Wayfinding Model For Pedestrian Navigation

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Abstract: Car navigation systems are now widely used, whereas pedestrian navigation systems have not yet found widespread application. Current pedestrian navigation systems are designed analogously to car navigation systems where the movement of vehicles is constrained by the street network (specifically the lanes). Such a wayfinding model does not reflect the possibilities of pedestrians, where movement is subject to different constrains compared to car drivers. In this paper we describe a new pedestrian wayfinding model that addresses this problem. A graph model is created which consists of decision points and edges connecting them. The free (walkable) space around decision points is expanded to decision scenes where pedestrian movement is modeled in more detail, thus allowing for flexible navigation comparable to unassisted pedestrians. We connect this model with the cognitive needs of users of pedestrian navigation systems and show how our approach incorporates these.

1 INTRODUCTION

Finding ones way in unknown or not very familiar environments is a common task that people experience regularly throughout their lives. A number of supporting tools are available, from conventional paper maps to modern location based services such as electronic navigation systems. Car navigation systems have long been the focus of research and are probably the most widely used example of location based services and mobile applications. Their use is now widespread and user acceptance is high. Pedestrian navigation systems on the other hand, as a related system, are still in their infancy and struggle to gain market acceptance.

User requirements and environmental affordances for pedestrians vary considerably compared to car drivers, and current pedestrian navigation systems do not take them sufficiently into account. One of the major factors is that pedestrian navigation systems have so far been very much based on car navigation systems; on the data level, the conceptual level as well as on the implementation level (Krüger et al. 2004). The necessary data sets for car navigation systems are well developed and suit the requirements of car navigation systems.

Pedestrians, however, are not constrained to the street network (specifically the lanes) like car drivers (Stark et al. 2007, Walter et al. 2006), which need more cognitive resources for driving the vehicle and paying attention to the surrounding traffic. Pedestrians face different challenges such as movement with a higher degree of freedom. In general they have more cognitive resources available for navigation, navigation instructions can therefore be presented in a more detailed and semantically rich way.

Figure 1: A part of Stephansplatz in Vienna (morguefile.com).

Pedestrians can move freely and a conventional graph of lanes does not reflect unconstrained movement in open space. For example, consider a wide and open area like Stephansplatz (Figure 1). The most obvious choice for traversing this area is for a pedestrian to directly walk towards the desired "exit" of this open area. Such behavior is generally not supported in current navigation systems (Stark et al. 2007), where the area would be reduced to a single decision point. This generalization distorts physical distance and therefore overestimates walking time, which may cause the device to propose routes that are in fact detours. One solution to this problem has been proposed by Walter et al. (2006). Our approach differs in that we ground the final graph representation of the walkable area in cognitive research.

While car navigation systems are not a viable metaphor for pedestrians, a high degree of automation can be used in the process of creating them. One major challenge for pedestrian navigation systems is to claim this advantage as well. Data sets of street networks are now well developed and widely available for many countries in Europe, North America and Asia. Pedestrian navigation generally does not happen on the street network. Consequently, we cannot get appropriate geographic data by simply using databases for car navigation services, which is currently done unsuccessfully with minor modifications (Stark et al. 2007).

We sketch an approach from the production of the required geographic data to the final graph model. Emphasis is put on providing a wayfinding model for ubiquitous services that can be provided at low or no cost at all, making automation an important design factor. Since the cognitive resources of users are limited, adequate communication of routes is a crucial and non-trivial issue. Considering the cognitive requirements of users during the design of the wayfinding model is therefore vital for user acceptance (Rehrl et al. 2007). We choose to explore image schemata to ground the wayfinding model in a cognitively adequate way. Image schemata are mental patterns (Johnson 1987) that are part of spatial conceptualizations of humans on an abstract level, and are being investigated for their use in pedestrian navigation systems (Rehrl et al. 2007). We incorporate these schemata into the design of the wayfinding model from the start. We expect it to be easier to derive cognitively adequate route instructions for a wayfinding model that considers spatial cognition in advance. Prior to the wayfinding model a data foundation (i.e., a graph model) is required, for which a methodology is presented. This methodology aims at allowing a maximum of automation. The theoretical wayfinding model is then discussed in detail.

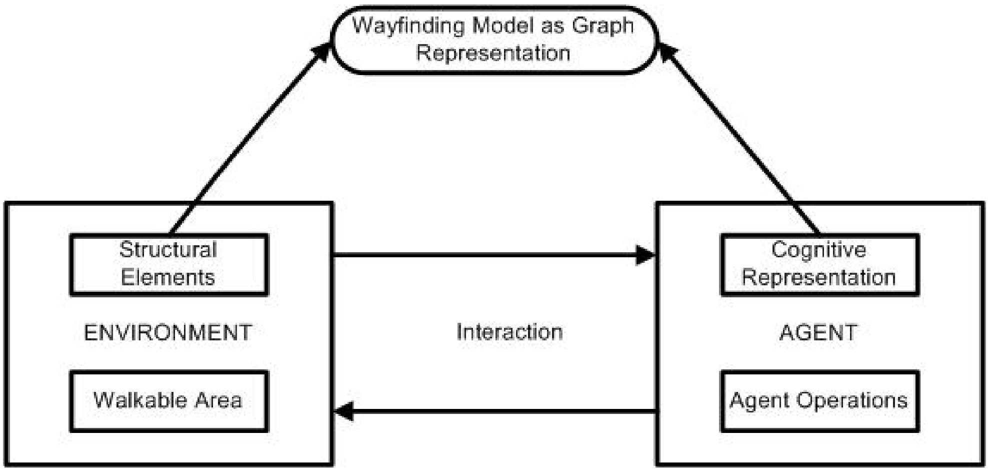

Figure 2: The wayfinding model.

The next section discusses our definition of the wayfinding model. Section 3 discusses the foundation of the wayfinding model in cognitive research and presents selected concepts from spatial cognition as well as image schemata. More detailed data sets are required for the underlying route graph of our system and we describe how these could be created in the subsequent section. We then discuss the concepts of our navigation system in more detail. The paper finishes with an outlook on current and future research and the conclusion.

2 DEFINITION OF THE WAYFINDING MODEL

Montello (2005) describes wayfinding as a constituent part of navigation alongside of locomotion. He defines navigation as the “coordinated and goal-directed movement of one's self (one's body) through the environment”. In this process, wayfinding represents the “goal-directed and planned movement of one's body around an environment in an efficient way”. We follow this definition and put emphasis on the efficiency of wayfinding of pedestrians with the assistance of navigation systems. We intend to increase this by matching the degree of freedom as well as basic environmental concepts of pedestrians with the navigation system.

The pedestrian is capable of physical operations and possesses mental capacities that allow interaction with the environment. The physical operations of the pedestrian encompass sensing as well as locomotion. The pedestrian acts upon the environment through the physical operations and receives sensory input in a recurring loop. Through this interaction the pedestrian acquires a cognitive representation of the environment that structures it in a way that makes it mentally accessible. This mental representation defines the walkable space as well as its internal semantics (Figure 2).

We use graphs to represent the part of the physical environment that is relevant for navigation. To ground the graph representation in cognitively adequate concepts, we first structure the walkable space using image schemata. The corresponding graph model differs from conventional representations of space that are found in contemporary pedestrian navigation systems, and is expected to support human navigation more efficiently.

3 SPATIAL COGNITION AND IMAGE SCHEMATA

Spatial cognition is an active field of research and its role for navigation services is widely acknowledged. We include findings of cognitive research in the design of the wayfinding model, following a bottom to the top approach. We believe that the inclusion of such concepts on each design stage will considerably improve the usability of navigation systems, thus allowing cognitively adequate user interfaces.

3.1 Spatial Cognition

Several cognitive models of space have been proposed over the years (Ittelson 1973, Downs and Stea 1982, Zubin 1989, Mark 1992). The work of Lynch (1960) is one of the earliest and most influential contributions in this field with regard to the cognitive structure of urban environments to date. Lynch distinguishes landmarks, nodes, paths and regions in the city. All of those have importance for pedestrian navigation systems to varying degrees, i.e., regions generally play a minor role compared to nodes. The structures that Lynch describes have proven their relevance over the decades and are basic concepts in contemporary navigation systems.

Montello (1993) distinguishes four major classes of psychological spaces, defined via their projective size relative to the human body: figural, vista, environmental and geographical. Of this selection we claim that vista space and environmental space are of relevance to the most common navigation tasks. Vista space describes the surrounding of a person that can be visually apprehended from a position without locomotion. This is the space that is of relevance for navigation when the pedestrian arrives at a decision point. The area perceived at a street intersection would be classified as vista space. Environmental space is the large scale space in which start-to-destination navigation takes place. This type of space cannot be apprehended without locomotion, as it is too big to be perceived from one position. Brief experience alone does not permit to form a mental model of this space, but it can be learned given enough exposure to it.

3.2 Image Schemata

Image schemas were introduced by Johnson (1987) and describe our conceptualization of physical reality. Image schemas are a part of embodied philosophy which claims that the mind can only be understood if the bodily experiences are taken into consideration. Johnson defines an image schema to be

> *"... a recurring, dynamic pattern of our perceptual interactions and motor programs that gives coherence and structure to our experience. In order for us to have meaningful, connected experiences that we can comprehend and reason about, there must be a pattern and order to our actions, perceptions and conceptions."*

These recurring mental patterns are a direct consequence of our physical and cognitive capabilities as well as our experience with the world. They are more abstract than concrete images in the mind and assumed to be invariant to cultural imprint and other differences between individuals. They allow us to establish connections between our experiences that have the same internal structure in common. Johnson (1987) and Lakoff (1987) describe an extensive (though not claiming to be exhaustive) list of image schemata. Out of this list they identify seven schemata as being spatial in nature: container, surface, near-far, verticality, path, link and centre-periphery.

Image schemata find a variety of applications. Especially the spatial sciences are a prominent field of application since many image schemata have spatial characteristics. Image schemata have already been used to model the physical environment of humans. For example, Raubal (2001) and Rüetschi and Timpf (2004, 2005) have used them to model the domains of airports and train stations, domains which are generally navigated by pedestrians. We continue this approach and employ image schemata for the wayfinding model of an outdoor navigation system. The wayfinding model at its current state of design relies on the container and the link schema to connect the wayfinding model to the cognitive needs of users. Future research will likely expand the selection.

- *Container schema:* The container schema represents containment. It consists of an inside, an outside and a boundary separating them. This schema is regularly used when entering or leaving a building (e.g., through a door).

- *Link schema:* The link schema generally represents a connection between objects as well as non physical linkage. Non physical links can be the relation to siblings and parents or the direct visual connection from spectator to object.

These image schemata are currently considered for the design of our wayfinding model, they structure the environment of pedestrians on the vista-space level of spatial granularity. Further research will show how this approach can be expanded to finer or coarser levels.

4 GRAPH BASIS FOR THE PEDESTRIAN NAVIGATION SYSTEM

Navigation services need geographic data for operation, for car navigation services this data is well defined and available. So far the databases of pedestrian and car navigation systems have been largely interchangeable. This fact causes many current pedestrian navigation systems to communicate routes in ways that pedestrians find difficult to interpret, or even restrict them to the constraints of car drivers due to data limitations.

In the following we briefly sketch the derivation of the necessary data for the envisioned navigation system, which is done analogously to Walter et al. (2006). This is a non trivial task since the walkable space is not as obvious as the street network. Firstly, a binary image of the walkable space and the non-accessible area is created. From this image the topological skeleton is then calculated that forms the basis of the graph representation of the walkable space. Although the envisioned procedure is described from the perspective of raster data, there is currently no preference for either raster or vector as both support skeletonizing. Elias (2007), for example, demonstrates successful creation of databases for pedestrian navigation systems by extracting data from a heterogeneous set of vector databases.

To get a data foundation for the pedestrian navigation system, we first define the walkable space within the targeted urban region. Walkable space is composed of sidewalks, pedestrian zones, park areas and so forth. With the use of these definitions a binary image is created that represents walkable space as well as its complement. Skeletonizing is then performed to automatically derive a graph that is usable for pedestrian navigation systems, reducing the walkable area to a form retaining skeleton (Serra 1982).

In case the surrounding environment contains blocking areas like traffic lanes and buildings, passages such as crosswalks and underpasses need to be introduced. This walkable space forms the outdoor navigation domain of the pedestrian. The example in Figure 3 shows how crosswalks are combined with the skeleton of the walkable space for passage over traffic lanes.

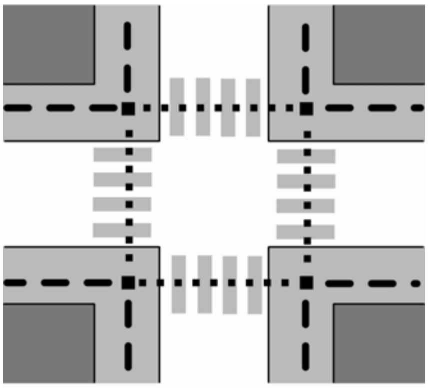

Figure 3: Crosswalks as passages through otherwise blocked space.

5 THE WAYFINDING MODEL

Navigation of pedestrians is not as constrained as car navigation, which requires the wayfinding model to mirror the flexibility of pedestrian locomotion as accurately as possible. Decision points are a valid aggregation for car drivers, but they are not sufficient for the more complex domain of pedestrians.

Decision Points become Decision Scenes

Decision points and navigation graphs in an unconstrained environment can be computed from binary images using skeletonizing algorithms. Lynch (1960, p.72) defines decision points as *"...strategic foci into which the observer can enter, typically either junctions of paths, or concentrations of some characteristic"*. He points out that, although conceptualized as nodes or points in a network, they may represent a large spatial area that is internally structured. We believe that this internal structure of decision points, although negligible for car navigation, must not be neglected for pedestrian navigation systems. An aggregation of the vista space around the decision point is therefore an oversimplification of the environment, and does not represent the many choices and shortcuts that are available to pedestrians. For example, when considering an open plaza the skeleton would derive a decision point in the centre of the plaza. Movement through this centre does not always make sense as it can be an unnecessary detour. This would be the case if the exits of the plaza are not opposite each other.

This consideration is also true for decision points in spatially more confined areas. In the presented wayfinding model we therefore consider the immediate environment in conjunction with the local decision points and speak of decision scenes. Decision scenes are defined as the local vista space around a particular decision point. A decision scene can be entered and left and is physically bounded by buildings and other solid obstacles that prevent movement. Regulatory constraints are imposed, e.g. by the traffic lanes that are – although physically traversable – not suited for passage. Decision scenes border each other within the walkable space, thus forming a partition of the walkable space. As decision scenes are physically bounded and can be entered and left, they concur with the mental representation of the container image schema.

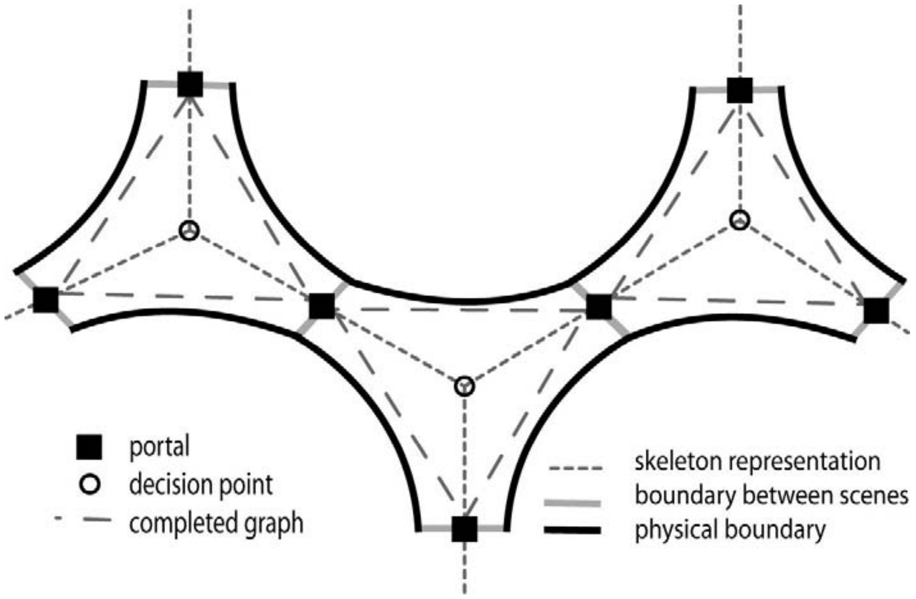

Figure 4: The final graph representation of the wayfinding model.

Entering and leaving decision scenes via portals

Decision scenes are not only spatially constrained by solid obstacles, but also border other decision scenes that need to be reached for navigating the environmental space. These borders between decision scenes shall be labeled portals and connect neighboring decision scenes. But portals are not limited to the border of decision scenes alone They may also encompass doorways of buildings and the likes, thus allowing fine grained navigation. In a graph representation the portals are abstracted to nodes. The concept of portal permits the transition from one container to another (e.g. decision scenes or buildings) which concurs with the link schema.

Internal Structure of Decision Scenes

For the complete wayfinding model, the walkable space is overlaid by its skeleton graph. The walkable space is then partitioned around the decision points, forming the decision scenes bounded by solid blocking objects, regulations and the border to neighboring decision scenes. After conceptualizing and partitioning the environmental space of pedestrians there is now need to represent unconstrained movement within decision scenes. The option of walking directly from one portal to another is represented by the complete graph constructed between the portals. With this complete graph, direct portal-to-portal navigation is modeled without the inclusion of the local decision point. Decision points are no longer vital for navigation unless they are the start or the destination. Figure 4 shows walkable space with decision points, the conventional navigation graph and the imposed complete graph within the decision scenes.

6 CURRENT AND FUTURE RESEARCH

So far we described the envisioned wayfinding model and its problem domains. In this section we specify the main research parts and directions we want to focus on.

- The sketched wayfinding model demands geographic data that is currently not used in commercial pedestrian navigation systems, and the question is raised if it is easily made available. Further research will show which data is needed and if either vector or raster representation is to be preferred. It is expected that the currently available data is not sufficient in supporting human-like navigation for pedestrians and techniques for acquiring this data need to be developed. Automation is a key factor for the creation of suitable databases to enable widespread commercial application.

- The next step is the evaluation of currently available datasets and their suitability for pedestrian navigation services. Consequently, test datasets will be composed and the automatic creation of a graph model will be investigated.

- The calculated shortest paths in current pedestrian navigation systems are currently based on street networks, which is an overestimate in many cases. The proposed model with its extended database promises to deliver more accurate estimations of the expectable travel time compared to street networks. Furthermore this is an objective criterion that measures the effectiveness of a navigation service.

- Automated creation of decision scenes is a non trivial task that needs to be solved. Different techniques will be investigated as potential candidates. One plausible approach is the voronoi diagram of the walkable space around decision points. The walkable space is partitioned by a voronoi diagram around the decision points in a way that cognitively adequate decision scenes can be derived.

- Decision scenes alone might not be sufficient for partitioning the pedestrian's domain around decision points. There are cases where pedestrians follow route segments without decision points along the way. In such a case, a partitioning of the walkable space by decision scenes may turn out to be impractical. One investigated solution to this problem is the introduction of corridors for long segments between decision points.

- So far the wayfinding model has been grounded in image schemata. While elaborating the current wayfinding model we will continue to ground it in cognitive science as far as possible.

7 CONCLUSION

In this paper we introduced a wayfinding model that is tailored more appropriately to the needs and capabilities of pedestrians than is currently employed by navigation services. We discussed the general shortcomings of current systems due to their foundation in car navigation services and how we aim at overcoming them. Free movement is the key issue in this research and a number of factors need to be considered. Firstly, the inclusion of research findings from spatial cognition on the image schematic level has been described. By considering human conceptions of space on the level of the wayfinding model, we believe that the design of such a pedestrian navigation service will be more cognitively adequate up to the interface level.

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