridge the gap between physical and conceptual structure (Freska 1999). We can identify two main dimensions of schematization: the first regards the approach taken to manipulate the representation of spatial information; the second regards which features of a space are manipulated.

With respect to the first dimension, broadly two kinds of approaches can be distinguished: data-driven and cognitive-conceptual approaches (see Figure 1; also cf. Klippel, 2003). Data-driven approaches generate schematic representations by altering data present in the base representation, very much as it is done in cartographic generalization. Typical examples are the simplification of an object's geometry or the omission of specific objects. Cognitive-conceptual approaches, on the other hand, utilize predefined building blocks for generating schematic representations, for example, by replacing objects or object configurations with prototypes that conceptually stand for these objects. These approaches are termed cognitive-conceptual since the prototypes used reflect human conceptualizations of the replaced features.

Furthermore, we distinguish between *object-schematization* and *space-schematization*. In object-schematization, the important objects are selected (e.g., landmarks) and an adequate representation for this type of object is generated, for example, by highlighting specific qualities of the selected objects or by reducing information of the surrounding objects. The selection of important objects is task-dependent—as is always the case in schematization. Space-schematization focuses on configurations of objects in space and properties of space. This kind of schematization systematically modifies properties of space. There are four main kinds for space-schematization: altering angles, enlarging or shrinking distances, forming and/or highlighting regions, and distorting space.

Figure 1: The cognitive conceptual approach (CCA) vs. data-driven approach (DDA) to schematization (from Klippel, 2003).



In combination, the different dimensions of schematization enable a structured classification of schematization methods that allows for a sensible selection and combination of methods for the task at hand. We will demonstrate this for some sample approaches in the following paragraphs.

Barkowsky et al. (2000) developed a method for schematizing map objects based on *discrete curve evolution* (Latecki & Lakämper, 1999). This method repeatedly removes the least significant point of an object's geometry until a stopping criterion (e.g., a significance threshold) is reached. The significance of a point is defined by the distance to, and angle between its neighboring points. This method is a good example for data-driven object-schematization. It manipulates the geometry of single objects by altering the polygon defining their boundary, thereby ensuring that topology and ordering between objects is kept.

An example of cognitive-conceptual object-schematization is the replacement of buildings or other built features with a symbol representing their function in a map. For example, fast-food restaurants and gas stations, or bus stops and subway stations, may be marked in a map with their symbolic counterparts, i.e., the brands' logo or an established symbol for a bus stop (cf. Elias et al., 2005).

Agrawala and Stolte (2001) developed a process for generating route maps, termed *line-drive*. This approach distorts distances according to the density of events. Areas with a higher density of events, i.e., turning actions, are depicted in full detail, while areas with low density are shrunk. That is, line-drive maps are not to scale: long segments without events, for example, driving along a highway for hundreds of kilometers, take up a small part of the map compared to their actual lengths. While small real world areas, for example, getting onto the highway from your home, may take up a part that is larger compared to their actual length (however, segments that are longer in the real world will always stay longer in the map as well). Agrawala and Stolte's work is an example of data-driven space-schematization as it schematizes a route and adjacent street segments, i.e., manipulates a spatial layout.

Another example of data-driven space-schematization is presented by Zipf and Richter (2002). In their approach, they divide the represented environment in zones depending on the distance to the area of interest. By fading out of colors and increasing simplification of geometry with increasing distance to the area of interest, they achieve a focus effect that draws a map reader's attention to the area of interest. Accordingly, these maps are termed *focus maps*.

Agrawala and Stolte's work is based on the toolkit approach by Tversky and Lee (1999). Tversky and Lee defined a pictorial and verbal toolkit for generating graphical and verbal route directions, respectively. These toolkits are based on empirical findings of how people respond to navigation assistance requests; both toolkits contain elements representing prototypes of wayfinding situations that, according to Tversky and Lee, are sufficient in constructing route instructions. These prototypes reflect what people in the experiment typically have drawn or written to describe a spatial situation, for example, a left turn.

In a similar line, Klippel (2003) empirically identified mental conceptualizations of turning situations in wayfinding. He terms these concepts *wayfinding choremes*. These choremes represent prototypes of turning actions that, in their graphical externalization, can be used to emphasize turning actions in wayfinding maps (Klippel et al., 2005c). In contrast to Tversky and Lee's (1999) toolkit approach, only the functionally relevant information (the incoming and outgoing branch) is replaced by a prototype; this prototypical representation remains embedded in a veridical spatial representation to ease matching and orientation. The categorization of the different schematization methods discussed is summarized in Table 1.

Table 1: Classification of schematization methods according to the categorization.

	data-driven	cognitive-conceptual
object-schematization	schematization based on discrete curve evolution (Barkowsky et al., 2000)	replacing objects with symbols (Elias et al., 2005)
space-schematization	line-drive maps (Agrawala & Stolte, 2001); focus maps (Zipf & Richter, 2002)	graphical and verbal toolkit (Tversky & Lee, 1999); wayfinding choremes (Klippel, 2003)

3. FROM 2D TO 3D SCHEMATIZATION

In this section, we will discuss how schematization principles that ease the usage of 2D maps employed for navigation assistance can be transferred to 3D virtual environments. At first, comparing the two navigation assistance tasks, navigation with the assistance of a schematic map and navigation in a modified (schematized) virtual environment, seems to be incompatible.

Maps present spatial information in a static 2D pictorial way. People get an indirect spatial knowledge experience from maps and can easily access survey knowledge from this representation. Because of the bird-eyes perspective of maps users build up an allocentric mental representation of the environment (Montello et al. 2004). But the constructed spatial knowledge differs from knowledge from direct experience (Thorndyke & Hayes-Roth 1982). Therefore, many studies have shown effects, such as that map users are less accurate in pointing to targets from various places in an environment and that there are alignment effects to the orientation of the map (Montello et al. 2004). Nevertheless, maps have the power to provide survey spatial information even in cases of very complex environments.

A virtual environment, on the other hand “[...] offers the user a more naturalistic medium in which to acquire spatial information, and potentially allows to devote less cognitive effort to learning spatial information than by maps" (Montello et al., 2004, p. 275). While this is an important argument for using VEs to get acquainted with an environment, also several navigational problems have been identified. VEs are interactive, real-time, 3D graphical displays/simulations of places or environments that change appropriately in response to behavior by users (e.g., active control by mouse or joystick). Users of VEs have a dynamic first-person perspective. They pick up information sequentially and have then to integrate this information into their mental representation of the environment. Many studies show that people can learn spatial information from a VE and build up an egocentric mental representation of this environment (Montello et al. 2004). It has also been shown that real world spatial cognition can be studied by using virtual environments (Nash et al. 2000). Currently, the degree to which VEs provide survey knowledge is not clear (Montello et al. 2004). But people have also difficulties in acquiring survey knowledge in the real world. It seems that the attention of the person spent on the relevant spatial information has a major effect. In our approach, we introduce a way of guiding attention by schematizing the virtual world.

Obviously, the two different sources of spatial information—a map and a virtual environment—provide different kinds of information. However, if we look at the cognitive tasks going on behind map reading and navigation in virtual 3D environments, we will see a strong correlation of supporting navigation with schematic representations in both 2D and 3D.

Using maps for navigation, wayfinders have to solve several cognitive tasks while reading the map. Roughly speaking, it involves four main steps. First, wayfinders have to extract the relevant spatial knowledge represented in the map. Then they have to align their personal spatial knowledge and the surrounding of the environment to the space depicted in the map. The next step is to determine which action has to be performed at the current location to get to the next decision point. Lastly, after performing this action wayfinders have to realign themselves again with the map and determine their changed location (Lobben, 2004). This procedure is repeated until a wayfinder reaches the destination. In a virtual environment, similar processes take part in navigation. Again, wayfinders need to access their mental representation of the environment, map it to the current perception (visual display) of the environment, and, based on this, decide on the next action to be performed. Again, this procedure is repeated until the destination is reached.

For both navigation tasks the importance of legibility serves as a common ground. The foundation of legibility in real environments has been laid by Kevin Lynch (1960) who analyzed which structural elements of a city allow for robust navigation performance. Here, 'robust' refers to a navigation that is based on a coherent mental representation of an environment and that can be performed (mostly) unaided and error-free. The concept of 'legibility', and the closely related 'imageability', can be understood as how easily someone can identify physical features in a city layout that are important to form an 'image', i.e., a mental representation of the layout. Good legibility enhances mapping spatial information perceived in the environment with a person's mental representation. Lynch identified five key elements: paths, edges, landmarks, nodes, and districts.

Schematization of geographic information aims at increasing legibility, i.e., at easing the task of mapping information read from a map to the represented environment. The schematization approaches introduced in Section 2 support the cognitive processes underlying map reading. Most of them achieve this by selective reduction of information and guidance of the attention of map users to the relevant aspects (e.g., line-drive or focus maps). Wayfinding choreme maps (Klippel et al., 2005c) not only support the mapping process, but also decision making by substituting functionally relevant branches of an intersection with a visual prototype that reflects the mental concept of the specific turning action to be performed. In 3D representations, several researchers take Lynch's elements into account when designing a virtual environment. Ingram and Benford (1996), for example, explore algorithms for constructing a structural design of virtual cities by automatically creating or enhancing legible features.

In conclusion, the enhancement of legibility of both the map and the virtual environment aims at easing the process of mapping representation and environment and at supporting the decision process to lower the cognitive effort of dealing with the navigation task. Additionally, the attention of the user should be guided to the relevant information by schematization. Therefore, even if the two navigation tasks, map-assisted navigation and navigation in VEs, seem to be different at first sight, the underlying cognitive processes that need to be supported are comparable. Thus, a transfer of schematization principles from 2D representations to the 3D representation of a virtual environment is a promising approach to foster navigation performance and acquisition of spatial knowledge. In the following section we will discuss this transfer. To this end, we pick up the examples presented in Section 2 and illustrate which additional possibilities we get and where the problems may be.

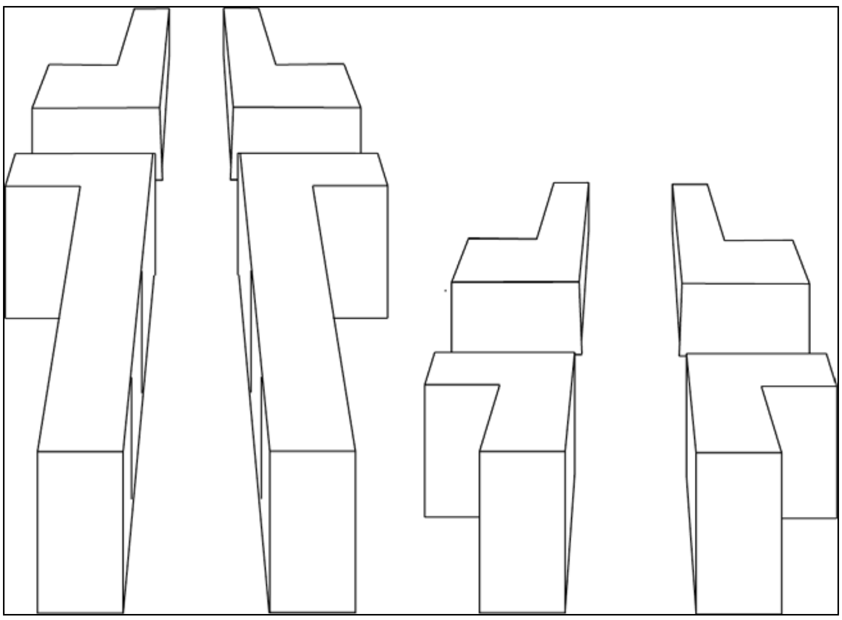
3.1 Transferring Schematization Principles

In this section, we will illustrate the transfer of schematization principles using three examples. We focus on space-schematization for two main reasons: first, space-schematization is a powerful way of constructing a cognitively adequate representation, and second, the manipulation of spatial layout in enhancing the legibility of virtual environments has hardly been used so far. This is even more remarkable as in virtual environments applying principles of space-schematization is particularly easy. To any given point in time, deformation of space can be restricted locally to the current field of view of the wayfinder. Thus, there is, for example, no need to maintain global topological consistency, as is the case in constructing maps. In fact, as Zetzsche et al. (2007) demonstrated, people navigating in a VE seem to be able to ignore topological or metric inconsistencies while still successfully navigating in the environment.

Even though object-schematization is not the focus of our work, it is a valid method of information reduction in virtual environments that is predominant in today's approaches. It can be done both through data-driven approaches, for example, in simplifying a building's geometry (e.g., Kada, 2007), or cognitive-conceptual approaches, for example, in displaying individual buildings of an area by always using the same graphical instance.

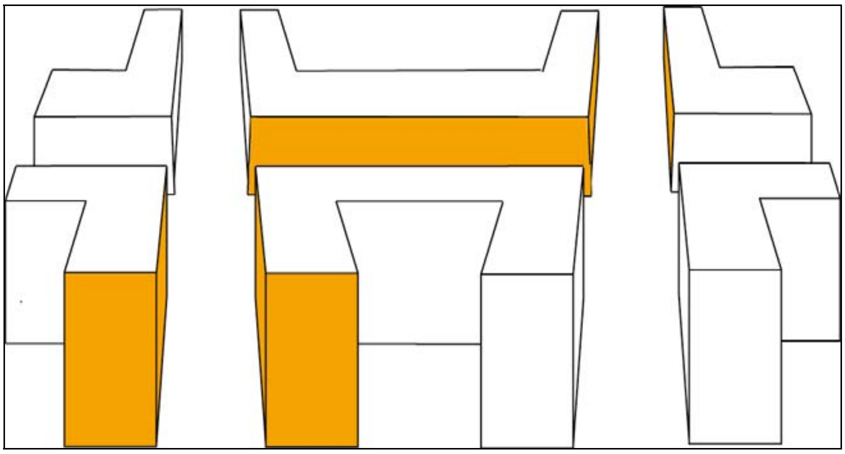
For space-schematization, the first example we look at is the line-drive route map of Agrawala and Stolte (2001), especially their approach of distance distortions according to the density of events. This principle can easily be transferred to 3D. In areas of a higher density of events, the level of detail may be increased and distances kept true to scale. Segments of a route where nothing important happens may be shrunk, i.e., they may be represented as shorter as they really are. Here, also less detail may be used. It can be expected that the benefit of focusing a wayfinder's attention on these areas exceeds the problem of presenting distance information that does not match with the real world situations because people have severe problems in estimating and using distances in virtual environments in the first place (Ruddle & Lessels 2006). By emphasizing the areas relevant for navigation, an increase in navigation performance and in the acquisition of spatial knowledge compared to the cluttered virtual cities that are usually used can be expected. Figure 2 presents a sketch of an unchanged intersection on the left and on the right the schematized version where the intersection itself is enlarged and the incoming segment is shrunk.

Figure 2: Sketch of a schematized intersection according to line-driven schematization. Left: original intersection; right: the distance-schematized intersection



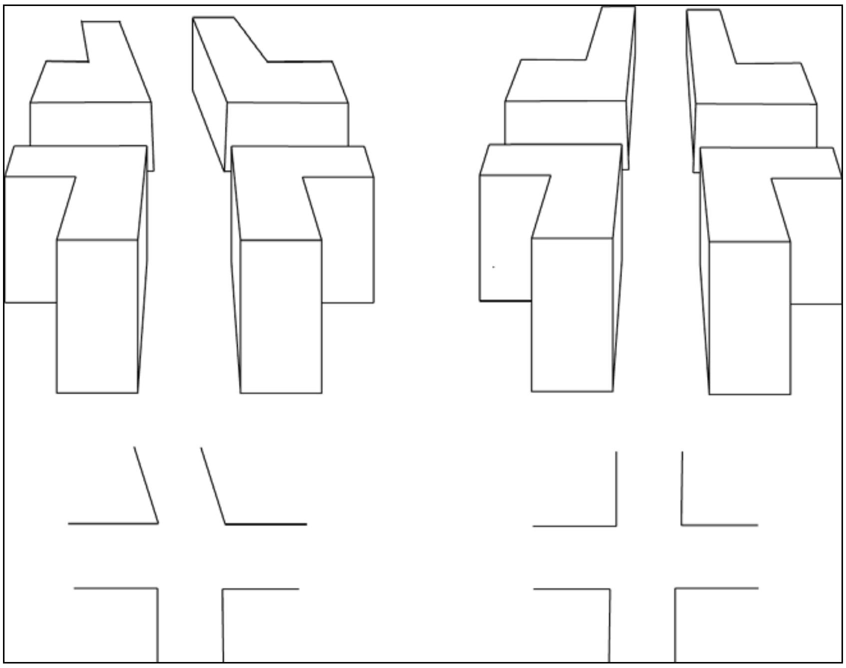
The next example for a data-driven space-schematization is the focus map presented by Zipf and Richter (2002). In this approach the attention of the map reader is focused on the relevant area by fading out of colors and increasing simplification of geometry. Transferring these principles to 3D is similar to the transfer described above. However this method does not really alter the spatial layout itself but only its visual appearance. There are two different options that can be pursued: first, the level of detail may be increasingly lowered with increasing distance to a given route; second, we can form regions of interest by highlighting specific features of areas, which eases acquiring survey knowledge. As already pointed out, subjects have problems in orienting in virtual environments, but studies by Wiener et al. (2004) show that highlighted regions change their navigation strategies. Combining the principles of focus map and forming of regions can help to get a better sense of orientation. Figure 3 illustrates focusing on a single route in 3D.

Figure 3: Sketch of schematizing a route segment by focus effects. The attention of the user is guided by highlighting the relevant area.



The last example covers Klippel's (2003) wayfinding choremes. By representing turning actions as prototypes this schematization approach emphasizes the action to be performed in a spatial situation. Wayfinding choremes can be applied in a 3D representation by locally changing the angular configuration of an intersection's branches. To this end, not only the angles of the streets have to be changed, but also the local configuration of buildings must be changed. However, this change can be restricted to the current view of the wayfinder and only needs to be kept until the next intersection. There, again angles can be adapted to the action to be performed at that intersection. While this approach may result in violations of global topology, local consistency is guaranteed, i.e., there are no breaks in a wayfinder's optical flow. The selective replacement of angles by their prototype (e.g., 90° instead of 79.3°) eases decision making. Also, mapping and orientation are eased because wayfinders in virtual environments have mostly to estimate angles for orientation (Riecke, 2003), which can be expected to be more accurate using prototypical angles. A sketched 3D version of a chorematic representation is presented in Figure 4.

Figure 4: Sketch of a schematized intersection using 3D choremes. Left: original intersection; right: the angle-schematized intersection Below: 2D intersection (left) and its chorematized version (right).



3.2 Caveats

We argued above how schematization principles for 2D representations can be transferred to 3D. In this section, we will discuss some of the problems and limitations of virtual environments and how these problems can be affected by the transfer of schematization principles. It is important to weigh the acquired benefits by schematizing a virtual environment against these possible upcoming problems.

One of the unpleasant problems in virtual environments is simulation sickness (Brooks 1999). People may become simulation sick if the optical flow presented on screen is significantly higher than the experienced ego-motion. This type of sickness can have different effects, such as nausea, loss of orientation, or vertigo. When schematizing the environment we have to take this into account, and avoid simulation sickness resulting from changing the level of detail or the configurations of buildings and angles, i.e., avoid to offset the optical flow against ego-motion.

More importantly, schematizing a virtual environment results in features being modeled in different quality, i.e., in different levels of detail. This may induce loosing the feeling of presence for a user (Nash et al. 2000). 'Presence', and the closely related 'immersion', can be defined as "a degree to which humans distally attribute ourselves to the virtual environment" (Nash et al. 2000, p. 22). However, many criteria besides the level of detail influence the feeling of presence. Other criteria are, for example, the field of view, the range of the environment, the motion (control unit of motion), or the self-representation of the user (Nash et al., 2000). Also, cognitive criteria, such as attentional resources, increase the feeling of presence. These criteria are enhanced by schematization, as we have argued above. Furthermore, the correlation between performance in a virtual environment and feeling of presence is mostly unknown today. Consequently, we should aim for a model of a virtual environment that is as schematized as necessary, while still keeping a sufficient level of realism.

One key application of using virtual environments is to train people for the represented real environment. Therefore, an essential question when schematizing a virtual environment is whether these environments can still be used to train people. Enhancing the legibility of a virtual world by applying principles of space-schematization significantly changes this world; it may create a different impression of the environment. Specific features may be highlighted, or distances and angles are different to the real environment. This may hinder transfer of acquired spatial knowledge in the virtual environment to the real world. However, space-schematization supports the underlying cognitive processes for navigation, and any changes to the environment are done specific to this task. Thus, it can be expected that mental representations that are formed based on this kind of virtual environment also support the same tasks in real environments. For example, the use of chorematic representations of intersections supports conceptualizing these intersections, i.e., eases forming a mental representation of the spatial configurations. A final answer with respect to the benefits of schematization in virtual environments requires empirical studies.,.

4. SUMMARY AND OUTLOOK

In this paper, we discussed the transfer of 2D schematization principles to 3D virtual environments. To this end, we devised a coherent categorization of schematization principles used to construct 2D representations of geographic space. Schematization is defined as a process of intentionally simplifying a representation beyond technical needs to achieve cognitive adequacy (Klippel et al., 2005b). The presented categorization emphasizes different concepts and functions of schematization principles. Schematization principles are characterized as either data-driven or cognitive-conceptual (according to Klippel, 2003). Furthermore, we introduced the distinction between object- and space-schematization. Object-schematization manipulates the appearance of single objects by, for example, highlighting specific qualities or by simplifying an object's geometry. In contrast, space-schematization alters the configuration of objects or other properties of space. The systematic modification of space can further be divided into altering angles, enlarging or shrinking distances, forming and/or highlighting regions, and distorting space. This categorization supports identifying the underlying concepts of different schematization principles, which is necessary in order to achieve the same consequences when applying these principles in 3D.

When transferring schematization principles to 3D representations, the central question that needs to be answered is whether these principles also increase legibility in 3D as they do in 2D. Our discussion has shown that this transfer is sensible. In both cases, the aim is to enhance the legibility of a representation by supporting the processes of mapping representation with environment and of decision-making. Furthermore, the schematization principles proposed for transformation focus on relieving inherent problems of virtual environments, such as the incorrect estimation of distances and angles. We argue that applying space-schematization principles can reduce these problems. Future work will evaluate this hypothesis in empirical studies.

We will also consider mixed cases. Schematic representations may use principles from both object- and space-schematization. An example for such a mixture of schematization principles is the route aware map (Schmid 2007). This map combines principles of strip maps that focus on the route to take and elements of survey maps. A route-aware map anticipates possible errors in interpreting the presented information and embeds additional information for critical areas. This mixture of schematization principles may be a prolific way to even further enhance the legibility of 3D virtual environments.

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