Information Visualization and Location-Based Services on Mobile Devices

Research-in-Progress

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ABSTRACT

With the widespread adoption of mobile devices and location-based services (LBSs), using location-based information from mobile devices has become increasingly common. However, accomplishing tasks on mobile devices remains challenging due to the complexity of location-based information and visualization constraints of mobile devices. Effective information visualization is, therefore, critical for improving user perceptions and usage. Based on theories of cognition and information visualization, we propose a novel hybrid approach that integrates presentation formats and interactivity features for information visualization. We implement the proposed approach on mobile devices and empirically evaluate it in a laboratory experiment. The results suggest that text- and map-based presentation formats significantly enhance user perceptions. Both semantic zoom and content filtering features have significant effects on perceived ease of use and perceived usefulness of mobile LBSs. Our theoretical and practical contributions, as well as plans for further testing and enhancing are discussed.

Keywords (Required)

Information visualization, presentation format, visualization interactivity, location-based information.

INTRODUCTION

Location-based services (LBSs) are information services accessible through mobile devices (e.g., smart phones and portable tablets) with network connectivity, and utilize information on the geographical location of the user (Steiniger et al. 2006; Virrantaus et al. 2001). Currently, 17.6% of smart phone users make use of LBSs (comScore 2011). Revenue from LBSs is expected to escalate from $2.8 billion in 2010 to $10.3 billion in 2015 (Sythoff and Morrison 2011). The proliferation of LBSs enables people to find information and complete tasks wherever they are and whenever the need arises. However, the ease of use and usefulness of LBSs has been challenged by the unique visualization constraints of mobile devices (e.g., small screen size and limited memory) (Adipat et al. 2011; Zhang 2007). The small screen size of mobile devices restricts the display of complex content provided by LBSs and places a heavy cognitive load on users (Adipat et al. 2011). Users tend to generate errors as cognitive load increases, thus resulting in poor user perceptions of LBSs. Therefore, visualizing location-based information on mobile devices in a way that improves perceptions in ease of use and usefulness of LBS are timely and important issues to address in recent technology advances.

Information visualization is defined as the use of technology-supported visual representations of interactive and abstract data (Card 2007; Card et al. 1999). It consists of (i) different types of presentation format, for example, a single format using text, or a composite format using maps and text (Steiniger et al. 2006), and (2) different levels of visualization interactivity, for example, progressive exposure such as semantic zooming or selective exposure such as content filtering (Benyon 2010; Card 2007). Being frequently studied in the desktop environments, information visualization has been proven beneficial in improving user experience by increasing processing resources available to users, reducing search for information, and enhancing detection of patterns (Benyon 2010; Card 2007). However, research on visualization of location-based information on mobile devices is still limited.

One of the common limitations of information visualization is the lack of theories to explain how presentation format and visualization interactivity can influence user perception of mobile LBSs under different task complexity. The cognitive fit theory suggests that a mismatch between task and information presentation may cause users to make extra cognitive effort transforming information into a format that is suitable for accomplishing the task (Adipat et al. 2011). Based on extant information visualization approaches and theories of cognition, we propose a hybrid approach to investigate the problems associated with information visualization and user perception.

This research aims to fill the above knowledge gaps by answering three important research questions:

1) Do the types of presentation format (e.g., single and composite) enhance user perception?
2) Can the levels of visualization interactivity (e.g., progressive and selective exposures) enhance user perception?
3) How does the impact of information visualization on user perception vary with task complexity?

The theoretical contribution of this research is to elucidate the role of information visualization on user perception of LBS, thus distinguishing perspectives in presentation formats from those in visualization interactivity to derive a contingent model for mobile usage. By identifying and integrating several theoretical approaches to information visualization, a parsimonious understanding of the relationships between information visualization and user perception will help researchers to better understand the user requirements when conceptualizing the design of mobile applications.

Our study also provides new practical insights on how to visualize location-based information on mobile devices. The evaluation and comparison of different presentation formats (e.g., text and map), interactivity features (e.g., semantic zooming and content filtering) and task complexities (e.g., single outcome and multiple outcomes tasks) offer empirical guidance to LBSs designers and developers.

RELATED WORK AND RESEARCH MODEL

Effective information visualization is critical for improving the user experience on mobile devices (Cartwright et al. 2001). Different types of presentation formats and interactivity features have been developed to alleviate the problems of information overload on small screen browsing. Based on previous literature, there are two types of formats to present location-based information on mobile devices: single and composite presentation formats. Existing visualization interactivity approaches can be represented by two categories: progressive and selective exposures. The strengths and weaknesses of each approach are summarized in Table 1.

Approach	Technique	Description	Strengths	Weaknesses
Single Presentation Format	Text Only	The information is represented by descriptive text.	Users can seek information by reading the text description.	Users cannot see the location distributions directly.
Composite Presentation Format	Text and Map	The location attribute of the information is represented by a data point on a geographical map. Other attributes are represented by descriptive text.	Users can see both the text description and distribution patterns of location attribute.	Multiple presentation formats may increase information load for users.
Progressive Exposure	Semantic Zoom	It allows pinching an on-screen item or reverse pinching the item to view it in full display.	It empowers users to control the level of details to display in each item.	The active operation to open or close screens to more details may create extra mental load.
Selective Exposure	Content Filter	It allows information to be blocked or allowed based on analysis of its content.	It empowers users to control the number of items to be displayed.	The active operation of filtering content may create extra mental load.

Table 1. Presentation Format and Visualization Interactivity on Mobile Devices

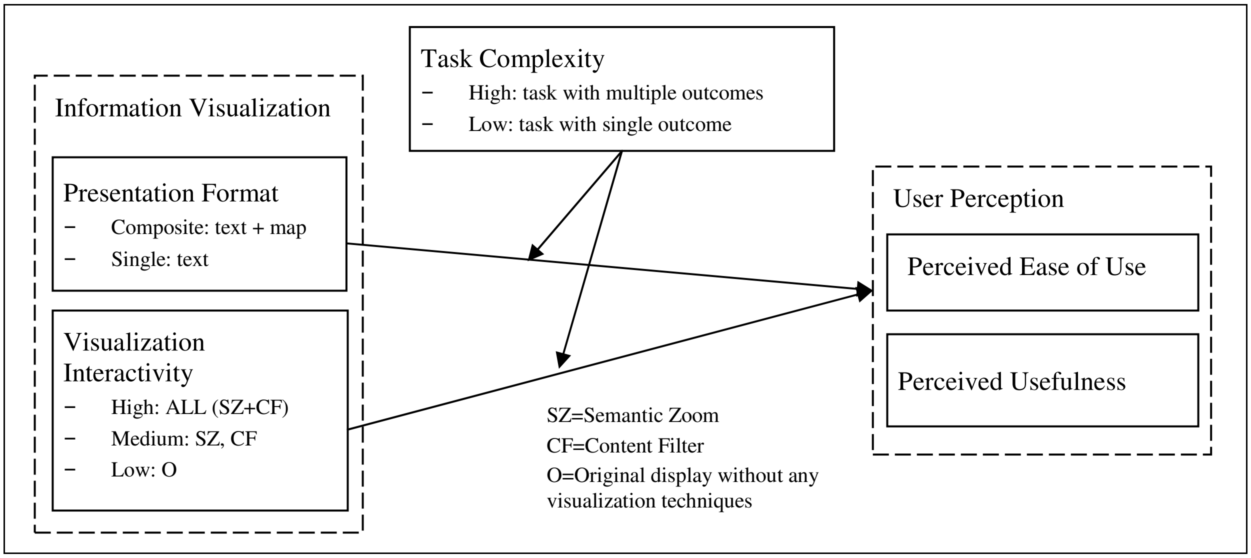

Figure 1 Research Model

THEORETICAL FOUNDATIONS AND HYPOTHESES

Presentation Format of Location-based Information

Human beings often create a representation of the environment in their minds as a "cognitive map" (Tolman 2007). It is allows the "mind's eye" to visualize images in order to reduce cognitive load, as well as enhance recall and learning of information. However, the process of constructing a cognitive map requires considerable attention and mental effort, reducing the limited capacity of one's working memory. A map is a visual representation of the distribution of events or places. Visualizing the map directly can enhance users' detection of information patterns, thus facilitating the construction of a cognitive map. Maps can also offer an overview of the information, a basic principle in the Shneiderman's (1996) visual information-seeking mantra.

Although a map can represent the location attributes in each information item, text is still needed to represent irrelevant location content such as description of places. The split attention effect (Chandler and Sweller 1992) indicates that if textual and graphical components are clearly indicated, they should be integrated together. Consistent with prior research, we argue that a composite presentation format, combining both text and map to represent location-based information, may enhance users' perception of the system (Adipat et al. 2011; Tegarden 1999). Thus, we hypothesize:

H1：Using text- and map-based composite presentation format in mobile LBS, compared to text only single presentation format, will be associated with greater (a) perceived ease of use, and (b) perceived usefulness.

Visualization Interactivity with Semantic Zoom

Scrolling up and down to browse a large volume of information on small screen devices is difficult. Users often want to have an overview of the information and access the details only when they want to. Details-on-demand is one of the basic principles in the visual information-seeking mantra (Shneiderman 1996). It refers to techniques that enable users to interactively select parts of data to visualize in detail while providing an overview of the whole informational concept (Benyon 2010; Shneiderman 1996).

Progressive exposure (Wilson and Davison 1971) is a way of accessing within-item details (i.e. content within an item) on demand. The theory posits that human's feeling of fear gradually fades if a feared object is gradually exposed to them (Wilson and Davison 1971). Similarly, when users seek information from mobile LBSs, users' information overload will diminish if the content is gradually revealed based on demand.

Semantic zoom is a visualization interactivity technique that exposes content gradually to users on demand (Perlin and Fox 1993). It enables users to activate a secondary display to read the detailed description. The semantic zoom feature allows pinching an on-screen item or reverse the pinching to view its full display. Deploying this feature, users can easily access the target information and bypass the irrelevant contents with less mental efforts. Thus, we hypothesize:

H2：Providing the semantic zoom function in mobile LBS, compared to those without this visualization interactivity feature, will be associated with greater (a) perceived ease of use, and (b) perceived usefulness.

Visualization Interactivity with Content Filter

Selective exposure (Frey 1986) is a way of obtaining between-item details (i.e. content about other items) on demand. The theory posits that people tend to select specific aspects of exposed information based on their own beliefs, attitudes, and decisions (Frey 1986). Information overload will be reduced if users are able to select the information exposed to them based on filtered content. If all information items are shown together, it induces greater cognitive load for users due to the redundancy of non-relevant items.

Content filter is a visualization interactivity technique whereby content is blocked or allowed based on an analysis of the content, rather than its source or other criteria (Benyon 2010; Card 2007). It allows users to control the displayed content and quickly focus on their interests by eliminating unwanted items (Shneiderman 1996). Users can easily obtain the target information and skip the irrelevant items with less mental effort.

H3：Providing the content filter function in mobile LBS, compared to those without this visualization interactivity feature, will be associated with greater (a) perceived ease of use, and (b) perceived usefulness.

Given these two types of visualization interactivity techniques, will more visualization interactivity features result in greater user perceptions? The theories underlying visualization interactivity are aimed at better visualization of content in a limited screen space to facilitate usage of mobile LBS. Specifically, the details-on-demand principle suggests that a greater number of approaches to hide irrelevant details should assist users in finding the target information more easily and accurately. The semantic zoom and content filter techniques are two independent yet complementary details-on-demand approaches (i.e., progressive and selective exposures). Thus, we hypothesize:

H4：Providing both the semantic zoom and content filter functions in mobile LBS, compared to providing only one of them, will be associated with greater (a) perceived ease of use, and (b) perceived usefulness.

Task Complexity as a Moderator

According to the cognitive fit theory, the correspondence between the task and information presentation leads to enhanced task performance for users (Vessey and Galletta 1991). If a mismatch between task and information presentation occurs, users must make extra cognitive effort to transform information into a format that is suitable for accomplishing the task (Adipat et al. 2011). Dennis and Carte (1998) extend the theory to a map-based display in geographic information systems whereby users made faster and more accurate decisions when working on tasks with multiple outcomes. When the task is complex, information that needs to be processed will increase.

H5：The greater the task complexity, the greater will be the positive effect of using text- and map-based composite presentation format on (a) perceived ease of use, and (b) perceived usefulness.

Both progressive and selective exposures are means of allowing users to seek the target information in an effective and efficient manner. They empower users with the ability to actively control the information exposed to them by filtering out irrelevant information (Jiang et al. 2010). As more information needs to be processed in accomplishing more complex tasks, both semantic zoom and content filter functions, either provided individually or in combination, are expected to improve user perceptions.

H6：The greater the task complexity, the greater will be the positive effect of providing semantic zoom function on (a) perceived ease of use, and (b) perceived usefulness.

H7：The greater the task complexity, the greater will be the positive effect of providing content filter function on (a) perceived ease of use, and (b) perceived usefulness.

H8：The greater the task complexity, the greater will be the positive effect of providing both semantic zoom and content filter functions on (a) perceived ease of use, and (b) perceived usefulness.

RESEARCH METHODOLOGY

Our research is in progress. We conducted a pilot laboratory experiment using a 2*2*4 factorial design with presentation format (text vs. text + map) and task complexity (low vs. high) as between-subject factors and visualization interactivity (four conditions) as within-subject factor. Participants were asked to perform four tasks using four different mobile LBSs. Each participant was randomly assigned to one of the four groups.

We developed the mobile LBSs on the Android operating systems and deployed them on Samsung Galaxy SII, the smart phone that we used in the experiment. Smart phones have been widely used for browsing and searching for location-based information. They are considered to be representative of mobile devices for the tasks of this nature. The Samsung Galaxy SII provides WLAN 802.11b for wireless Internet access and GPS for location tracking.

We implemented eight different prototype systems. Four systems presented information in text list, while another four systems presented information in a combination of text list and map according to the location tags. The four systems in each group used four interactivity conditions. In the first condition, the entire content of each information item was displayed on the main screen and did not have any interactivity features (O). In the second condition, only the key content of each information item was displayed on the main screen. Other content could be accessed by clicking on the target item and blocked by clicking on it again (SZ). In the third condition, the entire content of each information item was displayed on the main screen. There was a drop down list to filter the items based on a specific attribute of the items (CF). In the fourth condition, only the key content of each information item was displayed on the main screen. Other content were accessed by clicking on the target item and alternatively blocked by clicking on it again. Users could also use the drop down list to filter the items based on a specific attribute of the items (ALL).

Measurements

The presentation format was operationalized as single presentation format (i.e. text only view) and composite presentation format (i.e., text + map view). Visualization interactivity was operationalized as original visualization without any interactivity (O), visualization with semantic zoom (SZ), visualization with content filter (CF), and integrated visualization interactivity (SZ+CF). A task was more complex when there were a number of desirable outcomes and involved more information processing (Campbell 1988). Thus, task complexity was operationalized as information seeking with single outcomes (simple) or multiple outcomes (complex).

The instruments for measuring perceived ease of use and usefulness of information visualization were adapted from recent studies on technology acceptance model (Adipat et al. 2011; Davis 1989). Perceived ease of use refers to the degree to which a user believes that the mobile LBS can be used effortlessly. Perceived usefulness refers to the degree to which a user believes that the mobile LBS can improve his/her task performance. All the survey questions were measured on a seven-point Likert scale, with 1 indicating "strongly disagree" and 7 indicating "strongly agree". For example, the respondents were asked if "the mobile application was easy to use", and "the mobile interface was displayed in a way that was useful in searching for information."

Experimental Procedures

To minimize the potential learning effects resulting from the within-subjects design (Adipat et al. 2011; Boslaugh and Watters 2008), we randomized the sequences of four interactivity conditions and the selection of tasks for each participant. The participants went through a training session, in which they saw demonstrations of four versions of the mobile LBSs. The participants first performed information seeking tasks using one of the four mobile LBSs, and then wrote down their decision and reasons regarding a designated task. They were asked to complete a questionnaire related to their perceptions of the system they had just used. This process was repeated for each of the other three mobile LBSs. After participants had completed all of the tasks, they were asked to rank the four systems in terms of their preferences.

DATA ANALYSES AND RESULTS

A total of 72 undergraduate students from a large local university in Southeast Asia participated in the pilot study. Among them, 54.2% were male. The average age of the participants was 21.9. Through a pre-study questionnaire, we ensured that all participants had prior experience with mobile devices. In general, most participants had experience with mobile devices with Wi-Fi (97.2%) or 3G (70.8%). No significant difference was found across the four groups regarding the above aspects. Participants were randomly assigned to the four groups, with 18 participants in each group. Each participant received cash rewards for their participation in this study.

We used mixed between-within subjects ANOVA (also known as a split-plot ANOVA) to analyze the effect of visualization interactivity, presentation format and task complexity. The descriptive statistics and ANOVA summary tables of the dependent variables are reported in Tables 2 and 3. ANOVA on perceived ease of use shows a significant main effect of presentation format ($F(1,68)=4.772$, $p<0.05$) and interaction effects ($F(3,204)=3.835$) of visualization interactivity, presentation format and task complexity. ANOVA on perceived usefulness shows significant interaction effects ($F(3,204)=3.069$) of visualization interactivity, presentation format and task complexity. We asked participants to rank the four systems they had used after they completed all the tasks. 45.8% participants chose the integrated condition as their first preference, while 36.1% and 12.5% participants chose the content filter and semantic zoom conditions as their first preference respectively.

Source	df	PEOU			PU		
		Mean Square	F	Sig.	Mean Square	F	Sig.
Between-subjects							
PF	1	11.183	4.772	0.032(*)	11.480	3.240	0.076
TC	1	0.049	0.021	0.886	1.088	0.307	0.581
PF*TC	1	4.193	1.789	0.185	0.878	0.248	0.620
Within-subjects							
VI	3	0.106	0.312	0.817	0.741	0.828	0.480
VI*PF	3	0.409	1.207	0.308	1.931	2.155	0.095
VI*TC	3	0.610	1.800	0.148	0.412	0.046	0.711
VI*PF*TC	3	1.299	3.835	0.011(*)	2.749	3.069	0.029(*)
Note: TC=task complexity, PF=presentation format, VI=visualization interactivity, PEOU=perceived ease of use, PU=perceived usefulness. Mauchly's Test of Sphericity is non-significant (p>0.05), meaning the sphericity assumption has not been violated.							

Table 2. ANOVA Summary Table

	Rank 1	Rank 2	Rank 3	Rank 4
Original without visualization interactivity (O)	4(5.6%)	8(11.1%)	25(34.7%)	35(48.6%)
Visualization interactivity with semantic zoom (SZ)	9(12.5%)	16(22.2%)	18(25%)	29(40.3%)
Visualization interactivity with content filter (CF)	26(36.1%)	26(36.1%)	15(20.8%)	5(6.9%)
Visualization interactivity with both (ALL)	33(45.8%)	22(30.6%)	14(19.4%)	3(4.2%)

Table 3. Preliminary Comparisons of the Four System Conditions

CONCLUDING REMARKS

How to visualize location-based information is a critical issue as it influences users' experience with the usage of mobile LBSs. Limited empirical studies have been done to address this issue in IS area. Hence, our study aims to investigating the impact of different information visualization on the usage of mobile LBSs. We found that text- and map-based composite presentation format significantly enhanced users' perceived ease of use of mobile LBSs. Systems with both semantic zoom and content filter interactivity features obtained the highest ranking.

As this is a pilot study, we would attempt to refine the study design and conduct another experiment. The information visualization approaches that may influence user experience with mobile LBSs could be explored further. We would also adopt other measurements of user experience through objective feedback. Other possible confounding factors, for example, visual ability, social norms or environmental factors would be considered and modeled in the statistical analyses.

Although mobile LBSs are considered as important tools for users to complete their daily work (Church et al. 2010), little IS research has addressed this phenomenon. This paper provides theoretical and practical implications by exploring the impact of information visualization design, both the presentation format and visualization interactivity, on user perception of mobile LBSs. Theoretically, the study aims to extend and empirically test the information visualization principles in the context of mobile LBSs, for example, Google Latitude and Apple's Find My Friends. It contributes to the information visualization literature by examining the effects of visualization design in user perceptions of mobile LBSs. Practically, this study provides guidelines to system designers on how to design useful and intuitive LBSs. It suggests the importance of presentation format, visualization interactivity, and task complexity in joint influence on user experience with mobile LBSs. Thus, designers should engage in practices that improve the effectiveness of information presentation and interactivity, and consider the fit between task and system designs.

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REFERENCES

1. Adipat, B., Zhang, D., and Zhou, L. (2011) The Effects of Tree-View Based Presentation Adaptation on Mobile Web Browsing, *MIS Quarterly*, 35, 1, 99-122.
2. Benyon, D. (2010). Designing Interactive Systems: A Comprehensive Guide to Hci and Interaction Design (Second Edition). Pearson Education Limited.
3. Boslaugh, S., and Watters, P.A. (2008). Statistics in a Nutshell. O'Reilly Media.
4. Campbell, D.J. (1988) Task Complexity: A Review and Analysis, *Academy of management review*, 40-52.
5. Card, S. (2007). Information Visualizations, in *The Human-Computer Interaction Handbook, 2nd Edition,* A. Sears and J.A. Jacko (eds.). Mahwah, NJ: Lawrence Erlbaum Associates, 509-543.
6. Card, S.K., Mackinlay, J.D., and Shneiderman, B. (1999). Readings in Information Visualization: Using Vision to Think. Morgan Kaufmann.
7. Cartwright, W., Crampton, J., Gartner, G., Miller, S., Mitchell, K., Siekierska, E., and Wood, J. (2001) Geospatial Information Visualization User Interface Issues, *Cartography and Geographic Information Science*, 28, 1, 45-60.
8. Chandler, P., and Sweller, J. (1992) The Split-Attention Effect as a Factor in the Design of Instruction, *British Journal of Educational Psychology*, 62, 2, 233-246.
9. Church, K., Neumann, J., Cherubini, M., and Oliver, N. (2010). The Map Trap?: An Evaluation of Map Versus Text-Based Interfaces for Location-Based Mobile Search Services, in: *International World Wide Web Conference*. Raleigh, North Carolina, USA: ACM, 261-270.
10. comScore. (2011). "Nearly 1 in 5 Smartphone Owners Access Check-in Services Via Their Mobile Device ", from http://www.comscore.com/Press_Events/Press_Releases/2011/5/Nearly_1_in_5_Smartphone_Owners_Access_Check-In_Services_Via_their_Mobile_Device
11. Davis, F.D. (1989) Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology, *MIS Quarterly*, 13, 3, 319-340.
12. Dennis, A.R., and Carte, T.A. (1998) Using Geographical Information Systems for Decision Making: Extending Cognitive Fit Theory to Map-Based Presentations, *Information Systems Research*, 9, 2, 194-203.
13. Frey, D. (1986) Recent Research on Selective Exposure to Information, *Advances in experimental social psychology*, 19, 41-80.
14. Jiang, Z., Chan, J., Tan, B., and Chua, W.S. (2010) Effects of Interactivity on Website Involvement and Purchase Intention, *Journal of the Association for Information Systems*, 11, 1, 34-59.
15. Perlin, K., and Fox, D. (1993). Pad: An Alternative Approach to the Computer Interface: ACM, 57-64.
16. Shneiderman, B. (1996). The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations, *Visual Languages, 1996. Proceedings., IEEE Symposium on*, 336-343.
17. Steiniger, S., Neun, M., and Edwardes, A. (2006) Foundations of Location Based Services, *Lecture Notes on LBS*, 1.
18. Sythoff, J.t., and Morrison, J. (2011). Location-Based Services: Market Forecast, 2011-2015. Pyramid Research.
19. Tegarden, D.P. (1999) Business Information Visualization, *Communications of the AIS*, 1, 1es, p. 4.
20. Vessey, I., and Galletta, D. (1991) Cognitive Fit: An Empirical Study of Information Acquisition, *Information Systems Research*, 2, 1, 63-84.
21. Virrantaus, K., Markkula, J., Garmash, A., Terziyan, V., Veijalainen, J., Katanosov, A., and Tirri, H. (2001). Developing Gis-Supported Location-Based Services: IEEE, 66-75 vol. 62.
22. Wilson, G.T., and Davison, G.C. (1971) Processes of Fear Reduction in Systematic Desensitization: Animal Studies, *Psychological Bulletin*, 76, 1, p. 1.
23. Zhang, D. (2007) Web Content Adaptation for Mobile Handheld Devices, *Communications of the ACM*, 50, 2, 75-79.