International Journal of Spatial Data Infrastructures Research, 2008, Vol. 3, 3-19.

Special Issue GI-Days, Münster, 2007

Providing Other People's Trails for Navigation Assistance in Physical Environments*

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Abstract.
Asking other people the way has always been a widespread social wayfinding technique. In recent years wayfinding in unknown spatial environments has increasingly been supported by electronic navigation assistants. However, the social aspects of wayfinding, such as using other peoples' experiences, have widely been ignored in the context of electronic navigation systems. In electronic environments such as the WWW the availability of community knowledge - also driven by Web 2.0 paradigms - becomes more and more valuable to users. Other people's experiences, including recorded browsing paths and activities - so called user trails - are used for recommendation and navigation support and allow users to navigate vast information spaces more easily. In this paper we propose an approach for trail-based navigation in physical environments. An analysis and comparison of the concept of trails in both application areas establishes the basis for a trail model and the implementation of a trail-based navigation system prototype for mobile phones. Practical experiences with a prototype application and potential applications of trail-based navigation assistants are discussed in the context of a tourist scenario in the old town of Salzburg.

Keywords: wayfinding, trails, symbolic locations.

1. INTRODUCTION

Because of the growing popularity of car navigation aids portable navigation systems increasingly find their ways into peoples' daily lives, including outdoor activities such as hiking, biking or wayfinding in cities. Technical advances in the field of wireless communication, mobile end user devices and satellite positioning have driven the development and deployment of personal navigation assistants

DOI: 10.2902/1725-0463.2008.03.art2

in new application domains. Despite this rapid and positive development existing personal navigation assistants typically ignore proven human wayfinding strategies such as using symbolic names or landmarks for orientation. Mostly they interact with users through wayfinding instructions (e.g. "turn right in 400 meters") which, however, are hardly feasible without the help of technical assistance such as distance measurement. Existing electronic wayfinding aids rarely satisfy the cognitive abilities of humans. Several approaches are trying to cope with this problem by using different strategies. The most common are landmark-oriented wayfinding (Elias 2002; Raubal and Winter 2002), cognitive modelling of routes (Denis 1997; Winter 2002; Klippel et.al. 2005), and cognitive modelling of wayfinding environments (Raubal 1997; Rüetschi and Timpf 2004).

Another prominent strategy trying to prevent people from getting lost or helping them to find the right way is to ask other more experienced people the way. For example at famous places in cities thousands of people move around, visit interesting sights, explore new routes and solve wayfinding problems. Relying on the experiences of other wayfinders can lead to a significantly improved wayfinding strategy and can also improve the quality of the chosen route since the choice is based on the experience of one or more wayfinders. In the domain of the WWW so called recommender systems or navigation assistants utilise recommender processes, i.e. gathering other people's advice through information technology and thus enable social navigation (Dieberger 1997, Munro 1999) (Resnick and Varian 1997; Terveen and Hill 2001). However, this kind of exploitation of community knowledge (which recently also gained considerable attention from the Web 2.0 community) is missing in today's navigation systems.

In our recent work we argued that the metaphor of trails (Bush 1945), which are built from information about other users' browsing paths and activities, allows users to navigate vast information spaces more easily (Gams 2005). People "walking" through electronic environments choose similar routes when searching for similar aspects or topics as these routes can support other users' navigation. Motivated through the successful application of social navigation assistance in electronic environments (Reich and Gams, 2004; Gams 2005) we raised the question whether this approach can also be applied to navigation assistance in the physical world. In order to answer this question we have elaborated on the distinctive differences between trails in electronic environments and trails in physical environments. Based on the analysis and comparison of the fundamental concepts of trail-based navigation systems, we developed a trail model for physical environments, which is the main contribution in this paper. With this model we are able to represent trails not only by a sequence of co-ordinates but also by a sequence of symbolic locations.

This paper is structured as follows: after a discussion of related work in Section 2, we introduce the concept of trails and navigation in electronic environments in

Section 3. Section 4 discusses the differences between trails in electronic environments and trails in physical environments and defines requirements for a physical trail model. This analysis leads to the definition of the physical trail model in Section 5. Section 6 provides an overview of implementation issues and introduces the scenario for testing the prototype application. Section 7 summarizes the results and in Section 8 we conclude with a discussion on future application ranges.

2. RELATED WORK

For electronic environments a variety of navigation assistants - systems that record and evaluate peoples' paths (e.g. a browsing history) or past actions in order to help other people find their way around - have been developed, e.g. Memex (Chakrabarti et al., 2000) or Memoir (DeRoure et al., 2001). These systems enable people to share opinions and benefit from each others' experience. In previous work (Reich and Gams, 2001) we took an approach based on digital footprints, so called user trails for assisting navigation in electronic environments. With a trail-based recommender system we demonstrated how users could manage their individual information spaces more efficiently (Gams, 2005). Web application developers may benefit from trails as they reflect the users' approaches of how to access and traverse a Web application. Based on past trails and usage patterns designers are able to improve access to and navigation in a Web application (Gams and Reich 2006).

The idea of trails in the physical world originates from Hillier's work (Hillier 1996). In Hillier's "Space syntax", a theory of urban architecture and design, each location is regarded as a point or node in a network of different places. Any journey between two places is described as a path between nodes. The authors use people's paths through a city as an expression of their activities and interests. However, the concept of using people's paths in order to provide electronic navigation support in physical environments has never been seriously picked up. Although most of recent outdoor GPS[1]-receivers provide the possibility to load trajectories of geo-references, so called GPS-tracks, the concept of trails for social navigation assistance goes far beyond the concept of co-ordinate trajectories. Analysing recent scientific literature we found that social navigation assistance for pedestrians has not been sufficiently addressed by researchers during the last years. The GUIDE project showed that the use of electronic guide systems caused less social interaction. This led to an extension of the project in order to support co-operation and to establish a sense of community between city visitors (Cheverest et.al. 2000).

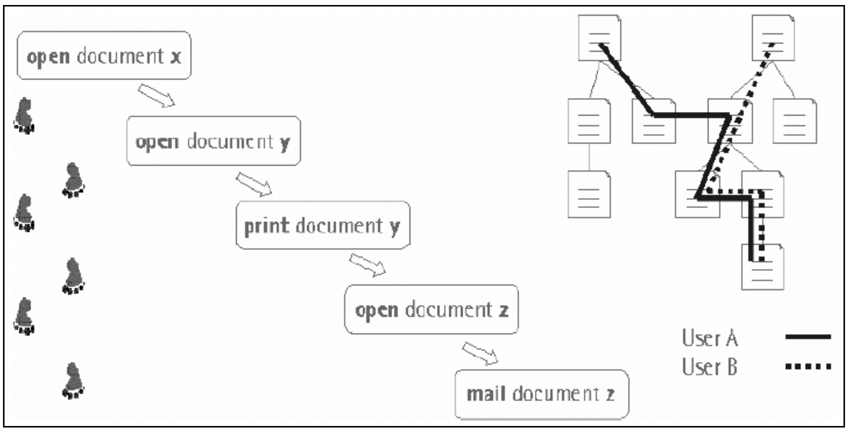
[1] Global Positioning System

The HyCon (HyperContext) Framework (Bouvin et.al. 2003) was designed to support context-sensitive hypermedia. The goal of the framework was to mix traditional hypermedia features, such as browsing or annotations with context-aware features like location, time or community relations. In Hansen et al. (2004) the authors introduced the notion of contextual trails with the focus on geo-based searches as well as electronic annotation of objects in the field. The approach mainly dealt with hypermedia annotations, not explicitly focusing on a trail model, a location model or trail recommendations. In the next section we look briefly at an analogy to help us in our physical world problem.

3. NAVIGATION AND TRAILS IN ELECTRONIC ENVIRONMENTS

In electronic environments people can leave trails accidentally whenever they handle information. Similar to navigation in the physical world (Montello 2005), navigation in electronic environments is characterised by locomotion to reach a goal and decision making between alternatives (Jul and Furans 1996). Navigation in digital worlds takes place not only in the WWW, but also in corporate and personal directories, together building the personal information space of a user. Maglio and Barrett (1997) demonstrated that people remember special key nodes or so called information anchor points to guide them to some information in the past. These anchor points can be specific nodes holding documents, identified by particular properties. Based upon these theories we described electronic trails (Gams, 2005) as a specific path through a set of document nodes, built from information about users paths and activities. By analysing trails we found that document nodes are often characterised by long duration of usage or interesting activities (e.g. opening a document in a file browser in contrast to viewing the file name) that have been carried out in the past (Figure1).

Figure 1: Trails in digital environments



Thus, we defined a trail as a non-empty finite sequence of trail marks ordered by a time stamp associated with a user's visit. A trail mark consists of (1) a node, (2) an associated activity, (3) a time stamp and (4) duration. Nodes represent wrappers of the actual (physical) documents that users manipulate. The location of a node can be abstractly interpreted as the identifier of a node or the reference to the content of a node. Activities refer to the actions which users perform on nodes such as “print”, “view” or “mail a node to a colleague”. Time related information can be used to specify additional properties of a trail or trail node, such as the date when a node was created. Duration is the amount of time a user has spent on performing an activity on a document (e.g. reading time).

Based on the common and extensible trail model, we developed a general trail similarity measure and a trail recommendation method, a selective procedure for finding users with similar trails and the recommendation of documents. We tested our trail model and the system in a controlled user experiment in the WWW and an Intranet environment. Users had to answer specific questions with and without the help of the system. The results of the user experiments have shown that users supported by trails were able to finish their tasks with less effort in time and number of navigational steps than without any help (Gams 2005).

4. REQUIREMENTS FOR A PHYSICAL TRAIL MODEL

Based on our successful validation of the concept of trails in electronic environments and previous work in the area of personal navigation we propose a physical trail model with the goal to map the metaphor of trails to the domain of physical environments. Although there are a number of similarities between both worlds, we have identified some significant differences which have to be addressed carefully.

Whereas in electronic environments a trail node typically points to the location of a document, in physical environments the concept of a trail node can be most likely compared to the notion of a location (Leonhardt 1998; Domnitcheva 2001) where people are intentionally passing by. Our definition of a location comes most closely to the notion of a geographic location, which is used to deal with geographic objects, such as streets, paths, places, sights or buildings. The following requirements for modelling a location have to be addressed by a physical trail model in order to be of use for trail-based navigation:

R1: User positions should be specified in a coordinate reference system. In order to support the tracking of a mobile client, such as a smart phone, by a satellite navigation system (e.g. GPS) and to gather location information, user positions have to be described by means of a co-ordinate reference system.

R2: Locations should be described by a location model. The notion of location in electronic environments, especially the WWW, is clearly defined by the concept of a URI (Unified Resource Identifier). With this concept each resource (typically a document) can be unambiguously referenced. In the physical world the concept of a location is less clear. Different conceptualisations of space (Egenhofer and Mark 1995) result in different notions of the term location (Hillier 1996; Leonhardt 1998; Hightower and Borriello 2001). Although global co-ordinate systems allow addressing each geographic position throughout the world, the expressiveness for human cognition is poor (Leonhardt 1998). Therefore the challenge is to select a suitable location model, which can be used for referencing physical trail nodes.

R3 Locations have to describe exclusive, non-overlapping areas. The current location has to be unambiguously determinable from a geographic position at any time. However, in order to facilitate hierarchical structuring, non-overlapping locations can be grouped to higher-level areas.

R4 Locations have to be referenced by unique identifiers. Similar to the concept of URIs in the WWW, physical locations have to be uniquely identifiable. The unique referencing of trail nodes allows composing a trail from a set of ordered and unique trail marks.

R5 Locations should have names intelligible to humans. In order to be of use for describing trails in a human readable form and for generating meaningful wayfinding instructions locations should be named with identifiers that are easily understandable for humans.

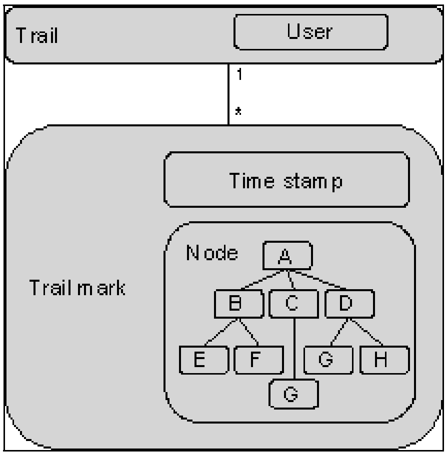
R6 Distance has to be considered. In electronic environments each node is only one click away from the other. Whereas the time needed to get from one node to another is marginal, the distances between two nodes in the physical world are important parameters for wayfinding and calculating routes. It is crucial to a physical trail model that distance between nodes matters. This has mainly to be considered in the selection of the location model.

R7 Openness of the model with respect to activity and its duration. In the virtual trail model the activity at each trail mark plays an important role in identifying the user's intention of visiting the node. In contrast to the digital world the activity at a location can hardly be captured. As only sensors or input from users can provide the system with behavioural information at specific locations, activity will be neglected by our physical trail model as a start. The duration is defined as the time needed to perform an activity and therefore it will not be acquired in physical space at present time, too. Nevertheless, progressive research in embedding sensor technology and processors in everyday appliances, such as clothes, will soon offer new possibilities of acquiring all kinds of physical activities in the near future. Thus, the model and the prototype have to be defined extensible enough to consider also the activity property of the model in future.

5. DEFINITION OF A PHYSICAL TRAIL MODEL

Based on the requirements above we have defined an adapted trail model for physical trails. Basically we have adopted the concept of trails as non-empty finite sets of trail marks (Figure 2). Every trail is associated with the user who created it and every trail mark comprises a time stamp, representing the time necessary to access a location

Figure 2: A trail model for physical trails

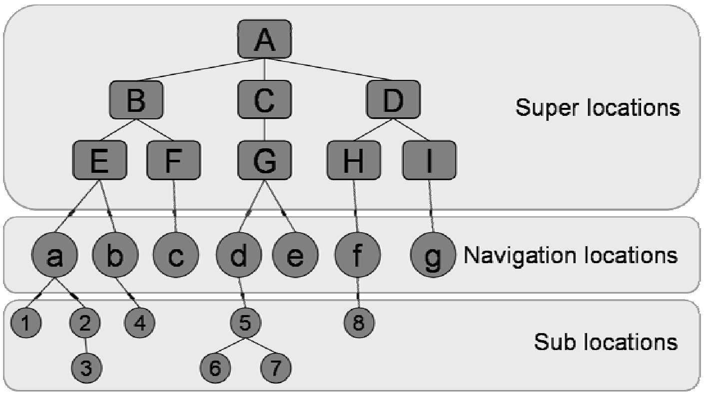


Concerning the trail nodes, modifications of the original trail model were necessary. According to requirement R2, and in order to describe locations in a formal way, location models are used as an expressive, flexible and efficient representation of location information (Addressing R2, R3, R4 and R5). With respect to different requirements for spatial reasoning and modelling effort, different location models have been studied. At least three groups of location models have been identified: geographic location models, symbolic location models and hybrid location models (Leonhardt 1998). A detailed survey of location models is presented in (Domnitcheva 2001).

For describing the location of a trail mark we decided to use a hybrid location model, because it met our requirements most closely. First, it was necessary to describe locations by means of a co-ordinate reference system (See R1) in order to support the mapping between GPS measured positions and symbolic locations (See R2). Second, it was necessary to reference locations with a unique location identifier for linking locations to a trail mark (See R4). The referencing guarantees the composition of arbitrary trails as well as the comparability of different trails by means of similarity measurements. Moreover, unique logical trail marks form a well suited database for generating route recommendations from any trail mark. And third we wanted to have human understandable descriptions of trail marks, which could be only provided by the symbolic part of a hybrid location model (Addressing R4).

Our location model is split into two levels, one holding the symbolic locations in trees and one holding the geometric information. The symbolic part of the model is hierarchical (Figure 3) and can therefore hold so-called super locations, which are a combination of locations identified by a unique identifier (e.g. part of a town). The trail nodes are represented on a sub-level by so-called navigation locations such as streets, places or buildings. Additionally, it is possible to detail further navigation locations in so-called sub-locations, which are suited to model significant spatial objects that are part of navigation locations (e.g. a fountain or a memorial).

Figure 3: Hierarchy of symbolic locations



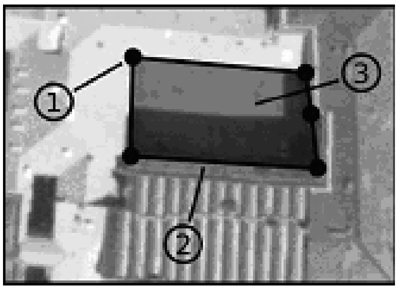
In order to identify unambiguously symbolic locations (similar to locations in the WWW) we used the concept of ALI (Aura Location Identifier) (Changhao and Steenkiste 2002). This concept of using URIs (Uniform Resource Identifiers) to describe symbolic locations met our requirements most closely. Examples of hierarchical locations in the old town of Salzburg are:

Salzburger Altstadt/Linke Altstadt/Herbert-Von-Karajan-Platz
Salzburger Altstadt/Linke Altstadt/Mozartplatz

Each trail mark holds a reference to a symbolic location described by an ALI. Super or sub locations are expressed by the hierarchy separator "/".

In our example *Linke Altstadt* is spatially included in *Salzburger Altstadt.* The geometric part includes basic geometric elements, so-called zones (Domnitcheva 2001), which are defined by co-ordinates. Figure 4 shows the geometric representation of a place including the points marking the borders (1), the connecting lines (2) and the area of the polygon (3). The definition of the border points also allows a computation of the distance between neighbouring zones (Addressing R6).

Figure 4: Geometric representation of a place in the old town of Salzburg



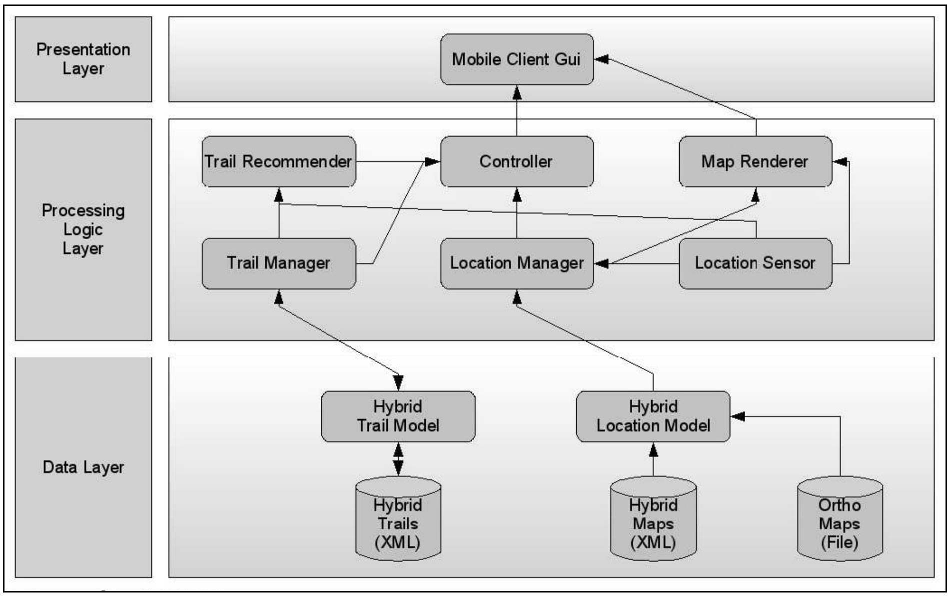
Each geographic zone is linked to a symbolic representation of the zone (Figure 3). For example, a geographic zone may be linked directly to a navigation location but also to any sub location. This linking allows describing the node of a trail mark symbolically as well as geographically. Moreover symbolic locations can be automatically derived from GPS-co-ordinates using the geographic zones. Together with the time stamp a trail mark gets the entire spatial-temporal information which is used for composing the spatial-temporal trail dimension.

Using the physical trail model it is possible to describe a trail as a temporal sequence of symbolic location identifiers, which is a crucial pre-requisite for generating human-readable trails and comparing them concerning different recommender functionalities. This makes the proposed trail model superior to simple GPS tracks. The next section shows how the trail model is integrated into the core of the trail-based navigation system.

6. ARCHITECTURE OF THE TRAIL-BASED NAVIGATION SYSTEM

The core of the system is split up into three modules providing functionalities for trail storage, trail processing and trail presentation (Figure 5).

Figure 5: Architecture of the trail-based navigation system

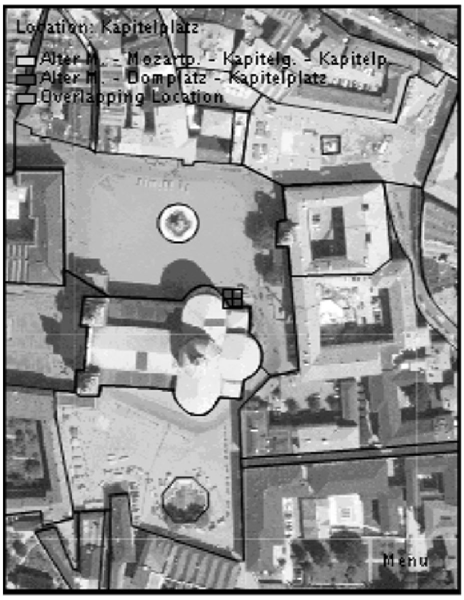


The basis for the storage of trails is defined by the trail model described in the previous section. For implementing the trail storage we developed a specific XML dialect called Hybrid Trails XML. This dialect defines all relevant elements, including trails, trail marks and trail nodes, as XML elements in order to describe fully a physical trail. Each trail is composed of geometrical locations (e.g. by using GPS co-ordinates) as well as symbolic locations. For linking the trail marks to symbolic locations and geographic zones we use the Hybrid Location Model. Geometric as well as symbolic representations of locations and the corresponding links are stored in the Hybrid Maps database. Therefore we use SVG Tiny[2], a XML format for two-dimensional vector graphics. The Hybrid Maps database stores vector representations of hierarchical locations and symbolic information of the locations as well as references to underlying map images (e.g. ortho maps) using SVG elements. The maps are stored in tiles in order to optimise the process of loading.

For the presentation of trails the SVG Tinyline framework[3] for Java-based smart phones is used. This framework offers functionalities for loading SVG Tiny XML files and navigating (e.g. panning, zooming) 2D vector graphics. Locations representing trail marks are visualized as an overlay on the base map (Figure 6). Locations belonging to different trails are visualised with different colours.

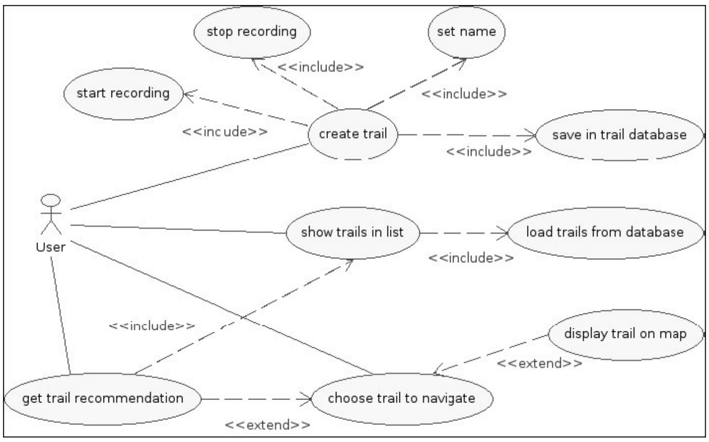
[2] http://www.w3.org/TR/SVGMobile/
[3] http://www.tinyline.com/

Figure 6: Visualisation of different locations belonging to trails in the old town of Salzburg



The main functionalities concerning the trail-based navigation system are implemented in the so called processing layer. Figure 7 gives an overview of the main use cases including “create a trail”, “show available trails”, “get a trail recommendation” and “choose a trail to navigate”. The modules in the processing layer (Figure 5) implement the functionalities expressed by the use cases.

Figure 7: Use cases for a trail-based navigation system



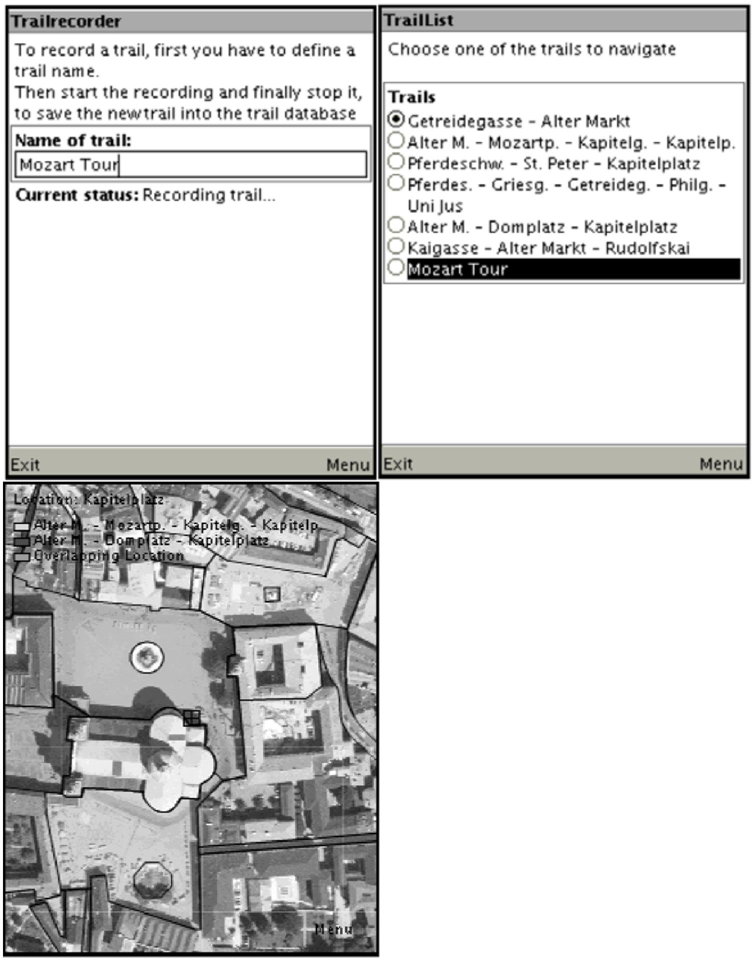
The Trail Manager in the Processing Logic Layer handles access to trails in the trail database. The Trail Recommender component recommends trails for a given position which is provided by the Location Manager. The Trail Recommender component may offer different plug-in algorithms, generating recommendations for the user, e.g. by determining the similarity of a user trail and trails recorded from other users. The Location Manager delegates all location requests from the controller to the responsible Location Sensor for gathering position data (e.g. data from a GPS receiver). The Map Renderer draws the maps (e.g. orthomaps) and the vector overlays on the screen. The Controller component receives all requests from the user and acts as the co-ordination and communication interface for user interaction. The system allows users to record their own trails and store them in the trail database. Previous recorded trails can either be selected by the user from a list or recommended by the system.

In order to deduce the symbolic trail from GPS trajectories we applied an algorithm for matching positions to geographic zones. Based on a clustering principle all outdoor zones on a map are covered by a set of uniform rectangles, so called tiles. The GPS coordinates are mapped as points on the map and assigned a corresponding tile. In order to match GPS positions to the right zone in ambiguous situations a time shifting algorithm using the time stamps of measured positions has been applied (Tradišauskas et al. 2004). This algorithm addresses the problem of locations which are covered by more than one tile by determining the most probable tile through analysing previous and if post-processed also future locations (Figure 8). Using this algorithm each GPS coordinate can be unambiguously assigned to a symbolic location.

7. EXPERIMENTS AND FIRST RESULTS

In order to evaluate the model and test the functionality and usability of our prototype a first test was conducted in the old town of Salzburg. We described the streets, places and buildings of the old town in our Hybrid Location Model. The prototype application allows tourists to record own trails, to request existing trails from the trail database and to request trail recommendations at arbitrary positions in the covered area.

Figure 8: (1) Recording of a new trail, (2) selection of previously recorded trails and (3) recommendations of trails (in the upper left corner of the screenshot) at an arbitrary GPS position (in the middle)



We installed our prototype on a Nokia N70 smart phone connected to an external GPS mouse that recorded the GPS position data. For our tests we used a simple similarity matching method, where any node of a saved trail matching the current position resulted in a recommendation of this trail. The participants were able to see where other users, who had passed the same location, have moved next by displaying their trails. However, the modular design of our prototype allows us to plug in and use different trail recommendation algorithms. The trail recommendations are outlined by using their symbolic location names and through colouring the referenced zones on the map in different colours. By selecting a recommended trail users are able to follow the trail by navigating it. At any position users were able to request another trail recommendation.

Our first experiment was conducted twofold. In the first phase our user group recorded their favourite trails by walking through the old town of Salzburg with our system installed on a mobile phone. All the trails were then collected on a server and distributed to the mobile phones trail base. In the second phase of the experiment the user group was able to consume the trail recommendation from the trails recorded in the first phase. After the experiments each user had to check the self recorded trail for any differences from the trail actually walked. Although, the surroundings in the old town, such as high buildings and very narrow streets, often reduced the GPS signal reception and thus accuracy of the GPS positioning, our model was able to correct these discrepancies. When analysing the trail database we verified that all trails were recorded correctly and displayed without discontinuities. Furthermore, all participants were able to follow the recommended trails according to the visual wayfinding instructions. Concluding, our tests proved the capability of our physical trail model to deduce symbolic locations from acquired co-ordinates and showed that the model is applicable in a tourist scenario in the old town of Salzburg.

8. SUMMARY AND POTENTIAL APPLICATION RANGE

The recent Web 2.0 hype has impressively shown the potential of community knowledge in electronic environments such as the WWW. A well established approach of utilising community knowledge is the use of recommender systems (Terveen and Hill 2001). Recommending other people's trails is one specific application of a recommender system. The usefulness of trail-based navigation in electronic environments has been shown in previous work (Gams 2005). In this work we applied the approach of trail-based navigation and recommendation support to physical environments. We proposed a physical trail model based on a hybrid location model. With the model it is possible to represent trails not only by a sequence of GPS co-ordinates but also by a sequence of symbolic locations. We implemented a trail-based navigation system and positively verified the model and the system in a tourist scenario in the old town of Salzburg. In future work we want to use the basic trail-based navigation system for testing different recommendation methods for different purposes and situations. Through a categorisation of trail marks we will be able to recommend thematic trails such as most famous shopping trails or most famous cultural trails. Moreover personalisation can lead to more customised trail recommendations.

For potential future applications it is expected that trail-based navigation systems can significantly improve the well established technique of social wayfinding for several reasons:

- First, people do not have to trust in wayfinding support of arbitrary persons but can select from a vast database of related trails. Recommendations are not only based on one or two persons but on potentially thousands of previously recorded trails. Furthermore, certain mass-frequented routes may establish merged trails that are more trusted by users. Annotations - a proved method of rating user-generated content in Web 2.0 - can also help increasing trust in route recommendations from navigation systems.
- Second, trails, enhanced with additional textual metadata on their locations, reflect a user's interest and can be categorised by the navigation system. Based on specific wayfinding requests and defined user profiles, not only the shortest route, but also trails appropriate to users' interests can be recommended.
- And third, oral route communication between arbitrary persons, e.g. belonging to different cultures, is not always easy. Electronic navigation systems can help to express wayfinding instructions in a standardised form and thus help to state wayfinding instructions more precisely. The proposed trail model establishes the basis for human-friendly route communication.

Summarising, we see a great potential in the idea of applying the metaphor of trails to different application areas to help people advancing their wayfinding strategies in physical spaces.

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