Visualizing Distant Objects on Mobile Phones: Choice of Resizable Icons

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ABSTRACT: Mobile phones have become so popular in navigation. Empirical studies, however, have implied several pitfalls of using these mobile systems. First of all, generated navigation guides with continuous routing information keep the users being mindless of the environment that impacts their acquisition of spatial knowledge. In addition, the small size of mobile screen causes the fragmentation of learned spatial knowledge. In order to enhance spatial orientation using mobile phones, designs attempt to display distant landmarks on screen as contextual cues to overcome those pitfalls. Some of these designs not only decrease the frequency of zooming but also contribute to users' spatial orientation by showing the direction to distant landmarks. Following the same direction, this study introduces an improved design that not only displays the direction but also the distance to distant landmarks by using size as an indicator of the distance. Considering human mind is not perfect at perceiving and convening accurate Euclidean information, the distance concept is represented by icons in different sizes. In particular, the authors design two kinds of mechanism, one of which is using icons at the ratio level that change in size continuously according to an established ratio and the actual distance between the user and a distant landmark. The other mechanism is using icons at ordinal level with three assigned sizes of icon based on a certain range of distance implying near, middle, and far. A designed user study was carried out to compare the efficiency of these types of mechanisms. Results show that ordinal icons are more effective than ratio icons in visualizing distances between distant landmarks. But users have challenges distinguishing distant landmarks from local landmarks regardless of the mechanism. A further step is needed to explore additional options of representing distance.

KEYWORDS: distant landmarks, edge icons, visualization, spatial orientation, mobile phones

Introduction

When a person is questing routes or locating him or herself in an unfamiliar environment, mobile phones are the most popular choice (Speake and Axon, 2012). Parush et al. (2007) suggested that the navigation systems with their displayed routing information keep users not aware of the environment. Researchers have emphasized the important roles of landmarks during the wayfinding process, suggesting landmarks as potential reference points to support users' spatial orientation (Michon and Denis, 2001; Raper et al., 2007; Waters and Winter, 2011). However, the small size of mobile screen inhibits the display of landmarks out of the view area, and the fragmentation of routing information impacts users' spatial knowledge as a result of frequently interacting with the mobile display for fear of disorientation (Schimid, 2008). To overcome these problems, studies have suggested that the visualization of distant landmarks (landmarks that out of the view and distant to the user's location) on mobile screen can be achieved by displaying abstract shapes or proxies at the border region of the screen, thus to further indicate the existence of distant landmarks to users without any manipulations on the screen (Burigat and Chittaro, 2011). For example, Baudisch and Rosenholtz (2003) used arc of circles called Halo while Gustafson et al. (2008) used part of triangle called Wedge to indicate distant locations (locations out of the mapped area). Through visualizing part of geometric shapes on the screen, users beware the existence of these off-screen locations. But both designs fail to signify what the partial geometric shapes on the screen represent (e.g. hospital or other spatial entities). Later Li et al. (2014) introduced a mechanism of displaying distant landmarks on the edge of screen that can distinguish local and distant landmarks, identify the type or function of each landmark by designing a unique shape for each of them, and support effective spatial orientation in terms of directions. This mechanism, however, did not consider the concept of distance in its design.

In short, the main purpose of these designs is to contribute to users' spatial knowledge by showing the direction to distant landmarks which serve as contextual cues indicating potential decision points as well as supporting cognitive mapping of a large-scale environment. This study introduces an improved design that embeds both concepts of direction and distance by using size as an indicator of distance from a user's location. Two kinds of mechanisms, based on the ratio and ordinal levels of measurement on the size of icons, are implemented and compared with regard to their efficiency of supporting understanding the distance and direction to distant landmarks.

Related work

When navigators quest in an unfamiliar environment using wayfinding systems, there is a trade-off between wayfinding performance and the acquisition of spatial knowledge (Li et al., 2014). Empirical studies have suggested that turn-by-turn navigation system offers users good wayfinding performance whereas distracts users from their knowledge acquisition (Parush et al., 2007). Instead, traditional paper maps keep users in the control role of acquiring survey knowledge but hinder their wayfinding performance (Münzer et al., 2012). One important reason that paper map outperforms turn-by-turn system is that the former has larger extent than the latter to allow users explore the necessary information for their wayfinding goals. When displaying map on mobile devices, other objects of interest outside the view area are hindered caused by the size of mobile screen. In order to overcome the problem, contextual cues are introduced (Burigat and Chittaro, 2011). Through displaying abstract shapes (Baudisch and Rosenholtz, 2003; Gustafson et al., 2008; Li et al., 2014) or proxies (Burigat and Chittaro, 2011; Irani et al., 2006; Zellweger et al., 2003) along the border of the screen, contextual cues can function as visual references to locations that are not actually mapped on-screen. Direction and distance are the two key concepts to indicate locations. Users are easily aware of the direction concept indicated by location of the cues. However, distance is less intuitive for users to comprehend because distance, as a quantitative concept, is difficult to transform as Euclidean information does not play an efficient role in human cognitive mapping (Tversky, 1992). Studies have suggested several approaches of encoding distance. For instance, The approach Halo (Baudisch and Rosenholtz, 2003) uses arc curvature while the approach Wedge (Gustafson et al., 2008) uses the attribute of isosceles triangle to indicate distance information. Other possible distance encoding approaches are introduced by Burigat et al. (2006) such as shape, color, length, size, line thickness of the edge proxies and labeled information.

With the increasing number of distant landmarks on screen, it results in crowding problem at the edge. For example, when two locations are close to each other, the proxies originated from two off-screen locations would overlap negatively affecting users to understand their representation. Some approaches have overcome the crowding problem. For instance, Halo can merge strongly overlapping arcs into a single multi-arc. This kind of concentric arc could avoid overlapping. Further, if locations are too cluttered, the system would set up a threshold to selectively display distant locations (Baudisch and Rosenholtz, 2003). Similar to but better than Halo, triangles in Wedge have greater flexibility of rotation than arcs in Halo to avoid overlapping through iterative algorithms (Burigat and Chittaro, 2011; Gustafson et al., 2008). Another instance is City Lights which simply uses multiple colors, transparence, or textures to distinguish distant locations when they are cluttered. In addition to the adoption of flexible attributes on graphic shapes, schematization or deformation of the fisheye view (Wolff, 2013) and variation in map scales (e.g. higher degree of generalization in the border of the viewport to put more distant locations onto the edge area) are also feasible to address the overcrowding problem (Gollenstede and Weisensee, 2014). However, those studies cannot solve the overlapping of landmark icons adopted in our design because of the less flexibility of rectangle and its larger projected size along the screen edge. Besides, the large amount of reference information crowded in a small screen would increase user's cognitive load as well as strengthening the system-user gap which is the dissociation between user variables and the system variable. Therefore, we introduce our selective method to display icons addressing overlapping.

Method

Display of distant landmarks

In this design, the user position is always marked at the center of the mobile screen with an icon. This location-aware mechanism gives users a chance to constantly access egocentric information and then integrate it with surroundings as well as displayed information to support their spatial orientation. Specifically the shape of each icon indicates the identity of the object. For each time the screen position changed (e.g. dragging, panning, or refreshing of the user position), the system could acquire the updated positions of all edge icons, remove old markers and then redraw new edge icons in terms of the latest position and distance. Since distant landmarks are re-projected as proxies along the screen edge, users can easily confuse them with local landmarks that are displayed at their actual locations on-screen. In order to prevent this misinterpretation, this design creates a small buffered area on all four edges of the screen with gray color and 50% transparency which divide the visual space into two portions: viewing area and edge buffer. In addition to the edge buffer, the authors add black frames around all distant landmarks to further distinguish them from local landmarks. This is to avoid the confusion when some local landmarks may fall into the edge buffer or these two types of landmarks are close to each other.

Distance encoding

Without panning or zooming, users could see existence and identities of a distant landmark as well as its direction according to the location and the shape of corresponding edge icons. Further, some studies consider distance concept together with the proxies of landmarks for locating the object that is out of the view but they fail to identify the identities of these landmarks. In this study, considering that human mind is not perfect at perceiving accurate Euclidean distance, the authors use the size of edge icon as a way to encode the distance between distant landmark and the user position, thus the distance concept is represented by icons of different sizes for relatively far or near. Figure 1 shows an example of how distant landmarks are re-mapped to indicate their positional information to the user. Two kinds of mechanism are designed that not only display the direction concept but also the distance concept of a distant landmark by changing its size to a user.

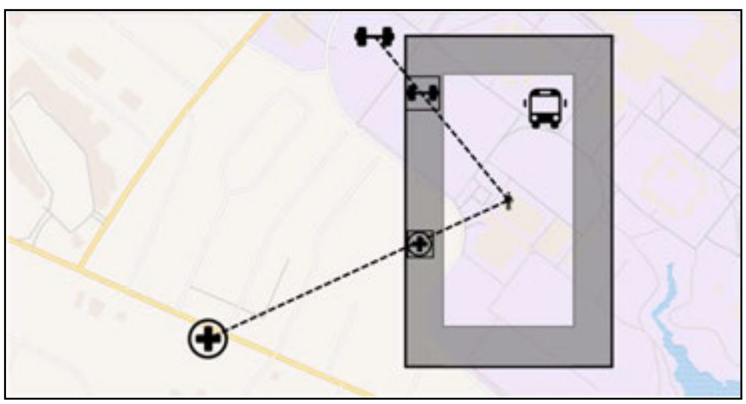

Figure 1: The approach of displaying distant landmarks on a small screen. Bold rectangle indicates mapped area on mobile screen. Two distant landmarks are re-projected onto the buffered area and resized in terms of their distances to a user (longer distance decreases the size of edge proxies). The user location is indicated by a human icon in the center of mobile screen.

In the ratio-scale mechanism, edge icons change in size continuously based on an established ratio to the actual distance between the user and a distant landmark. To make the change in size more sensitive to the varying distance, the ratio is only adopted by a small range of distance, that is, from 1000 to 4000 meters. This is in consideration of the definition of distant landmarks as well as the acceptable distance that humans can travel on foot. Distance to the user which is out of this range would be assigned a constant size accordingly for user's clear viewing. When distance is smaller than 1000 meters, edge icon size equals 100 X 100 pixels; when distance is larger than 1000 meters and smaller than 4000 meters, size equals $\{100 - [(\text{distance} - 1000)/(300/7)]\}^2$ pixels; when distance is larger than 4000 meters, size equals 30 X 30 pixels. These relationships are illustrated in Figure 2. It is worthy to mention that these two constant values, maximum and minimum sizes, are manually set up to ensure that icons representing all distances are legible.

In the ordinal-scale mechanism, three sizes of edge icon are assigned based on a certain range of distance implying near, middle, and far. Specifically, the large icon (90 X 90 pixels) corresponds to the distance less than 2000 meters; the small icon (35 X 35 pixels) corresponds to the distance larger than 3000 meters; and the middle icon (55 X 55 pixels) is settled between them. These relationships are also shown in Figure 2.

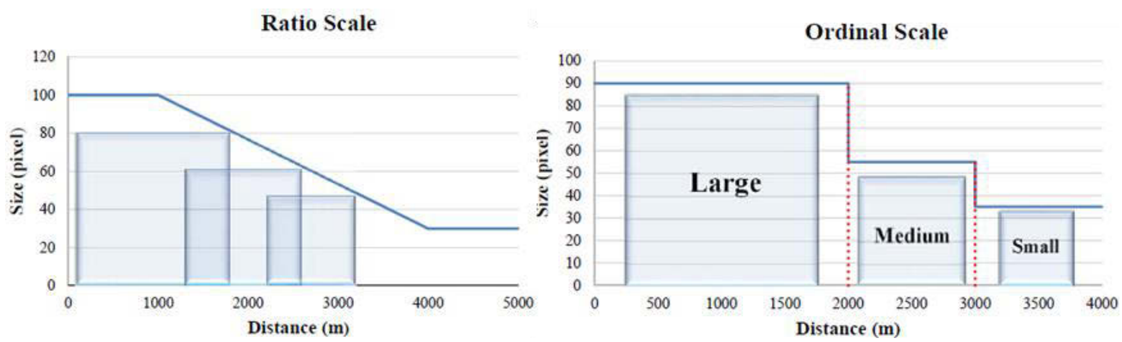

Figure 2: The relationship between the size of edge icon and the distance from correspondingly distant landmark to the user.

Optimization of spatial layout

Through selectively eliminating some less important edge icons, overlapped icons could be simplified for users. The authors adapt the criterion that closer landmarks are more helpful for users to navigate than further landmarks according to the first law of geography (Tobler, 1970). Therefore, there is an inversed linear relationship between the importance of landmarks and their distance to users. We introduced an overlap threshold for comparison: When two icons are adjacent to each other, the distance between their centers equals the average value of the side lengths of both icons. Then the distance between each pairs of icons is compared with its corresponding overlap threshold to determine if there is an overlap. In the case of two overlapped icons, the closer icon (higher importance) will be retained. If there are three or more icons overlapped with each other, the closest icon would be always retained because of its highest importance. Following this principle, the next closest icon would be retained if it does not overlap with the closest icon, otherwise it would be removed. For the third closest icon, it is compared with previously retained icons. Any overlapped situations would result in the elimination of this icon. Following the incremental distance sequence, each icon would be tested independently till the farthest icon. Figure 3 shows examples of solving overlapped issues of three icons.

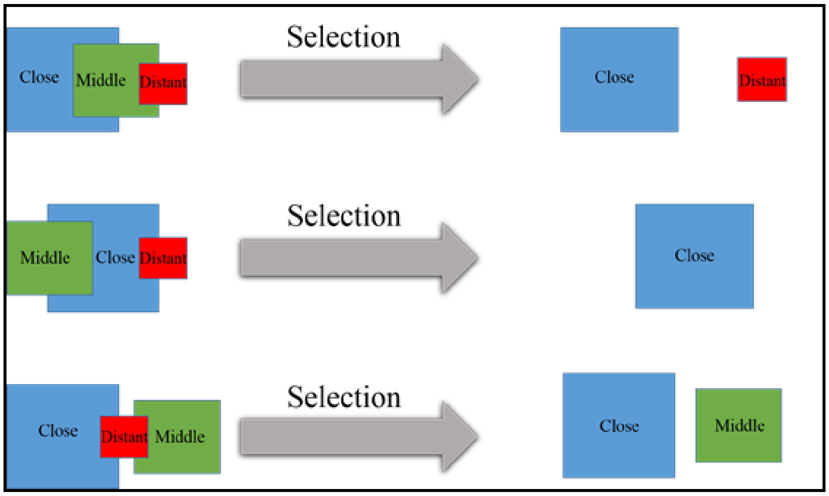

Figure 3: Examples of three overlapped icons to illustrate the selection of edge icons to visualize.

To implement this approach, the authors create two ArrayLists (dynamic data structures that meaning items can be added and removed from the lists): ArrayList A contains all distant landmarks ordered by their distance increment to the user; ArrayList B only contains a distant landmark with the shortest distance initially. The iterative process is comparing one landmark in ArrayList A in each iteration, from the shortest to longest distance, with each landmark in ArrayList B. If they do not overlap during the iteration, this landmark in ArrayList A will be added into ArrayList B and then the next iteration will start until all landmarks in ArrayList A have finished iterations. At the end, each landmark of ArrayList B would be visualized on screen to users. Figure 4 shows the procedure of solving overlapping issues.

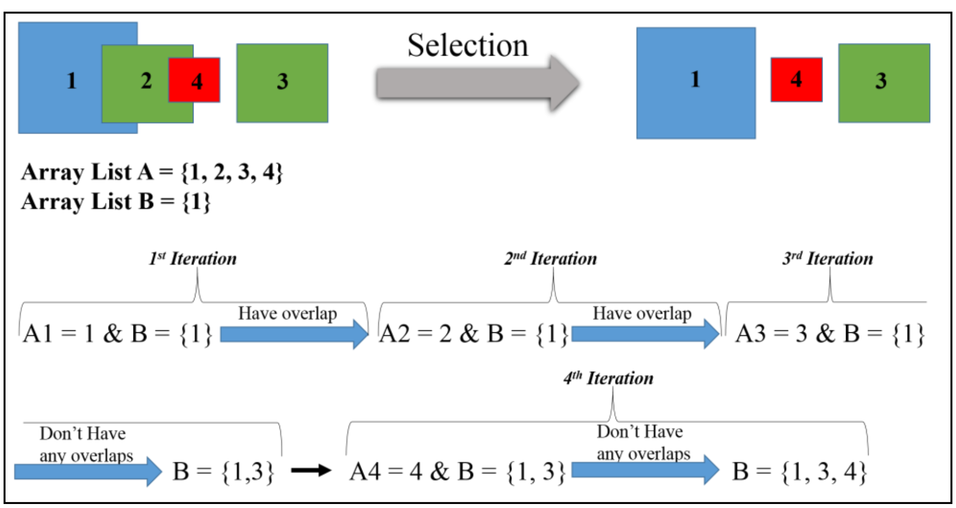

Figure 4: A sample process of dealing with four overlapping icons. The numbers embedded in the squares indicate the order of distance. "1" means the shortest distance whereas "4" means the longest distance.

Evaluation

The purpose of this evaluation is to compare the effects of resizable icons at ratio and ordinal scales on the perception of distance concept. This experiment was carried out through Amazon Mechanical Turk (MTurk), which is a crowd-sourcing network platform that enables individuals to post intelligence tasks online and recruit volunteers from around the world to work on tasks remotely (AmazonMechanicalTurk, 2016). Ideally, the online survey platform provides a large group of samples from various places to participate in this experiment. The selected area in this experiment is the uptown campus of the authors' university. The selection of landmarks was based on surveys of several native students who are familiar with the surroundings. Out from all visualized landmarks, 2 are local landmarks and 6 are distant landmarks. To exclude factor which is the familiarity of participants, we removed all of text labels displayed on the base map. Further in ratio scenario, all local and distant landmarks selected are replaced with pseudo ones (different identity for a location) as well as changed base map to make the distribution of edge icons distinct from that in ordinal scenario. Due to the use of online platform that participants have no access to the actual environment or mobile phone, and the purpose of the experiment which is to use size to encode distance information, we used screenshots of this application to simulate an interface users would view in actual environment. Although ordinal and ratio scenarios are carried out separately (the participants can only choose one of these two experiments at a time), there is a likelihood that participant who took one experiment may be interested in taking the other published one. This is the other reason that we used different base maps and pseudo icons (indicating the correct locations selected but with a different identity, e.g. gas station icon is replaced with gym icon). So participants who see both interfaces would assume that they represent two different areas. Figure 5 shows the pictures of two scenarios.

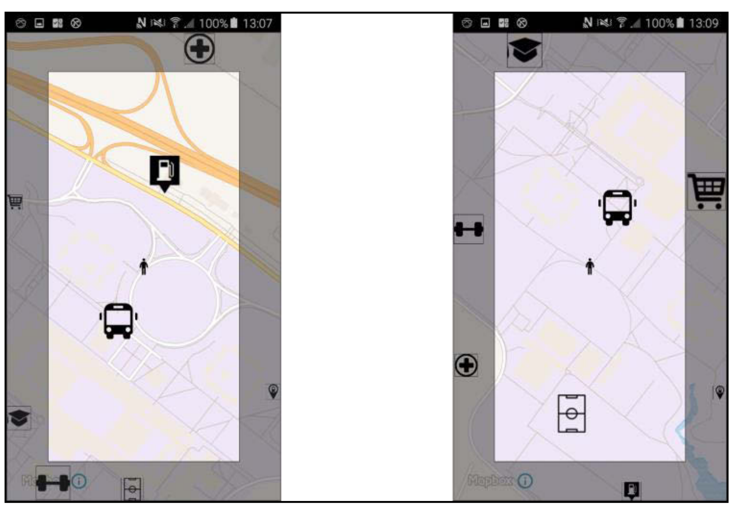

Figure 5: Two interfaces that participants saw in the experiments: ordinal scenario (left) and ratio scenario (right).

In total, 110 participants participated through MTurk in one of the two scenarios: ratio group includes 53 participants while 5 of them are invalid; ordinal group includes 57 participants in which 7 are invalid responses. Each participant has to answer ten questions in each scenario placed right next to the interface including four types of tasks: 1) Finding the closest and furthest locations to the participant's location; 2) Comparing distance between two on-screen locations 3) Comparing distance between on- and off-screen locations; and 4. Comparing distance between two off-screen locations. Participants had constant access to the interface throughout the experiment and no time restriction. Except the task1 that participants need to compare all eight landmarks, all other three types of tasks only require participants to compare a given pair of two icons.

Results and discussion

In all data analyses, participants' performances in the aforementioned categories as well as their time spent are used as dependent variables in individual tests. Results are presented in four major categories: the selection of the closest and furthest landmarks, distance comparison of two local landmarks, distance comparison between local and distant landmarks, and distance comparison between two distant landmarks. Regarding the total time (sec) to complete all experimental tasks, there is no significant difference between ratio group (*M* =339.31, *SD* = 147.33) and ordinal group (*M* = 293.86, *SD* = 68.35).

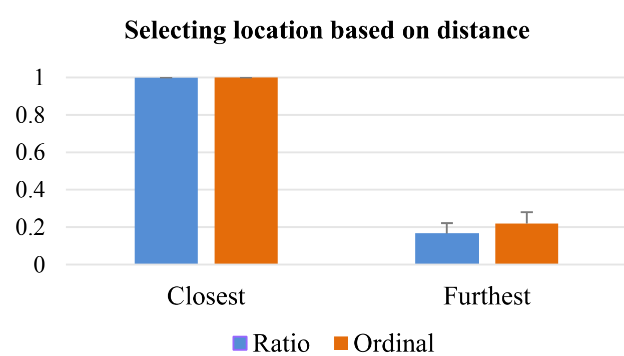

Figure 6: Average accuracy between scenarios in landmark selection tasks.

It is not surprising that all participants in both scenarios successfully select the closest landmark which is a local landmark most adjacent to the persons' location on screen. Because the closest landmark as local object shown on the screen is mapped in its actual location, it simulates humans' common experience using mobile maps. Similarly, participants have no problem judging relative distances between two local landmarks in both ratio (*M* = 0.98, *SD* = 0.04) and ordinal scenarios (*M* = 1.0, *SD* = 0). However, participants have challenges finding the furthest location in both ratio (*M* = 0.17, *SD* = 0.11) and ordinal scenarios (*M* = 0.22, *SD* = 0.12). The average accuracy of both test groups in finding the furthest landmark (*M* = 0.19, *SD* = 0.08) are significantly lower than that in the selection of the closest landmark (*M* = 1.0, *SD* = 0), t (1, 195) = 100.23, $p < 0.001$ (Figure 6). Particularly in the task of furthest landmark selection, the low accuracy of both groups might result from the confusion between local and distant landmarks, that is, mistakenly perceiving the location of edge icon as the actual location of distant landmarks. Another possible reason of the low accuracy in finding the furthest landmark is misinterpreting size and its associated distance, or just ignorance of the size variable.

In distance comparison between on- and off-screen locations, participants in ordinal group (*M* = 1.0, *SD* = 0) have higher accuracy than those in ratio group (*M* =0.75, *SD* = 0.06), t (1, 97) = 77.79, $p < 0.001$ (Figure 7). In ordinal scenario, however, considering that locations shown in the gray edge are further than the on-screen locations on screen, participants would judge the closer locations correctly even if they misinterpret the distant landmarks as local ones. It is possible that these participants did not fully understand those edge icons.

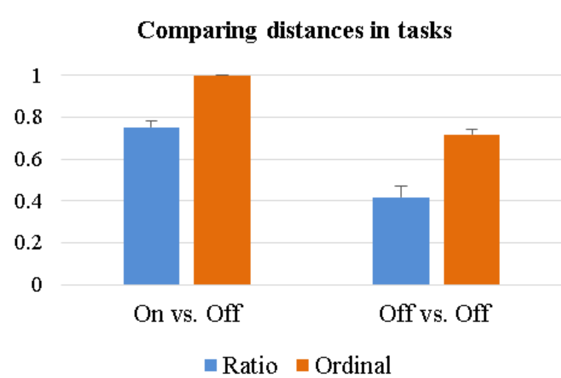

Figure 7: Accuracy of distance comparison of landmark pairs between test scenarios.

When comparing distance between two off-screen locations, Edge icons in ordinal group (*M* = 0.72, *SD* = 0.05) are more effective in judging relative distances between two distant landmarks than in ratio group (*M* = 0.42, *SD* = 0.11), t (1, 97) = 25.22, $p < 0.001$ (Figure 7). The possible reason is that ratio and ordinal scenarios used different mechanisms to visualize distance for distant landmarks. The relative distance comparison is a qualitative process (nearer or further). In ratio scenario, however, the continuous change of size presents too much information as a quantitative way to users during the process of browsing. In addition, although those edge icons are static in the experiment, the subtle differences among their sizes would be difficult to distinguish thus hinder participants to perform comparison. Unlike ratio scenario, the ordinal scenario only has three different sizes (qualitative information provided which is consistent with that of relative distance). The distinction among those fewer icon sizes is more noticeable, helping participants compare distance intuitively without additional quantitative information.

Conclusion

This study introduced an approach of displaying distant landmarks to support spatial orientation on mobile devices. The authors use size as the visual variable to encode distance of distant landmarks and implement two levels of measurement: One is ratio that the edge icons change in size continuously and proportionally according to the distance from corresponding distant landmarks to the user. The other one is ordinal that three different sizes of icon are used to represent three ranges of distance from near to the far. This improved design can support not only knowing the direction but also the acquisition of distance at some level. Ratio scenario, as a quantitative way of representing distance, is less efficient than ordinal scenario for perceiving distance. After using black frames around distant landmarks as well as gray buffer along the screen edge, however, users still have challenges distinguishing distant landmarks from local landmarks in both scenarios. More effective visualization options should be considered to assign distinctive appearance to visualized distant landmarks. One follow-up step is to consider using vagueness, saturation, or transparency in distant landmarks as well as updated indicators for their distance to user's location using ordinal level of measurement. In addition, it is necessary to note that the static screenshot used in this experiment is different from actual experience in a real environment. This may be one source of confusion between local and distant landmarks.

In the optimization of spatial layout, the overlapped edge icons are solved by retaining the most important visualizing references. In this study, distance to user's location is the only criterion used as a way to indicate its importance, which is insufficient. Some other ways to rank the importance of landmarks (e.g. popularity, scale, and connectivity) should be considered in future studies. These indicators can be evaluated by human participants as well as the study of their cognitive representations (Raubal, 2009) as weights. And then all of these weights based on different contexts can be combined with distance to build a weighted score in order to decide the importance of each landmark more comprehensively.

In summary, this study uses edge icons on mobile phones as contextual cues to indicate the existence and function of distant landmarks. Furthermore, the size of edge icons is the visual variable employed with two levels of measurement (ratio and ordinal) to represent distance of distant landmarks. In this study, ordinal scenario shows higher efficiency than ratio scenario. Based on this finding, future integration of additional visual variables (e.g. vagueness, saturation and transparency) in design will adopt ordinal level of measurement. In addition, this study provides a solution to overlapping problem when there are too many icons. Unlike Halo (Baudisch and Rosenholtz, 2003) or Wedge (Gustafson et al., 2008) that contextual cues are reshaped or rotated, off-screen locations in this design are ranked and selected according to their distance to users. A feasible follow-up is the integration of other characteristics of landmarks to rank their importance more comprehensively.

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