# Comparing the complexity of wayfinding tasks in built environments*

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**Abstract**

Wayfinding is a basic activity that people do throughout their entire lives as they navigate from one place to another. Many theories of spatial cognition have been developed to account for this behavior; however, most of the computational models focus on knowledge representation (e.g., cognitive maps) and do not consider the process of how people structure wayfinding tasks and space. This paper presents a computational method to compare the complexity of wayfinding tasks in built environments. As a measure for such complexity we use a simple wayfinding model that consists of two critical elements: choices and clues. We show that elements of people's perception and cognition can be used to determine the elements of the wayfinding model and, therefore, to compare the complexity of wayfinding tasks in built environments. A case study of wayfinding in airports demonstrates the applicability of the method. The integration of this method into the computational design process of built environments will help to identify architectural problems with regard to wayfinding prior to construction.

## 1 Introduction

People do wayfinding throughout their entire lives. They navigate from place to place, relying on knowledge that is mediated by structures and categories of understanding people's daily experiences in the space they live (Johnson 1987). Wayfinding is a natural skill that 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.

Over the last few years, research on human wayfinding has mainly dealt with the exploration of cognitive representations or what Norman (1988) calls "knowledge in the head." At the same time, little attention has been paid to "knowledge in the world," such as the processes of wayfinding (e.g., the information needs) (Gluck 1991) and the design of spatial environments (Arthur and Passini 1992). Norman argues that people do not need to have all knowledge in the head in order to behave precisely. Knowledge can be distributed—partly in the head, partly in the world, and partly in the constraints of the world. Norman further states that much of the information people need to perform a task is in the world and that the human mind is perfectly tailored to make sense of this world. Piaget and Inhelder (1967) have long since 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). To design built environments that are easy to navigate it is necessary to understand how people immediately make sense of spatial situations while performing a wayfinding task. Our work focuses on properties of the environments (i.e., "knowledge in the world") as perceived and cognized by people. Therefore, it deals primarily with the exploration of practical space as defined by Piaget and Inhelder. It is important to investigate people's perceptual and cognitive structures in order to be able to model them in future spatial information and design systems. These systems can then be used to simulate real-world applications, such as wayfinding tasks, in a cognitively plausible way, because they integrate human spatial concepts.

In this paper we present a computational method to compare the complexity of wayfinding tasks in built environments. The method is built upon a simple wayfinding model that consists of two critical elements: choices and clues. We show that these elements can be determined by using elements of people's perception and cognition. Johnson (1987) proposed that people use so-called *image schemata* to understand the world in which they live. Image schemata are recurring mental patterns that help people to structure space so that they know what to do with it. These patterns are highly structured themselves and grounded in people's experiences. Image-schematic reasoning is qualitative in nature, thereby focusing on the essential aspects and supporting common-sense reasoning. It often relates to topological information and avoids the use of absolute values, such as the exact position of an entrance within a coordinate system. Image schemata fit into the category of *alternative conceptualizations* or *cognitive models of space*—models that are built upon people's experiences with their environment.

This work is at the core of Naive Geography (Egenhofer and Mark 1995) which promotes the development of formal models of geographic space that match closely with human cognition. It targets real-world environments and, therefore, complements other studies that focus on simulations of spaces in geographic information systems (Freundschuh and Egenhofer 1997). To demonstrate the applicability of our method we apply it to wayfinding in airports—a special case of moving through a building. Passengers at an airport have to find their ways from check-in counters to gates, from gates to the baggage claim area, and between gates. They are often in a hurry and cannot afford to get lost. This can be a difficult task, because many airports are poorly designed, have poor signage, and are densely crowded. Also, many passengers are unfamiliar with the particular space and fast motion, which puts them in stressful situations. Finally, airport designers have to cope with providing architectural guidance in emergency situations such as fires. 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 method takes into account how people understand space. Its implementation should lead to computer systems that test airport space and other built environments in the design phase for complexity of particular wayfinding tasks people have to perform.

Our method of comparing the complexity of wayfinding in built environments contributes to the question of how people immediately understand and use their spatial environment. This is different from explaining how the environment is learnt. Even with a perfect cognitive map, people still have to make sense of spatial objects they perceive so that they know what to do with them. In this sense our approach forms a necessary supplement within the area of environmental interaction to the idea of a cognitive map and other wayfinding principles.

In Section 2 we review wayfinding research, discuss empirical studies of how people find their ways in built environments, and address computational wayfinding models. Section 3 introduces a simple wayfinding model for built environments. It explains the structure and the critical elements of the model. In Section 4 we demonstrate how elements of people's perception and cognition (i.e., image schemata) can be used to determine the critical elements of the wayfinding model. An application of the method to compare the complexity of a common wayfinding task in two different airports is shown in Section 5. Section 6 presents conclusions and suggests directions for future work.

## 2 Wayfinding research

Finding one's way in a built environment relies on a variety of elements. In this section we review human wayfinding research, empirical studies of how people find their ways in different large-scale spaces, and computational wayfinding models.

## 2.1 Human wayfinding

Human wayfinding research investigates the processes that take place when people orient themselves and navigate through space. Theories try to explain how people find their ways in the physical world, what people need to find their ways, how they communicate directions, and how people's verbal and visual abilities influence wayfinding. Lynch (1960 p.3) defines wayfinding as 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. The space in which human wayfinding usually takes place is called large-scale space (Kuipers 1978). Objects cannot be moved because they are larger than people, therefore, people have to navigate through large-scale space to learn about it. Examples for large-scale spaces are landscapes, cities, and houses.

### *2.1.1 Spatial knowledge and cognition*

People need to have spatial knowledge and various cognitive abilities to succeed in wayfinding (e.g., following a path). Human spatial knowledge of geographic space is assumed to consist of three levels (Siegel and White 1975): (1) *landmark knowledge* comprises salient points of reference in the environment, (2) *route knowledge* puts landmarks into a sequence (e.g., navigation paths), and (3) *survey* or *configurational knowledge* allows people to locate landmarks and routes within a general frame of reference (i.e., incorporating Euclidean measurements). The cognitive abilities depend on the task at hand. Finding one's way in a street network (Timpf *et al.* 1992, Car 1996) uses a different set of cognitive abilities than navigating from one room to another in a building (Gärling *et al.* 1983, Moeser 1988). People are usually good in applying their individual skills to the task at hand: if their spatial skills are weak, they use verbal skills to navigate, and vice versa (Vanetti and Allen 1988).

### *2.1.2 Cognitive maps*

People use clues within their environments (i.e., knowledge in the world) and/or representations of spatial knowledge about their environment to successfully perform wayfinding. One useful metaphor suggests that people have a *cognitive map* in their heads (Kuipers 1982)—a mental representation that corresponds to people's perceptions of the real world. Other metaphors, such as cognitive collage (Tversky 1993) or cognitive atlas (Hirtle 1998) have also been proposed. Considering the process of acquiring spatial knowledge of an environment, the cognitive map develops from a mental landmark map to a mental route map and should eventually result in a mental survey map. The last stage is closest to a cartographic map, though it still contains inaccuracies and distortions. People construct and develop their cognitive maps based on the recording of information through perception, natural language, and inferences. Complex environmental structures can lead to slower development of cognitive maps and also to representational inaccuracies.

Researchers from various disciplines have thoroughly investigated the role cognitive maps play in spatial behavior, spatial problem solving, acquisition, and learning (Kitchin 1994). Kitchin

(1996), for example, developed an integrative conceptual schema by drawing together theories about the knowledge's content, structure, and form of the cognitive map, the learning strategies used to acquire such knowledge, and the processes of spatial thought. These theories were combined with basic transactional theory to produce a detailed schema of spatial thought and behavior. Much less, however, has been found out about how people immediately understand different spatial situations while performing a wayfinding task. Gluck (1991) points out this lack of information by arguing that previous work on wayfinding concentrated on the description of the cognitive map and neglected affective and logistical concerns in most of the cases. As an alternative approach Gluck suggests to explore the information needs. He further envisions a typology of wayfinding scenarios and proposes the use of the *sense-making* investigation method: "'Sense-making' is a creative human process of understanding the world at a particular point in time and space limited by our physiological capacities, our present, past and future." (Gluck 1991 p.129). The idea behind the sense-making method is to look at the wayfinding process itself instead of looking at the representation.

### 2.2 Human wayfinding performance

The literature on *performance* discusses empirical results of how people find their ways. Investigations are based on collecting individuals' perceptions of distances, angles, or locations. An example for a typical experiment is the pairwise judgment of distance between points. Such experiments help in describing features of the cognitive map.

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* (i.e., "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)) 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. In Gärling *et al.*'s (1983) study of orientation in a large university department visual access was regarded as an important factor, because wayfinding performance of subjects with restricted sight improved less over time. The impact of orientation tools like floor plans was also investigated. The performance of subjects with restricted sight using floor plans improved as fast as that of subjects with no restricted sight, floor plans, therefore, counteract the negative effect. In another study Gärling *et al.* (1986) proposed to classify the environment by examining the degree of differentiation, the degree of visual access, and the complexity of spatial layout. The influence of floor plan complexity on both cognitive mapping and wayfinding performance, and the existence of an interaction between floor plan complexity and the quality of signage was demonstrated in two studies by O'Neill (1991a, 1991b). His results showed that an increase in floor plan complexity leads to a decrease in wayfinding performance. The presence of signage was an important factor but could not compensate for floor plan complexity. Seidel's (1982) study at the Dallas/Fort Worth Airport confirmed that the spatial structure of the physical environment has a strong influence on people's wayfinding behavior. For passengers arriving at the gate with direct visual access to the baggage claim, wayfinding was easier. In addition to Weisman's four classes of environmental variables, people's familiarity with the environment also has a big impact on wayfinding performance: frequency of prior use had a big facilitating effect in university buildings (Gärling *et al.* 1983) as well as in airports (Seidel 1982). Cornell *et al.* (1994) tested people's accuracy of place recognition and used the results to develop a model of wayfinding.

Research on people's wayfinding performance has been particularly helpful for establishing practical guidelines on how to design public buildings to facilitate wayfinding. Architects seem to have come to the 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 formgiving features. Some guidelines (Arthur and Passini 1992, 1990)—despite focusing on the design and placement of signage—highly stress the importance of architectural features. In "1-2-3 Evaluation and Design Guide to Wayfinding" Arthur and Passini (1990 p.A-1) introduce the term *environmental communication* (i.e., "transfer of orientation, wayfinding (direction), and other information within the built environment by means of signs and other communications devices or architectural features to enable people to reach destinations"), arguing that the built environment and its parts should function as a communication device. Arthur and Passini mention two major aspects regarding the understanding of buildings: (1) a *spatial* aspect that refers to the total dimensions of the building (e.g., walls enclose space and elements such as an interior atrium break it up) and (2) a *sequential* one that considers a building in terms of its destination routes. Destination routes should eventually lead to so-called destination zones. These are groupings of similar destinations within buildings into clearly identifiable zones (Arthur and Passini 1992). In order to facilitate wayfinding to such destination zones the circulation system should be of a form people can easily understand. It is further suggested that fewer decision points on any route and redundancy in wayfinding information are also facilitating effects.

## 2.3 Computer models for wayfinding

Cognitively based computer models generally simulate a wayfinder that can solve route-planning tasks with the help of a cognitive-map-like representation. The focus of these models is to find out how spatial knowledge is stored and used, and what cognitive processes operate upon it.

The TOUR model is considered the starting point for a computational theory of wayfinding (Kuipers 1978). It is a model of spatial knowledge whose spatial concepts are based mainly on observations by Lynch (1960) and Piaget and Inhelder (1967). With the TOUR model Kuipers simulates learning and problem solving while traveling in a large-scale urban environment. His main focus of attention is the cognitive map in which knowledge is divided into five categories: (1) routes, (2) topological street network, (3) relative position of two places, (4) dividing boundaries, and (5) containing regions. This knowledge is represented through environmental descriptions, current positions, and inference rules that manipulate them. Because TOUR copes with incomplete spatial knowledge of the environment, it learns about it by assimilation of observations into the given structure. 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), 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. In this model, two views of a suburban environment—an objective and a subjective (i.e., cognitive) one—are complemented by cognitive processes relating to spatial learning and navigation. The cognitive map is modeled through a hierarchical network consisting of nodes, links, subnodes, and sublinks (i.e., neurologically based information processing).

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

## 3 A wayfinding model for built environments

To compare the complexity of wayfinding tasks in built environments we use a simple wayfinding model that considers two critical elements: *choices* and *clues*; therefore, this model is called the choice-clue wayfinding model.

### 3.1 Choices

Choices relate directly to decision points in wayfinding. They are most apparent whenever a person has the opportunity to select among different paths. The use of choices as one measure for the complexity of wayfinding tasks in built environments is motivated by the fact that choices have a big impact on wayfinding complexity. The number of decision points directly influences the difficulty of performing a wayfinding task (Arthur and Passini 1992). We distinguish between points where subjects have one obvious choice to continue the wayfinding task and points where subjects have more than one choice to continue the wayfinding task. Points with “choice = 1” are called *enforced decision points*, while points with “choices > 1” are called *decision points*.

### 3.2 Clues

People use clues to make wayfinding decisions (i.e., how to proceed from viewpoints). Clues are properties of the built environment, such as signs and architectural features, and relate directly to Norman’s (1988) “knowledge in the world.” In our wayfinding model we use clues as the second measure for the complexity of wayfinding tasks in built environments. We distinguish between *existing* (i.e., “clues”) and *non-existing clues* (i.e., “no clues”). Existing clues are divided into *good clues* (i.e., complete clues that enable people to decide about the correct continuation of their path) and *poor clues* (i.e., incomplete or misleading clues that do not enable people to decide about the correct continuation of their path).

### 3.3 Combinations of choices and clues

The Cartesian product of the two types of choices (i.e., one choice vs. more than one choice) and three types of clues (i.e., good, poor, and none) identifies six situations in a wayfinding scenario. The choices define the columns of the wayfinding model, while the clues define the rows (Figure 1). Each of the six situations represents a different level of complexity.

- Choice = 1 and good clue(s): At an enforced decision point people are forced to continue in one direction. Good clues confirm that people are on the right track. Therefore, wayfinding is easy at these points.
- Choice = 1 and poor clue(s): Even though there is only one way to proceed, people might hesitate to follow the way because poor clues do not reassure them that they are still on the right track.
- Choice = 1 and no clue(s): Again, people might hesitate to follow the way because they have no confirmation of being on the right track.
- Choices > 1 and good clue(s): At decision points people need good clues to choose the correct path. If clues are complete, easy to read, and easy to understand, wayfinding at those points is easy.
- Choices > 1 and poor clue(s): Decision points with incomplete or misleading clues pose wayfinding problems for people.
- Choices > 1 and no clue(s): Decision points without any clues form the worst scenario for wayfinding. At such points people are lost.

***<Figure 1>***

After evaluating the six criteria of the choice-clue wayfinding model for each viewpoint, points in the two problem areas—i.e., choices > 1 and no clues or poor clues—are counted. When comparing a wayfinding task within two built environments with this model, the space with the higher rating of points within problem areas is considered more complex for wayfinding.

## 4 The use of mental patterns to determine choices and clues

The critical elements of the wayfinding model (i.e., the choices and clues) have to be determined in order to compare the complexity of wayfinding tasks in built environments. This can be done by looking at perceptual and cognitive concepts people use to structure and understand space. 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. The PATH schema, for example, represents movement and is, therefore, important for wayfinding. It is structured through a starting point, an endpoint, and a connection between these points and used whenever people move from one point to another. In order to establish directional and orientational spatial context—an *egocentric reference frame* which is based on people's bodies vs. an *allocentric reference frame* that is based on features of the environment (Levinson 1996, Kuhn and Blumenthal 1996)—people superimpose *orientational image schemata* upon general image schemata.

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.

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 and Frank 1996, Freundschuh and Sharma 1996). For instance, the English-language preposition "in" relates to the CONTAINER schema, whereas "on" describes situations related to the SURFACE schema (Mark 1989). The systematic analysis of the transcripts has the goal to extract the image schemata that people use to make sense of their environment while performing a wayfinding task. Some of the image schemata occur via metaphorical projections to describe non-spatial situations.

## 4.1 Extraction of image schemata from interviews

There has been the common view in artificial intelligence that expert knowledge can be much easier extracted than common-sense knowledge. Hayes (1985) on the other hand, states that basic intuitions are near the surface and relatively accessible by introspective interviewing. Such transcripts may be obtained either through an actual tour of the tested space or through simulations. Goldin (1982) compared actual and simulated information as alternative sources of environmental information and concluded that under some conditions, for instance, when the goal is to convey perceptual details, a film or slide presentation may provide as much detail as a live tour through the environment. Allen (1978) suggested that a "presentation of slides separated by spatial intervals may closely parallel typical visual experience in large-scale environments" and used such procedure to assess the relationship between people's visual perception and spatial representation of an urban environment. Another experiment utilized slides for route simulation to prove the navigational aid of landmarks on street maps (Deakin 1996).

We extract image schemata from interviews in which we record anticipated behavior of people interacting with a given environment. During the interviews people describe their spatial experiences as they imagine performing a wayfinding task in the built environment. For the subsequent comparison of the extracted image schemata we use a semi-formal representation in the form of predicates in which the predicate name refers to the image schema and the arguments refer to the object(s) that are involved in the image schema (Equation 1a). Arguments can also be image-schematic structures themselves (Equation 1b). Sequences of predicates represent sequences of image schemata as people observed and used them.

IMAGESCHEMA_X (argument_x1, …, argument_xn) (1a)

IMAGESCHEMA_Y (argument_y1, IMAGESCHEMA_Z (argument_z1, …, argument_zn), …, argument_yn) (1b)

***<Table 1>***

Table 1 shows for each image schema an example of the mapping from a natural-language description onto the predicate representation. The formalism provides a sufficiently standardized structure to detect the critical elements and to compare different descriptions, however, it is not used to perform automated deductions as in predicate calculus or a Prolog programming environment. To distinguish between different contexts, we use symbols in combination with image schemata.

?IMAGESCHEMA = Looking for a specific image schema.

- ?LINK (I, sign): "I'm *looking for* a sign."
- ?PATH (I, gateC57): "I'm *heading for* gate C57."

IMAGESCHEMA? = Not sure about a specific image schema.

- IN_CONTAINER (I, "C")?: "I'm *not sure* if I'm in 'C'."

NOT IMAGESCHEMA = Specific image schema does not exist.

- NOT LINK (I, letters): "I *can't read* the letters."
- NOT MATCHING (my gate, "A"): "Gate A is *not* my gate."

### 4.2 Extraction of choices and clues from image-schematic representations

To use the choice-clue wayfinding model for comparing the complexity of wayfinding tasks in built environments, the combinations of choices and clues must be evaluated for every viewpoint of the wayfinding task in the built environment. The image-schemata sequences extracted from the natural-language descriptions form the basis for this analysis.

Image schemata are used to decide whether a viewpoint is a decision point (i.e., choices >1) or an enforced decision point (i.e., choice = 1) by counting the different PATH schemata. A viewpoint qualifies as a decision point if there exist at least two different PATH schemata (Equation 2a). If only one PATH schema occurs, then the viewpoint qualifies as an enforced decision point (Equation 2b).

PATH (I, x) and PATH (I, y) => decision point (2a)

PATH (I, x) and NOT PATH (I, y•x) => enforced decision point (2b)

In a similar way, clues are determined. Many clues can be found by looking at the different LINK schemata. Most often people establish visual LINKS to signs in order to perceive information. But clues might also be certain architectural features such as a hallway that is perceived and cognized as a funnel and, therefore, suggests moving forward, for instance, COMPELLED_TO_BY (I, movingStraightAhead, funnel). The following rules about occurrences and sequences of image schemata help to infer clues:

| | |
|---|---|
| ?LINK (I, …) and LINK (I, …) ⇒ clue | ("I'm looking for a link and there is a link.") |
| ?LINK (I, …) and NOT LINK (I, …) ⇒ no clue | ("I'm looking for a link but I can't find it.") |
| LINK (I, …) and PATH (I, …) ⇒ good clue | ("I find a link from which I find a path.") |
| LINK (I, …) and NOT PATH (I, …) ⇒ poor clue | ("I find a link but it doesn't give me a path.") |

## 5 Comparing the complexity of a wayfinding task at two airports

We conducted interviews with human subjects to assess the difference in the complexity of a wayfinding task at Vienna International Airport (Austria) and Frankfurt International Airport (Germany). During the interviews subjects described their spatial experiences with two simulated airport spaces, while orienting themselves and navigating through the spaces. We selected Vienna International Airport because it is generally considered easy to navigate, and Frankfurt International Airport because it is often considered difficult to navigate. The test site Frankfurt International Airport was selected based on the results of a questionnaire that had been distributed to 25 frequent flyers (age ranging from fifteen to sixty years, about half of them female and the other half male). We asked these people at what airports they had most difficulties in finding their way from the check-in counter to the gate. Frankfurt was mentioned most often, followed by London Heathrow. Passengers also had trouble finding their ways at Los Angeles International Airport, Amsterdam Airport Schiphol, Atlanta Hartfield International Airport, and Paris Charles-de-Gaulle International Airport. As the main reasons for their answers people mentioned unclear and illogical infrastructures. Subsequent informal talks with the interviewees showed that most of them who had also been to Vienna International Airport found this airport easy to navigate.

### 5.1 Test setup

For both airports we used a sequence of color slides to simulate the route-following task from the departure hall (i.e., the check-in counter) to a specific gate. Subjects were shown a sequence of 16 slides from inside Vienna International Airport and 21 slides from inside Frankfurt International Airport. The route in Vienna was approximately 330 meters, while the route in Frankfurt was 360 meters. We used color slides instead of pictures (Raubal *et al.* 1997), because these can be projected onto a wall to give viewers a better impression of actually being involved in the environment tested. The slides were presented in a sequential order, featuring different situations that passengers face when they would perform the wayfinding task in the actual environments.

The focus of this human subjects testing was to receive data for the existence of image schemata in wayfinding, and not a thorough analysis of human behavior; therefore, we used a simplified experimental setup with a small subject pool and color slides in lieu of actual navigation space. During the interviews subjects were given the following task for Vienna International Airport (appropriate substitutions in the description were made for Frankfurt International Airport):

> "You are a passenger at Vienna International Airport in Austria. You are about to board Austrian Airlines flight OS501 leaving at 11:35 to New York. Your gate number is C57. For check-in you can use any of the counters 51-65. You are now standing in the departure hall, waiting to check in your luggage. Your task is the following: going from the departure hall to your gate."

Eight volunteers—four female and four male, each of them a native English speaker, not all of them spatially educated—were shown and tested on the same task at both airports. Half of the subjects saw the task inside Vienna International Airport first and the other half saw the task inside Frankfurt International Airport first. For every slide subjects were given the following two questions:

- What are the things and features you see on this picture and why did you choose them?
- How do you move on from here, referring to the things and features you noticed?

### 5.2 Analysis of Vienna International Airport

The task of going from the departure hall to the gate at Vienna International Airport consists of three subtasks that have to be performed in a sequential order. First, people have to check in, then move through passport control, and finally move through security control at the gate. Subjects were asked to describe their spatial experiences while finding the way from the departure hall to the gate (described as flight OS501 to New York departing from gate C57). Figures 2-4 show a sequence of slides taken from the duty-free area after the passport control. Each figure displays the view given to the test person and provides the translation from one subject's natural-language description into the corresponding image-schemata predicates.

***<Figure 2>***

***<Figure 3>***

***<Figure 4>***

## 5.3 Analysis of Frankfurt International Airport

The task of going from the departure hall to the gate at Frankfurt International Airport consists of five subtasks that have to be performed in a sequential order. First, people have to check in, then move through ticket control, security control, and passport control, and finally go to the gate. Subjects were asked to describe their spatial experiences while finding the way from the departure hall to the gate (described as flight LH4408 to Lyon departing from gate B45). Figure 5 offers the view of the space in the departure hall and gives the transcript and image-schematic mappings for one situation in the departure hall from one interview.

***<Figure 5>***

## 5.4 Comparison of the complexity of a wayfinding task at Vienna International Airport and Frankfurt International Airport

In this section we use the choice-clue wayfinding model and the image-schematic representations to provide evidence that the wayfinding task "going from the departure hall to the gate" is more complex in Frankfurt than in Vienna.

### *5.4.1 Analysis for Vienna International Airport*

Table 2 shows the analysis for Vienna International Airport. Each viewpoint was analyzed as in the following examples:

- Slide 3 (check-in area): This viewpoint represents a decision point because there are 2 paths (i.e., PATH (I, gate55) and PATH (I, gate54)). LINK (I, redCheck-inCounters) represents a good clue because it results in a path to the check-in counters. But the subject can't figure out if "55" refers to the track (i.e., LINK (I, signs) + MATCHING ("55", track)?) and where to put his luggage (i.e., MATCHING ("55", LEFT_OF (luggage-conveyor-belt, counter55))? + MATCHING ("55", RIGHT_OF (luggage-conveyor-belt, counter55))?). These are two poor clues. Also, the counters are not with Austrian Airlines (i.e., NOT MATCHING (check-in counters, "Austrian Airlines")), which is interpreted as a missing link to Austrian Airlines. Based on the facts that the viewpoint is a decision point and there are 2 poor clues and 1 missing clue the subject does not know which way to go. Therefore, slide 3 represents a viewpoint that falls into the model category of problems.

- Slides 6, 7, 8 (duty-free area after passport control, Figures 2-4): This viewpoint represents a decision point because the subject has 3 paths to choose from (i.e., PATH (I, gateA) + PATH (sign, B-C-gates) + PATH (I, A-C-gates)). One good clue prevents the subject from choosing the wrong way (i.e., COUNTERFORCE_TO (LINK (I, "A"), PATH (I, gateA))) and the other 2 good clues result in 2 correct paths (i.e., LINK (I, sign) + LINK (I, "B-C-gates") and LINK (I, sign) + LINK (I, "A,C")). The poor clue of a subdued flight-information-sign (i.e., LINK (I, flight-information-sign) + NOT ATTRACTED_BY (I, flight-information-sign)) does not prevent the subject from finding the correct path. Therefore, there are no wayfinding problems at this viewpoint.

***<Table 2>***

### *5.4.2 Analysis for Frankfurt International Airport*

Table 3 shows the final analysis for Frankfurt International Airport. Again, each viewpoint was analyzed as in the following examples:

- Slide 5 (departure hall, Figure 5): From the image-schematic representation can be inferred that this viewpoint represents a decision point: the subject mentions one path (i.e., PATH (I, blueSigns)) and is also looking for a path to his gate (i.e., ?PATH (I, myGate)). The subject sees something to the right but cannot make out what it is (i.e., LINK (I, RIGHT_OF (unspecifiedObjects, I)) + NOT MATCHING (unspecifiedObjects, cognitiveInformation)). He also sees a sign but concludes that he is in the wrong place (i.e., LINK (I, sign) + NOT MATCHING (environmentalInformation, cognitiveInformation)). Finally, he sees familiar blue signs in the distance. He can only make out a "C" on them but nothing else (i.e., LINK (I, FAR_FROM (blueSigns, I)) + MATCHING (blueSigns, previousBlueSigns) + LINK (I, "C") + NOT LINK (I, otherSign-information)). Because there are only three poor clues the subject has to look for a new reference point (i.e., ?LINK (I, newReferencePoint)). Therefore, slide 5 represents a viewpoint that falls into the model category of problems.
- Slide 19 (between passport control and gate): This viewpoint represents an enforced decision point because the architectural features suggest only one obvious way to go (i.e., PATH (startOfFunnel, endOfFunnel)). Although the subject does not notice any signs at first (i.e., NOT LINK (I, signs)) and then sees a poor clue (i.e., LINK (I, sign) + LINK (I, "44-unspecified #") + FAR_FROM (sign + "44-unspecified #, I)), there are two good clues that serve as confirmations to the subject for continuing in this direction: the subject sees a corridor (i.e., LINK (I, corridor)) and posts that present a funnel (i.e., LINK (I, posts) + LEFT_OF (COLLECTION (posts), funnel) + RIGHT_OF (COLLECTION (posts),

funnel)) that suggests moving forward. Therefore, the subject has no wayfinding problems at this viewpoint.

***<Table 3>***

The wayfinding task "going from the departure hall to the gate" has a higher rating of points within "problem areas" at Frankfurt International Airport (2) than at Vienna International Airport (1). Considering the fact that the two routes are almost equal in length, this result indicates that the chosen wayfinding task is more complex at Frankfurt International Airport than at Vienna International Airport. Other outcomes from the analysis reinforce the truth of this statement:

- Frankfurt has more decision points (10) than Vienna (5). At decision points people have to choose from different paths which usually makes wayfinding more difficult than at enforced decision points (Arthur and Passini 1992). Therefore, the wayfinding task is more complex in Frankfurt.
- The sum of all "poor" clues totals 14 in Frankfurt and only 5 in Vienna.
- The sum of all missing clues totals 7 in Frankfurt and only 3 in Vienna.

## 6 Conclusions and future work

This paper presented a computational method to compare the complexity of wayfinding tasks in built environments. In order to perform such comparison we used a simple wayfinding model where choices and clues function as complexity-measures. The application of the method to wayfinding in airports showed that concepts of people's perception and cognition (i.e., image schemata) can be used to determine the elements of the choice-clue wayfinding model and that these elements account for the complexity of wayfinding tasks in built environments. Our main argument was that by integrating people's perceptual and cognitive structures of space into spatial information and design systems, it is possible to simulate real-world applications, such as wayfinding tasks, in a cognitively plausible way.

Our work showed that people use a variety of image schemata to structure their wayfinding tasks in airports. Many image schemata are metaphorically projected and, therefore, metaphorical projections play an integral part in the descriptions and sense-making of space. The application to comparing the complexity of a particular wayfinding task at two different airports demonstrated that the use of image schemata is a powerful method to describe human spatial cognition related to navigation tasks. The integration of image schemata into the design process helps to identify architectural problems (with regard to wayfinding) prior to construction. The design process of easier-to-navigate built environments must take care of constraints, such as necessary LINKS and PATHS at different viewpoints. This can be done by using semi-formal image-schematic structures (i.e., ?LINK (I, …) ⇒ LINK (I, …) needed or ?PATH (I, …) ⇒ PATH (I, …) needed).

Several directions for future work regarding the representation of human cognitive concepts in spatial information systems remain open and some research questions have to be answered.

- 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. Formalizations of image schemata will contribute to the development of Naive Geography (Egenhofer and Mark 1995): the formal image-schematic structures shown in this paper can be considered as part of a naive geographic model for the particular task of wayfinding in airports.
- Sequences of image schemata are sufficient to describe wayfinding tasks in built environments at an abstract level. In order to fully describe wayfinding processes, the image-schematic structures and the choice-clue wayfinding model have to be enriched with relevant wayfinding principles that can be found in the literature.
- The demonstration of our method is only based on a few interviews. A more sophisticated and extended experimental design is needed to verify the cross-cultural universality of image-schematic representations. Instead of using slides to interview people about their spatial experiences, human-subjects testing may be done in real-world application space. Also, interviews should be done for different built environments, e.g., public transport buildings, hospitals, or libraries.
- Our analysis shows that many image schemata are not experienced in isolation, but are correlated with other image schemata—represented as tightly coupled image-schematic blocks. For example, the LINK, PATH, and SURFACE schemata are used together most of the time. These *superimpositions* of schematic structures (Johnson 1987) occur, because it is difficult to fully express a spatial situation using only one pattern. More research has to be done on which image schemata are used within block-structures and how they are connected.
- Finally, it has to be investigated which image schemata are relevant for the comparison of wayfinding tasks in built environments. One might look for a percentage-relation between important and unimportant image schemata used in the descriptions. LINKS and PATHS seem to be the most important schemata for wayfinding tasks, since people tend to perceive spatial features via LINKS before they decide where to go via PATHS. Image schemata like ON_SURFACE, on the other hand, seem to be trivial and, therefore, of less importance for the model.

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| **Choice(s)** / **Clue(s)** | | **Choice = 1**<br>Enforced decision point | **Choices > 1**<br>Decision point |
|---|---|---|---|
| **Clue(s)** | good | O.K. | O.K. |
| | poor | O.K.<br>("don't need clues")<br>Hesitation<br>("no confirmation") | Problems |
| **No clue(s)** | | O.K.<br>("don't need clues")<br>Hesitation<br>("no confirmation") | Problems |

**Figure 1:** Choice-clue wayfinding model.


| Transcript | Extracted image schemata |
| --- | --- |
| “I see shops.” | LINK (I, shops); |
| “It’s well-lit and it’s not claustrophobic.” | ATTRACTED_BY (I, light); |
| “I see the sign that says I should go down that hall to go to gate A.” | LINK (I, sign),<br>LINK (I, hall),<br>PATH_ALONG (I, gateA, SURFACE (hall)); |
| “That’s not the direction I want to go.” | COUNTERFORCE_TO (LINK (I, “A”), PATH (I, gateA)); |
| “The aisle can’t go very far.” | MATCHING (hall, aisle),<br>PATH (beginOfAisle, endOfAisle),<br>NOT FAR_FROM (beginOfAisle, endOfAisle); |
| “It disappears among the different shops.” | CENTER-PERIPHERY (aisle, shops), NEAR_FROM (shops, aisle); |

**Figure 2:** One subject’s transcript and image-schematic representation of slide 6, the duty-free area after passport control at Vienna International Airport.

| Transcript | Extracted image schemata |
|---|---|
| “It’s an open space.” | IN_CONTAINER (unspecifiedObjects, duty-freeSpace); |
| “I see the sign to the B-C-gates.” | LINK(I, sign), |
| | LINK (I, “B-C-gates”), |
| | PATH (sign, B-C-gates); |
| “I see information about the layout of the airport and flight information on the monitors.” | LINK (I, airportLayoutInformation), LINK (I, ON_SURFACE (flightInformation, monitors)); |
| “There are shops.” | LINK (I, shops); |
| “They stand out against the back.” | ATTRACTED_BY (I, shops), |
| | IN_BACK_OF (unspecifiedObjects, shops); |

**Figure 3:** Continuation to Figure 2’s transcript and image-schematic representation to slide 8, the duty-free area after passport control at Vienna International Airport.

| Transcript | Extracted image schemata |
|---|---|
| “I see lots of shops.” | LINK (I, shops),<br>FULL_OF (duty-freeArea, shops); |
| “I see a way to a sign that says ‘A, C’.” | LINK (I, sign),<br>PATH (I, sign),<br>LINK (I, “A, C”); |
| “There’s two ways to get to C.” | NOT MATCHING (PATH (I, gateC), PATH (I, gateC)); |
| “I see a flight-information-sign hanging from the ceiling.” | LINK (I, flight-information-sign),<br>IS_DOWN (flight-information-sign, ceiling); |
| “It’s subdued so I ignored it.” | NOT ATTRACTED_BY (I, flight-information-sign); |
| “I’m looking for gate C, the general gate-C-area.” | ?LINK (I, “gates C”); |
| “I go down the shops-area in the center.” | CENTER-PERIPHERY (IN_FRONT_OF (PATH (I, A-C-gates), I), shops),<br>IN_CONTAINER (shops, area),<br>ON_SURFACE (I, floor); |

**Figure 4:** Final view of the duty-free area after passport control at Vienna International Airport with transcript and image-schematic representation.

| Transcript | Extracted image schemata |
|---|---|
| "I see stuff off to the right, I can't make out what it is." | LINK (I, RIGHT_OF (unspecifiedObjects, I)), NOT MATCHING (unspecifiedObjects, cognitiveInformation); |
| "Phone booths or something like that." | MATCHING (unspecifiedObjects, phoneBooths)?; |
| "I see a sign hanging from the top." | LINK (I, sign), IS_DOWN (sign, ceiling); |
| "I'm in the wrong place." | IN_CONTAINER (I, place), NOT MATCHING (environmentalInformation, cognitiveInformation); |
| "It's about baggage." | LINK (I, "baggage"); |
| "I see advertising signs." | LINK (I, advertisingSigns); |
| "Way in the distance I see familiar blue signs." | LINK (I, FAR_FROM (blueSigns, I)), MATCHING (blueSigns, previousBlueSigns); |
| "I see a "C" but I don't see anything else." | LINK (I, "C"), NOT LINK (I, otherSignInformation); |
| "I'm not sure where I'm going." | ?PATH (I, myGate); |
| "I move forwards towards the blue indicator signs." | IN_FRONT_OF (PATH (I, blueSigns), I), ON_SURFACE (I, floor); |
| "I'm looking for a new reference point." | ?LINK (I, newReferencePoint); |

**Figure 5:** View of the departure hall at Frankfurt International Airport with one subject's transcript and image-schematic representations.

| Image schema | Example of natural-language description | Predicate representation |
|---|---|---|
| ATTRACTION | The sign *catches* the eye. | ATTRACTED_BY (I, sign) |
| CENTER-PERIPHERY | The hallway curves *around* the duty-free shops. | CENTER-PERIPHERY (duty-freeShops, hallway) |
| COLLECTION | There are *several* signs. | COLLECTION (signs) |
| COMPULSION | I do what other people are doing. | COMPELLED_TO_BY (I, unspecifiedAction, people) |
| CONTAINER | I am *in* the departure hall. | IN_CONTAINER (I, departureHall) |
| COUNTERFORCE | I don't need to go there—I've already checked in. | COUNTERFORCE_TO (ICheckedIn, PATH (I, check-inCounters)) |
| FRONT-BACK | I see the yellow signs *in front of* me. | IN_FRONT_OF (yellowSigns, I) |
| FRONT-BACK | There are people *behind* the counters. | IN_BACK_OF (people, counters) |
| FULL-EMPTY | It's quite *crowded* in the duty-free area. | FULL_OF (duty-freeArea, people) |
| LEFT-RIGHT | The even numbers are *on the left*. | LEFT_OF (evenNumbers, unspecifiedObject) |
| LEFT-RIGHT | *To the right* also gives me an option to go. | RIGHT_OF (PATH (I, gateC), I) |
| LINK | I *see* the yellow signs | LINK (I, yellowSigns) |
| MATCHING | The gates are *identical*. | MATCHING (gates, otherGates) |
| NEAR-FAR | I approach *closer* to the sign. | NEAR_FROM (I, sign) |
| NEAR-FAR | I can't read the signs *at this distance*. | FAR_FROM (I, signs) |
| PATH | I *move to* the ticket counter. | PATH (I, ticketCounter) |
| PATH | I *follow* B1 *along to* B2 to finally reach B45. | PATH_ALONG (B1, B45, B2) |
| SURFACE | People are *walking*. | ON_SURFACE (people, floor) |
| VERTICALITY | Signs *hanging from* the ceiling. | IS_DOWN (signs, ceiling) |
| VERTICALITY | There are signs *up above* the ticket counters. | IS_UP (signs, ticketCounters) |

**Table 1:** Image schemata, examples of natural-language descriptions, and their predicates.

| Slide# | Paths | Good clues | Poor clues | No clues |
|---|---|---|---|---|
| 1 | 1 | 1 | 0 | 1 |
| 2 | 1 | 1 | 0 | 0 |
| 3 | 2 | 1 | 2 | 1 |
| 4 | 2 | 2 | 1 | 1 |
| 5 | 1 | 1 | 0 | 0 |
| 6, 7, 8 | 3 | 3 | 1 | 0 |
| 9, 10 | 2 | 3 | 0 | 0 |
| 11 | 1 | 1 | 0 | 0 |
| 12 | 1 | 1 | 1 | 0 |
| 13 | >1 | 2 | 0 | 0 |
| 14 | 1 | 1 | 0 | 0 |
| 15 | 1 | 1 | 0 | 0 |
| 16 | 1 | 2 | 0 | 0 |
| **Σ** | **5 dp** | **20** | **5** | **3** |

**Table 2:** Paths and clues for Vienna International Airport (viewpoints within problem areas are highlighted, dp = decision points).

| Slide# | Paths | Good clues | Poor clues | No clues |
|---|---|---|---|---|
| 1 | 2 | 2 | 0 | 0 |
| 2 | 1 | 3 | 1 | 1 |
| 3 | 2 | 3 | 0 | 0 |
| 4 | 2 | 1 | 1 | 0 |
| 5 | >1 | 0 | 3 | 0 |
| 6 | 3 | 1 | 1 | 0 |
| 7 | >1 | 0 | 2 | 1 |
| 8 | 2 | 2 | 0 | 1 |
| 9 | 2 | 3 | 0 | 0 |
| 10 | 1 | 2 | 0 | 0 |
| 11 | 1 | 2 | 1 | 0 |
| 12 | 1 | 3 | 0 | 0 |
| 13 | 1 | 2 | 0 | 0 |
| 14 | 1 | 1 | 1 | 0 |
| 15 | 2 | 4 | 1 | 0 |
| 16 | 1 | 3 | 0 | 1 |
| 17 | 2 | 3 | 0 | 0 |
| 18 | 1 | 1 | 0 | 0 |
| 19 | 1 | 2 | 1 | 1 |
| 20 | 1 | 0 | 2 | 1 |
| 21 | 1 | 3 | 0 | 1 |
| **Σ** | **10 dp** | **41** | **14** | **7** |

**Table 3:** Paths and clues for Frankfurt International Airport (viewpoints within problem areas are highlighted, dp = decision points).

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