Personal Wayfinding Assistance

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Zusammenfassung

Jeden Tag legen wir viele verschiedene Wege zurück. Dabei ist es für uns kein Problem, uns in bekannten Umgebungen zurechtzufinden. Wir kennen den Weg vom Schlafzimmer zur Küche, von unserer Wohnung zur Arbeit, vom Parkplatz ins Büro, und am Ende des Arbeitstages von dort aus wieder nach Hause. All diese Wege haben wir in der Vergangenheit gelernt und finden deshalb ohne viel nachzudenken unser Ziel.

Sobald wir jedoch an die Grenzen unserer mentalen Karten stoßen und einen uns unbekannten Ort auffinden wollen, benötigen wir Hilfe. Manchmal fragen wir Freunde, ob sie uns den Weg beschreiben können, in anderen Fällen schauen wir auf einer Karte, wo sich dieser Ort genau befindet. Immer häufiger sind mittlerweile Mobiltelefone mit Wegfindungsassistenz ausgestattet. Sie sind klein und handlich, dadurch stets dabei und verfügbar, wenn sie gebraucht werden. Auf diese Weise können wir also fast überall für jeden Ort Wegfindungsassistenz bekommen. Während die geringe Größe Mobiltelefone also einerseits praktikabel macht, ist sie für die Darstellung von Karten jedoch von großem Nachteil. Denn um die vielen geographischen Informationen verständlich darstellen zu können, wird viel Platz benötigt. Doch meistens sind nicht alle in einer Karte abgebildeten Informationen notwendig, um eine bestimmte Route zu erklären. So ist zum Beispiel die Abbildung kleiner Parkwege für einen Autofahrer in der Regel nicht relevant. Verzichtet man auf einen großen Teil der nicht benötigten Information, kann man den Karteninhalt semantisch verdichten und die Karte so in vielen Fällen deutlich verkleinern, ohne auf notwendige Information verzichten zu müssen.

Eine gezielte Informationsreduktion erfordert eine genaue Kenntnis über den Benutzer, über die zu lösende Aufgabe, und über die Umgebung, in die diese eingebettet ist. In dieser kumulativen Dissertation entwickele ich ein Verfahren, welches das Vorwissen des Nutzers verwendet, um Karten an die Anforderungen mobiler Geräte mit kleinen Displays anzupassen. Dazu kristallisiere ich grundsätzliche Fragen, die während des Wegfindens auftreten können, heraus und setze sie mit dem Vorwissen des Benutzers in Beziehung. Dieses Verfahren ermöglicht die Erzeugung von persönlicher, kontext-spezifischer Wegfindungsassistenz in Form von Karten, die für kleine Displays optimiert sind.

Um dies zu erreichen stelle ich algorithmische Verfahren vor, die aus Trajektorien räumliche Benutzerprofile ableiten. Die individuellen Profile enthalten Informationen über die Orte, die ein Benutzer regelmäßig

aufsucht, und über die Wege, die dafür genutzt werden. Mit Hilfe dieser Daten können personalisierte Karten erzeugt werden, die für teilweise bekannte Umgebungen geeignet sind. In diesen Karten werden nur die unbekannten Anteile detailliert gezeigt. Die bereits bekannte Information wird vereinfacht. Dadurch können die Karten stark verkleinert werden, während der Informationsgehalt durch Einbindung persönlich bedeutsamer Orte erhalten bleibt. Die Verständlichkeit der individuellen Wegfindungsassistenz wird dadurch gewährleistet, dass auch die Namen der Orte dem Benutzer angepasst werden. In der Arbeit wird deshalb auch die Benennungspraxis von Orten untersucht und das Potential der automatischen Selektion und Generierung von Ortsnamen ausgelotet.

Personalisierte Karten funktionieren jedoch nur in Umgebungen, für die der Nutzer ein gewisses Maß an Vorwissen besitzt. Befindet er sich in völlig unbekannten Umgebungen, werden vollständige Information benötigt. In dieser Arbeit werden Verfahren vorgestellt, die den Benutzer in typischen Situationen unterstützen, die während der Wegfindung auftreten können. Ich stelle Lösungen vor, die den Erwerb von Kontext- und überblickswissen entlang der Route vermitteln sowie die Selbstlokalisierung im Falle einer Desorientierung unterstützen.

Abstract

We are traveling many different routes every day. In familiar environments it is easy for us to find our ways. We know our way from bedroom to kitchen, from home to work, from parking place to office, and back home at the end of the working day. We have learned these routes in the past and are now able to find our destination without having to think about it.

As soon as we want to find a place beyond the demarcations of our mental map, we need help. In some cases we ask our friends to explain us the way, in other cases we use a map to find out about the place. Mobile phones are increasingly equipped with wayfinding assistance. These devices are usually at hand because they are handy and small, which enables us to get wayfinding assistance everywhere where we need it. While the small size of mobile phones makes them handy, it is a disadvantage for displaying maps. Geographic information requires space to be visualized in order to be understandable. Typically, not all information displayed in maps is necessary. An example are walking ways in parks for car drivers, they are they are usually no relevant route options. By not displaying irrelevant information, it is possible to compress the map without losing important information.

To reduce information purposefully, we need information about the user, the task at hand, and the environment it is embedded in. In this cumulative dissertation, I describe an approach that utilizes the prior knowledge of the user to adapt maps to the to the limited display options of mobile devices with small displays. I focus on central questions that occur during wayfinding and relate them to the knowledge of the user. This enables the generation of personal and context-specific wayfinding assistance in the form of maps which are optimized for small displays. To achieve personalized assistance, I present algorithmic methods to derive spatial user profiles from trajectory data. The individual profiles contain information about the places users regularly visit, as well as the traveled routes between them. By means of these profiles it is possible to generate personalized maps for partially familiar environments. Only the unfamiliar parts of the environment are presented in detail, the familiar parts are highly simplified. This bears great potential to minimize the maps, while at the same time preserving the understandability by including personally meaningful places as references. To ensure the understandability of personalized maps, we have to make sure that the names of the places

are adapted to users. In this thesis, we study the naming of places and analyze the potential to automatically select and generate place names.

However, personalized maps only work for environments the users are partially familiar with. If users need assistance for unfamiliar environments, they require complete information. In this thesis, I further present approaches to support uses in typical situations which can occur during wayfinding. I present solutions to communicate context information and survey knowledge along the route, as well as methods to support self-localization in case orientation is lost.

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Contents

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1 Mobile Devices for Wayfinding Support

This is a cumulative dissertation. It consists of eight peer-reviewed articles which have been published in workshop and conference proceedings, and journals. The articles Schmid and Richter [2006], Schmid [2008], Schmid, Richter, and Laube [2009], Schmid and Kuntzsch [2009], Schmid [2009b,a], Schmid, Richter, and Peters [2010b], Schmid, Kuntzsch, Winter, Kazerani, and Preisig [2010a] represent the chapters 2 to 9 of this dissertation.

1.1 Motivation

Wayfinding is one of the most elementary activities of our lives. It is such a basic and automated activity that we do not recognize it all in our daily routines: we easily find our way from bed to kitchen, from home to work, from work to the supermarket, from vegetables to milk, and finally back home. But once we arrive at the demarcations of the environment we are familiar with, we recognize how hard it can be to find a new, yet unfamiliar place in the world. In this situation, since there is no established route we could take without mental effort, we have to acquire this knowledge with the help of assistance.

However, we are often not entirely unfamiliar with an environment; sometimes we do not want to know all available details of the environment, and sometimes we get lost on the way. This means, we are not always interested in one general form of wayfinding support. An ideal form of assistance should consider our particular requirements for the best and most effective support for a given situation.

One key to enable tailored wayfinding support are mobile devices, such as mobile phones. They offer a multitude of possibilities to show maps and to retrieve information from the user and the environment. The portability of these devices ensures that they are usually at hand when wayfinding assistance is required. This allows the development of tailored wayfinding assistance with a focus on the specific user and the particular situation the user is in.

In my thesis I will demonstrate the possibilities of context-specific wayfinding support with small mobile devices. In particular, I will emphasize the consideration of the wayfinding task and personalizing the assistance towards the individual user. The resulting support explicitly addresses the requirements the devices put on wayfinding assistance.

1.2 Wayfinding with Small Devices

Whenever we have to find our way to a given unknown place we need wayfinding support. This support can be for example another human we can ask for directions, a map, or a wayfinding application on our mobile phone. Mobile phones have become powerful computers with the possibility to show maps, to compute routes to places, and to determine the current location by means of e.g. GPS positioning. The combination of these three capabilities allows the implementation of complex wayfinding assistance applications. The ability to sense a user's current location helps to compute and update routes to a given destination. It further can support the user to keep track of the route while traveling to the destination, e.g. by visualizing the traveling progress on a map or by providing navigation instructions. As mobile phones are designed to be carried around in nearly any situation, this means wayfinding support can be queried where and when it is required. It does not have to be prefabricated anymore like printed maps.

The combination of mobility and ad-hoc computation allows the user to retrieve tailored support for different stages and circumstances involved in the wayfinding process. Traveling to a new destination consists of several typical stages. Before traveling a route from A to B, the route and its relation and embedding in the environment are inspected, typically by means of a map with a highlighted route. Once the relation is clarified the user is ready to travel. While following the route, users reassure if they are still on-route or observe the progress using a map and highlighted position obtained from the GPS receiver.

Each of the phases is driven by different questions of the user, like "Where am I now on the route?", "Where do I have to turn next?", or "Where is the destination with respect to places I already know?". Each of the questions reflect different typical tasks involved in wayfinding, namely the acquisition of survey and context information of a route, self-localization and route following. When we have precise questions, we want to retrieve concise answers. This means, we expect the wayfinding support system to answer them as accurately as possible and present the information as comprehensible as possible.

The mobile device at hand offers a multitude of possibilities to react to the needs of the users and assist them during the wayfinding process with tailored answers to specific questions. For instance, a mobile phone can be utilized to find out about the places a user knows by analyzing the movement of the user. This learned information can be used to communicate the location of new place effectively: if the yet unknown place is close to the work place of the user, the visualization of the relation of both places can be enough to clarify the location at a glance.

Mobile devices are not only handy and portable, but they buy their smallness with essential drawbacks in display size and interaction possibilities. Small displays are problematic when we want to show maps in a sufficient level of detail to understand a route. When the display is too small for showing the visual information comprehensibly, users will have to interact with the information to fully understand it. This means, if a route on a map cannot be shown at an appropriate scale, the user has to zoom in and out, or scroll within the map to understand it. When the device additionally limits the way the information can be manipulated, arriving at comprehension can be a stony path.

One solution to foster the comprehension of the wayfinding support is to tailor the assistance not only towards the specific wayfinding task, but also to the output medium – the small mobile device. We have to consider how we can present the required information on devices with small displays. Additionally we have to develop new ways to interact with the information when the available space is still not enough.

1.2.1 Small Displays and Maps

The generality of the problem of small displays and limited interaction possibilities becomes clear when we opt for maps as wayfinding support. The visualization of maps does not only require a high resolution, but also a sufficient size of the display. Although streets, street names, landmarks and all other elements of maps can be drawn arbitrarily small within the boundary of the resolution, the elements require a certain size to understood by a user. If this space is not available, it is up to the user to switch between views where for instance either the details at an intersection are in focus or the general course of the route is visible. There is no general solution to this problem — maps are generated from geographic information which is inherently highly constrained. It is not possible to magnify only selected streets, because all adjacent elements will either be occluded or dislocated. This leads straight into an inconsistent representation of the world, and it will be hard to draw a correct conclusion from it.

Though we require information to understand and follow a route, we do not require all information of the map covering the area of the route. For example, we usually do not need to know about small streets and parkways that are not located along the route. Beside being dispensable, this information also could be a source of distraction from the relevant information. If an application just draws a route on a general map, it loses the potential of highlighting it beyond coloring the route. At the same time the map would automatically add superfluous information and hampers the focusing on the relevant parts of the map. This means, in the same way we can compute routes between any pair of places, we can use the potential of selecting only the geographic information which is necessary to optimally support the understanding of a route, of the next decision to take, or of a location.

One key to identifying the important information for wayfinding assistance is to focus on the task at hand and to consider relevant contextual information. For example, when users are familiar with the environment, we can highlight only the relevant part of a route, namely the part which is yet unknown. Rather than using the available space of the display of a mobile phone for information that is already known to the user, we can adumbrate familiar parts and use the remaining space for unfamiliar and new information. The resulting map can be fundamentally different from a map showing all information, however, due to the reduced information it can be visualized more compactly by preserving the necessary information.

1.3 Notions and Terminology

This section presents the approach of this thesis. We will define the basic terms and clarify their role for the publications presented in chapters 2 to 9.

1.3.1 Wayfinding

Wayfinders have to perform a number of mental and physical tasks to navigate to a familiar or unknown destination. They have to reason about space to plan and choose a route out of several options, they have to interpret spatial situations along the route to identify the correct branch to turn. During navigation wayfinders also have to perform very basic tasks like identifying solid ground to walk securely, or avoiding to bump into obstacles. Concluding, navigating from A to a given B consists of two components: First, high-level reasoning and interpretation processes involved in *wayfinding* and second, rather basic sensory-motoric processes of *locomotion*, [e.g., Montello, 2005, Mallot, 1999]. In this work, we are only interested in wayfinding, thus reasoning about and interpretation of space and spatial representations and how the involved tasks can be supported by means of wayfinding assistance.

In the scope of this thesis, wayfinding is purposeful, motivated movement to a specific destination which is not contained in the immediate surrounding environment and is not visible from the vantage of the wayfinder. Wayfinding requires that wayfinders have a motivation to move themselves from A to B. There are manifold reasons, for example, going to work, shopping, visiting friends, consulting a doctor, going on holiday. Wayfinding happens along a *route* from A to B. A route is a defined sequence of paths selected from a network of paths, such as the street network of a city.

The visual horizon of a wayfinder is called vista space or isovists [see Montello, 1993, Benedikt, 1979, Batty, 2001]. When a place is beyond vista space, wayfinders cannot pilot the destination by means of basic sensory-motor coupled locomotion. This means, the information of how to navigate to the destination is not completely observable in the environment. In this situation the wayfinder requires additional information to be able to plan a route and to reach the destination. If the place and a route are already known, the wayfinder can reason and plan with the information stored in the mind of the wayfinder, the so-called *cognitive map* or *mental map* [e.g., Tolman, 1948, Tversky, 1993, Richardson et al., 1999]. If the place or a route is not known to the wayfinder, the missing spatial information has to be completed with external information: the wayfinding assistance.

1.3.2 Wayfinding Assistance

As long as origin, destination and a traversable route between them is known to wayfinders, there is no need for assistance. In the absence of comprehensive or sufficient information about either the origin, the destination, or a complete route between the origin and the destination, we need assistance to find the way. This means, we need to perform route planning and navigation with the help of external assistance or behavioral strategies [e.g., Montello, 2005, Allen, 1999, Golledge, 1992]. External assistance is any form of given representation of the environment which is not retrieved from the mind of the wayfinder or perceived directly in the environment (such as following signage). Maps and route directions are examples for external assistance in form of representations of the environment and the route. Representations typically describe an environment on a much smaller scale than reality and are selective in what they communicate. For example, maps do not represent every tree and route directions do not refer to every single house along the course [e.g., MacEachren, 1995, Klippel et al., 2005a].

Assistance has to be given because perceivable cues are not assistance per se; they are only meaningful if they are explicitly pointed to. A landmark like a church can be highly salient, but it only serves as an element of wayfinding assistance for a specific route if it is incorporated by an instruction or description. It is not the sheer presence of landmarks that makes them meaningful – but their explicit integration on a semantic level within assistance, [e.g., Daniel and Denis, 2006, Lovelace et al., 1999, Michon and Denis, 2001, Richter, 2008].

The purpose of wayfinding assistance is to help wayfinders to reach their destination by means of pointing them to helpful elements of the real world. There are many forms of describing a route from A to B. The variety spans from human or computer generated route directions, hand-drawn sketch maps, city maps, digital maps on the Internet to GPS assisted turn-by-turn navigation instructions, or hybrid combinations. Beside the usual types of assistance, there are many specialized forms for persons with special needs, like tactile or verbal assistance for visually impaired people.

1.3.2.1 Maps

One of the oldest and most comprehensive forms of wayfinding assistance are geographic maps [e.g., Akerman and Karrow, 2007]. The maps typically used for wayfinding are topographic maps. They visualize information of geographic space which is too large to be observed directly, such as a city or country. Maps communicate information about places without requiring the user to visit them.

As the scale of a map is usually much smaller than the size of entities in the real environment, the depicted information is highly simplified, [e.g., MacEachren, 1995]. The simplification is a result of technical requirements and cartographic generalization. Observations of geographic objects, like the curvature of objects, are usually recorded with discrete methods like sequences of positioning data and capture them with incomplete information. Additionally, as the resulting map is generated on a smaller scale than the objects are in reality, measurements have to be removed during reproduction because they cannot be distinguished anymore: due to the smaller scale, several objects are potentially mapped to the same position, thus information gets lost. The removal of the data, or rather the selection of what is still displayed on which scale, is subject to cartographic generalization. Depending on the purpose of the map, the human map-maker or the generating algorithm have to decide which elements are relevant to be represented in which level of detail on a given scale [e.g., McMaster and Shea, 1992].

Wayfinding maps typically depict street networks between distinguishable places of a certain level of granularity linked with the chosen scale. This means, the map of the main street network between the cities of a country does not contain small streets within the depicted cities or places like buildings. Instead, they show elements of the same information granularity, in this case cities and links between them. A city plan on the other hand displays the street network of a city and places on the level of e.g., buildings. As wayfinding maps contain the complete street network on a certain scale and for a defined portion of space, they can be used as a route planning tool between any distinguishable places contained in the map. Wayfinding maps are general problem solvers for all possible routes between the entities on the map.

Cognitive Complexity and Visual Complexity of Maps With the introduction of digital maps the route planning and selection is typically provided by a computer. The general street network maps are still used to visualize the route and its course within the embedding environment. This practice does not make use of the possibilities digital maps offer: in the same way it is possible to compute a route between any places automatically, it is also possible to generate specific maps for *this* distinct route.

The benefit of tailoring a map to a specific route can be found in the complexity of general wayfinding maps. Those maps have been designed for *all possible* wayfinding problems within the defined portion of space. Maps such as city plans have been designed to ensure their generality as a problem solver. At the time of printing, it is not possible to identify beforehand which information would be be necessary in the future for a specific map user. Printed wayfinding maps typically contain as much information as possible, as each of the depicted entities could be of interest to someone. For a static representation like a paper map, adding as much information as possible is the only solution if the assistance has to be small , portable, and general. However, the more and the more diverse information a map contains, the harder it is to interpret for human users. One reason is the increase of the *cognitive complexity* which is linked to mental processing of relations between the visualized objects. The more objects are visualized on a map, the more relations have to be maintained mentally. The second reason is the *visual complexity* which is linked to the amount of different symbols on a map. The higher the diversity of elements the higher is the chance of getting distracted by unnecessary information. This is called *visual clutter* [e.g., Phillips, 1977, Phillips and Noyes, 1982, Phillips, 1995, Rosenholtz et al., 2007]. In other words, there is a general conflict between the amount of information on maps and the efficiency of understanding the information. We can resolve this conflict by considering the query and selecting only information which is relevant to solve the task. E.g., if a route is selected for a car, we do not need to communicate small hiking trails in a park along the route which are contained in the general map. The same holds for detailed street network information far away of the route: this information is not only irrelevant for the driver, but also a source for visual clutter.

Maps, Route Directions, and Turn-by-Turn Instructions There are representations for routes that transport less information than maps. In route directions, a route is described as sequence of egocentric *actions* at decision points and usually incorporates outstanding features like landmarks from the environment in the direct vicinity of the route [e.g., Daniel and Denis, 2006, Lovelace et al., 1999, Michon and Denis, 2001, Richter, 2008]. Route directions trade-off their reduced complexity with a massive loss of helpful contextual information. They do not communicate configurational knowledge beyond features directly located along the route. In good route directions, this information is sufficient to navigate along a route, but it is not enough to understand the relationship between route and the embedding environment. Only with additional contextual information beyond the route it is possible to understand the environment and for example to recover from navigation errors that can occur during the wayfinding process.

Humans have a basic desire to understand the environment we are located in. If the environment is unfamiliar or only partially familiar, the understanding is highly dependent on the information offered about it. Visual representations are able to communicate configurational information very efficiently. When we use maps, we can immediately see how large objects are relatively to each other and how they are oriented to each other. The expression of complex spatial relations by means of verbal representations is a hard task and a huge number of mutual relations have to be made explicit so that configurations can be understood. However, not only the representation, but also the amount of information has great influence on understanding the environment. For example, in Aslan et al. [2006], Parush et al. [2007], Ishikawa et al. [2008] it is shown that users of position triggered turn-by-turn instructions (like GPS-based navigation devices) do not trust this form of information reduced assistance. Apart from a generally reported feeling of insecureness, the participants of the studies made more stops than map users, made larger direction estimation errors, and drew sketch maps with poorer topological accuracy. These are strong indicators that people do not learn the environment properly and seem not to trust the assistance.

The reason can be found in the use case of positioning based navigation devices: planning of a route and the guidance from current position to a destination. Users do not have to know where they are at any stage of the process, as this is completely left to the device. Users just have to follow the instruction to turn at the next decision point. The only remarkable cognitive performance left to wayfinders is the recognition of the decision point, which is in most cases within the vista of the wayfinder. Put differently, navigation is mainly reduced to the sensory-motor component locomotion, a process which does not require memory based mental operations [Wiener and Mallot, 2003].

Arguing for maps for wayfinding assistance is not a nostalgic look back: maps and map-like representations are the only media able to communicate significant spatial survey knowledge beyond a route. Even if we can build up spatial survey knowledge from traveling a number of routes and combining them mentally [see e.g., Ishikawa and Montello, 2006], routes disappear from the mental representation, because the more we rely on turn-by-turn directions, the less important the route and the environment become.

1.3.2.2 Mobile Maps

Wayfinding assistance is currently migrating to mobile devices such as mobile phones. This also includes to display maps to communicate spatial information. Most devices are equipped with positioning techniques such as GPS and electronic compasses. This combination allows automatic and effortless self-localization and egocentric alignment of maps which is relevant to easy map understanding, [e.g., Hermann et al., 2003].

However, when we visualize maps on mobile devices, we immediately face a hard problem: the small size of the screens that contrasts the demands of visualizing geographic information. Geographic information is inherently multi-relational constraint. The size and shape of entities, the distances between them, and their orientation in space are in a fragile equilibrium. When we alter only selected relations the global information gets inconsistent. For example changing the size of a street will either occlude other objects on the map or introduce spatial distortion.

The constraintness of geographic data makes it difficult to visually compress spatial data: when we want to show a route and its spatial embedding we can do this only on a scale which is not suitable for comprehending the decisive details of the route. When we zoom into the map to a decision point, we cannot see the general course of the route. As a result, users have to zoom-in and zoom-out or to scroll within the map to understand both the course and the relevant details. This is not only interaction intense and, thus, inconvenient, but also affects the knowledge acquisition and distorts the interpretation of the information as shown by Dillemuth [2007].

There are several general solutions to the problem of accessing punctual information in maps or to visualize contextual information in detailed views like multi-resolution visualization and adaptive map generalization, context-in-detail visualizations, off-screen visualizations, and context-specific adaptation.

The most general form of adapting the map to small displays is to develop information density metrics for them [Töpfer, 1976]. The information density metric describes the number of objects which are visualized on a certain scale on the display. An optimized metric ensures the general readability of a map by limiting the number of objects for a scale level, but it does not reduce the inherent information complexity of maps, [e.g., Follin et al., 2004].

Fisheye lenses and variable-scale maps are capable of showing a detailed area within the context of the embedding map [e.g., Keahey, 1998, Harrie et al., 2002b,a, Yamamoto et al., 2009]. This transformation works on top of already visualized data and highlights the elements in the center of a fisheye lens, while minimizing the scale of elements in the border regions of the lens. Fisheye lenses are not selective in what they highlight, which leads to a the situation that the space between elements is usually in focus (for example, the areas between streets). Furthermore, they heavily distort geographic information, especially in the border regions of the curvature. Another approach is the so-called key-map combination: this distortion free context-in-detail visualization combines a small overview map of a larger context area with a large detailed map [e.g., Frigioni and Tarantino, 2003]. In this combination, the small overview map is usually embedded within the detailed view, which is problematic as it occludes a substantial amount of map information.

Another direction of research is the visualization of off-screen features, i.e., important elements which cannot be seen on the screen when the map has a certain scale. These elements can be visualized by pointing from a map-view of constant scale by means of arrows, circle segments [Baudisch and Rosenholtz, 2003], or wedges [Gustafson et al., 2008]. These methods are suitable to point to distinct locations of interest, but do not offer a solution of minimizing the visual information. Off-screen pointers are additional information on top of a map and increase their visual complexity.

Lens-based highlighting, generalization, multi-scale visualizations and off-screen visualizations are not optimized for wayfinding assistance, but for cartographic display in general. All discussed approaches still use a general map with all available information as a basis to visualize and access specific information for a given specific route or location. That is, they still use the map as a general problem solver and overlay it with additional semantics.

In the next section we will focus on using contextual information to emphasize the relevant information for a specific wayfinding situation.

1.3.3 Map Adaptation by Context: $T \times E \times A \rightarrow R$

With the migration of maps and mapping services to the Internet and mobile devices, the access to geographic information became ubiquitously available. Whenever a computer is attached to the Internet or a mobile phone has the required information stored or can access a suitable service, maps can be queried in most parts of the world for most parts of the world.

This situation offers the possibility to generate maps not only *when* and *where* they are needed, but also to generate maps for *what* they are needed. When we consider the task to be solved behind a query, we can generate optimal assistance. As discussed in section 1.3.2.1, there is no optimal, efficient map that serves all queries. This means, we move away from the one general map that fits all towards the very specific map that is only valid and helpful for a certain query within a given context. Turning away from the survey map as the general (wayfinding) problem solver requires careful consideration of what elements of the map data are necessary and which context constituents are important in the map generation process, [e.g., Klippel, 2003, Nivala and Sarjakoski, 2003, Klippel et al., 2005a, Reichenbacher, 2004].

Mobile Context One of the main advantages for assisting wayfinding tasks with mobile devices is the possibility to adapt it to the current situation and the intention of the user [e.g., Dix et al., 2000, Reichenbacher, 2004, Sarjakoski and Nivala, 2005]. In contrast to stationary assistance, the mobile device is always in the same spatial situation as its user. This enables the device to potentially access the surrounding world and infer the motivation for usage by analyzing the behavior of the user. By reasoning about the context of the user, a system can ideally generate the most appropriate assistance for the very moment.

There exist a number of context models for ubiquitous and mobile application scenarios. In most approaches context is supposed to emerge from parameterizing a (non-exhaustive) list of factors that may play a role in the current situation (for an overview of context models see Chen and Kotz [2000]). Examples are the location of the users, their age and stress level, lighting conditions, mode of transportation, agenda entries, and display size of the mobile device. List-based context models inevitably have the stain of incompleteness: there might always be something left out of consideration which is relevant for a given task.

Context Models for Mobile Maps There are three context models for the generation of mobile maps. In Nivala and Sarjakoski [2003] the authors propose that the map should be adapted to information about the location of the user to the properties of the device, the purpose of use, the time of usage, the physical surroundings, navigation history, the current orientation, cultural and social background of the user, as well as abilities and personality information about the user. Nivala and Sarjakoski argue that these context constituents reflect basic user needs and their consideration increases the efficiency of maps.

The second, more generic model is proposed by Reichenbacher [2004]. His model is mainly arranged around the five basic user actions connected with maps: locating, navigating, searching, identifying, checking. He proposes visualization guidelines for each of the actions which can be combined to solve complex tasks, or user goals as Reichenbacher terms them. Examples are getting orientation, finding objects or persons, or getting an overview of the closer surrounding.

Both models use context constituents for the cartographic adaptation of maps to the mobile situation. Wayfinding is only one possible use case and is not defined in its own context, i.e., the context models and resulting representations are not optimized for wayfinding solutions.

The $TEAR$ Model In contrast to the more traditional context model of Nivala and Sarjakoski and the generalized action model of Reichenbacher, we take a process-oriented view of spatial context. The context model $TEAR$ as introduced in Freksa et al. [2007] is a *spatial context model*, therefore it does not treat *location* as one context variable among others, but defines context around spatial assistance scenarios. This qualifies $TEAR$ particularly as a basis for wayfinding assistance, as the represented constituents and processes of $TEAR$ directly reflect the nature of wayfinding. In Darken and Peterson [2001] the authors point out that

> *... an important point is that navigation is a situated action [...]. Planning and task execution are not serial events but rather are intertwined in the context of the situation. It is not possible nor practical to consider the task, the environment, and the navigator as separate from each other.*

In $TEAR$, context emerges from the consequences determined by the interplay of a small set of processes between defined constituents instead of listing a large number of attributes and their possible values (see Figure 1.1 for an illustration). The consideration of the interweaving of the wayfinding processes between all involved constituents enables us to move away from maps as general problem solvers towards highly efficient representations of the environment.

When we clarify the spatial task of a wayfinding process at hand (e.g., self-localization in the real environment, setting oneself in context of a route) and consider the agent and the specifics of the environment, we can develop generic assistance primitives. In a similar way as the action based model of Reichenbacher allows the accumulation of user goals from action primitives and can drive the selection and adjustment of information displayed on a map. Reichenbacher's action primitives represent basic spatial tasks, but the context model does not adapt to the spatial specifics of the environment and the user. An example is a user querying a route in an urban environment or in the mountains during hiking: depending on the actual environment the resulting map has to contain different information, [e.g., Rehrl et al., 2007]. If the user is familiar with parts of the environment, or is using a wheelchair, the model should consider this knowledge to plan accordingly.

Freksa et al. [2007] describe the spatial context of wayfinding assistance by means of the four involved constituents and the processes between

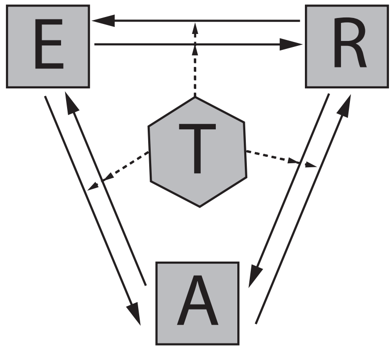

Figure 1.1: The process-oriented context model as introduced by Freksa et al. [2007]

them. See figure 1.1 for an illustration of the model with its four basic constituents. The $TEAR$ model consists of the four constituents:

- T is the spatial task to be solved by the agent A in the environment E with help from the representation R. Spatial tasks in this thesis are processes related to the superordinate wayfinding task.
- E is the environment the spatial task has to be solved in by the agent A with the help of the representation R. In this thesis, we only consider urban environments.
- A is the agent. In the scope of this thesis the agents are human users. Of particular interest are users that are partially familiar with the environment.
- R is the representation of the environment E. R can be any visual, tactile or auditive representation of an environment. In this work the representation is a map.

What About the Externalization Modality? It is arguable whether the externalization modality is an additional constituent in the proposed context model of Freksa et al. [2007]. The choice of the medium to query, manipulate, and display the spatial information has great influence on the dependencies between the four constituents. Especially the mobility and location awareness, the size of the display, and the interaction possibilities of different device classes (assumed the task will be solved by means of digital assistance) will change the way information is queried and how it has to be represented. For instance, a stationary device such as a desktop computer typically does not allow to localize oneself, while a small display is not suitable for communicating the map of a city in an appropriate scale. Even if the query is the same on two devices with fundamentally different communication properties, it will ideally not result in the same representation. In this thesis we do not extend the context model with respect to the externalization modality, because we assume the modality to be a location aware mobile device with a small screen and limited interaction possibilities (no full keyboard and no detached mouse pointer).

The Context Model in this Thesis The focus of this thesis is mobile wayfinding assistance with maps. This means, we are interested in generating maps to support a given user in an urban environment during or before wayfinding. The contributions in this work can be summarized by following instantiation of the context model:

$$T \times E \times A \rightarrow R$$

This means, we will consider the task T, the specifics of the environment E, and the knowledge of the agent A to generate personal wayfinding assistance R. In the following four sections we will define and discuss the tasks of the wayfinding process we will develop assistance for. To generate tailored assistance for these tasks, we will further take spatial structures from the environment, as well as the previous knowledge of the user into account. Finally, we will discuss the resulting assistance in the form of schematic maps.

1.3.3.1 T: The Tasks

As discussed in section 1.3.1, wayfinders need to have a reason why they want to move from A to B. The number of reasons is unlimited; examples are going to work, shopping, visiting friends, consulting a doctor, and going on holiday. We call this the *motivation* for wayfinding. In addition to the motivation of wayfinding, wayfinders finally need to move to the destination. This can be done by a number of *travel modalities* like by foot, bicycle, car, bus, train, plane, etc. Both, the motivation and the travel modality can be interpreted as a wayfinding task or as a part of a wayfinding task. They can pose additional requirements for assistance or offer possibilities to further tailor assistance to the context. Wayfinders cycling during their holidays might be happy to get advice about detours to sights along the route, while a car-driving patient is probably interested in the fastest way to and the closest parking lot next to the doctor.

In this thesis, we take a rather generic view on wayfinding tasks. This will allow us to develop assistance primitives, which can then serve as a basis for further context adaptation, in a similar way as cartographic approaches introduced in section 1.3.2.2 can be applied on top of every approach. For this reason we have a closer look at the wayfinding process itself. Following a given route from A to B consists of several processes or tasks which are necessary to reach the destination. Depending on the view on wayfinding (e.g., different motivations, travel modalities) and the definition of the relevant incorporated entities, there are different task models available.

Wayfinding Tasks Montello [2005] proposes *wayfinding* to be concerned with all questions about the identification of places which are not in perceivable vista space, planning routes towards them, and navigating the environment according to the plan defined by the route. I.e., Montello' model defines wayfinding as a process of three tasks: localization, planning, and following a planned route.

Lobben [2004] stresses the subtasks and cognitive processes involved in wayfinding supported by maps. The focus of this model is *self-localization* and *visualization* as key task related to navigational map reading. Visualization in the sense of Lobben refers to the ability of map readers to mentally transform the two-dimensional representation (the map) into a three-dimensional representation. Based on this representation, the map reader will build up a mental image of what can be expected along the route to come next and what actions have to be performed at specific points of a route. This mental visualization is a prerequisite of self-localization at places along the route: only if a decision point can be identified correctly, wayfinding can be successful. The fundamental difference between visualization and self-localization is the identification of spatial entities and configurations: during visualization the map-reader tries to identify a place in the real world learned by means of a representation, whereas during self-localization the map-reader tries to match a real world place against the entities of a map in order to determine the position in both, the real world and the representation. In this model *path integration* is the third pillar of map-based wayfinding assistance. The ability of path integration allows wayfinders to liberate themselves from external aids by relying on a mixture of gained knowledge and speculation about the structure of an environment. To summarize, Lobben emphasizes localization and wayfinding in partially familiar environments as key task in wayfinding.

Allen [1999] proposes a knowledge based view on wayfinding. Allen classifies wayfinding tasks into three categories: travel with the goal of reaching a *familiar destination* (e.g., commuting between home and work place), *exploratory travel* with the goal of returning to a *familiar point* (e.g., exploring the surrounding of a hotel during holiday), and travel with the goal of *reaching a novel destination* (e.g., finding a yet unknown given place). According to the three categories, Allen assigns the six *wayfinding means*: oriented search (e.g., visually orienting at distal landmarks), following a marked trail (e.g. following a highway signage), piloting (e.g. following an array of landmarks in route directions), path integration (e.g., finding a novel way back to a hotel in an explored new environment), habitual locomotion (e.g., daily commuting), and cognitive map based locomotion solely based on the mental map.

Wiener et al. [2009] present a comprehensive taxonomy from a knowledge-based perspective on the wayfinding process. Wiener et al. classify wayfinding according to the wayfinders knowledge of the environment and the intention. The focus of this taxonomy is wayfinding as an unaided process, thus with no signage, maps, or navigation assistance. I.e., wayfinding as a process between exploration under side constraints (e.g. the search for specific entities) and wayfinding with partial, structural background knowledge.

Chown et al. [1995] arrange their model $PLAN$ around what they believe to be the most basic component in wayfinding, *landmark identification*. Other elements are *path selection*, *direction selection*, and *abstract environmental overviews*. Similar to the approach of Siegel and White [1975], they structure wayfinding as a developmental process from landmark recognition to route knowledge to complex mental map development. This means, the core of $PLAN$ consists of localization, route planning, route following, and cognitive mapping.

Passini [1980, 1984] develops a conceptual framework of wayfinding consisting of the processes *cognitive mapping* by means of direct and indirect experience, *decision making* referring to the planning of routes, and *decision execution* referring to the actual movement. Timpf et al. [1992] propose a wayfinding model for highway networks. The authors describe a similar triad, namely *panning level*, *instructional level*, and in their case the *driver level* which refers in its essence to the spatial execution of the plan. An integrative framework (for virtual environments) is presented in Chen and Stanney [1999]. The authors structure their framework similarly to Passini [1980, 1984], Timpf et al. [1992] along the constituent processes cognitive mapping, decision making, and decision execution.

Wiener and Mallot [2003] describe a wayfinding model from a perceptional and mental representational point of view. Wiener and Mallot propose a fine-to-coarse planning algorithm. They argue that wayfinding with the cognitive map as a representation is planned and executed simultaneously on different levels of granularities: the overall route is compiled by targets from higher hierarchical regions (e.g., anchor points as defined by Couclelis et al. [1987]), the navigational refinement is then executed in what they call focal representations. Focal representations are finer spatial units (such as vistas) that allow for planning in working memory in contrast to planning in reference memory, which refers to the mental map. Every execution step is a combination of the current fine space held in working memory and the connection to the coarse representation of distant locations. Wiener and Mallot's processes "generate/update focal representation" and "update ego position" refer to the localization process, “plan shortest path towards closest target” refers to route planning, and “execute single step of route plan” refers to the spatial execution as proposed in other models.

Assisted Tasks in This Work Most of the discussed wayfinding models have a very particular view on the wayfinding process. But as wayfinding consists of basic recurring tasks, the models share a similar set of wayfinding processes. The common core processes are route planning and inspection, localization, route following, and cognitive mapping. These are the basic wayfinding tasks we develop support for and which we will discuss in sections 2-9 of this thesis.

1.3.3.2 E: The Environment

There are many different possible environments such as indoor, outdoor, urban, open space, and parks. Each environment has specifics which can be or have to be considered for spatial assistance. Paths in urban environments typically consist of defined street networks, while hiking trails in mountains are sometimes even hardly visible and only describable by configurations of spatial features (such as rock formations of a certain shape) along the trail. An effective and specialized assistance system has to consider the specific features of an environment for wayfinding and orientation. In mountain environments this can be hillsides or salient rocks [see e.g., Rehrl et al., 2007], whereas in urban environments these elements are streets and urban, man-made landmarks.

In this thesis we understand the environment as a system of perceptual and conceptual granularities which are used during communication about space and are important to understand the space one is located in. We analyze conceptual places like home and work, districts, cities, etc. Additionally we analyze perceptual entities as point-like landmarks and region-like features such as parks to create a sense of awareness for the structure of the environment.

1.3.3.3 A: The Agent

Agents can contribute in manifold ways to the context-model. They can put requirements and possibilities in the state of the model and influence the representation substantially. Examples are physical or cognitive disabilities as influencing factors on the remaining constituents. If the wayfinder is visually impaired, the representation has to be adapted accordingly, [e.g., Loomis et al., 1998]. Wayfinders in wheelchairs will benefit from route planning that avoids obstacles like stair sets or steep roads. A survey map should inform about critical points along the route, such as missing information about accessibility to certain areas.

A basic property of wayfinders independent from their physical abilities is their spatial familiarity with parts of the world. In the following section I will detail the understanding of spatial familiarity as a generic assistance primitive for this work and how it contributes to the results of the thesis.

Spatial Familiarity Spatial familiarity has great impact on wayfinding. For example route choice [Golledge, 1995, Stern and Portugali, 1999, Patel et al., 2006, Srinivas and Hirtle, 2006], route directions [e.g., Lovelace et al., 1999] and landmark selection [e.g., Gale et al., 1990a] are adapted to the individual level familiarity with the environment. This means wayfinders prefer routes they are familiar with and select landmarks as references they know and expect to be recognized.

According to Acredolo [1982], the key factors for "breeding" familiarity are: the *amount of exposure* which refers to the frequency and time spend in an environment, the *type of exposure* which refers to the travel modality, direct vs. indirect experience of the environment, the *characteristics of the observer* such as the age, physical and cognitive abilities, the *nature of the environment* like urban, rural, indoor, outdoor, complex vs. structured layouts, and *affective factors* such as the emotional state or the purpose of the presence.

However, tackling the development of spatial familiarity on an individual level is still rather unexplored. From a developmental perspective, the situation at hand is not trivial because the development of the mental map relies on multiple sources of spatial information. Each entity represented in the mental map has to be learned, [e.g., Tolman, 1948, Yeap and Jefferies, 2000, Montello, 1998]. Learning spatial facts does not necessarily imply the former physical presence at a certain place. Spatial knowledge can be acquired by multiple sources such as multimedia, fiction, discussions, route directions, and maps. Any source of spatial information is a potential source of knowledge, [e.g., Richardson et al., 1999, Goerger et al., 1998, Koh et al., 1999]. Spatial knowledge can be learned from multiple sources, but it is not possible to apply the same degree of freedom on the information learned from different sources. In Gale et al. [1990b] the authors show that knowledge acquired from video compared to knowledge acquired from direct exposure allows for similar results in landmark recognition. But the application of indirectly learned knowledge does not scale to real life navigation. This means, learned spatial facts are not automatically available for solving tasks.

The Understanding of Spatial Familiarity in this Work In this work, the establishment of spatial familiarity is understood as a product of the frequency of repeated traveling along routes and the visiting of places. The more often a wayfinder travels a route and/or visits a place, the better will be the representation of the crucial entities within the mental map. These entries are called *anchor points* [e.g., Couclelis et al., 1987].

When we know all necessary information to mentally plan and physically reach a destination from a particular origin, we are *familiar* with the environment. When we are familiar with an environment there is no need to consult an assistant. As soon as we consult a support tool, we are only *partially familiar* or completely *unfamiliar*. Consequently, we do not know parts or all of the crucial information.

The *level of familiarity* directly corresponds with the granularity of the spatial task: when we plan a route between two cities we can be familiar on the granularity of network links between them. But as soon as we want to plan a route to a distinct address, even the direct neighborhood can can turn out to be as only little known: there might be a street just around the corner we have never heard of, or an address we are not sure about. In some cases we can infer missing information from structural knowledge (e.g. even and odd house numbers at certain sides of a street, or zip codes for certain parts of a street), but in many cases we are simply forced to get support. This is the demarcation of being partially familiar from being familiar.

1.3.3.4 R: Schematic Maps

The focus of this work is on maps as means for mobile wayfinding assistance. The aim is to tailor the assistance to the wayfinding task under the consideration of the agent's familiarity with the environment, and the specifics of the environment.

The maps which qualify for this form of assistance are schematic maps. Schematic maps are context–specific maps with a focus on the task to solve. In addition to the technical constraints of topographic maps, the simplification processes of schematic maps are tailored to support cognitive processes of the map reader during reading, reasoning, and application of the gained knowledge. Schematic maps are task specific assistance and intended to support the solving of a specific wayfinding problem in a specific context.

A prominent example of everyday life is wayfinding assistance in public transportation systems like underground trains. The visualization of these networks and commuting lines is usually in form of schematic maps. The maps are highly abstracted from the actual course of the trains and only roughly preserve the correct spatial arrangement of the single stations [Berendt et al., 1998]. The focus of these maps is not the mapping of the stations with their locations in the real world, but the visualization of the sequence of stations, the topology of the network. In the context of wayfinding in public transportation networks this is the relevant information for the user.

Another example are LineDrive maps, which are optimized for long distance travels by car in highway networks. Agrawala and Stolte [2001] introduce an activity based schematization for driving routes. This schematization technique addresses the situation that driving routes often incorporate long parts where no decision is required during wayfinding. An example is driving driving on highways for a long time without leaving it or changing roads. When we visualize the geographic region on an according scale on a map, these parts can require a significant amount of the available limited interface space. This is contrary to the actual activity and cognitive load related to these parts. This can lead to situations where the important parts of a route will be literally suppressed while uncritical parts are dominant. Agrawala and Stolte propose to adapt the scale of the particular route elements to the corresponding wayfinding activity: at turns and changes, parts of the route where activity is required are illustrated in detail; parts with no required activity are highly simplified. Agrawala and Stolte relate the distance information to the activity required by the route and not to the geographic veridical scale. Further examples of schematic maps can be found in Zipf and Richter [2002], Klippel et al. [2005b], Richter et al. [2008].

Principles of Schematic Maps The idea of schematic maps is to identify a minimal but sufficient set of information and to present it in a way such that mental processes and representations are supported, matched, and directed towards the correct interpretation of the represented environment. Ideally only the information required to solve the task is selected to be displayed. The selected and displayed data can be further subject of geometry transforming operations like scaling, rotation, or translation. The reason for altering the information is to bring the relevant information into focus and to support human perception, reasoning, and the generation of mental knowledge representation by matching visualizations. In other words, schematic maps are the result of the process of simplifying a spatial representation beyond technical necessity in order to achieve cognitive adequacy [Klippel et al., 2005a]. Schematization captures the abstraction pertinent in human perception and cognition of space in order to focus on the relevant information for a given task [Freksa, 1999]. The abstraction captured by schematization processes may alter spatial information along several dimensions affecting map reading on a perceptual or cognitive level, or both [Peters and Richter, 2008].

Schematic maps are designed to match cognition, representation, and reasoning. This qualifies them as ideal candidates for context and task specific maps for mobile wayfinding assistance. The tailoring towards the individual, an isolated task, or the specifics of an environment allows the interpretation of geographic data such that the information is selective but still expressive. Put differently, the close examination of what information is really needed to solve a task opens the possibility to represent it in a way that is beneficial for both: the human interpretation and the representation under constraints, as it is the case with mobile devices.

1.4 Research Questions and Thesis

In my publications submitted as a cumulative thesis I explore the possibilities of personal, context-specific wayfinding assistance by considering the constraints and specifics of devices with small displays. I concentrate on context as the interplay between a (wayfinding) task, the familiarity with the environment of the user to be supported, and the environment assistance is queried for. These three contextual constituents determine the resulting assistance. In my thesis, I focus on maps as means to wayfinding assistance.

The aim of the thesis is to identify computational approaches to tailor wayfinding assistance towards the individual and to support the cognitive processing of the information by generating maps adequate for devices with small displays. More precisely, the thesis of my work is:

> *The consideration of context and the analysis of basic wayfinding tasks can be utilized for the generation of personal context- and task- specific map-based wayfinding assistance qualified for the application on small mobile devices.*

In my publications I tackle this thesis from different angles. I focus on maps as wayfinding assistance and on small mobile devices as visualization tools. In particular, I investigate individual spatial familiarity as the main contextual constituent of the user in my work. In this branch of my work I capitalize on the acquisition of a spatial user profile from movement data, on the representation of the user data, and the place naming practices of users. These three components are the basis to enable real individualized wayfinding support. They can be used to generate personalized maps based on the historic movement of individual users, and to label familiar places with names known to the user. Beside the user's individual spatial knowledge and concepts, I additionally focus on three important tasks of the wayfinding process: 1) acquisition of survey knowledge, which is necessary to understand the spatial context of a route, 2) route following support, which is important to trigger the correct decisions at the correct locations, 3) self-localization, which is always required when we are lost or when we want to identify and understand our location with respect to the surrounding environment.

The thesis is driven by three basic questions:

1. How can we generate individually meaningful wayfinding assistance?

2. How can we generate effective support for different spatial tasks (like obtaining survey knowledge, route following, or localization)?

3. And finally, how can we tailor the resulting assistance to the requirements put by small mobile devices?

1.5 Contributions

The answers to these questions provide several contributions in the area of spatial cognition and mobile human-computer interaction. More precisely it contributes to cognitively motivated map-based wayfinding assistance within the fields of small display cartography.

The contributions are threefold:

1. *Individual Spatial Profiling*: I developed the first parameter-free algorithm for on-line analysis of movement data streams. The task of this algorithm is to identify the individual meaningful places of individual users. Additionally I developed algorithms to compress and decompress trajectory data efficiently for the use for personalized spatial applications, such as personalized wayfinding assistance.

2. *Personalized Wayfinding Assistance*: This branch of my work builds upon the place recognition and compression algorithms. I developed a comprehensive theory for personalized wayfinding assistance with maps on small mobile devices. In four publications I discuss the automatic generation of personalized maps, so called *μMaps*, covering aspects from conceptual design considerations, matching mental and cartographic representations, and rendering algorithms. μMaps are a context-specific solution for the problem of visualizing maps on small displays: they can be reduced to only a small part of what is required by general maps by at the same time being easy to understand. As personalized wayfinding assistance is based on personally meaningful places, I describe how naming information of places can be derived from a crowd-sourcing perspective and geographic analysis.

3. *Task Specific Maps*: Beside personalized maps I further developed two task specific maps which fit into the framework of personalized wayfinding assistance, but also explicitly qualify as support for environments where no prior knowledge exists. The so called *route aware maps* are maps to provide survey information which is relevant for a given route. Route aware maps are a solution to communicate the spatial context of a route on different levels of granularity. They are an approach to clarify the general course of a route by at the same time eliminating unnecessary details. The

so called YAH^x maps are self-localization maps. YAH^x maps are an answer to the question "Where am I?". They solve the self-localization problem by communicating the position of a user on different levels of detail. YAH^x maps additionally provide novel interaction techniques which makes them efficient for fast spatial sense making.

1.6 Organization of This Thesis

The following eight chapters contribute to different aspects of personal and context-specific wayfinding assistance within the $TEAR$ model. In chapter 2 I will show how prior spatial knowledge can be captured by means of positioning sensors. Chapter 3 presents the conceptual basis for personalized wayfinding maps for mobile devices. The representation, simplification, and compression of spatial user profiles for personalized wayfinding assistance is discussed in chapter 4. Chapter 5 introduces the concept of integrating personal frames of reference for improved map understanding. The naming practice of places and the possibilities of generating automatic place descriptions for personalized wayfinding assistance is subject in chapter 6. The optimizing of personalized maps towards mental representation of spatial knowledge, while at the same time preserving geographic consistency is presented in chapter 7. Chapter 8 presents an approach for defining and selecting spatial context across multiple granularities of space for a specific route. And finally, a solution for successful self-localization by means of mobile You-Are-Here maps can be found in chapter 9.

Chapter 10 we presents a summary of the results in the light of the thesis and the research questions and discusses possible branches of future directions of research.

2 Extracting Places From Location Data Streams

Schmid and Richter [2006]

Traditionally, wayfinding assistance assumes that users are unfamiliar with the environment. When we have to consult a doctor we have never visited before, or if we want to go to a concert in a new venue we have to find out where these places are. In many cases they are not far from places we already know. If a wayfinding system knows about the places we know, it can guide us referring to already known references. This principle allows the generation of maps that are significantly smaller than general wayfinding maps, as they ideally just have to show a place in the vicinity of the destination and indicate the remaining unknown part.

In this publication we propose an algorithm to automatically extract the places users regularly visit from trajectories sensed by means of positioning sensors. The algorithm is the first of its class which is designed to work on on-line data, in contrast to other approaches working with historical data. The incoming data is analyzed lightweightly by generating clusters based on velocity trends. This self-adjusting principle allows the detection of places free from fixed parameters, the second novelty of the algorithm.

Extracting Places from Location Data Streams[1]

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1 Introduction

Current wayfinding research usually addresses the question of how people navigate, orientate and how they can be supported in unfamiliar environments. This scenario is important to understand the underlying concepts of wayfinding and to identify general principles applicable in wayfinding assistance. However, in every day live we usually perform wayfinding tasks in partial (not every place and path is known) familiar environments (e.g., if we look for the address of a particular doctor, shop or agency). Recently, as the location awareness of mobile devices constantly increases, people get interested in analyzing location data to extract spatial user profiles for location based services (e.g., [1,2,3,10,11]) or diary applications [4,5,8]. But only very few contributions attack the question of how familiarity with an environment and its mental representation can be captured, represented and used for wayfinding assistance (e.g., [12]) and, to the knowledge of the authors, no available wayfinding assistance system is able to integrate previous personal environmental knowledge. All systems implicitly assume the user to be completely unfamiliar with the present environment.

This assumption does not lead to wrong results, but it disregards cognitive and representational benefits for the user. If a system knows about the "spatial signature" (a unique set of places like a user's home, his work, his grocery, his cafés where he meets his friends, the kindergarten of his kids, ...) it can use this previous knowledge as a reference frame for personalized assistance. This spatial signature can be used as a personalized configuration for navigation assistance systems, mixed reality applications (like ubiquitous gaming), profile matching and scheduling applications. Integrated in a mobile device, like a mobile phone, such an assistance system can generate location sensitive route directions and maps based on the individual reference frame: a user's meaningful places and paths between them.

In the following example we assume a person working at the university of Bremen (the black dot on the map in Fig. 3). While being at home, he is looking for an unknown address close to the university. A query using Google Maps [13] results in route directions (Fig. 1) and a map displaying the route (Fig. 2). If a system integrates the previous knowledge of the user it can identify the destination to be close to his work place (the red dot in Fig. 3). The system also knows from where the user usually approaches his work (the blue line in Fig. 3). This way, the user can be presented with "lightweight" but meaningful maps (Fig. 3) and route directions referring to the user's personal landmark "***workplace***", like "pass your ***workplace*** and turn left into Enrique-Schmidt-Straße".

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Fig.1: Route directions for the example route

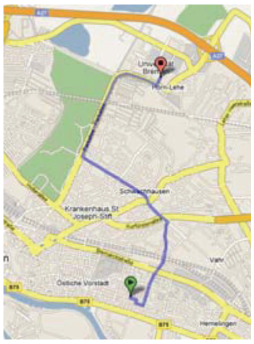

Fig.2: Overview Map

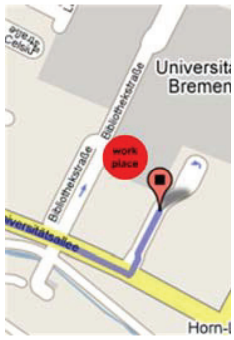

Fig. 3: Route information using previous knowledge integration

The integration of previous environmental knowledge in wayfinding assistance offers several benefits:

1. *Information Reduction and Implicit Reassurance*: If a path from place *A* to place *B* is well known to the user, he will not need a detailed description and can rely on his previous knowledge.
2. *Effective Map and Direction Generation for Mobile Devices*: Directions and maps can be reduced to a fraction of "naive" results without loosing relevant information. Mobile mapping will benefit from this property: maps can be adapted by translating the degree of familiarity to the displayed level of detail. Those parts of a route, which the user has good knowledge on, can be displayed with less details (i.e. highly schematized), and parts with no or little knowledge can be displayed in detail. This transformation is related to Agrawala's activity based map transformation [6]. A straightforward approach for destinations near reference points is to simply display the reference point and the unknown part of the route (as in Fig. 3).
3. *Display-free Navigation and Knowledge Acquisition*: Relying on previous knowledge, users do not need to stick to displays or maps; hence, their knowledge acquistion of the environment is fostered [9]. Users are supported through regionalized navigation which relies on their well-known regions and places; this reflects cognitive adequate processing and planning of routes ([7]). Furthermore, users can acquire new environmental knowledge faster through relating new locations to previously gained knowledge.
4. *Rapid Access to Maps*: If maps integrate individual meaningful places, map understanding will be more intuitive (e.g., "Place *A* is close to *Peter's house.")*. Couriers, taxi drivers or emergency car drivers, i.e. people which need rapid access to spatial information, will benefit from such knowledge integration.

2 Identifying Places from Location Data Streams

Crucial for integrating previous environmental knowledge is the extraction of meaningful spatio-temporal patterns from location data sets or location data streams. Usually, methods from machine learning are applied to extract this data, for example Baysean Filtering [11] or k-means [3]. Kang et al. [1] use a straightforward accumulative clustering algorithm, which considers spatial density of location data. We pursue a similar approach as it produces satisfying results; however, other than Kang et al. we do not rely on static parameters for noise and place detection. A further focus in our work is resource awareness in terms of memory consumption. In the following, we present our approach to pattern extraction.

2.1 Requirements

We address a mobile device scenario with limited computing and storage properties. We concentrate on on-the-fly analysis of location data streams. The basic idea is the same as in Kang et. al [1]: we check for each newly incoming location data from a constant stream whether it forms a cluster with the previous records. The decisive criterion for building a cluster is the consolidation of subsequent location samples within a range around a center-coordinate. The range is defined by the individual mean distance of the movements of a person.

Our aim is to model the environmental knowledge of a person at a meaningful level of detail. We are not only interested in mining places as they are defined by the authors above. As we address a wayfinding scenario we are also interested in individual reference points, like the traffic light one usually is waiting at, or the turn into a main street. This requires a high data sampling rate, a low threshold for clustering (to be able to identify minor places like junctions) and reinforcement of identified places (to ensure that artifacts and extraordinary events like unusual traffic jams do not lead to wrong results). Places are significant to users if they can assign them a label or if they couple them with recurrent activity (like always waiting at the same traffic light). We assume that people visit their meaningful major places in a certain frequency. Such visits have a recognizable longer duration as at minor places (e.g., a junction on the way to work). As a consequence, only those minor places are of significance, which have recognizable stay duration, and major places are of significance if they are regularly reinforced.

Our algorithm is designed for long term work. We assume a user to carry the location sensitive device (like a GPS enabled mobile phone) with him most of the time. Only a constant analysis of the environmental signature enables a system to really estimate individual environmental knowledge. Our algorithm constantly reinforces visited minor and major places; consequently artifacts and false positives are eliminated from the “knowledge base”.

2.2 The Extraction Algorithm

The location data stream based clustering algorithm *IDENTIFY-PLACES* illustrated in figure 5 requires a high data sampling rate. Our test data are 3 weeks of constant GPS tracking with a sampling rate of one sample per second. As an input it requires a location data stream (*LS),* a set of places (*DB*), the sampling rate (*T*), the overall mean distance (*DIST*) of all cluster unbound samples (those samples which are not member of a cluster) and a temporal lower bound threshold for place durations (*DUR*). *LS*, DB*, T* are system resources, *DIST* is a self-adjusting parameter and *DUR* is a pragmatic value, like 5 or 30 seconds. Clusters are only accepted if their duration is more than *DUR*. Data streams, like the ones we work on, often break off and restart later. These events are strong indicators for places as, for example, GPS signals usually are not received within buildings. If the distance between the last received signal and the first received signal of the new stream is below the threshold DIST and the duration is above *DUR*, IDENTIFY-PLACES has detected a place (steps 1 – 9).
As long as we are analyzing the stream to identify a possible cluster start and no feasible start can be found, *DIST* is getting updated (steps 32-34). If two subsequent samples are closer than *DIST*, IDENTIFY-PLACES tries to cluster the next samples. The cluster center is always a weighted mean coordinate of all members of a cluster (e.g. steps 10, 23, 26). If in the next step (after the next sampling interval) the new sample is close to the centroid (steps 25-27) the sample will be added to the cluster. If the distance of the sample to the centroid is larger than *DIST*, the sample is rejected, the cluster is finalized by the function UPDATE-CLUSTER, and the algorithm is set to identify new clusters (steps 28-32).
The update function UPDATE-CLUSTER (see figure 4), tries to update existing places with the currently identified cluster. If a corresponding place can be found (step 5), the cluster is removed from the original set and put in a list of candidates (steps 6-7). UPDATE-CLUSTER forces the elimination of artifacts by predicting the best integration assumption: it selects the candidate which builds a cluster center with the minimal distance to the optimal merging location (the unweighted mean of all candidates, steps 11-17). If a suitable candidate is identified, the new location for the merged place is computed (steps 18-19). While there are unprocessed clusters in the candidate set, the process is repeated. Finally, UPDATE-CLUSTER adds the new center and all remaining unreachable candidates to *DB (*steps 19-21).
IDENTIFY-PLACES has implicit noise detection and handling based on the past velocity during the last *n* measurements: If the current sample covers an unlikely distance the sample is ignored and the current mean distance (based on the last *n* samples) is assumed (see steps 17-18 and 35-38). The clustering itself is not aborted, since noisy samples with extreme distances (up to several hundred kilometers) are not unusual, especially in urban canyons (low signal areas) and outdoor-indoor transitions. Usually they are either of short duration (single events or durations of some seconds) or the signal is completely lost. In the first case IDENTIFY-PLACES does not fail, in the second case it just stores the last assured state (steps 39-42). Currently, the noise detection factor is set to *m* times the mean distance of the last *n* samples (step 18). We instantiated *m* with *n*, which worked fine with our data. Unlikely acceleration (distance outliers) can be detected using a buffer of the last *n* records; *n,* the size of *distanceBuffer,* is a pragmatic value, like 5 or 10, depending on

the sampling rate (the higher the sampling rate, the lower is *n*). We use on-the-fly initialization of *DIST, i.e.* we do not have a training phase. Due to the constant updating of *DIST*, initial errors will be eliminated after a few samples.

IDENTIFY-PLACES has several remarkable properties: clustering is based on the spatial density of samples. We do not have to consider temporal density, as the sampling rate is fixed. IDENTIFY-PLACES never computes or stores elements of the clusters, but only the centroids based on two subsequent samples $C_i, C_{i+1} \in LS$. Furthermore it is adaptive to the user, as it does not rely on static parameters for place identification. It is fail-save and robust regarding noisy events and can recover from previous (erroneous) states.

Function: UPDATE-CLUSTER (DB, newC, DUR, DIST, minDUR)
Input: A set *DB* consisting of places *P* (which are tuple consisting of the cluster center coordinates *C(x,y)*, *meanDuration* representing the mean duration spend at *C* and *visits* holding the total amount of visits), cluster center coordinates *newC(x, y),* the duration *DUR* spend at the cluster and a distance threshold *DIST*
Output: A set of places P
Side-Effects: Updates places P∈DB

```
if (DUR > minDUR)
    candidateSet ← ∅
    newP ← new P (newC, DUR, 1)
    for each Pi ∈DB do
        if (getDistance(newC, C∈Pi) < DIST)
            select and remove Pi from DB
            candidateSet ← candidateSet ∪ Pi
    minDist ← 0
    while (candidateSet ≠ Ø ∨ minDist ≠ DIST) do
        meanC ← compute mean coordinates based on all C∈Pi∈candidateSet
        minDist ← DIST
        for each Pi∈candidateSet do
            newCenter ← compute visit and duration weighted mean coordinates
                        based on newC, C∈ Pi
        tempDist ← getDistance(meanC, newCenter)
        if (tempDist < minDist)
            minDist ← tempDist
            tempP ← Pi
        select and remove Pi ≡ newP from candidateSet
        newP ← update newP with (newCenter, weighted mean duration of Pi and
                  newP, visits∈Pi+visits∈newP)
    DB ← DB ∪ newP
    DB ← DB ∪ candidateSet
return DB
```

Fig. 4: Function UPDATE-CLUSTER

3 Conclusions and Future Work

Unknown environments are a common setting in wayfinding research. However, this is an unrealistic scenario, since in every-day live we hardly find ourselves in completely unknown environments, but rather need to find unknown places in a partially known environment, like our home city.

Algorithm: IDENTIFY-PLACES (LS, T, DB, lastC, lastTS, DIST, DUR)
Input: A Location Data-Stream *LS* consisting of Coordinates $C_i(x, y)$ and corresponding Timestamps TS_i, the sampling rate *T*, the set *DB* of places *P* and the last assured algorithm state (*lastC*, lastTS), the mean overall distance between two cluster-unbound points *DIST*, the lower bound duration *DUR for* all places
Output: void
Side-Effects: Will update places P∈DB, DB, lastC, lastTS, DIST

```
oldC ← lastC
startTS ← lastTS
currC ← C_1 from LS
endTS ← TS_1 from LS
clustering ← false
distanceBuffer ← initialize distanceBuffer[n] with DIST
noisyData ← 1
if (distance of (oldC, currC) < DIST ∧ (duration of startTS, endTS) > DUR))
        clustering ← true
        clusterCenter ← compute mean coordinates for oldC, currC
        oldC ← clusterCenter
else    oldC ← currC
        startTS ← endTS
while LS is active after next t_i do
        currC ← C_{i+1} from LS
        endTS ← TS_{i+1} from LS
        distance ← (compute distance oldC, currC)/noisyData
        if (distance ≤ (mean distance of current content of locationBuffer) × m)
               noisyData ← 1
               distanceBuffer ← update distanceBuffer with distance
               if   (clustering = false ∧ distance < DIST)
                     clustering ← true
                     clusterCenter ← compute mean coordinates
                     oldC ← clusterCenter
               else if (clustering = true ∧ distance < DIST)
                     clusterCenter ← compute weighted mean coord. of clusterCenter, currC
                     oldC ← clusterCenter
               else if (clustering = true ∧ distance ≥ DIST)
                     clustering ← false
                     DB ← Update-Cluster(DB, clusterCenter, (endTS-startTS), DIST)
                     oldC ← currC
               else oldC ← currC
                     startTS ← endTS
                     DIST ← update weighted mean distance of cluster-unbound coordinates
                                 with distance
        else noisyData ← noisyData + 1
               distanceBuffer ← update distanceBuffer with current mean distance
        if (noisyData = length[distanceBuffer])
               re-initialize distanceBuffer
if (clustering = true ∧ (endTS-startTS > DUR))
        DB ← Update-Cluster(DB, clusterCenter, (endTS-startTS), 1, DIST)
lastC← currC
lastTS ← endTS
```

Fig. 5: Algorithm IDENTIFY-PLACES

Taking individual previous knowledge into account, wayfinding assistance systems can provide more efficient, compact, and truly adaptive support. In order to exploit this knowledge, users' familiarity with an environment needs to be captured and turned into a meaningful representation.

In this paper, we present an algorithm that allows identifying places meaningful to an individual user based on constant mining of (GPS) data streams. Places are recognized by recurring patterns in the data stream; frequency based reinforcement ensures that one-time events or erroneous measurements are excluded as places in the long run, leaving only places a user visits frequently or for longer periods of time.

In our current work we set up a location-sensitive P2P system, which we feed with spatial signatures as configurations for simulated spatial agents. In future this system will serve as an environment for collaborative labeling and filtering of places. Furthermore we will concentrate on the integration and extraction of cognitive plausible decision points, on-the-fly simplification and matching of trajectories and the extraction and representation of long term routines. Based on the gained previous knowledge profiles we will develop feasible means of representations such as maps or verbalization.

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3 Knowledge-based Wayfinding Maps For Small Display Cartography

Schmid [2008]

In this publication we develop the fundamental theory of μMaps. μMaps are personalized maps based on previous spatial knowledge captured by trajectory analysis as proposed in Schmid and Richter [2006]. The aim of μMaps is to generate maps which are as minimal as possible by at the same time presenting all relevant information to find a yet unknown place in a partially familiar environment.

We discuss the practical and theoretical demarcations of the approach and develop the conceptual basis for the representation primitives and the algorithmic basis for the generation of μMaps. In particular, we demonstrate that straightforward schematization techniques (such as linearization) potentially disturb the veridicality on geographic, conceptual, and activity levels. We introduce the concept of μMizing, a schematization technique that preserves veridicality on all levels. It is based on a combination of generalization and scaling of links between regions represented as recursive convex hulls. We further demonstrate that the resulting map can be significantly smaller compared to traditional maps for assumed unfamiliar wayfinders. Additionally, we present cartographic primitives for μMaps in different wayfinding scenarios like trip planning, route inspection, and navigation.

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Knowledge-based wayfinding maps for small display cartography

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Small displays are currently gaining importance as interfaces for geographic information. More specifically, mobile position-aware devices, such as mobile phones equipped with globally positioning system, are increasingly used for mobile wayfinding assistance. But their constrained displays are too small to reproduce conventional maps without an increasing effort for the user. For example, they have to zoom in and out, and to scroll through the map to understand the details and configurational relationships of the involved entities of a route. This fragmentation of the information is not just inconvenient, but actually affects the cognitive processing of the given information and lowers the effectiveness of the assistance. One way to attack this problem is to tailor maps to the individual knowledge of a user. If an assistance system knows about the places and paths a user knows, it can generate maps according to this information: those parts of a route, which the user has good knowledge of, can be displayed with less detail and parts with no or little knowledge can be emphasised. However, the transformation of maps with respect to previous knowledge is a yet unexplored field and requires new and basic considerations about map generation. In this work, we analyse prototypical spatial configurations, geographic veridicality and assistance scenarios. We demonstrate first prototypes of personalised maps for small display cartography.

Keywords: maps; personalisation; wayfinding assistance; navigation assistance; mobile cartography; schematisation

1. Introduction: wayfinding with maps in the age of turn-by-turn instructions

Wayfinding is a significant task in our lives. Recurrently, we have to find our way to an unknown destination. In such a case we typically consult a form of wayfinding assistance, like a map or a turn-by-turn navigation application (wayfinding decisions, like turning at a junction, are announced just before their execution is required). The first case, namely wayfinding maps are the subject of this article. There is a prominent question we (researchers on wayfinding maps) are regularly confronted with: why do we still focus on maps as wayfinding aids, especially as turn-by-turn navigation assistance is on the edge of ubiquity? Most people who have experienced the ease and effectiveness of a turn-by-turn navigation system are convinced by the contemporarity of the application: one has just to type in a destination and they will be guided effectively, fast and conveniently always with

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respect to one's current position. These systems usually react to navigation errors, blocked roads and traffic conditions and re-route the driver if required; the driver just has to mentally lean back and follow the instructions. In contrast to that, maps appear as an inopportune relict. Even if they are generated with respect to a particular query, this means that they only cover the requested geographic area and already contain a pre-computed and highlighted route, they still require close examination: what course does the route take, which elements along the route are significant or already known, and so forth. During navigation, the map has to be matched against the environment and vice versa to ensure successful wayfinding. But there is a huge positive side-effect which does not develop with turn-by-turn assistance: people collaterally learn the environment beyond the route and are, as a result, more independent from assistance (Richardson *et al.* 1999). There are observations that people do not learn the environment similarly well when they use turn-by-turn assistance instead of maps (Ishikawa *et al.* 2008). A possible explanation is that this kind of representation does not require a close examination of the environment anymore, and even navigation errors are immediately corrected (Burnett and Lee 2005, Parush *et al.* 2007). This means, if we want people to learn an environment and to navigate independently in large parts of it, maps seem to be indispensable. We believe that maps can be further improved to facilitate their successful parsing, understanding and use for wayfinding, especially in the context of mobile devices and mobile navigation support.

Today, wayfinding assistance is no longer limited to either paper maps or computers with comparable large displays. We can find wayfinding support in many mobile and semi-mobile devices, like mobile phones or PDAs or car navigation systems. The visual interfaces of all these devices are small displays. The actual sizes and resolutions of the displays differ from very small (as usually found on mobile phones) to a more moderate size and resolution (e.g. car navigation systems). Dillemuth (2007) has shown in her experiments that traditional interaction (like scrolling) with large visual information (the map) on small displays does affect knowledge processing of the information significantly. As geographic information usually requires space to be displayed properly, we have a need to develop different forms of represention for the required geographic information (usually in the form of maps) for these kinds of devices.

A key concept can be the schematisation of the required map. Schematisation is usually understood as the intentional distortion of a representation beyond technical needs to achieve cognitive adequacy (Klippel *et al.* 2005). In the following, we will have a look at some prominent schematisation approaches and highlight their essential cognitive concepts.

2. Wayfinding maps: selected schematisation techniques

Agrawala and Stolte (2001) introduce an activity-based schematisation for driving routes. It is based on the observation that driving routes often incorporate long parts where no decision activity (like turning or changing a road) is required during wayfinding. An example is driving for a long time on highways without leaving it or changing roads. When we visualise the geographic region in according scale on a map, these parts can require a significant amount of the available limited interface space. This is contrary to the actual activity and cognitive load related to these parts. As Agrawala and Stolte show in their pictorial examples, this can lead to situations where the important parts of a route will be literally suppressed while uncritical parts are dominant. They propose to adapt the scale of the particular route elements to the corresponding wayfinding activity: a high degree of required activity (and corresponding cognitive load) will lead to a more detailed view of the involved entities; a low degree of required activity will lead to a highly schematised view. As a result the distance information is no longer in a uniform scale, but relates to the activity required by the route. The result is a route strip map which requires significantly less display area if the route incorporates big parts with no required wayfinding activity.

Zipf and Richter (2002) introduce a different form of schematisation. They do not primarily aim at the compression of the visual representation of a route, but to improve the extraction and processing of the actual route and its context within a rich map, thus a map which contains significantly more information than required. They highlight the route by schematising and fading out map features depending on their proximity to the route. That is, the closer a feature of the map is to the actual route the higher is its level of detail and the intensity of its colouring; the more distant a feature is the more schematised and uncoloured is its appearance. This concept is based on the observation that a larger spatial context is helpful during wayfinding (in contrast to strip maps), but not all spatial regions are of equal interest for the given task. This idea was further extended by Klippel and Richter (2004) with the introduction of chorematic focus maps, which further improve map understanding. Junctions and turns of the route are represented by means of choremes (Klippel 2003), reflecting the prototypical mental representations of turns.

A promising approach to information reduction that at the same time preserves the meaning and the accessibility of geographic information is to generate maps according to the spatial knowledge of a user. Although they present no explicit mapping, the concept of Srinivas and Hirtle (2007) is important to this end. They introduce the concept of knowledge-based route chunking. Srinivas and Hirtle assume a path network encoded with a familiarity measure for certain locations. If a specific route incorporates two or more subsequent known segments, these are combined to one semantic unit. In their paper, Srivinas and Hirtle show how routes and their conceptual representations can be tailored to the knowledge of an individual by applying these chunking rules.

In Patel *et al.* (2006), the authors introduce a similar concept but focus more on the pictorial representation in forms of maps. Patel and co-authors refer to complete existing known routes between landmarks and introduce a cost function to select not only the fastest route but the route with the most well-known parts. As long as the cost for the route does not exceed a certain ratio, the longer route is assumed to be equivalent to the route choice that does not consider prior knowledge. An informal study shows that users are willing to accept longer routes if they incorporate well-known parts. Using this known sub-route, Patel and co-authors compress route directions and render personalised strip maps. They indicate prior knowledge by schematising the known parts of the route: the original street course is replaced with a straight line (space needle). The space needle does not attempt to reduce the required size for the route and the map, since it covers the same space. But it indicates the presence of previous knowledge.

3. Personalising wayfinding assistance with individual spatial knowledge

Personalised wayfinding assistance is not a new invention but a very natural form of support produced by humans for humans. If we ask somebody for directions, we usually get involved in a dialog (Tomko and Winter 2006). During this conversation the participants discuss familiar, unfamiliar and salient features of the route and consider the situation and the type of transportation of the wayfinder. Resulting from this process are directions tailored to knowledge and needs of the wayfinder (which is a subset of the knowledge of the assistant). Usually, the result leaves out descriptions that are unnecessary for the wayfinder, i.e. those parts of the route the wayfinder knows do not need to be explained in detail (e.g. Schmid and Richter 2006). This has two effects: first, the directions can be significantly shorter but still contain all relevant information; second, the remaining parts and elements of the route are related to already known elements, which helps to integrate the new facts into the existent mental map. If maps reflect this process, we can expect them to be efficient in terms of size (as parts of the environment do not need to be depicted in detail while other parts can be emphasised) and efficient in terms of mental processing, as the information is related to existing previous knowledge.

If we want to transfer this process to an application, namely the personalisation of maps under the consideration of individual knowledge of an environment, then the application will require access to this knowledge. To enable an application to access this particular knowledge, it needs to be developed and represented beforehand in an effective way. Patel *et al.* (2006), and Srinivas and Hirtle (2007) propose to enter the required knowledge manually: i.e. users have to enter exactly those places and routes that between them they actually know via a proper interface. The advantage of this approach is the availability of verified and fully labelled data. But this method only reflects the part of the knowledge an individual can recall and label at that given moment. We can expect that the resulting data will not reflect what a person really knows about the environment. Especially all the small and apparently insignificant places like junctions, the post office, the grocery, etc., will not be considered although they can play an important role in an individual's segmentation of space as discussed in Schmid (2007). Furthermore, it is clear if the data are not maintained regularly, it will soon become obsolete.

One promising way to resolve this problem is the maintenance of a spatial user profile based on the trajectories of an individual. Some years ago the recording of everyday trajectories was only possible either under laboratory conditions in specially modified test environments or with additional hardware, like GPS (Global Positioning System) handhelds. Currently we can record GPS-based trajectories with many everyday devices like mobile phones, wristwatches, or car navigation systems. These trajectories can be analysed according to inherent patterns: the visited places and travelled paths (Ashbrook and Starner 2003, Hightower *et al.* 2005, Schmid and Richter 2006). This information can be used as an input for a spatial user model which is constantly updated and maintained. The drawback in relying solely on a built-in GPS module as an input for a spatial user profile is the potentially highly fragmented and noisy datasets we will obtain. A major problem is the handling of personal mobile devices, because their use is contrary to the requirements of a GPS device: they are usually not carried at places where the signal reception is optimal (e.g. on the top of the head or at the window of the tram), but in jackets, trouser pockets or bags. This massively downgrades the quality of the received signals; they are only occasionally outside of pockets or bags and on account of this rarely in optimal receiving mode. A further error source lies in the mobility of the devices: they can be turned off, forgotten, stolen, lost, shared or lent. This means, they are not necessarily there where the user is and the user is not necessarily the 'owner' of the user profile. Additionally, all these devices operate with batteries and GPS is still an energy intense technology. Weak batteries are often a source for bad signals; empty batteries will result in signal loss. Another problem with GPS is the general visibility of the satellites.

The quality is usually good in open areas with no extreme topography such as parks, rural areas, etc. In densely built urban areas, the signals get reflected and distorted by the surfaces of walls of buildings and water bodies. The signals can usually not be received in a satisfying quality within buildings and vehicles. Especially during transportation this has implications: if a person moves with a car, bus, tram, train . . . or subway the trajectories are usually of unacceptable quality or simply not available. As a result we only obtain the transitions from one place to another, but we will miss out on the actual travelled route.

For real life applications, this means that a reliable spatial user profile cannot be solely obtained by manually entering spatial data or by GPS trajectory analysis. We will require the integration of multiple spatial sensors, non-spatial sensors and manual data. Future applications will have to communicate with the ticketing system of the public transportation to identify the travelled, untrackable routes, they will have to be able to receive positioning information from car navigation systems, and of course they have to be able to include external spatial sources, like internet route planner queries or manually entered spatial data. We have to enable the plausible interweaving of all possible sources of verifiable individual spatial knowledge to receive a clear and expressive spatial user model. Such a model should not only minimise the errors and inaccuracies introduced by sensors, but should also be able to express the mode of transportation (such as walking, car, active or passive navigation), environmental influences (e.g. daytime dependent illumination, weather conditions, viewpoint analysis) and individual conditions (stress level, emotional state) related to the learning of particular spatial layouts. All these factors can massively influence the perception and, consequently, the conceptualisation of an environment.

It is important to note that spatial knowledge is built up and fed by different sources and senses. Knowledge is not only assembled from direct perception during locomotion, but also from external sources, like maps, from videos, photos or information gained from conversations with other people. We can build concepts of the environment before we actually perceive it (Richardson *et al.* 1999). In order to give meaningful assistance, a personalised wayfinding assistance application must rely on verified data, i.e. prior knowledge for which it is assured that a user indeed possesses it. This means, personalised wayfinding assistance is mainly interested in physically perceived knowledge, which contains all forms of perceptual knowledge acquisition of the surrounding environment during locomotion (Golledge 1992).

The utilisation of physically perceived knowledge does still not guarantee the reflection of the actual knowledge of a user. First of all, we have to consider memory effects. Although (to the knowledge of the author) there exists no long-term study on spatial memory, we can assume that spatial knowledge – as any learned fact – is subject to fading, forgetting, systematic and individual errors. Places and routes we have not visited and travelled for a long time will most probably lack details when we recall them. Due to missing evidentiary functions, we are currently not able to state which parts of the knowledge will fade to which degree. Or, vice versa, we are not able to say which elements will be preserved to which level of detail.

Cognitive models of long-term memory usually include functionality to model loss of memory (which is usually equivalent to the reduced activation of neurons over time). These models are usually context specific, and once again, to the knowledge of the author, there exists no empirically supported model explicitly for spatial knowledge (e.g. Anderson *et al.* 2004, Schultheis *et al.* 2006).

We know from other areas of cognitive research that human memory is no veridical storage for experienced facts (e.g. Baddeley *et al.* 2001), and the same holds for spatial knowledge as well. Research on spatial memory unfolded a range of systematic errors related to spatial knowledge (see Tversky (1993), for an overview of prominent examples). A further critical influence on spatial knowledge acquisition is the level of involvement during navigation and transportation. One can travel passively by public transportation and at the same time read a book. Doubtlessly, the acquisition of knowledge will be very limited. As another extreme, one can navigate by paper map and instructions and potentially learn the environment beyond physical experienced space.

The observations and particularities of human spatial knowledge acquisition raise the question of the validity of trajectory-based user modelling. On the one hand we have a bunch of potential problem sources and effects, on the other hand we have pragmatic experiences with places and paths we travel and visit frequently. This question and its implication cannot be answered easily and will clearly require user-centred and, ideally, long-term studies.

3.1. *Conceptual elements of personalised wayfinding assistance*

Two key units of human conceptualisation of space are *places* and *paths*. The term place has no clear definition and is used ambiguously over a variety of publications and in different contexts (see Agarwal (2004) for an elaborative overview; see also Bennett and Agarwal (2007)). Observing commonsense and empirical studies lead to the interpretation that places are regions obtained as the result of structuring the world individually into semantic, perceptional or functional units for the purpose of spatial communication (as discussed in Montello (2003), Agarwal (2004), Wiener (2004), and Edwards (2007)). From the perspective of an individual, places are connected to activities and vice versa most activities are connected to places. It is hard to identify activities beside those grounded in travelling as their main purpose (like hiking or driving over large distances), which are not directly connected to a kind of place. This means, in the majority of cases whenever we perform any kind of activity, we visit a place in the course of doing so. And as activities usually need time to be performed, we can say that a place is a conceptualised geographical region where an individual spends more time than in other regions. The 'other' regions are the remaining parts of the physical presence, the travelled routes between the places. Consequently, there is no 'placelessness' since we are always physically present and ultimately have to perform at least basic activities (eating, resting, sleeping, etc.) which are covered by the concept of place. In the following, we will differentiate between a 'route' and a 'path': a route is the result of the query for a way between two places A and B, a path describes a known and, therefore, previously travelled route between two known places A and B. Whenever we refer to the term 'route', we mean the result of a route planning process, a path will always describe a previously travelled route as part of the previous spatial knowledge of a person. Routes and paths can intersect each other in any possible configuration.

3.1.1. *Major, minor and inferred places*

The question is now whether all places qualify in the same way as references in personalised wayfinding assistance. It is easy to see that this is not the case: there are places we know very well, places we can hardly remember and there are many places we are not aware of without pointing to a larger context. If we only take the perceived environment into account, we can differentiate between *major places* and *minor places*. Major places are purposefully visited places, they are characterised by relatively long duration stays, and people usually have an explicit name for them (home, work place, etc.). There are indications that people remember these places without frequent repetition, since the learning usually takes place in advance: people plan their activities and visit previously chosen places to exercise them. People usually do not visit places randomly to perform unconscious activities. This means, a major place is a place with a distinct and specifiable meaning to an individual. A major place can be labelled with respect to a particular experience, activity, salience or function. In contrast to that, minor places are 'collateral' places and they are not intentionally visited. Due to spatial particularities like junctions or construction sites, people are forced to spend time in some regions without explicit intention. If people are regularly at such a place, they start to learn it due to the inherent recurring activity and experience. But people usually do not have an explicit name for them. The names typically reflect the local spatial configurations ('the junction at the pharmacy'), landmark-like particularities ('at the crossover') or the involved destination ('the large junction on the way to the Uni'). A third, but not directly operational category of places is *inferred places*. Inferred places are places inferred from the structure or naming of the environment, like street names or street block conventions. For example, if a person knows that 'Peter's place' is in XYZ-Street 15 and the new unknown destination is in XYZ-Street 19, they are most likely close to each other. Although the wayfinder has never been to the place before, he can directly infer the relationship with existing knowledge without the consultation of wayfinding assistance.

Personally meaningful places are inline with the anchor-point hypothesis of Couclelis *et al.* (1987). According to the authors, 'anchor-points are the most important elements in a person's cognitive map', thus, personally experienced places which serve as structural fix points in the cognitive map, organisational 'top nodes' within each individual cognitive map. Major, minor and inferred places can be viewed as a refinement of the term anchor point. Couclelis and co-authors state that 'there appears no obvious method for identifying individual anchor points', which is still true for the complete set of possible places of a person. But due to the activity-driven definition of places and by means of trajectory analysis, we can identify the set of personally meaningful places which is grounded in recurring activity. As stated above, this set will obviously not cover all possible meaningful places, but a verifiable and utilisable subset.

3.1.2. *Familiar, partially familiar and unknown environments*

When we use the term environment in the context of knowledge-based wayfinding assistance, we mean the regions which are geographically relevant for an individual. An environment does not have to be limited to regions around the person's centre of life. The understanding of environment must be driven by the knowledge corresponding to it: each region a user has knowledge on is a possible environment for him. We can say that the environment of an individual is the vista-space (Montello 2003) around all locations the individual has physically ever been to. Additionally, in the context of personalised wayfinding assistance, we will have to answer the question how well the environment is known. Basically there are three categories of environments, independently from the actual level of knowledge: there are regions which an individual has full knowledge of, regions where he does not know all relationships between all features and regions in which he knows nothing. In other words, we can say that a familiar environment (FE) is the environment where an individual knows at a particular point in time all possible places and at least one route between each of them (full knowledge). A partially familiar

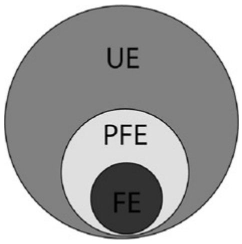

Figure 1. The relations between familiar (FE), partially familiar (PFE) and unfamiliar environments (UFE).

environment (PFE) is the environment where an individual does not know at a particular point of time all possible places and routes between each of them (partial knowledge). And finally, an unknown environment (UE) is the space where an individual has never physically been to, and which is not covered by the vista-space of the historical trajectories of the individual (no physically perceived knowledge is present at all). Figure 1 illustrates the relationships between the three types of environments: the FE is embedded within the PFE which is embedded in the UE.

Spatial familiarity is hard to express and even harder to measure. Couclelis *et al.* (1987) suggest a recognition- and labelling-based multidimensional measure to express familiarity. The basic idea is, if people recognise a place and can label it properly, they must have a high level of familiarity with this place (this anchor point).

3.1.3. *Labelling places – attaching individual semantics*

The communication of places for personalised wayfinding assistance has to rely on individually assigned labels. A large set of places in the user profile will not be public places or landmarks, but places such as 'home' or 'work'. In order to address the name or the concept of an identified place, an application has to know this name. In the prototype of our application, when a user visits a previously identified (major) place again, we pop up a window and ask the user to enter a description of the place. If a place is labelled, we assume this as a verification of the identified place, similar to Couclelis *et al.* (1987). In order to reduce the required manual entering of names (which is always a critical usability point), we are currently working on collaborative labelling techniques, the application of media based (e.g. photos taken at a place – personally or collaboratively), and phone-based activity detection (recurring calls at the same place). Collaborative labelling has the advantage of generating hierarchically meaningful conceptual regions with only small effort to the individual. Especially public places, like a university campus, only have to be labelled by a small group of people. Other people can either reuse already assigned labels or refine existing concepts (university *vs.* building name). Combined with geographic analysis we can expect further insights in human conceptualisation of semantic regions – what elements belong to concepts and where the borders run.

By applying the mentioned techniques, we expect more convenient data acquisition, and at the same time additional questions about the validity and quality of labels. Naming and recognising of places is no longer solely the responsibility of the addressed user, but in charge of a 'community'. This means, that the acceptance of labels will require a different familiarity measure: accepting a predefined label is clearly not as expressive as generating a new label. A key to this problem can be the enforcement of the selection of a finer or coarser concept or the refinement of an existing concept. An intended selection of a label expresses the familiarity with a place and the desired granularity connected with this place.

4. Personalised wayfinding maps – maps built around individually meaningful places

If we want to generate personalised wayfinding maps, we have to consider the basic requirements and elements of wayfinding maps. We have to examine which elements of the previous knowledge can replace elements of traditional maps, and how elements of the unknown parts of the environment can be integrated in a personal frame of reference.

First of all, let us have a look at the basic demands of a wayfinding map: for self-localisation a wayfinder has to identify the surrounding environment with the map at hand. For the unknown parts of the environment, we can rely on either established or experimental mapping (as illustrated in Section 2). But for the known parts of the environment and especially the transition points, i.e. those areas where familiarity ends and unfamiliarity starts, we will have to think about a suitable form of visual communication. This is necessary because the reference systems of the information changes: the unknown parts of the environment are expressed by means of geographic mapping, whereby the known parts directly refer to mental concepts of the user. We will have to make this change clear to avoid misinterpretations. Additionally, we will have to consider how the actual spatial relations between the elements of the PFE and the UE can be clarified and which information is required for successful map understanding.

During navigation, a wayfinder has to identify his physical location on the map and the surrounding environment on the map. When maps are used for pre-trip planning, i.e. the consultation of the map before the actual travelling, a wayfinder benefits from the meaningful integration of the route within the environment he will cross. This will help him to integrate the queried places and the route into his prior knowledge. For both scenarios the initial orientation, i.e. the alignment of the map with the environment is of crucial importance for the wayfinding success. A good map selects features that resolve local ambiguities with carefully selected landmarks and/or structural configurations and helps the wayfinder to identify the local configuration ('if you see the park on your left and the river to your right, you are oriented correctly'). For the UE, we can rely on any available method, for the PFE and the transition areas we will need a suitable bridge between the two frames of reference. The strongest pointers we have at hand are the major places of the prior knowledge. As these places have a very distinct meaning for an individual, we have very good anchor points for the indication of global and local orientation of a route. As soon as we incorporate prior spatial knowledge we can rely on places as references, even if no place is covered by the actual route. If we just refer to a part of a path, we can indicate at the transition points how the route enters the path and how the places are related to this location. If a route starts at a place, we can rely on the knowledge about the local configuration at the place; we only have to indicate in which direction a wayfinder has to follow the path ('go from here as you usually go to the university'). To foster the integration of new knowledge in existing knowledge, we have to make sure how the route and the new place(s) are related to existing entities of the spatial knowledge. We have to consider two basic cases: either the new place(s) and well known parts of the environment are in the same geographic region or they are in a distance such that references to well-known elements are not really helpful. Of course, different areas in the world have different concepts of scale: in dense urban areas 'far' means something else than in rural areas with a very low density of population and larger distances between places. The selection of known references must be driven by their closeness to a UE and the established level of knowledge connected to them. If a person is close to well established knowledge (e.g. where they live), we can clearly indicate the location or direction by nearby places. If the person is far from 'everyday knowledge', e.g. in a holiday resort, instead of pointing to the usual surroundings we can integrate the prominent patterns of the latest trajectories, like the way to the hotel or the church visited 1 h ago.

5. Knowledge-based schematisation of wayfinding maps: route-path configurations, assistance types and schematisation techniques

According to the definitions of the different kinds of environments, namely that FE and PFE are developed by trajectories, all known parts of the environment are connected to each other. An extreme interpretation can be that we only have three possible configurations of routes and paths in the FE/PFE and UE (in the following we will only refer to PFE instead of FE and PFE, as in the important properties they share the same concepts):

- *Route is contained in PFE*: This means that the start and endpoint of a route is completely contained in a combination of paths in the PFE (Figure 2).
- *Route overlaps PFE*: This describes the scenario depicted in Figure 3. A part of the route is addressable with a path; the other part of the route is in the UE. The part in the PFE can, but does not have to be a known place.
- *Route contains PFE*: A known path can be fully integrated within a route but both ends of the route are members of the UE (Figure 4).

In reality, of course, we can expect highly fragmented records of the real trajectories due to the particularities of the positioning devices used (like mobile phones equipped with GPS sensors). When we feed the knowledge presentation with this data, the resulting user model

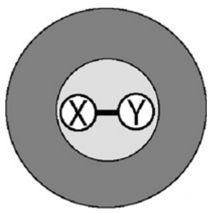

Figure 2. Elements contained in PFE.

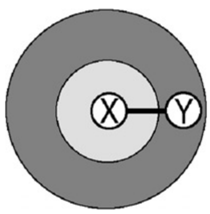

Figure 3. Elements overlap PFE.

will be fragmented as well. Under realistic conditions, we will have fragmented data and cannot expect a completely connected PFE. As a consequence, we will have to deal with complex configurations of UE and PFE (as illustrated in Figure 5). However, the three basic configurations are important for the identification of suitable schematisation principles. In the following, we will focus on the particularities of each configuration and propose suitable schematisation methods.

5.1. *Optimal route detection*

In this article, we assume a coherent PFE and just allow the three basic configurations discussed previously. As we want to generate a map for a particular route with respect to particular knowledge, the most basic step is the selection of a route from the desired point A to point B. There are several route selection strategies, but we will only focus on the shortest path with maximised known parts. In Patel *et al.* (2006), the authors only allow complex routes between landmarks, which can result in suboptimal routes in terms of length and time. We developed an algorithm which allows us to identify the path with maximised familiar parts and is shortest within the PFE. This means we can identify the shortest route with the minimal unknown elements. In this work we do not aim to compare it with results of other route selection strategies, as we primarily aim at the treatment of previous knowledge for map generation.

At this point we do not aim to identify a plausible tradeoff between an optimal route (under the fastest or shortest route assumption) and one integrating previous spatial knowledge. But it is clear as soon as we spread a personalised assistance system beyond the walls of our lab and encourage people to use the system in their real life settings, we will require an operational measure for the route selection. People will only use a new system if it is at least as effective as the old system it aims to replace and if they obtain an additional feature (which can also have a better interface or easier to extract information). Consequently, a personalised wayfinding system must be able to offer effective routes in

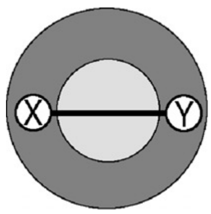

Figure 4. Elements contain PFE.

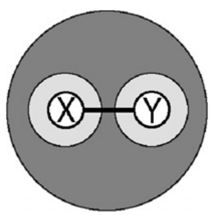

Figure 5. Fragmented PFE/UE configuration.

Algorithm: FIND-OPTIMAL-KNOWLEDGE-PATH (G, KG, S, D)
Input: A general network graph G, a previous knowledge graph KG $\subset$ G, a node S and a node D
Output: Returns the optimal path with respect to maximised previous spatial knowledge

1. KN $\leftarrow$ get list of all nodes of KG
2. entrancePath $\leftarrow$ FIND-N-SHORTEST-PATH (G, KN, S)
3. exitPath $\leftarrow$ FIND-N-SHORTEST-PATH (G, KN, D)
4. L $\leftarrow$ last node $\in$ entrancePath
5. F $\leftarrow$ last node$\in$ exitPath
6. knownPath $\leftarrow$ FIND-SHORTEST-PATH (KG, L, F)
7. **return** compiled path: entrancePath+knownPath+exitPath

Algorithm 1. The algorithm to detect an optimal route via PFE.

terms of quantitative measures, like distance or time. This will require further empirical analysis of the travel behaviour of people within their familiar environments and their natural route selection strategies when leaving them. A good starting point is the analysis of trajectories in unassisted travel: we can classify the different modes of transportation on a path and compute the distance difference between the actual travelled route and an 'optimal' route for each mode. If we can identify significant differences (e.g. a user accepts 14% longer routes), we could use this ratio as a clue for an individual operational measure. Besides the operational measure for the route choice, we will have to ensure that the selected route will be coherent and plausible while integrating the previous knowledge: it would be hard to understand why a user should leave a main road he would just have to follow just to find his way through small and winding side streets. This means, we will have to find measures and algorithms which ensure the integration of previous knowledge plausibly with respect to distance and coherence of the involved elements.

The algorithm FIND-OPTIMAL-KNOWLEDGE-PATH (Algorithm 1) works as follows: it requires two graphs, the street network graph G and the graph containing the previous knowledge KG (which is required to be a proper subset of G). Furthermore we require two nodes, which define the start- and endpoint of the route (S, D). The shortest path computation (in this context it should be interpreted as a graph search) can be performed with any algorithm, such as the Dijkstra algorithm. First of all, we compile a list of all nodes of KG and pass it on to the function FIND-N-SHORTEST-PATH (Algorithm 2) together with one of the nodes S, D. Here we compute the Euclidean distance of every pair of the two nodes S, D and all the nodes of the list KN (Steps 1–3). In the next step (Step 4), we sort the list according to the distances and compute the shortest path from S, D to the prior knowledge starting with the smallest Euclidean distance. The shortest so far identified path is stored and only replaced if a shorter one can be found (Steps 6–10). We can use the shortest path as a break condition for the shortest path algorithm. When we reach the point that the Euclidean distance is longer than the path distance, we can finally stop the search at this point, as it will not be possible to find a shorter path.

Back in the main algorithm, we now have to compile the three pieces (entrance part, known part, exit part) whereby we still have to find the shortest path within the PFE (a shortest path search from the entrance point to the exit point does just this). As a result, the presented algorithm will neither identify the shortest path, nor the shortest well known,

```
Function:  FIND-N-SHORTEST-PATH (G, KN, N)
Input:     A network graph G, a list of nodes KN of previous knowledge, a node N
Output:    Returns the shortest path between N and a node of KN, N will be the
           first node of the path.

for all KN_i ∈ KN
     d ← compute Euclidean distances between N and KN_i ∈ KN
     SN ← add (KN_i, d)
SN ← sort SN with respect to d
SKP ← compute shortest Path for N, KN_i ∈ (KN_i, d)_1 in G
for all (KN_i, d)_i ∈ SN
     temp ← compute shortest Path for N, KN_i ∈ (KN_i, d)_i in G
     if (temp < SKP)
          SKP ← temp
     if (SKP < d ∈ (KN_i, d)_{i+1})
          return SKP
return SKP
```

Algorithm 2. The function to identify the shortest route from the UE to the PFE.

but the path with the shortest parts within the UE and the shortest path within the PFE. The result of a query for a route between a location A and B consists of three elements:

- The starting point and a certain area around this place
- The destination and a certain area around it
- The known path which shares exactly one node with the area around the starting point and one with the area around the destination.

All three elements are represented as graphs. If one of these areas is contained in the PFE, they are only represented as one node.

5.2. *Linearisation and µ-mizing depending on route-path configurations and assistance types*

In the next step we are interested in visualising the resulting path conveniently. A straightforward schematisation for a known path is its linearisation, i.e. the complete abstraction from the geometric layout as proposed by Patel and colleagues. This works fine if the addressed path is fully contained by a route, i.e. its two places are completely integrated. But as soon as we only refer to parts of the path (which we explicitly allow), we face the problem that we will have to make clear where a required wayfinding action has to be performed. A straightforward approach is the segmentation of the known path into suitable sections, determined by cognitively plausible elements (such as landmarks, major junctions or places). The elements can be plotted along the linearised path with respect to their relative distance. This involves some tricky representational problems. Let us consider the situation depicted in Figure 6: A and B are known places and connected by the known path illustrated with the bold line. The user usually turns left from the main road into the street leading to B, the new place is at the extension of the main road. If we linearise the path as described above, we will introduce spatial (and most likely cognitive) artifacts. Figure 7 illustrates one possible arrangement of the schematised path. It indicates to turn right which is not required in the real environment, as the user only has to follow the main road straight on. In Figure 8, we can see how this schematisation

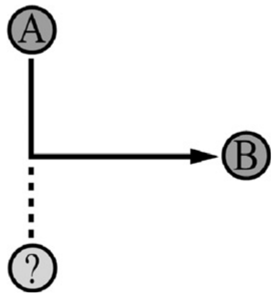

Figure 6. Original configuration.

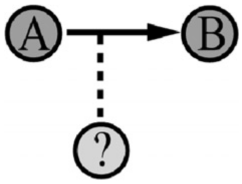

Figure 7. Horizontal linearisation.

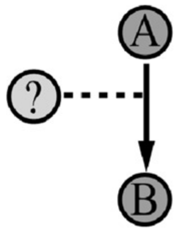

Figure 8. Vertical linearisation.

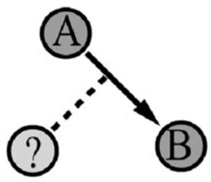

Figure 9. Spatially vertical linearisation.

introduces wrong spatial constraints. In terms of cardinal directions, it seems like the unknown place is west of A and B (instead of south). Furthermore, we can find the false activity indicator as in Figure 7. Figure 9 seems to work best in terms of spatial configuration of the known places, but still fails with the configuration of the unknown place as well as with the activity indication.

We require this veridicality, because in contrast to fully contained paths, we have to perform a different activity than usual on this path. The location of this decision point has to be inferred from the map which requires self localisation. Self-localisation in unknown environments requires a certain degree of veridicality, as the wayfinder has to identify the decision point in the environment. If the information on the map is misleading, especially at the critical decision point, the potential of navigation errors increases. We can conclude that linearisation is not a proper schematisation method for all spatial configurations. Especially when we refer only to parts of a path, we can easily identify configurations which will lead to problematic externalisations. The possible misinterpretation of potential wayfinding activities and/or the wrong interpretation of the spatial configuration can be attacked by abstractions which inherently contain the required information and/or will foster the understanding of the relationships of the addressed entities. We know from our own experience that people, while giving route directions, tend to de-emphasise elements which are known to the receiver. We can now carry these observations forward to the schematisation of complex route configurations. The primary element of the desired map is the route with its known and unknown parts. Especially the spatial layout of the known path has, due to its intrinsic configurational properties, a supporting role; if we preserve the layout properties of the known path and arrange the unknown elements with respect to their position relative to the path, we introduce a natural allocentric reference frame for the spatial relations and are able to preserve the correct interpretation of the locations of the new decision points. To preserve the spatial layout and at the same time achieve schematisation, we now have to apply two basic steps: generalisation and minimising. We will call the result of these two operations *μ-mizing*.

Generalisation describes the simplification of a polyline and is a widely applied technique in geographic visualisations. One well-known algorithm is the Douglas–Peucker algorithm, a cognitively motivated one is the Discrete Curve Evolution (Barkowsky *et al.* 2004). In our actual implementation, we apply discrete curve evolution to generalise the known path. A comprehensive overview of further approaches and their properties are offered in Stein (2003).

In Figure 10, we can see the basic steps involved in μ-mizing: the left image contains two unknown regions A and B connected by a part of the path between X and Y. In the first step we generalise the path; in the second step we minimise the schematised path such that the regions A and B do not touch. The algorithm sketch μ-MIZE-GRAPH (Algorithm 3) illustrates the functionality in more detail. The regions A and B and the path are a partition of a street network part. We split it up into three graphs: the regions A, B and the path P (Figure 10). P has to be chosen such that it exactly shares one node with A and with B. In the first step, we will generalise P. In the next two steps, we compute the convex hulls of A and B. In Step 3, we compute the shortest distance between the two hulls. From the distance and the two points we can immediately receive the

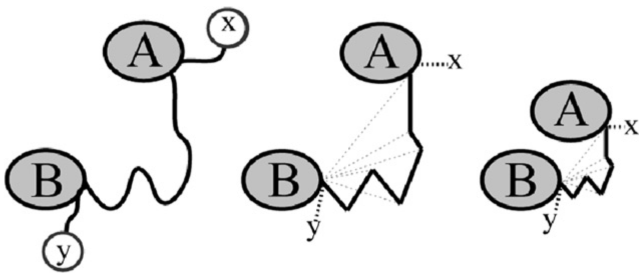

Figure 10. μ-Mizing of a route.

Algorithm: μ-MIZE-GRAPH (A, B, P)
Input: Two graphs A, B (the two unknown regions) and a graph P (the known path) connecting both graphs (they share a node)
Output: Will return a μ-mized graph of A, B, P

1. P $\leftarrow$ generalize P
2. CA $\leftarrow$ compute convex hull of A
3. CB $\leftarrow$ compute convex hull of B
4. v $\leftarrow$ get displacement vector between the two closest points of CA and CB
5. distVecs $\leftarrow$ get vectors between any node of P and refPoint
6. A $\leftarrow$ translate every node in A with v-ε
7. P $\leftarrow$ scale/minimize P
8. return A+B+C

Algorithm 3. μ-MIZE-PATH.

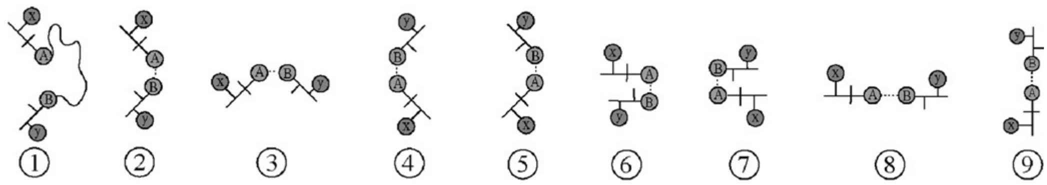

Figure 11. Eight possible linearisations of the route depicted in 1; see text for details.

transition vector, which will be applied to all nodes in A in Step 6. The displacement vector will be shortened by a certain value to guarantee that the two regions do not touch (which would be the case if we would directly apply the displacement vector). In Step 8, after the translation of A, we just have to minimise P with the according scale factor. The minimised path now serves as the constraining link to the global configuration of the involved elements. The layout of the path ensures that the unknown and known elements are in a mutually correct configuration.

The linearisation of routes is still a promising option for knowledge-based schematisation. Patel and colleagues propose the 'space needle', a geographically veridical linearisation of the known path. In Figure 11, we can see different linearisation possibilities of the path between the places A, B and route alignment options for different assistance scenarios. Let us assume a wayfinder travels from x to y via the path between A and B. We now have several possibilities to arrange the involved elements. Illustration 1 depicts the original configuration of the elements, i.e. their topological relationships in a cardinal reference frame. Illustration 2 follows the concept of Patel and colleagues: the path is schematised, but the cardinal directions and the topological relations are preserved; we also applied an additional minimisation of the Euclidean distance between A and B. By de-emphasising the path, the unknown parts of the route are clearly emphasised and the wayfinder is not distracted by the elements of the path. Illustration 3 shows an allocentric route perspective, where the linearised path is horizontally aligned and the unknown parts are veridically organised at the transition points. In illustration 4, we can see a typical navigation perspective: the starting point (x) is at the bottom of the map and the destination (y) is on the top. It is important to notice that this configuration does not correctly depict the exit/entrance angles at the transition points, but the

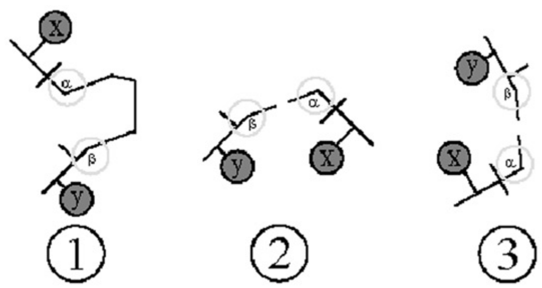

Figure 12. Illustration of the alignment steps for the linearised navigation perspective. X is the starting area and Y is the destination area.

geographic configuration. In illustration 5 we can see the navigationally veridical counterpart. In this illustration, the environments are aligned from an egocentric perspective. Illustrations 6 and 7 consider the conceptualisation of turns as identified in Tversky and Lee (1999) and Klippel (2003): when people draw sketch maps, they usually replace angles between streets with 90° prototypes, the choremes. In 6 and 7, we arrange the unknown part by a chorematised angle between the path and the remaining unknown part. Note that this linearisation is able to preserve the geographic relationships of the unknown areas before A and after B. Illustrations 8 and 9 show another possible linearisation: in contrast to the previous illustrations, they imply the identification of the correct orientation at the transition points A and B. This schematisation does not consider the geographic relationship between the unknown area and the path. This projection can be problematic if the situation at the transition points A and B is configurationally complex.

We decided to implement the schematisation corresponding to illustrations 2 and 5, as all other schematisations can be easily derived from them. The linearisation algorithm is based on the μ-mizing procedure. As in the μ-mizing procedure, we work on three key elements: the starting point area X, the path P and the destination area Y. We move X towards Y, but instead of minimising P, we replace it with a straight line. Scenario 4, which is the linearised navigation scenario, can be computed as illustrated in Figure 12. We select the angle α between the first junction on the path (starting at X travelling towards Y), that is, after the first place in travelling direction, and the angle β between the last junction before the second place in travelling direction (1). In the next step (2), we align both angles, such that the outgoing edges are in line. In the last step, we rotate the two parts in the desired position (here a navigation/egocentric perspective, i.e. the start environment X is aligned bottom-up).

5.3. *Navigation versus pre-trip planning*

We have to differentiate between maps for assistance during navigation and pre-trip planning situations (e.g. internet-based route planners), because they require a potential different presentation of the spatial information (in a pre-trip planning scenario a survey perspective is more helpful; the navigation scenario requires a map which is aligned with the current heading of the wayfinder). Of particular importance is the queried start place (‘from here’), as it can be part of the PFE, but might not be a known place. However, this does not mean that the wayfinder requires a pointer to where he is, as it can be his current position. He probably is just interested in the transition from the PFE to the UE. The other way around, if the current position is in the UE and the queried destination is in the PFE, the user most probably wants to know where the place is located with respect to his known places and landmarks. In the following, we will differentiate between those cases and illustrate different visualisations for the different assistance scenarios.

5.4. *Route partially integrates path*

If a route enters and exits a path not at places, it only partially integrates a path (Figure 21, configuration 4). The algorithm FIND-OPTIMAL-KNOWLEDGE-PATH allows the integration of only parts of a known path. In Figure 13, we can see a map with known paths (bold lines) and a route (thin dark line) between two queried places (solid circles). The places are assumed to be at the endpoints of the paths. The transition points are indicated with white circles. Note that the route in our cases always goes via the PFE. In Figure 14, we can see an extraction of this map: only the PFE (bold lines), the route (thin line) and the four relevant places are depicted. The thin black line shows the

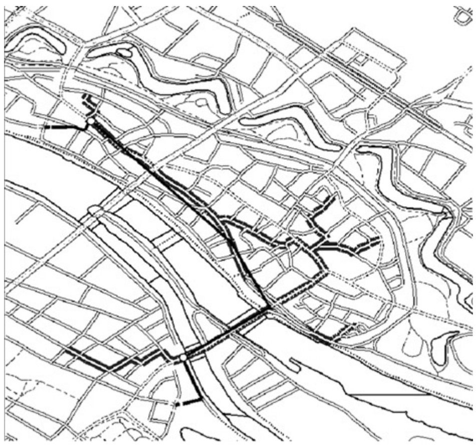

Figure 13. Survey map with prior knowledge and partially integrated path.

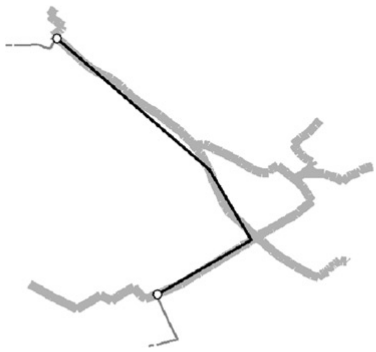

Figure 14. Extracted prior knowledge from Figure 13 and partially integrated path.

generalised part of the PFE of the route. Figures 15–17 show maps generated from the situation illustrated in Figures 13 and 14, respectively. Like in all other cases where no explicit reference point is addressed, we will have to clarify the spatial relations of the known and unknown elements. In the maps, the arrows point to the usually travelled path to the known places which serve as a reference for the particular query. We have chosen arrows because of the absence of established cartographic symbols for individually known elements like places. In Figure 15 we can see a μ-mized map, in Figure 16 we can see a linearised map (as in illustration 2 in Figure 21) and finally in Figure 17 we can see a linearised navigation map (illustration 5, Figure 21) with the start environment at the bottom.

5.5. *Route contains path*

We say a route contains a path, if both places of a path are part of the route, thus the whole path is a sub-route of the queried route (Figure 21, illustration 3). In this case we can assume that a wayfinder will recall the path and its entities correctly in the sense that he will find his way from the addressed point A to point B. There have been

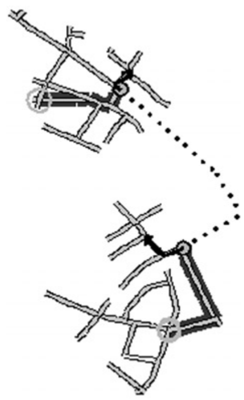

Figure 15. μ-Map.

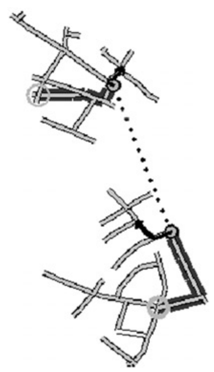

Figure 16. Linearised map.

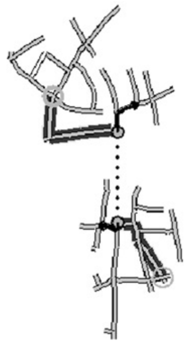

Figure 17. Linearised navigation map.

Figure 18. Fully contained path.

investigations on how people describe a known way to unfamiliar travellers by means of sketch maps (e.g. Tversky and Lee (1998, 1999)). These investigations show that surprisingly people remember the paths accurately. We aim at another type of support: instead of addressing an unfamiliar wayfinder, we want to address a familiar wayfinder that has the same knowledge as the assistant. This has particular consequences for the schematisation: we can interpret the results of the mentioned studies in a way that the assistant has good knowledge of the route; there is no indication that this knowledge will be affected by schematisation, especially if the frame of reference is clear. The key elements are the places addressed by the path, and not the layout, which in this case is irrelevant for the wayfinder. Figure 18 illustrates the relation of UE/PFE, Figure 19 shows the generated μ-map and Figure 20 depicts the linearised navigation map with the start environment at the bottom. In both maps the places are indicated with solid dots, the circles indicate the start point and the destination of the route.

5.6. *Route is contained by path*

Strict linearisation has a huge drawback: due to its abstraction from the actual layout, it will not provide the spatial configuration within the environment. In the case when the route is completely covered by a path (or multiple paths), we have to make clear where the queried places are located within the PFE (Figure 21, illustration 1). Waller *et al.* (2001) showed that the relative distance between landmarks is an important property for people

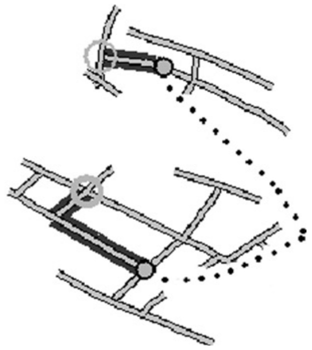

Figure 19. μ-Map.

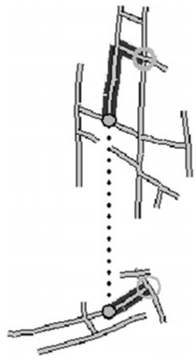

Figure 20. Linearised navigation map.

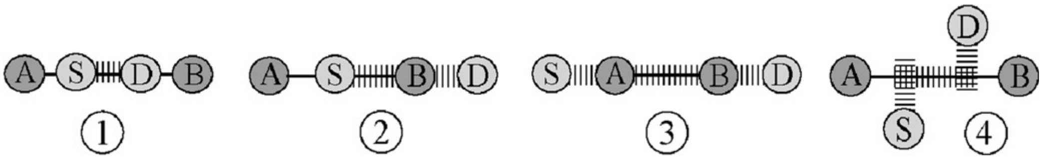

Figure 21. The four possible configurations between a queried route (dashed line between S, D) and a previously known path (bold line between A, B).

during wayfinding. Note that these findings could be interpreted as to disprove our concepts. But we have to consider that the experimental setup was designed not to tell the subjects about the intentionally distorted distances. Agrawala and Stolte's (2001) usability results show that people can use LineDrive maps properly, since they know about the schematisation and are able to interpret the map correctly. Furthermore, we can interpret both findings constructively: people can still use a highly schematised map (e.g. strictly linearised) if the relative distances between the required entities are met. This means, if we make clear *where* the queried places are located within the path in terms of *relative* distance to *significant* entities like places, landmarks or major structural elements (like main roads, junctions, etc.) we can use a linearised representation.

5.7. *Route overlaps path*

In this case one queried place is within the PFE, the other is located in the UE (see Figure 21, illustration 2 and Figure 22). This constellation requires the consideration of the different assistance types and configurations: in case the user navigates, and the start place is within the PFE, and the user is currently within the PFE, we can assume that he will be aware of it. This means, we only have to indicate the direction ('go to the university') and, starting at the transition area, we have to generate a map for UE (see Figure 23, the start environment at the bottom). In the converse case, when the wayfinder is in the UE and queries an unknown location within the PFE, we will have to assist him in the UE, and we have to indicate the location of the queried place within the PFE. If the user is not navigating and queries a place within the PFE, we can infer that he is not aware of this fact and have to indicate its respective location (see the μ-map in Figure 24). The direction of the other place in the path is indicated with the black arrow. In both maps, the start place and destination of the route are depicted with the solid circles.

6. Discussion and further work

In this article, we showed how different maps of the same geographic space can be generated with respect to the configuration of the previous knowledge and the route,

Figure 22. Route overlaps path.

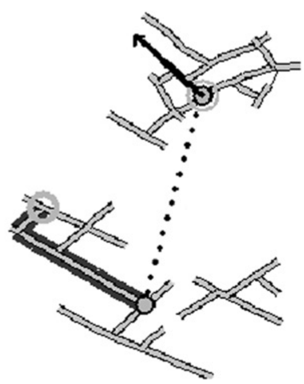

Figure 23. μ-Map with start place in the UE.

as well as the assistance scenario. The consideration of these relationships is important for the selection of the introduced schematisation principles linearisation and μ-mizing. We have seen that the resulting maps contain significantly less information than the corresponding survey maps and it is clear that this is a valuable property for mobile mapping. However, we did not consider how these maps can be optimised for different layouts and sizes of displays. Depending on the actual size of the target display we can, for instance, determine the size of the level of detail for the μ-mizing process, which includes not only the size of the path but also the size of the environment of the start and target region. Furthermore, we can optimise the route selection according to the route which results in the smallest map.

But will users be able to navigate with these maps? As any complex symbolic representation, people will have to learn the meaning of the depicted elements. To test whether the proposed schematisation will be interpreted as intended can only be shown by a usability study. The implementation of a user study under realistic conditions is an extensive task. If we want to test μ-maps partially incorporating known paths, we will have to collect the trajectories of multiple persons for several weeks or months, and to label and analyse them. After the data acquisition phase, we will have to conduct individual wayfinding tasks to test the performance of the maps. Obviously, this is a major task, raising questions of general feasibility and privacy. On the other hand, simplified tests, with prior negotiation about familiar and unfamiliar parts of the environment, can have massive influence on the results: the user profile is not built-up successively, which means that an examination of paths and places does not occur as intended. Additionally, by means of the negotiation, the subjects are clearly biased to the identified entities. A third option is testing in virtual reality. In a virtual world, we have ideal training and test conditions: we can ensure that every user is a novice to the virtual environment. This means, we can ensure the absence of a prior knowledge-based bias. Virtual worlds offer full control over tracking, learning conditions, labelling, and finally tests with maps covering the acquired knowledge for all possible scenarios. Besides all positive properties of a virtual environment, we have to face their problems as well: the navigation performance is usually affected by the involved controllers, the learning of virtual worlds is assumed to be different – and the most important point – long-term studies are not

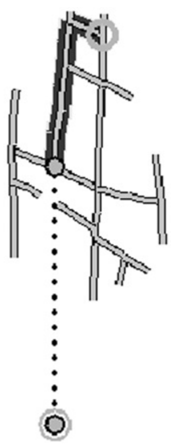

Figure 24. Linearised navigation map with start place in the PFE.

possible due to 'simulation sickness'. This sickness occurs after a comparable short time in virtual worlds and is explained by the missing interaction of the visual and vestibular system. To sum up, testing of personalised maps is difficult due to required individual knowledge. However, we believe that testing is important and will help to sharpen the externalisations of personalised maps. We propose an open evaluation similar to the testing of LineDrive Maps (Agrawala and Stolte 2001). With the increasing availability of position aware mobile phones and personal GPS trackers, people now have the possibility to integrate user profiling and assistance within their daily routines. Tests under real life conditions will clearly show whether personalised wayfinding assistance is desired by people or not. And by means of channelled feedback prototypes can be further improved towards general applicability.

So far it is not clear if the transition between the two frames of reference, namely the frame of individual knowledge and the geographic frame require either a strict separation or tight integration. These areas can be the crux for successful map understanding. Furthermore, so far it is unclear whether there exist conceptual primitives for the transition areas, such as wayfinding choremes (Klippel 2003) for turns. Such regularities in spatial conceptualisation would clearly foster an intuitive understanding of the information.

Wayfinding assistance based on the integration of previous knowledge has to be as effective as traditional wayfinding assistance. This especially means that it has to be based on routes which are accepted by the intended users. The acceptance will largely depend on the direct comparison between the ease of the cognitive load and quantitative measures, like distance and time. If we can identify the (most probably individual) border between these two extremes, we will have made a huge step towards the applicability of knowledge-based wayfinding assistance.

Knowledge-based strategies can also play a role in meeting the problem of 'mindless' wayfinders as described by Parush *et al.* (2007). They assume that the problem with turn-by-turn navigation assistance is the low level of required examination of the environment during the navigation. This causes the weak learning observed with subjects. They propose to actively involve the user in the wayfinding process. The level of granularity given by navigation devices does not have to be fixed at the finest level of granularity as offered by today's devices (every required turn is announced). This means, the level of granularity can be connected to the assumed level of knowledge of the user: if a route contains a sub-route a user has travelled in the past, the system can adjust the instructions to only relevant elements (either the major points of reference or the critical parts of a route). In order to generate suitable assistance, this system needs an individual user profile (which is able to differentiate between possible users, in case the device is shared) and it will need to access and communicate contextual information related to a known route.

7. Summary

Due to the positional awareness of mobile devices (like mobile phones), mobile map-based wayfinding assistance is gaining significant importance. But mobile devices have small and constrained display possibilities. However, the visualisation of geographic information, such as routes within an environment, can require a comparable large space.

This problem cannot only be attacked by scaling the information to the matching size or to segment the information to a high degree. It has been shown that these methods substantially affect the cognitive processing of the spatial information.

One possible solution to this problem is the transformation of the geographic space according to the knowledge a user has of this environment. In this article, we demonstrated how prior knowledge can be used to reduce the size of maps and at the same time to preserve the meaning for a particular user.

We discussed that there is no 'schematisation that fits all', as the different basic relations of the route with known and unknown parts of the environment require different mutual referencing. Additionally, it is beneficial to adapt the schematisation to the assistance type, like navigation or pre-trip planning. By differentiating between these two scenarios, we were able to further simplify and compress the visual output. We discussed the requirements of most combinations of relations between the possible relations between familiar/unfamiliar parts and the type of assistance. Following on from these considerations, we sketched the algorithmic basis to generate knowledge-based maps. The integration of individual previous knowledge with the route planning process requires the consideration of the intended strategy. We introduced an algorithm which is able to identify a route with minimised parts within the unknown parts of the environment and an optimal route incorporating familiar paths.

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4 Semantic Trajectory Compression

Schmid, Richter, and Laube [2009]

Personalized wayfinding assistance in the form of μMaps as proposed in chapter 3 requires a spatial user profile as input. Only if a system can access information about which places and paths between them are known to the user, a wayfinding system can generate personalized assistance. This paper describes the representational basis with a focus on space efficiency. We introduce an algorithm to compress trajectories effectively by at the same time preserving all relevant information and preparing it for semantic queries. We explore the benefit of utilizing spatial features as compression keys for trajectories. We transform a trajectory by means of context specific route direction heuristics into a qualitative representation, which is suitable for massive compression rates. At the same time we prepare the data to allow for efficient semantic queries, e.g., queries for visited places and dates, by treating these entities as compression primitives.

Semantic Trajectory Compression

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Abstract. In the light of rapidly growing repositories capturing the movement trajectories of people in spacetime, the need for trajectory compression becomes obvious. This paper argues for *semantic trajectory compression* (STC) as a means of substantially compressing the movement trajectories in an urban environment with acceptable information loss. STC exploits that human urban movement and its large–scale use (LBS, navigation) is embedded in some geographic context, typically defined by transportation networks. STC achieves its compression rate by replacing raw, highly redundant position information from, for example, GPS sensors with a semantic representation of the trajectory consisting of a sequence of *events*. The paper explains the underlying principles of STC and presents an example use case.

Keywords: Trajectories, Moving Objects, Semantic Description, Data Compression.

1 Motivation

Trajectories, the representation of movement by means of positioning fixes, usually contain data which can be considered as highly redundant information. Movement often happens along network infrastructure, such as streets or railway tracks, and the significant behavior patterns, such as stops, are performed along it as well. Especially in dense urban environments there are not many alternatives for reaching a certain destination other than to move along available network links. The representation and storage of trajectories by means of lists of fixes also pose questions about knowledge gain and further processing; trajectories are only meaningful when their spatial context is considered. Relating trajectories to their spatial context at an early stage will lead to improved means of analyzing them with standardized methods in a later stage.

Figure 1b is a visualization of a stream of raw positional data (Figure 1a) produced by a tracking system (e.g. GPS). Figure 1c depicts the same movement embedded in its geographical context. An object moved through a system of streets to reach its destination. The actual information contained in trajectories is the sequence of implicitly encoded spatio-temporal events, i.e., a single datum is usually not of interest, but rather the *significant* information with respect to

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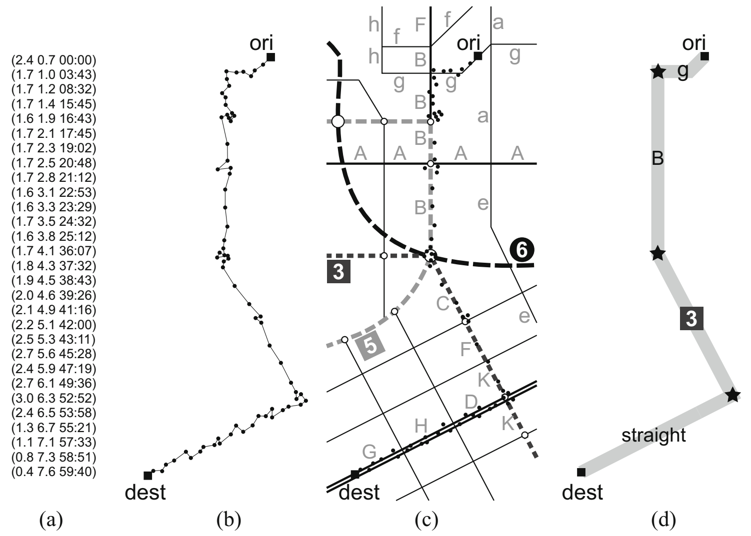


Fig. 1. Problem overview: (a) Raw positional data; (b) trajectory in two-dimensional space, moving from origin to destination; (c) trajectory embedded in geographic context, the semantically annotated *map* features a train line #6 with two stations; tram lines #3 and #5 with several stops; major streets (Upper case) and minor streets (lower case); (d) minimalist representation of the same trajectory, used for the semantic compression: origin, street g, street B, tram line #3, straight, destination

the movement. Significance depends on the application context, but is always based on the spatial course and the determination of events (usually stops).

Having a look at the trajectory, it becomes obvious that its course can be described by referring to elements of the network without loosing relevant information. The course can be expressed by the streets and tram tracks it moves along (street g, street B, tram line #3, and straight along the streets D, G, H). This is a minimalist representation of the movement (Figure 1d). Instead of using a large number of point coordinates, the movement can be described with elements of the transportation network, annotated with the behaviorally significant elements (in this case origin, stops, and destination).

Networks as a constraining basis for movement reduce the dimensionality of space and, thus, allow efficient indexing structures for moving objects [1]. Most work focused on the geometry of the underlying networks. However, the database community has acknowledged semantics—the meaningful annotation of moves with labels from the embedding environment —as being paramount for the interpretation and analysis of raw trajectory data [2, 3]. Whereas exploiting semantics is a young branch in spatial database research, in spatial cognition the semantics of movement has long been exploited for designing better wayfinding instructions [4, 5]. Going a step beyond utilizing spatial infrastructure as a suitable representation, a semantic representation of the trajectory can be implemented that focuses on qualitative change in course and events without loosing the conceptual information of the movement data.

2 Semantics in Trajectories

The majority of systems tracking the movement of individuals produce lists of time-stamped position samples, so-called *fixes* in the form of tuples (x, y, t). Even though this is a discrete approximation of the movement behavior, it is widely accepted to model the respective movement as a sequence of fixes, connected with straight line segments. In its most simple form a *trajectory* is a 2-dimensional polygonal line connecting the fixes of a moving individual. For example, in Figure1, an individual has moved from location origin ori to destination dest, starting at 00:00 arriving at 59:40. Figure 1a illustrates a trajectory's raw data, Figure 1b the respective trajectory in two-dimensional space. Note the raw data column only illustrates a subset of the plotted fixes.

A *map* is a semantically annotated network of edges and nodes. A map represents the transport network of an urban environment, featuring streets, bus, tram and train lines (see Figure 1c). In a map vertices are unambiguously defined, either by IDs or by (x, y) coordinate tuples. Further, edges may have a label (street name, or bus, tram, train line). This is a n : 1-relation as several edges can have the same label. Vertices of bus, tram, and train lines are stops and stations; these may be labeled with the stops' names. The labeling of edges and vertices can extend several levels. An edge may at the same time have a local street name (e.g., "Ostertorsteinweg"), be part of a national highway system (e.g., "A7"), and be part of a bus or tram line (e.g., "Tram #3").

3 Semantic Trajectory Compression

If movement happens in a transport network, as is usually the case in urban environments, trajectories can be mapped to a map representing this environment. The mapping of fixes to vertices and edges of the transport network then allows for exploiting this structure to restricting a trajectory's representation to the significant events. A network reduces the dimensionality of a two-dimensional movement space. It allows for concise positioning of a moving object through time-stamping along edges and at vertices, which both have unique identifiers. In a semantically annotated map, edges and vertices can be aggregated according to shared labels, for example their street names or the train lines. Often, several consecutive edges represent the same street and, thus, share the same label. Tram and bus lines may extend over large sections of an urban transport network. Thus, the semantic annotation of the network offers a high-level reference system for urban spaces, which is exploited in STC.

Taking this perspective, streets and tram, bus or train lines are viewed as *mobility channels* that moving objects hop on, ride for a while, and hop off again to catch another channel that brings them closer to their destination. In terms of trajectory compression, this perspective has the advantage that only little information needs to be retained for describing the movement of an individual in terms of riding such channels. For most kinds of movement storing a sequence of the identifiers of the specific channels and hop-on and hop-off times results in a sufficient approximation of the individual's movement through the network. At the same time, this drops a large amount of fixes, which are highly correlated and, hence, redundant. Semantic compression of trajectories makes use of principles and methods that have been previously implemented for the generation of cognitively motivated route descriptions (the GUARD process, cf. [6]). Broadly, it is based on three steps:

1. Identify the relevant events along the trajectory. Relevant events are origin and destination, as well as street intersections and public transport stops (see Figure 1c).
2. For each event, determine all possible descriptions of how movement continues from here. These descriptions are egocentric direction relations (straight, left, right, etc.; in Figure 1c straight from edge D to edge G) or changes in labels of network elements (in Figure 1c change from label street B to tram line #3) for capturing the motion continuation of an event.
3. Based on the descriptions, combine consecutive events into sequences of events. These sequences are termed (*spatial*) *chunks* [5]. The compressed trajectory consists of sequences of such spatial chunks (Figure 1d).

In decompression, the aim is to reconstruct movement through an environment. In the chosen semantic approach, decompression does not restore the original trajectory, but rather the path through the network along with inferred time-stamps. The path contains all information on changes of direction as well as places along the way; each such event point is coupled with a time-stamp stating when in the travel behavior it occurred. Note that for all reconstructed points in the decompressed trajectory, i.e., those that are not original points retained in the compressed trajectory, the time-stamp is calculated based on an assumed linear movement behavior between start and end point of a chunk. While this time estimation is a simplification resulting in information loss, it provides no limitation for the targeted applications (see Section 5).

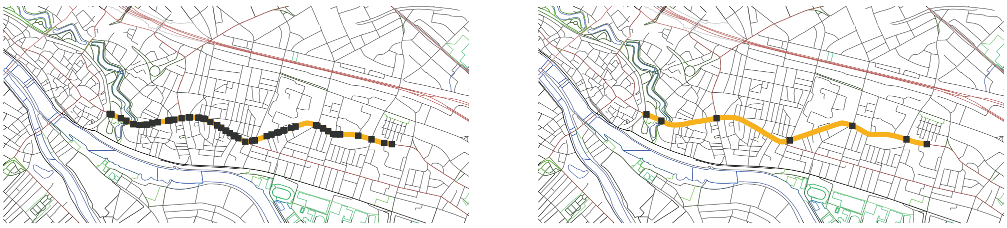
In a nutshell, the decompression algorithm iterates through the sequence of chunks stored in the compressed trajectory. It returns a sequence of vertices that are a geometric representation of the travelled path through the network. In more detail, beginning with the start vertex of a chunk the algorithm adds geometric edges to the reconstructed path until the end vertex is reached. To this end, it uses different strategies to determine which edge is to be added; these strategies depend on the description used for chunking. Each added vertex is linked to a time-stamp, which is calculated assuming constant movement speed, i.e., representing a fraction of time corresponding to the fraction of the distance travelled between start and end vertex.

4 Example Use Case

Figure 2 shows an example use case of applying semantic trajectory compression. The geometric representation of the path contains 115 points in space-time (115 tuples of (x, y, t)). It further comprises 52 events, i.e., 52 intersections and stops along the way. Performing compression yields the following 6 elements as result:

((3490254.00 5882064.00 00:00) (3490057.00 5882110.00 01:12) "Bei den Drei Pfählen")
((3490057.00 5882110.00 01:12) (3489534.00 5882241.50 04:47) "Am Hulsberg")
((3489534.00 5882241.50 04:47) (3488929.50 5882100.00 08:21) "Am Schwarzen Meer")
((3488929.50 5882100.00 08:21) (3488222.50 5882314.50 13:09) "Vor dem Steintor")
((3488222.50 5882314.50 13:09) (3487688.75 5882291.00 16:17) "Ostertorsteinweg")
((3487688.75 5882291.00 16:17) (3487544.75 5882351.00 17:21) "Am Wall")

As can be seen, STC achieves a high compression rate. Instead of the 115 original points, it ends up with only 6 items, which corresponds to a compression rate of 94.78%. Considering that each item in the compressed trajectory consists of three elements, the ratio is still 18 to 115 elements or 84.35%. Decompressing the compressed trajectory reconstructs the original path. It also keeps the time-stamps explicitly stated in the compressed trajectory. There are some differences in the geometric representation—in this case the reconstructed path contains 3 coordinates more than the original path. This can be explained with ambiguities in the underlying geographic data set that for some streets has individual representations of different lanes, resulting in different geometric representations. However, there is no visual or semantic difference between the original and the reconstructed path; all events of the original path are correctly reconstructed. Regarding time, the original time-stamps stored in the compressed trajectory are retained; all other reconstructed events are annotated with estimated time-stamps assuming linear movement within a chunk.



a) b)

Fig. 2. The map shows part of the inner-city region of Bremen, Germany. a) The displayed path (the bold line) runs from right to left. The dots on the path mark all event points along the way. b) The events stored in the compressed trajectory.

5 Conclusions and Outlook

This paper presents a novel approach for compressing large volumes of trajectory data by exploiting the semantic embedding of movement in a geographical context. Inspired by network-constrained object indexing and techniques used in spatial cognition and wayfinding, the paper presents *semantic trajectory compression* (STC). STC matches the movement to the underlying map and aggregates chunks based on identical semantic descriptions. Initial experiments with a set of use case trajectories captured with volunteers in the city of Bremen serve as a proof of concept, deliver promising results for future experiments and help to identify limitations and a road map for future work. After implementing an STC prototype, future work will focus on evaluating the STC algorithm with large and diverse trajectory data. Extensive experiments with real, recorded trajectory data shall identify possible conceptual shortcomings and reveal the runtime characteristics of the STC algorithm for various scenarios.

As a main contribution, the paper illustrates that the embedding of human movement in the geographic context of an urban street network can successfully be exploited for compressing large volumes of raw trajectory data with acceptable information loss. The reconstructed information is suited for a number of applications based on individual spatial profiles which are not built upon a fine-grained analysis of movement dynamics (e.g., ascending and descending velocity). Specifically, this holds for prior-knowledge based navigation support [7] which relies on previously visited places and traveled paths. Also, most applications within the field of Location Based Services that rather rely on a clean *model* of movement than its detailed dynamics will benefit from semantically compressed trajectories.

Acknowledgments

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5 Enhancing The Accessibility of Maps With Personal Frames of Reference

Schmid [2009b]

In this publication we detail considerations on the integration of personally meaningful places as pillars of reference frames in μMaps. As those places organize existing spatial knowledge in a compact way, they qualify as cognitive shortcuts to maps: places are the individual experiential key to understand schematized personalized maps. In order to allow the integration of partial routes (which facilitates the computation of near optimal routes), μMaps require the integration of places along or in the vicinity of the route. The correct selection of references is crucial for clarifying the course of a route along an array of known places. We discuss the propagation of the additional rendering constraints put by additional places within the generation process of μMaps.

Enhancing the Accessibility of Maps with Personal Frames of Reference

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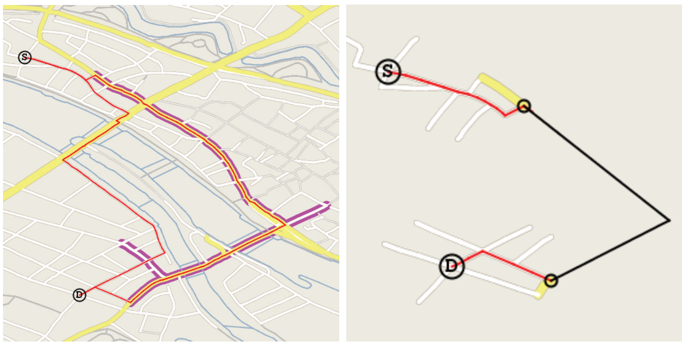
Abstract. The visualization of geographic information requires large displays. Even large screens can be insufficient to visualize e.g. a long route in a scale, such that all decisive elements (like streets and turns) and their spatial context can be shown and understood at once. This is critical as the visualization of spatial data is currently migrating to mobile devices with small displays. Knowledge based maps, such as µMaps are a key to the visual compression of geographic information: those parts of the environment which are familiar to a user are compressed while the unfamiliar parts are displayed in full detail. As a result µMaps consist of elements of two different frames of reference: a personal and a geographic frame of reference. In this paper we argue for the integration personally meaningful places in µMaps. Their role is to clarify the spatial context without increasing the visual representation and they serve as an experienced based key to different scales (the compressed and uncompressed parts of the environment) of µMaps.

1 Motivation

The visualization of complex geographic information is resource intense as it requires large display areas. In the wayfinding domain, even large screens can be insufficient to visualize a route in a scale, such that all decisive elements can be shown and understood at once. Internet based route planners typically choose a scale to display displaying the complete route at once. This practice entails significant interaction: users have to zoom in and out to understand the details of the course to follow. Beside inconvenience, [1] recently showed that the understanding of fragmented maps leads to corrupt spatial knowledge; zooming in and out of parts of the route only offers a certain view and results in fragmented mental processing and disturbed compilation. This is increasingly critical as the visualization of spatial data is currently migrating to mobile devices with small displays and limited interaction possibilities. I.e., in order to limit fragmentation and interaction, we have to develop new visualization methods for geographic information on mobile devices. [2] postulates task and context depended maps since general maps contain too much information. However, not many approaches have been proposed for the wayfinding task. [3] proposed an early turn-by-turn directions approach: they do not depict the whole route, but only the crucial steps. [4] propose Halo, a method to integrate remote locations in maps of partial views. By means of rings having their center at the remote location they point to, Halo preserves a sense of spatial context. However, Halo cannot adapt the visualization of complex spatial data to a small screen. In [5] the authors propose a fish-eye based map transformation: the area of interest is in the center of the fish-eye an the context is in the surrounding. Depending on the scale of the surrounding and the curvature of the lens function. The interaction with route information is still problematic, as the environment is constantly transformed and the single views are always integrated in a different environment. In [6] the authors demonstrate a method to visually compress routes by schematizing parts where no activity is required (like long parts on a highway). This effective idea only works on linear information (it shortens or stretches links), but does not integrate spatial context beyond the route.

1.1 Why Maps at all?

Turn-by-turn assistance challenges maps as wayfinding aids: why should one still use a complex representation to extract a rather small amount of information? The strongest argument is the fact that users of GPS based turn-by-turn systems do not learn the environment properly ([7, 8, e.g.]). Studies showed that users of turn-by-turn instructions made more stops than map users and direct-experience participants, made larger direction estimation errors, and drew sketch maps with poorer topological accuracy. These are strong indicators that people do not learn the environment properly and seem not to trust the assistance. We are currently at the edge of a technological evolution and can observe a significant change in how people access geographic information: cars are delivered with build in navigation devices, geographic information is accessed via Internet services. So far it is unclear how a possible life-long learning of the environment with rather context-free representations will affect the formation of a mental map. The so far available results suggest poor individual mental representations.



a) b)

Fig. 1. Generating a µMap: a) depicts the original map annotated with prior knowledge (bold magenta lines), the shortest path from S to D, and the path across previous knowledge. b) shows the corresponding µMap: the path across the prior knowledge is schematized and minimized, the unfamiliar parts are visualized in detail. Note the different space requirements of a) and b).

1.2 The Visual Compression of Geographic Information

Independent from the type of spatial assistance we use, the support of the cognitive processing of the required information has to be a priority; this is the key to understand and learn our world. The ideal spatial representation is one that reduces the cognitive efforts to an minimum, but still enables the understanding of all information necessary to solve a task (e.g. wayfinding). I.e., when we cope with small screens, we have to visually compress the information, but at the same time preserve the semantic accessibility. However, due to manifold topological and conceptual constraints, the algorithmic transformation of geographic data is a hard task; we have to preserve the consistency of all constraints between all visual elements.

E.g., straightening a curvy road might disturb topological relations of other entities (e.g. wrong placements of buildings afterwards). Furthermore, a transformation does not automatically guarantee visual compression - this can only be achieved by task specific maps: only the context dependent selection of features and minimization of constraints allows the effective reduction of the size of a representation.

1.3 Personalized Maps

One possible solution are personalized maps like µMaps [9]. By analyzing movements of users (with GPS), a spatial user profile is compiled. This profile consists of the places and paths a user regularly visits [10]. The profile is used to compute routes along personally meaningful places and paths. µMaps then compress the familiar parts (FP) of the route and highlight unfamiliar parts (UP), see Figure 1. The results are visually compressed maps, which are qualified for mobile devices [9]. Depending on the configuration of FP and UP of the route, µMaps can achieve very effective visual compression rates. Due to the encoded individual knowledge, µMaps still provide full semantic accessibility. µMaps are furthermore a constructive link between turn-by-turn assistance and map-based assistance: spatial learning is supported by relating new places to existing knowledge and makes future assistance dispensable. At the same time it does not only provide route knowledge, but offers full spatial configuration of FP and UP of the environment. However, the reduced representation of µMaps requires the clarification of the spatial embedding of the route to anchor a map unambiguously within the environment. The key is the addressing of the intrinsic *personal frame of reference* of the familiar parts of a route: personally meaningful places (e.g., "home", "work", "friend's place", etc.): These places also serve as a cognitive decompression code for the minimized familiar parts of the environment; they are the key to understand the varying scales and frames of reference of µMaps, and allow to anchor µMaps correctly within the real environment. In the following we call the elements of the UP to be part of the *geographic frame of reference* and the elements of the FP to be part of the *personal frame of reference*.

2 Place Selection and Visualization

µMaps relate a significant part of a route to existing knowledge, but they still need the clarification of the relation between the FP and the UP of the route. A route across familiar environments does not automatically guarantee the recognition of the course and the scale: it is extracted, schematized, minimized, and does so far not contain contextual information. Additionally, the user might not have traveled the selected route in the proposed sequence before. [11] showed that people rely on relative distance information when they learn places. They are able to find a place even if the distances between landmarks that are related to a place are altered. I.e., if we preserve the relative distance between places, users are able to decode the course and scale of the familiar part. If we assume places to be anchor points, thus individually meaningful landmarks ([12, e.g.]), we can utilize them as self-contained frames of references. Due to the spatial meaning of a place (a user knows how it is spatially related to the surrounding environment and to other familiar places), a pair of familiar places along a route is sufficient to clarify their mutual spatial relations and those between the FP and UP (they are relative to the familiar places and constrained by their sequence enforced by the route).

2.1 Spatial Disambiguation: Selection of Suitable Place References

We now have a look at the *selection* of suitable places for a given route. We are interested in places that do not (significantly) increase the size of a µMap and are

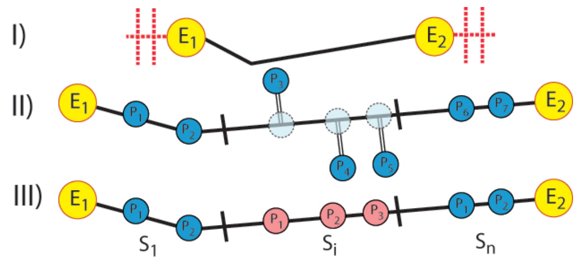


Fig. 2. Route segmenting and place selection: The black lines illustrate a familiar part of the route (red and black) with the entrance and exit points E_1, E_2, see illustration I. II shows only the familiar part with identified places: P_1, P_2, P_6, P_7 are located on the route, P_3, P_4, P_5 are located near the road in the familiar environment. The off-route places are linked on the route by means of their branch-off points in the street network (dashed gray circles). Illustration III shows the integration of the remote places in the route for the place selection algorithm.

at the same time meaningful. Place can be located on the route (*on-route places*) or they can be located near the route and are connected via paths across the FP. We call these places *remote places* and their links to the route *branch-offs*. If we select places located on the route we do not need to add pointers to remote places, which potentially increase the size of the representation (see c) in Figure 5). Places are *meaningful* for the specific route when they clarify the embedding of a particular route within the environment, and when they clarify the course of the route across the FP. In the following we describe the algorithm to identify suitable places for a FP.

1. In the first step we segment the FP (see illustration I in Figure 2) of a route into n parts and compile all places located on the route. See illustration II and III in Figure 2 for details. The selection of n has great influence on the resulting size of a map, the more segments we create, the more places we have to visualize (see Figure 5). However, as places serve as cognitive decompression codes, we have to identify a reasonable amount of segments for a route.
2. For each segment we check if there is a place located *on* the route. If this is not the case, we check at every branch along the route if there is a branch-off in a familiar environment.
   (a) For every familiar branch, we follow this path and every further branch-off as long as we reach the closest *remote place*. We mark every traversed edge and place as visited to avoid loops and multiple selections of one place from different contexts. Illustration II in Figure 2 shows the selection of remote places for the second segment of the FP. We do not select the same place as a reference for different FPs or for different segments in one FP, as it can entail representational conflicts (see Figure 3).
   (b) If we identified a place, we insert the branching point as dedicated places in the FP (see Illustration III in Figure 2).
3. In this step we select places according to their significance for a segment:
   (a) If there are places located on the route *and* at a significant location (a decision point), we select it to clarify the required action (see c) in Figure 5 for an example). If there are equal choices we select the place with the highest familiarity measure. If there are still equal choices we select the place which is located most central. If there is only one place on the route we select it, independent from the significance.
   (b) For the segments with no place at a significant location, if there are $n \geq 1$ places located *on-route* in the segment, we select places according to an

even distribution amongst the neighboring segments: we select the first pair of subsequent segments S_i, S_{i+1} and the respective place candidates $P_1^{S_i}, ..., P_n^{S_i}$ and $P_1^{S_{i+1}}, , ..., P_m^{S_{i+1}}$ (see illustration III in Figure 2). Places at significant locations are treated as fixed points. We treat them just as the entrance and exit points E_1, E_2, which are naturally fixed points (they are the transition between the geographic and the personal frame of reference). To optimize the distribution of places we apply following distance maximization:

$$
\begin{aligned}
x_1 &= \max_1(dist(E_1, P_i^{S_1})) \\
x_i &= \max_i(dist(P_{i-1}^{S_i}, P_i^{S_k})) \qquad\qquad n > i > 1 \\
x_{n+1} &= dist(x_n, E_2) \qquad\qquad (1)
\end{aligned}
$$

Places are under this condition selected when they maximize the distance to the previous and the subsequent place.

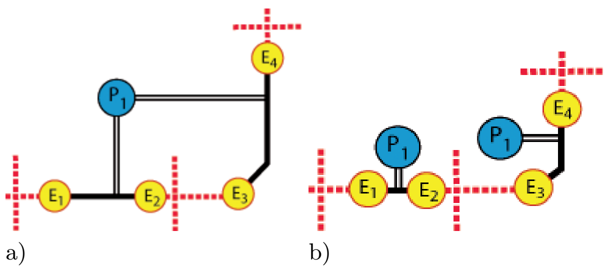


Fig. 3. Conflict due to the selection of the same remote place: the familiar parts of the route can have individual schematizations and minimizations, the pointers to the same place (see a)) can be conflicting and contradicting afterwards, see b).

Figure 4 illustrates the algorithm: illustration I is the initial situation - a FP and the elements E_1, E_2 and the places $P_1, ..., P_8$. P_2, P_6 are at significant locations and considered as fixed places. In illustration II we can see the segmentation of the FP into three parts. The algorithm now selects the fixed places P_2, P_6 as representatives for the first and the third segment, only the middle segment has a choice of optimizable places. The algorithm maximizes the distance between P_2 and P_3, P_4, P_5 and betweenP_6. In this case P_4 is selected (see illustration III in Figure 4).

3 Visualization

µMaps are visual representations of the environment, i.e. we need to visualize the personal frame of reference defined by the selected places. µMaps are intended to support the wayfinding process dynamically, i.e. they have to cover typical requirements of wayfinding assistance during all phases: the communication of survey knowledge and the support during navigation. To support cognitively adequate, we require specialized representations reflecting the task with matching visualizations ([13, e.g.]). This does not only hold for principle configurational issues, but also for the incorporated symbols. Entities on maps should either follow a cartographic convention or in case of non-existence new cartographic symbols have to be created ([14, e.g.]). Up to the knowledge of the author, there are no available symbols

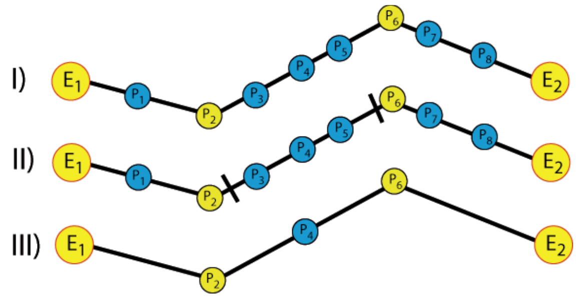


Fig. 4. The place selection process: I shows the initial situation withe the places P_2, P_6 at significant locations. II shows the segmentation of the route, and III the result of the selection process

for personally meaningful places and pointers to them. It is beyond the scope of this work, to analyze the requirements of these new kind of visual elements. We decided to use a straightforward visualization: in our examples and illustrations we will depict places as circles (illustrations) and solid dots (generated maps) and the pointers to them as lines.

3.1 Visualization of Places on the Route

The course of the FP of the route is schematized by means of the discrete curve evolution (DCE), see [15]. DCE simplifies the geometry by successively removing geometric control points from the shape information. Applying the DCE without explicitly considering the places, the coordinates of the places are no longer guaranteed to be located on the course of the route. I.e., we have to compute the schematization of FP differently; the schematization has to consider and preserve the position of places as the route is described in relation to them. In the following algorithm we sketch the positioning of places (and branches to remote places) on a schematized path:

1. In the first step we segment the route at the points where the *selected* places (or the branching points) are located. Illustration I in Figure 6 shows the initial situation. Illustration II depicts the segmentation of the route at the places P_1, P_2, P_3 into self-contained units.
2. In the second step, we schematize each segment by means of the DCE (see [15]). This will transform the places into fixed points of the curve and are not removed by the DCE. This step is important as we do not consider any other constraints, required by the DCE to declare fixed points.
3. In the third step we compile all segments again to one coherent FP. This can be done straightforwardly, as the positions of the contact points (places) are not altered in each segment (see Illustration III in Figure 6).

3.2 Visualization of Branch-Off Places

The question now is how we can visualize places which are not located on the route. In this case we need the differentiation between the two basic assistance types: communication of veridical survey knowledge and navigation support. In the following, we will differentiate between the two scenarios and show some examples for respective µMaps. Furthermore we have to propagate new local visualization constraints to the global map rendering.

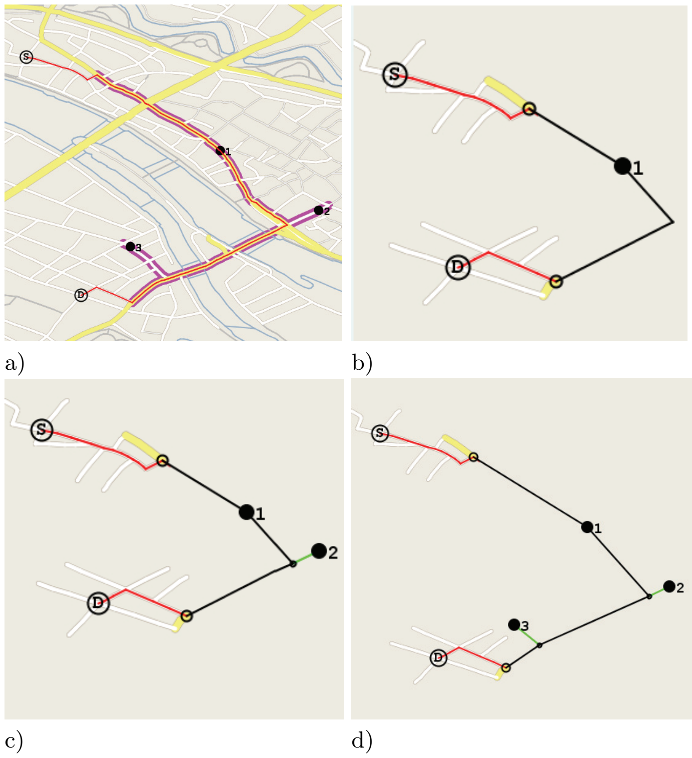


Fig. 5. Selecting places. a) The map of Figure 1 with the places 1, 2, 3 (bold black dots). Note the different schematization of the FP in b), c), d) due to the integration of places. b) the FP is only one single segment: place 1 is selected, as it is *on-route*. c) FP consists of two segments: place 1 (first segment), and place 2 (second segment) is selected. Place 2 branches off at a significant location. d, FP consists of three segments: all places are selected (each is within one of the three segments). Note the different compression rates: b) is the most compact map as it utilizes the on-route place 1. c, requires more space as it points to place 2 (although FP is compressed with the same ratio as b)). d) is significantly larger, because place 3 would intersect the unfamiliar part of the map on the bottom if we would apply the same minimization as in b) and c). This illustrates the effect of local rendering constraints on map compression (see Section 3.2).

Reference Frame Visualization for Survey Maps Survey maps are means to visualize the embedding of the route within the environment in a geographic veridical manner. I.e., the real geographic relations amongst the elements of the route, and between the route and the surrounding environment have to be represented according to a allocentric (geographic) frame of reference. Survey maps are intended to communicate overview information for a certain route. However, in µMaps, the familiar part of the route is always schematized and minimized (as otherwise no compression could be achieved), but the configuration of all elements is not altered. The schematization of the known paths works as described in Section 3.1: the places (and the branches to remote places) serve as constrained supporting points of the familiar part of the route. The crucial step for the veridical visualization of remote places are the paths to them: we depict the path within the familiar environment with the same degree of schematization and minimization as the route starting at the branching point at the route and ending at the configurable street network depth k, which is the number of expanded vertices from the branching point towards the place (see place 2 in Figure 5).

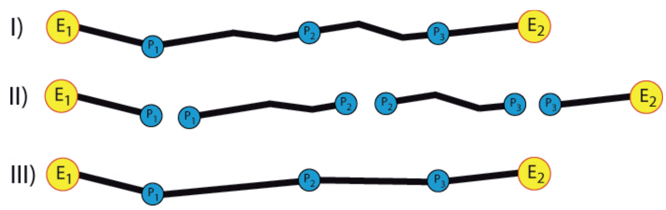


Fig. 6. Schematization with places as fixed points: illustration I shows the initial situation, II the segmentation with the places as start and endpoints of the segments, III the result of the schematization and compilation.

Reference Frame Visualization for Navigation Maps Navigation maps are intended to support the wayfinder during the wayfinding process. As discussed in [9], the maps follow the egocentric, bottom-up approach of mobile wayfinding maps: the part of the route which is "in-front" of the wayfinder (in terms of travel direction), is at the top of the display, the remaining parts at the bottom. A number of studies showed that people encode turning actions usually as 90 degree angles ([16, 17, e.g.]). The mental representation of turning actions are termed wayfinding choremes (see [17] and Figure 7 for an illustration). Branchings to remote places are, due to the egocentric and direct experience in the real environment mentally encoded as wayfinding choremes [17]. For this reason we depict the branch to the remote place by means of a choreme. We replace the real angle α with the angle α' of the respective choreme. However, as the spatial configuration at the particular point can be complex, the choreme holds between the segment of the route before the branch and the branch in travel direction (see Figure 7). This reflects the perception and the expectation of the wayfinder in the FP.

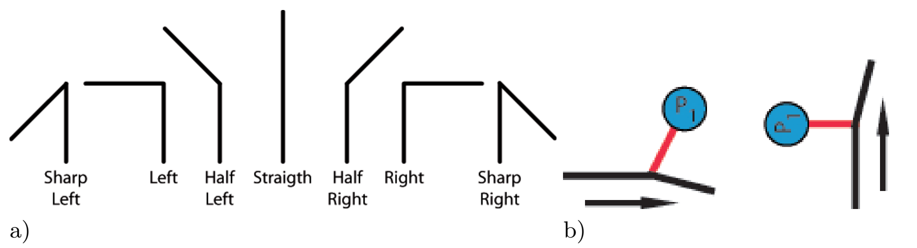


Fig. 7. The chorematization of places for the navigation perspective: a) depicts the set of wayfinding choremes. b) depicts a turn at a place within the FP (left is the initial configuration), on the right we see the navigation perspective of the intersection. The intersection is rotated in travel direction and the angle α is replaced by the angle α' of the corresponding wayfinding choreme.

Communicating Local Rendering Constraints for Global Rendering µMaps minimize the familiar part of the route by moving the closest points of the convex hulls of the unfamiliar environment U_i, U_{i+1} towards each other; so far the distance-to-keep was determined by a threshold h (see Figure 8). Now, with the integration of places, we have additional visualization constraints: a visual intersection of the used symbols has to be avoided, thus a distance threshold k between all elements has to be preserved. We can resolve the constraints by following procedure:

1. In the first step we determine the global minimization factor $min(h)$ for the FP between U_i, U_{i+1}, such that $dist(U_i, U_{i+1}) = h$.
2. In the second step, we determine the closest pair of elements by means of the euclidean distance (in Figure 8 it is E_1, P_1).
3. We then compute the minimization factor $min(k)$ for the familiar part, such that $dist(E_1, P_1) = k$.
4. If $\min(k) \geq \min(h)$, we apply $min(h)$ to the familiar part, $min(k)$ otherwise.

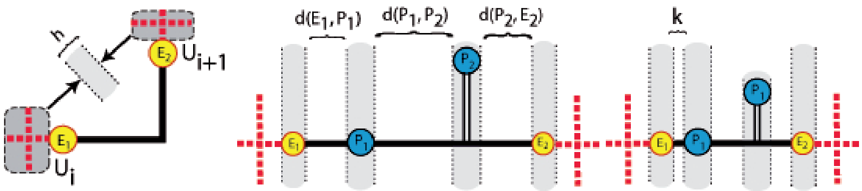


Fig. 8. Communication of local rendering constraints to the global minimization procedure: a) depicts the global minimization distance h. b) illustrates the minimization constraints of the visual elements of the FP, it is not possible to apply the global minimization factor to the FP. In c) we see the global minimization based on the local minimal distance k. See also d) in Figure 5 for an example.

4 Conclusions

µMaps are personalized wayfinding maps for devices with small displays like mobile phones. By means of relating a route to familiar parts of the environment, µMaps can achieve significant visual compression rates by at the same time preserving the individual accessibility. The clarification of the embedding in the environment is based on the integration of a personal frame of reference, the places and paths a users usually visits and travels. However, due to the schematization of the familiar parts of a route, the integration of personally meaningful places require basic considerations about the selection of places, as well about their visualization within µMaps. The selection process for places is based on three considerations: structural significance, segmentation and distribution, and minimalistic visual appearance. The visualization considers the support of two basic requirements for wayfinding maps: the communication of geographic veridical survey knowledge and navigation support. We introduced the selection algorithm, as well as the visualization primitives for both map use conditions. Additionally we discussed the requirements to communicate the additional rendering constraints for integrated places and how we can resolve the conflict between local and global minimization attempts.

Acknowledgments

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6 In-Situ Communication and Labeling of Places

Schmid and Kuntzsch [2009]

Places are the backbone of personalized wayfinding assistance. But only if a system can integrate the names of places, as known to and used by the user, the communication between personalized assistance and the user can be successful.

In this publication we study the labeling of places while people are present in the environment. We focus on two aspects: a) the labeling under positioning uncertainty and b) the influence of surrounding features on the selection of place labels. The first aspect is important if we want to allow systems to automatically resolve technical issues like positioning accuracy problems. They can be responsible for conflicts between sensed position and real locations during a labeling and label selection process. The second aspect is crucial for the understanding of the selection of the correct reference when a system proposes possible labels for a given position. We show that positioning accuracy issues can be resolved by harmonizing assigned labels, while the selection of references is usually based on visual and social saliency.

Our results show that people have a very diverse label selection for the same portion of space. The diversity of labels can be resolved if multiple labels are allowed, which is a strong indicator for the harmonization potential of conflicting label assignment. We further show that the operationalization of label selection and generation is possible by applying different rules for differently structured environments.

In-Situ Communication and Labeling of Places

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Abstract. An increasing number of applications is based on the concept of *personally meaningful places* detected in individual trajectory data. This class of applications will only be accepted if the individual effort of labeling places is reduced to a minimum and the proposed place labels are meaningful. To allow for either the automatic generation of place concepts and corresponding labels, or the maintenance of a collaborative place database, we require better understanding of how people conceptualize their familiar environments in-situ, thus while being *in* the place. In this paper we present the results of an in-situ place labeling study. Our results suggest that the harmonization of diverse labels for personally meaningful places is possible and the operators for the automatic computation of place names are seizable.

1 Introduction

Place is recognized as a central concept in geographic information sciences. The literature on place is rich and the history of trying to tackle the essentials of place is long. But as soon as we want to operationalize place for applications, we recognize that there are no obvious operators we can use, even the most basic concepts are unclear and far from empirical evidence. For computational purposes, the literature on place is as unseizable as the concept itself seems to be in general. Place is usually understood as a conceptual partitioning of space. However, there is nothing like a prototypical place or size of a place, as the partitioning is applied on many granularities of space, from the earth and beyond to a corner in a room and below. According to Relph (1976), place consists of three components: physical setting, thus the locale of a place, activities performed at a place and the meanings of a place to the public and the individual. This stresses the commonsense that place is not just an address or a point drawn on a map - place is always a construct created by the interplay of actual environmental setting, individual and public, as well as the experiences and activities established at the spatial partitioning. This theory is taken a step further towards operationalizability by earlier work of Lynch (1960). In his work he identified the structural elements in urban environment that influence the creation of place concepts. In the areas of space syntax (see e.g. Hillier & Hanson (1984)) the syntactic construction of neighborhoods (which are assumed to cover larger regions than places (see Cresswell (2004); Agarwal (2004, 2005)) is proposed by Dalton (2007). An individual perspective of place offers Seamon (via Cresswell (2004)). Seamon proposes spatio-temporal construction and anchoring of places by "everyday movement in space", i.e. routines or habits that anchor meaning to physical places. Following Seamon, places are the result of movement and activities performed at locations. Although not explicitly investigating place, Hagerstrand (1970) created the foundations of time-geography as a toolkit to analyze spatio-temporal life paths, the containers of individually constructed places. With the increasing availability of GPS sensors, researchers got more and more interested in analyzing trajectories according to the spatio-temporal patterns as suggested by Seamon and Hagerstrand. Especially in the fields of Location Based Services there are many application scenarios grounded in a personal experience of space. Marmasse (1999) propose a place detection to prompt users with location based To-Do lists. Ashbrook & Starner (2003) propose a place detection algorithm to forecast future locations based on past place visits. Liao et al. (2007) developed a framework to infer routines from GPS data to support cognitively impaired persons in public transportation systems. Bicocchi et al. (2007) develops an automated travel diaries. In Schmid & Richter (2006), we developed a fine grained place detection algorithm for familiarity estimation for personalized wayfinding assistance (Schmid (2008)). These examples stress the need to detect "personally meaningful places" to create personalized Location Based Services. They usually propose that users have to label the detected place accordingly. Hightower (2003) proposes to automatically generate labels for places, as manual approaches would not scale. Both positions are critical for applications: manual labeling will under circumstances not scale (as not every possible place will be labeled) and the assigned labels will not be meaningful to everybody. When we have a look at studies about spatial communication, we can notice the strong dependency from intention, mutual level of familiarity, and context on the choice of labels. In Weilenmann & Leuchovius (2004) the authors report on a study of analyzing mobile phone calls with respect to spatial communication. E.g., to describe their current location, subjects chose different levels of granularities and referred entities. The particular choice is depends on needs to obfuscate the real location or to clarify a location by a personal place of mutual knowledge (e.g. "I am home", "the place we met last time"). Duckham & Kulik (2005) propose a formal model for place obfuscation for Location Based Services, such a service requires transparent meaningful place names if a user needs to control the spatial extends of the obfuscation model. Weilenmann and Leuchovius also noticed, that subjects switched the description for the same place or made use of comparably rough descriptors without problematic consequences.

Zhou et al. (2005a) report about a diary study of subjects keeping track of the places they visited. Zhou et al. identified that peoples' communication practice highly depends on the purpose of communication, the mutual familiarity or the assumed familiarity with an area, as well as privacy issues. Although there seems to be good understanding of what a place is and how it can be described unambiguously on different levels of granularity, other studies show a high individual heterogeneity. When ever we use the term *heterogeneity* in this paper, it has always to be understood as the selection of *different* labels for the *same* or a *similar* place [1]. In Lovelace et al. (1999) tried to identify which spatial entities people refer to in familiar and unfamiliar routes. An interesting observation of this study was the strong heterogeneity of the addressed landmarks across the subjects. 31 subjects mentioned 119 different landmarks along the unfamiliar route, but only 16 had been mentioned by 30% or more of the subjects. It is worth to mention that the study took place on a university campus, a highly structured environment with a usually common spatial vocabulary. This study is a good example for heterogenous naming of spatial entities. [2] People are usually able to find a common name for a place, but so far it is unclear which entities they address when they describe a place in-situ (all place studies known to the authors are ex-situ or do test multiple subjects under the same conditions) and up to which degree this process can be automated.

2 Motivation

Personalized wayfinding assistance (PWA) as introduced by Schmid (2008, 2009) requires place labels to describe routes within a personal frame of reference. PWA is based on a spatial familiarity estimation by analyzing movements of users. By analyzing the trajectories with the place detection approach in Schmid & Richter (2006) a spatial user profile, consisting of meaningful places and paths is compiled. By means of the profile it computes routes along personally meaningful places and paths to generate cognitively ergonomic wayfinding assistance. In order to generate meaningful assistance, PWA requires labels (i.e. names) and spatial concepts (e.g. spatial extends, borders, membership functions, etc.) for the places a user visits and knows. Like in e.g. Marmasse (1999) the user will have to enter place names up to a certain extend. But to minimize the effort for the individual, we can either try to automatically generate place labels, as postulated by Hightower (2003) or we can set up a collaboratively maintained database for place names. In the first case we could just compute a label as it is required, in the latter case previously labeled places can be offered to users visiting the same places. Users can then adopt, reuse, or alter a label without much individual interaction. However, both solutions require a deeper understanding of place naming under ambiguous conditions and with respect to different granularities. When we generate user profiles with GPS sensors and mobile devices,

[1] As places are hard to define, the identity relation, thus the identification of the the same place is most certainly equally hard. We assume a place to be the same place if the same label or concept for a place is expressed at a geographically similar position and has a similar spatial scope.

[2] However, this study is not an in-situ study, all names for landmarks have been gathered with photographs or ex-situ, when the subjects have accomplished the given tasks. Ex-situ always incorporates a certain degree of reflection, a process where places are mentally pre-selected according to "mental" salience. We can assume that photographs bias the selection of references, as well as the ex-situ labeling will result in different results than asking "Where are you at the moment?".

we always have to face uncertainty. The usual positioning accuracy of mobile devices (carried e.g in pockets) are far from unambiguity. I.e., the computed places are not necessarily situated at the sensed location and a label would be attached to a wrong place or queried for the wrong position. Furthermore, places are extended spatial regions, but so far it is unclear how large these regions are in the context of "personally meaningful places" as required by a number of applications. It is further unclear what labels people choose for places in their familiar environment without being in an explicit communication situation. It is unknown how homogeneous or heterogeneous the set of assigned labels across multiple persons is and if they can be harmonized by a possibly higher-level concept of a place.

2.1 Understanding of Place

As indicated in Section 1, places exist on any scale and granularity and the selection of a particular concept is highly context dependent. In this paper we constrain ourselves on places as communicable (urban) units within Location Based Services requiring the widely used notion of "personally meaningful places". Intuitively, we have an idea what such a place can be. However, computers as the backbones of Location Based Services need operators and functions to harmonize heterogeneous labels for such places, in order to generate labels that are meaningful for humans, and all this on a granularity which is plausible in the given application context (like PWA, diaries, meeting assistants, etc). Only if we know more about how people conceptualize familiar places while they are in-situ (many scenarios require this condition, either for labeling of places or the location dependent communication of place knowledge) we can develop applications that simulate this conceptualization and foster the semantic access to spatial information.

2.2 Related Work

The aimed granularity is finer than existing approaches of modeling and generating places from available data. Up to the knowledge of the authors, there exist no approach for the computation of place names for a dense urban environment. Grothe & Schaab (2008) propose a machine learning approach for the identification of spatial footprints, thus shape approximations, for regions based on available Geo-tagged resources. The approach is interesting to identify concepts of large scale geographic regions. It requires a relatively large amount of tagged media and consequently will work well for popular places or regions. However, for all places without tags, the approach will fail. Unfortunately, most places on the granularity we address will not be tagged (e.g. living areas), whilst other will be tagged by plenty of users (e.g. touristic places). Schockaert et al. (2005) propose an automatic method to derive fuzzy spatial footprints by consulting gazetteers with complex phrases triggering constraint analysis including bordering regions. Twaroch et al. (2008) investigate on the mining of cognitively plausible place names from social networks to create alternatives in gazetteers. However, these approaches do not investigate on places that are on the granularity of personally meaningful places. They are either on the granularity of large geographic regions (e.g. alps), districts within cities, or few very specific (commonly known) places. None of the approaches do consider the in-situ labeling of places and how it relates to the surrounding environment. Additionally, they to not try to foster a bottom-up labeling and concept construction approach. This means it does not guide labeling constructively and is not flanked with additional analysis of the underlying geographic structures. It is known that spatial structures influence the conceptualization of space and it is possible to operationalize spatial properties (e.g. Lynch, 1960; Hillier & Hanson, 1984). Dalton (2007) utilizes these syntactic properties to automatically compute regions and borders for neighborhoods. This is an interesting approach to predetermine spatial regions, also on different level of granularities. However, this is a purely syntactic approach with no link to situated human concepts. We still do not know how people really refer to it and which elements they use to anchor a concept in the environment. A synthesis of both worlds, the syntactic analysis of spatial properties and the semantic partitioning and labeling seems to be one promising direction to take in the future.

3 The Study

From the perspective of PWA, we are interested in how people refer to places in-situ in their familiar environment and if similar labels can be automatically computed. However, we could not find evidence on how homogeneous or heterogeneous the selection and the assignment of names for places are across multiple persons, the possible spatial extents, and granularities of places. To move a step towards answering these questions, we set-up an explorative study. The goal of our study was the examination of following hypotheses:

3.1 Hypotheses

1. The location of a person clearly determines the selection of a place name.
2. The labeling of places in familiar environments is homogeneous across people and it is possible to develop computational models of place on one level of granularity (in our case a spatial region of the size of typical positioning uncertainty in dense urban environments).
3. Place labels allow for the computation of semantic higher-level concepts (coarser granularity of a concept of place), which can be utilized in context-aware service configuration and communication.

3.2 Design of the Study

We designed the study to gather place descriptions of subjects being present within a partially familiar environment in order to get insights about where a place is referred to as a place and in the (forced) case of ambiguous situations which place of the possible choices is selected.

Selection of Places We intended to introduce "undefinedness" of the places to be labeled. I.e., we wanted the participants not to label a specific entity like a building, but an area that is plausible in an positioning context of a Location Based Service application. [3] This allowed us to create ambiguity, with the intention to force people to select a reference out of multiple choices. We covered a range of place classes:

- **Places in structured environments**: places usually have clear names and functions. We covered a large area of the Bremen University campus (region A in Figure 1).
- **Places in less structured environments**: places and buildings are not clearly assigned with names or host a well-known functionality. We decided to cover a part of the "Technologie Park" (region B in Figure 1). In this area there are several companies, cafes, restaurants, spin-offs, external research institutes and a museum area.
- **Places in natural/unstructured environments**: such as places in parks or forests. A forest and recreation area is found in region C in Figure 1. Here we selected places containing either natural features (water bodies), infrastructures (bridges) or recreational objects (playground, horse stable, restaurant).

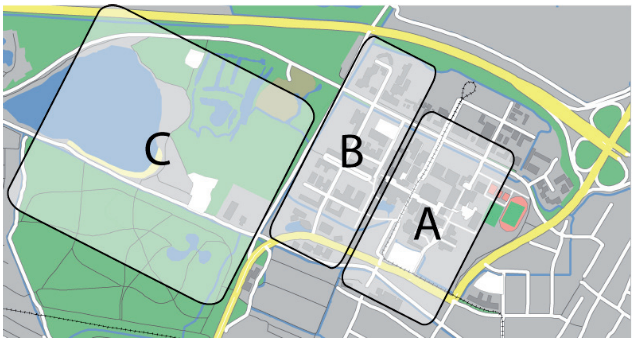

Fig. 1. The different environments within the covered region: A is the main university campus (structured environment), B is a part of the Technologie Park area (semi-structured environment) and C is the recreational area (unstructured environment).

[3] The motivation was to simulate positioning uncertainty within urban environments: when a position is estimated by a e.g. a GPS sensor, it always introduces a certain amount of uncertainty (e.g. 50 meters). When a place is now labeled with a positioning uncertainty of 50 meters, every entity within 50 meters can be the potentially really addressed entity (if we can reduce the label to a single entity at all). If we now add the uncertainty to the query as well (a user queries for a place name and has low positioning quality), the offered place name can be far from the actual location the user is currently at.

3.3 Place Communication

The communication of the pre-selected places is problematic: most modalities either bias subjects by means of the chosen medium (like an annotated map) or distract from the main task by applying navigation and positioning tasks. We decided not to use an annotated map, as we expected influence on the choice of labels. Guiding subjects and placing them at a particular location will bias them to label the pre-selected position.

For these reasons we designed maps without any labels and with no route to follow. For each subsequent pair of places we designed a map with two regions, one for the current place and one for the next place to navigate to. We did not incorporate a route, as the route would determine a particular approaching of a place. The density of the places was relatively high, such that there were only few alternatives at all.

Place Visualization We used regions of different shapes and sizes, each of them included multiple plausible references. The diameters of the regions ranged from 50-100 meters (which is plausible to the positioning uncertainty of low-cost GPS sensors). The subjects navigated freely inside the region and selected and labeled those places they thought the region represents. In the following we will call these regions *place regions*.

Fig. 2. Map cutouts from the place navigation map. The left map with the crosses was the first version of the place communication, the middle and right map the improved version using the place regions as place communicators. The right map contains the subsequent place of the map in the middle.

Place Visualization Modification In the first three trials we annotated the place with a cross, but always stated, that this cross was only marking a fuzzy location. The subjects should place themselves somewhere in the area around the cross at a location they thought they could label properly. It turned out, that this representation strongly determined the choice of labels: subjects tried to position themselves as accurate as possible at the location they thought the cross marked and tried to label this position as exact as possible. This lead to completely unlikely labels (”the second rightmost lantern in front of XY”’). As this problem could be clearly observed for all place-marks and across the first three subjects, we decided to alter the map and not to use the three data sets in our analysis. The usage of regions turned out to work as intended: the subjects now navigated freely in the region and selected places autonomously.

Place Region Modification We had to modify one place region due to an unexpected construction place: region 7.2 (see Figure 3) had to be altered, as the old region 7.1 was not accessible anymore.

Fig. 3. All 13 places which had to be labeled.

3.4 Subjects and Procedure

After discarding the data from the first three trials, we ran the study with 10 subjects, all were either students of higher semesters or scientific staff. They have been familiar with the university campus for three to six years. Both students and staff had a different background of studies and employment (computer science, law, biology, chemical engineering). The subjects walked the course of approximately 3.5 kilometers length in about two hours. The participants walked the course of approximately 3.5 km length in about 2 hours. There are variations as each subject took a slightly different route due to the experimental setup: the subjects carried a folder containing a stack of maps, each illustrating two subsequent regions (see figure 2). After successful navigation to the illustrated place region they had to turn the map to see the next map with the next pair of regions. I.e., they always only knew were they have been to and what the next region would be. They could never optimize their path according to the future regions and select places according to that. When our subjects entered a region, they were asked to select the label that would describe the place best for themselves. They had to place themselves at the position and mark it with a GPS waypoint; the conductor did the same. Each participant was tracked doubly (participant's GPS, conductor). The participants were equipped with a mobile phone containing a GPS tracking software. The conductor had a dedicated GPS device and walked just alongside the subject (estimated distance < 1 meter).

Labeling and GPS Tracking At each place we asked the subjects to answer a set of questions verbally. The conductor wrote the answers to files. Answers have never been corrected, no hints or feedback has been given at any point. The questions at every place asked for

- place names (multiple mentions were allowed)
- neighboring places in vicinity (multiple mentions were allowed)
- judgment of familiarity

After the subject completed the course and labeled all places, they had to answer a questionnaire containing questions about

- demographic information
- the subject of study/profession (determination of familiar area on the campus)
- their usual travel behavior within the regions A, B, C (see Figure 1)
- assumed labeling behavior depending on input modality

3.5 Limitations and Scope of the Study

We are aware that one limiting property of the study is the number of subjects, which can be considered as relatively low. However, when we think of labeling in a realistic setting, there will be only few places with a high number of labels and a large number of places with only very few labels. Insofar, the number of participants reflects something in between.

Another point is the predefinition of our place regions. However a more "natural" design of partitioning of space requires a large number of participants even for very few places. Our study setup allows us to simulate positioning within a certain degree of accuracy at specific locations. As discussed earlier, all of the regions contained entities of different kinds, which also can be expected to result in according heterogeneous labels for the respective regions.

This study is a place labeling study with the aim to identify the potential to harmonize heterogeneous place labels for locations which are potentially the same, similar or neighbored places. From our everyday life we know that people use different names for the same places or the same names for different places. This property causes sometimes some confusion, but is very helpful to talk about places in terms of regions or groups of entities. This property enables a new paradigm of place communication: moving away from the coordinates/distance based concept towards a pre-computation of regions and names. These regions can be addressed by the same label and is still uniquely understandable across groups of persons. However, not much is known about this property so far and we try to investigate on the first basic results covering this question.

4 Analysis

We received a total of 127 primary in-situ place labels (one is missing due to the construction place, two due to undetected navigation errors) of 10 subjects at 13 places. We call the first mention of a label for a place "primary", as we assume that this is the label subjects would instinctively use to describe a place (remember that we allowed multiple labels). All in all we received 175 labels of which 60 were unique labels. Of those 60 different labels, 28 have been chosen only a single time.

4.1 Homogeneity

A computational model of place, thus the automatic generation of place concepts would ideally identify the commonsense concept of a required place. The same holds for a bottom-up repository of place labels: only if we overcome coordinate based labeling and move toward region based labeling, we can find common identifiers for places. In this section we analyze the harmonization potential of diverse labels within same regions. We compared the number of unique labels in each region and computed the most common labels for each region as well. The results are summarized in Table 1. An overview over the of choice of alternative labels for place regions is given in Figure 4.

I	II	III	IV
1	7	Unibad (40%)	Unibad (60%)
2	5	Cartesium (70%)	Cartesium (70%)
3	3	Haltestelle NW1 (50%)	Haltestelle NW1 (75%)
4	10	MZH (50%)	MZH (50%)
5	5	Boulevard (50%)	Mensa (60%)
6	7	3* (each 30%)	3* (each 30%)
7.1	2	2* (each 50%)	2* (each 50%)
7.2	6	MPI (40%)	2* (each 40%)
8	9	Wiener/Fahrenheitstr. (40%)	Wiener/Fahrenheitstr. (40%)
9	4	Universum (100%)	Universum (100%)
10	2	Haus am Walde (100%)	Haus am Walde (100%)
11	4	2* (each 40%)	3* (each 40%)
12	5	Uni-See (80%)	Uni-See (80%)
13	3	2* (40%)	Haus am Walde (50%)

Table 1. The table shows the agreement on labels for each region. Column I is the region number, column II shows the diversity of unique labels from primary and alternative choices. Column III and IV show the most common label for each region and its relative frequency among primary labels (III) and among all labels (IV). Cells with asterisks show the number of different labels of equal mentions (a complete list of labels would be too comprehensive). Regions 3 (8 data sets), 7.1 (4 data sets) and 7.2 (5 data sets) differ from the maximum number (10) of data sets per region.

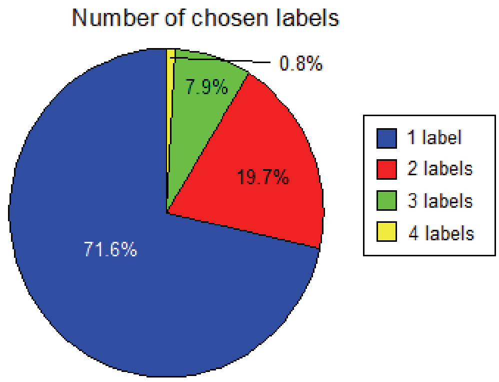

Fig. 4. The distribution of the numbers of chosen labels during single place labeling tasks.

From Table 1 we see the high number of unique place labels for all regions. The average number of unique labels in region C (3.5) strongly differs from those in regions A (6) and B (5.6), indicating a quantifiable measure for the density of well-known places in a region. However, every region has either a single most dominant label or a small set of labels common among subjects. Half of the subjects (55%) independently selected the same label, even though they could position themselves inside the rather coarse place regions, which, in all cases, contained a multitude of plausible entities. Considering this amount increases even further to about 60% when we also consider alternative labels. 28 of all 60 unique labels were only mentioned once.

4.2 Proximity

To gain insight to the influence of labeling location and the choice of labels, we measured and compared distances between the GPS location (presumably already including typical positioning errors of GPS) and the physical boundary (e.g. wall of a building, shore at a lake) of the primary referenced entities as well as nearby places known to the respective subject (see Section 3.4).

Subjects in most cases placed themselves towards the referred entities. However in most cases subjects did not minimize the distance between the labeling location and referenced entity. For each subject and each place region we compared the distances of the recorded labeling position for the primary label to the referred entity with the distances to other places referred to in the secondary (alternative) labels for the place region.

13 of the 127 primary labels referred to entities outside the place regions. As they are not analyzable with respect to the place regions, we excluded them from this analysis. We did the same for additional 14 labels, as they referred to rather unseizable concepts with no clearly computable boundaries ("South from the Kuhgraben heading towards Wiener Strasse"). Among the remaining 100

Fig. 5. The distribution of measured coordinates of labeling locations inside the 13 place regions. A positioning behavior towards certain (usually also labeled) entities is observable.

primary labels only ten labels referred to entities that were more distant than alternative labels.

4.3 Visibility

Proximity usually implies the visibility of entities. There were only few occasions where referred entities were not visible at all from the respective points of view. In region 6 three subjects referred to the central university cafeteria (which itself proved very important among subjects), while they at the same did not name a large visible building (Studentenwohnheim) which would be assumed as highly salient by a usual classification.

4.4 Saliency

For each region we classified spatial entities according to saliency (base area and height, as available from our geo-data). Other spatial features where selected according to their clear out-sticking from the "background", e.g. the lake or the playground in the forest.

Table 2 shows the (classified) most salient entities for each place region, according to computable entities and their properties (size and height) contained in available geo-data at the time of the analysis. The symbol > expresses "more salient than" relation between two given entities A and B (based on values of height h and the base area b) Entities located outside a place region are marked with a single asterisk. Entities on a granularity below building level were excluded from this view, as well as the large region-type entities. All references not explicitly listed are summarized as "others".

The results listed in Table 2 show that the correlation between saliency and the actually labeled entity is in some regions low. Even when we expand the

region ID	order of saliency & rate of reference
1	Sportturm (30%) > Unibad (40%) > others (30%)
2	MZH (10%) > GW2 (10%), VWG (10%) > Cartesium (60%), SFG (0%) > others (10%)
3	MZH* (0%) > NW1 (0%) > others (100%)
4	MZH (50%) > Glashalle (10%) > others (40%)
5	Studentenwohnheim (0%) > NW1 (0%) > Library (0%) > Glashalle (0%) > Mensa (40%) > others (60%)
6	ZHG (20%) > others (80%)
7.1	MZH* (50%) > Mensa (0%) > others (50%)
7.2	MPI (40%) > others (60%)
8**	others (100%)
9	Universum (100%) > Chocoladium (0%) > GW1 (0%) > others (0%)
10	Haus am Walde (100%) > others (0%)
11	Pavillon* (30%) > Stadtwaldsee (20%) > others (50%)
12	Uni-See (80%) > Spielplatz (10%) > others (10%)
13	Haus am Walde (40%) > Reiterhof (40%) > others (20%)

Table 2. An overview over salient spatial entities, ordered by the saliency. The ratio of the primary labels at the respective place regions are listed in brackets.

observation to the next salient entities, the number of references to not salient entities still can be considered as high. There are even examples where the most salient, clearly visible entities have been entirely ignored by all subjects. Figure 6 shows the ratio of the selection of salient/non-salient entities for place labels. The selection of salient entities correlates with the self-reported familiarity: The number of references to the most salient entity in each region increased as individual familiarity with the predefined regions decreased. Personal experience or "social saliency" seems to be dominant factors in-situ labeling.

4.5 Label Granularity

The dominant labeled entities were buildings (54,3% of all in-situ-labels). The reason for the selection of buildings as labels is possibly due to the respectively structured environment of a campus, but clearly can be observed in the other two regions as well. This observation raises the question, if the situated conceptualization of place in urban environments is equivalent to buildings. Of course this is not the general case and we observed different classes of labels:

- **Sub-Building-Level**: a label refers to a functional/logic unit inside a building (a company inside a bureau building, a cafeteria inside a building). 7 of the primary 127 (5,5%) labels can be assigned to this granularity.
- **Building-Level**: a label refers to an entire building without addressing finer structures. This was the dominant granularity for self-reported well-known regions. 69 labels directly referred to buildings (54,3%).
- **Transportation**: 9 (7,1%) labels referred to nodes of public transportation (bus and tram stations).

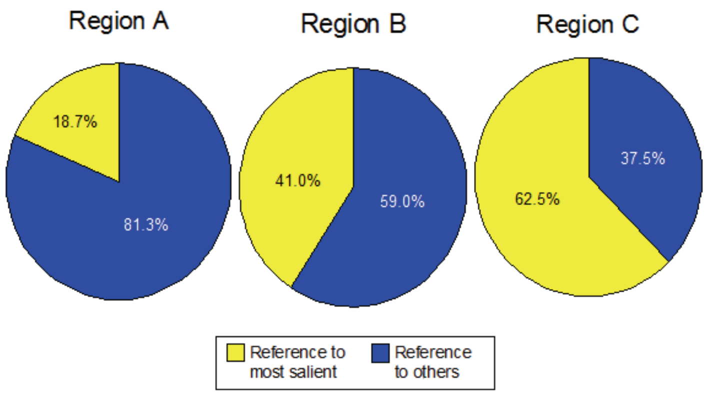

Fig. 6. The diagram shows the numbers of references to the most salient spatial entities for regions A, B and C. The interrelation between the amount of saliency-based references and the structuredness of the surrounding environment is observable.

- **Syntactic Level**: a label refers to syntactic constructs created from a spatial relation between entities (crossing of two streets, an open space between two or more known places, etc). Those kind of labels can only be understood when the referenced entities are already known. This level was often chosen when subjects estimated low familiarity with a location. 8 (6,3%) labels referred to entities of this category.
- **Region-Level**: a label refers to a region of a certain, vaguely defined spatial extent without a clearly defined borderline. Subjects only resorted to this strategy of labeling at place region 11, where there is no other known place to refer to in sight. Instead of making a reference to known nearby places (e.g. "Haus am Walde"), some subjects decided to refer to the entire forest. 13 (10,2%) labels were references to regions.
- **Natural Features**: a label refers to natural features; in our study just water bodies have been mentioned. 13 labels fell in this category (10,2%).
- **Others**: 8 (6,3%) labels referred to entities like mail boxes, sculptures, or stairs.

A noticeable observation is the high percentage of building-type labels in region C (similar to the urban regions A and B). The presence of a single well-known spatial entity in an otherwise unstructured region seems to attract a high number of references and implies a high homogeneity among place labels (see Section 4.1).

4.6 Region Blindness

Our assumption was that people at some point introduce higher-level concepts to describe places. In Weilenmann & Leuchovius (2004) the authors report that

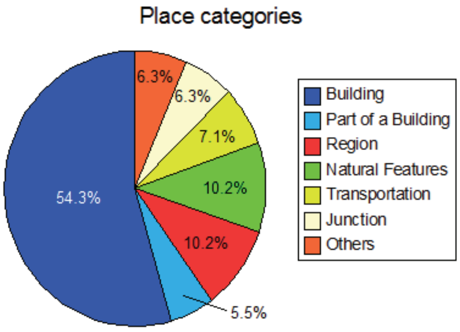

Fig. 7. The diagram shows the distribution of identified classes of labels. References to buildings are dominant, all other categories are used similarly often.

the selection of spatial granularity was adjusted very flexibly. Especially for rather unfamiliar regions, we expected the choice of labels like "Technologie Park", "Natural Sciences Part of Campus", or even "University". But our study strongly suggests that pure in-situ labeling of locations, thus the choice and assignment of a spatial label within the environment, is not the right modality to gather region based or hierarchical labels. Only at few points of the experiment subjects chose labels of coarser granularity. Rather the opposite strategy could be observed. When subjects were in a self-reported unfamiliar region, we observed two dominant labeling strategies. The choice of strategy among the subjects was consistent: every subject used either the strategy of "place extension" or "syntactic place determination", no subject mixed those two strategies over the place regions.

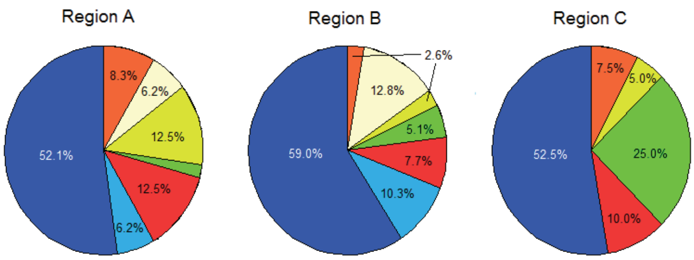

Fig. 8. The diagrams show the distribution of label classes over regions A,B and C. The same legend as in Figure 7 is effective. It is noticeable that the amount of references to buildings does not vastly differ between the three regions.

- **Place Extension**: Subjects selected known neighboring places to describe the current place region. The choice of the place was not necessarily driven by spatial closeness, sometimes producing references to buildings/objects far outside the current place region (in some cases referencing buildings more than 100m away from the current location); visibility seems to affect the choice of the label.
- **Syntactic Place Determination**: The other group of subjects selected syntactic elements from the environment to describe the place (e.g. street names at junctions, bus stop names).

There are two exceptions: the entity "Boulevard" in region A and the "Stadtwald" in region C (both in Figure 1. Both exceptions can be explained quite well: the "Boulevard" is a strongly connecting network link on the campus. It is a campus spanning bridge-like construction that connects main facilities of general university life (Mensa/Cafeteria, library, a shopping and dining facility). It is different from other entities on the campus and seems to be recognized as a self-contained place. The "Stadtwald" is a forest with the usual undefinedness and lack of unique structuring elements; at many points there is simply no better way to determine one's location than referring to the label "Stadtwald".

5 Discussion

Our first hypothesis assumes that the labeling location has direct influence on the choice of the label. It is not surprising that the results in section 4.2 clearly show that there is a strong correlation between the position and the choice of labels, as the referred entity in the majority of cases was the closest entity of its class. Visibility also has a great impact on the choice of labels. Only in few cases subjects decided to label occluded entities. 79.8% of all labels referred to the respectively most proximate entity (see Section 4.2), 97.6% of labels referred to an entity at least partially visible (see Section 4.3). In 77.2% of all labels both proximity and visibility were given at the same time. The influence of saliency the labels resulted in less clear results, in numerous cases subjects did not even mention the most salient feature in a region (see Section 4.4). This can be explained by the individual experienec with the environment. However this finding challenges salience based landmark models (see e.g. Elias (2003); Nothegger et al. (2004); Winter (2003)): cognitive inspired place models are not necesserily based on visual salience or structural importance, but on individual meaningfulness of places. This property has clear functional aspects: hub-like places, i.e., places where many people meet temporally (e.g. "Cafeteria") seem to be mentally more salient than visually salient entities. I.e., the most salient reference for a certain region might be the entity with the strongest impact on many people's daily routines. These results also have impact on the map offered to a user during labeling: depending on the granularity of concepts and the extents of places we want to gather, the application has to consider the possible visibility situation and the established experience of a user. An application will have to include or highlight plausible entities in the environment to streamline and harmonize the labeling of place regions.

Our second hypothesis assumes that place names across multiple persons for places of the size of "personally meaningful places" can be harmonized. We find strong support of this assumption from homogeneity analysis in section 4.1 - subjects are able to identify a number of different labels which sum up to a common name for a place (for the given region). Just as in the study of Lovelace et al. (1999), we observed that the number of different primary labels for a place region is in some cases high; However, although not the individually first choice, there are always alternative labels which are meaningful to most subjects and foster the harmonization. We can also observe and support the assumption of applications dealing with personally meaningful places: in-situ labels often reflect individually meaningful concepts. All subjects agreed that they would change the labeling behavior if the input modality would be constrained. I.e., in an application built on user-driven place labels, we can expect a inertial labeling behavior and as long as users can use previously defined labels for a place. The application itself has either to propose plausible candidates (which we will discuss in the next paragraphs), or has to induce the choice of high-level labels that are meaningful to a potentially larger group of persons. As we have seen from the visualization problems in the map material (see 3.3- the visualization of places has strong influence on the nature of labels. Depending on the kind of labels an application requires, it has to initiate and communicate the labeling process.

Our third hypothesis assumed that people will make use of different spatial granularities to describe a place. However, we observed a preference for entities with a clearly identifiable function or name. References to buildings or places inside buildings made up about 60% of all labels. Only about 10% of the primary labels referred to region concepts often in situations where the region as such is the only really adressable entity, e.g. the forrest instead of a bunch of trees. Interestingly, most of the region type labels could have been derived from existing geo-data as well (e.g. "Stadtwald", "Wiener Strasse"). Subjects never made attemps to disambiguate the location within the region by referring to close known elements (e.g "in the forest close to Haus Am Walde"). I.e., in-situ labels in familiar environments do not offer significant possibilities to deduct spatial semantic hierarchies. The concept place in the sense of "I am currently here" seems only to reflect the immediate environment or the closest known reference, usually on a granularity of clearly distinguishable entities. In an urban environment it is the granularity of buildings (at least for naming places) and sometimes functional units within buildings, in a natural environment like a forest, it is the forest. In contrast to the expectation of our third hypothesis, people tend either to expand entities on the granularity of buildings, or to fall back to elements on a finer level of granularity (street names, junctions). Only reflected or ex-situ communication, as verbal communication with other persons or visual communication in form of maps seem to introduce the expression of region concepts Weilenmann & Leuchovius (2004); Montello et al. (2003). When we want to retrieve human-centered hierarchical spatial information, we have to facilitate the expression of them - either by dialogs or by a careful pre-selection of possible regions. The combination of semantic and syntactic Dalton (2007) approaches is promising: there are clear correlations between the regions annotated in maps and the structural logic of space syntax. These observations imply two consequences: We cannot expect semantic higher-level concepts from situated labeling. I.e., we have to identify other sources of available information or have to constructively facilitate the fostering of region concepts. However, spatial entities on the granularity of buildings are obviously suitable and behavioral valid concepts for places in urban familiar environment. However, the strong environment dependency also implies that only if we really can assign a name or a function to a building, it is a meaningful reference. In residential areas where only few buildings with public meanings are present, street sections, natural features and the few public buildings are most likely suitable references (see Section 4.5).

6 Towards a Computational Model of Place

Applications utilizing personally meaningful places benefit from maintaining a collaborative repository of places, or from the automatic computation of places and places labels. Our study suggests that both cases are implementable. Users can find homogeneous names for place regions of rather large size (in our case 50-100 meters) and the labeling of places is in many cases functionally seizable. There are many established methods to compute the isovist-visibility of entities (see e.g. Batty (2001)) to select visible entities for a specific location (estimation), and computing the most proximate entity is relatively straightforward. The dominant usage of building labels support straightforward place interpretations as postulated in various approaches and the place name study of Zhou et al. (2005b). Zhou et al. found that people often rely on businesses to describe places, a source which is accessible via business directories. For residential areas we can generate labels with respect to rather structural elements (street names or nodes of public transportation). However, our subjects preferred hub-like places to classically visually salient places. The harmonization of bottom-up place labels can underly the same rationals: we can compute plausible areas based on visibility and proximity analysis and attach the labels to those regions instead of coordinates. The representation of the environment has great influence on the choice of labels and should be applied to foster labeling as required: the proposition of concept borders and commonsense regions but as well as of semantic regions. We could not observe any indication of introducing region concepts without map-like representations.

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7 Mental Tectonics — Rendering Consistent μMaps

Schmid [2009a]

This contribution to the theory of μMaps addresses representational issues connected to the small displays of mobile devices. In this paper we generalize the route computation to allow the incorporation of multiple knowledge fragments. In combination with the mental representation based encoding of the familiar parts of the route, the introduced algorithm can generate more compact and clearer structured μMaps, enhancing the readability on small displays. In particular, we develop an approach to harmonize spatial mental and geographic concepts for the generation of personalized wayfinding assistance in the form of μMaps. We show how unfamiliar environments can be expressed from a mental-encoding based perspective of familiar routes. We resolve the conflict of representing a route which is geographically distorted through the mental encoding and representation process, by at the same time preserving geographic veridicality by means of an hybrid optimization model. This model allows the flexible selection of angular representations if the deviation between mental encoding and real geographic relations is too large. As a result, all spatial features along the route are represented within the correct geographic partition while they are still expressed by mental encoding primitives.

Mental Tectonics - Rendering Consistent μMaps

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Abstract. The visualization of spatial information for wayfinding assistance requires a substantial amount of display area. Depending on the particular route, even large screens can be insufficient to visualize all information at once and in a scale such that users can understand the specific course of the route and its spatial context. Personalized wayfinding maps, such as μMaps are a possible solution for small displays: they explicitly consider the prior knowledge of a user with the environment and tailor maps toward it. The resulting schematic maps require substantially less space due to the knowledge based visual information reduction. In this paper we extend and improve the underlying algorithms of μMaps to enable efficient handling of fragmented user profiles as well as the mapping of fragmented maps. Furthermore we introduce the concept of mental tectonics, a process that harmonizes mental conceptual spatial representations with entities of a geographic frame of reference.

1 Introduction

The visualization of geographic data for wayfinding assistance on limited display resources is a demanding task: ideally we have to show the complete route on a level of detail such that all decisive elements (e.g. involved streets, turns, start and destination, landmarks, etc.) are clearly recognizable and easy to recall. Additionally, we have to prevent visual clutter, thus unnecessary visual elements which are known to affect the cognitive processing of visual information [1]. Depending on the area actually covered by a route (and of course depending on the available screen size) it can be hard to display the general course of a route and the details on street level at once. If we have the possibility to display all information at once in a suitable scale, we still have to face the problem of supporting the the cognitive processing of the information, e.g. focusing on the crucial elements of a route, which are typically decision points.

Current mapping services usually choose an output scale which ensures the complete coverage of the queried route on the available target display. If the route is not comparable short and/or the available display exceptionally large, this will typically result in afterward interaction with the generated map: the user will have to zoom-in and zoom-out either to understand the crucial details of the route or to understand the larger spatial context in which it is embedded. It has been shown that this interaction is problematic since both, map size and completeness of geographic information is crucial for successful knowledge acquisition and problem solving [2, 3].

A solution for these problems are schematic wayfinding maps; they visualize geographic data explicitly for the wayfinding task by considering cognitive spatial representations [4, 5] and interaction principles. Two examples for schematic maps are LineDrive Maps and Focus Maps. LineDrive Maps [6] reflect an activity based schematization for routes, based on the observation that routes often incorporate long parts where no decision activity (like turning or changing a road) is required. An example is driving for a long period on highways. When we visualize the geographic region in accordingly scale on a map, these parts can require a significant amount of the available limited interface space. Agrawala and Stolte propose to adapt the scale of the particular route elements to the corresponding wayfinding activity: a high degree of required activity will lead to a more detailed view of the involved entities; a low degree of required activity will lead to a highly schematized view. The result is a strip map which needs significantly less display area if the route incorporates large parts with no decisive wayfinding activity.

Focus maps, developed by Zipf and Richter introduce a different form of schematization [7, 8]. The primary aim is not the compression of the visual representation of a route, but to facilitate the extraction and processing of a route and its context from a rich map. FocusMaps highlight the route by schematizing and fading out map features depending on their proximity to the route. I.e., the closer a feature is to the actual route, the higher is its level of detail and the intensity of its color. This concept reflects the observation that a larger spatial context is helpful during wayfinding, but not all spatial regions are of equal interest for the given task.

1.1 Why Maps at all?

In times of GPS navigation, why should we use maps at all? GPS based step-by-step instructions are known to be superior in performance [9]. However, there are increasing indications that step-by-step assistance prevents people from learning the environment; further they advance and amplify an individual feeling of insecurity during navigation. Studies showed that users of turn-by-turn instructions made more stops than map users and direct-experience participants, made larger direction estimation errors, and drew sketch maps with poorer topological accuracy ([9, 10, e.g.]). These are strong indicators that people do not learn the environment properly and seem not to trust the assistance. We are currently at the edge of a technological evolution and can observe a significant change in how people access geographic information: cars are delivered with build in navigation devices, geographic information is accessed via Internet services. So far it is unclear how a possible life-long learning of the environment with rather context-free representations will affect the formation of a mental map.

In contrast to the negative side-effects of turn-by-turn assistance, maps enable people to learn complex configurations of the environment and allow them to navigate without assistance once they learned it [11, e.g.]. To improve future navigation assistance, we will have to reconsider the communication of route information. We will have to create a sense of place, an awareness for spatial context beyond the route (similarly to maps) within a reduced representation. A promising approach is the combination of the effectiveness of GPS-based assistance and the individual enabling of map based representations. However, displaying a dot on map is not enough, as we still have to consider the visualization problem for geographic data on small displays.

1.2 The Difficulty of Transforming Geographic Information

A fundamental set of human activity depends on a visualization of our environment. Tasks like wayfinding, spatial planning or thematic information visualization require conceptually veridical visualization of spatial information, which can require large display areas (just think of a detailed map of a city, a country, or even the world). In the context of this work the term *veridical* has to be understood as *geographically truthful*, the correct correspondence between represented entities and the entities within a representation. This demand is increasingly problematic as the the access to spatial data is currently migrating to mobile devices. I.e., we will have to adapt the visualization of geographic information for small screens by focusing on the specific task to be solved [12]. However, the algorithmic transformation of geographic data is computationally a hard task. Geographic data is in a fragile equilibrium: there are many implicit and explicit constraints which have to be considered in order to keep the results consistent with the real world. Straightening a curvy road might disturb topological relations of other entities (e.g. a building can be placed at the wrong side of the road afterward). Altering the size of selected elements can have similar effects (a region can suddenly contain more or less elements as in the real world). The aggregation of features or to omit features from the real world can cause semantic conflicts. This means, we cannot just demagnify some elements and magnify others – we will always have to check the consistency of all visible elements.

Mental Conceptual Consistency: At this point we have to distinguish between spatial/geographic consistency and mental conceptual consistency. *Spatial* consistency describes mutual configurational correctness between represented and real entities: all constraints, e.g. topology and size have to be satisfied relatively to each other. A survey map like a general city map is spatially consistent as it depicts all elements in their relative correct dimensions and orientations. In contrast to that, conceptual consistency describes the mutual correspondency between *mental* concepts of constraints amongst features and the elements of real world. I.e., conceptual consistency allows for explicit distortion of spatial constraints if they reflect human conceptual primitives and/or systematic distortions in the mental map (for an overview see [13]): the visual representation can be still understood as the distortions meet the conceptualization of and the expectations of the user in the real environment. Examples for maps of these kinds are the schematic maps discussed in Section 1.

Fig. 1. Generating a µMap: The map in a) shows the map annotated with previous knowledge (bold magenta/dark gray lines), the shortest path from S to D (red/light gray), and the path across prior knowledge (black). In b) we see the unfamiliar segments of the route connected by the path across previous knowledge. In c) the prior knowledge path is schematized. In d) the familiar, schematized path is minimized by means of the convex hull distance, and the unfamiliar segments of the route are moved towards each other. The final µMap in d) is significantly smaller than the original map in a).

2 Personalized Mapping with µMaps

One promising approach to effectively compress the visualization of geographic data is to tailor maps to the individual prior spatial knowledge of an user. The idea is following: with available technology (like GPS enabled mobile phones) it is possible to record and analyze the trajectories of an user and to constantly build-up a spatial user model [14, 15] consisting of the set of historically visited personally meaningful places and frequently traveled paths (the *prior knowledge* as referred to in the following). This user model serves as an input for the generation of e.g. µMaps [16]: if a user queries a route to an unknown destination (or from an unknown origin), the route planning incorporates the prior knowledge and tries to compute the course of the route along known elements. µMaps only display the unfamiliar segments of the route in full detail, the familiar segments are highly schematized and minimized. If a significant part of the actual route can be directed across familiar parts of the environment, the map can be compressed to only a fraction of the size required by traditional maps. Another benefit of µMaps is the abnegation of assistance where it is not required: the user is not cluttered with unnecessary information, and new knowledge is always related to existing knowledge (which facilitates spatial learning). The identified routes are cognitively "lightweight": as the user knows the familiar segment of the route, these parts of the route do not introduce additional decision points. In the following we will use the term *familiar segments* when we refer to the familiar parts of the environment incorporated by a route; likewise we will refer to the unfamiliar parts as *unfamiliar segments*. Unfamiliar segments have to be understood as the unfamiliar part of the route plus additional contextual information (e.g. parts of the street network, see Figures 1, 2, 7).

2.1 Routing Across Knowledge Fragments

a) b) c)

Fig. 2. Fragmented µMap. The map in a) shows the street network annotated with fragmented prior knowledge (magenta/dark gray), the shortest path between S and D (red/light gray), and the path across fragmented prior knowledge (black). b) shows the corresponding µMap, c) the chorematized µMap (see Section 3.2).

Routing Across Coherent Knowledge: The current algorithmic framework for generating µMaps considers coherent user profiles generated from idealistic trajectories. I.e., it assumes complete and error-free sensory information. However, especially GPS enabled mobile devices are known for noisy and fragmented data acquisition. Their handling is contrary to the requirements of a GPS device: they are usually carried at places with weak signal reception, e.g. in jackets, trouser pockets, or bags. This massively reduces the quality of the received signals and causes signal loss and therewith data loss. If the user moves while the device has no reception, it will result in data-gaps in the trajectory and finally leads to the fragmentation of the captured prior knowledge. The previously proposed route search algorithm implemented an explicit planning strategy by trying to minimize the unfamiliar segments of an route and at the same time maximizing the familiar segments (see [16]). This implies the identification of plausible shortest paths from the starting point toward, across, and from the prior knowledge to the destination, by at the same time optimizing the cumulative length of the route. This procedure ensures the overall shortest route for the given policy: maximizing the familiar parts and minimizing the visual output, ensuring the smallest possible maps. However this procedure is costly as the familiar segment of the route can be accessed at n points (depending on the number of topological street network vertices), which affects the length across the prior knowledge. Furthermore it does not integrate into existing routing frameworks easily. Similarly to the route search algorithm, the basic rendering algorithm was limited to basic configurations of familiar and unfamiliar segments.

Routing Across Fragmented Knowledge: To improve the mentioned points, we developed a Dijkstra [17] based algorithm, which is illustrated in the following. In the geo-data corresponding with the search for an optimal route, we require the edges to be annotated with a familiarity measure. The annotation itself takes place during map-matching, i.e. when the positioning information is matched with the geo-data. When the currently traveled street is identified, the corresponding topological edges of the underlying street network data are annotated as *known* to a certain degree. When the user now queries for a route between any places P_1, P_2, each familiar edge E_i is weighted differently to unfamiliar edges. Instead of using the geographic distance as the crucial weight, we implement a dynamic reduction factor d: to enforce the algorithm to enter prior known edges, we increase d temporally up to 50% of the geographic distance of the incorporated edges, i.e. we will virtually shorten them by the value of d. Edges which have not been priorly visited are not altered, thus their actual geographic lenght is used for the computation. As a result the algorithm prefers the assumed shorter edges, if incorporating prior knowledge is an option at all. As soon as it enteres an annotated vertex, we decrease d stepwise by 10% (thus, 40%, 30%, 20%) to the behavioral detour factor for in-situ route planning of up to 10%, see [18]. Humans are no perfect route planners and select routes in complex familiar environments that are up to 10% longer than the optimal route. The result of the dynamic shortening is a virtually deformed environment (the familiar edges are shorter), which attracts the algorithm to enter familiar edges by at the same time guaranteeing a shortest path under human behavioral route choice heuristics. I.e., the identified route is assured in the worst case to be only slightly longer than a route a human would select (only the first four steps of the shortening produce longer paths). The runtime complexity of the underlying Dijkstra is not affected as the distance modifications can be processed in linear time. An additional benefit is the implicit routing across fragmented knowledge: if the incorporation of multiple fragments is geographically plausible, the algorithm will prefer the selection of them, otherwise they will be not or only partially integrated (see e.g. Figure 7a).

Algorithm 1:
COMP-FRAG-µMAP($G, R, dist$)

Input : A graph G consisting of vertices and edges of the street network, a route R consisting of vertices in G, and the distance threshold $dist$ ensuring that functional components will be visually separated.
Output : Will return the µMap for R

$vec \leftarrow \emptyset$
$C \leftarrow \emptyset$
$S \leftarrow$ segment route R into familiar/unfamiliar segments s_i
forall $s_i \in S$ **do**
    if $s_i \equiv unfamiliar$ **then**
        $s_i \leftarrow$ extend street network around vertices of $s_i \in G$
    else
        $s_i \leftarrow$ `schematize(`s_i`)`
    $c_i \leftarrow$ `getConvexHull(`s_i`)`
    $C \leftarrow$ `add(`$C,\ c_i$`)`
forall $s_{i>1} \in S$ **do**
    if $s_i \equiv familiar$ **then**
        $c_{pre} \leftarrow$ `getConvexHull(`$\{c_1 \cup, ..., \cup c_{i-1}\} \in C$`)`
        $c_{suc} \leftarrow$ `getConvexHull(`$\{c_{i+1} \cup c_{i+2} \cup, ..., \cup c_n\} \in C$`)`
        $s_i \leftarrow$ scale s_i with the maximal possible minimization factor according to $dist$ between c_{pre} and c_{suc}
        $vec \leftarrow$ get displacement vector for the minimization factor
        forall $(s_j \equiv c_j \in S) \vee c_j \in c_{suc}$ **do**
            $s_j, c_j \leftarrow$ translate elements with $vec \times s_j, vec \times c_j$
return $\{s_1 \cup ... \cup s_n\} \in S$

2.2 Rendering Fragmented Routes

As µMaps are visual representations of the environment, we have to consider principle rendering issues. The rendering of µMaps across fragmented knowledge works in its core as follows. The familiar segments between unfamiliar segments of the environment are minimized by a convex hull based distance optimization: by computing a convex hull around each unfamiliar segment and minimizes the distance between their two closest points (the unfamiliar segments are moved towards each other, see Figure 1d). This method ensures geographic veridicality, as it preserves the spatial relationships amongst the unfamiliar segments. We now extend the basic algorithm, in order to treat fragmented routes, as discussed

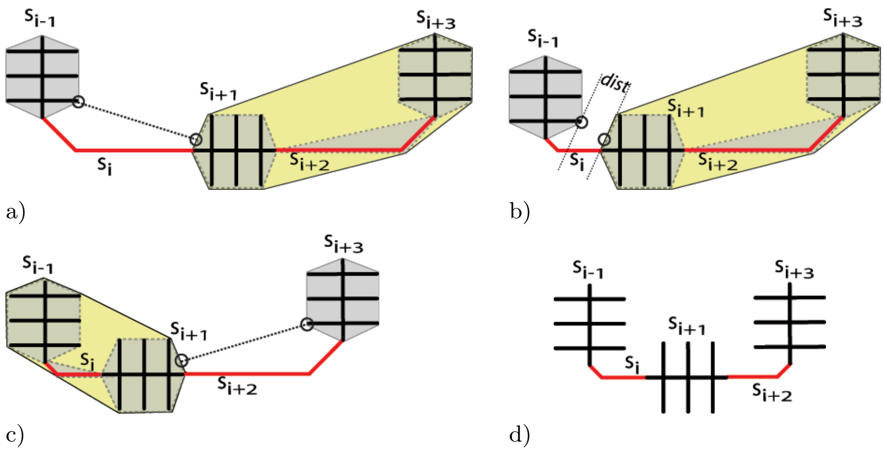


Fig. 3. Fragmented µMizing: a) illustrates the three *unfamiliar* segments $s_{i-1}, s_{i+1}, s_{i+3}$ and the *familiar* segments s_i, s_{i+2}. s_i will be minimized, all other segments are surrounded with their convex hulls. The green/light gray region is c_{suc}. The dashed line between the two circles is the shortest distance between c_{pre} the convex hull of s_{i-1} and c_{suc}. In b) s_i is minimized to the distance threshold *dist* between c_{pre}, c_{suc}. In c) s_{i+2} is minimized, the green region is c_pre, c_{suc} is the convex hull around s_{i+3}. d) illustrates the result of the fragmented minimization.

above. Figure 3 illustrates the functional core of Algorithm 1, Figure 2 shows a generated example. In the following we give a detailed description of COMP-FRAG-ROUTE, the algorithm to compute the schematization of µMaps for fragmented prior knowledge (see Algorithm 1).

The algorithm requires the street network graph G, the route R, and the distance threshold *dist*, the minimal distance to be kept between all visual elements. We initialize the algorithm by creating a variable for the displacement vector *vec*, C the list of all convex hulls for the list of segments S of R.

We segment R into familiar and unfamiliar segments $s_0, ..., s_i$ and store them in S (steps 1-3). A segment consists of a list of vertices of R. For each s_i, independent if it is familiar or unfamiliar we compute the convex hull c_1 and store it in C (steps 4-10). We require the convex hull to check the consistency of topological constraints between the segments. Figure 3a illustrates the convex hulls as gray regions around the familiar and unfamiliar segments of the route (the convex hull of s_i is not shown as it is not required in this step). For each familiar s_i in S we compute two complex convex hulls (steps 11-14) $c_{pre} = \{c_0 \cup, ... \cup c_{i-1}\}$ and $c_{suc} = \{c_{i+1} \cup, ... \cup c_n\}$ (s_i and c_i are to be interpreted as corresponding objects). In Figure 3a c_{pre} is identical with the convex hull of the unfamiliar segment s_{i-1}, c_{suc} is the illustrated yellow region. Only the corresponding convex hull c_1 of the familiar segment s_i is not a member of either c_{pre} or c_{suc}. c_{pre} contains all convex hulls of the segments of R before the current segment s_i; c_{pre}

the convex hulls of the remaining segments after s_i. When we minimize a s_i, we have to ensure that no other functional element of the map is interfered. I.e., we have to avoid touching or intersections of elements as an unwanted side-effect of the schematization. The convex hulls serve as a approximation of the shape of the segments of the map, and *dist* serves as the distance-to-keep between the convex hulls. In order to minimize s_i we compute the minimal possible distance according to *dist* between the closest points between c_{pre}, c_{suc}. We apply the minimization factor to all elements in s_i and apply the corresponding displacement vector *vec* to all elements in c_{suc} (steps 15-18) (see also Figure 1). Figure 3a shows the two closest points between c_{pre} and c_{suc} (dashed line). Figure 3b illustrates the result of the operation.

3 Mental Tectonics - Supporting Mental Prototypical Configurations

As denoted in 1.2, human spatial memory is not a veridical representation of the real world (see e.g., [13]). There is a number of systematic distortions introduced by the mental conceptual processing and encoding of spatial aspects, like the representation of direction concepts. When people are asked to draw sketch maps of routes or to verbalize them, they discretize the angular information to a high degree. Instead of drawing or verbalizing precise angles, they make use of prototypical patterns in both language and drawing. They say "turn left" instead of "turn for 281 °" or draw a 270 ° angle instead of the 281 ° angle. It is assumed that the turn-based encoding of the environment is responsible for this effect: when we learn an environment from navigating through it, we have to take a series of turning at decision points (e.g. we turn "left" or "right" at an intersection), but at the same time we have a very limited vocabulary for describing these actions.

Based on these observations, Tversky an Lee proposed verbal and pictorial toolkits for generating route directions and maps [20]. The idea behind these toolkits is to support the mental encoding of turns appropriately with matching external representations. Klippel further formalized the mental conceptualization of turning actions [21] with wayfinding choremes as prototypical representations as depicted in figure 4a. In [19] the authors identified different sector models for the mental discretization of angles at intersections into choremes. Depending if the situation implied communication (linguistic awareness) or not, the sectors to organize a set of turns significantly differed (see Figure 4b).

The conceptualization of turns has direct implications on how relations between entities of the environment are stored in the mental map and later recalled. When we travel along a route, we encode and store the incorporated turns by the corresponding wayfinding choreme. When we later recall a route, we recall the chorematized route instead of the route with real angular information. As a consequence, all involved elements (e.g. places, streets, landmarks) will be rearranged to be consistent with the currently processed route; the route and the mental locations of its elements are then prototypically arranged.

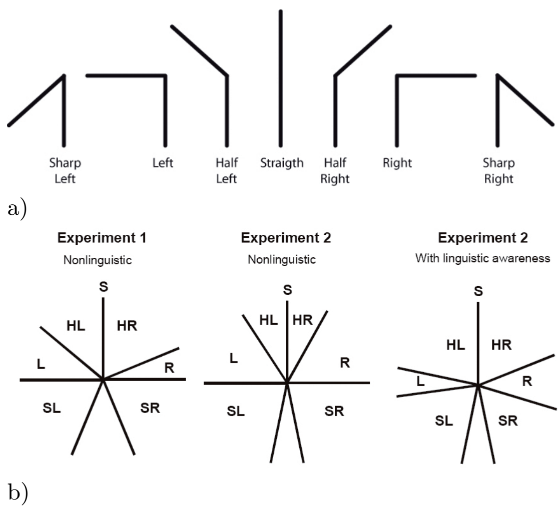


Fig. 4. Wayfinding choremes: a) shows the seven wayfinding choremes. b) The discretization sectors as described in [19], (Figure taken from [19]).

3.1 Mental Tectonics

Our goal is to visualize the familiar segments of the route as they are mentally represented and to arrange the unfamiliar segments according to them. In [22] the authors describe how to chorematize a strip map by means of using prototypical angles at intersections instead of the real angles, the so-called *chorematization*. Chorematization can easily result in maps violating the real spatial relations between origin and the destination; depending on the specific sequence of turns, the chorematized course of the route can be far from the real situation. However, as we relate to mental concepts and communicate new knowledge (which will be stored in the mental map), we have to provide geographic veridicality, i.e. a truthful allocentric configuration which is consistent with the real spatial situation. The placement of the new elements has to be carefully balanced between conceptual mental arrangements and real spatial constraints – a process we term *Mental Tectonics*. Otherwise the map will not meet the expectations and will introduce substantial distortions in the mental map.

Mental Tectonics is a method to generate personally meaningful µMaps with the aim to communicate survey knowledge. In order to facilitate the correspondency between the mental representation of the familiar segments, we represent the decision points along the route by means of wayfinding choremes (see Figure 5). However, in contrast to strip maps, µMaps visualize multiple complex parts of an environment; those parts need to be anchored correctly within the environment to preserve the correct mental embedding. Otherwise, due to the specific sequence of turns, different routes would relate the same parts of the environment mutually differently to each other within the same allocentric frame

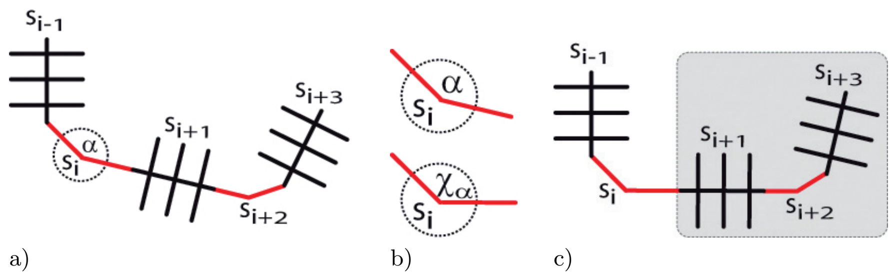


Fig. 5. Chorematizing a μMap: illustration a) depicts the original situation. s_i, s_{i+2} are *familiar* segments, all others are *unfamiliar*. b): α is replaced by the corresponding choreme χ_α. c) depicts the result of the chorematization step. Note the rearrangement of all entities in the gray region.

of reference (e.g. one route relates the segment A as "North" of B, a different route across the same segments A, B could relate A "South" of B).

3.2 Computing Mental Tectonics

The computation of cognitively and at the same time geographically veridical μMaps works as described in the following. First of all we require a sound discretization function for angles at intersection. As the discretization of angles is obviously context dependent (see [19]), and as it is unclear how the available empirical results scale to the mental encoding of familiar paths, in our implementation we used a pragmatic definition of the sector model. Especially the sector for "Straight" is in the empirical results under all conditions organized very strict. As this is contrary to our everyday experience where "Straight" is a more flexible relation, we decided to extend "Straight" to a sector of 30° (±15° around 0° (in an egocentric frame of reference), see Figure 6a for details.

The algorithm requires a route R, consisting of the familiar and unfamiliar segments and the contextual extensions of the unfamiliar segments (e.g. parts of the adjacent street network). Furthermore we require the set of choreme mappings X which allow to map a given angle to a respective choreme, as well as the error correction parameters e expressed as sectors around the borders of the choreme sectors (see Figure 6a+b). This parameter enforces geographic compensation at an early stage: whenever the global error plus the error of the current replacement results are above or below e, we select the neighbored and also plausible choreme to minimize the error. This method prevents the change of the configurational concept between the unfamiliar segments (within the egocentric reference frame of the wayfinding choremes). In our implementation we use a sector of 25° relative to the border as , thus ±12.5° around the border. I.e., the global error is reduced to $\|\chi_{\sphericalangle max}\| - \frac{e}{2}$ ($\|\chi_{\sphericalangle max}\|$ denotes the maximal angular sector of X, in our implementation the sectors of "Half-Left" and "Half-Right").

Algorithm 2:
COMP-MENTAL-TECTONICS(R, X, e)

Input : A route R consisting of vertices v, and the set of wayfinding choremes mappings X, and the global error reduction parameter e
Output : The chorematized and geographically veridical R

$globalErr \leftarrow 0$
$S \leftarrow$ segment route R into familiar/unfamiliar segments s_i
forall $s_i \in S$ **do**
    if $s_i \equiv familiar$ **then**
        $s_i \leftarrow$ `schematize(`s_i`)`
        forall $v_j \in s_i, v > 1$ **do**
            $\alpha \leftarrow$ `getAngle(`v_{j-1}, v_j, v_{j+1}`)`
            $\chi_\alpha \leftarrow$ get corresponding choreme $\chi_k \in X$
            if $\chi_\alpha < 0$ **then**
                $\chi_\alpha \leftarrow \|\chi_\alpha\|$
            $localErr \leftarrow (\chi_\alpha - \|\alpha\|)$
            if $localErr > 0 \wedge globalErr + localErr \geq e$ **then**
                $\chi_\alpha \leftarrow$ get χ_{k-1}
                $localErr \leftarrow (\chi_\alpha - \|\alpha\|)$
            else if $localErr < 0 \wedge globalErr + localErr \leq e$ **then**
                $\chi_\alpha \leftarrow$ get χ_{k+1}
                $localErr \leftarrow (\chi_\alpha - \|\alpha\|)$
            $globalErr \leftarrow globalErr + localError$
            $vec \leftarrow$ compute rotation and displacement vector for χ_α
            forall $v_{j>1} \in s_i \wedge s_{k>i} \in S$ **do**
                $v_{j>1}, s_k \leftarrow vec \times v_{j+2}, vec \times s_k$;
return $\{s_1 \cup ... \cup s_n\} \in S$

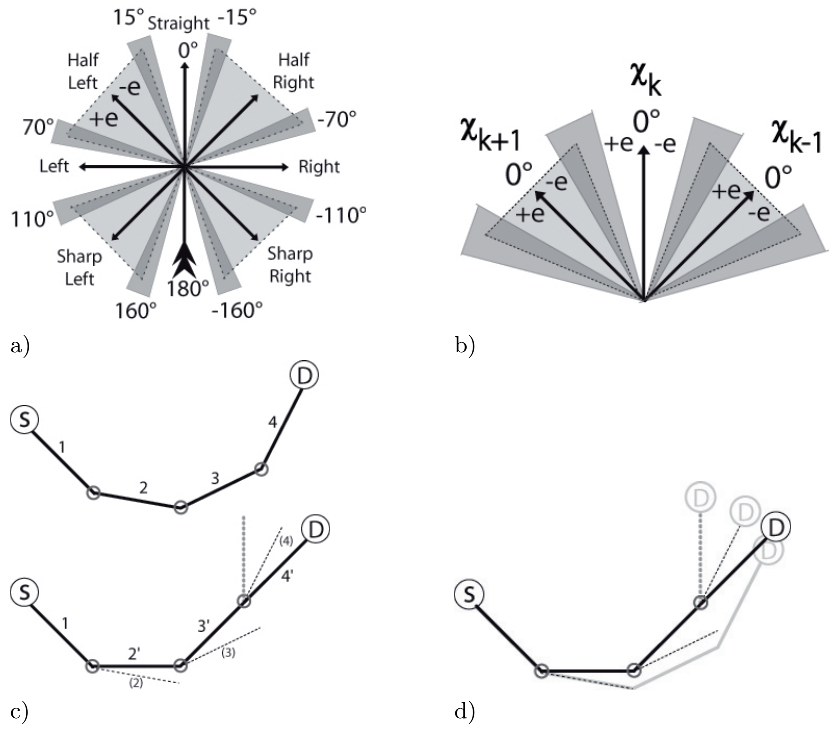
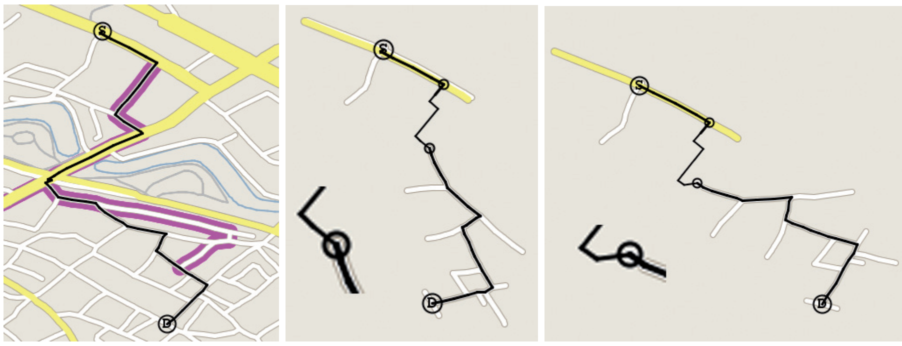


Fig. 6. Error minimization: a) the sector model with discretization borders in degrees relative to the egocentric frame of reference; the dark gray sectors illustrate the error correction parameter e around the choreme sector borders. b) if an angle is exactly the angle of the choreme χ_k, the error is 0. If it is larger than $+e$ or smaller than $-e$ the neighbored choreme $\chi_{k\pm1}$ is selected to minimize the global error. c) and d) see text in section 3.2 for details.

We initialize the accumulative global error variable $globalErr$ with 0 (we do not have a displacement error so far), we further need to keep track of the local error, this will be represented by $localErr$ later in the algorithm. We further split R into its familiar and unfamiliar segments and store them in the list S (steps 1-2). When we replace each angle along a route by a choreme, the accumulated displacement can be arbitrarily high (depending on the layout of the route): each replacement introduces a specific rotation and transition to the remaining parts. To tackle this problem, first of all we limit the numbers of chorematized turns to the most significant ones in the familiar segments by schematizing the path before chorematization (steps 3-5).

We now iterate through the remaining vertices $v_j \in s_i$. We compute the egocentric angle α from the vertices v_{j-1}, v_j, v_{j+1}. We select the corresponding choreme χ_k for α and compute the local error by subtracting α from χ_k (steps



a) b) c)

Fig. 7. Corrected µMap. The map in a) shows the street network annotated with prior knowledge (magenta lines/dark gray in b/w), the shortest path between S and D (red/light gray in b/w), and the path across fragmented prior knowledge (black). Note that the computation of the route did not enforce a path via prior knowledge (see further Section 2.1). b) shows the corresponding chorematized µMap. The resulting map violates geographic veridicality: the destination environment is located "South" of the start environment (cardinal directions). c) shows the corrected but still chorematized µMap. The destination environment is now veridically arranged "South-East" of the start environment (cardinal directions). Note the embedded enlarged parts of the crucial decision points.

6-9). Note that we express the error in deviation from the actual choreme by using absolute values for α and the choreme χ_α if it is smaller than 0. If the angle is exactly the angle of the choreme, the introduced error is 0. Otherwise it is the positive or negative difference (see Figure 6a+b). If the local error is 0, we apply the choreme without further checking, as the current global error is not affected. Otherwise we select the choreme $\chi_{k\pm1}$ to minimize the overall error (local + global) effectively. + refers to the choreme in positive direction, - in negative direction (see Figure 6a+b). $globalErr$ is updated accordingly (steps 10-14). $globalErr$ expresses the error as the deviation from the original geographic configuration and uses the reference frame of the egocentric choremes to optimize it. After replacing the choreme, we apply the actual displacement caused by replacement of for α with χ_α to all concerned elements (15-16). Finally, if all segments are treated accordingly, we return the route.

The route, or rather the map, still needs to be minimized to be a µMap. Obviously, we can nest Algorithm 2 within Algorithm 1. However the order of the execution is important: the chorematization should be computed prior to the minimization as the minimization requires the final layout as an input; Mental Tectonics modifies the layout of the route and implicitly changes the spatial constraints between the segments of the route.

Figure 6c and d) illustrates the compensation: in c, the top image shows the original path from S to D. In the bottom illustration we see the corresponding chorematized path (bold lines) and the original course (dashed lines). The accumulated error is the difference between the original edges and the chorematized edges. The error introduced with edge 4 is larger than e, thus we select the choreme that minimizes the error most effectively; in this case we select "Straight" instead of "Half-Left" (dashed bold gray line). in d) the overlay of the routes illustrates the effectiveness: although all edges are replaced by choremes, the geographic veridicality is preserved. D (dark circle) still meets the geographic constraints as no change of concept of D within the cardinal and the egocentric reference frame was enforced; compare with the alternative locations (light gray circles). Figure 7a-c shows a µMap generated with and without using Mental Tectonics. Compare the original situation in a), the chorematization without the correction in b), and c) the geographic veridical chorematization.

4 Discussion

When µMaps route across highly fragmented prior knowledge they can (depending on the route) generate a high number of familiar and unfamiliar segments. I.e., we have to identify a plausible number of fragments, and a minimum size for a familiar fragment. If a fragment is too small (e.g. only one street segment between two intersections), visualizing it will possibly cause more cognitive load than concealing its existence. Each transition from an familiar segment to an unfamiliar segment of a route (and vice versa) implicitly means the switch of the frame of reference: from the geographic frame of reference (unfamiliar segments) to the personal frame of reference (familiar segments). Each switch implies a certain cognitive load and will influence the effectiveness of the maps. In his classic publication Miller [23] proposes "$7{\pm}2$" information chunks as a general guideline for information representation, as this number demarcates a processing limit (which is of course not applicable to all domains similarly). If we follow this proposal as a rule of thumb and interpret the familiar and unfamiliar segments of the route each as chunks, we can integrate 2-3 familiar segments within the route. This depends on the actual configuration of familiar and unfamiliar segments; however, as between each familiar part must be one unfamiliar part, we have either 3-5 overall fragments when we allow 2 familiar segments, or 5-7 segments if we allow 3 familiar segments. The communication and processing of the change of the frame of reference can be enhanced by integrating personally meaningful anchor points of the personal frame of reference within the familiar segments of µMaps. In [24] we demonstrate the enhanced accessibility of personalized maps by integrating a selection of personally meaningful places according to their relevance for the course of the route (places are selected when they are highly familiar and/or located at significant locations along the route). They serve as a key to the compressed representation of µMaps and help to understand the scale and the actual course of the route.

The rendering of the familiar segments of the route benefits from chorematization as it supports the mental processing. However, this practice can disturb geographic relations up to a high degree. We showed that it is possible to use choremes to describe the route by at the same time preserving geographic consistency. Our proposed approach is only a local optimization and does not consider the global composition of angles along the route. A global approach could select specific decision points to control the effect of the correction.

The degree of schematization has great influence on the remaining geometry of a segment and is largely responsible for the introduced error after chorematization. A very strict schematization will result in a straight line, a moderate one will keep eventually too much details. The automatic identification of a suitable parameter is a hard task, as we usually have no operationizable parameters at hand. The preservation of the geographic veridicality after chorematization could be such a parameter: we can select the degree of schematization in dependency of the global error after the chorematization of the schematized segments. We found a suitable granularity if the global chorematization error is minimized.

Further, we implemented one fixed error correction for all choremes. This parameter could be more adaptive to the relationships among choremes: so far we implied that users will accept selection of a neighbored concept uniformly. However, the studies of [19] clearly show that the borders between choremes are varying, which also indicates context dependent flexibility in accepting changes of concepts (as different conditions resulted in different discretization sectors).

5 Conclusions and Outlook

The visualization of geographic data for wayfinding assistance on small displays is a critical task. Either the map has a very small scale and is hard to read, or the information is only partially visible. This leads to a substantially increased cognitive effort to process and to successfully understand the presented information. A possible solution are μMaps. μMaps transform the requested geographic space according to the familiarity of an individual user. The individual knowledge can be present in inconsistent or fragmented user profiles. To cope with this problem, we need to extend the existing algorithmic framework of μMaps. We present an Dijkstra based routing algorithm with dynamic weights considering human behavioral route choice heuristics. This results in improved routing and connects fragmented knowledge, if it is geographically and behaviorally plausible.

Based on this algorithm and potentially fragmented routes across several familiar segments, we introduced a rendering algorithm to optimize the representation of a μMaps accordingly. The minimization of familiar links between unfamiliar parts of the environment optimizes the distance locally for every pair of configuration of familiar and unfamiliar segments. Although μMaps explicitly address mental spatial concepts, they do not only have to support the mental representation and processing of familiar routes, but they have to support the mutual geographic veridicality of all spatial elements as well. I.e., they have to support mental conceptual consistency and spatial consistency at the same time. In this paper we introduce a method we call *Mental Tectonics* to balance mental conceptual configurations with geographic veridicality. This allows for relating new spatial knowledge to prior knowledge by integrating it in existing mental layouts. Mental Tectonics qualifies as a general method to integrate chorematized representations into a geographic frame of reference.

The integration of multiple prior knowledge fragments raises the question for the maximal and optimal amount of familiar and unfamiliar segments in a route. Although we can limit the number of allowed fragments pragmatically, only empirical studies will shed light on the cognitive demands and limits of understanding µMaps. A question which definitively requires an answer.

The interplay of route choice, schematization and chorematization has great influence on the layout of the resulting map. When the route incorporates large familiar segments, the applied human route choice heuristic usually allows for the selection of different paths (as it accepts up to 10% detour, which can result in multiple candidates). Since each route has a different layout, the selection of the actual path might not only dependent on a familiarity measure. Especially among equal choices, we could select the path with the best layout properties. An automated adjustment of the crucial parameters of the schematization algorithms under the consideration of geographic veridicality and map compactness would additionally foster the generation of compact and at the same time accessible maps, which is the ultimate goal of µMaps.

Acknowledgments

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8 Route Aware Maps: Multigranular Wayfinding Assistance

Schmid, Richter, and Peters [2010b]

In this publication we develop a novel schematic map to communicate multigranular spatial knowledge for a specific route. We address the problem of communicating all information which is required to understand the spatial context of a route and the course-specific properties in a cognitively comprehensive and at the same time compact representation.

Route aware maps are survey maps for routes, with the purpose of communicating the relevant spatial local and global context. The identification of the route context is built on a thorough analysis of the environment from the perspective of the route. In dependency of the course of the route, we select spatial regions on different levels of granularity to clarify the environmental embedding. In addition to the global context, we include the relevant parts of the street network and landmarks at decision points to clarify the local context that is relevant for orientation.

Additionally we support route following by introducing the concept of *coarse navigation*: we display additionally perceivable (e.g., parks) and conceptual regions (e.g., districts) along the route. In combination with alternative routes, this information serves as a navigation aid: with this coarse information it is possible to navigate without additional assistance even if the route is lost after a navigational error.

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Route Aware Maps: Multigranular Wayfinding Assistance

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In unfamiliar environments, people need assistance to find their way. One predominant form of such assistance is maps. In constructing these maps, there is a conflict between concentrating on the essential information for wayfinding, namely the route, and providing overview information of the environment. The former eases information extraction by reducing visual clutter, the latter allows for reorientation in the environment even if the route has been left. In this paper we present *route aware maps*, an approach that combines the best of both (map) worlds. We argue how route information can be embedded in its surrounding environment, i.e., the global spatial context, without introducing unnecessary visual clutter. We present a construction process that results in route aware maps and detail each step of this process. Route aware maps shall ease information extraction by focusing on the route as the crucial piece of information and at the same time impart the feeling of efficient and safe navigation by keeping the wayfinder in global context. Providing a global context in route following invokes spatial awareness with respect to the overall environment and, thus, decreases the (felt) risks of making wayfinding errors.
Keywords: wayfinding assistance, schematic maps, spatial context, key hole problem

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1 Introduction

To successfully navigate, wayfinders need to know which directions to turn to at the crucial spots along their way, namely the decision points. If the environment is unfamiliar, wayfinders need assistance in taking these decisions. This assistance needs to communicate all information that is necessary to reliably enable wayfinders to perform the right actions, but should refrain from providing any excess information as this aggravates correctly interpreting the assistance (cf. Schneider & Taylor, 1999; Baus et al., 2002; Richter & Klippel, 2005).

Likewise, there is evidence that assistance is most efficient if wayfinders feel confident about taking the correct decisions (Ross et al., 2004; Ishikawa et al., 2008). An important step in evoking this confidence is to keep a wayfinder in context. Being in context here refers to wayfinders knowing (approximately) where in an environment they are, i.e., to allowing for global orientation. Such global orientation invokes a "sense of place" with respect to the environment at hand. Knowing where you are in an environment allows for reorientation after a wayfinding error, which is crucial for the confidence of being able to find the way successfully.

In this paper, we present route aware maps, an approach to map-based assistance that on the one hand focuses on the essential information for wayfinding, namely the route, and on the other hand evokes a sense of place by intelligently embedding this route in its global context. The paper is structured as follows: in the next section, we will provide some more background on the conflict of focusing on essential information and keeping users in context by discussing the properties of different types of maps. Section 3 then introduces the construction process for route aware maps in detail. Here, we explicate the individual building blocks we combine to create route aware maps. Each building block in itself helps to embed the provided information in a global context. Section 4 discusses route aware maps in light of other approaches to graphical wayfinding assistance. Section 5, finally, concludes the paper with an outlook on future work.

2 Wayfinding and Maps

Wayfinding is a daily routine for people. It is a purposive, directed, motivated activity to follow a route from origin to destination (Golledge, 1999). According to Montello (2005), it reflects the cognitive processes going on during navigation, as opposed to locomotion, which covers the activities of the sensory and motor system. A route is a behavioral pattern describing the way someone takes from an origin to a destination; it covers a directed movement activity (Klippel, 2003; Montello, 2005). This is opposed to a path, which corresponds to physical entities, i.e., the segments of a network of ways, that movement has been performed on.

Wayfinding requires attention in order to be successfully performed. Still—

like for many daily routines—for frequently recurring ways, such as the way from your home to your work, the required level of attention will be low. No assistance is needed to reach your destination. In unknown environments, however, the required attention is high. And usually assistance is needed to successfully find your way in these environments. Such assistance is typically provided by verbal or graphical means, i.e., either as (spoken or written) text or as maps. The crucial information that needs to be communicated with this assistance is what to do at those places where there is more than one possible continuation of the route, i.e., at the decision points (Daniel & Denis, 1998). In this paper, we focus on maps as wayfinding assistance. Broadly, we can distinguish two types of maps: 1) strip-like maps that only present the route to take; 2) survey maps that show an overview of the environment (cf. also Freksa, 1999).

The first type of maps provides the smallest possible set of complete route information that is needed to find your way, i.e., that is required to (re-)orient along the route. These maps only depict the route with an indication of where the decision points are along that route. Accordingly, they have very little visual clutter as they depict *only* the route. However, in case a wayfinder deviates from the depicted route by mistake, there is no information available to reorient as there is no information provided that relates the route to its surrounding environment. Therefore, once off the route, the wayfinder is lost. In terms of spatial awareness, these maps provide knowledge on location only locally with respect to the route, but not globally with respect to the overall environment. Essentially, today's mobile navigation systems work the same way. They provide information on the next action to be performed when it is due; they hardly provide any overview information that would allow users to reorient themselves more globally. Of course, mobile navigation systems still provide information when the intended route has been left by re-calculating a route and starting again.

These arguments mostly also hold for sketch maps as they are often provided by people to indicate which way to go. These maps usually depict some salient features encountered along the way additionally to the route (cf. Tversky & Lee, 1998, 1999). But they still do not allow for a more global orientation as the embedding of the route in the environment is largely missing.

Secondly, there is the classical city map, which is nowadays often replaced by an electronic map extracted from the Internet. These maps show an overview of an environment by depicting information evenly distributed across the selected area. Accordingly, such maps contain a lot of excess information and, thus, visual clutter. Extracting, understanding and keeping track of the route to take is cognitively demanding (cf. Phillips, 1979; Rosenholtz et al., 2007). In principle, by displaying the route as it is embedded in its environment, these maps allow for communicating a sense of place, i.e., they provide global knowledge on one's location. However, this is masked by having to deal with a lot of unnecessary information.

In the following, we detail an approach to combining the best of both (map) worlds. We present *route aware maps* (RAMs) that concentrate on the route as the essential information to reach a destination, but also depict the information needed to anchor the route within its relevant spatial and functional context. Our aim is to develop a map, which highlights the route but still allows for (global) reorientation on different levels of granularity in case a wayfinder loses track and strays off the route. This map is schematic (Klippel et al., 2005) in that it focuses on the relevant information for successful route following. This goes beyond merely depicting only the route, but disregards excess information as it is provided by survey maps. We believe that RAMs provide a wayfinder with a sense of place by using a route-specific embedding of the essential wayfinding information in a global context. The elements selected for depiction shall impart the feeling of efficient and safe navigation.

3 Route Aware Maps

RAMs combine the concept of strip maps with means that allow for a wayfinder keeping a global orientation and recovering from wayfinding errors. Therefore, they increase a wayfinder's confidence during navigation. By embedding the route in its spatial context on different levels of granularity, we create assistance which allows for (approximate) navigation towards the goal even if a wayfinder makes errors. Due to the information presented additionally to the route we enable approximate localization and navigation, which lowers the burden on the wayfinder of being forced to take the right decision in order not to go astray (see Section 3.3.1 for more details).

RAMs can be used in both static as well as dynamic assistance. In a static scenario (e.g. print-out paper map) the information offered by RAMs is sufficient to allow wayfinders to follow a path and even make specific errors. In a dynamic scenario (e.g. GPS-assisted wayfinding), RAMs may serve as the means to communicate the spatial embedding of a route in the environment, especially on devices with small screens. These devices require a semantic selection of geographic entities in order to generate meaningful maps for the route and the current position of a wayfinder. RAMs provide mechanisms to detect and communicate the embedding context of the route, as well as the local context of wayfinders in their actual decision space to impart a sense of place on different levels of granularity. While in a static scenario RAMs would be produced once in advance of the trip, in a dynamic scenario they would be adaptive to the in-situ situation of network and traffic conditions, for example, and possibly changing requirements of the route to travel (e.g. due to an additional added target). In this article we focus on the generic generation process of RAMs and do not detail implications of a dynamization of RAMs, such as triggering recomputation, or adaptation of the visualization to changing positioning information.

Construction of RAMs starts with the route itself. This route between origin and destination may be computed using any available metric, for example classical shortest paths (Dijkstra, 1959), or cognitively motivated approaches, such as the simplest path (Duckham & Kulik, 2003), the most reliable path (Haque et al., 2007), or a path considering the corresponding simplest instructions (Richter & Duckham, 2008). Then, stepwise we add additional information to the map that results in the embedding of the route in its spatial context. More specifically, we add information on:

- Initial and final orientation: are important for getting the wayfinder off in the right direction and for "homing" when close to the origin (Section 3.1);
- alternative routes: may allow a wayfinder to get back on track once accidentally having left the route (Section 3.2.3);
- Regions: provide an anchoring of the route in the environment (Section 3.3.1);
- Landmarks: help to disambiguate locations along the route and help to identify locations in the environment (Section 3.3.2).

In the following, we argue for adding these types of information to the basic route information and explain how it is done.

3.1 Initial and Final Orientation

Origin and destination of a route are crucial parts for successfully finding one's way (e.g., Michon & Denis, 2001). At the origin, wayfinders need to initially orient themselves in order to get off in the right direction. The destination needs to be clearly identifiable in order to know that wayfinding has been successful. Further, especially in dense urban areas, such as a city center, there is an increased chance to miss crucial decisions and an increased need for reorientation near the destination. For example, this may be caused by a complex system of one-way streets or the need to find a parking space. Thus, it is sensible to not only guide wayfinders exactly to the destination location, but also to enable them to freely navigate in the nearby surroundings.

In order to support these two crucial processes, we display the environment around origin and destination in more detail. For the origin we extend the street network until no ambiguous situation is present any more: we expand the street network until each option the origin is reachable from is clarified by a defined configuration of streets (an identifiable intersection). Alternatively, if we identify a salient element (such as a park or a river) we employ the respective element instead to unambiguously identify this option. This first extension to the route allows a wayfinder for matching the spatial situations perceived in the environment around origin and destination with that depicted on the map. For the destination region we expand the route similarly, but with a slightly higher scope (see Figure 1).

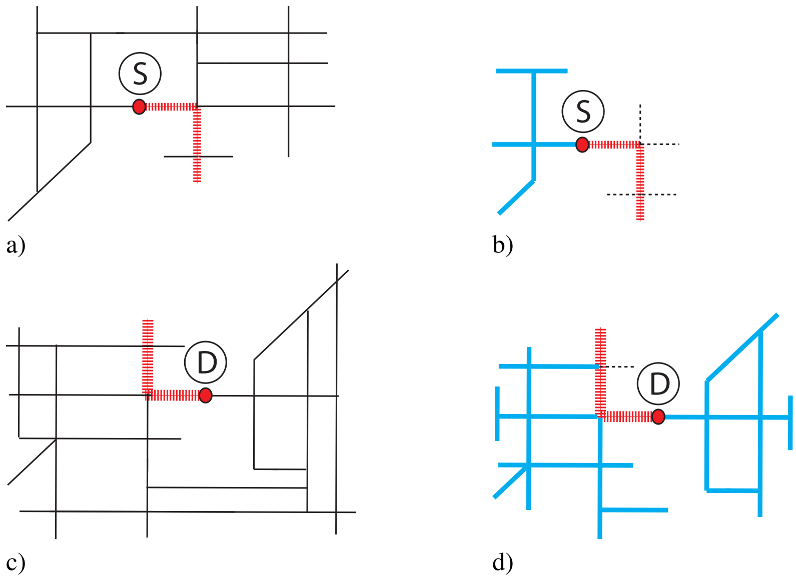


Figure 1.: Initial and final orientation: a) Original initial surrounding, S is the starting point; the bold dashed line shows the route; b) Embedding of the starting point; bold solid lines shows the embedding area, thin dashed lines show intersections along the route; c) Original final surrounding, D is the destination; d) Embedding of destination (with depth 3).

More precisely, we use the following algorithm for adding information on origin and destination location:

1. We select all outgoing branches of the origin of the route and select all which are not member of the route.
2. We expand each selected branch until we either reach an intersection or a salient landmark. The corresponding streets are displayed on the map.
3. We select all outgoing branches of the destination.
4. Starting with each selected branch, we add all additional branches of the street network graph up until a configurable depth k (without adding already existing branches again). The corresponding streets are displayed on the map.

3.2 Along the Route: Error Analysis and Alternative Routes

As discussed earlier, wayfinding is a complex process in which errors easily occur due to manifold reasons. Errors may happen due to the wayfinder being inattentive, because the provided assistance (in form of a map) does not match with the encountered situation in the environment in the way it has been expected, or simply because the environmental situation itself is ambiguous and hard to understand. While it is impossible to predict every possible error that may occur during wayfinding, in RAMs we integrate information that allows recovery from two kinds of errors:

1. *Local ambiguous* or complex configuration of an intersection: based on capturing how humans conceptualize turns at intersections (e.g., Klippel, 2003; Haque et al., 2007), we can identify how many possible choices there are at an intersection and whether these choices potentially conflict with each other;

2. *Global ambiguous* situations can originate from monotone, recurrent, cueless environments as they often occur in modern suburbs, for example. Decision points, i.e., the relevant intersections, can be easily confused with other intersections due to the similarity in the environmental structure and the density of intersections.

The analysis performed to identify both kinds of errors is motivated by how humans conceptualize wayfinding situations and follows an information-theoretic approach. Local error analysis is explained next, global error analysis in Section 3.2.2. To enable wayfinders to recover from these errors, we introduce alternative routes as explained in Section 3.2.3.

3.2.1 Local Error Analysis

The first kind of error is tackled by analyzing the configuration of an intersection's branches. We employ a method we term *Choreme Analysis* (CA). CA is similar to the approach of identifying the most unambiguous instructions, introduced by Haque et al. (2007), but with a different resolution:

1. We discretize all angles formed by the incoming branch with all other branches based on the wayfinding choreme direction model as proposed in Klippel & Montello (2007). As a result every angle is represented as a qualitative direction relation relative to the direction of travel.

2. According to this representation, we check if any two (or more) branches head in the same direction and hence are represented by the same relation. If this is the case and if they are relevant for the action to be performed at this intersection, a potential conflict is identified (cf. also Haque et al.,

2007; Richter & Klippel, 2005). A branch is relevant if its choreme representation corresponds to the direction to take at the intersection, i.e., if it is described by the same qualitative relation as the action to be performed at this intersection (e.g., "veer right"). Figure 2 illustrates such a conflict. Here, two outgoing branches of the intersection share the same direction concept.

3. We compute for every detected conflicting branch an alternative route to the destination (Section 3.2.3).

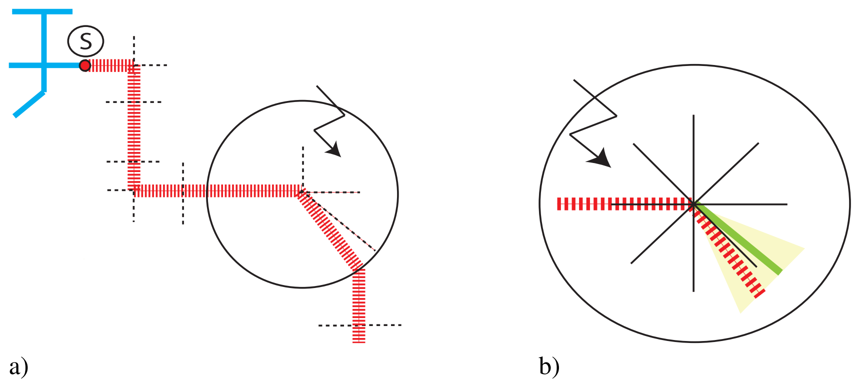


Figure 2.: Local error analysis: a) Critical situation: two outgoing branches share the same direction concept, a conflicting situation is identified; b) In more detail: the Choreme Analysis.

3.2.2 Global Error Analysis

The second kind of errors, namely errors resulting from the recurrent, uniform structure of an environment is analyzed in a similar fashion as the first. The aim is to tackle two problems simultaneously. The first remains in the representation of spatial features in maps; the second in the structure of the environment. Automatically generated maps are always data-driven representations. They use cartographic symbols to visualize a selection of the spatial entities that exist in the real world. Maps are selective and limited in their visual language, a key concept differentiating them from satellite photos (e.g., MacEachren, 1995). For example, the two images in Figure 3 show a rather monotone environment in Chicago. When traveling along the east-west axis the streets have names and are not numbered. Traveling in such environments requires close attention to the perceived

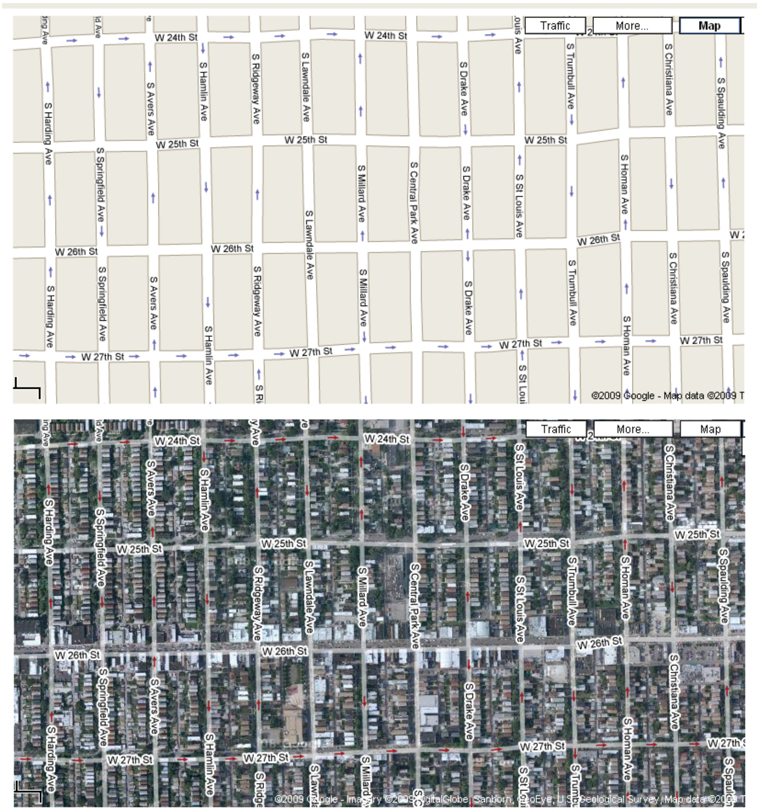


Figure 3.: A monotone environment in Chicago: at the top a map representation, at the bottom the corresponding satellite image. Images are taken from GoogleMaps.

environment in order to identify the correct decision point. Each intersection follows exactly the same conceptual configuration. There are no disambiguating elements, such as irregular structures or natural features, to segment the route beyond decision points. As Lynch (1960) pointed out, such monotone environments are hard to navigate.

We can operationalize uniformity in environmental structure as well as we can identify spatial particularities in order to support disambiguation. The algorithm works as follows and is illustrated in Figure 4:

1. We select a (configurable) number of intersections before and after the current decision point. "Before" and "after" are to be understood relative to the movement direction determined by the main route (cf. Richter & Klippel,

2007). In our current implementation, we select one intersection before and one after the decision point, even though this number may depend on the structure of the environment. Large grid environments, such as in Figure 3, may require a larger threshold than irregular environments (the analysis of the influence of an environment's structure on the required threshold is part of future work).

2. For all selected intersections, we calculate a qualitative representation of their configuration using a choreme encoding according to the CA as described above. However, here we are not interested in a single local configuration that may be conflicting, but in the similarity across the selected intersections' configurations.

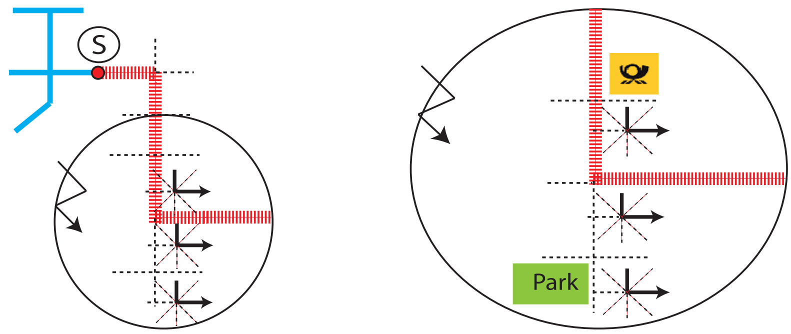
   (a) If the number of conceptual turns at two intersections is similar we mark the intersections as similar.

   (b) If the *similar* intersections have a unique feature located at them, which is not present at the other intersections marked as similar, we select this feature to disambiguate the current intersection. Consequently, we remove the similarity mark for this intersection again, as it can be unambiguously identified in its local neighborhood by this local feature. Disambiguating features, such as parks or water bodies, must be perceptually unambiguous, i.e., the cartographic style used to represent them on the map must be perceptually different from the way all other features in the local surroundings are depicted.

3. If there still exist unresolved ambiguities, we compute an alternative route for those intersections that are marked as similar.

3.2.3 Alternative Routes

Alternative routes (ARs) are a key concept of RAMs. They are the link to embedding the main route from origin to destination in the street network. Whenever the (local or global) error analysis identifies a possible error source on the main route we compute an AR from the location of the possible error either back to the main route or directly to the destination. This allows for extracting only the part of the street network, which is structurally important for the main route. Within the alternative routes, we do not perform any error analysis. Cognitively, these routes define the relevant spatial context on a network level and serve as a fall-back in case wayfinding errors have been made. Computationally, checking for errors on ARs as well would result in a recursive progression of potential errors that, in the worst case, would lead to displaying the complete street network and, thus, introducing unneeded visual clutter.



a) b)

Figure 4.: Global error analysis: a) Similarity analysis: the intersections before and after the decision point are identified as being similar with respect to their configuration, a conflicting situation is identified; b) The situation is disambiguated by representing landmarks (post office and park).

Calculating ARs is based on the approach of "simplest paths" introduced by Duckham & Kulik (2003). The AR algorithm works as follows and is illustrated in Figures 5 and 6:

1. We simulate a wayfinding error and "move" virtually off-route from the current decision point we identified as potential error source. In case of a local conflict, we move along a conflicting branch. In case of a global conflict, we take that branch at the conflicting intersection that corresponds to the branch we need to take at the actual decision point.

2. We block the branch we took. This will prevent the path search algorithm to simply compute the route back along this branch to the main route.

3. We compute the AR itself using the algorithm for "simplest paths." The algorithm penalizes nodes with many outgoing branches as they are deemed as complex; such nodes are mostly avoided. Therefore, in simplest paths competing branches hardly ever occur.

    - In every step of the simplest path algorithm we check if the current selected node is either a node on the main route or corresponds to the destination itself. In either case we have found a valid AR and stop.

4. The AR just found is displayed on the map.

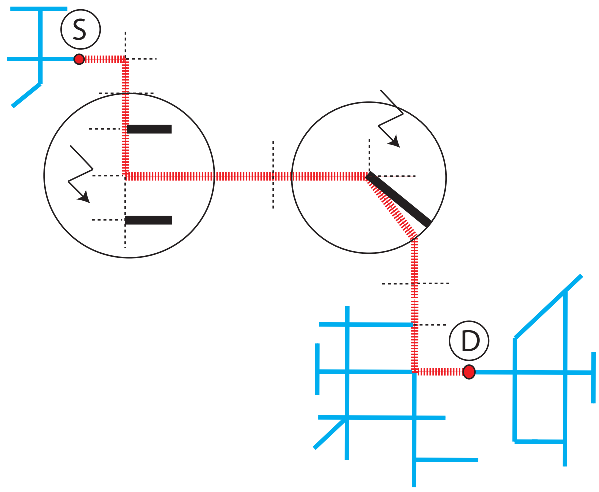


Figure 5.: Alternative routes: identifying all critical situations.

3.3 Global and Local Orientation

So far we have only dealt with local context, i.e., discussed information directly related to the route. However, with our aim of sparseness in providing information we need global spatial context as well to support successful wayfinding, especially when wayfinders get off the system of routes and need additional information to navigate to the destination. We need additional survey information in order to clarify the relations of the presented information (the main route and the ARs) to the actual environment wayfinding takes place in. We achieve this by introducing regions (Section 3.3.1) and landmarks (Section 3.3.2).

3.3.1 Global Orientation: Regions

In recent years, the impact of regions on human spatial conceptualization has been increasingly recognized. Wiener & Mallot (2003) identified region-based navigation strategies. Their work emphasized the concept of a graph-like representation of spatial information in which representations of locations are interlinked without having exact metrical information. They introduced the *hierarchical planning* hypothesis which claims that people plan routes by using different levels of a hierarchical representation of space and also that regions are explicitly represented in spatial memory. Seifert introduced a hierarchical spatial planning approach based on regions as primitives (e.g., Seifert et al., 2007). Schmid (2008) developed an approach to generating maps based on individually known places and

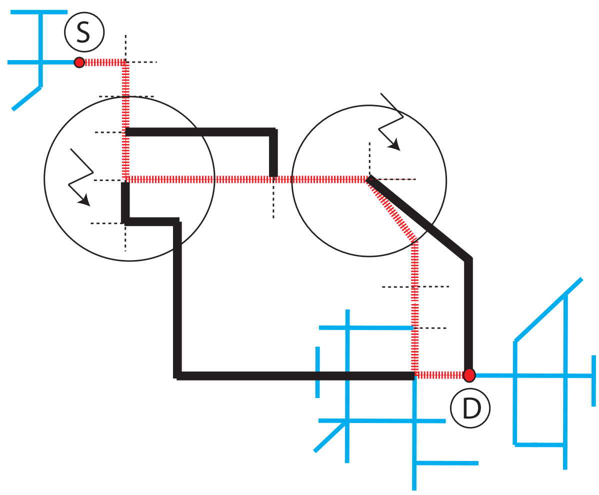


Figure 6.: Alternative routes: computing the ARs (bold solid lines) by employing the “simplest path” algorithm.

regions. Thus, just as landmarks (see below), regions are recognized as primitives in spatial orientation, navigation and communication.

In general, regions are hard to define as each individual seems to have a personal view of the concepts and borders of a region (e.g., Couclelis, 1996; Montello et al., 2003). This holds especially for natural regions or regions evolving from the social interactions of individual groups. Administrative regions, though, have well defined borders that have been fixed by an administrative body. Further, administrative regions may be identifiable by signage in the environment, for example, districts in a city may be labeled on street signs. But also some natural regions may be well usable for embedding a route in its environment, for example, clearly visible features such as large parks or water bodies.

These kinds of regions are integrated in the information displayed on RAMs in order to provide a global spatial context for wayfinding. In case they get lost, i.e., deviate from the route, wayfinders can navigate along regions to the region that contains the destination. In the following, we will explicate how the relevant regions can be identified automatically. Figure 7 shows the hierarchy of regions used in our approach. The top level regions we consider are those of country borders, followed by those of states within a country, cities and towns (or in general built-up areas). Within cities, we consider local particularities, namely districts and natural features. These features may be located within several regions, for example, the border between two districts may run through the middle of a park. We treat all regions within a city to be on the same level of granularity.

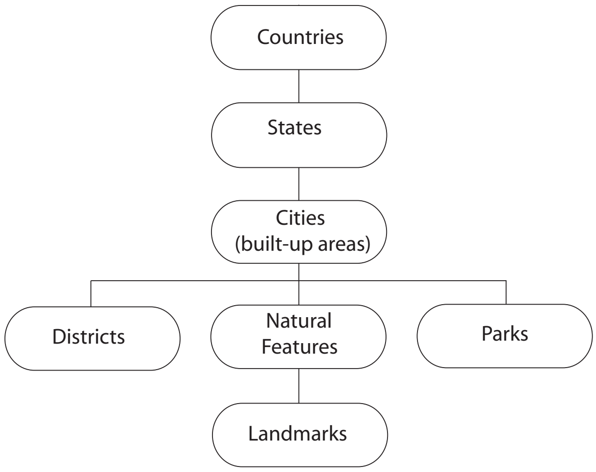


Figure 7.: The region hierarchy as implemented in the RAM process.

Selecting these regions for integration in RAMs is a pragmatic approach in terms of perceptibility, available data and computational efficiency. The algorithm for determining the regions to be included is illustrated next.

Pre-Processing and Query Optimization

The aim of the region extraction algorithm is to identify all regions that are relevant for the wayfinding problem. Relevant regions are those that contain parts of the routes—be it the main route or one of the alternative routes. These are the regions the wayfinders will pass through. The computation of the membership of a route within a region is based on the points contained in the route. If a point of the route is within a region, the region is considered relevant for the route. In terms of geographical data, regions are usually complex polygons (in our data some of the districts have up to 5000 geometric control points). Thus, depending on the type of regions and the length of the route, the number of regions and points to be checked can become very large, turning this into a computationally infeasible approach.

Therefore, to drive computation, initially we need to determine the region which completely contains the route. A route between Bremen and Hamburg would be fully contained in the region “Germany;” a route within Bremen would be completely contained within the region “Bremen.” This region is the starting point for a further refinement of the relevant regions. The encompassing region serves two purposes: 1) only those regions that belong to a category on lower levels of the hierarchy than the encompassing region (see Fig. 7) will be relevant for the routes, i.e., we can restrict our search to these levels; 2) in a similar line of argument, we can restrict the search for regions to the spatial extend covered by the encompassing region. We will treat each hierarchy level relevant for the region identification individually.

The key idea of processing all regions that may be relevant for the RAM to be constructed is the separation of their functional and geometric representations as well as the utilization of the neighborhood relation between regions. To this end, we need to do some preprocessing on the region data. For each region, we compute their bounding box as this allows for a faster comparison of spatial relations between regions. Namely, we need to test for intersection/touch and containment of regions. Using the bounding boxes, we calculate an adjacency matrix that stores intersection and containment of regions—a region containing another is taken to intersect with the contained region.

With this adjacency matrix, we can now navigate efficiently through the hierarchy of regions, i.e., our search space. We further restrict the containment check of route in regions by only checking for decision points, i.e., those points of a route that coincide with an intersection. As stated before, region selection is performed on each layer of the hierarchy individually. However, by means of the indexed data, we can interlink the different layers to further facilitate efficient processing of the information. The following algorithm selects relevant regions for the information so far contained in the route aware map, namely the main route, the street network around origin and destination, and the alternative routes (see Fig. 8).

1. We compute the bounding box of the RAM (the extend covered by main route, origin and destination, ARs).
2. We determine the region on the lowest possible level of the hierarchy that fully contains the bounding box of the route aware map.
3. For every route (main route and ARs) we iterate through all nodes that correspond to decision points.
4. We check for containment within any of the regions of the current level in the hierarchy. In the first pass, this is the level one below the level the encompassing region belongs to.
   - If no region contains a node of the route (not all region layers will cover the complete area as administrative regions do) we stop the search on this level and proceed with the next region layer at step 4.
5. If we have identified a region whose bounding box contains a node, we check again with the actual border of the region. Nodes being on the border of a region count as being contained as well.
   (a) If the node is really contained, we select the region and add it to the map.

(b) If the node is not contained, we select all neighbors of the selected region by means of the adjacency matrix. We check these neighbors for which of them contains the node.

6. If we have processed all nodes and there are still layers of the hierarchy we have not checked yet, we select one of these as new layer and repeat the process from step 3 on.

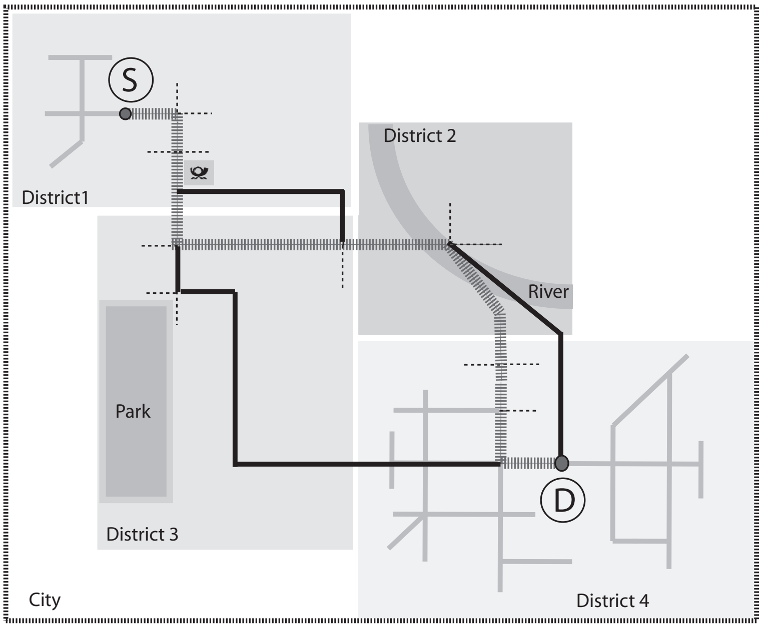


Figure 8.: Global orientation: Embedding the route in surrounding regions.

3.3.2 Local Orientation: Landmarks

Finally, in creating RAMs local landmarks are used to anchor route information in its surrounding environment. These landmarks serve two purposes: they help to disambiguate intersections and they foster orientation of wayfinders. In areas that are made up of structurally similar intersections, i.e., where the street network is very regular (see Section 3.2.2) landmarks may make the difference it takes to identify the intended intersection. Accordingly, for intersections identified to be structurally similar to their surrounding intersections, we check whether some landmarks may be used to identify them. This check is done as explained in our previous research (e.g., Richter & Klippel, 2007; Richter, 2007), but extended to include depictional considerations. Additionally to ambiguity checks we have used in our previous work, we also check whether potential landmarks would be depicted on the map using the same cartographic style as other features in the local surroundings, i.e., whether the feature categories they belong to are mapped using the same color and geometry. If two different types of features are depicted the same way (e.g., a fountain and a statue may both be depicted as a grey circle), they are not easily distinguished on the map and, therefore, do not unambiguously identify an intersection if both features are present in the surrounding area. In case a landmark located at the intended intersection unambiguously discriminates this intersection from its neighboring ones, it is included in the route aware map and, thus, solves a potential conflict.

Local landmarks may also be used to foster orientation, similar to global ones, i.e., those environmental features represented as regions. To this end, it is checked whether highly salient landmarks are located along the route (such as highly visible shops or monument buildings); these are added to the RAMs. However, to avoid visual clutter, we limit the number of landmarks added this way to only a few key features. Checking for such landmarks, again, is based on previous work.

3.4 Example

Figures 9 and 10 illustrate the steps of compiling a RAM based on geographical data of the city of Bremen. Figure 9a depicts the main route from origin S to destination D running through Bremen's inner city. Figure 9b shows the extracted strip map, the minimalist map-based representation of the route. In Figure 9c we disambiguate the start environment by extending the street network until the first intersection as described in Section 3.1. In the same step, we extend the street network around the destination (network depth of three topological nodes) and added the river as an additional landmark according to Section 3.3.2.

Figure 10a depicts the potentially problematic parts of the route and the resulting alternative routes (bold dark gray underlying lines). Figure 10b depicts the so so far compiled route (extended start and destination environments) with the extracted alternatives routes. Finally, in Figure 10c we add those regions which are relevant to the route (here, these are only districts as the route is contained in a single city). This results in the route aware map assisting a wayfinder to get from origin S to destination D.

Note that we do not display cartographic labels, such as names of streets or districts, to emphasis the principle generation process of RAMs. For actual usage, without this information a real anchoring of the streets, regions, and landmarks in the global context is likely not possible.

Figure 9.: a) shows the original (survey) map with the route (thin black line) from S to D. b) shows the extracted route, c) the route with disambiguated start environment and extended destination environment.

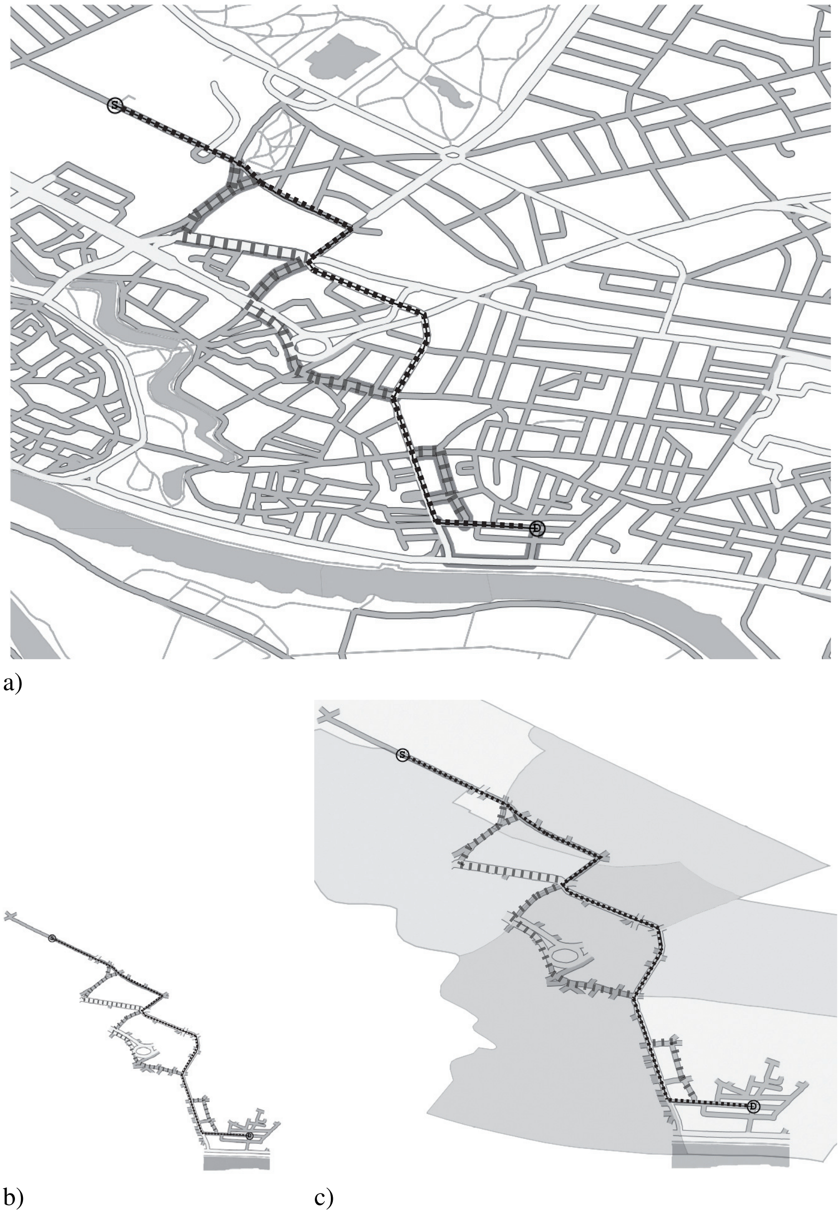


Figure 10.: a) shows the route in the original (survey) map with alternative routes (bold underlying lines). b) shows the extracted alternative routes, and c) depicts the final RAM with the relevant regions (in this case districts) for the main route and the alternative routes.

4 Discussion

Schematic wayfinding maps are by definition task specific representations (cf. Klippel et al., 2005) usually incorporating a stringent feature selection. The selection of features aims at efficient assistance with low cognitive demands tailored to a specific wayfinding task. There are different approaches to define, select, and visualize the relevant information for a given route underlying the specific wayfinding task, which leads to different schematization principles. In Agrawala & Stolte (2001), for example, the authors propose LineDrive Maps, which are based on the mental prototypical arrangements of intersections and activity based scaling of street segments. The resulting schematic maps represent a route as strip map with no further information on the surrounding environment and can be considered to be a data-driven schematization. As a contrast to this reduced representation, Focus Maps (Richter et al., 2008) use a rich representation of the environment and highlight the crucial elements (e.g., the route) by de-emphasizing non-relevant areas of the environment. This is achieved by a fading out of colors and a simplification of feature geometry based on proximity to the elements in focus. Schematization in Focus Maps is based on perceptual effects as the selection of features is mostly done via their color encoding. μ Maps (Schmid, 2008) show only the unfamiliar parts of a route in full detail, the familiar parts are schematized to a high degree. This kind of schematization exploits individual familiarity with an environment.

RAMs introduce a new type of schematization by taking these approaches a step further. They provide a multi-granular schematization since they select features of an environment on different levels of granularity. In that, they acknowledge the hierarchical representation of space by humans (e.g., Hirtle & Heidorn, 1993). They provide means to reach the overall goal—getting to the destination—and at the same time offer information for reaching this goal on different levels of granularity, thus offering alternatives and allow for approximate wayfinding in case task execution fails. Thus, while being task-specific, they allow for different executions of the task.

RAMs communicate survey knowledge dependent on the course of a particular route. They do not show the details of the street network, especially of remote locations in the same district, however, they communicate the configurations of important structural and conceptual elements of the environment in relation to the actual route. They are rather conceptual survey maps than general purpose maps. RAMs illustrate the structure of the environment for a route similarly to how a GPS-based wayfinding assistance system only communicates the route to travel. They focus on the crucial parts of survey information. General purpose survey maps on the other hand offer all information of a defined region as equally important.

However, the selection of, for example, regions also depends on the network incorporated by the route. If a route incorporates a longer part across a highway, the context of that part is different to the context of a part of a route within an inner city environment. While driving along a highway, we are most likely not interested in every district of a city we pass or potentially cross. The selection of the contextual information for such routes would benefit from additional considerations of coherent parts of the route with respect to the utilized transportation link. Thus, in generating RAMs, the (conceptual) scale of covered route segments should be considered as well and the construction process should be accordingly adapted—this might include activity-based scaling similar to Agrawala & Stolte (2001).

5 Conclusions

In this paper, we have presented an approach to map-based wayfinding assistance that we term *route aware maps*. These maps are designed to present all information that is needed to successfully reach a destination while aiming at sparseness in the display of that information. It combines the best of strip maps, which only present information on the route itself, with survey maps, which distribute information uniformly across the chosen area.

Next to the actual route from origin to destination, RAMs present the area around origin and destination in more detail to keep the wayfinders oriented at these crucial spots. The maps also integrate alternative routes at those points along the route where wayfinding errors likely occur due to the (local or global) ambiguity in the structure of the environment. Furthermore, RAMs embed the route in its global spatial context. To this end, those regions relevant for the route are identified and displayed allowing for approximate navigation using region information in case the route has been accidentally left; key local landmarks are shown as well and further the anchoring of the route within the environment. We take an information- and representation-theoretic approach to identifying this additional information that is required for successful navigation. We have detailed the construction process for route aware maps, stating algorithms for all intermediate steps, and discussed an example map.

We believe that route aware maps as they have been presented in this paper are a promising approach for solving two (related) problems in map-based navigation assistance: 1) provision of focused, easy to access assistance that still allows for error recovery; 2) the key-hole problem. The latter describes the problem of presenting local information in its global context such that users can easily relate both; it is especially crucial for the small displays of mobile devices. Thus, RAMs are not only more reliable in a given wayfinding situation, they may also help to overcome a major problem of today's assistance systems, namely that users do not really understand the spatial situation they are in and hardly remember anything of the route after reaching the destination as shown, for example, by Parush et al. (2007) and Ishikawa et al. (2008).

In the near future, we plan to test the performance of RAMs in empirical wayfinding studies in which we will compare the wayfinding performance of human subjects using route aware maps in real world navigation tasks with participants using 'classical' street-maps. We will also explore scale-dependent construction of RAMs and check whether additional salient objects should be included in the maps, for example, major roads that may provide additional global orientation, such as highways.

Acknowledgments

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9 Situated Local and Global Context in Mobile You-Are-Here Maps

Schmid, Kuntzsch, Winter, Kazerani, and Preisig [2010a]

In this paper we demonstrate the effectiveness of the coupling of interaction primitives with the semantics of a representation. This publication attacks the self-localization task of the wayfinding process: we develop so-called YAH^x maps to support fast and reliable self-localization in unfamiliar environments.

Self-localization is assisted by a system of cognitive and computational principles, as well as semantic interaction primitives. The algorithmic core of the YAH^x is a complex analysis of the environment surrounding the user. We develop a method to identify global references which are relevant orientation clues. We use them as a stable frame of reference to support geographic self-localization. We apply methods to analyze the relevant parts of the street network to reduce visual complexity by at the same time preserving correct mental processing of the presented information.

In detail, we develop a trajectory based localization and map alignment approach instead of a pure positioning and compass based method. By orienting the map with respect to the trajectory and not by current compass information, we segment the environment into "the area one comes from" and the remaining part, which is a cognitive shortcut to the interpretation and alignment of the map. Additionally, we use a stable and egocentric frame of reference with salient landmarks on different levels of granularity. Finally, we develop the concept of *reference adaptive zooming*, a method to rapidly adjust the scale of the map to semantic meaningful zoom levels with minimal interaction.

In user studies we evaluate the effectiveness of our approach and show that the overall performance of the map combined with interaction is superior to traditional approaches.

Situated Local and Global Orientation in Mobile You-Are-Here Maps

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ABSTRACT

This paper presents a novel solution to the focus-and-context problem of mobile maps provided for local and global orientation. Our solution is inspired by the design principles of static You-Are-Here maps and realizes principles of human spatial cognition to enable efficient communication of location information. We further propose selective interaction with the presented information to improve the speed and accuracy of interpretation of the geographic information. Tests show strong evidence for the cognitive and interaction efficiency of the resulting maps, as users were faster and more accurate than with conventional mobile maps.

Categories and Subject Descriptors: H.5.2 [Information Interfaces and Presentation]: User Interfaces — Graphical User Interfaces

General Terms: Algorithms, Experimentation, Human Factors, Measurement, Performance, Reliability.

Keywords: You-Are-Here Maps, Location-Based Services, Spatial Cognition, Detail-in-Context, Focus and Context, Localization, Spatial Awareness.

1. INTRODUCTION

Traditionally, *You-Are-Here maps* (YAH maps) are static maps of an environment, showing a you-are-here symbol and being displayed stationary in the environment to support local orientation, answering the question: “Where am I?”. Examples can be found, e.g., in parks, stations, or malls. These YAH maps are well-studied concerning principles of human spatial cognition, e.g. [13, 16].

This paper aims for generating a mobile equivalent to traditional YAH maps, i.e., situated YAH maps that are ubiquitously available on demand and meaningful for local orientation even from the small displays of mobile devices.

For many location-based services, visualizing the current location of a user has ever been a basic functionality. However, the prevalent techniques are content with illustrating a dot on a small-display map of a typically predefined scale, e.g., to show everything in 100 meters around the estimated position. More advanced techniques, addressing the focus-and-context issue on small displays more carefully, are discussed below. None of them draws explicitly from the principles of YAH map design, or the underlying principles of human spatial cognition.

We will consider the design principles of traditional YAH maps, namely local and global orientation, alignment to the user’s reference frame, selection of relevant information, and adaptation to positioning uncertainty, when we develop a conceptual model and methods to generate these mobile YAH maps. We will call these maps YAH^x maps from here on.

Local and global orientation. A stationary, e.g., wall-mounted YAH map provides a context-dependent global orientation with a focus on “you are here”. In contrast, most mobile services provide a map on the small display. To answer the question “Where am I?" requires the user to integrate multiple views of varying scales, switching between zoom levels. In contrast, a YAH^x map should address the focus-and-context problem: provide in a single view local orientation and the context of a larger environment at the same time. Several techniques for this problem were suggested, but we believe that they can be significantly improved by an additional criterion of relevance.

Relevance. YAH^x maps must be designed for fast and reliable information conveyance, i.e., the map representation of the environment has to concentrate on relevant information. Relevance is a matter of distance, such that methods are required to describe the directly perceivable surrounding in detail, but the embedding of this surrounding with increasing selectivity.

Positioning uncertainty. Wall-mounted YAH maps do not have any positioning uncertainty, but mobile YAH^x maps have to address the uncertainty of the various mobile positioning methods to reduce the potential of misapprehension to a minimum. Noise and consequently positioning uncertainty will probably remain an issue for mobile services, such that the typical dot on a map can be grossly misleading.

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In the rest of this paper we develop a novel way of generating YAH^x maps and their interaction functionality, addressing the issues discussed above by:

- considering location based on human perception and cognition, i.e., with high level of detail for everything that is near, and coarse information about what is far;
- adapting the base level of detail to the certainty about the current position, according to rules of relevance;
- allowing for fast and precise interaction with the underlying map to further determine the context of one's location by means of a larger spatial scope.

2. BACKGROUND AND RELATED WORK

This section collects the relevant work about communicating in varying degrees of granularity, and linking granularity to positioning uncertainty.

2.1 YAH maps

YAH maps serve the purpose of orientation for people in an unfamiliar environment. Accordingly, YAH maps are characterized by a YAH mark. They must follow two cognitive principles for effectiveness, *alignment* and *structure matching with the environment*, from which the criteria for their placement and design can be derived [13]. These criteria follow from the specific task of YAH maps, and have to be applied in addition to the rules of effective general map design (e.g., [10]). The criteria are, in short: *completeness* (they must contain all the information that is necessary to fulfill the given task, local orientation), *syntactic clarity* (all the relevant graphic features for a given task need to be easily perceptible and identifiable, and visual clutter needs to be avoided), and *semantic clarity* (all the symbols and map features need to be easily imbued with meaning in an unambiguous and consistent manner).

2.2 Small Display Cartography

Small display cartography has developed several approaches to cope with the problem of visualizing geographic information on small displays with sufficient level of detail. Approaches suggested so far are variable-scale maps, variable-focus maps, generalized and selective maps, and visualization of off-screen features. *Variable-scale maps* are suggested to address the focus-and-context problem [9]: They apply fisheye lenses to show an area detailed in the context of the embedding map. These transformations heavily distort the geographic information, especially in the border regions of the curvature. Also, this kind of mapping is translation- and rotation-sensitive, i.e., attached with heavy updating costs if the mobile user turns or moves. *Variable-focus maps* are designed to focus the map reader's attention to relevant parts of the map [28]. In the process of generating these maps two steps are involved, the selection of the relevant region, and the map manipulation to focus the attention on the relevant region. Typically the selected region is visually distinguished by parameters such as saturation or granularity. I.e., focus maps select, but they do not vary scale, and are still limited in providing global orientation by the small display. *Generalization and selection* was proposed in the context of route maps. Sketch maps neglect any map content that is not considered relevant, and apply rules of salience and relevance to draw a map of inhomogeneous scale [1]. Applying sketches for YAH^x maps has not yet been suggested. *Personalization* of maps with respect to the individual previous spatial knowledge of users have been suggested in [20, 21]. For these maps, the generation algorithms consider routing across familiar parts of the environment. If this is possible, the resulting μMaps will not show details for the familiar regions, and finally the resulting maps can be significantly smaller compared to conventional maps. *Off-screen features* can be visualized by pointing from a map-view of constant scale to off-screen locations by means of arrows, circle segments [2], or wedges [6]. The latter methods are typically applied with no text labels, i.e., applicable only where features of the same type are to be visualized. With their inability to distinguish between different feature types they are not suited to provide a global orientation. Global information is provided by a map inlet showing the global orientation at small scale, while the main map serves the local orientation at large scale, or alternatively, by multiple maps of various scales, requiring user interaction to zoom in and out. An example for the latter is sectoral zoom [19]. In [22] the authors describe a system to transform local, stationary YAH into mobile YAH maps. By means of a mobile phone with GPS and camera, they turn a photo of the stationary YAH map into a mobile, navigatable map. However, this approach does naturally not transform the geographic information into a suitable mobile representation, as it is based on photos of printed maps. A combination of variable scale, variable focus and generalization and selection was recently presented as 'focus plus glue plus context', extending the current focus-and-context paradigm for 'glue' [27]. We will develop another alternative in the next section, using elements of variable focus, generalization and selection, and visualization of off-screen features. We deliberately leave variable scale out, since this approach has never proven to help users building proper cognitive representations of their environment. Our alternative approach is based on spatial hierarchies and relevance, as cognitive principles. Cognitive spatial representations have a hierarchical structure, and that cognitive spatial reasoning is hierarchic [7]. Correspondingly, human verbal place descriptions are hierarchical [17], either coarse-to-fine or fine-to-coarse, and they adapt to position uncertainty by choosing an appropriate base granularity [25]. This paper will translate these principles into a graphic expression of a YAH^x place description.

3. A CONCEPTUAL MODEL OF YAH^x MAPS

3.1 Requirements

YAH^x maps can be requested by people everywhere in an ad-hoc manner. Thus the design of YAH^x maps has to catch up with the variety of environments a person can be in, and the variety of locations and orientations the person can have within this environment. These considerations suggest two guiding principles for the provision of YAH^x maps: an awareness of the local and global situation (*situatedness*), and an awareness of the body of the person and its physical and perceptual relations to the environment (*embodiment*). These principles are subsumed as *location context*. YAH^x maps also depend on the position uncertainty, suggesting a link with the granularity of the provided information, subsumed as *position context*.

In this paper other contextual aspects are explicitly excluded, such as the individual person's interests or tasks, the *personal context*. These aspects are excluded by traditional YAH maps as well, which also do not adapt to individual users.

3.2 Location context

Figure 1 shows a sketch of a conceptual model of feature selection and presentation. It realizes principles relating to the identified requirements and is based on Montello's distinction of vista, environmental and geographic spaces [15]—which we can associate

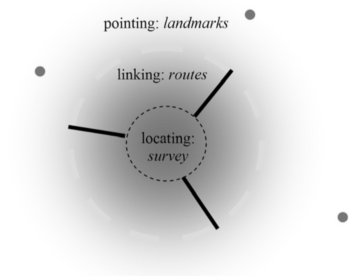


Figure 1: The three levels of detail in a visual You-Are-Here (YAH) presentation on a mobile display: survey information in the immediate neighborhood of a person, route information to selected landmarks in a larger neighborhood, and pointing to landmarks beyond that horizon.

with Worboys' three-valued nearness relation of 'near', 'not near, not far', and 'far' [26]—and Siegel and White's distinction of landmark, route and survey knowledge [23]. Correspondingly, in YAH^x maps *situatedness* can be realized by three levels of selectivity.

Vista space is the space that can be seen from a single viewpoint. It is either bound by physical barriers (e.g., in build environments or urban environments) or by a threshold distance of clear visibility (e.g., in open environments such as at sea or on open plains). Vista space is a conservative and user-context-free approximation of what is near from the position of the user or their mobile device, the conceptual model assumes that at this level all (visible) features in the environment are relevant, and calls for survey information.

Environmental space is learned by locomotion and integration. Still related to the body of the user, although by movement opportunities rather than by sight, the conceptual model translates environmental space into 'not near and not far' and suggests to present the links from vista space to far environment: (i) YAH maps are regularly used for wayfinding in complex environments, and (ii) routes in this range of distances still can be presented on small display maps. A formal parameter to limit this area autonomously for any type of environment could be a set threshold of what is comfortably reachable by locomotion, e.g., by foot.

Geographical space is learned from symbolic representations. Least based on the actual position or possibilities for locomotion, the conceptual model associates geographical space with 'far', and provides information in this area most selectively, only by prominence. Presenting only landmarks in this area facilitates global orientation by directions to landmarks. Detailed survey or route information at this level would only form visual clutter, and reduce the ability or efficiency of self-orientation.

In this conceptual model, nearness and prominence are antagonists. Near features are always presented, independent of their prominence. Routes are presented selectively, by their significance to facilitate movement from the current position to other destinations. Far features are only presented if they are prominent landmarks. I.e., the conceptual model requires strategies to identify significant links and prominent features in the environment.

Embodiment is further realized by map alignment to the egocentric reference frame of the user. Reference frames describe the relationships between spatial entities with respect to a potential observer [11]. In *egocentric* reference frames relationships are described with respect to the location, heading, and bearing of an observer—in our case the user of a YAH^x map. It has been shown that reasoning with maps that do not correspond with the orientation of the map user is a cognitively demanding and error-prone task, as the user has to mentally rotate the representation to achieve a mental match of the two information sources, the real and the represented environment [13]. I.e., to support an intuitive understanding of the spatial configuration of an environment for orientation, YAH maps have to show a representation that matches the current orientation of the map user.

However, there are two ways of orientation: one by the trajectory of the map reader—their *general heading*—and one by the current orientation of the mobile device—their implied *actual heading*. The general heading demarcates the environment into a *front*, the part of the environment not yet traversed, and a *back*, the part of the environment already traversed (in terms of near past events), a *left* and *right* (Figure 2). It is reasonable to assume that users will recognize the part they have already traversed on the map and in the real environment as they usually know where they come from. The general heading provides a stable map representation for an egocentric sector model. In comparison, using the actual heading, a widely used method in GPS assisted navigation devices when the map turns according to the compass information, map generation is subject to constant rotation and reassignment of references for the four egocentric sectors. Also, the available built-in compasses usually only work reliable while the user is constantly moving. Whenever users stand still and slowly turn around their axis (which is a typical behavior when we want to self-localize ourselves within the environment around us), the information can be arbitrarily wrong. Not least, the cognitive processing of highly dynamic spatial representations can be expected to be hard.

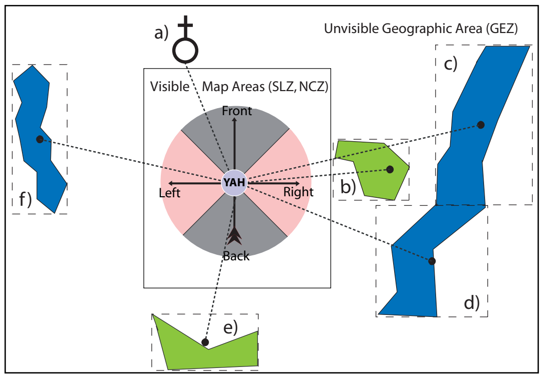


Figure 2: Egocentric embodiment: the surrounding environment is segmented in sectors for front, back, left, right. The details for the selection of the global references are described in Section 4.4.

3.3 Position context

Prior suggestions to deal with the uncertainty of positioning are about varying the radius of the dot on YAH maps, or alternatively, varying the scale of the underlying map accordingly [8]. Both methods are quantitative, controlled by the standard deviation of positioning. However, we believe that this information should be cognitively more intuitive, and hence, qualitative. The above model for location context already provides means to replace the position uncertainty by a meaningful spatial location: vista space. Vista space can be interpreted to communicate YAH information graphically on maps: features bounding vista space together with their relation to the map user can form this YAH information; i.e., only those features that can be seen by the user from the estimated position are actually relevant for orienting in the direct environment and necessary for being displayed in detail.

4. GENERATION OF YAH^x MAPS

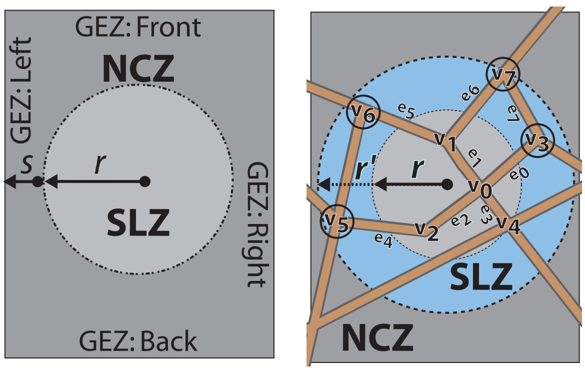
In this section we detail the automatic generation process and the operationalization of the theoretic considerations for YAH^x maps according to the conceptual model. For every map the actual position and its uncertainty, the near-past trajectory, and the spatial references of the embedding environment are considered. YAH^x maps will support self-localization, network-connectivity identification, as well as the determination of the global embedding of the depicted area. Additionally a semantic-selective interaction primitive will be introduced, a reference-adaptive zoom-function.

Realizing the concepts of Figure 1, YAH^x maps consist of three *context zones* (Figure 3):

Self-Localization Zone (SLZ): This zone, realizing the 'near' zone of self-locating in Figure 1, depicts the complete street network and the last part of the latest trajectory. Streets are labeled selectively to avoid clutter on the small display. Streets are labeled if they are (a) along the trajectory, (b) likely to be in the direct surrounding of the user, based on the observed position (keeping in mind that positioning information is uncertain), or (c) of high centrality (based on edge betweenness, which is explained below). Furthermore points of interest can be included to enable fast recognition of the direct surrounding.

Network-Connectivity Zone (NCZ): This zone, realizing the 'not near, not far' zone in Figure 1, relates the SLZ to the network links of the larger street network. In the NCZ only those streets that have a high centrality are depicted, addressing small-display problems as well as relevance principles. This zone starts at the SLZ, has the same scale and covers the rest of the display.

Global-Embedding Zone (GEZ): The GEZ, realizing the 'far' zone of pointing in Figure 1, is outside of the display. But the pointing information to what is beyond the display is brought back (Figure 3a): Text labels referring to remote landmarks are listed at the four sides of the display, corresponding to the four sectors of the egocentric reference frame imposed on the current heading of travel. This way, pointing is generalized to categorical directions, addressing cognitive load in combination with (usually) spatially extended landmarks. The scale of the YAH^x map is chosen adaptively to the uncertainty of the positioning.



a) b)

Figure 3: (a) Zones, and (b) the extension of the street network in NCZ.

4.1 Determination of the Orientation

A basic requirement of a YAH^x map is its inherent orientation matching: what is in front of the user has to be on top of the map, left/right elements on the left/right part of the map, and the environment behind the user on the bottom of the map. Usually the determination of orientation is implemented with compass information. However, for reasons discussed above the general heading is preferable due to providing more stable map views. The heading is computed from the map-matched trajectory of the user as input, i.e., taking the last traversed street segment before the query. This street segment points to what is ahead of the user, and the map is oriented accordingly. For a reliable map matching the positioning is required with sufficient frequency and an uncertainty smaller than the density of street segments.

4.2 Determination of Scale

The scale of the YAH^x map is determined by the uncertainty of the positioning information. The scale of the SLZ is chosen such that all possible addressed locations are depicted: if the uncertainty (σ_{xy}) is a number of meters, the radius r of the SLZ (see Figure 3) is set accordingly. Practically, SLZ is not strictly defined by a circle, but by network distance, including all vertices v_1, v_j reachable from an edge e_k within the radius r around the estimated position. Figure 3b illustrates this process: r corresponds with the positioning uncertainty, thus everything inside the circle of r natively belongs to the SLZ (v_0, v_1, v_2, v_4). However, the edges e_0, e_4, e_5, e_6, e_7 connect the vertices v_3, v_5, v_6, v_7 with the elements of the SLZ. I.e., r is extended to r', r' being the largest distance of these vertices from the current position, to include those entities as well. The reason for this procedure is to cover the immediate reachability and visibility of the possible network space: all elements in the SLZ can potentially be reached or seen. Using these demarcation entities is a realization of vista space, such that at least the next junction is visible. The scale of the YAH^x map is now chosen such that the SLZ preserves a minimal distance s to the border of the display, see Figure 3a.

4.3 Street Network Simplification

In the SLZ the level of detail of the street network reflects the originally available granularity from the data set. This is achieved by selecting vertices in a radius r around the current position of the user (see Algorithm 1, steps 5-7). The original SLZ now consists of both edges with both adjacent vertices inside r and edges with only one adjacent vertex inside r. The latter case leads to the expansion of the SLZ into radius r' (steps 8-12). The value of radius r' is the maximum among distances of vertices added to SLZ in this process from the YAH^x map center p. However, street network information requires a lot of space and is proven to introduce a significant amount of visual clutter (e.g., [18]). Thus the original street network graph G needs to be reduced to a sub-graph G' in order to reduce the visual clutter in the outlying parts of the map. As the task at hand is self-orientation, not the identification of a particular street or route, we can remove those streets in the NCZ which are not important to be visualized (as they are not necessary to describe the general structure of the street network). Only streets with a centrality measure above a certain threshold t are depicted, i.e., streets that are prominent and support the street network structurally (steps 13-17). As a consequence, we receive a thinned out street network G' which contains all necessary information for gaining configurational survey knowledge, but has significantly improved cognitive processing properties due to reduced detail.

Betweenness is a prominent measures of centrality [4]. Edge betweenness is a generalization of betweenness centrality to edges

Algorithm 1:
COMPUTE-STREET-NETWORK(G, p, r, t)

Input : A street-network graph G consisting of edges E and vertices V. p is the position/coordinate of the xYAH-Map center and r the radius of the *SLZ*, taking into account the positioning. t is an in-betweenness threshold and has to be exceeded by a street outside of the *SLZ* such that it is included in the *NCZ*.

Output : Returns G', a sub-graph of G consisting of all streets inside the *SLZ* using the extended *SLZ* radius r' and a selection of streets outside r' around p depending on the in-betweenness values of the streets.

$G' \leftarrow$ empty graph of a set of vertices V' and a set of edges E'.
$root \leftarrow$ a copy of the vertex from G closest to position p.
$E' \leftarrow \{root\}$
$V'' \leftarrow$ an empty list to be filled with the vertices contained inside radius r SLZ.
forall $v_i \in V$ **do**
    if `getDistance(getPosition(`v_i`), `p`)` $< r$ **then**
        $V'' \leftarrow V'' \cup \{v_i\}$
forall $v_i \in V''$ **do**
    forall $e_i \in E$ *with vertices* v_j, v_k **do**
        $V' \leftarrow V' \cup \{v_j\}$, if $v_j \notin V'$
        $V' \leftarrow V' \cup \{v_k\}$, if $v_k \notin V'$
        $E' \leftarrow E' \cup \{e_i\}$, if $e_i \notin E'$
forall e_i *between vertices* v_j, v_k *with* $e_i \in E$ *and* $e_i \notin E'$ **do**
    if `getInBetweenness(`e_i`)` $> t$ **then**
        $V' \leftarrow V' \cup \{v_j\}$, if $v_j \notin V'$
        $V' \leftarrow V' \cup \{v_k\}$, if $v_k \notin V'$
        $E' \leftarrow E' \cup \{e_i\}$
return G'

Algorithm 2:
COMPUTE-REFERENCE($R, p, v, sector$)

Input : A list R of candidates for orientation references, the position of the user p and the vector v denoting the orientation, $sector$, the current direction sector (*front*, *back*, *left*, *right*).

Output : Returns an element from R as a reference for the direction sector.

1 $bestCandidate \leftarrow r_1 \in R$
2 $maxQuality \leftarrow -1$
3 $currQuality \leftarrow 1$
4 **forall** $r_i \in R$ **do**
5     $currQuality \leftarrow currQuality * f_{dist}$(`getDistance(`$p$`, getReferencePoint(`$r_i$`)))`
6     $currQuality \leftarrow currQuality * f_{size}$(`getArea(`$r_i$`)`)
7     $cardAngle \leftarrow$ compute angle of the current cardinal direction from the orientation vector v and the cardinal direction angle constant. *front* direction equals the direction of the current orientation, *left* and *right* directions run orthogonal $(+/-90°)$ to the current orientation, *back* direction equals the opposite $(+180°)$ direction of current orientation. (Vector angles are given in relation to a fixed axis in the coordinate system.)
8     $referenceAngle \leftarrow$ compute angle of the vector between p and reference point of r_i (`getReferencePoint(`r_i`)`).
9     $currQuality \leftarrow currQuality * f_{angle}$(`getAngle(`$cardAngle$`, `$referenceAngle$`)`)
10     $currQuality \leftarrow currQuality * f_{type}$(`getType(`$r_i$`)`)
11   **if** $currQuality > maxQuality$ **then**
12         $bestCandidate \leftarrow r_i$
13         $maxQuality \leftarrow currQuality$
14 **return** $bestCandidate$

(here: street segments), and defines centrality in terms of the degree to which an edge falls on the shortest path between nodes. In a graph $G(V, E)$ consisting of vertices V and edges E, let $|SP_{jk}|$ denote the number of shortest paths between vertices $j, k \in V$, and $|SP_{jk(e)}|$ the number of shortest paths from j to k containing the edge $e \in E$. Edge betweenness of the edge e is defined as follows:

$$C_e = \sum_{\substack{j,k \\ j \neq k}} \frac{|SP_{jk(e)}|}{|SP_{jk}|} \tag{1}$$

Computations of edge betweenness can be performed for example within the space syntax software Mindwalk [3]. In the present context the edge betweenness of street segments is further processed, computing the betweenness of streets. In order to identify streets, here the Gestalt principle of good continuation is utilized [24]. Street segments are joined according to the Gestalt principle if they have small deflection angles. The threshold is chosen based on what people perceive as *straight* [12]. Once streets are formed the edge betweenness of their segments can be aggregated to a betweenness centrality of the street.

4.4 Determination of Global References

The GEZ points to remote landmarks that define the contextual frame of reference for a particular "where am I?" query form an egocentric perspective. Their automatic selection is based on two principles. Firstly, they have to express the global layout of an environment, e.g., a city [14]. Examples are rivers that wind through a city or larger parks that define the topography. Secondly, they must be still meaningful in the local context, thus we refer only to relatively close elements in a particular direction.

These kinds of structural landmarks are typically spatially extended with rather arbitrary shape. In contrast to that, points of interest (POIs) are easier to direct to (as they are point-like entities). However, we explicitly exclude POIs as references in the GEZ: although in some cases POIs are also strong global landmarks (e.g., the Eiffel tower in Paris), the majority do not qualify as global direction indicators (a gas station, a branch of fast food restaurant, or a shop). They are only relevant in the SLZ, to enable the better determination of the real location.

Preprocessing of entities.

Before selecting suitable entities, a definition of which entities make up good references in a dataset is needed. For this purpose we defined a pragmatic hierarchy of entities that we felt is suitable for a large number of urban environments. This hierarchy is given by *rivers*, then *parks*, and then *water bodies*. For each candidate entity the bounding box and a reference point (balance point of the bounding box) are computed. This reference point is crucial to address the entity in the selection phase.

Selection of entities.

For each of the four direction sectors (front, back, left, right) for the given query location all candidates are analyzed regarding their suitability as references for global orientation. Each reference candidate entity $r_i \in R$ possesses a number of quantifiable properties $p_1 ... p_n$ influencing its overall quality/usability in this context. This leads to a weight-based model for candidate selection: for each property p_i we define a quantification function $0 \leq f_i \leq 1$. We can now calculate the overall quality Q of an entity e as follows (see Algorithm 2), steps 5, 6, 9, 10):

$$Q(e) = \prod_{i=1..n} f_i(p_i(e)) \tag{2}$$

In the implementation of the YAH^x maps, we use the following sets of properties and quantification functions illustrated in the functions 3, 5, 6, and 4.

$$f_{dist}(d) = \begin{cases} \frac{r'}{d}, & d \geq r' \\ 0, & d < r' \end{cases} \tag{3}$$

Function 3 rates entities according to their distance d of their reference point to the center of the SLZ. This function guarantees the selection of entities which are meaningful in a local context: when two entities have similar properties, the closer entity is selected. To enable the integration of global references, that define a relevant part context-in-detail component of YAH^x maps, it is necessary to exclude all entities inside the SLZ radius r' from the list of candidates to guarantee a consistent reference model. Otherwise we would point to references already included in the view.

$$f_{size}(A) = \begin{cases} 1, & A \geq A_{max} \\ \frac{A}{A_{max}}, & A < A_{max} \end{cases} \tag{4}$$

Function 4 rates entities according to the size of their area A, assuming a correlation between the size of a entity and its prominence. An upper limit A_{max} is introduced to control the overall quality; it is used to regulate the behavior of the reference selection process: a small A_{max} increases the effects of the distance and angle quantification function, while a big value for A_{max} leads to a preference for big, usually natural features such as forests, rivers, or coastal lines.

$$f_{angle}(\alpha) = \begin{cases} cos(2\alpha), & |\alpha| \leq 45° \\ 0, & |\alpha| > 45° \end{cases} \tag{5}$$

Function 5 rates entities according to their angle α between a reference point and the cardinal direction axis (cardinal directions are relative to the current orientation of the user, see steps 7-9 in Algorithm 2). The angle between the entity reference point and the cardinal direction axis defines the quality of the direction concept: ideally the reference direction is aligned to the cardinal direction axis, as this defines a clear frame of reference. Figure 2 illustrates the concept of distance and angularity: in the right sector reference b is selected as it is closer and has less deviation from the ideal direction axis (see also Figure 4). A pure hierarchical approach would select the river (c, d).

$$f_{type}(T) = \begin{cases} 1.0, & T = "river" \\ 0.8, & T = "park/forest" \\ 0.5, & T = "water" \end{cases} \tag{6}$$

Function 6 rates the entity according to the hierarchy we implemented in the generation process. Although, there exist counter-examples (e.g., Venice in Italy), rivers are usually strong global landmarks for cities. The same accounts for large parks, and large water bodies such as lakes. Those references are usually well-known to both, familiar and unfamiliar users as they are easily recognizable on maps and are often used as references in spatial communication.

4.5 Fast Interaction with Adaptive Zooming

A solution to the self-localization problem does not just imply a specialized representation, but also entails the development of a supporting interaction primitive. It is likely that users will not always recognize the offered global references, either they simply do not know them, or the selection process picked a landmark a person would not use. This is a general problem of automation of such processes: Although in the general case good results can be expected, in the particular case such approach can fail due to the missing semantic background knowledge.

In order to allow for requests for more information on unrecognized references, a method developed from [19] is suggested. Robbins *et al.* propose a zoom function based on discrete, recursive grid zones mapped to the keyboard of a mobile phone: each number represents a grid cell of the map on the display; by pressing a number, the corresponding area of the map is enlarged to fit the screen. However, this intuitive zoom function is not goal-directed, i.e., cannot guarantee relevant information. A modification, however, matches the specific requirements of YAH^x maps: a mapping between the keys of a mobile device and the global references of the GEZ. The key '2' refers to the reference(s) of the back-sector, '9' to the front-sector, '4' to left, and '6' to right. Whenever one of these keys is pressed, the zoom is adjusted such that the SLZ, the NCZ, *and* the selected reference can be seen on the screen. In addition to that, when key '5' is pressed, the zoom is adjusted such that *all* references can be seen together on the screen. If '5' is pressed twice, the original YAH^x map is shown again. Figure 4 illustrates this concept. Although we implemented this concept for keys, it can be straightforwardly implemented for touchscreens as well: e.g., the zoom could be adjusted to the respective reference by pointing on it.

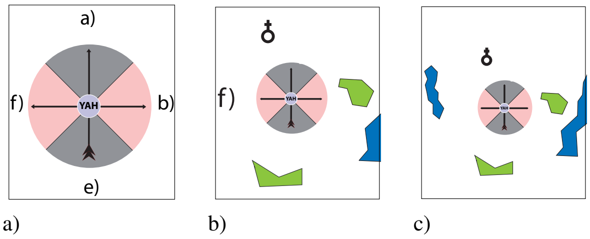


Figure 4: Reference-adaptive zooming. (a) The YAH^x map for Figure 2: the selected references are labeled on the corresponding sides of the screen. (b) When the key '6' is pressed, the zoom function adapts to include feature b. (c) When key '5' is pressed, the zoom adapts to include all features referred to in (a).

4.6 The YAH^x Map Generation Process

Concluding, the YAH^x map creation process consists of three different tasks as presented in Algorithm 3: street network simplification, global reference selection for all egocentric cardinal direction sectors, and the final visualization of the map in relation to the users trajectory. Based on the user's trajectory, we compute the position p and the current orientation vector v (steps 1-3) as input parameters for Algorithm 1 (step 4). A given list of entities eligible for the selection of one global reference for a sector is then the basis for Algorithm 2 (steps 5-8). The visualization considers the design principles described in 4.1 and 4.2 (steps 9-11), resulting in an output as illustrated in 5.

4.7 Example

Figures 5a) and b) show an example for the YAH^x maps used in the experiment described in Section 5. Figure 5a) shows the YAH^x view as initially presented, based on the map-matched trajectory; the reference entities in the four cardinal directions (front, back, left, right) are selected and addressed by their labels. The

Algorithm 3:
VISUALIZE-YAH^x $(G, R, trajectory, r, t)$

Input : A street-network graph G, a list R of candidates for orientation references, $trajectory$ an ordered set of coordinates representing the historical movement of the user. r is the radius of the *SLZ*, taking into account the positioning uncertainty. t is an in-betweenness threshold and has to be exceeded by a street outside of the *SLZ* such that it is included in the *NCZ*.

Output : A visualization of the YAH^{x}Map (e.g. a canvas filled with graphical elements).

$p \leftarrow$ position of last trajectory point p_n
$p' \leftarrow$ position of second-to-last trajectory point p_{n-1}
$v \leftarrow$ vector from p' to p
$G' \leftarrow$ `COMPUTE-STREET-NETWORK` (G, p, r, t)
$refFront \leftarrow$ `COMPUTE-REFERENCE` $(R, p, v, FRONT)$
$refLeft \leftarrow$ `COMPUTE-REFERENCE` $(R, p, v, LEFT)$
$refRight \leftarrow$ `COMPUTE-REFERENCE` $(R, p, v, RIGHT)$
$refBack \leftarrow$ `COMPUTE-REFERENCE` $(R, p, v, BACK)$
$orientation \leftarrow$ compute the angle of v with the fixed axis of the reference system.
$visualization \leftarrow$ visualize the street network G' with center in p, rotated by $-orientation$, zoom to include all of the *SLZ* with radius r in the viewport.
$visualization \leftarrow$ label cardinal directions with names of $refFront, refLeft, refRight, refBack$ accordingly.
return $visualization$

'front' direction is orientated towards the top of the display. The chosen zoom level allows the entire SLZ (expanded to radius r') to be displayed at once. Figure 5b) demonstrates the adaptive zoom for global orientation: the display zoom level adapts to the most distant reference entity to allow for an easy overview. Outside SLZ the street network is simplified and reduced to the most important streets (based on in-betweenness). Figures 5c) and d) show the same locations as displayed in the conventional maps. For better readability the street labels are disabled in all figures (see Figure 6 for a map part with displayed street labels).

Figure 5: An example for the maps used in the experiment. a) and b) are YAH^x maps used the experiment under map condition B_1; c) and d) are the corresponding conventional maps of condition B_2 (see Section 5.1). a) shows the initial view of the location to be identified (SLZ and NCZ). b) shows the reference-adaptive zoom with the strongly simplified street network around the SLZ, which is depicted in a). c) is the conventional map of the same environment as in a) but without the reference information. d) shows the complete underlying data including the complete street network from which the YAH^x was computed.

5. EXPERIMENT AND RESULTS

To evaluate this approach to YAH^x maps, a user study with 10 participants was made (6 male, 4 female, mean age 31.2). Participants had diverse professional backgrounds (computer science students, biologists, law students, psychologists).

5.1 Design

Successful and measurable self-localization with respect to a virtual or real location consists of two parts: the accurate identification of the location on a representation (the map) and the correct interpretation of the heading (orientation), i.e. how one is oriented within the environment. To test these variables, participants of the study were presented three different maps:

Map A, a north-up oriented reference map, was presented on a large 24” screen and used by all participants in both groups. This map was a web map well-known and frequently used by all participants (GoogleMaps [5]). The purpose of this map was the initial exploration and the indication of the correct position and orientation as a result from the self-localization task. The self-localization itself task was performed with the maps B_1, B_2 as described below.

Map B_1, the YAH^x map was shown on a 13” screen, but in the size and resolution of a current typical smart phone (480×320 pixels). B_1 offered the full range of cognitively motivated generation (three geographic zones, egocentric alignment), reference selection, and interaction (reference adaptive zooming) possibilities,

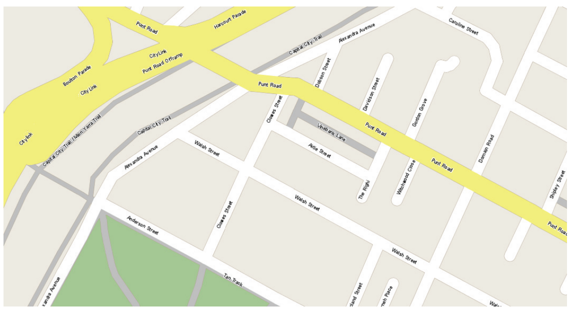


Figure 6: Example of the cartographic style of the maps used in the experiment. In the experiment the street labeling was turned on, in contrast to the examples of Figure 5.

as described in previous sections. Figures 5 a) and b) show an example YAH^x map from Melbourne as used in the experiment. In the experiment all labeling was displayed (see Figure 6).

Map B_2, the conventional mobile map, was used in the control group, i.e. this map did *not* have the described features of the YAH^x maps. However, the map was identical in the cartographic styles as well as in the behavior in the common functionality (discrete stepwise zooming and panning). Additionally and exactly as the YAH^x map, B_2 was egocentrically aligned; the reason for using this alignment is to avoid a bias effect due to the identical orientation of the reference map A and the maps used in the self-localization task. The same orientation would allow to just match structures of the environment (e.g. the street network in combination with salient features) without aware examination and reasoning about spatial configurations. Just as B_1, this map (B_2) was also shown on a 13" screen, but in the size and resolution of a current typical smart phone (480×320 pixels). Figures 5 c) and d) show an example conventional map from Melbourne as used in the experiment. In the experiment all labeling was displayed (see Figure 6).

The participants were randomly split into two groups: five participants had the combination B_1 and A (YAH^x and north-up reference map), five participants had the combination B_2 and A (conventional egocentric mobile map and north-up reference map). The 10 participants altogether performed 90 self-localization tasks (45 YAH^x localizations and 45 conventional localizations).

5.2 Task

Each participant had to self-localize oneself on 9 mobile maps of three cities (Bremen in Germany, Melbourne in Australia, and Vienna in Austria), i.e. three maps for each city. All 9 locations where identical across all participants and in both conditions (B_1, B_2). In a questionnaire beforehand of the study, the participants self-reported their familiarity with the three cities (0: unfamiliar, 10: very familiar). All participants have been familiar with Bremen (mean 6.5), unfamiliar with Melbourne (mean 0), and unfamiliar with Vienna (mean 0.4; only one participant reported a slight familiarity of 4). Additionally the participants were asked whether they had experience using maps on mobile devices. Only 1 of the 10 participants regularly used mobile maps, but the experience had no significant advantage in the experiment.

5.3 Procedure

As explained above, a commonly accepted measure for successful (virtual or real) self-localization is the identification of the correct location on a map and the accurate indication of the orientation. In a nutshell, this was the task the participants had to perform: learning an environment with map A, being positioned at a virtual location in either map B_1 (YAH^x condition) or B_2 (conventional condition), and finally localizing themselves (accurate localization and orienting) on A without seeing B_1, B_2 at the same time. A is a fundamentally different map (cartographic style, north up vs. egocentric alignment, interaction) than B_1, B_2. This fact is important as it forces the participants to recall the location by means of complex configurations from memory and perform costly cognitive processes (like mental rotations of spatial entities) without direct comparison of the maps. The accuracy of the mental effort of this task reflects the efficiency of the offered representation. In addition to the two basic parameters (accurate localization and orienting), we further measured the time and the number of interactions required by the participants to arrive at the self-localization. Prior to the experiment, all participants were informed about the self-localization task they would have to perform, and the involved time constraints. They were introduced to the map styles and were allowed as much time as they needed to learn the interaction with our system. Both groups (B_1, B_2) were instructed with the basic interaction possibilities (zooming in and out, panning to four sides with the arrow keys). The YAH^x group (B_1) was further instructed with the interpretation of the references of the GEZ and the reference-adaptive zoom functionality. The conductor was present through all phases of the experiment. After the participants of the YAH^x group completed all 9 self-localization tasks, we asked them if they liked the concept of the GEZ references and the interaction with the reference-adaptive zoom, and how they used the references to localize themselves in A. Additionally we asked them if they recognized that the street network was not displayed in full detail. In more detail the experiment procedure was this:

In the first step the participants had 2 minutes to learn the layout of those cities they had no experience with (Melbourne and Vienna) with map A on the large screen. They were pointed to the potential area of the self-localization tasks and instructed to try to gather as much of the information as possible they thought would help them afterwards to localize themselves reliably. After the 2 minutes, the screen was turned off.

In the second step depending on the group they were assigned to, the participants were presented either a YAH^x map (B_1) or the conventional map B_2 on the smaller screen. The participants had up to 5 minutes to perform as much interaction (YAH^x : zooming, panning, reference adaptive zooming; conventional map: zooming, panning) with the respective map until they indicated that they could successfully localize themselves on A. During this task, every single interaction with the map as well as the time required until the indication of self-localization was recorded.

In the third step the small screen was turned off, and the screen with A was turned on again. Now only using map A, the participants had now 2 minutes to identify the assumed correct location and orientation as previously displayed via the maps B_1, B_2 in step two. If they were not able to identify the location within the given time, they had 5 seconds to determine an approximate position on the map with the orientation they thought would be the correct one. Each indication of location and orientation was recorded and the deviation from the location on the maps of B_1 or B_2 was computed. The deviation between real and indicated location was rounded to 10 meters preciseness, the deviation in angle was discretized in 10° steps. We also recorded the required time to identify the location.

5.4 Results

Our results clearly show that YAH^x maps outperform the conventional mobile maps in every analyzed aspect (accuracy of positioning and orientation, number of required interactions, speed of self-localization), or show equal performance.

5.4.1 Positioning and Orientation

For accurate positioning it is necessary to analyze the deviation from the correct position and the correct orientation in B_1 or B_2 with respect to the indicated location and orientation in A. Table 1 shows clear evidence that YAH^x maps support more accurate positioning for both parameters.

5.4.2 Interaction and Self-Localization Time

Also orientation, the second subtask of self-localization, shows better performance when YAH^x maps are used. Figure 8 shows that the participants with YAH^x maps only required 43%-34% of the interaction. This is an important property, as especially the interaction with information on small, mobile devices is known to be frustrating if it is not effective. Additionally, the self-localization time, i.e., the time required to identify the location with B_1 (the

	Melbourne		Bremen		Vienna	
	YAH^x	conv.	YAH^x	conv.	YAH^x	conv.
O	9	49	8	13	8	41
P	562	461	0	26	246	320

Table 1: Positioning and Orientation Accuracy: Both, the mean accuracy of positioning (P) and orientation (O) across all participants and maps for each condition (YAH^x and conventional, denoted as 'conv.') are expressed as the deviation from the correct position/orientation. The accuracy of P is denoted in meters, O in angular degrees. The smaller the numbers, the better the performance; the ideal performance is 0, thus no deviation at all. All results are rounded.

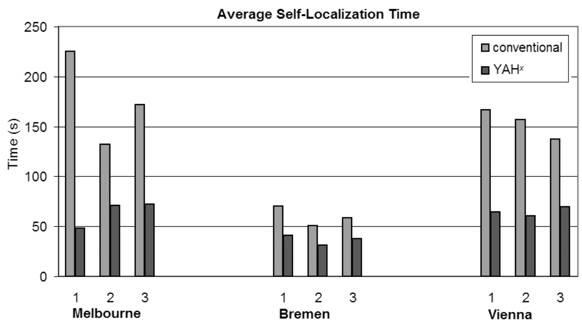


Figure 7: Self-localization times. The mean time required to identify the location on B_1, B_2 in seconds.

YAH^x map) is only 61%-36% of the self-localization time required with B_1 (conventional map), (see Figure 7). And finally, the identification of the correct location on A, thus the confirmation of the correct interpretation of B_1 or B_2 only required 63%-46% of the time (Figure 9) compared to reading the conventional mobile map without the YAH^x design and interaction principles. YAH^x maps seem to be especially effective in unfamiliar environments, the scenario we addressed in our initial motivation for the development of YAH^x maps. But even in the familiar condition they are clearly faster and more precise in all respects.

All participants of the YAH^x condition stressed that they liked the concept of the references and the selection of them. All stated

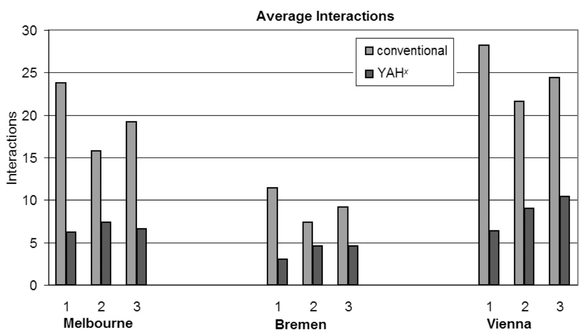


Figure 8: Numbers of interactions required. The mean interaction steps required to identify the location on B_1, B_2.

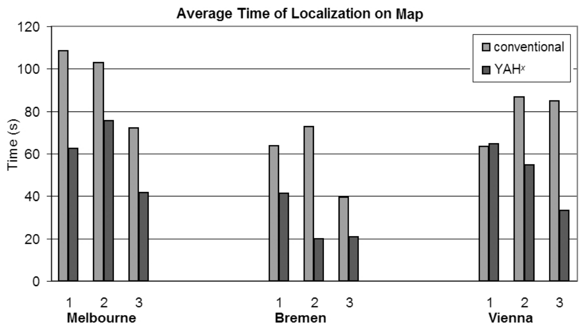


Figure 9: Times to orient on the reference map. The mean time required to point to the location presented on B_1, B_2 on the reference map A in seconds.

that it helped them to identify the location and to determine the correct orientation. All participants made heavy use of the reference-adaptive zooming. The usual self-localization pattern was to zoom-out to see all selected references, and to zoom-in again to see the initial view. This combination was usually repeated twice until the participants seemed to identify the area of the location. Afterwards they typically zoomed-out one or two steps, until they recognized a distinct layout pattern (combination of major streets, natural features) that further narrowed the target area. After completing this pattern, they indicated that they identified the location and tried to point to it on the map. Only in 2 of 45 cases participants chose to use zoom to a distinct reference.

6. DISCUSSION

The experiment clearly demonstrated that the introduction of global references within a local context, thus the integration of information on different levels of granularities, has an enormous effect on the performance to identify the local view within its embedding environment. The offered corresponding interaction by means of the reference-adaptive zoom function clearly minimized the required number of interactions and helped the participants to understand their location within a global context. However, although the adaptive zoom was anticipated by all participants, they only used the function to show all references at once. Complementary to this function, they developed the strategy to determine the correct partition of space around the location by zooming out as far as necessary to have a configuration that is unique and recognizable in the larger spatial context. The participants reported that they were looking for major streets and combinations of major streets with natural features (such as parks or water bodies). As this heuristic was observable across all participants in the YAH^x condition, this strategy could also be supported by a matching interaction primitive: a zoom adaptation to a unique structural configuration on a slightly larger scale than the initial YAH^x view.

Although all participants explicitly stated that they like the global references and the reference-adaptive zoom, they also stated that especially the integration of major public transportation hubs (such as railway and underground stations) would additionally improve the recognition of the correct location.

An interesting finding of our study was that only one participant recognized the truncation of the street network by means of the in-betweenness measure. The localization was not affected by reducing the detailedness of the street network, although the difference is visually significant (compare Figures 5 b) and d)). Presumably (although not explicitly tested) the reduced complexity of the map (especially on larger scales) supported the cognitive processing of the information and helped to focus on the relevant structural information.

7. CONCLUSIONS AND FUTURE WORK

In unfamiliar environments, self-localization is an important task. Although it is now possible to ubiquitously position ourselves on a map (e.g., by means of GPS), this does not automatically imply the understanding of the location within the real world such that the own location can be interpreted with respect to the embedding environment. Mobile devices used for GPS-based positioning, have small screens, which are known to be problematic in visualizing geographic information. Providing the information for local and global orientation requires either a large display or a more intelligent approach to visualization. This paper develops such an approach, based on cognitive principles.

The communication of the environment surrounding the user ideally should reflect the orientation of the user, i.e., it is purposeful to generate an egocentric perspective to address the environment. Inspired by the design principles of static YAH maps, we presented our approach to automatically generate situated, embodied and ubiquitous YAH maps (YAH^x maps). These maps describe the environment from an egocentric perspective and on different levels of granularity and selectivity. We defined three zones, for self-localization, for linking to the surrounding street network, and for the identification of the relation to global references of the environment. Additionally we offered a reference-adaptive zoom functionality to directly address the selected references intuitively and to adapt the scale of the zoom respectively.

In a self-localization study we evaluated the performance of the YAH^x maps and demonstrated their significant advantages over conventional approaches for location communication: our participants were able to localize themselves faster and more accurately. The offered representation and the corresponding interaction were highly appreciated by all participants and rated as a great support to identify the location in context.

In future work, we will investigate on further interaction primitives, such as the adaptation of the zoom level towards the first significant configuration, to shortcut the interaction heuristic observed during the experiment. Also a direct comparison with variable-scale maps or variable-focus maps is of interest. Existing methods for landmark identification and ranking can be considered to automate the input in the presented algorithms.

Acknowledgments

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10 Conclusions and Outlook

In this thesis, we developed a theory for map-based, context-specific wayfinding assistance tailored for mobile devices. As mobile devices are not suited to reproduce traditional maps, their usage requires the reconsideration of maps as supporting tools. Maps on mobile devices have to be smaller and communicate the relevant information more efficiently.

The approach we take in this thesis is to tailor maps to the context of the wayfinding situation. By analyzing all involved constituents of the wayfinding process we decided to align the requirements of wayfinding support with the spatial context model $TEAR$, introduced in section 1.3.3. This model emphasizes the role of task, environment, and agent for map based support. The clarification of what task has to be supported in which environment for which user helps to generate optimal assistance.

In the following sections we will discuss how this work meets the thesis and how it answers the research questions formulated in section 1.4. We will discuss the respective results along the constituents of the $TEAR$ model.

10.1 Task-Specific Results

We showed that wayfinding is not a coherent process, but consists of recurring tasks. These tasks reflect basic spatial queries and are the basis for the task-specific part of the assistance. We identified route planning and inspection, localization, route following and cognitive mapping as wayfinding primitives.

These tasks supported in manifold ways. In the theory of μMaps, introduced in chapters 1, 3, 5, and 7, we developed concepts for all wayfinding tasks. μMaps can be generated for the planning and inspection phase of a route as well as for in-situ navigation. μMaps inherently contribute to cognitive mapping as they are build upon previous spatial knowledge. In chapter 8, we developed a dedicated approach for gathering survey knowledge with Route Aware Maps. In chapter 9 we described a solution for rapid and robust self-localization by means of YAH^x maps.

YAH^x maps are in particular an answer to the question for support of spatial tasks. YAH^x maps are dedicated to support the self-localization task. The query for assistance can arise from an isolated situation, for example, if a wayfinder is lost in an unfamiliar environment. The need for assistance during self-localization can also be a part of a superordinate wayfinding process, for example when a wayfinder has to identify a decision point of the route. In chapter 9, we demonstrated how a rigorous analysis of the requirements of an isolated wayfinding task is the basis for efficient assistance. The task-specifics of the developed assistance are also part of the answer to the question for tailoring assistance to small devices. The more we focus on the isolated task, the better we know about the required information to solve it. YAH^x maps are the best answer how concentrating on relevant information enables us to tailor assistance towards mobile devices.

10.2 Environment-Specific Results

The environment has great influence on the information that needs to be presented to make wayfinding assistance understandable. In chapters 8 and 9 we described how the spatial properties of the environment can be used to clarify routes and locations within it. According to the task, we selected references on multiple granularities of space and used them as crucial communication units to enable the wayfinder to understand a given situation. In chapter 4, we detailed how environmental features can be utilized to support not only the user, but also the assistance system. We used street network information to represent and compress trajectories to prepare them for the integration of assistance.

10.3 Agent-Specific Results

The wayfinder, as the recipient of the assistance, offers additional possibilities to optimize wayfinding assistance. When wayfinders are partially familiar with the environment, assistance only has to point to the yet unknown parts of the environment and how it relates to known parts. The theory of μMaps found in chapters 1, 2, 5, 6, and 7, is a comprehensive approach to tailor maps towards the individual prior knowledge of users.

μMaps are the answer to the question for individually meaningful wayfinding assistance. In this branch of the work, we demonstrated how the knowledge about a user's prior knowledge is crucial to identify the minimally required set of information to generate meaningful assistance. To be able to generate personally meaningful assistance, the system has to analyze the spatial behavior of users. We developed approaches to identify and represent personally meaningful places from positioning sensors. In addition to the input data for personalized assistance, we studied how a system has to communicate this very individual data. The combination of individual spatial profiling, communication practices and cartographic representations results in individually meaningful assistance as proposed in this work.

10.4 Representation-Specific Results

The main part of the thesis is dedicated to the development of context-specific maps as wayfinding assistance on mobile devices. In chapters 3, 5, 7 we developed the theory of μMaps. These maps consider the task, the environment, but especially the knowledge of the user to communicate routes efficiently. For unfamiliar environments, we developed Route Aware Maps for route planning and inspection as found in chapter 8, as well as YAH^x maps for self-localization as described in chapter 9.

The consideration of tasks-specifics and agent-specifics contributes to the development of efficient support for an isolated task and the individual user. However, only when this specific knowledge is applied in an externalization, we can generate wayfinding assistance. In this work we demonstrated how Route Aware Maps, μMaps and YAH^x maps answer the question for qualified support for mobile devices.

10.5 Future Directions

This work concentrates on context-specific wayfinding assistance. Wayfinding is a highly dynamic process, and the more we tailor assistance towards isolated context instantiations, the more it has to reflect and cope with the dynamics posed by wayfinding itself.

With the exception of chapter 9, the work introduced in this thesis is rather static. This affects several aspects of the process from querying assistance, manipulation of entities in the representation, expression of request for different or modified data, to the specification of queries by interacting with the map.

Users want and need to interact with the map in different ways: searching for meaningful features, expressing queries in easy ways, or applying gestures to modify the scale, granularity or result visualized by a map. Intuitive interaction primitives are an important facet to successfully compete with the easiness of navigation systems: we will have to offer the possibility to express complex queries with no effort. In chapter 9 we demonstrated how useful carefully developed interaction methods are. Users are able to interact with the map in a goal driven way, which drastically reduces the amount of time and number of interactions while improving the performance.

This branch of future research will have to cope with the identification of user needs for a specific form of assistance. For instance, when a user does not recognize a place integrated in a μMap, the system is confronted with the requirement to offer a suitable alternative reference. However, the design of the corresponding interaction primitive has to be clear, intuitive and goal-driven. As the interaction is currently moving more and more towards touch and multi-touch technologies, we can eventually borrow established semantics from other application contexts. An example is the wiping of elements to proceed to the subsequent one. However, as we are dealing with complex spatial information and not a set of photos we want to browse through, the exchange of an place in a μMap will usually effect the configuration of the entities of the map itself.

In such a case, the alteration of the map could result in a globally different route and consequently a different map. In order to keep the user in the context of the current map, the alteration should ideally only change local information. This requires the consideration of two branches of future work: the first are partially updatable data models and algorithms working on them, the second branch is related to the conceptual cognitive aspect of dynamic maps. In order to keep the dynamic map understandable we require the map to be conceptually stable. We can achieve this stability by means of stable local and global frames of references as introduced in chapter 9. In this work we defined and selected a frame of reference for a single location and by utilizing the trajectory of the user as an additional source of information.

In the same way users do not want to interact intensively with applications to receive the best information, they will not be interested in finding out about the proper form of assistance for the task or context at hand. The assistants have to be sensitive to the relevant constituents and infer the best possible type of assistance based on ad-hoc context analysis. This also requires models for hybrid map usage employing the local and global frames of reference. These frames can serve as a mediator between different types of maps by keeping the elements, that the users can orient themselves with – constant over multiple maps and views.

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