From Visual Schematic to Tactile Schematic Maps

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Abstract. In the last years we could observe the migration of wayfinding assistance away from paper maps and stationary computers to small mobile devices. From the beginning it became clear, that a straightforward adaptation of geographic information on those devices will not work: the displays are too small to reproduce maps such that all necessary information can be shown at once. This requires the users to interact heavily with the device, a process which is not only bothersome but also has negative effects while interpreting the information. The fields of Small Display Cartography analyzed these problems, and especially the area of task specific maps—so called schematic maps—gained importance. Interestingly, wayfinding assistance for the visual impaired show similar characteristics: when assistance is given as and not in form of turn-by-turn instructions, we are faced with corresponding problems. The output medium is also constrained in size, the available space for reproducing the relevant information is limited as the tactile resolution of the users is naturally low. This paper surveys available approaches to information visualization developed in the fields of Small Display Cartography and shows how they can influence the development of tactile maps in the future.

1 Introduction

Finding one's way is a natural cognitive human activity and it is a basic requirement to get along in the spatial world. Wayfinding as one aspect of navigation includes goal-directed movement based on higher cognitive modules, as memory, planning and reasoning [24]. Humans manage to solve wayfinding tasks such as path following, path planing, and path search in different contexts such as indoor and outdoor spaces, urban and rural environments, real world spaces and virtual reality simulations. High wayfinding competence is grounded on different types of spatial knowledge, namely on landmark knowledge, on route knowledge as well as on survey knowledge [11]. Wayfinding competence can be characterized by the level of spatial reasoning (for example, making inferences about spatial location). Humans have learnt to solve wayfinding tasks either based on spatial familiarity (“unaided wayfinding”), which requires the existence of mental spatial knowledge of the respective area, or based on external assistance (“aided wayfinding”) such as signage, turn-by-turn instructions, route directions, or maps [36].

Maps, as some form of diagrammatic representations, have proven to be successful aids in wayfinding [23]. With maps, humans can gain some spatial knowledge about the world without being directly co-located at the location of interest. In such way, humans can learn about some geographical environment without being there. Maps can be brought into existence in a multitude of types and forms. Depending on the context maps are used in, i.e., the task they should support, the abilities of the map reader, the environment in that a map is going to be used etc. they might be small or huge, stationary or mobile, low-detailed or high-detailed, virtual or on paper, computer-generated or human-made, visual or tactile, to name but a few dimensions.

In the last years we could observe the migration of wayfinding assistance away from paper maps and stationary computers to virtual maps on small mobile devices. From the beginning it became clear, that a straightforward adaptation of geographic information on those devices will not work: the displays are too restricted in size and graphical resolution to reproduce maps such that all necessary information related to a route or a survey view can be shown at once.

1.1 Maps Supporting Spatial Reasoning Tasks

The explicit purpose of wayfinding is to arrive at a distinct place (point along a certain path) because of a reason (delivering something, seeing something, meeting somebody, going home, going to work, etc). The origin can be the location the wayfinder is at in the very moment or any other place in the future and the destination is a defined place a route can be planned to. To travel the route and finally arrive at the destination the wayfinder is implicitly required to acquire spatial knowledge and to develop a plan how to reach the destination—the route to navigate along. With route knowledge conveyed before or during the journey *path following* is possible; *path finding* is not necessary because the acquired route knowledge is sufficient[3]. In principle we can characterize basic wayfinding as a two step process (assuming that the origin and the destination is determined beforehand):

- *Representational Planning*: representational planning refers to the steps involved in the identification of places and the planning of routes between them. First of all, the appropriate *representation* covering the area of interest has to be identified. In the next step, the *places* of the route, such as the origin and the destination have to be identified within the representation. In the next step the actual route has to be identified and finally the selected route has to be extracted. Either just mentally, by memorizing the course and significant configurations along the route, or e.g. by means of sketch maps,

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[3] We use the taxonomy of wayfinding proposed by Wiener et al. [36] to differentiate between qualitatively different wayfinding tasks.

route directions, or annotations in the map. This point is crucial in planning: the better the extraction process, the better will be the conceptualization and understanding of the environment. Ideally, the extracted information helps the wayfinder to be as autonomous as possible during the wayfinding process.
- *Spatial Execution*: this stage refers to all processes related to the actual physical wayfinding process in the real environment. This requires a constant mental recall or revisiting of the representation communicating the information about the route. This continuous reassuring of the location is necessary to ensure the updating of the localization while the wayfinder is navigating and following the route. The expectations have to be matched against the situation, especially at landmarks and decision points.

The navigator might acquire the knowledge to be able to find a route and physically navigate it in different ways. The spatial knowledge might be communicated via different representational modalities [14], e.g. propositional means such as turn-by-turn directions or spatial means such as maps. Assistance with spatial means can rely on, at least, two different types of maps.

- *Route Maps*: Route maps only show the route with eventually sparse context information. But in contrast to route directions, the course and relative length of the route is visible (and does not only have to be inferred by means of adding distances and turns), and the extraction of actions is left to the wayfinders, forcing them to parse and understand the information correctly. Clearly, this form of representation is less selective than route directions, and fosters the acquisition of different and eventually richer information.
- *Survey Maps*: The most complex form of communicating a route is to highlight it in a embedding survey map. Survey maps communicate the spatial embedding of a route, thus spatial knowledge beyond the horizon of the route. A wayfinder is collaterally confronted with features like main roads, districts, lakes, rivers, parks, etc. located in vicinity of the route or decision points along the route. In addition to the extraction of the route and the transformation into actions, the wayfinder will learn how the route is embedded in the environment and what to expect roughly where.

1.2 The Role of Spatial Knowledge Acquisition

In the age of GPS assisted turn-by-turn directions, why should we deal with other forms of assistance? It has been shown that turn-by-turn outperform maps in terms of navigation success [25]. However, it was argued that technology focusing on conveying routes has no positive effects in acquiring spatial knowledge about the environment traveled [4, 25]. The more complex the information communicated by the assistance is, the richer could be the acquired knowledge. The better the understanding of the environment is, the better would be the orientation within it and the understanding of spatial relations between features. Finally, a good understanding of the environment will allow wayfinders to navigate it as free from assistance as possible.

2 Small Display Visual Maps and Schematization

Traditionally, geographic knowledge about the world is conveyed through conventional printed maps. Today, digital maps have conquered the mass market as part of navigation system and handheld appliances. These Small Display Visual Maps (SDVM) primarily convey route knowledge and can be found in systems for guided navigation, e.g. GPS-based guiding systems in cars or on mobile phones. The typical usage is in path following, i.e. to realize some predefined route along prominent landmarks in the geographic environment.

Maps are representations of geographic space and are always a result of a technically necessary simplification process. Due to the very limited bandwidth of the display in handheld devices the map can usually only display the most relevant features of the immediate surroundings at the current position. That is, the scale of the map is usually much smaller than the entities in the real environment are, and we have to simplify e.g. the geometries of depicted entities. A specific form of maps are so-called schematic maps. Schematic maps are task specific assistance and intended to support the solving of a specific (wayfinding) problem, such as self-localization, or route following. The idea behind schematic maps is to identify a minimal but adequate set of information and present it in a way such that mental processes and representations are supported. Schematization captures the abstraction pertinent in human perception and cognition of space in order to focus on the relevant information for a given task [6].

Schematic maps have great impact for the field of Small Display Cartography. In contrast to the rather traditional approach of digital mapping, namely reproducing the available geo-data in order to produce equivalents to survey paper maps, schematic maps inherently reduce the depicted information. This property qualifies schematic maps to play an important role in the development of maps for small mobile devices.

During the last years a number of schematic wayfinding maps have been developed. All of them follow unique schematization principles to communicate spatial knowledge efficiently for distinct conditions. The following survey presents some approaches with direct application in the mobile domain. We will further introduce to some concepts of the fields of Small Display Cartography to communicate geographic route information on small screens.

2.1 LineDrive

In [1] the authors introduce an activity based schematization 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. 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 schematized 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 [22] which requires significantly less display area if the route incorporates big parts with no required wayfinding activity.

2.2 Focus Maps

In [37] the authors introduce a form of schematization that improves 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 schematizing and fading out map features depending on their proximity to the route. 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 in [18] with the introduction of chorematic focus maps, which further improve map understanding. Junctions and turns of the route are represented by means of wayfinding choremes (see [17]), reflecting the prototypical mental representations of turns.

2.3 μMaps

In [29] the author introduces the principle of the so-called μMaps. These maps effectively compress the visualization of geographic data by tailoring maps to the individual prior spatial knowledge of an user. 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.

2.4 Route Aware Maps

In [31] the concept of Route Aware Maps (RAMs) is proposed. These maps consist of a main route and alternative routes from an origin to a destination. The alternative routes are communicated as alternative set of connections between both places. This set defines the spatial context in terms of the network it is embedded in. Those alternative routes serve as tool to design wayfinding assistance more robust with respect to navigation errors. In order to support the localization of the critical points on the route RAMs further place landmark and region information where they are plausible and available. RAMs additionally display perceivable (e.g. parks) and conceptual regions (e.g. districts) along the route to supported route following. With this information it is possible to navigate without additional assistance even if the route is lost after a navigational error.

2.5 YAH^{x}Maps

In [30] the authors developed the concept of YAH^{x}Maps, a schematic map that allows fast and reliable self-localization in unfamiliar environments. The self-localization task is supported on different levels: firstly by orienting the map with respect to the trajectory and not by current compass information, the environment is segmented into "the area one comes from" (as this is usually recognized) and the remaining part. Secondly, YAH^{x}Maps highlight the possible vista space by detailing this area and the main entities one orients within a street network. Thirdly, YAH^{x}Maps use a stable frame of reference with salient landmarks that are meaningful and allow reliable orientation on different levels of granularity, such as rivers or parks in an urban environment.

2.6 Halo and Wedges

The visualization of off-screen features is a main challenge in Small Display Cartography. While schematic maps try to visualize information on different levels of granularity, other approaches offer a visualization by pointing from a map-view of constant scale to off-screen locations. A prominent approach is the indication by means of arrows, circle segments [2], or wedges [13]. The latter methods are typically applied with no text labels, i.e., applicable only where features of the same type are to be visualized.

2.7 ZoneZoom

In [28] the author proposes a discrete recursive zoom functionality to access maps on constant scales. The map shown in the display is segmented into nine discrete regions and the nine numerical keys (1-9) are mapped to them. Whenever a key is pressed, the zoom enters the respective partition of the map at a higher scale. This view is again segmented into nine regions which can be accessed by the same functionality. The strength of this approach is the discrete and precise navigation within a map on different zoom scales. ZoneZoom allows fast access to details, however as it does not integrate a constant frame of reference across the different levels, this approach makes it hard to understand how parts of a route that are displayed on different segments and different levels relate to each other.

2.8 Summary

We have investigated some types of visual maps that were proposed for the usage with small display and that try to level certain disadvantages of that form of presentation. All of those approaches employ principles of schematization in distinct ways to communicate the relevant features while in the same time lower the cognitive burden for the user and make spatial reasoning (here, in the specific form of wayfinding) possible to avoid an unnecessarily cluttered, cognitively demanding and error-prone representation. The Table 1 shows an overview of the presented types of visual maps with a description of the schematization used and the given name of the schematization concepts.

Name	Schematization Description	Concept
LineDrive	Shorten route segments where no decision is necessary.	Shorten Segments
Focus Map	Fade out segments the more they are away from the route under consideration.	Adjust Distance
μMpas	Detail segments & regions that were not walked up to then, leave out contextual details of passed areas.	Consider Prior-Knowledge
Route Aware Maps	Show alternative routes and their contexts through decision points where following the main route might fail.	Show alternatives
YAH^{x}Maps	Detail segments & regions being seen next. Use a stable frame of reference with salient landmarks.	Consider Prior-Knowledge & Show Stable FoR
Halo & Wedges	Display off-screen landmarks at the edge of the map.	Show Stable FoR
ZoneZoom	Cut map into discrete pieces with defined relations to each other.	Provide Static Relations

Table 1. Overview of the concepts of schematization used in different types of visual schematic maps.

3 Non-Visual Maps

Maps can be brought into existence in different sensory channels (for example, visual maps, auditory maps, tactile maps) accustomed for differently enabled users. In the case of the non-visual domain tactile maps (to denote the represented area we call them Tactile Environment Maps (TEM)) have become an option to convey spatial knowledge to humans [26]. There are first prototypes of digital devices that are capable of presenting maps as dynamic tactile artifact, for example, the Hyperbraille [35]. In terms of availability and production cost, the only option for an individual, on-demand, fast and low-cost production of (static) TEMs seems to be the automatic construction and print-out with a tactile printer[4]. Printed TEMs are the result of such an automatic construction and print-out with an tactile embosser.

Due to the low resolution in the tactile modality, tactile maps cannot be populated as densely as visual ones. Theoretically, using larger maps in which the content was distributed over a larger surface could compensate for this. But the size of a tactile map is limited to the “regions that lie within easy reach of one person’s hands” [15, p. 92]. Consequently, schematization (similar to the process in visual maps) and distortions (differently to visual maps as perception is through the tactile sense) have to be introduced. Features in the map have be abstracted to the relevant ones by letting out non-meaningful details. Relevant

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[4] The tactile printer must be capable of processing line graphics—which many Braille printers cannot—e.g. the TIGER Emprint [9].

features (as single entities and as configuration) have to be distorted in such a way that they are easy to discriminate perceptually and easy to comprehend cognitively.

3.1 Acquisition of Spatial Knowledge with Tactile Maps

Due to the necessary abstraction, tactile maps are very sparsely populated with entities to ensure that the reader may distinguish every single one. Entities must have very different tactile characteristics to differentiate them, for example, in terms of pattern/texture, width, height etc. Overlapping or connected entities are often omitted to gain a clear separation and to avoid introducing ambiguities. Distortions of track networks can be used to emphasize certain concepts, for example, how streets intersect or connect. This could prevent misconception and subsequent problems in matching the remembered structure with the environment (e.g. when the navigator engages in a path following task).

As with visual maps there are potentially many types of tactile maps. For example, an adaption of the visual strip maps [22] is the tactile strip map [10]. Other types of maps, for example, the You-Are-Here Map maps [20] show a more holistic view of the environment and are meant to convey survey knowledge[5]. Survey knowledge is considered the most elaborate type of spatial knowledge as it can be used generically. In the context of this paper, we will consider tactile maps primarily as assistance for *unaided wayfinding*[6], i.e. to acquire survey knowledge before navigation to be able to use it for guiding exploration in some *informed search*. In the case of unaided wayfinding there is evidence that navigators' search behaviors and search strategies will be influenced by their pre-conceptualizations of the environment [3, 34].

Supporting the role of tactile maps, it was pointed out that they "have a clear advantage in facilitating the development of cognitive maps by providing a global perspective on the surrounding geography"[7] [32, p. 259]. By exploring tactile maps in map scale a person could acquire abstract survey knowledge of some area, that might be helpful for navigation in geographic scale. There is strong evidence that tactile maps are a promising aid to convey geographical knowledge to visually impaired persons [33, 5, 8, 19, 21].

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[5] According to [36], if survey knowledge is conveyed, *path planning* (i.e., route knowledge is not available and must be generated for a specific destination), *informed search* (i.e., landmark knowledge is not available and must be generated for a specific destination) or *cruising* (i.e., no other spatial knowledge available and no specific destination given) are possible when be in the depicted environment.

[6] In the context of this paper we will understand the term "unaided wayfinding" as being characterized by the absent of signage and navigation systems that support the re-evaluation of planning activities. Nevertheless, unaided wayfinding might take place with the help of prior spatial knowledge about the area.

[7] The exact nature of the representation is not of interest here. Different types have been proposed, for example, cognitive maps [16].

3.2 Transfer of Concepts from Small Display Visual Maps to Tactile Environment Maps

We have noticed that only limited content can be displayed in SDVMs because of the limited display size. The same is true in TEMs because of the limited resolution in the tactile modality. SDVMs have small rectangular graphical displays, approximately up to the size of a palm or whole hand, with a resolution of usually under 100dpi. TEMs are of a rather big size which is usually not smaller than an A4 sheet of paper. This makes it at least three times bigger than SDVMs. On the downside the resolution is much lower, about 20dpi in a typical tactile printer (with this resolution standard Braille can be embossed which is an indication that it is accustomed to the function of the human hand [15]). Consequently both types of displays do not differ that much in the total amount of basic structural entities (pixels and taxels, respectively) that can simultaneously be displayed.

Having found some structural similarities between SDVM and TEM that promise to the basis for a transfer of some schematization concepts, we will investigate the applicability of the identified concepts in the subsequent paragraphs.

Shorten Segments The schematization strategy to shorten route segments where no decision is necessary could make a lot of sense in tactile maps of various kind. The metric information is often lost in tactile maps anyway as the size of the entities in the map forces to impose a uneven scale over the map. When orientating oneself in the environment often metric information like absolute distances are not that crucial but enumeration are (for example, “the next intersection” or “at the). Therefore the schematization of the segments between two structural or object-like landmarks would be sensible in tactile maps.

Adjust to Distance To fade out segments depending on the distance from some route given would probably confuse the readers of tactile maps. With tactile perception there is no holistic view on the map. Readers but must concentrate on the local properties of the tactual entity and integrate them mentally. With survey maps it would be presumably hard to integrate different parts of the map and construct an survey if entities fade out. In general, the questions arises which parts of a survey map should fade which not. In studies that were part of the work reported in [12] we noticed that readers of tactile maps concentrated on the central part of the map, leaving out the periphery. This could be a hint on some kind of unconscious adjustment-to-distance behavior with the center of the map being the point of highest importance. But the reason for this behavior was unclear.

Consider Prior-Knowledge The concept to detail segments and regions that were not walked respectively passed by and to leave out contextual details of passed tracks and areas could be applicable in tactile maps as well. If the user is new to an environment than this principle has minor impact but if he already knows part of it then the resulting map can build on that knowledge by, for example, strongly abstracting the the known part and detailing the unknown more with landmarks etc. In maps for the preparation of an exploration (in contrast to walking the route assisted by a route map) prior knowledge could be used to customize the map. This could help to reduce clutter in the map and provide those details that the map reader does not know about. In contrast to leaving out details for already traveled areas in digital route maps, tactile survey maps have to serve for more general tasks. Thus leaving out one detail might just impair the ability of executing a certain task in the latter exploration.

Show Alternatives For route maps it might be advantageous to display the context of a given route by visualizing alternative routes through decision points where following the main route might fail. For tactile route maps this might be an option. The questions remains how to perceptually set the main route apart from the alternative. This is harder in the tactile domain than in the visual domain especially if the crossing of more than two routes are displayed. For tactile survey maps this concepts could be used to deemphasize the very prominent main tracks in a map by introducing side tracks as alternatives. The downside of such an approach is that the tactile maps would be more cluttered and harder to read.

Show Stable FoR The proposed usage of a stable frame of reference that builds upon salient, potentially off-screen landmarks is a concept that might be of a higher importance if considered for route maps where the orientation of the map changes often. But to embed a tactile map in the greater surrounding and to help the navigator to be aware of major salient landmarks with "global" meaning the idea to display hints at the frame of the map could be beneficial. Especially if more than one map is used and the relation maps come into play because they all have to be aligned mentally in the correct way and the matching of landmarks available in multiple maps could be helpful.

Provide Static Relations In the domain of tactile paper maps, the concept of cutting a map into discrete pieces and navigate in a discreet manner between them via static relations makes perfect sense as there is no such thing as dynamics and interaction like with digital maps. It has to be used to represent an environment that does not fit into one map. When cutting a big tactile map into pieces there probably should be some kind of alignment support, for example, by Showing Stable FoR or by providing a little overlap at the map frames. Dynamically changing scales as it can be observed in digital maps might be more problematic with tactile maps but should be investigated more closely.

4 Conclusion

We have already seen that there is no such thing as “the map” but that different types of maps are made for a different purposes, i.e., to help solving a certain class of spatial tasks. In the case of the Tactile Environment Maps and Small Display Visual Maps presented here, the former support learning about the structure of a spatial environment (i.e., focused on survey knowledge) and the latter are for the internalization of knowledge about specific routes (i.e., focused on route knowledge). The route knowledge learned from a SDVM is later used to solve tasks of path following that are know at the time of the exploration of the map. Thus it can be said that the knowledge acquisition behavior with SDVM is goal-orientated and can happen before or during traveling. In contrast to this, survey knowledge from a TEM is acquired without a specific path planing goal and before travel begins.

Nevertheless, we reason that some of the schematization concepts used in Small Display Visual Maps have the potential of being transfered to Tactile Environmental Maps. For static tactile maps the concept of *Providing Static Relations* is not a choice but a necessity as no dynamics are available. The concept to *Shorten Segments* where no activity is necessary could be mapped 1:1 to tactile maps as the knowledge obtained from such a map is qualitative and not metric anyway (in most cases). Considering *Prior Knowledge* might be a good idea as the map could be customized to the user’s prior knowledge, as it promises to free some space that can be occupied with information not known to the navigator. Showing a stable frame of reference could be very beneficial to the users of tactile maps because with such a stable FoR it would be possibly easier for the users to relate one view of an environment with the others.

Both, SDVM and TEM, are external spatial representations of the geographic world. As such, they are abstractions of the environment they depict, i.e. irrelevant details are omitted. To support human wayfinding task, qualitative aspect of spatial representation are more important than an geometrically exact image of the world [7]. They might not be topologically or geometrically correct[8]. Each abstraction is subject to some decisions that depend on the task to be solved and the user model employed. Constructions must always rely on what the user already knows about the environment, what he needs to know to solve the task, what features are of relevance and how to display the selected features. For example, the inclusion of sound and olfactory landmarks, inclinations etc. which are meaningful for visually impaired people could be beneficial in tactile maps.

The investigation of SVDM and TEMs for possible transfers of schematization principles has shown that there are multiple dimensions to be considered. First, there is the sensory dimension that was different here, i.e. visual perception vs. tactile perception. Second, there is the representational dimension that was same here, i.e. two spatial representations (if we had opted for route direc-

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[8] Correctness depends much on the metrics and evaluation used. For example, in the case of topology two inconclusive results may be obtained when using different calculi, e.g. RCC-8[27] and its simplified version RCC-5.

tions as propositional representations other conclusions might have been drawn). Third, there is the dimension of supported spatial task that was different here, i.e. route following vs. survey acquisition. If schematization concepts should be transfered from one type of map to the other we have to check how much the concepts relies on properties of these dimensions, if the goal type has the same properties and if not how the concepts could be reinterpreted and make some sense.

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