Schematic Maps as Wayfinding Aids[1]

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Abstract. Schematic maps are effective tools for representing information about the physical environment; they depict specific information in an abstract way. This study concentrates on spatial aspects of the physical environment such as branching points and connecting roads, which play a paramount role in the schematization of wayfinding maps. Representative classes of branching-points are identified and organized in a taxonomy. The use of prototypical branching points and connecting road types is empirically evaluated in the schematization of maps. The role played by the different functions according to which the map is classified is assessed, and main strategies applied during the schematization process are identified. Implications for navigational tasks are presented.

1 Introduction

Due to their abstracting power, schematic maps are ideal means for representing specific information about a physical environment. They play a helpful role in spatial problem solving tasks such as wayfinding. An important class of features for these tasks are route intersections (cf. Janzen et al., 2000, this volume). One of the challenges in constructing schematic maps consists in establishing clear relationships between detailed information found in the environment, and abstract / conceptual structures contained in the map. An important aim of any schematic wayfinding map is to efficiently support information to find a destination. Therefore, it is crucial to determine in which way and to what extent spatial information such as branching points and their connecting roads can be regarded essential or irrelevant, and therefore must be preserved or discarded during the schematization of a map.

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Aspects related to schematic maps as visual tools for communicating spatial concepts for wayfinding tasks must also be taken into account. Accordingly, the focus of this contribution is directed towards exploring spatial characteristics of branching points and their connecting roads in the schematization of wayfinding maps. The idea is to analyze how these features are affected during the process of schematization. After a brief review of selected literature in architecture, cognitive psychology, geography, and environmental design, we present a description of an empirical investigation, interpret results, and offer conclusions for the schematization of maps as wayfinding aids.

1.1 Spatial Orientation

A person's ability to establish his or her location in an environment is termed *spatial orientation* (e.g., Arthur & Passini, 1992; Correa de Jesus, 1994). From a cognitive point of view spatial orientation is considered as the capability to form a cognitive map (Tolman, 1948; Golledge et al., 1996; Downs & Stea, 1973). Successful spatial orientation involves the representation of a suitable cognitive map of the environment, within which the subject is able to establish his or her position. The concept of spatial orientation has been demonstrated to be helpful in exploring some of the spatial characteristics that facilitate cognitive mapping. Lynch (1960) was one of the pioneers who established direct relationships between the spatial orientation of people and their physical environments. Since then, extensive research has been done in this domain. As the concepts of spatial orientation and cognitive mapping mainly refer to the static relationship between a subject and a specific spatial layout, they often neglect the dynamic effect of moving through a spatial environment (Passini, 1984). In the light of this situation, a new perspective was needed to define spatial orientation whilst moving in space.

1.2 Wayfinding as Spatial Problem Solving

In the recent years, the notion of spatial orientation has been replaced by the concept of wayfinding, which refers to the process of moving through space and encompasses the goal of reaching a spatial destination (e.g. Garling et al., 1986; Downs & Stea, 1973; Kaplan, 1976; Passini, 1998). Since finding a way is concerned with perceiving, understanding, and manipulating space, this concept is understood as a process of spatial problem solving. Wayfinding involves cognitive and behavioral abilities which are performed to reach a destination (Arthur & Passini, 1992; Lawton et al., 1996). These abilities, which play a critical role in achieving a wayfinding goal (e.g. reaching a desired destination), can be classified into: i) decision making, ii) decision executing, and iii) information processing (Passini, 1984; 1998).

The availability of relevant information about the environment is an important factor in the process of decision making. In wayfinding tasks, successful decisions are generally based on suitable information about physical characteristics of the environment. These account for a description of a net of connecting roads to be followed, as well as for different types of branching points that may serve to connect roads to reach a specific destination.

In order to reach a destination, decisions have to be transformed into actions. It is in this process that decision execution takes place in a specific position within a certain environment. According to Arthur and Passini (1992) and Passini (1984) the execution of a decision involves the matching of a representation (mental or external) of the environment with the real environment itself.

Both decision making and decision execution are supported by information processing. Spatial perception (related to the process of acquiring knowledge from the environment) and spatial reasoning (related to the manipulation of spatial information) constitutes the main interrelated components of information processing (Passini, 1984; 1998).

In spatial problem solving, a map is seen as a base of knowledge instrumental for supporting information processing. By focusing on the visual representation of physical entities, such as connecting roads and branching points, our work will attempt to address main aspects derived from schematic maps.

1.3 Maps and Representation

While behavioral abilities are performed in the physical environment, cognitive abilities are carried out in the domain of cognitive representation. The relationships between the cognitive domain and the environment are essential for providing meaning to the structures and operations in the cognitive representation (Freksa, 1999). Accordingly, structures and operations in the representation of elements of the environment are responsible for the success or failure of wayfinding procedures (Downs & Stea, 1973).

Theoretical frameworks dealing with representation focus on the correspondence between elements and existing relationships in a represented world, and elements and existing relationships in a representing world (Palmer, 1978; Furbach et al., 1985). Whereas physical elements of an environment constitute the represented world, a map-like structure is considered a suitable medium for the representing world (MacEachren, 1995). Maps can be seen as derived from an aerial view, where meaningful entities and spatial relationships between entities are partially replaced by symbols (Berendt et al., 1998). Among different types of map representations, there are sketch maps and schematic maps. Sketch maps are related to verbal descriptions about spatial features (e.g. Suwa et al., 1998; Tversky & Lee, 1999; Freksa et al., 2000, this volume), schematic maps, on the other hand, are obtained by relaxing spatial and other constraints from more detailed maps (e.g. Barkowsky & Freksa, 1997).

1.4 Schematic Maps and Wayfinding

While topographic maps are intended to represent the real world as faithfully as possible, schematic maps are seen as conceptual representations of the environment. ”For many purposes, it is desirable to distort maps beyond the distortions required for representational reasons to omit unnecessary details, to simplify shapes and structures, or to make the maps more readable" (Freksa et al., 2000, this volume). Schematic maps provide a suitable medium for representing meaningful entities and spatial relationships between entities of the represented world. Moreover, they relate concrete and detailed spatial information from the physical environment to abstract and conceptual information stored in our brain. However, an instrumental condition is that a suitable relationship must exist between schematic maps and the represented world. The more clearly we relate schematic maps to the critical elements of the represented environment, the more easily users will find a wayfinding solution.

Schematic maps are external pictorial representations. An important feature of these external pictorial representations is that they reflect to a great degree the way we reason through abstract structures (Freksa, 1991). Thus, the way we represent spatial information will strongly depend on how we perceive and conceive of the environment.

Entities and conceptual aspects of the depicted domain that are symbolized in the schematic map vary according to the schematic map's purpose. In wayfinding, the schematization of branching points is important for reducing the cognitive effort when trying to find a destination. Freksa (1999) has proposed that an appropriate representation tool should include the following processes: i) identifying and selecting relevant aspects from the physical environment; ii) choosing an appropriate structure for the inferences to be made between the represented world and the representing world; iii) interpreting the results of the inferences.

A key question for constructing schematic maps is to select aspects that make them suitable for solving wayfinding problems. Identifying these aspects is what turns a schematic map into an ideal tool for supporting navigation and orientation. We claim that identifying relevant branching point situations from reality, building a taxonomy of branching points, and establishing a hierarchy of connecting roads will help produce schematic maps to ease wayfinding.

2 Branching Points and Wayfinding

In wayfinding tasks, spatial problem solving is strongly influenced by the nature of the intersections. By developing a wayfinding model for built environments, Raubal and Egenhofer (1998) pointed out that decision making is affected by the complexity of a wayfinding task. Major characteristics of branching points, where decisions have to be taken when seeking a destination, provide parameters to measure the complexity of a spatial problem solving task (Hillier et al., 1984; O'Neill, 1991a, 1991b; Peponis et al., 1990; Weisman, 1981), as well as for the construction of schematic maps.

Arthur and Passini (1992) noted that the number of branching points has an important influence on the difficulty of performing wayfinding. In solving spatial problems, the process of constructing a schematic map is directly affected by the number of routes that converge in a branching point, and by their respective angles. These are seen as essential elements for the organization of branching points into a general taxonomy.

2.1 A Taxonomy of Branching Points

Branching points are classified by the number of routes, roads, or branches that meet at an intersection and by the angles in which they intersect. Although an infinite number of cases is obtained by combining these two variables, we reduce the number of classes to a small set that can be qualitatively distinguished. Our qualitative approach intends to provide a suitable framework for dealing with major similarities and major differences among branching points.

We classify branching points into a taxonomy of two to eight routes or roads that meet at an intersection, and we distinguish four qualitatively different intersection angles: acute, perpendicular, obtuse, and straight on; moreover, we take into account rotation and mirror symmetries. We represent these categories by prototypes derived from an equiangular eight-sector-model (cf. Hernández, 1994; Frank, 1992). The concept of taxonomy helps to define and classify different types of complex intersections. In wayfinding tasks, this is more advantageous than simply referring to intersecting angles between roads. For example, it contributes to establishing and preserving important and specific relationships in the schematic map that otherwise may be lost. The schematization and classification of representative branching points of the physical environment is illustrated in Fig. 1 through the different categories and sub-categories of the proposed taxonomy. Although the taxonomy of representative branching points proposed in this study includes categories that embraces two to eight branches, the prototypes studied in this work were restricted to the categories of three and four branches.

We propose that the organization of branching point situations into main categories will contribute to perceiving, understanding, and organizing complex information from the environment through a reduced number of cases. Understanding about how representative a particular branching point is for actual problem solving situations will help to ease the schematization of maps.

2.2 Schematizing Maps

One of the problems in schematizing maps is how to deal with the relationships between all the details found in the environment and the abstract structures to be represented in the schematic map. We have posited that in the process of schematization, entities, relationships, and conceptual aspects of the real environment have to be represented according to the schematic map's intended function and purpose. Since branching points and connecting roads are relevant components of the physical environment, we claim that both play an important role in the schematization process.

Understanding about the main aspects and criteria for preserving, including, or eliminating these entities will contribute to the construction of efficient schematic maps. The classification of representative branching points into a general taxonomy is seen as an attempt to provide a structure for mapping relevant relationships between the represented world and the representing world. However, the question of how such a taxonomy could be used for the schematization of maps that are supposed to serve as wayfinding aids is still unclear.

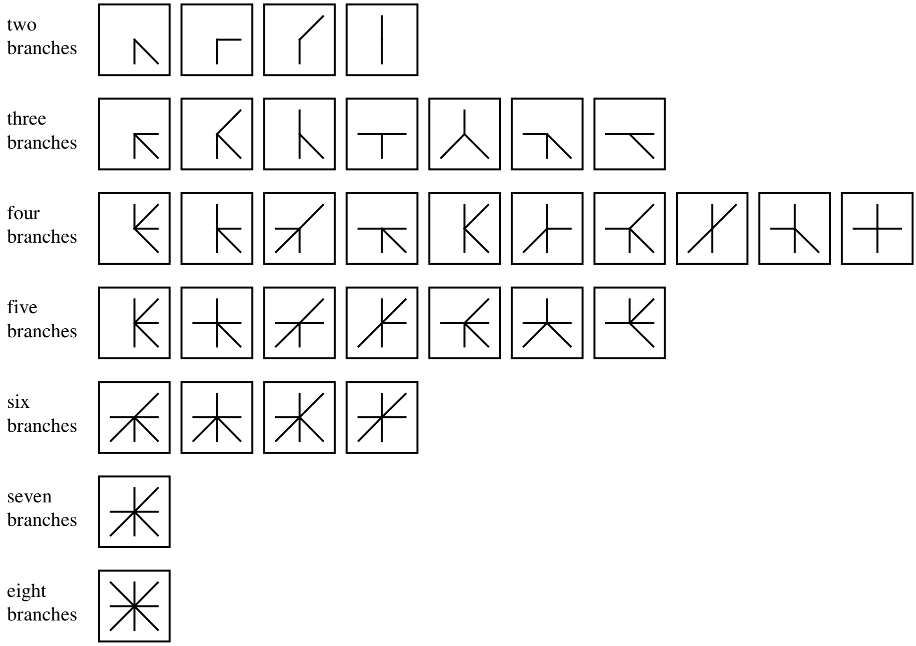

Fig. 1. Taxonomy of branching points for intersections with two to eight branches. Acute, perpendicular, obtuse, and straight on intersections are distinguished. Rotation and mirror symmetries are taken into account

3 Empirical Study

In this section we describe an empirical study which investigates the schematization of a wayfinding map by employing a taxonomy of qualitative branching points. We first describe the general objectives of the study and motivate the selection of a particular case study. Thereafter, the empirical task is described. This exploratory study is intended as an empirical contribution from a theoretical and computer science perspective.

3.1 Goals

Whilst referring to schematic maps, most spatial cognition literature focuses on specific aspects dealing with the issue of representation. However, it does not really concentrate its attention on the process of schematization that leads to the representation of the map itself. For this reason, an important aim of this empirical study is to focus both on aspects related to schematic map representation, as well as on the schematization process itself. Therefore, the empirical study aims at the following goals:

First, we explore in which way and to what extent a taxonomy of prototypical branching points can be successfully utilized for the schematization of maps. Particularly, we would like to confirm whether branching points found in the schematic map are constructed by referring to their corresponding prototypes of the proposed taxonomy. Moreover, we explore if right-left positions between schematized branching points are preserved with respect to those of the original map. Additionally, we analyze whether close distances between neighboring branching points are eliminated by merging with one another.

Second, we analyze in which way and to what extent different road types are affected during the process of schematization. A particular focus is set to examine the extent to which roads of the original map are eliminated. We are also interested in evaluating whether subjects are able to schematize connecting roads according to hierarchical structures (cf. Timpf, 1998).

Third, we study the role played in the schematization process by the different functions (e.g. cemetery, park, etc.) according to which the map is divided (from now on termed as *functional areas*). We are particularly interested in evaluating to what extent each function will affect the inclusion or elimination of the different road types.

Fourth, we explore possible reasoning strategies that could be applied during the map schematization process. A basic study will be carried out to identify cognitive patterns of behavior that may be applied by subjects while schematizing a map. Particularly, we would like to exhibit if any sequence of schematization can be found. Additionally, we explore whether hierarchical structures between roads are considered during the schematization process.

3.2 A Case Study: The Stadium

With the aim of studying map schematization, we carried out a case study in the 'real world', the Hamburg Volksparkstadion area (see Fig. 2). One of the reasons for choosing this environment is that it represents interesting examples of wayfinding problems. The Volksparkstadion area is surrounded by a variety of urban features such as parks, a cemetery, and parking lots that are organized according to a rather complex geometric layout. Furthermore, an intricate circulation system comprising streets, a freeway, and footpaths constitutes the network of ways leading to the stadium.

For the purposes of organizing and analyzing this spatial structure, a hierarchical representation was proposed a priori. Components of the circulation system were classified with respect to their assumed relative importance for the wayfinding task. Accordingly, while *border main roads* and *internal main roads* are part of a higher level hierarchy, *external roads*, *secondary roads* and *dead ends* form the lower levels of that hierarchy.

Another motivation for selecting this environment for a case study was an inadequate 'official' schematic map displayed at many locations in the stadium area (see Fig. 3). Presumably, this map was intended as a wayfinding aid for stadium visitors. In this map, the circulation system of the area can be considered over-simplified. As a result, essential spatial information has been discarded, and some spatial relationships of the physical environment have been severely distorted in the map. For example, critical spatial relationships like types of branching points and shape of roads leading to the stadium were altered, some are missing. The mismatch between characteristics of the physical environment, and their pictorial representation in the map is a critical factor that may impair wayfinding. We can assume that in some cases it might be better not to have a map at all than having a confusing or inaccurate map (cf. Levine, 1982).

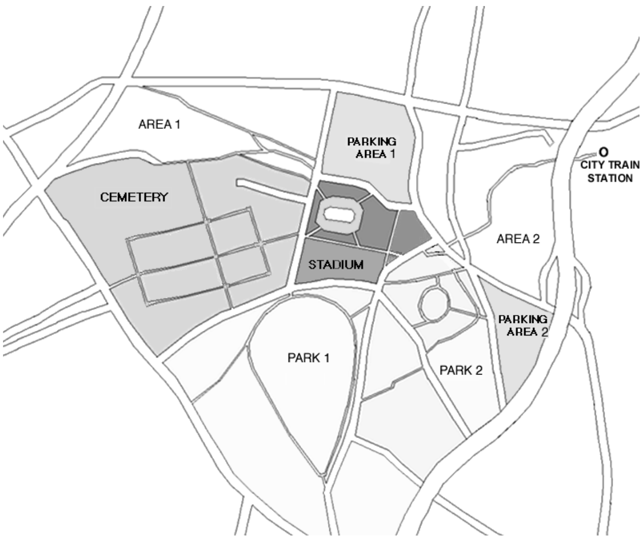

Fig. 2. City map of the Hamburg Volksparkstadion area

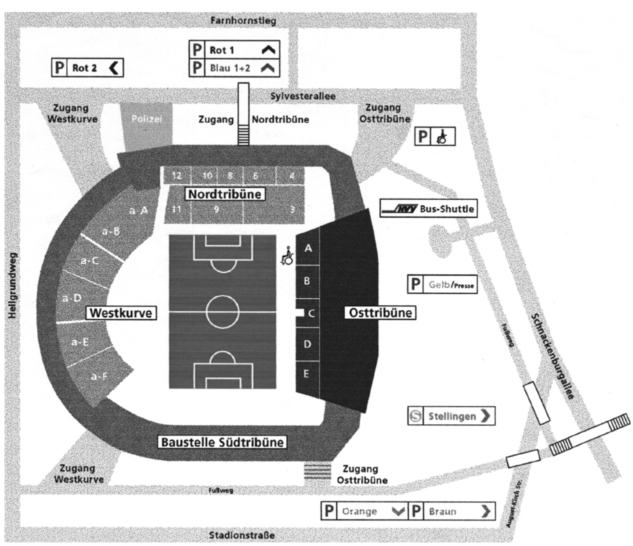

Fig. 3. Inadequate schematic map for wayfinding tasks in the Hamburg Volksparkstadion area

As this example of an inadequate schematic wayfinding map triggered the question for the aspects to be considered in producing more suitable maps, we investigated processes and strategies involved in producing schematic depictions of the illustrated area.

3.3 Description of the Empirical Study

Subjects. 15 subjects participated in the empirical tasks conducted in this study. Most of them were graduate students of the University of Hamburg Department for Informatics and the Doctoral Program in Cognitive Science.

Empirical Task and Materials. Subjects were provided with a task sheet containing procedural instructions, a warm-up task, and a description of the main task. In the warm-up task, subjects were presented a picture of a non-complex representation of a city area and were required to produce a new simplified map. An important requirement to carry out this task was to use the available taxonomy of 3 and 4 branches (see Fig. 1). In the main task, subjects were given visual information consisting of an A4 sheet containing a representation of the Hamburg Volksparkstadion area (see Fig. 2), and a similar picture of the taxonomy of branching points. The map of the area included data about freeways, streets, paths, and some urban features (e.g. stadium, cemetery, parks, and parking lots). Subjects were given the task to produce schematic maps to help wayfinders find their way to the stadium.

Since the schematic map to be produced was intended to help a variety of users find the way to the stadium, the type of transportation (e.g. by car, by bike, or by city train) potentially used by the wayfinders also was to be included. Subjects were asked to use the prototypes provided with the taxonomy of branching points as main constraints to carry out their map schematization task. They were required to evaluate and reconsider which type of information from the detailed map should be essentially included for schematization, and what could be simplified or eliminated when constructing an easily readable map. The task of completing the whole map dealt with the wayfinding aspect, but a main focus of this study was set on the schematization of the map.

Procedure. Sessions were carried out in an empirical research lab room. Individual sessions were restricted to approximately 45 minutes. During the first 5 minutes the subjects were made familiar with the problem and the requirements of the experiment. The next 10 minutes were assigned to carry out a warm-up task. The second part of the session was used to solve the schematization task. During the whole session, subjects were requested to think aloud; both their produced graphic output and their verbalizations were recorded on videotape. Subjects were not restricted with respect to the size of the map they were asked to produce. Nevertheless, they were provided with checkered sheets of A3 paper, which were considered to be large enough to construct the schematic map without facing any problem of lack of space. The experimenter answered procedural questions before starting the drawing procedure, but any further interaction was avoided during the empirical task. A signal was given 5 minutes before the end of each session.

4 Results

In the subsequent evaluation of the data, verbalizations were transcribed and, together with the sketches of the schematic maps produced during the empirical tasks, they were used to prepare a protocol. Both qualitative and quantitative results were evaluated; they are presented below.

4.1 Qualitative Results

Two examples of contrasting cases of schematic maps produced in the empirical study are shown in Fig. 4. Both maps have been schematized using the prototypes of the taxonomy of branching points. By comparing each example with the original map, we see that branching points of both schematic maps are constructed by considering their related prototypes of three and four branches in the given taxonomy. In addition, right / left relationships of branching points found in the new map are largely preserved with respect to those of the original map. However, by comparing one schematic map with the other, different levels of schematization are identified. Whereas in the first case almost no roads are eliminated, in the second one a large number of roads is not included in the schematic map. The group of eliminated roads is mostly constituted by *secondary roads* and *dead ends* that, as we will show in the next sections, often have to be regarded irrelevant for the purposes of wayfinding.

a) b)

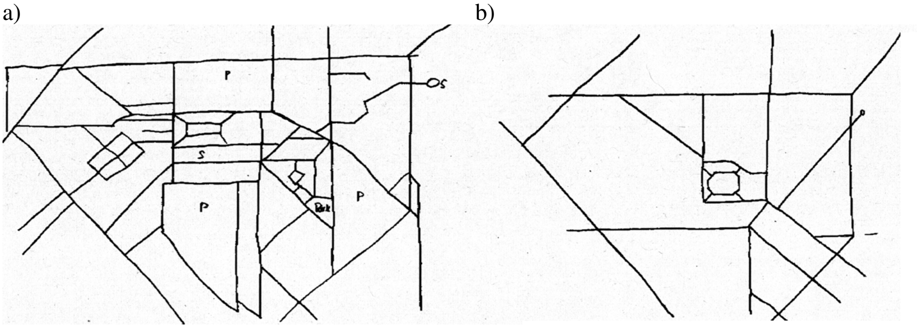

Fig. 4. Examples of two contrasting schematic maps: a) high-resolution depiction b) low-resolution depiction

4.2 Quantitative Results

To achieve the goals conveyed in Section 3.2, the performance of each of the 15 subjects that participated in the empirical task was assessed according to two key elements: i) the schematic map, and ii) the process of schematization. Quantitative results are informally presented as follows:

The Schematic Map. In this study we verified that a vast majority of the different branching point types embraced in the schematic map are preserved taking in consideration their related prototypes of the proposed taxonomy. In the experiments, 89% of branching points were schematized in terms of the prototypical cases. The experiments also showed that right / left relationships between branching points in the schematic map and those of the provided map are largely preserved. In other words, the relative right or left position between branching points has been maintained. 99% of right-left relationships between branching points are preserved. A further analysis was performed to examine if close distances between neighboring branching points are shortened to merge into a single branching point. By focusing on the five most closely located pairs of branching points, it was found that 63% were merged into a single branching point.

Results related to the inclusion or elimination of roads reveal that 34% of the total roads of the original map are eliminated in the new map. Accordingly, we found that within the eliminated roads, 40% correspond to *external main roads*, 52% belong to *secondary roads*, and 76% correspond to *dead ends*. However, only 4% of the eliminated roads belong to *border main roads*, and 5% to *internal main roads*. Additional results about the inclusion or elimination of road types with respect to their relationship with the functional areas upon which the map is organized were found:

Low percentages of connecting road elimination were found in the different functional areas of the map with respect to *border main roads*. For example, results show that 0% of the roads located in park 1, park 2, parking lot 1, and parking lot 2 were eliminated (see Table 1). Furthermore, few *main internal roads* were eliminated in the different functional areas of the map. Among these, 4.1% were observed in park 1, and 0% in parking lot 1 (see Table 2).

Table 1. Inclusion and elimination of *border main roads* with respect to the different functions in the map

%	eliminated	included
area 1	17.6	82.4
area 2	5.5	94.5
cemetery	4.4	95.6
park 1	0.0	100.0
park 2	0.0	100.0
parking lot 1	0.0	100.0
parking lot 2	0.0	100.0

Contrary to the previous results, high percentages of elimination of *secondary roads* were detected in most of the areas by which the map is classified. It was seen that 71% of the roads located in area 1, 70% of those located in park 1 were eliminated. However, a different situation was observed in the areas of the stadium and area 2, where only 7% and 3% of the *secondary roads* were eliminated, respectively (see Table 3). Moreover, regarding *dead ends*, results showed that 66.6% were eliminated in the area of the cemetery, and 80% in area 2.

Table 2. Inclusion and elimination of *main internal roads* with respect to the different functions in the map

%	eliminated	included
area 1	7.7	92.3
area 2	8.1	91.9
cemetery	8.8	91.2
park 1	4.1	95.9
park 2	7.2	92.8
parking lot 1	0.0	100.0
parking lot 2	6.6	93.4

Table 3. Inclusion and elimination of *secondary roads* with respect to the different functions in the map

%	eliminated	included
area 1	71.0	29.0
area 2	3.0	97.0
cemetery	68.0	32.0
park 1	70.0	30.0
park 2	62.0	38.0
stadium	7.0	93.0

The Process of Schematization. Findings derived from the study on particular cognitive patterns of behavior identified during the schematization process are presented as follows. 73% of subjects began to construct the schematic map starting from the area of the stadium, whereas only 27% start from the map's borders. Furthermore, most subjects schematize the map by referring to hierarchical relationships between roads. 53% of subjects schematized *main border roads* before *main internal roads* (see Table 4), and 80% of the subjects schematized *main internal roads* before *secondary roads* (see Table 5). These results are valid at least for that side of the map at which subjects started schematization. On the other hand, only 13% of the subjects neither considered the *main border / main internal roads* hierarchy, nor referred to the *main internal / secondary roads* hierarchy in any sector of the map. By exploring the main strategies used in the process of schematization, we divided the map into two main sectors or sides. Both sides relate to the right or left of the stadium, which is the main destination of the wayfinding task located in the center of the map. The terms *horizontal* and *vertical* strategies used below refer to the pattern of displacement effected by subjects while schematizing the sides of the map. 40% of the subjects schematized one sector of the map, and then completed the other sector (vertical strategy). On the other hand, 60% of the subjects schematized both sides of the map in parallel, iterating from one side to the other (horizontal strategy).

Referring to the schematization of the whole map, 33% of those subjects who used the horizontal strategy failed to schematize from *main internal roads* to *secondary internal roads*, but all of those subjects who used the vertical strategy had a 100% success. Furthermore, 56% of those who use the horizontal strategy failed to schematize from *border roads* to *main internal roads*, but only 33% of those subjects who used the vertical strategy failed to do so. Moreover, it was seen that those subjects who used the vertical strategy were able to preserve branching points from the map (as considered in the taxonomy) by 12% more than those who used the horizontal strategy. It was also found that subjects who used the vertical strategy were able to preserve right-left relationships between branching points by 20% more than those who used the horizontal strategy. Finally, it was observed that those who used the vertical strategy eliminated roads of every type by 10% more than those who used the horizontal strategy.

Table 4. Hierarchies considered in the schematization process (from *border main roads (bmr)* to *main internal roads (mir)*)

%	from *bmr* to *mir*	from *mir* to *bmr* or oscillation
one side of the map	53.0	47.0
whole map	20.0	80.0

Table 5. Hierarchies considered in the schematization process (from *main internal roads (mir)* to *secondary roads (sr)*)

%	from *mir* to *sr*	from *sr* to *mir* or oscillation
one side of the map	80.0	20.0
whole map	40.0	60.0

5 Discussion

The Schematic Map. Results indicate that the taxonomy of branching points provided in the empirical task is helpful for carrying out the schematization of the original map. Subjects manage to construct the new map using the prototypical branching points supplied with the assigned taxonomy. Moreover, most branching points of the new map are schematized by considering their related prototypes in the given taxonomy. Although schematizing maps involves undesirable effects such as modifications of branching points, findings illustrate about the effectiveness of the taxonomy in general, and the qualitative angle constraint in particular, as appropriate tools for preserving important relationships between road connections in the environment and branching points depicted in the schematic map.

Another important finding shows that right / left distinctions between schematized branching points are largely preserved with respect to those of the original map; in other words, this means that in most cases we found that those branching points located to the left or to the right of another one, are fully preserved in the new map as well. Although some changes and distortions are likely to occur as a direct result of both the qualitative angle constraints and nature of the schematizing process, it is worth saying that right / left relationships are by no means part of such modifications.

However, it has to be argued that such relationships are seen as an important component for orientation in wayfinding.

Occasionally, distances between closely located branching points are simplified by merging two branching points into one. In some cases, this operation is also applied for merging three branching points into one. It must be noted, however, that the relationship between the environment and the map is subject to metrical scale reduction. The bigger this reduction, the larger the visual distortions between branching points. In specific cases in which schematic maps are represented in very small scales, relatively larger or medium distances will probably be wrongly perceived as shorter ones. Consequently, merged branching points might cause mismatches with the use of the schematic map in the real environment. In other words, although merged branching points in the schematic map are regarded as an effective mechanism of simplification, scale should also be referred to as an important parameter.

Regarding the simplification and schematization of roads, we have seen that one third of the (total) roads of the provided map is eliminated from the new map. Within these, we have found that almost half of the *external roads* are eliminated from the map. Furthermore, more than half of the cases of *secondary roads* and *dead ends* count as irrelevant for the purposes of wayfinding, and are therefore eliminated. However, *border main roads* and *internal main roads* are largely preserved in the new map. All these findings suggest possible relations between the relative importance of a road with respect to the specific wayfinding task, and its consequent inclusion or elimination in the schematic map. In order to gather more refined evidence about these arguments, we have also studied the relationship between road types and the functional areas upon which the map is organized.

Based on the previous findings, we have proposed a general classification in which both *border main roads* and *internal main roads* are part of a higher level hierarchy, and *secondary roads* and *dead end roads* are included in the lower levels of that hierarchy. The experiments indicate that roads being part of a high hierarchical level are generally preserved in the new map independently of the relative importance of the functional area in which they are located. This means that in the process of deciding whether to include a higher-level road in a schematic map or not, the meaning of functional areas may be irrelevant or of lesser importance.

However, a different conclusion is presented with respect to roads belonging to a low hierarchical level, where preserving or eliminating them mostly depends on the role played by the functional area in which any of these roads is located. This argumentation serves to explain why in contrast to what happened in most functional areas of the map, *secondary roads* are largely preserved in the stadium area (indispensable to reach the main destination), and in area 2 (vital to connect with the city train). On the other hand, it becomes reasonable to argue that since *dead ends* do not play any vital role for wayfinding to places outside those roads, they are largely eliminated in the map.

The Process of Schematization. The second part of the analysis focuses on the process of schematization. By analyzing the verbalizations of subjects, it is observed that most of them start constructing the schematic map from the stadium area. It seems reasonable to hypothesize that subjects felt more confident to start the schematizing process by first structuring the map from the stadium (the destination roads lead to) and then continue doing so with respect to the remaining areas of the map. It is worth saying that only a third of the subjects started to schematize the map from the *main border roads* to the inner areas of the map.

In addition, two main aspects related to the process of schematization and construction of the map are identified. While the first one deals with the consideration of hierarchies, the second one focuses on such hierarchies with respect to different schematization strategies.

First, it is observed that most subjects construct the schematic map by referring to hierarchical relationships between roads. The dominant pattern of behavior for the majority of subjects shows that at least for one side of the map, *main border roads* are schematized before *main internal roads*, and *main internal roads* are generally schematized before *secondary roads*. Observing the whole map, we found that almost half of the subjects schematize *main internal roads* before *secondary roads* in all sectors, but few of them schematize *main border roads* before *main internal roads*. On the other hand, it is worth saying that a minority of the subjects schematizes the map without referring to any hierarchical relationship at all. Considering the findings of this study, it is argued that thinking in hierarchical structures is generally used as a successful aid helping most subjects to construct the schematic map.

Second, two main strategies are identified in the process of map schematization. The first one shows that less than half of the subjects schematize first of all one side of the map, and thereafter complete the other sector (vertical strategy). In the second one, a little more than half of the subjects schematize both sides of the map in parallel, sequentially alternating from one side to the other (horizontal strategy).

From previous findings of this study, we see that few subjects who use the vertical strategy are unable to schematize the whole map from *main border roads* to *main internal roads*, and from *main internal roads* to *secondary roads*. It is claimed that most subjects who use the vertical strategy (from one side of the map to the other one) learn from their experiences acquired in one side of the map. Thus, when they schematize the other side of the map they are able to recall and re-apply such experiences in a systematic and hierarchical way. The same cannot be said regarding the horizontal strategy, which refers to the parallel schematization of both sides of the map. We saw that most subjects are able to schematize using the hierarchical relationship from *main internal roads* to *secondary roads*, but half of them fail to schematize from *main border roads* to *main internal roads*. Alternating between cyclical oscillations that go from one side of the map to the other, the horizontal strategy privileges the *main internal roads / secondary roads* hierarchy. Contrasting with findings related to the vertical strategy, using the horizontal strategy for this hierarchical relationship does not completely help in recalling experiences learned in one side of the map and systematically applying them to the other one.

By comparing the vertical and horizontal strategies, we conclude that the vertical strategy proves to be more helpful than the horizontal strategy. Schematizing one complete sector of the map, and thereafter proceeding with the other one contributes to: i) structure visual information according to hierarchies; ii) learn from experiences it in a systematic and organized way; iii) increase the preservation of branching points from the map as regarded in the taxonomy; iv) increase the elimination of unnecessary roads.

6 Conclusions

The focus of this research was set on the schematization of maps for wayfinding tasks. By considering main findings of this study, conclusions and possible implications for navigation in the real environment are presented. We have seen that subjects were able to establish strong relationships between the provided taxonomy and the map. Both branching points and right-left relationships between branching points were generally preserved in the schematized map. These results strengthen what was pointed out in Section 3.2, where we criticized the inaccurate and confusing official schematic map displayed at many locations in the stadium area. We claimed that mismatches between the physical environment and the wayfinding map were caused as a consequence of many important spatial relationships that were oversimplified. The fact that in our study subjects tend to avoid such kind of mismatches is a clear reference to the conceptual differences that exist between schematization and undesirable oversimplification. This aspect should not be ignored when constructing wayfinding maps.

It can also be argued that if subjects are able to construct schematic maps considering the assigned taxonomy, they are also potentially able to use these types of maps while performing wayfinding tasks in a real environment. Some light has been shed on the classical dilemma of what to include and what to eliminate in a schematic map. The high percentage of road elimination shows that not always all the existing roads in a real environment must be included in a schematic map. It was shown that this largely depends on the relative hierarchical level of the road, or on the importance of the functional area where the road is located represents regarding the wayfinding task. The latter suggests that decisions of what type of roads might be included in a map should not be taken on the mere basis of just geometrical considerations. Their relative meaning regarding wayfinding also counts. The finding that most subjects construct the schematic map by considering hierarchical relationships between roads could have important implications for navigation in the environment. This reference to hierarchies suggests that stressing relative relationships between roads could be seen as an important aid for wayfinding.

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