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

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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.

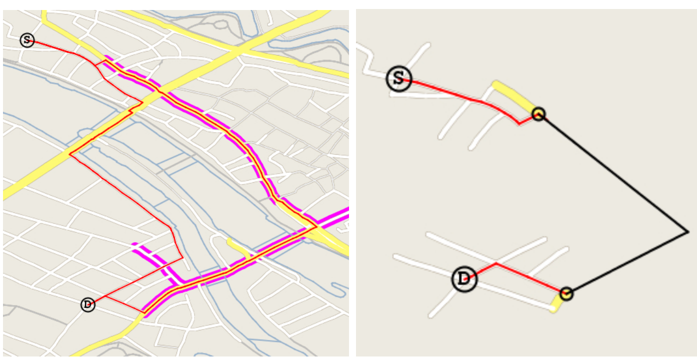
1.2 The Visual Compression of Geographic Information

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



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).

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 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.

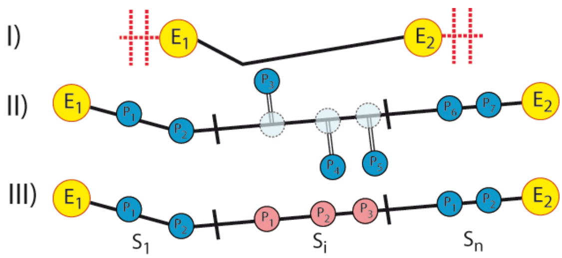


Fig. 2. Route segmenting and place selection: The black lines illustrate a familiar part of the route (red and black) with the entrance and exit points E_1, E_2, see illustration I. II shows only the familiar part with identified places: P_1, P_2, P_6, P_7 are located on the route, P_3, P_4, P_5 are 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.

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).

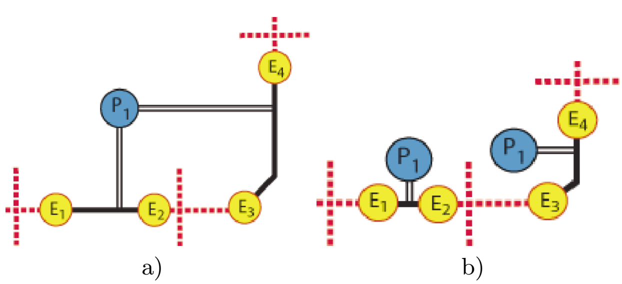


Fig. 3. Conflict due to the selection of the same remote place: the familiar parts of the route can have individual schematizations and minimizations, the pointers to the same place (see a)) can be conflicting and contradicting afterwards, see b)

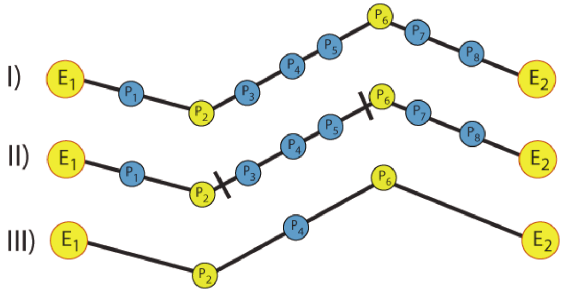


Fig. 4. The place selection process: I shows the initial situation withe the places P_2, P_6 at significant locations. II shows the segmentation of the route, and III the result of the selection process.

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:

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

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

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 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).

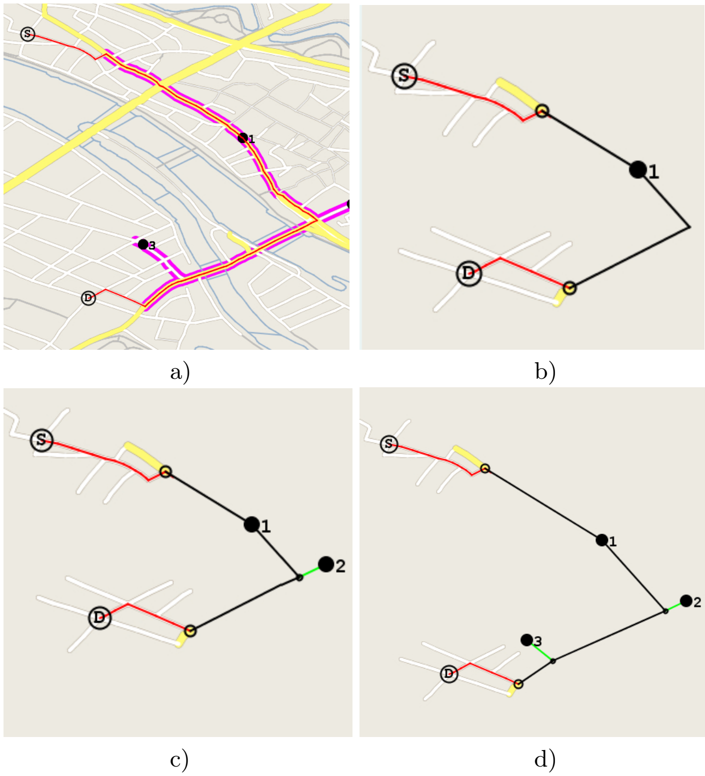


Fig. 5. Selecting places. a) The map of Figure 1 with the places 1, 2, 3 (bold black dots). Note the different schematization of the FP in b), c), d) due to the integration of places. b) the FP is only one single segment: place 1 is selected, as it is *on-route*. c) FP consists of two segments: place 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).

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.

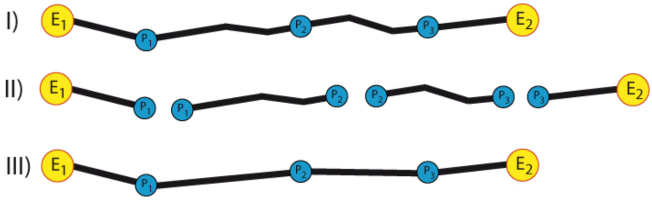


Fig. 6. Schematization with places as fixed points: illustration I shows the initial situation, II the segmentation with the places as start and endpoints of the segments, III the result of the schematization and compilation

Reference Frame Visualization for 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).

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.

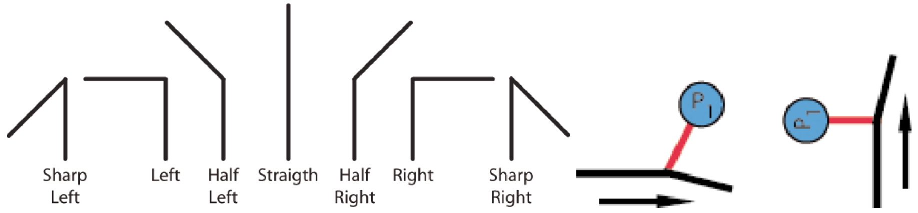


Fig. 7. The chorematization of places for the navigation perspective: a) depicts the set of wayfinding choremes. b) depicts a turn at a place within the FP (left is the initial configuration), on the right we see the navigation perspective of the intersection. The intersection is rotated in travel direction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

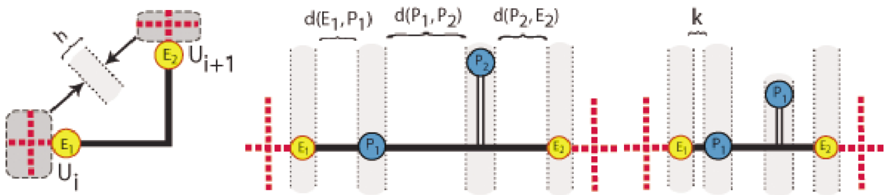


Fig. 8. Communication of local rendering constraints to the global minimization procedure: a) depicts the global minimization distance h. b) illustrates the minimization constraints of the visual elements of the FP, it is not possible to apply the global minimization factor to the FP. In c) we see the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

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.

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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