Structuring Space with Image Schemata: Wayfinding in Airports as a Case Study

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Abstract. Wayfinding is a basic activity people do throughout their entire lives as they navigate from one place to another. In order to create different spaces in such a way that they facilitate people's wayfinding it is necessary to integrate principles of human spatial cognition into the design process. This paper presents a methodology to structure space based on experiental patterns, called *image schemata*. It integrates cognitive and engineering aspects in three steps: (1) interviewing people about their spatial experiences as they perform a wayfinding task in the application space, (2) extracting the image schemata from these interviews and formulating a sequence of subtasks, and (3) structuring the application space (i.e., the wayfinding task) with the extracted image schemata. We use wayfinding in airports as a case study to demonstrate the methodology. Our observations show that most often image schemata are correlated with other image schemata in the form of image-schematic blocks and rarely occur in isolation. Such image-schematic blocks serve as a knowledge-representation scheme for wayfinding tasks.

1. Introduction

Wayfinding is a natural process people learn as small children (Piaget and Inhelder 1967) and develop as they grow up. It takes place in many different situations, such as driving across a country, walking in a city, or moving through a building (Gluck 1991). In all of these situations people have one thing in common: they use *common-sense knowledge* of geographic space—knowledge that is mediated by structures and categories of understanding people's daily experiences in the space they live (Johnson 1987).

Over the last years, research on human wayfinding has mainly dealt with the exploration of cognitive representations and did not focus on the processes of how people immediately make sense of information along their ways. Alexander *et al.*

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(1977) presented research on the process of structuring space by developing a language consisting of patterns that are based on the experiental nature of things. These patterns help people to structure their environment. Johnson (1987) proposed that people use so-called *image schemata* to understand the world in which they live. Image schemata are presented to be non-propositional, recurring patterns that are grounded in people's experience and help them to structure space in order to know what to do with it. Image schemata fit into the category of *alternative conceptualizations* or *cognitive models of space*—models that are built upon people's experiences with the environment. The literature offers many different cognitive categorizations of space (Freundschuh and Egenhofer 1997). Couclelis and Gale (1986) distinguish six kinds of spaces: pure Euclidean, physical, sensorimotor, perceptual, cognitive, and symbolic space. However, the gap between *perceptual space* (i.e., objects are apprehended through the senses at one place and one time) and *cognitive space* (i.e., sensory images of objects are linked to elements of cognition, such as beliefs and knowledge) might just be a definitional one, because there seems to be a strong connection between the two. As Lee (1973) pointed out, percepts are not free of concepts and concepts are not free of percepts. In order to link perceptual and cognitive space, bridges need to be built.

In this paper we propose to represent space with image schemata. They serve as the structural components of a spatial task. Our approach combines concepts of two different scientific fields—cognitive science and engineering. We show that by using image schemata it is possible to establish a "common language" between a user and the engineer who can translate people's views of space into formal models. With the integration of other wayfinding information and principles these models can then be used to simulate real-world applications, such as wayfinding tasks, in a cognitively plausible way. After testing and restructuring the model space for ease of wayfinding, the engineer may translate the final structure back into the real-world space. The result is expected to be a more user-friendly spatial environment.

The contribution of this paper is twofold: on the one hand, it presents a way to model processes of structuring space; on the other hand, it provides a tool to bridge the gap between perceptual and cognitive space, because image schemata are cognitive concepts that also occur in the perceptual domain. To demonstrate our methodology we apply it to wayfinding in airports—a special case of moving through a building. Passengers at an airport have to find their way from check-in to their gate, from their gate to the baggage claim, and between gates. They are often in a hurry and must not get lost. This can be a difficult task, because many airports are poorly designed, have poor signage, and are densely crowded. Making wayfinding easier for passengers at an airport requires to design airport space in such a way that it facilitates people's structuring processes of tasks. The proposed methodology takes into account how people understand space. Therefore, its implementation should lead to computer systems that test airport space or other public buildings in the design phase for complexity of particular wayfinding tasks people have to perform.

The remainder of this paper continues with a review of common-sense knowledge and human wayfinding, and discusses empirical studies of how people find their ways and computational wayfinding models (Section 2). Section 3 reviews the concept of *image schema* and relates our approach to previous work. Section 4 presents a methodology to structure space based on such experiental patterns. An application of the methodology to a wayfinding task in an airport is shown in Section 5. Section 6 presents conclusions and suggests directions for further research.

2. Related Work

The process of structuring space such that it facilitates wayfinding is based on three research directions: (1) common-sense geographic knowledge, (2) human wayfinding, and (3) empirical studies and computer models for wayfinding. In this section we review the most characteristic parts of the literature that serve as a backbone for our work.

2.1 Common-Sense Geographic Knowledge

Since people's first experiences with the environment they have been establishing knowledge about the world in which they live. People need this basic knowledge for their everyday activities, such as walking, eating, learning, and shopping, and call it *common-sense knowledge*. Kuipers (1978) defines common-sense knowledge of space as "knowledge about the physical environment that is acquired and used, generally without concentrated effort, to find and follow routes from one place to another, and to store and use the relative position of places." Current spatial computer models support common-sense knowledge of geographic space only insufficiently. Representations are primarily based on Cartesian coordinates and therefore "the standard concepts of space are not always appropriate" (Frank 1992). People's reasoning is mainly based on common sense and they often do not think mathematically in everyday affairs. Instead of doing exact calculations, people most often apply methods of qualitative spatial reasoning (Frank 1996, Cohn 1995, Frank 1992, Freksa 1992), which rely on magnitudes and relative, instead of absolute, values. People also usually use topological instead of metrical information. Topological properties of objects stay invariant under such transformations as translations, rotations, and scalings. By using abstract geometrical analysis Piaget and Inhelder (1967) demonstrated that fundamental spatial concepts are topological, but not Euclidean at all.

Naive Geography is one current field of study that deals with common-sense geographic worlds (Egenhofer and Mark 1995). It establishes the link between knowledge that people have about their surrounding geographic space and the development of formal models that integrate this knowledge. Egenhofer and Mark give two different research methodologies as part of the framework for developing tools for "naive" users: (1) the development of formalisms of naive geographic models for particular tasks and (2) the testing and analyzing of formal models.

2.2 Human Wayfinding

Human wayfinding research investigates how people find their ways in the physical world, what they need to find it, how they communicate directional information, and how people's verbal and visual abilities influence wayfinding. According to Lynch (1960 p.3) wayfinding is based on "a consistent use and organization of definite sensory cues from the external environment." The ultimate goal of human wayfinding is to find the way from one place to another.

People need to have spatial knowledge—which is assumed to consist of landmark, route, and survey knowledge (Siegel and White 1975)—and various cognitive abilities, such as recognizing objects, in order to succeed in wayfinding. It is further assumed that such knowledge is represented in a cognitive map, which is a mental representation that corresponds to people's perception of the real world, although other metaphors, such as cognitive collages and spatial mental models, have also been proposed (Tversky 1993). Recent studies suggest that cognitive maps are structured hierarchically (Hirtle and Heidorn 1993). One consequence of hierarchies in cognitive maps is that they may have an influence on wayfinding performance, e.g., bias in spatial judgments such as distance estimates (Hirtle and Jonides 1985).

Researchers from various disciplines have thoroughly investigated the role cognitive maps play in spatial behavior, spatial problem solving, acquisition, and learning (Kitchin 1994). Much less, however, has been found out about how people immediately understand different spatial situations, i.e., how they structure and make sense of *practical* space[1] while performing a wayfinding task. Gluck (1991), therefore, suggested to explore the information needs—what information people need in order to understand their environment at a particular point in time. The idea behind this *sense-making* method is to look at the wayfinding process itself instead of looking at the final product (i.e., the cognitive map).

2.3 Empirical Studies and Computer Models for Wayfinding

Empirical results of how people find their ways are based on collecting individuals' perceptions of distances, angles, or locations. On the other hand, cognitively based computer models generally simulate a wayfinder that can solve route-planning tasks with the help of a cognitive-map-like representation. Both research directions contribute to the description of the features of the cognitive map.

From the perspective of empirical work, Kevin Lynch's (1960) "The Image of the City" is regarded as the foundation for human wayfinding research. His goal was to develop a method for the evaluation of city form based on the concept of *imageability*[2] and to offer principles for city design. Based on his investigations Lynch divided the contents of the city images into paths, edges (boundaries), regions, nodes, and landmarks. These elements were described as the building blocks in the process of making firm, differentiated structures at the urban scale and have been the basis for later research on wayfinding.

Weisman (1981) identified four classes of environmental variables that influence wayfinding performance within built environments: (1) visual access, (2) the degree of architectural differentiation, (3) the use of signs and room numbers to provide identification or directional information, and (4) plan configuration. His results were confirmed by other researchers who used various settings for their studies, such as airports (Seidel 1982), university buildings (O'Neill 1991a, Gärling *et al.* 1983), and libraries (O'Neill 1991b). People's familiarity with the environment was also found to have a big impact on wayfinding performance (Gärling *et al.* 1983, Seidel 1982).

Research on people's wayfinding performance has been particularly helpful for establishing practical guidelines (e.g., Arthur and Passini 1992, 1990) on how to design public buildings in order to facilitate wayfinding. Architects have come to the

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[1] This term goes back to Piaget and Inhelder (1967) who argued that spatial behavior and spatial representations are very different. They distinguished between *practical* space (i.e., acting in space) and *conceptual* space (i.e., representing space).

[2] "*imageability*: that quality in a physical object which gives it a high probability of evoking a strong image in any given observer." (Lynch 1960 p.9)

conclusion that facilitating people's wayfinding needs more than putting up signs, because most of the time signage cannot overcome architectural failures (Arthur and Passini 1992); therefore, wayfinding principles have to be considered during the design process—both for the overall spatial structure and for the form-giving features.

From the perspective of computer models for wayfinding, Kuipers's (1978) TOUR model presents a computational model of spatial knowledge whose concepts are primarily based on observations by Lynch (1960) and Piaget and Inhelder (1967). It simulates learning and problem solving while traveling in a large-scale urban environment. A subsequent application to the TOUR model utilizes an approach to robot learning based on a hierarchy of types of knowledge of the robot's senses, actions, and spatial environment (Kuipers *et al.* 1993).

Several other cognitively based computer models, such as TRAVELLER (Leiser and Zilbershatz 1989), SPAM (McDermott and Davis 1984), and ELMER (McCalla *et al.* 1982), have been developed to simulate learning and problem solving in spatial networks. NAVIGATOR (Gopal *et al.* 1989) integrates concepts from both cognitive psychology and artificial intelligence. It represents basic components of human information processing, such as filtering, selecting, and forgetting. The goal of this computer model was to investigate how the process of extracting and using environmental information is conducted by the architecture of human information processing.

The focus of these computer models lies primarily in the exploration of the cognitive map; however, by neglecting the processes of how people assign meaning to their spatial environment as they navigate through it, these models fail to incorporate components of common-sense knowledge. Golledge (1992) finds it possible that spatial knowledge is not well described by existing theories and, therefore, calls for more research on human understanding and use of space.

3. Image Schemata

The key point of the proposed methodology is to incorporate elements of human perception and cognition into the process of structuring space for ease of wayfinding. In this section we introduce the main component of this methodology.

3.1 What is an Image Schema?

Johnson (1987) proposes that people use recurring, imaginative patterns—so-called *image schemata*—to comprehend and structure their experiences while moving through and interacting with their environment. Image schemata are supposed to be pervasive, well-defined, and full of sufficient internal structure to constrain people's understanding and reasoning. They are more abstract than mental pictures, because they can essentially be reduced to topology, and less abstract than logical structures, because they are constantly operating in people's minds while people are experiencing the world (Kuhn and Frank 1991). An image schema can, therefore, be seen as a very generic, maybe universal, and abstract structure that helps people to establish a connection between different experiences that have this same recurring structure in common. Table 1 gives a selective list of Johnson's (1987 p.126) image schemata.

The CONTAINER schema, for example, represents containment. Its internal structure consists of an inside, an outside, and a boundary. People use this schema when entering a building (i.e., a CONTAINER). By crossing the boundary (e.g., through a doorway) they are moving from the outside into the inside of the building. The PATH schema represents movement and is, therefore, important for wayfinding. It is structured through a starting point, an endpoint, and a connection between these points. People use it whenever they move from one point to another. Johnson claims that, although image schemata can be drawn as diagrams and represented propositionally, it is impossible to capture their continuous nature as structures of people's understanding. Formalizations of image schemata as categories have used algebraic specifications (Kuhn and Frank 1991, Rodríguez and Egenhofer 1997). Our methodology of structuring space with image schemata is presented in a semi-formal way and focuses on wayfinding tasks that are performed in this space.

CONTAINER	BALANCE	COMPULSION
BLOCKAGE	COUNTERFORCE	RESTRAINT REMOVAL
ENABLEMENT	ATTRACTION	MASS-COUNT
PATH	LINK	CENTER-PERIPHERY
CYCLE	NEAR-FAR	SCALE
PART-WHOLE	MERGING	SPLITTING
FULL-EMPTY	MATCHING	SUPERIMPOSITION
ITERATION	CONTACT	PROCESS
SURFACE	OBJECT	COLLECTION

Table 1: Selective list of image schemata (Johnson 1987 p.126).

3.2 Image Schemata Related to Previous Work

Image schemata relate to common-sense knowledge—and particularly to Kuipers's definition of common-sense geographic knowledge (Section 2.1)—because people apply such patterns to use the physical environment without concentrated effort. Image schemata can also be seen as part of the topological information that is essential for common-sense reasoning. Relating image schemata to real world situations and objects is based on topological concepts (e.g., people can relate a building to the CONTAINER schema, because they perceive its inside-outside structure). Image-schematic reasoning is qualitative as well, because people do not use absolute values—such as the exact position of an entrance within a coordinate system—in their everyday lives. Finally, formalizations of image schemata will contribute to the development of Naive Geography (Egenhofer and Mark 1995): the result of our case study can be considered as part of a naive geographic model for the particular task of wayfinding in airports.

Research on human wayfinding offers many general principles and conditions (Section 2.3). Our method of structuring wayfinding tasks and space with image schemata contributes to the question of how people immediately understand and use their spatial environment. This is different to explaining how the environment is learnt: even when having a "perfect" cognitive map, people still have to make sense of spatial objects they perceive in order to know what to do with them. In this sense our approach does not contradict the idea of a cognitive map or other wayfinding principles, but forms a necessary supplement within the area of environmental interaction.

The basic idea for facilitating wayfinding is to organize space and spatial design models based on users's *cognitive perceptions*. The process of structuring space has on the one hand to involve perceptual and cognitive aspects, and on the other to provide to the application designer tools and constructs to check and guarantee space integration constraints such as "there is always a PATH that leads from the check-in counter to the airport gate."

4. A Methodology to Structure Space with Image Schemata

In this section we present a methodology to structure and represent space according to elements of people's perception and cognition. This methodology allows for the development of spatial models that are closer to human perception and cognition of a real-world space than models based on Cartesian coordinate systems. This is important for the creation of user-friendly environments that facilitate wayfinding. The methodology consists of three sequential stages: (1) during interviews people describe their spatial experiences while performing a wayfinding task in the application space; (2) these interviews are analyzed, image schemata extracted, and a task sequence is also formulated; and (3) the extracted image schemata are used to structure the wayfinding task and, therefore, the application space.

4.1 Interviews

Interviewing is a method to record behavior (Agar 1996). Tobler (1976) suggested interviews as a means of recording mental maps. At this stage we use interviews to record anticipated behavior of people interacting with a given environment, i.e., to record perceptual and cognitive space. During the interviews people describe their spatial experiences as they perform a wayfinding task in the application space. This is the only step where the application user is involved in the process of structuring the space.

4.2 Interview-Analysis and Extraction of Image Schemata

The second step consists of a systematic analysis of the transcripts of the interviews with the goal to extract the image schemata that people use to make sense of their environment while performing a wayfinding task. Mark and Frank (1996) showed how image schemata can be deduced from natural-language expressions describing geographic situations. The image schema that has been in the speaker's mind while making a statement can be inferred from the preposition used (Mark 1989). Freundschuh and Sharma (1996) used the same approach in a pilot study to assess the geographic content of children's narratives and investigate the relationships between locatives (i.e., words that describe relationships between places, e.g., in, on, under, and near) and spatial image schemata. One of their results was that books for different age levels utilized a standard set of locatives, suggesting the possibility to express most spatial image schemata with few locative terms. Our way of extracting image schemata from natural-language descriptions also exploits the proposed connection to spatial locatives (i.e., prepositions).

Another important aspect at this stage is the split-up of tasks into sequences of subtasks. A *task* is defined as a process within a specific time frame and consists of a source (i.e., start) and a target (i.e., end). Tasks are made of subtasks and are called *complex* if they are not atomic, i.e., cannot be subdivided into tasks. In the airport-case-study (Section 5) the timeline of a task is defined based on qualitative interest.

4.3 Structuring Wayfinding Tasks and Space with Image Schemata

At this stage a model of the application space is built, which is based on a representation of the extracted image schemata. The advantage of this approach is the incorporation of people's cognitive aspects into engineering processes. In order to (re)organize the application space from the perspective of wayfinding application users are interviewed, instead of architects who have the domain knowledge of the application. By analyzing user requirements and organizing common-sense knowledge (i.e., image schemata) the design process comes closer to the user and more semantics are added to the information. Figure 1 shows the stages of the proposed methodology.

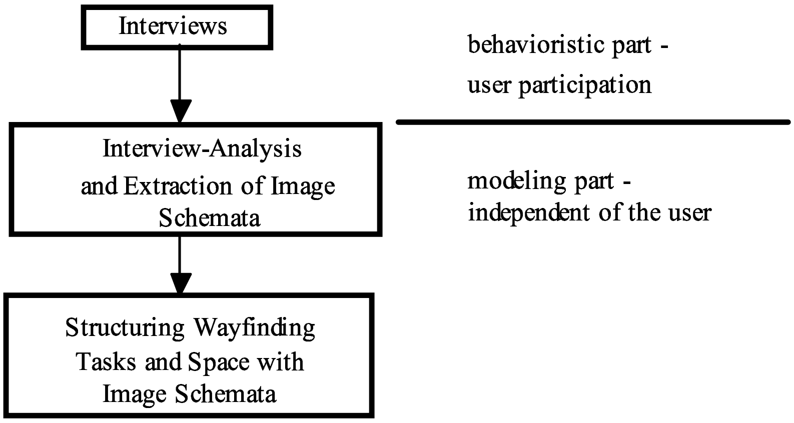

Figure 1: The three stages of the methodology to structure wayfinding tasks and space with image schemata.

Consider one starts with specifying the task using the proposed methodology, thus going the other way of first specifying perceptual and cognitive space, i.e., space how it should be. Then, a translation must be possible from perceptual and cognitive space to physical space. Such a translation cannot be complete without additional aspects. These aspects comprise wayfinding principles and conditions and practical guidelines for the design of user-friendly environments (Section 2.3).

5. Application to Airport Space

The goal of the methodology developed in the previous section was to establish a spatial model that comes close to human perception and cognition of a real-world space. In this section we demonstrate the usefulness of this methodology by applying it to a wayfinding task in airport space, following the three steps of interviewing, extracting image schemata from the interviews, and structuring the spatial task with the extracted image schemata.

5.1 Interviews

Subjects were shown pictures of Vienna International Airport (Austria) and asked to describe their spatial experiences while finding the way from the departure hall to their gate. The goal was to get on a flight to Istanbul (Turkey) departing at gate C53.

Subjects were asked to focus their description on architectural features and signs of the airport. Pictures were presented in a sequential order, featuring different situations that passengers have to face while performing the wayfinding task. As an example we give the transcript of one interview:

Picture 1: Departure hall.

> "I am in the departure hall and I can see the yellow signs in front of me, telling me the direction of how I have to move through this hall. It's a long space with ticket counters running down the side, so I am basically sort of funneled through. The hall has got a clear open area to walk. There are signs hanging from the ceiling but they look like advertisements, so I am kind of directed towards the bright yellow signs at the end. The color is good for directing me towards that end."

Picture 2: Ticket counters.

> "Now I move to the ticket counter and again the space is such that it looks like all ticket counters are lined up in a row; there are signs above them for the different flights, so that's quite clear."

Pictures 3, 4, 5: Towards passport control, signs.

> "Then I move along to where it's going towards passport control and I can see the yellow signs directing me towards C and an arrow; I am supposed to be looking for Istanbul and C53. They have got the letters for the destination yellow and they are using a different color for the gates. So, somehow my eyes are more attracted to the yellow letters with the city and then I look at the gate. It tells me it's boarding C53, so I have confirmation about that. And again, the yellow signs are good. A, B, C, D for the different terminals, so I am heading towards C. It looks pretty clear. It is an open space."

Picture 6: Duty-free area.

> "The next picture is the duty-free area. I do not explicitly see gate C. There are signs for A straight ahead and D off to the side and there is a pillar standing up. There is a pillar which might be blocking C. There seems to be an arrow going off to the right. It's quite crowded here. The space is much narrower than in the other photographs. So the area around the duty-free shops seems to be a more congested area, it is not such an open space. We have clear yellow signs but we do have an architectural feature that might be blocking my view to C."

Picture 7: Hallway between duty-free area and gate area.

> "In the next picture again, I don't see C explicitly listed in the yellow signs and people are walking towards me. I am not sure where I am supposed to be going here. This is actually confusing. We have a hallway, the signs are not obstructed by anything. I can see all the signs. It is not too busy here although it's kind of a narrow hallway. Open space, there are pillars but they are off to one side. Now they are not blocking anything. A, B and D are indicated where they are. So I am either just approaching C, I have lost the C sign."

Pictures 8, 9: Gate area.

> "Finally I guess I am at my departure gate. C53 is labeled clearly. I would have no problem heading towards C53. It's a room. It's got some big pillars with seats kind of around them. Signs are just all hanging from the ceiling. I don't see anything blocked there, so I see where my gate is."

5.2 Interview-Analysis and Extraction of Image Schemata

One result of the interview-analysis is the decomposition of the wayfinding task into a sequential order of subtasks.

Task: Going from the departure hall to the gate.

Subtasks:
- 1a Finding the ticket-counter in the departure hall.
- 1b Going to the ticket-counter.
- 2 Moving along the departure hall to find the passport control.
- 3 Going through the passport control.
- 4a Finding the way to the gate area.
- 4b Moving from the duty-free area to the gate area.
- 5a Finding the correct gate.
- 5b Going to the gate.

The subtasks (1a, 1b), (4a, 4b), and (5a, 5b) have been put into pairs, because in most of the cases they occur in parallel. For instance, people are looking for the ticket-counter and moving through the departure hall at the same time.

The list of spatial image schemata used by Freundschuh and Sharma (1996) consists of seven elements (i.e., CONTAINER, SURFACE, NEAR-FAR, VERTICALITY, PATH, LINK, and CENTER-PERIPHERY). Our interview-analysis shows that people apply a larger variety of image schemata to structure wayfinding tasks in airports. In the following section we present a short description of a selection of the extracted image schemata, the semi-formal structures applied to extract them, and examples for their occurrence in natural-language terms.

CONTAINER

A CONTAINER has an inside, an outside, and a boundary, and represents the idea of containment. In an airport people apply the CONTAINER schema to buildings as well as to gates and signs.

- in (I, departure hall): "I am in the departure hall."
- not in ("C", signs): "I don't see C listed in the yellow signs."
- CONTAINER (departure hall): "I enter this hall which is the departure hall."
- CONTAINER (gate): "I enter the gate."

SURFACE

This schema is a trivial one and people need it all the time while standing or walking. One interviewee used the SURFACE schema to refer to the absence of moving corridors that are part of some airports: "They don't have this corridor which you can *stand on*."

- SURFACE (hall): "The hall has got a clear open area to walk."
- moving, walking, going -> SURFACE: "People are walking."

PATH

The PATH schema is especially important for wayfinding tasks as people always move along PATHS. A PATH has a starting point, an endpoint, and a connection between them.

- PATH (I, ticket counter): "Now I move to the ticket counter."
- towards (I, C) -> PATH (I, C): "I am heading towards C."

LINK

People relate connected objects via LINKS. Such LINKS occur both in our spatial and temporal experience. Airport-passengers try to establish visual LINKS between their current position and the location of the object they are looking for. LINKS (not necessarily visual LINKS) are transitive, e.g., if a LINK exists between the passenger's position and a sign, and another LINK between the same sign and an object location, then there is a LINK between the passenger and the object.

- LINK (I, signs): "I can see the yellow signs."
- above (signs, ticket counters): "There are signs above them (i.e., the ticket counters)."
- LINK (ticket counter, ticket counter, etc.): "All ticket counters are lined up in a row."

CENTER-PERIPHERY

This image schema is used for orientation. In most of the cases the passenger functions as the center[3] and the surrounding environment is periphery. But sometimes the center is an object of the environment.

- CENTER-PERIPHERY (I, objects of departure hall): "I am in the departure hall and I can see the yellow signs in front of me."
- around (pillars, seats): "It's got some big pillars with seats around them."

ATTRACTION

While performing a wayfinding task people always seem to be spatially attracted to certain features.

- directed towards (I, signs): "I am kind of directed towards the bright yellow signs."
- ATTRACTION (I, letters): "My eyes are more attracted to the yellow letters."

BLOCKAGE

BLOCKAGES are obstacles (e.g., walls or pillars) that stand in the way of PATHS and LINKS and, therefore, render wayfinding tasks more difficult.

- blocking (pillar, "C"): "There is a pillar which might be blocking C."
- blocking (architectural feature, view to C) = blocking (architectural feature, LINK (I, C)): "Architectural feature that might be blocking my view to C."

FULL-EMPTY

Wayfinding in airports gets more difficult when the space is crowded; therefore, this image schema has to be taken into account.

- full (duty-free area, people): "It's quite crowded here (i.e., in the duty-free area)."
- empty (hallway, people): "It is not too busy here."

MATCHING

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[3] "Our world radiates out from *our bodies* as perceptual centers from which we see, hear, touch, taste, and smell our world." (Johnson 1987 p.124)

In order to know that they are on the right track or have arrived at the right gate, people have to match their cognitive information with the environmental information (e.g., the content of signs).

- MATCHING (cognitive information "C53", environmental information "C53"): "It tells me it's boarding C53, so I have confirmation about that."

BALANCE

A well-structured, balanced spatial design facilitates environmental interaction for users.

- BALANCE (ticket counters): "Again the space is such that it looks like all ticket counters are lined up in a row."
- BALANCE (signs): "We have clear yellow signs."

OBJECT

The OBJECT schema is a trivial one as people use it all the time to identify discrete entities in space.

- OBJECT (yellow sign), OBJECT (ticket counter), OBJECT (gate), etc.

ENABLEMENT

The criteria for using this image schema are a potential force vector and the absence of barriers or blocking COUNTERFORCES.

- can[4] (I, see signs): "I can see the yellow signs." The same meaning could also be expressed as enables (LINK (I, signs), I, see signs): "The visual link between myself and the yellow signs enables me to see them."
- enables (MATCHING (cognitive information "C53", environmental information "C53"), I, have confirmation): "It tells me it's boarding C53, so I have confirmation about that."

SCALE

This schema is based on the "more" or "less" aspect of human experience. People use the SCALE schema to understand quantitative amount and qualitative degree.

- more (congestion): "The area around the duty-free shops seems to be a more congested area."

COLLECTION

People experience COLLECTIONS as sums of individual objects. COLLECTIONS may form areas, such as a COLLECTION of gates forms a gate area. Groupings of similar destinations into zones facilitates wayfinding if these groupings are clearly identified (Arthur and Passini 1992).

- COLLECTION (ticket counters): "All ticket counters are lined up in a row."

FRONT-BACK

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[4] "Modal verbs, such as *can, may, must, could, might,* are verbs that pertain to our experience of actuality, possibility, and necessity" (Johnson 1987 p.48).

Although not included in Johnson's list of image schemata, this seems to be an important orientational schema for wayfinding, e.g., "Having things always in front of me seems to be more useful." and "If I don't find the C, I go back and retrace myself."

- in front of (I, signs): "I can see the yellow signs in front of me."
- straight ahead (I, signs): "There are signs for A straight ahead."

VERTICALITY

This image schema is also missing in Johnson's list, but it is important for wayfinding in airports, because many signs are near the ceiling. The VERTICALITY schema is structured by two points and a vertical dimension in-between them.

- VERTICALITY (signs, ceiling): "Signs hanging from the ceiling."
- above (signs, ticket counters): "There are signs above them (i.e., the ticket counters)."
- stand up (pillar): "There is a pillar standing up."

5.3 Structuring Wayfinding Tasks and Space with Image Schemata

In order to structure the wayfinding task "find the way from the departure hall to the gate" based on experiental patterns, we use the sequence of subtasks and the extracted image schemata. It is important that these concepts used to structure the application space correspond with the concepts used by people as part of their perceptual and cognitive processes; otherwise, such a representation "will be of little if any use to geographers, spatial analysts, or geographic information systems users" (Abler 1987). In the following section we present the results of our analysis (i.e., the image-schematic representation of the wayfinding task) for one subtask, using the interview of Section 5.1. Similar analyses were performed for the remaining subtasks.

Subtask 2: Moving along the departure hall to find the passport control.

Transcript	*Extracted Image Schemata*
"Then I move along to where it's going towards passport control and I can see the yellow signs directing me towards C and an arrow."	PATH, LINK (I, passport control), SURFACE (departure hall), CENTER-PERIPHERY (I, objects of departure hall), ENABLEMENT (PATH (I, passport control), I, move along), OBJECT (passport control); LINK (I, signs), OBJECT (signs), ENABLEMENT (LINK (I, signs), I, see signs), COLLECTION (yellow signs);
"I am supposed to be looking for Istanbul and C53."	looking for: LINK (I, "Istanbul" and "C53"), MATCHING (cognitive information "Istanbul" and "C53", environmental information "Istanbul" and "C53");
"They have got the letters for the destination yellow and they are using a different color for the gates."	BALANCE (yellow letters for destination and different color for gates)

“So, somehow my eyes are more attracted to the yellow letters with the city, and then I look at the gate.”	LINK, ATTRACTION (I, letters), ENABLE-MENT (LINK (I, letters), I, ATTRACTION (I, letters)); LINK (I, gate), ENABLEMENT (LINK (I, gate), I, look at gate);
“It tells me it’s boarding C53, so I have confirmation about that.”	MATCHING (cognitive information “C53”, environmental information “C53”), ENABLEMENT (MATCHING (cognitive information “C53”, environ-mental information “C53”), I, have confirmation);
“And again, the yellow signs are good.”	BALANCE (yellow signs), SCALE (yellow signs, good), COLLECTION (signs), OBJECT (signs);
“A, B, C, D for the different terminals, so I am heading towards C.”	PATH, LINK, CENTER-PERIPHERY (I, C), SURFACE (departure hall), ENABLEMENT (PATH (I, C), I, heading towards C);
“It looks pretty clear. It is an open space.”	BALANCE (spatial situation), SCALE (spatial situation, pretty clear);

Table 2: Transcript and image-schematic representation of subtask 2.

Figure 2: View from the departure hall towards passport control at Vienna International Airport.

5.4 Superimposition of Image Schemata

People use a variety of image schemata to structure their wayfinding tasks in airports. The previous analysis shows that most of these patterns are not experienced in isolation, but are correlated with other image schemata. Such *superimpositions* of schematic structures (Johnson 1987 p.125) occur, because it is difficult to fully express a spatial situation using only one pattern. Typical examples for such superimpositions are:

- PATH + LINK + SURFACE: “I move to the ticket counter.” implies that there is a LINK between the subject’s current position and the ticket counter (i.e., a PATH). The activity of moving affords a SURFACE.
- At least one other image schema is needed to experience ENABLEMENT, e.g., a PATH between two points enables people to walk from one point to the other; visual LINKS between people and OBJECTS enable them to view these OBJECTS.
- VERTICALITY + LINK: Most often the VERTICALITY schema is experienced as a vertical LINK, e.g., “Signs hanging from the ceiling.” implies such a vertical LINK between the signs and the ceiling.
- ATTRACTION + LINK: In many cases a visual LINK is a precondition for experiencing ATTRACTION, e.g., “My eyes are more attracted to the yellow letters.”
- CONTAINER + OBJECT: People experience signs as individual entities that contain information, e.g., “I don’t see C explicitly listed in the yellow signs.”
- BLOCKAGE + OBJECT: BLOCKAGES are experienced when OBJECTS are in the way, e.g., “A pillar which might be blocking C.”
- COLLECTION + OBJECT: People perceive COLLECTIONS of things as well as the individual OBJECTS, e.g., “All ticket counters are lined up in a row.”
- Orientational image schemata, such as CENTER-PERIPHERY and FRONT-BACK, are superimposed upon other patterns in order to establish a directional spatial context.

Such superimpositions or *image-schematic blocks* form an integral part of the task-representation. They are usually complemented by some individual patterns such as orientational image schemata. The number of block-sequences may be a possible indication for space-complexity in regard to ease of human wayfinding and should, therefore, be taken into account during spatial design processes.

6. Conclusions and Future Work

This paper presented a methodology to structure wayfinding tasks and space with image schemata. These experiental patterns are part of people’s perceptual and cognitive processes and help them to understand a spatial environment. In order to demonstrate the methodology we applied it to wayfinding in airports. Image schemata were extracted from interviews and then used to build a knowledge-representation for a wayfinding task in airport space. It was shown that such a representation consists of tightly coupled image-schematic blocks, complemented by individual patterns. We argue that an image-schematic representation of the application space matches better with people’s real-world spatial interactions than coordinate-based models, which neglect people's perceptual and cognitive processes. Therefore, the integration of image schemata into the design process should lead to more user-friendly spatial environments.

Several directions for future work in the representation of human cognitive concepts in spatial information systems remain open.

- In order to represent image schemata in spatial information and design systems, they have to be formalized. Attempts to formalize the CONTAINER and SURFACE schemata have already been made (Kuhn and Frank 1991, Rodríguez and Egenhofer 1997), but in order to represent and simulate complex processes such as wayfinding, a more comprehensive set of image schemata must be formalized in an integrated algebra. Such formalizations should also take the force dynamics of image schemata into consideration.
- The demonstration of our methodology is only based on a few interviews. More human-subjects testing is needed to verify the universality of image-schematic blocks. Instead of using pictures to interview people about their spatial experiences, human-subjects testing may be done in the real-world application space. Many of the stresses of navigating in an airport, such as overcrowdedness or timetrouble, could influence a dynamic knowledge acquisition. As Allen *et al.* (1978) and Deakin (1996) pointed out, the results of testing people's spatial perceptions with a sequence of pictures may not be equal to their perceptions while walking through the actual environment. Also, interviews should be made for different spatial environments, such as public transport buildings, hospitals, or libraries.
- The number of image schemata that are necessary for the successful completion of a particular task might be an indication for the complexity of a space. This assumption could be verified by comparing the same wayfinding task within two different spatial environments and counting the number of occurring image schemata per task as a metric. Our assumption is that people's wayfinding performance in an application space increases when the number of image schemata per task decreases.

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8. References

R. Abler (1987) The National Science Foundation National Center for Geographic Information and Analysis. *International Journal of Geographical Information Systems* 1(4): 303-326.

M. Agar (1996) *The Professional Stranger: An Informal Introduction to Ethnology*. Academic Press.

C. Alexander, S. Ishikawa, M. Silverstein, M. Jacobson, I. Fiksdahl-King, and S. Angel (1977) *A Pattern Language, Towns-Buildings-Construction*. Oxford University Press, New York.

G. Allen, A. Siegel, and R. Rosinski (1978) The Role of Perceptual Context in Structuring Spatial Knowledge. *Journal of Experimental Psychology: Human Learning and Memory* 4(6): 617-630.

P. Arthur and R. Passini (1990) *1-2-3 Evaluation and Design Guide to Wayfinding*. Public Works Canada, Technical Report.

P. Arthur and R. Passini (1992) *Wayfinding: People, Signs, and Architecture.* McGraw-Hill Ryerson, Toronto.

A. Cohn (1995) The Challenge of Qualitative Spatial Reasoning. *ACM Computing Surveys* 27(3): 323-325.

H. Couclelis and N. Gale (1986) Space and Spaces. *Geografiske Annaler* 68B: 1-12.

A. Deakin (1996) Landmarks as Navigational Aids on Street Maps. *Cartography and Geographic Information Systems* 23(1): 21-36.

M. Egenhofer and D. Mark (1995) Naive Geography. in: A. Frank and W. Kuhn (Eds.), *Spatial Information Theory-A Theoretical Basis for GIS*. *Lecture Notes in Computer Science* 988, pp. 1-15, Springer, Berlin-Heidelberg-New York.

A. Frank (1992) Spatial Reasoning—Theoretical Considerations and Practical Applications. in: *EGIS'92*, Munich, Germany.

A. Frank (1996) Qualitative spatial reasoning: cardinal directions as an example. *International Journal of Geographical Information Systems* 10(3): 269-290.

C. Freksa (1992) Using Orientation Information for Qualitative Spatial Reasoning. in: A. Frank, I. Campari, and U. Formentini (Eds.), *Theories and Methods of Spatio-Temporal Reasoning in Geographic Space*. *Lecture Notes in Computer Science 639* Lecture Notes in Computer Science 639, pp. 162-178, Springer-Verlag.

S. Freundschuh and M. Egenhofer (1997) *Human Conceptions of Spaces: Implications for Geographic Information Systems*. National Center for Geographic Information and Analysis, Technical Report.

S. Freundschuh and M. Sharma (1996) Spatial Image Schemata, Locative Terms and Geographic Spaces in Children's Narrative: Fostering Spatial Skills in Children. *Cartographica, Monograph 46, Orienting Ourselves in Space* 32(2): 38-49.

T. Gärling, E. Lindberg, and T. Mäntylä (1983) Orientation in buildings: Effects of familiarity, visual access, and orientation aids. *Journal of Applied Psychology* 68: 177-186.

M. Gluck (1991) Making Sense of Human Wayfinding: Review of Cognitive and Linguistic Knowledge for Personal Navigation with a New Research Direction. in: D. Mark and A. Frank (Eds.), *Cognitive and Linguistic Aspects of Geographic Space*. *Series D: Behavioural and Social Sciences* 63, pp. 117-135, Kluwer Academic Publishers, Dordrecht, The Netherlands.

R. Golledge (1992) Place Recognition and Wayfinding: Making Sense of Space. *Geoforum* 23(2): 199-214.

S. Gopal, R. Klatzky, and T. Smith (1989) NAVIGATOR: A Psychologically Based Model of Environmental Learning Through Navigation. *Journal of Environmental Psychology* (9): 309 - 331.

S. Hirtle and P. Heidorn (1993) The Structure of Cognitive Maps: Representations and Processes. in: T. Gärling and R. Golledge (Eds.), *Behavior and Environment: Psychological and Geographical Approaches*. Oxford University Press, New York.

S. Hirtle and J. Jonides (1985) Evidence of Hierarchies in Cognitive Maps. *Memory & Cognition* 13(3): 208-217.

M. Johnson (1987) *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason*. The University of Chicago Press, Chicago.

R. Kitchin (1994) Cognitive Maps: What are they and why study them? *Journal of Environmental Psychology* 14: 1-19.

W. Kuhn and A. Frank (1991) A Formalization of Metaphors and Image-Schemas in User Interfaces. in: D. Mark and A. Frank (Eds.), *Cognitive and Linguistic Aspects of Geographic Space*. *Behavioural and Social Sciences - Vol. 63* pp. 419-434, Kluwer Academic Publishers, Dordrecht, Boston, London.

B. Kuipers (1978) Modeling Spatial Knowledge. *Cognitive Science* 2(2): 129-154.

B. Kuipers, R. Froom, W.-Y. Lee, and D. Pierce (1993) The Semantic Hierarchy in Robot Learning. in: J. Mahadevan (Ed.), *Robot Learning*. pp. 141-170, Kluver Academic, Boston.

H. Lee (1973) *Percepts, concepts, and theoretic knowledge*. Memphis State University Press, Memphis.

D. Leiser and A. Zilbershatz (1989) The Traveller—A Computational Model of Spatial Network Learning. *Environment and Behavior* 21(4): 435-463.

K. Lynch (1960) *The Image of the City*. MIT Press, Cambridge, Massachusetts.

D. Mark (1989) Cognitive Image-Schemata for Geographic Information: Relations to User Views and GIS Interfaces. in: *GIS/LIS'89*, Orlando, Florida, November 1989, pp. 551-560.

D. Mark and A. Frank (1996) Experiential and Formal Models of Geographic Space. *Environment and Planning B* 23: 3-24.

G. McCalla, L. Reid, and P. Schneider (1982) Plan Creation, Plan Execution, and Knowledge Acquisition in a Dynamic Microworld. *International Journal of Man-Machine Studies* 16(89-112).

D. McDermott and E. Davis (1984) Planning Routes through Uncertain Territory. *Artificial Intelligence* 22: 107-156.

M. O'Neill (1991a) Effects of signage and floor plan configuration on wayfinding accuracy. *Environment and Behavior* 23: 553-574.

M. O'Neill (1991b) Evaluation of a conceptual model of architectural legibility. *Environment and Behavior* 23: 259-284.

J. Piaget and B. Inhelder (1967) *The Child's Conception of Space*. Norton, New York.

M. Rodríguez and M. Egenhofer (1997) *Image-Schemata-Based Spatial Inferences: The Container-Surface Algebra*. Department of Spatial Information Science and Engineering, University of Maine, USA, Technical Report.

A. Seidel (1982) Way-Finding in Public Spaces: The Dallas/Fort Worth, USA Airport. in: *20th International Congress of Applied Psychology*, Edinburgh, Scotland.

A. Siegel and S. White (1975) The development of spatial representations of large-scale environments. in: H. Reese (Ed.), *Advances in child development and behavior*. 10, Academic Press, New York.

W. Tobler (1976) The geometry of mental maps. in: R. Golledge and G. Rushton (Eds.), *Spatial choice and spatial behavior*. pp. 69-81, Ohio State University Press, Columbus, Ohio.

B. Tversky (1993) Cognitive Maps, Cognitive Collages, and Spatial Mental Model. in: A. Frank and I. Campari (Eds.), *Spatial Information Theory: Theoretical Basis for GIS*. *Lecture Notes in Computer Science* 716, pp. 14-24, Springer Verlag, Heidelberg-Berlin.

J. Weisman (1981) Evaluating architectural legibility: Way-finding in the built environment. *Environment and Behavior* 13: 189-204.