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.

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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

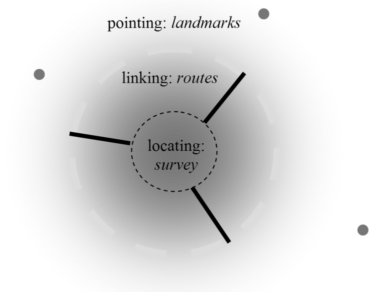

Figure 1: The three levels of detail in a visual You-Are-Here (YAH) presentation on a mobile display: survey information in the immediate neighborhood of a person, route information to selected landmarks in a larger neighborhood, and pointing to landmarks beyond that horizon.

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.

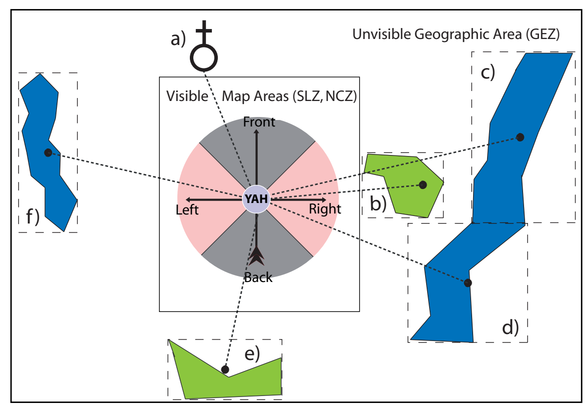

Figure 2: Egocentric embodiment: the surrounding environment is segmented in sectors for front, back, left, right. The details for the selection of the global references are described in Section 4.4.

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.

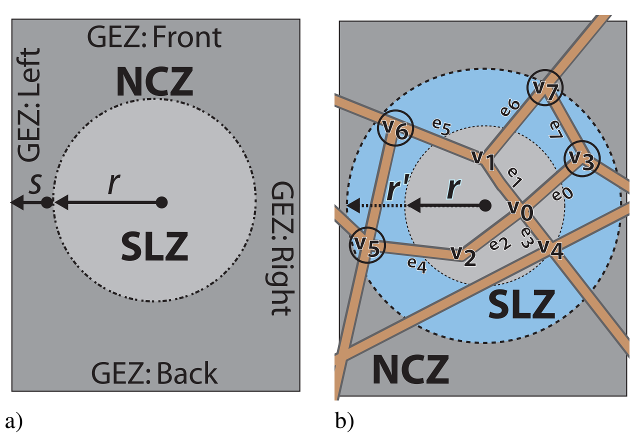

Figure 3: (a) Zones, and (b) the extension of the street network in NCZ.

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:

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

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 $p_1 \ldots p_n$ 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):

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

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.

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

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.

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

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.

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

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).

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

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

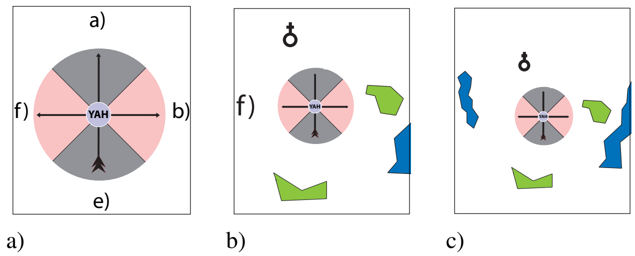

Figure 4: Reference-adaptive zooming. (a) The YAH^x map for Figure 2: the selected references are labeled on the corresponding sides of the screen. (b) When the key '6' is pressed, the zoom function adapts to include feature b. (c) When key '5' is pressed, the zoom adapts to include all features referred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

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.

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).

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 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.

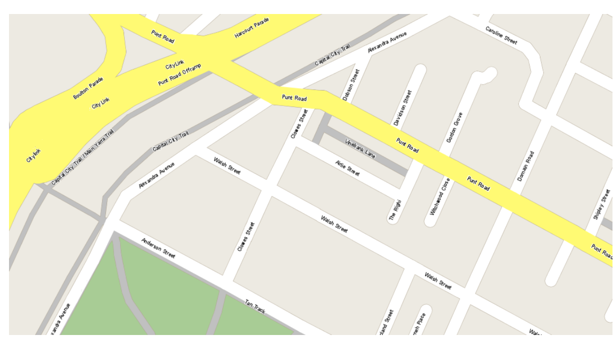

Figure 6: Example of the cartographic style of the maps used in the experiment. In the experiment the street labeling was turned on, in contrast to the examples of Figure 5.

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.

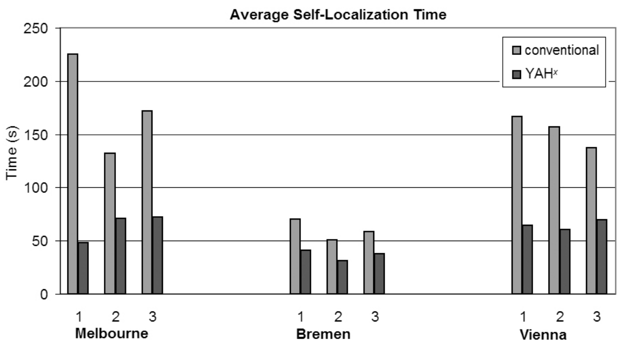

Figure 7: Self-localization times. The mean time required to identify the location on B_1, B_2 in seconds.

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

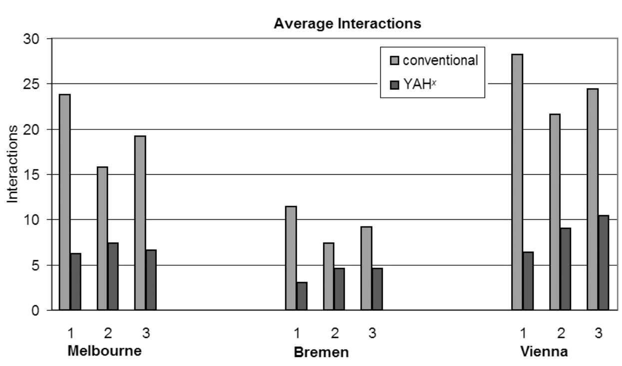

Figure 8: Numbers of interactions required. The mean interaction steps required to identify the location on B_1, B_2.

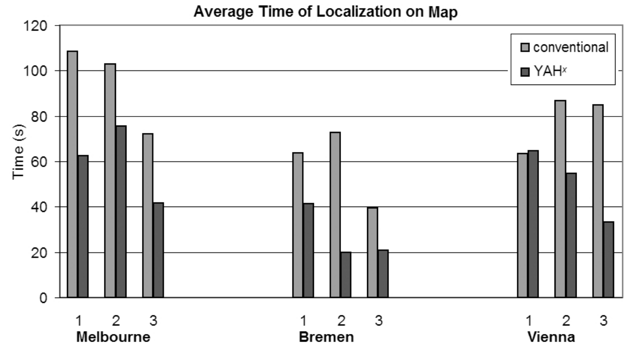

Figure 9: Times to orient on the reference map. The mean time required to point to the location presented on B_1, B_2 on the reference map A in seconds.

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-betweeness 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.

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