Interaction and Presentation Techniques for Situated Visualization

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ABSTRACT
As computation, sensing and display become more mobile and distributed, the locus of interaction shifts to the environment and objects we encounter in the environment. This shift changes how we view the world and our expectations about interacting with our surroundings, creating the opportunity for *situated visualization*—visually representing data in its spatial and semantic context. Examples include visualizing information about a plant species near a physical specimen or mapping relevant urban GIS data directly onto the user's view of the city through augmented reality. My dissertation investigates presentation and interaction techniques for situated visualization.

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INTRODUCTION

Card and Mackinlay [4] define visualization as "the use of computer-based, interactive visual representations of data to amplify cognition." They discuss a variety of ways in which visualization makes this possible. Yet, visualization often appears on the office desktop, away from the objects and spaces where it is most relevant. Mobile computing makes it possible to bring visualization along with us in devices such as UMPCs and smart phones. Such devices can act as both opaque surfaces for user interfaces and transparent panes through which we perceive and interact. Similarly, more immersive displays such as digital binoculars, telescopes, and mass market head-worn displays for video viewing are appearing on the market. Both hand-held and head-worn displays can support mobile *augmented reality* (AR). AR overlays virtual sensory information on the physical world, in real-time and registered in 3D. This makes it possible to display visualizations in the physical environment.

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Situated Visualization

Of particular interest to us are visualizations that are relevant to the location or physical context in which they are displayed. Typically, visualizations are shown on a standalone display, whether desktop, hand-held, or head-worn. In these cases, the physical background has no meaningful relationship to the visualization. In contrast, I use the term *situated visualization* to describe a visualization that is related to its environment; for example, by being specific to the surrounding spatial context. Situated visualizations gain meaning through both the visualization and the relationship between the visualization and environment. Examples include visualizing information about a plant species near a physical plant based on the shape of the leaf and mapping relevant urban GIS data directly onto the user's view of the city.

Although I am not the first to develop situated visualizations (as I describe below when discussing related work), I propose the term to represent a set of visualizations and related techniques that have interesting commonalities. My theory of situated visualization borrows the concept of figure-ground relationships from applications of gestalt theory to visual design [10]. In this model, the figure is typically virtual and the ground is typically physical. The combination of the two creates a unified perceived reality. I characterize five aspects of situated visualizations to help design, compare, and analyze specific visualizations:

- semantic relevance between the figure and ground,
- spatial and temporal relevance between figure and ground,
- locus of presentation (display, body, object, world),
- visual representation, and
- interaction technique.

RESEARCH QUESTIONS AND THESIS GOALS

To make situated visualization useful and effective, I am pursuing a course of experimentation to explore presentation and interaction techniques that support common visualization tasks, while acknowledging the unique aspects of situated visualization: presence overlaid on the physical world and connection with the physical world. In this investigation, I address the following questions:

What theoretical framework should we use to classify and characterize situated visualizations? In the HCI community, it is useful to create a design space and taxonomy for new and existing user interface techniques (e.g., [3, 4, 7]). This provides a common vocabulary for discussing the research and helps define areas that need to be explored.

What are the best ways to present and display situated visualizations? I hypothesize that gestalt rules apply in terms of learning tasks and that spatial proximity is an important aspect of comparison and inspection.

What user interface techniques can we use to best interact with situated visualizations and visualization elements? A variety of techniques exist for interacting with visualizations. Here I focus on Shneiderman's visual information seeking mantra [13] ("Overview first, zoom and filter, then details on demand.") and investigate related paradigms for pattern seeking and image identification/comparison in situated visualization. I hypothesize that direct manipulation techniques paired with direct presentation of virtual elements in proximity to relevant physical elements will maximize speed, accuracy, and comprehension of visualization tasks.

What are the benefits of situated visualization and in what tasks and contexts are they most appropriate? I believe that certain tasks, such as inspection/comparison, spatial learning, and in-situ pattern seeking and discovery can benefit from enhanced cognition through situated visualizations compared to alternatives.

What design principles apply to creating situated visualizations? An important goal of this research is to take results from evaluations and codify them into a set of design principles that can be used when developing situated visualizations for future applications.

RELATED WORK

A large body of research has informed and inspired our own work. Here I highlight some of the most relevant.

Lave and Wegner [9] describe *situated learning* as a way of learning in context and embedded in the cultural, social, and physical environment. This is in contrast to learning in a classroom away from the context. Situated learning is related to a branch of cognitive psychology called *situated cognition*, which aims to study human behavior in real situations, where cognition is intimately tied to context. I apply this to visualizations where context can be both semantic and spatial and the representation can be embedded using mobile computing and AR.

In a sense, visualization is always present in AR. However, much work on visualization in AR has no relevance to the physical reality in which it is presented. Graph nodes [1] and visualizations [5] more typically float in space and benefit from the collaborative or tangible aspects afforded by AR. Annotation more directly relates to the physical world. For example, Bell et al. [2] developed view management systems for AR that focused on labeling and annotation rather than visualization in general.

In addition to these, there are some types of visualization that I consider to be situated visualizations because they are related to the environment or an object in the environment. Gillet and Olson use AR to visualize magnetic fields around a physical model of a molecule [6], where the visual representation and spatial layout have meaning. King et al. display GIS viticulture data on a physical space in the AR-Vino system [8]. Both systems notably focus on data display and do not provide any direct means of interacting with the visualization—both systems use a keyboard for user input, although Gillet and Olson change visual point of view through manipulation of the molecular model. More recently, the Vidente project [12] has been investigating visualization of subsurface features such as pipelines and power cables for utility field workers. Their approach takes geographic data models of subsurface features and transcodes them for visualization and filtering. In contrast, I am investigating visualizations that do not have an inherent visual representation and in some cases change based on actively sensing semantic aspects of the physical world.

APPROACH AND PROCESS

My research is structured to investigate situated visualization techniques across a spectrum of semantic and spatial relevance through the development, use, and evaluation of working system prototypes. I conduct my research through an iterative process that incorporates ethnographic design research, user interface invention, system development, evaluation, synthesis, and theoretical construction. To ground my research, I have developed specific prototype applications as examples and test beds for investigating interaction techniques. These prototypes have been developed in two application spaces: botanical species identification in the field and site visits for architects, urban designer and urban planners. Evaluation includes objective comparisons of display methods and systems, measuring task performance, and ascertaining user preferences through a combination of user studies, structured interviews, and informal feedback. My approach involves collaboration with experts in other fields, including psychologists, urban designers and planners, and botanists, as a way to validate my work and to contribute to both the computer science community and society at large.

Botanical Species Identification

In the first application space, I have collaborated with botanists from the Smithsonian Institution and computer scientists at the University of Maryland (UMD) to develop prototypes that speed identification and collection of botanical species in the field. These robust prototypes use computer vision algorithms developed at UMD to find matching species. Since matching is imperfect, a set of possible matches needs to be returned and human intervention is required for comparison with the original species. I have developed a workflow based on ethnographic study [14] that incorporates image acquisition, visualization of matching species, inspection and comparison of potential matches, selection of correct matches, as well as review of historical matches on a given field trip and browsing the entire database. With this workflow as a guide, I have developed a variety of prototype Electronic Field Guides (EFGs) that have been used by botanists and non-scientists in demonstrations, as well as actual field use.

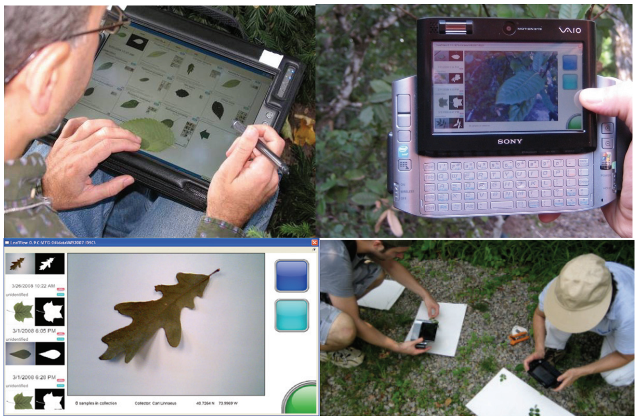

Fig. 1. Clockwise from top left (a) LeafView, (b) LeafView UMPC (c) Botanists using system during field study. (d) Main screen with live capture window, history collection, and context status.

The *LeafView* prototype (Fig. 1) has undergone two major and several minor iterations. The prototype was used as an initial platform for exploring visualization in the field using a Tablet PC for display and a wireless camera for image acquisition. The visualization is viewed in context and is semantically relevant but not spatially relevant to the physical leaf. The prototype [16] has been in use by our colleagues at the Smithsonian and demonstrated at UIST 2006, the Smithsonian Institution, the National Geographic BioBlitz 2007 and two events with members of the U.S. Congress. The second iteration, *LeafView UMPC*, based on feedback from extensive use of the first iteration, uses a UMPC to integrate display and acquisition into the same device. This prototype has been used for test collection in the field this summer. A third proposed iteration, *LeafViewAR*, integrates LeafView with AR prototypes discussed in the next paragraph.

In contrast to the LeafView prototypes which display visualization away from the physical leaf specimen, I developed two AR user interfaces (Fig. 2) to explore the significance of visualizations that are both semantically relevant (based on leaf image) and displayed in physical proximity to the leaf, embedded in the physical world. The *Tangible AR EFG* (TAR-EFG) moves the visualization of results from the device to the leaf and explores manipulation of the visualization via tangible AR using object-fixed visualization. *Visual Hints* extend the TAR-EFG by supporting visualization of potential actions in the physical world. These techniques have been evaluated in a comparative study [15]. The *Head-Movement Controlled AR EFG* provides a hands-free interface and displayed the visualization of species fixed in space to the body of the botanist (body-fixed). This explores both semantic relationships from species identification and spatial relationships of virtual representations in the physical world. The tangible and head movement controlled AR user interface techniques have been implemented and evaluated in a comparative, structured interview study [14] involving four of our botanist colleagues. The tangible AR prototype has been demonstrated at ISMAR 2006, the Smithsonian Institution, the National Geographic BioBlitz 2007, and two events with members of the U.S. Congress. Portions of the same underlying architecture are used for all prototypes and can be used and extended for future research.

Site Visits

In the second application space, I am collaborating with faculty from Columbia University's Graduate School of Architecture, Planning, and Preservation (GSAPP) to develop prototypes that use situated visualization to enable new ways of discovering patterns during site visits. Urban designers, urban planners, and architects often visit a site prior to a design activity related to the site. These site visits are used for different purposes by different professionals, but the general goals are to get a sense for the physical site, find patterns, and discover and record new insights about the physical location and its characteristics. Site visits are similar to ethnographic study in HCI research, but focus on the physical place. I have developed a prototype handheld system, SiteLens (Fig. 3), which builds on lessons learned from the EFG prototypes and explores situated visualization of environmental data such as CO levels in the area of New York called Manhattanville, using the conceptual model of an intelligent camera. The system explores locus of presentation, interaction, and representation of situated visualizations. A first set of exploratory interactions was developed to understand issues involved in outdoor tracking, data curation, and interaction with situated visualizations. These issues were discussed in workshops at CHI 2007 and 2008. The prototype has been used to elicit feedback from colleagues in the GSAPP and will be revised and extended for a more formal user study and potential use in an urban planning class.

DISCUSSION

Each of these prototypes explores a combination of situated visualization characteristics. Although every prototype visualizes data relevant to a physical object or space, the relationship between the figure and ground, locus of presentation, visual representation, and interaction technique are

Fig. 2. Clockwise from top left (a) TAR EFG (b) View through a video see-through display of results and a virtual voucher in hand. (c) View through optical see-through display of HMCAR. (d) Visual hint.

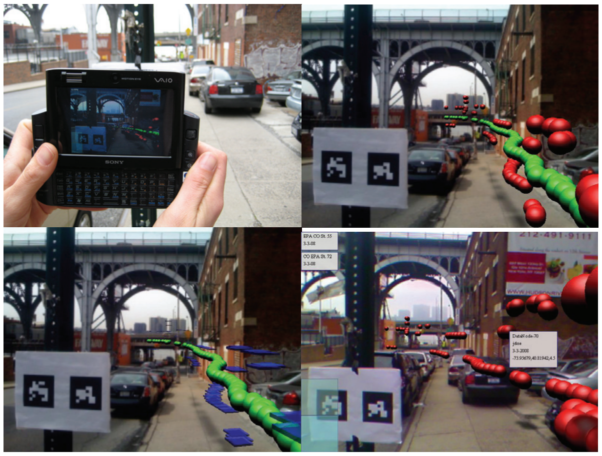

Fig 3. Clockwise from top left. (a) SiteLens handheld (b) displaying locally geocoded (red) and spatialized (green) data (c) combining display-fixed and world-fixed representations. (d) alternative visual representations.

varied to provide insight into design alternatives.

In terms of figure-ground relationship, I explore presence (LeafView) and proximity (LeafView UMPC, HMCAR-EFG), as well as spatially contiguous layout relevant to an object (TAR-EFG, Visual Hints) or a scene (SiteLens). Presence can reflect relevance, but increasing spatial proximity aids in comparison and spatial contiguity supports discovery and observation of patterns that combine the physical and the virtual. In a sense, this shifts from reflecting purely semantic relevance to both semantic and spatial relevance.

I explore locus of presentation through screen-fixed (LeafView, LeafView UMPC), body-fixed (HMCAR-EFG), object-fixed (TAR EFG, Visual Hints) and world-fixed (SiteLens) display. SiteLens, in particular, combines screen-fixed with world-fixed to explore the use of locus to reflect the spatial relevance of data. When data is spatialized but not inherently spatial, contiguity can be perceived as meaningful when it is not.

All of these prototypes utilize some form of direct manipulation for interaction. Stylus (LeafView) and touch-based (LeafView UMPC, SiteLens) interactions are necessary for interacting through or with surfaces, while tangible interfaces (TAR-EFG, Visual Hints) support direct interaction with the union of the figure and ground. Alternatives such as head-movement control provide benefits such as hands-free interaction, but do not take advantage of existing spatial skills for interacting with a visualization embedded in the physical world.

Visual presentation is explored in all prototypes. I look at scale and the use of semantic zooming [11] in 2D (LeafView) and 3D (TAR-EFG), where physical distance and gestures can be used for both magnification and semantic zooming. SiteLens explores representation more directly, where data must reflect quantitative values, but not be confused with depth cues or visual aspects of the scene.

OPEN CHALLENGES

While a significant portion of my research has been completed, there are still several aspects that need to be explored. The SiteLens prototype requires a second iteration to explore better alternatives to presentation and interaction. This will be followed by a user study and potential use by a class of urban planning students in the early fall. I would also like to investigate a hybrid hand-held AR version of the EFG that incorporates AR representations into the UMPC architecture together with a comparative study. As these are completed, I will be developing the framework and design principles as a means of comparing and analyzing the body of work.

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REFERENCES

1. Belcher, D., Billinghurst, M., Hayes, S., and Stiles, R., "Using Augmented Reality for Visualizing Complex Graphs in Three Dimensions,"*ISMAR*, 84-93, 2003.
2. Bell, B., Feiner, S., and Höllerer, T., "View management for virtual and augmented reality," *UIST*, 101-110, 2001.
3. Bier, E.A., Stone, M.C., Fishkin, K., Buxton, W., and Baudel, T., "A taxonomy of see-through tools," *CHI*, 358-364, 1994.
4. Card, S.K., Mackinlay, J.D., and Shneiderman, B., "Information Visualization: Using Vision to Think." San Francisco, CA: Morgan Kaufmann, 1999.
5. Fuhrmann, A., Loffelmann, H., Schmalstieg, D., and Gervautz, M., "Collaborative visualization in augmented reality," *Comp. Graphics and Apps., IEEE*, vol. 18, pp. 54-59, 1998.
6. Gillet, A. and Olson, A., "Tangible Augmented Interfaces for Structural Molecular Biology," *ISMAR*, poster, 2006.
7. Ishii, H. and Ullmer, B., "Tangible Bits: Towards Seamless Interfaces between People, Bits, and Atoms," *CHI*, Atlanta, GA, 234-241,1997.
8. King, G.R., Piekarski, W., and Thomas, B.H., "ARVino—Outdoor augmented reality visualisation of viticulture GIS data," *ISMAR*, 52-55, 2005.
9. Lave, J. and Wenger, E., *Situated Learning: Legitimate Peripheral Participation*: Cambridge University Press, 1991.
10. Mullet, K. and Sano, D., *Designing visual interfaces: Communication oriented techniques*. Englewood Cliffs, NJ: Prentice Hall, 1995.
11. Perlin, K. and Fox, D., "Pad: an alternative approach to the computer interface," *SIGGRAPH*, Marina del Rey, CA, 57-64,1993.
12. Schall, G., Mendez, E., Kruijff, E., Veas, E., Junghanns, S., Reitinger, B., and Schmalstieg, D., "Handheld Augmented Reality for Underground Infrastructure Visualization," *To appear in Journal of Personal and Ubiquitous Computing*, 2008.
13. Shneiderman, B., "The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations," IEEE Symposium on Visual Languages, Boulder, CO, 336-343,1996.
14. White, S., Feiner, S., and Kopylec, J., "Virtual Vouchers: Prototyping a Mobile Augmented Reality User Interface for Botanical Species Identification," *3DUI*, 119-126,2006.
15. White, S., Lister, L., and Feiner, S., "Visual Hints for Tangible Gestures in Augmented Reality," *ISMAR*, 47-50,2007.
16. White, S., Marino, D., and Feiner, S., "Designing a Mobile User Interface for Automated Species Identification," *CHI*, San Jose, CA, 291-295, 2007.